DEPARTMENT OF ELECTRICALS AND ELECTRONICS ENGINEERING

(ACADEMIC YEAR: 2022-2023)

EC3301 – ELECTRON DEVICES AND CIRCUITS

(Regulation 2021)

Semester- III

LECTURE NOTES

NAME-

REG NO-

EC8353 ELECTRON DEVICES AND CIRCUITS

OBJECTIVES:

The student should be made to:

- Understand the structure of basic electronic devices.
- Be exposed to active and passive circuit elements.
- Familiarize the operation and applications of transistor like BJT and FET.
- Explore the characteristics of amplifier gain and frequency response.
- Learn the required functionality of positive and negative feedback systems.

UNIT I PN JUNCTION DEVICES 9

PN junction diode –structure, operation and V-I characteristics, diffusion and transition capacitance - Clipping and Clamping circuits-Rectifiers – Half Wave and Full Wave Rectifier,– Display devices- LED, Laser diodes, Zener diodecharacteristics- Zener Reverse characteristics – Zener as regulator

UNIT II TRANSISTORS AND THYRISTORS 9

BJT, JFET, MOSFET- structure, operation, characteristics and Biasing UJT, Thyristors and IGBT - Structure and characteristics.

UNIT III AMPLIFIERS 9

BJT small signal model – Analysis of CE, CB, CC amplifiers- Gain and frequency response –MOSFET small signal model– Analysis of CS and Source follower – Gain and frequency response- High frequency analysis.

UNIT IV MULTISTAGE AMPLIFIERS AND DIFFERENTIAL AMPLIFIER 9

BIMOS cascade amplifier, Differential amplifier – Common mode and Difference mode analysis – FET input stages – Single tuned amplifiers – Gain and frequency response – Neutralization methods, power amplifiers –Types (Qualitative analysis).

UNIT V FEEDBACK AMPLIFIERS AND OSCILLATORS 9

Advantages of negative feedback – voltage / current, series , Shunt feedback –positive feedback –Condition for oscillations, phase shift – Wien bridge, Hartley, Colpitts and Crystal oscillators.

TOTAL: 45 PERIODS

OUTCOMES:

Upon Completion of the course, the students will be ability to:

- Explain the structure and working operation of basic electronic devices.
- Able to identify and differentiate both active and passive elements
- Analyse the characteristics of different electronic devices such as diodes and transistors
- Choose and adapt the required components to construct an amplifier circuit.
- Employ the acquired knowledge in design and analysis of oscillators

TEXT BOOKS:

1. David A. Bell,"Electronic devices and circuits", Oxford University higher education, 5th edition 2008.
2. Sedra and smith, "Microelectronic circuits",7th Ed., Oxford University Press

REFERENCES:

1. Balbir Kumar, Shail.B.Jain, "Electronic devices and circuits" PHI learning private limited, 2nd edition 2014.
2. Thomas L.Floyd, "Electronic devices" Conventional current version, Pearson prentice hall, 10^{th} Edition, 2017.
3. Donald A Neamen, "Electronic Circuit Analysis and Design" Tata McGraw Hill, 3rd Edition, 2003.
4. Robert L.Boylestad, "Electronic devices and circuit theory", 2002.
5. Robert B. Northrop, "Analysis and Application of Analog Electronic Circuits to Biomedical Instrumentation", CRC Press, 2004

UNIT I PN JUNCTION DEVICES

INTRODUCTION

ELECTRONICS

Electronics is that branch of science and technology which makes use of the controlled motion of electrons through different media and vacuum. The ability to control electron flow is usually applied to information handling or device control.

APPLICATION OF ELECTRONICS

- Communication and Entertainment.
- Industrial.
- Medical science.
- Defence.

ELECTRONICS COMPONENTS

Active Component.
Passive Component.

PASSIVE COMPONENTS

The electronics components which are not capable of amplifying or processing an electrical signal are called as passive component.

Examples –
1. Resistor.
2.Capacitor.
3. Inductor.

ACTIVE COMPONENTS

The electronics components which are capable of amplifying or processing an electrical signal are called as passive component.

Examples –
1.Transistors.
2. Logic Gates.

SEMICONDUCTORS, CONSTRUCTION AND CHARACTERISTICS OF DEVICES.

Silicon was first identified by Antoine Lavoisier in 1784 (as a component of the Latin *silex*, *silicis* for flint, flints), and was later mistaken by Humphry Davy in 1800 for a compound. In 1811 Gay-Lussac and Thénard probably prepared impure amorphous silicon through the heating of potassium with silicon tetrafluoride. In 1874, Berzelius, generally given credit for discovering the element silicon, prepared amorphous silicon using approximately the same method as Lussac. Berzelius also purified the product by repeatedly washing.

Occurrence of silicon

Measured by mass, silicon makes up 25.7% of the Earth's crust and is the second most abundant element in the crust, after oxygen.2. Silica occurs in minerals consisting of (practically) pure silicon dioxide in different crystalline forms. Amethyst, agate, quartz, rock crystal, chalcedony,flint, jasper, and opal are some of the forms in which silicon dioxide appears. Biogenic silica occurs in the form of diatoms, radiolaria and siliceous sponges.

Production

Silicon is commercially prepared by the reaction of high-purity silica with wood, charcoal, and coal, in an electric arc furnace using carbon electrodes. At temperatures over 1,900 °C (3,450 °F), the carbon reduces the silica to silicon according to the chemical equations:

$$SiO2 + C \; Si + CO \rightarrow 2SiO2 + 2 \; C \; Si + 2 \; CO \rightarrow$$

Germanium(Ge)

Germanium was discovered comparatively late because very few minerals contain it in high concentration. Germanium ranks near fiftieth in relative abundance of the elements in the Earth's crust Germanium production

Germanium tetrachloride is either hydrolyzed to the oxide (GeO_2) or purified by fractional distillation and then hydrolyzed. The highly pure GeO2 is now suitable for the production of germanium glass. The pure germanium oxide is reduced by the reaction with hydrogen to obtain germanium suitable for the infrared optics or semiconductor industry:

$GeO_2 + 2 H_2 Ge + 2 H \rightarrow 2O$.

The germanium for steel production and other industrial processes is normally reduced using carbon.

$GeO_2 + C Ge + CO \rightarrow 2$.

Difference between conductors, semiconductor& Insulators.

Conductors:-

materials that have a low value of resistivity allowing them to easily pass an electrical current due to there being plenty of free electrons floating about within their basic atom structure. When a positive voltage potential is applied to the material these "free electrons" leave their parent atom and travel together through the material forming an electron or current flow. Examples of good conductors are generally metals such as Copper, Aluminium, Silver etc.

Insulators:-

Insulators on the other hand are the exact opposite of conductors. They are made of materials, generally non-metals, that have very few or no "free electrons" floating about within their basic atom structure because the electrons in the outer valence shell are strongly attracted by the positively charged inner nucleus. Insulators also have very high resistances, millions of ohms per metre, and are generally not affected by normal temperature changes (although at very high temperatures wood becomes charcoal and changes from an insulator to a conductor). Examples of good insulators are marble, fused quartz,p.v.c. plastics, rubber etc.

Semi-conductors:-

materials such as **Silicon** and **Germanium**, have electrical properties somewhere in the middle,between those of a "Conductor" and an "Insulator".They are not good conductors nor good insulators(hence their name **semi**-conductors).

PN JUNCTION DIODE

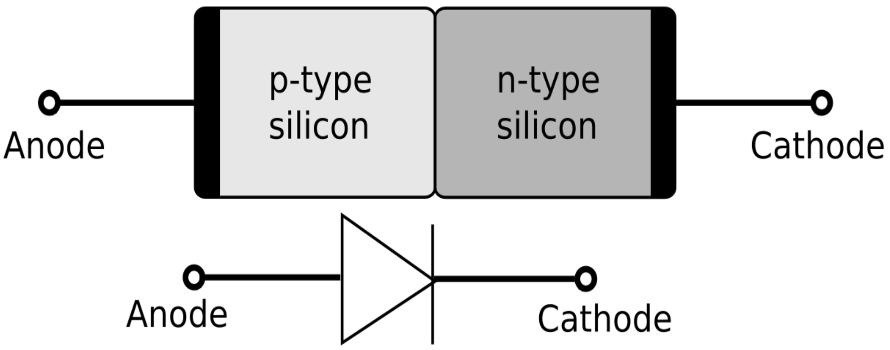
A **p–n junction** is formed by joining p-type and n-type semiconductors together in very close contact. The term *junction* refers to the boundary interface where the two regions of the semiconductor meet. If they were constructed of two separate pieces this would introduce a grain boundary, so p–n junctions are created in a single crystal of semiconductor by doping, for example by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layer of crystal doped with another type of dopant).

P-N junctions are elementary "building blocks" of almost all semiconductor electronic devices such as diodes, transistors, solar cells, LEDs, and integrated circuits; they are the active sites where the electronic action of the device takes place. For example, a common type of transistor, the bipolar unction transistor, consists of two p–n junctions in series, in the form n–p–n or p–n–p.

PN junction diode

Definition:
"A semiconductor device with two terminals, typically allowing the flow of current in one direction only.

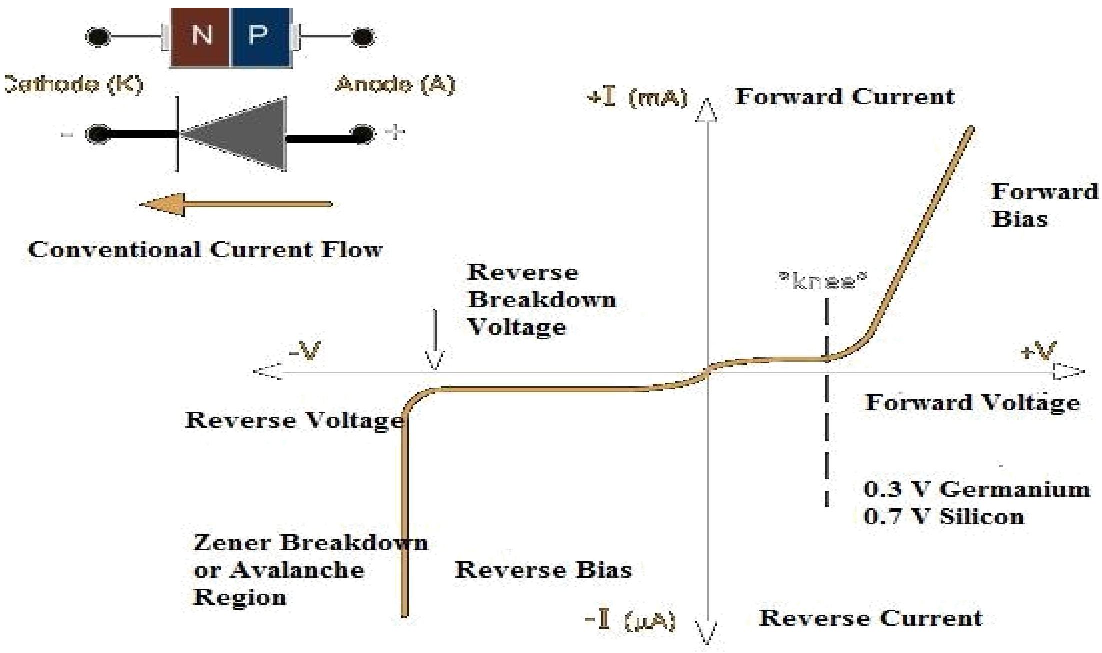
"A diode is a specialized electronic component with two electrodes called the anode and the cathode. They are made with semiconductor materials such as silicon, germanium, or selenium. The fundamental property of a diode is its tendency to conduct electric current in only one direction."
"A Diode is an electronic device that allows current to flow in one direction only. It is a semiconductor that consists of a p-n junction. They are used most commonly to convert AC to DC"



Drift
Applying an electric field across a semiconductor will cause holes and free electrons to *drift* through the crystal. The total current is equal to the sum of hole current and electron current.
Diffusion
A drop of ink in a glass of water *diffuses* through the water until it is evenly distributed. The same process, called *diffusion*, occurs with semiconductors. For example, if some extra free electrons are introduced into a p-type semiconductor, the free electrons will redistribute themselves so that the concentration is more uniform.

In DIFFUSION, the free electrons move away from the region of highest concentration. The higher the localized concentration, the greater will be the rate at which electrons move away. The same process applies to holes in an n-type semiconductor. Note that when a few minority carriers are diffusing through a sample, they will encounter a large number of majority carriers. Some recombination will occur. A number of both types of carrier will be lost.

Construction and Working of PN Diode
A diode is made from a small piece of semiconductor material, usually silicon, in which half is doped as a p region and half is doped as an n region with a pn junction and depletion region in between. The p region is called the anode and is connected to a conductive terminal. The n region is called the cathode and is connected to a second conductive terminal. The basic diode structure and schematic symbol are shown below.



V-I **Characteristic for Forward Bias**

When a forward-bias voltage is applied across a diode, there is current. This current is called the *forward current* and is designated *I*F. The resistor is used to limit the forward current to a value that will not overheat the diode and cause damage. With 0 V across the diode, there is no forward current. As you gradually increase the forward- bias voltage, the forward current *and* the voltage across the diode gradually increase, a portion of the forward-bias voltage is dropped across the limiting resistor. When the forward-bias voltage is increased to a value where the voltage across the diode reaches approximately 0.7 V (barrier potential), the forward current begins to increase rapidly, As you continue to increase the forward-bias voltage, the current continues to increase very rapidly, but the voltage across the diode increases only gradually above 0.7 V. This small increase in the diode voltage above the barrier potential is due to the voltage drop across the internal dynamic resistance of the semiconductive material.

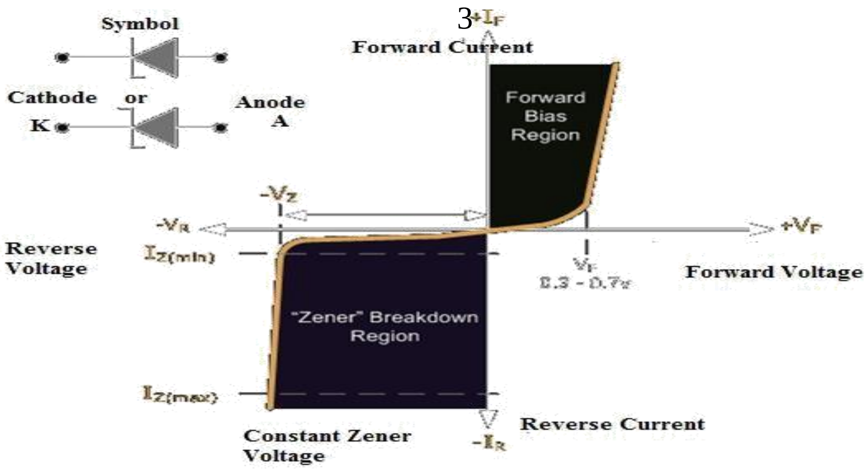
Graphing the V-I Curve:

If you plot the results of the type of measurements show you get the **V-I characteristic** curve for a forward-biased diode. The diode forward voltage (*V*F) increases to the right along the horizontal axis, and the forward current (*I*F) increases upward along the vertical axis.

Dynamic Resistance:

Unlike a linear resistance, the resistance of the forward-biased diode is not constant over the entire curve. Because the resistance changes as you move along the *V-I* curve, it is called *dynamic* or *ac resistance.* Internal resistances of electronic devices are usually designated by lowercase italic *r* with a prime, instead of the standard *R.* Below the knee of the curve the resistance is greatest because the current increases very little for a given change in voltage The resistance begins to decrease in the region of the knee of the curve and becomes smallest above the knee where there is a large change in current for a given change in voltage.

V-I Characteristic for Reverse Bias



When a reverse-bias voltage is applied across a diode, there is only an extremely small reverse current (*I*R) through the *pn* junction. With 0 V across the diode, there is no reverse current. As you gradually increase the reverse-bias voltage, there is a very small reverse current and the voltage across the diode increases. When the applied bias voltage is increased to a value where the reverse voltage across the diode (*V*R) reaches the breakdown value (*V*BR), the reverse current begins to increase rapidly. As you continue to increase the bias voltage, the current continues to increase very rapidly, but the voltage across the diode increases very little above *V*BR. Breakdown, with exceptions, is not a normal mode of operation for most *pn* junction devices.

Graphing the V-I Curve If you plot the results of reverse-bias measurements on a graph, you get the *V-I* characteristic curve for a reverse-biased diode. The diodereverse voltage (*V*R) increases to the left along the horizontal axis, and the reverse current (*I*R) increases downward along the vertical axis.

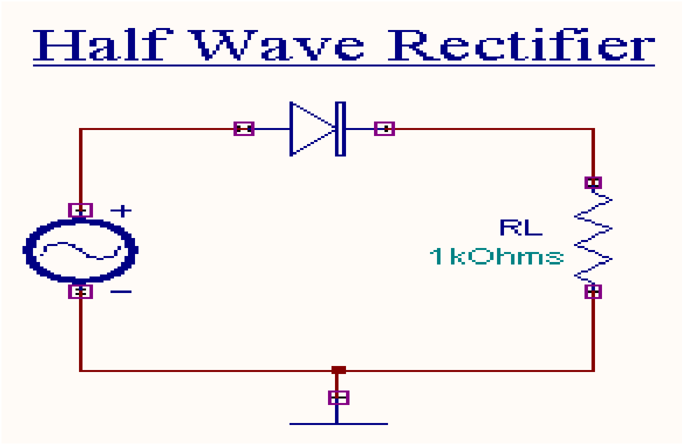
There is very little reverse current until the reverse voltage across diode reaches approximately the breakdown value (*V*BR) at the knee of the curve. After this point, the reverse voltage remains at approximately *V*BR, but *I*R increases very rapidly, resulting in overheating and possible damage if current is not limited to a safe level. The breakdown voltage for a diode depends on the doping level. Reverse voltage (*V*R) increases to the left along the horizontal axis, and the reverse current (*I*R) increases downward along the vertical axis.
There is very little reverse current until the reverse voltage across diode reaches approximately the breakdown value (*V*BR) at the knee of the curve. After this point, the reverse voltage remains at approximately *V*BR, but *I*R increases very rapidly, resulting in overheating and possible damage if current is not limited to a safe level. The breakdown voltage for a diode depends on the doping level.

RECTIFIER:

Rectifier is a circuit which converts AC in to DC. They are two types

1. Half Wave Rectifier
2. Full Wave Rectifier

1. Half Wave Rectifier



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— The Half wave rectifier is a circuit, which converts an ac voltage to dc voltage. The primary of the transformer is connected to ac supply. This induces an ac voltage across the secondary of the transformer.

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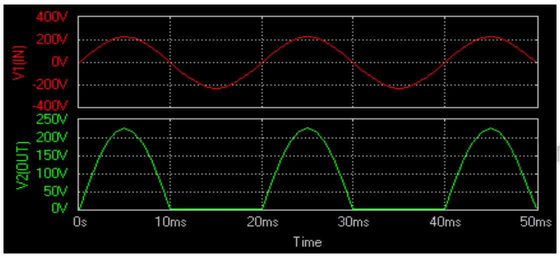
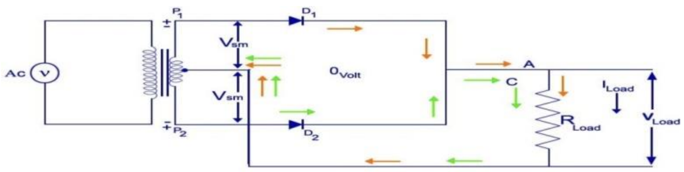
During the positive half cycle of the input voltage the polarity of the voltage across the secondary forward biases the diode. As a result a current I_L flows through the load resistor, R_L. The forward biased diode offers a very low resistance and hence the voltage drop across it is very small. Thus the voltage appearing across the load is practically the same as the input,

Half Wave rectifier output waveform



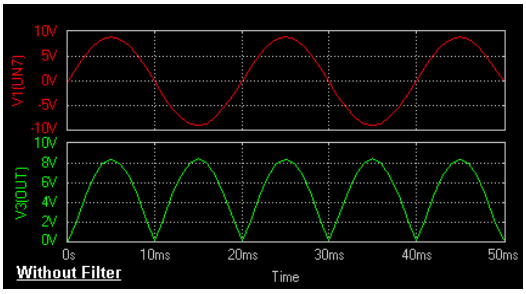
FULL WAVE RECTIFIER

A Full Wave Rectifier is a circuit, which converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. It uses two diodes of which one conducts during one half cycle while the other conducts during the other half cycle of the applied ac voltage.



CENTRE - TAP FULL- WAVE RECTIFIER CIRCUIT

The output waveform



Working of Centre-Tap Full Wave Rectifier

As shown in the figure, an ac input is applied to the primary coils of the transformer. This input makes the secondary ends P1 and P2 become positive and negative alternately. For the positive half of the ac signal, the secondary point D1 is positive, GND point will have zero volt and P2 will be negative. At this instant diode D1 will be forward biased and diode D2 will be reverse biased. As explained in the theory behind P-N Junction and Characteristics of P-N Junction Diode, the diode D1 will conduct and D2 will not conduct during during the positive half cycle. Thus the current flow will be in the direction P1-D1-C-A-B-GND. Thus, the positive half cycle appears across the load resistance RLOAD. During the negative half cycle, the secondary ends P1 becomes negative and P2 becomes positive. At this instant, the diode D1 will be negative and D2 will be positive with the zero reference point being the ground, GND. Thus, the diode D2 will be forward biased and D1 will be reverse biased. The diode D2 will conduct and D1 will not conduct during the negative half cycle. The current flow will be in the direction P2-D2-C-A-B-GND.

i) Peak Current

The instantaneous value of the voltage applied to the rectifier can be written as Vs = Vsm Sin ωt

Assuming that the diode has a forward resistance of RFWD ohms and a reverse resistance equal to infinity, the current flowing through the load resistance RLOAD is given as

Im = Vsm/ (R**F** + R **Load**)

ii) Output Current

Since the current is the same through the load resistance RL in the two halves of the ac cycle, magnitude od dc current Idc, which is equal to the average value of ac current, can be obtained by integrating the current i1 between 0 and pi or current i2 between π and 2π.

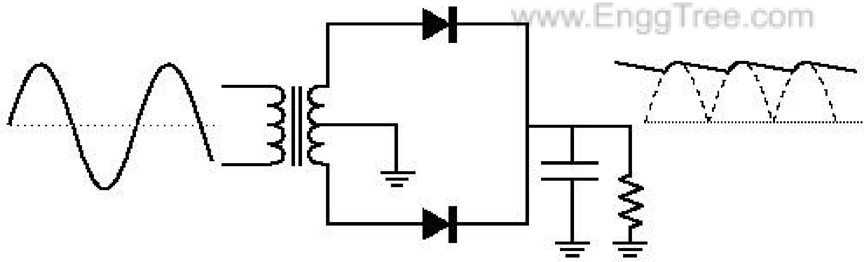
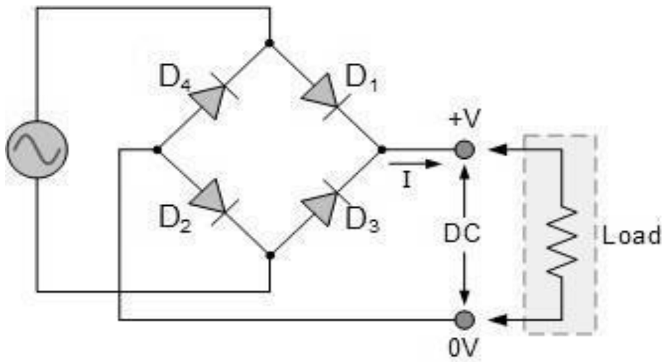


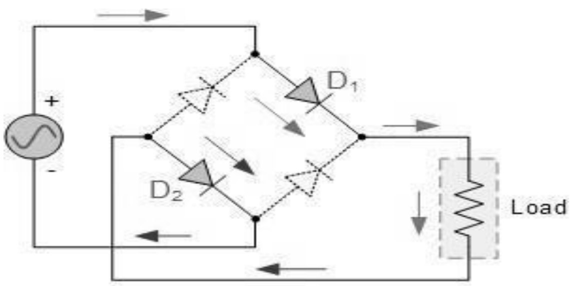
Fig.Center tapped full wave rectifier with capacitive filter

<u>Full Wave Bridge Rectifier</u>

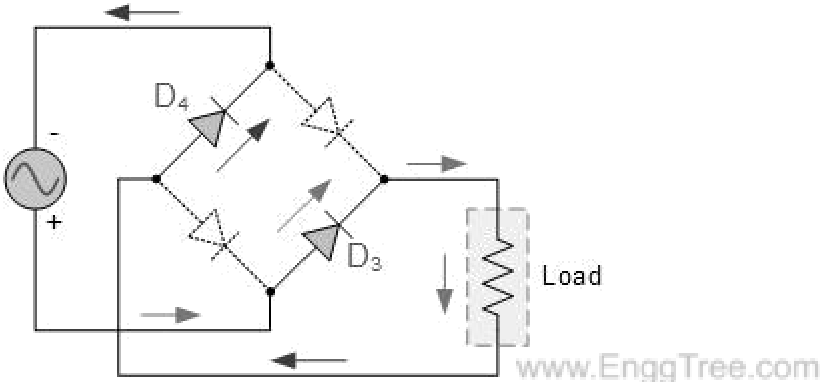
Full Wave Bridge Rectifier uses four individual rectifying diodes connected in a closed loop “bridge” configuration to produce the desired output. The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.



The four diodes labelled D1 to D4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.



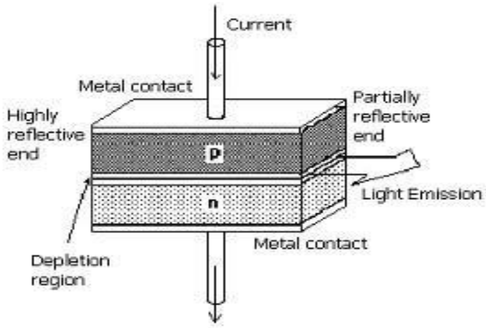
During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch "OFF" as they are now reversing biased. The current flowing through the load is the same direction as before.
The Negative Half-cycle



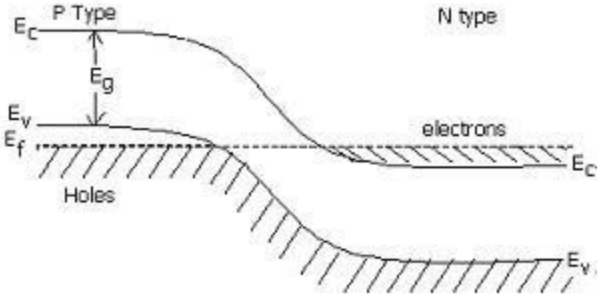
As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for the previous two diode full-wave rectifier, therefore the average DC voltage across the load is 0.637Vmax.However in reality, during each half cycle the current flows through two diodes instead of just one so the amplitude of the output voltage is two voltage drops (2 x 0.7 = 1.4V) less than the input VMAX amplitude. The ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply or 120Hz for a 60Hz supply.)Although we can use four individual power diodes to make a full wave bridge rectifier, pre-made bridge rectifier components are available "off-the-shelf" in a range of different voltage and current sizes that can be soldered directly into a PCB circuit board or be connected by spade connectors. The image to the right shows a typical single phase bridge rectifier with one corner cut off. This cut-off corner indicates that the terminal nearest to the corner is the positive or +ve output terminal or lead with the opposite (diagonal) lead being the negative or -ve output lead. The other two connecting leads are for the input alternating voltage from a transformer secondary winding.
Ripple factor: Ripple factor for bridge rectifier is 0.482

LASER DIODE

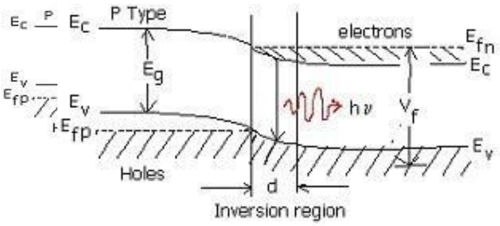
PN-junction Laser: A semiconductor laser is a specially fabricated pn junction device (both the p and n regions are highly doped) which emits coherent light when it is forward biased. It is made from Gallium Arsenide (GaAs) which operated at low temperature and emits light in near IR region. Now the semiconductor lasers are also made to emit light almost in the spectrum from UV to IR using different semiconductor materials. They are of very small size (0.1 mm long), efficient, portable and operate at low power. These are widely used in Optical fibre communications, in CD players, CD-ROM Drives, optical reading, laser printing, etc. P and N regions are made from same semiconductor material (GaAs). A p type region is formed on the n type by doping zinc atoms. The diode chip is about 500 micrometer long and 100 micrometer wide and thick. The top and bottom face has metal contacts to pass the current. The front and rare faces are polished to constitute the resonator.



When high doped p and n regions are joined at the atomic level to form pn-junction, the equilibrium is attained only when the equalization of Fermi level takes place in this case the Fermi level is pushed inside the conduction band in n type and the level pushed inside the valence band in the p type.



When the junction is forward biased, at low voltage the electron and hole recombine and cause spontaneous emission. But when the forward voltage reaches a threshold value the carrier concentration rises to very high value. As a result the region "d" contains large number of electrons in the conduction band and at the same time large number of holes in the valence band. Thus the upper energy level has large number of electrons and the lower energy level has large number of vacancy, thus population inversion is achieved. The recombination of electron and hole leads to spontaneous emission and it stimulate the others to emit radiation. Ga As produces laser light of 9000 Å in IR region.



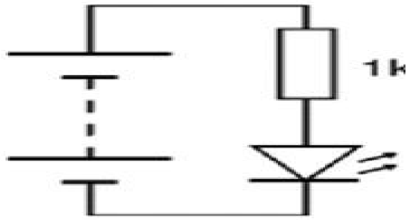
Light Emitting Diode (LED)

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the colour of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

Construction of LED

An n-type layer is grown on a substrate and p-type is deposited on it by diffusion. The metal anode connections are made at the outer edges of p-type so as to allow more control surface area for the light to escape.

Symbol of LED

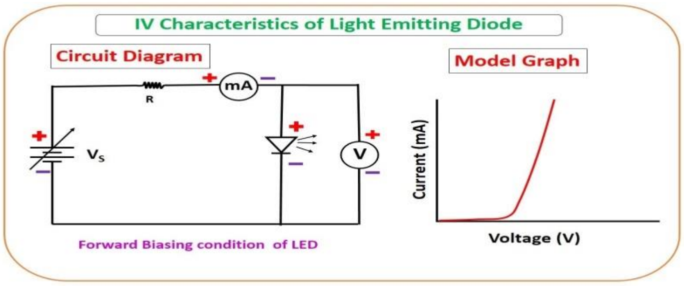


Material used in LED

In silicon and germanium diodes , most of electrons give up their energy in the form of heat while a little amount in the form of light which is insignificant of use. Semiconductor material which mainly used-

1.GaAs (invisible)
2.GaP(red or green light)
3.GaAsP(red or yellow light)

CIRCUIT DIAGRAM OF LED



Operation of LED

It is based upon the phenomenon of electroluminance, which is emission of light from a semiconductor under the influence of an electric field. Recombines occurs at P-N juction as electron from N side recombines with holes on p-side. When recombination take place the charge carrier give up energy in the form of heat and light.

Comparison between an LD and LED

Laser Diode

- Stimulated radiation
- Narrow line width
- Coherent
- Higher output power
- A threshold device
- Strong temperature dependence
- Higher coupling efficiency to a fiber

LED

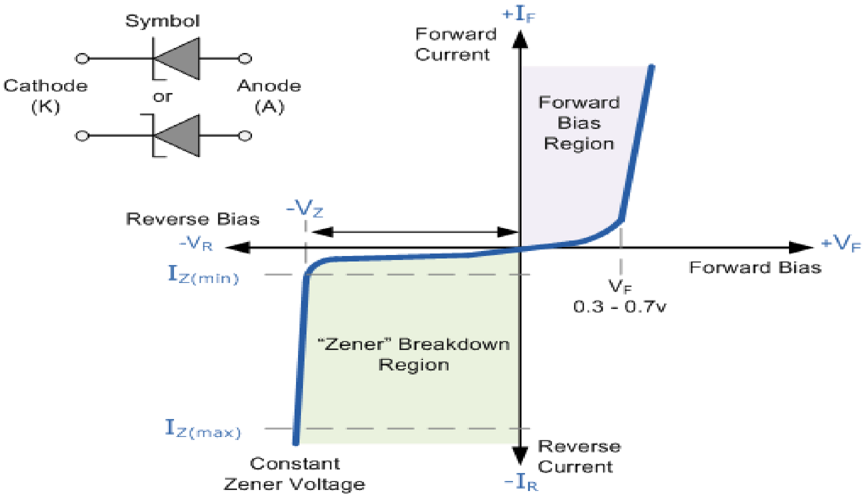
- Spontaneous radiation
- Broad spectral
- Incoherent
- Lower output power
- No threshold current
- Weak temperature dependence
- Lower coupling efficiency

Zener Diode

The **Zener diode** is like a general-purpose signal diode consisting of a silicon PN junction. When biased in the forward direction it behaves just like a normal signal diode passing the rated current, but when a reverse voltage is applied to it the reverse saturation current remains fairly constant over a wide range of voltages. The reverse voltage increases until the diodes breakdown voltage VB is reached at which point a process called *Avalanche Breakdown* occurs in the depletion layer and the current flowing through the zener diode increases dramatically to the maximum circuit value (which is usually limited by a series resistor). This breakdown voltage point is called the "zener voltage" for zener diodes.

The point at which current flows can be very accurately controlled (to less than 1% tolerance) in the doping stage of the diodes construction giving the diode a specific *zener breakdown voltage*, (Vz) ranging from a few volts up to a few hundred volts.

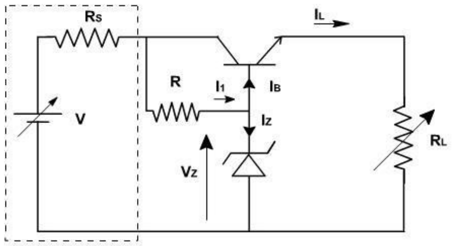
Zener Diode I-V Characteristics:



The **Zener Diode** is used in its "reverse bias" or reverse breakdown mode, i.e. the diodes anode connects to the negative supply. From the I-V characteristics curve above, we can see that the zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode and remains nearly constant even with large changes in current as long as the zener diodes current remains between the breakdown current IZ (min) and the maximum current rating IZ (max). This ability to control itself can be used to great effect to regulate or stabilize a voltage source against supply or load variations. The fact that the voltage across the diode in the breakdown region is almost constant turns out to be an important application of the zener diode as a voltage regulator. The function of a regulator is to provide a constant output voltage to a load connected in parallel with it in spite of the ripples in the supply voltage or the variation in the load current and the zener diode will continue to regulate the voltage until the diodes current falls below the minimum IZ (min) value in the reverse breakdown region.

Zener shunt regulator

Zener Diodes can be used to produce a stabilized voltage output with low ripple under varying load current conditions. By passing a small current through the diode from a voltage source, via a suitable current limiting resistor (RS), the zener diode will conduct sufficient current to maintain a voltage drop of Vout. We remember from the previous tutorials that the DC output voltage from the half or full-wave rectifiers contains ripple superimposed onto the DC voltage and that as the load value changes so to does the average output voltage. By connecting a simple zener stabilizer circuit as shown below across the output of the rectifier, a more stable output voltage can be produced.



Operation of the circuit:

The current through resistor R is the sum of zener current IZ and the transistor base current IB (= IL / β).

$I_L \quad I_Z \quad I_B$

The output voltage across RL resistance is given by

$V_0 \quad V_Z \quad V_{BE}$

Where VBE=0.7 V Therefore, VO= constant.

The emitter current is same as load current. The current IR is assumed to be constant for a given supply voltage. Therefore, if IL increases, it needs more base currents, to increase base current Iz decreases. The difference in this regulator with zener regulator is that in later case the zener current decreases (increase) by same amount by which the load current increases (decreases). Thus the current range is less, while in the shunt regulators, if IL increases by ΔIL then IB should increase by ΔIL / β or IZ should decrease by ΔIL / β. Therefore the current range control is more for the same rating zener.In a power supply the power regulation is basically, because of its high internal impedance. In the circuit discussed, the unregulated supply has resistance RS of the order of 100 ohm. The use of emitter follower is to reduce the output resistance and it becomes approximately.

R h

$R \quad z \quad ie \; 0 \; \overline{\quad\quad}$

$fe \quad\quad 1 \; h$

Where RZ represents the dynamic zener resistance. The voltage stabilization ratio SV is approximately

$V \; \frac{V_0}{V_i} \; S \quad \frac{R_Z}{R_Z \; R_i}$

SV can be improved by increasing R. This increases VCE and power dissipated in the transistor. Other disadvantages of the circuit are.

1. No provision for varying the output voltage since it is almost equal to the zener voltage.

Change in VBE and Vz due to temperature variations appear at the output since the transistor is connected in series with load, it is called series regulator and transistor is allow series pass transistor.

$$= \frac{\int \frac{e_i}{R} dt}{C} \qquad \left(\because i = \frac{e_i}{R}\right)$$

$$= \frac{1}{RC} \int e_i \, dt$$

$$\propto \int e_i \, dt \qquad (\because RC \text{ is constant})$$

$$\therefore \quad \text{Output voltage} \propto \int \text{input}$$

Output wave forms. The output wave form from an integrating circuit depends upon time constant and shape of the input wave. Two important cases will be discussed :

(i) **When input is a square wave.** When the input fed to an integrating circuit is a square wave, the output will be a triangular wave as shown in Fig. 20.23 *(i)*. As integration means summation, therefore, output from an integrating circuit will be the sum of all the input waves at any instant. This sum is zero at *A* and goes on increasing till it becomes maximum at *C*. After this the summation goes on decreasing to the on set of negative movement *CD* of the input.

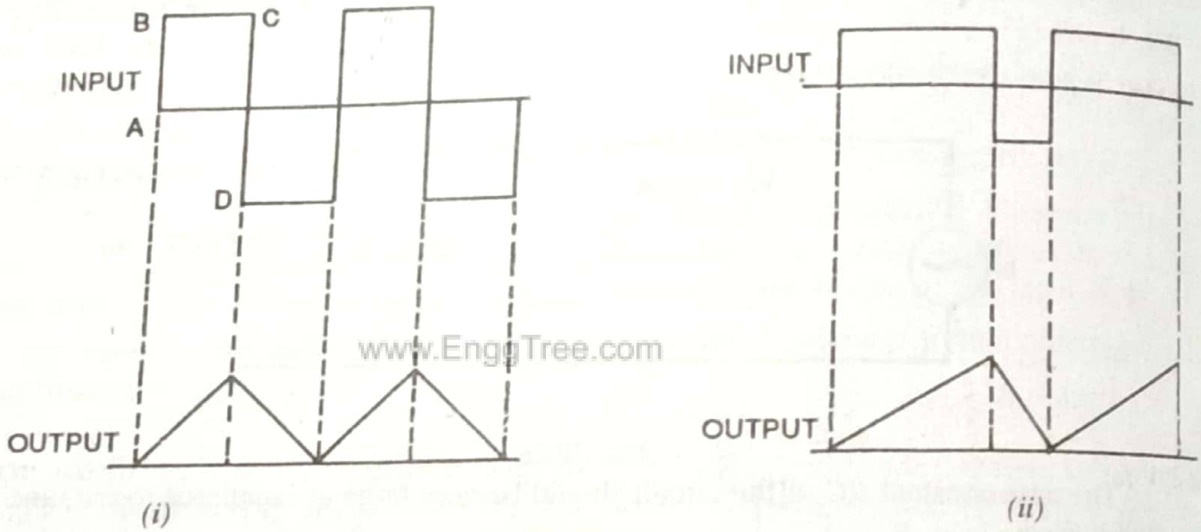


Fig. 20.23

(ii) **When input is rectangular wave.** When the input fed to an integrating circuit is a rectangular wave, the output will be a saw-tooth wave as shown in Fig. 20.23 *(ii)*.

20.17. Important Applications of Diodes

We have seen that diodes can be used as rectifiers. Apart from this, diodes have many other applications. However, we shall confine ourselves to the following two applications of diodes:

(i) as a clipper *(ii)* as a clamper

A clipper (or limiter) is used to clip off or remove a portion of an a.c. signal. The half-wave rectifier is basically a clipper that eliminates one of the alternations of an a.c. signal.

A clamper (or *dc* restorer) is used to restore or change the *dc* reference of an *ac* signal. For example, you may have a $10V_{pp}$ *ac* signal that varies equally above and below 2V *dc*.

20.18. Clipping Circuits

The circuit with which the wave form is shaped by removing (or clipping) a portion of the applied wave is known as a ***clipping circuit.***

Clippers find extensive use in radar, digital and other electronic systems. Although several clipping circuits have been developed to change the wave shape, we shall confine our attention to diode clippers. These clippers can remove signal voltages above or below a specified level. The important diode clippers are *(i)* positive clipper *(ii)* biased clipper *(iii)* combination clipper.

(i) **Positive clipper.** A positive clipper is that which removes the positive half-cycles of the input voltage. Fig. 20.24. shows the typical circuit of a positive clipper using a diode. As shown, the output voltage has all the positive half-cycles removed or clipped off.

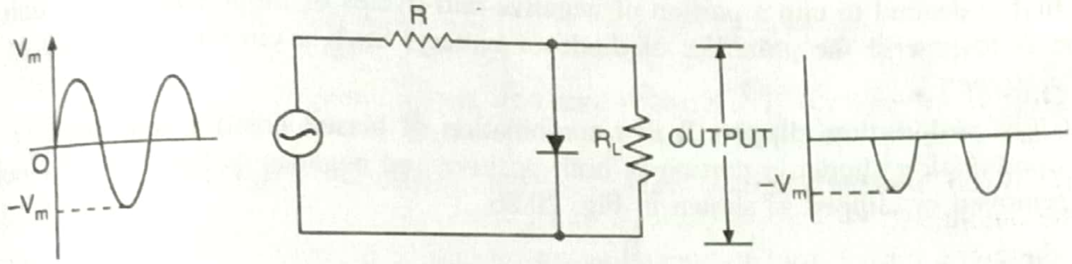


Fig. 20.24

The circuit action is as follows. During the positive half cycle of the input voltage, the diode is forward biased and conducts heavily. Therefore, the voltage across the diode (which behaves as a short) and hence across the load R_L is zero. Hence *output voltage during positive half-cycles is zero.

During the negative half-cycle of the input voltage, the diode is reverse biased and behaves as an open. In this condition, the circuit behaves as a voltage divider with an output of

$$\text{Output voltage} = \frac{R_L}{R + R_L} V_m$$

Generally, R_L is much greater than R.

$$\therefore \quad \text{Output voltage} = -V_m$$

It may be noted that if it is desired to remove the negative half-cycle of the input, the only thing to be done is to reverse the polarities of the diode in the circuit shown in Fig. 20.24. Such a clipper is then called a *negative clipper.*

(ii) **Biased clipper.** Sometimes it is desired to remove a small portion of positive or negative half-cycle of the signal voltage. For this purpose, biased clipper is used. Fig. 20.25 shows the circuit of a biased clipper using a diode with a battery of *V* volts. With the polarities of battery shown, a portion of each positive half-cycle will be clipped. However, the negative half-cycles will appear as such across the load. Such a clipper is called *biased positive clipper.*

The circuit action is as follows. The diode will conduct heavily so long as input voltage is greater than +V. When input voltage is greater than +V, the diode behaves as a short and the output equals +V. The output will stay at +V so long as the input voltage is greater than +V. During the period the input voltage is less than +V, the diode is reverse biased and behaves as an open. Therefore, most of the input voltage appears across the output. In this way, the biased positive clipper removes input voltage above +V.

During the negative half-cycle of the input voltage, the diode remains reverse biased. Therefore, almost entire negative half-cycle appears across the load.

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* It may be noted that all the input voltage during this half-cycle is dropped across *R*.

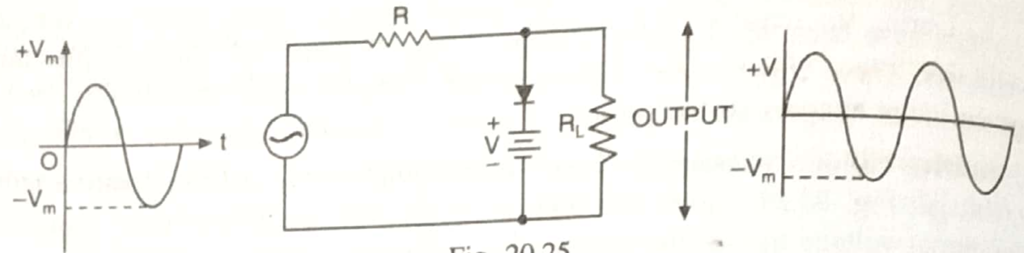


Fig. 20.25

If it is desired to clip a portion of negative half-cycles of input voltage, the only thing to be done is to reverse the polarities of diode or battery. Such a circuit is then called a *biased negative clipper.*

(*iii*) **Combination clipper.** It is a combination of biased positive and negative clippers. With a combination clipper, a portion of both positive and negative half-cycles of input voltage can be removed or clipped as shown in Fig. 20.26.

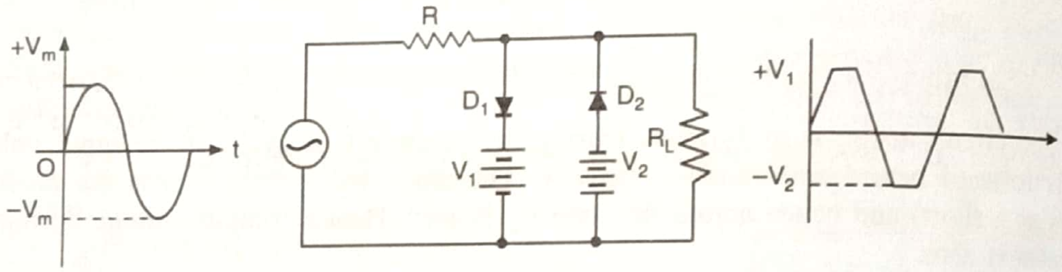


Fig. 20.26

The circuit action is as follows. When positive input voltage is greater than +V_1, diode D_1 conducts heavily while diode D_2 remains reverse biased. Therefore, a voltage +V_1 appears across the load. This output stays at +V_1 so long as the input voltage exceeds +V_1. On the other hand, during the negative half-cycle, the diode D_2 will conduct heavily and the output stays at −V_2 so long as the input voltage is greater than −V_2.

Between +V_1 and −V_2 neither diode is on. Therefore, in this condition, most of the input voltage appears across the load. It is interesting to note that this clipping circuit can give square wave output if V_m is much greater than the clipping levels.

Example 20.5. *For the negative series clipper shown in Fig.20.27, what is the peak output voltage from the circuit?*

Solution. When the diode is connected in series with the load, it is called a series clipper.

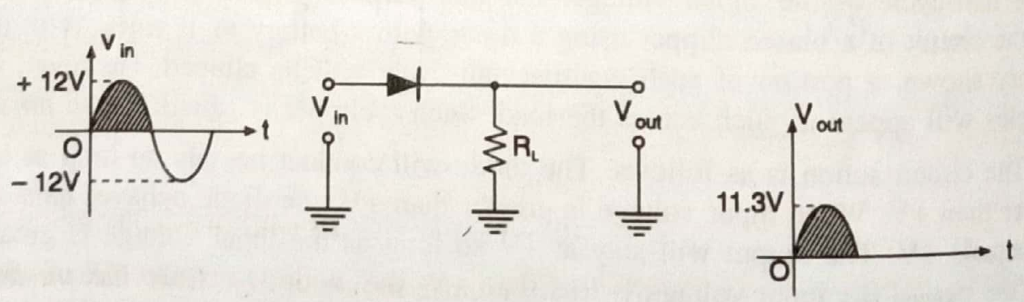


Fig. 20.27

Since it is a negative clipper, it will remove negative portion of input *a.c.* signal.

(*i*) During the positive half-circle of input signal, the dioide is forward biased. As a result, the diode will conduct. The output voltage is

$$V_{out\ (peak)} = V_{in\ (peak)} - 0.7 = 12 - 0.7 = \mathbf{11.3V}$$

Note. The series resistance R protects the diode and signal source when diode is forward biased. However, the presence of this resistance affects the output voltage to a little extent. It is because in a practical clipper circuit, the value of R is much lower than R_L. Consequently, output voltage will be approximately equal to V_{in} when the diode is reverse biased.

20.19. Applications of Clippers

There are numerous clipper applications and it is not possible to discuss all of them. However, in general, clippers are used to perform one of the following two functions:

(*i*) Changing the shape of a waveform

(*ii*) Circuit transient protection

(*i*) **Changing the shape of waveform.** Clippers can alter the shape of a waveform. For example, 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 alternations of an a.c. voltage.

(*ii*) **Circuit Transient protection.** *Transients can cause considerable damage to many types of circuits *e.g.*, a digital circuit. In that case, a clipper diode can be used to prevent the transient form reaching that circuit.

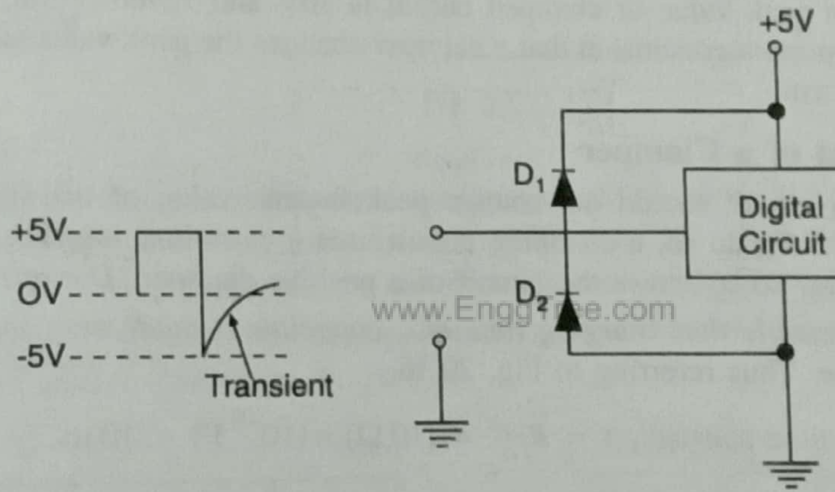


Fig. 20.34

Fig. 20.34 shows the protection of a typical digital circuit against transients by the diode clipper. When the transient shown in Fig. 20.34 occurs on the input line, it causes diode D_2 to be forward biased. The diode D_2 will conduct; thus shorting the transient to the ground. Consequently, the input of the circuit is protected from the transient.

20.20. Clamping Circuits

A circuit that places either the positive or negative peak of a signal at a desired d.c. level is known as a **clamping circuit.**

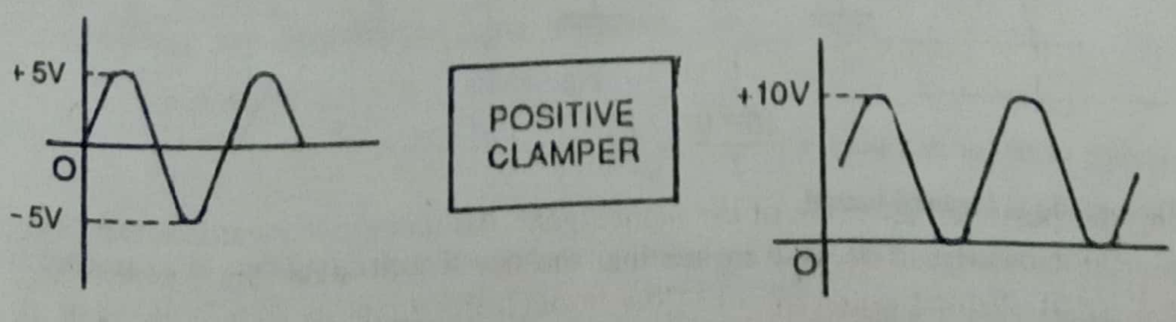


Fig. 20.35

* A transient is a sudden current or voltage rise that has an extremely short duration.

A clamping circuit (or a clamper) essentially adds a *d.c.* component to the signal. Fig. 20.35 shows the key idea behind clamping. The input signal is a sine wave having a peak-to-peak value of 10V. The clamper adds the *d.c.* component and pushes the signal upwards so that the negative peaks fall on the zero level. As you can see, the wave form now has peak values of +10V and 0V.

It may be seen that the shape of the original signal has not changed; only there is vertical shift in the signal. Such a clamper is called a *positive clamper.* The negative clamper does the reverse *i.e.* it pushes the signal downwards so that the positive peaks fall on the zero level.

The following points may be noted carefully :

(*i*) The clamping circuit does not change the peak-to-peak or r.m.s value of the wave form. Thus referring to Fig. 20.35 above, the input wave form and clamped output have the same peak-to-peak value *i.e.*, 10V in this case. If you measure the input voltage and clamped output with an a.c. voltmeter, the readings will be the same.

(*ii*) A clamping circuit changes the peak and average values of a wave form. This point needs explanation. Thus in the above circuit, it is easy to see that input waveform has a peak value of 5V and average value over a cycle is zero. The clamped output varies between 10V and 0V. Therefore, the peak value of clamped output is 10V and *average value is 5V. Hence we arrive at a very important conclusion that a clamper changes the peak value as well as the average value of a wave form.

20.21. Basic Idea of a Clamper

A clamping circuit should not change peak-to-peak value of the signal; it should only change the *dc* level. To do so, a clamping circuit uses a capacitor, together with a diode and a load resistor R_L. Fig. 20.36 shows the circuit of a positive clamper. *The operation of a clamper is based on the principle that charging time of a capacitor is made very small as compared to its discharging time.* Thus referring to Fig. 20.36,

**Charging time constant, $\tau = R_f C = (10\ \Omega) \times (10^{-6}\ \text{F}) = 10\ \mu\text{s}$

Total charing time, $\tau_C = {}^{+}5R_f C = 5 \times 10 = 50\ \mu\text{s}$

++Discharging time constant, $\tau = R_L C = (10 \times 10^3) \times (1 \times 10^{-6}) = 10\ \text{ms}$

Total discharging time, $\tau_D = 5\ R_L C = 5 \times 10 = 50\ \text{ms}$

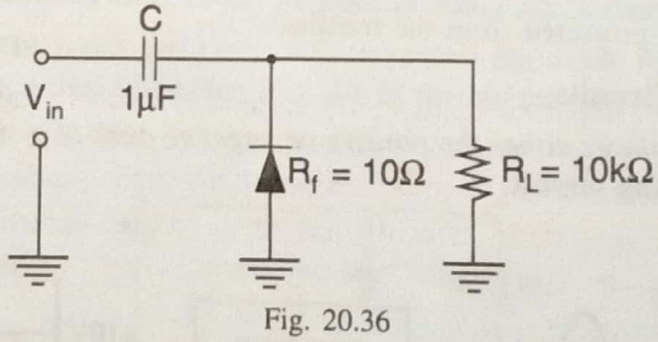


Fig. 20.36

* Average value (or *dc* value) $= \dfrac{10+0}{2} = 5\text{V}$

** When diode is forward biased

\+ From the knowledge of electrical engineering, we know that charging time of a capacitor is $\simeq 5RC$.

++ When diode is reverse biased.

at forward bias → charging time छोटा है।
at Reverse bias → Discharging time बड़ा है।

It may be noted that charing time (*i.e.*, 50 µs) is very small as compared to the discharging time (*i.e.*, 50 ms). This is the basis of clamper circuit operation. In a practical clamping circuit, the values of C and R_L are so chosen that discharging time is very large.

20.22. Positive Clamper

Fig. 20.37 shows the circuit of a *positive clamper. The input signal is assumed to be a square wave with time period T. The clamped output is obtained across R_L. The circuit design incorporates two main features. Firstly, the values of C and R_L are so selected that time constant $\tau = CR_L$ is very large. This means that voltage across the capacitor will not discharge significantly during the interval the diode is non conducting. Secondly, R_LC time constant is deliberately made much greater than the time period T of the incoming signal.

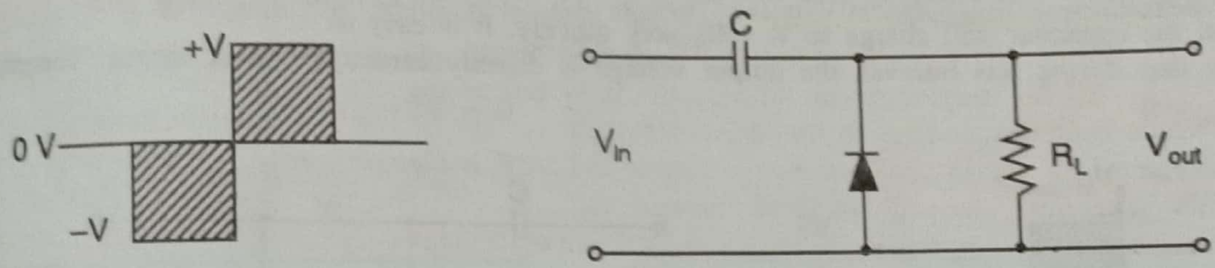
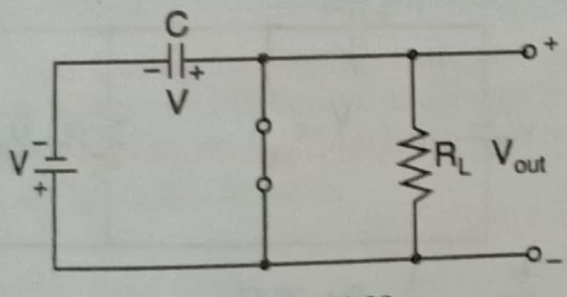


Fig. 20.37

Operation

(*i*) During the negative half cycle of the input signal, the diode is forward biased. Therefore, the diode behaves as a short as shown in Fig. 20.38. The charging time constan. (= CR_f, where R_f = forward resistance of the diode) is very small so that the capacitor will charge to V volts very quickly, It is easy to see that during this interval, the output voltage is directly across the short circuit. Therefore, $V_{out} = 0$.



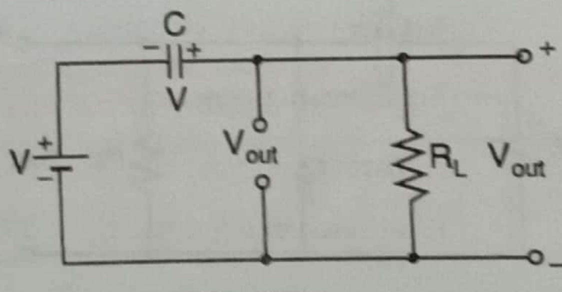


Fig. 20.39

Fig. 20.38

(*ii*) When the input switches to +V state (*i.e.*, positive half-cycle), the diode is reverse biased and behaves as an open as shown in Fig. 20.39. Since the discharging time constant (= CR_L) is much greater than the time period of the input signal, the capacitor remains almost fully charged to V volts during the off time of the diode. Refering to Fig. 20.39 and applying Kirchhoff's voltage law to the input loop, we have,

$$V + V - V_{out} = 0$$

or

$$V_{out} = 2V$$

* If you want to determine what type of clamper you are dealing with, here is an easy memory trick. If the diode is pointing up (away from ground), the circuit is a positive clamper. On the other hand, if diode is pointing down (towards ground), the circuit is a negative clamper.

The resulting waveform is shown in Fig. 20.40. It is clear that it is a positively clamped output. That is to say the input signal has been pushed upward by V volts so that negative peaks fall on the zero level.

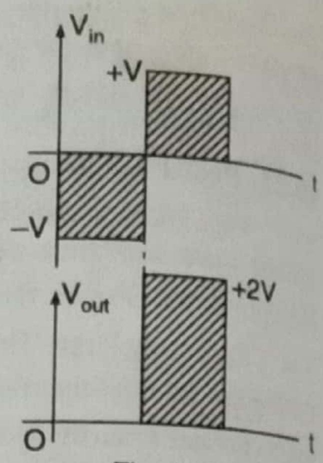


Fig. 20.40

20.23. Negative Clamper

Fig. 20.41 shows the circuit of a negative clamper. The clamped output is taken across R_L. Note that only change from the positive clamper is that the connections of diode are reversed.

(*i*) During the positive half–cycle of the input signal, the diode is forward biased. Therefore, the diode behaves as a short as shown in Fig. 20.42. The charging time constant $(= CR_f)$ is very small so that the capacitor will charge to V volts very quickly. It is easy to see that during this interval, the output voltage is directly across the short circuit. Therefore, $V_{out} = 0$.

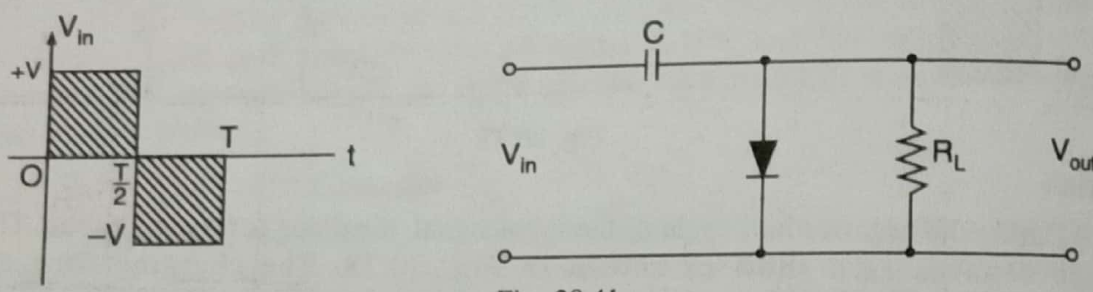


Fig. 20.41

(*ii*) When the input switches to – V state (*i.e.*, negative half-cycle), the diode is reverse biased and behaves as an open as shown in Fig. 20.43. Since the discharging time constant $(= CR_L)$ is much greater than the time period of the input signal, the capacitor almost remains fully charged to V volts during the off time of the diode. Referring to Fig. 20.43 and applying Kirchhoff's voltage law to the input loop, we have,

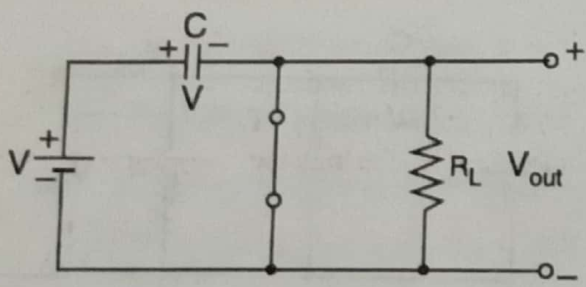


Fig. 20.42

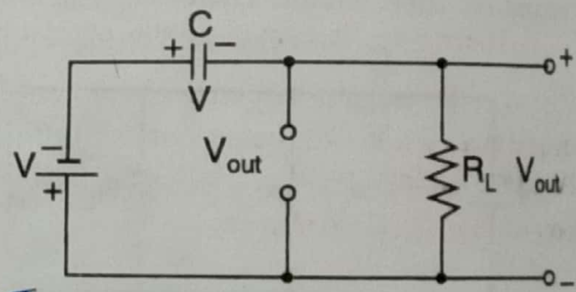


Fig. 20.43

$$- V - V - V_{out} = 0$$

or $$V_{out} = -2V$$

The resulting waveform is shown in Fig. 20.44. Note that total swing of the output signal is equal to the total swing of the input signal.

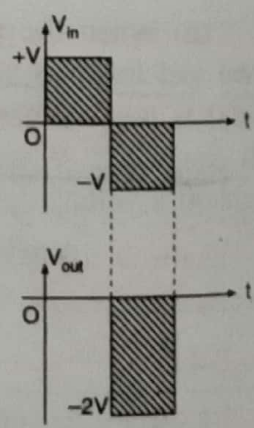


Fig. 20.44

UNIT I - PN JUNCTION DEVICES

JUNCTION DIODE

CTURE :

→ In a piece of Semiconductor material, if one half is doped P-type impurity and the other half is doped by N-type [im]purity, a P-N Junction is formed

→ The plane dividing the two halves (or) planes are called junction

→ A small amount of pentavalent impurities such as arsenic, [anti]mony (or) phosphorous are added to the semiconductor to get [N-ty]pe semiconductor

→ The addition of pentavalent impurity increases the number [of] electrons in the conduction band.

→ As a result, the number of electrons far exceeds the [num]ber of holes. therefore, electrons are the majority carriers and [hole]s are the minority carriers in N-type semiconductor.

→ A small amount of trivalent impurity such as aluminum, [bor]on are added to pure semiconductor to get the P-type [semi]conductor.

→ This impurity increases the number of holes in the [...] band. therefore holes are the majority carriers and

→ At the junction, there is a tendency for the free electrons to diffuse over to P-side and holes to N-side. This process is called diffusion.

→ When the free electrons diffused from 'n' side into 'p' side, it recombine with the holes and leaves a negatively charged immobile ions near the junction of 'P'.

→ Similarly, the holes diffusing from 'p' region into 'n' region, recombine with electrons and leaves the positively charged immobile ions near the junction of 'P' 'n'.

→ After certain extent, the immobile positive ions deposited across 'n' region prevents further charge carrier diffusion from 'P' region into 'n' regions. Similarly the immobile negative ions deposited across 'P' region prevents further charge carrier diffusion from 'n' region into 'P' region. This immobile ions forms a region called depletion region.

→ The existence of these immobile ions develops the potential difference across the junction, this potential acts as a barrier for further conduction between the junction. This potential is called barrier potential (or) cut in voltage.

→ The cut in voltage for Germanium is 0.3 V and 0.7 V for Silicon diodes.

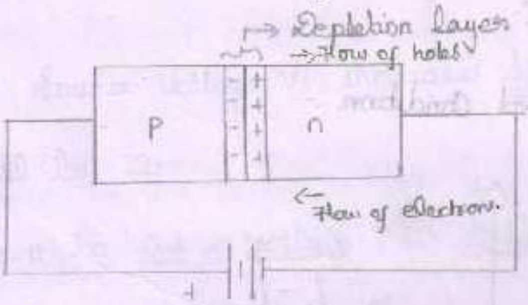
OPERATION :

i) Under Forward bias Condition :

→ When positive terminal of the battery is connected to P-type and negative terminal of the battery to the N-type, the P-N junction is forward biased.

→ Positive terminal of the battery sucks electrons from P material leaving holes there. These holes travel through P material towards the negative charge at p-n junction and partly neutralised the negative charge.

→ Similarly, negative terminal of the battery injects electron into n layer. These electrons move through n-material, reach the junction thereby partly neutralising the positive charge which results in reduction of depletion region.



ii) Under Reverse bias Condition.

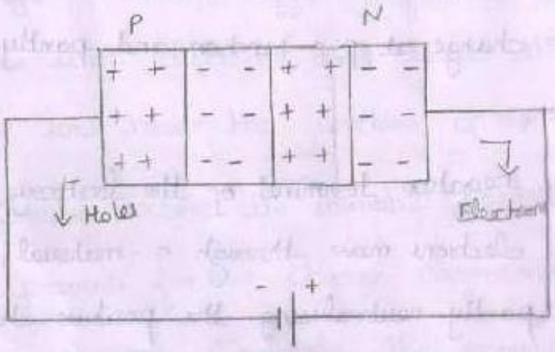
→ When the negative terminal of the battery is connected to P-type and positive terminal of the battery is connected to N type, the bias applied is known as reverse bias.

→ During reverse biased condition, the holes in the P-side are attracted towards negative terminal of the battery and the electrons in the N-side are attracted towards positive terminal

→ As a result, the width of the depletion region increases. Therefore the electric field produced is in the same direction similar to the electric field of the potential barrier

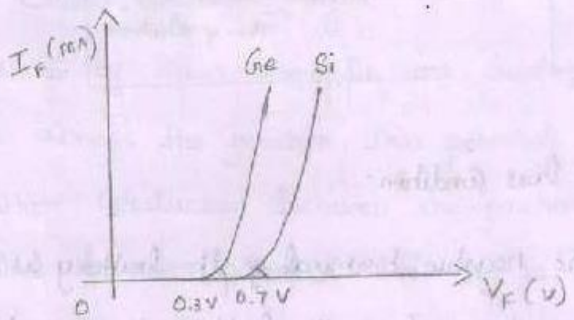
→ Due to this effect, the width of the potential barrier will increase which prevents the flow of majority carriers.

→ This is the operation performed by a PN junction diode during reverse bias condition



V-I characteristics :

i) Under Forward biased condition :



→ A plot between Voltage and Current gives the V-I characteristics of PN junction diode

→ V_0 → barrier potential

V_F → Forward Voltage

i) $V_F < V_0$

→ When Forward Voltage (V_F) increases, the forward Current (I_F) is almost Zero

→ This is because, the potential barrier prevents holes from P region and electrons from N region to flow across depletion region in the opposite direction.

ii) $V_F > V_0$

→ During this Condition, the potential barrier at the junctions disappears Completely and as a result the holes Cross the junction from P type to N type and the electrons Cross the junction from N type to P type and hence a large amount of Current will flow in the external Circuit

Operation:-

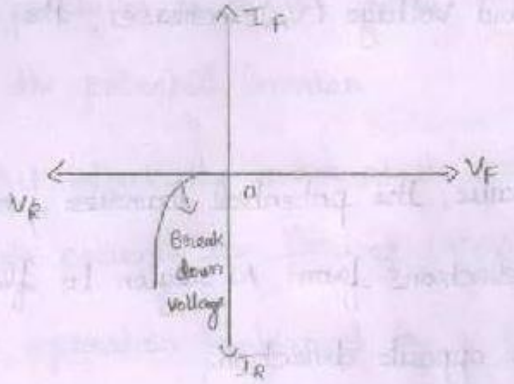
→ When the source Voltage V_S, increases from Zero Value, the diode Current will be Zero

→ From $V_S = 0$ to Cut in Voltage (or) threshold Voltage, the forward diode Current is Very Small

→ Beyond the Cut in Voltage, the diode Current rises rapidly and the diode will Start to Conduct

→ The Cut in voltage for silicon is 0.7 V and for Germanium it is 0.3 V.

ii) Under reverse biased Condition:



→ Under reverse biased condition, no current should flow in the external circuit. But practically, a very small amount of current will flow.

→ This is because that during the reverse biased condition, the thermally generated holes in the P-region are attracted towards the nega ~~positive~~ terminal of the battery and the electrons in the N-region are attracted towards the positive terminal of the battery. At the same time, the electrons in the P region and holes in the N region move towards the junction and will flow towards their majority carrier side which results in a small reverse current. This current is known as reverse saturation current.

→ The magnitude of the reverse saturation current will depend on the junction temperature.

→ For large applied reverse bias, the electrons from N type towards positive terminal of the battery will acquire energy to gain velocity in order to dislodge the valence electrons

→ These dislodged electrons will acquire sufficient energy to dislodge the parent electrons.

→ As a result, a large number of electrons will form which is known as avalanche of free electrons.

→ This process will lead to breakdown in the junction which will result in very large reverse current.

→ The reverse voltage at which the junction breakdown occurs is known as Breakdown Voltage.

TRANSITION CAPACITANCE:

→ During the reverse biased condition, the holes in the P-side will attract towards the negative terminal of the battery and electrons in N-side will attract towards the positive terminal of the battery.

→ Since the majority carriers in P and N side are moved away from the junction, more immobile charges will be uncovered.

→ Due to this, the width of the depletion layer will get increased.

→ The process of uncovering the immobile charges will be considered as the capacitive effect and the parallel layers of oppositely charged immobile ions forms the capacitance (C_T).

$$C_T = \left| \frac{dQ}{dV} \right|$$

dQ → increase in charge caused by change in voltage dV

where C_T is called transition (or) space charge (or) barrier (or) depletion region capacitance

DIFFUSION CAPACITANCE:

→ Diffusion capacitance is defined as the rate of change of injected charge with applied voltage.

$$C_D = \frac{dQ}{dV}$$

→ dQ → change in number of minority carriers stored outside the depletion region

dV → change in voltage across diode

C_D → Diffusion capacitance

→ Diffusion capacitance will exists during forward biased condition.

→ The value of diffusion capacitance is larger than the transition capacitance.

→ The value of C_D increases exponentially with diode forward current.

→ The value of C_D is directly proportional to diode forward current and inversely proportional to frequency.

→ The value of C_D ranges from 10 to 1000 pF

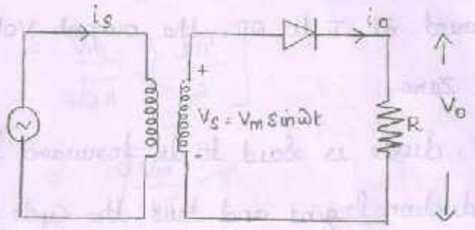
RECTIFIERS :

→ Rectification is the process of Conversion of alternating input Voltage to direct output Voltage.

→ Rectifier will Convert ac power to dc power.

→ It may be of half wave rectifier and full wave rectifier.

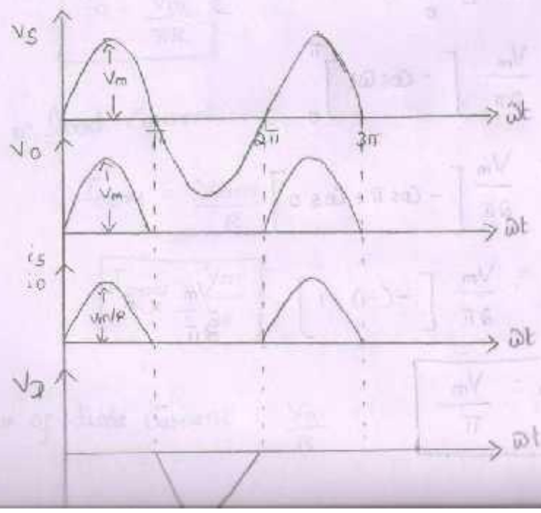
Half wave rectifier :-



→ In the half wave rectifier Circuit, for one Cycle of Supply Voltage, there is one half Cycle of output.

→ The Circuit Consist of a transformer, a diode and the load. The load may be R, RL (or) RL with flywheel diode.

operation :-



→ During positive half cycle, diode is forward biased, and it is said to be conducting from $\omega t = 0^\circ$ to $\omega t = \pi$.

→ During this process, the output voltage, $V_o = V_s$ (source voltage) and the load current will be $i_o = V_o / R$.

→ At $\omega t = \pi$, the output voltage will be zero and for resistive load, the load current will also be zero.

→ After $\omega t = \pi$, the source voltage will become negative and the diode D is said to be reverse biased and therefore it will get turn off and will go into blocking state.

→ During the period $\omega t = \pi$ to 2π, the output voltage and output current will be zero.

→ After $\omega t = 2\pi$, diode is said to be forward biased and therefore the conduction begins and thus the cycle repeats.

→ During the conduction of diode, the diode voltage will be zero.

Average value of output voltage

$$V_0 = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin\omega t \, d\omega t\right]$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$= \frac{V_m}{2\pi}\left[-\cos\pi + \cos 0\right]$$

$$= \frac{V_m}{2\pi}\left[-(-1)+1\right] = \frac{V_m}{2\pi} \times 2$$

$$\boxed{V_0 = \frac{V_m}{\pi}}$$

$$V_{orms} = \left[\frac{1}{2\pi} \int_0^{\pi} V_m^2 \sin^2\omega t \, d\omega t \right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}} \left[\int_0^{\pi} \frac{1-\cos 2\omega t}{2} \, d\omega t \right]^{1/2}$$

$$= \frac{V_m}{\sqrt{4\pi}} \left\{ \left[\omega t - \frac{\sin 2\omega t}{2} \right]_0^{\pi} \right\}^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}} \left\{ \frac{\pi - \sin 2\pi}{4} - \frac{0 \sin 0}{4} \right\}^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}} \left\{ \frac{\sqrt{\pi}}{2} \right\}$$

$$= \sqrt{\frac{V_m^2}{4\pi} \times \pi}$$

$$\boxed{V_{orms} = \frac{V_m}{2}}$$

Average Value of load Current.

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

$$\boxed{I_o = \frac{V_m}{\pi R}}$$

Rms Value of load Current

$$I_{orms} = \frac{V_{orms}}{R}$$

$$\boxed{I_{orms} = \frac{V_m}{2R}}$$

Peak Value of diode Current $= \frac{V_m}{R}$

Peak Inverse Voltage:

→ It is defined as the maximum voltage that appears across the diode during its blocking state.

$$PIV = V_m = \sqrt{2} \times V_s$$

Input power factor:

$$I.P.F = \frac{\text{Power delivered to load}}{\text{Input VA}}$$

$$= \frac{V_{orms} \times I_{orms}}{V_s \times I_{orms}}$$

$$= \frac{V_{orms}}{V_s} = \frac{\sqrt{2}V_s}{2V_s}$$

$$I.P.F = 0.707 \text{ lag}$$

~~Full Wave Rectifier~~ Output dc power:-

$$P_{dc} = V_o I_o = \frac{V_m . I_m}{\pi^2}$$

Output ac power:

$$P_{ac} = V_{orms} \cdot I_{orms} = \frac{V_m I_m}{4}$$

Rectifier efficiency:-

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_m I_m}{\pi^2} \times \frac{4}{V_m I_m}$$

$$= \frac{4}{\pi^2}$$

$$\eta = 40.53\%$$

Ripple factor:

→ It is defined as the ratio of rms value of ac voltage (or) current to the average value of ac voltage (or) current.

$$RF = \frac{\sqrt{V_{rms}^2 - V_0^2}}{V_0} = \frac{V_r}{V_0}$$

$$= \frac{\sqrt{\left(\frac{V_m}{2}\right)^2 - \left(\frac{V_m}{\pi}\right)^2}}{V_0} = \frac{0.3856 \times V_m}{\frac{V_m}{\pi}}$$

$$= 0.3856 \times \pi$$

$$\boxed{R.F. = 1.211}$$

Transformer Utilisation Factor:-

-> It is defined as the ratio of dc power delivered to the load to the VA rating of the transformer

$$TUF = \frac{P_{dc}}{V_S I_S} = \frac{V_m I_m}{\pi^2} \times \frac{2\sqrt{2}}{V_m I_m}$$

$$\boxed{TUF = 0.2865}$$

Advantage:

-> It is a simple and low cost circuit.

Disadvantages:

-> Has low rectification efficiency.
-> High ripple factor
-> Transformer is not fully utilised
-> Regulation is poor

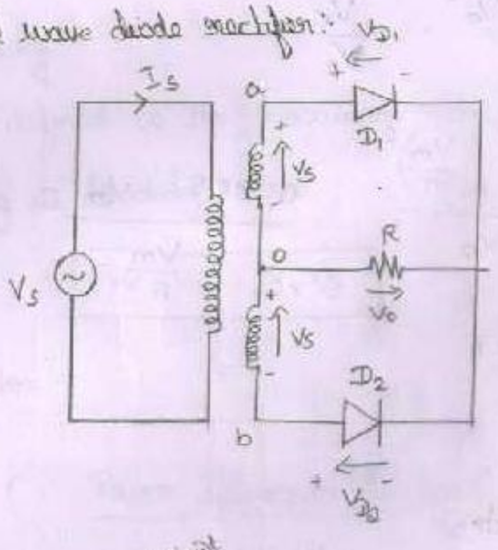
Full Wave rectifier:-

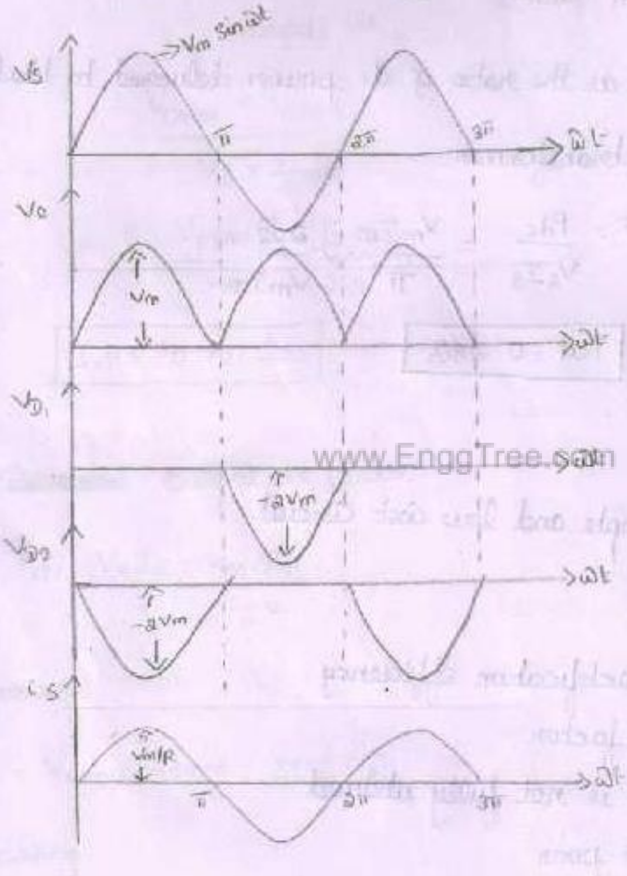
-> It is of two types

i) Centre tapped full wave diode rectifier
ii) Full wave diode bridge rectifier

-> In the full wave rectifier, for one cycle of source voltage, there are two pulses of output voltage

Centre taped full wave diode rectifier:-





Operation:-

-> When 'a' is positive with respect to 'B', the diode D_1 Conducts for π radians.

-> In the next half cycle, 'b' is positive with respect to 'a', therefore the diode D_2 Conducts up from π to 2π radians.

-> Similarly when 'a' is positive with respect to 'b', D_2 is subjected to reverse voltage of $2V_s$. In the next half cycle, diode D_1 experiences a reverse Voltage of $2V_s$

Average output Voltage. $V_0 = \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t \, d\omega t$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{V_m}{\pi}\left[-\cos\pi + \cos 0\right]$$

$$= \frac{V_m}{\pi}\left[-(-1)+1\right]$$

$$V_0 = \frac{2V_m}{\pi}$$

Average output Current. $I_0 = \frac{V_0}{R}$

Rms value of output voltage. $V_{orms} = \left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2 \omega t \, d\omega t\right]^{1/2}$

$$\boxed{V_{orms} = \frac{V_m}{\sqrt{2}}}$$

Rms value of load Current. $I_{orms} = \frac{V_{orms}}{R}$

Output dc power. $P_{dc} = V_0 I_0 = \frac{2V_m}{\pi} \times \frac{2 I_m}{\pi}$

$$P_{dc} = \frac{4}{\pi^2} V_m I_m$$

output ac power. $P_{ac} = V_{orms} I_{orms} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} = \frac{V_m I_m}{2}$

$$P_{ac} = \frac{V_m I_m}{2}$$

Rectifier efficiency. $\eta = \frac{P_{dc}}{P_{ac}} = \frac{4}{\pi^2} \times V_m I_m \times \frac{2}{V_m I_m} = \frac{8}{\pi^2}$

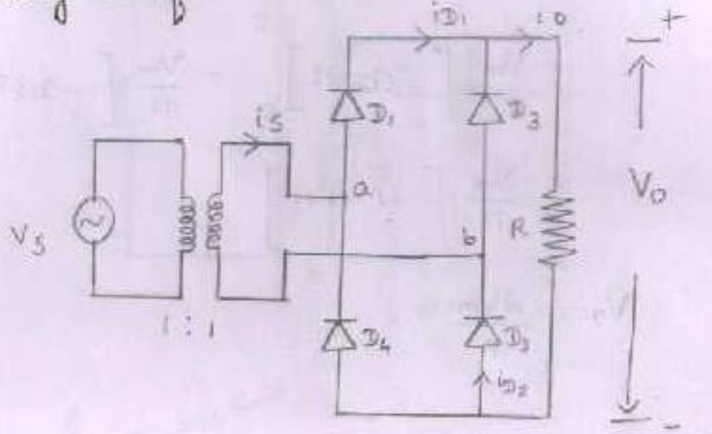
$$\eta = 0.8106$$

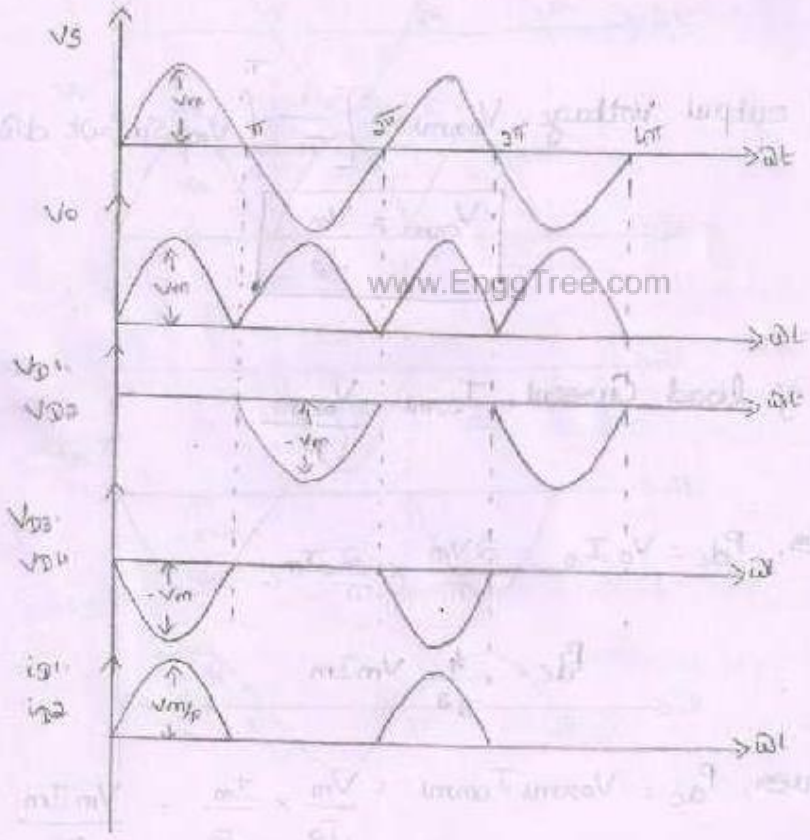
Ripple factor. $RF = \frac{V_r}{V_0} = \frac{\sqrt{V_{orms}^2 - V_0^2}}{V_0} = \sqrt{\left(\frac{V_m}{\sqrt{2}}\right)^2 - \left(\frac{2V_m}{\pi}\right)^2} = \frac{0.3077 V_m \times \pi}{2V_m}$

RF = 0.483

TUF = 0.672

Full Wave Bridge Rectifier:



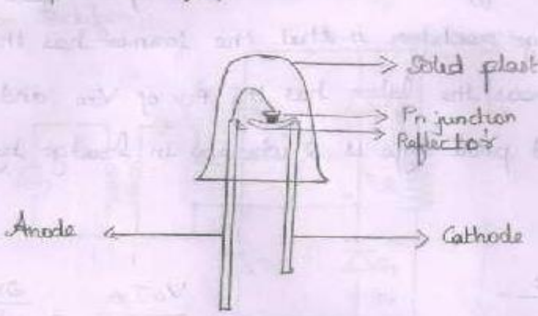


→ when 'a' is positive with respect to 'b', the diodes D_1 and D_2 will Conduct with a Voltage of V_{ab}

→ During this operation, the diodes D_3 and D_4 is subjected to reverse Voltage of the Value V_s.

→ when 'b' is positive with respect to 'a', the diodes D_3 and D_4 will Conduct with a Voltage of V_{ba} and the diodes D_1 and D_2

Construction :



→ The pn junction diode is mounted on a cup shaped reflector.

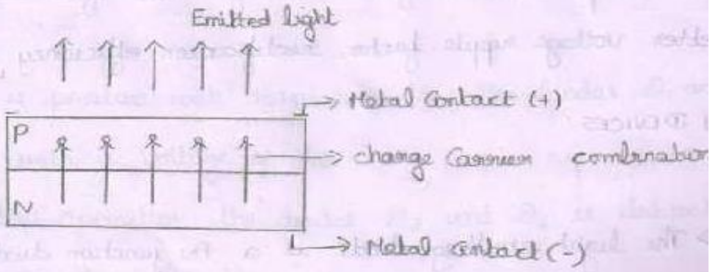
→ wire connection will be provided for anode and cathode connection.

→ The whole device is encapsulated in an epoxy lens. The lens can be either coloured (or) colorless.

→ The type of the pn junction material will determine the color of the light emitted from the energised LED.

→ Some of the LED's have glass particles embedded in the epoxy lens to diffuse the emitted light and thereby increasing the viewing angle of the device.

Structure :



→ An N-type layer is grown on a substrate and a P-type layer is deposited on it by diffusion. The process of carrier is subjected to a reverse voltage of V_S.

→ The major difference between the mid point full wave rectifier and full wave bridge rectifier is that the former has the peak Inverse Voltage of $2V_m$ whereas the later has the PIV of V_m. and the number of diodes used in mid point type is 2 whereas in bridge type is 4.

TUF:

$$TUF = \frac{P_{dc}}{VA \text{ rating of transformer}} = \frac{V_o I_o}{V_S I_S} = \frac{\frac{2V_m}{\pi} \times \frac{2I_m}{\pi}}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}$$

$$= \frac{4V_m I_m}{\pi^2} \times \frac{2}{V_m I_m} = \frac{8}{\pi^2}$$

$$\boxed{TUF = 0.8106}$$

→ From the above equation, it is clear that the transformer is utilised efficiently in bridge rectifier than the mid point type

→ The bridge rectifier type is economical.

→ PIV is defined as the maximum voltage that a diode can withstand under reverse biased condition

→ Compared to half wave rectifier, the full wave rectifier has better voltage ripple factor, rectification efficiency and TUF.

DISPLAY DEVICES:

LED:

→ The light emitting diode is a PN junction diode. It works based on the principle of electroluminescence which emits light when the PN junction diode is forward biased

→ In order to allow more Central Surface area for the light to escape. the metal anode Connections are made at the outer edges of P layer.

→ To reduce the reabsorption problem, domed lenses are used

Operation:

→ when the LED is forward biased, the electrons and holes move towards the junction and the recombination will take place.

→ As a result of the recombination process, the electrons lying in the Conduction bands of N region will fall into the holes lying in the Valence band of P region.

→ The difference in the energy level between the Conduction band and Valence band is radiated in the form of light energy.

→ Thus the recombination of electrons and holes will generate the light and their excess energy is transferred to an emitted photon.

→ The brightness of the light is directly proportional to the forward bias Current.

→ The wavelength of the emitted light depends on the energy gap of the material

→ The efficiency of generation of light increases with increase in the injected Current and with a decrease in temperature.

→ As the Colour of the emitted light depends on type of material, if Gallium arsenide is used, there will be infrared radiation. If Gallium phosphide is used, the emitted light will be in red (or) green Colour. The emitted light will be red (or) yellow in Colour if Gallium arsenide phosphide is used.

→ For the protection purpose of LED, resistance of 1 kΩ (or) 1.5 kΩ must be connected in series with the LED.

Characteristics:-

→ The operating voltage level of LED is from 1.5 V to 3.3 V.

→ The operating current is in the range of some tens of milliamperes.

→ The switching speed is 1 ns

→ The power requirement ranges from 10 to 150 mW with a lifetime of 1,00,000+ hours.

Application:

→ Calculators.

→ Digital meters

→ Intercoms

→ Burglar alarm systems

→ digital watches.

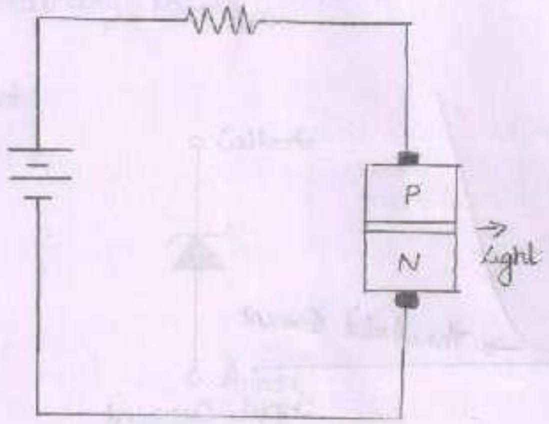
LASER DIODES

→ LASER stands for light amplification by stimulated emission of radiation

→ The laser emits radiation with a single wavelength (or) a very narrow band of wavelengths which is in the range of 1 µm to 100 µm in width

→ The emitted laser light has a single colour i.e., it is monochromatic and it is also a coherent type of light.

Structure



-> A pn junction of gallium arsenide or Combination of gallium arsenide Combined with other materials is manufactured with a precisely defined length related to the wavelength of the light to be emitted.

-> The ends of the junction are each polished to a mirror surface and usually have an additional reflective coating.

-> One end is partially reflective so that light can pass through when lasing occurs.

Operation :

-> when free electrons recombine with holes, the photons which is emitted reflect back and forth between the mirror surfaces.

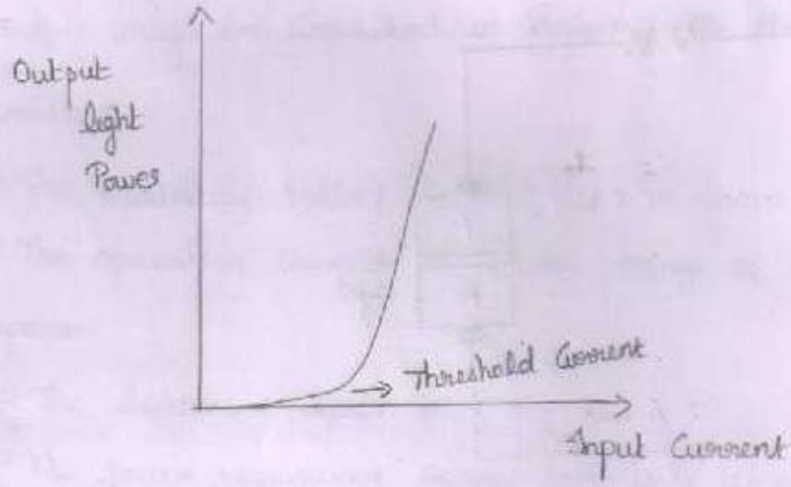
-> Since the photons bounce back and forth, they induce an Avalanche effect.

-> The region between the mirrored ends acts like a Cavity that filters the light and purifies it colour.

-> One of the mirror surfaces is semitransparent. From this surface, a fine thread like beam of photons emerge out.

-> All the phonons of laser light have same frequency and also they are in phase

Characteristics :



→ The above characteristics between the Input Current and output light power shows that this device has a well defined threshold (level of forward Current at which

→ Below the threshold value, the device exhibits low level of spontaneous emission.

Application:

Bar Codes

Fibre optic Communication

playing music from a Compact disc.

Zener diode

→ In a normal pn junction diode, when the reverse Voltage reaches the breakdown voltage value, the Current through the junction and the power dissipated at the junction will be high.

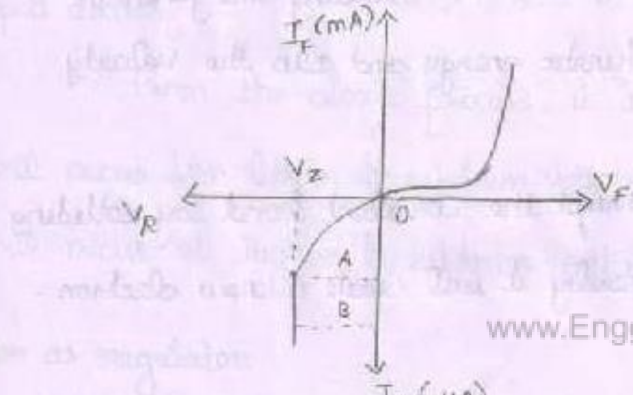
→ This phenomenon is very dangerous and the diode will also be get damaged.

→ In order to overcome this problem, the diodes are Constructed with adequate power dissipation Capabilities which will allow them to operate even in breakdown region

→ Zener diode is one of the above type which is heavily doped than the ordinary diode.

Circuit Symbol:

V-I characteristics



→ Under forward biased Condition, the operation of Zener diode is similar to the PN junction diode.

→ Under reverse biased Condition, a small leakage Current will flow. If the reverse voltage across Zener diode is increased, a Value of Voltage is reached at which reverse breakdown occurs, which is indicated by a sudden increase of Zener Current.

→ The breakdown Voltage Value depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and therefore the breakdown will occur at lower reverse Voltage and also the breakdown voltage is sharp.

→ The lightly doped diode has a higher breakdown voltage.

→ The sharp increasing current under breakdown condition is due to

Avalanche breakdown

Zener breakdown.

Avalanche breakdown:

→ When there is increase in the applied reverse bias, the field across the junction also increases.

→ Thermally generated carriers while crossing the junction will acquire more amount of kinetic energy and also the velocity of the carrier also increases.

→ The electrons will disrupt the covalent bond by colliding with the immovable ions and thereby it will create a new electron-hole pairs.

→ Again the new carriers will acquire energy from the field and they will collide with immobile ions and hence another electron-hole pairs will generate

→ The above process repeats again and results in the generat of more amount of charge carriers within a short time

→ This process of carrier generation is known as Avalanche multiplication. It will result in the flow of large amount of current

Zener breakdown:

→ When the P and N regions are doped heavily, the width of the depletion region will increase when the applied voltage is 6V or below 6 V and also the field across the depletion region will increase which will make the condition suitable for Zener breakdown

→ Because of strong electric fields, rupture of Covalent bonds will take place at the junction of PN junction diode when P and N regions are heavily doped.

→ The newly Created electron hole pairs will increase the reverse Current in reverse biased PN junction diode.

→ The increase in the Current will take place during reverse bias below 6V for heavily doped diodes.

→ The Zener breakdown voltage will be high for lightly doped diodes.

→ From the above process, it is clear that Zener breakdown will occur for lower breakdown voltage and Avalanche breakdown will occur at higher breakdown voltage.

Zener as regulator:-

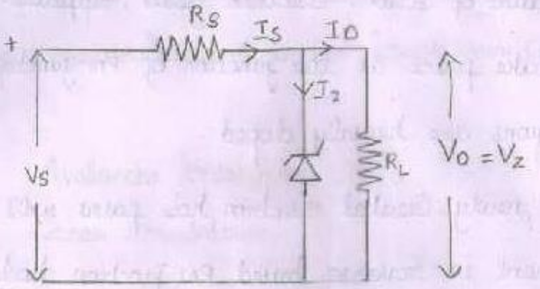
→ From the characteristics of Zener diode, it is clear that eventhough the Current through the diode increases, the voltage across the diode remains almost Constant.

→ Due to the above characteristics, the voltage across the diode Can be used as a reference voltage and hence this diode can be used a Voltage regulator.

→ Voltage regulator is nothing but a electrical or electronic device which maintains the voltage of a power Source within acceptable limits.

→ The voltage regulator is needed to keep the Voltages within the range that Can be tolerated by the equipment.

& automatically maintains a Constant Voltage level.



→ For operating Zener diode as a voltage regulator, it must satisfy two requirements

i) it should be reverse biased with a voltage greater than the breakdown voltage (or) Zener voltage

ii) a Series resistor R_s must be Connected in series in order to limit the reverse Current through the diode below its rated Value.

→ For operating Zener diode as a Voltage regulator, it must be reverse biased as long as the input voltage does not fall below Zener breakdown voltage. the voltage across the diode will be Constant and therefore the load voltage will also be Constant.

→ If V_z is the Voltage across Zener diode, then the Source Current will be

turn on and they remain in on-state due to regener[ative]
action. But they can be turned off by a power circuit.

→ Then the controllable switches have been used
has the characteristics of controlled turned on and turn
off properties which includes various transistors like B[JT]
MOSFET, GTO, IGBT.

→ The power semiconductor devices are used in
in power electronic circuits, used as freewheeling diod[es]
ac to dc conversion, for recovery of trapped energy a[nd]
also as switches in dc choppers and inverters.

UNIT-II

TRANSISTORS

→ Transistors are the devices which can be turned on and turned off by the application of control signals. i.e, they can be used as a controllable switches.

BJT :-

→ BJT is a three terminal semiconductor device whose operation depends upon the interaction of both majority and minority carriers and hence its name is Bipolar.

→ It is a current controlled device

Construction:-

→ The BJT is a three layer two junction semiconductor device

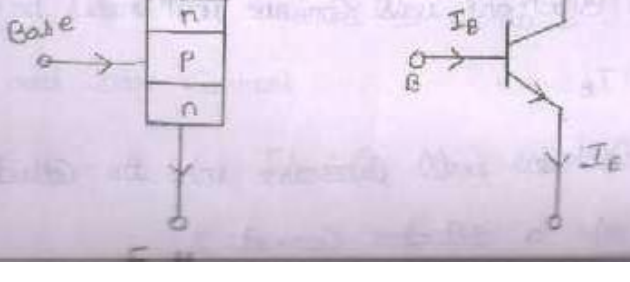
→ The BJT has three terminals namely Collector, Emitter and base.

→ The BJT has two configuration namely,

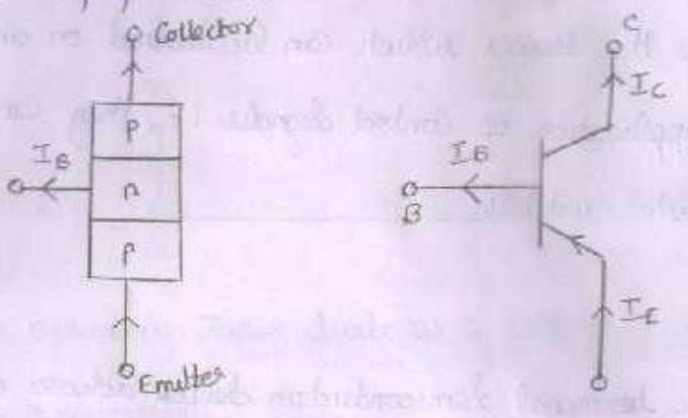
npn transistor

pnp transistor

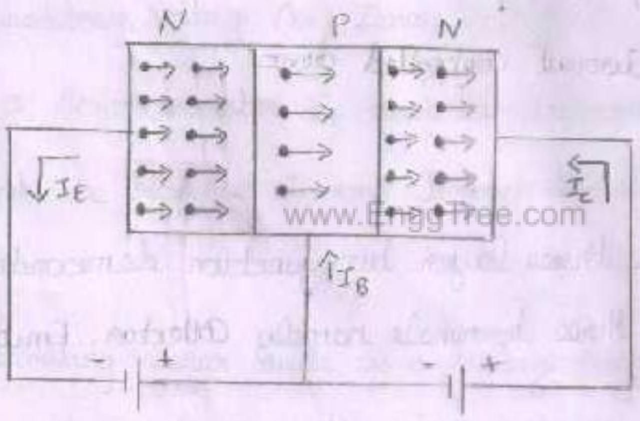
→ When one p-region is sandwiched between two n region, npn transistor configuration is obtained. This type of configuration is easy to manufacture and it is cheaper also and hence this type is used in high voltage and high current application.



→ When one of the n region is Sandwiched between two P regions, a pnp transistor is obtained.



Operation of NPN transistor:-



→ When forward bias is applied to the emitter base junction of a NPN transistor, a lot of electrons will Crossover from the emitter region to the base region.

→ Since the base is lighty doped with p-type impurity, the number of holes in the base region is Very Small and therefore the number of electrons Combines with holes in the P type base region is also Very Small.

→ As a result few electrons will Combine with holes to Constitute a base Current I_B.

→ The remaining electrons will Crossover into the Collector region in order to Constitute a collector Current

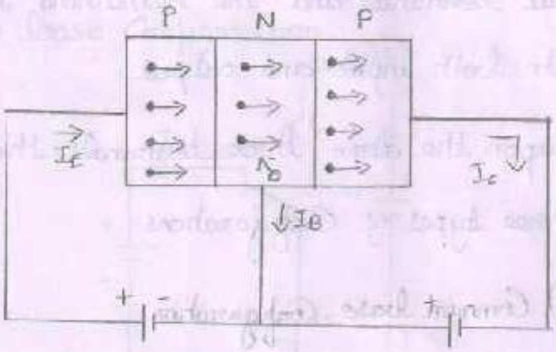
→ The emitter Current is obtained by summing up of base and Collected Current.

$$I_E = -(I_C + I_B)$$

→ In the external Circuit of NPN BJT, the emitter Current is given by,

$$I_E = I_C + I_B$$

Operation of PNP transistor:



→ when forward bias is applied to the emitter base junction of PNP transistor, more number of holes will Crossover to the base region from the emitter region since the base is lightly doped with N-types of impurity.

→ Since the number of electrons in the base region is Very Small, the number of holes Combined with electrons in N type base region is also Very Small and this Combination will Constitute a base Current I_B.

→ The remaining holes will Crossover into the Collector region to Constitute Collector Current I_C

→ The emitter Current is obtained by summing up of Collector and base Current

$$I_E = (I_C + I_B)$$

→ In the external Circuit of PNP BJT, the emitter Current is given by,

$$I_E = I_C + I_B$$

Types of Configuration :-

→ when a transistor is to be Connected to a Circuit, one of the terminal is used as input terminal, other terminal Can be used as output terminal and the remaining third terminal is Common to both input and output.

→ Depending upon the above three terminals, the BJT Can be Connected in three types of Configurations.

i) Common base Configuration

ii) Common emitter Configuration.

iii) Common Collector Configuration

Common base Configuration :

→ also called as grounded base Configuration

→ Input terminal → emitter

Output terminal → Collector

Common terminal → base

Common Emitter Configuration :-

→ also called as grounded emitter Configuration

Input terminal → base

Output terminal → Collector

Common terminal → Emitter

Common Collector Configuration:

→ also called as grounded Collector Configuration

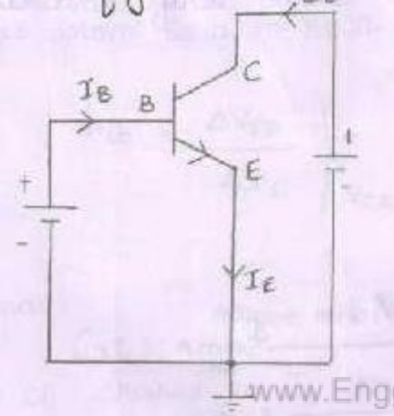
Input terminal - base

output terminal - emitter

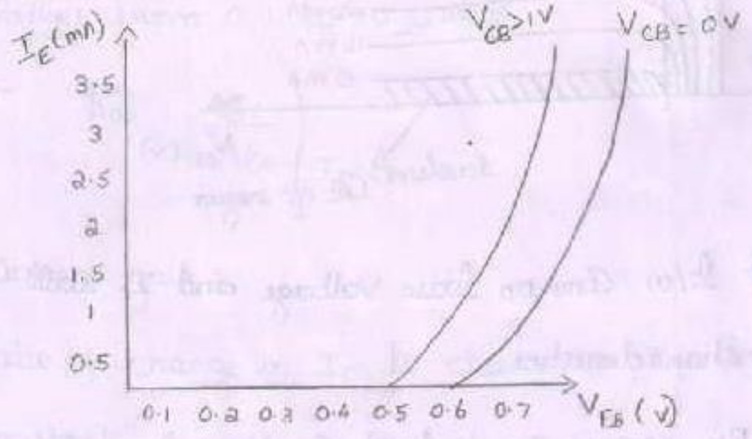
Common terminal - Collector

Characteristics of BJT under different Configuration:

i) Common base Configuration:-



Input Characteristics:-



→ A plot between the Emitter base Voltage and Emitter Current will give the I/p characteristics under CB Configuration

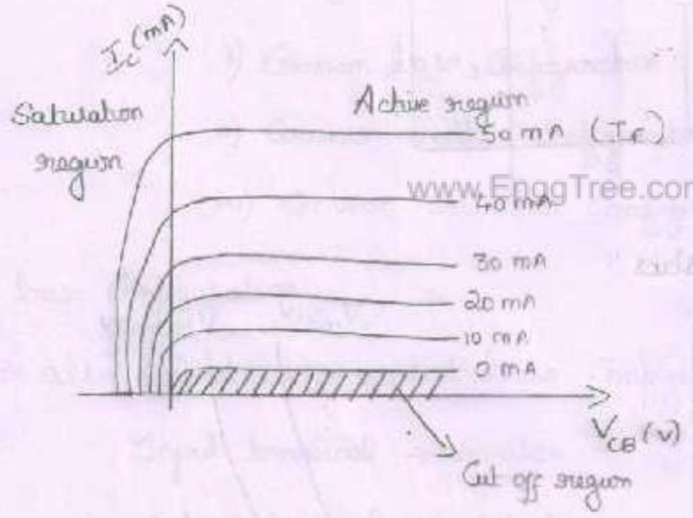
→ The Input characteristics is obtained by the keeping the V_{CB} as Constant at Zero volt and by increasing I_E from zero initially by increasing V_{EB}

→ The junction will behave as a forward biased diode, when V_{CB} is zero and EB junction is forward biased and as a result I_E increases rapidly with small increase in V_{EB}.

→ The width of the base region will get decreased when V_{CB} is increased by keeping V_{EB} as constant which result in increase of I_E.

→ Because of this, the curve shift towards the left when V_{CB} is increased.

Output characteristics:



→ A plot b/w common base voltage and I_C will give the o/p characteristics

→ Here, by keeping I_E is kept constant by adjusting V_{EB}, the V_{CB} is increased and I_C is noted for each I_E. And it is repeated for different I_E.

→ I_C is independent of V_{CB} and the curves are parallel to the axis of V_{CB} for constant values of I_E and also it is noted that I_C flows when V_{CB} is zero.

Transistor parameters:

a) Input impedance:-

→ Ratio of change in emitter voltage to change in emitter current with collector voltage as constant.

→ Ranges from 20 Ω to 50 Ω.

$$h_{ib} = \frac{\Delta V_{EB}}{\Delta I_E}\bigg|_{V_{CB}\ \text{constant}}$$

b) Output admittance:

→ Ratio of change in I_C to change in V_{CB} by keeping I_E as constant.

→ Ranges from 0.1 to 10 μmhos.

$$h_{ob} = \frac{\Delta I_C}{\Delta V_{CB}}\bigg|_{I_E\ \text{constant}}$$

c) Forward current gain:

→ Ratio of change in I_C to change in I_E by keeping V_{CB} as constant.

→ Ranges from 0.9 to 1.0

$$h_{fb} = \frac{\Delta I_C}{\Delta I_E}\bigg|_{V_{CB}\ \text{constant}}$$

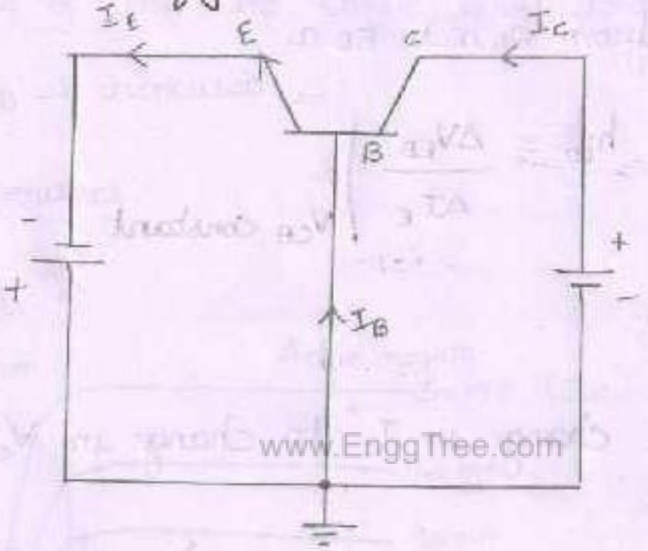
d) Reverse Voltage gain:

→ Ratio of change in V_{EB} to change in V_{CB} with Constant I_E.

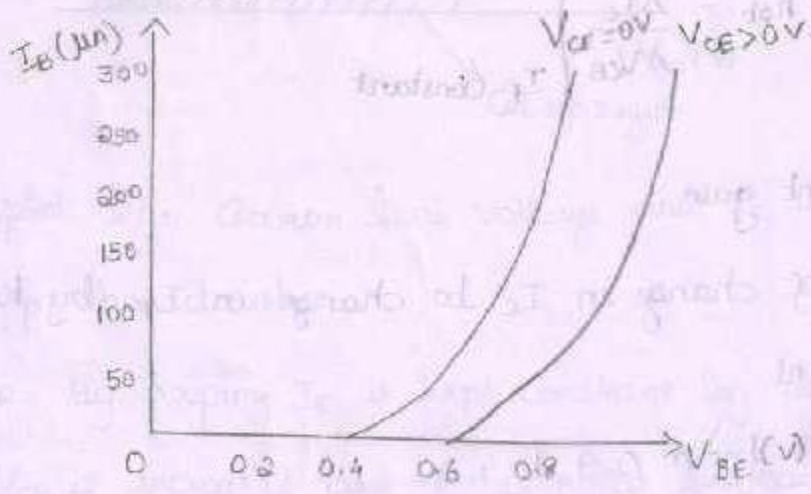
→ It is in the order of 10^{-5} to 10^{-4}

$$h_{rb} = \frac{\Delta V_{EB}}{\Delta V_{CB}} \Bigg|_{I_E \text{ Constant}}$$

ii) Common Emitter Configuration:



Input characteristics:



→ A plot b/w V_{BE} and I_B by keeping V_{CE} as Constant will result in Input characteristics.

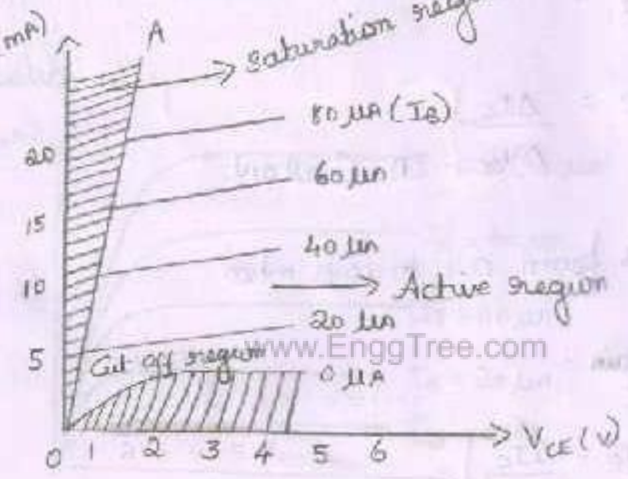
→ By keeping V_{CE} as Constant at Zero volt, I_B is increased from Zero by increasing V_{BE}

for each value of I_B ... is repeated for large fixed values of V_{CE}

→ If $V_{CE}=0$, the emitter base junction will be forward biased. If V_{CE} is increased, the width of the depletion region will increase and therefore the width of the base will decrease which results in decrease in I_B

→ when $V_{CE}=0$, in order to get same I_b, V_{BE} should be increased.

Output characteristics :-



→ A plot b/w V_{CE} and I_C with Constant I_B will give the output characteristics

→ By keeping I_B as Constant, by adjusting V_{BC}, V_{CE} is increased from zero and I_c is noted for each Value of V_{CE}.

→ It has three regions

Saturation region

Cut off region

active region

→ The part of the Curve left of OA is the Saturation region and the line OA is the Saturation line. Both junctions are forward biased

→ Region below the curve for $I_B=0$ is the Cut off region. Both junctions are reverse biased.

Spacing and Slope is called active region. In this Emitter base junction is forward biased and Collector base junction is reverse biased.

Transistor parameters :-

a) Input Impedance :-

$$h_{ie} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right| V_{CE} \text{ Constant}$$

-> ranges from 500 to 2000 Ω.

b) Output admittance.

$$h_{oe} = \left.\frac{\Delta I_C}{\Delta V_{CE}}\right| I_B \text{ Constant}$$

-> ranges from 0.1 to 10 μ mhos

c) forward Current gain :

$$h_{fe} = \left.\frac{\Delta I_C}{\Delta I_B}\right| V_{CE} \text{ Constant}$$

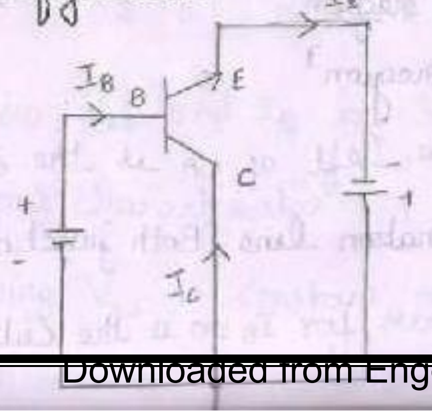
-> ranges from 20 to 200

d) Reverse voltage gain :

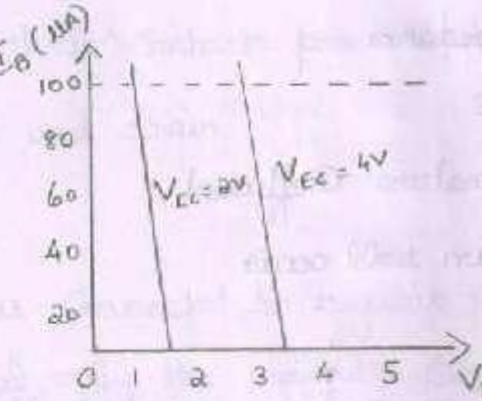
$$h_{re} = \left.\frac{\Delta V_{BE}}{\Delta V_{CE}}\right| I_B \text{ Constant}$$

-> In the order of 10^{-5} to 10^{-4}.

Common Collector Configuration :-

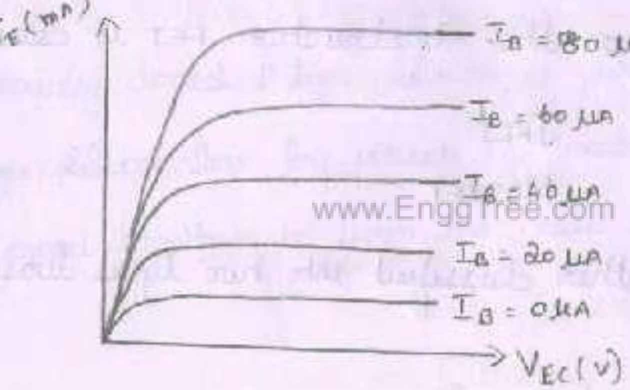


Input characteristics:



→ In this, by keeping V_{EC} as constant, V_{BC} is increased in equal steps and the corresponding increase in I_B is noted which is repeated for different values of V_{EC}.

Output characteristics:



→ By keeping I_B as constant, V_{EC} is increased in equal steps and the corresponding I_C is noted which gives the output characteristics.

Application:

→ Amplifier and Oscillator Circuits
→ Switch in digital Circuits
→ Computers
→ Satellites
→ Communication System

Disadvantage:-

-> has low input impedance.

-> High Switching loss

-> has negative temperature Coefficient.

-> Secondary breakdown will occur.

JFET:

-> Field Effect Transistor is a device in which the flow of the Current through the Conducting region is controlled by electric field.

-> In this type of device, the Conduction of Current is by majority Carriers only, and hence it is a unipolar device.

-> Depending upon the Construction, FET is classified into

JFET

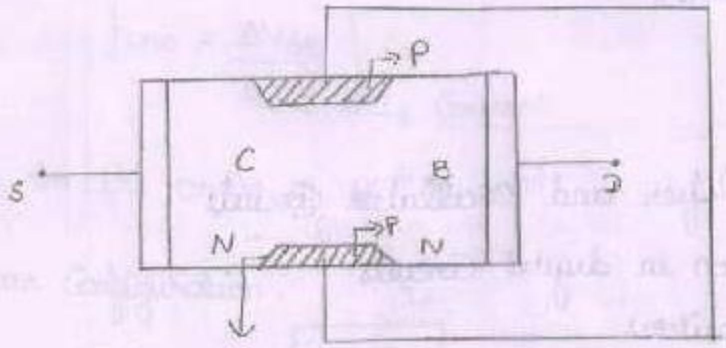
MOSFET

-> JFET is further classified into two types based on the majority Carriers.

N-Channel JFET - Majority Carriers -> electrons

P channel JFET - Majority Carriers -> holes

Construction:



->It Consist of three terminal

Gate

Drain

Source

Disadvantage:-

-> has low input impedance

-> High Switching loss

-> has negative temperature Coefficient

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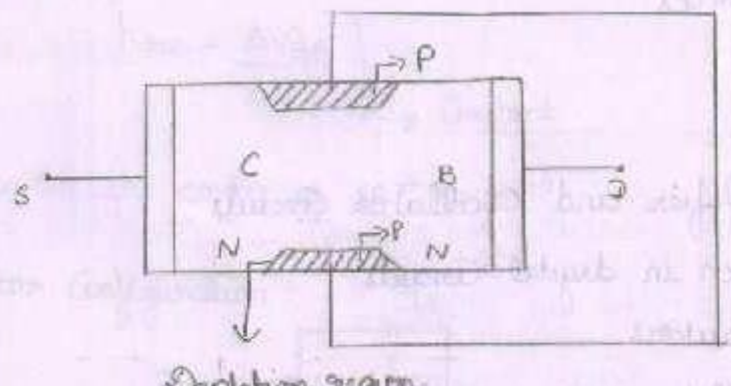
Construction:



-> It consist of three terminal

Gate

Drain

Source

→ N-channel JFET has N type bar which is made up of Silicon. The ohmic contacts present at two ends of the bar are called Source and drain.

Source :-

→ It is connected to negative pole of the battery. Through this terminal only the majority carriers (electrons) in the N-type bar enter the bar.

Drain :

→ It is connected to positive pole of the battery. The majority carriers will leave the bar through this terminal.

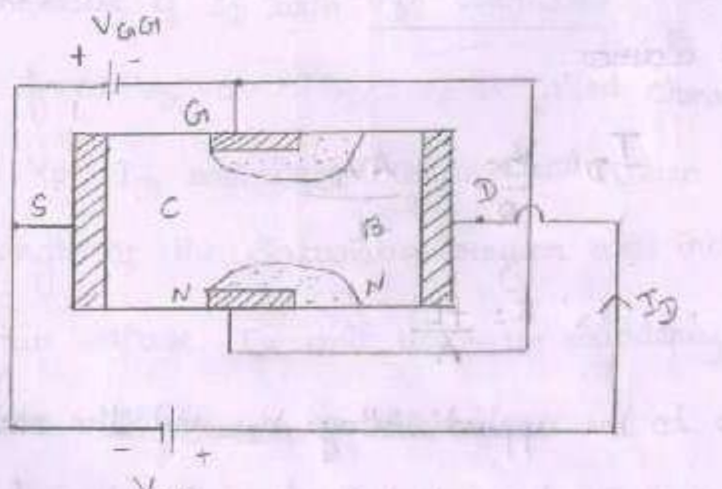
Gate :-

→ A heavily doped P type silicon is diffused on both sides of the N-type silicon bar by which PN junctions are formed. These layers are joined together to form the Gate terminal.

Channel :

→ The region BC in the N type bar between the depletion region is called the channel.

Operation :



i) $V_{GS} = 0$ and $V_{DS} = 0$:-

-> when no voltage is applied between drain and source and gate and source, the thickness of the depletion region around the PN junction will be uniform.

ii) $V_{DS} = 0$ and V_{GS} is decreased from zero :-

-> In this case, the thickness of the depletion region will be increased since the PN junction is reverse biased.

-> This is because, when V_{GS} is decreased from zero, the reverse bias voltage across the PN junction is increased and therefore the thickness of the depletion region in the channel also increases until the two depletion region make contact with each other and the channel in this condition is called cut off and the value of V_{gs} required to cut off the channel is called cut off voltage V_c.

iii) $V_{GS} = 0$ and V_{DS} is increased from zero :

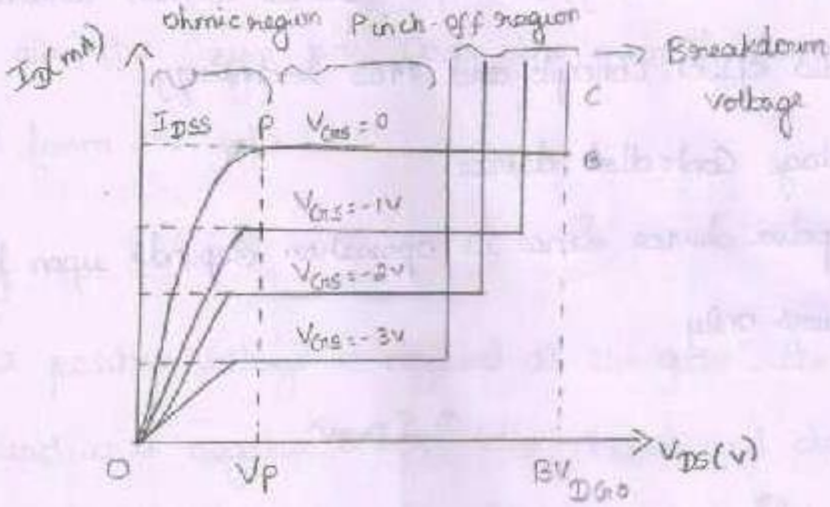
-> when $V_{GS} = 0$, drain is positive with respect to source. During this condition, electrons (majority carriers) will flow through N-channel from source to drain, and as a result I_D will flow from drain to source.

$$I_D = \frac{V_{DS}}{R} = \frac{AV_{DS}}{\rho L}$$

$$\therefore R = \frac{\rho L}{A}$$

-> Due to the applied voltage V_{DS} and the resistance of the channel, there is a positive potential along the channel therefore the reverse across the PN junction will increase and also the for the wedge shape of the channel.

Characteristics:



→ When V_{DS} is increased the cross sectional area of the channel will get reduced

→ At certain value of (V_P) of V_{DS}, the area at B becomes minimum. At this voltage the channel is said to be pinched off and the voltage V_P is called pinch off voltage

→ The above characteristics has three region

Ohmic region

Pinch off region

Breakdown voltage region.

→ When V_{DS} increased from zero, I_D will increase along OP and the rate of increase of I_D with V_{DS} decreased.

→ The region from $V_{DS}=0V$ to $V_{DS}=V_P$ is called Ohmic region.

→ When $V_{DS}=V_P$, I_D will be maximum and when V_{DS} increased beyond V_P, the length of the saturation region will increase

→ At certain voltage, I_D will decrease suddenly and this is due to the avalanche multiplication of electrons.

→ The drain voltage at which the breakdown occurs is denoted by BV_{DGO}

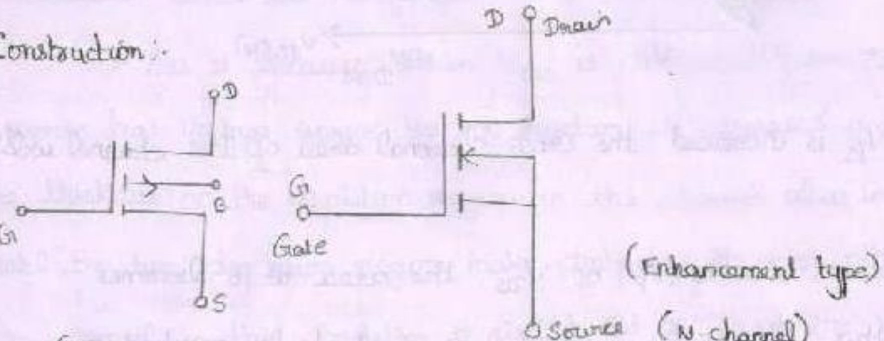
MOSFET :-

→ It is a recently developed device which combines the areas of field effect concept and MOS technology.

→ Voltage controlled device.

→ Unipolar device since its operation depends upon flow of majority carriers only

Construction :-



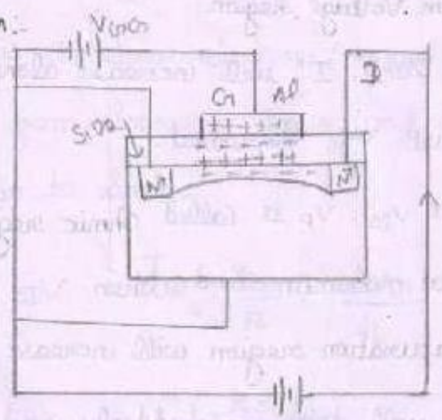
(P channel)

→ There are two basic forms

Enhancement MOSFET

Depletion MOSFET

Construction :-



→ Two highly doped N^+ regions are diffused in a lightly doped substrate of P type silicon substrate.

→ One N^+ region is source and other is drain & which is separated by 10^{-3} cm

→ A thin insulating layer of SiO_2 is grown over the Surface and over this SiO_2 layer, a thin layer is aluminium is formed. and also this layer will Cover the overall channel region and it will from the gate G.

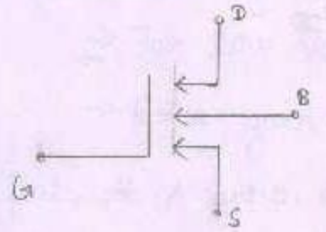
Operation:

→ If a positive Voltage is applied at the gate, the positive charge will induce a negative charge b/w Source and drain and as a result an electric field is produced b/w Source and drain.

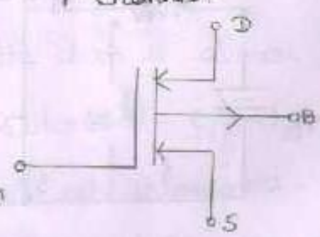
→ When the +ve Voltage on gate increases, the induced negative charge in the Semiconductor will increase and hence the Conductivity increases and Current will flow from Source to drain.

Depletion MOSFET

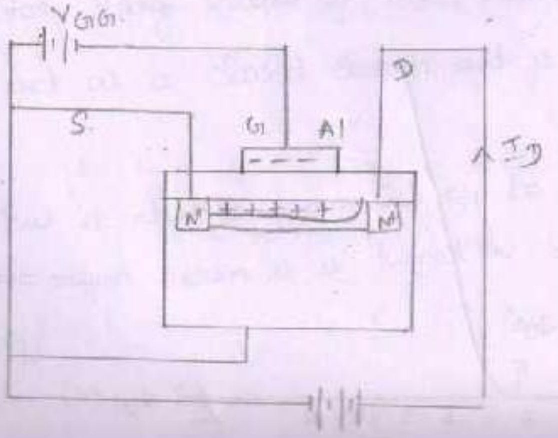
N-channel:



P channel:



Construction:



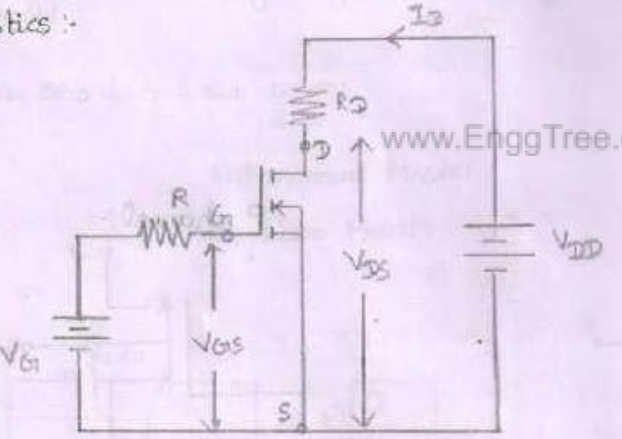
→ N-channel is diffused between the Source and drain and the remaining Construction is Similar to the enhancement MOSFET.

Operation :

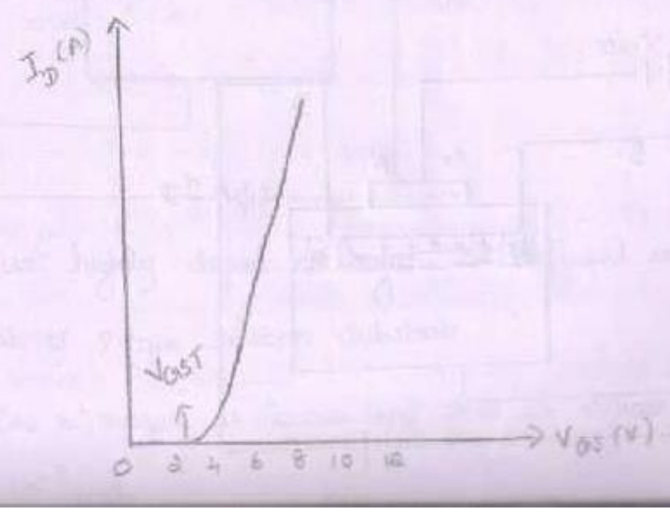
→ when D is at positive potential with respect to Source, the electrons will flow from S to D through N channel. and as a result I_D will flow through D to S.

→ If the gate voltage is made negative, the positive charge will induced which will cause the depletion of mobile electrons and hence a depletion region is produced and its shape will depend upon V_{GS} and V_{DS}.

Characteristics :-



Transfer characteristics

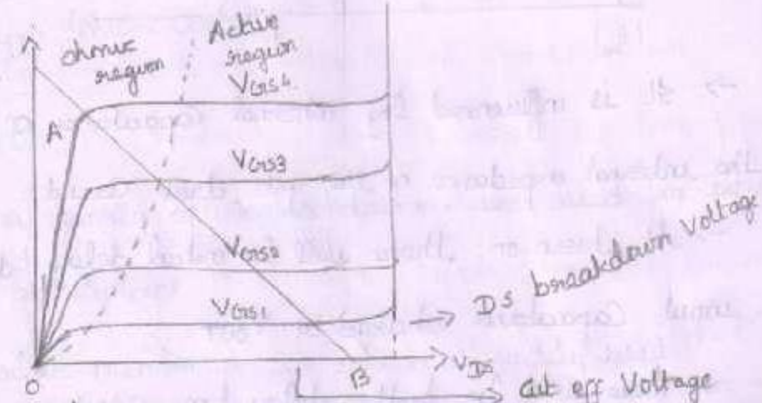


→ It shows the Variation of drain Current as a function of gate Source Voltage.

→ V_{GST} is the minimum positive Voltage between gate and Source to induce N-channel. It is in the order of 2 to 3 V.

→ For a threshold Voltage below V_{GST}, device will be in OFF State

Output characteristics:



→ The Variation of I_D as a function of V_{DS}, with V_{GS} as a parameter will give the output Characteristics.

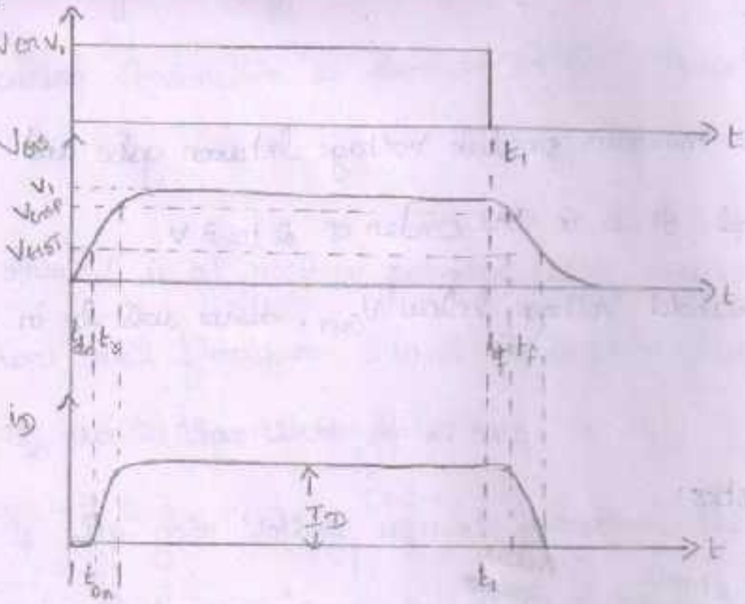
→ For low Values of V_{DS}, the char is almost linear.

→ For a given V_{GS}, if V_{DS} is increased, O/p characteristics is flat. At A and B, a load line will get intersected. A indicates a fully on Condition and B indicates a fully off state.

→ For large Values of V_{GS}, MOSFET will turned ON and it will act as a closed Switch and it will reach ohmic region.

→ Thus it changes from Cut off to active region and then to ohmic region when it is turned on and Vice Versa when it is turned off.

Switching characteristics:



-> It is influenced by internal capacitance of the device and the internal impedance of the gate drive circuit.

-> At turn-on, there will be initial delay t_{dn} during which input capacitance charges to V_{GST}.

-> There will be further delay time called rise time during which gate voltage rises to V_{GSP} used to turn on the MOSFET.

-> The total turn on time is given by,

$$t_{on} = t_{dn} + t_r$$

-> As soon as the removal of gate voltage at time t_1, turn-off process will be initiated.

-> t_{df} is the time during which input capacitance discharges from V_1 to V_{GSP}.

-> t_f is the time during which input capacitance discharge from V_{GSP} to threshold voltage.

-> when $V_{GS} \leq V_{GST}$, MOSFET will be turned off.

Advantage:

- -> High input impedance
- -> Lower switching losses
- -> Has positive temperature coefficient.
- -> Absence of secondary breakdown.

Application:

- -> Induction heating
- -> Robotics
- -> Stepper motor control.

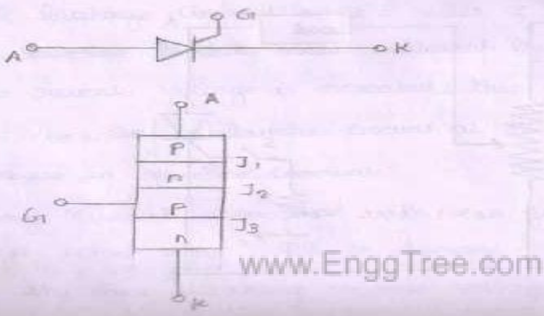
Thyristor:-

-> Denotes a family of semiconductor devices used for power control in dc and ac systems.

-> The earliest member is SCR which is widely used.

-> It is derived from the combination of THYRatron and transISTOR because it is a solid state device like transistor and has characteristics similar to thyratron tube.

Construction:-



→ It is a four layer three junction p-n-p-n Semiconductor Switching device

→ It has three terminals

Anode
Cathode
Gate

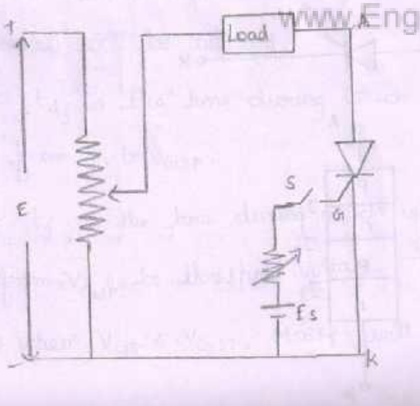
→ Normally, it consist of four layers of alternate P type and n type silicon semiconductors forming three junction J_1, J_2, J_3.

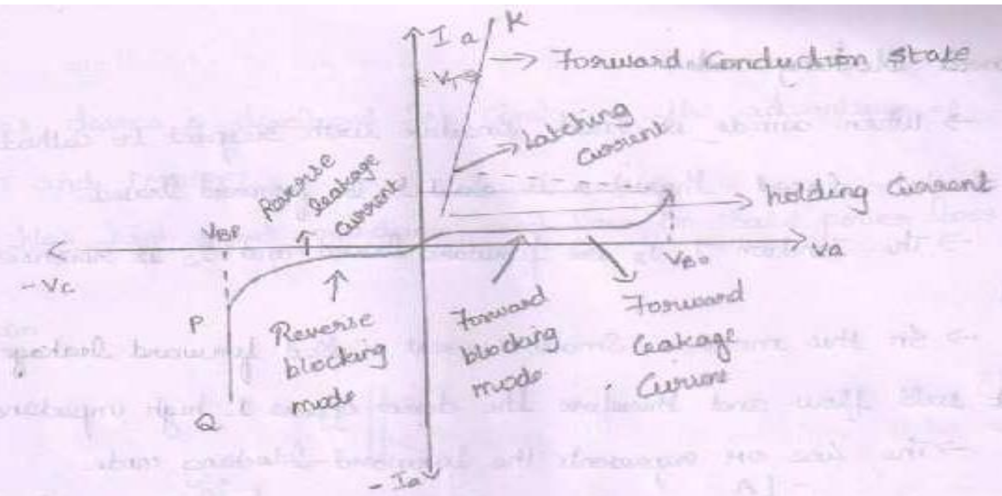
→ For tightening the thyristor to the heat sink with a help of a nut, a threaded portion is needed.

→ The terminal connected to outer P region is called anode and terminal connected to outer n region is called Cathode and that connected to inner P region is called Gate.

→ When the thyristor is used for large current rating, thyristor need better cooling and it can be achieved by mounting them on heat sinks.

Characteristics :-





→ It has three basic modes of operation

Reverse blocking mode

Forward blocking mode

Forward Conduction mode

Reverse blocking mode:

→ When Cathode is made positive with respect to anode with Switch S open, the thyristor is reverse biased

→ Junctions J_1, J_3 are reverse biased and J_2 is forward biased

→ A Small leakage Current of the order of few mA will flow. This is the reverse blocking mode indicated by OP.

→ If the reverse voltage is increased, then at reverse breakdown voltage V_{BR}, an avalanche occurs at J_1 and J_3 and there is rapid increase in reverse Current.

→ A large Current associated with V_{BR} give rise to more losses in SCR which may result in damage to the thyristor. Therefore the max working reverse voltage should does not

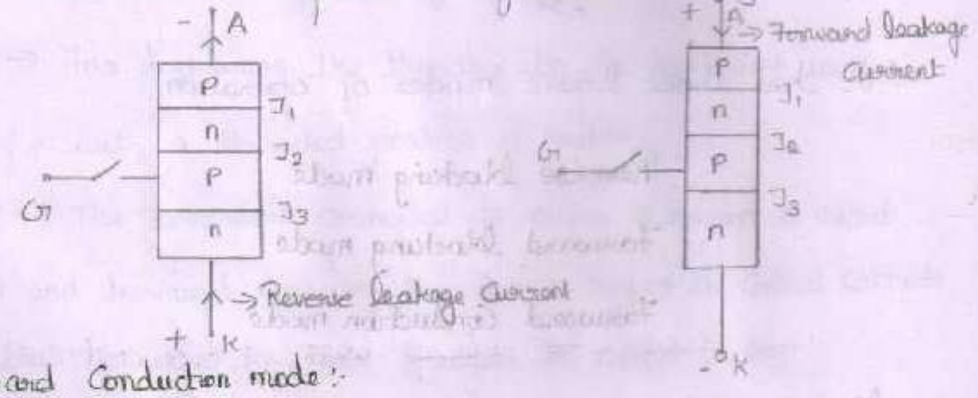
Forward blocking mode:

-> When anode is made positive with respect to cathode, with switch closed, thyristor is said to be forward biased.

-> The junction J_1, J_3 are forward biased and J_2 is reverse biased

-> In this mode a small current called forward leakage current will flow and therefore the device offers a high impedance.

-> The line OM represents the forward blocking mode.



Forward Conduction mode:

-> When anode to cathode forward voltage is increased with gate circuit open, reverse biased junction J_2 will have an avalanche breakdown at a voltage called forward breakover voltage (V_{BO})

-> After this breakdown, the device will get turned on with point M at once shifting to N and then to a point anywhere between N and K.

-> The region NK represents the forward conduction mode.

-> A thyristor can be brought from forward blocking mode to forward conduction mode by turning it on by applying

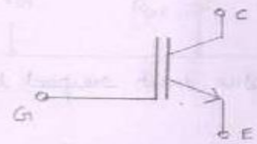
i) positive gate pulse between gate and cathode

ii) a forward breakover voltage across anode & cathode.

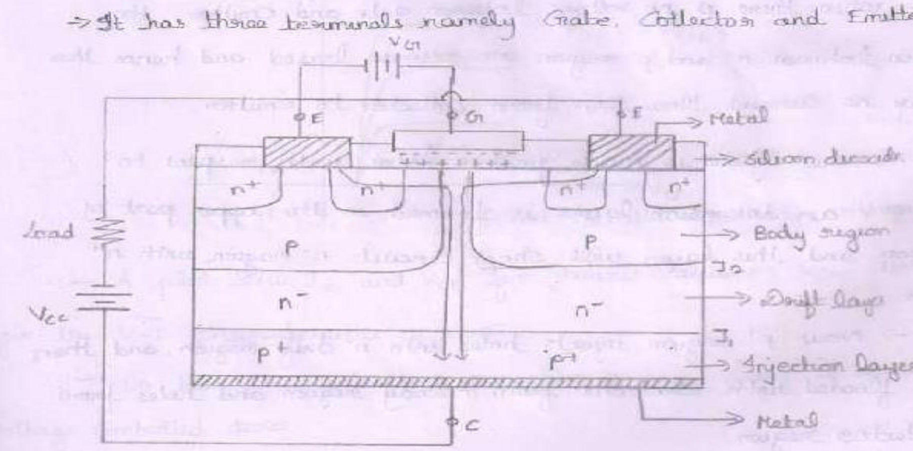
→ This device is developed by combining the advantage of both BJT and PMOSFET.

→ Has high input impedance and low on-state power loss.

Construction:-



→ It has three terminals namely Gate, Collector and Emitter.



→ On p substrate, two heavily doped n^+ regions are diffused.

→ An insulating layer of SiO_2 is grown on the surface.

→ Now the insulating layer is etched in order to embed metallic source and drain terminals.

→ n^+ regions make contact with Gate and Collector terminals.

→ p^+ substrate is called injection layer since it injects holes into n^- layer. The n^- layer is called drift region.

→ The thickness of the n^- layer determines the voltage blocking capability of IGBT

→ The P layer is called body of IGBT. The n^- layer in b/w P^+ and P regions serves to accomodate the depletion layer of Pn^- junction.

Working :-

→ when collector is made positive with respect to emitter, the device gets forward biased.

→ when there is no voltage between gate and emitter, the junction between n^- and p region are reverse biased and hence there will be no current flow b/w from collector to emitter.

→ when gate is made positive betw with respect to emitter, an inversion layer is formed in the upper part of P region and this layer will short circuit n^- region with n^+ region

→ Now p^+ region injects holes into n^- drift region and then it is flooded with electrons from P body region and holes from P^+ collector region

→ Due to the above operation, conductivity of n^- region will get increased and therefore IGBT gets turned ON and begins to conduct I_c.

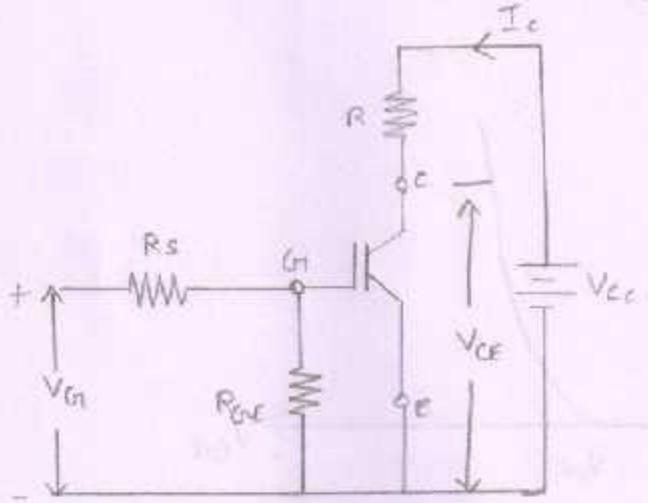
$$I_c = I_E$$

$$I_E = I_h + I_e$$

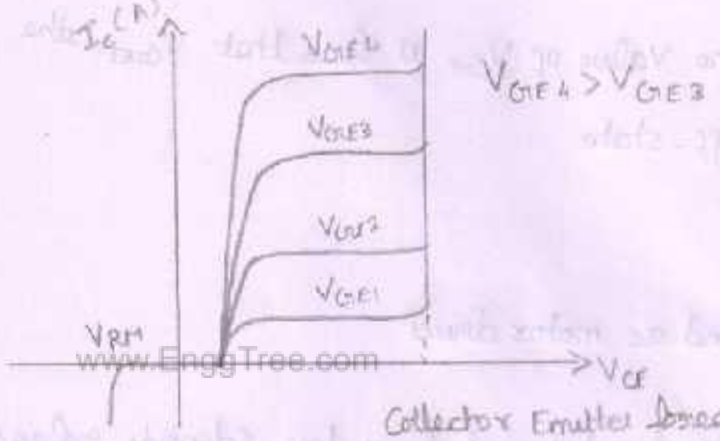
I_h → hole current

I_e → electron current

Characteristics:



V-I characteristics:



→ A plot b/w I_c and V_{CE} for various values of V_{GE} will give the V-I characteristics of IGBT.

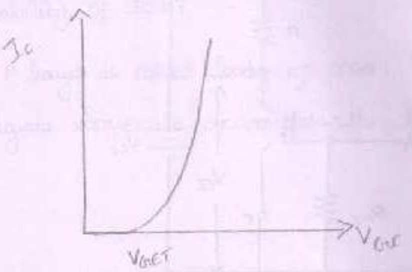
→ In this the controlling parameter is V_{GE} since it is a voltage controlled device.

→ The characteristics is similar to BJT in the forward direction.

→ When the device is OFF, J_2 blocks forward voltage and if reverse voltage appears across collector and emitter, J_1 block it.

→ V_{RM} is the maximum reverse breakdown voltage.

Transfer characteristics:



→ A plot b/w I_c and V_{GE} gives the transfer characteristics

→ when the value of V_{GE} is less that V_{GET}. the device will be in off-state

Application:

→ Dc and ac motor drives

→ UPS

→ power supplies and drives for solenoids, relays

Amplifier :

⇒ It is a Circuit which increases the amplitude of the given input Signal without changing the frequency.

⇒ It is used in radio, television & Communication Circuits.

⇒ The amplifying elements are BJT and FET

Classification :

a) Based on transistor Configuration

CE amplifier
Cc amplifier
CB amplifier

b) Based on active device

BJT amplifier
FET amplifier

c) Based on operating condition

Class A
Class B
Class AB
Class c

d) Based on number of stages

Single stage
Multi stage

e) Based on output

Voltage amplifier
power amplifier

f) Based on frequency response

Audio frequency

Intermediate frequency

Radio frequency

g) Based on Bandwidth

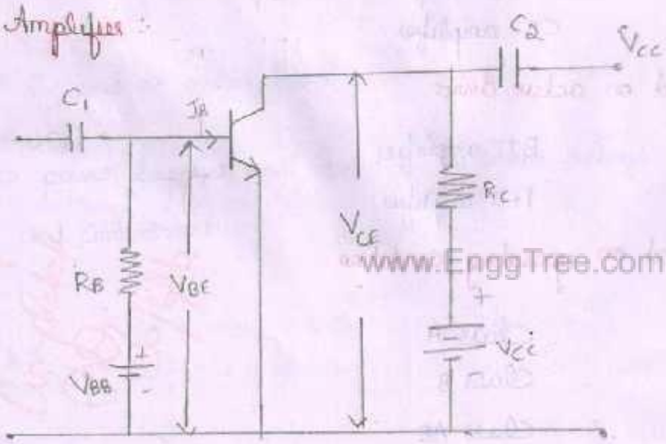
Narrow Band

Wide Band.

Single stage Amplifier:

-> It has only one amplifying device.

BJT - CE Amplifier:



-> The EB junction is forward biased by V_{BB} and CB junction is reverse biased by V_{CC} and hence the transistor remains in active region throughout the operation.

-> C_1, C_2 are the coupling capacitor to provide d c isolation at the input and output of the amplifier

→ I/p signal is given to BE circuit and the amplified output signal is taken from CE circuit.

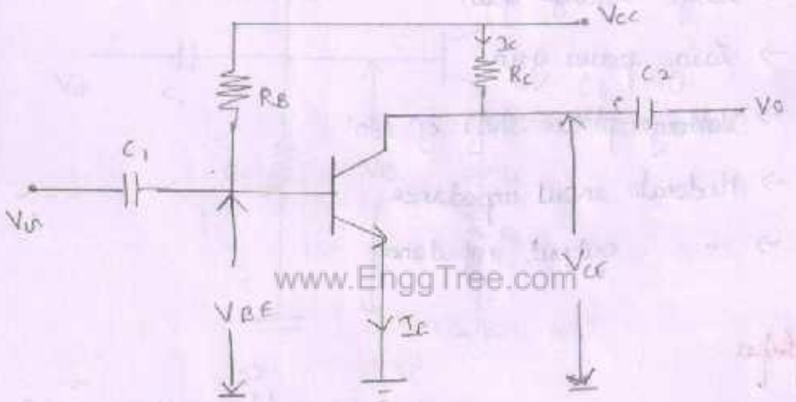
under d.c condition

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

$$I_c = \beta I_B$$

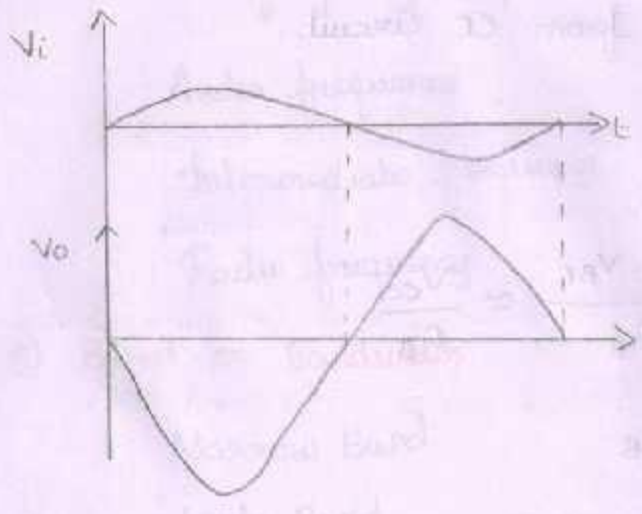
$$V_{CE} = V_{CC} - I_c R_C$$

CE Amplifier with a single power supply



→ when a.c is applied, during positive half cycle, the forward bias of the base emitter junction V_{BE} is increased and hence I_B will increase.

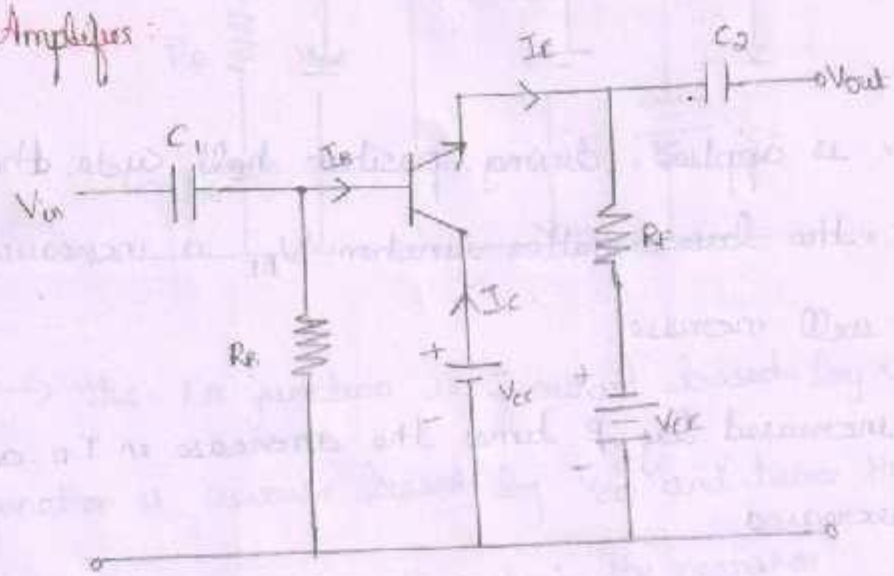
→ I_c is increased by β times the increase in I_B and V_{CE} will get decreased.



Characteristics:

- → Large Current gain
- → Large Voltage gain
- → Large power gain
- → Voltage phase shift of 180°
- → Moderate input impedance
- → " output impedance

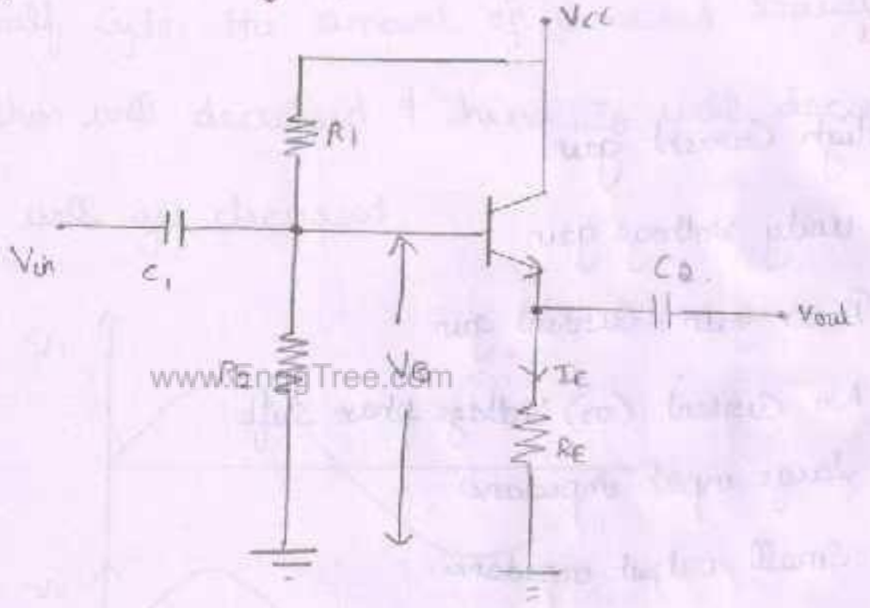
CC Amplifier:



→ The EB junction is forward biased by power supply V_{EE} and CB is reverse biased by V_{CC} therefore the transistor remains in the active region throughout the operation.

→ I/p signal is given to base-collector circuit and output signal is taken from emitter collector circuit.

CC Amplifier with single power supply



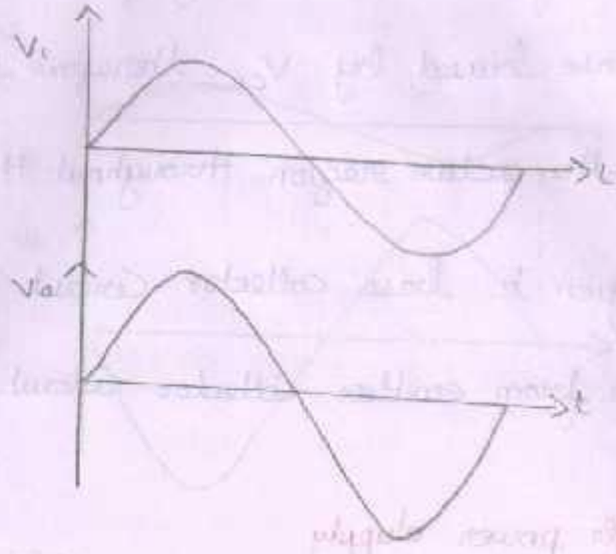
$V_o = I_E R_E$

$V_o = \beta I_B R_E$

→ When a.c signal is applied, during positive half cycle, V_B increases and hence I_B will increase.

$$I_E = I_C + I_B$$

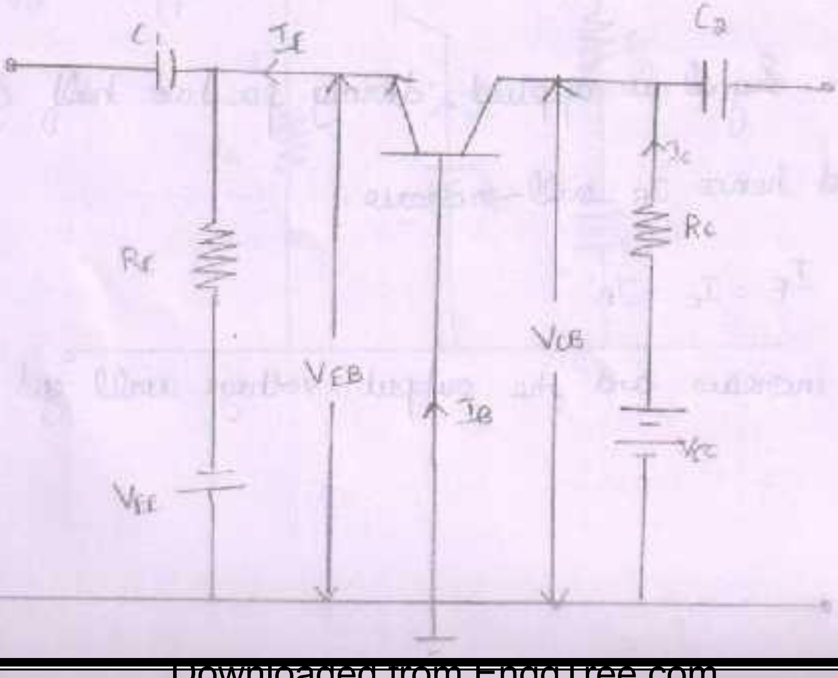
→ I_E will increase and the output voltage will get increase.



Characteristics :-

- → High Current gain
- → unity Voltage gain
- → Power gain = Current gain
- → No Current (or) Voltage phase shift
- → Large input impedance
- → Small output impedance.

CB Amplifier :-

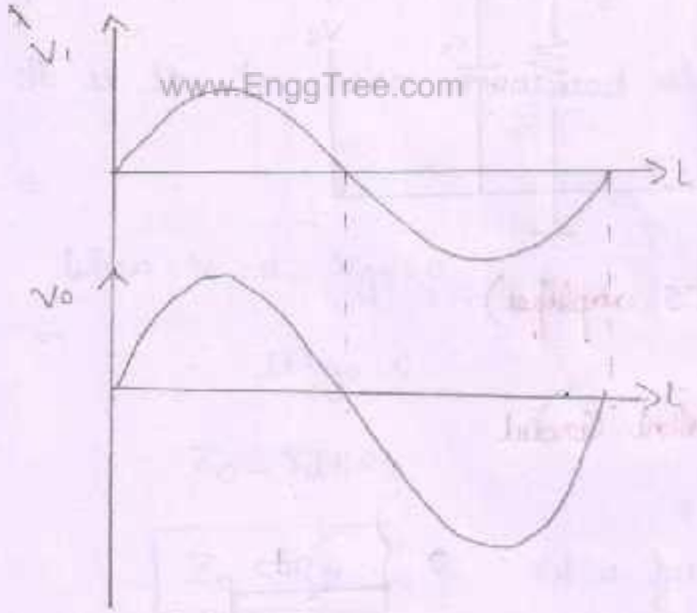


→ The EB junction is forward biased by V_{EE} and CB junction is reverse biased by V_{CC} and hence transistor remains in the active region throughout the operation

→ I/p signal is given to emitter base circuit and O/p signal is taken from collector base circuit

$$V_0 = V_{CC} - I_C R_C$$

→ When a.c signal is applied at the input, during positive half cycle, the amount of forward biased base to BE junction will decreased & hence I_B will decrease and also I_C will get decreased.



Characteristics

→ Current gain less than unity

→ High Voltage gain

→ Power gain = Voltage gain

→ No phase shift for current (or) Voltage

→ Small input and large output impedance

FET Amplifiers :-

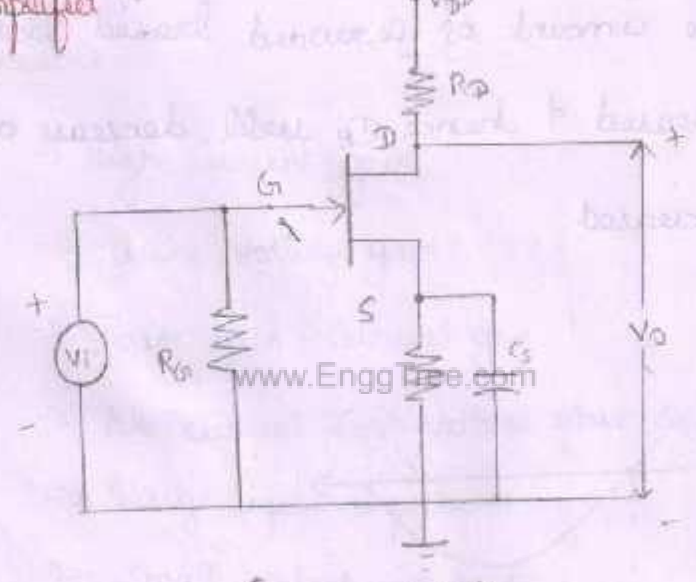
→ The small signal model of FET is used for analysing the FET amplifiers configuration.

Common Source

Common drain (or) Source follower

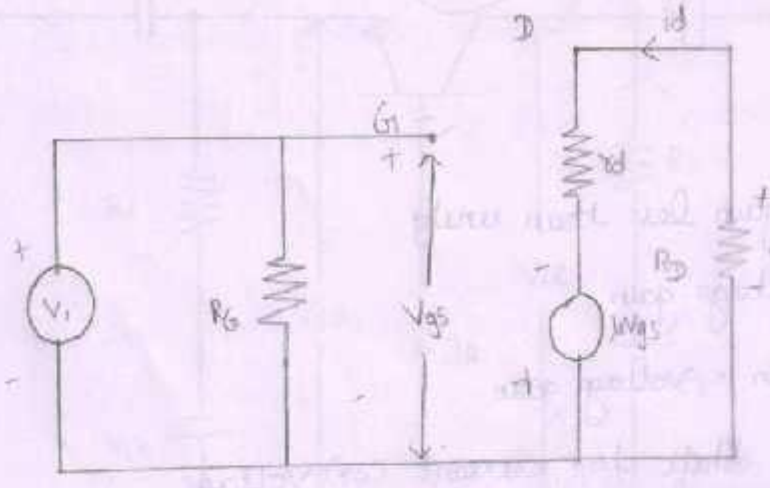
Common gate

CS Amplifier :-



(CS amplifier)

Small Signal Equivalent Circuit :-



Voltage gain:

$$V_0 = \frac{-R_D}{R_D + r_d} \mu V_{gs}$$

$V_{gs} = V_i$ (input voltage)

$$\text{Voltage gain. } A_V = \frac{V_o}{V_i} = \frac{-\mu R_D}{R_D + r_d}$$

Input Impedance

$$Z_i = R_G$$

$$R_G = R_1 \parallel R_2$$

Output Impedance

→ It is the impedance measured at the output terminal with $V_i = 0$.

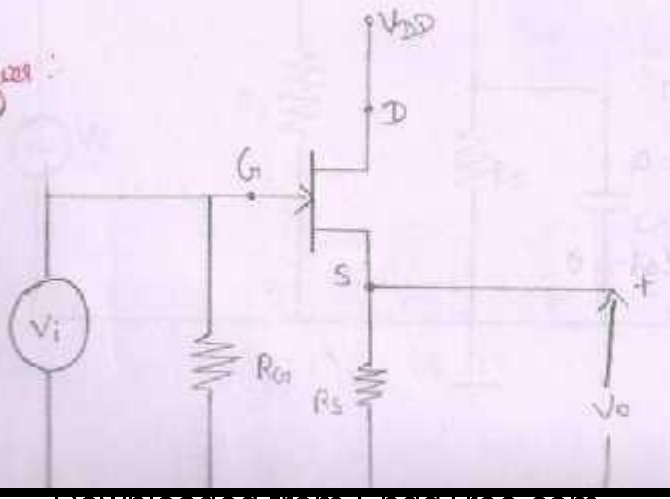
When $V_i = 0$, $V_{gs} = 0$

$\therefore \mu V_{gs} = 0$

$$Z_0 = r_d \parallel R_D$$

$$\boxed{Z_0 \simeq R_D} \quad \because r_d \text{ is far greater than } R_D$$

CD Amplifier:



Output Impedance. $Z_0 = \frac{r_d}{\mu+1} \parallel R_S$.

If $\mu >> 1$,

$$Z_0 \simeq \frac{r_d}{\mu} \parallel R_S$$

$$= \frac{1}{g_m} \parallel R_S$$

Frequency Response

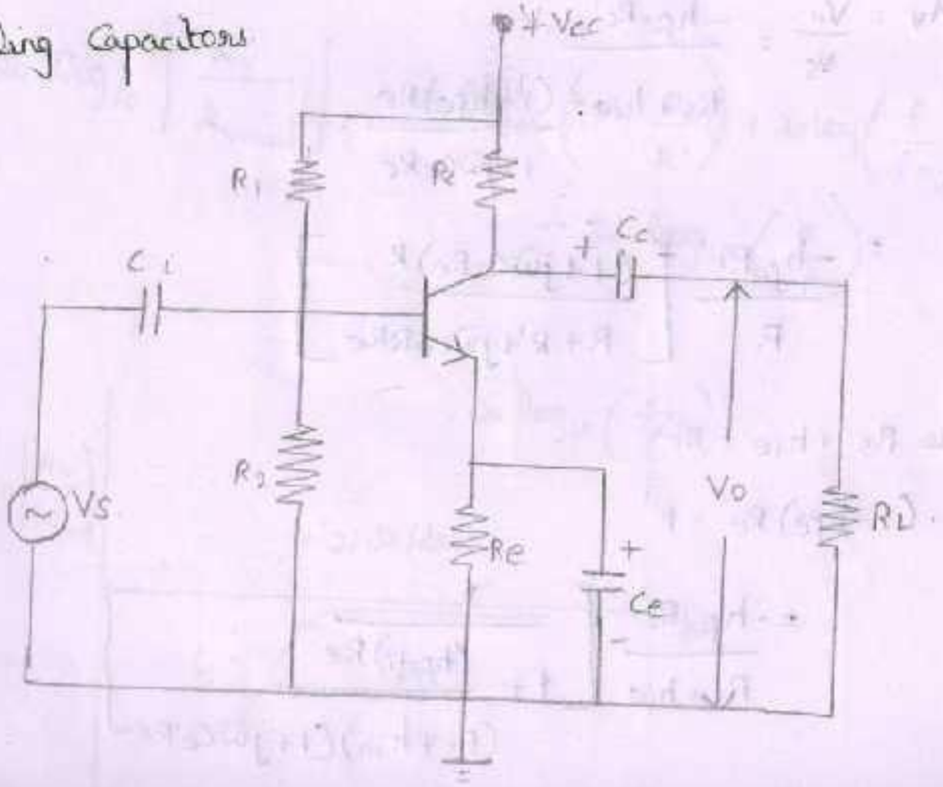
→ Defined as the measure of output parameter variation with respect to variation of input frequency.

→ The ratio of amplitude of the output sinusoidal to the amplitude of input sinusoidal is defined as amplifier gain.

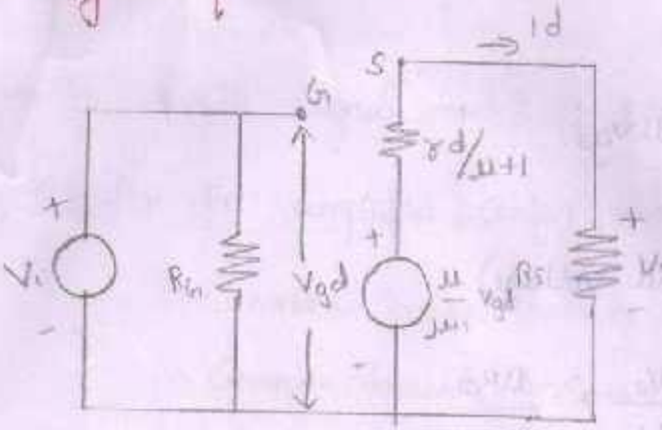
Low Frequency response of BJT Amplifiers.

→ It is determined by the emitter bypass capacitor and the coupling capacitors

→



Small signal equivalent circuit



Output Voltage $V_o = \frac{R_S}{R_S + \frac{r_d}{\mu+1}} \times \frac{\mu}{\mu+1} V_{gd}$

$$V_o = \frac{\mu R_S V_{gd}}{(\mu+1) R_S + r_d}$$

$V_{gd} = V_i$

Voltage gain

$$A_v = \frac{V_o}{V_i} = \frac{\mu R_S}{(\mu+1) R_S + r_d}$$

Input Impedance

$$Z_i = R_G$$

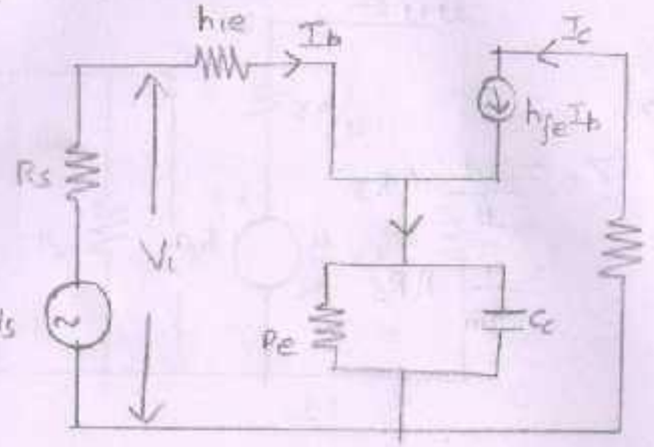
Output Impedance

→ $V_i = 0$

$V_{gd} = 0$

$\frac{\mu}{\mu+1} V_{gd} = 0$

Small signal hybrid equivalent circuit



$$V_o = -h_{fe} i_b R_c'$$

$$I_b = \frac{V_s}{R_s + R_i}$$

$$Z_e = \frac{R_e}{1 + j\omega C_e R_e}$$

$$V_o = \frac{-h_{fe} R_c' V_s}{R_s + h_{ie} + (1+h_{fe}) Z_e} = \frac{-h_{fe} R_c' V_s}{R_s + h_{ie} + \frac{(1+h_{fe}) R_e}{1 + j\omega C_e R_e}}$$

$$A_v = \frac{V_o}{V_s} = \frac{-h_{fe} R_c'}{R_s + h_{ie} + \frac{(1+h_{fe}) R_e}{1 + j\omega C_e R_e}}$$

$$= \frac{-h_{fe} R_c'}{R} \left[\frac{(1 + j\omega C_e R_e) R}{R + R' + j\omega C_e R R_e} \right]$$

where $R_s + h_{ie} = R$

$(1+h_{fe}) R_e = R'$

$$= \frac{-h_{fe} R_c'}{R_s + h_{ie}} \left[\frac{1}{1 + \frac{(h_{fe}+1) R_e}{(R_s + h_{ie})(1 + j\omega C_e R_e)}} \right]$$

$$A_v = \frac{-h_{fe} R_c}{R_s + h_{ie}} \left[\frac{1 + j\omega C_e R_e}{1 + j\omega C_e R_e + \frac{(1+h_{fe}) R_e}{R_s + h_{ie}}} \right]$$

$$A_v = \frac{-h_{fe} R_c}{R\left(1 + \frac{R'}{R}\right)} \left[\frac{1 + j\omega C_e R_e}{1 + \frac{j\omega C_e R_e R}{R + R'}} \right]$$

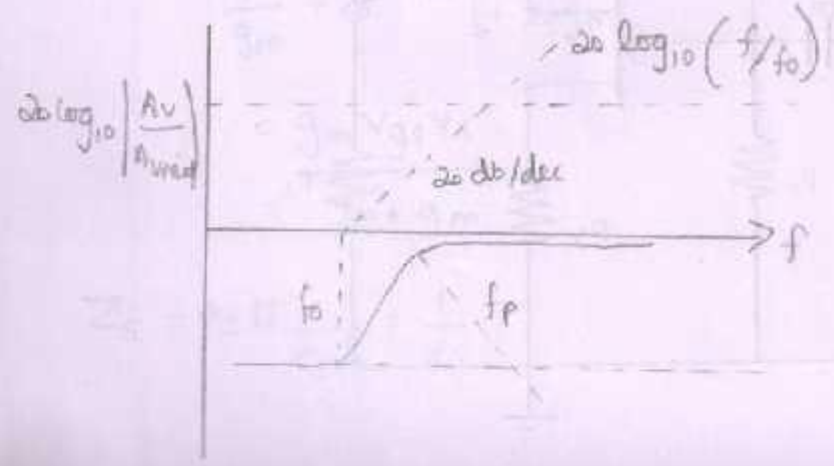
$$A_{vmid} = -\frac{h_{fe} R_c}{R}$$

$$A_v = \left[\frac{A_{vmid}}{1 + R'/R} \right] \left[\frac{1 + j(f/f_o)}{1 + j(f/f_p)} \right]$$

where $f_o = \frac{1}{2\pi C_e R_e}$, $f_p = \left(\frac{R+R'}{2\pi C_e R_e R}\right) \frac{1 + \left(\frac{R'}{R}\right)}{2\pi C_e R_e}$

Gain in db,

$$20 \log_{10} \left| \frac{A_v}{A_{vmid}} \right| = 20 \log_{10} \left(1 + \frac{R}{R'} \right) + 20 \log \left(\frac{f}{f_o} \right) - 20 \log_{10} \left(\frac{f}{f_p} \right)$$



$\frac{R'}{R} >> 1$ & $f_P >> f_0$ at $f = f_P$

$$\left| \frac{A_v}{A_{vmid}} \right| = \frac{1}{1 + \left(\frac{R'}{R^*}\right)} \frac{f_P/f_0}{\sqrt{1+1}} = \frac{1}{\sqrt{2}}\left(\frac{f}{f_P}\right)$$

$$f_1 = f_P \approx \frac{(1+h_{fe})}{(R_S + h_{ie})2\pi C_e}$$

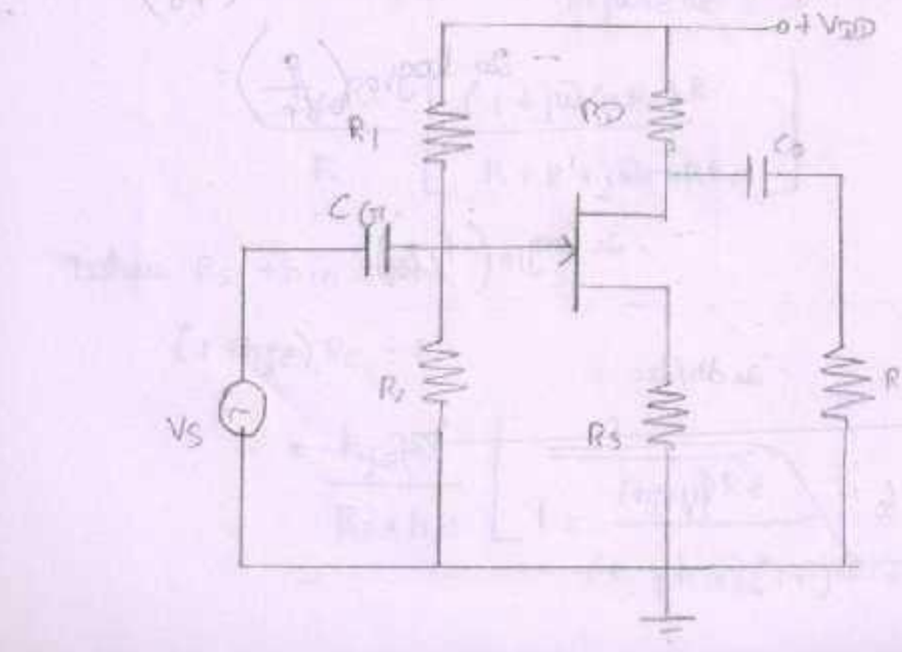
Effect of Coupling Capacitor:

$$\frac{1}{\omega C_{in}} = R_i + R_S$$

$$\omega = \frac{1}{C_{in}(R_S + R_i)}$$

$$f_1 = \frac{1}{2\pi C_{in}(R_S + R_i)}$$

Low Frequency response of JFET amplifier:



$$V_{gs} = \frac{V_s R_G}{R_G + R + \frac{1}{sC_G}}$$

$$= \frac{V_s R_G . s}{(R_G+R)\, s + \frac{1}{C_G}}$$

$$V_{gs} = \frac{V_s R_G}{R_G+R}\left[\frac{s}{s+\frac{1}{C_G(R_G+R)}}\right]$$

$$\frac{V_{gs}}{V_s} = \frac{R_G}{R_G+R} \times \left[\frac{s}{s+\frac{1}{C_G(R_G+R)}}\right]$$

$$= \frac{R_G}{R_G+R}\left[\frac{s}{s+1/\tau}\right]$$

$$\boxed{\omega_{P1} = \frac{1}{C_G(R_G+R)} = 1/\tau}$$

Effect of bypass Capacitor:

$$I_d = \frac{V_{gs}}{\frac{1}{g_m} + Z_s} = \frac{g_m V_{gs}}{1 + Z_s g_m}$$

$$= \frac{g_m V_{gs} Y_s}{Y_s + g_m}$$

$$Z_s = R_s \,||\, \frac{1}{C_s s} = \frac{1}{Y_s}$$

$$I_d = \frac{g_m\left(\frac{1}{R_S} + sC_S\right)V_{gs}}{\frac{1}{R_S} + sC_S + g_m}$$

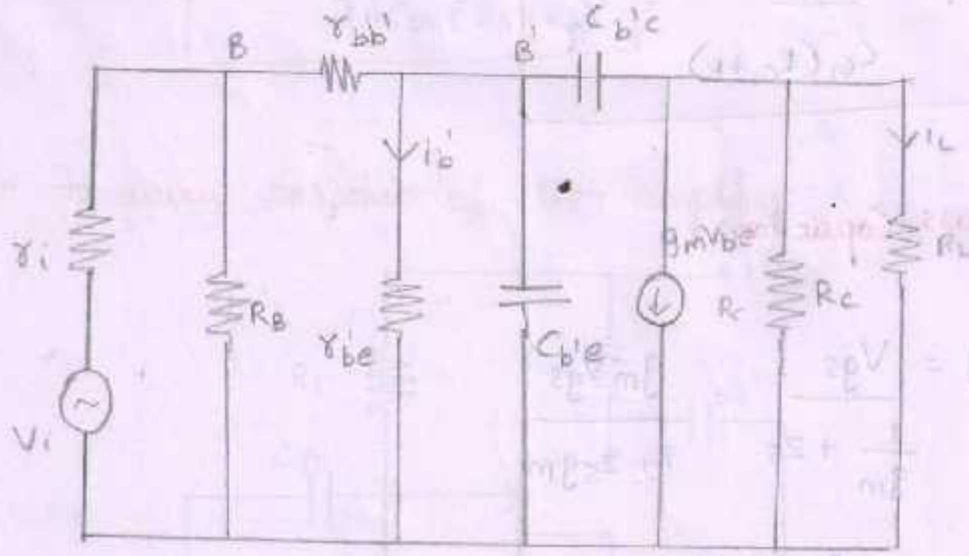
$$I_d = \frac{g_m V_{gs}\left(s + \frac{1}{R_S C_S}\right)}{s + \left(\frac{1}{R_S} + g_m\right)\frac{1}{C_S}}$$

$$\omega_{P2} = \frac{1}{C_S}\left(\frac{1}{R_S} + g_m\right)$$

$$\omega_2 = \frac{1}{R_S C_S}$$

High frequency analysis

i) BJT amplifier:



Let $r_{b'e} = h_{ie}$

$g_m V_{b'e} = h_{fe} I_b$

$$g_m = \frac{h_{fe}}{h_{ie}}$$

$R_{b'e} = r_{b'e} \parallel (R_b + r_{b'b})$

$R_0 = R_c \parallel R_L$

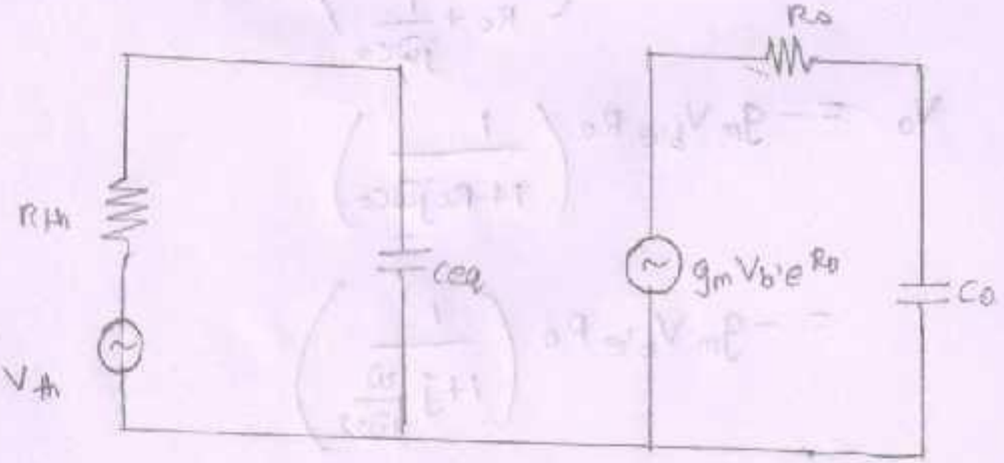
$C_{eq} = C_{b'e} + C_{b'c}(1 + A_v)$

$C_{eq} = C_{b'e} + C_{b'c}(1 + g_m R_L)$

$$C_0 = \frac{C_{b'c}(1+A)}{A}$$

$$= \frac{C_{b'c}(1+g_m R_L)}{g_m R_L}$$

$$C_0 = C_{b'c}\left(1 + \frac{1}{g_m R_L}\right)$$



$$V_{th} = \frac{R_{b'e} V_s}{r_i + R_{b'e}}$$

$$V_{b'e} = \left(\frac{\frac{1}{j\omega C_{eq}}}{R_{th} + \frac{1}{j\omega C_{eq}}} \right) \left(\frac{R_{b'e} \cdot V_s}{r_i + R_{b'e}} \right)$$

$$V_{b'e} = \left(\frac{1}{R_{th} j\omega C_{eq} + 1} \right) \left(\frac{R_{b'e}}{r_i + R_{b'e}} \right) V_s$$

$$= \frac{1}{1 + j\left(\frac{\omega}{\omega_{21}}\right)} \left(\frac{R_{b'e}}{r_i + R_{b'e}} \right) V_s$$

$$W_{21} = \frac{1}{R_{th} C_{eq}}$$

By Considering o/p Circuit,

$$V_o = -g_m V_{b'e} R_o \left(\frac{\frac{1}{j\omega C_o}}{R_o + \frac{1}{j\omega C_o}} \right)$$

$$V_o = -g_m V_{b'e} R_o \left(\frac{1}{1 + R_o j\omega C_o} \right)$$

$$= -g_m V_{b'e} R_o \left(\frac{1}{1 + j\frac{\omega}{\omega_{22}}} \right)$$

$$W_{22} = \frac{1}{R_o C_o}$$

$$A_v = \frac{V_o}{V_s} = \frac{V_{b'e}}{V_s} \cdot \frac{V_o}{V_{b'e}}$$

$$A_v = -\frac{1}{1+j\frac{\omega}{\omega_{21}}} \left(\frac{R_{b'e}}{r_i + R_{b'e}}\right) g_m \cdot R_o \left(\frac{1}{1+j\left(\frac{\omega}{\omega_{22}}\right)}\right)$$

$$A_v = A_{V01} \, V_{V02} \left(\frac{1}{1+j\frac{\omega}{\omega_{21}}}\right) \left(\frac{1}{1+j\left(\frac{\omega}{\omega_{22}}\right)}\right)$$

$$A_v = A_{Vo} \left(\frac{1}{1+j\frac{\omega}{\omega_{21}}}\right) \left(\frac{1}{1+j\left(\frac{\omega}{\omega_{22}}\right)}\right)$$

Unit IV Completed

$$A_{V_1} = \frac{V_2}{V_1} = A_1 \angle \theta_1$$

$A_1 \rightarrow$ Voltage gain of first stage

$\theta_1 \rightarrow$ phase angle between output and input Voltage of this stage.

Illy, $A_V = \frac{V_0}{V_1} = \frac{V_2}{V_1} \cdot \frac{V_3}{V_2} \cdots \frac{V_n}{V_{n-1}} \cdot \frac{V_0}{V_n}$

$$= A_{V_1} \cdot A_{V_2} \cdot A_{V_3} \cdot A_{V_4} \cdots A_{V_{n-1}} \cdot A_{V_n}$$

$$= A_1 A_2 \ldots A_n \angle \theta_1 + \theta_2 + \ldots + \theta_n$$

$$A_V = A \angle \theta$$

→ The Voltage gain interms of Current gain.

$$A_V = \frac{A_i R_L}{R_i}$$

For n^{th} stage, $A_{Vn} = \frac{A_i R_{Ln}}{R_{in}}$

→ The Curren gain and input impedance of n^{th} stage is given by.

$$A_{in} = \frac{-h_{fe}}{1 + h_{oe} R_{Ln}}$$

$$R_{in} = h_{ie} + h_{re} A_{In} R_{Ln}$$

→ It is important to note that which type of Connection must be used in Cascade to obtain the maximum Voltage gain and other desired characteristics.

→ The CC Configuration will not be used in intermediate Stage hence the voltage gain is less than unity.

→ In many Cases, CC (or) CB stage is used as input because of impedance Consideration even at the expense of Voltage (or) Current gain.

Effect of Cascading of Amplifiers

→ when one (or) more stage Connected in Cascade, the output of the first stage is Connected to the input of the second stage and So on, result in which there will be a significant change in the overall frequency response.

→ In the high frequency region, the output Capacitance C_o must include the wiring Capacitance (or) Stray Capacitance, the parasitic Capacitance and miller Capacitance.

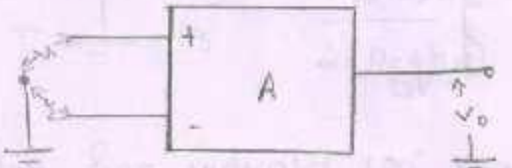
→ Further there will be additional low frequency levels due to the second stage having the lowest cutoff frequency. The lower cutoff frequency is determined by the stage having the highest lower cutoff frequency.

→

Differential Amplifier :

⇒ The function of differential amplifier is to amplify the difference between two signals.

→ The need for differential amplifier arises in many physical measurements where response from d.c to many megahertz is required.



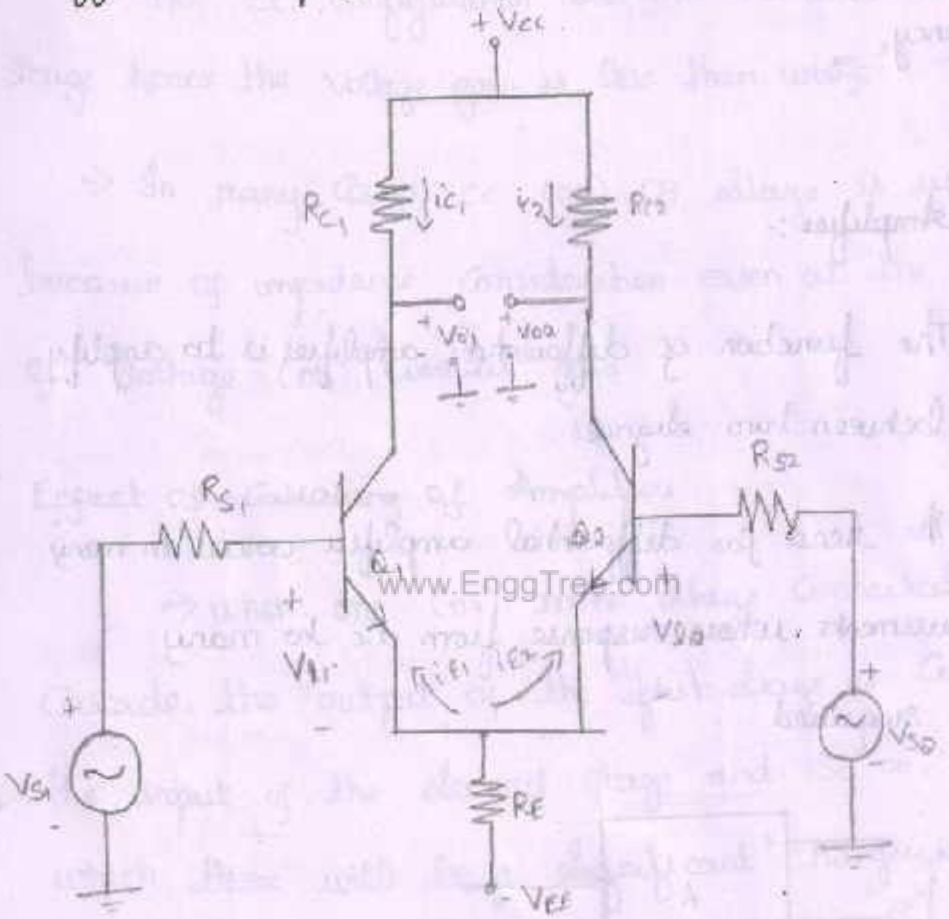
→ The output signal in a differential amplifier is proportional to the difference between the two input signal.

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

→ If $V_1 = V_2$, the output Voltage is zero. A non-zero output is obtained if V_1 and V_2 are not equal.

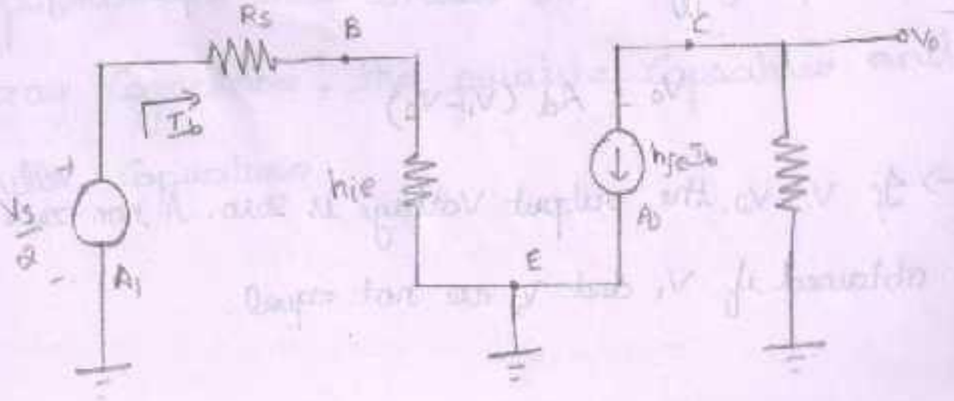
→ The difference mode input voltage is defined as $V_d = (V_1 - V_2)$ and the common mode input voltage is defined as $V_{cm} = \frac{(V_1 + V_2)}{2}$

Differential amplifier using BJT :-



A.C analysis

Differential mode gain:



→ Let the two signals have a magnitude of $V_s/2$ and differ from each other by 180° phase shift.

→ Since $I_{E_1} = I_{E_2}$ and out of phase by 180°, they cancel each other.

→ Applying KVL to loop A_1, the input loop,

$$I_b (R_s + h_{ie}) = \frac{V_s}{2}$$

$$I_b = \frac{V_s}{2(R_s + h_{ie})}$$

→ Apply KVL to loop A_2, the output voltage is

$$V_0 = -h_{fe} I_b R_c$$

$$V_0 = -h_{fe} R_c \frac{V_s}{2(R_s + h_{ie})}$$

$$\frac{V_0}{V_s} = \frac{-h_{fe} R_c}{2(R_s + h_{ie})}$$

→ Negative sign indicates 180° phase difference between input and output. As the magnitude of the input signals are equal, and are out of phase by 180°, we have,

$$V_{id} = V_1 - V_2 = \frac{V_s}{2} - \left(-\frac{V_s}{2}\right) = V_s$$

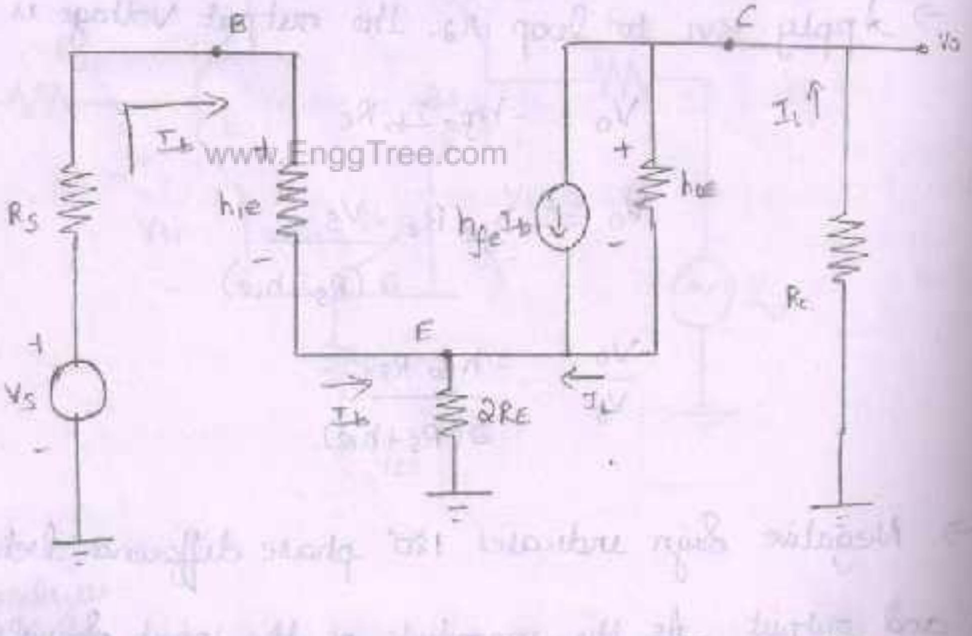
$$A_d = \frac{V_0}{V_{id}} = \frac{V_0}{V_s} = \frac{h_{fe} R_c}{2(R_s + h_{ie})}$$

→ When the output of a differential amplifier is measured with reference to the ground point, it is called unbalanced output.

→ A_d for a balanced case can be derived by considering the balanced output across two collectors of Q_1 & Q_2.

$$A_d = \frac{2 h_{fe} R_C}{2(R_S + h_{ie})} = \frac{h_{fe} R_C}{R_S + h_{ie}}.$$

Common mode gain :-



→ For common mode analysis, consider that the input signals are having same magnitude V_s and are in same phase. Therefore

$$V_C = \frac{V_1 + V_2}{2} = \frac{V_S + V_S}{2} = V_S.$$

$$V_o = A_c V_c \quad \therefore \; A_c = \frac{V_o}{V_S}$$

→ The current through R_E is $2I_E$. The emitter resistance is assumed to be $2R_E$ and emitter current to be I_E instead of $2I_E$.

→ Current through $R_C = I_L$

Effective emitter resistance $= 2R_E$

Current through emitter resistance $= I_L + I_b$

Current through $h_{oe} = (I_L - h_{fe} I_b)$

Applying KVL to the input side,

$$I_b R_S + I_b h_{ie} + 2R_E (I_L + I_b) = V_S$$

$$V_S = I_b (R_S + h_{ie} + 2R_E) + I_L (2R_E)$$

$$V_o = -I_L R_C$$

→ Apply KVL to output loop.

$$I_L R_C + 2R_E (I_L + I_b) + \frac{(I_L - h_{fe} I_b)}{h_{oe}} = 0$$

$$I_L R_C + 2R_E I_L + 2R_E I_b + \frac{I_L}{h_{oe}} - \frac{h_{fe} I_b}{h_{oe}} = 0$$

$$I_b \left[2R_E - \frac{h_{fe}}{h_{oe}} \right] + I_L \left[R_C + 2R_E + \frac{1}{h_{oe}} \right] = 0$$

$$I_L \left[R_C + 2R_E + \frac{1}{h_{oe}} \right] = -I_b \left[2R_E - \frac{h_{fe}}{h_{oe}} \right]$$

$$\frac{I_L}{I_b} = \frac{\left[\frac{h_{fe}}{h_{oe}} - 2R_E \right]}{\left[R_C + 2R_E + \frac{1}{h_{oe}} \right]}$$

$$\frac{I_L}{I_b} = \frac{h_{fe} - 2R_E h_{oe}}{1 + h_{oe}(2R_E + R_C)}$$

$$I_b = \frac{I_L\left[1 + h_{oe}(2R_E + R_C)\right]}{h_{fe} - 2R_E h_{oe}}$$

$$V_S = \frac{I_L\left[1 + h_{oe}(2R_E + R_C)\right](R_S + h_{ie} + 2R_E)}{\left[h_{fe} - 2R_E h_{oe}\right]} + I_L 2R_E$$

$$\frac{V_S}{I_L} = \frac{\left[1 + h_{oe}(2R_E + R_C)\right](R_S + h_{ie} + 2R_E)}{h_{fe} - 2R_E h_{oe}} + 2R_E$$

$$= \frac{\left[1 + h_{oe}(2R_E + R_C)\right](R_S + h_{ie} + 2R_E) + 2R_E(h_{fe} - 2R_E h_{oe})}{h_{fe} - 2R_E h_{oe}}$$

$$\frac{V_S}{I_L} = \frac{h_{oe} R_C\left[R_S + h_{ie} + 2R_E\right] + 2R_E(1 + h_{fe}) + R_S(1 + 2R_E h_{oe}) + h_{ie}(1 + 2R_E h_{oe})}{h_{fe} - 2R_E h_{oe}}$$

Reassanging the last two terms in the numerator, we get

$$\frac{V_S}{I_L} = \frac{h_{oe} R_C\left[2R_E + R_S + h_{ie}\right] + 2R_E(1 + h_{fe}) + (R_S + h_{ie})(1 + 2R_E h_{oe})}{(h_{fe} - 2R_E h_{oe})}$$

$$h_{oe} R_C << 1$$

$$\therefore \frac{V_S}{I_L} = \frac{2R_E(1 + h_{fe}) + (R_S + h_{ie})(1 + 2R_E h_{oe})}{h_{fe} - 2R_E h_{oe}}$$

$$\therefore A_c = \frac{V_o}{V_s} = \frac{-I_L R_c}{V_s}$$

$$= \frac{-(h_{fe} - 2R_E h_{oe}) R_C}{2R_E(1+h_{fe}) + (R_S + h_{ie})(1+2R_E h_{oe})}$$

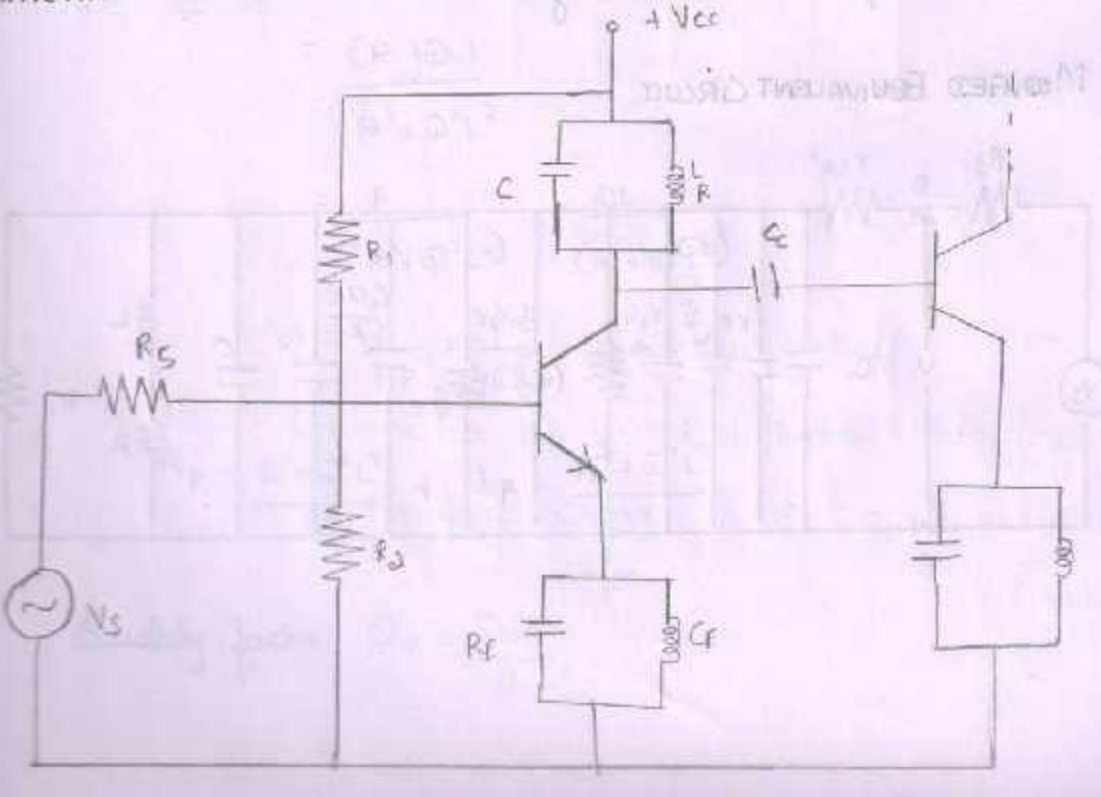
$$= \frac{R_C(2R_E h_{oe} - h_{fe})}{2R_E(1+h_{fe}) + (R_S+h_{ie})(1+2R_E h_{oe})}$$

$$A_c = \frac{-R_c h_{fe}}{R_S + h_{ie} + 2R_E(1+h_{fe})}$$

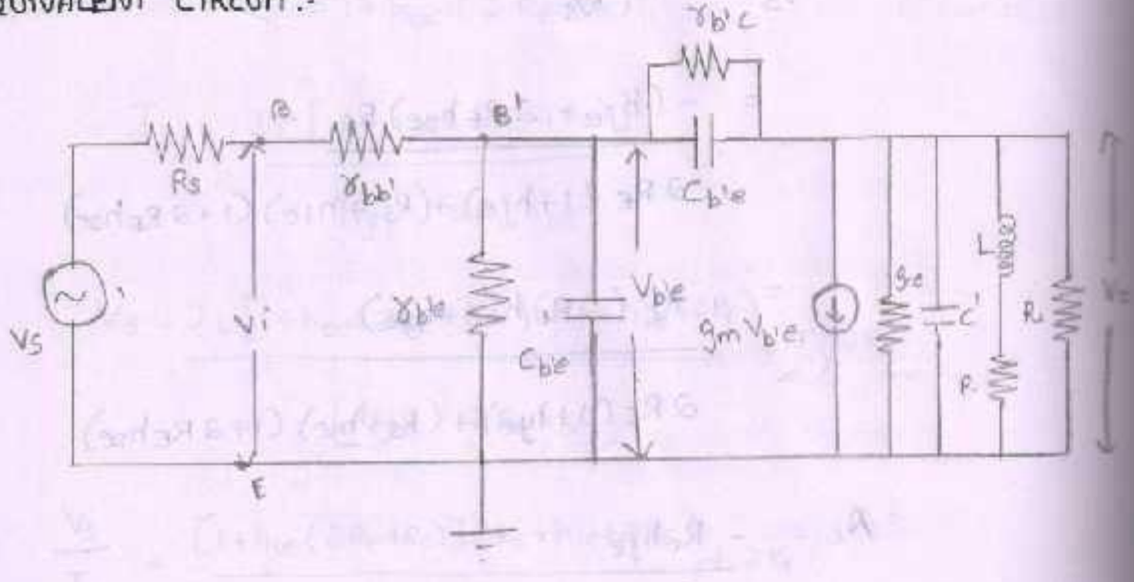
SINGLE TUNED AMPLIFIERS:

⇒ Single tuned amplifiers use one parallel resonant circuits as the load impedance in each stage and all the tuned circuits are tuned to the same frequency.

CAPACITIVE COUPLED SINGLE TUNED AMPLIFIER



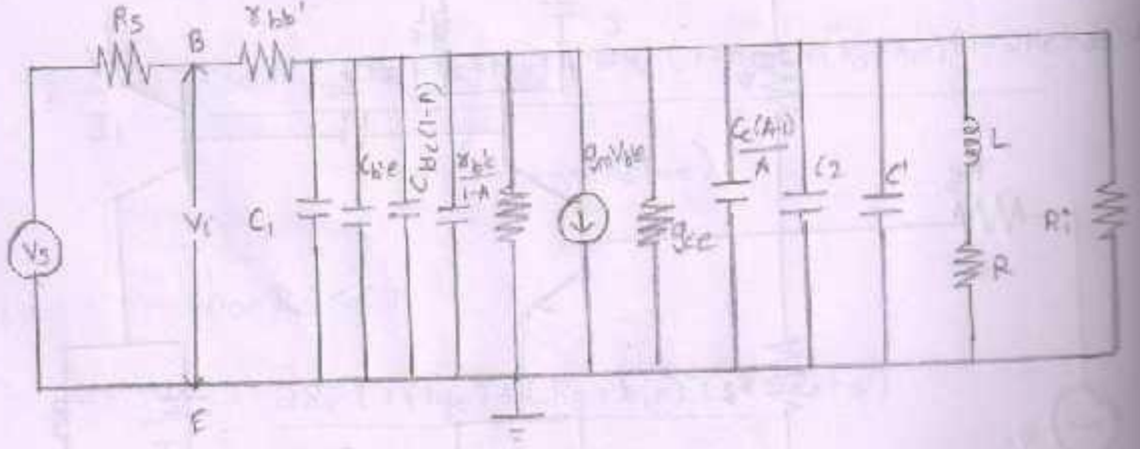
EQUIVALENT CIRCUIT :-



⇒ In the Capacitance coupled single tuned amplifier, output across the tuned circuit is coupled to the next stage through the coupling capacitor C_c. The tuned circuit formed by L and C' resonates at the frequency of operation.

→ In the equivalent circuit, R_i is the input resistance of the next stage.

MODIFIED EQUIVALENT CIRCUIT



→ In the simplified circuit, all the capacitances in the input circuit can be grouped together to form C_S given by,

$$C_S = C_{b'e} + C_1 + C_{b'c}(1-A)$$

→ Similarly, all the capacitances in the output circuit can be grouped together to form C given by

$$C = C_{b'c}\left(\frac{A-1}{A}\right) + C_2 + C'$$

$$g_{ce} = \frac{1}{r_{ce}} = h_{oe} - g_m h_{re} \approx h_{oe} = \frac{1}{R_o}$$

→ The reactances of the bypass capacitor C_E and the coupling capacitor C_c are negligibly small at the operating frequency and those elements can be neglected.

$$Y_i = \frac{1}{R+j\omega L} = \frac{(R-j\omega L)}{(R+j\omega L)(R-j\omega L)}$$

$$= \frac{(R-j\omega L)}{R^2+\omega^2L^2}$$

$$= \frac{R}{(R^2+\omega^2L^2)} - j\frac{\omega L}{(R^2+\omega^2L^2)}$$

$$= \frac{1}{R_P} + \frac{1}{j\omega L_P}$$

$$R_P = \frac{R^2+\omega^2L^2}{R} \quad \& \quad L_P = \frac{R^2+\omega^2L^2}{\omega^2 L}$$

Quality factor, $Q_0 = \frac{\omega_0 L}{R}$

$$R_p = \frac{R^2 + \omega^2 L^2}{R}$$

$$= \frac{R\left(R + \frac{\omega^2 L^2}{R}\right)}{R}$$

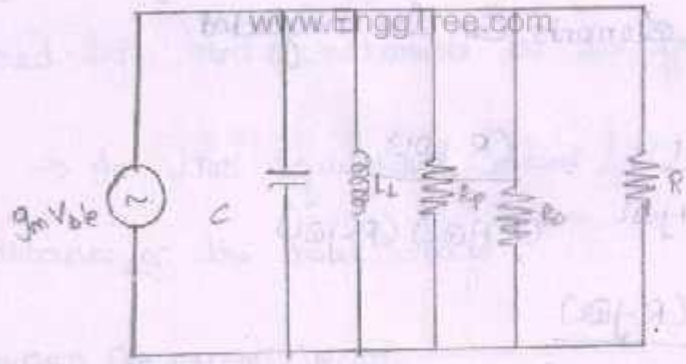
$$R_p \simeq \frac{\omega^2 L^2}{R}$$

$$L_p = \frac{R^2 + \omega^2 L^2}{\omega^2 L}$$

$\div$ num & den by $\omega^2 L$

$$L_p = \frac{R^2}{\omega^2 L} + L$$

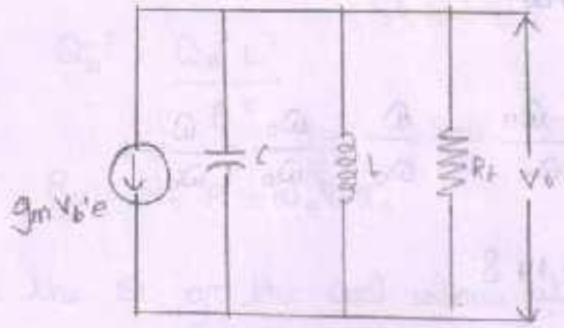
$$L_p \simeq L.$$



$$\frac{1}{R_t} = \frac{1}{R_o} + \frac{1}{R_p} + \frac{1}{R_i}$$

→ The effective quality factor or the circuit magnification ~~circuit~~ factor of the entire output circuit including R_p and R_i at resonant frequency ω_o is given by.

$$Q_e = \frac{\text{Susceptance of } L \text{ (or) } C}{\text{Conductance of } R_t}$$



$$Q_e = \omega_0 C R_t = \frac{R_t}{\omega_0 L}$$

From the output circuit $V_o = -g_m V_{b'e} Z$.

$$Y = \frac{1}{Z}$$

$$= \frac{1}{R_t} + \frac{1}{j\omega L} + j\omega C$$

$$= \frac{1}{R_t}\left[1 + \frac{R_t}{j\omega L} + j\omega C R_t\right]$$

Multiplying numerator and denominator by ω_0.

$$Y = \frac{1}{R_t}\left[1 + \frac{R_t \omega_0}{j\omega L \omega_0} + \frac{j\omega\omega_0 C R_t}{\omega_0}\right]$$

$$\frac{R_t}{\omega_0 L} = \omega_0 C R_t = Q_e$$

$$Y = \frac{1 + jQ_e\left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right]}{R_t}$$

$$Z = \frac{1}{Y} = \frac{R_t}{1 + jQ_e\left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right]}$$

δ indicate the fractional frequency variation i.e., variation in frequency is expressed as a fraction of the resonant frequency.

$$\delta = \frac{\omega - \omega_0}{\omega_0} = \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega_0} = \frac{\omega}{\omega_0} - 1$$

$$\frac{\omega}{\omega_0} = 1 + \delta$$

$$Z = \frac{R_t}{1 + jQ_e\left[(1+\delta) - \frac{1}{1+\delta}\right]}$$

$$= \frac{R_t}{1 + jQ_e\left[\frac{(1+\delta)^2 + 2\delta - 1}{1+\delta}\right]}$$

$$Z = \frac{R_t}{1 + 2jQ_e\delta\left[\frac{\delta/2 + 1}{(1+\delta)}\right]}$$

$\delta << 1$

$$Z = \frac{R_t}{1 + j2Q_e\delta}$$

At resonance, $\omega = \omega_0$ & $\delta = 0$.

$$Z = R_t = R_0 \parallel R_p \parallel R$$

$$R_p = \frac{\omega_0^2 L^2}{R} = \frac{\omega_0 L}{\omega_0 CR}$$

$$= \frac{L}{CR}$$

$$R_p = \frac{\omega_0^2 L^2}{R}$$

$$Q_0 = \frac{\omega_0 L}{R}$$

$$Q_0^2 = \frac{\omega_0^2 L^2}{R^2}$$

$$R_p = Q_0^2 R = \omega_0 L Q_0$$

Q_0 is the Q of the coil alone at resonance

$$V_{b'e} = V_i \frac{r_{b'e}}{r_{bb'} + r_{b'e}}$$

$$V_o = -g_m V_{b'e} Z$$

$$= -g_m \left(V_i \frac{r_{b'e}}{r_{bb'} + r_{b'e}} \right) Z$$

$$A = \frac{V_o}{V_i} = -g_m \left(\frac{r_{b'e}}{r_{bb'} + r_{b'e}} \right) Z$$

$$A = -g_m \left(\frac{r_{b'e}}{r_{bb'} + r_{b'e}} \right) \frac{R_t}{1 + j2Q_e\delta}$$

→ The Voltage gain at resonance $\delta = 0$ is given by,

$$A_{res} = -g_m \left(\frac{r_{b'e}}{r_{bb'} + r_{b'e}} \right) \cdot R_t$$

$$\frac{A}{A_{res}} = \frac{1}{1 + j2\delta Q_e}$$

$$\left|\frac{A}{A_{res}}\right| = \frac{1}{\sqrt{1+(2\delta Q_e)^2}}$$

$$\phi = -\tan^{-1} 2\delta Q_e$$

$\phi \rightarrow$ phase angle of $\frac{A}{A_{res}}$

At ω_1, $\delta = \frac{1}{2Q_e}$

$$\left|\frac{A}{A_{res}}\right| = \frac{1}{\sqrt{2}} = 0.707$$

At ω_2 above ω_0.

$$\delta = \frac{1}{2Q_e}$$

$$\therefore \left|\frac{A}{A_{res}}\right| = \frac{1}{\sqrt{2}} = 0.707$$

The 3 dB bandwidth $\Delta\omega = \omega_2 - \omega_1$

$$= \frac{[(\omega_2 - \omega_0) + (\omega_0 - \omega_1)]\omega_0}{\omega_0}$$

$$= \left[\frac{(\omega_2 - \omega_0)}{\omega_0} + \frac{(\omega_0 - \omega_1)}{\omega_0}\right]\omega_0$$

$$\Delta\omega = [\delta + \delta]\omega_0$$

$$\Delta\omega = 2\delta\omega_0$$

But $\delta = \frac{1}{2Q_e}$

$$2\delta = \frac{1}{Q_e}$$

$$\Delta\omega = \frac{\omega_0}{Q_e}$$

$$Q_e = \omega_0 C R_t = \frac{R_t}{\omega_0 L}$$

$$\Delta\omega = \frac{\omega_0}{R_t \omega_0 C} = \frac{1}{R_t C} \text{ rad/s}$$

GAIN AND FREQUENCY RESPONSE:

→ In order to obtain a high gain, several identical stages (or) tuned amplifiers can be used in cascade.

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

→ The high voltage gain is accompanied by a narrow bandwidth.

→ The relative gain of the single tuned amplifier with respect to the gain at resonant frequency f_0.

$$\left|\frac{A}{A_{res}}\right| = \frac{1}{\sqrt{1+(2\delta Q_e)^2}}$$

→ The gain of the n stage cascaded amplifier becomes

$$\left|\frac{A}{A_{res}}\right|^n = \left[\frac{1}{\sqrt{1+(2\delta Q_e)^2}}\right]^n$$

$$= \frac{1}{\left[1+(2\delta Q_e)^2\right]^{n/2}}$$

→ The 3 dB frequencies for the n stage Cascaded amplifier can be found by equating $\left|\frac{A}{A_{res}}\right|^n$ to $\frac{1}{\sqrt{2}}$

$$\left|\frac{A}{A_{res}}\right|^n = \frac{1}{\left[\sqrt{1+(2\delta Q_e)^2}\right]^n} = \frac{1}{\sqrt{2}}$$

$$\left[\sqrt{1+(2\delta Q_e)^2}\right]^n = \sqrt{2}$$

$$1+(2\delta Q_e)^2 = 2^{1/n}$$

$$2\delta Q_e = \pm\sqrt{2^{1/n}-1}$$

→ Substituting for δ, the fractional frequency variation,

$$\delta = \frac{\omega - \omega_0}{\omega_0} = \frac{f - f_0}{f_0}$$

$$2\left(\frac{f-f_0}{f_0}\right) Q_e = \pm\sqrt{2^{1/n}-1}$$

$$2(f-f_0) Q_e = \pm f_0 \sqrt{2^{1/n}-1}$$

$$f_2 - f_0 = \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

→ The bandwidth of n stage identical amplifier is

$$B_{1n} = f_2 - f_1$$

$$= (f_2 - f_0) + (f_0 - f_1)$$

$$= \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1} + \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

$$= \frac{f_0}{Q_e}\sqrt{2^{1/n}-1}$$

$$= B_1\sqrt{2^{1/n}-1}$$

→ Where B_{1n} is the bandwidth of n stages of the Cascade amplifier and B_1 is the bandwidth for Single Stage

→ Bandwidth of n stages B_{1n} is equal to B_1 multiplied by a factor of $\sqrt{2^{1/n}-1}$

→ when $n = 2$; $\sqrt{2^{1/n}-1} = 0.643$

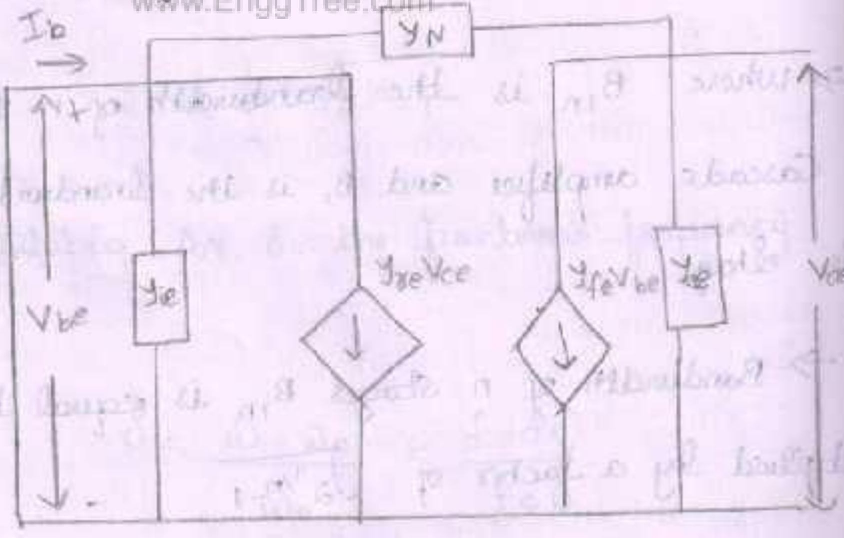
$n = 3$; $\sqrt{2^{1/n}-1} = 0.510$.

→ The bandwidth is reduced to 64.3% for two stages and 51% for three stages of Cascade amplifier.

NEUTRALISATION :-

→ The technique used for the elimination of potential oscillation is called Neutralisation.

→ BJT and FET are potentially unstable over some frequency range due to the feedback parameter present in them. If the feedback can be cancelled by an additional feedback signal that is equal in magnitude and opposite in sign, the transistor becomes unilateral from input to output till the oscillations completely stop. This is achieved by neutralisation.



$$y_{re} = \frac{I_b}{V_{ce}}\Bigg|_{V_{be}=0}$$

→ with input terminal shorted.

$$I_b = y_{re}V_{ce} - Y_N V_{ce}$$

$$\therefore \; I_b = V_{ce}\,[\,y_{re} - y_N\,]$$

$$\frac{I_b}{V_{ce}} = y_{re} - y_N$$

$$y'_{re} = y_{re} - y_N$$

→ For perfect neutralisation, $y'_{re} = 0 \therefore y_{re} = y_N$. This indicates that oscillation does not exist if the designed circuit element matches y_{re} for all values of frequency and operating conditions.

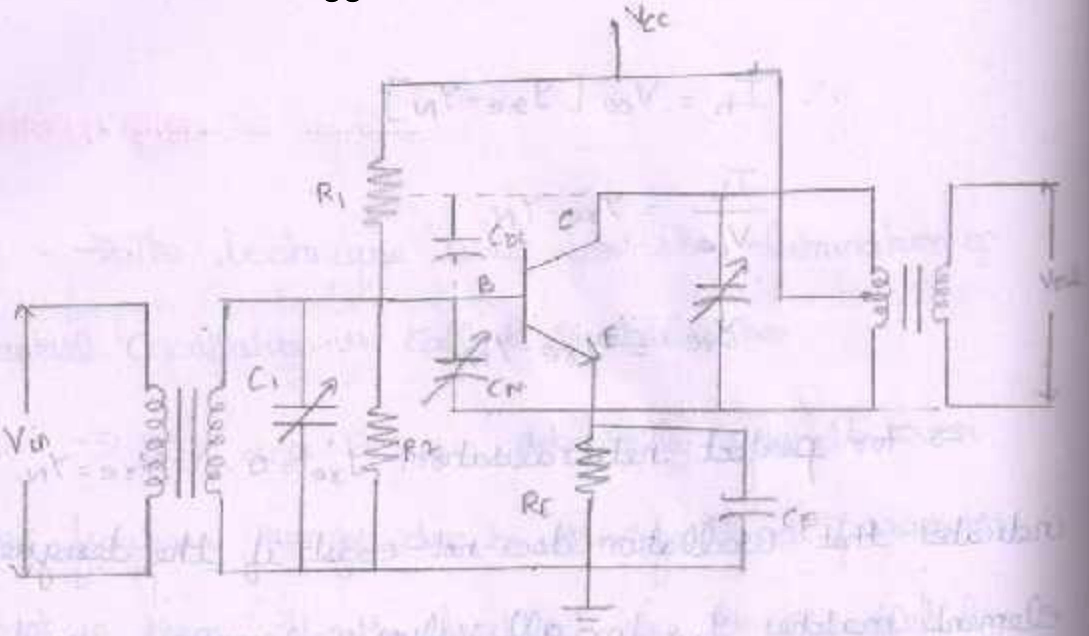
$$y_{re} = -j\omega C_{re}$$

→ The fabrication of capacitor is complex, an inductor with negative susceptance $B = f(1/\omega L)$ is preferred.

→ The inductor acts as a short circuit at d.c condition and need not be considered. This can be eliminated by using a fixed capacitance that is transformer coupled to for 180° phase shift to produce neutralisation over a limited frequency range.

Hazeltine Neutralisation method:-

→ This method is employed in tuned RF amplifiers to maintain stability.



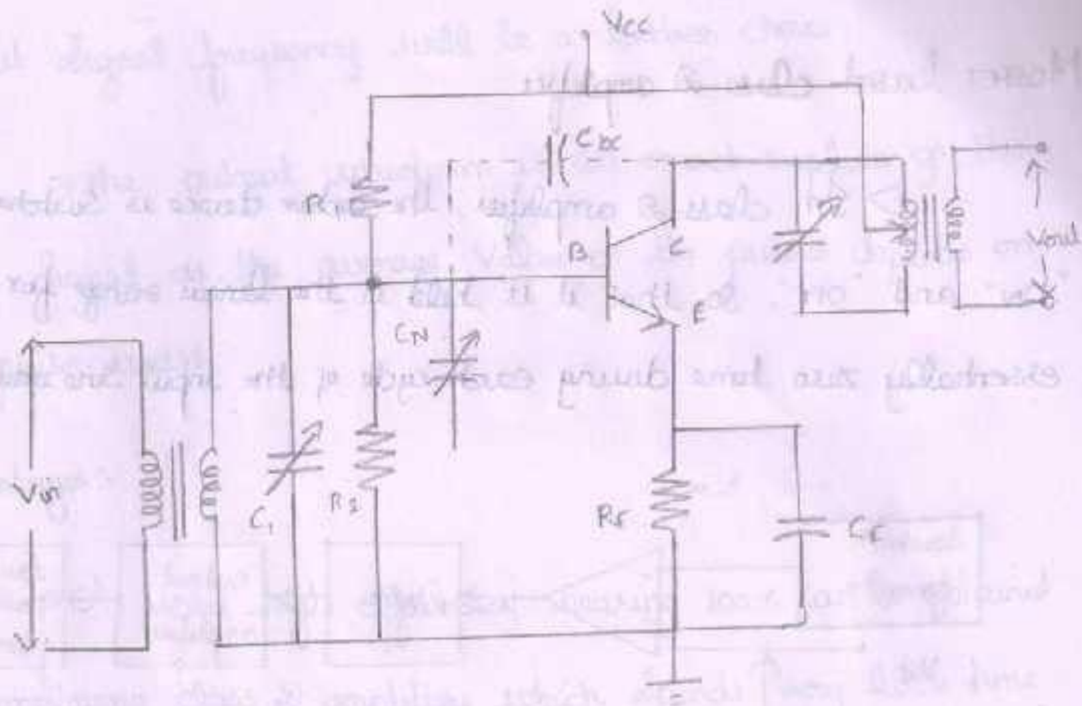
→ The undesired effect of the collector to base capacitance of the transistor is neutralised by introducing a signal which cancels the signal coupled through the collector to base capacitance.

→ C_N is connected from the bottom of coil to the base of the transistor. The neutralisation process is achieved by C_N. It introduces a signal to the base of the transistor such that is cancels out the signal fed to the base by C_{bc}.

→ A variable capacitor is used for neutralisation as the value of C_{bc} changes with time. By adjusting C_N, exact neutralisation is achieved.

Neutrodyne neutralisation technique:

→ The modified version of Hazeltine technique is the Neutrodyne neutralisation technique.



→ C_N is Connected to the lower end of the Secondary Coil of the next Stage. It is insensitive to any Variation in the Supply Voltage V_{CC} and provides higher stabilisation for the tuned amplifier.

POWER AMPLIFIER:

→ It is designed to switch large Currents ON & OFF using MOSFET devices

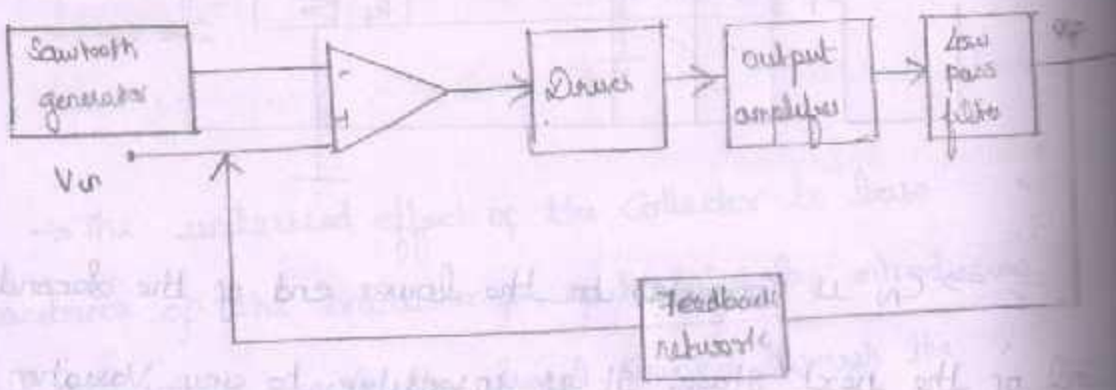
→ MOSFET based class-D amplifier is Commonly employed.

→ The advantage of using MOSFET is that the turn-off time is not delayed by minority Carrier storage as it is in BJT.

→ Current in MOSFET is due to majority Carriers only and they are not subjected to thermal runaway

MOSFET based class-D amplifier

→ In class-D amplifier, the active device is switched "ON" and "OFF". So that it is held in the linear range for essentially zero time during each cycle of the input sine wave



→ The analog signal modulates the saw tooth waveform so that a pulse width modulated output is obtained, which drives the class D output amplifier, causing it to switch ON and OFF as the pulses switch between high & low

→ A class D amplifier must have a filter circuit to extract the signal to be amplified from the pulsed waveform.

→ As the signal may have many frequency components a low pass filter having a cut off frequency nearer to the highest signal frequency will be a better choice.

⇒ The output waveform is an exact replica of the input signal as the average value of the pulses depends on the pulse width.

Advantages:

⇒ A very high efficiency nearing 100% can be obtained by employing class D amplifiers which spends very little time in active region, which minimises the power dissipation

Drawbacks:

⇒ Filters with sharp cutoff frequencies are complex in design. High speed switching of large current generates noise through electromagnetic coupling called electromagnetic interference

Unit-IV Completed

UNIT - 4 -

MULTISTAGE AMPLIFIERS & DIFFERENTIAL AMPLIFIER

BIMOS CASCADE AMPLIFIER :

→ When the amplification of a single stage amplifier is not sufficient for a particular purpose (or) when the input (or) output impedance is not of correct magnitude for the intended application, two (or) more stages may be connected in cascade.

→ The main function of cascading stages is that the larger overall gain is achieved

UNIT -5.FEEDBACK AMPLIFIERS AND OSCILLATORS

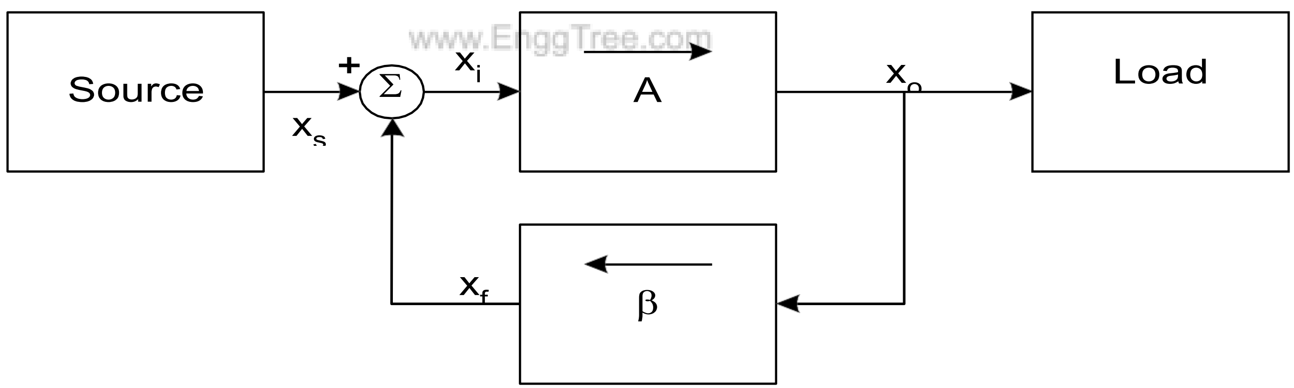
Feedback Amplifiers

- Desensitize The Gain
- Reduce Nonlinear Distortions
  - Reduce The Effect of Noise
  - Control the Input And Output Impedances

Extend The Bandwidth Of The Amplifier

The General Feedback Structure

Basic structure of a feedback amplifier. To make it general, the figure shows signal flow as opposed to voltages or currents (i.e., signals can be either current or voltage).



The open-loop amplifier has gain A → $x_o = A*x_i$

Output is fed back through a feedback network which produces a sample (x_f) of the output (x_o) → $x_f = \beta x_o$

Where β is called the feedback factor

The input to the amplifier is $x_i = x_s - x_f$ (the subtraction makes feedback negative)

Implicit to the above analysis is that neither the feedback block nor the load affect the amplifier's gain (A). This not generally true and so we will later see how to deal with it. The overall gain (closed-loop gain) can be solved to be:

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1+A\beta}$$

Aβ is called the loop gain

1+Aβ is called the “amount of feedback”

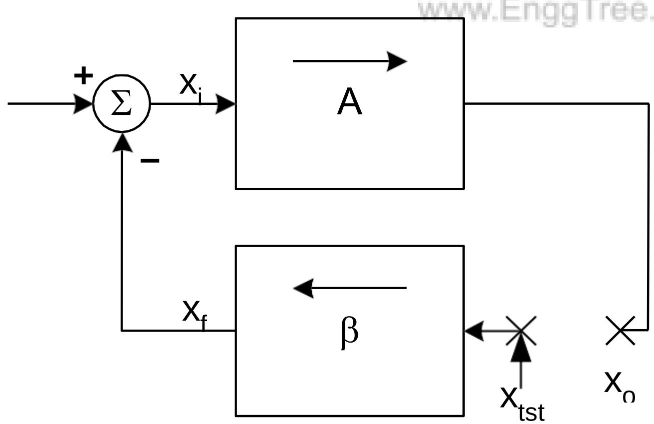
Finding Loop Gain

Generally, we can find the loop gain with the following steps:

1. Break the feedback loop anywhere (at the output in the ex. below)
2. Zero out the input signal x_s
3. Apply a test signal to the input of the feedback circuit
4. Solve for the resulting signal x_o at the output
   If x_o is a voltage signal, x_{tst} is a voltage and measure the open-circuit voltage If x_o is a current signal, x_{tst} is a current and measure the short-circuit current
5. The negative sign comes from the fact that we are apply negative feedback

$x_s=0$

$x_o = Ax_i = -Ax_f$



$x_f = \beta x_{tst}$

$x_i = 0 - x_f$

$= -\beta A x_{tst}$

loop gain $= -\dfrac{x_o}{x_{tst}} = \beta A$

Negative Feedback Properties

Negative feedback takes a sample of the output signal and applies it to the input to get several desirable properties. In amplifiers, negative feedback can be applied to get the following properties

–Desensitized gain – gain less sensitive to circuit component variations

–Reduce nonlinear distortion – output proportional to input (constant gain independent of signal level)

–Reduce effect of noise

–Control input and output impedances – by applying appropriate feedback topologies

–Extend bandwidth of amplifier

These properties can be achieved by trading off gain

Gain Desensitivity

Feedback can be used to desensitize the closed-loop gain to variations in the basic amplifier. Let's see how. Assume beta is constant. Taking differentials of the closed-loop gain equation gives…

$$A_f = \frac{A}{1+A\beta} \qquad dA_f = \frac{dA}{(1+A\beta)^2}$$

Divide by A_f

$$\frac{dA_f}{A_f} = \frac{dA}{(1+A\beta)^2}\,\frac{1+A\beta}{A} = \frac{1}{1+A\beta}\,\frac{dA}{A}$$

This result shows the effects of variations in A on A_f is mitigated by the feedback amount. 1+*Abeta* is also called the desensitivity amount

We will see through examples that feedback also affects the input and resistance of the amplifier (increases R_i and decreases R_o by 1+Abeta factor)

Bandwidth Extension

Mentioned several times in the past that we can trade gain for bandwidth Consider an amplifier with a high-frequency response characterized by a single pole and the expression:

Apply negative feedback beta and the resulting closed-loop gain is:

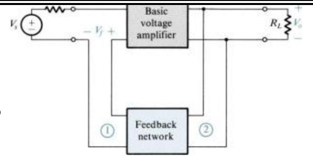
$$A(s) = \frac{A_M}{1 + s/\omega_H}$$

$$A_f(s) = \frac{A(s)}{1 + \beta A(s)} = \frac{A_M/(1 + A_M\beta)}{1 + s/\omega_H(1 + A_M\beta)}$$

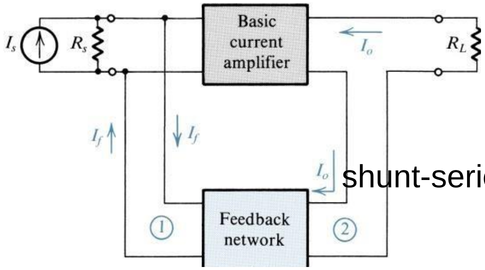
•Notice that the midband gain reduces by $(1+A_M beta)$ while the 3-dB roll-off frequency increases by $(1+A_M beta)$

Basic Feedback Topologies

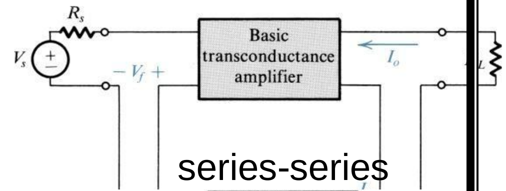
Depending on the input signal (voltage or current) to be amplified and form of the output (voltage or current),amplifiers can be classified into four categories. Depending on the amplifier category, one of four types of feedback structures should be used (series-shunt, series-series, shunt-shunt, or shunt-series) Voltage amplifier – voltage-controlled voltage Source
Requires high input impedance, low output impedance Use series-shunt feedback (voltage-voltage feedback) Current amplifier – current-controlled current source
Use shunt-series feedback (current-current feedback)
Transconductance amplifier – voltage-controlled current source Use series-series feedback (current-voltage feedback) Transimpedance amplifier – current-controlled voltage source Use shunt-shunt feedback (voltage-current feedback)



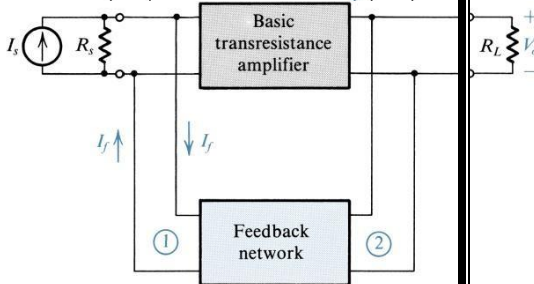
series-shunt



shunt-series

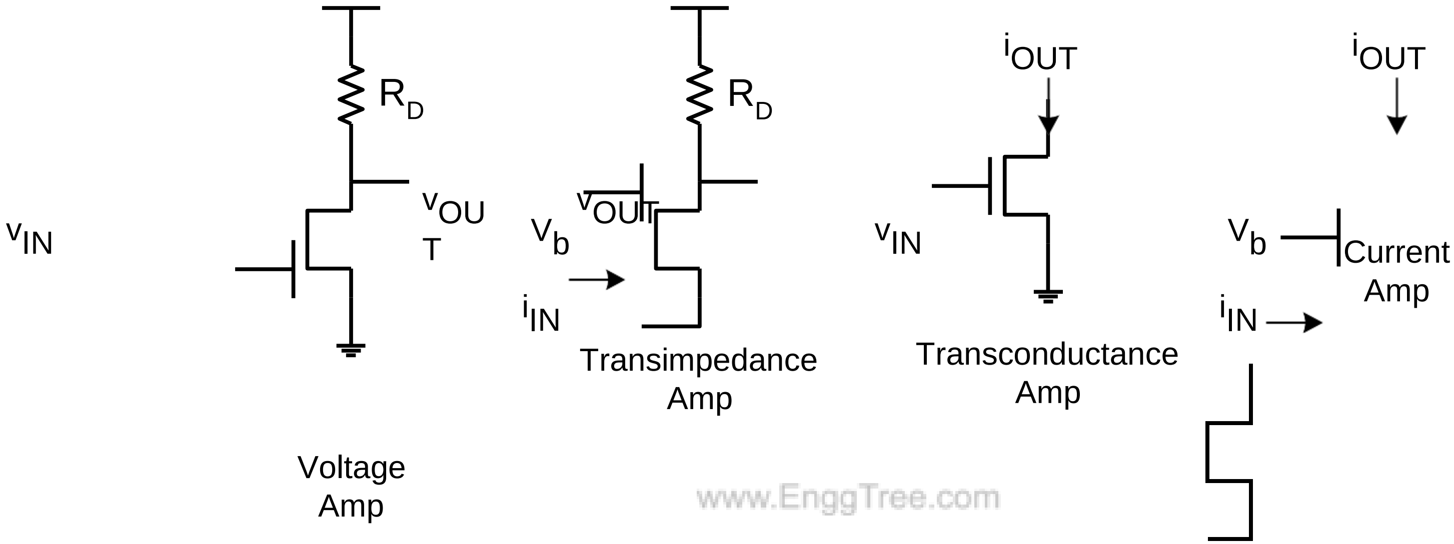


series-series

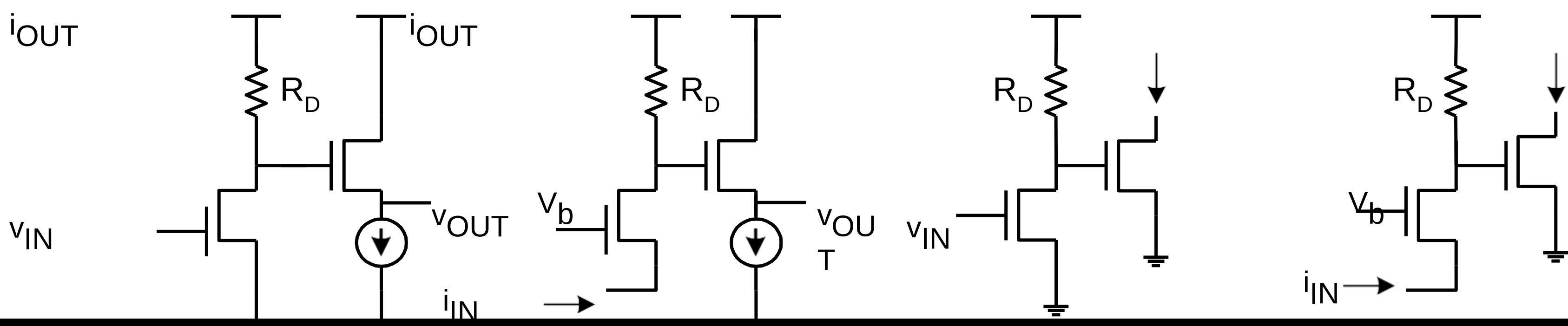


shunt-shunt

Examples of the Four Types of Amplifiers



- Shown above are simple examples of the four types of amplifiers. Often, these amplifiers alone do not have good performance (high output impedance, low gain, etc.) and are augmented by additional amplifier stages (see below) or different configurations (e.g., cascoding).

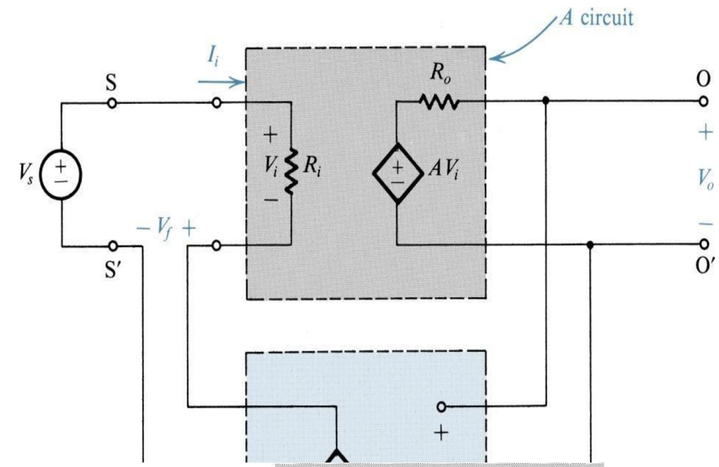


Examples of the Four Types of Amplifiers

lower Z_{out} lower Z_{out} higher gain higher gain

Series-Shunt Feedback Amplifier

(Voltage-Voltage Feedback)



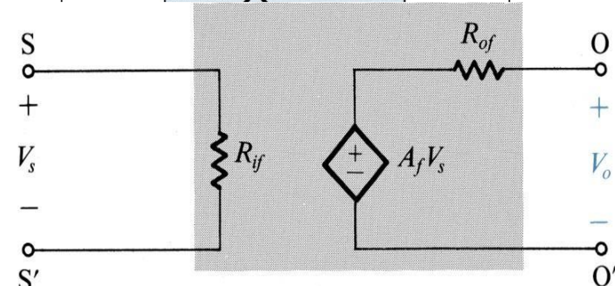
Samples the output voltage and returns a feedback voltage signal

Ideal feedback network has infinite input impedance and zero output resistance

Find the closed-loop gain and input resistance The output resistance can be found by

applying a test voltage to the output

So, increases input resistance and reduces output resistance → makes amplifier closer to ideal VCVS



$$V_f = \beta V_o$$

$$V_i = V_s - V_f$$

$$V_o = A(V_s - \beta V_o)$$

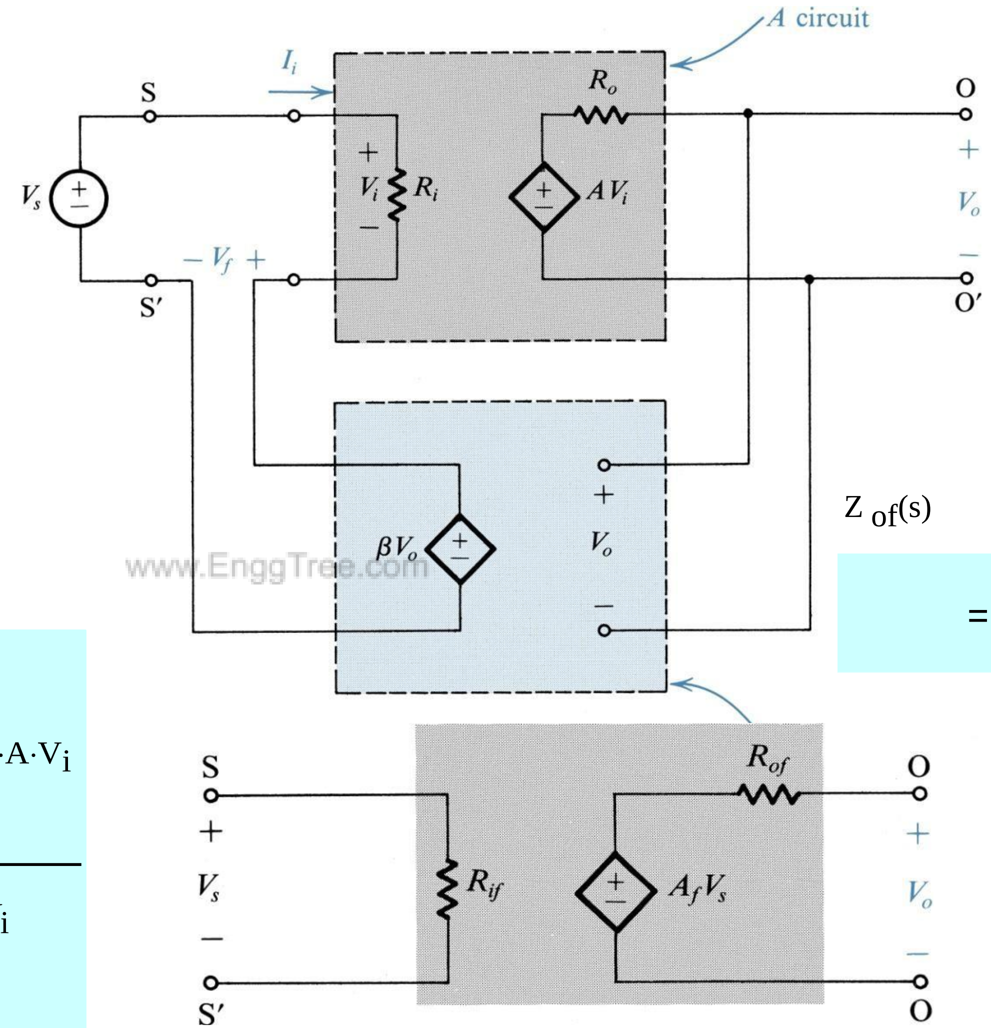
$$A_f \equiv \frac{V_o}{V_s} = \frac{A}{1+\beta A}$$

$$R_{if} = \frac{V_s}{I_i} = \frac{V_s}{V_i / R_i} = R_i \frac{V_s}{V_i} = R_i \frac{V_i + \beta A V_i}{V_i} = R_i(1+A\beta)$$

$$R_{of} = \frac{R_o}{1+\beta A}$$

The Series-Shunt Feedback Amplifier

The Ideal Situation



The series-shunt feedback amplifier:
(a) ideal structure;
(b) equivalent circuit.

$Z_o(s)$

$$Z_{of}(s) = \frac{Z_o(s)}{1 + A(s)\cdot\beta(s)}$$

$$A_f = \frac{V_o}{V_s} = \frac{A}{1 + A\cdot\beta}$$

$$R_{if} = \frac{V_s}{I_i} = R_i\cdot\frac{V_s}{V_i} = R_i\cdot\frac{V_s}{V_i} = R_i\cdot\frac{V_i + \beta\cdot A\cdot V_i}{V_i}$$

$$R_{if} = R_i\cdot(1 + A\cdot\beta)$$

$$Z_{if}(s) = Z_i(s)\cdot(1 + A(s)\cdot\beta(s))$$

Series-Series Feedback Amplifier

(Current-Voltage Feedback)

For a transconductance amplifier (voltage input, current output), we must apply the appropriate feedback circu

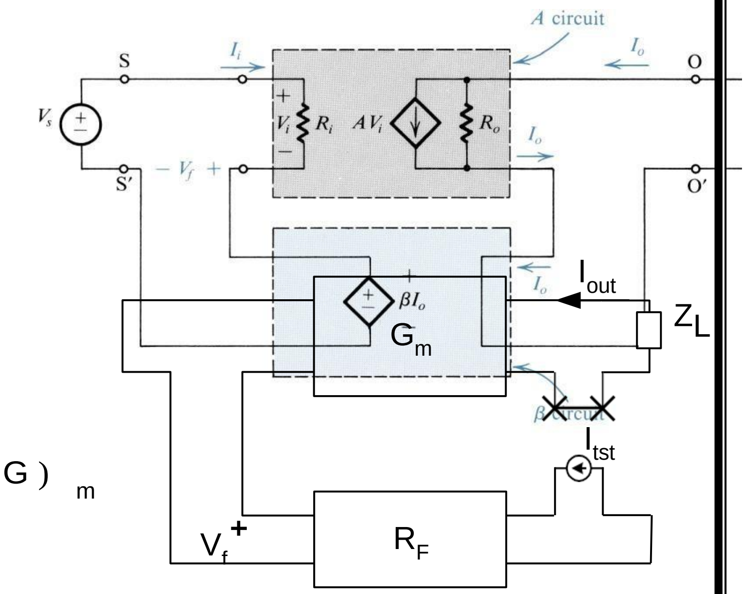
Sense the output current and feedback a voltage signal. So, the feedback current is a transimpedance block that converts the current signal into a voltage.

To solve for the loop gain:

Break the feedback, short out the break in the curren sense and applying a test current

To solve for R_{if} and R_{of}

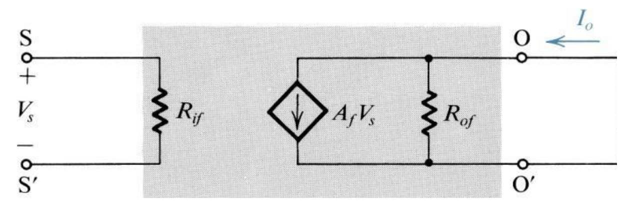
Apply a test voltage V_{tst} across O and O'



$$A \equiv \frac{I_o}{V_i} \text{ (also called } G_m\text{)}$$

$$A_f \equiv \frac{I_o}{V_s} = \frac{A}{1+A\beta}$$

$$\text{Loop Gain} = A\beta = -\frac{I_{out}}{I_{tst}} = G_m R_f$$



$$R_{if} = \frac{V_s}{I_i} = \frac{V_i + V_f}{I_i} = \frac{R_i I_i + \beta I_o}{I_i} = \frac{R_i I_i + A\beta V_i}{I_i} = R_i(1+A\beta)$$

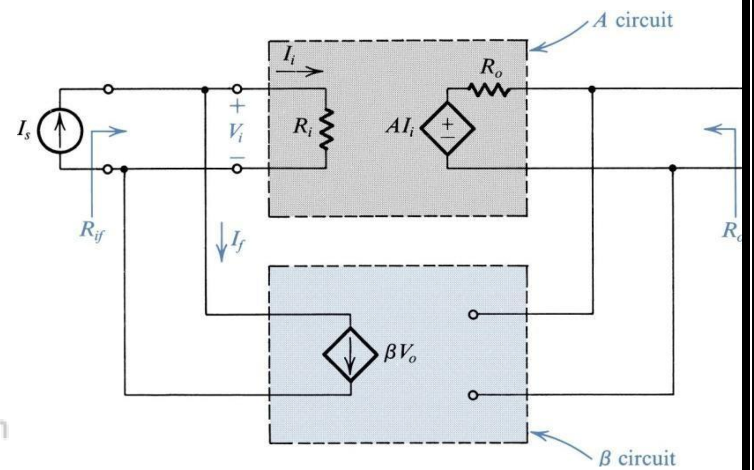
$$R_{of} = \frac{V_{tst}}{I_{tst}} = \frac{(I_{tst} - AV_i)R_o}{I_{tst}} = \frac{(I_{tst} + A\beta I_{tst})R_o}{I_{tst}} = (1+A\beta)R_o$$

Shunt-Shunt Feedback Amplifier

(Voltage-Current Feedback

2. When voltage-current FB is applied to a transimpedance amplifier, output voltage is sensed and current is subtracted from the input

- **i)** The gain stage has some resistance
- **ii)** The feedback stage is a transconductor
- **iii)** Input and output resistances (R_{if} and R_{of}) follow the same form as before based on values for A andbeta



$$A = \frac{V_o}{I_i}$$

$$I_s = I_i + I_f = \frac{V_o}{A} + \beta V_o$$

$$A_f \equiv \frac{V_o}{I_s} = \frac{A}{1+A\beta}$$

$$R_{of} = \frac{R_o}{(1+A\beta)}$$

Shunt-Series Feedback Amplifier

(Current-Current Feedback)

3. A current-current FB circuit is used fo current amplifiers

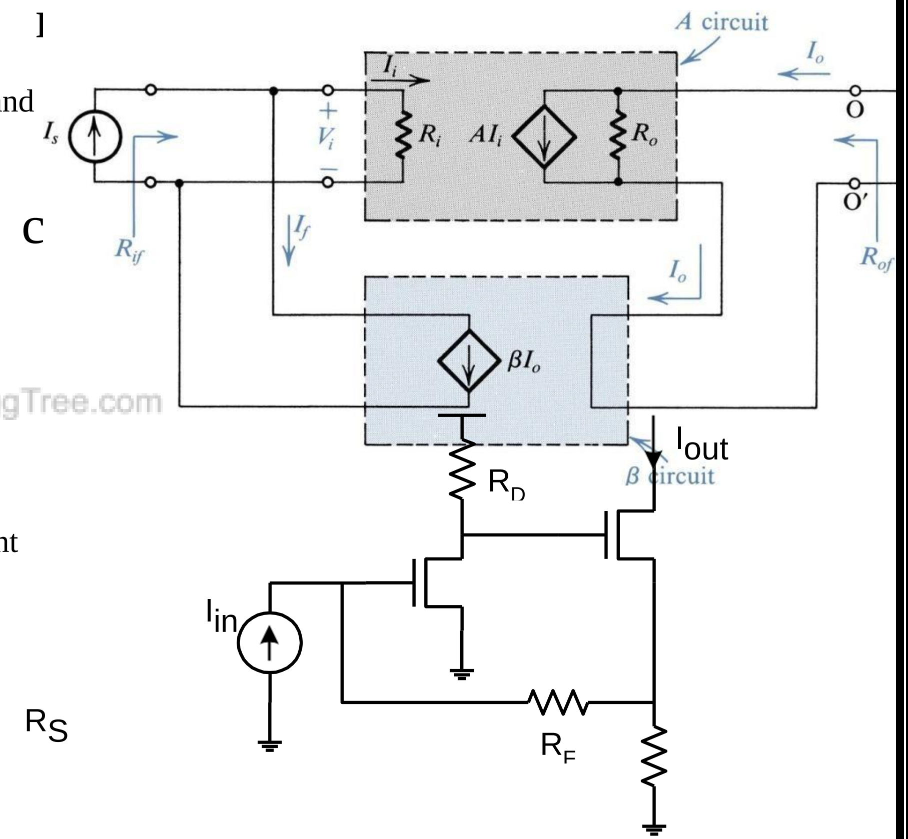
- **i)** For the b circuit – input resistance should be low and output resistan be high

4. A circuit example is shown

- **i)** R_S and R_F constitute the FBcircuit
  - R_S should be small and R_F large
- **ii)** The same steps can be taken to

solve for *A*, *Abeta*, *Af*, R_{if}, and R_{of}

- Remember that both *A* and *b* circuits are current controlled current sources



Parameter	Voltage series	Current Series	Voltage Shunt	Current shunt
Gain with feedback	Decreases	Decreases	Decreases	Decreases
Stabilty	Improves	Improves	Improves	Improves
Frequency Response	Improves	Improves	Improves	Improves
Frequency Distortion	Decreases	Decreases	Decreases	Decreases
Noise and non linear distortion	Decreases	Decreases	Decreases	Decreases

The General Feedback Structure

Exercise

$A_f := 10$ $\quad A := 10^4$

a) $\beta = \dfrac{R1}{R1 + R2}$

b) $A_f = \dfrac{A}{1 + A \cdot \beta}$

$\beta := 1$

given

$A_f = \dfrac{A}{1 + A \cdot \beta}$

$\beta := \text{Find}(\beta)$ $\quad \beta = 0.1$

$\dfrac{R1}{R1 + R2} = 0.1$ $\quad \dfrac{R2}{R1} = 9$

c) $\text{Amount\_Feedback} := 20 \cdot \log(1 + A \cdot \beta)$

$\text{Amount\_Feedback} = 60$

d) $V_s := 1$ $\quad V_o := A_f \cdot V_s$ $\quad V_o = 10$

$V_f := \beta \cdot V_o$ $\quad V_f = 0.999$

$V_i := V_s - V_f$ $\quad V_i = 10 \times 10^{-4}$

e) $A := 0.8 \cdot 10^4$ $\quad A_f := \dfrac{A}{1 + A \cdot \beta}$ $\quad A_f = 9.998$

$\dfrac{10 - 9.998}{10} \cdot 100 = 0.02$

Some Properties of Negative Feedback

Gain Desensitivity

A

$$A_f = \frac{\quad}{1 + A \cdot \beta}$$

deriving

$$dA_f = \frac{dA}{(1 + A \cdot \beta)^2}$$ dividing by $$A_f = \frac{A}{1 + A \cdot \beta}$$

$$\frac{dA_f}{A_f} = \frac{1}{(1 + A \cdot \beta)} \cdot \frac{dA}{A}$$

The percentage change in Af (due to variations in some circuit parameter) is smaller than pecentage cahnge in A by the amount of feedback. For this reason the amount of feedb

$1 + A \cdot \beta$

is also known as the desensitivity factor.

Some Properties of Negative Feedback

Bandwidth Extension

High frequency response with a single pole

$$A(s) = \frac{A_M}{1 + \frac{s}{\omega_H}}$$

A_M denotes the midband gain and ω_H the upper 3-dB frequenc

$$A_f(s) = \frac{A(s)}{1 + \beta \cdot A(s)}$$

$$A_f(s) = \frac{\frac{A_M}{(1 + A_M \cdot \beta)}}{1 + \frac{s}{\omega_H \cdot (1 + A_M \cdot \beta)}}$$

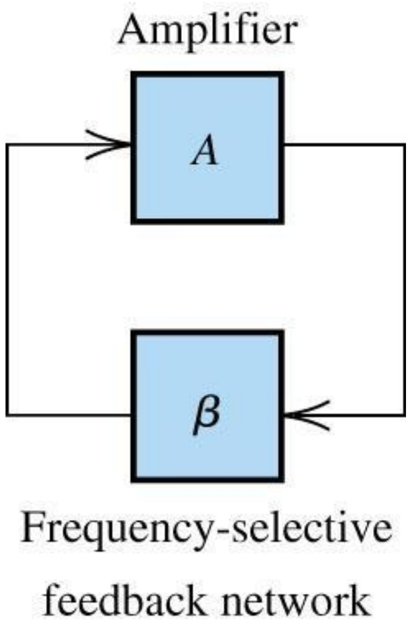
$$\omega_{Hf} = \omega_H \cdot (1 + A_M \cdot \beta)$$

$$\omega_{Lf} = \frac{\omega_L}{1 + A_M \cdot \beta}$$

Oscillator principle

Oscillator

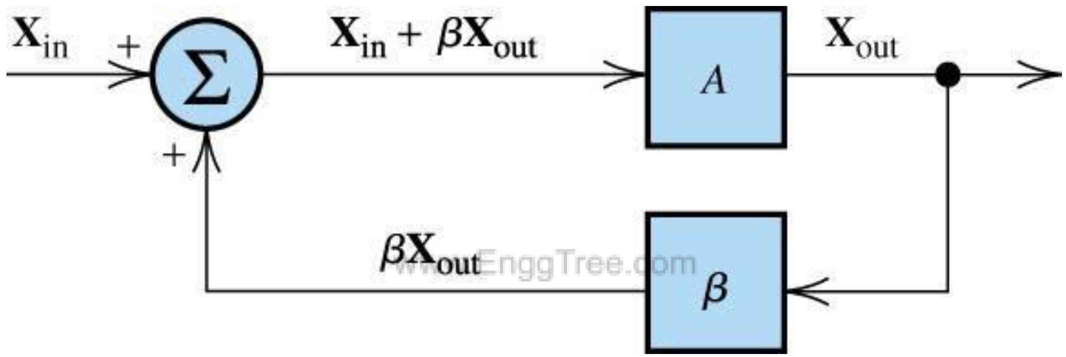
5. Oscillators are circuits that generate periodic signals.
6. An oscillator converts DC power from power supply to AC signals power spontaneously – without the need for an AC input source (Note: Amplifiers convert DC power into AC output power only if an external AC input signal is present.)
7. There are several approaches to design of oscillator circuits. The approach to be discussed is related to the feedback using amplifiers. A frequency-selective feedback path around an amplifier is placed to return part of the output signal to the amplifier input, which results in a circuit called a linear oscillator that produces an approximately sinusoidal output.
8. Under proper conditions, the signal returned by the feedback network has exactly the correct amplitude and phase needed to sustain the output signal.



The Barkhausen Criterion I

9. Typically, the feedback network is composed of passive lumped components that determine the frequency of oscillation. So, the feedback is complex transfer function, hence denoted as $\beta(f)$

10. We can derive the requirements for oscillation as follows: initially, assume a sinusoidal driving source with phasor Xin is present. But we are interested in derive the conditions for which the output phasor Xout can be non-zero even the input Xin is zero.



The output of the amplifier block can be wrtten as $X_{out} = A(f)[X_{in} + \beta(f)X_{out}]$

solve for X_{out}, we obtain $X_{out} = \dfrac{A(f)}{1 - A(f)\beta(f)} X_{in}$

If X_{in} is zero, the only way the the output can be nonzero is to have $A(f)\beta(f) = 1$

11. The above condition is know as Barkhausen Criterion.

The Barkhausen Criterion II

12. The Barkhausen Criterion calls for two requirement for the loop gain . First, the magnitude of the loop gain must be unity. Second, the phase angle of the loop gain must be zero the frequency of oscillation. (e.g, if a non-inverting amplifier is used, then the phase angle of $j\beta(f)$ must be zero. For a inverting amplifier, the phase angle should be 180)

13. In real oscillator design, we usually design loop-gain magnitude slightly larger than unity at the desired frequency of oscillation. Because a higher gain magnitude results in oscillations that grow in amplitude with time, eventually, the amplitude is clipped by the amplifier so that a constant- amplitude oscillation results.

14. On the other hand, if exact unity loop gain magnitude is designed, a slight reduction in gain would result in oscillations that decays to zero.

15. One important thing to note is that the initial input Xin is not needed, as in real circuits noise and transient signals associated with circuit turning on can always provide an initial signal that grows in amplitude as it propagates around the loop (assuming loop gain is larger than unity).

tives:

Different types of oscillators:

16. An oscillator has a positive feedback with the loop gain infinite. Feedback-type sinusoidal oscillators can be classified as LC (inductor-capacitor) and RC (resistor-capacitor) oscillators.

- Tuned oscillator
- Hartley oscillator
- Colpitts oscillator
- Clapp oscillator
- Phase-shift oscillator
- Wien-bridge and
- Crystal oscillator

Difference between an amplifier and
an oscillator:

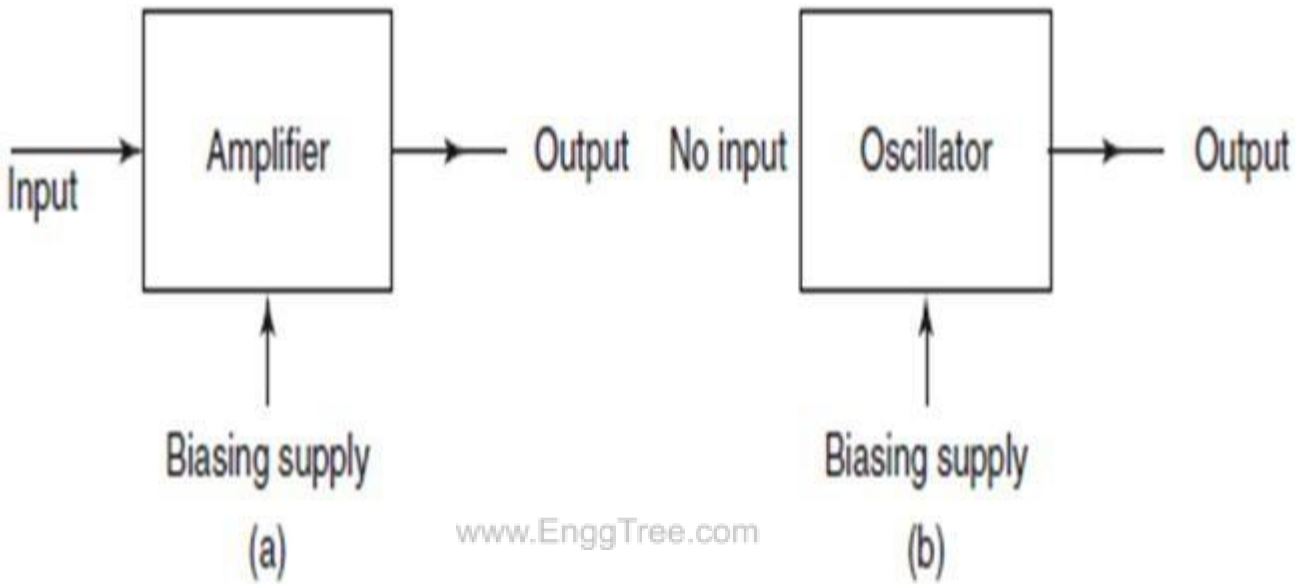


Figure Schematic block diagrams showing the difference between an amplifier and an oscillator

CLASSIFICATIONS OF OSCILLATORS:

17. The classification of various oscillators is shown in Table .

Table Different types of oscillators and their frequency ranges

Type of Oscillator	*Frequency Range Used*
1. Audio-frequency oscillator	20 Hz – 20 kHz
2. Radio-frequency oscillator	20 kHz – 30 MHz
3. Very-high-frequency oscillator	30 MHz –300 MHz
4. Ultra-high-frequency oscillator	300 MHz – 3 GHz
5. Microwave oscillator	3 GHz – 30 GHz
6. Millimeter wave oscillator	30 GHz – 300 GHz

CIRCUIT ANALYSIS OF A

GENERAL OSCILLATOR:

- This section discusses the general oscillator circuit with a simple generalized analysis using the transistor, as shown in Fig. .
- An impedance z1 is connected between the base B and the emitter E, an impedance z2 is connected between the collector C and emitter E. To apply a positive feedback z3 is connected between the collector and the base terminal.
- All the other different oscillators can be analyzed as a special case of the generalized analysis of oscillator.

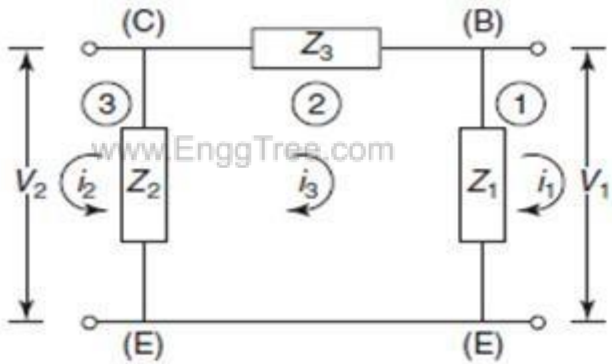


Figure A generalized oscillator circuit analysis

CIRCUIT ANALYSIS OF A GENERAL OSCILLATOR:

18. The above generalized circuit of an oscillator is considered using a simple transistor-equivalent circuit model. The current voltage expressions are expressed as follows:

$$v_1 = h_i i_1 + h_r v_2 \simeq h_i i_1$$

As the numerical value of $h_r v_2$ is negligible:

$$v_1 = h_i i_1$$

$$i_2 = h_f i_1 + h_0 v_2 \simeq h_f i_1$$

As the numerical value of $h_0 v_2$ negligible the Eq. (12-3) can be written as:

$$i_2 = h_f i_1$$

Applying KVL at loop (1) of Fig. by considering that current through the impedance z_1 is $(i_1 - i_3)$, we get:

$$v_1 + z_1 (i_1 - i_3) = 0$$

or, $$v_1 = -z_1(i_1 - i_3) = z_1 (i_3 - i_1)$$

Substituting the value of voltage v_1 from Eq. (12-2) in Eq. (12-5) we get:

$$h_i i_1 + z_1 i_1 - z_1 i_3 = 0$$

or, $$i_1 (h_1 + z_1) - z_i i_3 = 0$$

Applying KVL at loop (3) by considering voltage across the impedance z_2:

$$v_2 + z_2(i_3 + i_2) = 0$$

CIRCUIT ANALYSIS OF A GENERAL OSCILLATOR:

Substituting the value of current i_2 we get:

$$v_2 = -z_2(h_f i_1 + i_3)$$

or, $$z_2 h_f i_1 + z_2 i_3 + v_2 = 0$$

Applying the KVL at loop (2) by considering voltage across z_3 we get,

$$i_3 z_3 + (i_2 + i_3) z_2 + (i_3 - i_1) z_1 = 0$$

or, $$i_3 z_3 - v_2 + v_1 = 0$$

or, $$i_3 z_3 = v_2 - v_1$$

Substituting the value of v_1 in Eq. we get:

$$i_3 z_3 = v_2 - h_i i_1$$

or, $$i_3 z_3 - v_2 + h_i i_1 = 0$$

or, $$-(v_2 - i_3 z_3 - h_i i_1) = 0$$

or, $$v_2 - h_i i_1 - z_3 i_3 = 0$$

CIRCUIT ANALYSIS OF A GENERAL OSCILLATOR:

Eq. can be rewritten as:

$$i_1(h_i + z_1) + 0.\, v_2 + (-z_1)i_3 = 0$$

$$-i_1 z_2\, h_f + 1.\, v_2 + z_2\, i_3 = 0$$

$$-i_1 h_i + 1.\, v_2 + (-z_3)i_3 = 0$$

Eliminating three variables i_1, v_2, i_3 using Camers rule, and from Eqs. , we get the following matrix:

$$\begin{vmatrix} (h_i + z_1) & 0 & -z_1 \\ z_2 h_f & 1 & z_2 \\ -h_i & 1 & -z_3 \end{vmatrix} = 0$$

or $$(h_i + z_1)[-z_3 - z_2] + 0 + (-z_1)[z_2 h_f + h_i] = 0$$

or $$-z_3 h_i - z_2 h_i - z_1 z_3 - z_1 z_2 - z_1 z_2 h_f - z_1 h_i = 0$$

or $$-h_i[z_3 + z_2 z_1] - z_1 z_2\,[1 + h_f] - z_1 z_3 = 0$$

or $$h_i[R + jx] + z_1 z_2\,[1 + h_f] + z_1 z_3 = 0$$

CIRCUIT ANALYSIS OF A GENERAL OSCILLATOR:

Let,

$$z_1 = R_1 + jx_1 \simeq jx_1 \qquad \Theta \quad R_1 \simeq x_1$$

$$z_2 = R_2 + jx_2 \simeq jx_2 \qquad R_2 \simeq x_2$$

$$z_3 = R_3 + jx_3 \simeq jx_3 \qquad \& \quad R_3 \simeq x_3$$

By adding, we get:

$$(z_1 + z_2 + z_3) = (R + jx)$$

where, $R = (R_1+R_2+R_3)$ is not negligible in comparison with $x = x_1 + x_2 + x_3$ as we shall see $x = 0$ at frequency of oscillation.

$$\therefore \qquad z_1z_2(h_f + 1) + (z_1 + z_2 + z_3)h_i + z_1z_3 = 0$$

$$-x_1x_2(h_f + 1) + (R + jx)\,h_i - x_1x_3 = 0$$

$$-x_1[x_2(h_f + 1) + x_3] + (R + jx)h_i = 0$$

CIRCUIT ANALYSIS OF A GENERAL OSCILLATOR:

Equating imaginary parts $[\Theta\, jx_1 jx_2 = -x_1 x_2]$:

$$jxh_i = 0 \qquad \text{(+ve) inductive impedance}$$

$$\therefore \quad x = 0 \qquad \text{(−ve) capacitive impedance}$$

$$x_1 + x_2 + x_3 = 0$$

Equating real parts we get:

$$-x_1 x_2 [h_f + 1] + R \cdot h_i - x_1 x_3 = 0$$

$$x_1 x_2 h_f + x_1 (x_2 + x_3) - R \cdot h_i = 0$$

From the Eq we get:

$$x_2 + x_3 = -x_1$$

Substituting the value of Eq we get:

$$x_1 x_2 h_f - x_1^2 - R \cdot h_i = 0$$

$$h_f = \frac{x_1}{x_2} + \frac{R \cdot h_i}{x_1 x_2}$$

This is the general condition for oscillation for an oscillator.

Different types of oscillator circuits with different configurations can be analysed through this general method. This makes the analysis simpler.

Hartley Oscillator:

Hartley oscillator contains two inductors and one capacitor, as shown in Fig. where, x_1 and x_2 are inductances, and x_3 is a capacitance, i.e., $x_1 = \omega L_1, x_2 = \omega L_2, x_3 = -1/\omega C$.

Substituting the values in Eq. we get the condition for oscillation, considering R is small.

$$h_f = \frac{\omega L_1}{\omega L_2} + \frac{R \cdot h_i}{\omega^2 L_1 L_2}$$

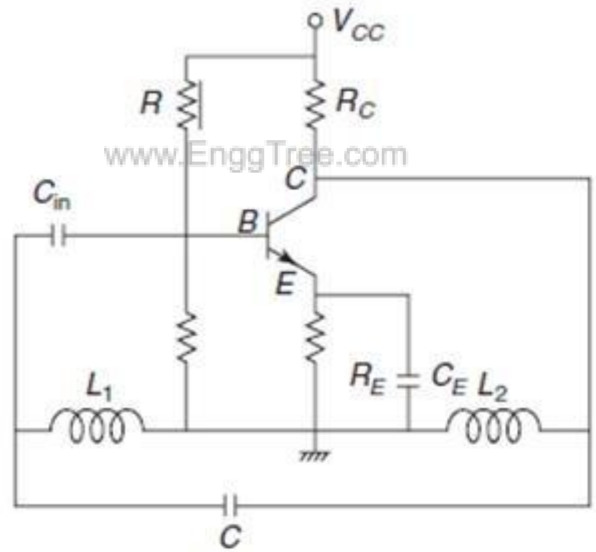


Figure Hartley Oscillator

Hartley Oscillator:

Substituting the values in Eq. we get the condition for oscillation, considering R is small.

$$h_f = \frac{\omega L_1}{\omega L_2} + \frac{R \cdot h_i}{\omega^2 L_1 L_2}$$

∴ $$h_f = \frac{L_1}{L_2}$$

$$h_f = \frac{L_1}{L_2} + \frac{RCh_i}{L_{11}}$$

Where

$$L_{11} = \frac{L_1 L_2}{L_1} + L_2$$

$$L_{11} = L_1 L_2 / L_1 + L_2$$

$$L_{11}(L_1 + L_2) = L_1 L_2$$

$$L_{11} \times \frac{1}{\omega 2C} = L_1 L_2$$

$$\Theta\ x_1 + x_2 = -x_3$$

$$\omega L_1 + \omega L_2 = -\left(\frac{-1}{\omega C}\right)$$

$$L_1 + L_2 = -\frac{1}{\omega^2 C}$$

∴ $$\frac{L_1}{L_2} + \frac{Rh_i}{\omega^2 L_1 L_2} = \frac{L_1}{L_2} + \frac{Rh_i}{\omega^2 L_1 L_2} = \frac{L_1}{L_2} + \frac{Rh_i C}{L_{11}}$$

Colpitts Oscillator:

$$R = \frac{C_2}{C_1} + Rh_i \frac{1}{L}(C_1 + C_2) Rh_i$$

$$R = \frac{C_2}{C_1}\left[\text{neglecting } \frac{Rh_i}{L}(C_1 + C_2)\right]$$

The circuit diagram of Colpitts oscillator is shown in Fig.

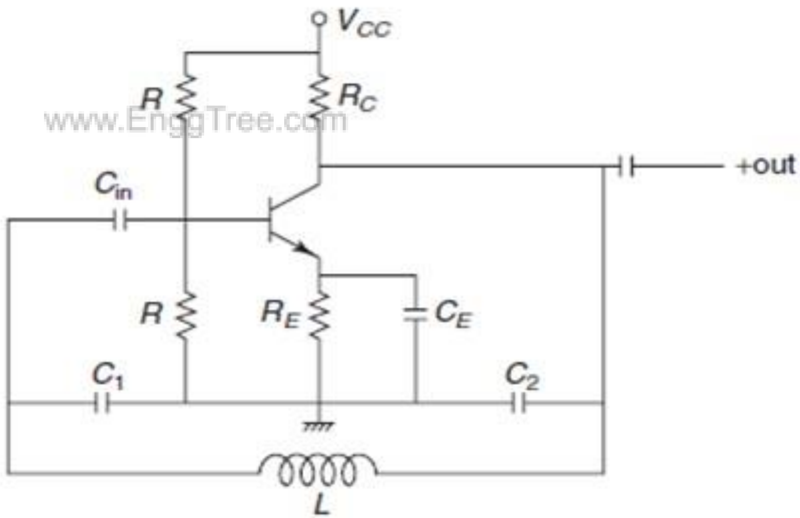


Figure Colpitts oscillator

Colpitts Oscillator:

Colpitt oscillator contains two capacitors and one inductor, as shown in Fig. X_1 and X_2 are capacitances, X_3 is inductance, Z_1 and Z_2 are capacitors, C_1 and C_2 are capacitances, and Z_3 is an inductor of inductance L.

$$X_1 = -\frac{1}{\omega C_1}$$

$$X_2 = -\frac{1}{\omega C_2}$$

$$X_3 = \omega L$$

$$X_1 + X_2 + X_3 = 0$$

$$-\frac{1}{\omega C_1} - \frac{1}{\omega C_2} + \omega L = 0$$

$$\frac{1}{\omega}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = \omega L$$

Colpitts Oscillator:

$$\frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_2}\right)=\omega^2,\ \omega=\sqrt{\frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_2}\right)}$$

Frequency of oscillation:

$$2\pi f=\frac{1}{\sqrt{LC}}\Rightarrow f=\frac{1}{2\pi\sqrt{LC}}$$

Where,

$$\frac{1}{C'}=\frac{1}{C_1}+\frac{1}{C_2}$$

$$h_f=\frac{X_1}{X_2}+\frac{Rh_i}{X_1X_2}$$

Therefore, condition for oscillation:

$$h_f=\frac{C_2}{C_1}+Rh_i\,\omega^2C_1C_2$$

$$=\frac{C_2}{C_1}+R_{hi}\,\omega^2C_1C_2$$

R = Resistance of the coil 2

$$R=\frac{C_2}{C_1}+Rh_i\frac{1}{L}\cdot\frac{C_1+C_2}{C_1\cdot C_2}\cdot C_1\,C_2\ \left[\because \omega^2=\frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_2}\right)\right]$$

Phase-Shift Oscillator:

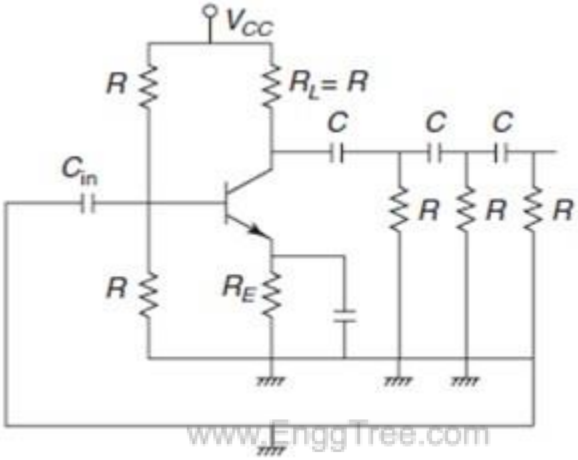


Figure Phase-shift oscillator: equivalent circuit using the approximate equivalent circuit of the transistor

Eliminating i_1, i, i^1,

$$\begin{vmatrix} i_1 & i & i^1 \\ (2R + jx_c) & 0 & -R \\ Rh_f & (2R + jx_c) & -R \\ -R & -R & (2R + jx_c) \end{vmatrix}$$

Phase-Shift Oscillator:

The circuit diagram of a phase-shift oscillator with three pairs of RC combination is shown in Fig.

The equivalent circuit representation of phase-shift oscillator is shown in Fig. By applying KVL in the circuit in Fig. we have the mesh ABCHIJ at loop (2).

$$(i + h_f i_1) R + (i - i^1) R + \frac{i}{jwc} = 0$$

$$\left(2R + \frac{1}{jwc}\right) i + R h_f i_1 - R i^1 = 0$$

$$(2R + jx_c)\, i + R h_f i_1 - R i^1 = 0$$

At mesh CDGH [at loop (3)]:

$$(i^1 - i) R + \frac{1}{j\omega c} i^1 + (i^1 - i_1) R = 0$$

$$(2R + jx_c) i^1 - Ri - Ri_1 = 0$$

At mesh CDEFGH [at loop (4)]:

$$(i_1 - i^1) R + jx_c\, i_1 + R i_1 = 0$$

$$(2R + jx_c)\, i_1 - R i^1 = 0$$

Phase-Shift Oscillator:

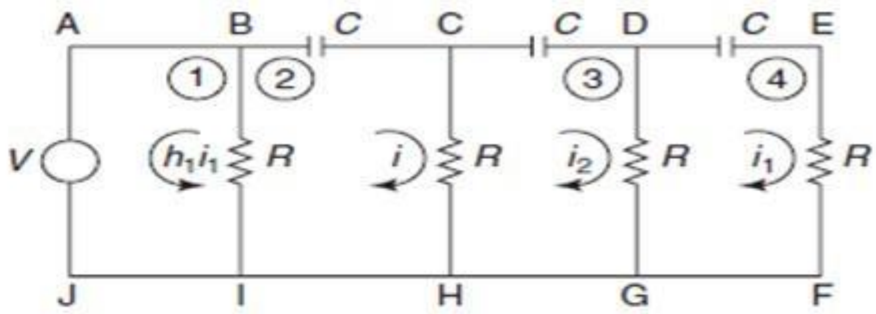


Figure Equivalent circuit representation of a phase-shift oscillator

Dividing each element of the determinant by R:

$$\therefore \quad \frac{1}{R}\begin{vmatrix} R(2+jx_c/R) & 0 & -R \\ R_{hf} & R(2+jx_c/R) & -R \\ -R & -R & R(2+jx_c/R) \end{vmatrix} = 0$$

Let $$\frac{X_C}{R} = a$$

$$\therefore \quad \begin{vmatrix} (2+ja) & 0 & -1 \\ h_f & (2+ja) & -1 \\ -1 & -1 & (2+ja) \end{vmatrix} = 0$$

Phase-Shift Oscillator:

Let $$\frac{X_C}{R} = a$$

$$\therefore \quad \begin{vmatrix} (2+ja) & 0 & -1 \\ h_f & (2+ja) & -1 \\ -1 & -1 & (2+ja) \end{vmatrix} = 0$$

$$(2+ja)\,[(2+ja)^2 - 1] + 0 + (-1)\,[-h_f + 2 + ja] = 0$$

$$(2+ja)\,[4 + 4ja - a^2 - 1] + h_f - 2 - ja = 0$$

$$8 + 8ja - 2a^2 - 2 + 4ja - 4a^2 - ja^3 - ja + h_f - 2 - ja = 0$$

$$-ja^3 + 8 + 12ja - 6a^2 - 4 - 2ja + h_f = 0$$

$\therefore$ Equating the imaginary parts:

$$j\,(-a^3 - 2a + 12a) = 0$$

$$a\,(10 - a^2) = 0$$

$$a^2 - 10 = 0$$

$$\therefore \quad a = \sqrt{10}$$

Phase-Shift Oscillator:

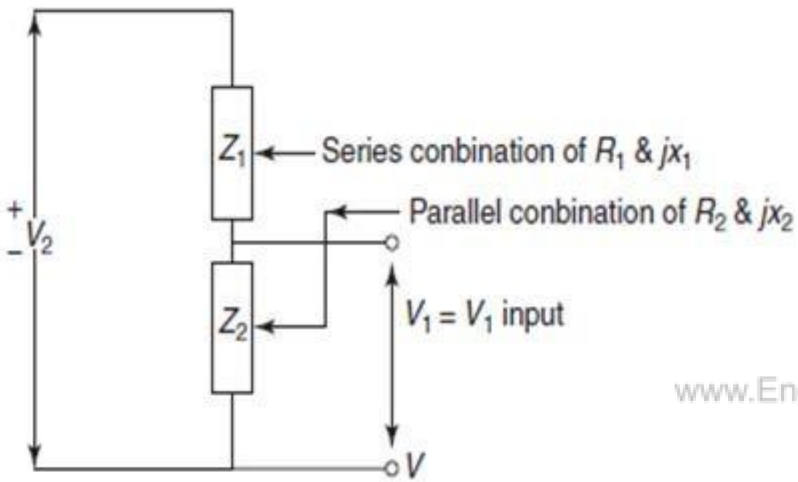


Figure Equivalent diagram of a phase-shift oscillator

$$\frac{XC}{R} = \sqrt{10}$$

$$\frac{X_c^2}{R^2} = 10$$

$$\frac{1}{\omega^2 C^2 R^2} = 10$$

$$\omega^2 = \frac{1}{10C^2R^2}$$

$$\omega = \frac{1}{\sqrt{10}\,CR}$$

Phase-Shift Oscillator:

∴ Frequency of oscillation is:

$$f = \frac{1}{2\pi\sqrt{10}\,CR}$$

Equating the real parts we get:

$$8 - 6a^2 - 4 + h_{fe} = 0$$

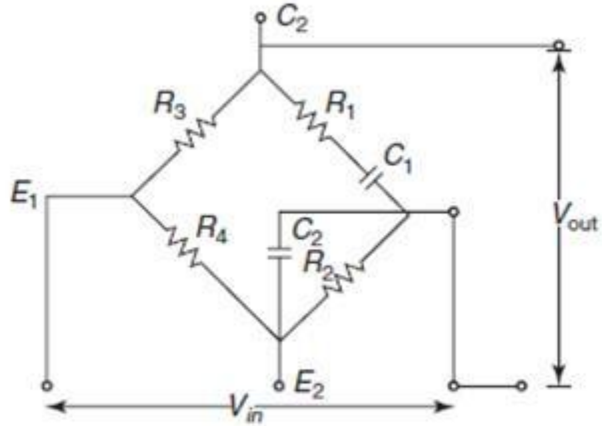
$$h_{fe} = 4 + 6a^2 - 8 = 4 + 6.10 - 8$$

$$= 4 + 60 - 8$$

$$= 56$$

For sustained oscillations, h_{fe} of 56 for $R = R_L$
The equivalent diagram of a phase-shift oscillator is shown in Fig.

Wien-Bridge Oscillator:



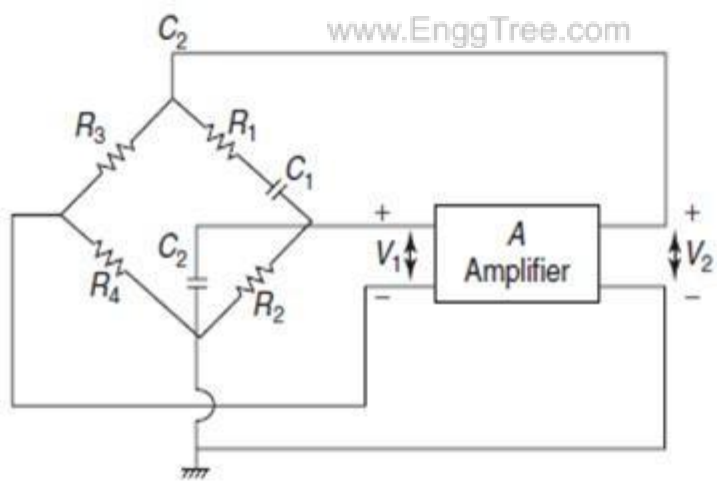


Figure Wien-bridge oscillator with an amplifier

Wien-Bridge Oscillator:

Wein-bridge oscillator is the series and parallel combination of a resistance R and a capacitor C. According to Barkhausen criteria, $A_v\beta = 1$.

Since $A_v\beta = 1$,

$$\beta = \frac{1}{A_v} = \frac{v_f}{v_0} = \frac{v_{zi}}{(z_1 + z_2)i}$$

$$A_v = \frac{1}{\beta} = \frac{z_1 + z_2}{z_2} = 1 + \frac{z_1}{z_2}$$

$$z_1 = R + jx_1 \text{ [series combination]}$$

$$\frac{1}{z_2} = \frac{1}{R_2} + \frac{1}{jx_2} \quad \text{[parallel combination]}$$

$$A = 1 + (R_1 + jx_1)\left(\frac{1}{R_2} + \frac{1}{jx_2}\right)$$

$$= 1 + \left(\frac{R_1}{R_2} + \frac{x_1}{x_2}\right) + j\left(\frac{x_1}{R_2} - \frac{R_1}{x_2}\right)$$

Wien-Bridge Oscillator:

The two-stage *RC* coupled amplifier can be used by equating real and imaginary parts. Considering only the real parts, we get:

$$A = 1 + \frac{R_1}{R_2} + \frac{x_1}{x_2}$$

Considering only the imaginary parts, we get:

$$\frac{x_1}{R_2} - \frac{R_1}{X_2} = 0$$

$X_1 X_2 = R_1 R_2$ (frequency of oscillation)

$$R_1 R_2 = \frac{1}{w^2 c_1 c^2}$$

$$w^2 = \frac{1}{C_1 C_2 R_1 R_2}$$

Wien-Bridge Oscillator:

If $R_1 = R_2 = R$ & $C_1 = C_2 = C$

$$A = 1 + 1 + 1 = 3$$

And,

$$w^2 = \frac{1}{C^2R^2} \Rightarrow w = \frac{1}{CR}$$

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

At balance condition:

$$\frac{R_3}{R_4} = \frac{Z_1}{Z_2} \text{(for oscillation)}$$

Wien-Bridge Oscillator:

From the circuit diagram of the wien-bridge oscillator, as given in Fig. we get:

$$\frac{R_3}{R_4} = \left(R_1 + \frac{1}{jwc_1}\right)\left(\frac{1}{R_2} + jwc_2\right)$$

$$= \left(\frac{R_1}{R_2} + \frac{C_2}{C_1}\right) + j\left(\omega C_2 R_1 - \frac{1}{\omega C_1 R_2}\right)$$

Equating imaginary parts we get:

$$\omega c_2 R_1 = \frac{1}{\omega C_1 R_2}$$

$$\omega^2 = \frac{1}{C^2 R^2}$$

$\because R_1 = R_2 = R$ and $C_1 = C_2 = \mathrm{C}$

$\therefore$

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1}$$

$$\frac{R_3}{R_4} = \frac{R}{R} + \frac{C}{C} = 1 + 1 = 2$$

Wien-Bridge Oscillator:

19. Advantages of Wien-Bridge Oscillator:

20. The frequency of oscillation can be easily varied just by changing *RC network*

21. High gain due to two-stage amplifier

22. Stability is high

Disadvantages of Wien-Bridge Oscillator

23. The main disadvantage of the Wien-bridge oscillator is that a high frequency of oscillation cannot be generated.

CRYSTAL OSCILLATOR:

24. Crystal oscillator is most commonly used oscillator with high-frequency stability. They are used for laboratory experiments, communication circuits and biomedical instruments. They are usually, fixed frequency oscillators where stability and accuracy are the primary considerations.

25. In order to design a stable and accurate LC oscillator for the upper HF and higher frequencies it is absolutely necessary to have a crystal control; hence, the reason for crystal oscillators.

26. Crystal oscillators are oscillators where the primary frequency determining element is a quartz crystal. Because of the inherent characteristics of the quartz crystal the crystal oscillator may be held to extreme accuracy of frequency stability. Temperature

27. compensation may be applied to crystal oscillators to improve thermal stability of the crystal oscillator.

28. The crystal size and cut determine the values of L, C, R and C'. The resistance R is the friction of the vibrating crystal, capacitance C is the compliance, and inductance L is the equivalent mass. The capacitance C' is the electrostatic capacitance between the mounted pair of electrodes with the crystal as the dielectric.

Circuit Diagram of CRYSTAL OSCILLATOR:

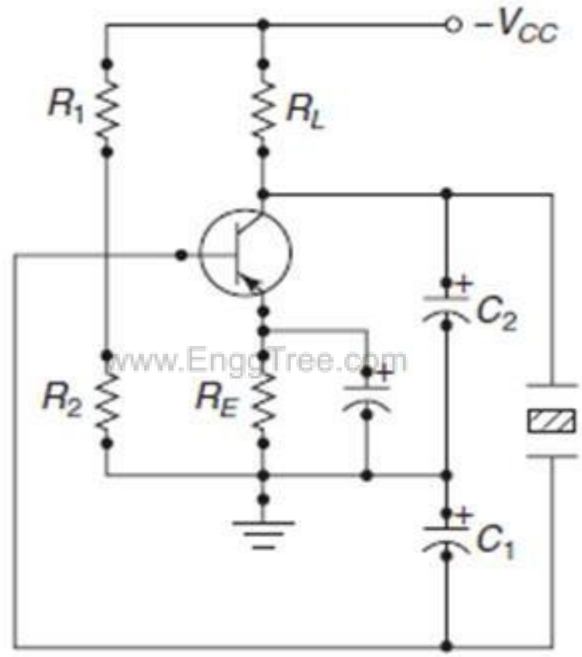


Figure Circuit of a crystal oscillator

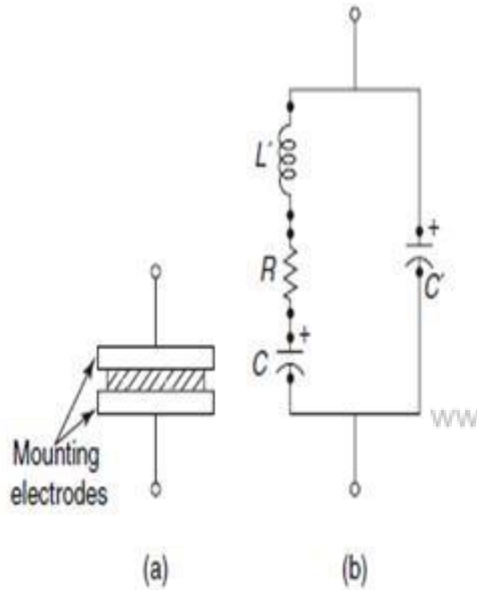


Figure (a) Symbol of a vibrating piezoelectric crystal (b) Its equivalent electrical circuit

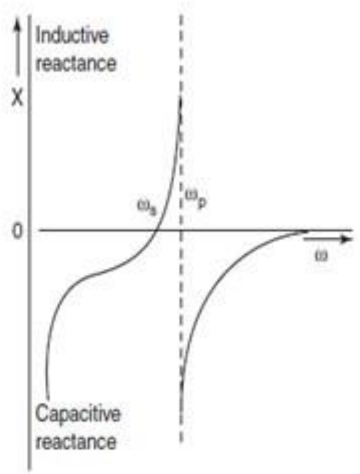


Figure Reactance vs. frequency graph

Circuit Analysis of CRYSTAL OSCILLATOR:

The circuit of Fig has two resonant frequencies. At the series resonant frequency f_s the reactance of the series LC arm is zero, that is:

$$\omega_s L - \frac{1}{\omega_s C} = 0$$

or
$$\omega_s = \frac{1}{\sqrt{LC}}$$

ω_p is the parallel resonant frequency of the circuit greater than ω_s where:

$$\left(\omega_p L - \frac{1}{\omega_p C}\right) = \frac{1}{\omega_p C'}$$

or
$$\omega_p^2 = \frac{1}{L}\left(\frac{1}{C} + \frac{1}{C'}\right)$$

or $$\omega_p = \sqrt{\frac{1}{2}\left(\frac{1}{C} + \frac{1}{C'}\right)}$$

Therefore, ω_p and ω_s are as shown in Fig. 12-12. At the parallel, resonant frequency, the impedance offered by the crystal to the internal circuit is very high.

The resonant frequencies of a crystal vary inversely as the thickness of the cut.

$$f = \frac{1}{t}$$

APPLICATIONS OF OSCILLATORS:

- Oscillators are a common element of almost all electronic circuits. They are used in various applications, and their use makes it possible for circuits and subsystems to perform numerous useful functions.
- In oscillator circuits, oscillation usually builds up from zero when power is first applied under linear circuit operation.
- The oscillator's amplitude is kept from building up by limiting the amplifier saturation and various non-linear effects.
- Oscillator design and simulation is a complicated process. It is also extremely important and crucial to design a good and stable oscillator.
- Oscillators are commonly used in communication circuits. All the communication circuits for different modulation techniques—AM, FM, PM—the use of an oscillator is must.
- Oscillators are used as stable frequency sources in a variety of electronic applications.
- Oscillator circuits are used in computer peripherals, counters, timers, calculators, phase-locked loops, digital multi-metres, oscilloscopes, and numerous other applications.

POINTS TO REMEMBER:

29. 1. Oscillator converts dc to ac.

30. 2. Oscillator has no input signal.

31. 3. Oscillator behaviour is opposite to that of a rectifier.

32. 4. The conditions and frequencies of oscillation are classified as:

Types of Oscillator	*Condition of Oscillation*	*Frequency of Oscillation*
Hartley Oscillator	$h_f = \frac{\omega L_1}{\omega L_2} + \frac{Rh_i}{\omega^2 L_1 L_2}$	$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\frac{1}{[(h_{oe}L_1L_2/h_{ie}) + C(L_1 + L_2)]^{1/2}}$ Simply, $f = \frac{1}{2\pi\sqrt{C(L_1 + L_2)}} = \frac{1}{2\pi\sqrt{LC'}}$
Colpitts Oscillator	$h_f = \frac{C_2}{C_1} + Rh_i \cdot \omega^2 C_1 C_2$	$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\left(\frac{h_{oe}}{h_{ie}C_1C_2} + \frac{1}{LC_1} + \frac{1}{LC_2}\right)^{1/2}$
Phase-Shift Oscillator	The transistor should have an h_{fe} of 56 when $RL = R$.	$f = \frac{1}{2\pi\sqrt{10}CR}$
Wein-Bridge Oscillator	$\frac{R_1}{R_2} = 2$	$f = \frac{\omega}{2\pi} = \frac{1}{2\pi RC}$
Crystal Oscillator	—	$f_p = \frac{\omega_P}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{C + C'}{LCC'}}$

1. General condition for oscillation for an oscillator:

$$h_f = \frac{x_1}{x_2} + \frac{R_{hi}}{x_1 x_2}$$

2. Frequency of oscillation for a Hartley oscillator:

$$f = \frac{1}{2\pi}\sqrt{C(L_1 + L_2)}$$

3. Condition for oscillation for a Colpitts oscillator:

$$h_f = \frac{C_2}{C_1} + Rh_i\,\omega^2 C_1 C_2$$

4. Frequency of oscillation for a phase-shift oscillator:

$$f = \frac{1}{2\pi\sqrt{10}\,CR}$$

5. Frequency of oscillation for a Wien-Bridge oscillator:

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

6. If the feedback signal aids the externally applied input signal, the overall gain is given by:

$$Af = \frac{A}{1 - A\beta}$$

7. Value of M required for sustained oscillations is given by:

$$M = \frac{R_B}{h_{fe}}(CR + h_{oe}L) + CR\frac{h_{ie}}{h_{fe}} + L\frac{\Delta_{he}}{h_{fe}}$$

8. Oscillation frequency of a Clapp oscillator is given by:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{C_0} + \frac{1}{C_1} + \frac{1}{C_2}\right)}$$

9. Condition for sustained oscillation for a phase-shift oscillator is given by:

$$h_{fe} = 23 + 29\frac{R}{R_L} + 4\frac{R_L}{R}$$