

LECTURE NOTES

ON

ANALOG ELECTRONICS AND OP-AMP

4TH SEMESTER

PREPARED BY

MR. JASOBANTA BARIK

PTGF IN ELECTRICAL ENGINEERING DEPARTMENT,

GOVERNMENT POLYTECHNIC, PURI

P-N JUNCTION DIODE

①

Syllabuses

- P-N Junction Diode
- Working of Diode
- V-I characteristic of PN Junction diode
- DC load line
- Important terms such as ideal diode, knee voltage
- junction break down
 - Zener break down
 - Avalanche break down
- P-N Diode clipping circuit
- P-N Diode clamping circuit

def?

→ When a p-type Semiconductor is suitable joined to n-type Semiconductor, the contact surface is called P-N Junction.

→ P-N Junction diode is a two terminal device consisting of a P-N junction formed either in Ge or Si crystal.

→ When a p-type material is intimately joined to n-type, a P-N junction is formed.

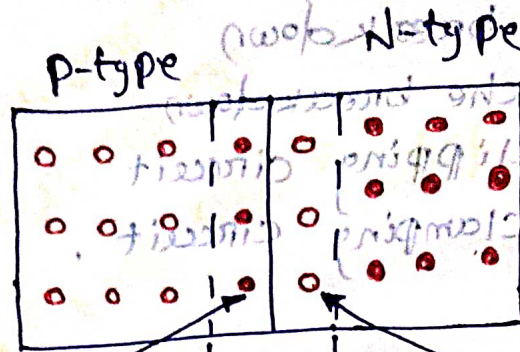
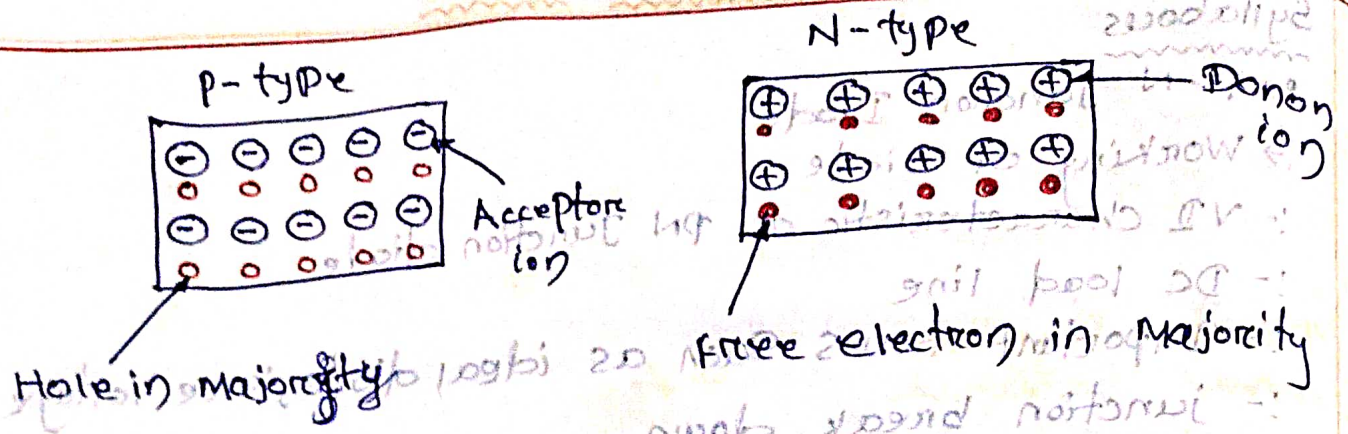
→ A P-N junction is formed from a piece of Semiconductor (say Ge^{OR} Si) by diffusing p-type material to one half side and n-type material to other half side. The plane dividing the two zones is known as a junction.

→ p-type Semiconductor has negatively acceptor ions and positively charged free holes.

→ n-type Semiconductor has positively donor ions and negatively charged free holes.

→ P = Hole
N = free electron

(2)



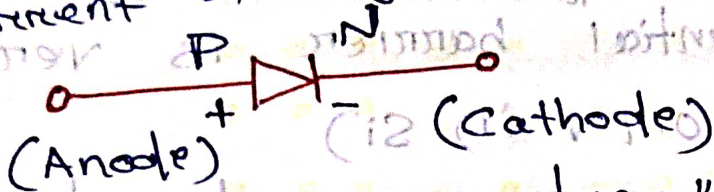
Now, Let us consider that the two pieces are joined together as in fig. 1.

As P type material has a high concentration of holes and N-type material has a high concentration of free electron and hence there is a tendency of holes to diffuse over N-side and electron diffuse P-side. The process is known as diffusion.

So due to diffusion, some of the holes from P-side cross over to N-side where they combine with electrons and become neutral. Similarly some of the electron from N-side cross over to P-side where they combine with holes and become neutral.

→ Thus a region is formed which is known as depletion layer or charged free region or space charge region because there is no charge available for conduction.

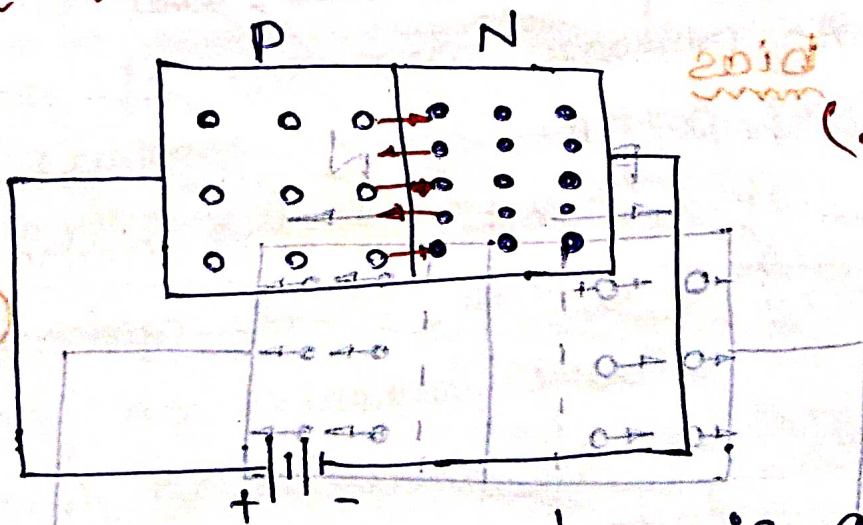
Diode Symbol
→ Diode is an electrical component that allows the flow of current in only one direction.



"P" stands for "High voltage",
"N" stands for "Low voltage".

Working of Diode
In order to consider the working of a diode we shall consider the effect of forward bias and reverse bias across the P-N junction.

* Forward Bias



(Diode on state behaves like closed ckt)

→ When an external voltage is applied to a P-N junction in such a direction that it cancels the potential barrier and permits the current flow is called as forward bias.

④

→ To apply a forward bias, the positive terminal of a battery is connected to P-type Semiconductor while the negative terminal is connected to N-type Semiconductor as shown in fig.

→ The applied forward potential establishes an electric field opposite to the potential barrier.

→ Therefore the potential barrier is very small.

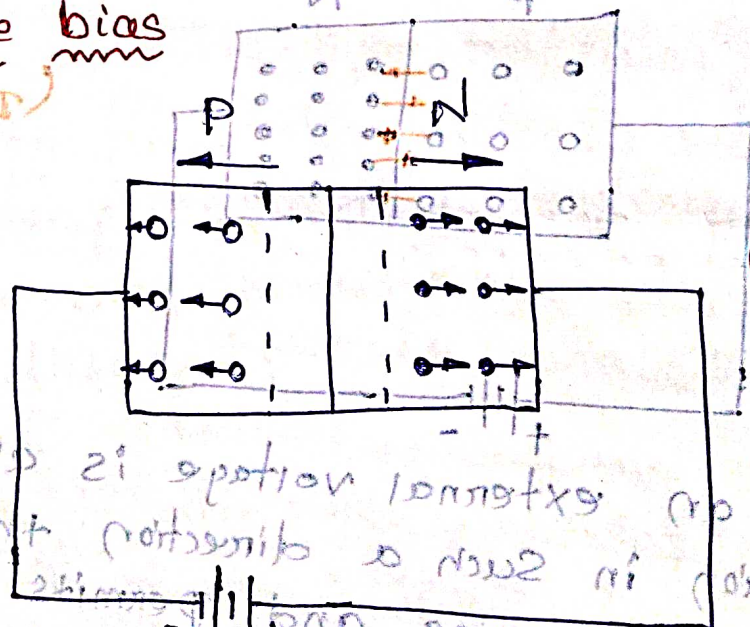
→ As the potential barrier is very small
(0.3 V in Ge & 0.7 V in Si)

→ Therefore, a small forward voltage is sufficient to completely eliminate the barrier.

→ When potential barrier is eliminated by the forward voltage, junction resistance becomes zero.

Note:- In forward bias the potential barrier is neglected i.e. almost zero so the Diode behaves in close circuit or short circuit.

* Reverse bias



(Diode off state, behaves like open circuit)

⇒ When an external voltage is applied to P-N junction in such a direction that it increases the potential barrier then it is called as Reverse bias.

⇒ For Reverse bias, the positive terminal of the battery is connected to N-type semiconductor and negative terminal to P-type semiconductor as shown in fig.

⇒ The applied Reverse voltage establishes an electric field which acts in the same direction of potential barrier.

⇒ Therefore, the resultant field at the junction is strengthened and the barrier height is increased.

⇒ This increased potential barrier prevents the flow of charge carriers across the junction.

⇒ In this way a high resistance path is established.

⇒ When the junction is Reverse biased, the electrons in N-type semiconductor and holes in P-type semiconductor are attracted away from the junction.

⇒ Since there is no recombination of electron-hole pairs, no current flows in the circuit.

(i) The junction potential barrier is strengthened.

(ii) The junction offers a high resistance.

(iii) Practically, no current flows in the circuit.

(iv) A little current flows through the junction due to minority carriers.

Note :- In Reverse bias the potential barrier is increased and Diode behaves like off state or

Diode is open circuit.

Conclusion

From the above discussion, we conclude that when a P-N junction is forward biased, it has low resistance path and hence current flows in the circuit.

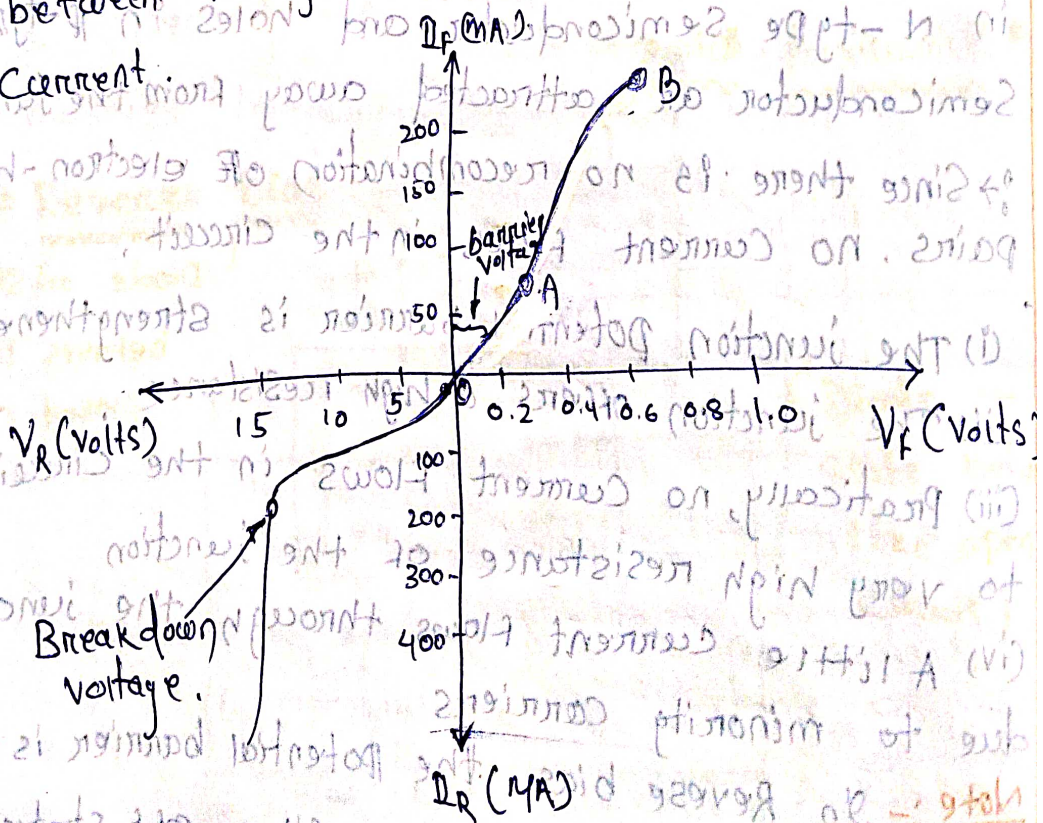
On the other hand, when it is reverse biased, it has high resistance path and no current flows in the circuit.

def

Thus P-N junction diode is one-way device which offers low resistance in forward biased behaves like conductor and high resistance in reverse biased like insulator.

V-I CHARACTERISTICS OF P-N JUNCTION DIODE

V-I characteristics of a P-N junction is the curve between voltage across the junction & the circuit current.



∴ In $V-I$ characteristic graph voltage is taken along x axis & current along y axis. The characteristic can be studied under three conditions.

* zero external voltage or no bias.

* forward bias

* Reverse bias.

Zero external voltage

∴ when the external voltage is zero i.e. no bias condition circuit is open.

∴ The potential barrier at junction doesn't permit current flow.

∴ Therefore the circuit current is zero as indicated by the point 'O'.

forward bias

∴ When forward bias to the p-n junction (P type connected to +ve terminal & N type connected to negative terminal) the potential barrier is reduced.

∴ At some forward voltage (0.7 V for Si and 0.3 V for Ge) the potential barrier is all together eliminated & current starts flowing in the circuit.

∴ From now onwards the current increases with the increase in forward voltage. Thus a rising curve OB is obtained with forward bias.

∴ From the forward characteristics it is seen that at first (region OA), the current increases very slowly & the curve is non linear.

∴ It is because the external applied voltage is used in overcoming the potential barrier.

∴ However once the external voltage exceeds the potential barrier voltage, the p-n junction behaves like ordinary conductor.

(4)

∴ Therefore the current raises very sharply with increase in external voltage (region AB on the curve). Here the curve is almost linear.

Reverse Bias

∴ With Reverse bias to the p-n junction that is type connected to -ve terminal & n type connected to +ve terminal, potential barrier at the junction is increased.

∴ Therefore, the junction resistance becomes very high & no current flows to the circuit.

∴ However in practice a very small current (of order of micro ampere) flows in the circuit with reverse bias as shown in Reverse characteristics.

∴ This is called reverse saturation current & due to the minority charge carrier.

∴ In p type material a few free electrons & in n type materials a few holes are present the undesirable carrier are called minority carrier.

∴ In reverse voltage is increase continuously the kinetic energy of electrons (minority carrier) may become high enough to knock out electron from the semiconductor atoms.

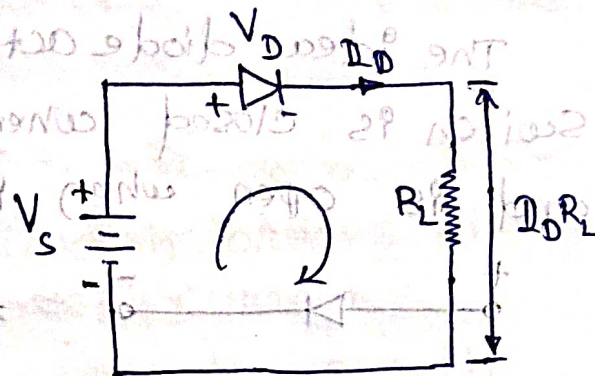
∴ At this stage breakdown of the junction occurs characterized by a sudden rise of reverse current and a sudden fall of the resistance of barrier region. This may destroy the junction permanently.

NOTE:- The forward current through a P-n junction is due to the majority carriers produced by the impurity.

→ However, reverse current is due to the minority carriers produced due to breaking of some covalent bonds at room temperature.

DC LOAD LINE

→ Consider a crystal diode connected in series with a load resistance R_L across a supply voltage V_s .



→ Here the diode is forward biased.

def → A line drawn on the characteristics of the device that represents all d.c. conditions that could exist within the circuit for given values of V_s and R_L is called D.C. load line.

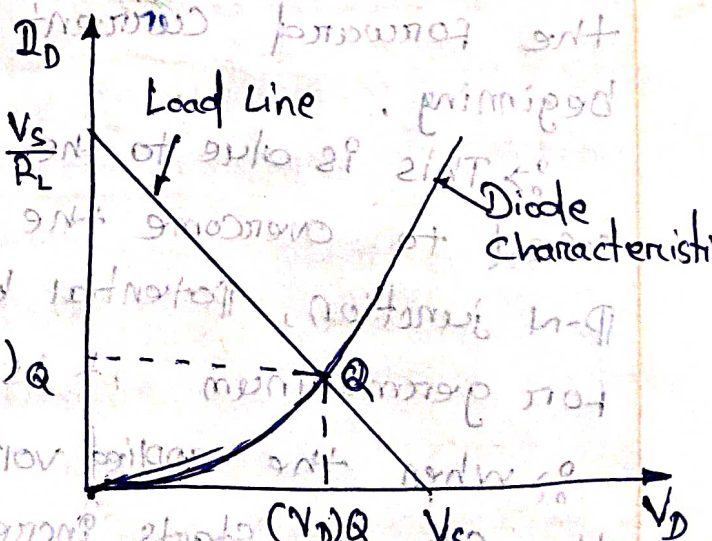
→ Applying KVL to the diode circuit, we have

$$V_s - V_D - I_D R_L = 0$$

$$\Rightarrow I_D R_L = V_s - V_D$$

$$\Rightarrow I_D = \frac{V_s - V_D}{R_L}$$

$$\Rightarrow I_D = \frac{V_s}{R_L} - \frac{V_D}{R_L}$$



→ So d.c. load line is a straight line.

Important Terms

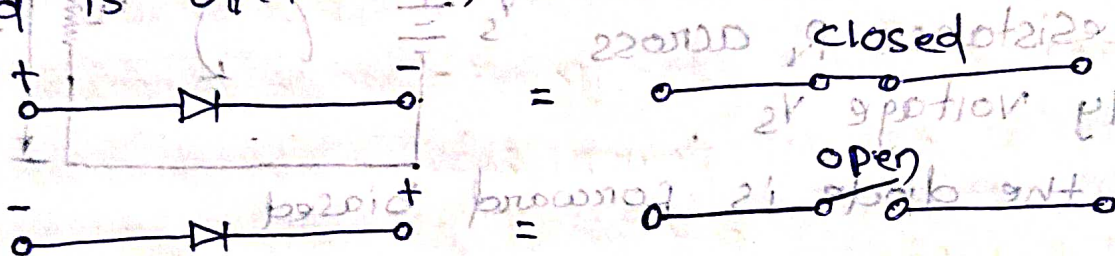
Ideal diode

An ideal diode is a two terminal device which has the following properties.

- (i) Conducts with zero resistance when forward biased
- (ii) offers an infinite resistance when reverse biased

The ideal diode acts like an automatic switch.

Switch is closed when the diode is forward biased and is open when it is reverse biased.



Knee voltage

Def: Knee voltage is defined as the forward voltage at which the current through the junction starts increasing rapidly.

⇒ We have seen that when a diode is forward biased, the forward current increases very slowly in the beginning.

⇒ This is due to the fact that applied voltage is used to overcome the potential barrier. For silicon P-N junction, potential barrier is 0.7 volt whereas for germanium it is 0.3 volt.

⇒ When the applied voltage exceeds the knee voltage, the current starts increasing rapidly.

Junction breakdown

- Under a normal reverse voltage, a very little reverse current flows through a P-N junction.
- But when the reverse voltage is increased a point is reached when the junction breaks down with sudden rise in reverse current.
- The critical value of the voltage is known as breakdown voltage (V_{BR}).
- The breakdown voltage is defined as the reverse voltage at which p-n junction breaks down with sudden rise in reverse current.
- The breakdown voltage depends upon the width of the depletion layer.
- Junction breakdown depends upon two mechanisms i.e. (a) Zener breakdown
(b) Avalanche breakdown

Zener breakdown

- The Zener breakdown takes place in junction which are heavily doped (having narrow depletion layer).
- When breakdown voltage is applied, a very strong electric field appears across narrow depletion layer which breaks the bonds.
- Now, electron-hole pairs are generated.
- A small further increase in reverse voltage produces large number of current carriers which suddenly increase the reverse current.

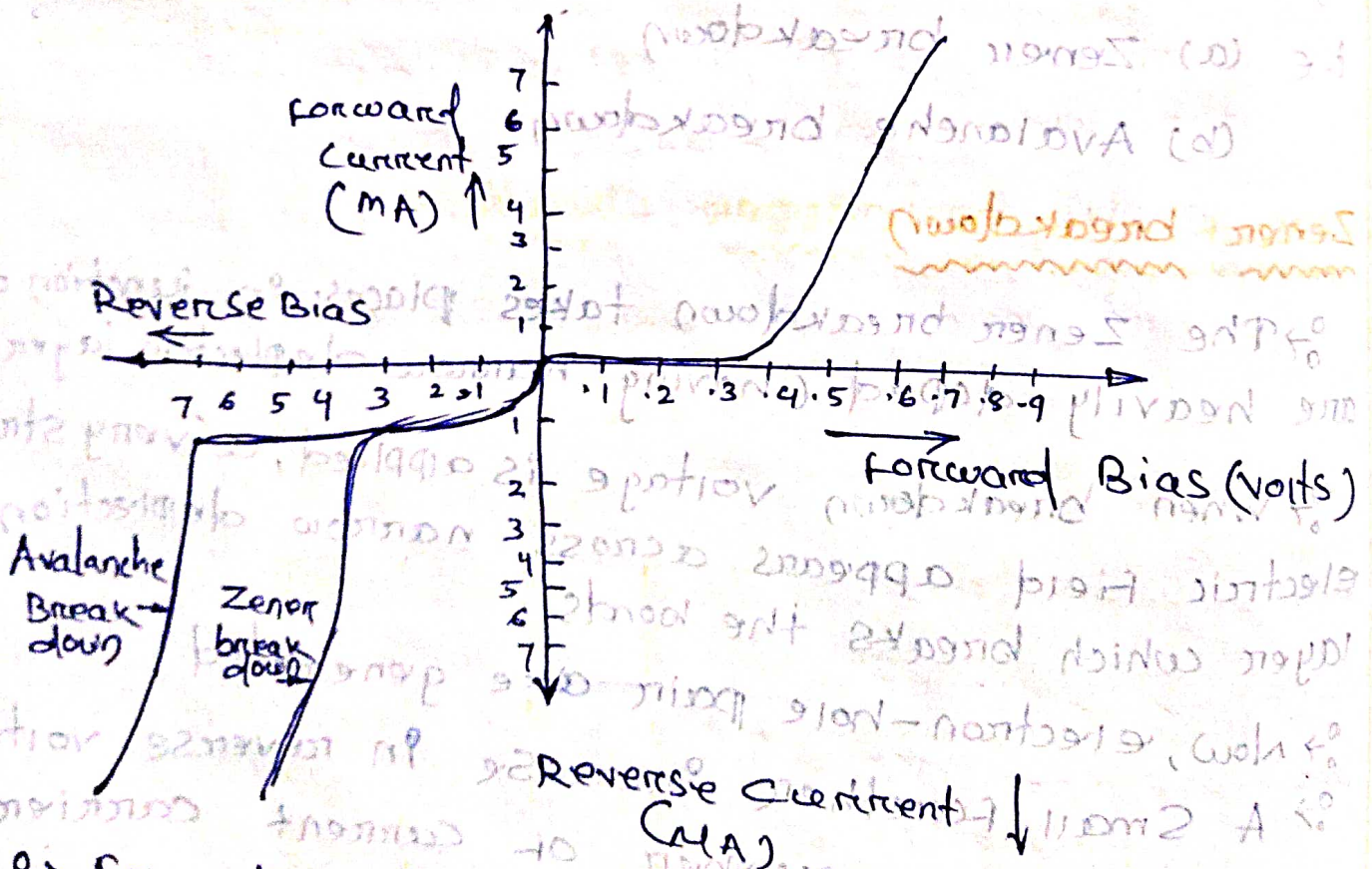
Avalanche Breakdown - The Process of applying high voltage and in free electrons is called avalanche breakdown

→ Avalanche breakdown occurs in a P-n junction diode which is moderately doped and has a thin junction. (means its depletion layer width is high)

→ Avalanche breakdown usually occurs when we apply a high reverse voltage across the diode (obviously higher than the Zener breakdown voltage, say V_z)

→ By increased the applied reverse voltage, the electric field across junction will keep increasing. If applied reverse voltage (V_a) and the depletion layer width is (d). then the generated electric field

$$E_a = \frac{V_a}{d}$$



→ From the above fig we can see that avalanche breakdown occurs at a voltage (V_a) which is higher than Zener breakdown voltage (V_z)

P-N Diode Clipping Circuit

→ A circuit which removes or cuts unwanted portion of a wave form is called clipping circuit.
 → It is used for Amplitude limiting and noise elimination.

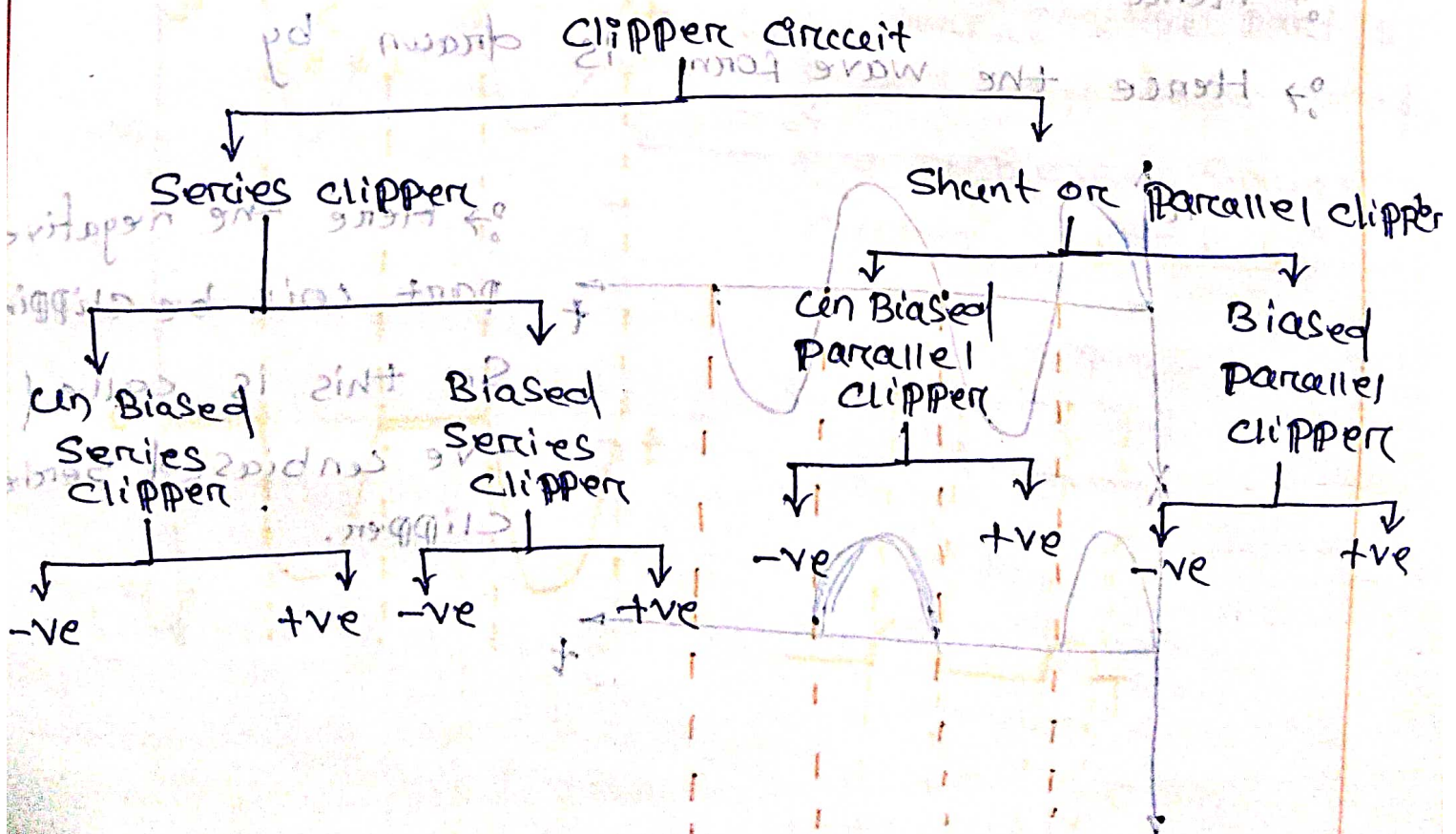
OR

→ A wave shaping circuit which controls the shape of out waveform by removing or clipping a portion of the applied wave is known as clipping circuit.

→ For clipping circuit at least two components of a diode (which acts as a closed switch when forward-biased and an open circuit when reverse biased) and a resistor are required.

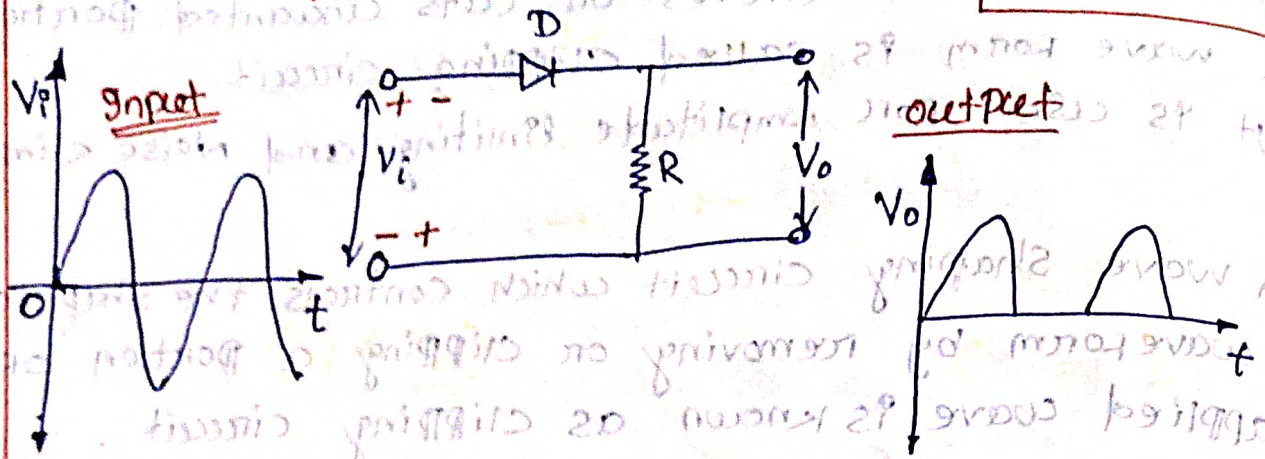
→ Some times a d.c battery is also used to fix the clipping level.

→ Clippers are used in radar, digital and other electronic devices.

Classification of Clipper Circuit

-ve cen biased Series clipper

F.B = ON / close
R.B = OFF / open



Case-1 $V_i > 0$

⇒ when $V_i > 0$ then the Diode is forward biased.
The Diode is on state then that position diode is conduct current.

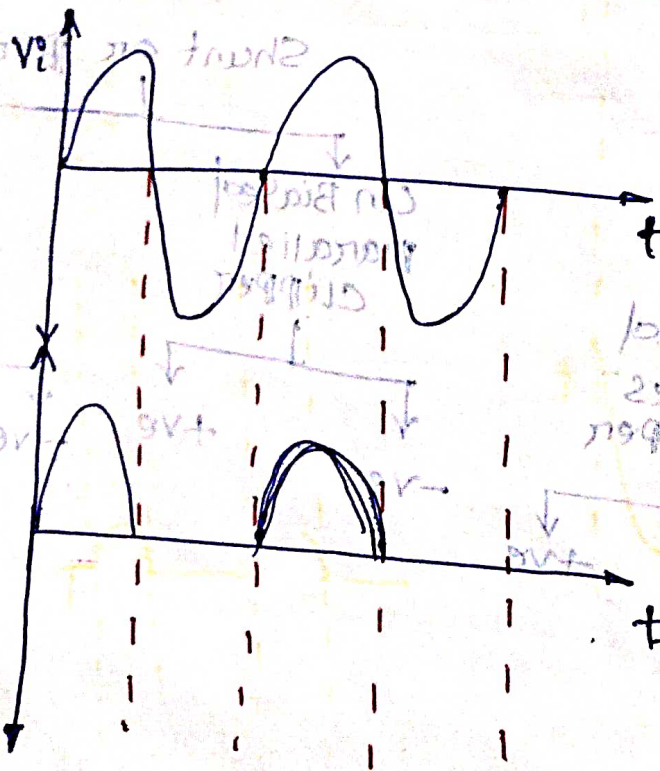
⇒ Hence the input signal is same as the output signal.

Case-2 ($V_i < 0$)

⇒ when $V_i < 0$ then the Diode is Reverse biased then the Diode is off state or open state.

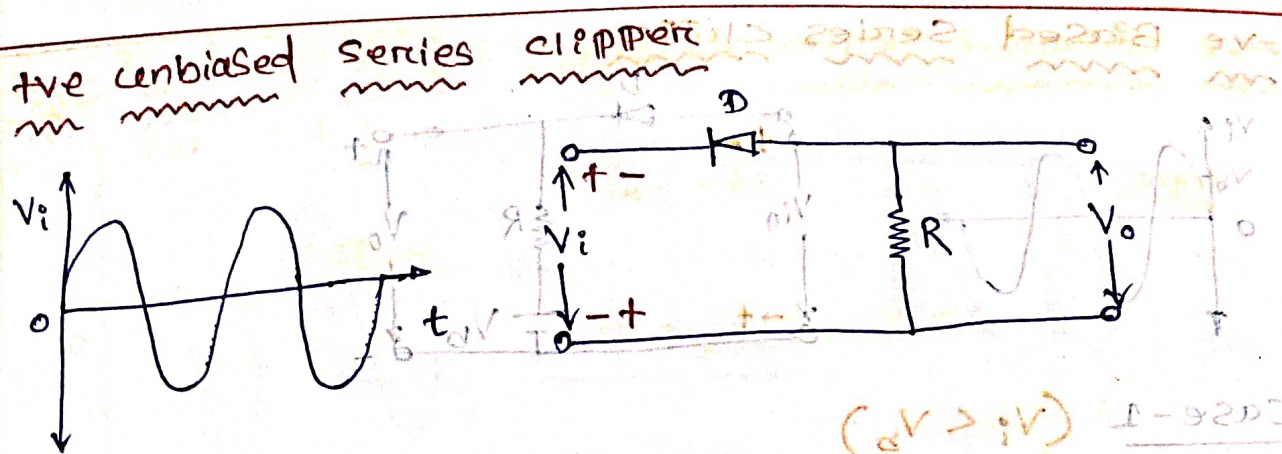
⇒ Hence the diode doesn't conduct current.

⇒ Hence the wave form is drawn by



⇒ Here the negative part will be clipping

So this is called -ve cen biased series clipper.



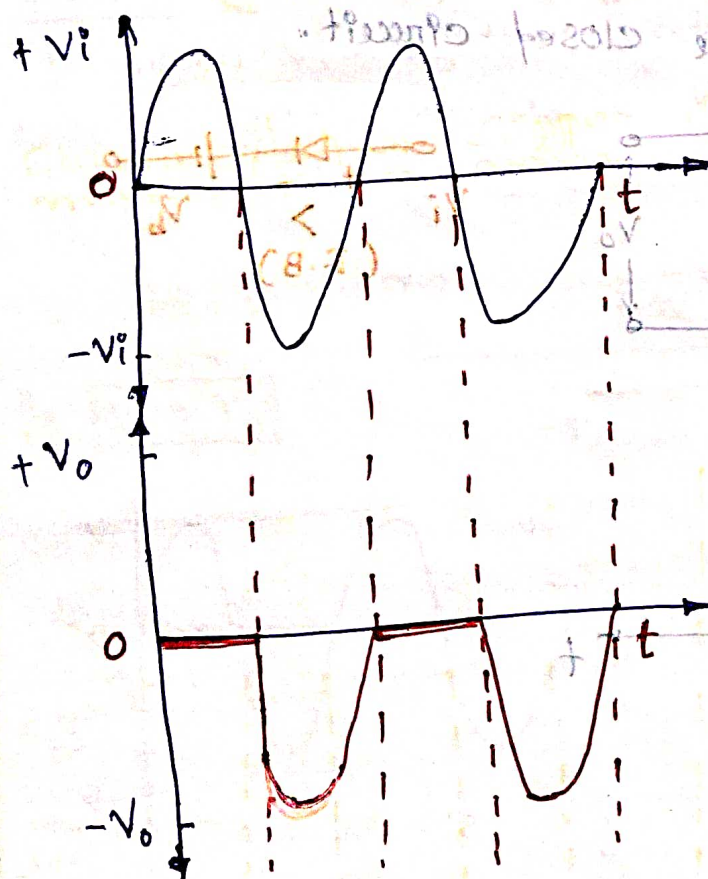
Case-1 ($V_i \geq 0$)

When $V_i > 0$ then the Diode is Reverse biased, then the Diode doesn't Conduct current.

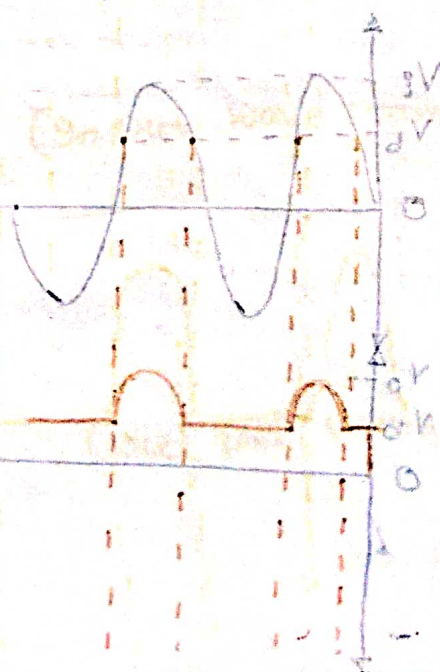
Case-2 ($V_i < 0$)

When, $V_i < 0$ then the Diode is forward biased.
 then the Diode is on state & circuit is closed.
 Hence the Diode Conduct current.

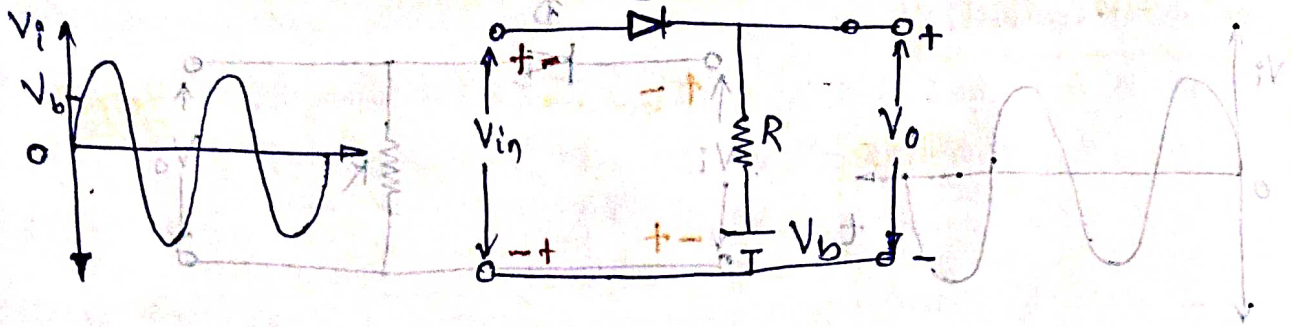
The wave form is given by



Here positive part is clipped then it is called positive biased series clipper.



-ve Biased Series Clipper

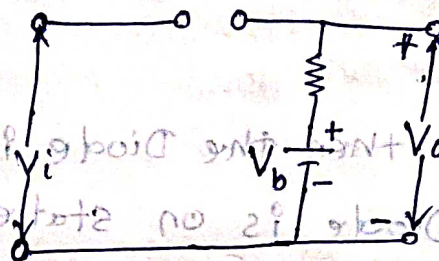


Case-1 ($V_i < V_b$)

When, $V_i < V_b$ then the Diode is Reverse Biased.

Then it acts as open circuit.

Like this :-



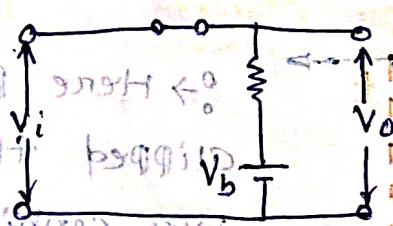
$$V_o = V_b$$

Case-2 ($V_i > V_b$)

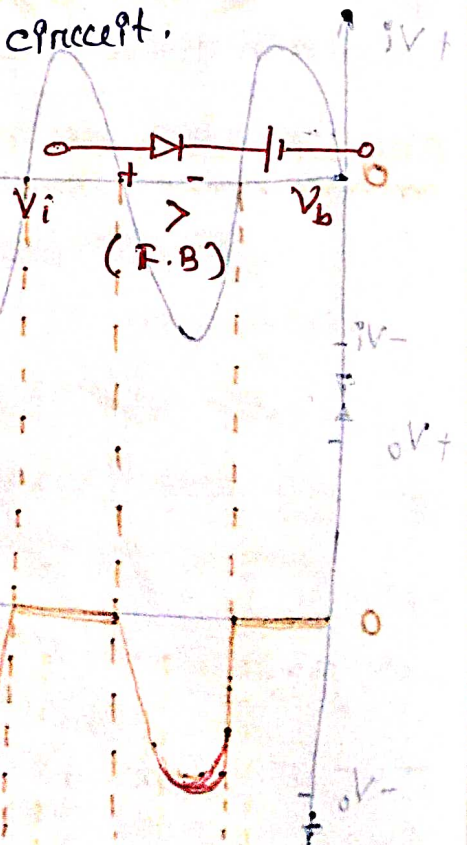
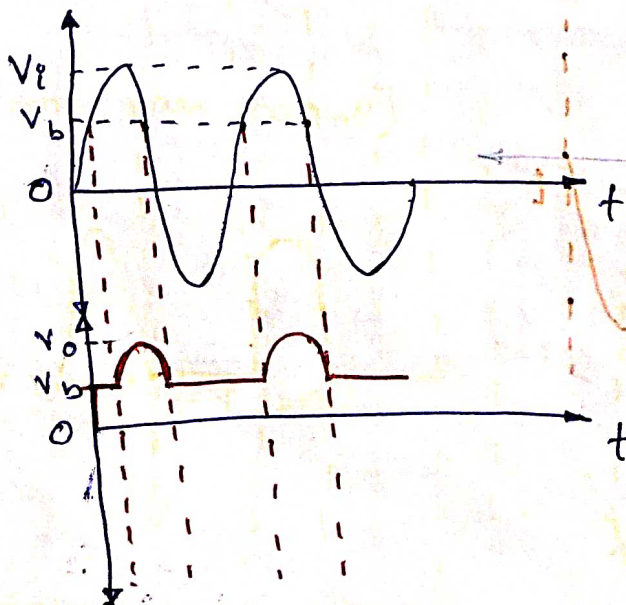
When $V_i > V_b$ then the Diode is forward biased.

Then it acts as a closed circuit.

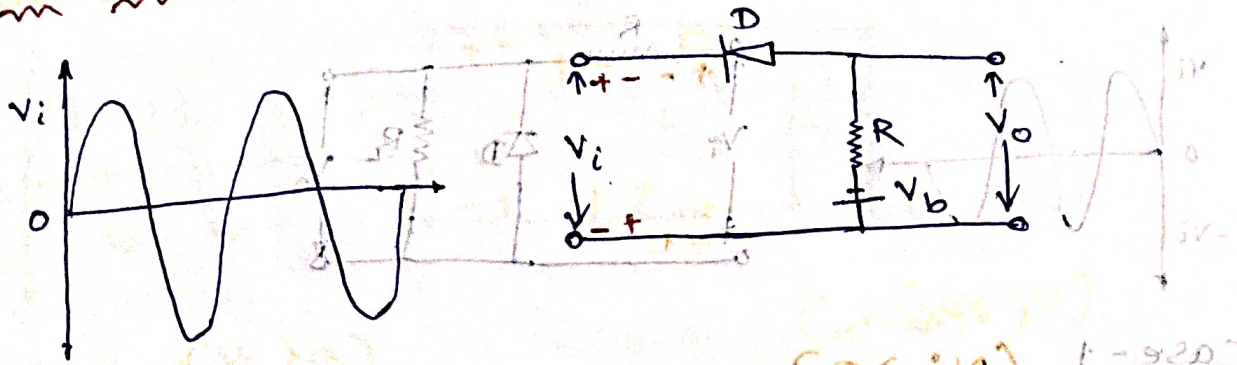
Like this



$$V_o = V_i$$



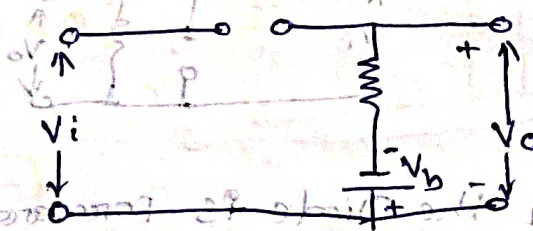
Positive Biased Series clipper



Case-1 ($V_i > V_b$)

When $V_i > V_b$ then Diode is Reverse biased in this condition diode is open circuit.

Like



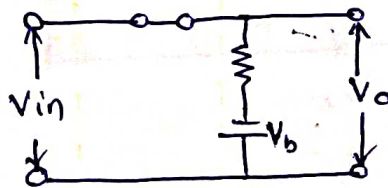
When $V_i > V_b$, then diode behaves like an open circuit.

$$V_o = -V_b$$

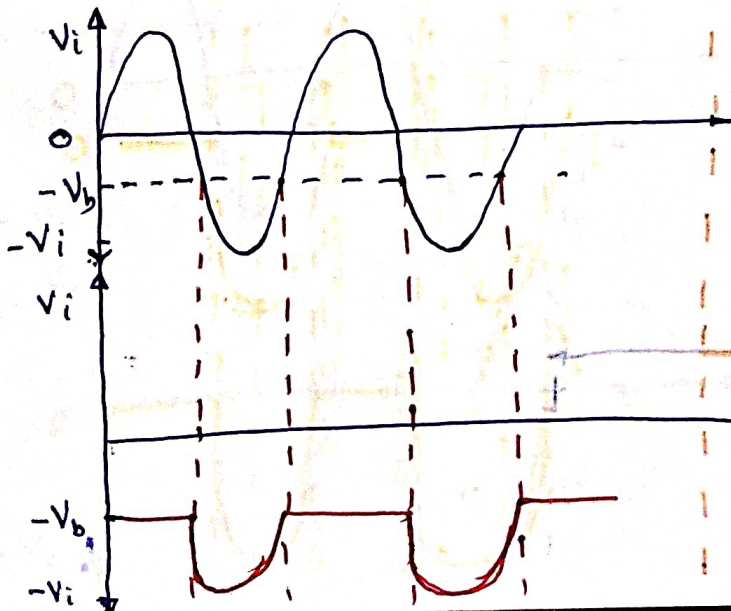
Case-2 ($V_i < V_b$)

When $V_i < V_b$ then Diode is forward biased in this condition Diode behaves as a closed circuit.

Like this



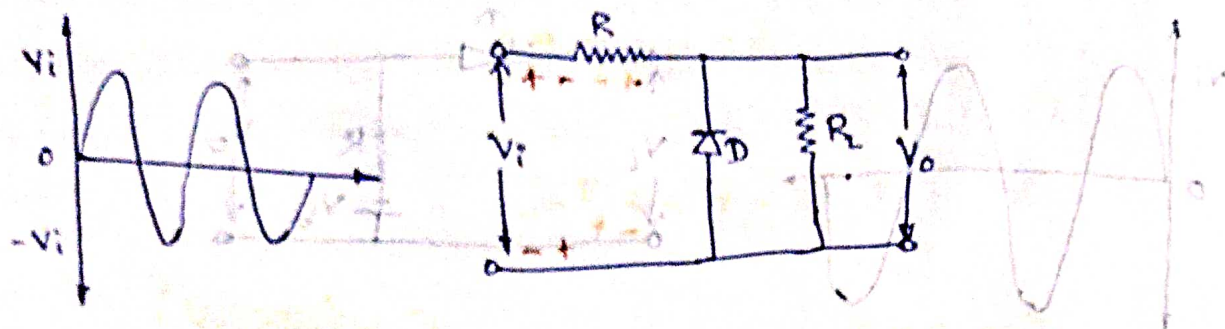
$$V_i = V_o$$



(Input wave form)

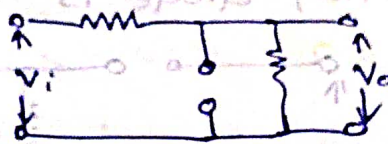
(Output wave form)

-ve unbiased parallel clipper



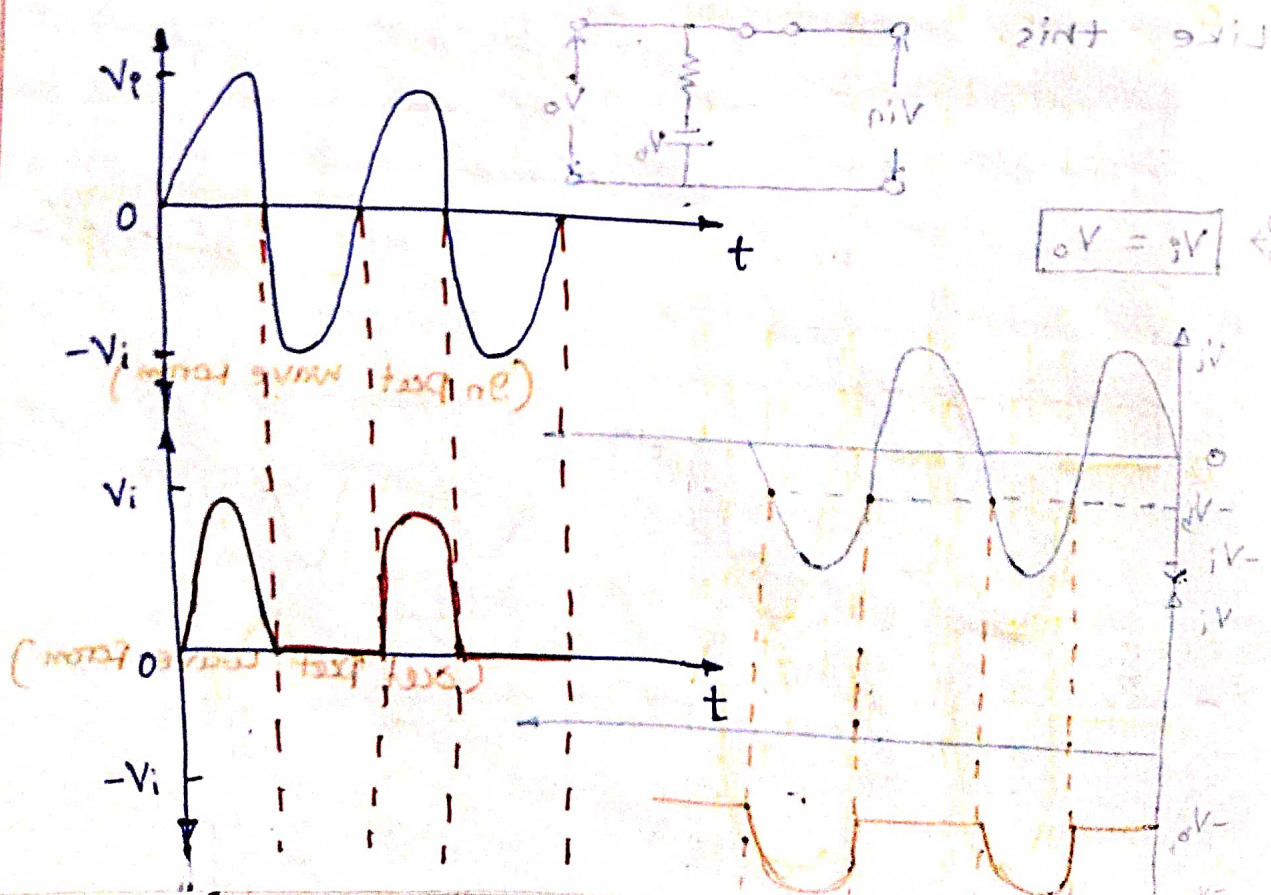
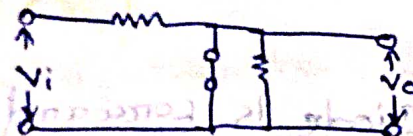
Case-1 ($V_i > 0$)

- When $V_i > 0$, then the Diode is Reverse Biased.
- On this state Diode is open circuit
- $V_o = V_i$

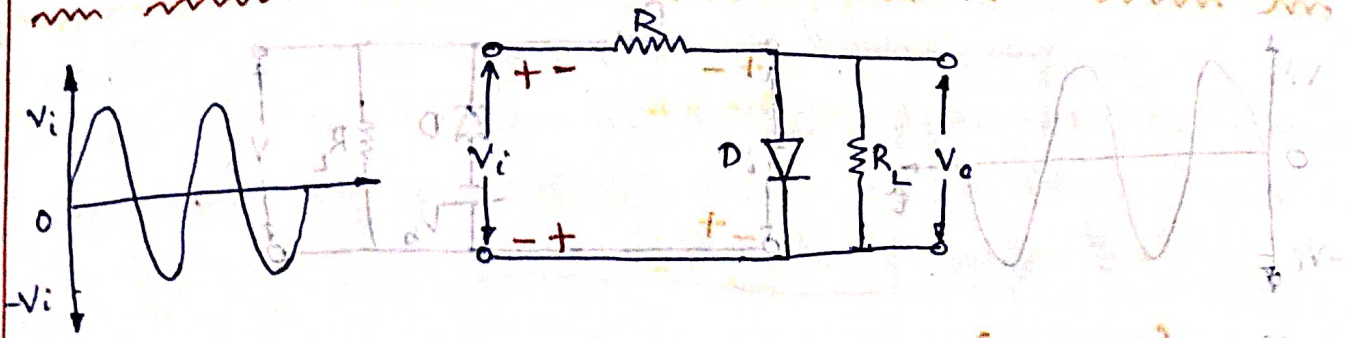


Case-2 ($V_i < 0$)

- When $V_i < 0$, then the Diode is forward biased.
- On this state Diode behaves like a short circuited.
- i.e.
- $V_o = 0$

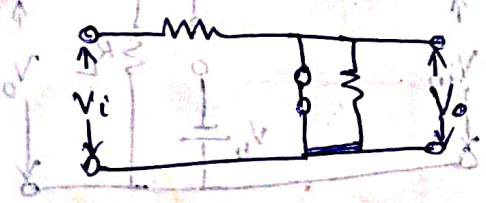


+ve unbiased parallel clipper



Case-1 ($V_i > 0$)

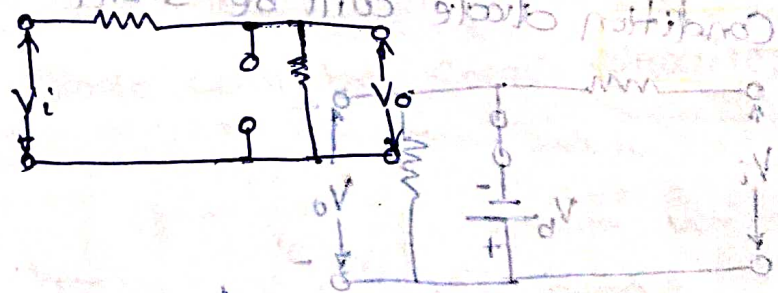
- When $V_i > 0$, then the Diode is forward biased
- Then this state Diode will be short circuited.
- Like this



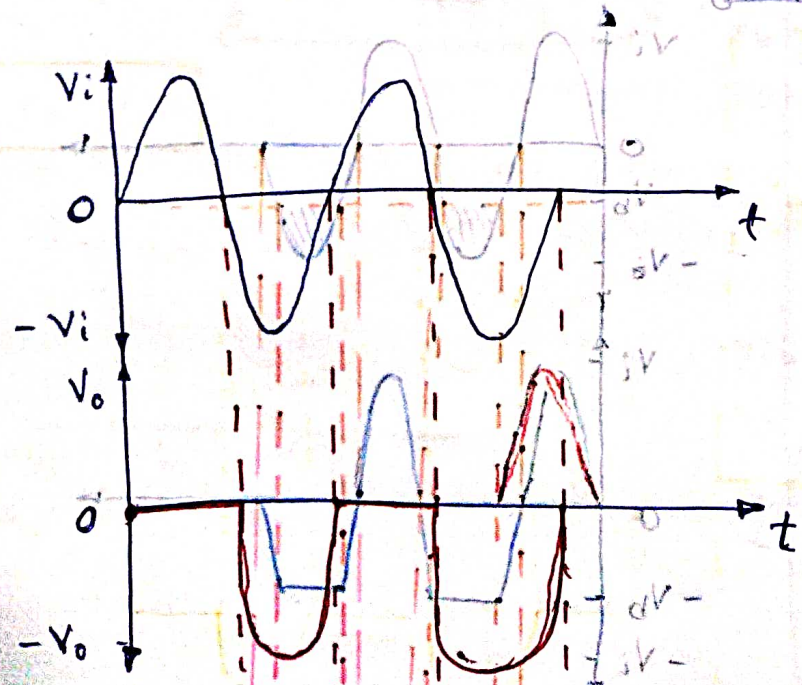
→ $V_o = 0$

Case-2 ($V_i < 0$)

- When $V_i < 0$ then the diode is Reverse biased. In this state diode behaves like a open circuited.
- Like this

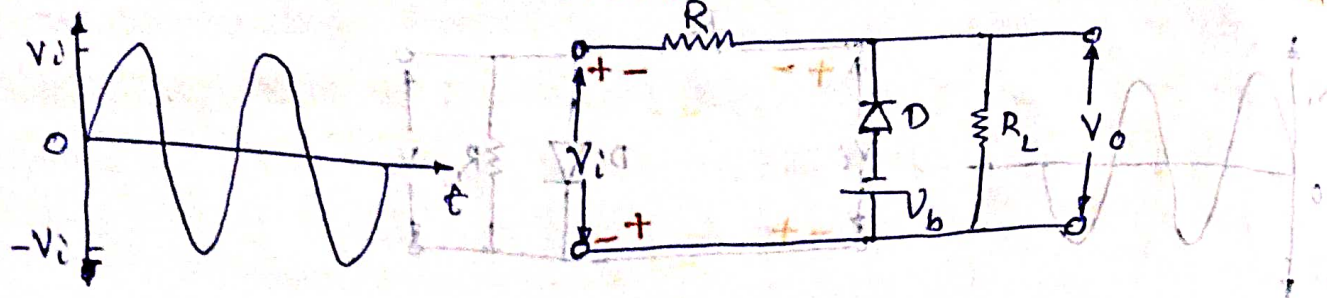


→ $V_o = V_i$



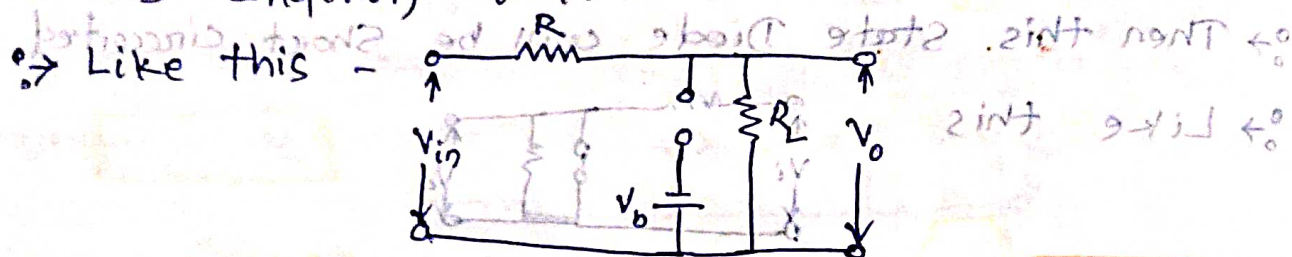
$V_o = -V_i$

-ve biased Parallel clipper



Case-1 (\$V_i > V_b\$)

→ When $V_i > V_b$, then the Diode is Reverse biased. In this condition diode is open circuited.

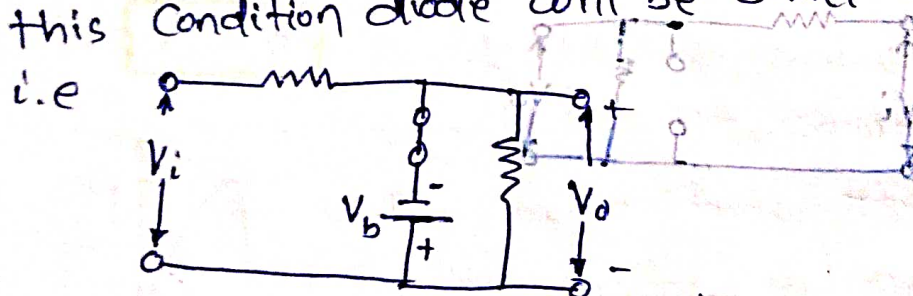


→ $V_o = 0$

$V_o = 0V$

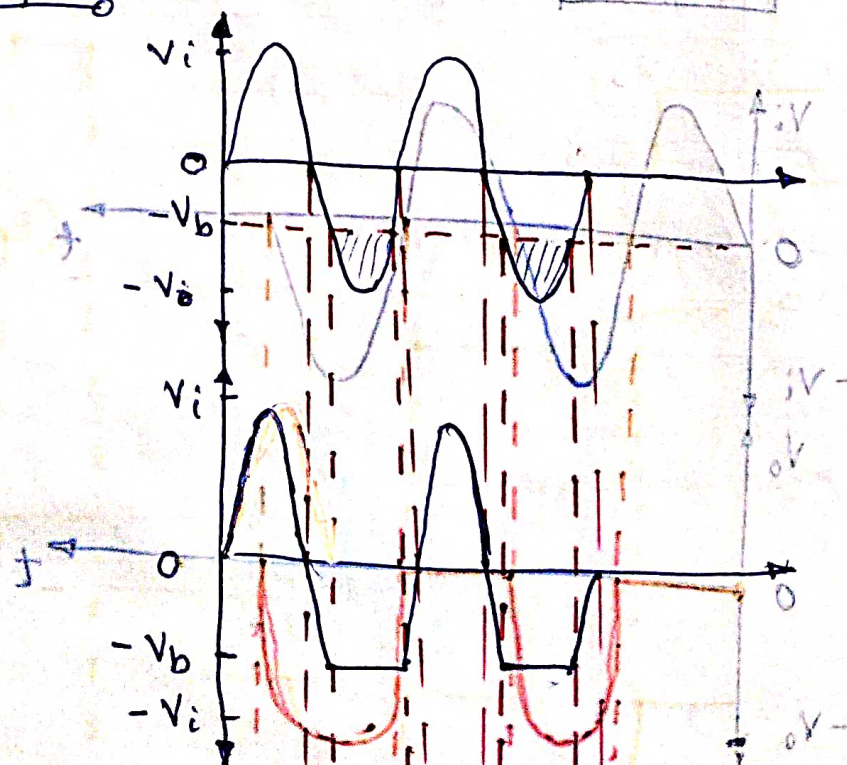
Case-2 (\$V_i < V_b\$)

→ When $V_i < V_b$, then the diode is forward biased. In this condition diode will be short circuited.

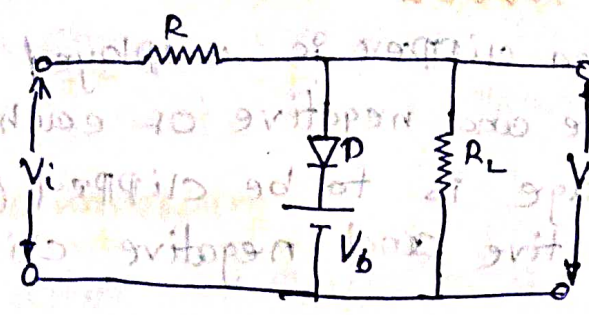
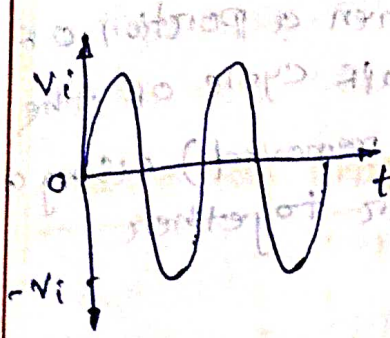


→ $V_o = -V_b$

$V_o = -V_b$



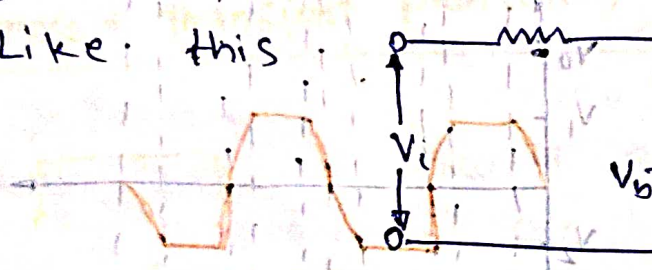
Parallel Clipper



Case - 1 ($V_i < V_b$)

⇒ when $V_i < V_b$, then the Diode is Reverse biased, in this condition Diode will be open circuited.

∴ Like this:

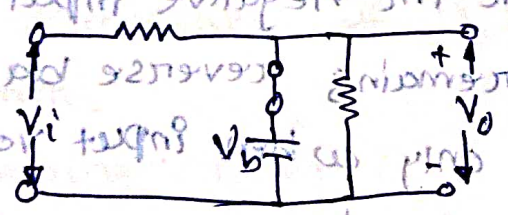


⇒ $V_o = V_i$

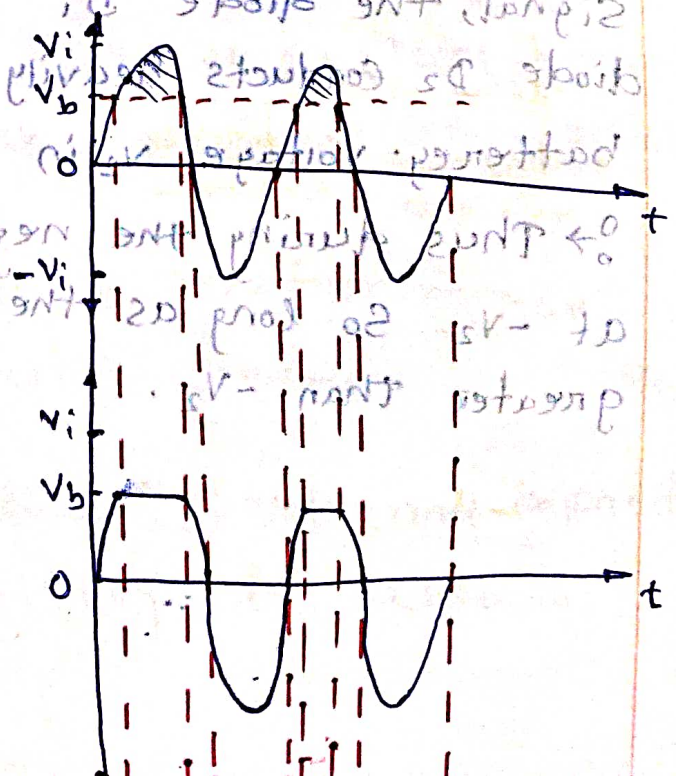
Case - 2 ($V_i > V_b$)

⇒ when $V_i > V_b$, then the Diode is forward biased, in this condition Diode will be short circuited.

Like this:

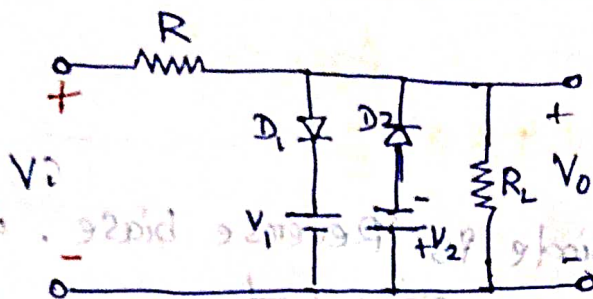


$V_o = V_b$

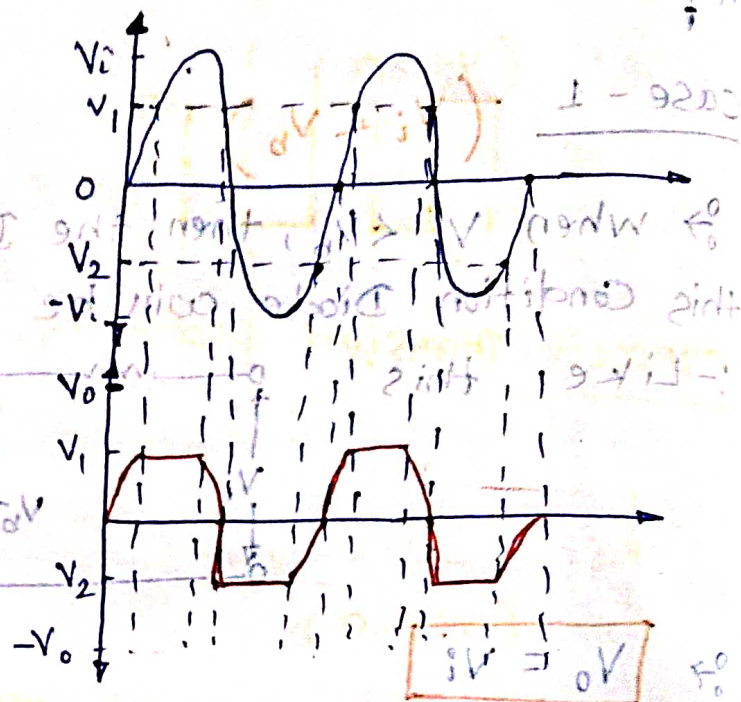


Combination clipper

→ Combination clipper is employed when a portion of both positive and negative of each half cycle of the input voltage is to be clipped (or removed) using biased positive and negative clipper together.



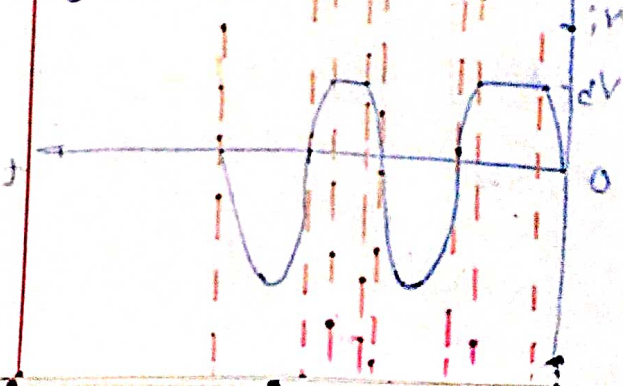
→ For positive input voltage signal when input voltage exceeds battery voltage V_1 , diode D_1 conducts heavily while diode D_2 is reverse biased and



so voltage V_1 appears across the output. This output voltage V_1 stays as long as input signal voltage exceeds V_1 .

→ On the other hand, for the negative input voltage signal, the diode D_1 remains reverse biased and diode D_2 conducts heavily only when input voltage exceeds battery voltage V_2 in magnitude.

→ Thus during the negative half cycle the output stays at $-V_2$ so long as the input signal voltage is greater than $-V_2$. A box contains the text 'V = 0V'.



Application of clipper circuit

Generally, clipper circuit are used in - change the shape of waveform, and circuit Transient protection.

⇒ change the shape of waveform

Clippers can alter the shape of a waveform.
For ex:- a clipper can be used to convert a sine wave into a rectangular wave, square wave etc.

⇒ They can limit either the negative or positive alternation or both alternation of an a.c voltage.

⇒ circuit Transient protection

⇒ Transients can cause considerable damage to many types of circuit e.g., a digital circuit. In the case, a clipper diode can be used to prevent the transient from reaching that circuit.

P-N DIODE CLAMPING CIRCUIT

defn

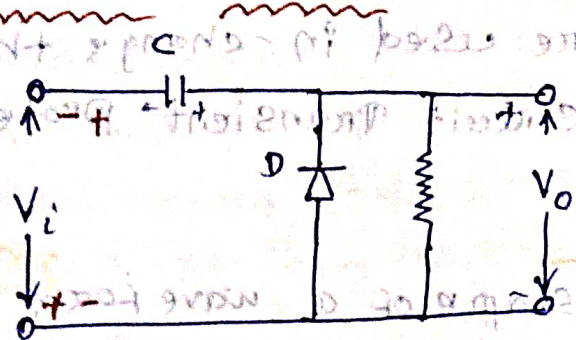
Clamper circuit is a circuit which shift the wave form to a desired DC level without distorting the wave form.

OR:- Clamping circuit is a device that places either the positive or negative peak of a signal at a desired level.

⇒ It can be classified as two categories i.e. positive clamper & Negative clamper.

⇒ Clamping circuit's diode, Resistor and capacitor and some times d.c battery is also required.

positive clamper



Here two case is occur.

i.e. Case-1 ($\frac{T}{2} < t < T$)

In this case Diode is forward biased. Hence this conduct current. and Diode is S.C

$$V_o = 0 \quad V_c = V_i$$

Case-2 ($T < t < \frac{3T}{2}$)

In this case Diode is Reverse biased, and it is behaves like a open circuit.

Now we applying

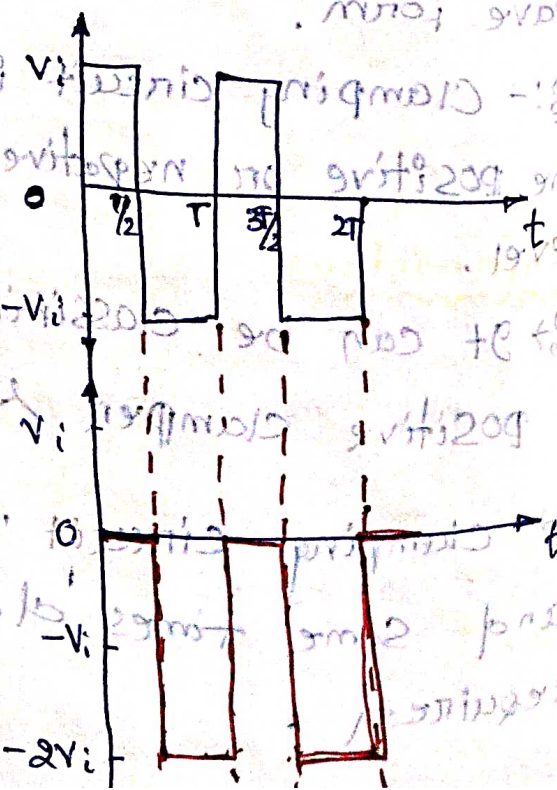
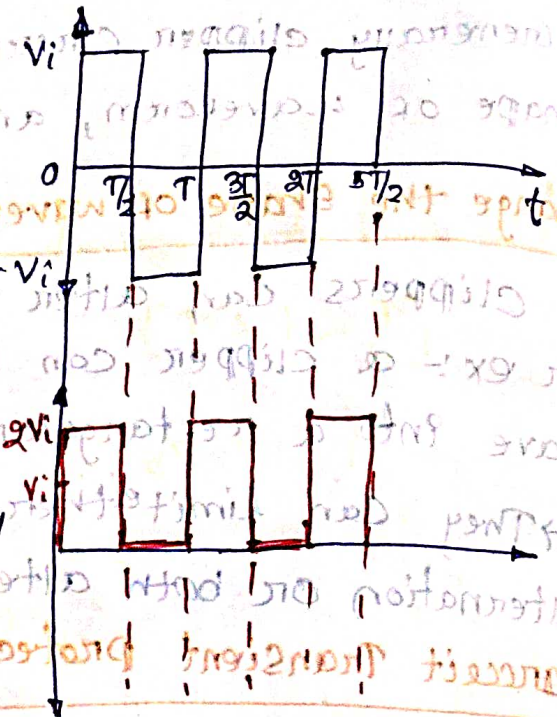
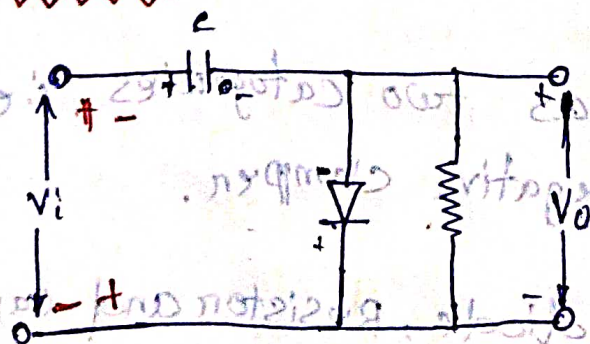
$$-V_i - V_c + V_o = 0$$

$$\Rightarrow -V_i - V_i + V_o = 0$$

$$\Rightarrow -2V_i = -V_o$$

$$\Rightarrow V_o = 2V_i$$

Negative clamper



Case-1 ($0 < t < T/2$)

when In this case Diode will be forward biased and it behaves like a closed circuit.

$$V_o = 0 \quad V_c = V_i$$

Case-2 ($T/2 < t < T$)

In this case Diode will be Reverse biased and it behaves like a open circuit.

by KVL Analysis

$$\Rightarrow +V_i + V_c + V_o = 0$$

$$\because V_c = V_i$$

$$\Rightarrow V_i + V_i + V_o = 0$$

$$\Rightarrow 2V_i + V_o = 0$$

$$\Rightarrow V_o = -2V_i$$

Chapter-2

SPECIAL SEMICONDUCTOR DEVICES

2.1 $\Rightarrow$ Thermistors, Sensors & barretters

2.2 $\Rightarrow$ Zener diode

2.3 $\Rightarrow$ Tunnel diode

2.4 $\Rightarrow$ PIN diode

Thermistors

$\Rightarrow$ The word Thermistors is a combination of thermal and resistor i.e, it is an thermally sensitive resistor.

$\Rightarrow$ The electrical characteristic of thermistors is a function of its temperature which depends on both the surrounding temperature and on internal power dissipation.

→ The Thermistors are classified according to their temperature Coefficient of resistance.

→ Thermistors are two types 1. PTC 2. NTC

* PTC (Positive temperature Coefficient Thermistors)

:- They have positive temp. Coefficient of resistivity i.e. the resistance increases as temp. increases.

* NTC (Negative temperature Coefficient Thermistors)

:- They have negative temp. Coefficient of resistivity i.e. the resistance decreases as temp. increases. Most thermistors have negative temp. Coefficient.

✓ def:- Thermistor is a bulk semiconductor device which has negative temperature Coefficient of resistivity i.e. the resistance decreases exponentially with increasing temp.

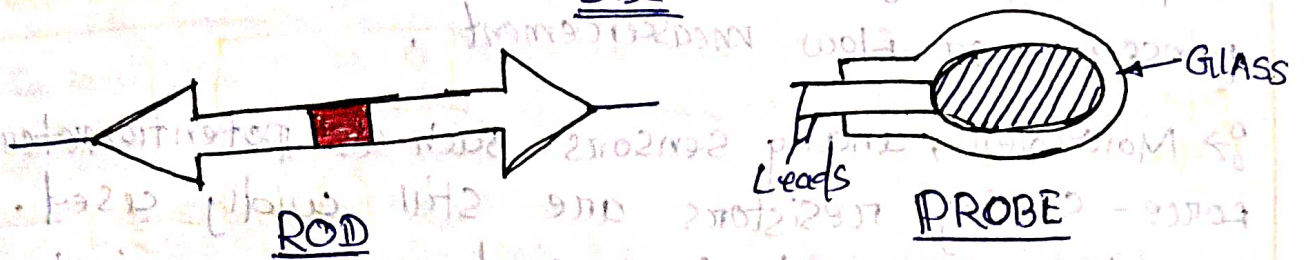
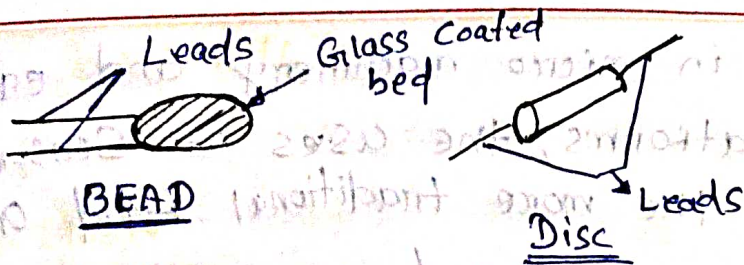
→ The reason of negative temp. Coefficient of resistivity of a semiconductor is that when its temp. is increased the concentration of current carriers (free electrons and holes) also increases which results a decrease in resistance.

→ We know that the properties of Ge and Si are very sensitive to impurities and hence these materials are not used for thermistors.

✓ → Commercially thermistors are made of mixture of metallic oxide, such as (manganese, nickel, cobalt, copper, iron and cerium).

→ Thermistors are made in the shape of rod, bead and disc or probe.

→ Resistance value of thermistors are available from 100Ω to $10 M\Omega$.



Application

- Thermistors are used in Electronic Circuits to Compensate for the change in resistance.
- for measurement and control of temperature as in ovens.
- They are extensively used as sensing elements in microwave power measuring equipments.
- As temperature sensor for electronic thermometry.
- For regulating ac voltage (unlike Zener diode which can regulate dc voltage).
- It is also used for measurement of level, flow and pressure of liquid, composition of gases and vacuum measurement. It is used for providing time delay.

Sensors

→ A Sensor is a device that detects events or changes in quantities and provides a corresponding output, generally as an electrical or optical signal; for example, a thermocouple converts temperature to an output voltage.

→ Sensors are used in everyday objects such as touch-sensitive elevator buttons and lamps which dim or brighten by touching the base.

→ With advances in micro machinery and easy to use microcontroller platforms, the uses of sensors have expanded beyond the more traditional field of temperature, pressure or flow measurement.

→ Moreover, analog sensors such as potentiometers and force-sensing resistors are still widely used. Applications include manufacturing and machinery, airplanes and aerospace, cars, medicine and robotics.

→ A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes.

→ For instance, if the mercury in a thermometer moves 1 cm when the temperature changes by 1°C , the sensitivity is $1\text{ cm}/^{\circ}\text{C}$.

→ Sensors need to be designed to have a small effect on what is measured; making the sensors smaller often improves this and may introduce other advantages.

→ Technological progress allows more and more sensors to be manufactured on a microscopic scale as microsensors using MEMS technology.

→ In most cases, a microsensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches.

Barretter

→ Barretters have a positive temperature coefficient and is formed by appropriately mounted piece of Wollaston platinum wire having diameter approximately $1.25\text{ }\mu\text{m}$. It is capable of yielding power information over the range of 10^{-5} mW to 20 mW .

⇒ Barretters are short length wires with fine diameter with operating range around 1500°C .

Zener diode

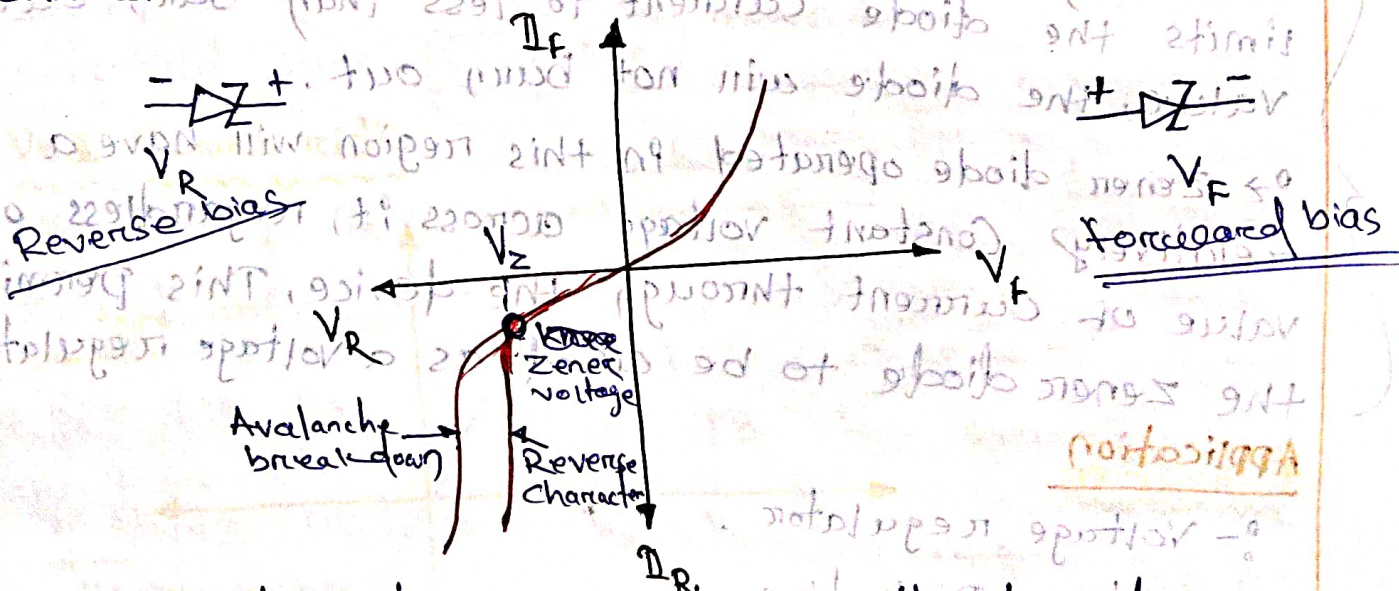
⇒ Zener diode is a reverse biased heavily-doped Silicon (or germanium) P-N junction diode which is operated in the breakdown region.

⇒ Due to higher temperature and current capability, silicon is preferred in comparison to germanium.

⇒ The symbol is Zener diode $\rightarrow$ 

⇒ It has already been discussed that when the reverse bias on a crystal diode is increased, a critical voltage, called Breakdown voltage is reached where the reverse current increases sharply to a high value.

⇒ The breakdown region is the ^{Zener voltage} ~~area~~ of the reverse characteristics as shown in Fig.



⇒ The Satisfactory explanation of this breakdown of the junction was first given by the American Scientist C. Zener.

⇒ The breakdown voltage is sometimes called Zener voltage and the sudden increase in current is known as Zener current.

→ The breakdown or Zener voltage depends upon the amount of doping. If the diode is heavily doped depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage.

Important points

1. A Zener diode is like an ordinary diode except it is properly doped to have a sharp breakdown voltage.
 2. A Zener diode is always reverse connected i.e. it is always reverse biased.
 3. A Zener diode has sharp breakdown voltage, called Zener voltage V_Z .
 4. When forward biased, its characteristics are those of ordinary diode.
 5. The Zener diode is not immediately burnt just because it has entered the breakdown region.
- As long as the external circuit connected to the diode limits the diode current to less than burn out value, the diode will not burn out.

→ Zener diode operated in this region will have a relatively constant voltage across it, regardless of the value of current through the device. This permits the Zener diode to be used as a voltage regulator.

Application

- :- Voltage regulator.
- :- Meter Protection.
- :- As peak clipper.
- :- As reference element.
- :- Switching operation.

Tunnel Diode

→ A Tunnel diode (also known as a Esaki diode) is a type of Semiconductor diode that has effectively "negative resistance" due to the quantum mechanical effect called tunneling.

→ Tunnel diodes have a heavily doped Pn junction.

→ The heavy doping results in a broken band gap, where conduction band electron states on the N-side are more or less aligned with valence band holes states on the P-side.

→ A Tunnel diode is one of the most commonly used negative conductance devices. It is also known as Esaki diode after L. Esaki for his work on this effect.

→ Tunnel diode's depletion layer width is very small.

→ In the current voltage characteristics of tunnel diode, we can find a negative slope region when forward bias is applied.

V-I characteristic

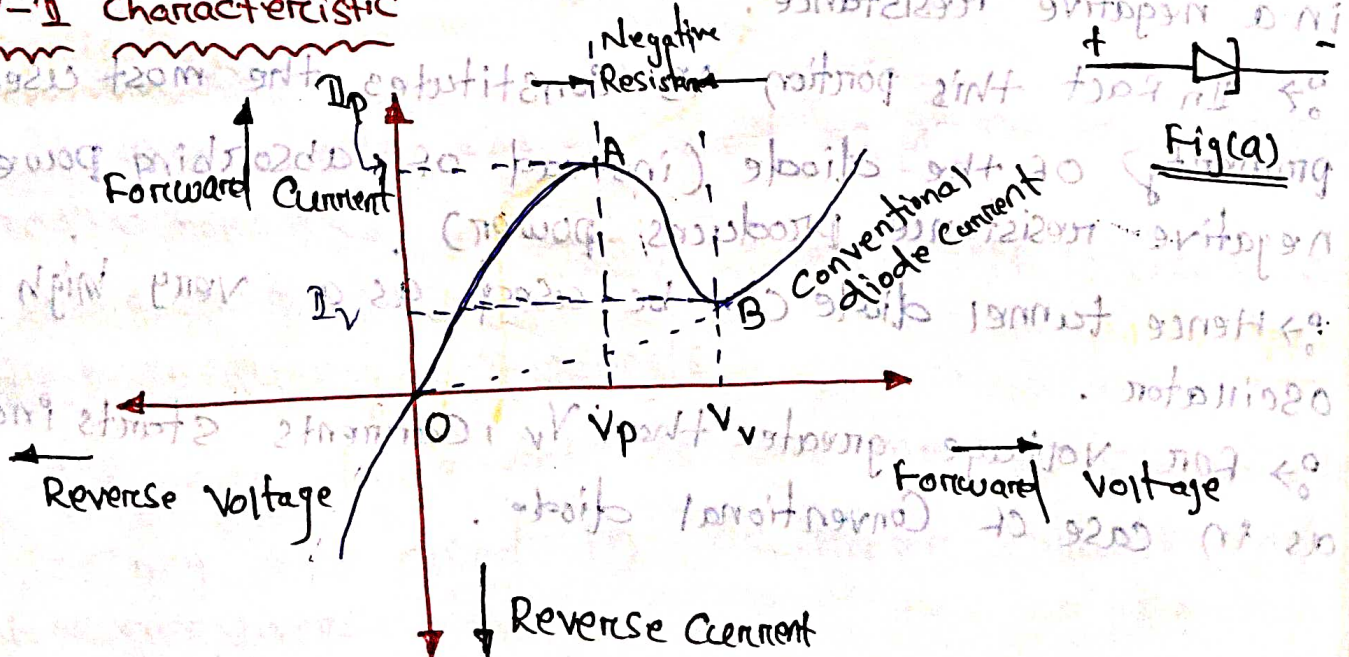


Fig-b

→ Figure (a) shows the symbol of tunnel diode and Fig (b) shows the $V-I$ characteristics.

→ The right hand side portion is the normal forward biased diode region of the device.

→ As soon as the forward bias is applied, significant current is produced.

→ The current quickly reaches its peak value I_p when the applied forward voltage reaches a value V_p .

The peak current value is denoted by point A.

→ The current variation in the vicinity of origin is due to quantum mechanical tunnelling of electrons through narrow space charge region of the junction. So as the voltage increase from zero to V_p and the current increases from 0 to I_p .

→ When forward voltage is further increased, the diode current starts decreasing. The current decreases to I_v corresponding to valley voltage V_v . This situation is denoted by a point B. Thus from point A to B, the current decreases as voltage increases. This results in a negative resistance.

→ In fact this portion AB constitutes the most useful property of the diode (instead of absorbing power, a negative resistance produces power).

→ Hence tunnel diode can be used as a very high frequency oscillator.

→ For voltage greater than V_v , current starts increasing as in case of conventional diode.

Fig. 5.2.1

FOLLOWING ARE FEW IMPORTANT POINTS REGARDING DIODE

- 2 (i) Between points A and B, the current decreases with increase in voltage. This shows that the tunnel diode has a negative resistance in this region. The portion AB constitutes the most important property of tunnel diode which makes it useful in high frequency oscillations.
- (ii) For voltages above V_v (Valley voltage), the current starts increasing as in case of conventional diode.
- (iii) The reverse current increases with increasing reverse voltage.
- (iv) If we take currents between I_v and I_p and draw perpendiculars to current axis, they cut the curve corresponding to three voltages, one corresponding to curve OA, other at V_p and the third with respect to curve AB. Thus each current can be obtained at three different applied voltages. This feature makes the tunnel diode useful in pulse and digital circuits.

Application

→ Tunnel diode can be used as a switch, amplifier, and oscillator.

→ Since it shows a fast response, it is used as high frequency components.

→ Tunnel diode acts as logic memory storage device.

∴ They are used in oscillator circuits, and FM receivers etc.



PIN DIODE

⇒ PIN Diode has highly improved switch time in comparison with PN diode.

⇒ PIN Diodes are therefore, extensively used as microwave switches.

⇒ Here a high resistivity intrinsic layer is sandwiched between p^+ and n^+ regions.

⇒ Due to increased separation between p and n regions the capacitance decreases. So PIN diode has fast response time. Therefore PIN Diode are useful at high frequencies.

WORKING



⇒ With no bias applied, there will be diffusion of carriers because there is concentration gradient across the junction. The diffusion of electron and holes produce a depletion layer across pI and IN junction.

⇒ The layers penetrate to a little distance in p and n regions while a large distance in I region.

⇒ In this way, the device has a high value of resistance.

⇒ As the reverse bias is applied and gradually increased, the depletion layer becomes more and more thick until the entire I region is swept free of mobile carriers.

⇒ The applied bias necessary for this to happen is termed as the swept out voltage.

⇒ And now PIN Diode acts like a constant capacitance.



⇒ In most microwave applications it is necessary to have the Π region swept out.

⇒ If this is not done the current flow by mobile carriers in high resistivity Π region constitutes and undue source of signal loss.

:- Hence when PIN diode used as microwave switch it is biased on off conditions.

Application

⇒ It can be used as alternator.

⇒ It is used as constant impedance device.

⇒ PIN Diodes can be used in construction of phase modulator and amplitude modulator.

⇒ It can be used as phase shifter.

⇒ It can be used as T-R switch in radar applications.

Chapter - 3

RECTIFIER CIRCUITS & FILTERS

⇒ Classification of filter

⇒ Analysis of half wave, full wave centre tapped and Bridge rectifier and calculate

* DC output current and voltage

* RMS output current and voltage.

* Rectifier frequency

* Ripple factor

* Regulation

* Transformer utilization factor

* Peak inverse voltage.

⇒ Filters

* Shunt capacitor filter.

* Chock input filter

* π filter.

For the operation of most of electronic devices and circuits, a d.c. source is required.

⇒ It is advantageous to convert domestic a.c. supply into d.c. voltage.

⇒ The process of converting a.c. voltage into d.c. voltage is called rectification.

⇒ This is achieved with (i) rectifier (ii) filter and (iii) voltage regulator circuits.

Rectifier

Rectifiers are further classified in two categories.

- * Half-wave Rectifier

- * Full-wave Rectifier

Half wave Rectifier

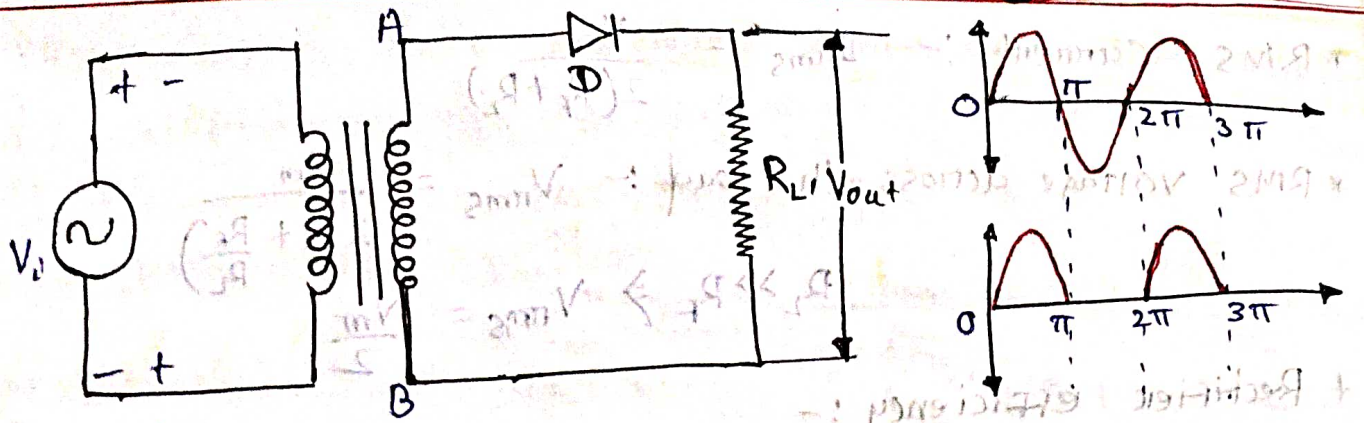
⇒ A rectifier is defined as the electronic device for converting a.c. voltage or current into unidirectional voltage or current.

⇒ For this purpose a unidirectional conduction device such as P-N Diode is used.

⇒ A half wave rectifier is one which converts a.c. voltage into a pulsating voltage using only one half cycle of the applied a.c. voltage.

⇒ The a.c. voltage to be rectified is applied to single diode connected in series with a load resistor R_L .

⇒ When it is required to step up or step down the input voltage, a power transformer is used as shown in fig.



operation

→ The A.C. voltage across the secondary winding changes polarities after every half cycle. During the +ve half cycle of input A.C. voltage, A becomes positive with respect to end B. This makes the diode forward biased & hence it conducts current.

→ During the -ve half cycle, end A is negative with respect to end B. Under this condition the diode is reverse biased & it conducts no current.

→ Therefore current flows through the diode during +ve half cycle of input A.C. voltage only, it is blocked during the -ve half cycles.

→ In this way current flows through the load R_L always in the same direction. Hence D.C. output is obtained across R_L . It may be noted that output across the load is pulsating D.C.

R_F = Forward bias diode resistance

ANALYSIS FORMULA

* D.C. output current :-
$$I_{dc} = \frac{V_m}{\pi(R_F + R_L)}$$

$(R_L \gg R_F)$:-
$$I_{dc} = \frac{V_m}{\pi R_L} = 0.318 \frac{V_m}{R_L}$$

* D.C. output voltage :-
$$V_{dc} = \frac{V_m}{\pi(1 + \frac{R_F}{R_L})}$$

$R_L \gg R_F \Rightarrow V_{dc} = \frac{V_m}{\pi} = 0.318 V_m$

* RMS Current :- $I_{rms} = \frac{V_m}{2(R_f + R_L)}$

* RMS voltage across the load :- $V_{rms} = \frac{V_m}{2(1 + \frac{R_f}{R_L})}$

$R_L \gg R_f \Rightarrow V_{rms} = \frac{V_m}{2}$

* Rectifier efficiency :-

The rectifier efficiency is defined as the ratio of d.c. output to the a.c. input power i.e.

$\gamma = \frac{P_{dc}}{P_{ac}} = 40.6\%$

* Ripple factor :- (γ)

→ The output of a rectifier consists of d.c. component as well as a.c. component.

→ The a.c. component in the output is called as ripple. This is undesirable.

→ Thus smaller is the ripple, more effective will be the rectifier.

→ The ripple factor (γ) gives an idea about the waviness of the rectified voltage and is defined as the ratio of the effective value of the a.c. component of voltage or current to the direct or average value. Hence,

$\gamma = \frac{\text{ripple voltage}}{\text{d.c. voltage}} = \frac{\text{rms value of a.c. component}}{\text{d.c. value of wave}}$

$\gamma = \frac{V_{rms}}{V_{dc}} = \frac{(V_r)_{rms}}{V_{dc}} = \frac{(I_r)_{rms}}{I_{dc}}$

$\gamma = \frac{V_r}{V_{dc}} = \frac{I_r}{I_{dc}}$

* Regulation :- The regulation is defined as the variation of d.c output voltage with change in d.c. load current thus.

$$\text{percentage Regulation} = \frac{V_{\text{no, load}} - V_{\text{full load}}}{V_{\text{full load}}} \times 100$$

* Transformer utilisation factor

The dc power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. So transformer utilisation factor is defined as

$$\text{TUF} = \frac{\text{d.c power to be delivered to the load}}{\text{a.c rating of the transformer Secondary}}$$

$$= \frac{P_{\text{d.c}}}{P_{\text{a.c (rated)}}} = 0.287$$

* peak inverse voltage (PIV)

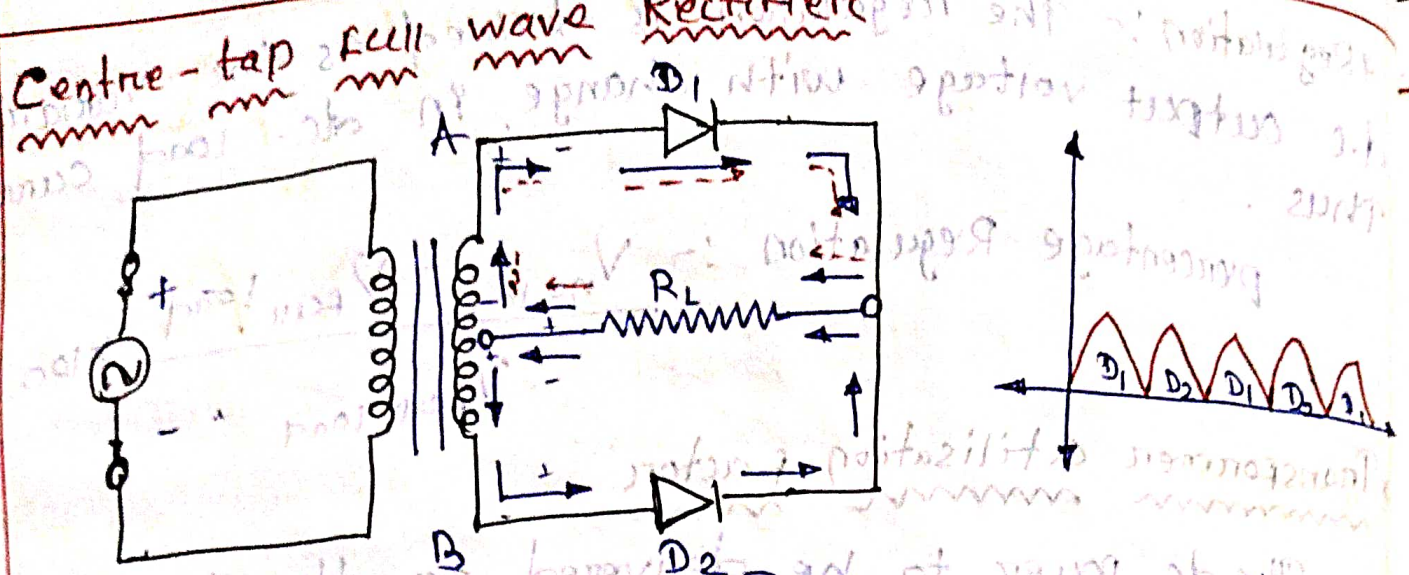
:- peak inverse voltage is the maximum voltage across the diode in the reverse direction
:- it is denoted as V_m

* Full wave Rectifier

→ A full wave Rectifier utilises both half-cycle of input A.c voltage to produce the D.c output.

→ it is of two types

- (i) Centre tap full wave Rectifier
- (ii) Full wave bridge rectifier.



→ The circuit employs two Diode D_1 & D_2 as shown in a Secondary Centre tapped Secondary winding AB is used with two diodes connected so that each uses one half cycle of input AC voltage.

→ In other words, Diode D_1 utilizes the AC voltage appearing across the upper half (OA) of Secondary winding for rectification which diode D_2 uses the lower half winding (OB).

Operation

→ During the positive half-cycle of Secondary Voltage the end A of the Secondary winding becomes positive & end B negative.

→ This makes the Diode D_1 forward biased & diode D_2 reverse biased. Therefore diode D_1 conducts which diode D_2 does not work.

→ The Conventional Current flow is through diode D_1 Load resistance R_L & the upper half of Secondary winding as shown by dotted arrows.

→ During the negative half cycle end A of Secondary winding becomes negative & end B positive. Therefore diode D_2 conducts while D_1 does not.

→ The conventional Current flow is through diode D_2 , load R_L & lower half winding as shown by solid arrows.

→ Referring to fig, it may be seen that current in the load R_L in the same direction for both half cycle of input AC voltage. Therefore DC is obtained across the load R_L .

ANALYSIS FORMULA

DC or Average Current :- $0.637 I_m$

2000mA

DC output voltage :- $0.636 I_m R_L$

RMS Current :- $\frac{I_m}{\sqrt{2}}$

Rectifier Efficiency (γ) = $\frac{P_{dc}}{P_{ac}} = 81.2\%$

Ripple Factor = $\frac{I_{rms}}{I_{dc}} = 1.11$

Regulation :- $V_{dc} = \frac{2 I_m R_L}{\pi} = \frac{2 V_m}{\pi} - I_{dc} R_f$

Peak Inverse voltage (PIV) =

Peak Inverse voltage is the maximum possible voltage across a diode when it is reverse biased. Consider that diode D_1 is in forward biased i.e. conducting and diode D_2 is reversed biased i.e. nonconducting.

In this case a voltage V_m is developed across the load resistor R_L . Voltage across diode D_2 is the sum of the voltage across load resistor R_L and voltage across the lower half of transformer secondary V_m . Hence PIV of Diode

$$D_2 = V_m + V_m = 2V_m$$

similarly PIV of Diode $D_1 = 2V_m$

Transformer utilisation Factor

- The average TUF in full wave rectifying circuit determined by considering the primary and secondary winding separately. There are two secondary here.
- Each secondary is associated with one diode. This is just similar to secondary of half wave rectifier.
- Each secondary has TUF as 0.287.

Advantages

- The D.C output voltage and load current values are twice than that of a half wave rectifier.
- The ripple factor is much less (0.482) than that of a half rectifier (1.21).
- The efficiency is twice (81.2%) than that of half wave rectifier (40.6%).

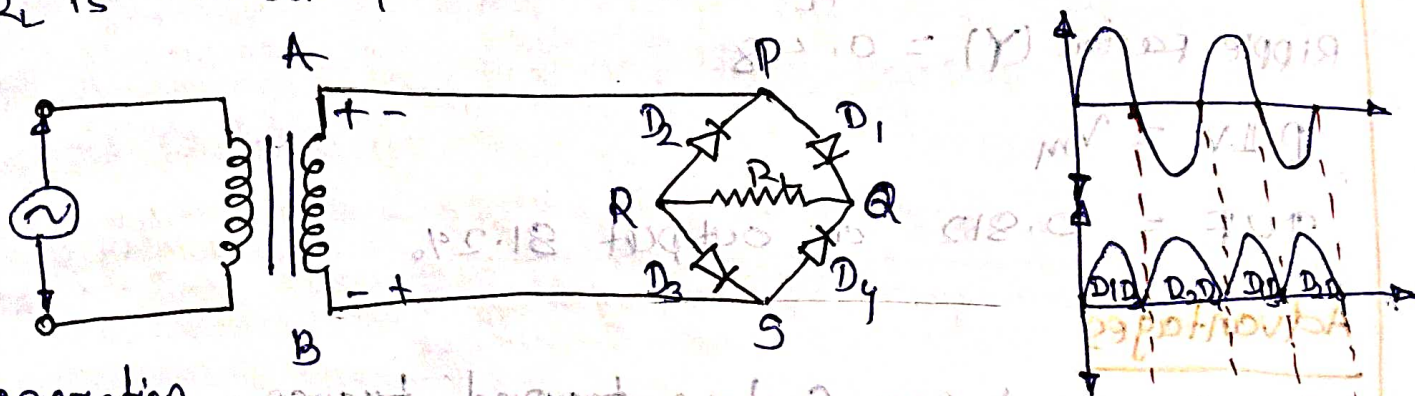
Disadvantage

- It is difficult to locate the centre tap on the secondary winding.
- The P.C output is small as each diode utilize only one half of the transformer secondary voltage.
- The diode used must have high peak inverse voltage.

→ Full wave Bridge Rectifier

- The need for a centre tapped power transformer is eliminated in the bridge rectifier.
- It contains four diode D_1, D_2, D_3 & D_4 connected to form bridge.
- The A.C supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer.

→ Between other ends of the bridge, the load resistance R_L is connected.



Operation

→ The bridge rectifier consists of 4 diodes such as D_1, D_2, D_3 & D_4 are connected in a bridge arrangement. Shown in fig.

→ In the +ve half-cycle, point A becomes +ve & B becomes -ve, so diode D_1 & D_3 are forward biased & hence conduct as D_2 & D_4 are reverse biased hence not conduct.

→ So, current flows in the direction A-P-Q-R-S. So the output voltage which is drawn across R_L is due to diode pair D_1 & D_3 .

→ In -ve half-cycle, point A becomes -ve & B becomes +ve, so diode D_2 & D_4 are forward biased hence conduct but D_1 & D_3 are reverse biased hence does not conduct.

→ So the current flows in the conduction B-S-Q-P-A. So the output voltage drawn across R_L is due to diode pair D_2 & D_4 .

ANALYSIS FORMULA

$$I_{dc} = 0.636 I_m$$

$$V_{dc} = 0.636 V_m = 0.636 I_m R_L$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\text{Efficiency } (\eta) = \frac{0.812}{1 + \frac{P_F}{P_L}} \text{ OR } = 81.2\%$$

$$\text{Ripple factor } (r) = 0.48$$

$$PIV \approx V_m$$

$$\eta_{UF} = 0.812 \text{ OR output } 81.2\%$$

Advantages

- The need for Centre-tapped transformer is eliminated
- The output is twice that of the Centre tap circuit for the same Secondary voltage
- The PIV is one half that of the Centre tap circuit (for DC output)
- It is suitable for high voltage

Disadvantages

- It requires four diodes
- Internal resistance high

Comparison of Rectifiers

Sl. No.	Particulars	Half wave	Centre tap	Bridge
01.	No. of diodes	2	4	4
02.	Transformer necessary	no	yes	no
03.	Max. efficiency	40.6%	81.2%	81.2%
04.	Ripple factor	1.21	0.48	0.48
05.	output frequency	f_{in}	$2f_{in}$	$2f_{in}$
06.	PIV	V_m	$2V_m$	V_m

Ripple factor

The ratio of r.m.s value of A.C Component to the DC component in the rectifier output is known as ripple factor. i.e.,

$$\text{Ripple Factor} = \frac{\text{R.M.S Value of A.C Component}}{\text{Value of DC component}} = \frac{I_a}{I_{dc}}$$

Filters

- A filter circuit is a device which removes the ac component of rectifier output but allows the d.c component to reach load.

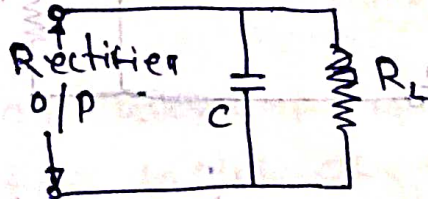
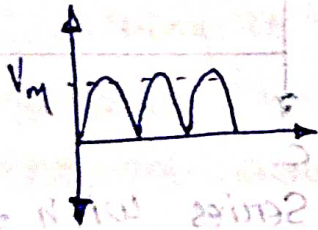
∴ filter circuit mostly have 3 types i.e.

* Shunt capacitor filter.

* choke input filter

* π filter.

Shunt capacitor filter



∴ It consists of a capacitor 'C' placed across the rectifier output in parallel with the load R_L .

∴ The pulsating DC of the rectifier is applied to the capacitor.

∴ As the rectifier voltage increases, it charges the capacitor & supplies current to the load.

∴ At point A the capacitor is charged to the peak value V_m of the rectifier voltage. Now the rectifier voltage starts decrease.

→ As this occurs, the capacitor discharge through the load & voltage across it (i.e. across parallel combination of R-C) decreases as shown by the line AB.

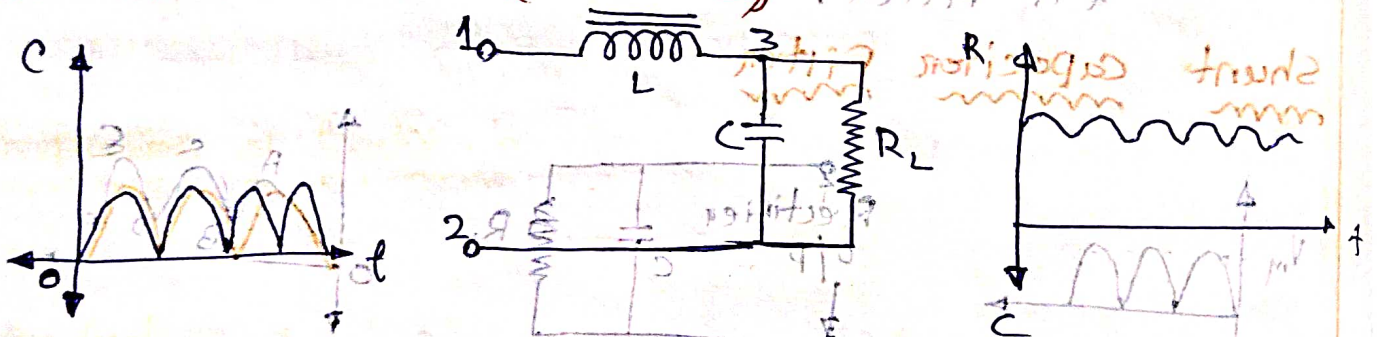
→ The voltage across the load will decrease only slightly because immediately the next voltage peak comes & recharges the capacitor.

→ This process is repeated again & again the output voltage wave form becomes A-B-C-D-E-F.

→ It may be seen that very little ripple is left in the output.

→ The capacitor filter circuit is extremely popular because of its low cost, small size, little weight and good characteristics.

Choke input filter or (LC filter)



→ It consists of a choke connected in series with the rectifier output & a filter capacitor (across the load).

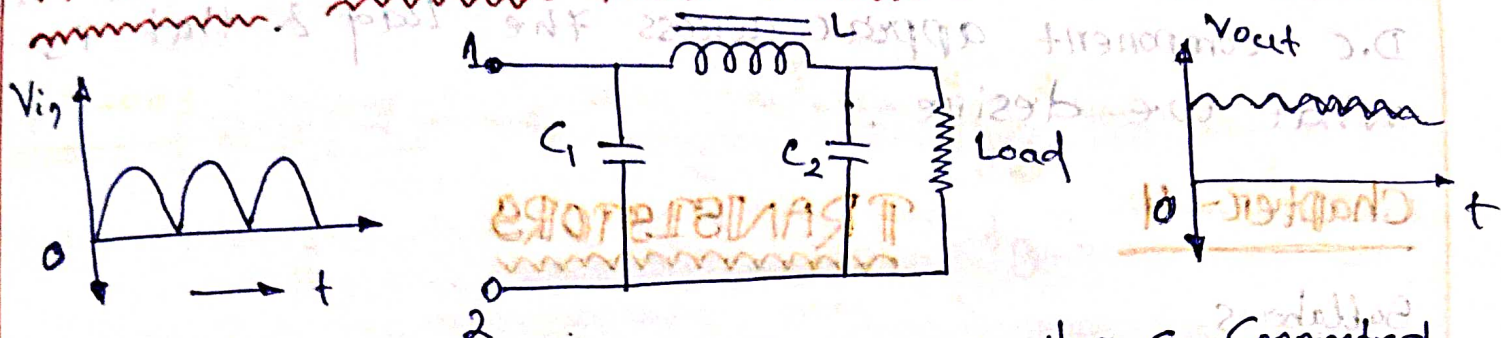
→ Only single filter section is shown but several identical sections are efficiently used to reduce the pulsation.

→ The pulsating output of the rectifier is applied across terminal 1 & 2 of the filter circuit.

→ As discussed the pulsating output of rectifier contains AC and DC components.

⇒ The choke offers high opposition to the AC components but negligible opposition to the DC components.
 ⇒ The result is that most of the AC components appear across the choke, while whole of DC components pass through the choke on its way to load.

π Filter (capacitor input filter)



⇒ π filter consists of a filter capacitor C_1 connected across the rectifier output.

⇒ A choke L in series with another filter capacitor C_2 connected across the load.

⇒ Only one filter section is shown but several identical sections are used to improve the smoothing action.

⇒ The resulting wave form of the rectifier is applied across the input of the filter.

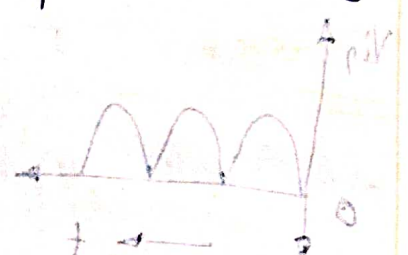
⇒ The filter action (of the three components C_1 , L & C_2 of the filter) is described below.

⇒ The filter capacitor C_1 offers low reactance to AC components of rectifier output - while it offers infinite reactance to the DC component.

Therefore C_1 by passes all applicable amount of AC component while the DC component continues its journey to the choke L .

→ The Choke L offers high reactance to the A.C. Component but it offers almost zero reactance to the d.c. Component therefore allows the d.c. Component to flow through it, while the a.c. Component is blocked.

→ The Filter Capacitor C_2 bypasses the A.C. Component which the choke has failed to block. Therefore only D.C. Component appears across the load & that is what we desire.



Chapter - 4

TRANSISTORS

Syllabus

- * Principle of Bipolar Junction Transistor
- * Different modes of operation of transistor.
- * Current Components in a transistor.
- * Transistor as an amplifier
- * Transistor circuit configuration & its characteristics
 - CB Configuration
 - CE Configuration
 - CC Configuration

Introduction

→ A transistor is a semiconductor device used to amplify or switch electrical signal and power.

OR → A transistor is a device that regulates current or voltage flow and acts as a switch or gate for electronic signal.

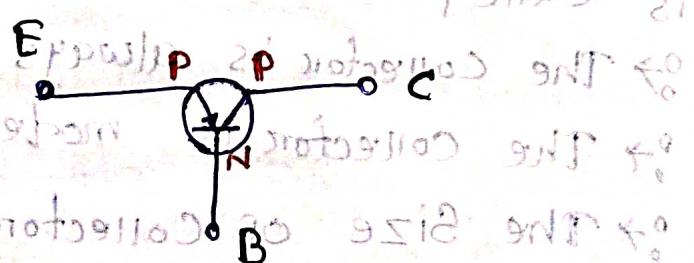
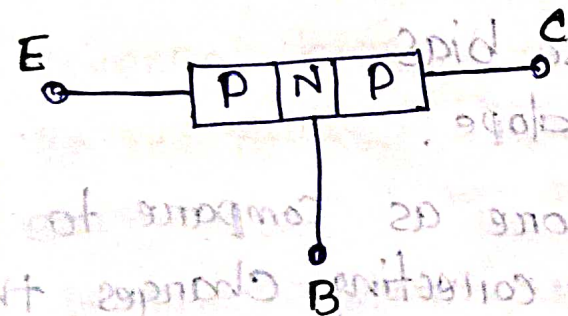
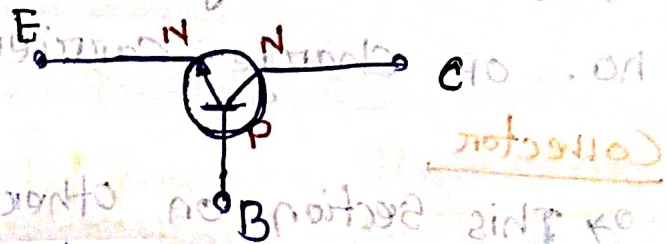
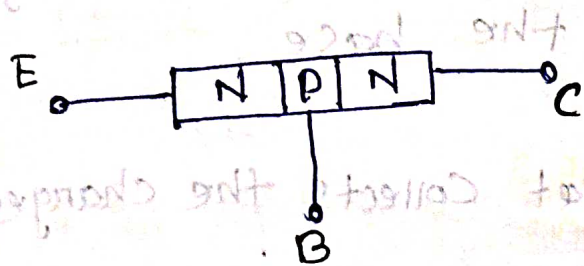
By polar junction Transistor (BJT)

→ A transistor consist of two PN junction formed by sandwiching either P type or N type Semiconductor between a pair of opposite site.

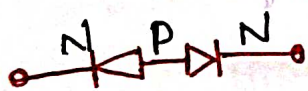
→ It is of two types

(i) NPN Transistor

(ii) PNP Transistor



→ There are two PN junction so a transistor may be considered as a combination of two diodes back to back.



→ There are three terminals one taken from each type of Semiconductor.

→ The middle section is a very thin layer which is the most important factor in the function of transistor.

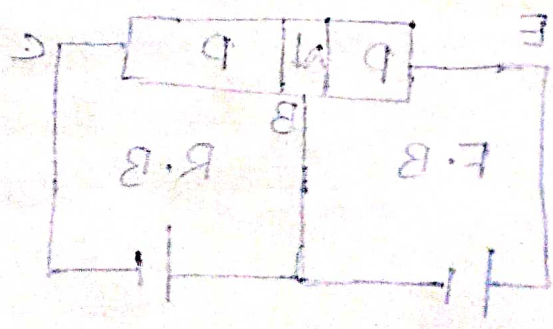
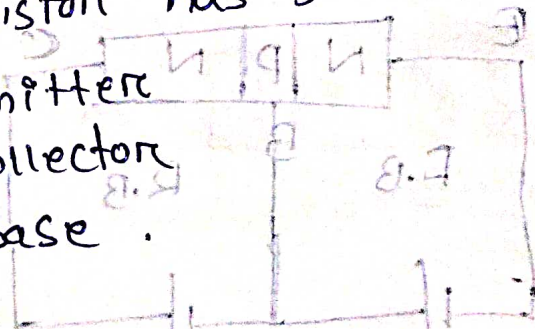
Transistor terminal

transistor has 3 terminals

(i) Emitter

(ii) Collector

(iii) Base



Emitter

⇒ This section supplies charge carriers (electrons or holes)

⇒ The emitter is always forward biased with respect to base. So that it can supply a large no. of majority charge carriers.

⇒ It is heavily doped. So that it can inject a large no. of charge carriers into the base.

Collector

⇒ This section on other side that collects the charges is called the collector.

⇒ The collector is always reverse bias.

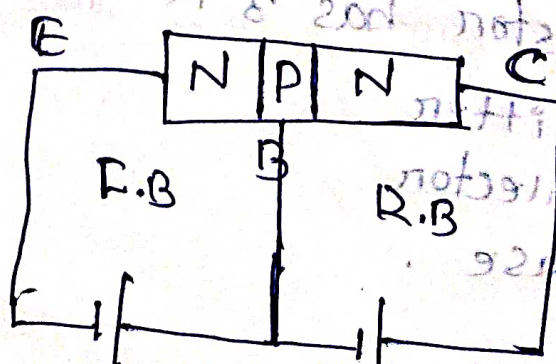
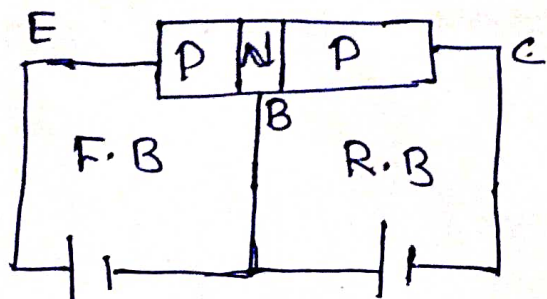
⇒ The collector is moderately doped.

⇒ The size of collector is more as compare to emitter & base because while collecting charges the collector is heated. So for dissipating extra heat more surface area is required. So size of collector is larger as compare to other two sections.

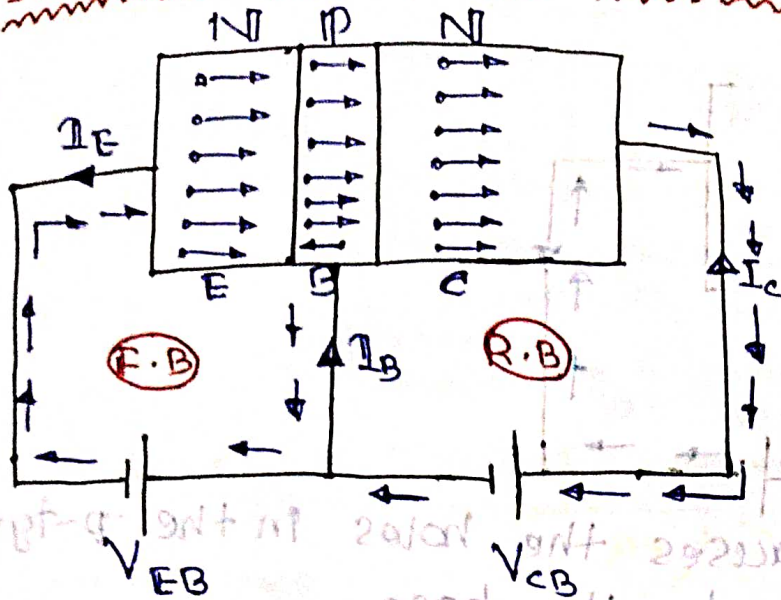
Base

⇒ The middle section which forms two P-N junction between the emitter & collector is called the base.

⇒ This section is very thin as compared to other two sections & it is also lightly doped.



Different modes of operation in Transistors



imp. Amplification

F.B - R.B = Active Region
 R.B - F.B = Inverse Active Region
 F.B - F.B = Saturation Region
 R.B - R.B = Cut-off Region

→ In NPN Transistor the base emitter junction is forward biased and collector base junction is reverse biased.

→ The forward bias causes the electrons in the n-type emitter to flow forward the base.

→ This constitutes the emitter current I_E as these electron flow through the p-type base, this tends to combine with hole.

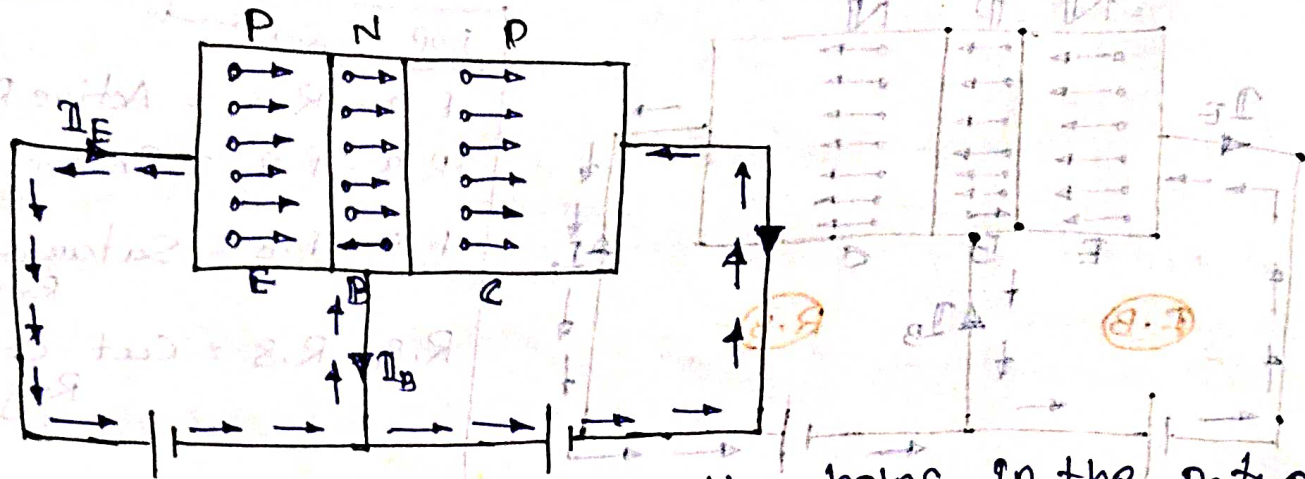
→ As the base is lightly doped & very thin, there are only few electrons (less than 5%) combine with holes to constitute base current I_B .

→ The remainder (more than 95%) cross over into the collector region to constitute collector current I_C flow in the collector circuit.

→ It is clear that emitter current is the sum of collector and base current.

$$I_E = I_B + I_C$$

Working of PNP Transistor



→ The forward bias causes the holes in the p-type emitter to flow towards the base.

→ This constitutes emitter current I_E .

→ As these holes cross into n-type base, they tend to combine with the electrons.

→ As the base is lightly doped & very thin, therefore only a few holes (less than 5%) combine with the electrons to constitute base current (I_B).

→ The remainder (more than 95%) cross into the collector region to constitute collector current I_C .

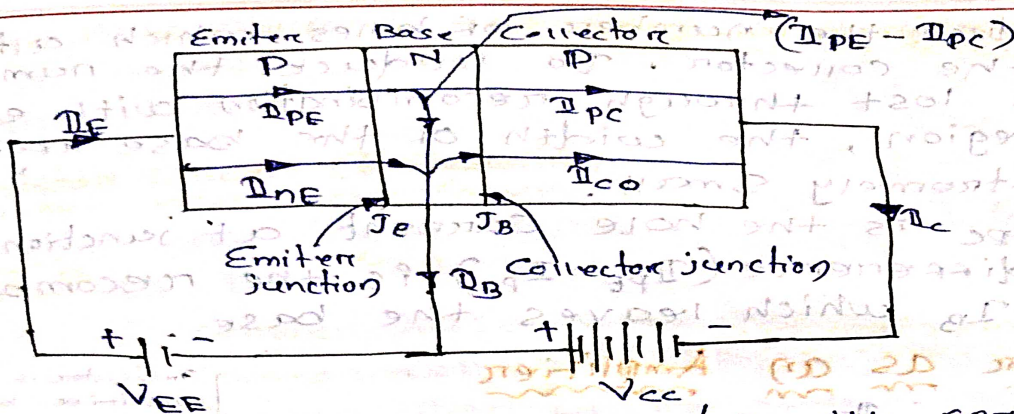
→ In this way, almost the entire emitter current flows in the collector current.

→ It may be noted that current conduction with PNP transistor is by holes.

→ However, in the external connecting wires the current is still by electron.

Current Components in a Transistor

→ Fig shows the various current components which flow across the forward-biased emitter junction and reverse-biased collector junction in PNP transistor.



(Current components in a transistor with forward biased emitter and reverse biased collector)

The emitter current consists of the following two parts.

(i) Hole current I_{PE} constituted by holes (holes crossing from emitter into base)

(ii) Electron current I_{NE} constituted by electrons (electrons crossing from base into the emitter).

∴ Total emitter current

$$I_E = I_{PE} + I_{NE}$$

majority minority

⇒ In commercial transistor the doping of emitter region is made much heavier than base and hence the electron current components I_{NE} constituted by electrons is negligible small in comparison with hole current I_{PE} . Thus the commercial PNP transistor the emitter current consists of almost entirely of holes.

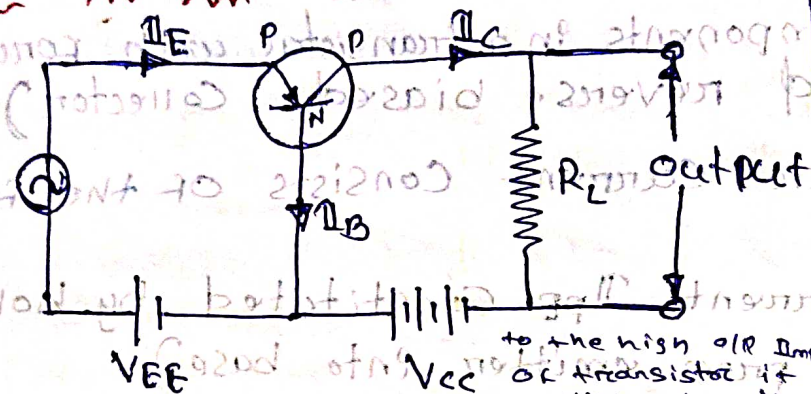
⇒ A few of holes crossing the junction J_E combine with the electrons in N-type base and rest of them cross the collector junction J_C . This reduces the no. of holes which ultimately reach the collector.

→ To reduce the number of holes which ultimately reach the collector. To reduce the number of holes so lost through recombination with electrons in N-region, the width of the base region is kept extremely small.

→ Let I_{pc} is the hole current at junction J_c .

→ The difference $(I_{pe} - I_{pc})$ is the recombination current I_B which leaves the base.

Transistor as an Amplifier



Transistor is used as an amplifier bcz it has low I_E impedance, high O/P impedance. As amplifier raises the strength of i/p signal. Normally transistor is used as amplifier in (CE) configuration bcz it is provided gain. Overall we can see due to low I_E impedance there is no distortion at I_E side and due to high O/P impedance it amplifies the i/p signal.

→ Figure shows the basic circuit of a transistor amplifier.

Here the weak signal to be amplified is applied between emitter base circuit and the output is taken across the load resistor R_L connected in the collector circuit.

→ A dc voltage V_{EE} is also connected in the input circuit. Now the question is that why V_{EE} is connected in the circuit?

→ Let, for instant, V_{EE} is not connected in the circuit. Now the negative peak of the applied signal, the emitter base junction is reverse biased.

→ This is not desirable because to achieve faithful amplification, the input circuit should always remain forward biased.

→ For this purpose, emitter bias battery V_{EE} or such a magnitude that input circuit is always forward biased.

Transistor Circuit Configuration

There are three types of configuration are in present as transistor.

i.e ① Common base (CB)

② Common Collector (CC)

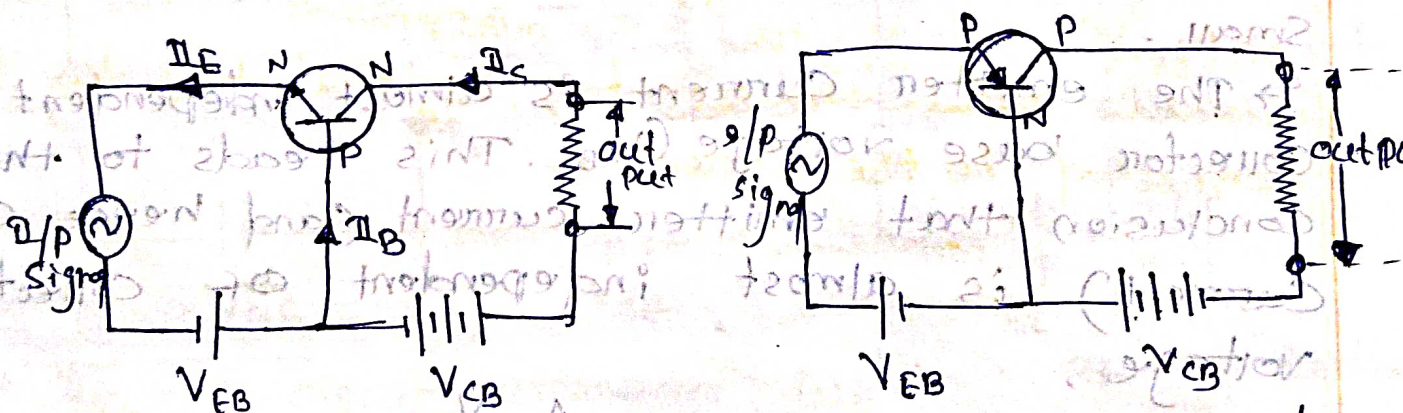
③ Common Emitter (CE)

→ Here the term 'Common' is used to denote the transistor lead which is common to the input and output circuits.

→ This is because when a transistor is connected in circuit, four terminals are required (two for input and two for output) while a transistor has only three terminals.

→ This difficulty is removed by making one terminal of the transistor common to both input and output terminals. The common terminal is generally grounded.

Common Base Connection



→ In this circuit arrangement input is applied between emitter and base. Output is taken from collector and base.

→ Here the base is common to both i/p & o/p circuit & hence the name common base connection.

Current amplification factor (α)

The ratio of change in collector current to the change in emitter current at constant collector base voltage (V_{CB}) is known as current amplification factor.

$$\text{i.e. } \alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}$$

Input characteristics

→ It is the curve between emitter current (I_E) &

Base Emitter voltage (V_{EB})

at constant collector

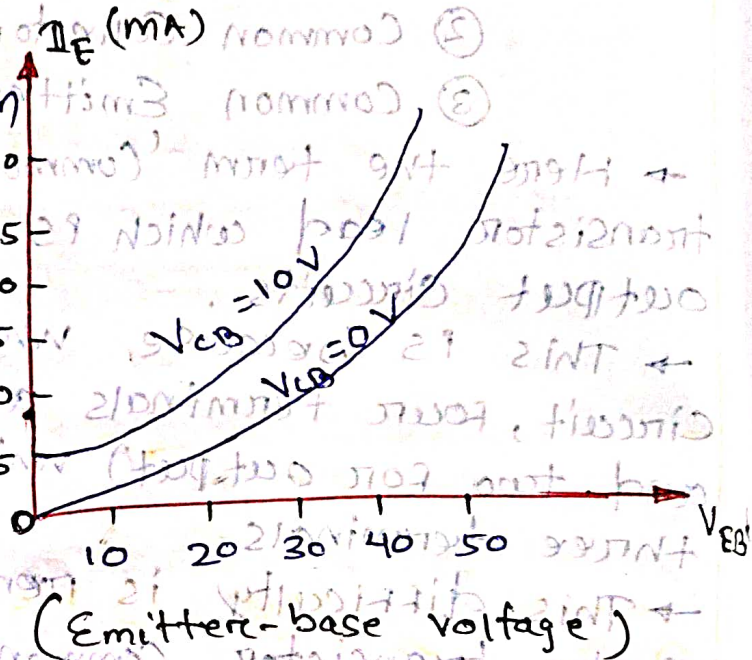
base voltage (V_{CB}).

→ The emitter current is generally taken along y-axis & emitter base

voltage x-axis.

→ The emitter current I_E increases rapidly with small increases in emitter base voltage (V_{EB}). It means the input resistance is very small.

→ The emitter current is almost independent of collector base voltage (V_{CB}). This leads to the conclusion that emitter current (and hence collector current) is almost independent of collector voltage.



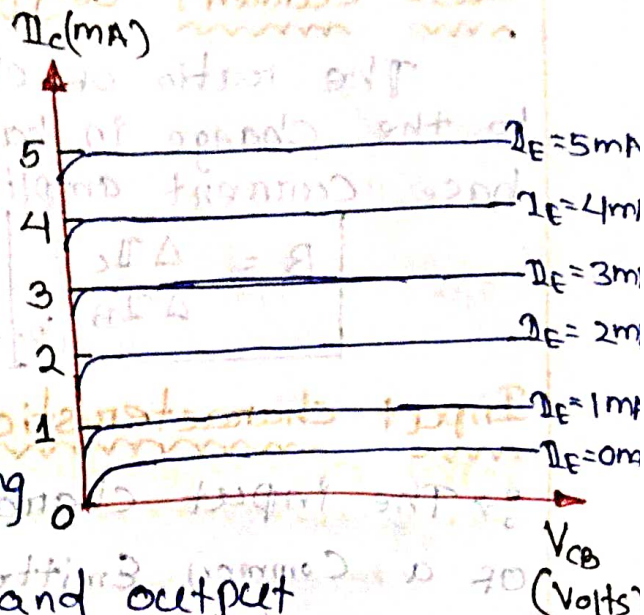
$$\text{Input resistance } r_{iE} = \frac{\Delta V_{BE}}{\Delta I_E} \text{ at constant } V_{CB}$$

Output characteristics

⇒ It is the curve between Collector current (I_C) & Collector Base voltage (V_{CB}) at constant Emitter current (I_E).

⇒ Generally, collector current is taken along y-axis and Collector Base voltage (V_{CB}) along x-axis.

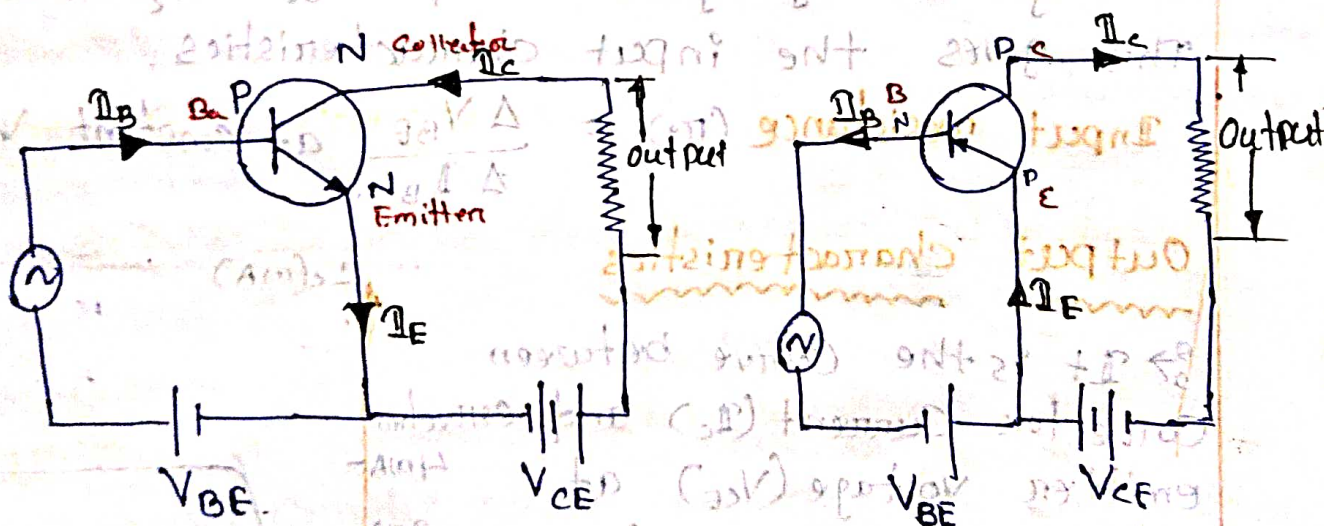
⇒ The fig shows the input and output characteristics of typical transistor in C.B Configuration.



$$\text{Output resistance } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

∴ The output resistance of CB circuit is very high, of the order of several tens of kilo-ohms.

⇒ Common Emitter Configuration



⇒ In this circuit arrangement input is applied between base and emitter, and output is taken from the emitter and collector.

⇒ Here emitter of the transistor is common in both input & output circuits and hence the name Common Emitter Connection.

Base Current Amplification Factor (β)

The ratio of change in collector current (ΔI_C) to the change in base current (ΔI_B) is known as base current amplification factor i.e.

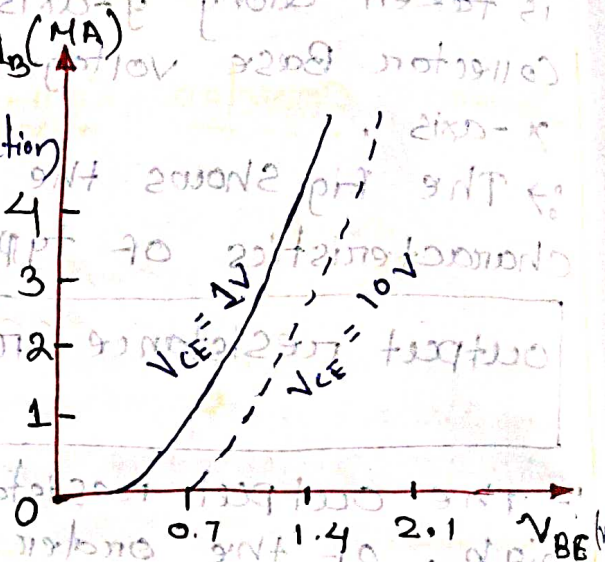
$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad V_{CE} \text{ constant}$$

Input characteristics

→ The input characteristic I_B (mA) of a Common Emitter Connection can be determined by the circuit as shown in fig. 3

→ Keeping V_{CE} at Constant (Let 10V), note the base current I_B for various values V_{BE} .

→ Then Plot readings obtained on the graph, taking I_B along y-axis and V_{BE} along x-axis. This gives the input characteristics.

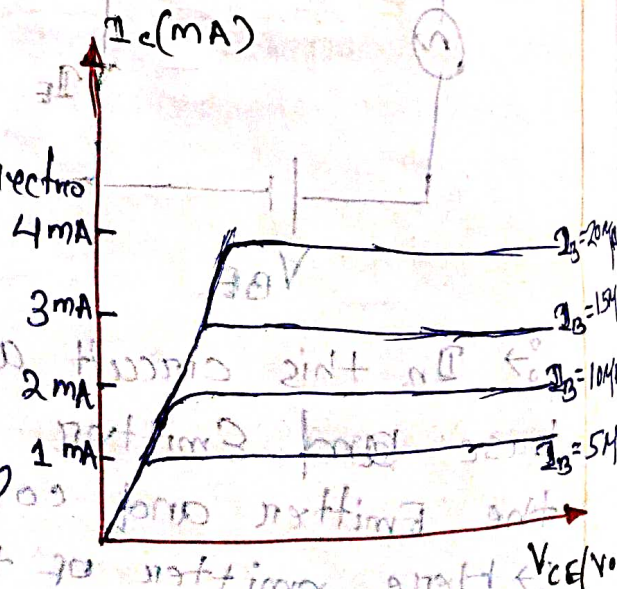


Input resistance (r_i) = $\frac{\Delta V_{BE}}{\Delta I_B}$ at constant V_{CE}

Output characteristics

→ It is the Curve between Collector Current (I_C) and collector emitter voltage (V_{CE}) at constant base current (I_B).

→ The output characteristics of CE circuit can be drawn with the help of above circuit arrangement.

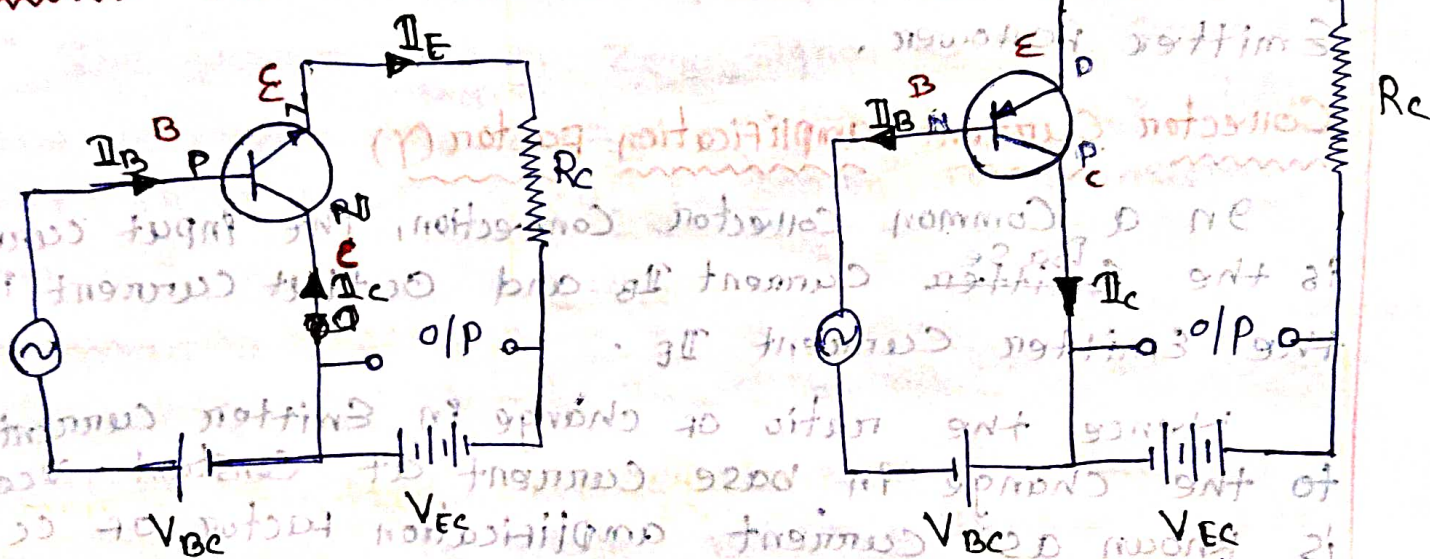


→ Keeping the base current I_B fixed at some value say, 5mA; note the collector current I_C for various value of V_{CE} .

→ Then plot the reading on a graph, taking I_C along y-axis and V_{CE} along x-axis.

→ This gives the output characteristics at $I_B = 5\text{mA}$ as shown in Fig. The test can be repeated for $I_B = 10\text{mA}$ to obtain the new output characteristics.

Common Collector Configuration



→ In this circuit arrangement input is applied between base & collector while output is taken between the emitter and collector.

→ Here collector of the transistor is common to both input & output circuits and hence the name Common Collector Connection.

Characteristics of Common Collector Connection

→ In a common collector circuit connection the load resistor is connected from emitter to ground, so the collector is tied to ground even though the transistor is connected in a manner similar to the CE connection.

→ Hence there is no need for a set of common-collector characteristics to choose the parameters of the circuit. The output characteristics of the CC configuration

is same as CE Configuration.

→ For CC Connection the output characteristics are Plot I_E versus V_{CE} for a constant value of I_B .

→ There is an almost unnoticeable change in the vertical scale of I_C of the CE connection if I_C is replaced by I_E for CC Connection.

→ The input characteristics of CC Connection, the CE characteristics is sufficient to obtain the required information.

→ Hence Common collector connection is known as Emitter follower.

Collector Current Amplification Factor (γ)

In a Common collector Connection, the input current is the ^{Base} ~~Emitter~~ current I_B and output current is the Emitter current I_E .

Hence the ratio of change in Emitter current to the change in base current at constant V_{CE} is known as current amplification factor of CC connection and is denoted as (γ) Gamma.

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

Chapter-5

TRANSISTOR CIRCUITS

5.1 → Transistor biasing

5.2 → Stabilization

5.3 → Stability factor

5.4 → Different Method of Transistors Biasing

→ Base Resistor method

→ Collector to base bias

→ Self bias or voltage divider method.

Transistor Biasing

Transistor Biasing is the process of providing DC voltage which helps in the functioning of the transistor.

Among the basic functions of a transistor is its amplification. For faithful amplification (amplified magnitude of signal without any change in shape), the following three conditions must be classified

- (i) Emitter-base junction should be forward biased.
- (ii) Collector-base junction should be reversed biased.
- (iii) There should be proper Zero Signal Collector Current.

"The proper flow of Zero Signal Collector Current and the maintenance of ^{proper} collector-emitter voltage during the passage of signal is known as transistor biasing".

→ When a transistor is not properly biased, it works inefficiently and produces distortion in the output signal.

→ Hence a transistor should be biased correctly.

→ A transistor is biased either with the help of battery or associating a circuit with the transistor.

Stabilization

→ "The process of making operating point independent of temp. changes or variations in transistor parameters is known as stabilization."

→ After stabilization the Zero Signal I_C and V_{CE} become independent of temperature variations or replacement of transistor.

→ A good biasing circuit always ensure the stabilization of operating point.

$$I_C = I_B(1 + \beta) + I_{CBO}$$

Stability factor (S)

The stability factor (S) is defined as the rate of change of Collector Current (I_c) w.r.t the collector leakage current (I_{co}) at constant β and V_{BE} . is called Stability factor (S) i.e

$$S = \frac{\partial I_c}{\partial I_{co}} \text{ , } V_{BE} \text{ \& } \beta \text{ are Constant}$$

where $\Rightarrow I_c$ = Collector current

I_{co} = Leakage current or Reverse Saturation Current.

OR $S_B = \frac{\partial I_c}{\partial V_{BE}} \cdot \frac{\partial V_{BE}}{\partial I_{co}}$

$\Rightarrow$ Stability factor $S_B = \frac{\partial I_c}{\partial V_{BE}}$

This is defined as the rate of change of Collector current (I_c) w.r.t β at constant V_{BE} and I_{co}

β = Base Current amplification factor

V_{BE} = input Base Emitter voltage

$\Rightarrow$ Stability factor (S_V) :- This is defined as the rate of change of I_c w.r.t V_{BE} at constant β and I_{co}

$$S_V = \frac{\partial I_c}{\partial V_{BE}}$$

Expression for Stability factor (S)

When a transistor is biased in the active region of its characteristics, the collector current I_c at any point is related to the base current I_B by the following expression.

$$I_c = \beta I_B + (\beta + 1) I_{co}$$

Differentiating w.r.t I_C at constant β

$$\frac{\partial I_C}{\partial I_C} = \frac{\partial}{\partial I_C} [\beta I_B + (\beta + 1) I_{CO}]$$

$$\Rightarrow 1 = \frac{\partial}{\partial I_C} \beta I_B + \frac{\partial}{\partial I_C} (\beta + 1) I_{CO}$$

$$\Rightarrow 1 = \beta \frac{\partial I_B}{\partial I_C} + (\beta + 1) \frac{\partial I_{CO}}{\partial I_C}$$

$$\Rightarrow 1 = \beta \frac{\partial I_B}{\partial I_C} + (\beta + 1) \cdot \frac{1}{S}$$

$$\Rightarrow 1 - \beta \frac{\partial I_B}{\partial I_C} = (\beta + 1) \cdot \frac{1}{S}$$

$$\Rightarrow S = \frac{(\beta + 1)}{1 - \beta \frac{\partial I_B}{\partial I_C}}$$

Different methods of Transistor Biasing

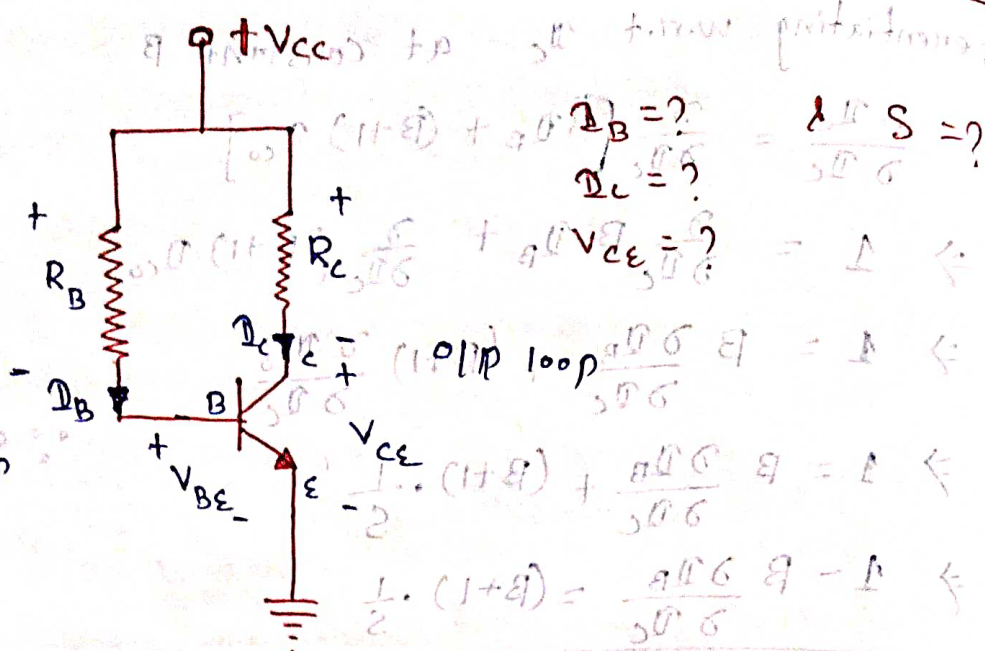
From the point of view of Simplicity and economy, only one source of supply in the output circuit is used. Some of the methods used for providing bias for a transistor are as follows.

- Base Resistor method or fixed bias method
- Collector to base
- Self bias or voltage divider bias.

→ The value of collector load is selected in such a way that the voltage between collector and emitter should not fall 0.5 volt for germanium and 0.7 volt for silicon.

Base Resistor method or (fixed bias method)

→ The transistor base current I_B remains constant for given values of V_{CC} and therefore the transistor operating point must be remains fixed. Hence it's called fixed biasing.



→ In this figure shows an NPN transistor connected in CE configuration with resistor biased. In this method a high resistance R_B is connected between positive terminal of supply V_{CC} and base of the tra

→ Applying KVL at g/p loop

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$\Rightarrow I_B R_B = V_{CC} - V_{BE}$$

$$\Rightarrow I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

Since V_{BE} as very small is $0.3V$ for Ge and $0.7V$ for Silicon. So V_{BE} is neglected i.e.

$$I_B = \frac{V_{CC}}{R_B}$$

→ As we already know

$$I_C = \beta I_B + (\beta + 1) I_{CBO}$$

$$\Rightarrow I_C = \beta I_B + I_{CEO}$$

$$\Rightarrow I_C \approx \beta I_B$$

$$\Rightarrow I_C = \beta \frac{V_{CC} - V_{BE}}{R_B}$$

$I_{CEO} = (\beta + 1) I_{CBO}$
 I_{CBO} = leakage Reverse current

$$I_C = \beta \frac{V_{CC} - V_{BE}}{R_B} + (\beta + 1) I_{CBO}$$

→ Applying KVL at o/p section

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - I_C R_C$$

Advantages

- This biasing circuit is very simple as only one resistance R_B is required.
- Biasing conditions can easily be set and the calculations are simple.

then find out Stability factor (S) = ?

$$S = \frac{\partial I_C}{\partial I_{CO}} = \frac{\partial}{\partial I_{CO}} \left[\beta \left(\frac{V_{CC} - V_{BE}}{R_B} \right) \right] + \frac{\partial}{\partial I_{CO}} (\beta + 1) I_{CO}$$

$$= \beta \frac{\partial}{\partial I_{CO}} \left(\frac{V_{CC}}{R_B} \right) - \frac{\partial}{\partial I_{CO}} \left(\frac{V_{BE}}{R_B} \right) + \frac{\partial}{\partial I_{CO}} (\beta I_{CO} + I_{CO})$$

$$= \beta \cdot 0 - 0 + (\beta + 1)$$

$$S = \beta + 1$$

Collector to Base bias

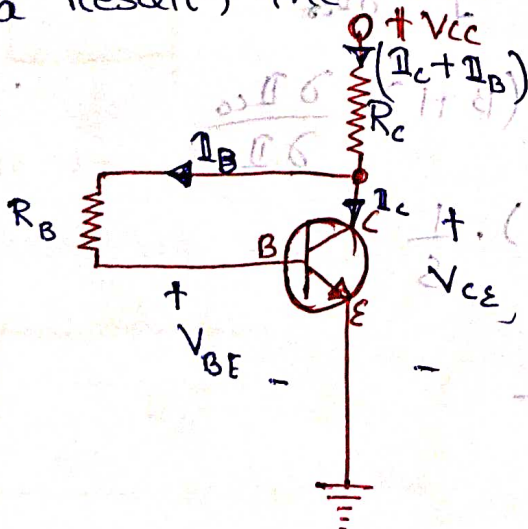
→ The circuit of an NPN transistor connected in CE Configuration with collector to base bias.

→ This circuit is same as base bias circuit except that the base resistor R_B is returned to collector rather than to V_{CC} supply.

→ Using this circuit there is considerable improvement in the stability.

→ If the collector current I_C tends to increase, the d.c voltage drop across R_C increases and consequently V_{CE} decreases.

→ As a result, the base current I_B also reduces.



$$I_B = ?$$

$$V_{CE} = ?$$

$$I_C = ?$$

$$S = \frac{I_C}{I_{CO}} = \frac{\beta + 1}{\beta}$$

Applying KVL at i/p loop

$$V_{CC} - R_C(I_C + I_B) - I_B R_B - V_{BE} = 0$$

$$\Rightarrow V_{CC} - I_C R_C - I_B R_C - I_B R_B - V_{BE} = 0$$

$$\Rightarrow I_B R_C + I_B R_B = V_{CC} - I_C R_C - V_{BE}$$

$$\Rightarrow I_B (R_C + R_B) = \frac{V_{CC} - I_C R_C - V_{BE}}{1} = \frac{30V - 10V}{1} = 20V$$

$$\Rightarrow I_B = \frac{V_{CC} - I_C R_C - V_{BE}}{R_C + R_B}$$

Applying KVL at o/p section

$$V_{CC} - R_C(I_C + I_B) - V_{CE} = 0$$

$$\Rightarrow V_{CE} = V_{CC} - R_C(I_C + I_B)$$

$$\Rightarrow V_{CE} = V_{CC} - R_C I_C - R_C I_B$$

As we know $I_C = \beta I_B + (\beta + 1) I_{CO}$

$$\Rightarrow I_C = \beta \left[\frac{V_{CC} - V_{BE} - I_C R_C}{R_C + R_B} \right] + (\beta + 1) I_{CO}$$

$$\Rightarrow I_C = \frac{\beta}{R_B + R_C} (V_{CC} - V_{BE} - I_C R_C) + (\beta + 1) I_{CO}$$

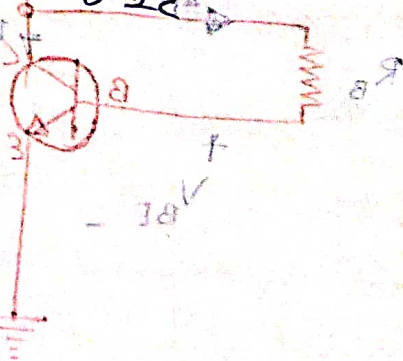
$$S = \frac{\partial I_C}{\partial I_{CO}} \text{ at constant } \beta \text{ \& } V_{BE}$$

$$\frac{\partial I_C}{\partial I_{CO}} = \frac{\partial}{\partial I_{CO}} \left[\frac{\beta}{R_B + R_C} (V_{CC} - V_{BE} - I_C R_C) \right] + \frac{\partial}{\partial I_{CO}} (\beta + 1) I_{CO}$$

$$\Rightarrow 1 = \frac{\beta}{R_B + R_C} (0 - 0 - R_C) + (\beta + 1) \frac{\partial I_{CO}}{\partial I_{CO}} \quad \therefore \frac{1}{S} = \frac{\partial I_{CO}}{\partial I_C}$$

$$\Rightarrow 1 = \frac{\beta \cdot (-R_C)}{R_B + R_C} + (\beta + 1) \cdot \frac{1}{S}$$

$$\Rightarrow 1 + \frac{\beta R_C}{R_B + R_C} = \frac{\beta + 1}{S}$$



$$\Rightarrow \frac{R_B + R_C + \beta R_C}{R_B + R_C} \times S = \beta + 1$$

$$\Rightarrow S = \frac{(\beta + 1)(R_B + R_C)}{R_B + R_C + \beta R_C}$$

$$\Rightarrow S = \frac{(\beta + 1)(R_B + R_C)}{R_B + R_C(\beta + 1)}$$

$$S = \frac{(R_C + R_B)(\beta + 1)}{R_B + R_C(\beta + 1)}$$

here
 $R_B \ll R_C$
 $R_B \approx R_C$

$$S = \frac{(\beta + 1)(R_B + R_C)}{(\beta + 1)R_C}$$

$$S = \frac{R_B + R_C}{R_C} \Rightarrow S \approx \frac{R_C}{R_C} \approx 1$$

$$S \approx 1$$

* Self bias or voltage divider bias

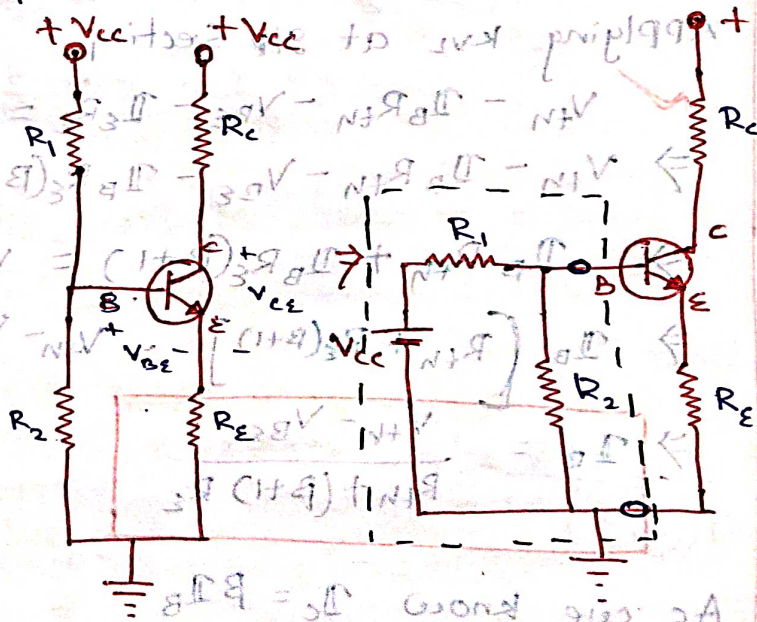
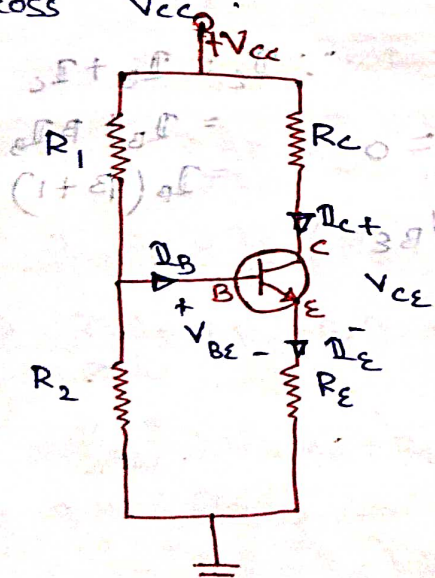
→ A very commonly used biasing arrangement is Self bias or emitter bias.

→ This is also known as universal bias stabilization.

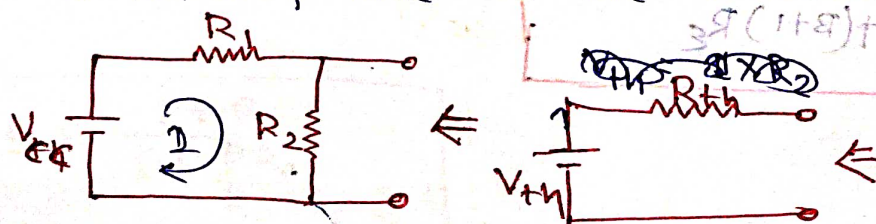
→ In this method two resistances R_1 & R_2 are connected across supply voltage V_{CC} and provide biasing.

→ The emitter resistance R_E provides stabilization.

→ The name voltage divider is derived due to the fact that resistors R_1 & R_2 form a potential divider across V_{CC} .



then we are solving in Thevenin's Circuit in above figure black dotted line so the thevenin's ckt.

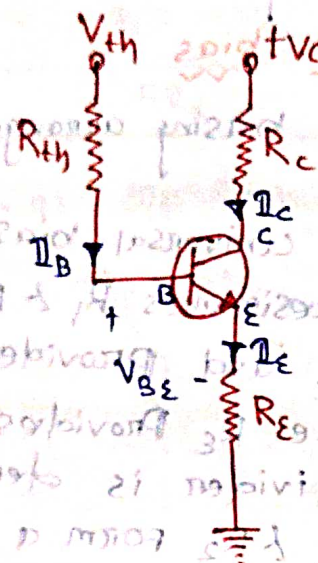


$$R_{th} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{th} = \frac{V_{cc} R_2}{R_1 + R_2}$$

$$\Rightarrow V_{th} = \frac{V_{cc} R_2}{R_1 + R_2}$$

Then the final circuit is like this



Applying KVL at g/p Section.

$$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$$

$$\Rightarrow V_{th} - I_B R_{th} - V_{BE} - I_B R_E (B+1) = 0$$

$$\Rightarrow I_B R_{th} + I_B R_E (B+1) = V_{th} - V_{BE}$$

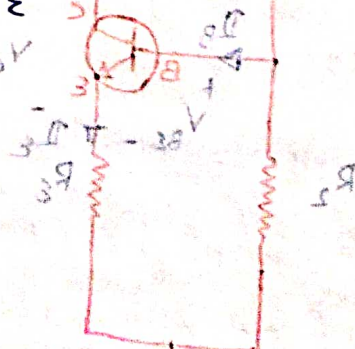
$$\Rightarrow I_B [R_{th} + R_E (B+1)] = V_{th} - V_{BE}$$

$$\Rightarrow I_B = \frac{V_{th} - V_{BE}}{R_{th} + (B+1) R_E}$$

As we know $I_C = \beta I_B$

$$\Rightarrow I_C = \beta \frac{(V_{th} - V_{BE})}{R_{th} + (B+1) R_E}$$

$$\begin{aligned} \therefore I_E &= I_B + I_C \\ &= I_B + \beta I_B \\ &= I_B (B+1) \end{aligned}$$



Applying KVL at o/p Section

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} - I_C R_C - V_{CE} - I_C R_E = 0$$

$$\Rightarrow V_{CC} - I_C (R_C + R_E) - V_{CE} = 0$$

$$\Rightarrow V_{CE} = V_{CC} - I_C (R_C + R_E)$$

For finding Stability Factor (S)

$$V_{th} = I_B R_{th} + V_{BE} + I_E R_E$$

$$\Rightarrow V_{th} = I_B R_B + V_{BE} + (I_B + I_C) R_E \quad \because R_{th} = R_B \quad \therefore I_E = I_B + I_C$$

Differentiating V_{th} w.r.t to I_C at V_{BE} constant

$$\frac{\partial (V_{th})}{\partial I_C} = 0$$

$$\Rightarrow 0 = \frac{\partial}{\partial I_C} [I_B R_B + V_{BE} + (I_B + I_C) R_E]$$

$$\Rightarrow 0 = \frac{\partial}{\partial I_C} I_B R_B + \frac{\partial}{\partial I_C} V_{BE} + \frac{\partial}{\partial I_C} R_E (I_B + I_C)$$

$$\Rightarrow 0 = \frac{\partial I_B}{\partial I_C} R_B + 0 + \frac{\partial}{\partial I_C} R_E I_B + \frac{\partial}{\partial I_C} R_E I_C$$

$$\Rightarrow 0 = \frac{\partial I_B}{\partial I_C} R_B + \frac{\partial I_B}{\partial I_C} R_E + \frac{\partial I_C}{\partial I_C} R_E$$

$$\Rightarrow 0 = \frac{\partial I_B}{\partial I_C} (R_B + R_E) + R_E$$

$$\Rightarrow \frac{\partial I_B}{\partial I_C} (R_B + R_E) = -R_E$$

$$\Rightarrow \frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_B + R_E} \quad \text{we know } S' = \frac{\beta + 1}{\left(\frac{\partial I_B}{\partial I_C}\right) \beta}$$

$$\Rightarrow S = \frac{\beta + 1}{\left(\frac{-R_E}{R_B + R_E}\right) \beta}$$

$$S = \frac{1 + \beta}{1 + \frac{\beta R_E}{R_B + R_E}}$$

(Chapter-6) TRANSISTOR AMPLIFIERS & OSCILLATORS

- 6.1 → Practical circuit of transistor amplifier.
- 6.2 → DC load line and DC equivalent ckt.
- 6.3 → AC load line and AC equivalent ckt.
- 6.4 → calculation of gain
- 6.5 → phase Reversal
- 6.6 → H parameters of transistor.
- 6.7 → Simplified H-parameters of transistor.
- 6.8 → Generalised approximate model.
- 6.9 → Analysis of CB, CE, CC amplifier using generalised approximate model.
- 6.10 → Multistage transistor amplifier.
 - 6.10.1 → R.C Coupled amplifier
 - 6.10.2 → Transformer coupled amplifier
- 6.11 → feed back in amplifier.
 - 6.11.1 → General theory of feedback.
 - 6.11.2 → Negative feedback ckt
 - 6.11.3 → Advantages of negative feedback.
- 6.12 → power amplifier and its classification.
 - 6.12.1 → Difference between ~~power~~ ^{voltage} amplifier & power a
 - 6.12.2 → Transformer Coupled class A power amplifier
 - 6.12.3 → Class A Push-Pull Amplifier
 - 6.12.4 → Class B Push-Pull Amplifier
- 6.13 → Oscillators
 - 6.13.1 → Types of oscillators
 - 6.13.2 → Essentials of transistor oscillator.
 - 6.13.3 → Principle of operation of ~~tuned~~ ^{tuned} Collector, Hartly, Colpitt, Phase shift, Wein bridge oscillator (no mathematical derivation)

What is amplifier

→ An amplifier is an electronic device that increase the voltage, current or power of a signal.

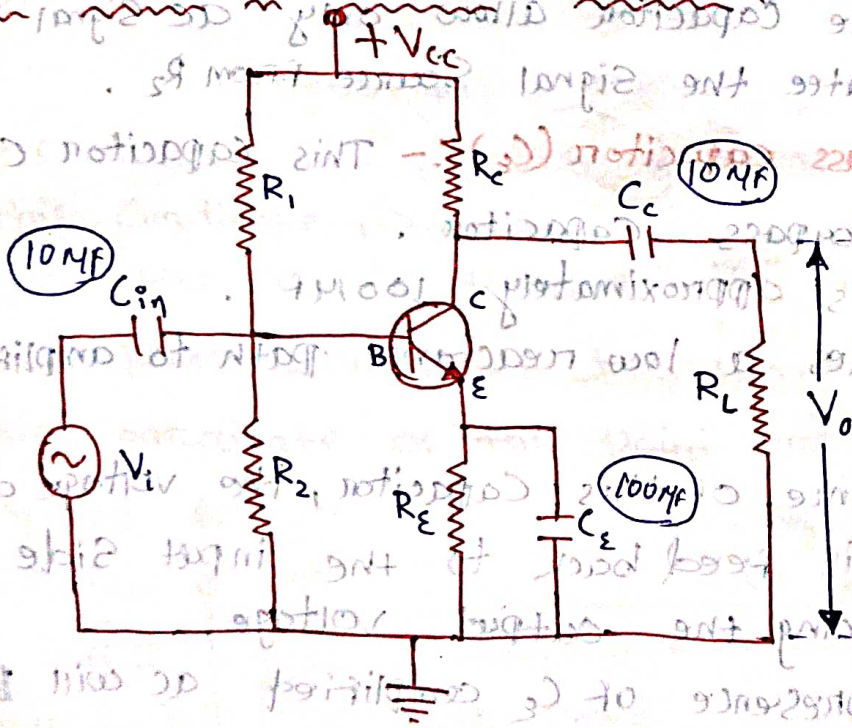
→ It is also used in wireless communication & loud speaker

OR
It is defined as a device that increase the voltage, current or power of an input signal with the aid of transistor by furnishing the additional power from a separate power source.

→ When only one transistor with its associated circuit is used for amplifying a weak signal, the amplifier is known as single stage transistor amplifier.

→ A practical amplifier is generally uses a number of stages of amplification is known as multistage amplifier.

Practical circuit of transistor amplifier



A Practical circuit of transistor amplifier in Common emitter Configuration as shown in figure.

The various circuit elements and their functions are described below.

(i) Biasing circuit :- The Resistor R_1 , R_2 & R_E form the biasing & stabilization circuit.

(ii) The load (R_L):- The Resistance R_L connected to the output is known as load. When a number of stages are used then R_L represents the input resistance of the next stage.

(iii) Coupling capacitor (C_c):- This capacitor passes a.c signal from one side to other side. Its value approximately 10 μF . This is also known as blocking capacitor because it does not allow the d.c voltage to pass through load. Due to presence of C_c , the output across the resistor R_L is free from the collector's d.c voltage.

(iv) Input capacitor (C_{in}):- This capacitor couples the signal to the base of the transistor. This is an electrolytic capacitor of value approximately 10 μF .
→ In the absence of capacitor the source resistance will come in parallel with R_2 and thus change the bias. Thus the capacitor allow only a.c signal to flow but isolate the signal source from R_2 .

(v) Emitter bypass capacitor (C_e):- This capacitor C_e works as a bypass capacitor.

→ Its value is approximately 100 μF .

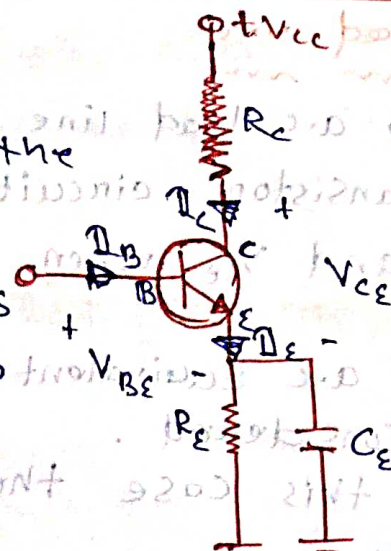
→ This provides a low reactance path to amplified a.c signal.

→ In the absence of this capacitor, the voltage developed across R_e will feed back to the input side thereby reducing the output voltage.

→ Thus in presence of C_e amplified a.c will pass through this.

DC load line

"The dc load line is a line on the output characteristics of a transistor which gives the values of I_C and V_{CE} corresponding to zero signal conditions."



Applying KVL at o/p section

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} = I_C R_C + V_{CE} + I_E R_E$$

$$\Rightarrow V_{CC} = V_{CE} + I_C (R_C + R_E)$$

Here V_{CC} and $(R_C + R_E)$ are constant, therefore it represents a straight line known as load line.

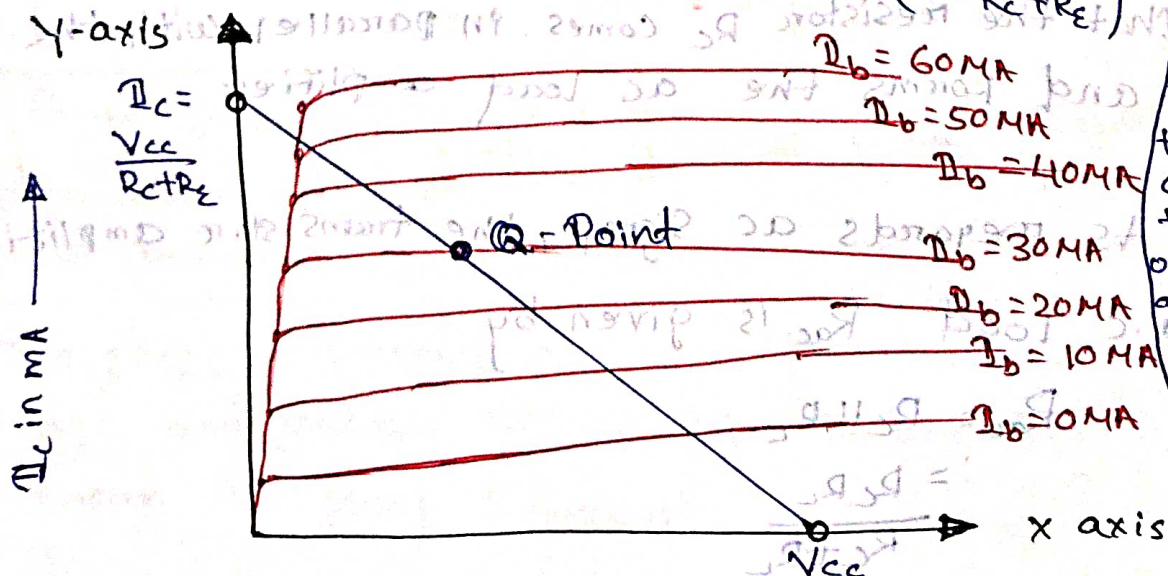
(i) We put $I_C = 0$, V_{CE} would be maximum

$$\therefore V_{CE(\max)} = V_{CC}$$

This locate the point 'B' on x-axis. below graph: this coordinate $(V_{CC}, 0)$

(ii) We put $V_{CE} = 0$, then $I_C = \frac{V_{CC}}{R_C + R_E}$, This locate the second point (say A) of the load line y-axis.

This coordinate of this point are $(0, \frac{V_{CC}}{R_C + R_E})$

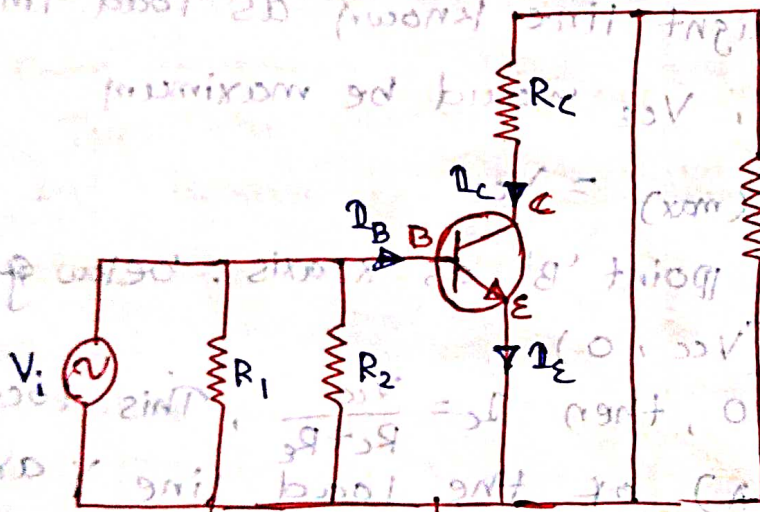


$I_B = 30\mu A$ is set by the biasing ckt. then the intersection of $30\mu A$ and load line i.e. a Q-point

Ac load, line

"The a.c load line is a line on the output-character of transistor circuit which gives the values of I_C and V_{CE} when signal is applied."

- For a.c Equivalent circuit, only a.c Condition are to considered.
- In this case the variations are so fast that Capacitors may be treated as short circuited.
- Moreover, we need not consider the d.c supplies
- So, in order to draw a.c Equivalent circuit we reduce all the d.c sources to zero and short circuit all the capacitors.



→ That the resistor R_C comes in parallel with the load R_L and forms the ac load amplifier.

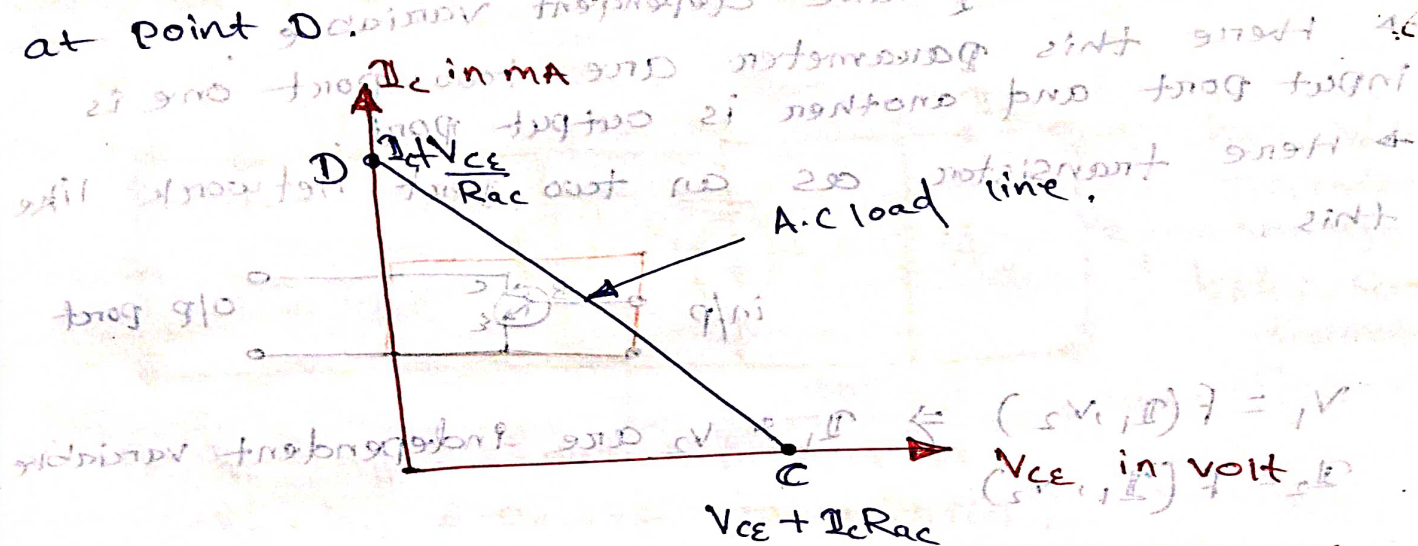
As regards ac signal, the transistor amplifier a.c load R_{ac} is given by

$$R_{ac} = R_C \parallel R_L$$

$$= \frac{R_C R_L}{R_C + R_L}$$

From above figure, maximum collector-emitter voltage
 $= V_{CE} + I_C R_{AC}$. This locates at point 'c' in below
 fig.

Maximum Collector Current $= I_C + \frac{V_{CE}}{R_{AC}}$, This locates
 at point 'D'.



Calculation of gain

→ The ratio of the output electrical quantity to the input of the amplifier is called gain.

→ Voltage gain $(A_v) = \frac{V_{out}}{V_{in}}$

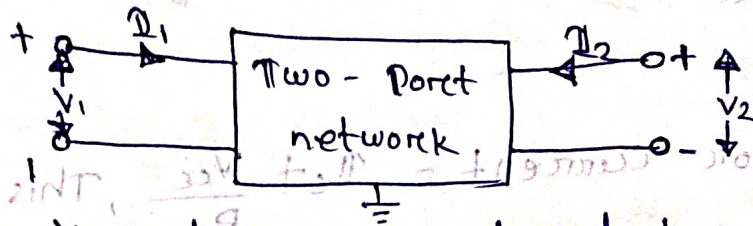
→ Current gain $(A_i) = \frac{I_{out}}{I_{in}}$

→ Power gain $(A_p) = \frac{P_{out}}{P_{in}}$

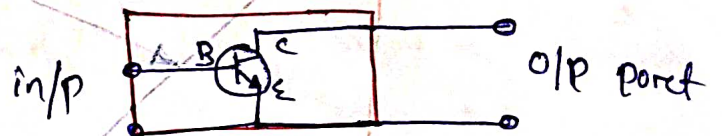
Phase Reversal

"The phase difference of 180° between input voltage and output voltage in common emitter amplifier is known as phase reversal."

H-parameter of transistor



- here V_1 and I_2 are dependent variable
- Here this parameter are two port one is input port and another is output port.
- Here transistor as an two port network like this.



$V_1 = f(I_1, V_2) \Rightarrow I_1, V_2$ are independent variable
 $I_2 = f(I_1, V_2)$

$$\begin{aligned} V_1 &= h_{11} i_1 + h_{12} V_2 \quad \text{--- (1)} \\ I_2 &= h_{21} i_1 + h_{22} V_2 \quad \text{--- (2)} \end{aligned}$$

$$h_{11} = \left. \frac{V_1}{i_1} \right|_{V_2=0} = \text{input impedance} = h_{ie} \quad (\Omega)$$

$$h_{21} = \left. \frac{i_2}{i_1} \right|_{V_2=0} = \text{forward current gain} = h_{fe}$$

$$h_{12} = \left. \frac{V_1}{V_2} \right|_{i_1=0} = \text{Reverse voltage gain} = h_{re}$$

$$h_{22} = \left. \frac{i_2}{V_2} \right|_{i_1=0} = \text{output admittance (mho, Siemen)} = h_{oe}$$

The above Equation we can written as

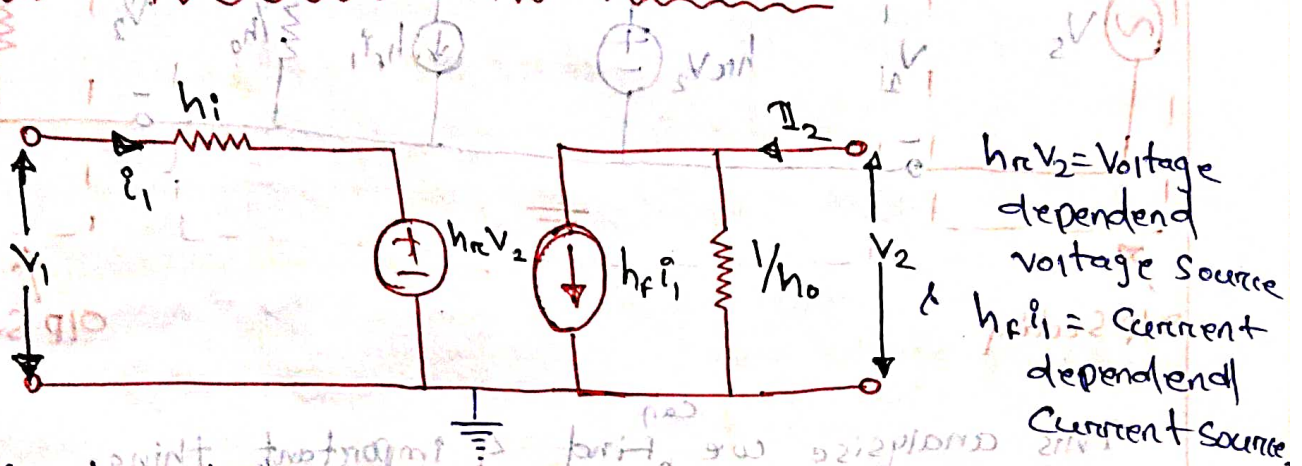
$$V_1 = h_{ie} i_1 + h_{re} V_2 \quad \text{--- (3)}$$

$$I_2 = h_{fe} i_1 + h_{oe} V_2 \quad \text{--- (4)}$$

EQ-③ & ④ we can written in Matrix form

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

Simplified H-parameter of transistor



Here, $h_{11} = h_{11} = \text{input impedance } (\Omega)$

$h_{12} = h_{12} = \text{Reverse voltage gain}$

$h_{21} = h_{21} = \text{forward current gain}$

$h_{22} = h_{22} = \text{output admittance } (\Omega) \text{ or Siemens}$

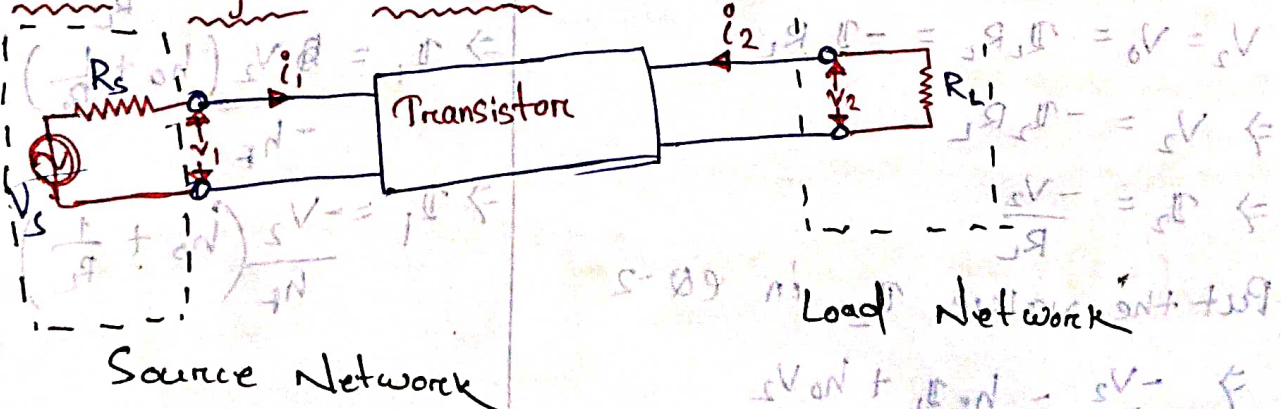
Notation of Common Emitter

$h_{ie}, h_{re}, h_{fe}, h_{oe}$

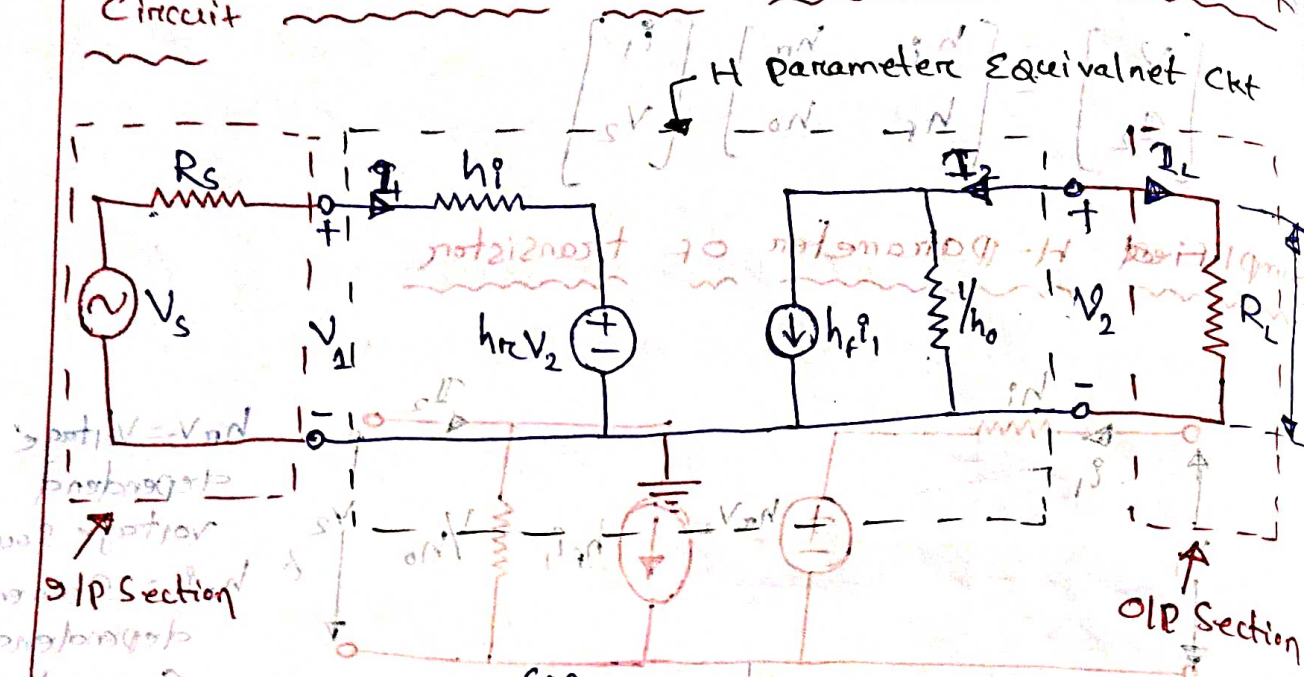
C.C $\rightarrow h_{ic}, h_{rc}, h_{fc}, h_{oc}$

C.B $\rightarrow h_{ib}, h_{rb}, h_{fb}, h_{ob}$

Small Signal Analysis



Small Signal Analysis with H-parameters Equivalent Circuit



This analysis we can find 4 important things

- ① Voltage gain ($A_v = \frac{V_2}{V_1}$)
- ② Current gain ($A_i = \frac{I_2}{I_1} = -\frac{I_L}{I_1}$)
- ③ I/p impedance ($Z_i = \frac{V_1}{I_1}$)
- ④ O/p impedance ($Z_o = \frac{V_2}{I_2}$)

As we know,

$$V_1 = h_i I_1 + h_r V_2 \quad \text{--- (1)}$$

$$I_2 = h_f I_1 + h_o V_2 \quad \text{--- (2)}$$

* Voltage gain ($A_v = \frac{V_2}{V_1}$)

$$V_2 = V_o = I_L R_L = -I_2 R_L$$

$$\Rightarrow V_2 = -I_2 R_L$$

$$\Rightarrow I_2 = \frac{-V_2}{R_L}$$

Put the value I_2 in eq-2

$$\Rightarrow \frac{-V_2}{R_L} = h_f I_1 + h_o V_2$$

$$\Rightarrow -V_2 = R_L (h_f I_1 + h_o V_2)$$

$$\Rightarrow -h_f I_1 = h_o V_2 + \frac{V_2}{R_L}$$

$$\Rightarrow I_1 = -V_2 \left(h_o + \frac{1}{R_L} \right) / h_f$$

$$\Rightarrow I_1 = \frac{-V_2}{h_f} \left(h_o + \frac{1}{R_L} \right)$$

Put this value I_1 in eq-1

$$\Rightarrow V_1 = h_f \left[\frac{-V_2}{h_f} \left(h_o + \frac{1}{R_L} \right) \right] + h_{re} V_2$$

$$\Rightarrow V_1 = \frac{-V_2 h_i}{h_f} \left(\frac{h_o R_L + 1}{R_L} \right) + h_{re} V_2$$

$$\Rightarrow V_1 = -V_2 \left[\frac{h_i (h_o R_L + 1)}{h_f R_L} + h_{re} \right]$$

$$\Rightarrow V_1 = -V_2 \left[\frac{h_i (1 + h_o R_L) + h_{re} h_f R_L}{h_f R_L} \right]$$

$$\Rightarrow \frac{V_1}{V_2} = - \left[\frac{h_i (1 + h_o R_L) + h_{re} h_f R_L}{h_f R_L} \right]$$

$$\Rightarrow \boxed{\frac{V_2}{V_1} = \frac{h_f R_L}{h_i (1 + h_o R_L) + h_{re} h_f R_L}} \quad \leftarrow \text{Voltage gain (A}_v\text{)}$$

* Current gain (A_i)

In this fig $\Rightarrow V_2 = V_o = I_2 R_L = -I_2 R_L$
 $V_2 = -I_2 R_L$

Put this value in eq-2

$$\Rightarrow I_2 = h_f I_1 + h_o (-I_2 R_L)$$

$$\Rightarrow I_2 = h_f I_1 - h_o I_2 R_L$$

$$\Rightarrow h_f I_1 = I_2 + h_o I_2 R_L$$

$$\Rightarrow h_f I_1 = I_2 (1 + h_o R_L)$$

$$\Rightarrow \frac{h_f I_1}{1 + h_o R_L} = I_2$$

$$\Rightarrow \frac{h_f}{1 + h_o R_L} = \frac{I_2}{I_1}$$

$$\Rightarrow \boxed{-\frac{I_2}{I_1} = \frac{-h_f}{1 + h_o R_L}} \quad \leftarrow \text{Current gain (A}_i\text{)}$$

* Input Impedance (Z_i) = $\frac{V_1}{I_1}$ Put the value in eq-②

$$V_2 = V_o = I_L R_L = -I_2 R_L$$

$$\Rightarrow V_2 = -I_2 R_L$$

$$\Rightarrow I_2 = \frac{-V_2}{R_L}$$

Putting this value I_2 in eq-② $\Rightarrow I_2 = V_2 \left[\frac{-h_f h_r}{R_s + h_i} \right]$

$$\Rightarrow \frac{-V_2}{R_L} = h_f I_1 + h_o V_2$$

$$\Rightarrow \frac{-V_2}{R_L} - h_o V_2 = h_f I_1$$

$$\Rightarrow -V_2 \left(\frac{1}{R_L} + h_o \right) = h_f I_1$$

$$\Rightarrow -V_2 \left(\frac{1 + h_o R_L}{R_L} \right) = h_f I_1$$

$$\Rightarrow -V_2 = \frac{h_f I_1 R_L}{1 + h_o R_L}$$

$$\Rightarrow V_2 = \frac{-h_f I_1 R_L}{1 + h_o R_L}$$

Put this value V_2 in eq-①

$$\Rightarrow V_1 = h_i I_1 - \frac{h_r h_f I_1 R_L}{1 + h_o R_L}$$

$$\Rightarrow V_1 = I_1 \left(h_i - \frac{h_r h_f R_L}{1 + h_o R_L} \right)$$

$$\Rightarrow \frac{V_1}{I_1} = h_i - \frac{h_r h_f R_L}{1 + h_o R_L}$$

Input Impedance (Z_i)

* Output Impedance (Z_o) = $\frac{V_2}{I_2}$ $V_s = 0$

Applying KVL at g/p loop

$$0 + I_1 R_s + I_1 h_i + h_r V_2 = 0$$

$$I_1 (R_s + h_i) = -h_r V_2$$

$$I_1 = \frac{-h_r V_2}{R_s + h_i}$$

$$\Rightarrow I_2 = V_2 \left[\frac{h_o - h_f h_r}{R_s + h_i} \right]$$

$$\Rightarrow \frac{I_2}{V_2} = \frac{h_o - h_f h_r}{R_s + h_i}$$

$$\Rightarrow \frac{I_2}{V_2} = \frac{h_o (R_s + h_i) - h_f h_r}{R_s + h_i}$$

$$\Rightarrow \frac{V_2}{I_2} = \frac{R_s + h_i}{h_o (R_s + h_i) - h_f h_r}$$

Output Impedance (Z_o)

Small Signal Analysis in Common Base Configuration Amplifier

there are, input voltage (V_1) in stead of $= V_e$

output voltage (V_2) $= V_c$

input current (I_1) $= I_e$

output current (I_2) $= I_c$

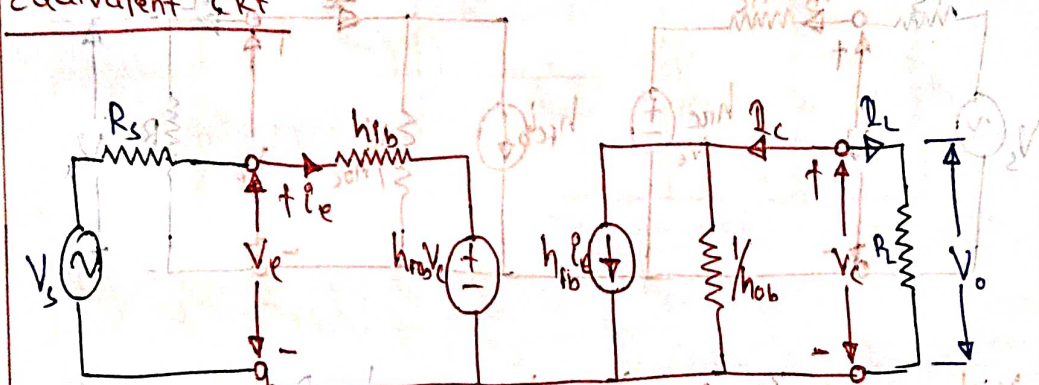


The general H parameter Equation is

$$V_e = h_{ib} i_e + h_{rb} V_c \quad \text{--- (1)}$$

$$I_c = h_{fb} i_e + h_{ob} V_c \quad \text{--- (2)}$$

Equivalent ckt



$$\text{Voltage gain } (A_{vb}) = \frac{V_2}{V_1} = \frac{V_c}{V_e} = \frac{-h_{fb} R_L}{h_{ib} - h_{fb}(1 + h_{ob} R_L) + h_{rb} h_{fb} R_L}$$

$$\text{Current gain } (A_{ib}) = \frac{-I_2}{I_1} = \frac{-I_c}{I_e} = \frac{-h_{fb}}{1 + h_{ob} R_L}$$

$$\text{Input impedance } (Z_{ib}) = \frac{V_1}{I_1} = \frac{V_e}{I_e} = \frac{h_{ib} - h_{rb} h_{fb} R_L}{1 + h_{ob} R_L}$$

$$\text{Output impedance } (Z_{ob}) = \frac{V_2}{I_2} = \frac{V_c}{I_c} = \frac{R_s + h_{ib}}{h_{ob}(R_s + h_{ib}) - h_{fb} h_{rb}}$$

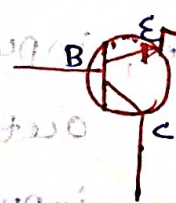
Common Collector Amplifier

Here, Input voltage (V_1) = V_b

Output voltage (V_2) = V_e

Input Current (I_1) = I_b

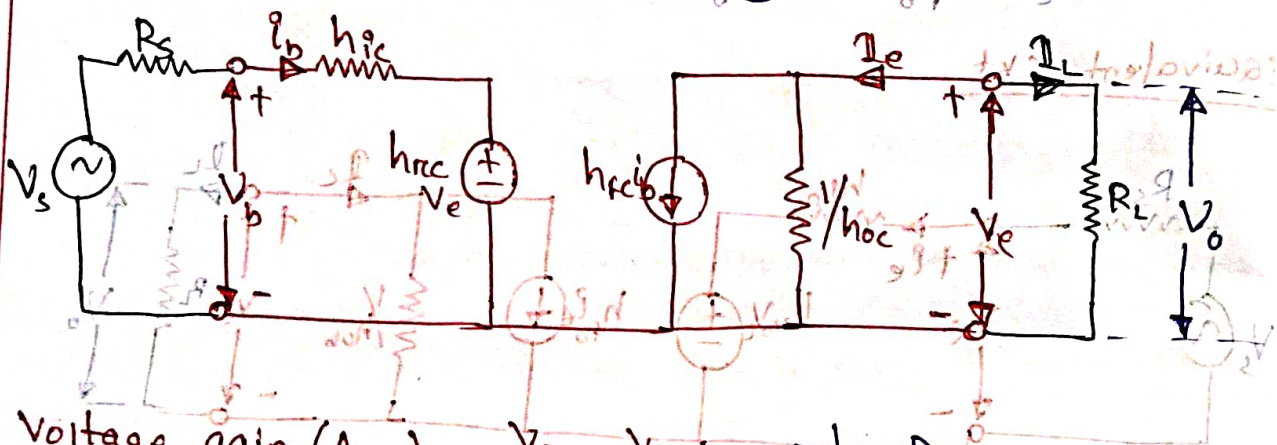
Output Current (I_2) = I_e



The general h parameter Equation

$$V_b = h_{ic} i_b + h_{rc} V_e \quad \text{--- (1)}$$

$$I_e = h_{fc} i_b + h_{oc} V_e \quad \text{--- (2)}$$



$$\text{Voltage gain } (A_{vc}) = \frac{V_2}{V_1} = \frac{V_e}{V_b} = \frac{-h_{fc} R_L}{h_{ic} (1 + h_{oc} R_L) + h_{rc} h_{fc} R_L}$$

$$\text{Current gain } (A_{ic}) = \frac{I_2}{I_1} = \frac{-I_L}{I_b} = \frac{-h_{fc}}{1 + h_{oc} R_L}$$

$$\text{Input impedance } (Z_{ic}) = \frac{V_1}{I_1} = \frac{V_b}{I_b} = h_{ic} - \frac{h_{rc} h_{fc} R_L}{1 + h_{oc} R_L}$$

$$\text{Output impedance } (Z_{oc}) = \frac{V_2}{I_2} = \frac{V_e}{I_e} = \frac{R_s + h_{ic}}{h_{oc} (R_s + h_{ic}) - h_{fc} h_{rc}}$$

$$\text{--- (3)}$$

Common Emitter amplifier

Input voltage (V_1) = V_b

Output voltage (V_2) = V_c

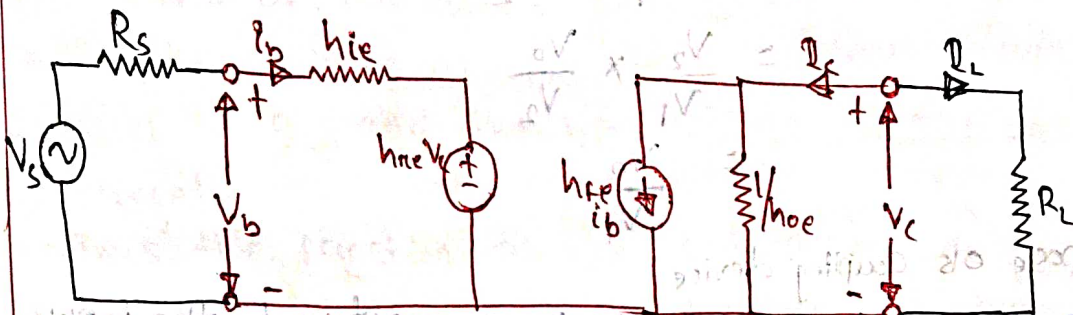
Input Current (I_1) = I_b

Output Current (I_2) = I_c

The general h parameter Equation

$$V_b = h_{ie} i_b + h_{re} V_c \quad \text{--- (1)}$$

$$I_c = h_{fe} i_b + h_{oe} V_c \quad \text{--- (2)}$$



$$\text{Voltage gain } (A_{ve}) = \frac{V_2}{V_1} = \frac{V_c}{V_b} = \frac{-h_{fe} R_L}{h_{ie} (1 + h_{oe} R_L) + h_{re} h_{fe} R_L}$$

$$\text{Current gain } (A_{ie}) = \frac{I_2}{I_1} = \frac{I_c}{I_b} = \frac{-I_c}{I_b} = \frac{-h_{fe}}{1 + h_{oe} R_L}$$

$$\text{Input impedance } (Z_{ie}) = \frac{V_1}{I_1} = \frac{V_b}{I_b} = h_{ie} - \frac{h_{re} h_{fe} R_L}{1 + h_{oe} R_L}$$

$$\text{Output impedance } (Z_{oe}) = \frac{V_2}{I_2} = \frac{V_c}{I_c} = \frac{R_s + h_{ie}}{h_{oe} (R_s + h_{ie}) - h_{fe} h_{re}}$$

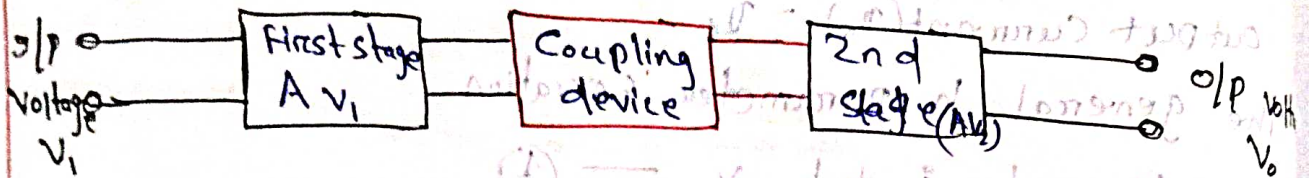
Multistage Transistor Amplifier

→ When the voltage Amplification or power gain of a Single stage amplifier is insufficient to meet the requirement, then multistage transistor is used.

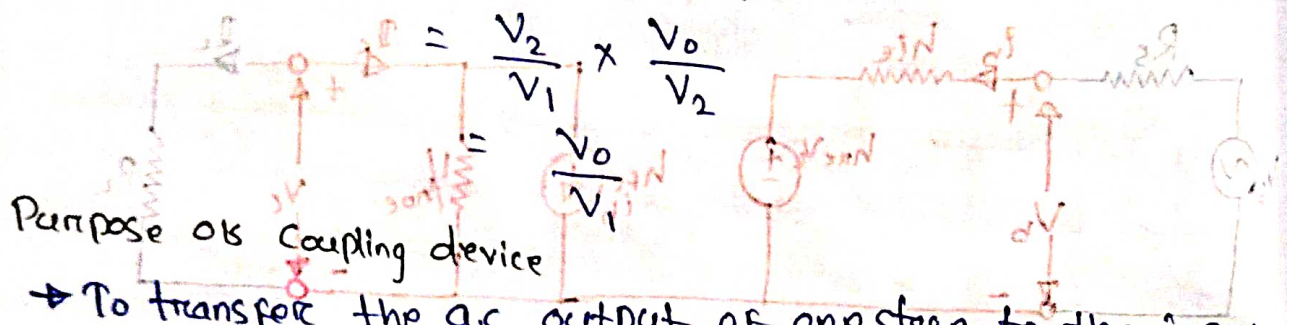
→ In multistage amplifier, the output of the first stage is combined to the next stage through a coupling device. The process is known as cascading.

→ A two stage amplifier connected in cascade as shown in Fig.

→ The overall voltage gain of cascade of two stages is the product of voltage gain of individual stages.



Voltage gain (A_v) = $A_{v1} \times A_{v2}$

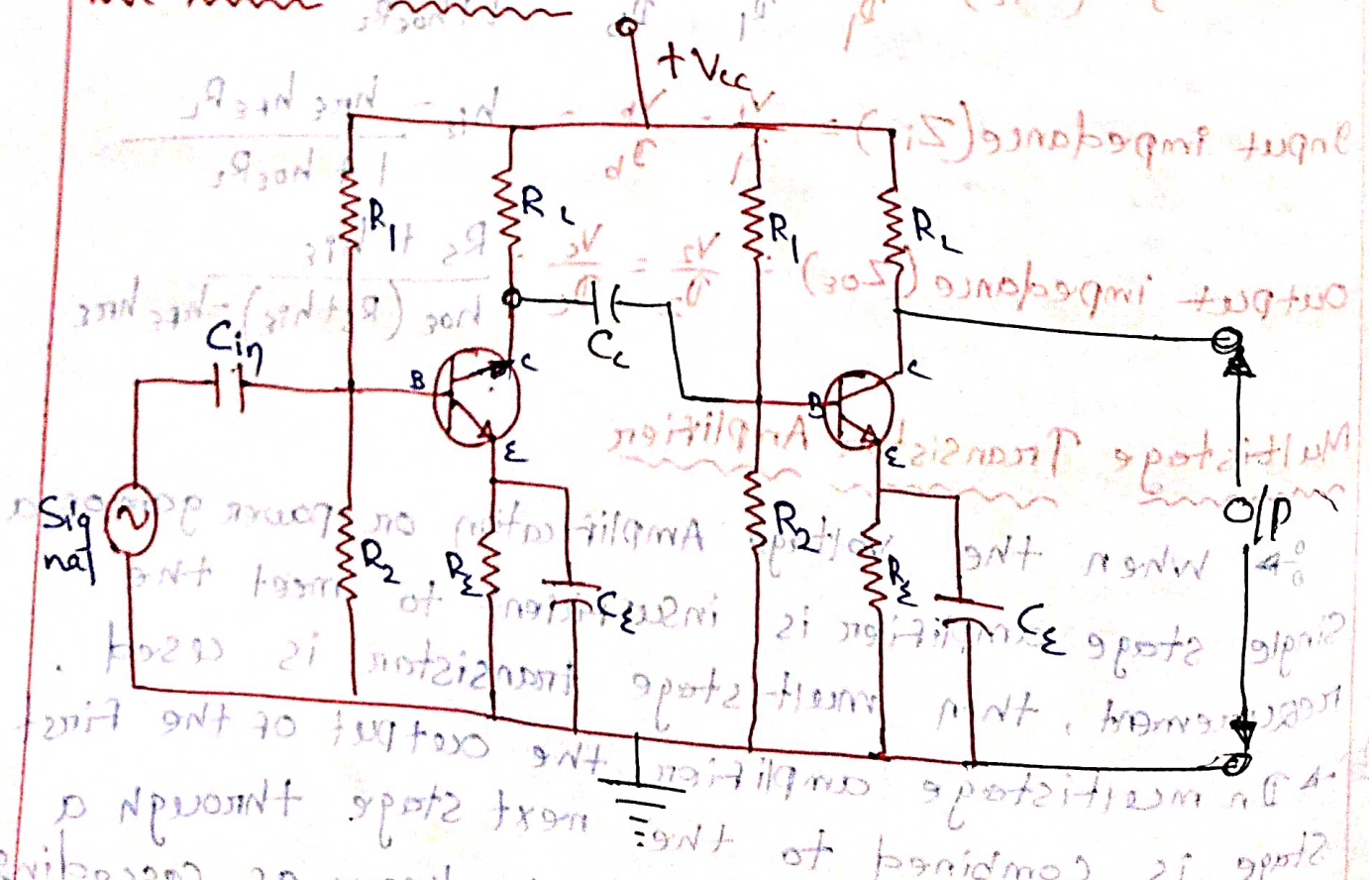


Purpose of coupling device

→ To transfer the ac output of one stage to the input of next stage.

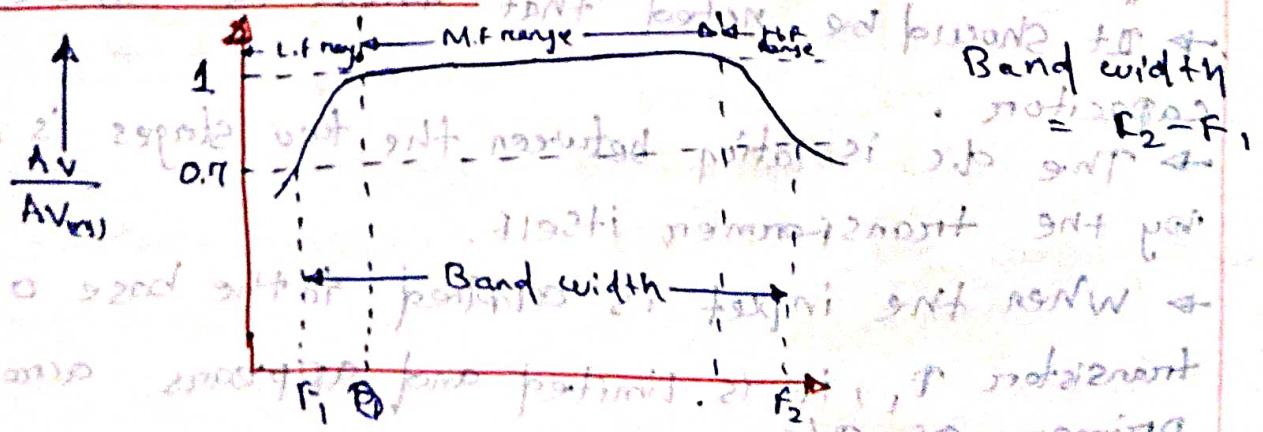
→ To block the d.c. to pass from one stage to the next stage i.e. to isolate the d.c. condition.

R-C coupled amplifier

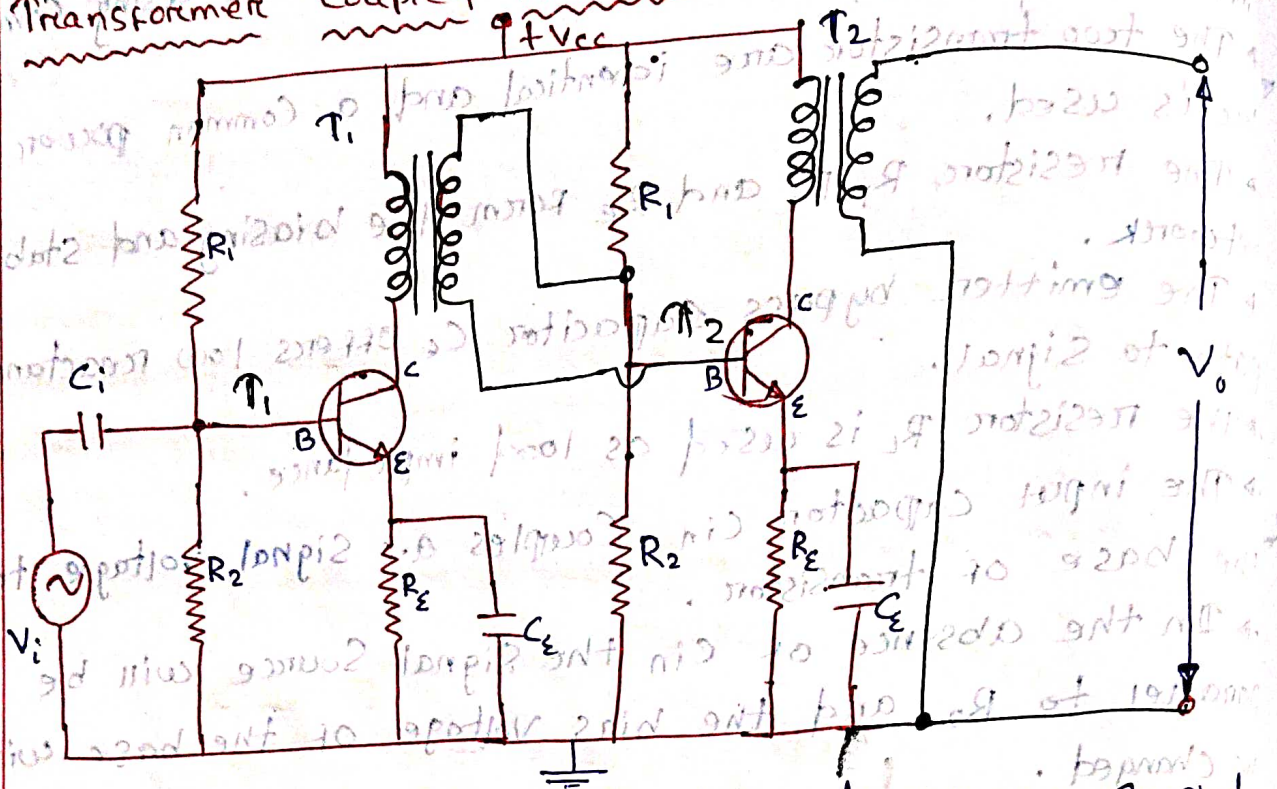


- This fig shows two stages R-C Coupled amplifiers using Common Emitter Configuration.
- The two transistors are identical and a Common power Supply V_{CC} is used.
- The resistors R_1 , R_2 and R_E form the biasing and stabilisation network.
- The emitter bypass Capacitor C_E offers low reactance path to signal.
- The resistor R_L is used as load impedance.
- The input capacitor C_{in} couples a.c signal voltage to the base of transistor.
- In the absence of C_{in} the signal source will be in parallel to R_2 and the bias voltage of the base will be changed.
- Thus the function of C_{in} is to allow only the alternating current from signal source to flow into input circuit.
- The output of the first stage is coupled to the input of second stage through coupling capacitor C_c .
- This allows the a.c component of the signal to pass to the second stage and blocks the d.c components.
- As coupling from one stage to the next stage is achieved via coupling capacitor (C_c) followed by a connection to shunt resistor; therefore, the amplifier is known as resistance-capacitance coupled amplifier.

Frequency Response Curve



Transformer Coupled Amplifier



→ The circuit diagram of two stages transformer coupled amplifier as shown in fig.

→ Here coupling transformer T_1 is used to feed the output of the first stage to the input of next stage.

→ The collector load is replaced by primary wind of the transformer.

→ The secondary is connected between base of the second stage and voltage divider i.e., the secondary of transformer gives input to the next stages.

→ The transformer T_2 is the output transformer.

→ The other components are same as in R-C coupled amplifier.

→ It should be noted that there is no coupling capacitor.

→ The d.c isolation between the two stages is provided by the transformer itself.

→ When the input is applied to the base of transistor T_1 , it is limited and appears across the primary of T_1 .

→ By magnetic induction, it is passed to the Secondary
 → Now the output is applied to the base of Transistor T_2 .

→ The amplified output appears across the primary of the Transformer T_2 .

Feedback in Amplifier

The voltage gain, input impedance, output impedance, bandwidth etc, are few important characteristics of an amplifier.

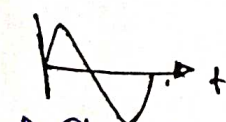
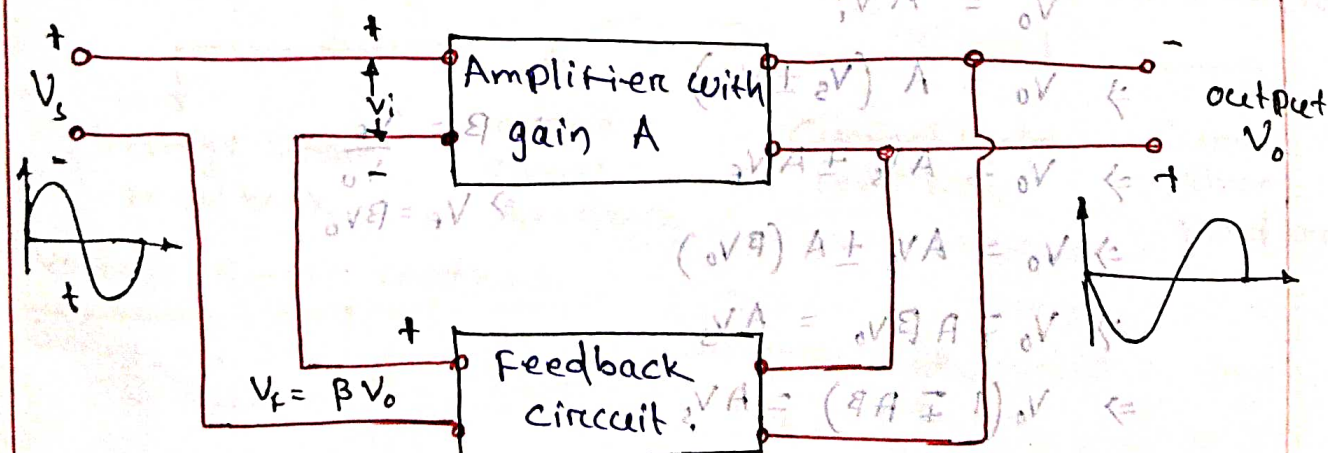
These parameters are nearly constant for a given amplifier. Sometimes, we are required to change these parameters, This can be achieved by a technique known as feedback.

"The process of combining a fraction of output energy back to the input is known as feedback."

General theory of feedback

$$\frac{A}{1 - AB} = A_f$$

→ The general theory of feedback can be understood with the help of block diagram.



Introduce to 180° Phase shift

→ The feedback amplifier has two parts i.e. amplifier and feedback circuit.

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

→ The feedback circuit consists of resistors.

→ This returns a fraction (say β) of the output back to input.

→ Let A be the gain of Amplifier i.e. the ratio of output voltage V_o to the input voltage V_i . This is gain of the Amplifier without feedback.

→ The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

→ This voltage is added (positive feedback) or subtracted (negative feedback) from the signal voltage V_s .

Now $V_i = V_s + V_f$ (Positive feedback)

$V_i = V_s - V_f$ (Negative feedback)

→ The quantity $\beta = V_f / V_o$ is called as feedback or feedback fraction.

$$A_f = \frac{A}{1 + \beta A} \quad (\text{Negative feedback})$$

$$A_f = \frac{A}{1 - \beta A} \quad (\text{Positive feedback})$$

Gain of feedback amplifier

$$V_o = A V_i$$

$$\Rightarrow V_o = A (V_s \pm V_f)$$

$$\Rightarrow V_o = A V_s \pm A V_f$$

$$\Rightarrow V_o = A V_s \pm A (\beta V_o)$$

$$\Rightarrow V_o \mp A \beta V_o = A V_s$$

$$\Rightarrow V_o (1 \mp \beta A) = A V_s$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{A}{1 \mp \beta A}$$

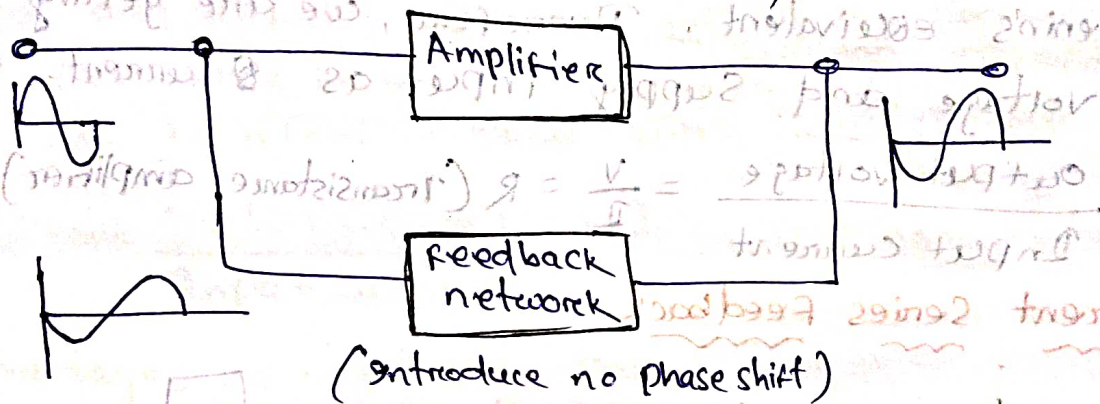
$$A_f = \frac{A}{1 - \beta A} \quad (\text{Positive f/b})$$

$$A_f = \frac{A}{1 + \beta A} \quad (\text{Negative f/b})$$

Negative Feedback circuit

When the feedback signal is out of phase with the input signal and thus opposes it then the feedback is called as negative feedback.

→ The negative feedback amplifier introduces a phase shift of 180° in the input while the feedback network introduces no phase shift i.e., the feedback network is designed in such a way that it does not introduce any phase shift.



→ Negative feedback circuits are two types: i.e.

Negative feedback

Negative voltage feedback

Negative current feedback

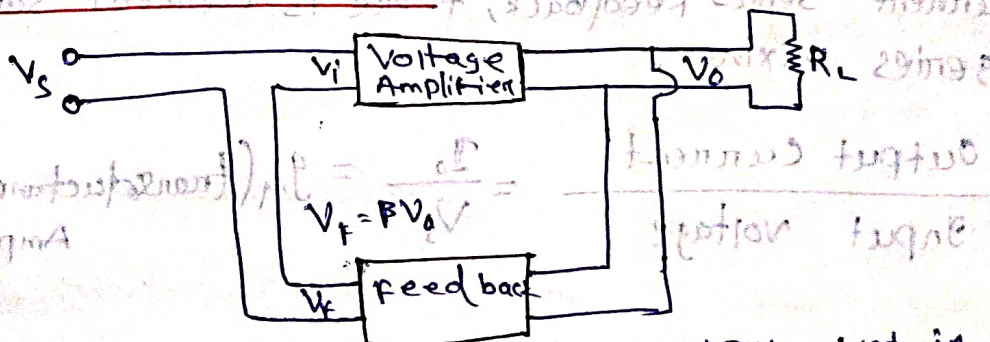
Voltage Series feedback

Voltage Shunt feedback

Current Series feedback

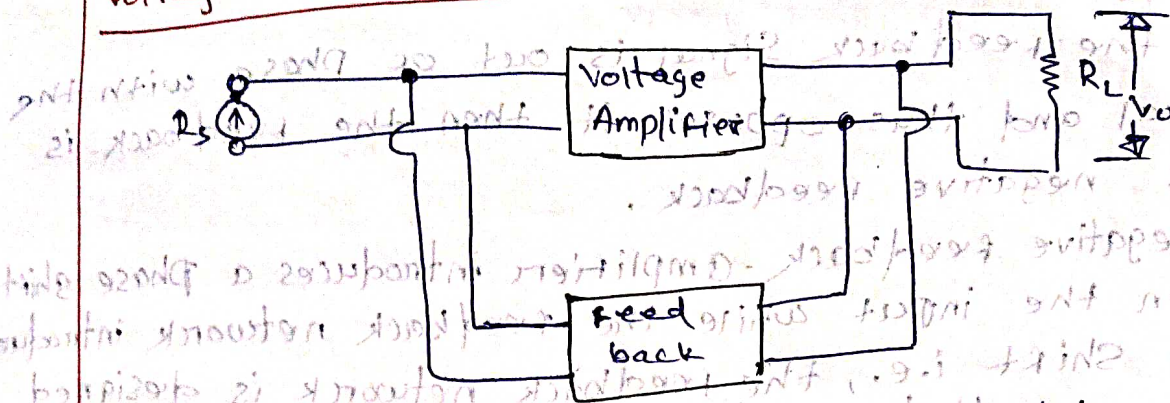
Current Shunt feedback

Voltage Series feedback



The feedback circuit shunt the output but in series with the input. So, the output impedance is decreased (Parallel Combination) while the input impedance is increased (Series Combination) due to f/b.

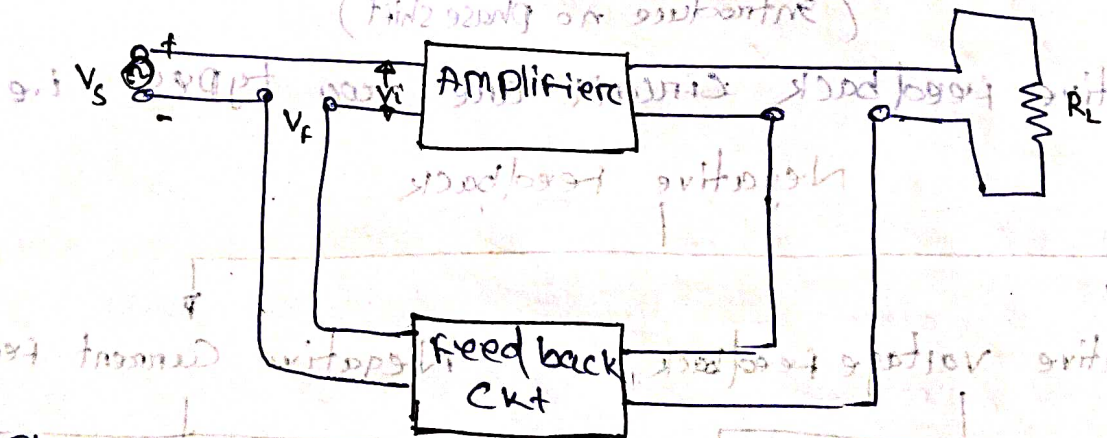
Voltage shunt feedback



For shunt mixing, the input source must be a current source. For voltage sampling, the output must be a Thevenin's equivalent. Therefore, we are getting an output voltage and supply input as a current. So,

$$\frac{\text{output voltage}}{\text{Input current}} = \frac{V}{I} = R \text{ (Transistance, amplifier)}$$

Current Series feedback



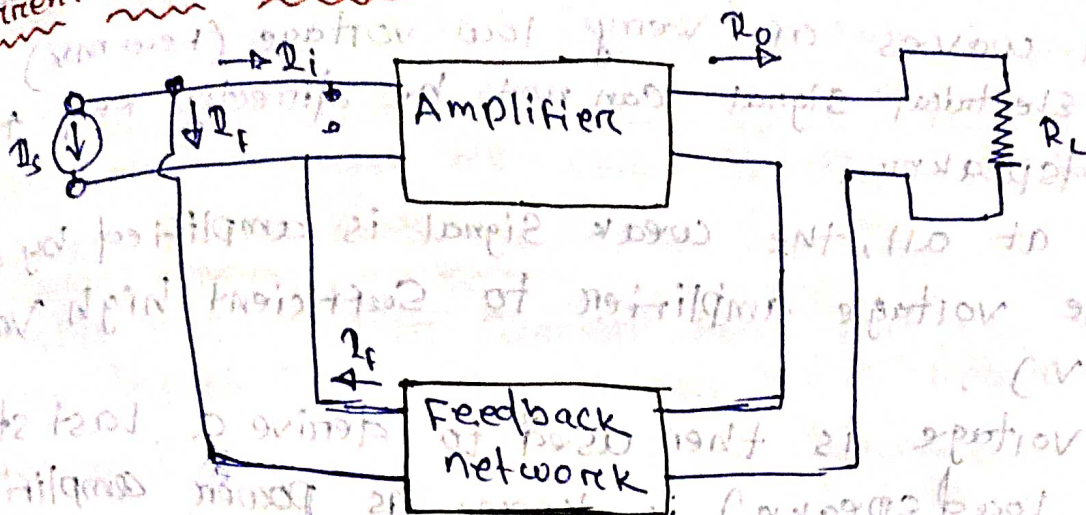
→ The block diagram of Current-Series feedback is shown in fig.

→ This is also known as Series fed feedback.

→ In Current Series feedback, there is current sampling plus series mixing.

$$\frac{\text{Output current}}{\text{Input voltage}} = \frac{I_o}{V_s} = g_m \text{ (transductance Amplifier)}$$

Current Shunt feedback



- In Current Shunt feedback, a Current I_o is tapped from output and applied at the input of feedback network.
- output feedback network which is in the form of Current is mixed in shunt with input Current I_s .

$$\frac{\text{Output Current}}{\text{Input Current}} = \frac{I_o}{I_i} \text{ Current Amplifier}$$

Advantages of negative feedback

- Gain decreases
- Control slip resistance & o/p resistance
- Reduction in noise
- Change input & output impedance
- Increase Bandwidth

* Power Amplifier

- "The Power Amplifier are large signal amplifiers which raise the power level of the signals".
- OR power Amplifier is a device which converts d.c power to a.c power and whose action is controlled by the input signal.

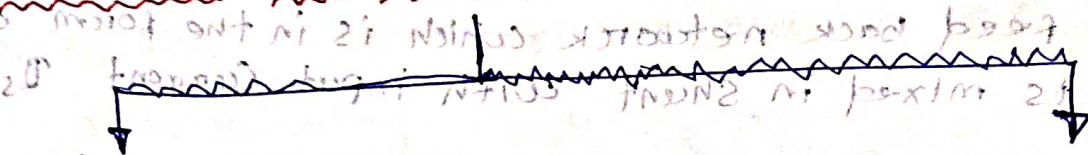
Lets take a Example -

- Here, a person speaks into a microphone and the audience hear the speech of the person.

→ The microphone converts the sound waves into electrical waves of very low voltage (few mv).
 → This electrical signal can not be directly fed to the loudspeaker.
 → First at all, the weak signal is amplified by a multistage voltage amplifier to sufficient high value (few V).

→ This voltage is then used to drive a last stage (before loudspeaker) is known as power amplifier.

Classification of Power Amplifiers



Audio - Power Amplifier → The audio power Amplifiers raise the power level of signals that have audio frequency range (20 Hz to 20 kHz). They are also known as

Small Signal power Amplifier.

Radio Power Amplifier → Radio power amplifier or tuned power Amplifier raise the power level of signals that have radio frequency range. They are also known as large signal power Amplifier.

It is further Classified as three types.

Class A power Amplifier - When the collector current flows at all times during the full cycle of signal, the power amplifier is known as Class A

Class B Power Amplifier

When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as class B power amplifier.

Class C Power Amplifier

When the collector current flows for less than half cycle of the input signal, the amplifier is known as class C amplifier.

* Difference between Voltage Amplifier & Power Amplifier

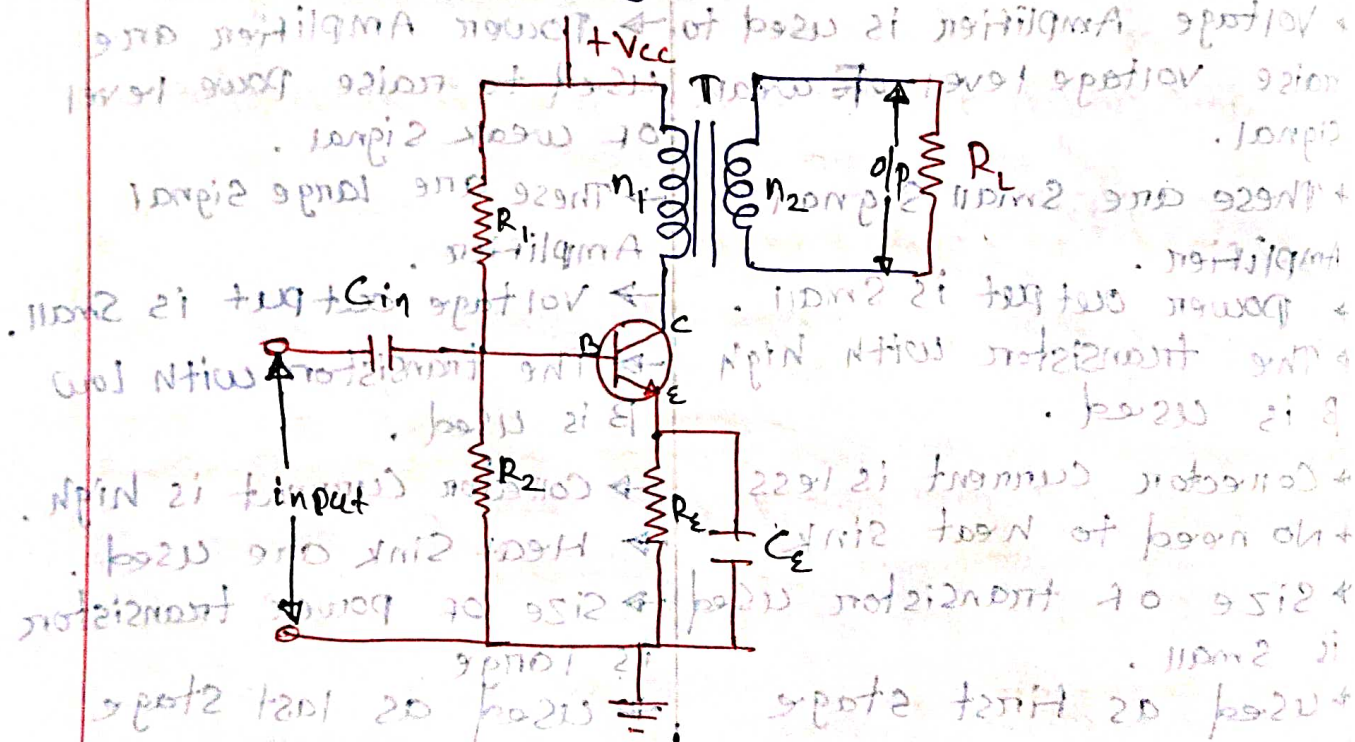
<u>Voltage Amplifier</u>	<u>Power Amplifier</u>
→ Voltage Amplifier is used to raise voltage level of weak signal. → These are small signal amplifier. → power output is small. → The transistor with high β is used. → Collector current is less. → No need to heat sink. → Size of transistor used is small. → used as first stage amplifier. → Output impedance is high.	→ Power Amplifier are used to raise power level of weak signal. → These are large signal amplifier. → Voltage output is small. → The transistor with low β is used. → Collector current is high. → Heat Sink are used. → Size of power transistor is large. → used as last stage amplifier. → Output impedance is low.

* Transformer Coupled Class A Amplifier

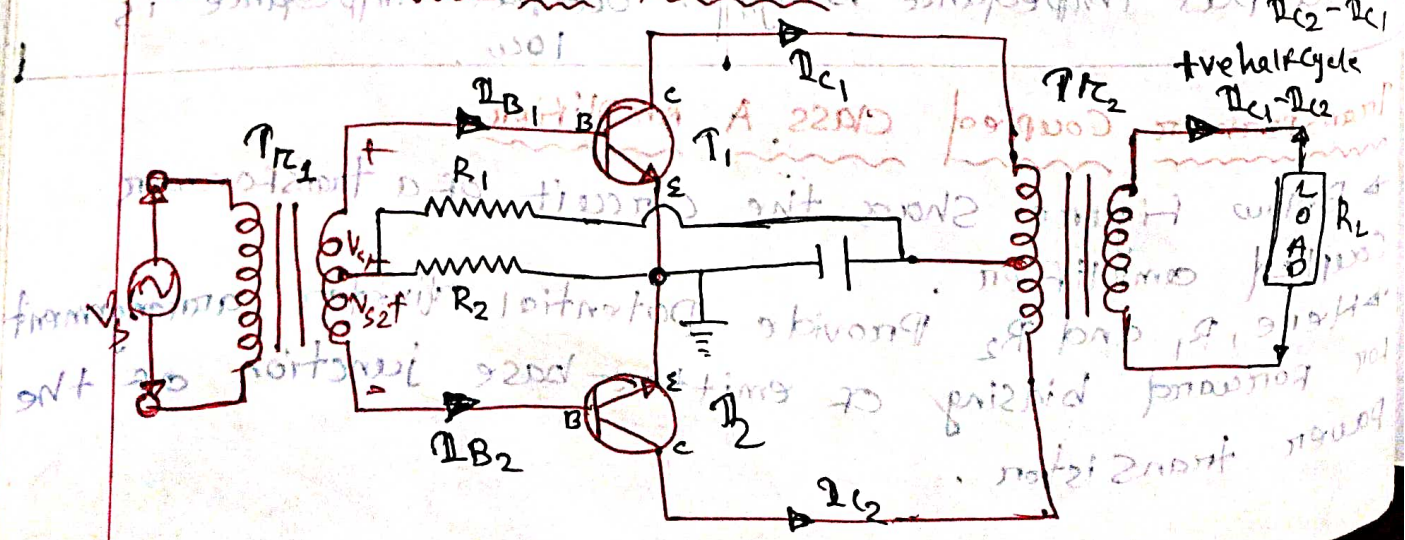
→ Below figure shows the circuit of a transformer coupled amplifier.

→ Here, R_1 and R_2 provide potential divider arrangement for forward biasing of emitter-base junction of the power transistor.

- R_e is the emitter resistor for bias stabilization and
- C_e is bypass capacitor for R_e to the prevent a.c. voltage.
- The capacitor C_{in} blocks any d.c. from the previous stage.
- Input signal from a pre-amplifier is applied to the input terminals
- T is step down Transformer.
- The high impedance primary of the transformer is connected to high impedance collector circuit.
- The low impedance secondary is connected to the load (generally loudspeaker)



Class A Push-Pull Amplifier



Circuit arrangement

- The circuit arrangement as shown in fig.
- In push pull amplifier arrangement two identical transistors T_1 and T_2 are used.
- The emitter terminals of the two transistors are connected together.
- The input signal is applied to the inputs of two transistors through centre tapped transformer, Tr_1 .
- This transformer provides opposite polarity signal to the two transistor inputs.
- The collectors of both the transistors are connected to the primary of the (output) transformer Tr_2 .
- This transformer is also centre tapped.
- The collector terminals of the two transistors are connected to the supply V_{CC} through the primary of output transformer.
- Resistor R_1 & R_2 provide the biasing arrangement.
- The load is (generally a loud speaker) is connected across the secondary of transformer.

Operation

- Case - 1 (In +ve half cycle)
- In +ve half cycle of input voltage V_s , the secondary voltage V_{s1} will be +ve while V_{s2} will be -ve.
 - Therefore transistor T_1 is more F.B while T_2 is less F.B. Therefore I_{C1} will increase and I_{C2} will decrease.
 - The o/p current I_L is proportional to the difference betⁿ I_{C1} and I_{C2} .

$$\text{i.e. } I_L = \frac{N_1}{N_2} (I_{C1} - I_{C2})$$

- Therefore in +ve half cycle of V_s The o/p current I_L will be +ve.

$$\text{i.e. } V_L = I_L R = \frac{N_1}{N_2} (I_{C1} - I_{C2}) R$$

Case-2 (9n -ve half cycle)

→ 9n -ve half cycle of input voltage V_s , the Secondary voltage V_{s2} will be +ve while V_{s1} will be -ve
→ Therefore Transistor T_2 is more P.B while T_1 is less P.B. Therefore I_{C2} will increase and I_{C1} will decrease.

→ The o/p current I_L is proportional to the difference betⁿ I_{C1} & I_{C2}

$$\text{i.e. } I_L = \frac{N_1}{N_2} (I_{C2} - I_{C1})$$

$$\rightarrow V_o = I_L R = \frac{N_1}{N_2} (I_{C2} - I_{C1}) R$$

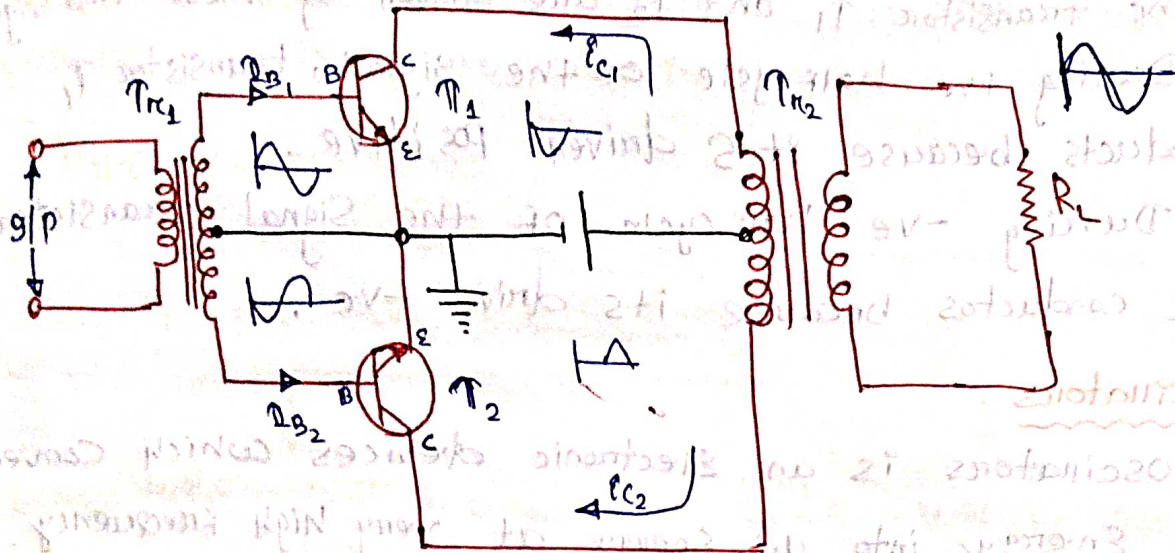
Hence we are obviously observed that, when I_{C1} is greater and I_{C2} is lower then I_{C1} pull the more power from fixed V_{CC} , obviously I_{C2} will draw low power. So, It's a kind of push-pull technology. (that So push-pull Class-A Amplifier)

Class-B Push-Pull Amplifier

→ We have seen that Class A push pull Amplifier reduce the harmonic distortion but the Conversion efficiency is only 50%.

→ To increase the efficiency and output power for a given transistor dissipation capability, class B Push pull amplifier is used.

→ The circuit arrangement as shown in fig.



- The circuit arrangement of class B push pull amplifier is the same as that of class A push pull amplifier except that the transistors are biased at cut-off.
- This is done by providing zero bias on the base of each transistor by connecting the base and emitter together.
- As shown in the figure, the bases of the two C-E connected identical transistors have been connected to the opposite ends of the secondary of the input transformer T_{r1} and collectors ends to the primary of the output transformer T_{r2} .
- In order to get balanced circuit, the emitters of the transistors are connected to the centre tap of the secondary of transformer T_{r1} and V_{CC} is connected to the centre tap on the primary of transformer T_{r2} .
- The two bases have been earthed.

Operations

- When no signal is applied, both the transistors are cut-off. Hence no current is drawn from supply source V_{CC} . So there is no power wastage on standby.
- When the input signal is applied the phase splitter transformer T_{r1} produces two signals which are 180° out of phase with each other.

- The transistor T_1 and T_2 are driven by these two signals.
- During the half-cycle of the signal, transistor T_1 conducts because it's driven positive.
- During -ve half-cycle of the signal, transistor T_2 conducts because its drive -ve.

Oscillators

- Oscillators is an electronic devices which convert D.C. energy into a.c. energy at very high frequency.
- So the function of an oscillator is opposite to that of a rectifier which converts a.c. power into d.c. power.

OR → It is a device used to produce sinusoidal or non sinusoidal wave forms without the application of an external input signal is an oscillator.

Essential Components of an oscillator

The Essential Components of an oscillator are

* Tank Circuit

* Amplifier

* Feed back circuit

Tank circuit - This circuit is also known as L-C circuit and consists of an inductor of inductance L and a capacitor of capacitance C . Tank circuit is used

to produce oscillations. The frequency of oscillation is determined by the value of L and C .

Amplifier - It may be BJT or FET amplifier, D.C. power or the voltage supply is converted in a.c. power which is fed to the tank circuit. The oscillation produced by the tank circuit are fed as input to the amplifier for amplification.

Feedback circuit → This circuit is used to provide positive feedback to the input.

Types of oscillators

Oscillators

Audio frequency oscillator
(Low frequency)

Radio frequency oscillator
(High frequency)

R-C Phase shift oscillator

Wein-Bridge oscillator

Hartley oscillator

Colpitt oscillator

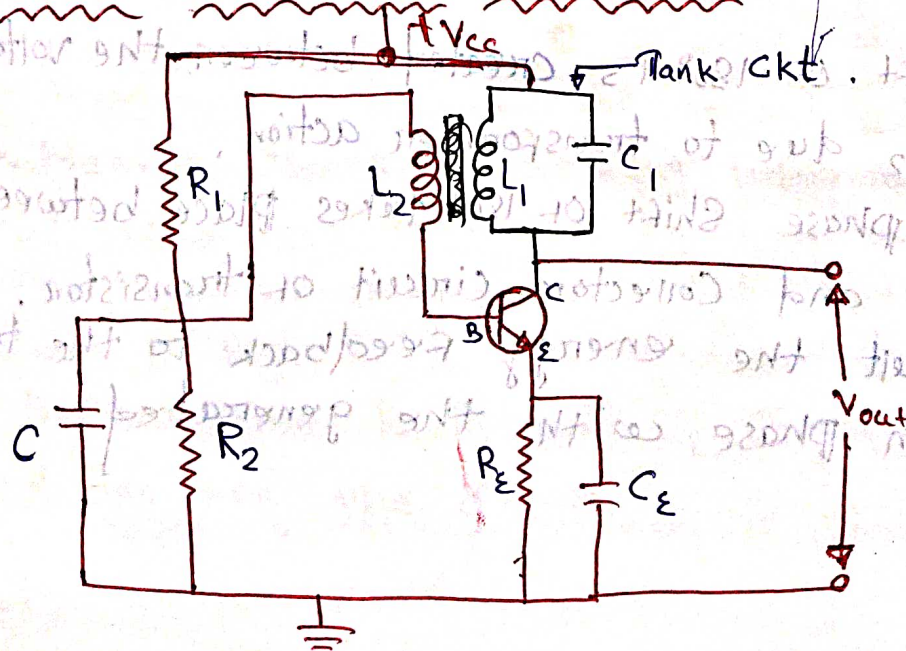
Audio frequency oscillator

The oscillators which generate signals in the audio frequency range are known as audio frequency oscillator. (a few Hz to 20 kHz)

Radio frequency oscillator

The oscillators which generate signals in the radio frequency range are called radio frequency oscillator. (20 kHz - 30 MHz)

TUNED COLLECTOR OSCILLATOR



→ The circuit diagram for tuned collector is shown.

→ The circuit contains a tuned circuit L_1-C_1 in the collector for the transistor hence it is called as tuned collector oscillator.

→ The frequency of required oscillations depends upon the values of L_1, C_1 and is given by

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

V. C. model

→ The coil L_2 in the base circuit is magnetically coupled to L_1 .

→ R_1, R_2, R_e and C_e are used for biasing and stabilization to circuit.

→ When the supply is ON, collector current starts increasing and charges the capacitor C_1 .

✓ → When this capacitor is fully charged, it discharges through coil L_1 , setting up oscillations.

✓ → These oscillations induce some voltage in coil L_2 .

✓ → The voltage across L_2 is applied between base and emitter appears in the amplified form in the collector circuit, thus overcoming the losses occurring in the tank circuit.

→ The phase of feedback is correct i.e. energy supplied to the tank circuit is in phase with the generated oscillations.

→ A phase shift of 180° is created between the voltage of L_1 and L_2 due to transformer action.

→ A further phase shift of 180° takes place between base-emitter and collector circuit of transistor.

→ As a result the energy feedback to the tank circuit is in phase with the generated oscillations.

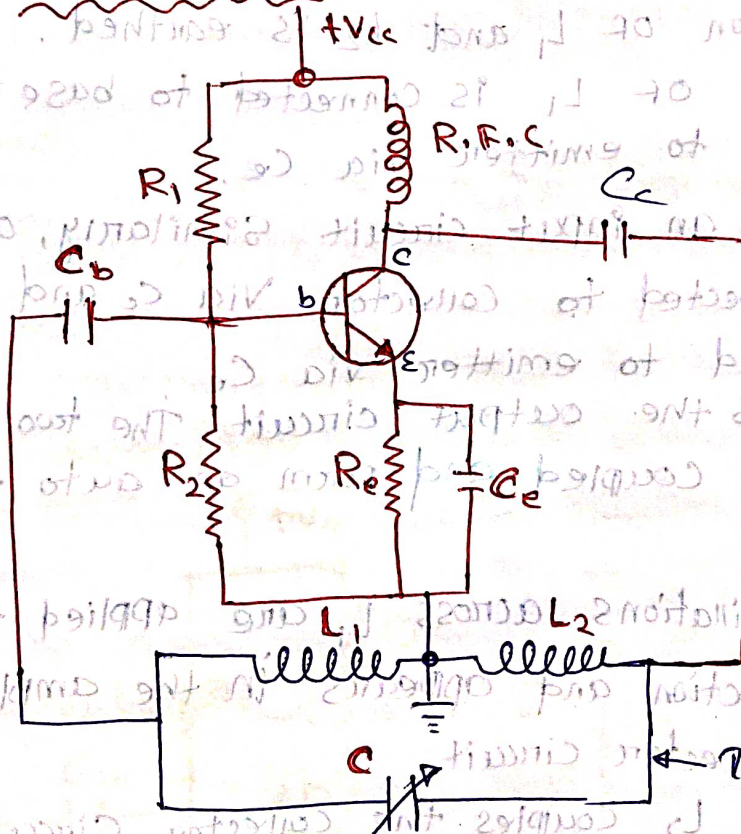
Advantages

- using LC oscillations wide range of frequencies can be obtained.
- Easy to tune.

Disadvantages

- for low frequency, the size of the inductor and capacitor becomes very large.
- Therefore for low frequencies this circuit is expensive.
- Temperature variations easily affect the frequency of oscillations.

HARTLEY OSCILLATORS



← Tank circuit.

- Hartley oscillator is very popular and is commonly used as a local oscillator in radio receivers.
- The circuit arrangement of a Hartley oscillator is shown in fig.
- The resistors R_1 , R_2 and R_E provides necessary bias condition for the circuit.

→ Capacitor C_e Provides a.c ground thereby Prevents any signal degeneration. This also Provides temperature stabilisation.

→ The radio frequency choke (RFC) Offers very high impedance to high frequency currents i.e. acts like a short and a.c open.

→ Thus it Provides d.c load for Collector and keeps a.c Current out of d.c Supply Source.

→ The function of C_c and C_b to block d.c and to provide an a.c Path.

→ The frequency determining network is a parallel resonant circuit consisting of inductor L_1 and L_2 and variable capacitor C .

→ The junction of L_1 and L_2 is earthed.

→ One side of L_1 is connected to base via C_c and to other to emitter via C_e .

→ So L_1 is an input circuit. Similarly, one end of L_2 is connected to collector via C_c and other end is connected to emitter via C_e .

→ So L_2 is the output circuit. The two parts are inductively coupled and form an auto transformer.

Working

→ The oscillations across L_1 are applied to the base emitter junction and appears in the amplified form in the collector circuit.

→ The coil L_2 couples the collector circuit energy back into the tank circuit by means of mutual inductance between L_1 and L_2 .

→ Thus Energy is being continuously supplied to the tank circuit to overcome the losses occurring in it.

→ The tank circuit Produces 180° Phase Shift.

→ Transistor amplifier Produces further 180° phase Shift.

- Thus the total phase shift is 360° or 0° .
- In this way energy feed back to the tank circuit is in phase with oscillations.

$$R = \frac{1}{2\pi V_{CC}}$$

Advantages

- Easy to tune
- Adaptability to a wide range of frequencies.
- used as a local oscillator in Radio and TV receivers.

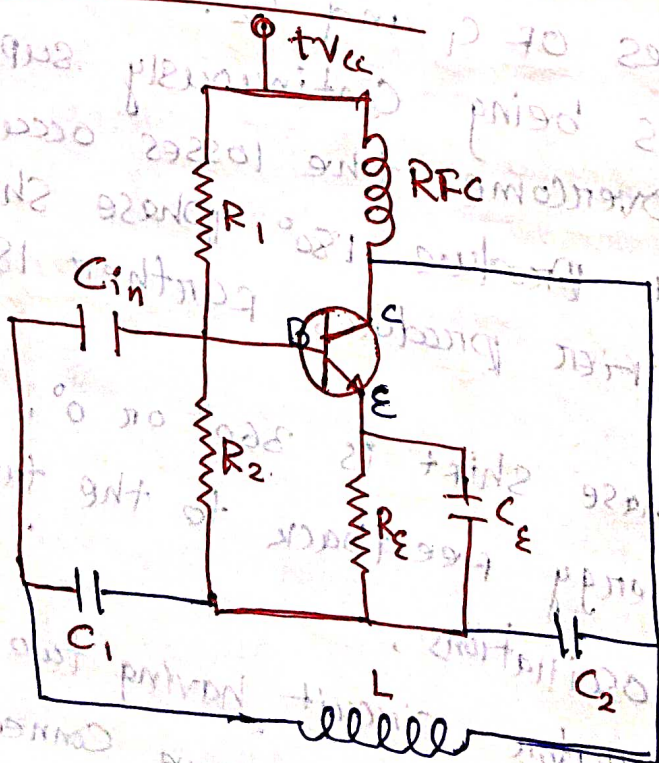
Disadvantage

- It requires inductors / transformer.
- Cost is high
- Poor frequency stability.
- It is not suitable for generating a pure sine wave.

Applications

- As a local oscillator in Radio receivers
- As a local oscillator in TV receivers
- For induction and dielectric heating purpose
- High frequency applications

COLPITT OSCILLATOR



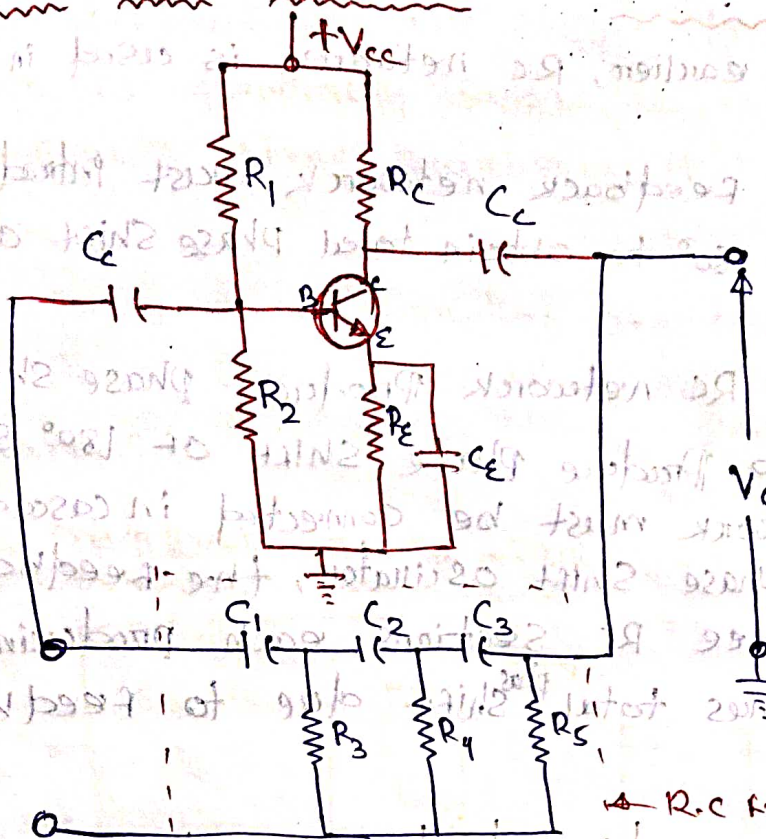
- The circuit diagram of Colpitt's oscillator is shown in Fig.
- The tank circuit is made up of C_1 , C_2 and L .
- The resistors R_1 , R_2 and R_E provide the required biasing and stability to the circuit.
- The capacitor C_E by passes the Emitter Current.
- The capacitor C_{in} blocks the d.c. Component.
- The radio frequency coil blocks a.c. Component.
- When the power is on, Collector Current starts rising and charges the capacitors C_1 and C_2 .
- These capacitors discharge through coil L setting up oscillations.
- The Frequency of oscillations is given by

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

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

- The oscillations across C_1 are applied to the emitter junctions and appears in the amplified form in the collector circuit.
- The Magnitude of feedback depends upon the relative capacitance values of C_1 and C_2 .
- Thus energy is being continuously supplied to the tank circuit to overcome the losses occurring in it.
- The tank circuit produces 180° phase shift.
- Transistor amplifier produces further 180° phase shift.
- Thus the total phase shift is 360° or 0° .
- In this way, energy feedback to the tank circuit is in phase with oscillations.
- A Colpitts oscillator circuit having two capacitors of 10 pF and 100 pF respectively are connected in parallel with an inductor of 10 mH . Determine Frequency of oscillations of the circuit.

R-C Phase shift oscillator



→ The circuit diagram for R-C phase shift oscillator is shown in figure.

→ It consists of a conventional single transistor amplifier and R-C phase shift network.

→ The phase shift network consists of three sections

$$R_3C_1, R_4C_2 \text{ \& } R_5C_3$$

→ At some particular frequency f_0 the phase shift of each section is 60° , so that the total phase shift produced by the RC network is $(3 \times 60^\circ) = 180^\circ$

→ The frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$

$$R_1 = R_3 = R_4 = R_5$$

$$C = C_1 = C_2 = C_3$$

→ The feedback phase is correct. A phase shift of 180° is produced by the transistor amplifier.

→ A further phase shift of 180° is produced by the R-C network.

→ As a result the phase shift around the entire loop is 360°

→ R-C phase shift oscillator using op-amp

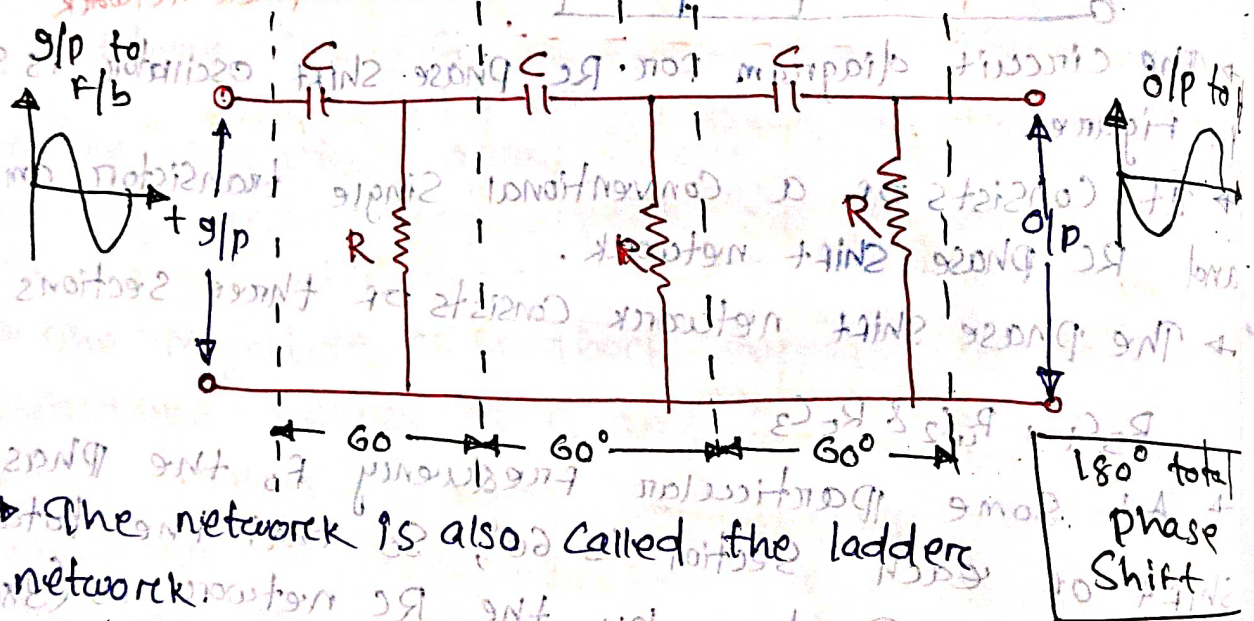
RC feedback network

→ As stated earlier, RC network is used in feedback path.

→ In oscillator, feedback network must introduce a phase shift of 180° to obtain total phase shift around loop as 360° .

→ Thus if one RC network produces phase shift of $\phi = 60^\circ$, then to produce phase shift of 180° such three RC network must be connected in cascade.

→ Hence in RC phase shift oscillator, the feedback network consists of three RC sections, each producing a phase shift of 60° , thus total phase shift due to feedback is $(60 \times 3) = 180^\circ$.



→ The network is also called the ladder network.

→ All the resistance values and all the capacitance values are same, so that for a particular frequency each section of R and C produces a phase shift of 60° .

Advantages

→ It does not require transformers or inductors.

→ Its cost is less.

→ It can be used to produce very low frequency.

→ The circuit provides good frequency stability.

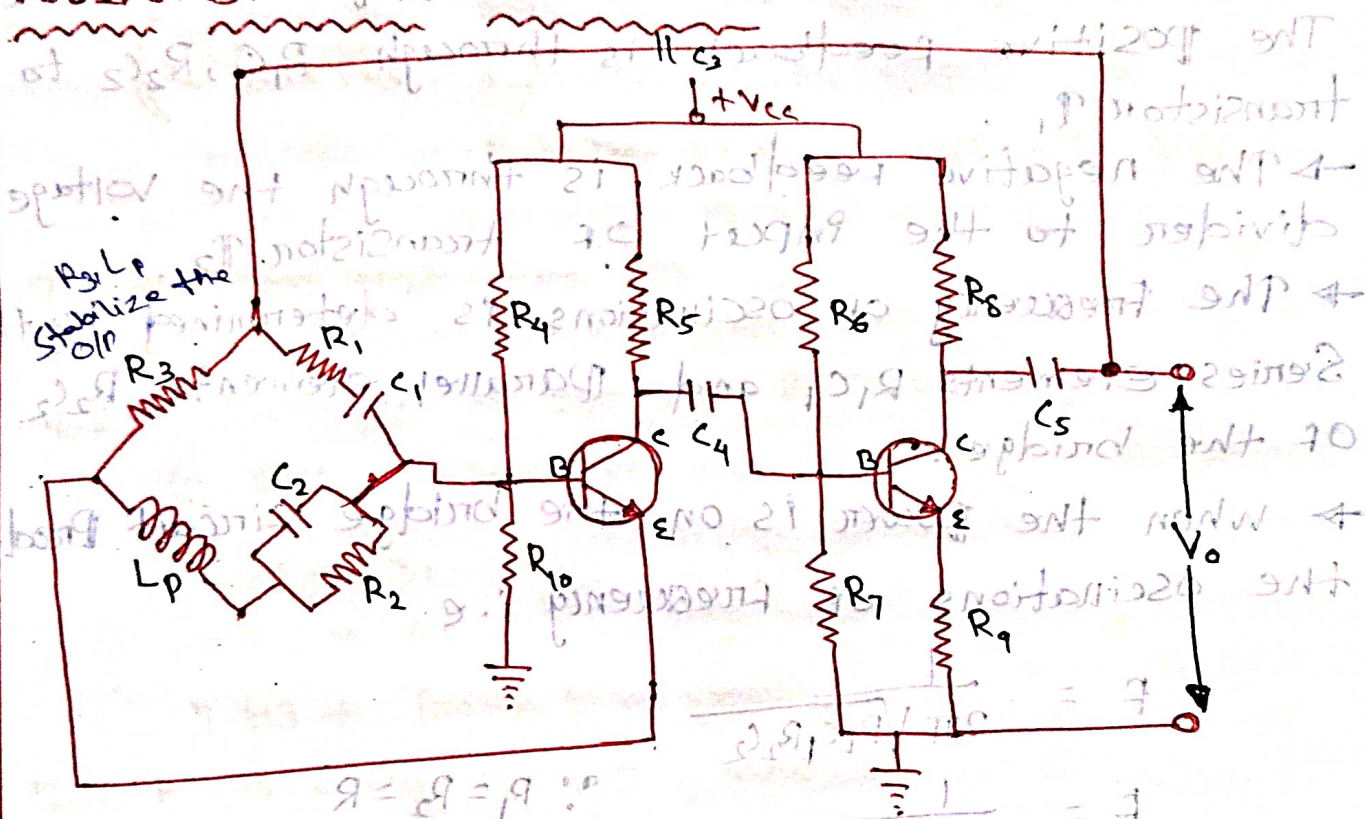
Disadvantages

- It is difficult for the circuit to start oscillations as feedback is generally small.
- The circuit gives small output.

Application

- RC Phase shift oscillators are used in signal generators.
- RC phase shift oscillators are used in audio applications.

WEIN BRIDGE OSCILLATOR



- The circuit of Wein bridge oscillator employs two stages of amplifier.
- The circuit of Wein bridge oscillator is shown in Fig.
- The output of last stage is coupled to the input of the first stage through coupling network.
- The provides necessary positive feedback for the circuit to work as an oscillator.
- Each amplifier stage gives phase shift of 180° , thus the two transistors combined produces a total phase shift of 360° phase shift, which

→ This oscillators can be used to generate Frequency from 10 Hz to 10 MHz.

→ It is extensively used as audio oscillator. Its output is free from circuit fluctuations and ambient temperature.

→ The Bridge circuit has the arms R_1, C_1, R_3, R_2, C_2 and tungsten lamp L .

→ Resistor R_3 and L_p are used to stabilize the amplitude of the output.

→ The circuit uses positive and negative feedback. The positive feedback is through R_1, C_1, R_2, C_2 to transistor T_1 .

→ The negative feedback is through the voltage divider to the input of transistor T_2 .

→ The frequency of oscillations is determined by Series elements R_1, C_1 and Parallel elements R_2, C_2 of the bridge.

→ When the power is on, the bridge circuit produces the oscillations of frequency i.e.

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$$f = \frac{1}{2\pi RC}$$

$$\because R_1 = R_2 = R$$

$$C_1 = C_2 = C$$

→ The desired frequency of oscillations can be produced by varying the two capacitors C_1 and C_2 simultaneously.

→ These oscillations are fed to first transistor T_1 .

→ After amplification these oscillations are fed to the second transistor T_2 .

→ First transistor T_1 serves as an amplifier and

Second Transistor T_2 serves as an inverter.

→ A total phase shift of 360° is obtained at the o/p.

Advantages

- output is constant.
- Its working is quite simple and easy.
- overall gain is high.
- It has far better stability.
- Frequency of oscillations can be easily adjusted.

Disadvantage

- Cannot be used to generate very high frequency.
- Costly, as more components are used.

(CHAPTER-7)

FIELD EFFECT TRANSISTOR

7.1 → Classification of FET

7.2 → Advantages of FET over BJT

7.3 → Principle of operation of BJT

7.4 → FET PARAMETER (no-mathematical derivation)

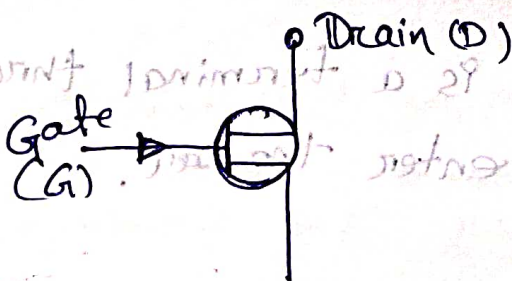
7.4.1 → DC drain resistance

7.4.2 → AC drain resistance

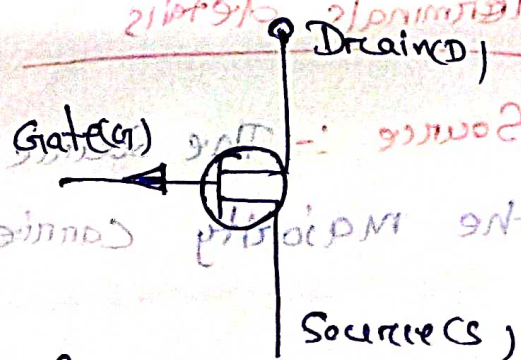
7.4.3 → Trans-Conductance

7.5 → Biasing of FET

- Field effect transistor is a semiconductor device which depends for its operation on the control of current by an electric field.
- FET is a low noise device



(N-channel)



(P-channel)

- FET is a three terminal unipolar semiconductor in which output current is controlled by an electric field.
- FET operation depends upon the flow of carriers (either electrons or holes).
- Device can also be used as an amplifier.
- FET is a voltage controlled device whose current (I_D) can be controlled by applied voltage between Gate and Source terminals (V_{GS}).
- FET is a unipolar device since current is carried by either holes (p channel) or electrons (n channel).
- This is a temperature dependent device; Rise temp. causes increase in channel resistance which in reduced flow of current from the source drain.
- Comparatively requires less space and hence preferred to use in VLS.

Advantages of FET over BJT

- Current flow is due to majority carriers only.
- Immune to radiation.
- High input resistance.
- Less noise than BJT.
- No effect voltage at zero drain current.
- High thermal stability.

Terminals details

Source :- The Source 's' is a terminal through which the majority carriers enter the bar.

Drain :- The drain 'D' is a terminal through which the majority carriers leave the bar.

Gate :- The two p-regions are internally connected and a single lead is brought out; This is called gate terminal.

Channel - This is the region of the n-type material between the two gate regions, through which the majority carriers move from source to drain.

BJT

FET

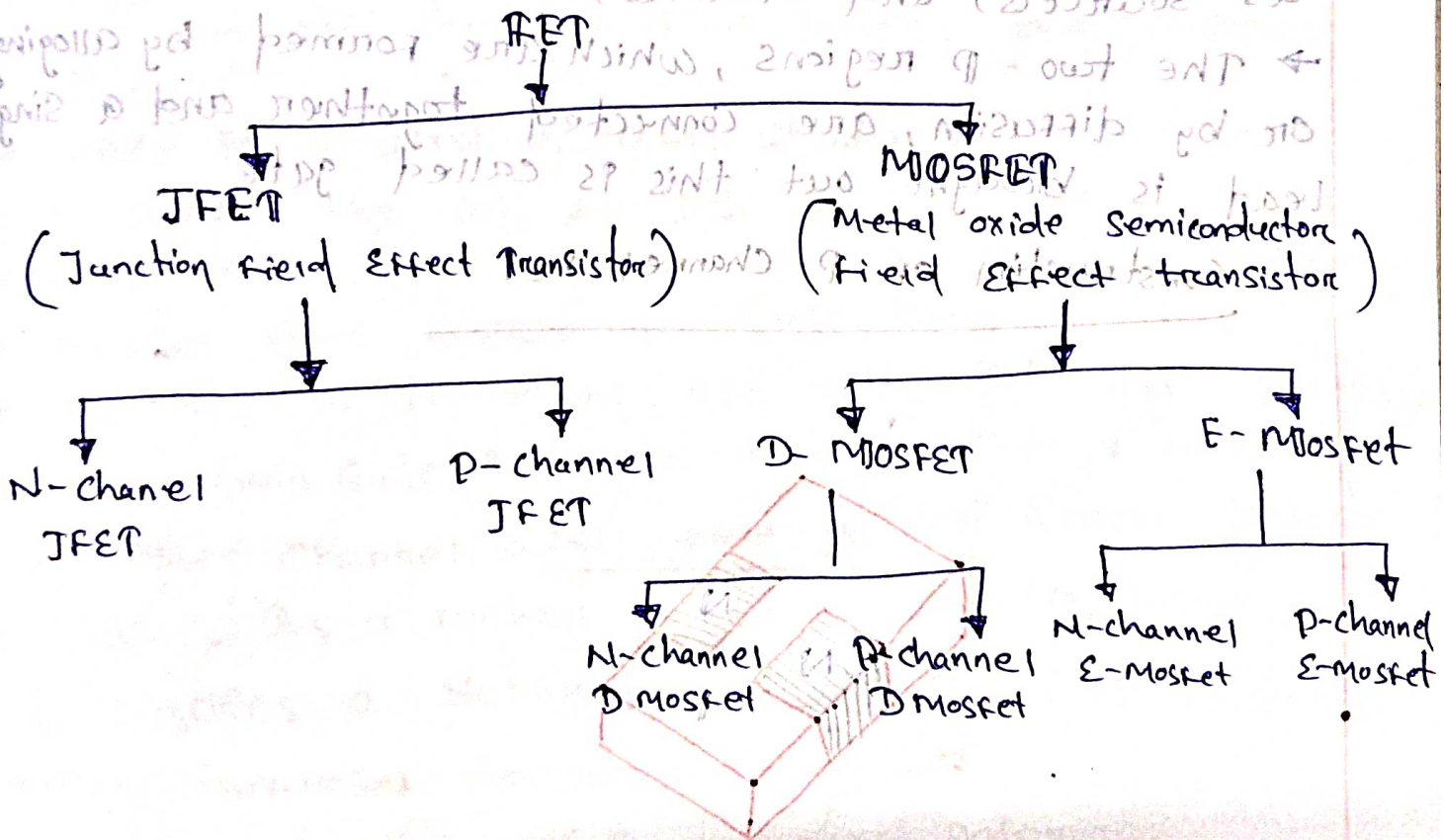
Base (B) → Gate (G)

Emitter (E) → Source (S)

Collector (C) → Drain (D)

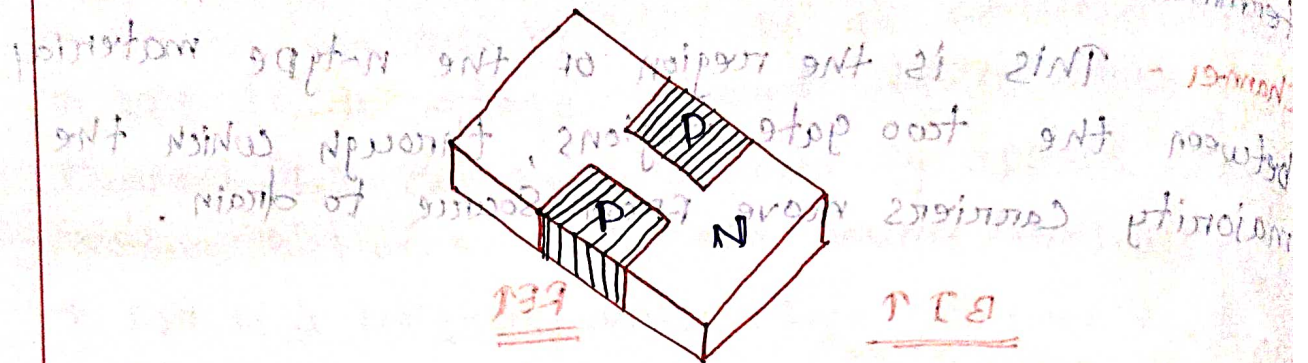
Classification

OK FET



Principle of operation of JFET

Construction of N channel JFET

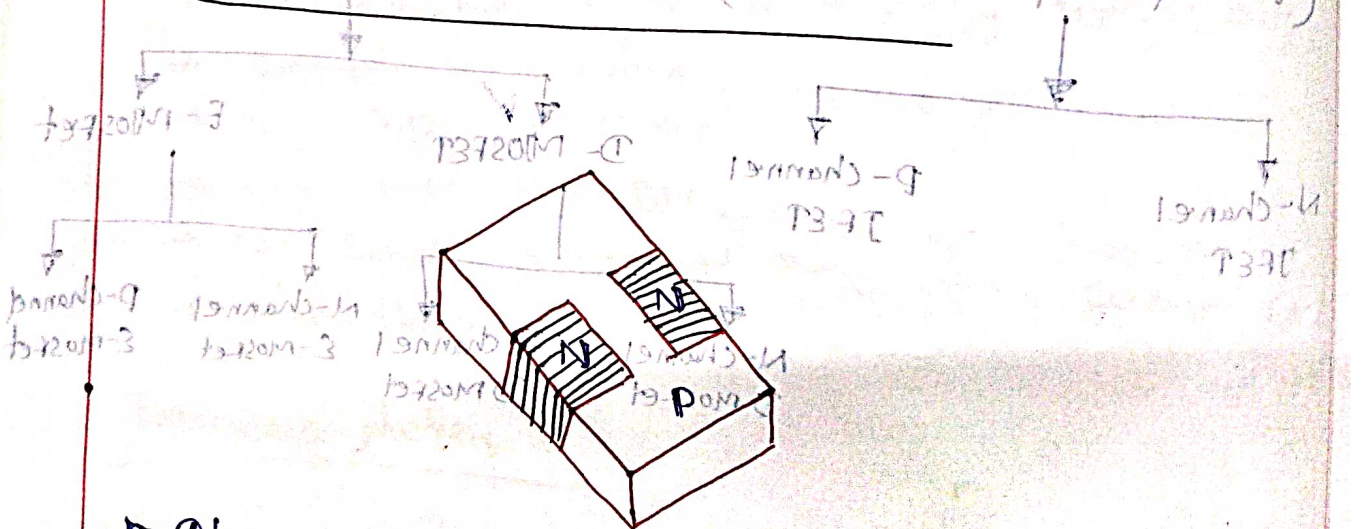


→ It consists of an n-type silicon bar referred as channel and two small pieces of p-type material attached to its sides forming pn junction.

→ If the bar is of n-type the JFET is called as n-channel JFET; the channel ends are designated as Source (S) and Drain (D).

→ The two - p regions, which are formed by alloying or by diffusion, are connected together and a single lead is brought out this is called gate.

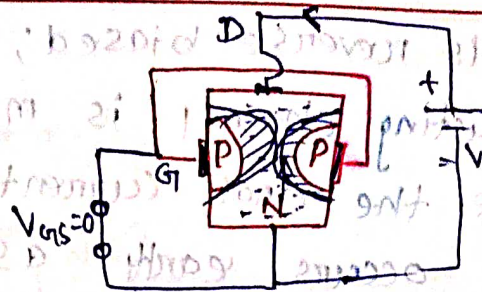
Construction of P-channel JFET



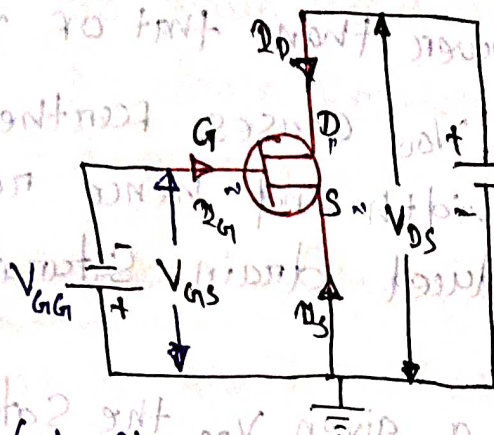
→ The principle of working on n-channel JFET and p channel JFET are similar.

→ The only difference being that n-channel JFET current is carried by electrons.

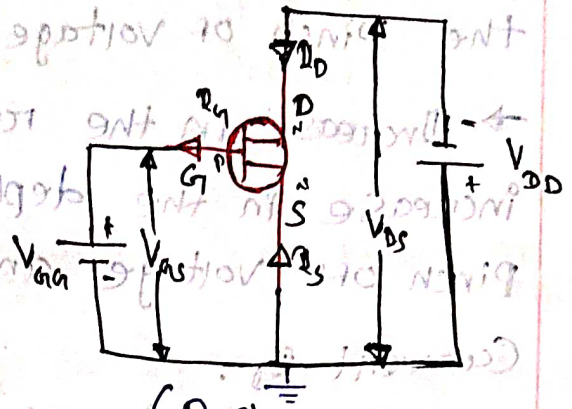
Operation of JFET



$$V_{GS} = 0, V_{DS} > 0$$



(N-channel)



(P-channel)

→ The majority Carriers Contribute to Current flow in the channel.

→ When gate terminal is connected directly to Source, $V_{GS} = 0$ and V_{DS} is increased gradually, A small drain Current begins to flow initially and increases linearly.

→ There is a potential drop across the channel and the reverse bias across the pn junction is not uniform, Drain side is more positive and the reverse bias gradually increases from source to drain side.

→ As V_{DS} is increased, the depletion width particularly on the drain side increases and reaches a maximum, And the channel width reduces and reaches certain minimum. As a result, the Current I_D increases and reaches a Saturation value I_{DSS} , in spite of further increases in V_{DS} .

→ The V_{DS} at which I_D attains saturation is called Pinch-off voltage (V_P).

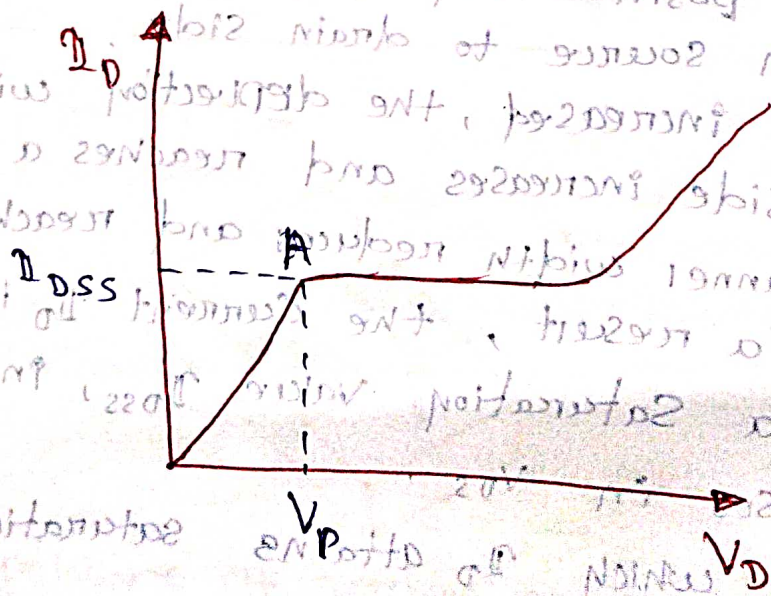
→ When V_{as} is reverse biased, the depletion width in the conducting channel is more than it is for $V_{as} = 0$. Hence the drain current saturation due to depletion rise occurs early as V_{DS} is increased, the pinch off voltage is lower than that of $V_{as} = 0$.

→ Increase in the reverse V_{as} causes further increase in the depletion width and hence reduced pinch off voltage and reduced drain saturation current I_{DSS} .

→ As V_{as} is increased, for a given V_{DS} the saturation current I_D reduces and FET behaves like voltage controlled current source.

Pinch off voltage (V_p)

→ Pinch off voltage is the voltage across the drain to the source (V_{DS}) of a FET, after which the drain to source current (I_D) becomes constant is called pinch off voltage.



I_{DSS} = Drain Saturation current

FET PARAMETER

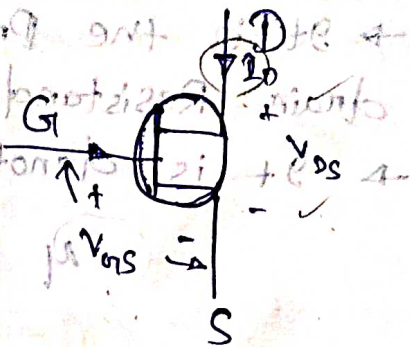
Different Parameters are

Transconductance (g_m)

Dc drain Resistance (R_d)

Ac drain Resistance (r_d)

Amplification factor (μ)



Trans Conductance (g_m) (Mutual Conductance) or figure of merit.

→ It is the ratio of change in o/p current (I_D) to the change in input voltage (V_{GS}) at constant V_{DS} .

→ It is denoted as (g_m)

$$g_m = \left. \frac{\Delta I_D}{\Delta V_{GS}} \right|_{V_{DS} \text{ constant}}$$

Dc drain Resistance (R_d)

→ It is the Ratio of output voltage (V_{DS}) to the output current (I_D).

→ It is denoted as R_d .

$$R_d = \frac{V_{DS}}{I_D}$$

Ac drain Resistance (r_d)

→ It is the ratio of change in output voltage (V_{DS}) to the change in input current (I_D) at constant V_{GS} .

→ It is denoted as r_d

$$r_d = \left. \frac{\Delta V_{DS}}{\Delta I_D} \right|_{V_{GS} \text{ constant}}$$

* Voltage divider circuit

Amplification factor (μ)

→ It is the Product of Trans Conductance and Drain Resistance (r_d)

→ It is denoted as $\mu = g_m \times r_d$

$$\mu = \frac{\Delta I_D}{\Delta V_{GS}} \times \frac{\Delta V_{DS}}{\Delta I_D}$$

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

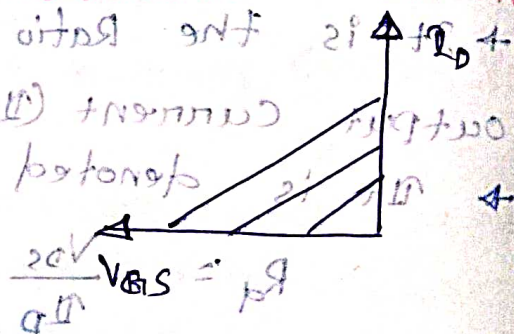
→ It is also defined as the ratio of change in output voltage to change in input voltage

Transfer characteristics

→ It is the g/p characteristics, curve between output current with input voltage or input current at constant output voltage

→ I_D vs V_{GS} or I_G

Constant V_{DS}



Biasing of FET

→ Biasing deals with setting a fixed level of current which should flow through the FET with a desired fixed voltage drop across the FET junction

→ The Commonly used biasing circuits for FET are

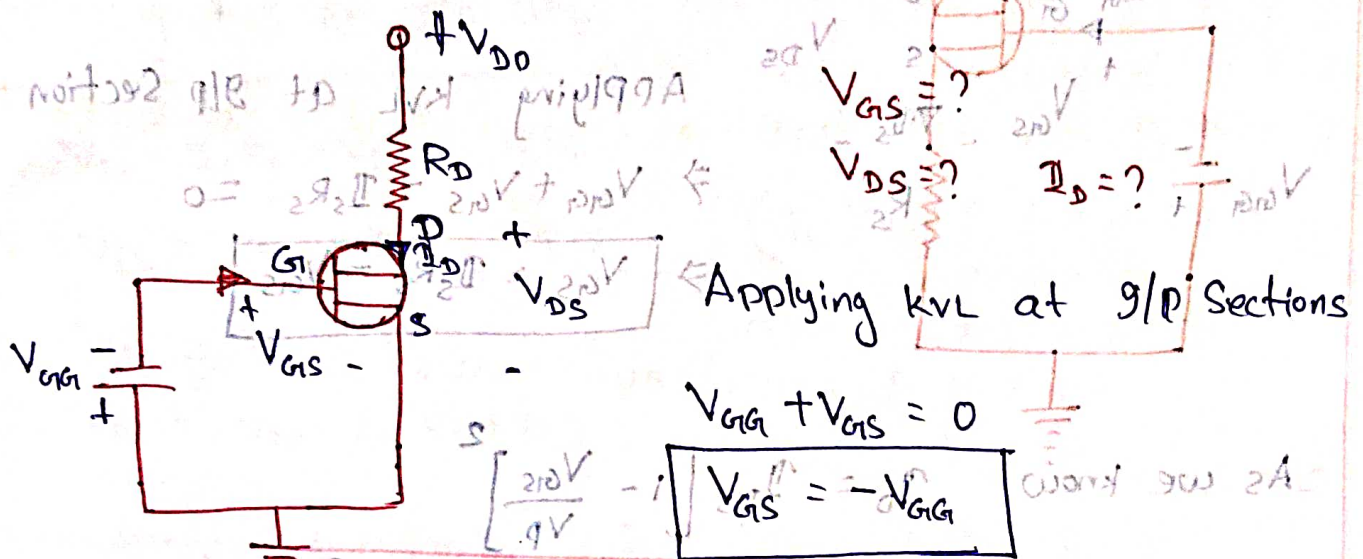
* Fixed bias

* Self bias

* Voltage divider bias

→ whatever be the biasing method, the gate-source junction of a JFET will always be reverse biased.
 → The general relationships which can be applied to the dc analysis of all FET amplifier are $I_G \approx 0$ and $I_D = I_S$

fixed bias



As we know, $I_D = I_{DSS} \left(1 + \frac{V_{GS}}{V_p} \right)^2$ ← Remember that

$$\Rightarrow I_D = I_{DSS} \left(1 + \frac{V_{GG}}{V_p} \right)^2$$

Here, I_{DSS} = Drain Saturation Current

V_{GG} = g/p voltage

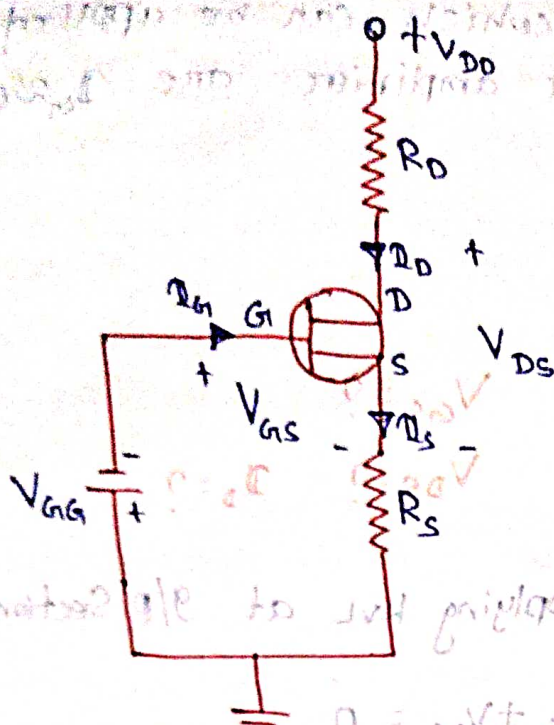
V_p = Pinch off voltage

Applying KVL at o/p section

$$\Rightarrow V_{DD} - I_D R_D - V_{DS} = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D$$

Voltage divider bias



$$V_{GS} = ?$$

$$V_{DS} = ?$$

$$I_D = ?$$

Applying KVL at g/p Section

$$\Rightarrow V_{GG} + V_{GS} - I_S R_S = 0$$

$$\boxed{V_{GS} = I_S R_S - V_{GG}}$$

As we know $I_D = I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right]^2$

$$\boxed{I_D = I_{DSS} \left[1 - \frac{(I_S R_S - V_{GG})}{V_P} \right]^2}$$

Applying KVL at o/p Section

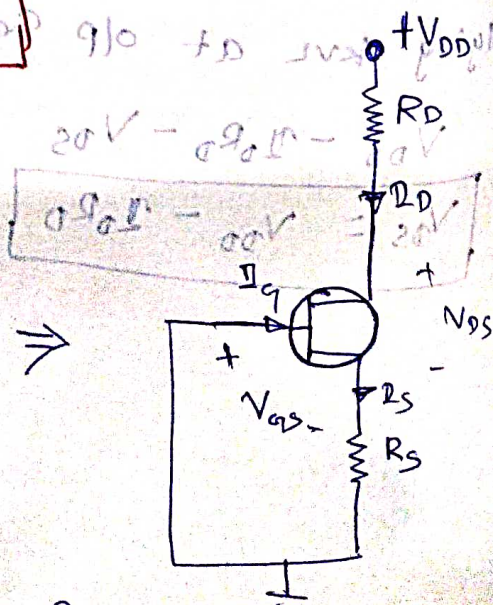
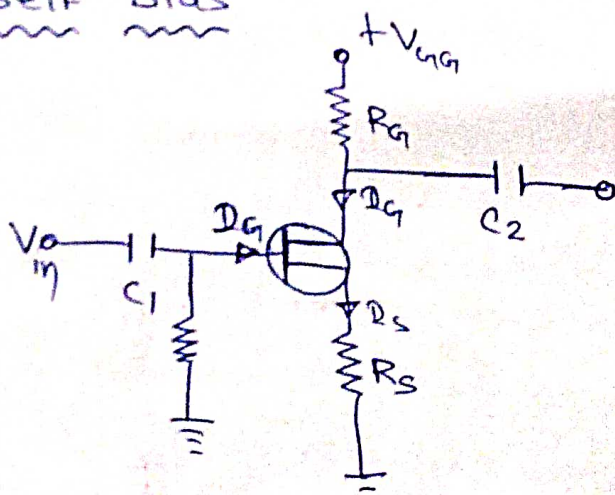
$$+V_{DD} - I_D R_D - V_{DS} - I_S R_S = 0 \quad \therefore I_S = I_D$$

$$\Rightarrow V_{DD} - I_D R_D - V_{DS} - I_D R_S = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_D R_S$$

$$\boxed{\Rightarrow V_{DS} = V_{DD} - I_D (R_D + R_S)}$$

Self Bias



Applying KVL at i/l Side

$$V_{GS} + I_S R_S = 0$$

$$\Rightarrow V_{GS} = -I_S R_S$$

$$I_S \approx I_D$$

$$\Rightarrow V_{GS} = -I_D R_S$$

As we know,

$$I_D = I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right]^2$$

$$\Rightarrow I_D = I_{DSS} \left[1 + \frac{I_D R_S}{V_P} \right]^2$$

Applying KVL at o/p Side

$$V_{DD} - I_D R_D - V_{DS} - I_S R_S = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_S R_S \quad (I_S \approx I_D)$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_D R_S$$

$$\Rightarrow V_{DS} = V_{DD} - I_D (R_D + R_S)$$

* Difference between BJT over FET?

~~BOD~~ FET

BJT

→ It is unipolar device (Conduction is only due to one type of carrier either electron or hole)

→ It is voltage control device

→ It is low noise

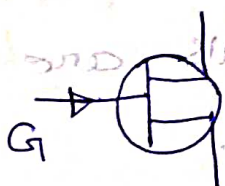
→ High input impedance (due to Reverse bias)

→ Better thermal stability

→ Ex - Transconductance

→ Higher input resistance

→ Size is small



→ It is Bipolar device (Conduction by both type of Carriers i.e. electron and hole)

→ It is Current control device

→ It is High noise

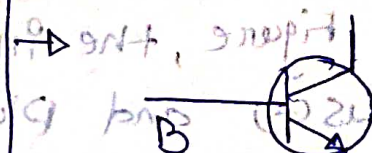
→ Low input impedance (due to forward bias)

→ Less thermal stability

→ Ex - Voltage gain

→ Low input resistance

→ Size is big



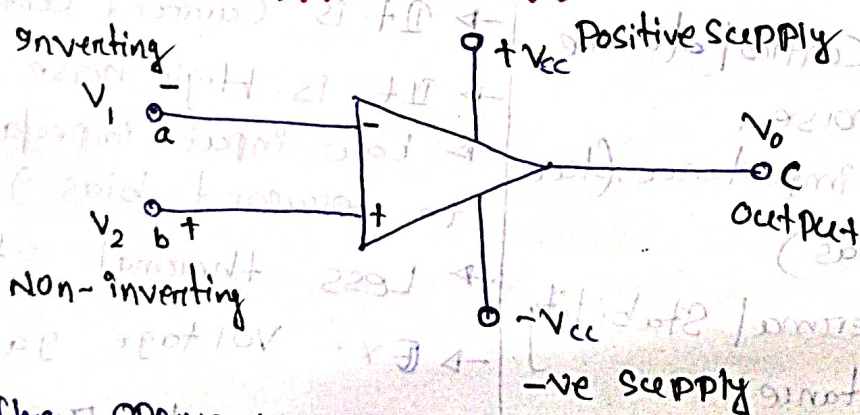
- 8.1 → General circuit Simple of OPAMP and IC - CA-741
- 8.2 → Operational amplifier stages.
- 8.3 → Equivalent Circuit of operational amplifier.
- 8.4 → open loop OP-AMP Configuration.
- 8.5 → OPAMP with feed back.
- 8.6 → Inverting OP-AMP.
- 8.7 → Non-Inverting OP-AMP
- 8.8 → Voltage follower & buffer.
- 8.9 → Differential amplifier
 - 8.9.1 → Adder or Summing amplifier
 - 8.9.2 → Sub tractor
 - 8.9.3 → Integrator
 - 8.9.4 → Differentiator
 - 8.9.5 → Comparator.

Introduction

- OPAMP stands for Operational Amplifier.
- It is a integrated circuit who can amplify the weak signal.

- OR Operational amplifier is a direct coupled, high negative feedback amplifier.
- Their gain 10^5 to 10^6

General Circuit Simple of OPAMP



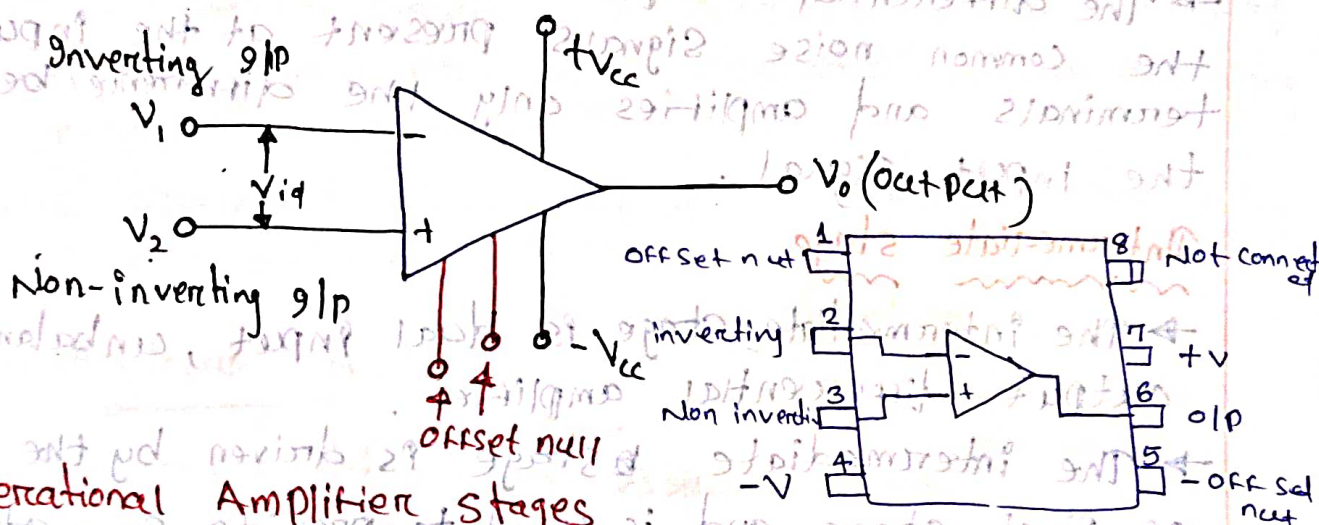
- The OPAMP has two input terminals and a single output terminal.
- In this figure, the input terminals are marked with minus (-) and Plus (+) signs.
- The ~~input~~ terminals are marked with a circle and a cross, which is called as

→ The negative sign indicates that a signal applied at terminal a will appear amplified but phase inverted (opposite polarity) at terminal c.

→ Similarly, the terminal b (marked +) is called as non-inverting input terminals.

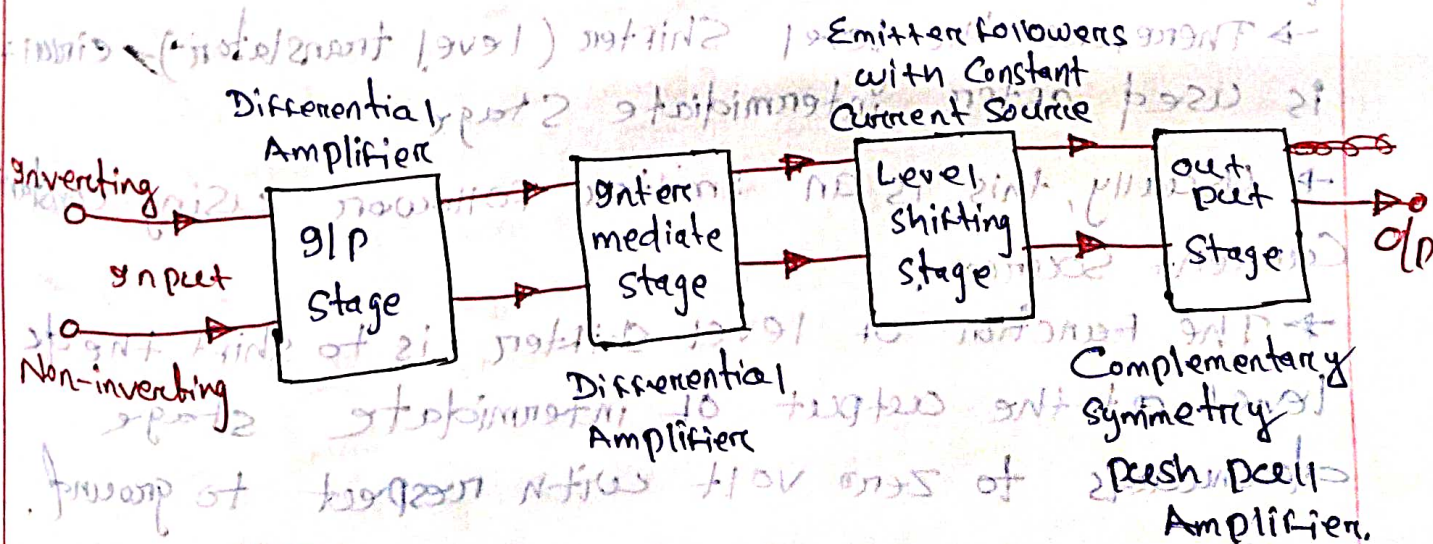
→ Here, the positive sign indicates that a signal applied at the terminal b will appear amplified but in phase (same polarity) at the terminal 'c'.

Circuit Symbol of IC-CA 741 OPAMP



Operational Amplifier Stages

- A general purpose op-amp is a multi stage circuit.
- In general, it consists of four stages - Input stage, Intermediate stage, level shifting stage and output stage.
- The fig shows the block diagram of a typically opamp.



It consists of two differential amplifiers followed by a level shifter and an output stage.

Input stage

- The input stage is a dual input, balanced output differential amplifier.
- The function of differential amplifier is to provide most of the voltage gain to opamp.
- It also establishes the input resistance of the opamp.
- The differential amplifier in the input stage rejects the common noise signals present at the input terminals and amplifies only the difference between the input signal.

Intermediate stage

- The intermediate stage is dual input, unbalanced output differential amplifier.
- The intermediate stage is driven by the output of first stage and is used to provide some additional gain.

Level shifting stage

- As direct coupling is used, the d.c. at the output of the intermediate stage is well above the ground potential.

→ Therefore the level shifter (level translator) circuit is used after intermediate stage.

→ Usually, this is an emitter follower using constant current source.

→ The function of level shifter is to shift the d.c. level at the output of intermediate stage downwards to zero volt with respect to ground.

output stage

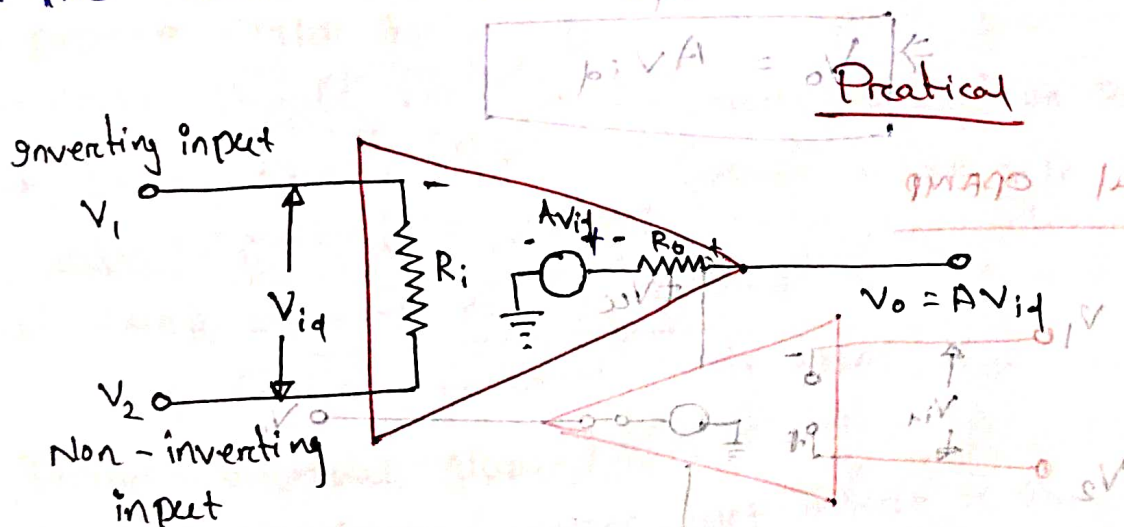
→ The output stage is generally Push Pull or Complementary Symmetry Push Pull Amplifier.

→ Its function is to increase large Output Voltage Swing Capability, large Output Current Swing Capability of the amplifier and to provide low output resistance.

Equivalent circuit of OP AMP

→ The equivalent circuit of an OPAMP is helpful in analyzing the operating principles of an OPAMP and in observing the effects of feedback.

→ The equivalent circuit of an OPAMP is shown in Fig.



→ V_1 is the voltage at inverting terminal and V_2 is the voltage at the non-inverting terminal.

→ V_{id} is the difference between two input voltage

$$\text{is } (V_2 - V_1)$$

→ R_i is the input resistance which appears between the inverting and non-inverting input terminals.

→ R_o is the output resistance which is Thevenin equivalent resistance looking back into the output terminals of OPAMP.

→ Source AV_{id} is the equivalent Thevenin voltage source.

An Ideal opamp

Input resistance (R_i) = ∞

Output resistance (R_o) = 0

and differential gain (A_{v_d}) = ∞

As we already know $V_{id} = V_2 - V_1$

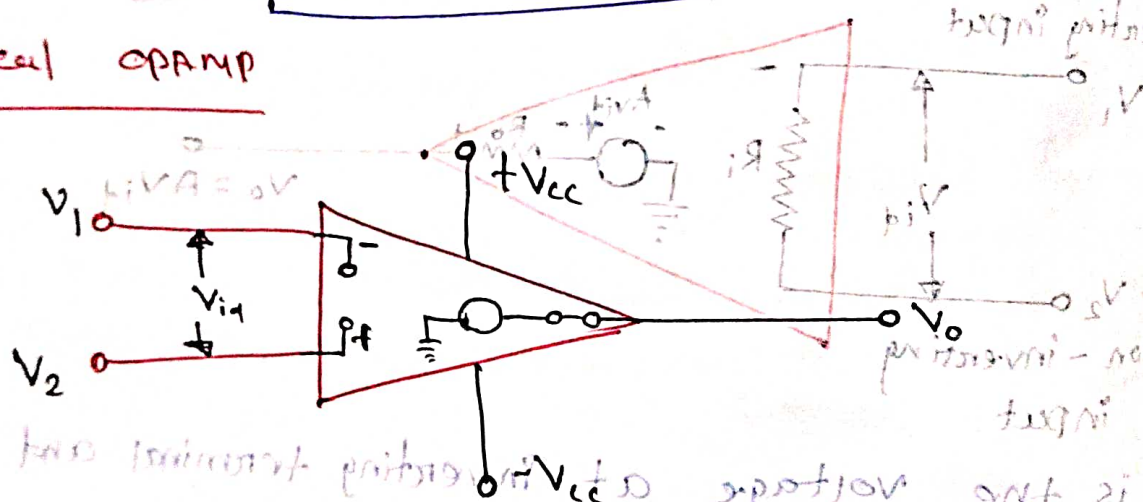
The gain of amplifier (A) = $\frac{\text{out put}}{\text{difference between two input signals}}$

$$\Rightarrow A = \frac{V_o}{V_2 - V_1}$$

$$\Rightarrow A = \frac{V_o}{V_{id}}$$

$$\Rightarrow \boxed{V_o = A V_{id}}$$

Ideal opamp



In ideal opamp R_i = open ckt.
 R_o = short ckt.

Characteristics of an ideal op-amp

An ideal op-amp has the following characteristics

* At infinite voltage gain.

* At infinite band width.

* At infinite input resistance.

* Zero output resistance.

- * Perfect balance
- * Zero offset voltage
- * Infinite CMRR (Common mode Rejection Ratio)
- * Infinite Slew rate

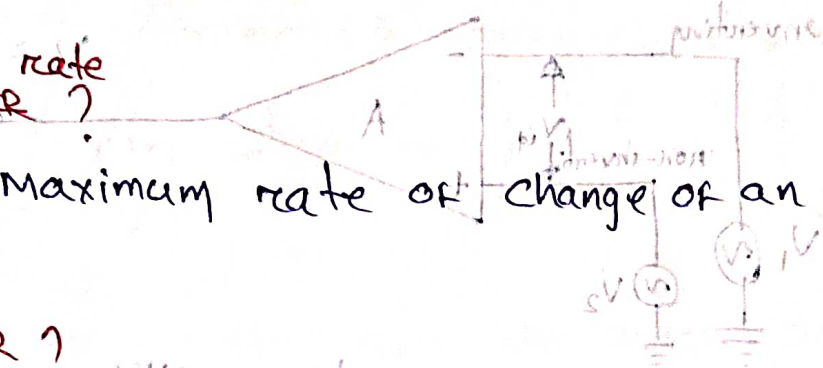
* Zero drift.
 * virtual grounded.

* what do you mean by offset voltage?

when input signal voltage is zero, then the output signal will also be zero. It is called offset voltage.

* Define ~~CMRR~~ Slew rate?

It is the maximum rate of change of an opamp o/p voltage.



* Define CMRR?

→ CMRR Stands for Common mode Rejection Ratio.

→ It is the ratio of Common mode gain to the differential mode gain.

$$\rightarrow \text{CMRR} = \frac{\text{Common mode gain}}{\text{differential mode gain}}$$

* Define virtual grounded?

→ virtual ground means that there is the voltage is zero volt, but mechanically it is not grounded. So, no current flow from point to ground is called virtual ground.

Open Loop Configuration

→ When there exists no connections between the o/p and i/p terminals of opamp (i.e. no feedback) then it is known as open loop opamp.

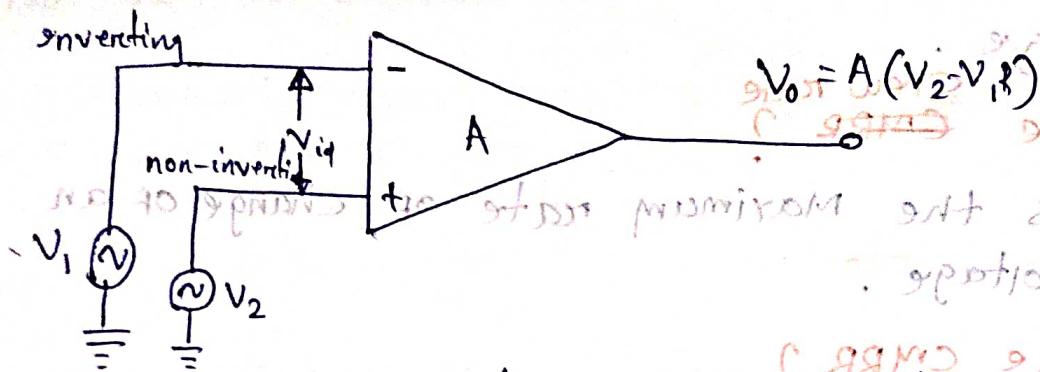
→ In this case, the opamp functions as high gain Amplifier.

There are three open loop configuration

- Differential amplifier
- Inverting amplifier
- Non inverting amplifier

→ It is important mention here that opamp amplifier a.c and d.c input signals.

Differential amplifier



→ The open loop differential amplifier as shown in fig.

→ Here V_1 and V_2 are signals applied to inverting and non-inverting terminals respectively.

→ V_1 and V_2 may be either a.c or d.c as op-amp can amplify both types of signals.

→ Here source resistance are not considered because they are negligibly small in comparison with very high input resistance of op-amp.

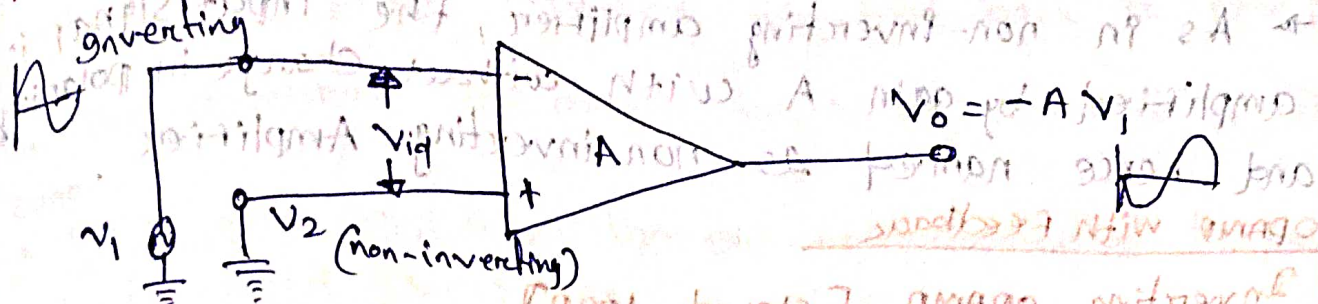
→ As the op-amp amplifies the difference between two input signals and hence this configuration is called as differential amplifier.

$$V_0 = A V_{id} = A (V_2 - V_1)$$

$$A_{ol} = \frac{V_0}{V_{id}}$$

A_{ol} = gain in open

Inverting Amplifier



- In this configuration the input voltage is applied to the inverting input terminal as shown in fig.
- The non-inverting terminal is grounded i.e. $V_2 = 0$

$$V_0 = A V_{id} = A (V_2 - V_1)$$

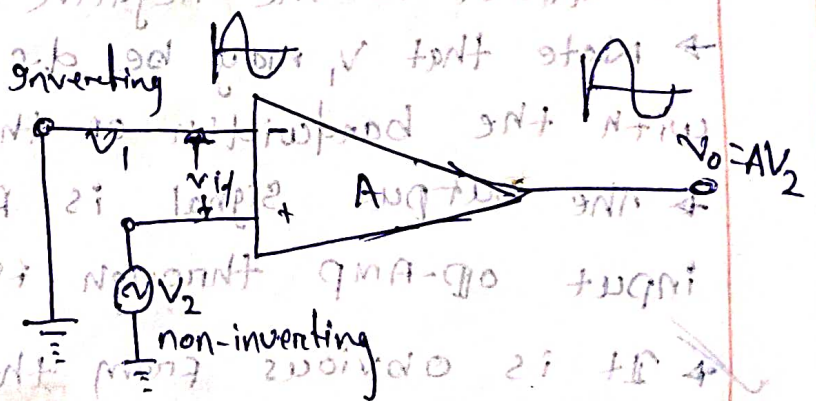
$$\boxed{V_0 = -A V_1}$$

- The negative sign indicates that the output voltage is out of phase with respect to input i.e. output voltage is 180° out of phase w.r.t input.
- Thus in inverting amplifier, the input is amplified gain: A with change in polarity.
- Hence the name is given inverting amplifier.

Non Inverting Amplifier

- In this configuration, the input signal is applied to the non-inverting input terminal of op-amp as shown in fig.

- The inverting terminal is grounded.



$$V_0 = A V_{id} = A (V_2 - V_1)$$

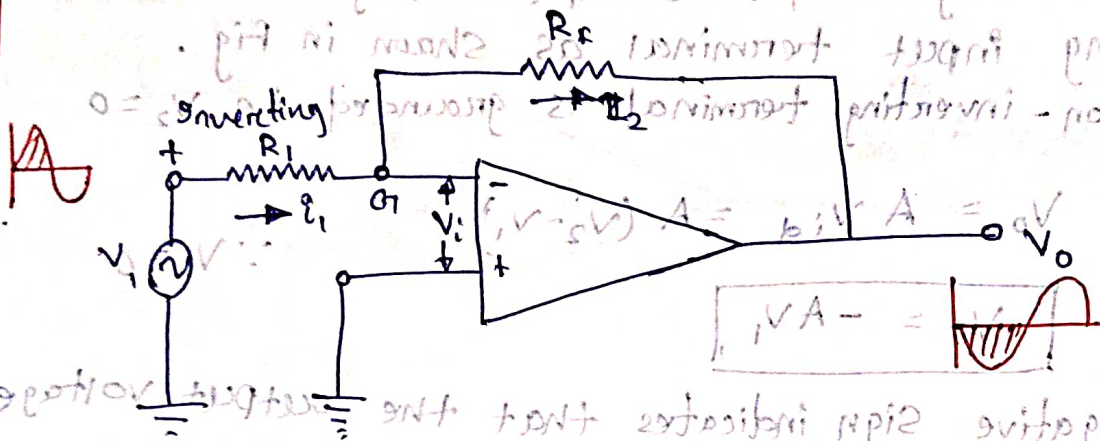
$$\boxed{V_0 = A V_2}$$

→ This shows that output voltage is gain A times voltage V_2 and is in phase with the input.

→ As in non-inverting amplifier, the input signal is amplified by gain A without change in polarity and hence named as non-inverting amplifier.

* OPAMP with feedback

Inverting opAMP [closed loop]



→ Figure shows the basic inverting amplifier with an input resistance R_1 and a feedback resistor R_f .

→ In this mode of operation, the positive input terminal of the amplifier is grounded and the input signal is applied to the negative input terminal.

→ Note that V_1 may be d.c. voltage or an a.c. signal with the bandwidth of the amplifier.

→ The output signal is fed back to the inverting input op-amp through feedback resistor R_f .

→ It is obvious from the figure that the feedback currents are algebraically added at point 'G'. So, this point is called as summing point.

→ When the input voltage V_1 is applied at the input terminal, the point G attains some positive potential.

- Now there exists output voltage V_o .
- Due to negative feedback, a fraction of the output voltage with phase inverted is fed back to the point G .
- The algebraic sum of the two voltages at G is almost zero.
- Thus, the point G , although not connected to ground, but is held virtually at ground.

gain

The current i_1 flowing through point G is given by

$$i_1 = \frac{V_i - V_i}{R_i} = \frac{V_i}{R_i} \quad \text{and } (\because V_i = 0 \text{ due to virtual ground concept})$$

$$i_2 = \frac{V_i - V_o}{R_f} = \frac{-V_o}{R_f}$$

$$i_1 = i_2$$

$$\Rightarrow \frac{V_i}{R_i} = -\frac{V_o}{R_f}$$

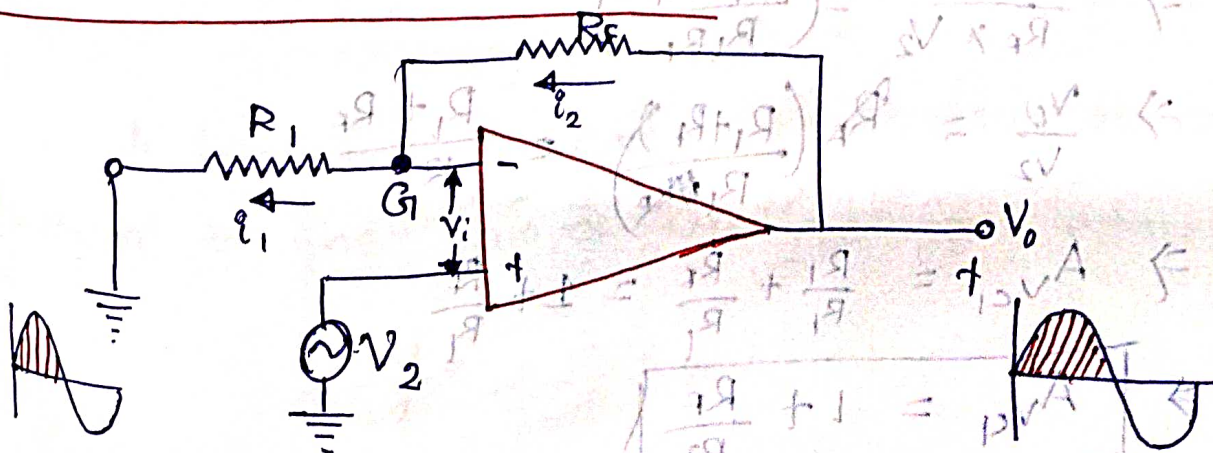
$$\Rightarrow V_i R_f = -V_o R_i$$

$$\Rightarrow -\frac{R_f}{R_i} = \frac{V_o}{V_i} = A_v$$

As we know, the ratio of o/p voltage V_o and input voltage V_i is known as closed loop gain:

$$A_v = -\frac{R_f}{R_i}$$

NON-INVERTING OPAMP



- Here, the input voltage V_2 is applied to the non-inverting terminal and hence the name non-inverting amplifier.
- The potential of point G is also V_2 since the gain of OPAMP is infinite.
- The polarity of V_o is the same as that of V_2 .
- The voltage across R_1 is V_2 and across R_F is $(V_o - V_2)$.

Expression for closed-loop gain

Current of $i_1 = \frac{V_2}{R_1}$ and $i_2 = \frac{V_o - V_2}{R_F}$

Applying KCL at point G, $i_2 = i_1$

$$\Rightarrow i_2 - i_1 = 0$$

$$\Rightarrow -i_1 + i_2 = 0$$

$$\Rightarrow -\frac{V_2}{R_1} + \frac{V_o - V_2}{R_F} = 0$$

$$\Rightarrow -\frac{V_2}{R_1} + \frac{V_o}{R_F} - \frac{V_2}{R_F} = 0$$

$$\Rightarrow \frac{V_o}{R_F} = \frac{V_2}{R_1} + \frac{V_2}{R_F} = V_2 \left(\frac{1}{R_1} + \frac{1}{R_F} \right)$$

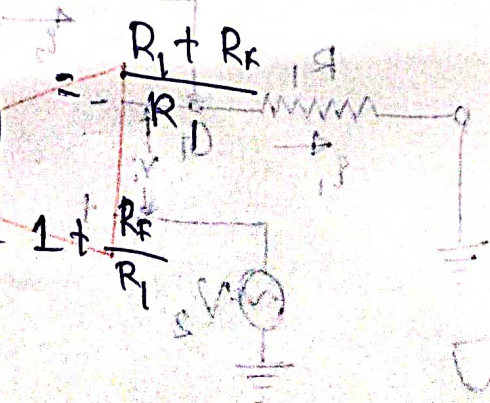
$$\Rightarrow \frac{V_o}{R_F} = V_2 \left(\frac{R_1 + R_F}{R_1 R_F} \right)$$

$$\Rightarrow \frac{V_o}{R_F \times V_2} = \left(\frac{R_1 + R_F}{R_1 R_F} \right)$$

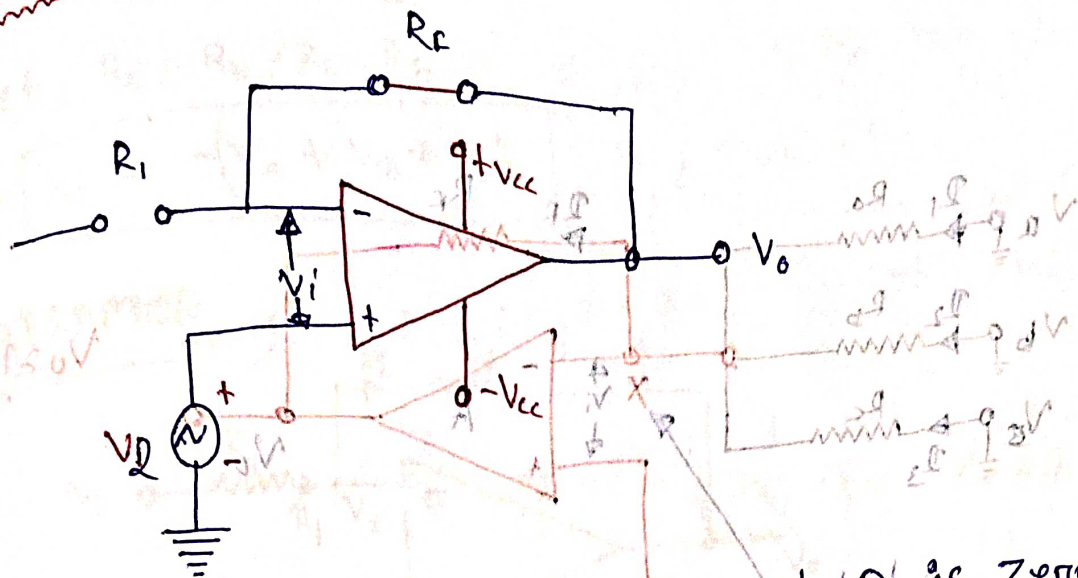
$$\Rightarrow \frac{V_o}{V_2} = \left(\frac{R_1 + R_F}{R_1} \right)$$

$$\Rightarrow A_{V_{cl}} = \frac{R_1 + R_F}{R_1} = 1 + \frac{R_F}{R_1}$$

$$\Rightarrow A_{V_{cl}} = 1 + \frac{R_F}{R_1}$$



Voltage Follower OR Buffer Amplifier



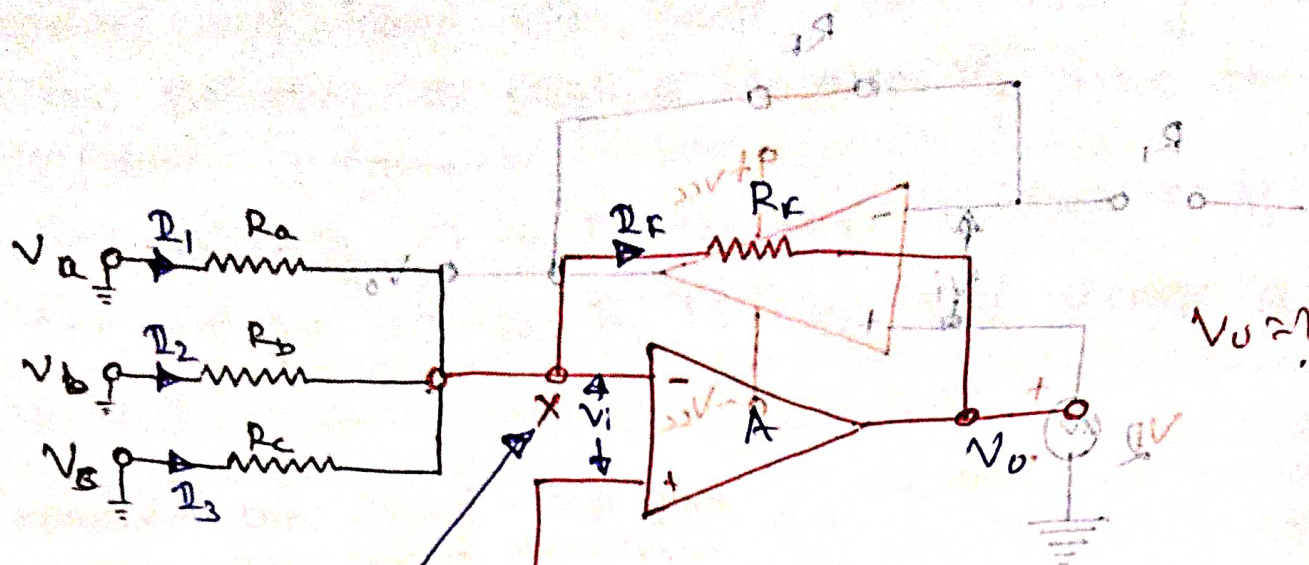
- If R_i is infinite (open circuit) and R_f is zero (short-circuit), the circuit of non-inverting amplifier as shown in fig.
- This circuit is known as voltage follower or buffer amplifier or source follower or unity gain amplifier or isolation amplifier.
- Then $A_v = 1$, i.e. $V_o = V_i$.
- Thus the output voltage is equal in phase with input i.e., op-amp circuit acts as a voltage follower.

ADDER OR SUMMING AMPLIFIER

- The op-amp circuit can be designed to add the various input voltages with required amplification. Such a circuit is called summing amplifier.

A Summer is a circuit the output of which is equal to the sum of applied input voltages.

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



Virtual earth Summing Point

→ The fig shows the inverting configuration of op-amp.

Here R_a, R_b, R_c = Input resistance

V_a, V_b, V_c = Input voltages

R_f = feedback resistor, $A = \infty$

→ Assuming that amplifier is ideal we have $A = \infty$

→ Now Current $I_1 = \frac{V_a}{R_a}$

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

$$I_2 = \frac{V_b}{R_b}$$

$$I_3 = \frac{V_c}{R_c}$$

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

→ Applying KCL at node x

$$I_1 + I_2 + I_3 = I_f$$

$$\Rightarrow \frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} = \frac{-V_o}{R_f}$$

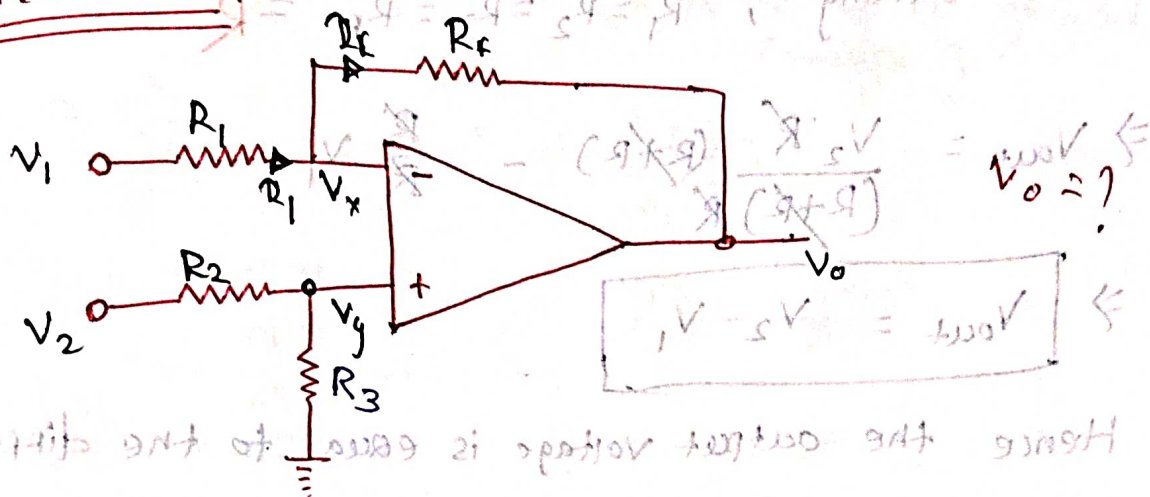
$$\Rightarrow -V_o = \frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b + \frac{R_f}{R_c} V_c$$

$$\Rightarrow V_o = - \left(\frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b + \frac{R_f}{R_c} V_c \right) \quad \frac{1 \mu V \cdot 9}{1 \mu V \cdot 9} = 1 \mu V \cdot 9$$

Let $R_A = R_B = R_C = R_F$

$$\Rightarrow \boxed{V_o = -(V_A + V_B + V_C)}$$

SUBTRACTOR



As we know $V_x = V_y$ (due to virtual ground concept)

$$V_y = \frac{V_2 R_3}{R_2 + R_3} = V_x \text{ (voltage division rule)}$$

Here $R_1 = R_f$

$$\Rightarrow \frac{V_1 - V_x}{R_1} = \frac{V_x - V_{out}}{R_f}$$

$$\Rightarrow \frac{V_1 - V_x}{R_1} = \frac{V_x - V_{out}}{R_f}$$

$$\Rightarrow R_f (V_1 - V_x) = R_1 (V_x - V_{out})$$

$$\Rightarrow R_f V_1 - R_f V_x = R_1 V_x - R_1 V_{out}$$

$$\Rightarrow R_1 V_{out} = R_1 V_x + R_f V_x - R_f V_1$$

$$\Rightarrow R_1 V_{out} = V_x (R_1 + R_f) - R_f V_1 \quad \text{(Putting the value in } V_x \text{)}$$

$$\Rightarrow R_1 V_{out} = \frac{V_2 R_3}{R_2 + R_3} (R_1 + R_f) - R_f V_1$$

$$\Rightarrow R_1 V_{out} = \frac{V_2 R_3}{R_2 + R_3} (R_1 + R_F) - R_F V_1$$

$$\Rightarrow V_{out} = \frac{V_2 R_3 (R_1 + R_F)}{(R_2 + R_3) R_1} - \frac{R_F}{R_1} V_1$$

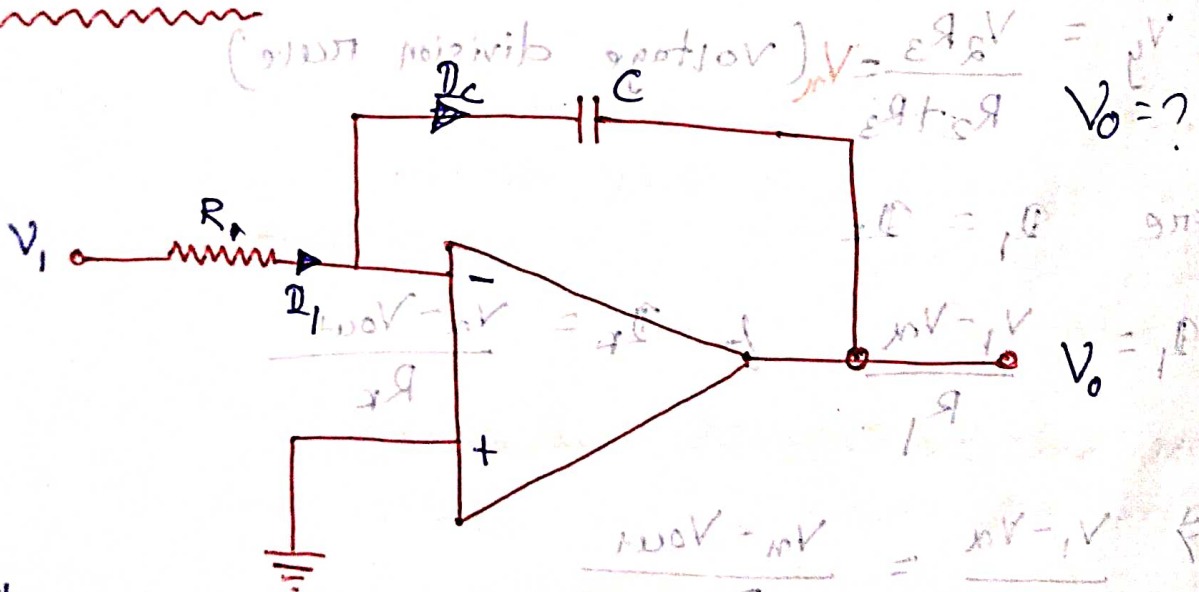
Let taking, $R_1 = R_2 = R_3 = R_F = R$

$$\Rightarrow V_{out} = \frac{V_2 \cdot R}{(R + R) R} (R + R) - \frac{R}{R} V_1$$

$$\Rightarrow \boxed{V_{out} = V_2 - V_1}$$

Hence the output voltage is equal to the difference between two input voltage.

INTEGRATOR



- The circuit of integrator as shown in fig.
- This circuit produces an output voltage which is proportional to the time integral of the input.
- Due to this reason, this is known as integrator.
- The integrator is an inverting op-amp. In an inverting op-amp, the feedback resistor R_f has been replaced by a capacitor C .

- feedback through the capacitor forces a virtual ground to exist at the inverting input terminal.
- Now, the voltage across the Condenser is simply the output voltage V_o .

As we know $I_1 = I_c$ (Due to virtual ground Concept)

$$I_1 = \frac{V_1}{R}, \quad I_c = C \frac{d(V_o)}{dt}$$

$$\frac{V_1}{R} = -C \frac{dV_o}{dt}$$

$$\Rightarrow \frac{dV_o}{dt} = \frac{-V_1}{RC}$$

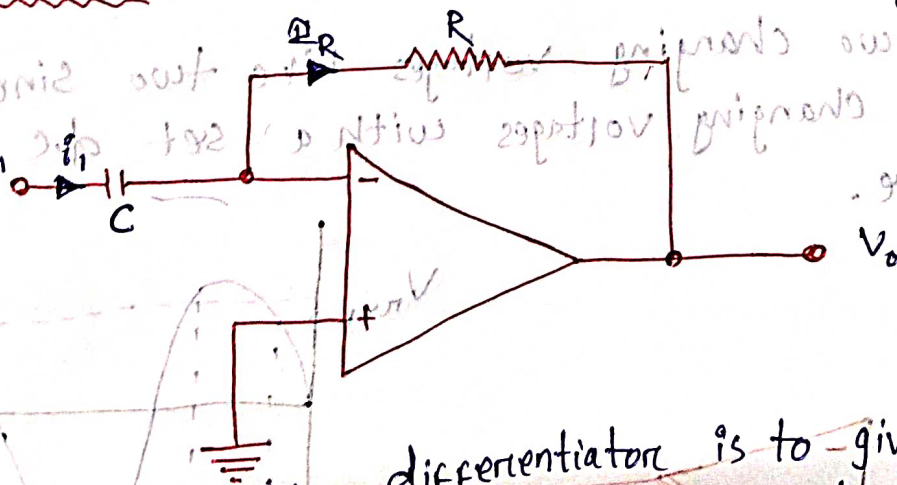
$$\Rightarrow \boxed{V_o = \frac{-1}{RC} \int V_1 dt}$$

$$\boxed{\frac{V_o}{dt} = \frac{V_1}{RC} = 0V}$$

Hence, we will see output voltage is equal to the integral of input. So this is called

Integrator amplifier

Differentiator



- The function of the differentiator is to give an output voltage which is proportional to the rate change of the input voltage.
- The circuit of a differentiator is the same as that of an op-amp except that the input resistance R_1 is

→ When we feed linearly increasing voltage to differentiator, we get a constant d.c. output
 → So, it is an inverse mathematical operation to that of an integrator.

As we know $I_i = I_R$

$$I_i = C \frac{dv_i}{dt}$$

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

$$\Rightarrow C \frac{dv_i}{dt} = \frac{V_o}{R}$$

$$V_o = RC \frac{dv_i}{dt}$$

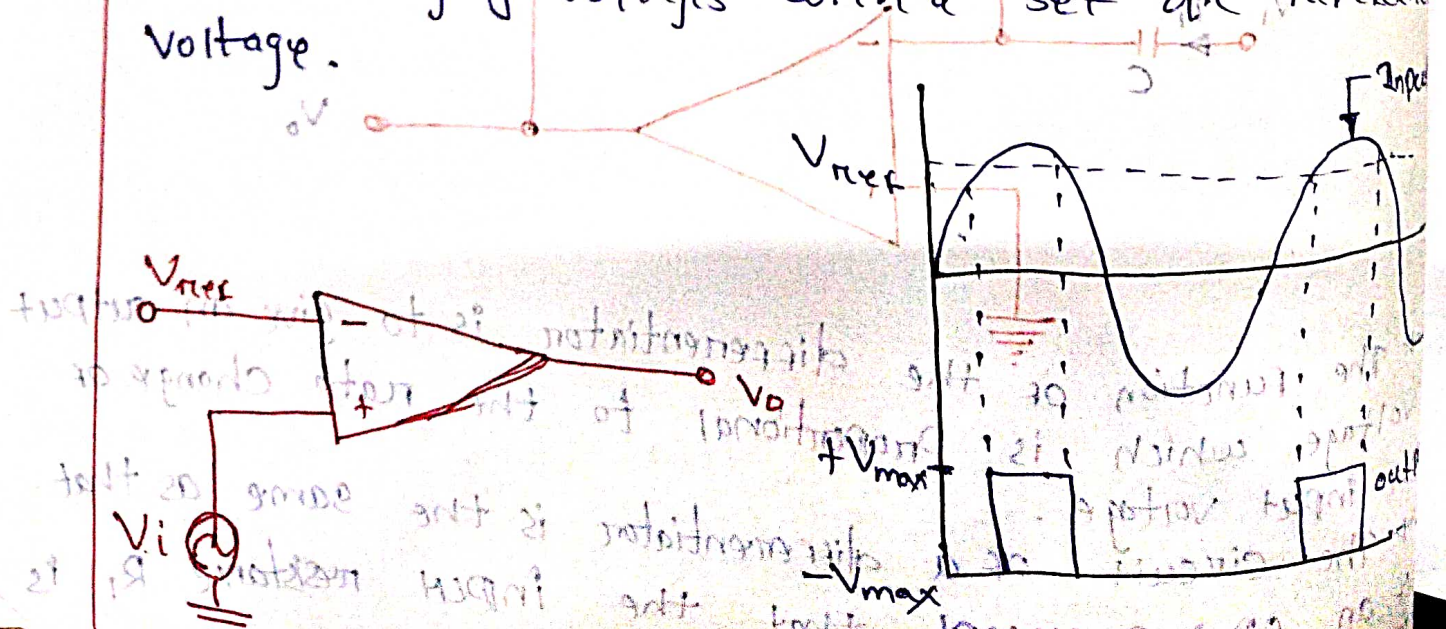
$$\frac{dv_o}{dt} = \frac{V_i}{RC}$$

$$V_o = \frac{1}{RC} \int V_i dt$$

COMPARATOR

Comparator is a circuit which compares two voltages and provides an output that indicates the relation between them. Hence Comparator may be used to compare.

- (i) two changing voltages like two sine waves.
- (ii) a changing voltages with a set d.c. reference voltage.



- The circuit for a comparator along with its input and output waveforms is shown in fig.
- As evident from circuit diagram, OP-AMP is operated in open-loop configuration.
- The input voltage is applied to the non-inverting input terminal and a set d.c reference voltage V_{ref} is applied to the inverting terminal of the OP-AMP.
- As the open loop gain of OP-AMP is very high, it goes into saturation even with small input voltage.
- Thus the two possible output levels of this comparator are $+V_{sat}$ ($+V_{max}$) and $-V_{sat}$ ($-V_{max}$).

✓

11/10/21