UNIT-I

SYLLABUS

Semiconductor Diodes: P and N type semiconductors. Energy Level Diagram. Conductivity and Mobility, Concept of Drift velocity. PN Junction Fabrication (Simple Idea). Barrier Formation in PN Junction Diode. Static and Dynamic Resistance. Current Flow Mechanism in Forward and Reverse Biased Diode. Drift Velocity. Derivation for Barrier Potential, Barrier Width and Current for Step Junction.

Conductor

A material that allows electricity to pass through it is known as conductor. Charges are allowed to move freely in the conductor. E.g.: Usually metals are conductors.

Insulator

A material which does not allow electricity to pass through it is known as insulator. Charges are not allowed to move in insulator. E.g.: Plastic, wood are insulators.

Semiconductors

A material that can behave as a conductor as well as an insulator is known as semiconductor.

E.g.: germanium, silicon etc.

Conductivity

The measurement of charges which are allowed to flow in a material is known as conductivity of the material.

Resistivity

The measurement of the resisting power i.e. restriction to the flow of charge in the material, is called as resistivity.

conductivity = 1/resistivity

	Resistivity	Conductivity
Conductors	10^{-2} to 10^{-8} Ωm	10^{2} to 10^{8} Sm^{-1}
Semiconductors	10^{-5} to 10^{6} Ωm	10^{5} to 10^{-6} Sm^{-1}
Insulators	10^{11} to 10^{19} Ωm	10^{-11} to 10^{-19} Sm^{-1}

Observations

- Conductors have high conductivity and very low resistivity.
- Insulator have low conductivity and high resistivity.
- Semiconductors have conductivity and resistivity in between the conductor and insulator.

Types of Semiconductors

- Elemental Semiconductors: Silicon (Si), Germanium (Ge)
- Compound Semiconductors: There can be three types of Compound semiconductors –

- Inorganic semiconductors: Cadmium sulphide (Cd S), Gallium arsenide (Ga As), Cadmium selenide (Cd Se), Indium phosphide (In P).
- Organic semiconductors: Anthracene, Phthalocyanine.
- Organic Polymers: Polypyrrole, Polyaniline, Polythiophene.

Energy Level

In an isolated atom, the energy processed by the electrons in the same orbit is almost equal. When the atoms are placed in a crystal form the energy level of each electron changes due to the effect of other closely placed atoms.
There are two types of electrons present in an atom

- **Valence electron** − An atom requires eight electrons in the outer most orbit to be stable. So the atom shares electrons with another atom to attain stability, this is known as valence fulfilment. In valence fulfilment the electron that is shared between the two atoms is known as valence electron.

- **Free electron** − If an electron receives energy externally such as due to heat the electron moves out of the valence band and becomes free. The free electron has a greater energy than the valence electron.

When electric current is passed through the material the free electrons move towards the positive direction of current resulting in conduction of current through the material.
In crystal formation the energy level of electron can be categorised into two distinct energy levels or energy bands.

Valence Band − Valence band contains valence electrons. The valence band can be completely filled with electrons or sometimes partially filled with electrons but it is never empty. As these are valence electrons they are not affected by the electric filled.

Conduction Band − Conduction band contains free electrons. It can be empty or partially filled with electrons. As these are free electrons they conduct electricity through the material.

Forbidden Band / Energy Gap (E_g) − The forbidden band is completely empty as there are no electrons in it. To move an electron from the valence band to the conduction band an energy equal to the energy gap is required.

N type Semiconductors

When Si or Ge crystal is doped with pentavalent impurity we get n type semiconductor.
Example of pentavalent atom: Phosphorous (P), Arsenic (As), Antimony (Sb).
Pentavalent atom has 5 electrons in its valence shell. Figure shows the structure of n type semiconductor. Every pentavalent dopant atom finds 4 neighboring Si atoms. It shares its 4 valence electrons with four Si atoms to form octet and Si atoms become stable.

Since valence orbit can hold maximum 8 electrons, the 1 extra electron of dopant atom is not the part of covalent bonding and hence it becomes free electron. The free electron of phosphorous atom has energy 0.01eV less than the conduction band energy of Silicon. At room temperature these free electrons move to the conduction band and are available for conduction of electricity.

Due to these extra free electrons in the crystal structure, the number of electrons become greater than the number of holes in the crystal.

Note − Number of holes will decrease but will never become zero, there would be a small number of holes present in the crystal.

Relationship between the number of electrons and number of holes is given by -

$$\mathbf{n_e \times n_h = n_i^2}$$

Where,

n_e = number of electrons.

n_h = number of holes.

n_i = total number of charge carriers.

Conduction band is crowded by electrons and holes in the valence band are decreased in N type semiconductor. In N type semiconductor electrons are majority charge carriers and holes are minority charge carriers. Since every pentavalent dopant atom donates 1 electron for conduction; it is called donor type dopant. As we can control the number of dopant i.e. we can control the number of free electrons and hence control the conductivity of semiconductor.

P-Type Semiconductors

When Si or Ge crystal or intrinsic semiconductor is doped with measured quantity of trivalent impurity such as indium(In), boron (B), aluminum (Al), we get p type semiconductor. The trivalent atom has three electrons in valence shell. Every trivalent dopant atom shares its 3 electrons with 3 neighboring Si atoms to form covalent bond. But, the bond between dopant atom and 4th neighbor is not completed as trivalent atom has no more electron to share. Hence creating a vacancy that acts as a hole. This hole has tendency to accept any electron in its close vicinity. For this reason, trivalent impurity is called as an acceptor type dopant. At room temperature, an electron from neighboring atom can jump into the hole. This hole disappears and new hole is created at the position of displaced electron.

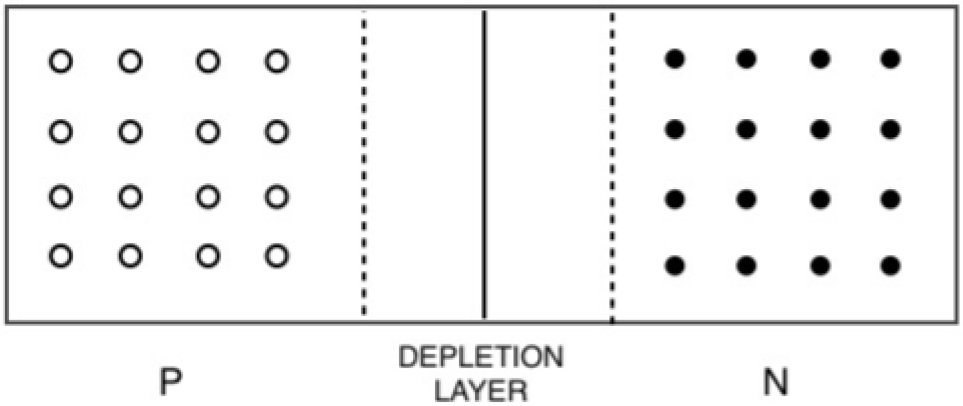
As this semiconductor has large number of holes and conductivity is because of positively charged holes, it is called p type semiconductor. In P type semiconductor holes are majority charge carriers and electrons are minority charge carriers. The number of holes is comparatively very large than the number of electrons.

$$\mathbf{n_h >> n_e}$$

Though P type semiconductor has large numbers of holes, its net charge is zero.

P-N Junction

When half part of a Si crystal is doped with trivalent impurity and half with pentavalent impurity, we get P-N junction diode.The border where p-region meets with n-region is called the junction.



P and N type junction develops a depletion-layer around it due to the recombination of electrons from N-side and holes on P-side. No charge carriers are present in this region as combination of holes and electrons create neutral atoms, hence depletion-layer has high resistance. No charge carriers from either side is allowed to cross the depletion layer. Due to losing electrons 'N' develops a positive charge layer, and 'P' develops a negative charge layer. Hence an electric field or potential difference is developed between the two. This potential difference prevents the flow of majority charge carriers across the junction, hence called as potential barrier. When no external source is connected to diode it is said to be unbiased diode. Majority charge carriers i.e. holes in the P side and electrons in the N side cannot flow through the depletion-layer, but minority charge carriers i.e. electrons in P side and holes in N side can flow through depletion-layer. P-N junction diode acts as an insulator.

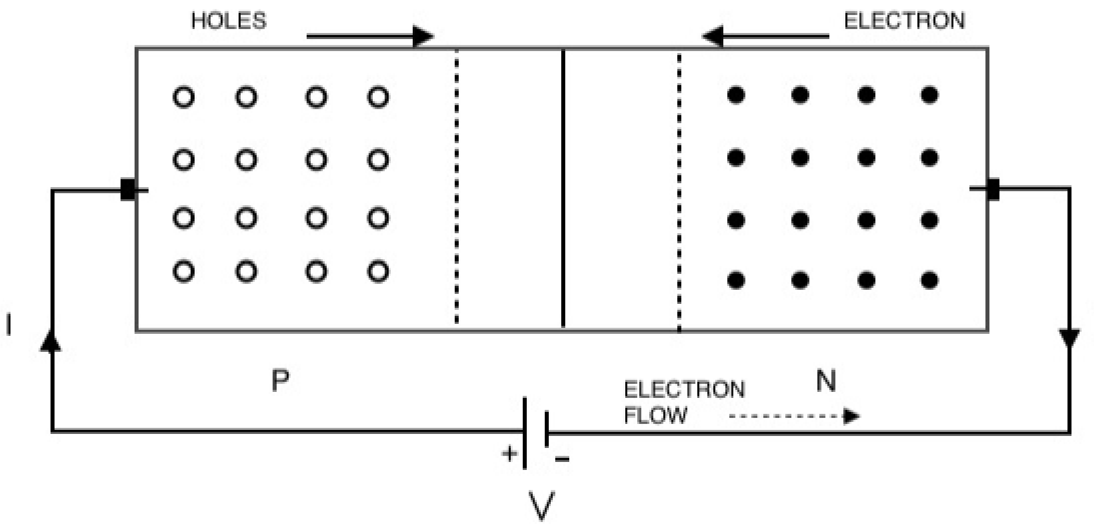
Biasing of P-N Junction

Biasing in the process of applying potential difference to the semiconductor. Biasing is achieved by applying EMF across the P-N junction diode.
Biasing can be of two types –

- Forward biasing
- Reverse biasing

Forward biasing

When positive terminal of the battery is connected to P-side and negative terminal to N-side it is called forward biasing and the diode is said to be forward biased.



When forward biased, electrons from N-side and holes from P-side are pushed towards the junction. The depletion layer's width decreases. As depletion layer decreases, potential barrier also decreases. The potential difference within the P-N junction diode is known as induced potential ($V_{induced}$) and potential difference applied externally is called applied potential ($V_{applied}$).

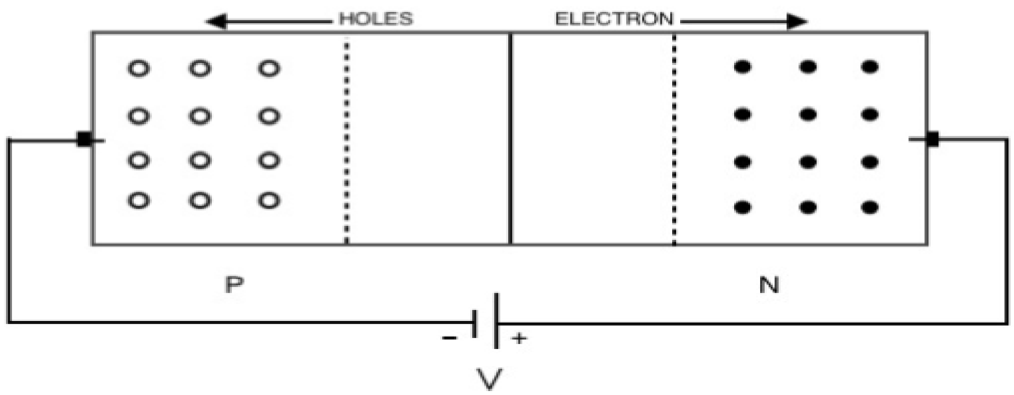
Total Potential Difference = $V_{Induced} + V_{Applied}$

The direction of both the potential are opposite to each other therefore, as the applied potential increases it reduces the effect of induced potential. When the applied potential is equal to the induced potential then, the net potential equals to zero and the depletion layer vanishes.

As there is no depletion layer, large number of electrons and holes cross the junction. They recombine and large current flows through the diode. After recombining, the electrons travel as valence electrons then leave the Pregion and enter positive terminal of the source. A continuous current flows in the diode. That is, on forward biasing, P-N junction diode acts as conductor.

Reverse Biasing Of P-N Junction

When positive terminal of the battery is connected to N-side and negative terminal to P-side, it is known as reverse biasing and the diode is said to be reversed biased.



In reverse biasing, free electrons and holes move away from the junction. Hence, increasing the width of depletion layer. As the depletion layer increases, potential barrier also increases.

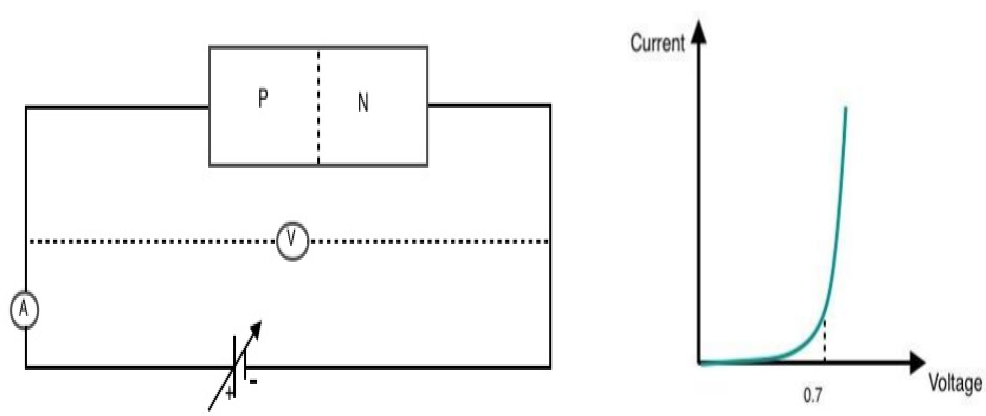
In reverse biasing the induced and applied potential are in the same direction i.e. the net potential will increase with the increasing applied potential. Higher will be the net potential in the diode, higher will be the resistance. Majority charge carriers cannot move across the junction, hence current will not be allowed to flow across the diode. That is, on reverse biasing, P-N junction diode acts as insulator. The current flowing in the reverse biased circuit due to the minority charge carrier is known as reverse current.

Characteristic Of P-N Junction

To study V-I characteristic of diode the external source is connected to diode through rheostat so that variable voltage can be applied to diode. A voltmeter is connected parallel to diode to read diode voltage and current meter is connected in series with diode to measure resulting current. Characteristics can be studied separately for forward biasing and reverse biasing.

Forward characteristic

When forward biased (Si diode), initially current does not flow until biasing is less than potential barrier (0.7 V) but it increases suddenly beyond 0.7 V and current is directly proportional to voltage.



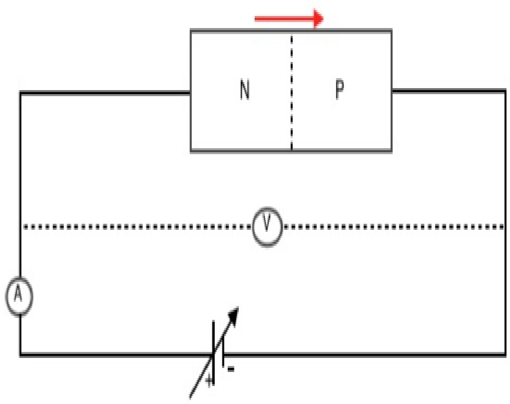
Resistance in forward biasing is dynamic resistance which is given by -

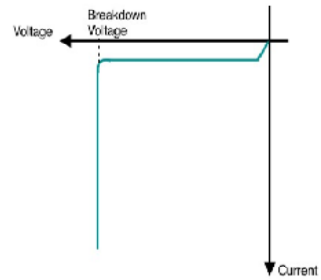
$$\mathbf{R = \Delta v/\Delta i}$$

Resistance in forward biasing in the range of few ohm to ten kilo ohm.

Reverse characteristic

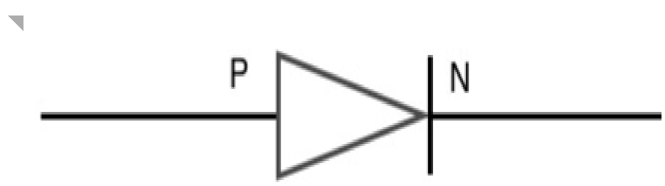
When the diode is reverse biased, there is no crossing of majority carriers and current is approximately zero.





A very small current of the order nA flows because of minority carriers in depletion region. This current is called reverse current.When reverse biasing increases, at a particular high value, the reverse current increases suddenly and a large amount of atoms are broken down in the depletion layer. This is called breakdown of diode. If this reverse current is not controlled, p-n junction gets damaged due to excess heating. The reverse voltage, at which the diode breakdown occur is called breakdown voltage (V_{BR}). For general purpose diode, the reverse voltage is always kept below the breakdown voltage.Resistance in forward biasing is in the range of thousand kilo ohm.

Symbol for P-N junction



Conductivity:-

Electrical conductivity is the measure of the ability to carry a current. Electrical conductivity is also known as specific conductance.

Mobility(u):-

Mobility is measurement of how quickly an electron pass through a conductor and it's magnitude is equal to drift speed per unit electric field intensity.

Here is the derivation of relation between mobility and conductivity:

Drift Velocity

Subatomic particles like electrons move in random directions all the time. When electrons are subjected to an electric field they do move randomly but they slowly drift in one direction, in the direction of the electric field applied. The net velocity at which these electrons drift is known as **drift velocity**.

PN Junction Fabrication

Basically, the semiconductor material, say silicon, is "doped" with a substance that makes the new molecules/crystals either more easily provide electrons (N material) or more easily accept electrons (P material). Doping comes in a number of flavors, but in general you want the chemical transformation of the material on well controlled boundaries. Photomasks have been used to control exposure or reaction to different chemicals and make sure doping happens in controlled regions and geometries, but other techniques exist.

There are a number of modern techniques for doing all of this. Sometimes it involves adding a chemical layer. Sometimes it is changing the properties of select portions of the material surface with light, x-rays, or ions (this forms the geometry as we can control the application of the energetic action). Other times, parts of the layer can will be removed with acid, based on the application of the energetic action. This process is repeated over and over in various combinations to get the metal, insulators, p and n materials in the shape desired.

Simple diodes require very few steps, and can be made in bulk relatively inexpensively. More complex diodes that are designed to operate at very high frequencies can see many steps to get just the right shape. As the frequency exceeds 40 GHz the shape of the region edges cause diode like actions given the energy threshold is greater in one direction than the other.

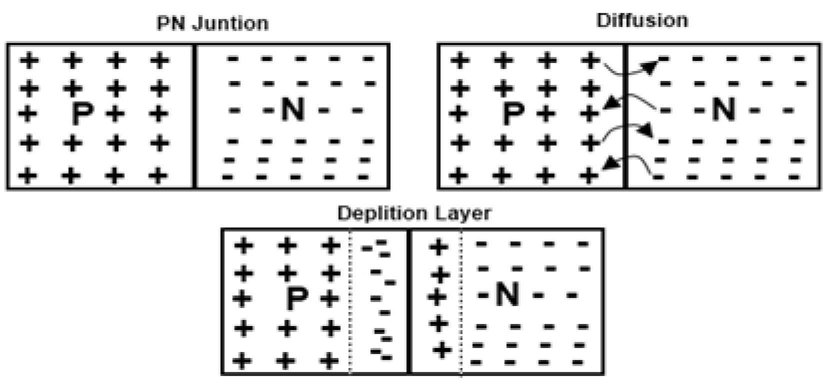
Barrier formation

p–n junction is a junction 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 more often 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).

Formation of the Depletion Region-At the instant of the PN junction formation free electrons near the junction diffuse across the junction into the P region and combine with holes. Filling a hole makes a negative ion and leaves behind a positive ion on the N side. These two layers of positive and negative charges form the depletion region, as the region near the junction is depleted of charge carriers. As electrons diffuse across the junction a point is reached where the negative charge repels any further diffusion of electrons. The depletion region now acts as a Barrier.

Barrier Potential

The electric field formed in the depletion region acts as a barrier. External energy must be applied to get the electrons to move across the barrier of the electric field. The potential difference required to move the electrons through the electric field is called the barrier potential. Barrier potential of a PN junction depends on the type of semiconductor material, amount of doping and temperature. This is approximately 0.7V for silicon and 0.3V for germanium.



Static and Dynamic Resistance.

Static Resistance is the normal ohmic **resistance** in accordance with Ohm's Law. It is the ratio of voltage and current and is a constant at a given temperature. ... **Dynamic resistance** refers to the change in current in response to a change in voltage at a specific region of the VI curve.

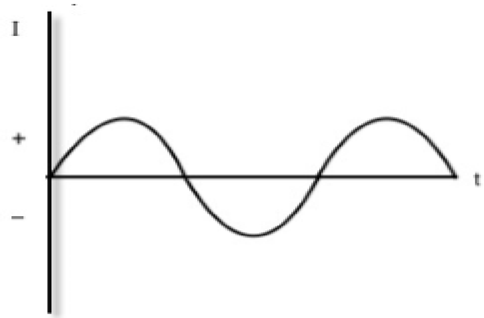
UNIT-II

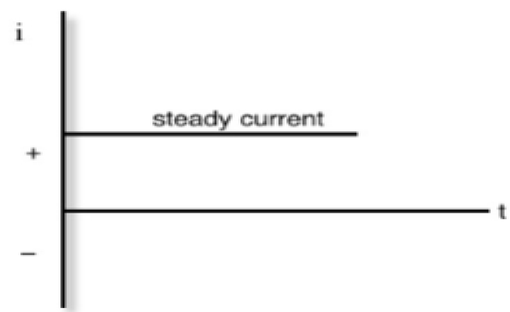
SYLLABUS

Two-terminal Devices and their Applications: Rectifier Diode: Half-wave Rectifiers. Centre-tapped and Bridge Full-wave Rectifiers, Calculation of Ripple Factor and Rectification Efficiency, C-filter, Zener Diode and Voltage Regulation. Principle and structure of LEDs, Photodiode and Solar Cell.
Bipolar Junction transistors: n-p-n and p-n-p Transistors. Characteristics of CB, CE and CC Configurations. Current gains α and β Relations between α and β. Load Line analysis of Transistors. DC Load line and Q-point. Physical Mechanism of Current Flow. Active, Cutoff and Saturation Regions.

Rectifier-Principle

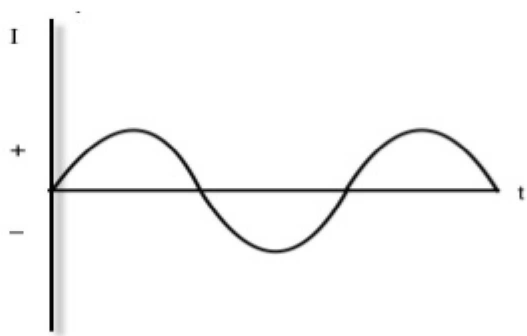
Majority of electronic devices require direct current sources for their operations. But domestic electric supply is available in alternating current form. Therefore, it has to be converted in direct current.Rectifier is a device which coverts alternating current to direct or steady current is known a rectifier.

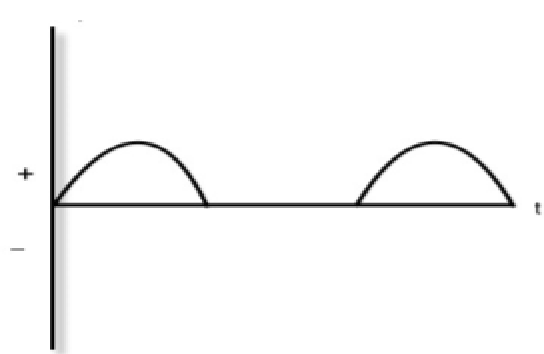




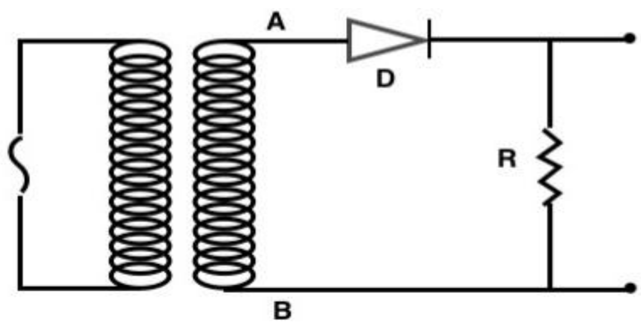
Half wave rectifier

Half wave rectifier converts only half cycle of alternating current to direct current, the remaining half cycle is wasted.





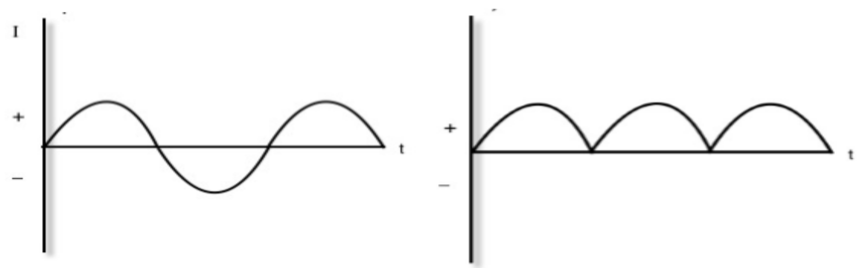
The input current is bidirectional and output current is unidirectional. The current obtained is pulsated or bumpy. Only a single diode is used in half wave rectifier.



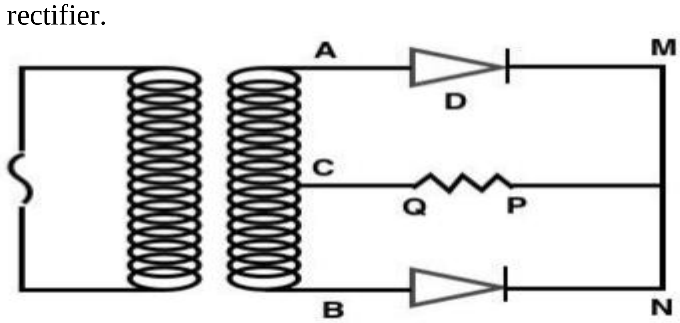
An A.C supply is provided to the transformer. The diode is connected in series with load (electronic device) resistance R_L. During every positive half cycle of the A.C input, point A becomes positive w.r.t. point B, and diode becomes forward biased and current is allowed to flow. During every negative half cycle of the A.C input, point A becomes negative w.r.t. point B, and diode becomes reverse biased and current is not allowed to flow.

Full Wave-Rectifier

Full wave rectifier converts the complete cycle of alternating current to direct current. No input current is wasted.



The input current is bidirectional and output current is unidirectional. Two diode are required for full wave rectifier.



This rectifier requires centre tapped secondary transformer. During positive half cycle of A.C input, point A is positive w.r.t point C and point B is negative w.r.t. point C, therefore the diode D_1 is forward biased and diode D_2 is reverse biased. The current flows through diode D_1 and passes through the load R_L, path of current is AMPQCA. During negative half cycle of A.C input, point B is positive w.r.t point C and point A is negative w.r.t point C, therefore the diode D_2 is forward biased and diode D_1 is reverse biased. The current flows through diode D_2, and passes through the load R_L, path of current is BNPQCB.

6.18 Ripple Factor

The output of a rectifier consists of a d.c. component and an a.c. component (also known as *ripple*). The a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output ; the smaller this component, the more effective is the rectifier.

The ratio of r.m.s. value of a.c. component to the d.c. component in the rectifier output is known as **ripple factor** *i.e.*

$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c component}}{\text{value of d.c. component}} = \frac{I_{ac}}{I_{dc}}$$

6.20 Filter Circuits

Generally, a rectifier is required to produce pure d.c. supply for using at various places in the electronic circuits. However, the output of a rectifier has pulsating *character *i.e.* it contains a.c. and d.c. components. The a.c. component is undesirable and must be kept away from the load. To do so, a *filter circuit* is used which removes (or *filters out*) the a.c. component and allows only the d.c. component to reach the load.

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

Obviously, a filter circuit should be installed between the rectifier and the load as shown in Fig. 6.40. A filter circuit is generally a combination of inductors (*L*) and capacitors (*C*). The filtering action of *L* and *C* depends upon the basic electrical principles. A capacitor passes a.c. readily but does not **pass d.c. at all. On the other hand, an inductor †opposes a.c. but allows d.c. to pass through it. It then becomes clear that suitable network of *L* and *C* can effectively remove the a.c. component, allowing the d.c. component to reach the load.

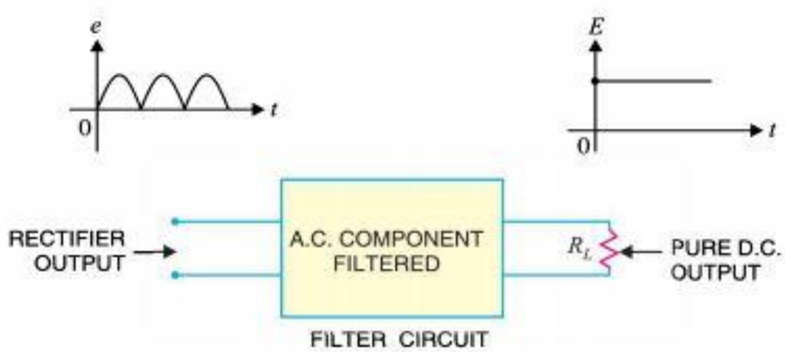
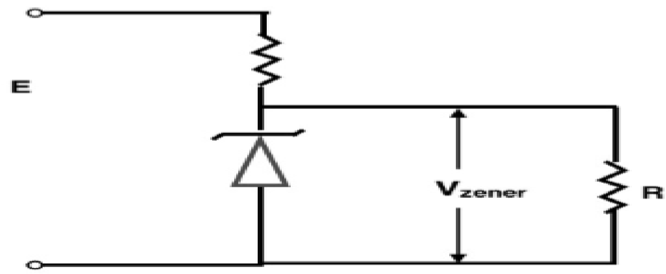


Fig. 6.40

Zener–Diode

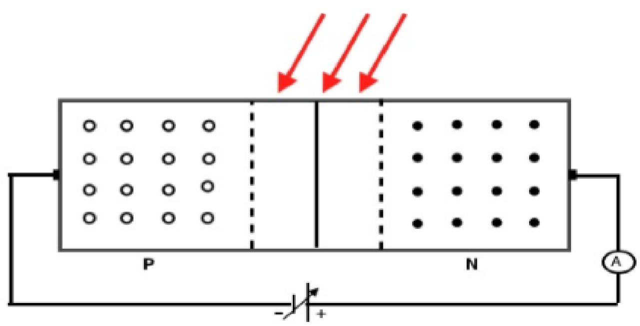
Zener diode is P-N junction diode. It is used for regulation of voltage supplied. It is highly doped and used in reverse biasing. Zener diode is designed to operate in breakdown region.



When reverse bias reaches a particular value, the current increases suddenly. This voltage is called Zener breakdown voltage or simply Zener voltage (V_Z). Breakdown for a given Zener diode depends upon doping level of P and N regions. Generally, this value is small, such as 1.5V, 2V. It is clear from characteristic that, in breakdown region, voltage across Zener diode remains almost constant even when current through it changes by large amount.

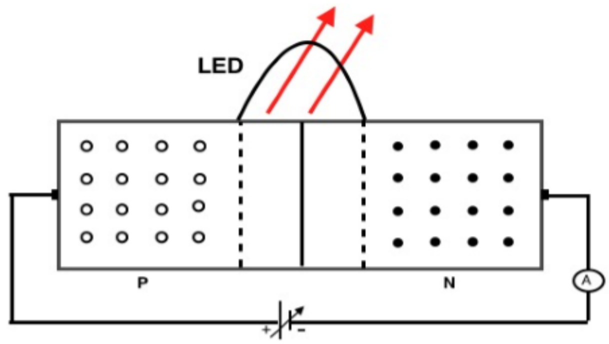
Photo Diode

Photo diode converts light energy to electrical energy, hence they can detect presence of light. For photo diode reverse biasing is used. Initially the rheostat is adjusted such that there is no reading shown in ammeter though there is current flowing through the circuit this current is known as dark current. In depletion layer only atoms are present. When light is incident on atoms in depletion layer it supplies energy to electron of that atom and this electron becomes a free electron. The free electron is pulled towards the N region and this helps in the conduction of current. This current flowing through the circuit is indicated by the ammeter and is known as photo current. Photo current indicates the intensity/presence of light.

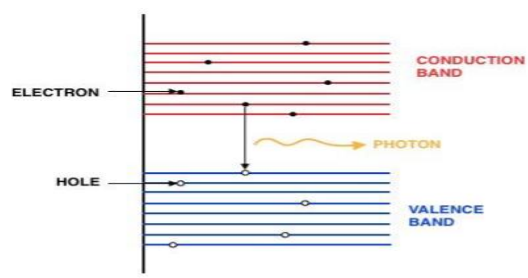


Light Emitting Diode(LED)

Light emitting diode is a special type of P-N junction diode that has energy gap greater than 1.8eV.

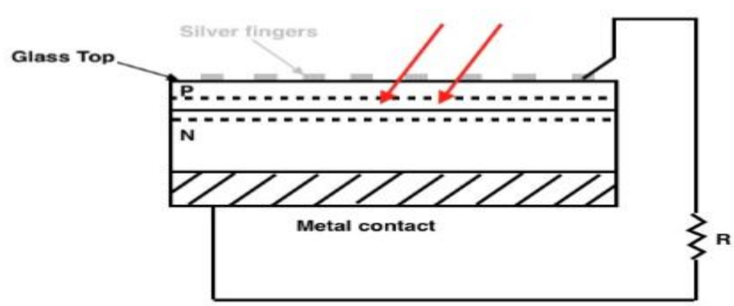


When the free electrons fall from conduction band to valence band, the energy equal to band gap (E_g) is released in the form of photons. The photon has energy **E = hv**, for the photon to be visible to human eye it should have a frequency **v** greater than visible light hence, the energy gap should have a value greater than 1.8eV hence, Silicon and Germanium cannot be used. Light emitting diodes are used in forward bias. This results in reduction of depletion layer allowing the free electrons to recombine with the holes i.e. minority charge carriers recombine and release energy slightly less than energy gap. This gives light of different colors. Gallium-Arsenide LED emits infrared light. Ga-As-P LED emits red and yellow light. Ga-P LEDs emit red, green light. LEDs cannot be used in reverse biased because if we reach the breakdown voltage a large amount of current will flow through it and the LED will burn out. Their reverse breakdown voltage is low about 5V.



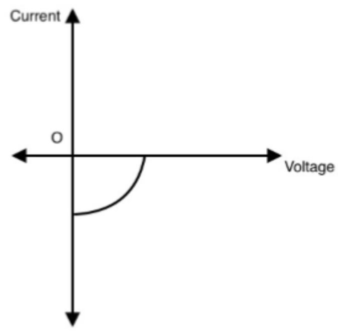
Solar-Cell

Solar cell, which is also known as photovoltaic cell, converts solar (light) energy directly into electrical energy.



Solar cell is a P-N junction diode that has very thin layer of P-type semiconductor (thickness is in μm) so that light can reach the junction. The photon that is reaching the junction should have energy greater than the energy gap. Metallic contacts are formed on both the layers for external circuit connections. At the top silver fingers are used, as silver is the best conductor and they are used to absorb photo electrons. This displacement of charges sets up a potential difference across two regions, with P-side as positive and N-side as negative. If external load RL is connected, current flows through it and we get electrical energy. Typically, a solar cell can generate photo voltage from 0.5 V to 1.2 V.

V-I characteristic of solar cell



Applications of solar cell

- Charging storage batteries.
- Charging satellite batteries.
- Pumps and other electronic appliances in the far-off areas use solar cell.
- Radiophones.

Transistor

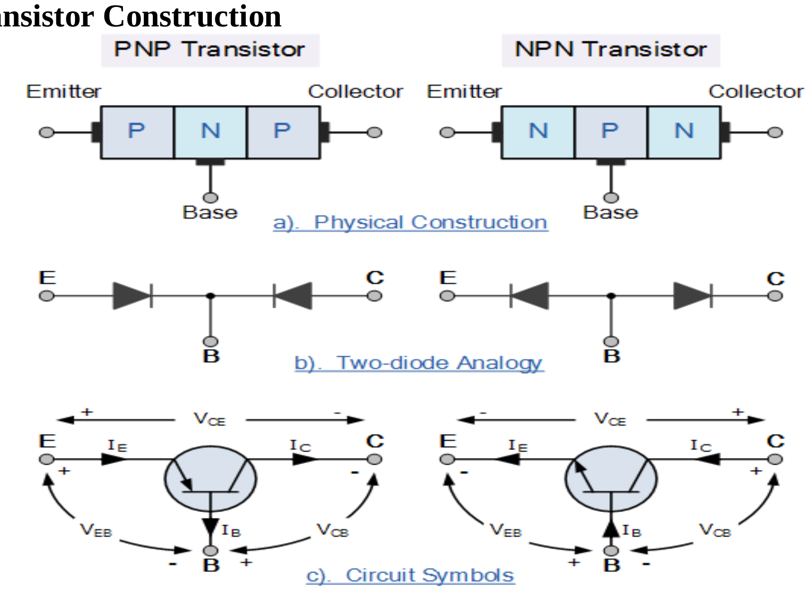
If we now join together two individual signal diodes back-to-back, this will give us two PN-junctions connected together in series that share a common **P** or **N** terminal. The fusion of these two diodes produces a three layer, two junction, three terminal device forming the basis of a **Bipolar Junction Transistor**, or **BJT** for short. Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics). Then bipolar transistors have the ability to operate within three different regions:

1) Active Region – the transistor operates as an amplifier and $I_c = \beta . I_b$
2) Saturation – the transistor is "Fully-ON" operating as a switch and I_c = I(saturation)
3) Cut-off – the transistor is "Fully-OFF" operating as a switch and $I_c = 0$
4)

A Typical Bipolar Transistor

The word Transistor is an acronym, and is a combination of the words Transfer aristorused to describe their mode of operation way back in their early days of development. There are two basic types of bipolar transistor construction, PNP and NPN, which basically escribes the physical arrangement of the P-type and N-type semiconductor materials from which they are made. The **Bipolar Transistor** basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively. Bipolar Transistors are current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing voltage applied to their base terminal acting like a current-controlled switch. The principle of operation of the two transistor types PNP andNPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.

Bipolar Transistor Construction



The construction and circuit symbols for both the PNP and NPN bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal. The direction of the arrow always points from the positive P-type region to the negative N-type region for both transistor types, exactly the same as for the standard diode symbol.

Bipolar Transistor Configurations

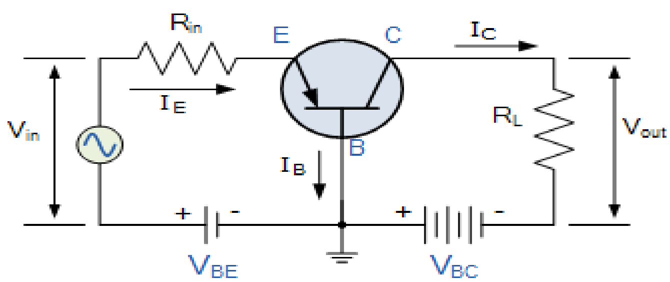
As the **Bipolar Transistor** is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor vary with each circuit arrangement.

1) Common Base Configuration – has Voltage Gain but no Current Gain.
2) Common Emitter Configuration – has both Current and Voltage Gain.
3) Common Collector Configuration – has Current Gain but no Voltage Gain.

The Common Base (CB) Configuration

As its name suggests, in the **Common Base** or grounded base configuration, the BASE connection is common to both the input signal AND the output signal with the input signal being applied between the base and the emitter terminals. The corresponding output signal is taken from between the base and the collector terminals as shown with the base terminal grounded or connected to a fixed reference voltage point.
The input current flowing into the emitter is quite large as its the sum of both the base current and collector current respectively therefore, the collector current output is less than the emitter current input resulting in a current gain for this type of circuit of "1" (unity) or less, in other words the common base configuration "attenuates" the input signal.

The Common Base Transistor Circuit



This type of amplifier configuration is a non-inverting voltage amplifier circuit, in that the signal voltages Vin and Vout are "in-phase". This type of transistor arrangement is not very common due to its unusually high voltage gain characteristics. Its input characteristics represent that of a forward biased diode while the output characteristics represent that of an illuminated photo-diode.

Also this type of bipolar transistor configuration has a high ratio of output to input resistance or more importantly "load" resistance (RL) to "input" resistance (Rin) giving it a value of "Resistance Gain". Then the voltage gain (Av) for a common base configuration is therefore given as:
Common Base Voltage Gain

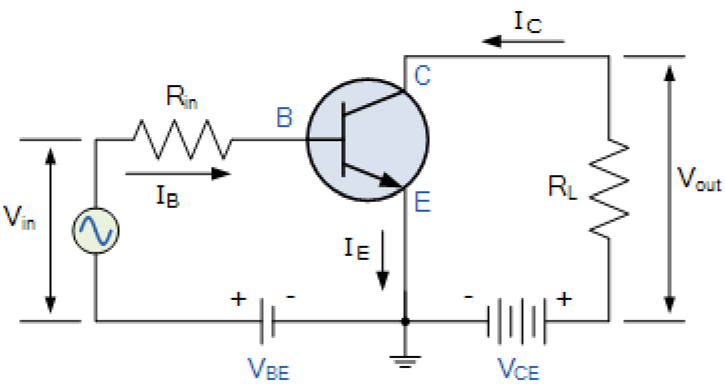
$$A_V = \frac{Vout}{Vin} = \frac{I_C \times R_L}{I_E \times R_{IN}}$$

Where: Ic/Ie is the current gain, alpha (α) and RL/Rin is the resistance gain.
The common base circuit is generally only used in single stage amplifier circuits such as microphone pre-amplifier or radio frequency (Rf) amplifiers due to its very good high frequency response.

The Common Emitter (CE) Configuration

In the **Common Emitter** or grounded emitter configuration, the input signal is applied between the base and the emitter, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers and which represents the "normal" method of bipolar transistor connection. The common emitter amplifier configuration produces the highest current and power gain of all the three bipolar transistor configurations. This is mainly because the input impedance is LOW as it is connected to a forward biased PN-junction, while the output impedance is HIGH as it is taken from a reverse biased PN-junction.

The Common Emitter Amplifier Circuit



In this type of configuration, the current flowing out of the transistor must be equal to the currents flowing into the transistor as the emitter current is given as Ie = Ic + Ib.

As the load resistance (RL) is connected in series with the collector, the current gain of the common emitter transistor configuration is quite large as it is the ratio of Ic/Ib. A transistors current gain is given the Greek symbol of Beta, (β). As the emitter current for a common emitter configuration is defined asIe = Ic + Ib, the ratio of Ic/Ie is called Alpha, given the Greek symbol of α. Note: that the value of Alpha will always be less than unity. Since the electrical relationship between these three currents, Ib, Ic and Ieis determined by the physical construction of the transistor itself, any small change in the base current (Ib), will result in a much larger change in the collector current (Ic). Then, small changes in current flowing in the base will thus control the current in the emitter-collector circuit. Typically, Beta has a value between 20 and 200 for most general purpose transistors. So if a transistor has a Beta value of say 100, then one electron will flow from the base terminal for every 100 electrons flowing between the emitter-collector terminal. By combining the expressions for both Alpha, α and Beta, β the mathematical relationship between these parameters and therefore the current gain of the transistor can be given as:

$$\text{Alpha}, (\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta}, (\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha.I_E = \beta.I_B$$

$$\text{as: } \alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

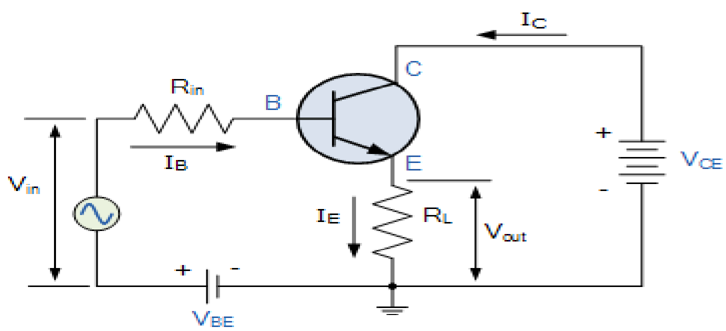
$$I_E = I_C + I_B$$

Where: "Ic" is the current flowing into the collector terminal, "Ib" is the current flowing into the base terminal and "Ie" is the current flowing out of the emitter terminal. Then to summarise a little. This type of bipolar transistor configuration has a greater input impedance, current and power gain than that of the common base configuration but its voltage gain is much lower. The common emitter configuration is an inverting amplifier circuit. This means that the resulting output signal is 180^o "out-of-phase" with the input voltage signal.

The Common Collector (CC) Configuration

In the **Common Collector** or grounded collector configuration, the collector is now common through the supply. The input signal is connected directly to the base, while the output is taken from the emitter load as shown. This type of configuration is commonly known as a**Voltage Follower** or **Emitter Follower** circuit. The common collector, or emitter follower configuration is very useful for impedance matching applications because of the very high input impedance, in the region of hundreds of thousands of Ohms while having a relatively low output impedance.

The Common Collector Transistor Circuit



The common emitter configuration has a current gain approximately equal to the β value of the transistor itself. In the common collector configuration the load resistance is situated in series with the emitter so its current is equal to that of the emitter current. As the emitter current is the combination of the collector AND the base current combined, the load resistance in this type of transistor configuration also has both the collector current and the input current of the base flowing through it. Then the current gain of the circuit is given as:

The Common Collector Current Gain

$$I_E = I_C + I_B$$

$$A_i = \frac{I_E}{I_B} = \frac{I_C + I_B}{I_B}$$

$$A_i = \frac{I_C}{I_B} + 1$$

$$A_i = \beta + 1$$

This type of bipolar transistor configuration is a non-inverting circuit in that the signal voltages of Vin and Vout are "in-phase". It has a voltage gain that is always less than "1" (unity). The load resistance of the common collector transistor receives both the base and collector currents giving a large current gain (as with the common emitter configuration) therefore, providing good current amplification with very little voltage gain.

We can now summarise the various relationships between the transistors individual DC currents flowing through each leg and its DC current gains given above in the following table.

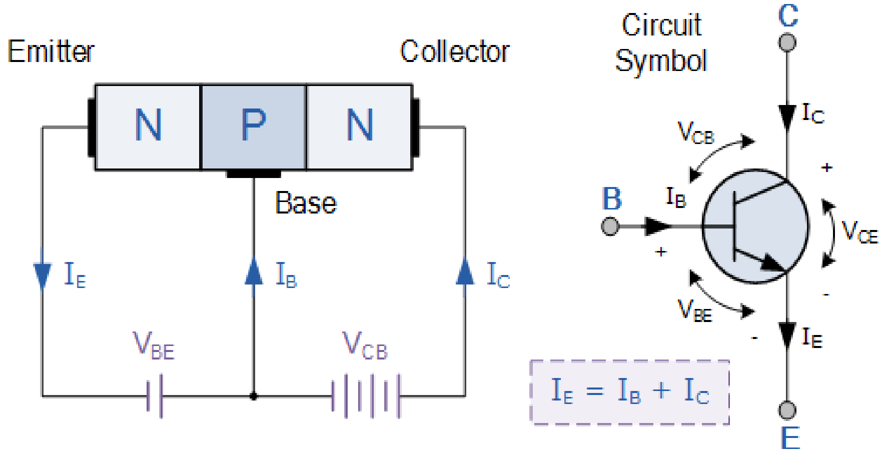
Relationship between DC Currents and Gains

$I_E = I_B + I_C$ $I_C = I_E - I_B$ $I_B = I_E - I_C$	$\alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta}$ $\beta = \frac{I_C}{I_B} = \frac{\alpha}{1-\alpha}$
$I_B = \frac{I_C}{\beta} = \frac{I_E}{1+\beta} = I_E(1-\alpha)$	
$I_C = \beta.I_B = \alpha.I_E$	$I_E = \frac{I_C}{\alpha} = I_B(1+\beta)$

Bipolar Transistor Summary

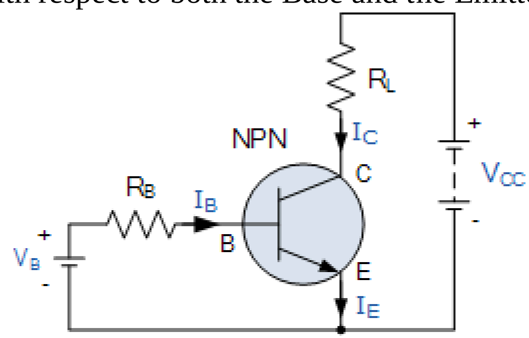
Then to summarise, the behaviour of the bipolar transistor in each one of the above circuit configurations is very different and produces different circuit characteristics with regards to input impedance, output impedance and gain whether this is voltage gain, current gain or power gain and this is summarised in the table below. The most commonly used transistor configuration is the **NPN Transistor**. We also learnt that the junctions of the bipolar transistor can be biased in one of three different ways – **Common Base**, **Common Emitter** and**Common Collector**. In this tutorial about bipolar transistors we will look more closely at the "Common Emitter" configuration using the **Bipolar NPN Transistor** with an example of the construction of a NPN transistor along with the transistors current flow characteristics is given below.

A Bipolar NPN Transistor Configuration



(Note: Arrow defines the emitter and conventional current flow, "out" for a Bipolar NPN Transistor.)

The construction and terminal voltages for a bipolar NPN transistor are shown above. The voltage between the Base and Emitter (V_{BE}), is positive at the Base and negative at the Emitter because for an NPN transistor, the Base terminal is always positive with respect to the Emitter. Also the Collector supply voltage is positive with respect to the Emitter (V_{CE}). So for a bipolar NPN transistor to conduct the Collector is always more positive with respect to both the Base and the Emitter.



NPN Transistor Connection

Then the voltage sources are connected to an NPN transistor as shown. The Collector is connected to the supply voltage V_{CC} via the load resistor, RL which also acts to limit the maximum current flowing through the device. The Base supply voltage V_B is connected to the Base resistor R_B, which again is used to limit the maximum Base current. So in a NPN Transistor it is the movement of negative current carriers (electrons) through the Base region that constitutes transistor action, since these mobile electrons provide the link between the Collector and Emitter circuits. This link between the input and output circuits is the main feature of transistor action because the transistors amplifying properties come from the consequent control which the Base exerts upon the Collector to Emitter current. Then we can see that the transistor is a current operated device (Beta model) and that a large current (Ic) flows freely through the device between the collector and the emitter terminals when the transistor is switched "fully-ON". However, this only happens when a small biasing current (Ib) is flowing into the base terminal of the transistor at the same time thus allowing the Base to act as a sort of current control input.

The transistor current in a bipolar NPN transistor is the ratio of these two currents (Ic/Ib), called the *DC Current Gain* of the device and is given the symbol of hfe or nowadays Beta, (β). The value of β can be large up to 200 for standard transistors, and it is this large ratio between Ic and Ib that makes the bipolar NPN transistor a useful amplifying device when used in its active region as Ib provides the input and Ic provides the output. Note that Beta has no units as it is a ratio. Also, the current gain of the transistor from the Collector terminal to the Emitter terminal, Ic/Ie, is called Alpha, (α), and is a function of the transistor itself (electrons diffusing across the junction). As the emitter current Ie is the sum of a very small base current plus a very large collector current, the value of alpha α, is very close to unity, and for a typical low-power signal transistor this value ranges from about 0.950 to 0.999

α and β Relationship in a NPN Transistor

$$\text{DC Current Gain} = \frac{\text{Output Current}}{\text{Input Current}} = \frac{I_C}{I_B}$$

$$I_E = I_B + I_C \;\ldots\ldots\; (\text{KCL}) \quad \text{and} \quad \frac{I_C}{I_E} = \alpha$$

$$\text{Thus:} \quad I_B = I_E - I_C$$

$$I_B = I_E - \alpha I_E$$

$$I_B = I_E\,(1-\alpha)$$

$$\therefore \; \beta = \frac{I_C}{I_B} = \frac{I_C}{I_E(1-\alpha)} = \frac{\alpha}{1-\alpha}$$

By combining the two parameters α and β we can produce two mathematical expressions that gives the relationship between the different currents flowing in the transistor.

$$\alpha = \frac{\beta}{\beta+1} \quad \text{or} \quad \alpha = \beta(1-\alpha)$$

$$\beta = \frac{\alpha}{1-\alpha} \quad \text{or} \quad \beta = \alpha(1+\beta)$$

$$\text{If} \quad \alpha = 0.99 \qquad \beta = \frac{0.99}{0.01} = 99$$

The values of Beta vary from about 20 for high current power transistors to well over 1000 for high frequency low power type bipolar transistors. The value of Beta for most standard NPN transistors can be found in the manufactures data sheets but generally range between 50 – 200.

The equation above for Beta can also be re-arranged to make Ic as the subject, and with a zero base current (Ib = 0) the resultant collector current Ic will also be zero, (β x 0). Also when the base current is high the corresponding collector current will also be high resulting in the base current controlling the collector current. One of the most important properties of the **Bipolar Junction Transistor** is that a small base current can control a much larger collector current.

UNIT-III

SYLLABUS

Amplifiers: Transistor Biasing and Stabilization Circuits. Fixed Bias and Voltage Divider Bias. Transistor as 2-port Network. h-parameter Equivalent Circuit. Analysis of a single-stage CE amplifier using Hybrid Model. Input and Output Impedance. Current, Voltage and Power Gains. Classification of Class A, B & C Amplifiers. Coupled Amplifier: Two stage RC-coupled amplifier and its frequency response.
Feedback in Amplifiers: Effects of Positive and Negative Feedback on Input Impedance, Output Impedance, Gain, Stability, Distortion and Noise.

A transistors steady state of operation depends a great deal on its base current, collector voltage, and collector current and therefore, if a transistor is to operate as a linear amplifier, it must be properly biased to have a suitable operating point.

Establishing the correct operating point requires the proper selection of bias resistors and load resistors to provide the appropriate input current and collector voltage conditions. The correct biasing point for a bipolar transistor, either NPN or PNP, generally lies somewhere between the two extremes of operation with respect to it being either “fully-ON” or “fully-OFF” along its load line. This central operating point is called the “Quiescent Operating Point”, or Q-point for short.When a bipolar transistor is biased so that the Q-point is near the middle of its operating range, that is approximately halfway between cut-off and saturation, it is said to be operating as a Class-A amplifier. This mode of operation allows the output current to increase and decrease around the amplifiers Q-point without distortion as the input signal swings through a complete cycle. In other words, the output current flows for the full $360^{o}$of the input cycle.The function of the “DC Bias level” or “no input signal level” is to correctly set the transistors Q-point by setting its Collector current (I_C) to a constant and steady state value without an input signal applied to the transistors Base.This steady-state or DC operating point is set by the values of the circuits DC supply voltage (Vcc) and the value of the biasing resistors connected the transistors Base terminal.

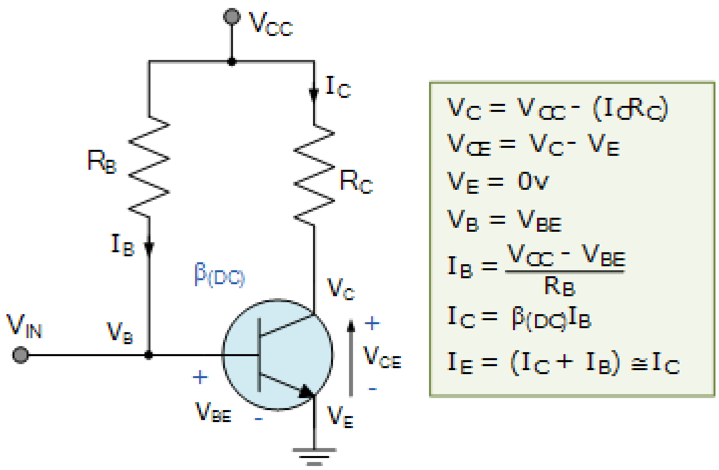
Since the transistors Base bias currents are steady-state DC currents, the appropriate use of coupling and bypass capacitors will help block bias current setup for one transistor stage affecting the bias conditions of the next. Base bias networks can be used for Common-base (CB), common-collector (CC) or common-emitter (CE) transistor configurations. In this simple transistor biasing tutorial we will look at the different biasing arrangements available for a Common Emitter Amplifier.

Common Emitter Amplifier

One of the most frequently used biasing circuits for a transistor circuit is with the self-bias of the emitter-bias circuit where one or more biasing resistors are used to set up the initial DC values of transistor currents, (I_B), (I_C) and (I_E).
The two most common forms of transistor biasing are: *Beta Dependent*and *Beta Independent*. Transistor bias voltages are largely dependent on transistor beta, (β) so the biasing set up for one transistor may not necessarily be the same for another transistor. Transistor biasing can be

achieved either by using a single feed back resistor or by using a simple voltage divider network to provide the required biasing voltage.
The following are five examples of transistor Base bias configurations from a single supply (Vcc).

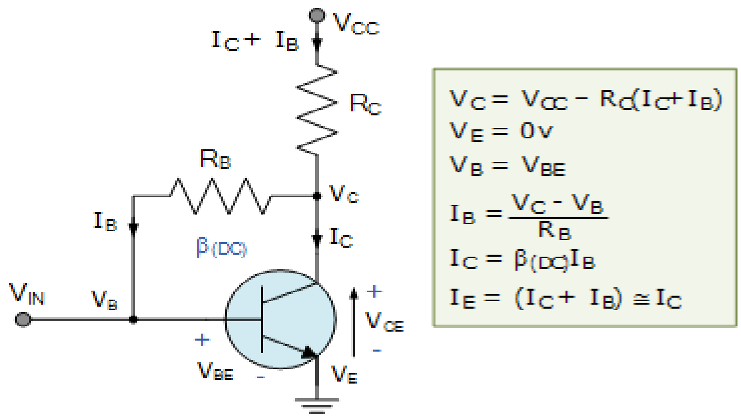
Fixed Base Biasing a Transistor



The circuit shown is called as a "fixed base bias circuit", because the transistors base current, I_B remains constant for given values of Vcc, and therefore the transistors operating point must also remain fixed. This two resistor biasing network is used to establish the initial operating region of the transistor using a fixed current bias.
This type of transistor biasing arrangement is also beta dependent biasing as the steady-state condition of operation is a function of the transistors beta β value, so the biasing point will vary over a wide range for transistors of the same type as the characteristics of the transistors will not be exactly the same.

The emitter diode of the transistor is forward biased by applying the required positive base bias voltage via the current limiting resistor R_B. Assuming a standard bipolar transistor, the forward base-emitter voltage drop will be 0.7V. Then the value of R_B is simply: $(V_{CC} – V_{BE})/I_B$ where I_B is defined as I_C/β.

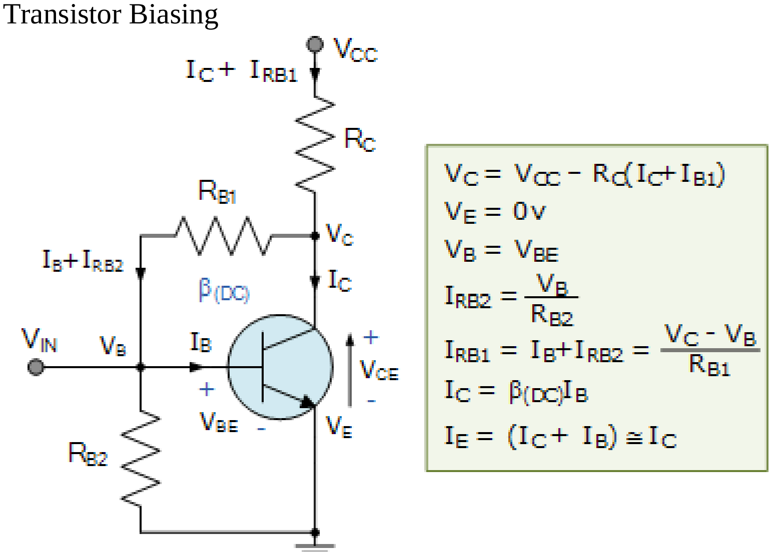
With this single resistor type of biasing method the biasing voltages and currents do not remain stable during transistor operation and can vary enormously. Also the temperature of the transistor can adversely effect the operating point.
Collector Feedback Biasing a Transistor



This self biasing collector feedback configuration is another beta dependent biasing method that requires only two resistors to provide the necessary DC bias for the transistor. The collector to base feedback configuration ensures that the transistor is always biased in the active region regardless of the value of Beta (β) as the DC base bias voltage is derived from the collector voltage, V_C providing good stability.

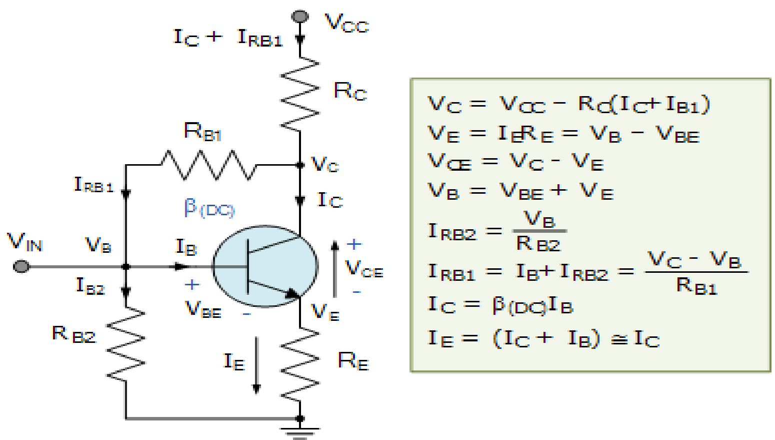
In this circuit, the base bias resistor, R_B is connected to the transistors collector C, instead of to the supply voltage rail, Vcc. Now if the collector current increases, the collector voltage drops, reducing the base drive and thereby automatically reducing the collector current to keep the transistors Q-point fixed. Then this method of collector feedback biasing produces negative feedback as there is feedback from the output to the input through resistor, R_B.
The biasing voltage is derived from the voltage drop across the load resistor, R_L. So if the load current increases there will be a larger voltage drop across R_L, and a corresponding reduced collector voltage, V_C which will cause a corresponding drop in the base current, I_B which in turn, brings I_C back to normal.

The opposite reaction will also occur when transistors collector current becomes less. Then this method of biasing is called self-biasing with the transistors stability using this type of feedback bias network being generally good for most amplifier designs.
Dual Feedback Transistor Biasing



Adding an additional resistor to the base bias network of the previous configuration improves stability even more with respect to variations in Beta, (β) by increasing the current flowing through the base bias resistors.The current flowing through R_{B1} is generally set at a value equal to about 10% of collector current, I_C. Obviously it must also be greater than the base current required for the minimum value of Beta, β.One of the advantages of this type of self biasing configuration is that the resistors provide both automatic biasing and Rf feedback at the same time.

Transistor Biasing with Emitter Feedback

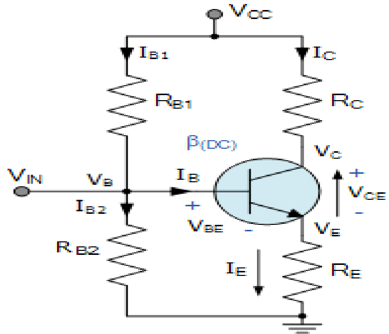


This type of transistor biasing configuration, often called self-emitter biasing, uses both emitter and collector-base feedback to stabilize the collector current even more as resistors R_B and R_E as well as the emitter-base junction of the transistor are all effectively connected in series with the supply voltage, V_{CC}.

The downside of this emitter feedback configuration is that the output has reduced gain because of the base resistor connection as the collector voltage determines the current flowing through the feedback resistor, $R_B$producing what is called “degenerative feedback”.The current flowing from the emitter, I_E (which is a combination ofI_C + :I_B) causes a voltage drop to appear across R_E in such a direction, that it forward biases the emitter-base junction.So if the emitter current increases, voltage drop IR_E also increases.

Since the polarity of this voltage reverse biases the emitter-base junction, $I_B$automatically decrease. Therefore the emitter current increase less than it would have done had there been no self biasing resistor.Resistor values are generally set so that the voltage drop across emitter resistor R_E is approximately 10% of V_{CC} and the current flowing through resistor R_{B1} is 10% of the collector current I_C.This type of transistor biasing configuration works best at relatively low power supply voltages.

Voltage Divider Transistor Biasing



$$V_C = V_{CC} - R_C I_C = (V_E + V_{CE})$$
$$V_E = I_E R_E = V_B - V_{BE}$$
$$V_{CE} = V_C - V_E = V_{CC} - (I_C R_C + I_E R_E)$$
$$V_B = V_{BE} + V_E = V_{RB2} = \left(\frac{R_{B2}}{R_{B1} + R_{B2}}\right) V_{CC}$$
$$I_{B2} = \frac{V_B}{R_{B2}}$$
$$I_{B1} = I_B + I_{B2} = \frac{V_C - V_B}{R_{B1}}$$
$$I_B = \frac{V_B}{R_B + (1+\beta) R_E}$$
$$I_C = \beta_{(DC)} I_B$$
$$I_E = I_C + I_B = \frac{V_E}{R_E}$$

The common emitter transistor is biased using a voltage divider network to increase stability. The name of this biasing configuration comes from the fact that the two resistors R_{B1} and R_{B2} form a voltage or potential divider network with their center point connecting the transistors base terminal directly across the supply.This voltage divider configuration is the most widely used transistor biasing method, as the emitter diode of the transistor is forward biased by the voltage dropped across resistor R_{B2}. Also, voltage divider network biasing makes the transistor circuit independent of changes in beta as the voltages at the transistors base, emitter, and collector are dependant on external circuit values.

To calculate the voltage developed across resistor R_{B2} and therefore the voltage applied to the base terminal we simply use the voltage divider formula for resistors in series Generally the voltage drop across resistor R_{B2} is much less than for resistor R_{B1}. Then clearly the transistors base voltage V_B with respect to ground, will be equal to the voltage across R_{B2}.The current flowing through resistor R_{B2} is generally set at 10 times the value of the required base current I_B so that it has no effect on the voltage divider current or changes in Beta.

The goal of Transistor Biasing is to establish a known Q-point in order for the transistor to work efficiently and produce an undistorted output signal. Correct biasing of the transistor also establishes its initial AC operating region with practical biasing circuits using either a two or four-resistor bias network.In bipolar transistor circuits, the Q-point is represented by (V_{CE}, I_C) for the NPN transistors or (V_{EC}, I_C) for PNP transistors.

The stability of the base bias network and therefore the Q-point is generally assessed by considering the collector current as a function of both Beta (β) and temperature.Here we have looked briefly at five different configurations for “biasing a transistor” using resistive networks. But we can also bias a transistor using either silicon diodes, zener diodes or active networks all connected to the base terminal of the transistor or by biasing the transistor from a dual power supply.

Amplifier Classes

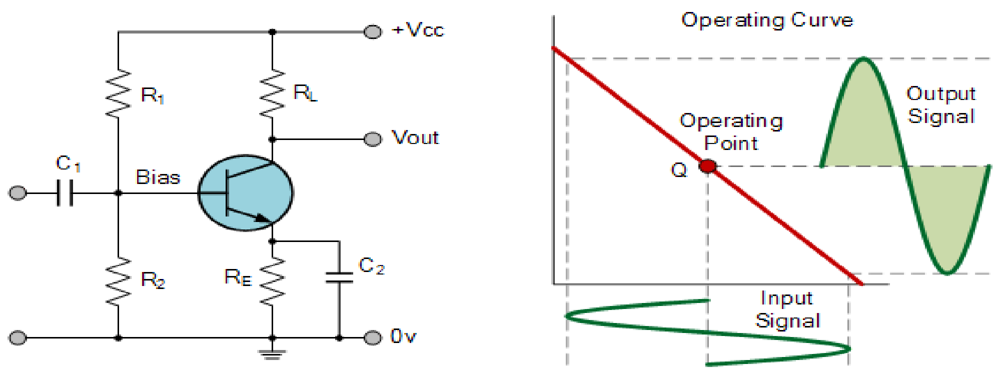
The classification of an amplifier as either a voltage or a power amplifier is made by comparing the characteristics of the input and output signals by measuring the amount of time in relation to the input signal that the current flows in the output circuit.For the transistor to operate within its “Active Region” some form of “Base Biasing” was required. This small Base Bias voltage added to the input signal allowed the transistor to reproduce the full input waveform at its output with no loss of signal.However, by altering the position of this Base bias voltage, it is possible to operate an amplifier in an amplification mode other than that for full waveform reproduction.

With the introduction to the amplifier of a Base bias voltage, different operating ranges and modes of operation can be obtained which are categorized according to their classification. These various mode of operation are better known as Amplifier Class.Audio power amplifiers are classified in an alphabetical order according to their circuit configurations and mode of operation. Amplifiers are designated by different classes of operation such as class "A", class "B", class "C", class "AB", etc. These different amplifier classes range from a near linear output but with low efficiency to a non-linear output but with a high efficiency.

No one class of operation is "better" or "worse" than any other class with the type of operation being determined by the use of the amplifying circuit. There are typical maximum efficiencies for the various types or class of amplifier, with the most commonly used being:

1) Class A Amplifier – has low efficiency of less than 40% but good signal reproduction and linearity.
2) Class B Amplifier – is twice as efficient as class A amplifiers with a maximum theoretical efficiency of about 70% because the amplifying device only conducts (and uses power) for half of the input signal.
3) Class AB Amplifier – has an efficiency rating between that of Class A and Class B but poorer signal reproduction than class A amplifiers.
4) Class C Amplifier – is the most inefficient amplifier class as only a very small portion of the input signal is amplified therefore the output signal bears very little resemblance to the input signal. Class C amplifiers have the worst signal reproduction.
5)

Class A Amplifier



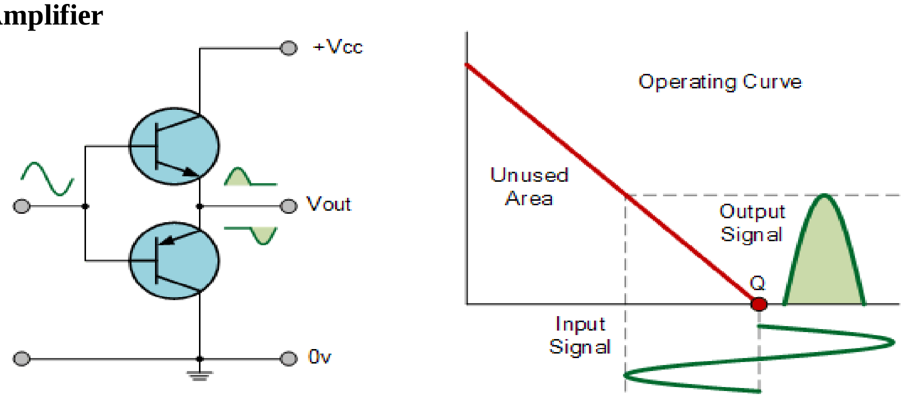
To achieve high linearity and gain, the output stage of a class A amplifier is biased "ON" (conducting) all the time. Then for an amplifier to be classified as "Class A" the zero signal idle current in the output stage must be equal to or greater than the maximum load current (usually a loudspeaker) required to produce the largest output signal.As a class A amplifier operates in the linear portion of its characteristic curves, the single output device conducts through a full 360 degrees of the output waveform. Then the class A amplifier is equivalent to a current source.Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion.

However, as the output device is "ON" at all times, it is constantly carrying current, which represents a continuous loss of power in the amplifier. Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

Class B Amplifier

Class B amplifiers were invented as a solution to the efficiency and heating problems associated with the previous class A amplifier. The basic class B amplifier uses two complimentary transistors either bipolar of FET for each half of the waveform with its output stage configured in a "push-pull" type arrangement, so that each transistor device amplifies only half of the output waveform.In the class B amplifier, there is no DC base bias current as its quiescent current is zero, so that the dc power is small and therefore its efficiency is much higher than that of the class A amplifier. However, the price paid for the improvement in the efficiency is in the linearity of the switching device.

Class B Amplifier



When the input signal goes positive, the positive biased transistor conducts while the negative transistor is switched "OFF". Likewise, when the input signal goes negative, the positive transistor switches "OFF" while the negative biased transistor turns "ON" and conducts the negative portion of the signal. Thus the transistor conducts only half of the time, either on positive or negative half cycle of the input signal.

Then we can see that each transistor device of the class B amplifier only conducts through one half or 180 degrees of the output waveform in strict time alternation, but as the output stage has devices for both halves of the signal waveform the two halves are combined together to produce the full linear output waveform.

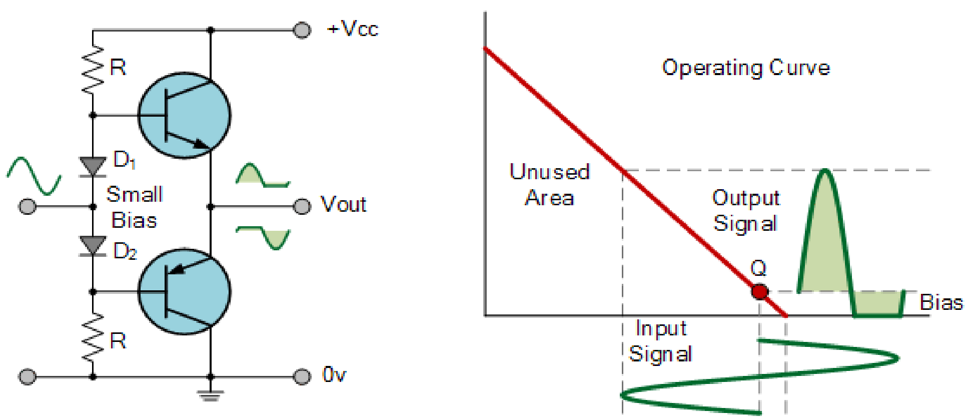
This push-pull design of amplifier is obviously more efficient than Class A, at about 50%, but the problem with the class B amplifier design is that it can create distortion at the zero-crossing point of the waveform due to the transistors dead band of input base voltages from -0.7V to +0.7.. Then in a class B amplifier, the output transistor is not "biased" to an "ON" state of operation until this voltage is exceeded.This means that the the part of the waveform which falls within this 0.7 volt window will not be reproduced accurately making the class B amplifier unsuitable for precision audio amplifier applications.

Class AB Amplifier

As its name suggests, the Class AB Amplifier is a combination of the "Class A" and the "Class B" type amplifiers we have looked at above. The AB classification of amplifier is currently one of the most common used types of audio power amplifier design. The class AB amplifier is a variation of a class B amplifier as described above, except that both devices are allowed to conduct at the same time around the waveforms crossover point eliminating the crossover distortion problems of the previous class B amplifier.

The two transistors have a very small bias voltage, typically at 5 to 10% of the quiescent current to bias the transistors just above its cut-off point. Then the conducting device, either bipolar of FET, will be "ON" for more than one half cycle, but much less than one full cycle of the input signal. Therefore, in a class AB amplifier design each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

In other words, the conduction angle of a class AB amplifier is somewhere between 180^o and 360^o depending upon the chosen bias point as shown.
Class AB Amplifier



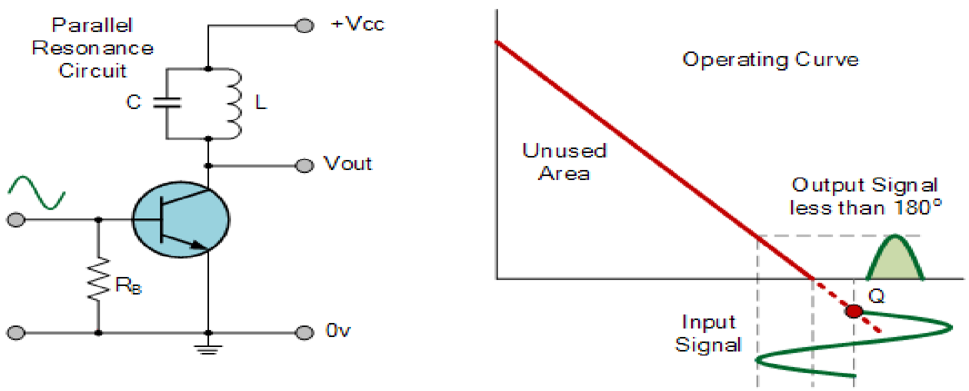
The advantage of this small bias voltage, provided by series diodes or resistors, is that the crossover distortion created by the class B amplifier characteristics is overcome, without the inefficiencies of the class A amplifier design. So the class AB amplifier is a good compromise between class A and class B in terms of efficiency and linearity, with conversion efficiencies reaching about 50% to 60%.

Class C Amplifier

The Class C Amplifier design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned here. The previous classes,A, B and AB are considered linear amplifiers, as the output signals amplitude and phase are linearly related to the input signals amplitude and phase.However, the class C amplifier is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cut-off point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.

While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers.

Class C Amplifier

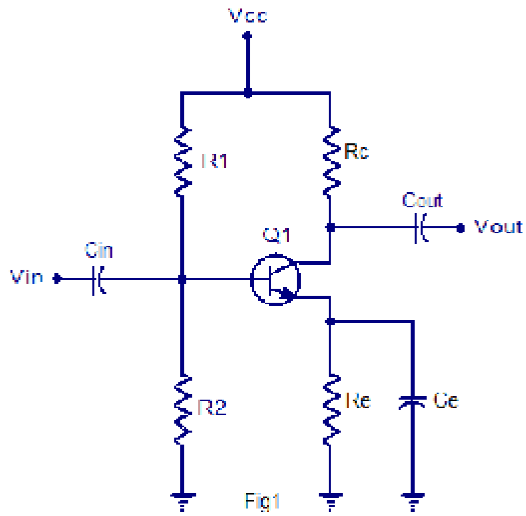


Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

Common emitter RC coupled amplifier.

The common emitter RC coupled amplifier is one of the simplest and elementary transistor amplifier that can be made. Don't expect much boom from this little circuit, the main purpose of this circuit is pre-amplification i.e to make weak signals strong enough for further processing or amplification. If designed properly, this amplifier can provide excellent signal characteristics. The circuit diagram of a single stage common emitter RC coupled amplifier using transistor is shown below.



Comon emitter RC coupled amplifier

RC coupled amplifier

Capacitor Cin is the input DC decoupling capacitor which blocks any DC component if present in the input signal from reaching the Q1 base. If any external DC voltage reaches the base of Q1, it will alter the biasing conditions and affects the performance of the amplifier.R1 and R2 are the biasing resistors. This network provides the transistor Q1's base with the necessary bias voltage to drive it into the active region.

The region of operation where the transistor is completely switched of is called cut-off region and the region of operation where the transistor is completely switched ON (like a closed switch) is called saturation region. The region in between cut-off and saturation is called active region. Refer Fig 2 for better understanding. For a transistor amplifier to function properly, it should operate in the active region.

Let us consider this simple situation where there is no biasing for the transistor. As we all know, a silicon transistor requires 0.7 volts for switch ON and surely this 0.7 V will be taken from the input audio signal by the transistor. So all parts of there input wave form with amplitude ≤ 0.7V will be absent in the output waveform. In the other hand if the transistor is given with a heavy bias at the base ,it will enter into saturation (fully ON) and behaves like a closed switch so that any further change in the base current due to the input audio signal will not cause any change in the output. The voltage across collector and emitter will be 0.2V at this condition (Vce sat = 0.2V). That is why proper biasing is required for the proper operation of a transistor amplifier.

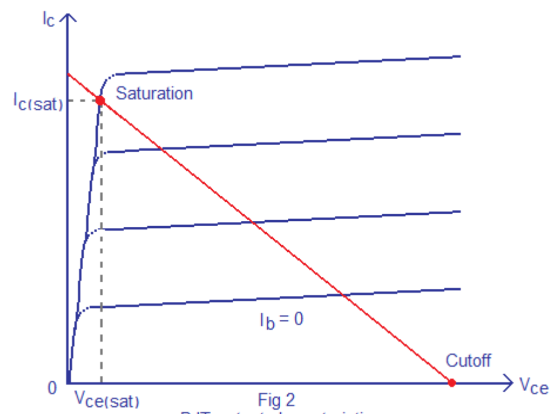


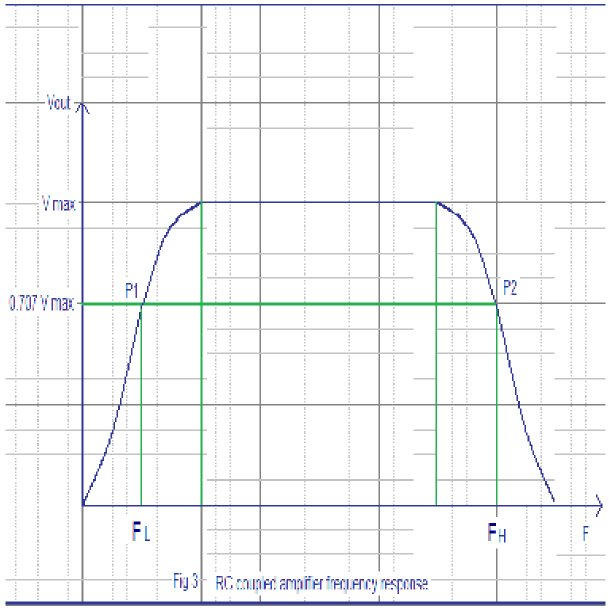
Fig 2
BJT output characteristics

BJT output characteristics

Cout is the output DC decoupling capacitor. It prevents any DC voltage from entering into the succeeding stage from the present stage. If this capacitor is not used the output of the amplifier (Vout) will be clamped by the DC level present at the transistors collector.
Rc is the collector resistor and Re is the emitter resistor.

Values of Rc and Re are so selected that 50% of Vcc gets dropped across the collector & emitter of the transistor.This is done to ensure that the operating point is positioned at the center of the load line. 40% of Vcc is dropped across Rc and 10% of Vcc is dropped across Re. A higher voltage drop across Re will reduce the output voltage swing and so it is a common practice to keep the voltage drop across Re = 10%Vcc . Ce is the emitter by-pass capacitor. At zero signal condition (i.e, no input) only the quiescent current (set by the biasing resistors R1 and R2 flows through the Re).

This current is a direct current of magnitude few milli amperes and Ce does nothing. When input signal is applied, the transistor amplifies it and as a result a corresponding alternating current flows through the Re. The job of Ce is to bypass this alternating component of the emitter current. If Ce is not there , the entire emitter current will flow through Re and that causes a large voltage drop across it. This voltage drop gets added to the Vbe of the transistor and the bias settings will be altered. It reality, it is just like giving a heavy negative feedback and so it drastically reduces the gain.



Feedback in Amplifiers

Feedback.

A feedback system is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system. Feedback is comprised of a sub-circuit that allows a fraction of the output signal from a system to modify the effective input signal in such a way as to produce a response that can differ substantially from the response produced in the absence of such feedback.Feedback.

Systems are very useful and widely used in amplifier circuits, oscillators, process control systems as well as other types of electronic systems. But for feedback to be an effective tool it must be controlled as an uncontrolled system will either oscillate or fail to function. The basic model of a feedback system is given as:

Feedback System Block

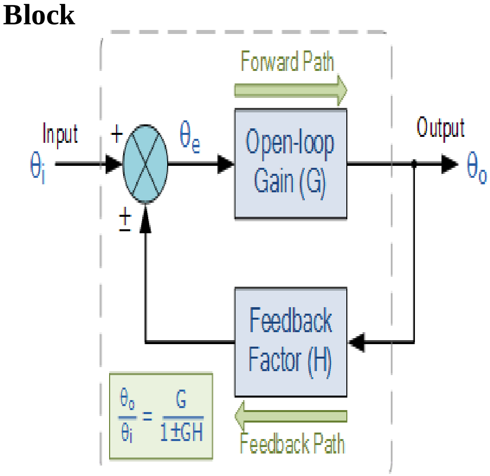


Diagram Model

This basic feedback loop of sensing, controlling and actuation is the main concept behind a feedback control system and there are several good reasons why feedback is applied and used in electronic circuits:

1) Circuit characteristics such as the systems gain and response can be precisely controlled.
2) Circuit characteristics can be made independent of operating conditions such as supply voltages or temperature variations.
3) Signal distortion due to the non-linear nature of the components used can be greatly reduced.
4) The Frequency Response, Gain and Bandwidth of a circuit or system can be easily controlled to within tight limits.

Whilst there are many different types of control systems, there are just two main types of feedback control namely: Negative Feedback and Positive Feedback.

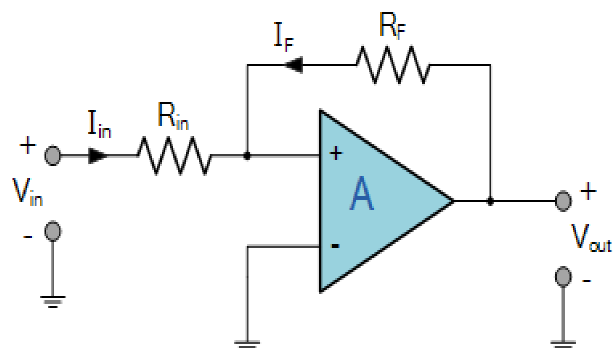
Positive Feedback Systems

In a “positive feedback control system”, the set point and output values are added together by the controller as the feedback is “in-phase” with the input. The effect of positive (or regenerative) feedback is to “increase” the systems gain, ie, the overall gain with positive feedback applied will be greater than the gain without feedback. For example, if someone praises you or gives you positive feedback about something, you feel happy about yourself and are full of energy, you feel more positive.

However, in electronic and control systems to much praise and positive feedback can increase the systems gain far too much which would give rise to oscillatory circuit responses as it increases the magnitude of the effective input signal.

An example of a positive feedback systems could be an electronic amplifier based on an operational amplifier, or op-amp as shown.

Positive Feedback System



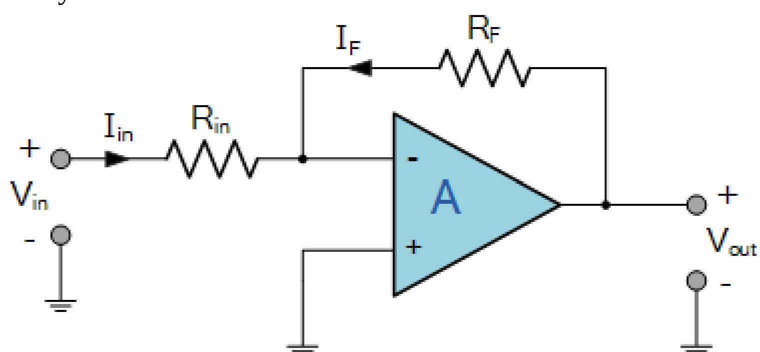
Positive feedback control of the op-amp is achieved by applying a small part of the output voltage signal at Vout back to the non-inverting (+) input terminal via the feedback resistor, R_F.If the input voltage Vin is positive, the op-amp amplifies this positive signal and the output becomes more positive. Some of this output voltage is returned back to the input by the feedback network.Thus the input voltage becomes more positive, causing an even larger output voltage and so on. Eventually the output becomes saturated at its positive supply rail.

Likewise, if the input voltage Vin is negative, the reverse happens and the op-amp saturates at its negative supply rail. Then we can see that positive feedback does not allow the circuit to function as an amplifier as the output voltage quickly saturates to one supply rail or the other, because with positive feedback loops "more leads to more" and "less leads to less".Then if the loop gain is positive for any system the transfer function will be: Av = G / (1 – GH). Note that if GH = 1 the system gain Av = infinity and the circuit will start to self-oscillate, after which no input signal is needed to maintain oscillations, which is useful if you want to make an oscillator.

Although often considered undesirable, this behaviour is used in electronics to obtain a very fast switching response to a condition or signal. One example of the use of positive feedback is hysteresis in which a logic device or system maintains a given state until some input crosses a preset threshold. This type of behaviour is called "bi-stability" and is often associated with logic gates and digital switching devices such as multivibrators.

Negative Feedback Systems

In a "negative feedback control system", the set point and output values are subtracted from each other as the feedback is "out-of-phase" with the original input. The effect of negative (or degenerative) feedback is to "reduce" the gain. For example, if someone criticises you or gives you negative feedback about something, you feel unhappy about yourself and therefore lack energy, you feel less positive.Because negative feedback produces stable circuit responses, improves stability and increases the operating bandwidth of a given system, the majority of all control and feedback systems is degenerative reducing the effects of the gain.An example of a negative feedback system is an electronic amplifier based on an operational amplifier as shown.
Negative Feedback System



Negative feedback control of the amplifier is achieved by applying a small part of the output voltage signal at Vout back to the inverting (–) input terminal via the feedback resistor, Rf.If the input voltage Vin is positive, the op-amp amplifies this positive signal, but because its connected to the inverting input of the amplifier, and the output becomes more negative.

Some of this output voltage is returned back to the input by the feedback network of Rf.Thus the input voltage is reduced by the negative feedback signal, causing an even smaller output voltage and so on. Eventually the output will settle down and become stabilised at a value determined by the gain ratio of Rf ÷ Rin.Likewise, if the input voltage Vin is negative, the reverse happens and the op-amps output becomes positive (inverted) which adds to the negative input signal. Then we can see that negative feedback allows the circuit to function as an amplifier, so long as the output is within the saturation limits.

So we can see that the output voltage is stabilised and controlled by the feedback, because with negative feedback loops “more leads to less” and “less leads to more”.

Then if the loop gain is positive for any system the transfer function will be: $Av = G / (1 + GH)$. The use of negative feedback in amplifier and process control systems is widespread because as a rule negative feedback systems are more stable than positive feedback systems, and a negative feedback system is said to be stable if it does not oscillate by itself at any frequency except for a given circuit condition.Another advantage is that negative feedback also makes control systems more immune to random variations in component values and inputs. Of course nothing is for free, so it must be used with caution as negative feedback significantly modifies the operating characteristics of a given system.

UNIT-IV

SYLLABUS

Sinusoidal Oscillators: Barkhausen's Criterion for self-sustained oscillations. RC Phase shift oscillator, determination of Frequency. Hartley & Colpitt oscillators.
Operational Amplifiers (Black Box approach): Characteristics of an Ideal and practical Op-Amp. (IC 741) Open-loop and Closed-loop Gain. Frequency Response. CMRR. Slew Rate and concept of Virtual ground.

An oscillator is an electronic device which generates sinusoidal waves when excited by a DC input supply voltage. There are two types of approaches to generate sine waves.

1) Using resonance phenomena (This can be implemented with a separate circuit or using the non linearity of the device itself)
2) By appropriately shaping a triangular waveform.

Multivibrator is a circuit which generate non sinusoidal wave forms such as square, triangular, pulse e.t.c.Oscillators are circuits which generates sinusoidal wave forms. Multi vibrators are basic building blocks in function generators and nonlinear oscillators whereas oscillators are basic building blocks in inverters.

Barkhausen criterion

The frequency of oscillation at which sinusoidal oscillator operates is the frequency for which the total shift introduced, as the signal proceeds from the input terminals, through the amplifier and feedback network, and back again to the input, is precisely zero(or an integral multiple of 2*Π).

Stated simply the condition $A*\beta = -1$ at $\omega = \omega_o$, i.e. the magnitude of loop gain should be one and phase of loop gain should be unity (the feedback network introduces 180^0 phase shift, the other 180^0phase shift is provided by mixer) is called Barkhausen criterion.

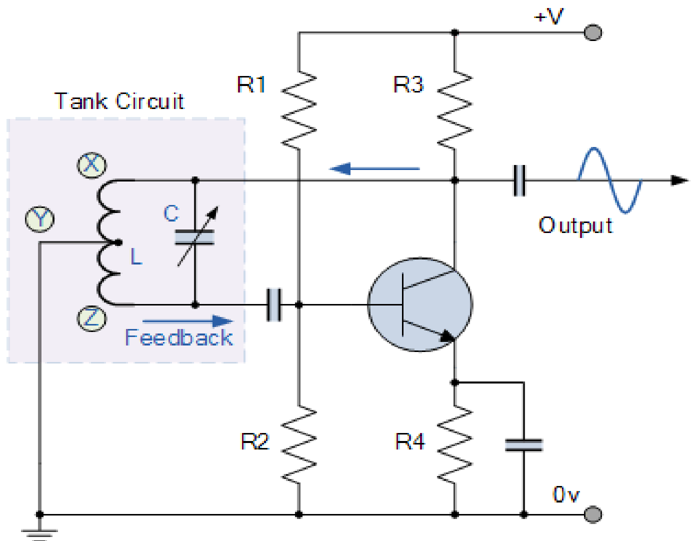
A closed loop system with negative feedback can be represented by a

$$\text{Transfer function} = A/(1+A*\beta).$$

Often feedback network consists of only resistive elements and is independent of frequency but amplifier gain is a function of frequency. Hence the loop gain $A*\beta$ is a function of frequency. There may exist a frequency ω_o at which its magnitude is one and phase is 180^0 i.e. $A*\beta = -1$ (Barkhausen criterion).

At that frequency overall gain of system is very large theoretically infinite. Noise at the input of amplifier consists of all frequencies with negligible amplitudes. For all frequencies other than the oscillator frequencies the amplifier gain will not be enough to elevate them to significant amplitudes. But at that frequency where oscillator oscillates it provides very large gain and the amplitude of corresponding sine wave will be limited by the nonlinearity of the active device.The frequency of oscillation depends mostly on few circuit parameters such as passive elements such as resistance, inductance, and capacitance e.t.c. The principle cause of drift of these circuit parameters is temperature. Therefore compensation measures should be taken for balancing temperature induced variations.

Basic Hartley Oscillator Design



When the circuit is oscillating, the voltage at point X (collector), relative to point Y (emitter), is 180^o out-of-phase with the voltage at point Z (base) relative to point Y. At the frequency of oscillation, the impedance of the Collector load is resistive and an increase in Base voltage causes a decrease in the Collector voltage.Then there is a 180^o phase change in the voltage between the Base and Collector and this along with the original 180^o phase shift in the feedback loop provides the correct phase relationship of positive feedback for oscillations to be maintained.

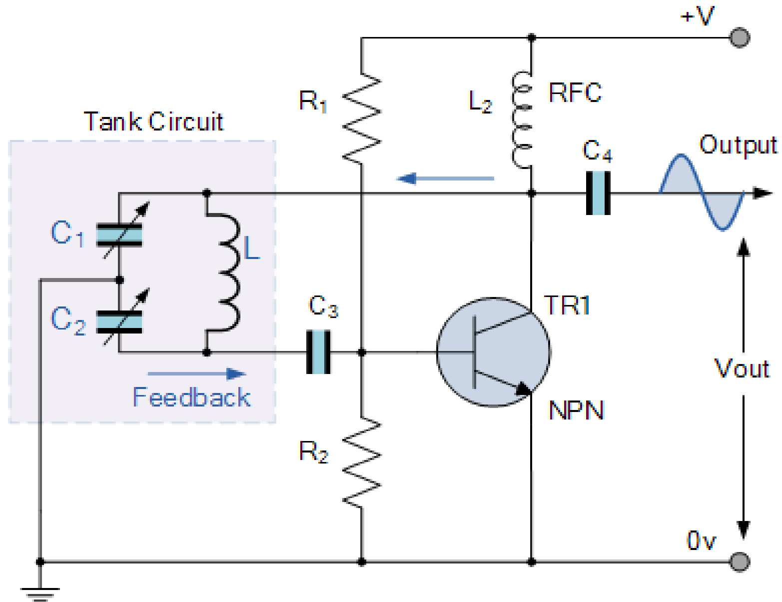
The amount of feedback depends upon the position of the "tapping point" of the inductor. If this is moved nearer to the collector the amount of feedback is increased, but the output taken between the Collector and earth is reduced and vice versa. Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the capacitors act as DC-blocking capacitors.In this Hartley Oscillator circuit, the DC Collector current flows through part of the coil and for this reason the circuit is said to be "Series-fed" with the frequency of oscillation of the Hartley Oscillator being given as.

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

$$\text{where: } L_T = L_1 + L_2 + 2M$$

The frequency of oscillations can be adjusted by varying the "tuning" capacitor, C or by varying the position of the iron-dust core inside the coil (inductive tuning) giving an output over a wide range of frequencies making it very easy to tune. Also the Hartley Oscillator produces an output amplitude which is constant over the entire frequency range.

Basic Colpitts Oscillator Circuit



The emitter terminal of the transistor is effectively connected to the junction of the two capacitors, C1 and C2 which are connected in series and act as a simple voltage divider. When the power supply is firstly applied, capacitors C1 and C2 charge up and then discharge through the coil L. The oscillations across the capacitors are applied to the base-emitter junction and appear in the amplified at the collector output.Resistors, R1 and R2 provide the usual stabilizing DC bias for the transistor in the normal manner while the additional capacitors act as a DC-blocking bypass capacitors.

A radio-frequency choke (RFC) is used in the collector circuit to provide a high reactance (ideally open circuit) at the frequency of oscillation, (fr) and a low resistance at DC to help start the oscillations.The required external phase shift is obtained in a similar manner to that in the Hartley oscillator circuit with the required positive feedback obtained for sustained undamped oscillations. The amount of feedback is determined by the ratio of C1 and C2. These two capacitances are generally "ganged" together to provide a constant amount of feedback so that as one is adjusted the other automatically follows.The frequency of oscillations for a Colpitts oscillator is determined by the resonant frequency of the LC tank circuit and is given as:

$$f_r = \frac{1}{2\pi\sqrt{L C_T}}$$

where C_T is the capacitance of C1 and C2 connected in series and is given as:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{or} \quad C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

The configuration of the transistor amplifier is of a Ce amplifier with the output signal 180^o out of phase with regards to the input signal. The additional 180^o phase shift require for oscillation is achieved by the fact that the two capacitors are connected together in series but in parallel with the inductive coil resulting in overall phase shift of the circuit being zero or 360^o.The amount of feedback depends on the values of C1 and C2. We can see that the voltage across C1 is the the same as the oscillators output voltage,Vout and that the voltage across C2 is the oscillators feedback voltage. Then the voltage across C1 will be much greater than that across C2.

Therefore, by changing the values of capacitors, C1 and C2 we can adjust the amount of feedback voltage returned to the tank circuit. However, large amounts of feedback may cause the output sine wave to become distorted, while small amounts of feedback may not allow the circuit to oscillate.Then the amount of feedback developed by the Colpitts oscillator is based on the capacitance ratio of C1 and C2 and is what governs the the excitation of the oscillator. This ratio is called the “feedback fraction” and is given simply as:

$$\text{Feedback Fraction} = \frac{C_1}{C_2}\%$$

Operational Amplifiers

Opamp is a short form of operational amplifier which is capable of performing mathematical operations and signal conditioning(opamp is the heart of Instrumentation amplifier which is the front end signal conditioner of all data acquisition systems). Opamp is a DC coupled amplifier which amplifies even DC signals. Signetics μa741 series Opamp is one of the most successful opamp series. If input is given to inverting terminal with non inverting terminal grounded output will be exactly 180 degrees out of phase with input, hence the name inverting terminal. Similarly if input is given to Non inverting terminal with inverting terminal grounded, output will be exactly in phase with input. Above arguments are true provided they are no storage elements in the circuit with opamp.

Differential amplifier stage: Differential amplifier stage provides the following main functions:

(1) **High input impedance**: Generally differential amplifier stage is employed with constant current source in the emitter circuit; this ensures irrespective of input voltage fluctuations emitter current remains constant and provides high resistance to any fluctuations in the collector current(alternatively you can thought of a transistor biased at some quiescent point now if input voltage at base changes small signal input resistance is given by Δ Vbe/Δ Ib where Δ Ib is approximately zero as we have biased emitter current at a fixed current dictated by constant current source so input resistance will be very high). Even multiple differential stages are employed.

(2) **High Common Mode Rejection Ratio**: This is one of most desirable future essential to filter out the noise (noise will be common to both input terminals). By employing high resistance in the emitter circuit as CMMR is inversely related to emitter circuit resistance (constant current source provides high resistance when connected in series) and by carefully matching the transistors(very difficult even with highly advanced technology) high CMMRs can be achieved. After rejecting a lot of noise in the input signal is amplified in the next stage.

a) Gain stages: This intermediate stage will be provided with number of gain modules which are responsible for high gain of opamp. These modules are generally common emitter stages .Often level shifter module is also used to force the output voltage to ground potential i.e reference ground.

b) Output stage: This is generally a push pull amplifier (Power amplifier stage to drive more current or in turn more power) or common collector stage (which acts as buffer) which provides unit voltage gain with very low output resistance and high current gain.
Ideal Opamp characteristics

Ideal operational amplifier are characterized by

1) Infinite gain
2) Infinite input resistance
3) Zero output resistance (order of 10's of ohms)
4) Infinite bandwidth (practically restricted by slew rate)
5) Linear irrespective of entire analog signal range No offsets and, so on
6)

A real Opamp exhibits imperfections from ideal characteristics of an opamp due to practical limitations such as improper matching of transistors in differential stages, due to bulk and parasitic capacitance's e.t.c. Some of dc error voltages, currents and bandwidth limitations of an opamp are as follow

Slew rate of opamp

It is the maximum rate at which output can change in an opamp. It is one of the major limitations in an opamp. It is expressed in volt/second. The output gets distorted if the rate at which output changes exceeds slew rate.

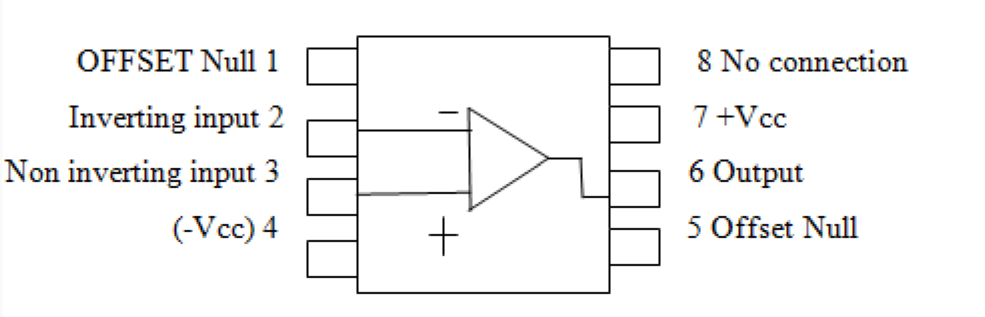
CMRR

CMRR is acronym for Common Mode Rejection Ration which is used to quantify how good a differential amplifier is. Let V1=V1d+Vn and V2=V2d+Vn where differential input signal is Vd = V1d-V2d and Vn is the common input signal. The output of differential amplifier will be of the form Vo = Ad*(Vd) +Ac*Vn, then the Common Mode Rejection Ratio of an differential amplifier is defined as the

Where Ad is differential mode signal gain and Ac is common mode signal gain.

741 Opamp Pin configuration

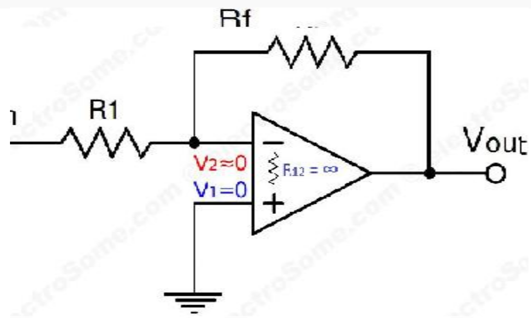
The pin configuration of opamp is as follows



Where pins 1 and 5showing Offset Null's along with potentiometer arrangement are used to nullify offset voltages. Positive offsets are nullified with pin 1 and negative offsets are nullified using pin 5.+Vcc and -Vcc are positive and negative supply voltages respectively generally within a range of + or _12 to + or – 24 .Pins 2 and 3 are inverting and non inverting input terminals respectively. Maximum differential input voltages will be specified in datasheets which should be exceeded, Opamp may get damaged due to high power dissipation. Pin 6 is single ended output terminal from which output will be taken.

Virtual ground

As the name indicates it is virtual, not real ground. For some purposes we can consider it as equivalent to ground. In opamps the term virtual ground means that the voltage at that particular node is almost equal to ground voltage (0V). It is not physically connected to ground. This concept is very useful in analysis of opamp circuits and it will make a lot of calculations very simple.



- gain = Vo/Vin

As gain is infinite, Vin = 0

1) Vin = V2 – V1
2) In the above circuit V1 is connected to ground, so V1 = 0. Thus V2 also will be at ground potential.
3) V2 = 0.

UNIT-V

SYLLABUS

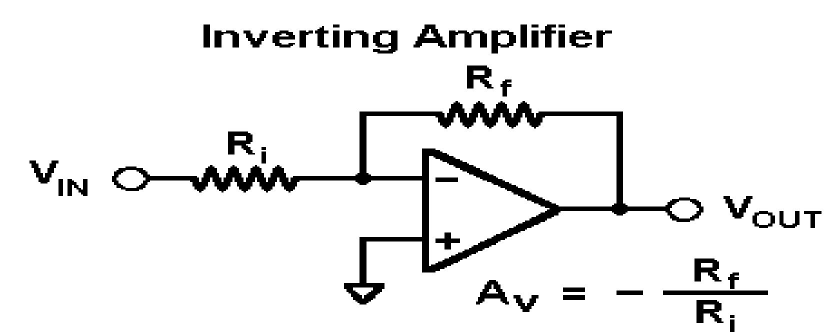
Applications of Op-Amps: Inverting and non-inverting amplifiers, Adder, Subtractor, Differentiator, Integrator, Log amplifier, Zero crossing detector, Wein bridge oscillator. **Conversion:** Resistive network (Weighted and R-2R Ladder). Accuracy and Resolution. A/D Conversion (successive approximation)

Inverting amplifier

Definition

Inverting amplifier is one in which the output is exactly 180^0 out of phase with respect to input(i.e. if you apply a positive voltage, output will be negative). Output is an inverted(in terms of phase) amplified version of input.

Circuit operation



Applying KCL at inverting node we get

$$(0-V_i)/R_i+(0-V_o)/R_f = 0$$

By rearranging the terms we will get

$$\text{Voltage gain } A_v = V_o/ V_i = – R_f/R_i .$$

Gain

Gain of inverting amplifier $A_v= – R_f/R_i$.

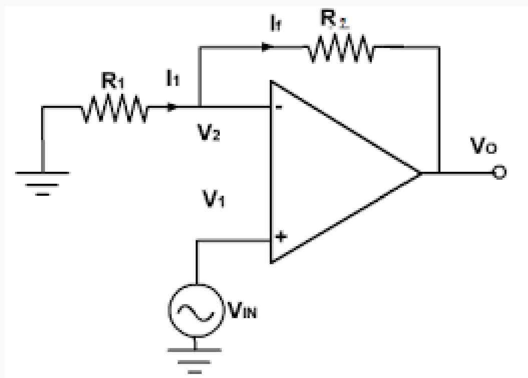
Non Inverting amplifier

Definition

Non Inverting amplifier is one in which the output is in phase with respect to input(i.e. if you apply a positive voltage, output will be positive). Output is an Non inverted(in terms of phase) amplified version of input.

Circuit operation

The inverting amplifier using opamp is shown in the figure below



Assuming the opamp is ideal and applying the concept of virtual short, the voltage at the inverting terminal is equal to non inverting terminal. Applying KCL at inverting node we get

$$(V_i-V_o)/R_2+(V_o-0)/R_1 = 0$$

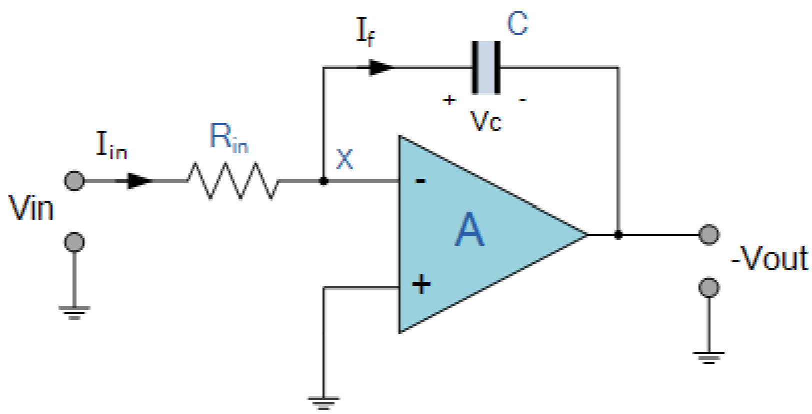
By rearranging the terms we will get

$$\text{Voltage gain } A_v = V_o/ V_i = (1+ R_f/R_i)$$

<u>Gain</u>

Gain of non inverting amplifier A_v= $(1+ R_f/R_i)$.

Op-amp Integrator Circuit



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

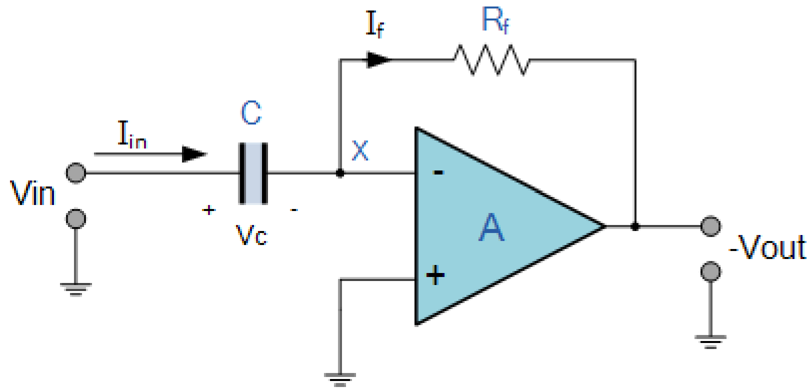
In other words the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

When a step voltage, Vin is firstly applied to the input of an integrating amplifier, the uncharged capacitor C has very little resistance and acts a bit like a short circuit allowing maximum current to flow via the input resistor, Rin as potential difference exists between the two plates. No current flows into the amplifiers input and point X is a virtual earth resulting in zero output. As the impedance of the capacitor at this point is very low, the gain ratio of Xc/Rin is also very small giving an overall voltage gain of less than one, (voltage follower circuit).

As the feedback capacitor, C begins to charge up due to the influence of the input voltage, its impedance Xc slowly increase in proportion to its rate of charge. The capacitor charges up at a rate determined by the RC time constant, (τ) of the series RC network. Negative feedback forces the op-amp to produce an output voltage that maintains a virtual earth at the op-amp's inverting input.

Since the capacitor is connected between the op-amp's inverting input (which is at earth potential) and the op-amp's output (which is negative), the potential voltage, Vc developed across the capacitor slowly increases causing the charging current to decrease as the impedance of the capacitor increases. This results in the ratio of Xc/Rin increasing producing a linearly increasing ramp output voltage that continues to increase until the capacitor is fully charged.

Op-amp Differentiator Circuit



The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no current flow to the amplifier summing point, X resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependant on the rate of change of the input signal.

At low frequencies the reactance of the capacitor is "High" resulting in a low gain (R*f*/Xc) and low output voltage from the op-amp. At higher frequencies the reactance of the capacitor is much lower resulting in a higher gain and higher output voltage from the differentiator amplifier.

However, at high frequencies an op-amp differentiator circuit becomes unstable and will start to oscillate. This is due mainly to the first-order effect, which determines the frequency response of the op-amp circuit causing a second-order response which, at high frequencies gives an output voltage far higher than what would be expected. To avoid this the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor across the feedback resistor R*f*.

Since the node voltage of the operational amplifier at its inverting input terminal is zero, the current, i flowing through the capacitor will be given as:

$$I_{IN} = I_F \text{ and } I_F = -\frac{V_{OUT}}{R_F}$$

The charge on the capacitor equals Capacitance x Voltage across the capacitor

$$Q = C \times V_{IN}$$

The rate of change of this charge is:

$$\frac{dQ}{dt} = C\frac{dV_{IN}}{dt}$$

but dQ/dt is the capacitor current,i

$$I_{IN} = C\frac{dV_{IN}}{dt} = I_F$$

$$\therefore\ -\frac{V_{OUT}}{R_F} = C\frac{dV_{IN}}{dt}$$

from which we have an ideal voltage output for the op-amp differentiator is given as:

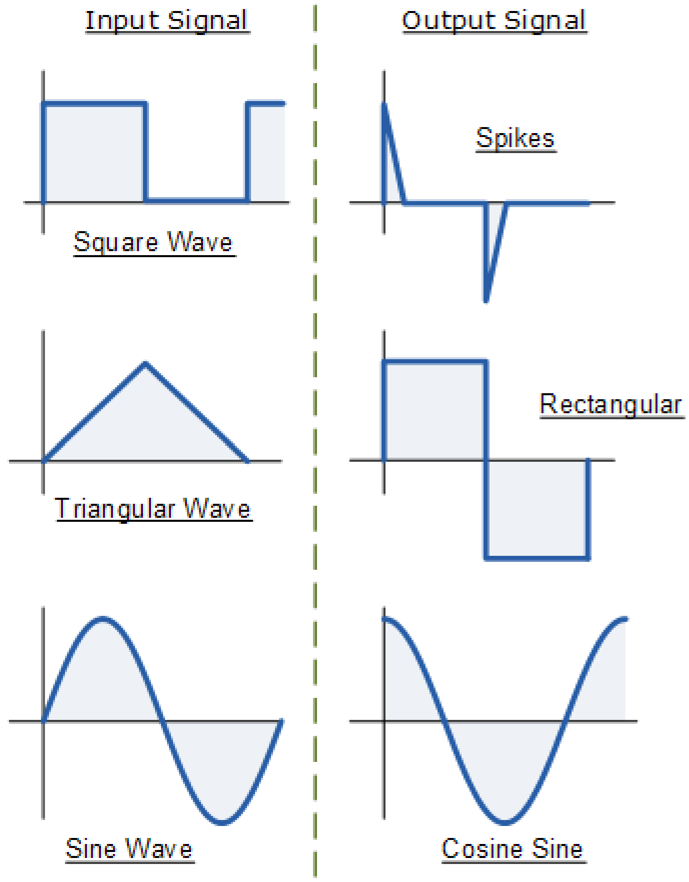
$$V_{OUT} = -R_F C\frac{dV_{IN}}{dt}$$

Therefore, the output voltage Vout is a constant -R*ƒ*.C times the derivative of the input voltage Vin with respect to time. The minus sign indicates a 180^o phase shift because the input signal is connected to the inverting input terminal of the operational amplifier.

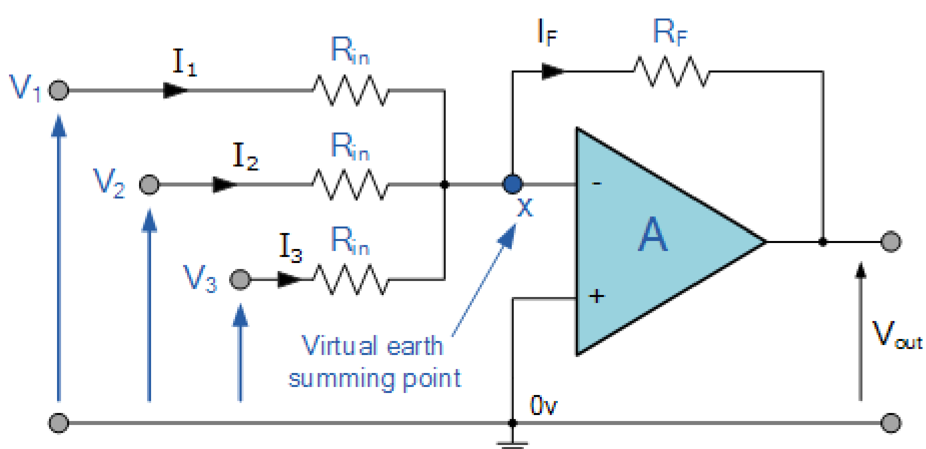
One final point to mention, the **Op-amp Differentiator** circuit in its basic form has two main disadvantages compared to the previous operational amplifier integrator circuit. One is that it suffers from instability at high frequencies as mentioned above, and the other is that the capacitive input makes it very susceptible to random noise signals and any noise or harmonics present in the source circuit will be amplified more than the input signal itself. This is because the output is proportional to the slope of the input voltage so some means of limiting the bandwidth in order to achieve closed-loop stability is required.

Op-amp Differentiator Waveforms

If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependant upon the RC time constant of the Resistor/Capacitor combination.



Summing Amplifier Circuit



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

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

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

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

However, if all the input impedances, (Rin) are equal in value, we can simplify the above equation to give an output voltage of:

Summing Amplifier Equation

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

We now have an operational amplifier circuit that will amplify each individual input voltage and produce an output voltage signal that is proportional to the algebraic "SUM" of the three individual input voltagesV_1, V_2 and V_3. We can also add more inputs if required as each individual input "see's" their respective resistance, Rin as the only input impedance.

This is because the input signals are effectively isolated from each other by the "virtual earth" node at the inverting input of the op-amp. A direct voltage addition can also be obtained when all the resistances are of equal value and Rf is equal to Rin.

A **Scaling Summing Amplifier** can be made if the individual input resistors are "NOT" equal.

Then the equation would have to be modified to:

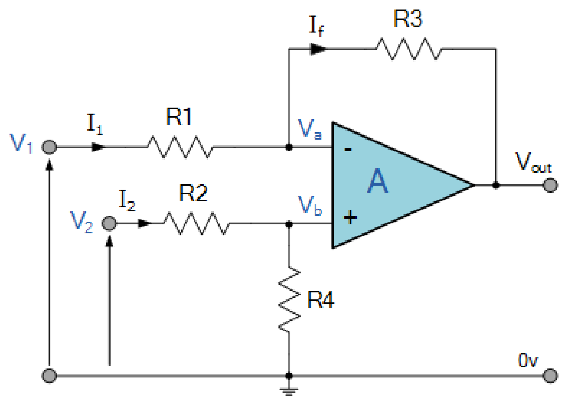
$$-Vout = V1\left(\frac{Rf}{R1}\right) + V2\left(\frac{Rf}{R2}\right) + V3\left(\frac{Rf}{R3}\right) \ldots .etc$$

To make the math's a little easier, we can rearrange the above formula to make the feedback resistor R_F the subject of the equation giving the output voltage as:

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

This allows the output voltage to be easily calculated if more input resistors are connected to the amplifiers inverting input terminal. The input impedance of each individual channel is the value of their respective input resistors, ie, R_1, R_2, R_3 … etc.

Differential Amplifier



By connecting each input in turn to 0v ground we can use superposition to solve for the output voltage Vout.

$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2}, \quad I_f = \frac{V_a - (V_{out})}{R_3}$$

$$\text{Summing point } V_a = V_b$$

$$\text{and } V_b = V_2\left(\frac{R_4}{R_2 + R_4}\right)$$

$$\text{If } V_2 = 0, \text{ then: } V_{out(a)} = -V_1\left(\frac{R_3}{R_1}\right)$$

$$\text{If } V_1 = 0, \text{ then: } V_{out(b)} = V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$$

$$V_{out} = -V_{out(a)} + V_{out(b)}$$

$$\therefore V_{out} = -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(\frac{R_1 + R_3}{R_1}\right)$$

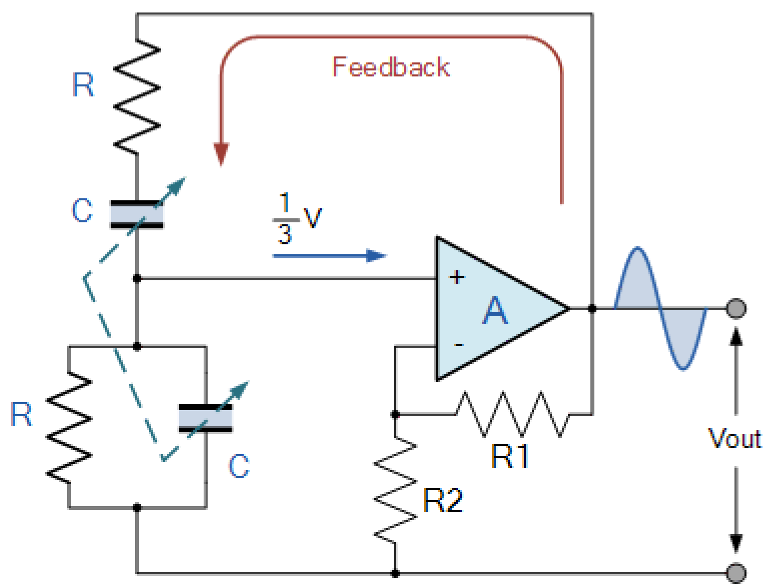
When resistors, R1 = R2 and R3 = R4 the above transfer function for the differential amplifier can be simplified to the following expression:

Differential Amplifier Equation

$$V_{OUT} = \frac{R_3}{R_1}\left(V_2 - V_1\right)$$

If all the resistors are all of the same ohmic value, that is: R1 = R2 = R3 = R4 then the circuit will become a **Unity Gain Differential Amplifier** and the voltage gain of the amplifier will be exactly one or unity. Then the output expression would simply be Vout = V2 – V1. Also note that if inputV1 is higher than input V2 the output voltage sum will be negative, and ifV2 is higher than V1, the output voltage sum will be positive.

Wien Bridge Oscillator



The output of the operational amplifier is fed back to both the inputs of the amplifier. One part of the feedback signal is connected to the inverting input terminal (negative feedback) via the resistor divider network of R1 and R2 which allows the amplifiers voltage gain to be adjusted within narrow limits. The other part is fed back to the non-inverting input terminal (positive feedback) via the RC Wien Bridge network.

The RC network is connected in the positive feedback path of the amplifier and has zero phase shift a just one frequency. Then at the selected resonant frequency, (*f*r) the voltages applied to the inverting and non-inverting inputs will be equal and "in-phase" so the positive feedback will cancel out the negative feedback signal causing the circuit to oscillate.

The voltage gain of the amplifier circuit MUST be equal too or greater than three "Gain = 3" for oscillations to start because as we have seen above, the input is 1/3 of the output. This value, ($Av \geq 3$) is set by the feedback resistor network, R1 and R2 and for a non-inverting amplifier this is given as the ratio 1+(R1/R2).

Also, due to the open-loop gain limitations of operational amplifiers, frequencies above 1MHz are unachievable without the use of special high frequency op-amps.

Wien Bridge Oscillator Frequency

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

Where:

1) fr is the Resonant Frequency in Hertz
2) R is the Resistance in Ohms
3) C is the Capacitance in Farads

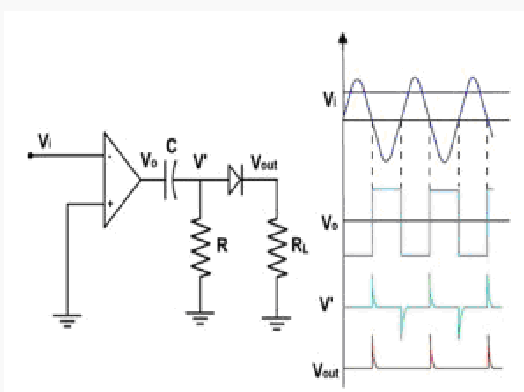
Op amp zero crossing detector

Definition

In opamp zero crossing detectors the output responds almost discontinuously every time the input passes through zero. It consists of a comparator circuit followed by differentiator and diode arrangement.

Circuit operation

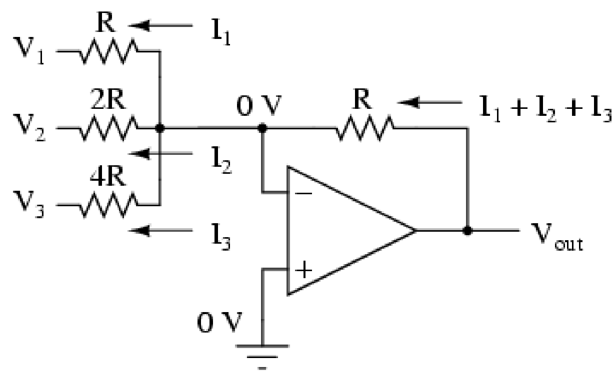
The circuit of zero crossing detector is shown in the figure below



Since the opamp is in open loop configuration $V_o = A_v*(V_i-0)$ the output of opamp i.e. V_o will be at Positive saturation voltage $+V_{cc}$ when ever $V_i > 0$ V and is at negative saturation voltage $-V_{cc}$ when $V_i < 0$ V. whenever the output of opamp transits from $+V_{cc}$ to $-V_{cc}$ the capacitor C charges to $+V_{cc}$ if the output of opamp changes from $-V_{cc}$ to $+V_{cc}$ and it discharges through R to $-V_{cc}$ if the output of opamp changes from $-V_{cc}$ to $+V_{cc}$ .The differentiator circuit(combination of capacitor and resistor) provides an output V’ = R*C*dV_o/dt consisting of peaks at times where the square wave crosses zero voltage. The diode is kept to filter off the zero crossings where input voltage crosses zero voltage in rising fashion.

Digital to Analogue Converters (DAC)

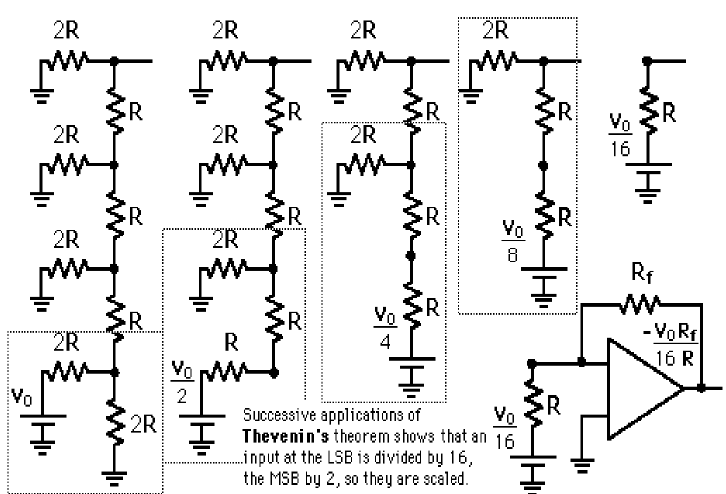
1) A Binary Weighted Ladder:



$$V_{out} = -\left(V_1 + \frac{V_2}{2} + \frac{V_3}{4}\right)$$

Starting from V_1 and going through V_3, this would give each input voltage exactly half the effect on the output as the voltage before it. In other words, input voltage V_1 has a 1:1 effect on the output voltage (gain of 1), while input voltage V_2 has half that much effect on the output (a gain of 1/2), and V_3 half of that (a gain of 1/4). These ratios are the same ratios corresponding to position weights in the binary system. If we drive the inputs of this circuit with digital gates so that each input is either 0 volts or full supply voltage, the output voltage will be an analog representation of the binary value of these three bits.

2) A R-2R Ladder:



A 4-bit R-2R Ladder DAC

The basic theory of the R-2R ladder network is that current flowing through any input resistor (2R) encounters two possible paths at the far end. The effective resistances of both paths are the same (also 2R), so the incoming current splits equally along both paths. The half-current that flows back towards lower orders of magnitude does not reach the op amp, and therefore has no effect on the output voltage. The half that takes the path towards the op amp along the ladder can affect the output. The inverting input of the op-amp is at virtual earth. Current flowing in the elements of the ladder network is therefore unaffected by switch positions.
If we label the bits (or inputs) bit 1 to bit N the output voltage caused by connecting a particular bit to Vr with all other bits grounded is: Vout = Vr/2N
where N is the bit number. For bit 1, Vout =Vr/2, for bit 2, Vout = Vr/4 etc.
Since an R/2R ladder is a linear circuit, we can apply the principle of superposition to calculate Vout. The expected output voltage is calculated by summing the effect of all bits connected to An R/2R ladder of 4 bits would have a full-scale output voltage of 1/2 +1/4 + 1/8 + 1/16 = 15Vr/16 or 0.9375 volts (if Vr=1 volt) while a 10bit R/2R ladder would have a full-scale output voltage of 0.99902 (if Vr=1 volt).

Performance Characteristics of DAC

The performance characteristics of a DAC include resolution, accuracy, linearity, monotonicity, and settling time:

• Resolution.

The resolution of a DAC is the reciprocal of the number of discrete steps in the output. This, of course, is dependent on the number of input bits. For example, a 4-bit DAC has a resolution of one part in 2" - 1 (one part in fifteen).Expressed as a percentage, this is (1/15)100 = 6.67%. The total number of discrete steps equals 2" - 1, where *n* is the number of bits. Resolution can also be expressed as the number of bits that are converted.

• **Accuracy.**

Accuracy is a comparison of the actual output of a DAC with the expected output. It is expressed as a percentage of a full-scale, or maximum, output voltage. For example, if a converter has a full-scale output of 10V and the accuracy is ±0.1 %, then the maximum error for any output voltage is (10 V)(0.001) =10 rnV. Ideally, the accuracy should be, at most, ±'/2 of an LSB. For an 8-bit converter, 1 LSB is 1/256 = 0.0039 (0.39% of full scale). The accuracy should be approximately ±0.2%,

• **Linearity.**

A linear error is a deviation from the ideal straight-line output of a DAC. A special case is an offset error, which is the amount of output voltage when the input bits are all zeros.

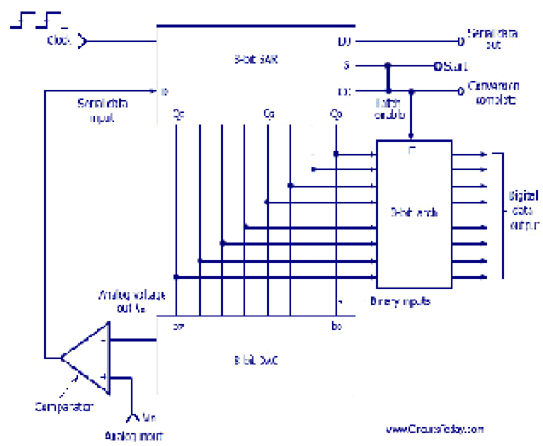
• **Monotonicity.**

A DAC is monotonic if it does not take any reverse steps when it is sequenced over its **entire range of input bits.**
• Settling time.

Settling time is normally defined as the time it takes a DAC to settle within ±'/2 LSB of its final value when a change occurs in the input code.

Successive Approximation Type Analog to Digital Converter:

A successive approximation A/D converter consists of a comparator, a successive approximation register (SAR), output latches, and a D/A converter. The circuit diagram is shown below



Successive Approximation Type Analog to Digital Converter

.

The main part of the circuit is the 8-bit SAR, whose output is given to an 8-bit D/A converter. The analog output V_a of the D/A converter is then compared to an analog signal V_{in} by the comparator. The output of the comparator is a serial data input to the SAR. Till the digital output (8 bits) of the SAR is equivalent to the analog input V_{in}, the SAR adjusts itself. The 8-bit latch at the end of conversation holds onto the resultant digital data output.

Working

At the start of a conversion cycle, the SAR is reset by making the start signal (S) high. The MSB of the SAR (Q7) is set as soon as the first transition from LOW to HIGH is introduced. The output is given to the D/A converter which produces an analog equivalent of the MSB and is compared with the analog input V_{in}.If comparator output is LOW, D/A output will be greater than V_{in} and the MSB will be cleared by the SAR.

If comparator output is HIGH, D/A output will be less than V_{in} and the MSB will be set to the next position (Q7 to Q6) by the SAR. According to the comparator output, the SAR will either keep or reset the Q6 bit. This process goes on until all the bits are tried. After Q0 is tried, the SAR makes the conversion complete (CC) signal HIGH to show that the parallel output lines contain valid data. The CC signal in turn enables the latch, and digital data appear at the output of the latch. As the SAR determines each bit, digital data is also available serially. As shown in the figure above, the CC signal is connected to the start conversion input in order to convert the cycle continuously.The biggest advantage of such a circuit is its high speed. It may be more complex than an A/D converter, but it offers better resolution.

KARPAGAM UNIVERSITY ,COIMBATORE-21

DEPARTMENT OF PHYSICS

CLASS:I B.Sc PHYSICS

Analog Systems and Applications (16PHU202)

Questions	opt1
UNIT-I	
A crystal diode has ………	one pn junction
A crystal diode has forward resistance of	kΩ
If the arrow of crystal diode symbol is positive w.r.t. bar, then diode is ………….. biased	forward
The reverse current in a diode is of the order	kA
The forward voltage drop across a silicon diode is about …………………	2.5 V
A crystal diode is used as ……………	an amplifier
The d.c. resistance of a crystal diode is ………….. its a.c. resistance	the same as
An ideal crystal diode is one which behaves as a perfect ……….. when forward biased	conductor
The ratio of reverse resistance and forward resistance of a germanium crystal d	1 : 1
The leakage current in a crystal diode is due to …………….	. minority carriers
If the temperature of a crystal diode increases, then leakage current ………..	remains the same
The PIV rating of a crystal diode is …………..	the same as
. If the doping level of a crystal diode is increased, the breakdown voltage…………	remains the same
The knee voltage of a crystal diode is approximately	applied voltage
When the graph between current through and voltage across a device is a straight line, the device is referred to as ……………….	linear
When the crystal current diode current is large, the bias is …………	forward
A crystal diode is a …………… device	non-linear

A crystal diode utilises ……………..	reverse
If the doping level in a crystal diode is increased, the width of depletion layer………..	remains the same
In a semiconductor diode, the depletion region is removed when:	the diode is in its forward conducting state
The forward threshold voltage for a germanium diode is about:	0.2 V
The term 'covalent bonding' refers to:	the introduction of an impurity
Why is heat produced in a diode?	due to the power rating of the diode
Since diodes are destroyed by excessive current, circuits must have:	more dopants
The arrow in the schematic symbol of a diode points to	p-type material, which is called the anode
The characteristic curve for the complex model of a silicon diode shows that	the barrier potential increases slightly with an increase in current
A pn junction allows current flow when	both the n-type and p-type materials have the same potential
When a diode is forward biased, the voltage across it	is inversely proportional to the current
The peak inverse voltage (PIV) across a nonconducting diode in a bridge rectifier equals approximately:	the peak value of the secondary voltage
Testing a good diode with an ohmmeter should indicate	high resistance when forward or reverse biased

What circuit activity may shift a characteristic curve so that diode operating points are different?	higher power (heat)
The diode ________.	is the simplest of semiconductor devices
What does a high resistance reading in both forward- and reverse-bias directions indicate?	A good diode
Which capacitance dominates in the reverse-bias region?	depletion
What is the state of an ideal diode in the region of nonconduction?	An open circuit
How many orbiting electrons does the germanium atom have?	4
How many terminals does a diode have?	2
What unit is used to represent the level of a diode forward current I_F?	A
The diffused impurities with ________ valence electrons are called donor atoms.	4
Which of the following devices can check the condition of a semiconductor diode?	Digital display meter (DDM)
Which of the following is an atom composed of?	Electrons
How many valence electrons does a silicon atom have?	1
What is the resistor value of an ideal diode in the region of conduction?	0 ohm
Which of the following elements is most frequently used for doping pure Ge or Si?	Boron
Which of the following ratings is true?	Si diodes have higher PIV and narrower temperature ranges than Ge diodes.
The ideal diode is a(n) ________ circuit in the region of nonconduction.	open
Which capacitance dominates in the forward-bias region?	Diffusion
In what state is a silicon diode if the voltage drop across it is about 0.7 V?	No bias
A semiconductor has ……….. temperature coefficient of resistance.	Positive
The most commonly used semiconductor is ……….	silicon

When a pentavalent impurity is added to a pure semiconductor, it becomes ………	An insulator
Addition of pentavalent impurity to a semiconductor creates many ……..	Free electrons
. A pentavalent impurity has ………. Valence electrons	3
An n-type semiconductor is ………	Positively charged
A trivalent impurity has ….. valence electrons	3
Addition of trivalent impurity to a semiconductor creates many ……..	Free electrons
A hole in a semiconductor is defined as …………….	A free electron
In a semiconductor, current conduction is due to ……..	Only holes
The battery connections required to forward bias a pn junction are	ve terminal to p and –ve terminal to n
In the depletion region of a pn junction, there is a shortage of ……..	Acceptor ions
A pn junction acts as a ……….	Controlled switch

UNIT-II

A zener diode has ………..	one pn junction
A zener diode is used as …………….	an amplifier
The doping level in a zener diode is …………… that of a crystal diode	the same as
A zener diode is always ………… connected	reverse
In the breakdown region, a zener didoe behaves like a …………… source.	constant voltage
A zener diode is destroyed if it…………..	is forward biased
A zener diode is …………………. Device	a non-linear
If the PIV rating of a diode is exceeded, ………………	the diode conducts poorly

The ……………….. filter circuit results in the best voltage regulation	choke input
The maximum efficiency of a half-wave rectifier is	40.6 %
The most widely used rectifier is ……………….	1. half-wave rectifier
If the junction temperature of LED is increased the radiant output power:	Decreases
The LED is usually made of materials like:	GaAs
What does LED stands for	Light emitting doide
The most commonly used semiconductor in the manufacture of a transistor is …………	germanium
The arrow in the symbol of a transistor indicates the direction of	electron current in the emitter
In a transistor, signal is transferred from a …………… circuit	high resistance to low resistance
As the temperature of a transistor goes up, the base-emitter resistance ……………	Decreases
The voltage gain in a transistor connected in ………………. arrangement is the highest	CE
The power gain in a transistor connected in ……………. arrangement is the highest	CE
The most commonly used transistor arrangement is …………… arrangement	CE
The collector of a transistor is …………. doped	heavily
The emitter of a transistor is ………………… doped	heavily
The input impedance of a transistor is ………….	low
A transistor is a …………… operated device	current
The element that has the biggest size in a transistor is ………………..	collector
The base of a transistor is ………….. doped	heavily
The number of depletion layers in a transistor is …………	3
It is generally desired that a transistor should have …………….. input impedance	low
The phase difference between the output and input voltages of a CE amplifier is ………………..	180
The dc load line on a family of collector characteristic curves of a transistor shows the	saturation region.
A transistor data sheet usually identifies β_{DC} as	h_{re}.

When a transistor is used as a switch, it is stable in which two distinct regions?	saturation and active
For a silicon transistor, when a base-emitter junction is forward-biased, it has a nominal voltage drop of	0.7 V.
The value of β_{DC}	is fixed for any particular transistor.
The term BJT is short for	base junction transistor.
A BJT has an I_B of 50 μA and a βDC of 75; I_C is:	375 mA
A certain transistor has I_C = 15 mA and I_B = 167 μA; β_{DC} is:	15
For normal operation of a pnp BJT, the base must be _____ with respect to the emitter and _____ with respect to the collector.	positive, negative
A transistor amplifier has a voltage gain of 100. If the input voltage is 75 mV, the output voltage is:	1.33 V
A 35 mV signal is applied to the base of a properly biased transistor with an r'_e = 8 Ω and R_C = 1 kΩ. The output signal voltage at the collector is:	3.5 V
What is the order of doping, from heavily to lightly doped, for each region?	base, collector, emitter
What are the two types of bipolar junction transistors?	npn and pnp
Which of the following is true for an npn or pnp transistor?	$I_E = I_B + I_C$
What is the ratio of I_C to I_B?	β_{DC}
What is the ratio of I_C to I_E?	β_{DC}
In what range of voltages is the transistor in the linear region of its operation?	$0 < V_{CE}$
What does DC vary with?	I_C
What is (are) common fault(s) in a BJT-based circuit?	pens or shorts internal to the transistor
What is (are) general-purpose/small-signal transistors case type(s)?	TO-18
The magnitude of dark current in a phototransistor usually falls in what range?	mA

First solar cell was invented in 1883 by	A. George Fritts.
Most of the majority carriers from the emitter ………………..	1. recombine in the base
The current IB is …………	1. electron current
In a transistor …	IC = IE + IB
The value of α of a transistor is ……	1
The output impedance of a transistor is …	low
If the value of α is 0.9, then value of β is ………..	90
The leakage current in CE arrangement is ……………. that in CB arrangemen	more than
The collector-base junction in a transistor has …	forward bias at all times
The emitter-base junction in a transistor has …	forward bias at all times

UNIT-III

When negative voltage feedback is applied to an amplifier, its voltage gain	Is increased
The value of negative feedback fraction is always	<1
There are …………… *h* parameters of a transistor	2
The *h* parameter approach gives correct results for	Large signals only
The dimensions of *hie* parameter are	Mho
If the operating point changes, the *h* parameters of transistor	Also change
If temperature changes, *h* parameters of a transistor	Also change
A feedback circuit usually employs ……………… network	Resistive
The gain of an amplifier with feedback is known as ………….. gain	Resonant
When voltage feedback (negative) is applied to an amplifier, its input impedance	Is increased
When current feedback (negative) is applied to an amplifier, its input impedance ………….	Is increased
Negative feedback is employed in	Oscillators
Emitter follower is used for …	Current gain
Quiescent power is the power dissipation of a transistor	with no signal input.

A class B amplifier operates in the linear region for	slightly more than 180° of the input cycle.
In a class AB amplifier, if the V_{BE} drops are not matched to the diode drops or if the diodes are not in thermal equilibrium with the transistors, this can result in	a current mirror.
Which amplifier is commonly used as a frequency multiplier?	class A
The least efficient amplifier among all classes is	class B.
A class A amplifier has a voltage gain of 30 and a current gain of 25. What is the power gain?	30
You have an application for a power amplifier to operate on FM radio frequencies. The most likely choice would be a _____ amplifier.	class A
A class A amplifier with R_C = 3.3 kΩ and R_E = 1.2 kΩ has a V_{CC} = 20 V. Find $I_{C(sat)}$.	4.4 mA
A class C amplifier has a tank circuit in the output. The amplifier is conducting only 28°. The output voltage is	0 V.
In practice, the efficiency of a capacitively coupled class A amplifier is about _____%.	25
The Q-point is at cutoff for class _____ operation.	A
Class _____ amplifiers are normally operated in a push-pull configuration in order to produce an output that is a replica of the input.	A
The maximum efficiency of a class B amplifier is _____ percent.	50
A class _____ amplifier is biased slightly above cutoff and operates in the linear region for slightly more than 180º of the input cycle.	A
Which class of amplifier operates in the linear region for only a small part of the input cycle?	A
Class D operation can achieve power efficiency of over _____.	90%
The beta of a power transistor is generally _____.	more than 200
A form of class A amplifier having maximum efficiency of _____ uses a transformer to couple the output signal to the load.	90%
The reflected impedance seen from one side of the transformer to the other side is _____.	N_1/N_2

In a class A transformer-coupled power amplifier, _____ winding resistance of the transformer determine(s) the dc load line for the circuit.	the ac
The slope of the ac load line in the class A transformer-coupled transistor is _____.	$-1/R_L$ (load resistor)
The amount of power dissipated by the transistor is the _____ of that drawn from the dc supply (set by the bias point) and the amount delivered to the ac load.	product
A class A amplifier dissipates _____ power when the load is drawing maximum power from the circuit.	the least
In a class A transformer-coupled amplifier, the _____ the value of V_{CEmax} and the _____ the value of V_{CEmin}, the _____ the efficiency to (from) the theoretical limit of 50%.	larger, smaller, farther
In class B operation, the current drawn from a single power supply has the form of _____ rectified signal.	a full-wave
The highest efficiency is obtained in class B operation when the level of $V_L(p)$ is equal to _____.	$0.25V_{CC}$
_____ transistors can be used to build a class B amplifier.	npn and pnp
The complementary Darlington-connected transistor for a class B amplifier provides _____ output current and _____ output resistance.	higher, higher
The fundamental component is typically _____ any harmonic component.	larger than
An amplifier has a power gain of 100. Its db gain is ……	0 db
In order to get more voltage gain from a transistor amplifier, the transistor used should have	Thin base
The purpose of a coupling capacitor in a transistor amplifier is to	Increase the output impedance of transistor
The purpose of emitter capacitor (i.e. capacitor across RE) is to	Avoid voltage gain drop
The ratio of output impedance of a CE amplifier is …	About 1
If a transistor amplifier feeds a load of low resistance (e.g. speaker), then voltage gain will be …	. About 1
If the input capacitor of a transistor amplifier is short-circuited, then…	Transistor will be destroyed

A CE amplifier is also called ………….. circuit	Grounded emitter
The value of collector load RC in a transistor amplifier is ……….. the output impedance of the transistor.	The same as
The d.c. load of a transistor amplifier is generally ………….. that of a a.c. load	The same as
In transistor amplifiers, we generally use ………….. capacitors.	Electrolytic
The output power of a transistor amplifier is more than the input power because the additional power is supplied by	Transistor
A transistor amplifier has high output impedance because …	Emitter is heavily doped
For highest power gain, one would use …………….. configuration	CC
RC coupling is used for ………………. amplification	Voltage
In an RC coupled amplifier, the voltage gain over mid-frequency range	Changes abruptly with frequency
An advantage of RC coupling scheme is the	Good impedance matching
The best frequency response is of ………. coupling	RC
Transformer coupling is used for ………….. amplification	Voltage
In an RC coupling scheme, the coupling capacitor CC must be large enough …	To pass d.c. between the stages
The noise factor of an ideal amplifier expressed in db is	0
When a multistage amplifier is to amplify d.c. signal, then one must use …….. coupling	RC
……….. coupling provides the maximum voltage gain	RC
RC coupling is not used to amplify extremely low frequencies because	There is considerable power loss

UNIT-IV

An ideal operational amplifier has_____	Unity open loop gain

The gain of an operational amplifier_____at high frequencies because of capacitances within operational amplifier	Decreases
An operational amplifier can amplify_______	Only AC
The two input terminals of an operational amplifier are known as_____	Positive & Negative
The operational amplifier input is a ______ amplifier	Inverting
The gain of an actual operational amplifier is around______	1,000
IC 741 is ______ operational amplifier	Frequency compensated
IC 741 offset Voltage adjustment range is____	15mV
CMRR stands for ______	Common Modulation Rejection Ratio
The range of the input common-mode voltage is______	13V
Output Resistance of IC 741______	60 Ohm
PSRR Stands for ______	Power Sector Resistance Range
CMRR is typically ______dB	100dB
Built in short circuit protection is guaranteed to withstand______of current	10 mA
Supply current in IC 741 is____mA	1.5
Power consumption in operational amplifier is________	85mW
The slew rate of operational amplifier is_____	Zero
The small voltage applied at the input terminals to make output voltage zero is called_____	Input bias current
The total number of Inputs in IC741____	1
The power supply voltage to op-amp may ranges from_____	5v to 12v
In operational amplifier pin 2 is called____	Power supply terminal
In operational amplifier pin 3 is called____	Power supply terminal
In operational amplifier pin 6 is called____	Power supply terminal
In operational amplifier pin 7 and 4 are connected to ____	Power supply terminal
In operational amplifier pin 1 and 5 are used for____	dc offset
Operational amplifier have _____ basic terminals	Two

Operational amplifier have _____output impedance	High
Operational amplifier have _____open loop voltage gain	Infinite
Operational amplifier is a voltage controlled_____ source	Current
The operational amplifier is a ______ terminal device	Single
The operating temperature range of IC 741 is__	0*C to 70*c
An ideal op-amp has no current from source and its response is independent of_________	Voltage
An op-amp with open loop gain of 90dB with dc signal has gain of_____through audio and radio frequencies	70dB
The rate of which the voltage across the capacitor in operational amplifier is given by_____	I/C
The input offset voltage is measured is______	V
The common mode rejection ratio is measured in____	V
The unit of slew rate is__	mV/sec
Op-amp IC 741 has a _____ slew rate	Low
The open-loop gain of the op-amp decreases at the rate of____	(-10)dB decade
. An oscillator produces……………. oscillations	Damped
An oscillator employs ……………… feedback	Positive
Hartley oscillator is commonly used in …	Radio receivers
In a phase shift oscillator, we use …………. RC sections	1
In a phase shift oscillator, the frequency determining elements are	L and C
An oscillator differs from an amplifier because it	Has more gain
One condition for oscillation is	A phase shift around the feedback loop of 180o
A second condition for oscillations is …	A gain of 1 around the feedback loop
For an oscillator to properly start, the gain around the feedback loop must initially be	1

In Colpitt's oscillator, feedback is obtained …	By magnetic induction
………….. is a fixed frequency oscillator	Phase-shift oscillator
An oscillator converts …	dc. power into d.c. power
In an LC transistor oscillator, the active device is …	LC tank circuit
In an LC circuit, when the capacitor is maximum, the inductor energy is	. Minimum
In an LC oscillator, the frequency of oscillator is ……………. L or C.	Proportional to square of
An LC oscillator cannot be used to produce ……………….. frequencies	High
Quartz crystal is most commonly used in crystal oscillators because	It has superior electrical properties
The signal generator generally used in the laboratories is ………….. oscillator	Wien-bridge
An important limitation of a crystal oscillator is …	Its low output
In an LC oscillator, if the value of L is increased four times, the frequency of oscillations is	Increased 2 times

UNIT-V

The _________ is a miniature, low cost electronic circuit consisting of active and passive components that are joined on a single crystal chip.	Integrated Resistor
GSI stands for	Giant Scale Integration
A small single crystal rod of silicon is called	Ingot
The Instrumentation amplifier is used in________	Communication based circuits
The function of a _______ is used to compare the peak values of the input	Comparator
In differentiator the output waveform is the _____ of input waveform	Equal
If we interchange the resistor and capacitor of the differentiator the circuit is _____	Integrated

A______ is used for low voltage dc and ac volt meter, LED and zener diode tester	V-I convertor
The reference voltage is set to zero in_____	Window detector
The other name of zero crossing detector is______	Triangular wave to square wave generator
The sine wave to square wave generator is other wise known as____	Window detector
The type of circuit in which unknown input is marked between 2 threshold levels is known as	Zero crossing detector
The output of schmitt trigger circuit is _____	Sine wave
Hysteresis in schmitt tigger is also known as____	Phase meter
Backlash refers to _____ phenomenon	Phase meter
In astable multivibrator,both the states are_____state	Bistable
A _________ is a circuit which compares a signal voltage applied at one input of an op-amp with known reference voltage.	Rectifier
The smallest amount of difference in voltage required at the inputs of comparator to make the output change its state is known as ______	Response time
Which converters uses integrating op-amp	Parallel A/D
A differential amplifier	is a part of an Op-amp
When a differential amplifier is operated single-ended,	the output is grounded
In differential-mode,	opposite polarity signals are applied to the inputs
In the common mode, …………	both inputs are grounded
The Op-amp can amplify	a.c. signals only
A comparator is an example of an	current source
A digital-to-analog converter is an application of the	adjustable bandwidth circuit
The ramp voltage at the output of an op-amp integrator	increases or decreases exponentially

Another name for a unity gain amplifier is:	difference amplifier
A noninverting closed-loop op-amp circuit generally has a gain factor:	<1
In order for an output to swing above and below a zero reference, the op-amp circuit requires:	a resistive feedback network
Input impedance [Z_{in} (I)] of an inverting amplifier is approximately equal to:	R_i
The closed-loop voltage gain of an inverting amplifier equals:	the ratio of the input resistance to the feedback resistance
All of the following are basic op-amp input modes of operation EXCEPT	inverting mode
A circuit whose output is proportional to the difference between the input signals is considered to be which type of amplifier?	common-mode
If the input to a comparator is a sine wave, the output is a:	ramp voltage
The major difference between ground and virtual ground is that virtual ground is only a	voltage reference
The Schmitt trigger is a two-state device that is used for:	pulse shaping
When a capacitor is used in place of a resistor in an op-amp network, its placement determines:	open- or closed-loop gain
An output that is proportional to the addition of two or more inputs is from which type of amplifier?	differentiator
An ideal amplifier should have:	high input current
Which of the following is a type of error associated with digital-to-analog converters (DACs)?	nonmonotonic error
A 4-bit R/2R digital-to-analog (DAC) converter has a reference of 5 volts. What is the analog output for the input code 0101.	3.125
A binary-weighted digital-to-analog converter has an input resistor of 100 k. If the resistor is connected to a 5 V source, the current through the resistor is:	50 micro A
The practical use of binary-weighted digital-to-analog converters is limited to:	R/2R ladder D/A converters
The difference between analog voltage represented by two adjacent digital codes, or the analog step size, is the:	quantization

The primary disadvantage of the flash analog-to digital converter (ADC) is that:	it requires the input voltage to be applied to the inputs simultaneously
What is the major advantage of the R/2R ladder digital-to-analog (DAC), as compared to a binary-weighted digital-to-analog DAC converter?	It only uses two different resistor values.
The resolution of a 0–5 V 6-bit digital-to-analog converter (DAC) is:	64%
Which is not an analog-to-digital (ADC) conversion error?	differential nonlinearity

opt2	opt3	opt4	Answer
two pn junctions	three pn junctions	none of the above	one pn junction
Ω	MΩ	none of the above	Ω
reverse	direct	none of the above	forward
mA	μA		μA
3 V	10 V	0.7 V	0.7 V
a rectifier	an oscillator	a voltage regulator	a rectifier
more than	less than	none of the above	less than
insulator	resistance material	none of the above	conductor
100 : 1	1000 : 1	40,000 : 1	40,000 : 1
majority carriers	junction capacitance	none of the above	minority carriers
decreases	increases	becomes zero	increases
lower than	more than	none of the above	lower than
. is increased	is decreased	none of the above	is decreased
breakdown voltage	forward voltage	barrier potential	barrier potential
. active	nonlinear	passive	linear
inverse	poor	reverse	forward
bilateral	linear	none of the above	non-linear

forward	forward	none of the above	forward
is decreased	or reverse in increased	none of the above	in increased
the diode is in its reverse non-conducting state	there is no potential difference between the anode and cathode	none of the above	the diode is in its forward conducting state
0.4 V	0.6 V	,8V	0.2V
the sharing of valence electrons	the generation of surplus electrons		the sharing of valence electrons
due to voltage across the diode	due to the PN junction of the diode	due to current passing through the diode	due to current passing through the diode
higher voltage sources	current limiting resistors	higher current sources	
n-type material, which is called the anode	the p-type material, which is called the cathode	the n-type material, which is called the cathode	the p-type material, which is called the anode
the barrier potential decreases slightly with an increase in current	the barrier potential stays fixed at 0.7 V	the barrier potential is 0 V	the barrier potential stays fixed at 0.7 V
the p-type material is more positive than the n-type material	there is no potential on the n-type or p-type materials	the n-type material is more positive than the p-type material	the p-type material is more positive than the n-type material
directly proportional to the source voltage	is directly proportional to the current	remains approximately the same	remains approximately the same
twice the peak secondary voltage	half the peak secondary voltage	r times the peak value of the secondary voltage	the peak value of the secondary voltage
ı resistance when reverse biased and low resistance when forward biased	low resistance when forward or reverse biased	high resistance when forward biased and low resistance when reverse biased	high resistance when reverse biased and low resistance when forward biased

higher resistance	lower current	lower voltage	higher resistance
has characteristics that closely match those of a simple switch	is a two-terminal device	All of the above	All of the above
An open diode	A shorted diode	A defective ohmmeter	An open diode
conversion	Ω0 Diffusion	Ω40 None of the above	depletion
A short circuit	Unpredictable	Undefined	An open circuit
12	32	45	32
3	4	6	2
mA	v	mV	mA
3	5	0	5
Multimeter	Curve tracer	All of the above	All of the above
Protons	Neutrons	All of the above	All of the above
2	3	4	4
5 k ohm	15 Kohm	Ω9 K ohm	0 0hm
Gallium	Indium	All of the above	All of the above
Si diodes have higher PIV and wider temperature ranges than Ge diodes	Si diodes have lower PIV and narrower temperature ranges than Ge diodes.	Si diodes have lower PIV and wider temperature ranges than Ge diodes.	Si diodes have higher PIV and wider temperature ranges than Ge diodes
closed	neutal	none of these	open
Transition	Depletion	None of the above	Diffusion
Forward bias	Reverse bias	Zener region	Forward bias
Zero	Negative	None of the above	Negative
Bermanium	carbon	copper	silicon

An intrinsic semiconductor	p-type semiconductor	n-type semiconductor	n-type semiconductor
Holes	Valence electrons	Bound electrons	Free electrons
2	5	4	5
Negatively charged	. Electrically neutral	None of the above	Negatively charged
4	5	6	3
Holes	Valence electrons	Bound electrons	Holes
The incomplete part of an electron pair bond	A free proton	A free neutron	The incomplete part of an electron pair bond
Only free electrons	Holes and free electrons	None of the above	Holes and free electrons
-ve terminal to p and +ve terminal to n	-ve terminal to p and –ve terminal to n	None of the above	+ve terminal to p and –ve terminal to n
Holes and electrons	Donor ions	None of the above	. Holes and electrons
Bidirectional switch	Unidirectional switch	. None of the above	Unidirectional switch
two pn junctions	three pn junctions	none of the above	one pn junction
a voltage regulator	a rectifier	a multivibrator	voltage regulator
less than	more than	none of the above	more than
forward	both forward and reverse	none of the above	reverse
constant current	constant resistance	none of the above	constant voltage
is reverse biased	carrier more than rated current	none of the above	carrier more than rated current
a linear	an amplifying	none of the above	a non-linear
the diode is destroyed	the diode behaves like a zener diode	none of the above	the diode is destroyed

capacitor input	resistance input	none of the above	choke input
50.00%	35%	80%	40.60%
1. centre-tap full-wave rectifier	1. bridge full-wave rectifier	1. none of the above	bridge full-wave rectifier
Increases	same	1. none of the above	decreases
CU	C	Al	GaAS
Light emitting detector	light energy	light emitting disply	
Silicon	Aluminium	galium	Silicon
electron current in the collector	hole current in the emitter	donor ion current	hole current in the emitter
low resistance to high resistance	high resistance to high resistance	. low resistance to low resistance	low resistance to high resistance
Increases	same	1. none of the above	decreases
CB	CC	CBE	CE
CB	CC	CBE	CE
CB	CC	CBE	CE
moderately	lightly	none of the above	moderately
moderately	lightly	none of the above	heavily
high	0	very high	low
voltage	both voltage and current	none of the above	current
base	emitter,	none of the above	collector
moderately	lightly	none of the above	lightly
2	1	4	2
high	very low	very high	high
0	90	270	180
cutoff region.	active region.	all of the above	all of the above
h_{fe}.	I_C.	V_{CE}.	h_{fe}

active and cutoff	saturation and cutoff	none of the above	saturation and cutoff
0.3 V.	0.2 V.	V_{CC}.	0.7 V
varies with temperature.	varies with I_C.	varies with temperature and I_C.	varies with temperature and I_C.
binary junction transistor.	both junction transistor.	bipolar junction transistor.	bipolar junction transistor
37.5 mA	3.75 mA	0.375 mA	3.75 mA
167	0.011	90	90
positive, positive	negative, positive	negative, negative	negative, positive
7.5 V	13.3 V	15 V	7.5 V
28.57 V	4.375 V	4.375 mV	4.375 V
emitter, collector, base	emitter, base, collector	collector, emitter, base	emitter, collector, base
pnn and nnp	ppn and nnp	pts and stp	npn and pnp
$I_B = I_C + I_E$	$I_C = I_B + I_E$	none of the above	$I_E = I_B + I_C$
h_{FE}	α_{DC}	either β_{DC} or h_{FE}, but not α_{DC}	either β_{DC} or h_{FE}, but not α_{DC}
$\beta_{DC} / (\beta_{DC} + 1)$	α_{DC}	either $\beta_{DC} / (\beta_{DC} + 1)$ or α_{DC}, but not β_{DC}	either $\beta_{DC} / (\beta_{DC} + 1)$ or α_{DC}, but not β_{DC}
$0.7 < V_{CE} < V_{CE(max)}$	$V_{CE(max)} > V_{CE}$	none of the above	$0.7 < V_{CE} < V_{CE(max)}$
ºC	both I_C and ºC	I_C, but not ºC	both I_C and ºC
open bias resistor(s)	external opens	all of the above	all of the above
TO-92	TO-39	all of the above	all of the above
µA	nA	pA	nA

A. Jefferson Fritts.	A. Charles Fritts.	A. Fornster Fritts.	A. Charles Fritts.
recombine in the emitter	1. pass through the base region to the collector	1. none of the above	1. pass through the base region to the collector
1. hole current	1. donor ion current	1. acceptor ion current	1. electron current
IB = IC + IE	IE = IC – IB	IE = IC + IB	IE = IC + IB
>1	<1	0	<1
high	0	very low	high
10	30	55	90
less than	the same as	. none of the above	more than
reverse bias at all times	low resistance	none of the above	reverse bias at all times
reverse bias at all times	low resistance	none of the above	forward bias at all times
Is reduced	Remains the same	none of the above	Is reduced
>1	0	1	<1
3	5	6	2
Small signals only	Both small and large signals	none of the above	Small signals only
Ohm	Farad	Ampere	Ohm
Do not change	May or may not change	none of the above	Also change
Do not change	May or may not change	. none of the above	Also change
Capacitive	Inductive	none of the above	Resistive
Open loop	Closed loop	none of the above	Closed loop
Is reduced	Remains the same	none of the above	Is increased
Is reduced	Remains the same	none of the above	Is reduced
Rectifiers	Amplifiers	. none of the above	Amplifiers
Impedance matchin	Voltage gain	none of the above	Impedance matchin
with no load.	under full load.	along the dc load line.	with no signal input

360° of the input cycle.	slightly less than 180° of the input cycle.	much less than 180° of the input cycle.	slightly less than 180° of the input cycle
diode separation.	crossover distortion.	thermal runaway.	thermal runaway
class B	class C	ClassD	class C
class A.	class AB.	class C.	class B
25	1.2	750	750
class B	class C	class AB	class C
6.1 mA	16.7 mA	20 mA	4.4 mA
a dc value equal to V_{CC}.	a sine wave.	a square wave with a frequency determined by the tank.	a sine wave.
40	70	10	10
B	C	AB	B
B	C	AB	AB
25	70	79	79
B	C	AB	AB
B	C	AB	C
78.50%	50%	25%	90%
100 to 200	less than 100	0	less than 100
78.50%	50%	25%	50%
$(N_1/N_2)^2$	$(N_1/N_2)^{1/3}$	$N_1\times N_2$	$(N_1/N_2)^2$

the dc	both the ac and dc	neither the ac nor dc	the dc
$1/(a^2R_L)$	$-1/(a^2R_L)$	$1/R_L$	$-1/(a^2R_L)$
difference	average		difference
about the same	the most	None of the above	the least
larger, smaller, closer	smaller, larger, closer	None of the above	larger, smaller, closer
a half-wave	both a full-wave and a half-wave	None of the above	a full-wave
$0.50V_{CC}$	V_{CC}	$2V_{CC}$	V_{CC}
nMOS and pMOS	Both npn and pnp or nMOS and pMOS	None of the above	Both npn and pnp or nMOS and pMOS
higher, lower	lower, lower	lower, higher	higher, lower
the same as	smaller than	None of the above	larger than
10db	20db	30db	20 db
Thin collector	Wide emitter	None of the above	Thin base
Protect the transistor	Pass a.c. and block d.c.	Provide biasing	Pass a.c. and block d.c.
Forward bias the emitter	Reduce noise in the amplifier	None of the above	Avoid voltage gain drop
Low	high	moderate	moderate
Low	high	moderate	1. Low
Biasing conditions will change	Signal will not reach the base	None of the above	Biasing conditions will change

Grounded base	Grounded collector	None of the above	Grounded emitter
Less than	More than	None of the above	Less than
Less than	More than	None of the above	More than
Mica	Paper	Air	Electrolytic
Biasing circuit	Collector supply VCC	None of the above	Collector supply VCC
Collector has reverse bias	Collector is wider than emitter or base	None of the above	Collector has reverse bias
Cb	CE	CBE	CE
Current	Power	None of the above	Voltage
Is constant	1. Changes uniformly with frequency	None of the above	Is constant
Economy	High efficiency	None of the above	Economy
Transformer	Direct	None of the above	Direct
Current	Power	None of the above	Power
Not to attenuate the low frequencies	To dissipate high power	To dissipate high heat	Not to attenuate the low frequencies
1	10	20	0
Transformer	Direct	None of the above	Direct
Transformer	Direct	None of the above	Transformer
There is hum in the output	Electrical size of coupling capacitor becomes very large	None of the above	Electrical size of coupling capacitor becomes very large
Zero input impedance	Infinite output impedance	Infinite bandwidth	Infinite bandwidth

Increases	Zero	Infinite	Decreases
Only DC	Both AC and DC	Any current	Both AC and DC
Differential & Non differential	Inverting & Non inverting	High & low	Inverting & Non inverting
Non Inverting	Differential	Summing	Differential
10,000	1,00,000	10,00,000	10,00,000
Amplitude compensated	Time compensated	Pulse Compensated	Frequency compensated
10 mV	12 mV	14 mV	15mV
Common Mode Rejection Ratio	Collector Mode Resictor Ratio	Collector Mode Rejection Ratio	Common Mode Rejection Ratio
12V	14V	10V	13V
50 Ohm	75 Ohm	80 Ohm	75 Ohm
Pulse Signal Rejetion Ratio	Power Supply Resictor Ratio	Power Supply Rejection Ratio	Power Supply Rejection Ratio
90dB	75dB	60dB	90dB
	25mA	100mA	25mA
d. Space points	3.17	5.2	2.8
75mW	50mW	100mW	85mW
5V/uS	1.5V/uS	0.5V/uS	0.5V/uS
Thermal drift	Input offset voltage	Input offset current	Input offset voltage
2	3	4	2
5v to 22v	9v to 12v	5v to 30v	5v to 22v
Inverting input terminal	Non inverting input terminal	Output treminal	Inverting input terminal
Inverting input terminal	Non inverting input terminal	Output treminal	Non inverting input terminal
Inverting input terminal	Non inverting input terminal	Output treminal	Output treminal
Inverting input terminal	Non inverting input terminal	Output treminal	Power supply terminal
ac offset	Connect with AFO	Connect with power supply	dc offset
Three	eight	one	eight

Low	Zero	Infinite	Zero
Zero	High	Low	Infinite
Voltage	Amplifier	Convertor	Voltage
Multi	Duel	widely	Multi
70*c to 100*c	>100*c	<0*c	0*C to 70*c
Noise	Current	Temperature	Temperature
80dB	90dB	100dB	90dB
C/I	V/I	I/V	I/C
KV	mV	uV	mV
mV	dB	uV	dB
dB	V/uS	uV/Sec	V/uS
High	Moderate	Unity	Low
(-20)dB decade	(-30)dB decade	(-40)dB decade	(-20)dB decade
Undamped	Modulated	None of the above	Undamped
Negative	Neither positive nor negative	Data insufficient	Positive
Radio transmitters	TV receivers	None of the above	Radio receivers
23	2	3	3
R, L and C	R and C	R and L	R and C
Requires no input signal	Requires no d.c. supply	Always has the same input	Requires no input signal
A gain around the feedback loop of one-third	A phase shift around the feedback loop of 0o	A gain around the feedback loop of less than 1	A phase shift around the feedback loop of 0o
No gain around the feedback loop	The attention of the feedback circuit must be one-third	The feedback circuit must be capacitive	A gain of 1 around the feedback loop
>1	<1	0	>1

By a tickler coil	. From the centre of split capacitors	None of the above	From the centre of split capacitors
Hartely-oscillator	Colpitt's oscillator	Crystal oscillator	Crystal oscillator
.d c. power into a.c. power	mechanical power into a.c. power	none of the above	.d c. power into a.c. power
Biasing circuit	Transistor	none of the above	Transistor
Maximum	Half-way between maximum and minimum	none of the above	Minimum
Directly proportional to	Independent of the values of	Inversely proportional to square root of	Inversely proportional to square root of
Audio	Very low	Very high	Very low
It is easily available	It is quite inexpensive	None of the above	It has superior electrical properties
Hartely	Crystal	Phase shift	Wien-bridge
Its high Q	Less availability of quartz crystal	Its high output	Its low output
Decreased 4 time	Increased 4 times	Decreased 2 times	Decreased 2 times
Integrated Capacitor	Integrated Circuit	Integrated Inductor	Integrated Circuit
Gun Scale Integration	Greater Scale Integration	Geometric Scale Integration	Giant Scale Integration
wafer	plasma	seed crystal	seed crystal
Computer applications	Electronic circuits	industrial and consumer applications	industrial and consumer applications
Encoder	Peak detector	Clipper	Peak detector
Derivative	NonDerivative	Multiplier	Derivative
Summing	Non-inverting	Inverting	Integrated

I-V converter	Peak detector	Comparator	V-I convertor
Zero crossing detector	Peak detector	Level detector	Zero crossing detector
Sine wave to square wave generator	Square wave to triangular wave generator	Square wave to sine wave generator	Sine wave to square wave generator
Zero crossing detector	Peak detector	Level detector	Zero crossing detector
Level detector	Peak detector	Window detector	Window detector
Square wave	Triangular	saw tooth wave	Square wave
Timer	Backlash	Regenarative	Backlash
Timer	Regenarative	Hysteresis	Hysteresis
Monostable	Quasi stable	Tri stable	Quasi stable
amplifier	Op-amp	Comparator	Comparator
Threshold	Accuracy	Resolution	Accuracy
Single slope A/D	Dual slop A/D	Both (b) and ©	Dual slop A/D
has one input and one output	has two outputs	answers (1) and (2)	answers (1) and (2)
one input is grounded and signal is applied to the other	both inputs are connected together	the output is not inverted	one input is grounded and signal is applied to the other
the gain is one	the outputs are of different amplitudes	only one supply voltage is used	opposite polarity signals are applied to the inputs
the outputs are connected together	an identical signal appears on both the inputs	the output signal are in-phase	an identical signal appears on both the inputs
d.c. signals only	both a.c. and d.c. signals	neither d.c. nor a.c. signals	both a.c. and d.c. signals
active filter	nonlinear circuit	linear circuit	nonlinear circuit
voltage-to-current converter	scaling adder	noninverting amplifier	scaling adder
increases or decreases at a linear rate	is constant	is always increasing and never decreasing	increases or decreases at a linear rate

comparator	single ended	voltage follower	voltage follower
>1	0	1	>1
zero offset	a wide bandwidth	a negative and positive supply	a negative and positive supply
$R_f + R_i$	∞	$R_f - R_i$	R_i
the open-loop voltage gain	the feedback resistance divided by the input resistance	the input resistance	the feedback resistance divided by the input resistance
common-mode	double-ended	single-ended	inverting mode
double-ended	darlington	differential	differential
sine wave	rectangular wave	sawtooth wave	rectangular wave
current reference	power reference	difference reference	voltage reference
peak detection	input noise rejection	filtering	pulse shaping
integration or differentiation	saturation or cutoff	addition or subtraction	integration or differentiation
difference	summing	analog subtractor	summing
zero offset	high output impedance	moderate gain	zero offset
incorrect output codes	offset error	nonmonotonic and offset error	nonmonotonic and offset error
0.3125	30.12	312.5	3.125
5000A	50mA	5mA	50 micro A
4-bit D/A converters	8-bit D/A converters	op-amp comparators	4-bit D/A converters
accuracy	resolution	monotonicity	resolution

a long conversion time is required	a large number of output lines is required to simultaneously decode the input voltage	a large number of comparators is required to represent a reasonable sized binary number	a large number of comparators is required to represent a reasonable sized binary number
It has fewer parts for the same number of inputs.	Its operation is much easier to analyze.	The virtual ground is eliminated and the circuit is therefore easier to understand and troubleshoot.	It only uses two different resistor values.
63%	1.56%	15.60%	1.56%
missing code	incorrect code	offset	differential nonlinearity