Electronics and Instrumentation

Group A

Electronics

Semiconductor materials, intrinsic and extrinsic semiconductors.

p-n junction diodes, rectifiers-;half wave, full wave, capacitive filters, Zener diodes, their operation, characteristics and applications.

Transistors-p-n-p and n-p-n transistors, transistor as amplifier-CE, transistor characteristics, blasting and biasing stability, small signal equivalent circuits. Field effect devices-MOSFET - characteristics and applications. BJT -characteristics.

Amplifiers-Hybrid parameter equivalent circuits for common emitter configuration, current and voltage gain, . input-output impedance, frequency response_ concepts of feedback amplifiers, regenerative feedback and conditions for oscillation.

Thyristors-characteristics and applications. Triacs and GTOs.

Integrated circuits: IC devices. OP AMP applications. Analogue to, Digital Conversion (ADC), Digital to Analogue Conversion (DAC).

Group B

Instrumentation

Indicating instruments, Moving coil, moving iron, rectifier and dynamometer type meters for measurement of voltage, current, resistance and power, Integrating meters.

Electronic voltmeters-peak, r.m.s. and average reading type voltmeters. CRO-functional block diagram, operation and application.

Electronic instruments. Q-meters, distortion meters, spectrum analyzers, audio oscillators and RF signal generators, introduction to digital voltmeters; digital display devices.

Sensors and transducers. Resistive, inductive and capacitive pickups for non electrical quantities. Analogue and digital data acquisition and transmission systems.

Electronics and Instrumentation

Group A

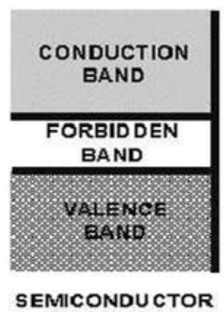
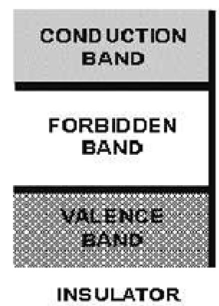
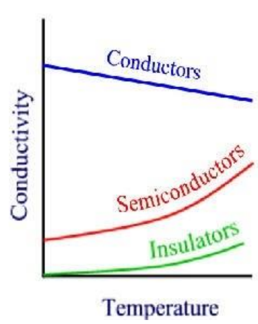
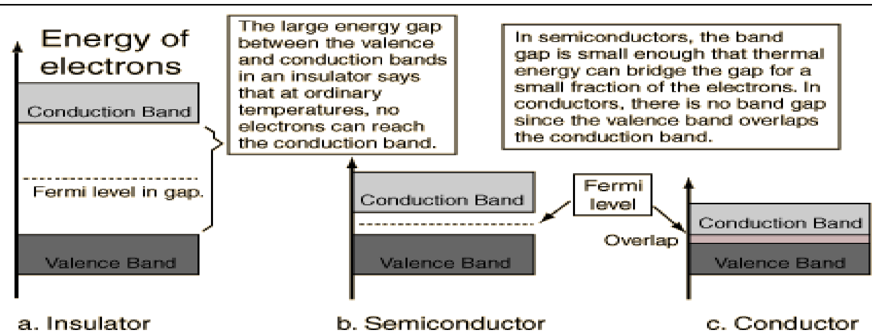
SEMICONDUCTOR MATERIALS

OHMS LAW **V=IR**

Resistivity

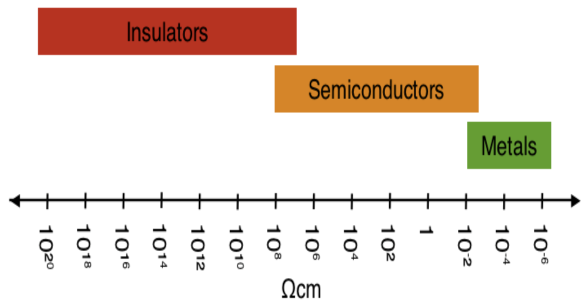
It is the ratio of the voltage difference across it to the current flowing through it.
Resistivity is the inverse to conductivity.

Semiconductor Basics

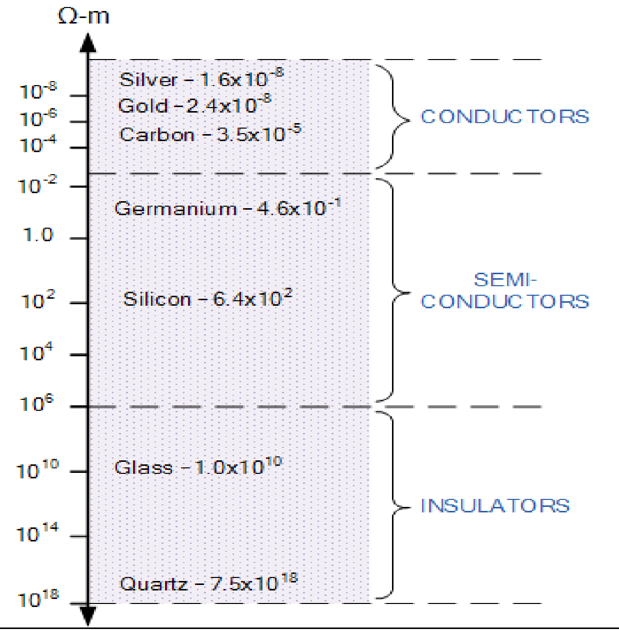
Electronic Materials classification based on Resistivity		
1. Conductors.	**2. Semi-conductors.**	**3. Insulators.**
Have Low Resistance which allows electrical current flow.	Can allow or suppresses electrical current flow.	Have high Resistance which suppresses electrical current flow.
Example: Copper, silver, gold and aluminum.	Example: Carbon, silicon, germanium, and gallium arsenide.	Example: Glass, ceramics, plastics and wood.
		
E_c, E_g=0, EV	**E_c, E_g=1.1 eV, EV**	**E_c, E_g=9eV, EV**
Energy gap is in between the bands.		
		

Diodes are unidirectional semiconductor devices that will only allow current to flow through them in one direction only (Forward Biased Condition). Diodes (made of s**emiconductor)** material which has a positive "P-region" at one end and a negative "N-region" at the other. Diode (resistivity) between conductor and an insulator.

Resistivity Chart



Notice that there is a very small margin between the resistivity of the conductors such as silver and gold, compared to a much larger margin for the resistivity of the insulators between glass and quartz.



Conductors

When a +VE **voltage** potential is **applied** to the material these "free electrons" leave their parent atom and travel together through the material **forming an electron drift**, known as a current.

Domino Effect=free flow of current in Carbon because these materials have very few electrons in their outer "Valence Shell" or ring, resulting in them being easily knocked out of the atom's orbit.

Insulators

They are exact opposite of conductors. They are made of materials, generally non-metals, that have very few or no "free electrons" floating about within their basic atom structure because the electrons in the outer valence shell are strongly attracted by the positively charged inner nucleus.

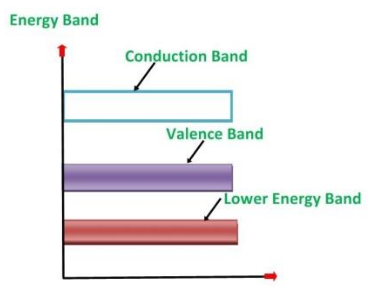
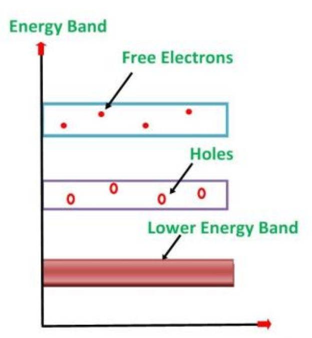
Insulators also have very high resistances, millions of ohms per metre, and are generally not affected by normal temperature changes (although at very high temperatures wood becomes charcoal and changes from an insulator to a conductor). Examples of good insulators are marble, fused quartz, p.v.c. plastics, rubber etc.

Insulators play a very important role within electrical and electronic circuits, because without them electrical circuits would short together and not work. For example, insulators made of glass or porcelain are used for insulating and supporting overhead transmission cables while epoxy-glass resin materials are used to make printed circuit boards, PCB's etc. while PVC is used to insulate electrical cables as shown.

Semiconductor Basics

Semiconductors materials (silicon, germanium & gallium arsenide), have electrical properties somewhere in the middle, between those of a "conductor" and an "insulator". They are not good conductors nor good insulators (hence their name "semi"-conductors). They have very few "free electrons" because their atoms are closely grouped together in a crystalline pattern called a "crystal lattice" but electrons are still able to flow, but only under special conditions.

The ability of semiconductors to conduct electricity can be greatly improved by replacing or adding certain donor or acceptor atoms to this crystalline structure thereby, producing more free electrons than holes or vice versa. That is by adding a small percentage of another element to the base material, either silicon or germanium.

TYPES OF SEMICONDUCTORS	
1. Intrinsic Semiconductor.	**2. Extrinsic semiconductor.**
The pure form of the semiconductor is known as the intrinsic semiconductor	Semiconductor in which intentionally impurities are added for making it conductive is known as the extrinsic semiconductor.
There conductivity become zero at room temperature	They have little conductive at room temperature.
	
Its valence band is completely filled and the conduction band is completely empty. When the temperature is raised and some heat energy is supplied to it, some of the valence electrons are lifted to conduction band leaving behind holes in the valence band as shown below.	A semiconductor to which an impurity at controlled rate is added to make it conductive is known as an extrinsic Semiconductor. An intrinsic semiconductor is capable to conduct a little current even at room temperature, but it is not useful for the preparation of various electronic devices. Thus, to make it conductive a small amount of suitable impurity is added to the material.
	**Doping** The process by which an impurity is added to a semiconductor is known as Doping. The amount and type of impurity which is to be added to a material has to be closely controlled during the preparation of extrinsic semiconductor. Generally, one impurity atom is added to a 10^8 atoms of a semiconductor.

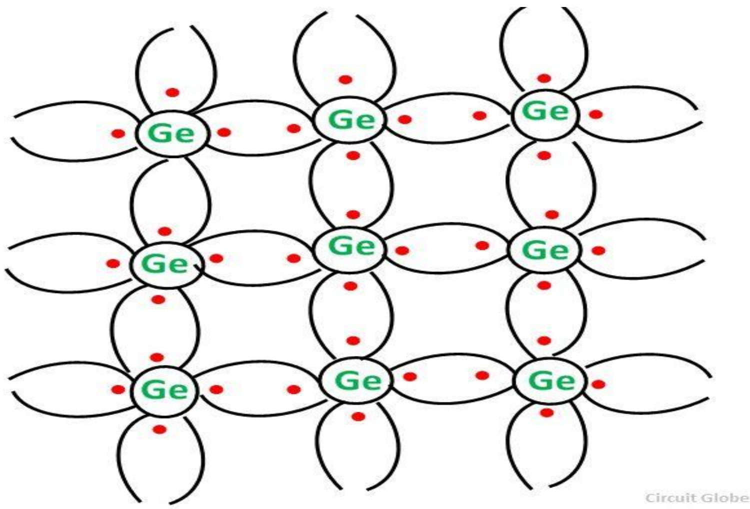
The electrons reaching at the conduction band move randomly. The holes created in the crystal also free to move anywhere. This behavior of the semiconductor shows that they have a negative temperature coefficient of resistance. This means that with the increase in temperature, the resistivity of the material decreases and the conductivity increases.	The purpose of adding impurity in the semiconductor crystal is to increase the number of free electrons or holes to make it conductive. If a Pentavalent impurity, having five valence electrons is added to a pure semiconductor a large number of free electrons will exist. If a trivalent impurity having three valence electrons is added, a large number of holes will exist in the semiconductor. Depending upon the type of impurity added the extrinsic semiconductor may be classified as **n type semiconductor** and **p type semiconductor**.

n Type Semiconductor

When a small amount of **pentavalent impurity** is added to a pure semiconductor providing a large number of free electrons in it, the extrinsic semiconductor thus formed is known as **n-Type Semiconductor.** The conduction in the n-type semiconductor is because of the free electrons denoted by the pentavalent impurity atoms. These electrons are the excess free electrons with regards to the number of free electrons required to fill the covalent bonds in the semiconductors.

The addition of Pentavalent impurities such as arsenic and antimony provides a large number of free electrons in the semiconductor crystal. Such impurities which produce n-type semiconductors are known as **Donor Impurities**. They are called a donor impurity because each atom of them donates one free electron crystal.

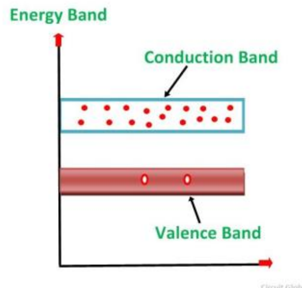
Pentavalent impurity + pure semiconductor = n-Type Semiconductor
Pentavalent impurity + pure semiconductor = extrinsic semiconductor
Pentavalent impurity + **pure semiconductor--→ conduction due to large number of free electrons**



When a few Pentavalent impurities such as **Arsenic** whose atomic number is **33**, which is categorised as **2, 8, 15** and **5**. It has five valence electrons, which is added to germanium crystal. Each atom of the impurity fits in four germanium atoms as shown in the figure above.

Hence, each Arsenic atom provides one free electron in the Germanium crystal. Since an extremely small amount of arsenic, impurity has a large number of atoms; it provides millions of free electrons for conduction.

Energy Diagram of n-Type Semiconductor



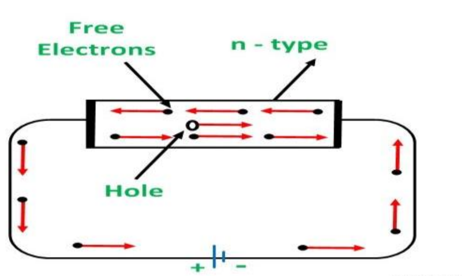
A large number of free electrons are available in the conduction band because of the addition of the Pentavalent impurity. These electrons are free electrons which did not fit in the covalent bonds of the crystal. However, a minute quantity of free electrons is available in the conduction band forming hole- electron pairs.

The following points are important in the n-type semiconductor.

- The addition of Pentavalent impurity results in a large number of free electrons.
- When thermal energy at room temperature is imparted to the semiconductor, a hole-electron pair is generated and as a result, minute quantities of free electrons are available. These electrons leave behind holes in the valence band.
- Here n stands for negative material as the number of free electrons provided by the Pentavalent impurity is greater than the number of holes.

Conduction through n-Type Semiconductor

In the n-type semiconductor, a large number of free electrons are available in the conduction bands which are donated by the impurity atoms. The figure below shows the conduction process of an n-type semiconductor.



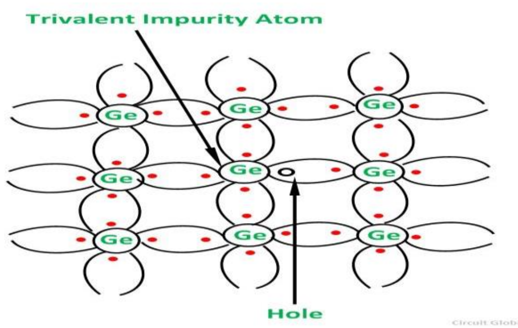
When a potential difference is applied across this type of semiconductor, the free electrons are directed towards the positive terminals. It carries an electric current. As the flow of current through the crystal is constituted by free electrons which are carriers of negative charge, therefore, this type of conductivity is known as **negative** or **n-type conductivity.** The electron-hole pairs are formed at room temperature. These holes which are available in small quantity in valence band also consist of a small amount of current. For practical purposes, this current is neglected.

p Type Semiconductor

The extrinsic **p-Type Semiconductor** is formed when a **trivalent impurity** is added to a pure semiconductor in a small amount, and as a result, a large number of holes are created in it. A large number of holes are provided in the semiconductor material by the addition of trivalent impurities like **Gallium** and **Indium.** Such type of impurities which produces p-type semiconductor are known as an **Acceptor Impurities** because each atom of them create one hole which can accept one electron.

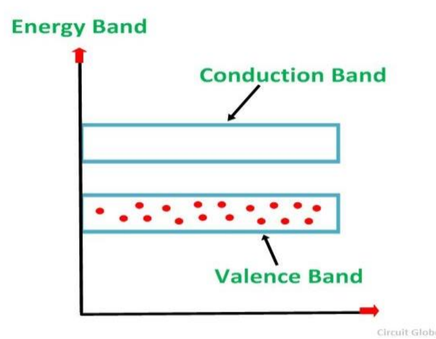
A trivalent impurity like gallium, having three valence electrons is added to germanium crystal in a small amount. Each atom of the impurity fits in the germanium crystal in such a way that its three valence electrons form covalent bonds with the three surrounding germanium atoms as shown in the figure below.

Trivalent impurity + pure semiconductor = p-Type Semiconductor
Trivalent impurity + pure semiconductor = extrinsic semiconductor
Trivalent impurity + pure semiconductor--→ conduction due to large number of free Holes



In the **fourth covalent bonds**, only the germanium atom contributes one valence electron, while gallium atom has no valence bonds. Hence, the fourth covalent bond is incomplete, having one electron short. This missing electron is known as a **Hole**. Thus, each gallium atom provides one hole in the germanium crystal.As an extremely small amount of Gallium impurity has a large number of atoms, therefore, it provides millions of holes in the semiconductor.

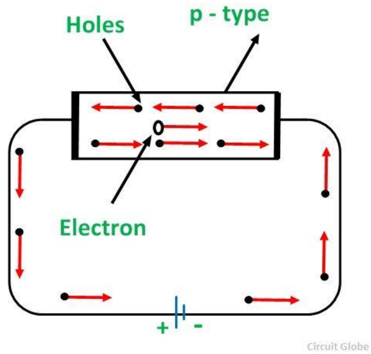
Energy Band Diagram of p-Type Semiconductor



A large number of holes or vacant space in the covalent bond is created in the crystal with the addition of the trivalent impurity. A small or minute quantity of free electrons is also available in the conduction band. They are produced when thermal energy at room temperature is imparted to the germanium crystal forming electron-hole pairs. But the holes are more in number as compared to the electrons in the conduction band. It is because of the predominance of holes over electrons that the material is called as a p-type semiconductor. The word “p” stands for the positive material.

Conduction through p Type Semiconductor

Here large number of holes are created by the trivalent impurity. When a potential difference is applied across this type of semiconductor as shown in the figure below.



The holes are available in the valence band are directed towards the negative terminal. As the current flow through the crystal is by holes, **which are carrier of positive charge, therefore, this type of conductivity i**s known as **positive** or **p type conductivity**. In a p type conductivity the valence electrons move from one covalent to another.

The conductivity of n type semiconductor is nearly double to that of p type semiconductor. The electrons available in the conduction band of the n type semiconductor are much more movable than holes available in the valence band in a p type semiconductor. The mobility of holes is poor as they are more bound to the nucleus. Even at the room temperature the electron hole pairs are formed. These free electrons which are available in minute quantity also carry a little amount of current in the p type semiconductors.

Periodic Table of Semiconductors

Elements Group 13	Elements Group 14	Elements Group 15
3-Electrons in Outer Shell (Positively Charged)	4-Electrons in Outer Shell (Neutrally Charged)	5-Electrons in Outer Shell (Negatively Charged)
(5)Boron (B)	(6)Carbon (C)	(15)Phosphorus (P)
(13)Aluminium (Al)	(14)Silicon (Si)	(33)Arsenic (As)
(31)Gallium (Ga)	(32)Germanium (Ge)	(51)Antimony (Sb)

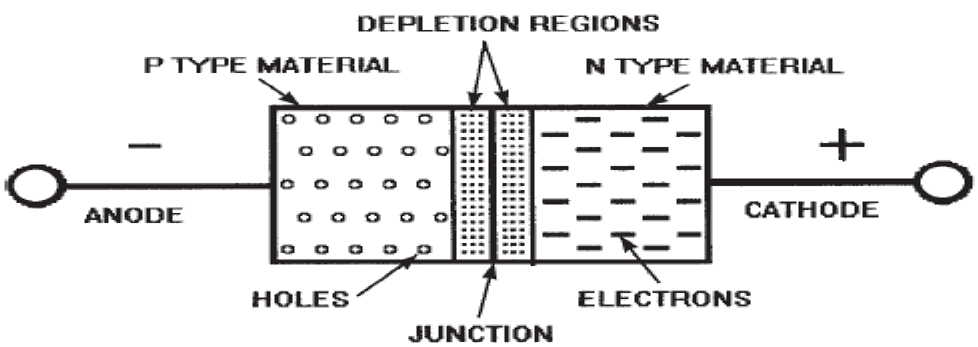
P-N Junction Diode/ semiconductor device
A p-n junction diode is 2-terminal / 2-electrode semiconductor device, which **allows the electric current in only one direction** while blocks the electric current in opposite or reverse direction.

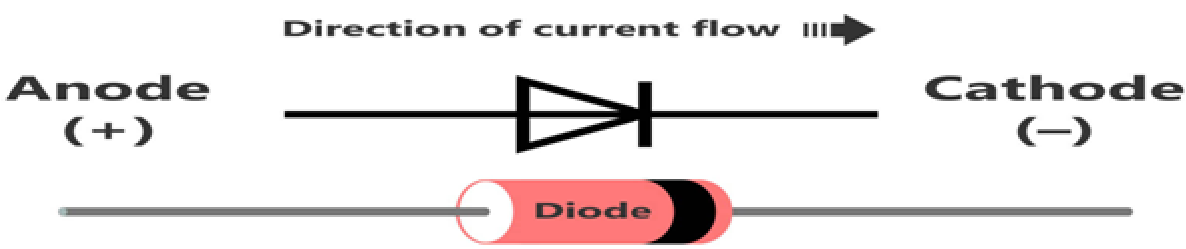
Diode ---- forward biased------- Allows the electric current flow.
Diode ---- reverse biased---------Blocks the electric current flow.

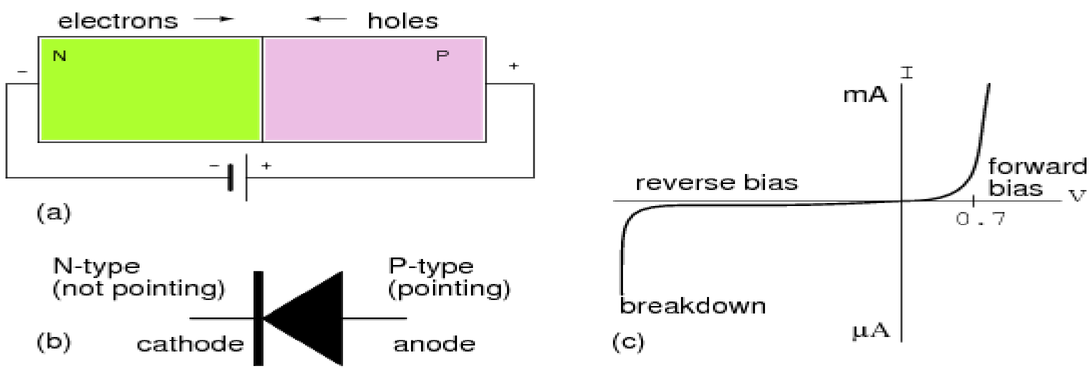
n-type semiconductors----- free electrons ----majority charge carriers
P-type semiconductors----- holes--------------majority charge carriers.

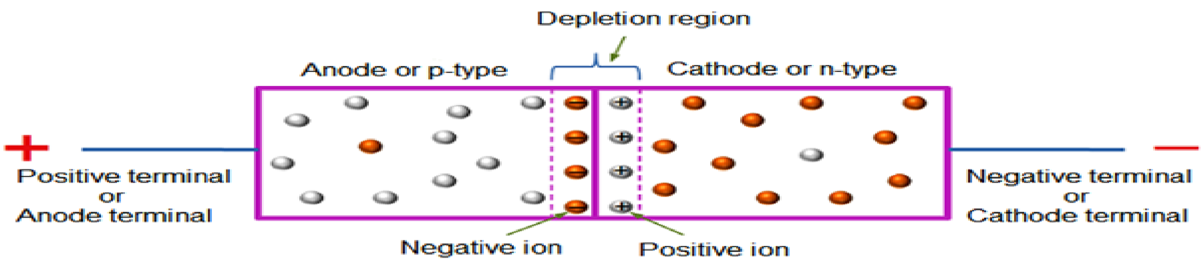
n-type semiconductor is joined with the p-type semiconductor to form , a p-n junction is formed. The p-n junction, which is formed when the p-type and n-type semiconductors are joined, is called as p-n junction diode.

The p-n junction diode is made from the semiconductor materials such as silicon, germanium, and gallium arsenide. For designing the diodes, silicon is more preferred over germanium.

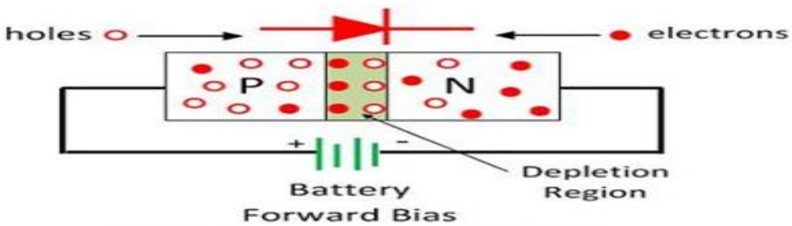




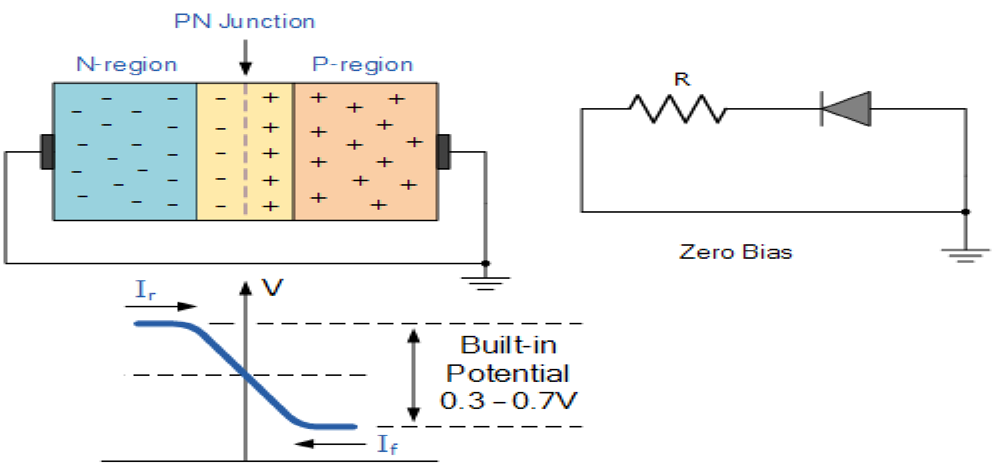


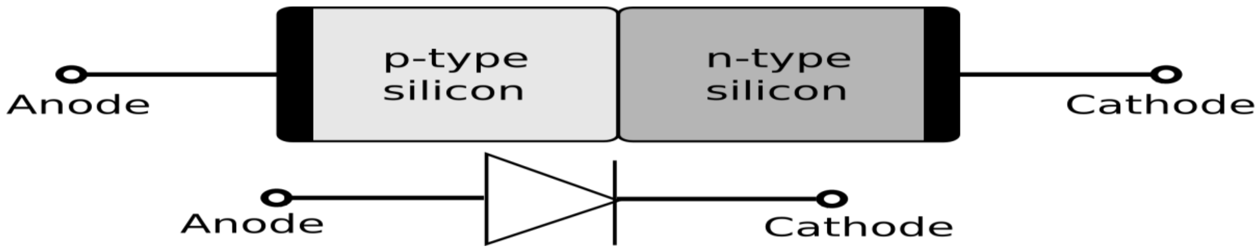


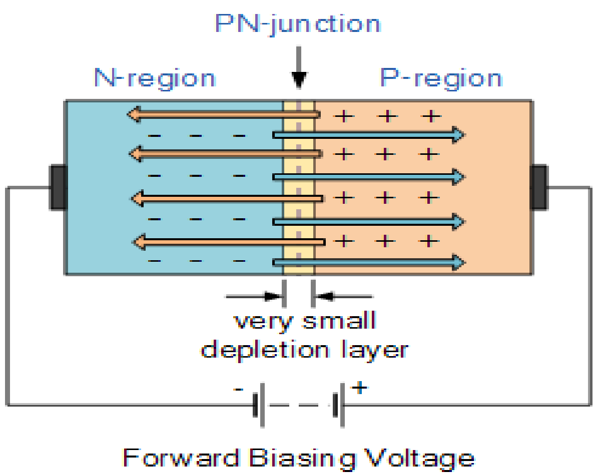
Forward biased

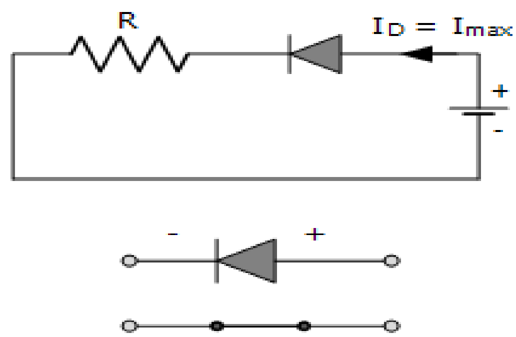


PN Junction Diode in Forward Bias









In the above figure, arrowhead of a diode indicates the conventional direction of electric current when the diode is forward biased (from positive terminal to the negative terminal). The holes which moves from positive terminal (anode) to the negative terminal (cathode) is the conventional direction of current. The free electrons moving from negative terminal (cathode) to the positive terminal (anode) actually carry the electric current. However, due to the convention we have to assume that the current direction is from positive terminal to the negative terminal.

Biasing of p-n junction semiconductor diode

The process of applying the external voltage to a p-n junction semiconductor diode is called biasing. External voltage to the p-n junction diode is applied in any of the two methods: forward biasing or reverse biasing.

If the p-n junction diode is forward biased, it allows the electric current flow. Under forward biased condition, the p-type semiconductor is connected to the positive terminal of battery whereas; the n-type semiconductor is connected to the negative terminal of battery.
If the p-n junction diode is reverse biased, it blocks the electric current flow. Under reverse biased condition, the p-type semiconductor is connected to the negative terminal of battery whereas; the n-type semiconductor is connected to the positive terminal of battery.

Terminals of pn junction diode

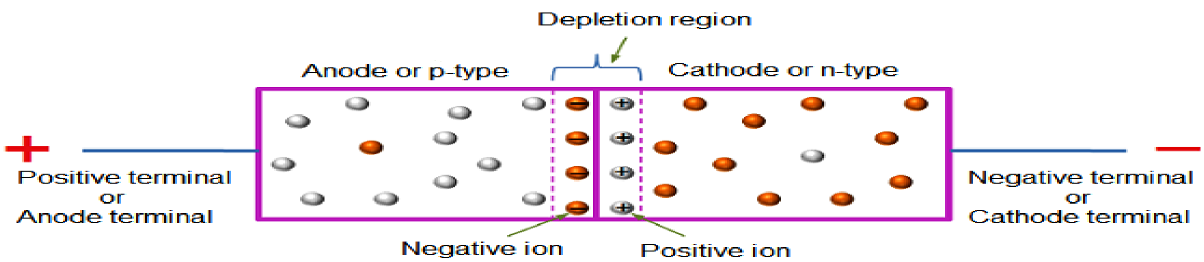
Generally, terminal refers to a point or place at which any object begins or ends. For example, bus terminal or terminus is a place at which all the buses begins or ends. Similarly, in a p-n junction diode, terminal refers a point at which charge carriers begins or ends.

P-n junction diode consists of two terminals: positive and negative. At positive terminal, all the free electrons will ends and all the holes will begins whereas at negative terminal all the free electrons will begins and all the holes will ends.

Terminals of diode under forward bias

In forward biased p-n junction diode (p-type connected to positive terminal and n-type connected to negative terminal), anode terminal is a positive terminal whereas cathode terminal is negative terminal.

Anode terminal is a positively charged electrode or conductor, which supplies holes to the p-n junction. In other words, anode or anode terminal or positive terminal is the source of positive charge carriers (holes), the positive charge carriers (holes) begins their journey at anode terminal and travel through the diode and ends at cathode terminal.



Forward biased

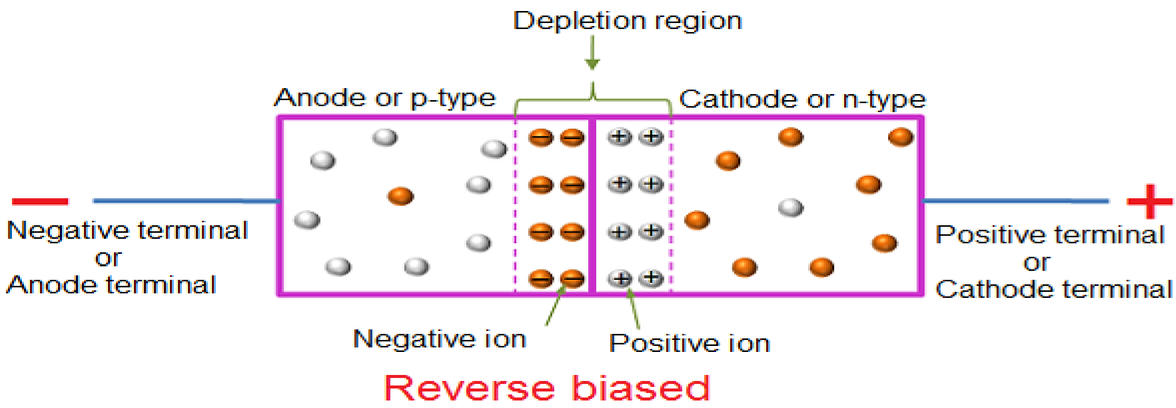
Cathode is the negatively charged electrode or conductor, which supplies free electrons to the p-n junction. In other words, cathode terminal or negative terminal is the source of free electrons, the negative charge carriers (free electrons) begins their journey at cathode terminal and travel through the diode and ends at anode terminal.

The free electrons are attracted towards the anode terminal or positive terminal whereas the holes are attracted towards the cathode terminal or negative terminal.

Terminals of diode under reverse bias

If the diode is reverse biased (p-type connected to negative terminal and n-type connected to positive terminal), the anode terminal becomes a negative terminal whereas the cathode terminal becomes a positive terminal.

Anode terminal or negative terminal supplies free electrons to the p-n junction. In other words, anode terminal is the source of free electrons, the free electrons begins their journey at negative or anode terminal and fills the large number of holes in the p-type semiconductor. The holes in the p-type semiconductor get attracted towards the negative terminal. The free electrons from the negative terminal cannot move towards the positive terminal because the wide depletion region at the p-n junction resists or opposes the flow of free electrons.



Cathode terminal or positive terminal supplies holes to the p-n junction. In other words, cathode terminal is the source of holes, the holes begins their journey at positive or cathode terminal and occupies the electrons position in the n-type semiconductor. The free electrons in the n-type semiconductor gets attracted towards the positive terminal. The holes from the positive terminal cannot move towards the negative terminal because the wide depletion region at the p-n junction opposes the flow of holes.

p-n junction diode Advantages

1. Convert AC to DC.
2. Used in power supply devices.
3. Allows current is forward biased.
4. In reverse biased, it blocks the current flow. In other words, the p-n junction diode becomes on when it is forward biased whereas the p-n junction diode becomes off when it is reversed biased (I.e. it acts as **switch**). Thus, the p-n junction diode is used as electronic switch in digital logic circuits.

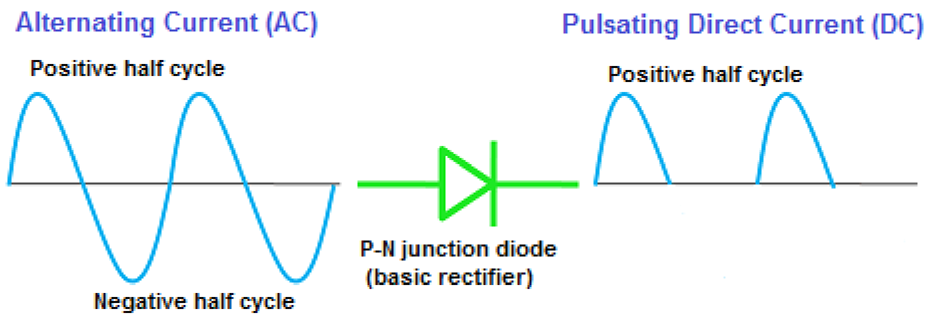
Half wave Rectifier

A rectifier is a diode / group of diodes which converts the **Alternating Current (AC) into Direct Current (DC)**. We know that a diode allows electric current in one direction and blocks electric current in another direction. This principle to construct various types of rectifiers.

Based on Number of diodes used/ arrangement of diode in the circuit, Rectifiers are classified as
Types of rectifiers: 1. Half wave rectifier. 2. Full wave rectifier.

Half wave rectifier

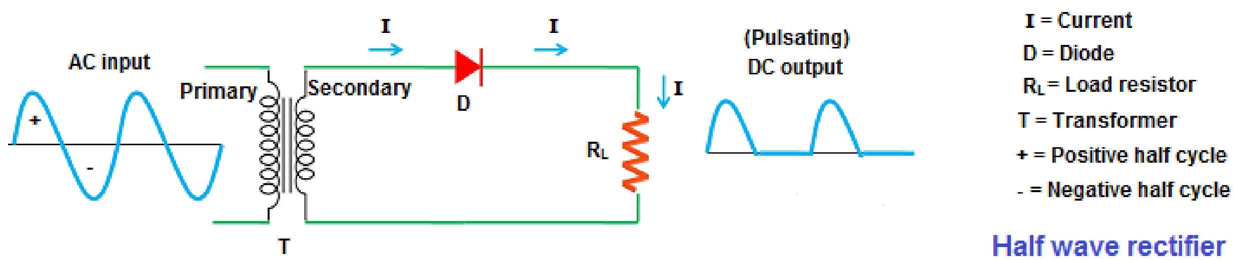
It converts the positive half cycle (positive current) of the input signal into pulsating DC (Direct Current) output signal. Or It allows only half cycle (either positive half cycle or negative half cycle) of the input AC signal while the half cycle is blocked.



For example, if the positive half cycle is allowed then the negative half cycle is blocked. Similarly, if the negative half cycle is allowed then the positive half cycle is blocked. However, a half wave rectifier will not allow both positive and negative half cycles at the same time. Therefore, the half cycle (either positive or negative) of the input signal is wasted.

What is half wave rectifier?

We use only a single diode to construct the half wave rectifier. It is made up of an AC source, transformer (step-down), diode, and resistor (load). The diode is placed between the transformer and resistor (load).



AC source: It supplies Alternating Current to the circuit. The alternating current is often represented by a sinusoidal waveform.

Transformer

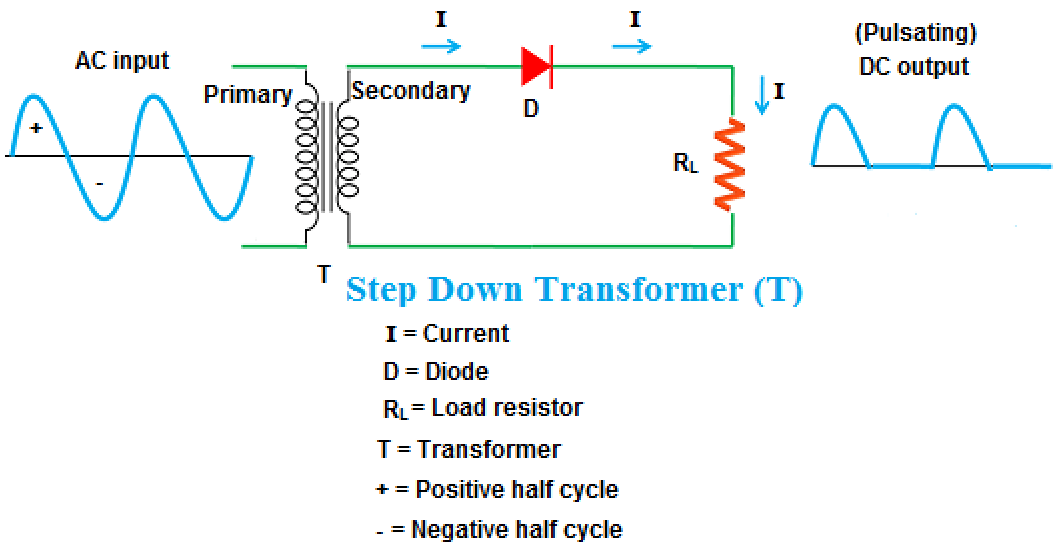
It is a device which reduces or increases the AC voltage. The step-down transformer reduces the AC voltage from high to low whereas the step-up transformer increases the AC voltage from low to high. In half wave rectifier, we generally use a step-down transformer because the voltage needed for the diode is very small. Applying a large AC voltage without using transformer will permanently destroy the diode. So we use step-down transformer in half wave rectifier. However, in some cases, we use a step-up transformer.

In the step-down transformer, the primary winding has more turns than the secondary winding. So the step-down transformer reduces the voltage from primary winding to secondary winding.

Diode: It is a 2 terminal device that allows electric current in one direction and blocks electric current in another direction.

Resistor: It is an electronic component that restricts the current flow to a certain level.

Half wave rectifier operation
Positive half wave rectifier
The input **AC voltage / signal** (60 Hz) applied to the **step down transformer** reduces this high voltage into low voltage. Thus, a low voltage is produced at the secondary winding of the transformer. The low voltage produced at the secondary winding of the transformer is called secondary voltage (VS). The low AC voltage produced by the step-down transformer is directly applied to the diode.



Positive half wave rectifier

When low AC voltage is applied to the diode (D), during the **positive half cycle of the signal**, the diode is forward biased and allows electric current whereas, during the negative half cycle, the diode is reverse biased and blocks electric current. In simple words, the diode allows the positive half-cycle of the input AC signal and blocks the negative half-cycle of the input AC signal.

Low AC voltage---→Diode--→**positive half cycle of the signal--→**Diode--→ forward biased ----→allows electric current
Negative half cycle--→Diode---→Reverse biased ---→Blocks electric current.
In simple words, the diode allows the positive half-cycle of the input AC signal and blocks the negative half-cycle of the input AC signal.

The positive half-cycle of the input AC signal applied to the diode is analogous to the forward DC voltage applied to the p-n junction diode similarly the negative half-cycle of the input AC signal applied to the diode is analogous to the reverse DC voltage applied to the p-n junction diode. We know that diode allows electric current when it is forward biased and blocks electric current when it is reverse biased. Similarly, in an AC circuit, the diode allows electric current during the positive half cycle (forward biased) and blocks electric current during the negative half cycle (reverse biased).

The positive half wave rectifier does not completely block the negative half cycles. It allows a small portion of negative half cycles or small negative current. This current is produced by the minority carriers in the diode.

The current produced by the minority carriers is very small. So it is neglected. We can't visually see the small portion of negative half cycles at the output.
In an ideal diode, the negative half cycles or negative current is zero.

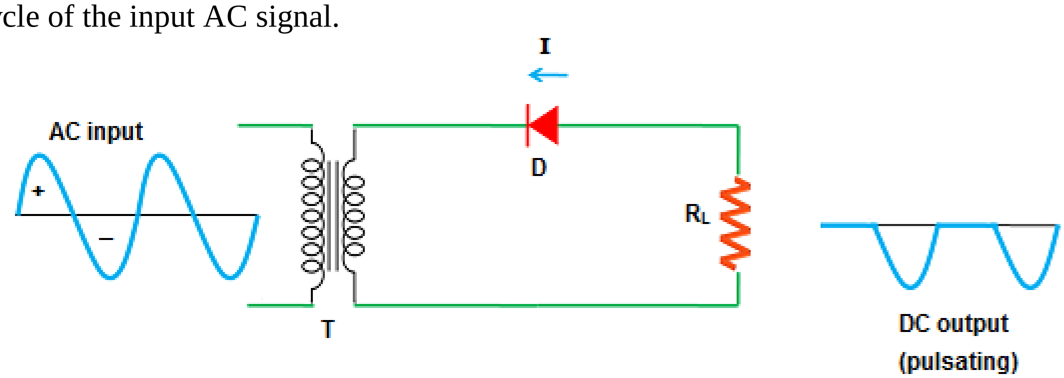
The resistor placed at the output consumes the DC current generated by the diode. Hence, the resistor is also known as an electrical load. The output DC voltage or DC current is measured across the load resistor RL.
The electrical load is nothing but an electrical component of a circuit that consumes electric current. In half wave rectifier, the resistor consumes the DC current generated by the diode. So the resistor in half wave rectifier is known as a load.

Sometimes, the **load** is also refers to the **power consumed by the circuit**.
The load resistors are used in half wave rectifiers to restrict or block the unusual excess DC current produced by the diode.

Thus, the half wave rectifier allows positive half cycles and blocks negative half cycles. The half wave rectifier which allows positive half cycles and blocks negative half cycles is called a positive half wave rectifier. The output DC current or DC signal produced by a positive half wave rectifier is a series of positive half cycles or positive sinusoidal pulses.
Now let's take a look at the negative half wave rectifier........

Negative half wave rectifier
The construction and working of negative half wave rectifier is almost similar to the positive half wave rectifier. The only thing we change here is the direction of a diode.
When AC voltage is applied, the step-down transformer reduces the high voltage to low voltage. This low voltage is applied to the diode.

Unlike the positive half wave rectifier, the negative half wave rectifier allows electric current during the negative half-cycle of input AC signal and blocks electric current during the positive half-cycle of the input AC signal.



Negative half wave rectifier

During the negative half cycle, the diode is forward biased and during the positive half cycle the diode is reverse biased, so the negative half wave rectifier allows electric current only during the negative half cycle.

Thus, the negative half wave rectifier allows negative half cycles and blocks positive half cycles. The negative half wave rectifier does not completely block the positive half cycles. It allows a small portion of positive half cycles or small positive current. This current is produced by the minority carriers in the diode. The current produced by the minority carriers is very small. So it is neglected. We can't visually see this small positive half cycles at the output.
In an ideal diode, the positive half cycle or positive current is zero.

The **DC current /voltage** produced by the negative half wave rectifier is measured across the **load resistor RL**. The output DC current or DC signal produced by a negative half wave rectifier is a series of negative half cycles or negative sinusoidal pulses.

Thus, a negative half wave rectifier produces a series of negative sinusoidal pulses.
In a perfect or ideal diode, the positive half cycle or negative half cycle at the output is exactly same as the input positive half cycle or negative half cycle. However, in practice, the positive half cycle or negative half cycle at the output is slightly different from the input positive half cycle or negative half cycle. But this difference is negligible. So we can't see the difference with our eyes.

Thus, the half wave rectifier produces a series of positive sinusoidal pulses or negative sinusoidal pulses. This series of positive pulses or negative pulses is not a pure direct current. It is a pulsating direct current.

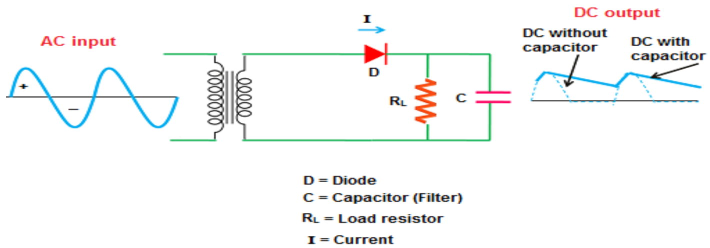
The pulsating direct current changes its value over a short period of time. But our aim is to produce a direct current which does not change its value over a short period of time. Therefore, the pulsating direct current is not much useful.

Half wave rectifier with capacitor filter

A filter converts the pulsating direct current into pure direct current. In half wave rectifiers, a capacitor or inductor is used as a filter to convert the pulsating DC to pure DC.

The output voltage produced by a half wave rectifier is not constant; it varies with respect to time. In practical applications, a constant DC supply voltage is needed.

In order to produce a constant DC voltage, we need to suppress the ripples of a DC voltage. This can be achieved by using either a capacitor filter or inductor filter at the output side. In the below circuit, we are using the capacitor filter. The capacitor placed at the output side smoothen the pulsating DC to pure DC.



Half wave rectifier with filter capacitor

Half wave rectifier Characteristics
Ripple factor
The direct current (DC) produced by a half wave rectifier is not a pure DC but a pulsating DC. In the output pulsating DC signal, we find ripples. These ripples in the output DC signal can be reduced by using filters such capacitors and inductors.

In order to measure how much ripples are there in the output DC signal we use a factor known as ripple factor. The ripple factor is denoted by γ. The ripple factor tells us the amount of ripples present in the output DC signal.

A large ripple factor indicates a high pulsating DC signal while a low ripple factor indicates a low pulsating DC signal. If the ripple factor is very low then it indicates that the output DC current is closer to the pure DC current. In simple words, the lower the ripple factor the smoother the output DC signal.

Ripples factor = (RMS value of AC component / DC component) of the output voltage
Ripple factor = Ratio of ripple voltage / DC voltage

Where, rms = root mean square
It should be kept as minimum as possible to construct a good rectifier.
The ripple factor is given as

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

Finally, we get $\gamma = 1.21$
The unwanted ripple present in the output along with the DC voltage is 121% of the DC magnitude. This indicates that the half wave rectifier is not an efficient AC to DC converter. The high ripples in the half wave rectifier can be reduced by using filters.

DC current IDC=I_{max} / π

Output DC voltage (VDC)
It is the voltage appeared at the load resistor (RL).
Output DC voltage (VDC) = output DC current * load resistance RL=VDC = $I_{DC} R_L$
Output DC voltage (VDC) = V_{SMAX}/ π
Where, VSmax = Maximum secondary voltage

Peak inverse voltage (PIV)
It is the maximum reverse bias voltage up to which a diode can withstand. If the applied voltage is greater than the peak inverse voltage, the diode will be destroyed.

During the positive half cycle, the diode is forward biased and allow electric current. This current is dropped at the resistor load (RL). However, during the negative half cycle, the diode is reverse biased and does not allows electric current, so the input AC current or AC voltage is dropped at the diode. The maximum voltage dropped at the diode is nothing but an input voltage. Therefore, peak inverse voltage (PIV) of diode = VSmax

Rectifier efficiency= output DC power / the input AC power. = Half wave rectifier is 40.6%
Root mean square (RMS) value of load current IRMS

$$I_{RMS} = \frac{I_m}{2}$$

Root mean square (RMS) value of output load voltage VRMS
The root mean square (RMS) value of output load voltage in a half wave rectifier is

$$V_{RMS} = I_{RMS}\, R_L = \frac{I_m}{2}\, R_L$$

Form factor (F.F) = RMS value / DC value =half wave rectifier is F.F = 1.57

Half wave rectifier Advantages
Few components, low cost and Easy to construct

Half wave rectifier Disadvantages
Power loss
It either allows the positive half cycle or negative half cycle. So the remaining half cycle is wasted. Approximately half of the applied voltage is wasted in half wave rectifier. Produces low output voltage.

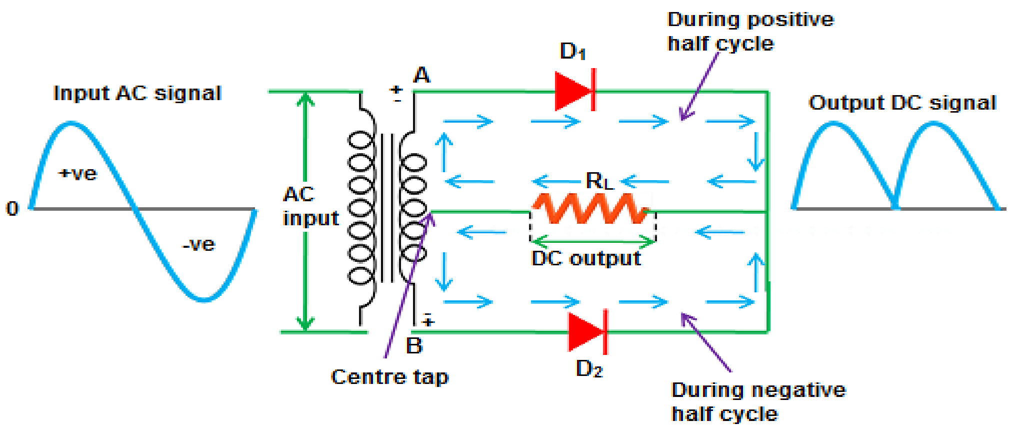
Full wave rectifier
The process of converting the **AC current** into **DC current** is called rectification. Rectification can be achieved by using a single **diode** or group of diodes. These diodes which convert the AC current into DC current are called rectifiers. Types Rectifiers are generally classified into two types: **half wave rectifier** and full wave rectifier.

A half wave rectifier uses only a single diode to convert AC to DC. So it is very easy to construct the half wave rectifier. However, a single diode in half wave rectifier only allows either a positive half cycle or a negative half cycle of the input AC signal and the remaining half cycle of the input AC signal is blocked. As a result, a large amount of power is wasted. Furthermore, the half wave rectifiers are not suitable in the applications which need a steady and smooth DC voltage. So the half wave rectifiers are not efficient AC to DC converters.

We can easily overcome this drawback by using another type of rectifier known as a full wave rectifier. The full wave rectifier has some basic advantages over the half wave rectifier. The average DC output voltage produced by the full wave rectifier is higher than the half wave rectifier. Furthermore, the DC output signal of the full wave rectifier has fewer ripples than the half wave rectifier. As a result, we get a smoother output DC voltage.

Full wave rectifier definition

A full wave rectifier is a type of rectifier which converts both half cycles of the AC signal into pulsating DC signal.

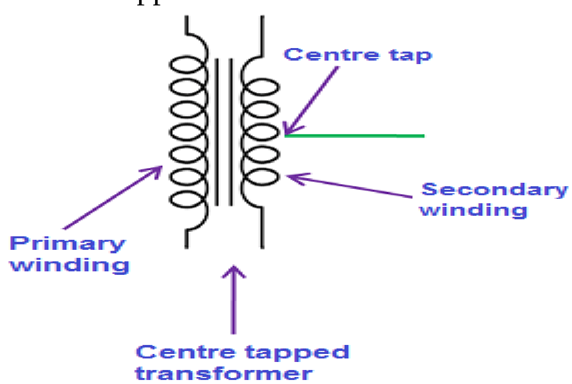


As shown in the above figure, the full wave rectifier converts both positive and negative half cycles of the input AC signal into output pulsating DC signal.

The full wave rectifier is classified into two types: **center tapped full wave rectifier and full wave bridge rectifier.**

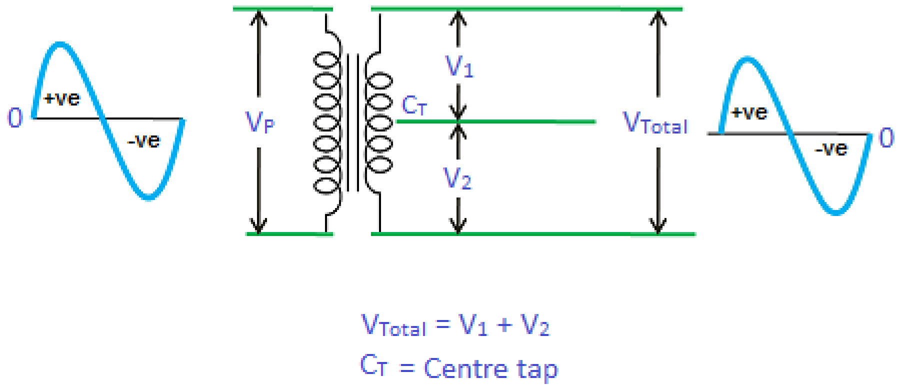
Center tapped transformer

When an additional wire is connected across the exact middle of the secondary winding of a transformer, it is known as a center tapped transformer.



The wire is adjusted in such a way that it falls in the exact middle point of the secondary winding. So the wire is exactly at zero volts of the AC signal. This wire is known as the center tap.

It works almost similar to a normal transformer. Like a normal transformer, the center tapped transformer also increases or reduces the AC voltage. However, a center tapped transformer has another important feature. That is the secondary winding of the center tapped transformer divides the input AC current or AC signal (V_P) into two parts.



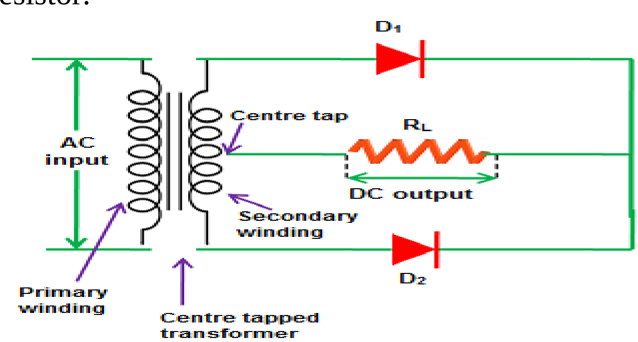
The upper part of the secondary winding produces a positive voltage V_1 and the lower part of the secondary winding produces a negative voltage V_2. When we combine these two voltages at output load, we get a complete AC signal.

I.e. $V_{Total} = V_1 + V_2$

The voltages V_1 and V_2 are equal in magnitude but opposite in direction. That is the voltages (V_1 and V_2) produced by the upper part and lower part of the secondary winding are 180 degrees out of phase with each other. However, by using a full wave rectifier with center tapped transformer, we can produce the **voltages** that are in phase with each other. In simple words, by using a full wave rectifier with center tapped transformer, we can produce a current that flows only in single direction.

What is center tapped full wave rectifier

It is a type of rectifier which uses a center tapped transformer and two diodes to convert the complete AC signal into DC signal.It is made up of an AC source, a center tapped transformer, two diodes, and a load resistor.



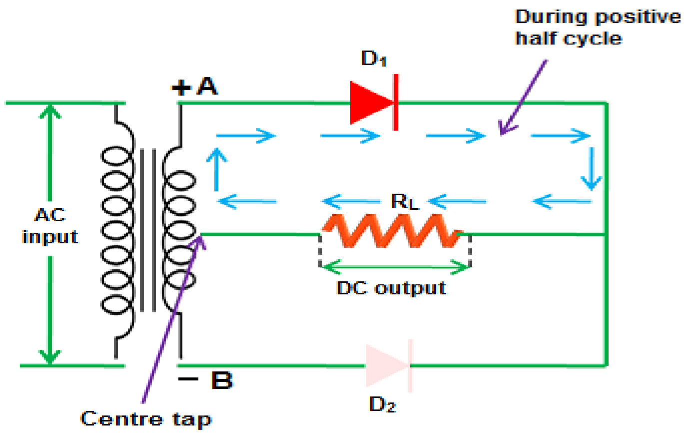
The AC source is connected to the primary winding of the center tapped transformer. A center tap (additional wire) connected at the exact middle of the the secondary winding divides the input voltage into two parts.

The upper part of the secondary winding is connected to the diode D_1 and the lower part of the secondary winding is connected to the diode D_2. Both diode D_1 and diode D_2 are connected to a common load R_L with the help of a center tap transformer. The center tap is generally considered as the ground point or the zero voltage reference point.

How center tapped full wave rectifier works

It uses a center tapped transformer to convert the input AC voltage into output DC voltage. When input AC voltage is applied, the secondary winding of the center tapped transformer divides this input AC voltage into two parts: positive and negative.

During the positive half cycle of the input AC signal, terminal A become positive, terminal B become negative and center tap is grounded (zero volts). The positive terminal A is connected to the p-side of the diode D_1 and the negative terminal B is connected to the n-side of the diode D_1. So the diode D_1 is forward biased during the positive half cycle and allows electric current through it.



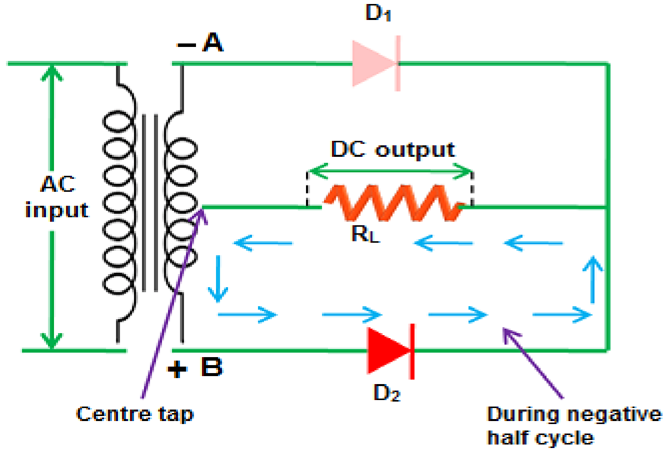
On the other hand, the negative terminal B is connected to the p-side of the diode D_2 and the positive terminal A is connected to the n-side of the diode D_2. So the diode D_2 is reverse biased during the positive half cycle and does not allow electric current through it.

The diode D_1 supplies DC current to the load R_L. The DC current produced at the load R_L will return to the secondary winding through a center tap.

During the positive half cycle, current flows only in the upper part of the circuit while the lower part of the circuit carry no current to the load because the diode D_2 is reverse biased. Thus, during the positive half cycle of the input AC signal, only diode D_1 allows electric current while diode D_2 does not allow electric current.

During the negative half cycle of the input AC signal, terminal A become negative, terminal B become positive and center tap is grounded (zero volts). The negative terminal A is connected to the p-side of the diode D_1 and the positive terminal B is connected to the n-side of the diode D_1.

So the diode D_1 is reverse biased during the negative half cycle and does not allow electric



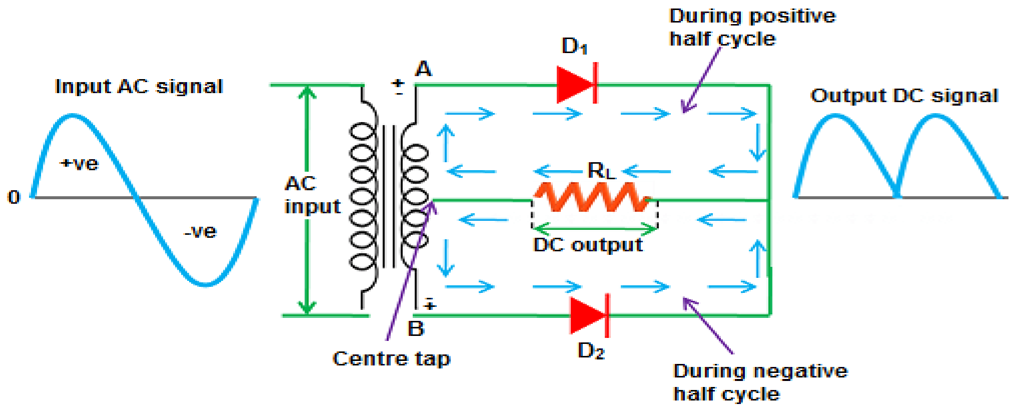
current through it.

On the other hand, the positive terminal B is connected to the p-side of the diode D_2 and the negative terminal A is connected to the n-side of the diode D_2. So the diode D_2 is forward biased during the negative half cycle and allows electric current through it.

The diode D_2 supplies DC current to the load R_L. The DC current produced at the load R_L will return to the secondary winding through a center tap.

During the negative half cycle, current flows only in the lower part of the circuit while the upper part of the circuit carry no current to the load because the diode D_1 is reverse biased. Thus, during the negative half cycle of the input AC signal, only diode D_2 allows electric current while diode D_1 does not allow electric current.

Thus, the diode D_1 allows electric current during the positive half cycle and diode D_2 allows electric current during the negative half cycle of the input AC signal. As a result, both half cycles (positive and negative) of the input AC signal are allowed. So the output DC voltage is almost equal to the input AC voltage.

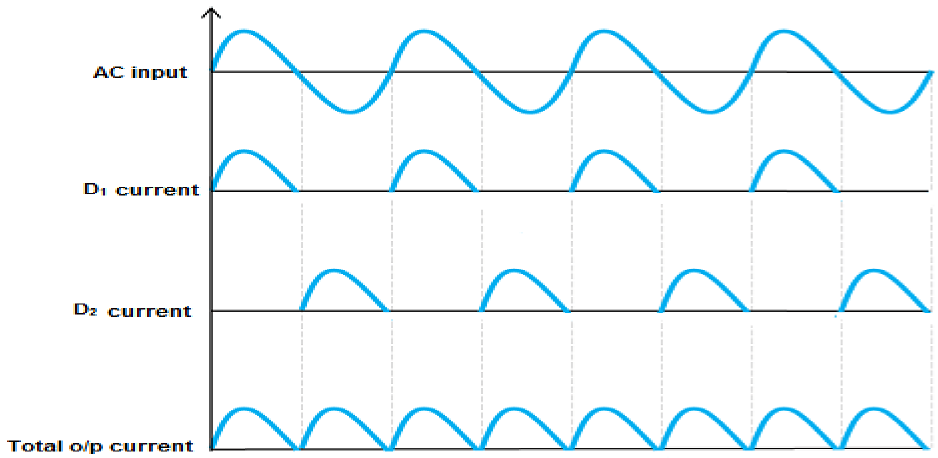


A small voltage is wasted at the diode D_1 and diode D_2 to make them conduct. However, this voltage is very small as compared to the voltage appeared at the output. So this voltage is neglected. The diodes D_1 and D_2 are commonly connected to the load R_L. So the load current is the sum of individual diode currents.

We know that a diode allows electric current in only one direction. From the above diagram, we can see that both the diodes D_1 and D_2 are allowing current in the same direction. We know that a current that flows in only single direction is called a direct current. So the resultant current at the output (load) is a direct current (DC). However, the direct current appeared at the output is not a pure direct current but a pulsating direct current.

The value of the pulsating direct current changes with respect to time. This is due to the ripples in the output signal. These ripples can be reduced by using filters such as capacitor and inductor. The average output DC voltage across the load resistor is double that of the single half wave rectifier circuit.

Output waveforms of full wave rectifier



The first waveform represents an input AC signal. The second waveform and third waveform represents the DC signals or DC current produced by diode D_1 and diode D_2. The last waveform represents the total output DC current produced by diodes $D_1$and D_2. From the above waveforms, we can conclude that the output current produced at the load resistor is not a pure DC but a pulsating DC.

Characteristics of full wave rectifier

Ripple factor

It is used to measure the amount of ripples present in the output DC signal. A high ripple factor indicates a high pulsating DC signal while a low ripple factor indicates a low pulsating DC signal.

Ripple factor =Ripple voltage /pure DC voltage

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

$\gamma = 0.48$

Rectifier efficiency
It indicates how efficiently the rectifier converts AC into DC. A high percentage of rectifier efficiency indicates a good rectifier while a low percentage of rectifier efficiency indicates an inefficient rectifier.

Rectifier efficiency = DC output power / AC input power= η = output P_{DC} / input P_{AC}

It of a full wave rectifier is 81.2%.It of a full wave rectifier is twice that of the half wave rectifier. So the full wave rectifier is more efficient than a half wave rectifier

Peak inverse / reverse voltage (PIV)
It is the maximum voltage a diode can withstand in the reverse bias condition. If the applied voltage is greater than the peak inverse voltage, the diode will be permanently destroyed. The peak inverse voltage (PIV) = $2V_{smax}$

DC output current
At the output load resistor R_L, both the diode D_1 and diode D_2 currents flow in the same direction. So the output current is the sum of D_1 and D_2 currents.
The current produced by D_1 is I_{max} / π and the current produced by D_2 is I_{max} / π.
So the output current $I_{DC} = 2I_{max} / \pi$
Where, I_{max} = maximum DC load current

DC output voltage appeared at the load resistor R_L is given as
$V_{DC} = 2V_{max} / \pi$
Where, V_{max} = maximum secondary voltage

Root mean square (RMS) value of load current I_{RMS}

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

Root mean square (RMS) value of the output load voltage V_{RMS}

$$V_{RMS} = I_{RMS}\, R_L = \frac{I_m}{\sqrt{2}}\, R_L$$

Advantages of full wave rectifier with center tapped transformer
High rectifier efficiency
Full wave rectifier has high rectifier efficiency than the half wave rectifier. That means the full wave rectifier converts AC to DC more efficiently than the half wave rectifier.

Low power loss
In a half wave rectifier, only half cycle (positive or negative half cycle) is allowed and the remaining half cycle is blocked. As a result, more than half of the voltage is wasted. But in full

wave rectifier, both half cycles (positive and negative half cycles) are allowed at the same time. So no signal is wasted in a full wave rectifier.

Low ripples
The output DC signal in full wave rectifier has fewer ripples than the half wave rectifier.

Disadvantages of full wave rectifier with center tapped transformer
High cost
The center tapped transformers are expensive and occupy a large space.

Full wave rectifier with filter
The device that converts **Alternating Current (AC)** into **Direct Current (DC)** is referred to as **rectifier**.

In **half wave rectifier,** the conversion of Alternating Current (AC) into Direct Current (DC) is not efficient. Half wave rectifier allows either positive half cycle or negative half cycle of the input AC signal and the remaining half cycle is blocked. As a result, a large power is wasted. Also, the output Direct Current (DC) produced by the half wave rectifier contains large ripples. This ripple voltage fluctuates with respect to time. So it is not suitable for practical applications.

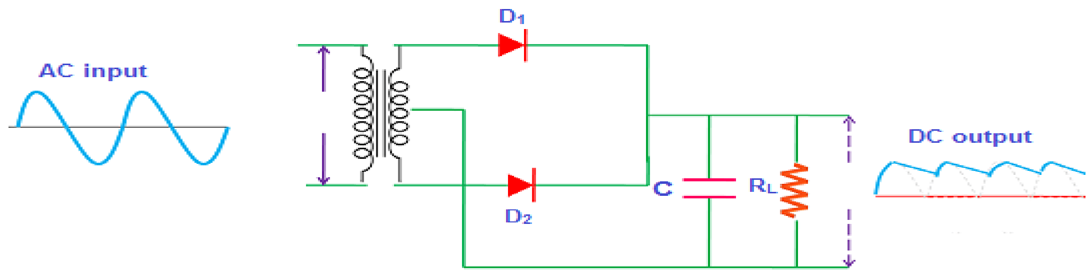
To overcome these problems, **we use filters at the output.** Even though we use filters at the output, the DC signal obtained at the output is not a pure DC. Furthermore, the power loss is high in half wave rectifier. Therefore, to reduce the power loss and reduce the ripples at the output, we go for another type of rectifier known as full wave rectifier.

As the name suggests, the full wave rectifier rectifies both positive and negative half cycles of the input AC signal. Even though the full wave rectifier rectify both positive and negative half cycles, the DC signal obtained at the output still contains some ripples. To reduce these ripples at the output, we use a filter.

The filter is an electronic device that converts the pulsating Direct Current into pure Direct Current. The filter is made up of a combination of electronic components such as resistors, capacitors, and inductors. The property of inductor is that it allows the DC components and blocks the AC components. The property of a capacitor is that it allows the AC components and blocks the DC components.

In this tutorial, a center tapped full wave rectifier with a filter made up of capacitor and resistor is explained. **The filter made up of capacitor and resistor is known as capacitor filter.**
In the circuit diagram, the capacitor C is placed across the load resistor R_L.
The working of the full wave rectifier with filter is almost similar to that of the half wave rectifier with filter. The only difference is that in the half wave rectifier only one half cycle (either positive or negative) of the input AC current will charge the **capacitor** but the remaining half cycle will not charge the capacitor. But in **full wave rectifier, both positive and negative half cycles of the input AC current will charge the capacitor.**

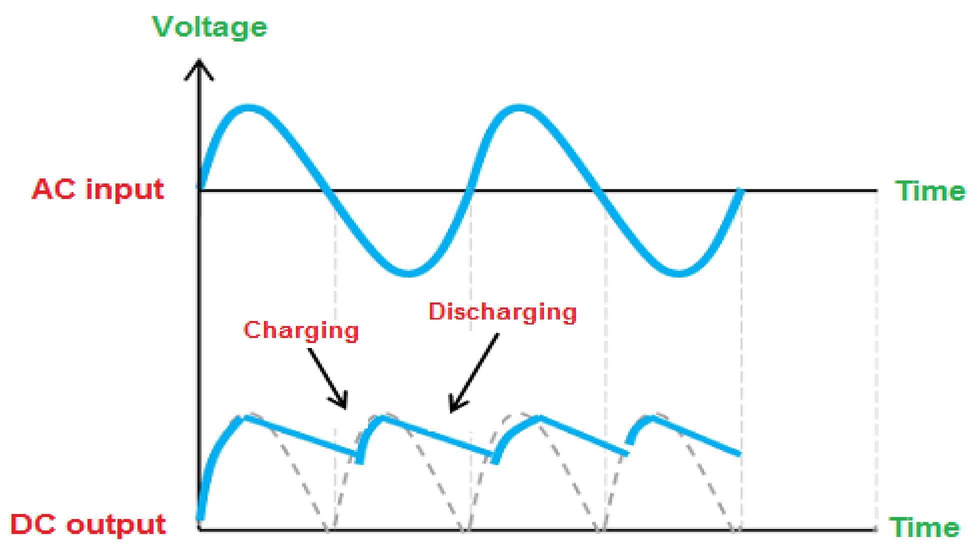
The main duty of the capacitor filter is to short the ripples to the ground and blocks the pure DC (DC components), so that it flows through the alternate path and reaches output load resistor R_L. When input AC voltage is applied, during the positive half cycle, the diode D_1 is forward biased and allows **electric current** whereas the diode D_2 is reverse biased and blocks electric current. On the other hand, during the negative half cycle the diode D_2 is forward biased (allows electric current) and the diode D_1 is reverse biased (blocks electric current).



Full wave rectifier with capacitor filter

During the positive half cycle, the diode (D_1) current reaches the filter and charges the capacitor. However, the charging of the capacitor happens only when the applied AC voltage is greater than the capacitor voltage.

Initially, the capacitor is uncharged. That means no **voltage** exists between the plates of the capacitor. So when the voltage is turned on, the charging of the capacitor happens immediately. During this conduction period, the capacitor charges to the maximum value of the input supply voltage. The capacitor stores a maximum charge exactly at the quarter positive half cycle in the waveform. At this point, the supply voltage is equal to the capacitor voltage.



When the AC voltage starts decreasing and becomes less than the capacitor voltage, then the capacitor starts slowly discharging.

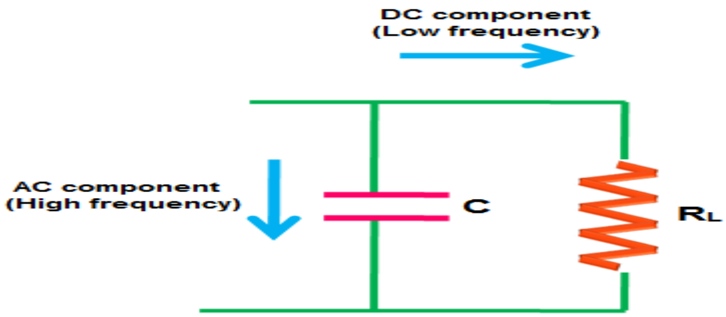
The discharging of the capacitor is very slow as compared to the charging of the capacitor. So the capacitor does not get enough time to completely discharged. Before the complete discharge of the capacitor happens, the charging again takes place. So only half or more than half of the capacitor charge get discharged.

When the input AC supply voltage reaches the negative half cycle, the diode D_1 is reverse biased (blocks electric current) whereas the diode D_2 is forward biased (allows electric current). During the negative half cycle, the diode (D_2) current reaches the filter and charges the capacitor. However, the charging of the capacitor happens only when the applied AC voltage is greater than the capacitor voltage.

The capacitor is not completely uncharged, so the charging of the capacitor does not happens immediately. When the supply voltage becomes greater than the capacitor voltage, the capacitor again starts charging.

In both positive and negative half cycles, the current flows in the **same direction across the load resistor R_L.** So we get either complete positive half cycles or negative half cycles. In our case, they are complete positive half cycles.

How exactly the capacitor filter removes the ripples in the signal
The pulsating Direct Current (DC) produced by the full wave rectifier contains both AC and DC components.



Filter Capacitor Circuit to Block DC and Pass AC
Filter which passes high frequency signals and blocks low frequency signals.

Zener diode
A normal **p-n junction diode** allows electric **current only in forward biased condition.** When forward biased voltage is applied to the p-n junction diode, it allows large amount of electric current and blocks only a small amount of electric current. Hence, a **forward biased p-n junction diode** offer only a small resistance to the electric current.

When reverse biased voltage is applied to the p-n junction diode, it blocks large amount of electric current and allows only a small amount of electric current. Hence, a reverse biased p-n junction diode offer **large resistance to the electric current.**
If reverse biased voltage applied to the p-n junction diode is **highly increased**, a sudden rise in current occurs. At this point, a small increase in **voltage will rapidly increases the electric current.** This sudden rise in electric current causes a junction breakdown called **zener or avalanche breakdown.** The voltage at which zener breakdown occurs is called zener voltage and the sudden increase in current is called zener current.

A normal p-n junction diode does not operate in breakdown region because the excess current **permanently damages the diode.** Normal p-n junction diodes are not designed to operate in **reverse breakdown region.** Therefore, a normal p-n junction diode does not operate in reverse breakdown region.

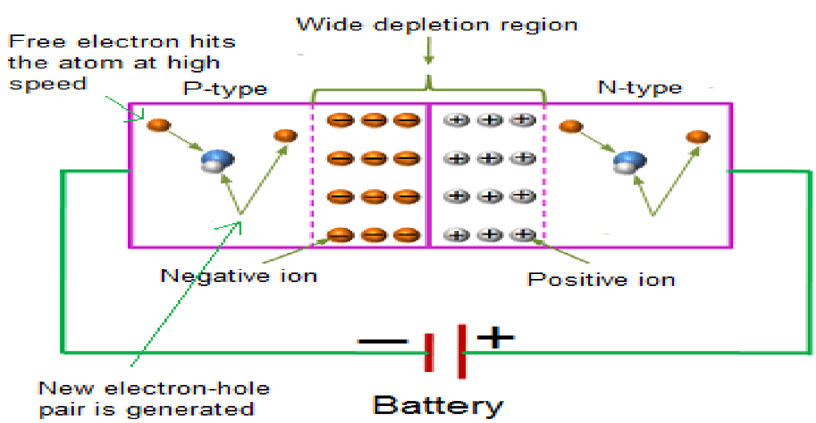
What is zener diode?
A zener diode is a special type of device designed to operate in the zener breakdown region. Zener diodes acts like normal p-n junction diodes under forward biased condition. When forward biased voltage is applied to the zener diode it **allows large amount of electric current and blocks only a small amount of electric current.**

Zener diode is **heavily doped than the normal p-n junction diode.** Hence, it has very thin **depletion region**. Therefore, zener diodes allow more electric current than the normal p-n junction diodes. Zener diode allows electric current in **forward direction like a normal diode but also allows electric current in the reverse direction if the applied reverse voltage is greater than the zener voltage. Zener diode is always connected in reverse direction because it is specifically designed to work in reverse direction.**

Zener diode definition
A zener diode is a p-n junction semiconductor device designed to operate in the reverse breakdown region. The breakdown voltage of a zener diode is carefully set by controlling the doping level during manufacture. The name zener diode was named after the **American physicist Clarance Melvin Zener** who discovered the zener effect. Zener diodes are the basic building blocks of electronic circuits. They are widely used in all kinds of electronic equipments. Zener diodes are mainly used to protect electronic circuits from over voltage.

Breakdown in zener diode
zener diode 2 types of reverse breakdown regions**: avalanche breakdown & zener breakdown.**

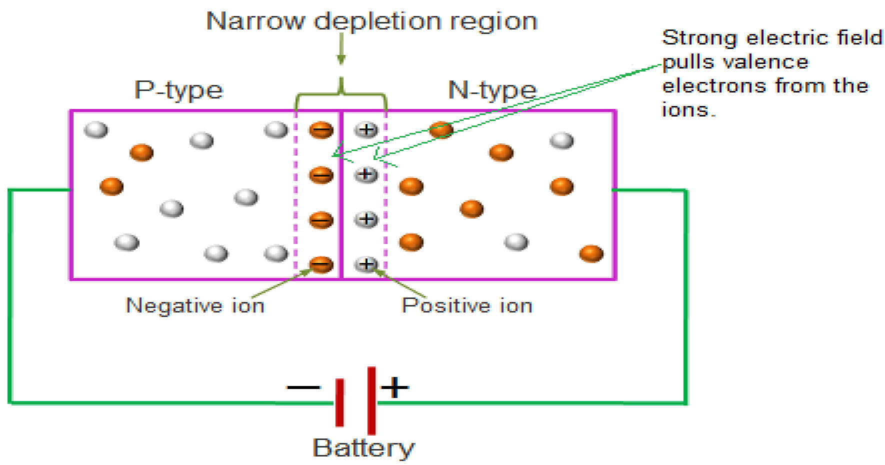
Avalanche breakdown
It occurs in both normal diodes and zener diodes at **high reverse voltage**. When high reverse voltage is applied to the p-n junction diode, the **free electrons** (minority carriers) gains large amount of **energy** and accelerated to greater velocities.



The free electrons **moving at high speed will collides with the atoms and knock off more** electrons. These electrons are again accelerated and collide with other atoms. Because of this continuous collision with the atoms, a large number of free electrons are generated. As a result, electric current in the diode increases rapidly. **This sudden increase in electric current may permanently destroys the normal diode.** However, avalanche diodes may not be destroyed because they are carefully designed to operate in avalanche breakdown region. Avalanche breakdown occurs in zener diodes with zener voltage (V_z) greater than 6V.

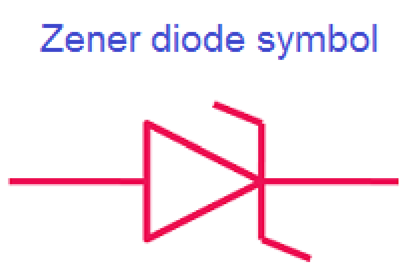
Zener breakdown

It occurs in heavily doped p-n junction diodes because of their narrow depletion region. When reverse biased voltage applied to the diode is increased, the narrow depletion region generates strong electric field.



When reverse biased voltage applied to the diode reaches close to zener voltage, the electric field in the depletion **region is strong enough to pull electrons from their valence band.** The valence electrons which gains sufficient energy from the strong electric field of depletion region will breaks bonding with the parent atom. The **valance electrons** which break bonding with parent atom will become free electrons. This free electrons carry electric current from one place to another place. **At zener breakdown region, a small increase in voltage will rapidly increases the electric current. Zener breakdown occurs at low reverse voltage whereas avalanche breakdown occurs at high reverse voltage.** Zener breakdown occurs in zener diodes because they have very thin depletion region. Breakdown region is the normal operating region for a zener diode. Zener breakdown occurs in zener diodes with zener voltage (V_z) less than 6V.

Symbol of zener diode



In zener diode, electric current flows from both anode to cathode and cathode to anode.

VI characteristics of zener diode

When forward biased voltage is applied to the zener diode, it works like a normal diode. However, when reverse biased voltage is applied to the zener diode, it works in different manner.

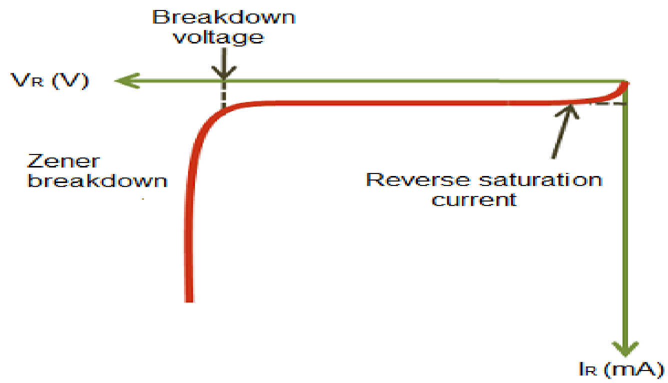


Fig: Zener breakdown

When reverse biased voltage is applied to a zener diode, it allows only a small amount of leakage current until the voltage is less than zener voltage. When **reverse biased voltage applied to the zener diode reaches zener voltage**, it starts allowing **large amount of electric current. At this point, a small increase in reverse voltage will rapidly increases the electric current.** Because of this sudden rise in electric current, breakdown occurs called zener breakdown. However, zener diode exhibits a controlled breakdown that does damage the device.
The zener breakdown voltage of the zener diode is depends on the amount of doping applied. If the diode is heavily doped, zener breakdown occurs at low reverse voltages. On the other hand, if the diode is lightly doped, the zener breakdown occurs at high reverse voltages. Zener diodes are available with zener voltages in the range of **1.8V to 400V.**

Advantages of zener diode

Power dissipation capacity is very high, high accuracy, Small size and Low cost

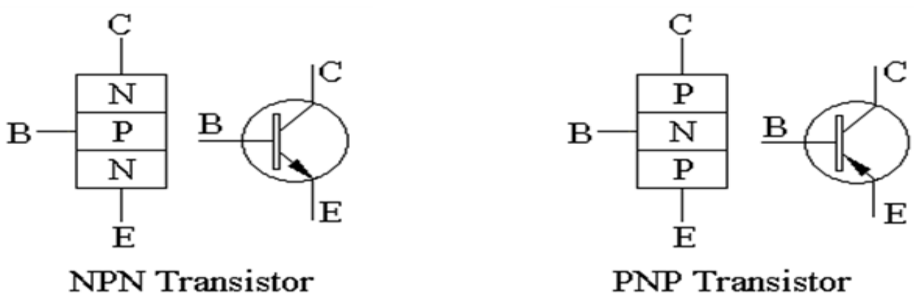
Applications of zener diode Used as

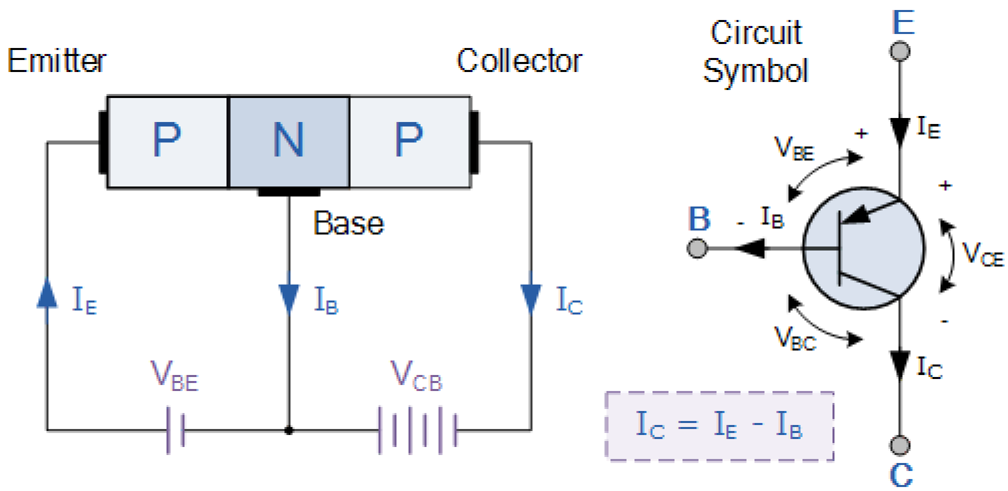
Voltage reference, voltage stabilizers / shunt regulators, switching operations, clipping and clamping circuits and protection circuits

Transistor as PNP and NPN

PNP Transistor

The **PNP Transistor** is the exact opposite to the **NPN Transistor** device .





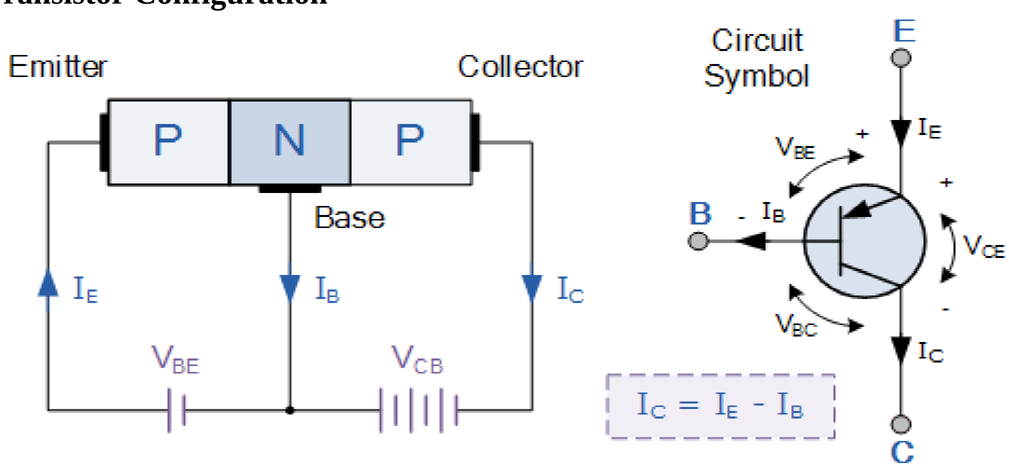
Basically, in this type of transistor construction the two diodes are reversed with respect to the NPN type giving a **P**ositive-**N**egative-**P**ositive type of configuration, with the arrow which also defines the Emitter terminal this time pointing inwards in the transistor symbol.

Also, all the polarities for a PNP transistor are reversed which means that it “sinks” current into its Base as opposed to the NPN transistor which “sources” current through its Base. The main difference between the two types of transistors is that **holes are the more important carriers for PNP transistors,** whereas **electrons** are the important **carriers for NPN transistors.**

Then, PNP transistors use a small base current and a negative base voltage to control a much larger emitter-collector current. In other words for a PNP transistor, the Emitter is more positive with respect to the Base and also with respect to the Collector.

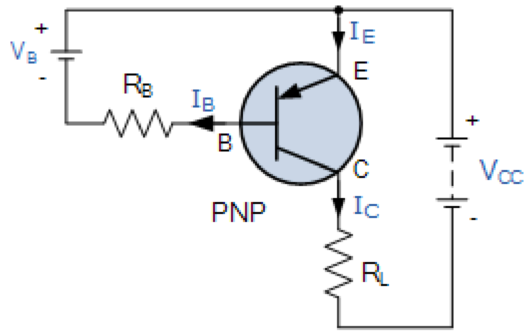
The construction of a “PNP transistor” consists of two P-type semiconductor materials either side of an N-type material as shown below.

A PNP Transistor Configuration



(Note: Arrow defines the emitter and conventional current flow, “in” for a PNP transistor.)

The construction and terminal voltages for an NPN transistor are shown above. The **PNP Transistor** has very similar characteristics to their NPN bipolar cousins, except that the polarities (or biasing) of the current and voltage directions are reversed for any one of the possible three configurations looked at in the first tutorial, Common Base, Common Emitter and Common Collector.



PNP Transistor Connection

The voltage between the Base and Emitter (V_{BE}), is now negative at the Base and positive at the Emitter because for a PNP transistor, the Base terminal is always biased negative with respect to the Emitter. Also the Emitter supply voltage is positive with respect to the Collector (V_{CE}). So for a PNP transistor to conduct the Emitter is always more positive with respect to both the Base and the Collector.

The voltage sources are connected to a PNP transistor are as shown. This time the Emitter is connected to the supply voltage V_{CC} with the load resistor, RL which limits the maximum current flowing through the device connected to the Collector terminal. The Base voltage V_B which is biased negative with respect to the Emitter and is connected to the Base resistor R_B, which again is used to limit the maximum Base current.

NPN Base -------------------→Current Flow Collector-------------------→emitter.	PNP----On Low Signal NPN---Off High

Difference Between PNP and NPN

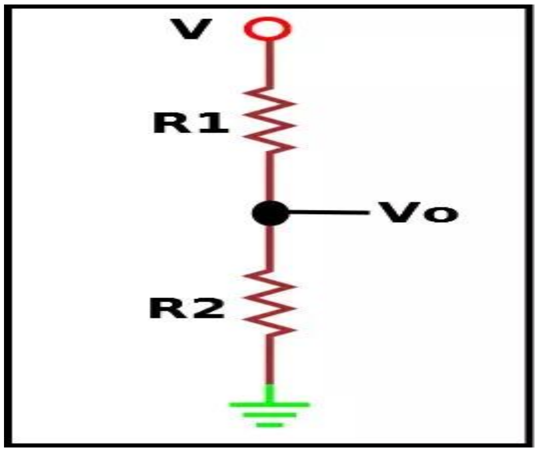
1. Both PNP and NPN transistors are composed of different materials and current flow of these transistors is also dissimilar.
2. In an NPN transistor, the current flows from the **collector (C) to the Emitter** (E), whereas in a PNP transistor, the current flows from the **emitter to the collector**.
3. PNP transistors are made up of two layers of P material with a sandwiched layer of N The NPN transistors are made up of two layers of N material and sandwiched with one layer of P material.
4. In an NPN transistor, a positive voltage is given to the **collector terminal** to produce a current flow from the collector to For PNP transistor; a positive voltage is given to the emitter terminal to produce current flow from the emitter to collector.
5. The working principle of an NPN transistor is such that **when you increase current to the base terminal, then the transistor turns ON and it** conducts fully from the collector to emitter. When you decrease the current to the base terminal, the transistor turns ON less and until the current is so low, the transistor no longer conducts across the collector to emitter, and shuts OFF.

6. The working principle of a PNP transistor is such that when the current exists at the base terminal of the transistor, then the transistor shuts OFF. When there is not current at the base terminal of the PNP transistor, then the transistor turns ON.

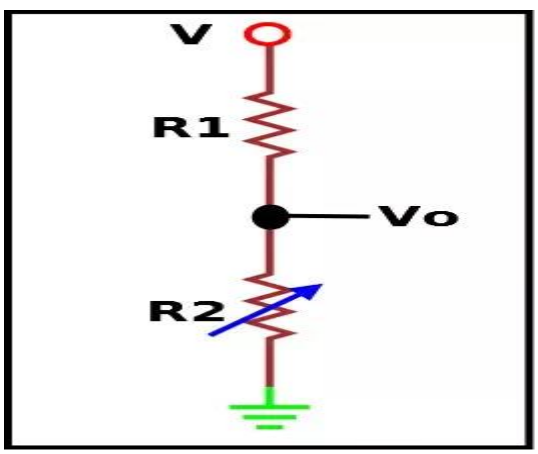
Transistor as amplifier

What is a transistor, how does it work, and how can it be used as an amplifier or switch?

To understand how an amplifier works, you need to first understand how a Voltage Divider circuit functions. Below is a simple Voltage Divider Circuit.



The output Vo depends on V, R1 and R2. For example if V = 100V, R1 = 40 Ohms and R2 = 60 Ohms. Then Vo = V * (R2/(R1+R2) = 100 * (60/100) = 60V. By changing the values of V, R1 and R2 the output Vo can be changed. Now let us change the resistor R2 with a Variable Resistor.



In the above circuit V and R1 are fixed and R2 is a variable. So, if we change R2, Vo will change. We generally call this as Regulator. Now let us have a **variable resistor whose resistance can be changed by the voltage instead of manual control.**

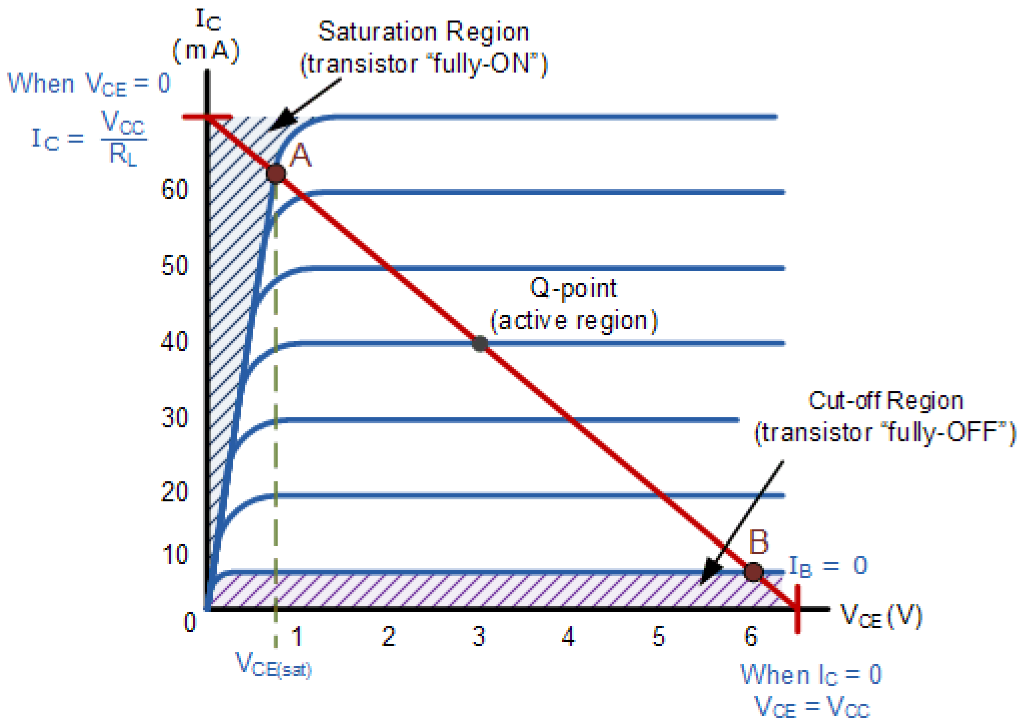
In the above circuit the value of R2 is changed by the voltage Vi. If we change Vi then Vo is changed. **The relation between Vo and Vi is called Amplification Factor.** Here is a surprise. The resistor who's resistance is changed by voltage (current) is nothing but a Transistor.

Actually Transistor acts as only a variable resistor. The value of resistor between Collector and Emitter is changed by the base current. The Transistor acts as a Regulator (Variable Resistor) or a switch (ON/OFF).

Transistor has 3 operating modes.
1. Cut-off (Switch - OFF). 2- Saturation (Switch - ON). 3- Active (Regulator).

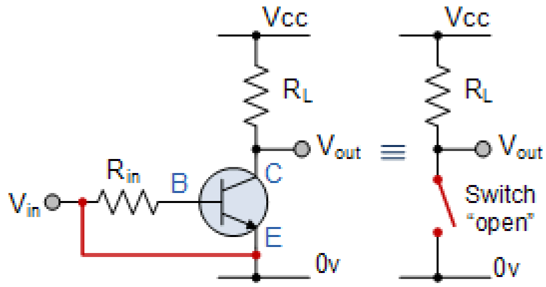
Cut-off Mode	**Saturation Mode**	**Active Mode**
Vb < Vbe (Generally 0.7V) So Ib = 0A Ic = 0A Vc = Ic x Rc = 0V Vo = Vcc - Vc = Vcc	Ic > Ic.max Ic.max = Vcc/Rc Ic = β Ib Ic = Ic.max Vc = Ic x Rc = Vcc Vo = Vcc - Vc = 0V	0 < Ic < Ic.max Ib = (Vb - Vbe)/Rb Ic = β x Ib Vc = Ic x Rc Vo = Vcc - Vc 0V < Vo < Vcc
When a Transistor acts as a Regulator, it is called an Amplifier. When a Transistor acts as a Switch, it is called a Gate. Transistor in Active Mode - Analog Electronics. Transistor in Cutoff/Saturation Mode - Digital Electronics		

Operating Regions



1. Cut-off Region
Here the operating conditions of the transistor are zero input base current (IB), zero output collector current (IC) and maximum collector voltage (VCE) which results in a large depletion layer and no current flowing through the device. Therefore the transistor is switched "Fully-OFF".

Cut-off Characteristics



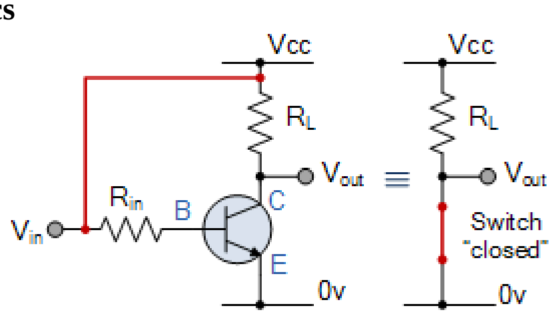
- The input and Base are grounded (0v)
- Base-Emitter voltage VBE < 0.7v
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows (IC = 0)
- VOUT = VCE = VCC = "1"
- Transistor operates as an "open switch"

Then we can define the "cut-off region" or "OFF mode" when using a bipolar transistor as a switch as being, both junctions reverse biased, VB < 0.7v and IC = 0. For a PNP transistor, the Emitter potential must be negative with respect to the Base.

2. Saturation Region

Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current resulting in the minimum collector emitter voltage drop which results in the depletion layer being as small as possible and maximum current flowing through the transistor. Therefore the transistor is switched "Fully-ON".

Saturation Characteristics

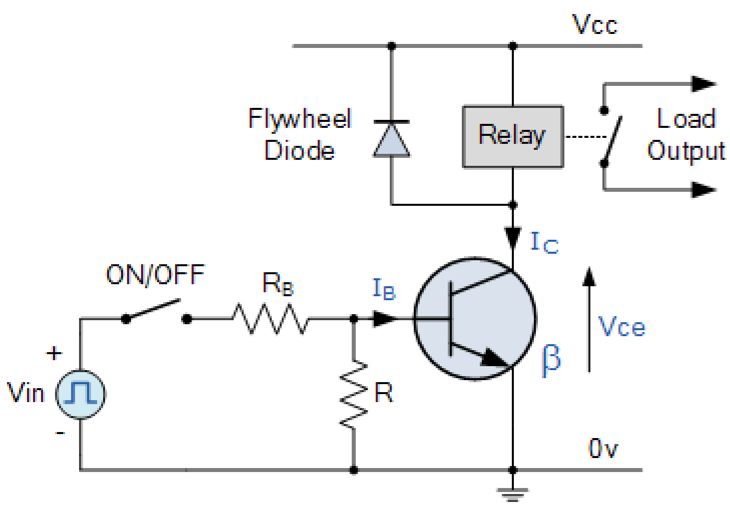


- The input and Base are connected to VCC
- Base-Emitter voltage VBE > 0.7v
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows (IC = Vcc/RL)
- VCE = 0 (ideal saturation)
- VOUT = VCE = "0"
- Transistor operates as a "closed switch"

Then we can define the "saturation region" or "ON mode" when using a bipolar transistor as a switch as being, both junctions forward biased, VB > 0.7v and IC = Maximum. For a PNP transistor, the Emitter potential must be positive with respect to the Base.

Then the transistor operates as a "single-pole single-throw" (SPST) solid state switch. With a zero signal applied to the Base of the transistor it turns "OFF" acting like an open switch and zero collector current flows. With a positive signal applied to the Base of the transistor it turns "ON" acting like a closed switch and maximum circuit current flows through the device.

Basic NPN Transistor Switching Circuit



The circuit resembles that of the Common Emitter circuit we looked at in the previous tutorials. The difference this time is that to operate the transistor as a switch the transistor needs to be turned either fully "OFF" (cut-off) or fully "ON" (saturated). An ideal transistor switch would have infinite circuit resistance between the Collector and Emitter when turned "fully-OFF" resulting in zero current flowing through it and zero resistance between the Collector and Emitter when turned "fully-ON", resulting in maximum current flow.

In practice when the transistor is turned "OFF", small leakage currents flow through the transistor and when fully "ON" the device has a low resistance value causing a small saturation voltage (VCE) across it. Even though the transistor is not a perfect switch, in both the cut-off and saturation regions the power dissipated by the transistor is at its minimum.

In order for the Base current to flow, the Base input terminal must be made more positive than the Emitter by increasing it above the 0.7 volts needed for a silicon device. By varying this Base-Emitter voltage VBE, the Base current is also altered and which in turn controls the amount of Collector current flowing through the transistor as previously discussed.

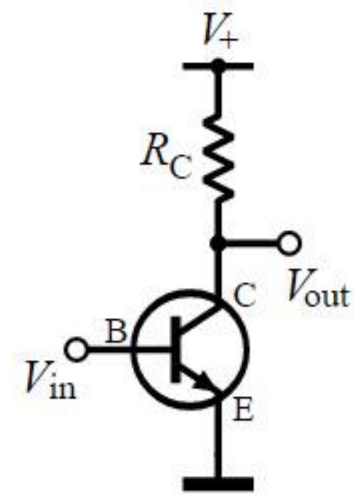
When maximum Collector current flows the transistor is said to be **saturated**. The value of the Base resistor determines how much input voltage is required and corresponding Base current to switch the transistor fully "ON".

Transistor as amplifier – CE (Common Emitter)

There are **different types of transistor amplifiers** operated by using an AC signal input. Which are interchanged between the positive value and negative value, hence this is the one way of presenting the **common emitter amplifier circuit** to function **between two peak values.** This process is known as the **biasing amplifier** and it is an important amplifier design to establish the exact operating point of a transistor amplifier which is ready to receive the signals hence it can reduce any distortion to the output signal.

What is a Common Emitter Amplifier?

The common emitter amplifier is a 3 single stage BJT and is used as a voltage amplifier. The input of this amplifier is taken from the base terminal, the output is collected from the collector terminal and the **emitter terminal is common for both the terminals.**



Common Emitter Amplifier

Working of Common Emitter Amplifier

It consists of voltage divider biasing, **used to supply the base bias voltage as per the necessity.** The voltage divider biasing has a potential divider with two resistors are connected in a way that the midpoint is used for supplying base bias voltage.

There are different types of electronic components in the common emitter amplifier which are **R1 resistor is used for the forward bias**, the **R2 resistor** is used for the **development of bias**, the **RL resistor** is used at the output it is called as the **load resistance**. The RE resistor is used for the thermal stability. The C1 capacitor is used to **separate the AC signals from the DC biasing voltage** and the capacitor is known as the coupling capacitor.

The figure shows that the bias vs gain common emitter amplifier transistor characteristics, if the R2 resistor increases then there is an increase in the forward bias and R1 & bias are inversely proportional to each other. The alternating current is applied to the base of the transistor of the common emitter amplifier circuit then there is a flow of small base current. Hence there is a large amount of current flow through the collector with the help of the RC resistance. The voltage near the resistance RC will change because the value is very high and the values are from the 4 to

10kohm. Hence there is a huge amount of current present in the collector circuit which amplified from the weak signal, therefore common emitter transistor work as an amplifier circuit.
R2 High-→Forward Bias-→Less R2

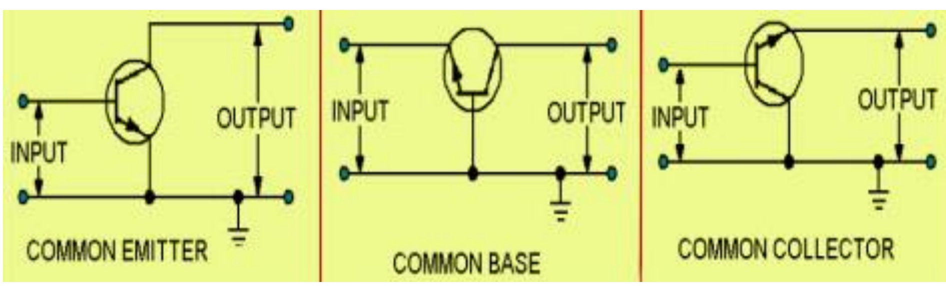
Voltage Gain of Common Emitter Amplifier
The current gain of common emitter amplifier is defined as the ratio of **change in collector current to the change in base current.** The voltage gain is defined as the **product of the current gain** and the ratio of the **output resistance** of the collector to the input resistance of the base circuits.

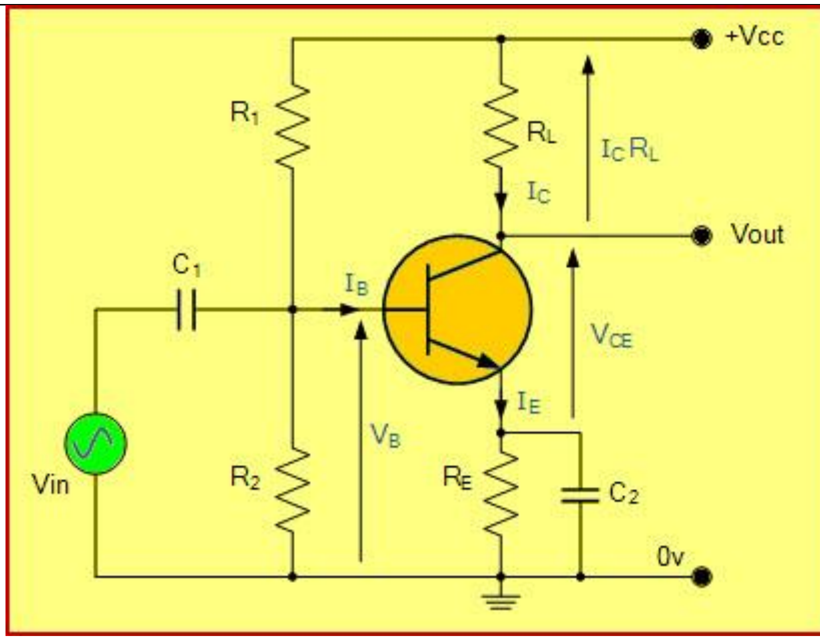
$$\beta = \frac{\Delta I_c}{\Delta I_b}$$

$$A_v = \beta \frac{R_c}{R_b}$$

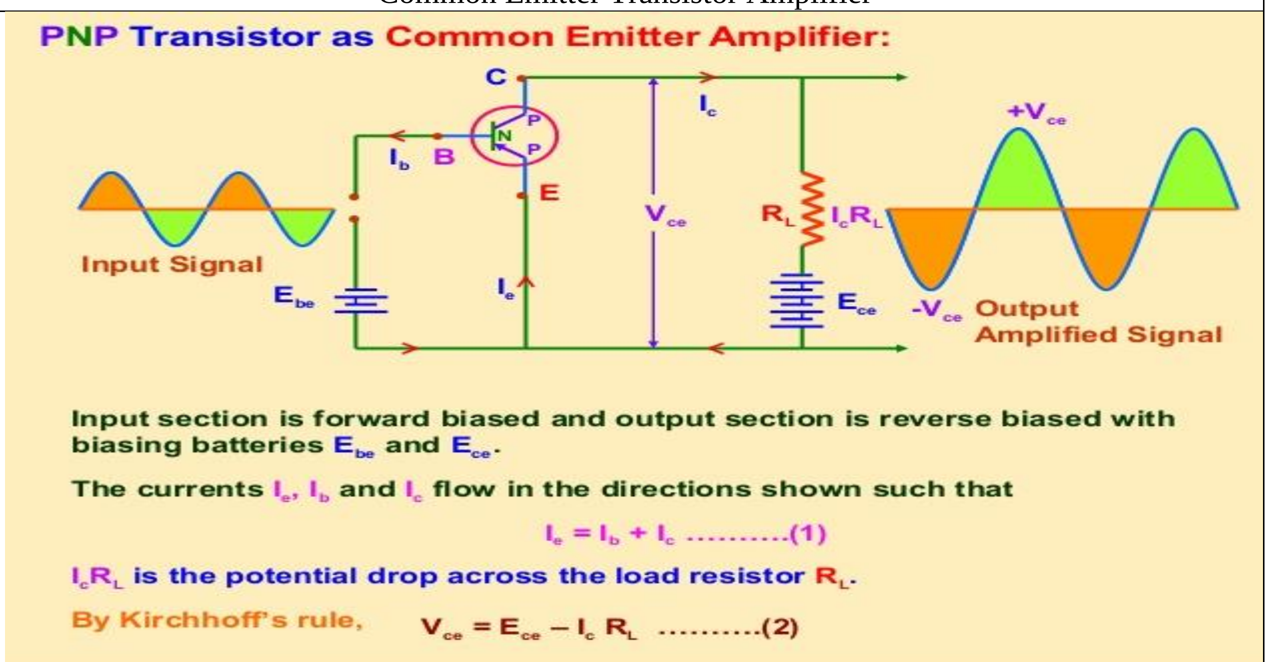
Voltage & Current Gain of Common Emitter Amplifier

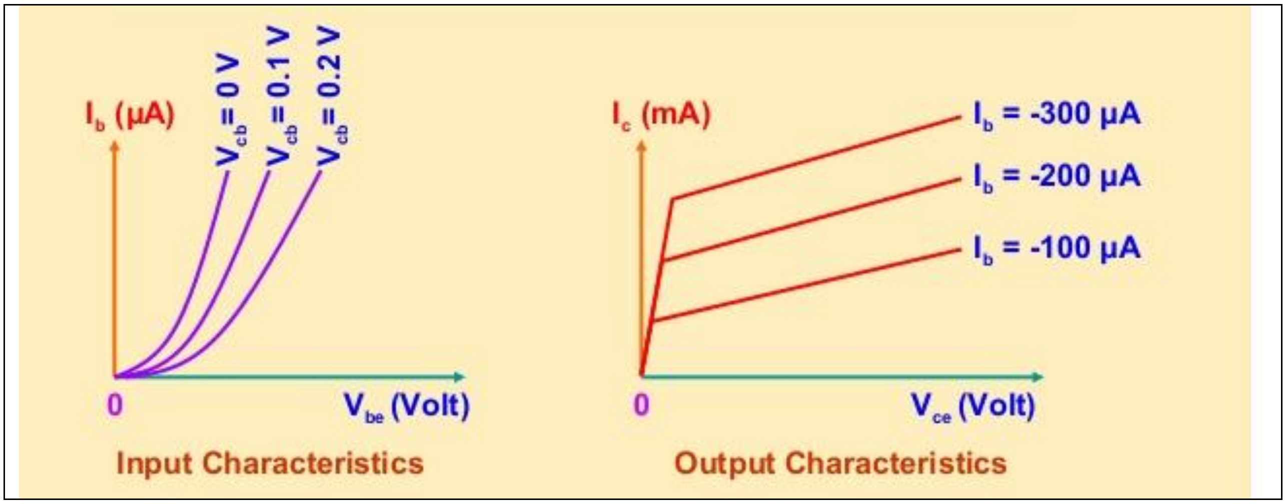
Common Emitter Transistor Amplifier





Common Emitter Transistor Amplifier





Gains in Common Emitter Amplifier:

1) **Current Amplification Factor or Current Gain:**

(i) **DC current gain:** It is the ratio of the collector current (I_c) to the base current (I_b) at constant collector voltage.

$$\beta_{dc} = \left[\frac{I_c}{I_b}\right]_{V_{ce}}$$

(ii) **AC current gain:** It is the ratio of change in collector current (ΔI_c) to the change in base current (ΔI_b) at constant collector voltage.

$$\beta_{ac} = \left[\frac{\Delta I_c}{\Delta I_b}\right]_{V_{ce}}$$

2) **AC voltage gain:** It is the ratio of change in output voltage (collector voltage ΔV_{ce}) to the change in input voltage (applied signal voltage ΔV_i).

$$A_{V\text{-}ac} = \left[\frac{\Delta V_{ce}}{\Delta V_i}\right] \quad \text{or} \quad A_{V\text{-}ac} = \left[\frac{\Delta I_c \times R_o}{\Delta I_b \times R_i}\right] \quad \text{or} \quad A_{V\text{-}ac} = \beta_{ac} \times \text{Resistance Gain}$$

Also $A_V = g_m R_L$

3) **AC power gain:** It is the ratio of change in output power to the change in input power.

$$A_{P\text{-}ac} = \left[\frac{\Delta P_o}{\Delta P_i}\right] \quad \text{or} \quad A_{P\text{-}ac} = \left[\frac{\Delta V_{ce} \times \Delta I_c}{\Delta V_i \times \Delta I_b}\right] \quad \text{or} \quad A_{P\text{-}ac} = \beta_{ac}^2 \times \text{Resistance Gain}$$

4) **Transconductance:** It is the ratio of the small change in collector current (ΔI_c) to the corresponding change in the input voltage (base voltage (ΔV_b) at constant collector voltage.

$$g_m = \left[\frac{\Delta I_c}{\Delta V_b}\right]_{V_{ce}} \quad \text{or} \quad g_m = \frac{\beta_{ac}}{R_i}$$

Relation between α and β:

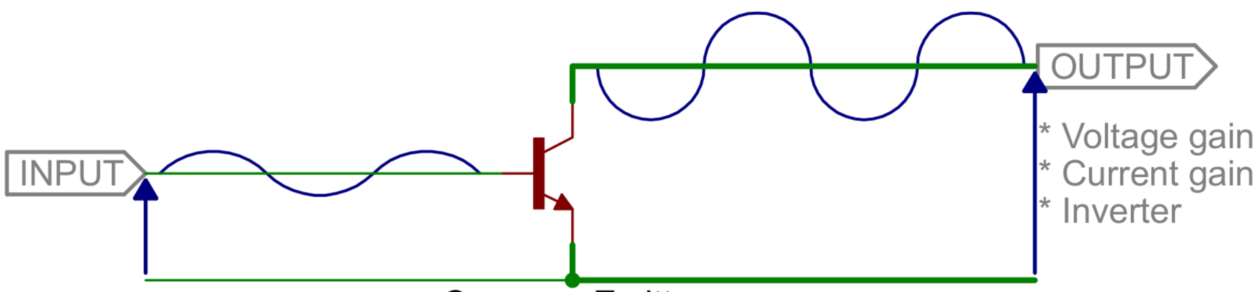
$$I_e = I_b + I_c$$

Dividing the equation by I_c, we get

$$\frac{I_e}{I_c} = \frac{I_b}{I_c} + 1$$

But $\alpha = \left[\frac{I_c}{I_e}\right]$ and $\beta = \left[\frac{I_c}{I_b}\right]$

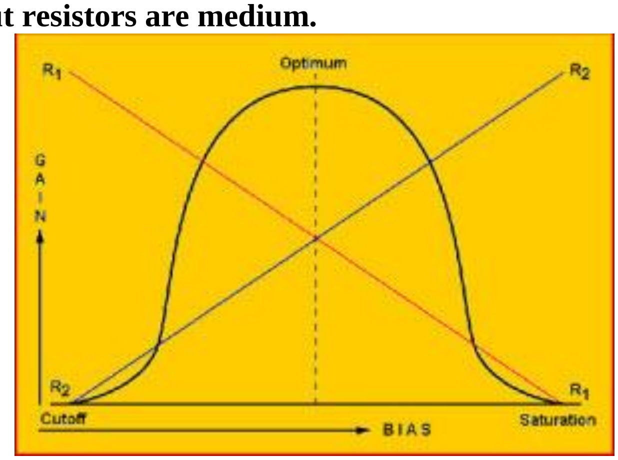
$$\therefore \quad \frac{1}{\alpha} = \frac{1}{\beta} + 1 \quad \text{or} \quad \boxed{\beta = \frac{\alpha}{1-\alpha}} \quad \text{and} \quad \boxed{\alpha = \frac{\beta}{1+\beta}}$$



Common Emitter

Characteristics of Common Emitter Amplifier

- voltage ,power gain is high in the common emitter amplifier
- There is a phase relationship of 180 degrees in input and output
- The **input and output resistors are medium.**



Characteristics Graph

Applications of Common Emitter Amplifier
Used in low-frequency voltage amplifiers, RF circuits and Low noise amplifiers

Advantages of Common Emitter Amplifier
1. The common emitter amplifier has a **low input impedance** and it is an inverting amplifier
2. The **output impedance** of this amplifier is high
3. This amplifier has highest power gain when combined with medium voltage and current gain
4. The current gain of the common emitter amplifier is high

Disadvantages of Common Emitter Amplifier
1. In the **high frequencies**, the common emitter amplifier **does not respond**
2. The voltage gain of this amplifier is **unstable**
3. The **output resistance** is **very high**
4. High thermal instability
5. High output resistance

Transistor Characteristics
It are the plots which represent the relationships between the **current and the voltages of a transistor in a particular configuration.** By considering the transistor configuration circuits to be analogous to two-port networks, they can be analyzed using the characteristic-curves which can be of the following types

Input Characteristics: These describe the changes in **input current with the variation in the values of input voltage** keeping the output voltage constant.

Output Characteristics: This is a plot of output **current versus output voltage** with constant input current.

Current Transfer Characteristics: This characteristic curve shows the variation of output current in accordance with the input current, keeping output voltage constant.

Common Base (CB) Configuration of Transistor
This configuration offers **low input impedance, high output impedance, high resistance gain and high voltage gain.**

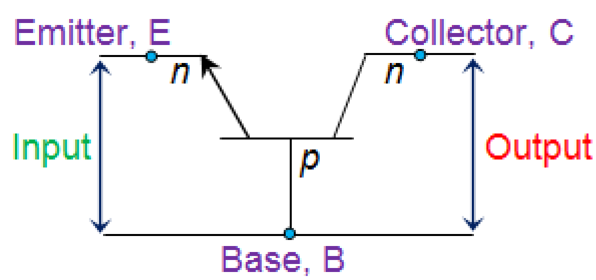


Figure 1 Common Base (CB) Configuration

Input Characteristics for CB Configuration of Transistor

Figure 2 shows the input characteristics of a CB configuration circuit which describes the variation of emitter current, IE with Base-Emitter voltage, VBE keeping Collector-Base voltage, VCB constant.

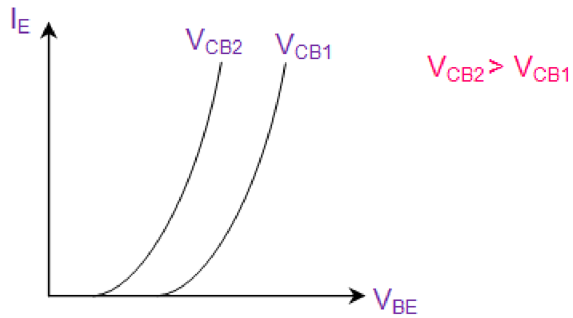


Figure 2 Input Characteristics for CB Configuration

Input resistance as

$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_E}\bigg|_{V_{CB}=constant}$$

Output Characteristics for CB Configuration of Transistor

The output characteristics of CB configuration (Figure 3) show the variation of collector current, IC with VCB when the emitter current, IE is held constant. From the graph shown, the output resistance can be obtained as

$$R_{out} = \frac{\Delta V_{CB}}{\Delta I_C}\bigg|_{I_E=constant}$$

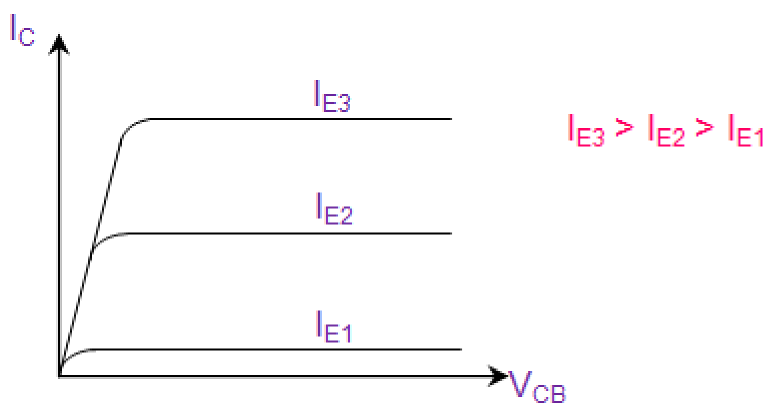


Figure 3 Output Characteristics for CB Configuration

Current Transfer Characteristics for CB Configuration of Transistor

Figure 4 shows the current transfer characteristics for CB configuration which illustrates the variation of IC with the IE keeping VCB as a constant. The resulting current gain has a value less than 1 and can be mathematically expressed as

$$\alpha = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}=constant}$$

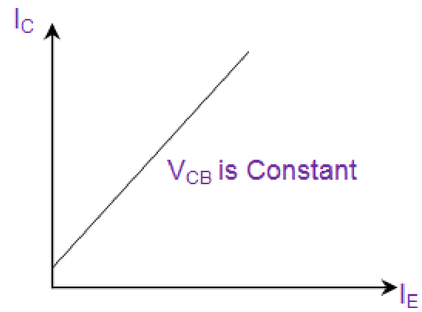


Figure 4 Current Transfer Characteristics for CB Configuration

Common Collector (CC) Configuration of Transistor

This transistor configuration has the collector terminal of the transistor common between the input and the output terminals (Figure 5) and is also referred to as emitter follower configuration. This offers high input impedance, low output impedance, voltage gain less than one and a large current gain.

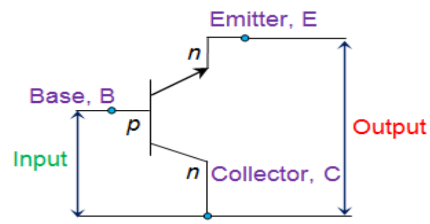


Figure 5 Common Collector (CC) Configuration

Input Characteristics for CC Configuration of Transistor

Figure 6 shows the input characteristics for CC configuration which describes the variation in IB in accordance with VCB, for a constant value of Collector-Emitter voltage, V_{CE}.

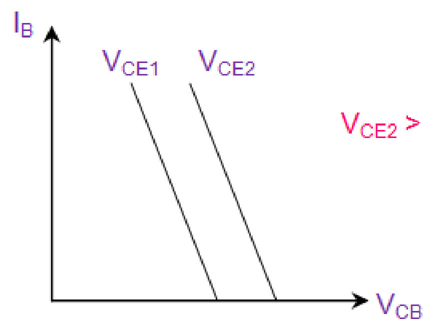


Figure 6 Input Characteristics for CC Configuration

Output Characteristics for CC Configuration of Transistor

Figure 7 shows the output characteristics for the CC configuration which exhibit the variations in IE against the changes in VCE for constant values of IB.

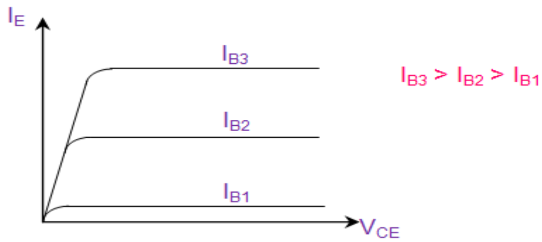


Figure 7 Output Characteristics for CC Configuration

Current Transfer Characteristics for CC Configuration of Transistor

This characteristic of CC configuration (Figure 8) shows the variation of IE with IB keeping VCE as a constant.

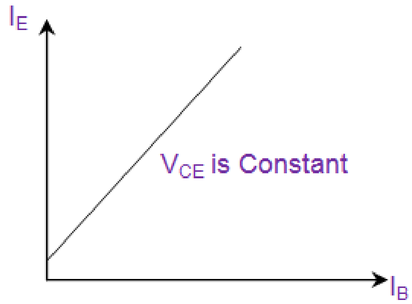


Figure 8 Current Transfer Characteristics for CC Configuration

Common Emitter (CE) Configuration of Transistor

In this configuration, the emitter terminal is common between the input and the output terminals as shown by Figure 9. This configuration offers medium input impedance, medium output impedance, medium current gain and voltage gain.

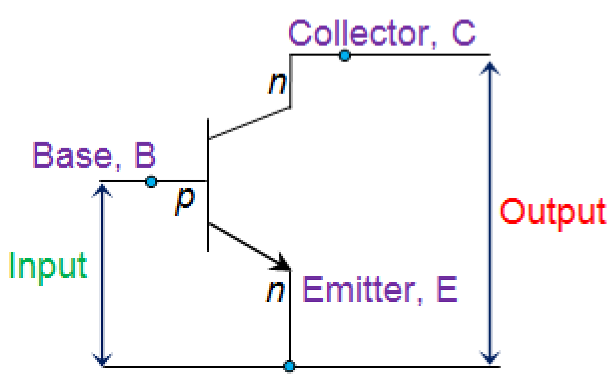


Figure 9 Common Emitter (CE) Configuration

Input Characteristics for CE Configuration of Transistor

Figure 10 shows the input characteristics for the CE configuration of transistor which illustrates the variation in IB in accordance with VBE when VCE is kept constant.

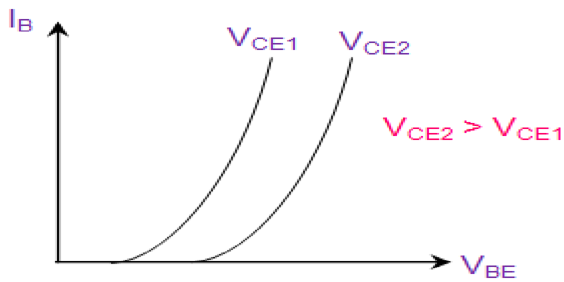


Figure 10 Input Characteristics for CE Configuration

From the graph shown, the input resistance of the transistor can be obtained as

$$R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}=constant}$$

Output Characteristics for CE Configuration of Transistor

The output characteristics of CE configuration (Figure 11) are also referred to as collector characteristics. This plot shows the variation in IC with the changes in VCE when IB is held constant. From the graph shown, the output resistance can be obtained as

$$R_{out} = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B=constant}$$

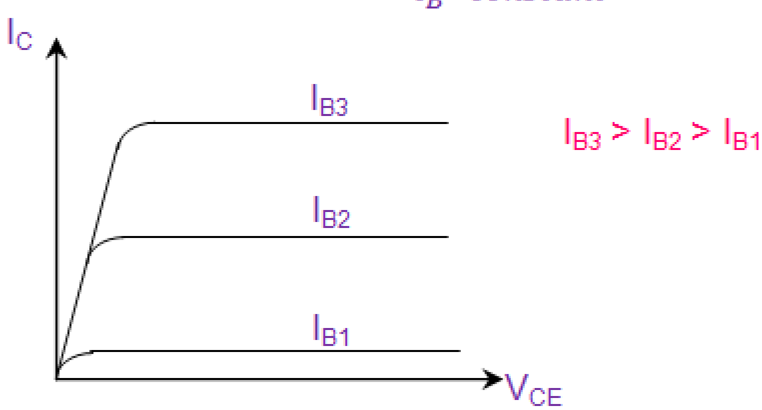


Figure 11 Output Characteristics for CE Configuration

Current Transfer Characteristics for CE Configuration of Transistor

This characteristic of CE configuration shows the variation of IC with IB keeping VCE as a constant. This can be mathematically given by

$$\beta = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=constant}$$

This ratio is referred to as common-emitter current gain and is always greater than 1.

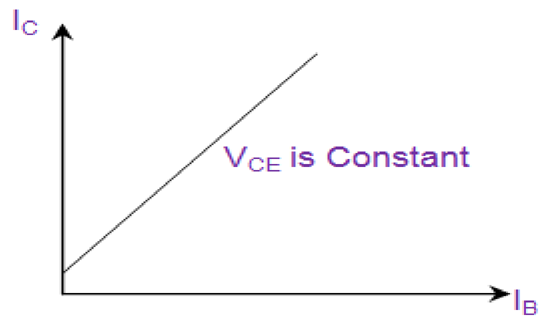


Figure 12 Transfer Characteristics for CE Configuration

Lastly, it is to be noted that although the characteristic curves explained are for **BJTs**, similar analysis holds good even in the case of **FETs**.

Blasting and biasing stability

Biasing of Bipolar Junction Transistor or BJT

It is the **process of applying external voltages to it**. In order to **use the BJT** for any application like amplification, the two junctions of the transistor **CB and BE should be properly biased according to the required application.** Depending on whether the two junctions of the transistor are forward or reverse biased, a transistor is capable of operating in three different modes.

Cutoff Mode of BJT

The BJT is fully off in this state. In the cutoff mode both the **base emitter as well as collector base junction is reverse biased.** The BJT is equivalent to an open switch in this mode.

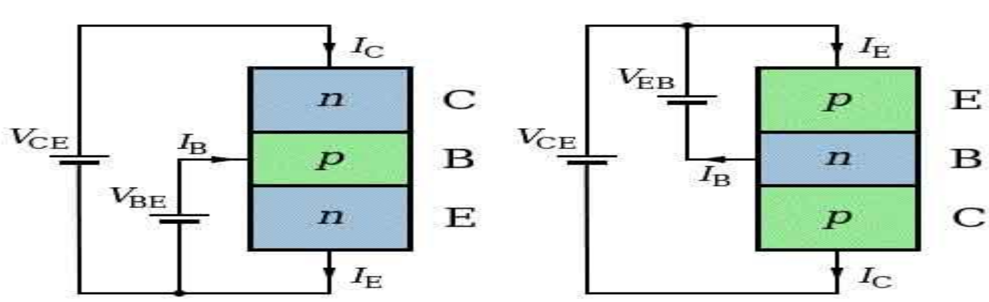
Saturation Mode of BJT

The transistor is fully on in this state. The CB as well as BE junctions are forward biased. The BJT operates like a closed switch in the saturation mode. If a BJT is in saturation mode than it should satisfy the following condition, $|\, I_B \,| \;\geq\; \left(\frac{|\, I_C \,|}{\beta_{DC}} \right)$

Where, βDC is common emitter current amplification factor or current gain.

Active Mode of BJT

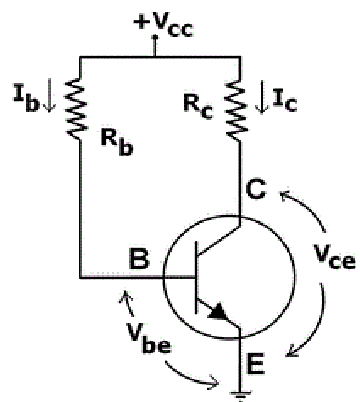
In order to use the transistor as an amplifier, it must be operated in the active mode. The BE junction is forward biased whereas the CB junction is reverse biased. Figure below shows both n-p-n and p-n-p transistors biased in the active mode of operation.



Biasing Circuits of BJT

To make the Q point stable different biasing circuits are tried. The Q point is also called as operating bias point, is the point on the DC load line (a load line is the graph of output current vs. output voltage in any of the transistor configurations) which represents the DC current through the transistor and voltage across it **when no ac signal is applied.**

Fixed Bias or Base Bias



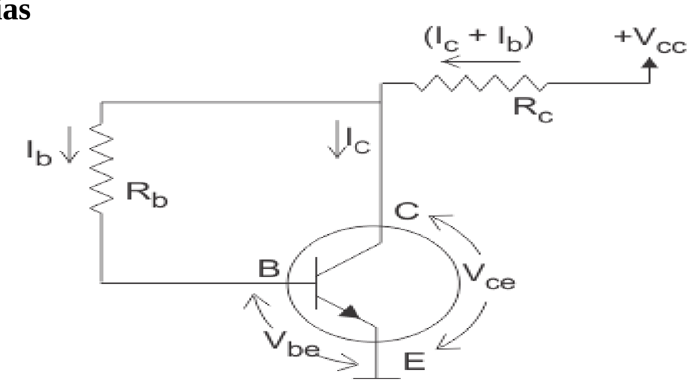
In this condition a **single power source is applied to the collector and base** of the transistor using only two **resistors**. Applying **KVL** to the circuit,

$$V_{CC} = I_B R_B + V_{BE}$$

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

Thus, by merely changing the value of the resistor the base current can be adjusted to the desired value. And by using the current gain (β) relationship, IC can also be found out accordingly. Hence the Q point can be adjusted just by changing the value of the resistor connected to the base.

Collector to Base Bias



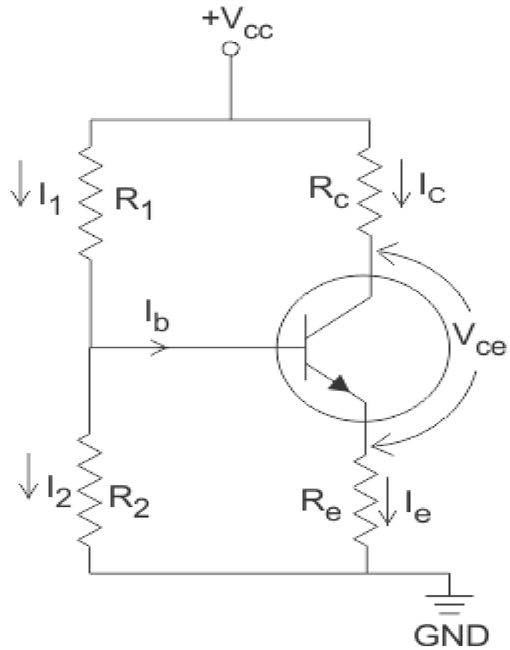
This connection is mostly used to stabilize the operating point against temperature changes. In this type, the base resistor is connected to the collector instead of connecting it to the supply. So any thermal runaway will induce IR drop in the collector resistor. The base current can be derived as,

$$I_b = \frac{V_{CC} - V_{BE}}{R_b + (\beta + 1)R_C}$$

If VBE kept constant and there is an increase in temperature, then the collector current increases. However, a larger collector current causes the voltage drop across the collector resistor to increase, which reduces the voltage across the base resistor. This will reduce the base current, hence resulting less collector current. Because an increase in collector current with temperature is opposed, the operating point is stable.

Self Bias or Voltage Divider Bias

The circuit diagram for self bias is shown below. This is the most widely used biasing circuit.



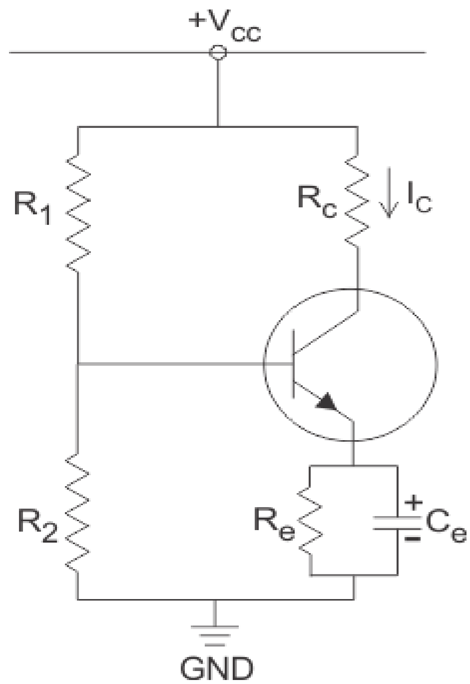
The **electrical resistances** R1 and R2 form a potential divider arrangement to apply a fixed **voltage** to the base. Consider only the base circuit, the approximate voltage across the base is

$$V_B = V_{R2} = \frac{V_{CC} \times R_2}{R_1 + R_2}$$

Consider only the collector circuit, the approximate emitter current will be,

$$I_E = \frac{(V_B - V_{BE})}{R_E}$$

In the above circuit, as the emitter resistor causes ac as well as DC feedback the AC voltage gain of the amplifier is reduced. This can avoided by connecting **a capacitor in parallel** with the emitter resistor as shown below.

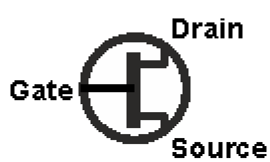


Field Effect Devices – MOSFET
FET history
The idea of the FET has been known for many years. It has some of its earliest foundations in a proposal made by **Lilienfield in 1926**, and to another paper by Heil in 1935.

What is a Field Effect Transistor?
The FET is based around the concept that **charge on a nearby object can attract charges within a semiconductor channel.**

The FET consists of a semiconductor channel **with electrodes** at either end referred to as the drain and the source. **A control electrode called the gate is placed in very close proximity to the channel so that its electric charge is able to affect the channel**

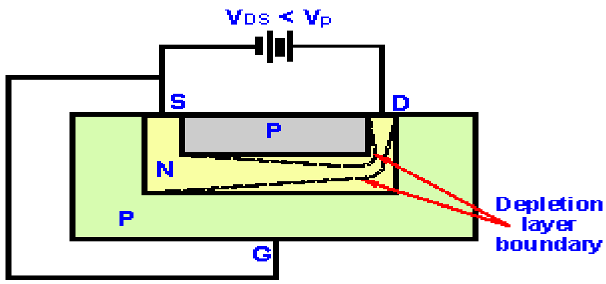
In this way, the gate of the FET controls the flow of carriers (electrons or holes) flowing from the source to drain. It does this by controlling the size and shape of the conductive channel. The semiconductor channel where the current flow occurs may be either P-type or N-type. This gives rise to two types or categories of FET known as P-Channel and N-Channel FETs.



Junction FET circuit symbol

The electric field to control the current is applied to a third electrode known as a gate. As it is only the electric field that controls the current flowing in the channel, the device is said to be voltage operated and it has a high input impedance, usually many megohms. This can be a distinct advantage over the bipolar transistor that is current operated and has much lower input impedance.

The external field on the gate may serve to deplete the channel of carriers, in which case the FET is known as a depletion mode FET, or it may serve to enhance the carriers in the channel when it is known as an enhancement mode FET.

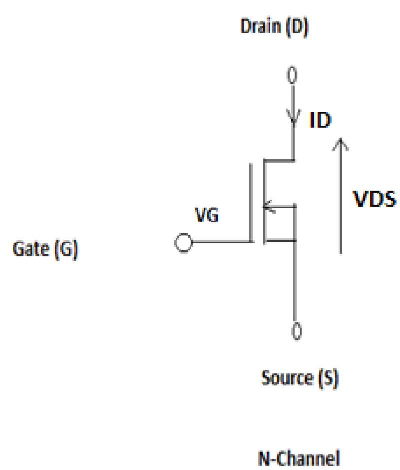
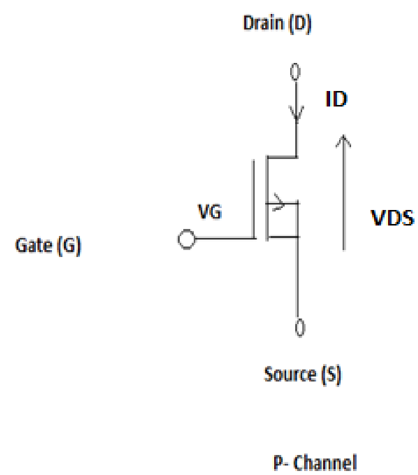


Junction FET working below saturation

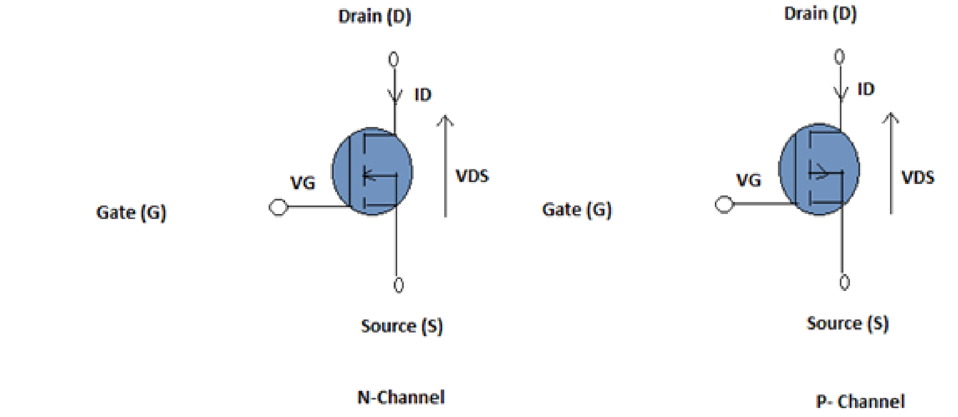
What is MOSFET with Working? MOSFET as a Switch

Introduction

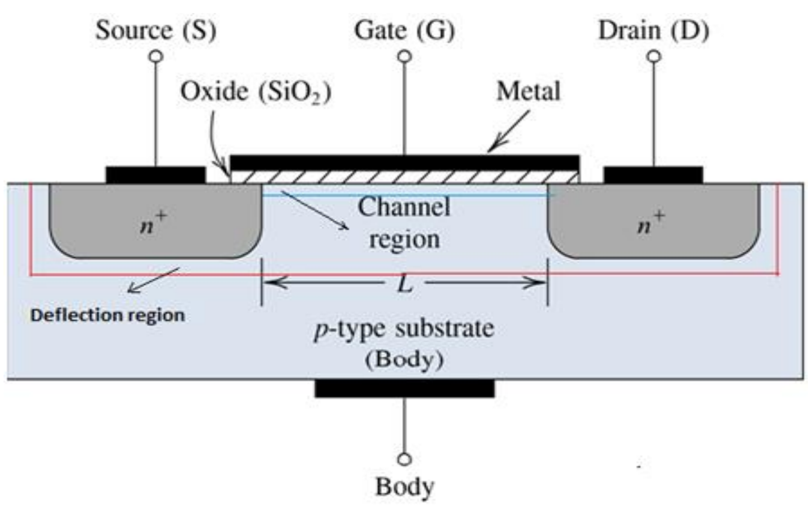
The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes. The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits.

The MOSFET can function in two ways: 1. Depletion Mode. 2. Enhancement Mode.	
Depletion Mode: When there is no voltage on the gate, the channel shows its maximum conductance. As the voltage on the gate is either positive or negative, the channel conductivity decreases. For example	 

Enhancement mode:
When there is no voltage on the gate the device does not conduct. More is the voltage on the gate, the better the device can conduct.



Working Principle of MOSFET:
The aim of the MOSFET is to be able to control the voltage and current flow between the source and drain. It works almost as a switch. The working of MOSFET depends upon the MOS capacitor. The MOS capacitor is the main part of MOSFET. The semiconductor surface at the below oxide layer which is located between source and drain terminal. It can be inverted from p-type to n-type by applying a positive or negative gate voltages respectively. When we apply the positive gate voltage the holes present under the oxide layer with a repulsive force and holes are pushed downward with the substrate. The depletion region populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage, a hole channel will be formed under the oxide layer.



MOSFET Block Diagram

Electronics and Instrumentation

Amplifiers
It is an electronic device that **increases the voltage**, **current**, or **power** of a **signal**. Amplifiers are used in **wireless** communications and broadcasting, and in **audio** equipment of all kinds. They can be categorized as either **weak-signal amplifiers or power amplifiers.**

Weak-signal amplifiers are **used primarily in wireless receivers.** They are also employed in acoustic pickups, audio tape players, and compact disc players. A weak-signal amplifier is designed to deal with exceedingly small input signals, in some cases measuring only a few nanovolts (units of 10-9 volt). Such amplifiers must generate minimal internal noise while increasing the signal voltage by a large factor. The most effective device for this application is the field-effect transistor. The specification that denotes the effectiveness of a weak-signal amplifier is sensitivity, defined as the number of microvolts (units of 10-6 volt) of signal input that produce a certain ratio of signal output to noise output (usually 10 to 1).

Power amplifiers are used in wireless transmitters, broadcast transmitters, and hi-fi audio equipment. The most frequently-used device for power amplification is the **bipolar transistor.** However, **vacuum tubes**, once considered obsolete, are becoming increasingly popular, especially among musicians. Many professional musicians believe that the vacuum tube (known as a "valve" in England) provides superior fidelity.

Two important considerations in power amplification are power output and efficiency. Power output is measured in watts or kilowatts. Efficiency is the ratio of signal power output to total power input (wattage demanded of the power supply or battery).

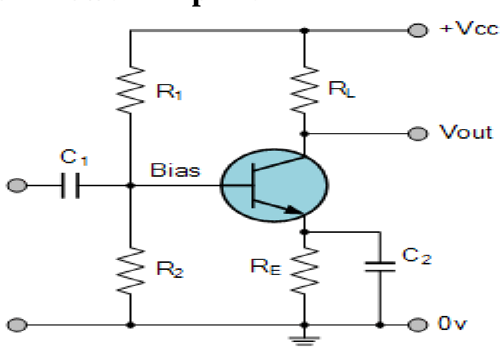
Amplifier Characteristics
Bandwidth: The frequency range at which the amplifier can operate.
Noise: The amount of unwanted extra information included in the output.
Skew Rate: The maximum rate of change of output.
Gain: Perhaps the most important, the ratio between the magnitudes of input and output signals.
Stability: The ability to provide constant and reliable output.
Linearity: The degree of proportionality between input and output signals.
Efficiency: It is the ratio between the output power and power consumed.
Output Dynamic Range: Ratio between the largest and smallest useful output levels.

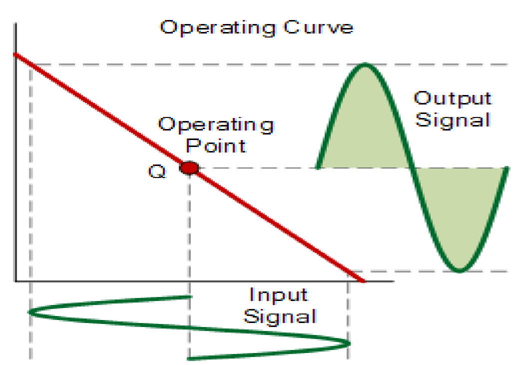
Types of Amplifiers (Based on input and output parameters)
Current Amplifier: As the name suggests, an amplifier that makes the given input current higher. It is characterized by a low input impedance and high output impedance.
Voltage Amplifier: An amplifier that amplifies given voltage for a larger voltage output. It is characterized by a high input impedance and low output impedance.
Transconductance Amplifier: An amplifier that changes **output current according to changing input voltage.**
Transresistance Amplifier: An amplifier that **changes output voltage** according to changing input current. It is also known as a current-to-voltage converter.

Power Amplifiers: It refers to the amount of power provided by the power supply circuit or the amount of power delivered to the load. It is usually used in the last output stages of a circuit. Examples include: audio power amplifiers, servo motor controllers, push-pull amplifers and RF power amplifiers. Again, we'll look at the classifications of power amplifiers specifically in a little bit, since they're very important.
Operational Amplifiers (Op-Amps): An op-amp is an integrated circuit that acts as a voltage amplifier, and has differential input. It has a positive and negative input, but a single output with very high gain. Originally, op-amps were created using valves.
Valve (or) Vacuum Tube Amplifiers: An amplifier that uses vacuum tubes to provide an increased power or voltage output is known as a valve (or) vacuum tube amplifier. As mentioned above, op-amps were originally of the valve type, but were replaced by ICs once they got cheaper, in smaller applications at least. In high power applications, they're still in use because of their cost effectiveness and output quality. They are used in radar, military, high power radio and UHF transmitter applications.
Transistor Amplifiers: It specially to engineering students, a transistor amplifier is a multi configuration high output amplifier that uses transistors as the working base. These include bipolar junction transistors (BJTs) and metal oxide semiconductor field-effect transistors (MOSFETs).
Klystron: A special type of linear beam vacuum tube, used as an amplifier in high radio frequencies. It is highly precise and used in large scale operations, usually comes under Microwave amplifiers.
Instrument Amplifiers: Used to amplify sound, voice or music. Used mainly in musical instrument applications.
Distributed Amplifiers: Amplifiers that use transmission lines to temporarily split the input and amplify each segment individually are called distributed amplifiers. They're commonly found in oscilloscopes.
These are just a few types of amplifiers in use right now, and it's pretty obvious that each of them has an area of specialization, more or less. There are a vast number of applications in the world, and there's an amplifier for almost all of them.

Types of Power Amplifiers
classified on the basis of the proportion of the input cycle during which the amplifier is giving an output. The proportion of the active input cycle is also known as conduction angle. For example, a 360 degrees conduction angle means that the device is always on, a conduction angle of 180 degrees means that the device is on only for half of each cycle.

Class A Power Amplifier

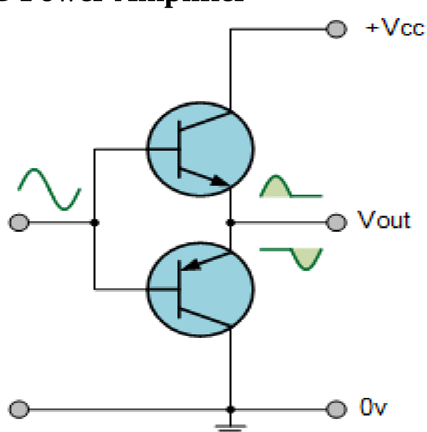


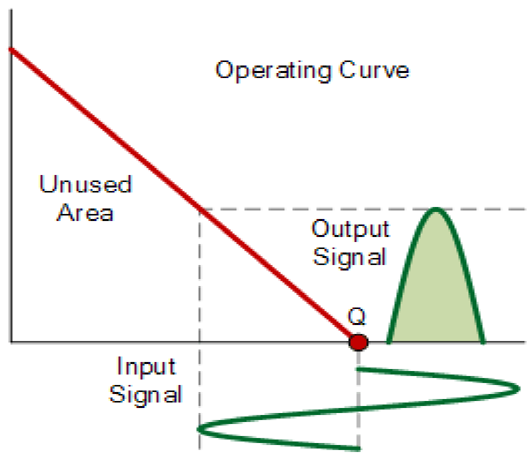


An amplifier that conducts during the full cycle, or has a conducting angle of 360 degrees is known as a Class A power amplifier. It is the simplest and most common type of power amplifier, because of low signal distortion levels. It has its fair share of disadvantages though, and is generally not used in high power applications. Some of its characteristics are:

- Low signal distortion levels
- Simple design
- The device is always conducting due to amplifying element bias
- No turn on time or charge storage problems
- Quite stable
- Highest linearity
- Low efficiency due to being on all the time, around the vicinity of 25-50%
- High heat output during operation

Class B Power Amplifier

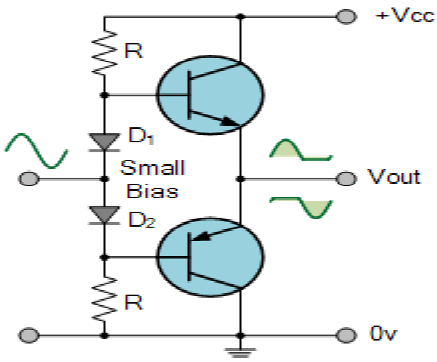


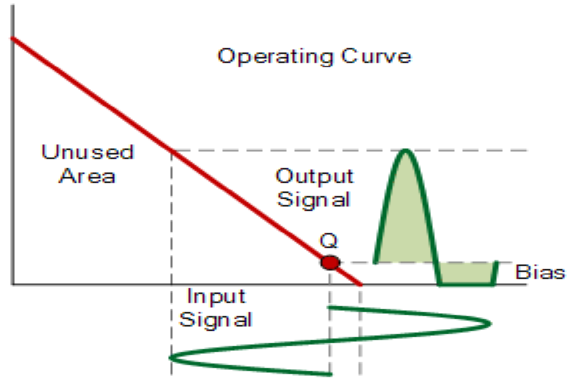


Class B Power Amplifiers, unlike Class A, work for only half of each input cycle, which means they have a conducting angle of 180 degrees. In simple words, these amplifiers amplify only half of the input cycle. On paper that probably sounds unusable, but in reality, it's quite different. A Class B amplifier consists of a positive and negative transistor, which run alternatively, amplifying the positive and negative cycle respectively, which in the end is combined to form a full output cycle. It's a more efficient design, and has its own set of advantages and disadvantages compared to the Class A power amplifier. It's characterized by:

- Uses 2 complementary transistors, one each for the positive and negative cycle
- Much higher efficiency, around 75-78.5%
- Lesser heat output
- Stable and reliable
- Requires at least 0.7 V to start conducting, which means anything under it doesn't register, so cannot be used for precise applications
- Combines 2 half cycles to form one full cycle

Class AB Power Amplifier

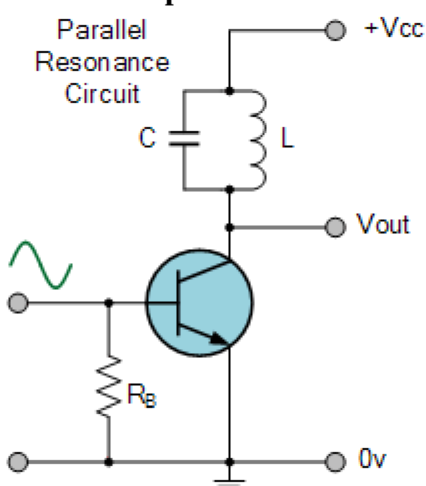


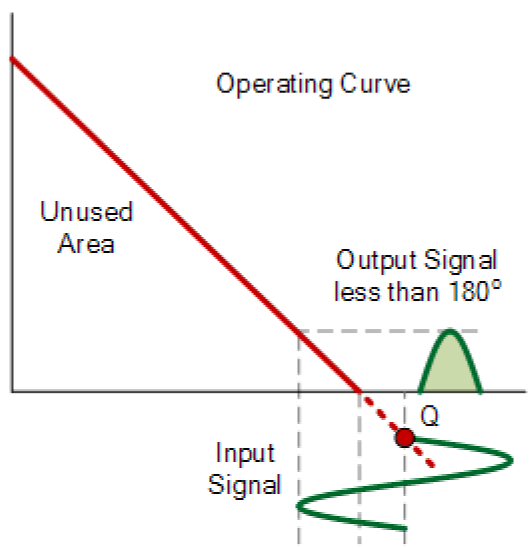


A Class AB Power Amplifier is, as the name suggests, a mix of Class A and Class B power amplifiers. Like the Class B amplifier, it also uses 2 conducting elements (transistors), but they both run at the same time. This eliminates the 'dead zone' from -0.7 V to + 0.7 V seen in the Class B power amplifier. But in this case, while each transistor conducts for more than a half cycle, they conduct less than a full cycle completely. So the conduction angle is somewhere around 180 degrees and 360 degrees, commonly shown as 270 degrees in some cases. Here are it's characteristics:

- Uses 2 transistors that work together
- Each transistor is active for slightly less than a full cycle but more than a half cycle
- Combines Class A and Class B characteristics
- No crossover distortion
- Fairly efficient, at around 50-60%
- Most common audio amplifier design

Class C Power Amplifier





A Class C Power Amplifier is something of an oddity compared to the other 3 types listed above. It's the most efficient, but has the lowest operating cycle and linearity. Since it's heavily biased, it stays on for less than half of an input cycle, and thus has a conducting angle somewhere around the vicinity of 90 degrees. This result in the high efficiency mentioned above, but also causes high distortion in the output signal, so Class C amplifiers are usually not used as audio amplifiers. They're used in certain radio frequency applications where efficiency is key. Its most important characteristics are:

- Least linear among power amplifiers
- Very high efficiency of around 80-90%
- High output distortion
- Two operating modes, tuned and un-tuned
- Low power dissipation

Class D Power Amplifier

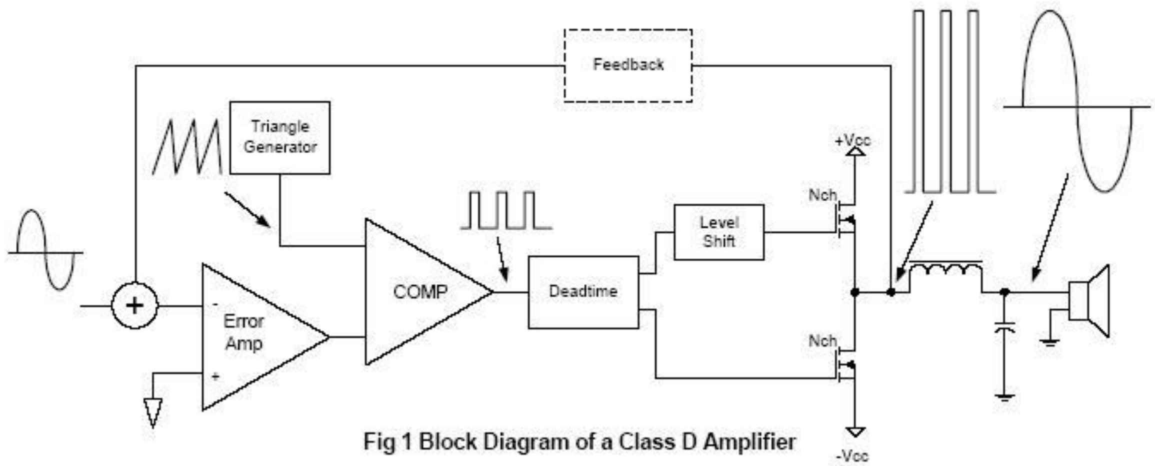
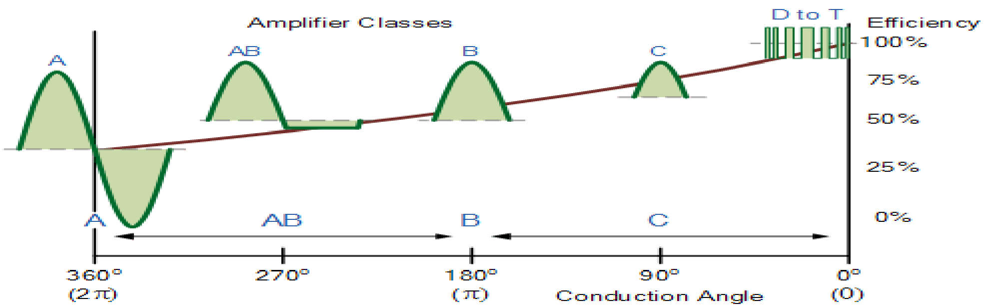


Fig 1 Block Diagram of a Class D Amplifier

And finally, we have Class D Power Amplifiers, which sometimes aren't considered among the 4 mentioned above. It's a non-linear switching amplifier in which the two transistors function as switches instead of linear gain devices. It converts the analog signal into digital via pulse width modulation, pulse density modulation or something similar before being amplified. The end result is a cycled output with high efficiency and gain, without too much distortion. Although originally used to control motors, they are now used as audio power amplifiers as well. Contrary to popular belief, the 'D' in the name doesn't stand for digital, because the converted signal is pulse width modulated analog, and not pulse width modulated digital. It is characterized by:

- High efficiency, can theoretically be 100%
- Low power dissipation
- Low power consumption
- More complex than other types of power amplifiers
- Precise and accurate output

And that's it about amplifiers! We hope that the types of amplifiers as well as the types of power amplifiers are clearer now, and if you have any questions about the information, feel free to comment below!



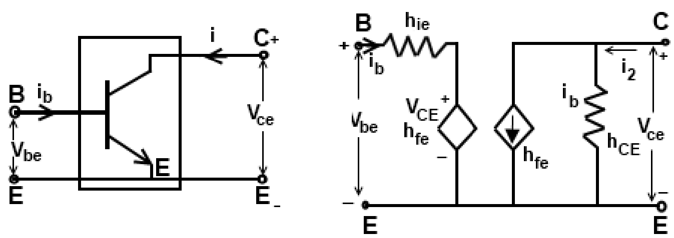
Hybrid Equivalent For CE Transistor

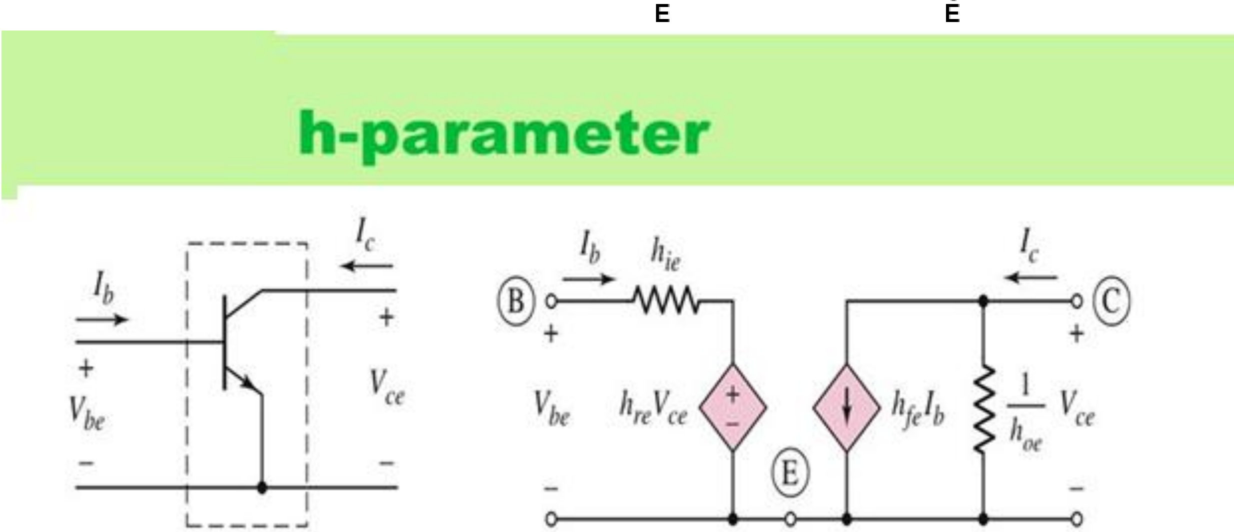
The figure shows the transistor connected in common emitter configuration and the figure also shows the hybrid equivalent circuit of such a transistor.

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

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

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





(a)
Common-emitter transistor

(b)
h-parameter model of C-E BJT

Hybrid expression

Expression can be obtained from the general hybrid formulas derived in this article Hybrid Equivalent of Transistor by adding a second subscript letter 'e' (which stands for common emitter) with the h-parameters and are as discussed below.

Current Gain

It is given by the relation,

$A_i = -(h_{fe}/(1 + h_{oe}.r_L))$

Where r_L is the A.C load resistance. Its value is equal to the parallel combination of resistance R_c and R_L. Since h_{fe} of a transistor is a positive number, therefore A_i of a common emitter amplifier is negative.

Input Resistance

The resistance looking into the amplifier input terminals (i.e. base of a transistor) is given by the relation,

$R_i = h_{ie} + h_{re}.A_i.r_L = h_{ie} - ((h_{re}.h_{fe})/(h_{oe} + (1/r_L)))$

The input resistance of the amplifier stage (called stage input resistance R_{is}) depends upon the biasing arrangement. For a fixed bias circuit, the stage input resistance is,

$R_{is} = R_i//R_B$

If the circuit has no biasing resistances, then $R_{is} = R_i$.

Voltage Gain

It is given by the relation,

$A_v = A_i.r_1/R_i$

Since the current gain (A_i) of a common emitter amplifier is negative, therefore the voltage gain (A_v) is also negative.

It means that there is a phase difference of 180^o between the input and output. In other words, the input signal is inverted at the output of a common emitter amplifier. The voltage gain, in terms of h-parameters, is given by the relation.

$A_v = h_{fe}.r_1/(h_{ie} + \Delta h.r_L)$

Where

$\Delta h = h_{ie}.h_{oe} - h_{re}.h_{fe}$

Output Resistance

The resistance looking into the amplifier output terminals is given by the relation,

$R_o = (R_S + h_{ie})/(R_S.h_{oe} + \Delta h)$

Where

R_S = Resistance of the source, and

$\Delta h = h_{ie}.h_{oe} - h_{re}.h_{fe}$

The output resistance of the stage,

$R_{oe} = R_o // r_L$

Overall Voltage Gain

It is given by the relation,

$A_V = (A_V.R_{is})/(R_S + R_{is})$

Current and Voltage Gain
Because amplifiers have the **ability to increase the magnitude of an input signal**, it is useful to be able to rate an amplifier's amplifying ability in terms of an output/input ratio. The technical term for an amplifier's output/input magnitude ratio is gain. As a ratio of equal units (power out / power in, voltage out / voltage in, or current out / current in), **gain is naturally a unitless measurement. Mathematically, gain is symbolized by the capital letter "A".**

For example, if an amplifier takes in an AC voltage signal measuring 2 volts RMS and outputs an AC voltage of 30 volts RMS, it has an AC voltage gain of 30 divided by 2, or 15:

$$A_V = \frac{V_{output}}{V_{input}}$$

$$A_V = \frac{30\ V}{2\ V}$$

$$A_V = 15$$

Correspondingly, if we know the gain of an amplifier and the magnitude of the input signal, we can calculate the magnitude of the output. For example, if an amplifier with an AC current gain of 3.5 is given an AC input signal of 28 mA RMS, the output will be 3.5 times 28 mA, or 98 mA:

$$I_{output} = (A_I)(I_{input})$$

$$I_{output} = (3.5)(28\ \text{mA})$$

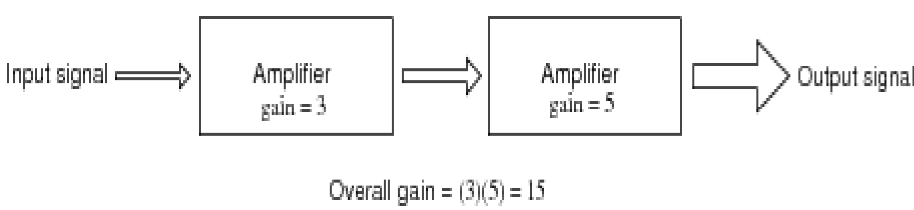
$$I_{output} = 98\ \text{mA}$$

Electrical amplifier gains may be expressed in terms of voltage, current, and/or power, in both AC and DC. A summary of gain definitions is as follows. The triangle-shaped "delta" symbol (Δ) represents change in mathematics, so "ΔVoutput / ΔVinput" means "change in output voltage divided by change in input voltage," or more simply, "AC output voltage divided by AC input voltage":

	DC gains	AC gains
Voltage	$A_V = \frac{V_{output}}{V_{input}}$	$A_V = \frac{\Delta V_{output}}{\Delta V_{input}}$
Current	$A_I = \frac{I_{output}}{I_{input}}$	$A_I = \frac{\Delta I_{output}}{\Delta I_{input}}$
Power	$A_P = \frac{P_{output}}{P_{input}}$	$A_P = \frac{(\Delta V_{output})(\Delta I_{output})}{(\Delta V_{input})(\Delta I_{input})}$
	$A_P = (A_V)(A_I)$	

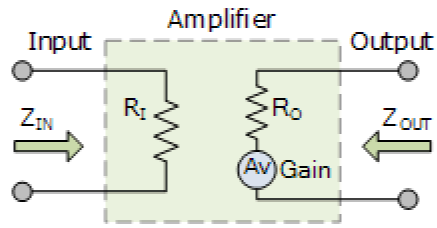
Δ = "change in . . ."

If multiple amplifiers are staged, their respective gains form an overall gain equal to the product (multiplication) of the individual gains. (Figure below) If a 1 V signal were applied to the input of the gain of 3 amplifier in Figure below a 3 V signal out of the first amplifier would be further amplified by a gain of 5 at the second stage yielding 15 V at the final output.



The gain of a chain of cascaded amplifiers is the product of the individual gains

Input and Output Impedance of a Amplifier
Input Impedance of an Amplifier
The Input Impedance of an amplifier defines its input characteristics with regards to current and voltage looking into the amplifiers input terminals



Input Impedance, Zin or Input Resistance as it is also called, is an important parameter in the design of a transistor amplifier and as such allows amplifiers to be characterized according to their effective input and output impedances as well as their power and current ratings.

An amplifiers impedance value is particularly important for analysis especially when cascading individual amplifier stages together one after another to minimize distortion of the signal.

Amplifiers can have **high input impedance, low output impedance,** and virtually any arbitrary gain, but were amplifiers input impedance is lower than desired, the output impedance of the previous stage can be adjusted to compensate or if this is not possible then buffer amplifier stages may be needed.

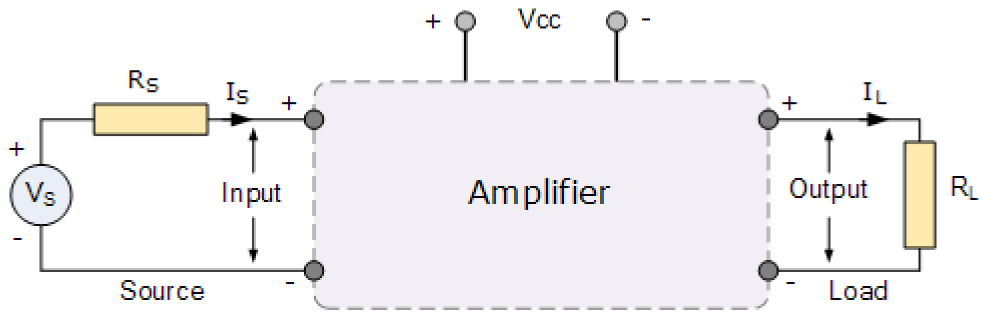
In addition to voltage amplification (Av), an amplifier circuit must also have current amplification (Ai). Power amplification (Ap) can also be expected from an amplifier circuit. But as well as having these three important characteristics, an amplifier circuit must also have other characteristics like high input impedance (Zin), low output impedance (Zout) and some degree of bandwidth, (Bw). Either way, the "perfect" amplifier will have infinite input impedance and zero output impedance.

When looking from the outside in, these terminals have input impedance, Zin and an output impedance, Zout. **The input and output impedance of an amplifier is the ratio of voltage to current flowing in or out of these terminals. The input impedance may depend upon the source supply feeding the amplifier while the output impedance may also vary according to the load impedance, RL across the output terminals.**

The input signals being amplified are usually alternating currents (AC) with the amplifier circuit representing a load Z to the source. The input impedance of an amplifier can be tens of ohms, (Ohms Ω's) to a few thousand ohms, (kilo-ohms kΩ's) for bipolar based transistor circuits up to millions of ohms, (Mega-ohms MΩ's) for FET based transistor circuits.

When a signal source and load are connected to an amplifier, the corresponding electrical properties of the amplifier circuit can be modeled as shown.

Output and Input Impedance Model



Where, VS is the signal voltage, RS is the internal resistance of the signal source, and RL is the load resistance connected across the output. We can expand this idea further by looking at how the amplifier is connected to the source and load.

When an amplifier is connected to a signal source, the source "sees" the input impedance, Zin of the amplifier as a load. Likewise, the input voltage, Vin is what the amplifier sees across the input impedance, Zin. Then the amplifiers input can be modeled as a simple voltage divider circuit.

Frequency Response

Amplifiers and filters are widely used electronic circuits that have the properties of amplification and filtration, hence their names.

Amplifiers produce gain while **filters alter the amplitude and/or phase characteristics of an electrical signal with respect to its frequency. As these amplifiers and filters use resistors, inductors, or capacitor networks (RLC) within their design, there is an important relationship between the use of these reactive components and the circuit's frequency response characteristics.**

When dealing with **AC circuits** it is assumed that they **operate at a fixed frequency**, for example either 50 Hz or 60 Hz. But the response of a linear AC circuit can also be examined with an AC or sinusoidal input signal of a constant magnitude but **with a varying frequency such as those found in amplifier and filter circuits. This then allows such circuits to be studied using frequency response analysis.**

Frequency Response of an electric or electronics circuit **allows us to see exactly how the output gain (known as the magnitude response) and the phase (known as the phase response) changes at a particular single frequency, or over a whole range of different frequencies from 0Hz,** (d.c.) to many thousands of mega-hertz, (MHz) depending upon the design characteristics of the circuit.

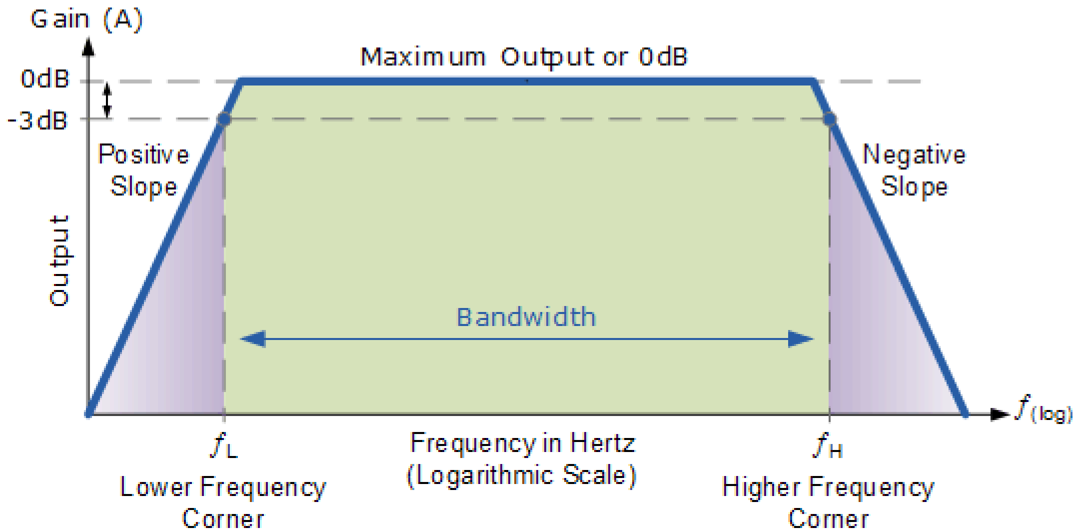
Generally, the frequency response analysis of a circuit or system is shown by plotting its **gain, that is the size of its output signal to its input signal,** Output/Input against a frequency scale over which the circuit or system is expected to operate. Then by knowing the circuits gain, (or loss) at each frequency point helps us to understand how well (or badly) the circuit can distinguish between signals of different frequencies.

The frequency response of a given frequency dependent circuit can be displayed as a graphical sketch of magnitude (gain) against frequency (f). **The horizontal frequency axis is usually plotted on a logarithmic scale while the vertical axis representing the voltage output or gain, is usually drawn as a linear scale in decimal divisions.** Since a systems gain can be both positive or negative, the y-axis can therefore have both positive and negative values.

In Electronics, the Logarithm, or "log" for short is defined as the power to which the base number must be raised to get that number.

Graphical representations of frequency response curves are called Bode Plots and as such Bode plots are generally said to be a semi-logarithmic graphs because one scale (x-axis) is logarithmic and the other (y-axis) is linear (log-lin plot) as shown.

Frequency Response Curve



Then we can see that the frequency response of any given circuit is the variation in its behaviour with changes in the input signal frequency as it shows the band of frequencies over which the output (and the gain) remains fairly constant. **The range of frequencies either big or small between fL and fH is called the circuit's bandwidth. So from this we are able to determine at a glance the voltage gain (in dB) for any sinusoidal input within a given frequency range.**

Bode diagram is a logarithmic presentation of the frequency response. Most modern audio amplifiers have a flat frequency response as shown above over the whole audio range of frequencies from 20 Hz to 20 kHz. **This range of frequencies, for an audio amplifier is called its Bandwidth, (BW) and is primarily determined by the frequency response of the circuit.**

Frequency points fL and fH relate to the lower corner or cut-off frequency and the upper corner or cut-off frequency points respectively were the circuits gain falls off at high and low frequencies. These points on a frequency response curve are known commonly as the -3dB (decibel) points. So the bandwidth is simply given as:

$$\text{Bandwidth, (BW)} = f_H - f_L$$

The decibel, (dB) which is 1/10th of a bel (B), is a common non-linear unit for measuring gain and is defined as 20log10(A) where A is the decimal gain, being plotted on the y-axis.

Therefore the amount of output power delivered to the load is effectively "halved" at the cut-off frequency and as such the bandwidth (BW) of the frequency response curve can also be defined as the range of frequencies between these two half-power points.

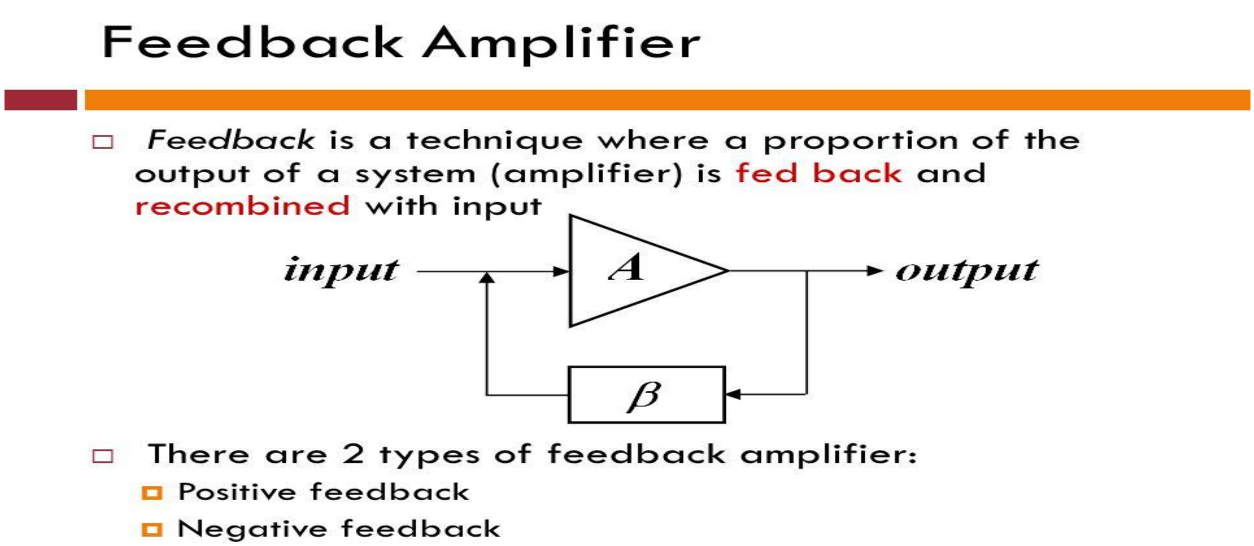
Frequency Response Summary

In this tutorial we have seen how the range of frequencies over which an electronic circuit operates is determined by its **frequency response**. The frequency response of a device or a circuit describes its operation over a specified range of signal frequencies by showing how its gain, or the amount of signal it lets through changes with frequency. Bode plots are graphical representations of the circuits frequency response characteristics and as such can be used in solving design problems. Generally, the circuits gain magnitude and phase functions are shown on separate graphs using logarithmic frequency scale along the x-axis.

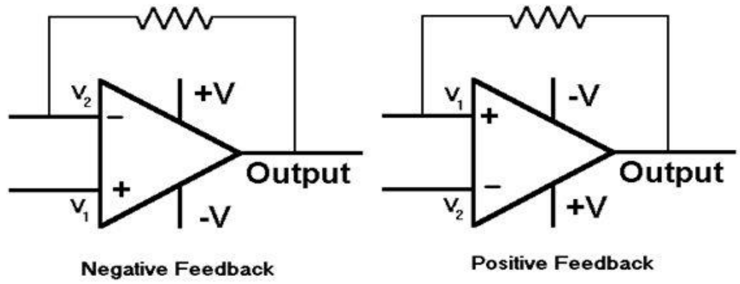
Bandwidth is the range of frequencies that a circuit operates at in between its upper and lower cut-off frequency points. These cut-off or corner frequency points indicate the **frequencies at which the power associated with the output falls to half its maximum value.** These half power points corresponds to a fall in gain of 3dB (0.7071) relative to its maximum dB value.

Most amplifiers and filters have a flat frequency response characteristic in which the bandwidth or pass band section of the circuit is flat and constant over a wide range of frequencies. Resonant circuits are designed to pass a range of frequencies and block others. They are constructed using resistors, inductors, and capacitors whose reactances vary with the frequency, their frequency response curves can look like a sharp rise or point as their bandwidth is affected by resonance which depends on the Q of the circuit, as a higher Q provides a narrower bandwidth.

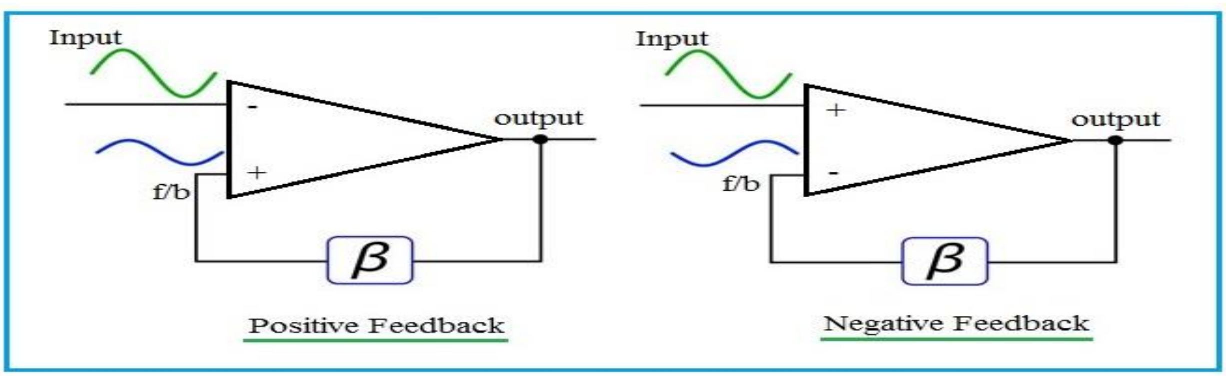
Concept of feedback amplifiers



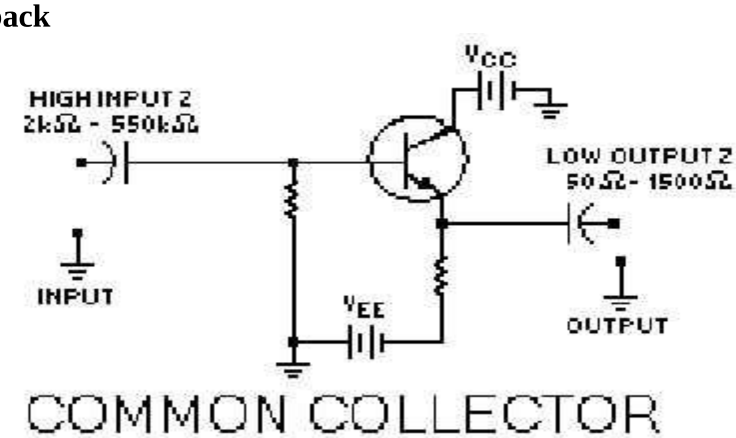
Feedback



- Negative Feedback
  - As information is fed back, the output becomes more stable. Output tends to stay in the "linear" range. The linear range is when $V_{out}=A(V_1-V_2)$ vs. being in saturation.
  - Examples: cruise control, heating/cooling systems
- Positive Feedback
  - As information is fed back, the output destabilizes. The op-amp tends to saturate.
  - Examples: Guitar feedback, stock market crash
  - Positive feedback was used before high gain circuits became available.

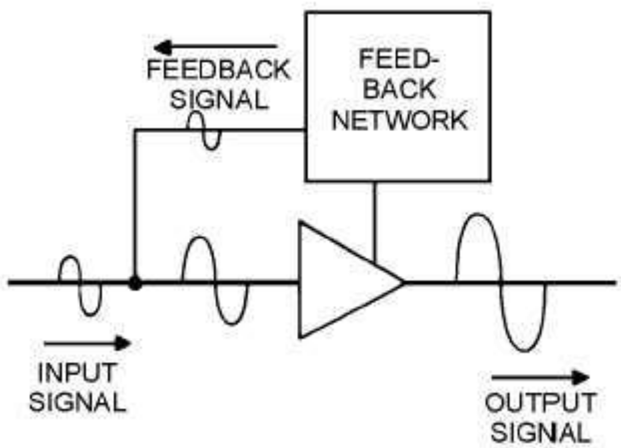


Regenerative feedback



FEEDBACK is the process of coupling a portion of the output signal back to the input of anamplifier.

POSITIVE (REGENERATIVE) FEEDBACK is provided when the feedback signal is in phasewith the input signal. **Positive feedback** increases the gain of an amplifier.



NEGATIVE (DEGENERATIVE) FEEDBACK is provided when the feedback signal is 180^o outof phase with the input signal. Negative feedback decreases the gain of an **amplifier** but improves fidelityand may increase the **frequency response** of the amplifier.

Conditions for Oscillations
What is an Oscillator
An oscillator provides a source of repetitive A.C. signal across its output terminals without needing any input (except a D.C. supply). The signal generated by the oscillator is usually of constant amplitude. The wave shape and amplitude are determined by the design of the oscillator circuit and choice of component values. The frequency of the output wave may be fixed or variable, depending on the oscillator design.

Types of Oscillator

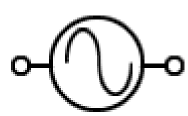
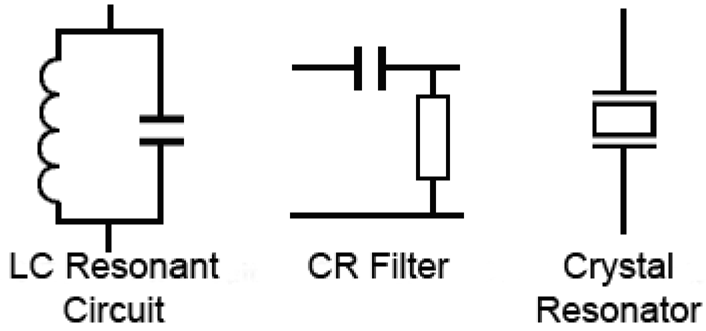


Fig. 1.0.1 Oscillator (AC Source) Circuit Symbol

Oscillators may be classified by the type of signal they produce.
1. SINE WAVE OSCILLATORS produce a sine wave output.
2. RELAXATION OSCILLATORS and **ASTABLE MULTIVIBRATORS** produce Square waves and rectangular pulses.
3. SWEEP OSCILLATORS produce sawtooth waves.

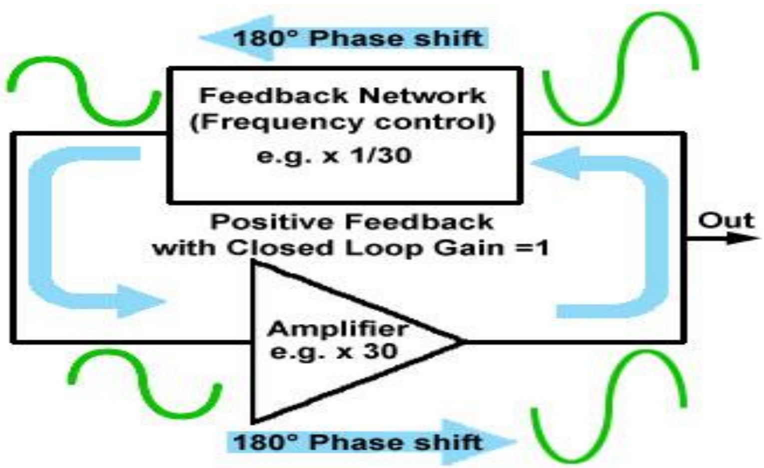
Sine Wave Oscillators



Inductors and capacitors are combined in a resonating circuit that produces a very good shape of sine wave and has quite good frequency stability.

An alternative name for this type of oscillator is an "astable multivibrator", this name comes from the fact that they contain more than one oscillating element. There are basically two oscillators, i.e. "vibrators", each feeding part of its signal back to the other, and the output changes from a high to a low state and back again continually, i.e. it has no stable state, hence it is astable. Relaxation oscillators can be built using several different designs and can work at many different frequencies. Astables may typically be chosen for such tasks as producing high frequency digital signals. They are also used to produce the relatively low frequency on-off signals for flashing lights.

Oscillator Operation



3 Parts of an Oscillator
1. An amplifier. This will usually be a voltage amplifier and may be biased in class A, B or C.
2. A wave shaping network. This consists of passive components such as filter circuits that are responsible for the shape and frequency of the wave produced.
3. A POSITIVE feedback path. Part of the output signal is fed back to the amplifier input in such a way that the feedback signal is regenerated, re-amplified and fed back again to maintain a constant output signal.

Commonly an oscillator is **constructed from an amplifier** that has **part of its output signal fed back to its input.** This is done in such a way as to keep the amplifier producing a signal without the need for any external signal input as shown in Fig. 1.1.1. It can also be thought of as a way of converting a DC supply into an AC signal.

Positive feedback

The feedback in the amplifier section of an oscillator must be POSITIVE FEEDBACK. This is the condition where a fraction of the amplifier's output signal is fed back to be in phase with the input, and by adding together the feedback and input signals, the amplitude of the input signal is increased. For example, a common emitter amplifier creates a phase change of 180° between its input and output, the positive feedback loop must therefore also produce a 180° phase change in the signal fed back from output to input for positive feedback to occur.

The result of a small amount of positive feedback in amplifiers is higher gain, though at the cost of increased noise and distortion. If the amount of positive feedback is large enough however, the result is oscillation, where the amplifier circuit produces its own signal.

Using Positive Feedback

When an amplifier is operated without feedback it is operating in "open loop" mode. With feedback (either positive or negative) it is in "closed loop" mode. In ordinary amplifiers negative feedback is used to provide advantages in bandwidth, distortion and noise generation, and in these circuits the closed loop gain of the amplifier is much less than the open loop gain. However when positive feedback is used in an amplifier system the closed loop gain (with feedback) will be greater than the open loop gain, the amplifier gain is now increased by the feedback. Additional effects of positive feedback are reduced bandwidth, (but this does not matter in an oscillator producing a sine wave having a single frequency), and increased distortion. However even quite severe distortion in the amplifier is allowed in **some** sine wave oscillator designs, where it does not affect the shape of the output wave.

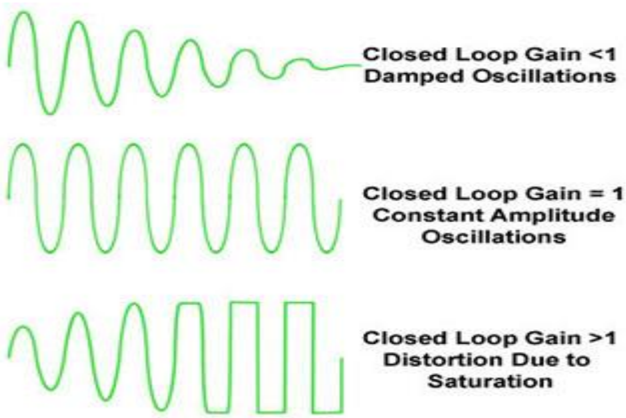
In oscillators using positive feedback it is important that amplitude of the oscillator output remains stable. Therefore the closed loop gain must be 1 (unity). In other words, the gain within the loop (provided by the amplifier) should exactly match the losses (caused by the feedback circuit) within the loop. In this way there will be no increase or decrease in the amplitude of the output signal, as illustrated in Fig. 1.1.2.

The conditions for oscillation

Positive feedback must occur at a frequency where the **voltage gain of the amplifier is equal to the losses (attenuation) occurring in the feedback path.** For example if 1/30th of the output signal is fed back to be in phase with the input at a particular frequency, and the gain of the amplifier (without feedback) is 30 times or more, oscillation will take place.

The oscillations should take place at **one particular frequency**.
The amplitude of the oscillations **should be constant.**
There are many **different oscillator designs in use**, each design achieving the above criteria in different ways. Some designs are particularly suited to producing **certain wave shapes, or work best within a certain band of frequencies.** Whatever design is used however, the way of achieving a signal of **constant frequency** and **constant amplitude** is by using one or more of three basic methods

.
Method 1
Make sure that **positive feedback** occurs only at **one frequency**, the required frequency of oscillation. This may be achieved by ensuring that only signals of the required **frequency are fed back,** or by ensuring the feedback **signal is in the correct phase** at only one frequency.
Method 2
Make sure that **sufficient amplification for oscillation** can take place only at the required frequency, by using an amplifier that has an extremely narrow bandwidth, extending to the frequency of oscillation only.
Method 3
Use amplifiers in "switch mode" to switch the **output between two set voltage levels**, together with some form of time delay to control the time at which the amplifiers switch on or off, thus controlling the periodic time of the signal produced.



The Need For Amplitude Stability

Methods 1 and 2 are used extensively in sine wave oscillators, while method 3 is useful in square wave generators, sometimes called aperiodic (untuned) oscillators. Oscillators using method 3 often use more than one amplifier and timing circuit, and so are called multivibrators (more than one oscillator).

Constant Amplitude
As shown in Fig. 1.1.1 oscillators must have an amplifier, a positive feedback loop and some method of controlling the frequency of oscillation. In **RF sine wave oscillators the frequency may be controlled by an LC tuned circuit,** but as well as controlling the frequency of oscillation, there must also be some means, such as negative feedback, of stabilising the amplitude of the signal produced.

Without this stabilisation the oscillations would either die away and stop (damped oscillation) or rapidly increase in amplitude until the amplifier produces severe distortion due to the transistors within the amplifier becoming "saturated" as shown in Fig. 1.1.2. To produce a constant amplitude output the gain of the amplifier is automatically controlled during oscillation.

Thyristor –Characteristics and Applications

It is 4 layer three-terminal device. Four layers are formed by alternating n-type semiconductor and p-type semiconductor materials. Consequently there are three pn junctions formed in the device. It is a bistable device. The three terminals of this device are called anode (A), cathode (K) and gate (G) respectively. The gate (G) terminal is control terminal of the device. That means, the **current** flowing through the device is controlled by electrical signal applied to the gate (G) terminal. The anode (A) and cathode (K) are the power terminals of the device handle the large applied voltage and conduct the major current through the thyristor. For example, when the device is connected in series with load circuit, the load current will flow through the device from anode (A) to cathode (K) but this load current will be controlled by the gate (G) signal applied to the device externally.

A tyristor **is on-off switch** which is used to **control output power of an electrical circuit by switching on and off the load circuit periodically in a preset interval.** The main difference of thyristors with other digital and electronics switches is that, a thyristor can handle large current and can withstand large voltage, whereas other digital and electronic switches handle only tiny current and tiny voltage.

When positive potential applied to the anode with respect to the cathode, ideally no current will flow through the device and this condition is called **forward – blocking** state but when appropriate gate signal is applied, a large forward anode current starts flowing, with a small anode-cathode potential drop and the device becomes in forward-conduction state. Although after removing the gate signal, the device will remain in its forward-conduction mode until the polarity of the load reverses. Some thyristors are also controllable in switching from forward-conduction back to a forward-blocking state.

Application of Thyristor

As we already said that a thyristor is designed to handle large current and voltage, it is used mainly in **electrical power** circuit with system voltage more than 1 kV or currents more than 100 A. The **advantage** of using thyristors as **power control device** is that as the power **is controlled by periodic on-off switching operation** hence (ideally) there is no internal power loss in the device for controlling power in output circuit. Thyristors are commonly used in some alternating power circuits to control alternating output power of the circuit to optimize internal power loss at the expense of switching speed. In this case thyristors are turned from forward-blocking into forward-conducting state at some predetermined phase angle of the input sinusoidal anode-cathode voltage waveform.

Thyristors are also very popularly used in inverter for converting **direct power to alternating power of specified frequency.** These are also used in converter to convert an alternating power into alternating power of different amplitude and frequency.This is the most common **application of thyristor**.

Thyristors Types

1. Silicon Controlled Rectifier (SCR).
2. Gate Turn-off Thyristor (GTO) and Integrated Gate Commutated Thyristor (IGCT);
3. MOS-Controlled Thyristor (MCT)

4. Static Induction Thyristor (SITh).

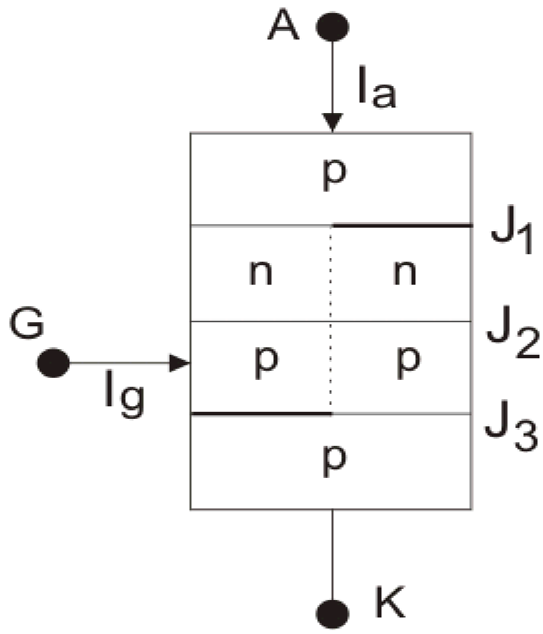
Basic Construction of Thyristor

A high- resistive, n-base region, presents in every thyristor. As it is seen in the figure, this n-base region is associated with junction, J_2. This must support the large applied forward voltages that occur when the switch is in its off- or forward-blocking state (non-conducting). This n-base region is typically doped with impurity phosphorous atoms at a concentration of 10^{13} to 10^{14} per cube centimeter. This region is typically made 10 to 100 micrometer thick to support large voltages. High-voltage thyristors are generally made by diffusing aluminum or gallium into both surfaces to create p-doped regions forming deep junctions with the n-base. The doping profile of the p-regions ranges from about 10^{15} to 10^{17} per cube centimeter. These p-regions can be up to tens of micrometer thick. The cathode region (typically only a few micrometer thick) is formed by using phosphorous atoms at a doping density of 10^{17} to 10^{18} cube centimeter. For higher forward-blocking voltage rating of thyristor, the n-base region is made thicker. But thicker n-based high-resistive region slows down on off operation of the device. This is because of more stored charge during conduction. A device rated for forward blocking voltage of 1 kV will operate much more slowly than the thyristor rated for 100 V. Thicker high-resistive region also causes larger forward voltage drop during conduction. Impurity atoms, such as platinum or gold, or electron irradiation are used to create charge-carrier recombination sites in the thyristor. The large number of recombination sites reduces the mean carrier lifetime (average time that an electron or hole moves through the Si before recombining with its opposite charge-carrier type). A reduced carrier lifetime shortens the switching times (in particular the turn-off or recovery time) at the expense of increasing the forward-conduction drop. There are other effects associated with the relative thickness and layout of the various regions that make up modern thyristors, but the major trade off between forward-blocking voltage rating and switching times and between forward-blocking voltage rating and forward-voltage drop during conduction should be kept in mind.

Basic Operating Principle of Thyristor

Although there are different **types of thyristors** but **basic operating principle of all thyristor** more or less same. The figure below represents a conceptual view of a typical thyristor. There are three p–n junctions J_1, J_2 and J_3. There are also three terminals anode (A), cathode (K) and gate (G) as levelled in the figure. **When the anode (A) is in higher potential with respect to the cathode, the junctions J1 and J3 are forward biased** and **J2 is reverse biased and the thyristor is in the forward blocking mode.** A thyristor can be considered as back to back connected two bipolar transistors. A p-n-p-n structure of thyristor can be represented by the p-n-p and n-p-n transistors, as shown in the figure. Here in this device, the collector current of one transistor is used as base current of other transistor. When the device is in forward blocking mode if a hole current is injected through the gate (G) terminal, the device is triggered on.

When potential is applied in reverse direction, the thyristor behaves as a reverse biased diode. That means it blocks current to flow in revere direction. Considering I_{CO} to be the leakage current of each transistor in cut-off condition, the anode current can be expressed in terms of gate current.



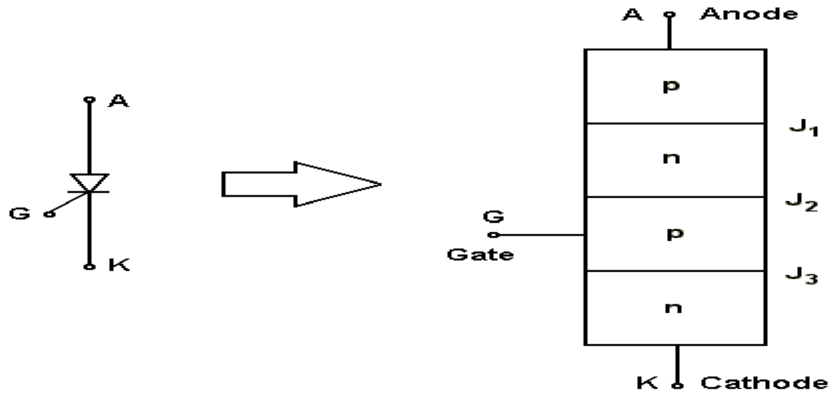
Where α is the common base current gain of the transistor ($\alpha = I_C/I_E$). The anode current becomes arbitrarily large as ($\alpha_1 + \alpha_2$) approaches unity. As the anode–cathode voltage increases, the depletion region expands and reduces the neutral base width of the n_1 and p_2 regions. This causes a corresponding increase in the α of the two transistors. If a positive gate current of sufficient magnitude is applied to the thyristor, a significant amount of electrons will be injected across the forward-biased junction, J_3, into the base of the $n_1p_2n_2$ transistor. The resulting collector current provides base current to the $p_1n_1p_2$ transistor. The combination of the positive feedback connection of the npn and pnp BJTs and the current-dependent base transport factors eventually turn the thyristor on by regenerative action. Among the power semiconductor devices known, the thyristor shows the lowest forward voltage drop at large current densities. The large current flow between the anode and cathode maintains both transistors in saturation region, and gate control is lost once the thyristor latches on.

Transient Operation of Thyristor

A thyristor is not turned on as soon as the gate current is injected, there is one minimum time delay is required for regenerative action. After this time delay, the anode current starts rising rapidly to on-state value. The rate of rising of anode current can only be limited by external current elements. The gate signal can only turn on the thyristor but it cannot turn off the device. It is turned off naturally when the anode current tends to flow in reverse direction during the reverse cycle of the alternating current. A thyristor exhibits turn-off reverse recovery characteristics just like a diode. Excess charge is removed once the current crosses zero and attains a negative value at a rate determined by external circuit elements. The reverse recovery peak is reached when either junction J_1 or J_3 becomes reverse biased. The reverse recovery current starts decaying, and the anode-cathode voltage rapidly attains its off-state value. Because of the finite time required for spreading or collecting the charge plasma during turn-on or turn-off stage, the maximum dI/dt and dV/dt that may be imposed across the device are limited in magnitude. Further, device manufacturers specify a circuit-commutated recovery time, for the **thyristor**, which represents the minimum time for which the thyristor must remain in its reverse blocking mode before forward voltage is reapplied.

Thyristor Characteristics

A thyristor is a 4 layer pnpn semiconductor device consisting of three pn junctions. It has three terminals: an anode a cathode and a gate. Figure shows the thyristor symbol and a sectional view of the three pn junctions.



Thyristor Symbol & pn Junctions

When the anode voltage is made positive with respect to the cathode, junctions $\mathbf{J}_1$ and $\mathbf{J}_3$ are forward biased and junction $\mathbf{J}_2$ is reverse biased. The thyristor is said to be in the forward blocking or off-state condition. A small leakage current flows from anode to cathode and is called the off-state current.

If the anode voltage $\mathbf{V}_{AK}$ is increased to a sufficiently large value, the reverse biased junction $\mathbf{J}_2$ would breakdown. This is known as avalanche breakdown and the corresponding voltage is called the forward breakdown voltage $\mathbf{V}_{BO}$. Since the other two junctions $\mathbf{J}_1$ and $\mathbf{J}_3$are already forward biased, there will be free movement of carriers across all three junctions. This results in a large forward current. The device is now said to be in a conducting or on-state. The voltage drop across the device in the on-state is due to the ohmic drop in the four layers and is very small (in the region of 1 V). In the on-state the anode current is limited by an external impedance or resistance as shown in figure 4.2(a).

V-I Characteristics of Thyristor

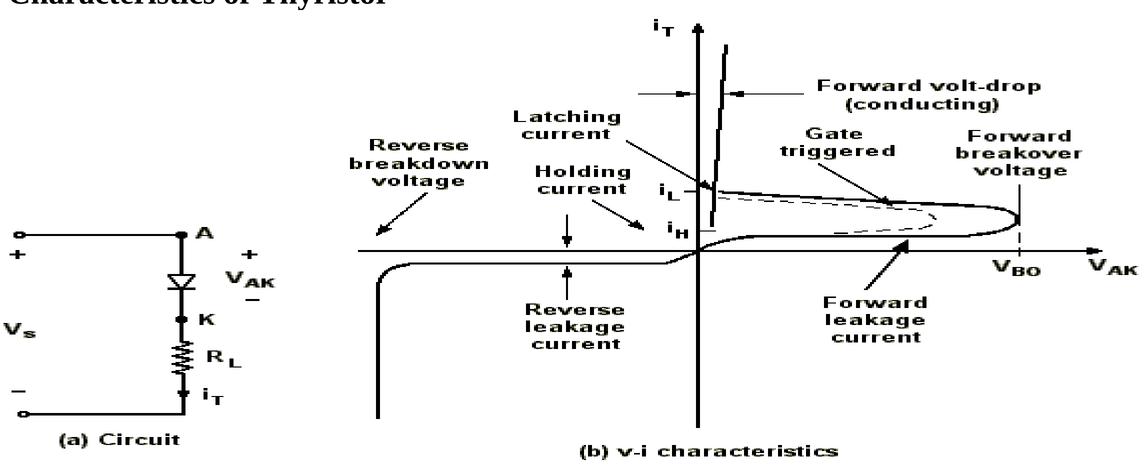


Figure 4.2 Thyristor Circuit & V-I Characteristics

1. Latching Current I_L

This is the minimum anode current required to maintain the thyristor in the on-state immediately after a thyristor has been turned on and the gate signal has been removed.If a gate current greater than the threshold gate current is applied until the anode current is greater than the latching current I_L then the thyristor will be turned on or triggered.

2. Holding Current I_H

This is the minimum anode current required to maintain the thyristor in the on-state.
To turn off a thyristor, the forward anode current must be reduced below its holding current for a sufficient time for mobile charge carriers to vacate the junction. If the anode current is not maintained below I_H for long enough, the thyristor will not have returned to the fully blocking state by the time the anode-to-cathode voltage rises again. It might then return to the conducting state without an externally-applied gate current.

3. Reverse Current I_R

When the cathode voltage is positive with respect to the anode, the junction J_2 is forward biased but junctions J_1 and J_3 are reverse biased. The thyristor is said to be in the reverse blocking state and a reverse leakage current known as reverse current I_R will flow through the device.

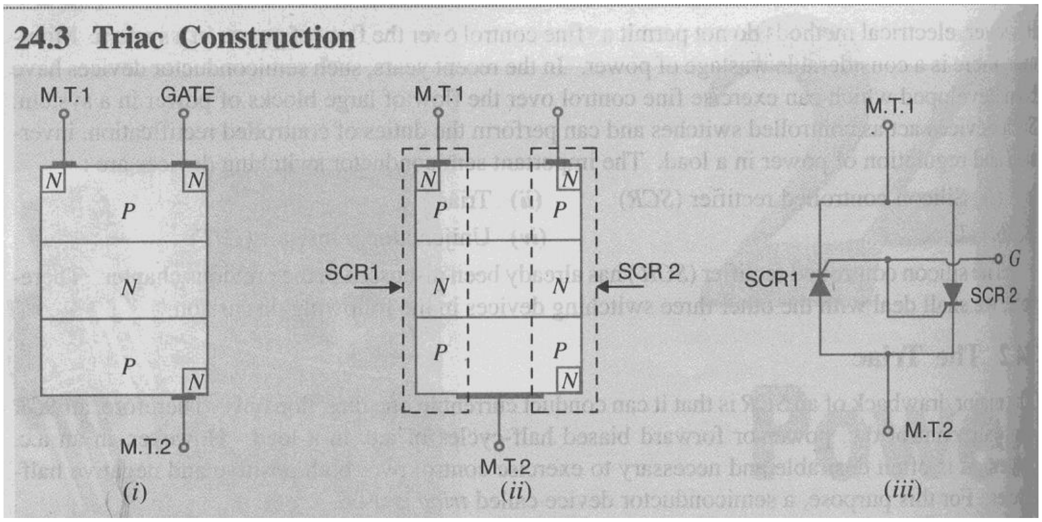
Forward Break over Voltage V_{BO}

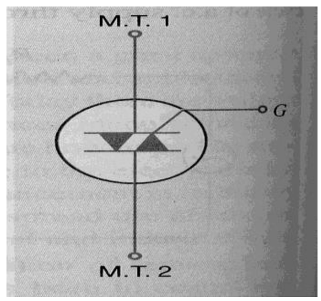
If the forward voltage V_{AK} is increased beyond V_{BO} , the thyristor can be turned on. But such a turn-on could be destructive. In practice the forward voltage is maintained below V_{BO} and the thyristor is turned on by applying a positive gate signal between gate and cathode.
Once the thyristor is turned on by a gate signal and its anode current is greater than the holding current, the device continues to conduct due to positive feedback even if the gate signal is removed. This is because the thyristor is a latching device and it has been latched to the on-state.

Triacs and GTO

TRIAC

A triac is three terminal semiconductor switching device which can control alternating current in a load. It is an abbreviation for triode ac switch tri indicates that the device has three terminals and ac means that the device controls alternating current or can contact current in either direction.



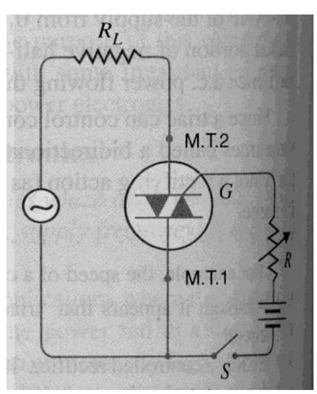


Operation

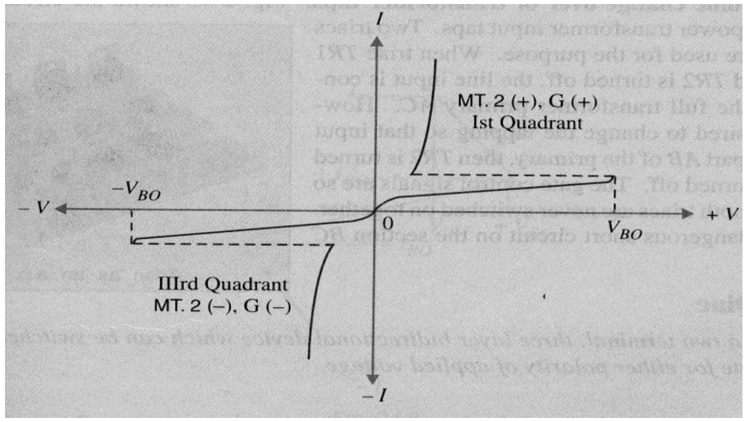
The ac supply to be controlled across the main terminals of triac through a load resistance Rl the gate circuit consists of battery a current limiting resistor R and switch S .

With switch S open there will be no gate current and the triac is cut off. Even with no gate current, the triac can be turned on provided supply voltage become equal to the breakover voltage of traic the noramal way to turn on triac is by introducing a proper gate current.

When switch S is closed the gate current starts flowing in the gate circuit in a similar manner to scr , the breakover voltage of the triac can be varied by making proper gate current to flow.with a few milliamperes introduced at the gate , the triac will start conducting wheter terminal MT2 is positive or negative with respect to MT1if terminal MT2 is positive w.r.t. MT1 the triac turns on and the conventional current will flow from MT2 to MT1. if the terminal MT2 is Negative w r to MT1. the traic is again tured on but this time the conventional current flows from MT1 to MT2



Characteristics



The V-I characteristics for triac in the Ist and III rd quadrants are essentially identical to those of an SCR in the first quadrant. The triac can be operated with either positive or negative gate controlled voltage but in normal operation usually the gate voltage is positive in Quadrant I and Negative in Quadrant III.

The supply voltage at which the triac is turned on depends upon the gate current. the grater the gate current , the smaller supply voltage at which the triac is turned on .this permits to use a triac to control ac power in a load 0 to full power in a smooth and continues manner with no loss in the controlling device.

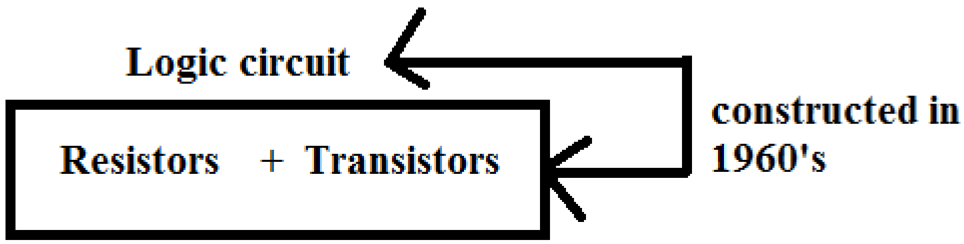
Applications of the Triac
As a high power lamp switch
Electronic change over of transformer taps.

GATE TURN OFF THYRISTOR (GTO)

- The gate turn off thyristor is a PN PN device can be turned like an ordinary thyristor by a pulse of Positive gate current.
- It can be easily turned off by a negative gate pulse of approximate amplitude.
- As no forced commutation circuitry is required for GTO's .these devices are compact and less cost.
- The negative gate current required to turn off a GTO is quite a large percentage (20 to 30%) of anode current 800A.
- GTO require a negative current Pulse of 200A peak for turning it off.

VI characteristics
1. The latching current for large power GTO's is several amperes (2A) as compared to 100-500mA for conventional thyristors of the same rating.
2. If Gate current is not able to turn on the GTO, it behaves like a high voltage low gain transistor with considerable anode current.

Integrated Circuits
1. In 1960s logic circuits were constructed with bulky components, such as transistors and resistors that came as individual parts.



2. Integrated circuit chips are manufactured on a silicon wafer and wafer is cut to produce the individual chips, which are then placed inside a special type of chip package.

3. **GORDON MOORE LAW OR MOORE'S LAW**

It states that **the number of transistors will be doubled that could be placed on a chip every 1.5 to 2 years.**

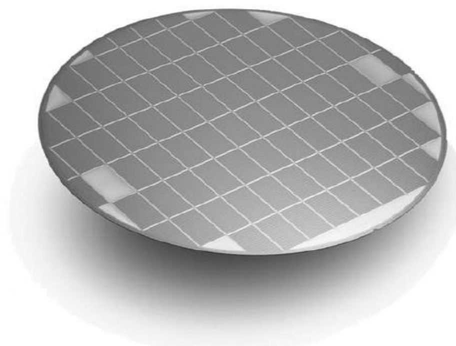


Figure 1.1 A silicon wafer (courtesy of Altera Corp.).

4. The designer place the logic circuits on a single chip, designing circuits involve number of chips placed on PCB (printed circuit board).

5. Logic circuit ----→transistors + resistors-------→chip----------→wafer

Table 1.1 A sample of the International Technology Roadmap for Semiconductors.

	Year					
	2006	2007	2008	2009	2010	2012
Technology feature size	78 nm	68 nm	59 nm	52 nm	45 nm	36 nm
Transistors per cm^2	283 M	357 M	449 M	566 M	714 M	1,133 M
Transistors per chip	2,430 M	3,061 M	3,857 M	4,859 M	6,122 M	9,718 M

TYPES OF CHIPS

1. Standard chips. 2. Programmable logic devices 3.custom chips.

STANDARD CHIPS

It chip contains a small amount of circuitry (**<100 transistors**) and performs a **simple function and fixed functionality.**

DRAWBACK

In standard chips is that the functionality of each chip is fixed and cannot be changed.

Based on the number of components used (typically based on the number of transistors used), they are as follows

Small-scale integration consists of only a few transistors (tens of transistors on a chip), these ICs played a critical role in early aerospace projects.

Medium-scale integration consists of some hundreds of transistors on the IC chip developed in the 1960s and achieved better economy and advantages compared to the SSI ICs.

Large-scale integration consists of thousands of transistors on the chip with almost the same economy as medium scale integration ICs. The first microprocessor, calculator chips and RAMs of 1Kbit developed in the 1970s had below four thousand transistors.

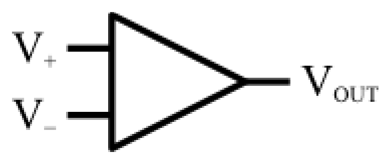
Very large-scale integration consists of transistors from hundreds to several billions in number.(Development period: from 1980s to 2009)

Ultra large-scale integration consists of transistors in excess of more than one million, and later wafer-scale integration (WSI), system on a chip (SoC) and 3D integrated circuit (3D-IC) were developed.

The conventional Integrated circuits are reduced in practical usage, because of the invention of the nano-electronics and the miniaturization of ICs being continued by this **Nano-electronics technology.** However, the conventional ICs are not yet replaced by nano-electronics but the usage of the conventional ICs is getting diminished partially.

OPAMP Applications

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



These amplifiers are called "operation" amplifiers because they were initially designed as an effective device for performing arithmetic operations in an analog circuit. The op-amp has many other applications in signal processing, measurement, and instrumentation.

Operational amplifiers are the basic building blocks of **Analogue electronic circuits**. They are linear devices with all properties of a DC amplifier. We can use external resistors or capacitors to the Op Amp is many different ways to make them different forms of amplifies such as Inverting amplifier, Non inverting amplifier, Voltage follower, Comparator, Differential amplifier, Summing amplifier, Integrator etc. OPAMPs may be single, dual, quad etc. OPAMPs like CA3130, CA3140, TL0 71, LM311 etc have excellent performance with very low input current and voltage. The ideal Op Amp has three important terminals in addition to other terminals. The input terminals are Inverting input and Non inverting input. The third terminal is the output which can sink and source current and voltage. The output signal is the amplifiers gain multiplied by the value of the input signal.

5 Ideal characters of an Op Amp:

1. Open Loop gain

Open loop gain is the gain of the Op Amp without a positive or negative feedback. An ideal OP Amp should have an infinite open loop gain but typically it range between 20,000 and 2, 00000.

2. Input impedance

It is the ratio of the input voltage to input current. It should be infinite without any leakage of current from the supply to the inputs. But there will be a few Pico ampere current leakages in most Op Amps.

3. Output impedance

The ideal Op Amp should have zero output impedance without any internal resistance. So that it can supply full current to the load connected to the output.

4. Band width

The ideal Op Amp should have an infinite frequency response so that it can amplify any frequency from DC signals to the highest AC frequencies. But most Op Amps have limited bandwidth.

5. Offset

The output of the Op Amp should be zero when the voltage difference between the inputs is zero. But in most Op Amps, the output will not be zero when off but there will be a minute voltage from it.

OPAMP Pin Configuration:

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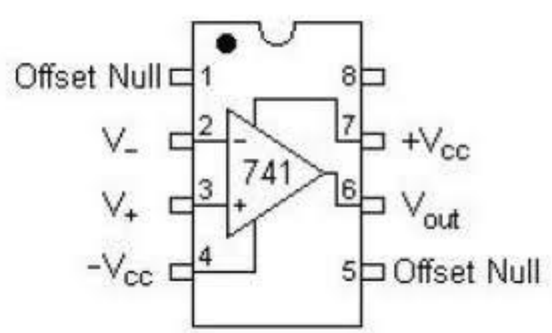
<tr>
<td>


</td>
<td>In a typical Op Amp there will be 8 pins. These are
Pin1 – Offset Null
Pin2 – Inverting input INV
Pin3 – Non inverting input Non-INV
Pin4 – Ground- Negative supply
Pin5 – Offset Null
Pin6 – Output
Pin7 – Positive supply
Pin8 – Strobe</td>
</tr>
</table>

4 types of gain in OPAMPs

Voltage gain – Voltage in and voltage out
Current gain – Current in and Current out
Transconductance – Voltage in and Current out
Tran's resistance – Current in and voltage out

Working of an Operational Amplifier

Here we used an operational amplifier of LM358. Usually a non-inverting input has to be given to a biasing and the inverting input is the real amplifier; connected this to a feedback of 60k resister from output to the input. And a resister 10k is connected in series with a capacitor and a supply of 1V sine wave is given to the circuit, now we will see how gain will be governed by

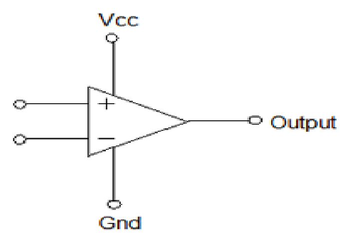
R2/R1=60k/10k=6 gain, then the output is 6V. If we change the gain by 40 then the output is 4V of sine wave.

Normally, it is a dual power supply amplifier, it easily configured to a single power supply by the use of a resister network. In this, resister R3 and R4 place a voltage of half of the supply voltage across the non-inverting input which causes the output voltage to also be half of the supply voltage forming a sort of bias voltage resisters R3 and R4 can be any value from 1k to 100k but in all cases they should be equal. An additional, 1 F capacitor has been added to the non-inverting input to reduce noise caused by the configuration. The use of coupling capacitors for input and output is required for this configuration.

3 OPAMP applications

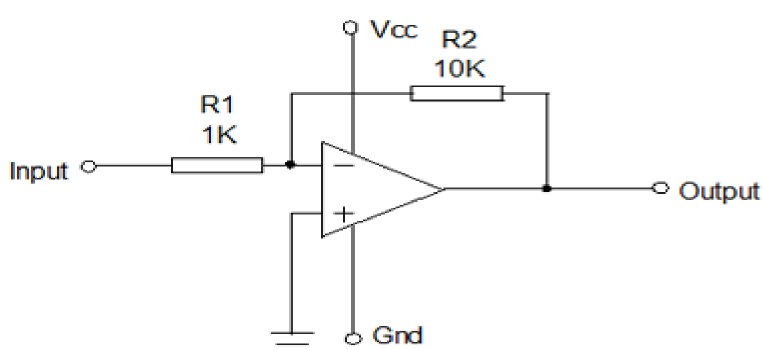
1. Amplification

The amplified output signal from the Op Amp is the difference between the two input signals.



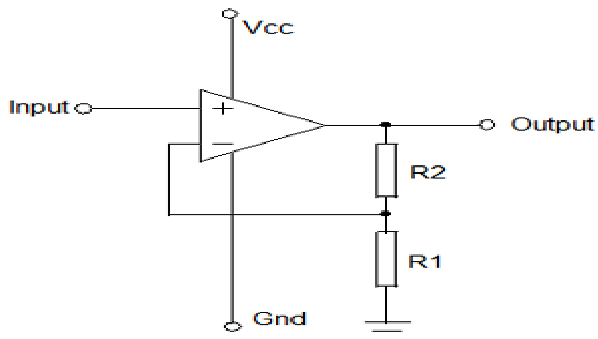
The diagram shown above is the Op Amp simple connection. If both the inputs are supplied with the same voltage, the Op Amp will then takes the difference between the two voltages and it will be 0. The Op Amp will multiply this with its gain 1,000,000 so the output voltage is 0. When 2 volts is given to one input and 1 volt in the other, then the Op Amp will takes its difference and multiply with the gain. That is 1 volt x 1,000,000. But this gain is very high so to reduce the gain, feedback from the output to the input is usually done through a resistor.

Inverting Amplifier:



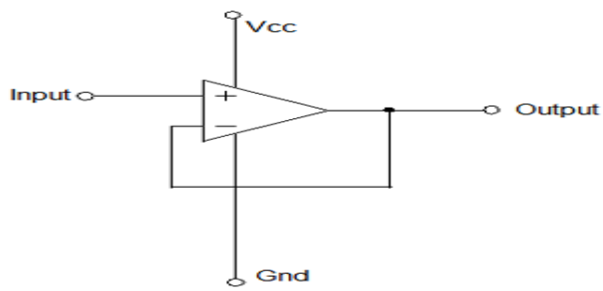
The circuit shown above is an inverting amplifier with the Non inverting input connected to the ground. Two resistors R1 and R2 are connected in the circuit in such a fashion that R1 feeds the input signal while R2 returns the output to the Inverting input. Here when the input signal is positive the output will be negative and vice versa. The voltage change at the output relative to the input depends on the ratio of the resistors R1 and R2. R1 is selected as 1K and R2 as 10K. If the input receives 1 volt, then there will be 1 mA current through R1 and the output will have to become – 10 volts in order to supply 1 mA current through R2 and to maintain zero voltage at the Inverting input. Therefore the voltage gain is R2/R1. That is 10K/1K = 10

Non-inverting Amplifier:



The circuit shown above is a Non inverting amplifier. Here the Non inverting input receives the signal while the Inverting input is connected between R2 and R1. When the input signal moves either positive or negative, the output will be in phase and keeps the voltage at the inverting input same as that of Non inverting input. The voltage gain in this case will be always higher than 1 so (1+R2/R1).

2. Voltage Follower



The circuit above is a voltage follower. Here it provides high input impedance, low output impedance .When the input voltage changes, the output and the inverting input will change equally.

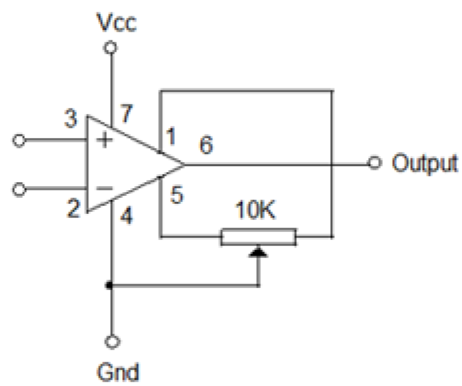
3. Comparator

Operational amplifier compares the voltage applied at one input to the voltage applied at the other input. Any difference between the voltages ever if it is small drives the op-amp into saturation. When the voltages supplied to both the inputs are of the same magnitude and the same polarity, then the op-amp output is 0Volts. A comparator produces limited output voltages which can easily interface with digital logic, even though compatibility needs to be verified.
Here we have an op-amp used as a comparator with the inverting and non-inverting terminals and connected some potential divider and meter to them and a voltmeter at the output and LED to the output. The basic formula for comparator is that when'+' is more than the '–'then the output is high (one), otherwise output is zero. When the voltage on the negative input is the below the reference voltage, the output is high and when the negative input goes above the voltage on the positive, the output goes to low.

3 Requirements for OPAMPs:

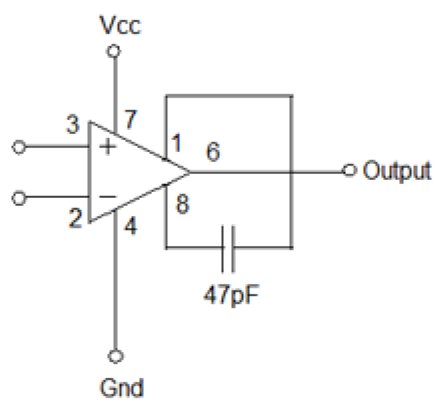
1. Offset Nulling

Most of the OPAMP has an Offset voltage at the output even if the input voltages are same. To make the output to zero voltage, the offset nulling method is used. In most Op-Amps there is a small offset because of their inherent property and results from the mismatches in the input bias arrangement. So a small output voltage is available at the output of some Op-amps even if the input signal is zero. This drawback can be rectified by providing a small offset voltage to the inputs. This is known as the Input Offset voltage. To remove or Null the Offset, most Op-Amps have two pins to enable the offset nulling. For this, a Pot or Preset with a typical value of 100K should be connected between the pins 1 and 5 with its Wiper to the ground. By adjusting the preset, output can be set at Zero voltage.



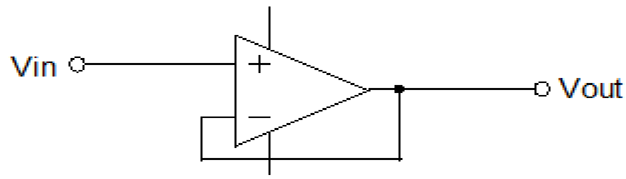
2. Strobing or Phase compensation

Op-Amps may become unstable sometimes and to make them stable for the entire frequency bands a Cap is usually connected between its Strobe pin 8 and pin1. Usually a 47pF disc capacitor is added for **phase compensation** so that the OpAmp will remain stable. This is most important if the OpAmp is used as a sensitive Amplifier.



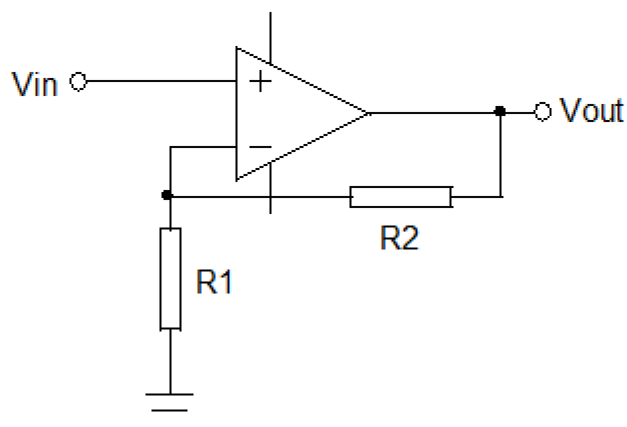
3. Feedback

As you know, the Op-Amp has very high level of amplification typically around 1,000,00 times. Suppose the Op-Amp has 10,000 gain, then the Op-Amp will amplify the difference of voltage in its Non inverting input (V+) and Inverting input (V-). So the output voltage V out is 10,000 x (V+ – V-)



In the diagram, the signal is applied to the Non inverting input and in Inverting input is connected to the output. So V+ = V in and V- = Vout. Therefore Vout = 10,000 x (Vin – Vout). Hence the output voltage is almost equal to the input voltage.

Now let us see how the Feedback works. Simply adding a resistor between the inverting input and the output will reduce the gain considerably. By taking a fraction of the output voltage to the inverting input can reduce the amplification considerably.



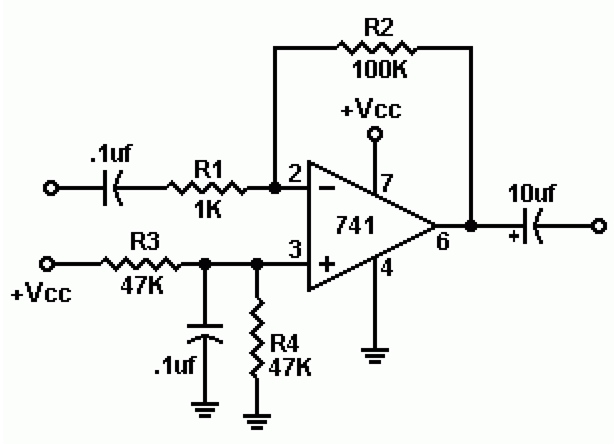
As per the earlier equation, V out = 10,000 x (V+ – V-). But here a feedback resistor is added. So Here V+ is Vin and V- is R1.R1+R2 x V out. Therefore V out is 10,000 x (Vin – R1.R1+R2xVout). So V out = R1+R2.R1x Vin

Negative Feedback:
Here the output of the Op-Amp is connected to its Inverting (–) input, thus the output is fed back to the input so as to reach equilibrium. Thus the input signal at the Non Inverting (+) input will be reflected at the output. The Op-amp with the negative feedback will drive its output to level necessary and hence the voltage difference between its inverting and non inverting inputs will be almost zero.

Positive Feedback:
Here the output voltage is fed back to the Non inverting (+) input. The input signal is fed to the Inverting input. In positive feedback design, if the Inverting input is connected to ground, then the output voltage from the Op-amp will depends on the magnitude and polarity of voltage at the Non inverting input. When the input voltage is positive, then the output of the Op-Amp will be positive and this positive voltage will be fed to the Non inverting input resulting in a full positive output. If the input voltage is negative, then the condition will be reversed.

An Application of Operational Amplifiers – Audio Preamplifier

Filters and pre-amplifiers:
Power amplifiers will come after the pre-amplifiers and before the speakers. Modern CD and DVD players don't need pre-amplifiers. They need volume control and source selectors. By using switching controls and passive volume we can avoid pre-amplifiers.



Let us have a brief about Audio power amplifiers
The power amplifier is a component that can drive the loud speakers by converting the low-level signal into large signal. The job of power amplifiers is producing relatively high voltage and high current. Commonly the range of voltage gain is in between 20 to 30. The power amplifiers are having very low output resistance.

Specifications of Audio Power Amplifier
Maximum output power:
The output voltage is independent of load, for both small and large signals. The given voltage applied to load causes twice the amount of current. Hence twice the amount of power will be delivered. The power rating is the continuous average sine wave power such that the power can be measured by employing a sine wave whose RMS voltage is measured on long term basis.

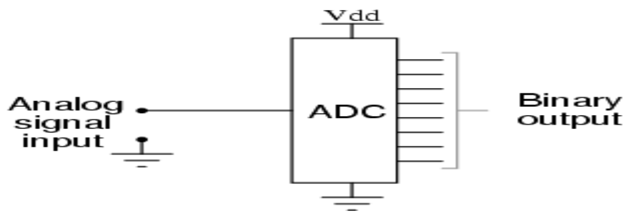
Frequency response
The frequency response must extend full audio band 20 Hz to 20 KHz. The tolerance to the frequency response is ±3db. The conventional way of specifying the bandwidth is an amplifier is down by 3db from the nominal 0db.

Noise
The power amplifiers should produce low noise when the power amplifiers are using with high frequencies. The noise parameter may be weighted or un-weighted. Un-weighted noise will be specified over 20 KHz-bandwidth. Based on the ear's sensitivity weighted noise specification will be taken into consideration. The weighted noise measurement tends to attenuate the noise at higher frequencies hence weighted noise measurement is quite better than un-weighted noise measurement.
Distortion
Total harmonic distortion is the common distortion usually specified at different frequencies. This will be specified at a power level which is given with the power amplifier driving load impedance.

Analog - Digital Conversion

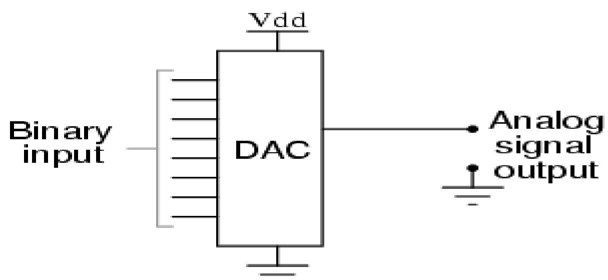
Connecting digital circuitry to sensor devices is simple if the sensor devices are inherently digital themselves. Switches, relays, and encoders are easily interfaced with gate circuits due to the on/off nature of their signals. However, when analog devices are involved, interfacing becomes much more complex. What is needed is a way to electronically translate analog signals into digital (binary) quantities, and vice versa. An **analog-to-digital converter**, or ADC, performs the former task while a digital-to-analog converter, or DAC, performs the latter.

An ADC inputs an analog electrical signal such as voltage or current and outputs a **binary number.**

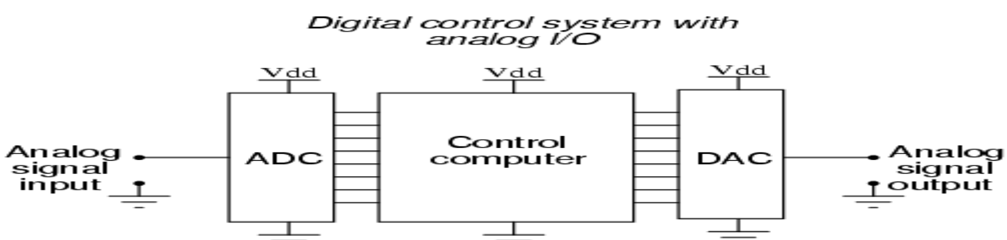


Digital-Analog Conversion

A DAC, on the other hand, inputs a binary number and outputs an analog voltage or current signal.



Together, they are often used in digital systems to provide complete interface with analog sensors and output devices for control systems such as those used in automotive engine controls:



It is much easier to convert a digital signal into an analog signal than it is to do the reverse. Therefore, we will begin with DAC circuitry and then move to ADC circuitry.

Electronics and Instrumentation

Group B

Instrumentation

Indicating instruments, Moving coil, moving iron, rectifier and dynamometer type meters for measurement of voltage, current, resistance and power, Integrating meters.

Electronic voltmeters-peak, r.m.s. and average reading type voltmeters. CRO functional block diagram, operation and application.

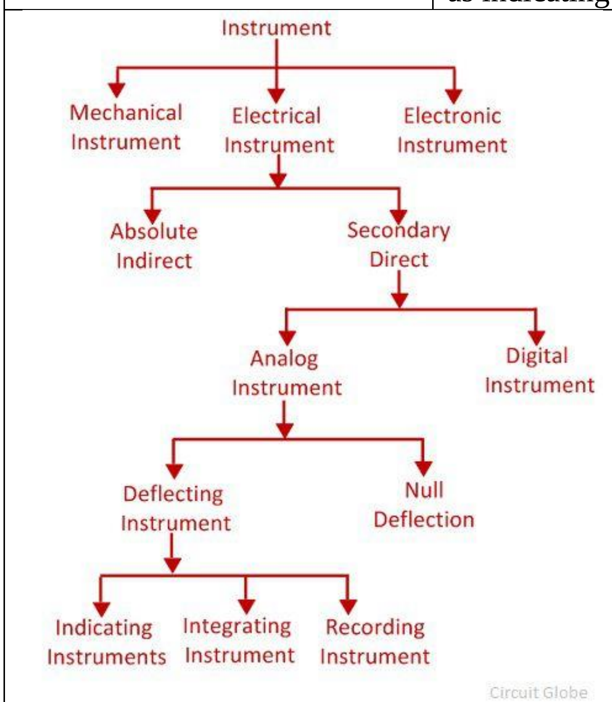
Electronic instruments: Q-meters, distortion meters, spectrum analyzers, audio oscillators and RF signal generators, introduction to digital voltmeters; digital display devices.

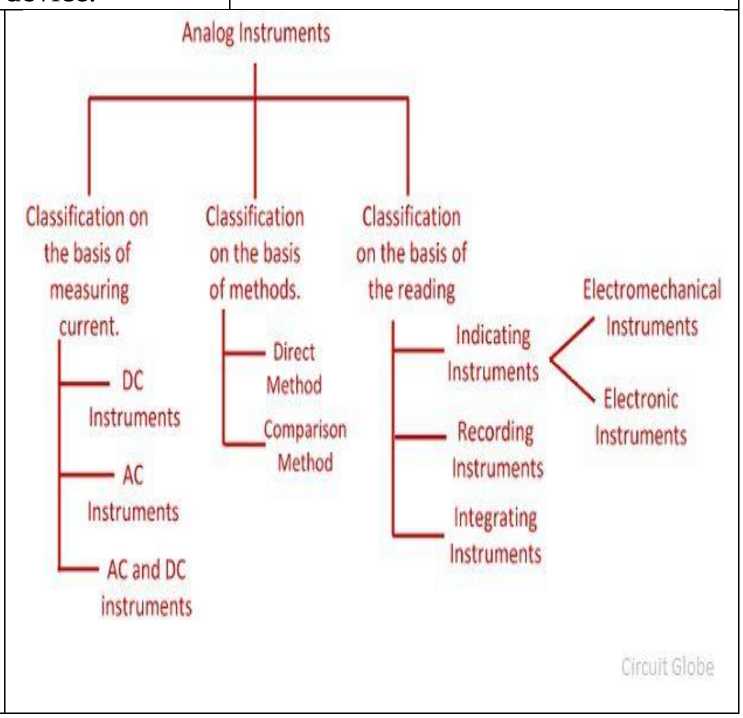
Sensors and transducers. Resistive, inductive and capacitive pickups for non electrical quantities. Analogue and digital data acquisition and transmission systems.

Group B

INSTRUMENTATION

Measuring Instruments Classification		
1. Mechanical instruments	**2. Electrical instruments**	**3. Electronic instruments**
They are reliable for static and stable conditions. **Disadvantage:** They are unable to respond rapidly to measurement of dynamic and transient conditions.	**Electrical methods** of indicating the output of **detectors** are more rapid than mechanical methods. They depend upon mechanical meter movement as indicating device.	They have very fast response. **Example**: **cathode ray oscilloscope** (CRO) is capable to follow dynamic and transient changes of the order of few nano seconds (10^{-9} sec).





Other classification of instruments

1. Primary / Absolute Instruments	2. Secondary instruments
a. They **give deflections in terms of physical constants** and not measurable on a graduated scale. b. The **electrical quantity value** to be measured are given by these instruments. **c. used electricians** and **engineers**. Standard measurements and are maintained by **national laboratories and similar institutions.** **Examples:** Tangent galvanometer, Raleigh current balance and Absolute electrometer	a. They **give a ready measure of the quantities** with the help of graduated scales. b. The value of the electrical quantity to be measured is **determined from the deflection of these instruments**. c. With an absolute instrument these instruments are calibrated. ie, the secondary instruments are compared with known standards or absolute instruments. d. **used** in general for all **laboratory purposes**. **Examples**: ammeters, voltmeter, wattmeter, energy meter (watt-hour meter), ampere-hour meters etc.

Types of Secondary Instruments
(CLASSIFICATION BASED ON THE NATURE OF THEIR OPERATIONS)
1. Indicating instruments. 2. Recording instruments. 3. Integrating instruments.

1. INDICATING INSTRUMENTS
the value of the **electrical quantity is indicated by these instruments at the time** when it is being measured. Pointers moving over the scale give the indication.
Example: Ammeters, Voltmeters and wattmeter.

2. Recording Instruments
A continuous **record of variations** of the **electrical quantity** over a long period of time is given by these instruments. It has a moving system which carries an inked pen which rests tightly on a graph chart. Examples: Graphic recorders and galvanometer recorders.

3. Integrating instruments
The **total amount of electrical energy supplied** over a period of time is measured by these instruments. Examples: Ampere hour meters, watt-hour meters, energy meters e.t.c.

Based on Effects Used
Every electrical instrument needs a force on the moving system to indicate or represent the quantity being measured. This force may be due to one of the several effects as;
Magnetic effect and Electromagnetic effect, Chemical Effect, Thermal Effect, Electrostatic Effect and Induction Effect

Secondary Instruments Classification
a. It is based on the various effects of electric current / voltage upon which their operation depend. They are:

Efeect	Used In
Magnetic effect	ammeters, voltmeters, watt-meters, integrating meters etc.
Heating effect	Ammeters and voltmeters.
Chemical effect	dc ampere hour meters

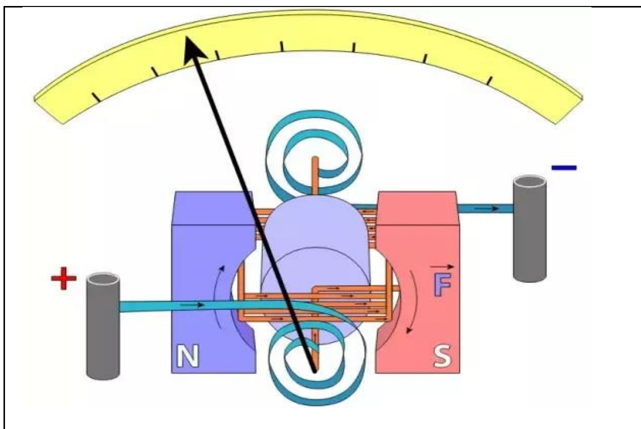
Electrostatic effect	voltmeters
Electromagnetic induction effect	ac ammeters, voltmeters, watt meters and integrating meters

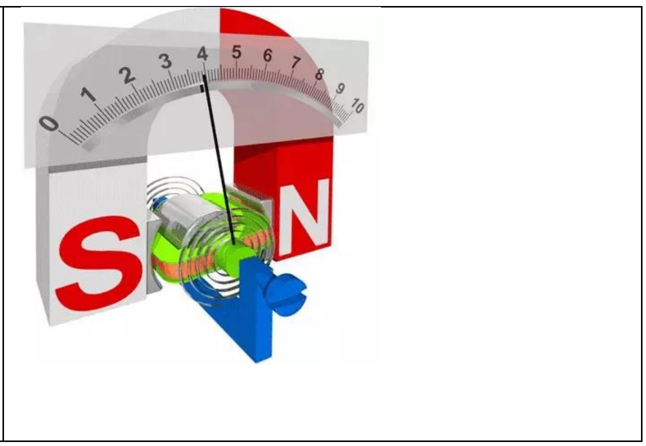
Electrical Measuring Instruments Definitions
True Value
It is the perfectly **correct /exact value** in any measuring scheme.
Accuracy: It expresses **how much** is near the **measured value to the true value**.
Precision: It tells the method which gives the **best possible accuracy**.
Error = Measured Value - True value.
Sensitivity (to feel / realize)**: When an instrument is reacting** to even a **slight difference in the input quantity** we can say that instrument is very sensitive.
Resolution: It the smallest changed in the input signal that can be detected by the instrument and expressed as a fraction / percentage / full-scale value.
Instrument Efficiency= measured quantity / power taken by the instrument at full scale deflection.

MOVING COIL (DC IS PREFERRED)
Both moving coil / moving iron instruments are used measure the voltage and current of circuits.

Here a **copper coil is wrapped** on a **iron core** and is placed in between the poles of permanent magnet and a long pointer is stuck to the coil and it will run to the dial which moves in both ways inside the dial to represent the current. When there is no current passed there **won't be magnetic field generated in the coil and the pointer remains in rest position.**

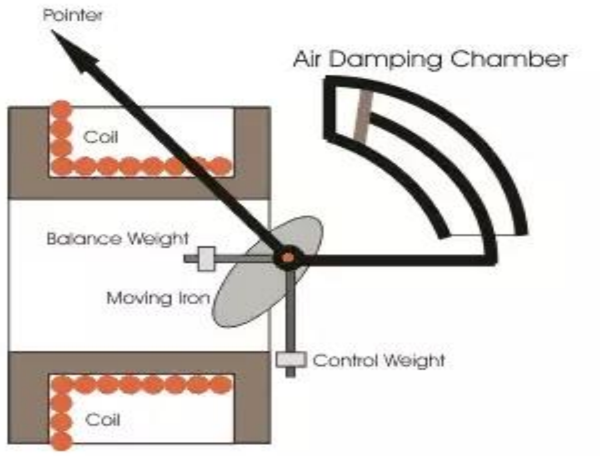
When **current is passed through the coil**, then **magnetic field is induced in the coil**, and that magnetic field is **repelled by the magnetic field produced by the permanent magnet** which makes the coil to rotate which in turn moves the pointer in the **dial from rest position to maximum depending on the amount of current passed to the coil.** (**DC is preferred** in this case rather than AC i will tell you the reason in the end).



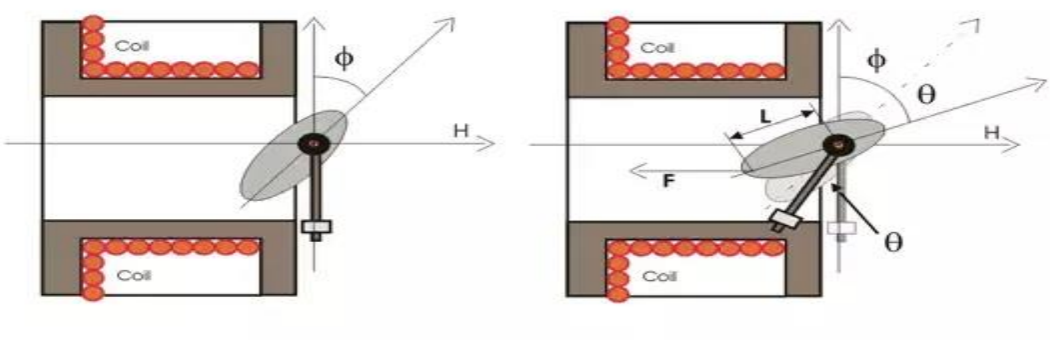


MOVING IRON
AC and DC both are preferred in the moving iron instruments.
Types of Moving iron instruments.
1. Attraction (or single-iron) type. **2. Repulsion (or double iron) type.**

ATTRACTION TYPE
Here a **thin iron disc is placed** in front of the coil in which **a pointer is mounted** which moves in the dial.



When **current flows through the coil iron disc** moves from **lesser magnetic field to higher magnetic field which in turns the pointer in the dial.**

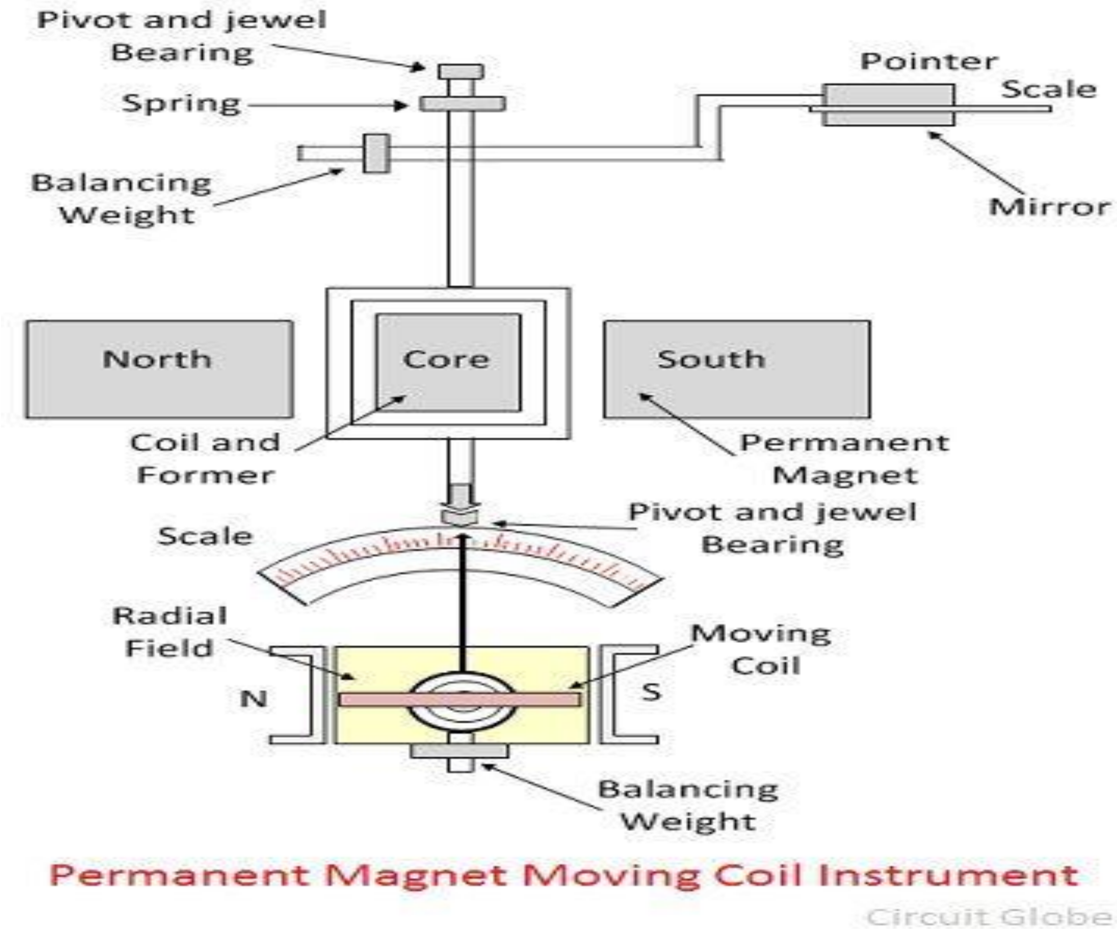


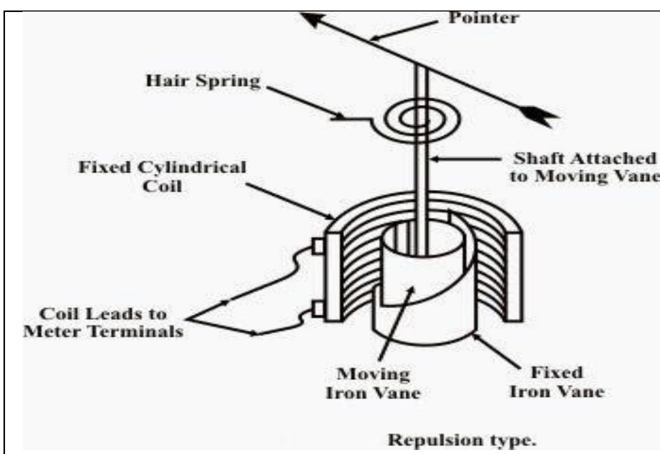
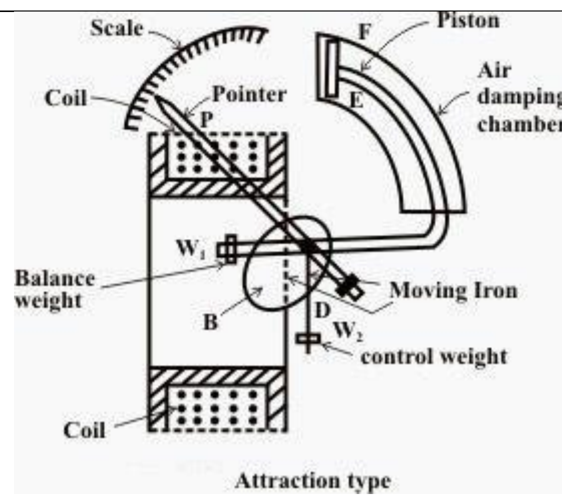
Reason why AC is not used in moving coil is that, as per the construction of moving coil instruments, magnetic field produced in the coil is repelled by the magnetic field produced in the permanent magnet which rotates the coil and this happens as long as the current flows through, but if we pass AC, then due to the transients produced by AC, it will damage the magnet temporarily or permanently depending upon the amount of current passed through the coil.

Moving-iron instruments
In these the movable system consists of one or more pieces of specially-shaped soft iron, which are so pivoted as to be acted upon by the **magnetic field** produced by the current in coil.

Different components of a moving-iron instrument
Moving element: a small piece of soft iron in the form of a vane or rod.
Coil: to produce the magnetic field due to current flowing through it and also to magnetize the iron pieces.
In repulsion type, a **fixed** vane or rod is also used and magnetized with the same polarity.
Control torque is provided by spring or weight (gravity).
Damping torque the damping device consisting of an air chamber and a moving vane attached to the instrument spindle.

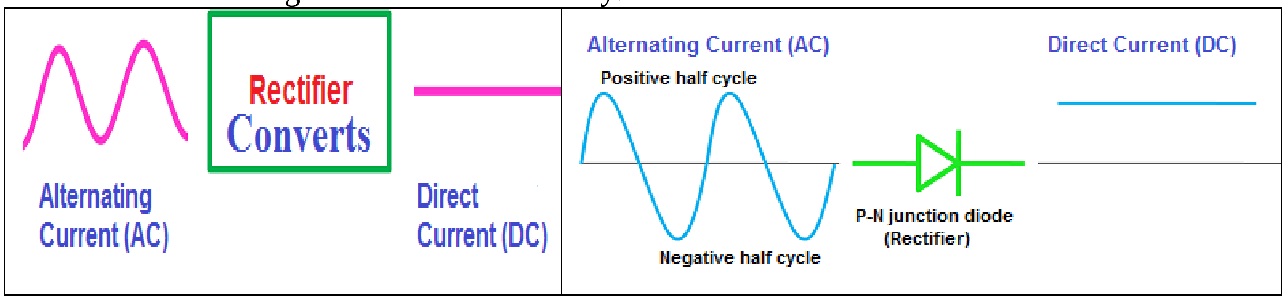
Deflecting torque produces a movement on an aluminum pointer over a graduated scale.



 Figure 1 – Repulsion moving iron-instrument	 Figure 2 – Attraction moving iron instrument

RECTIFIER & DYNAMOMETER TYPE METERS FOR MEASUREMENT OF VOLTAGE

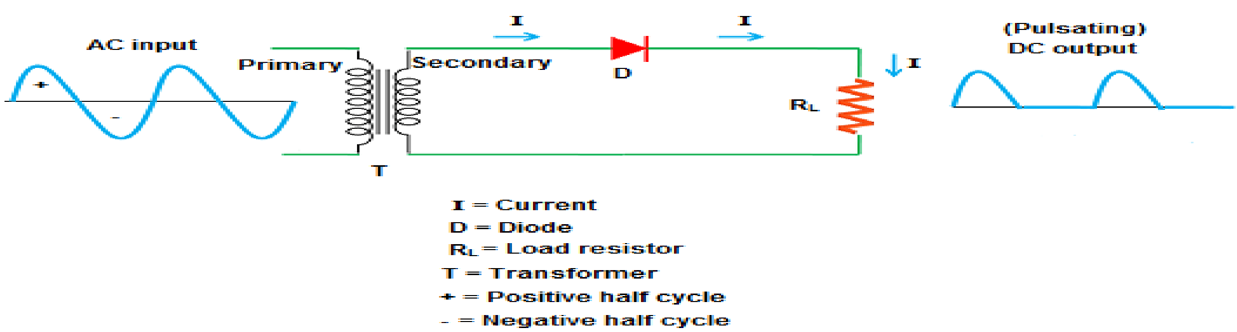
RECTIFIER (AC→Rectifier→DC)
It is an electrical device which converts an alternating current into a direct one by allowing a current to flow through it in one direction only.



When **AC voltage /current** is applied across the P-N junction diode, during the positive half cycle the diode is forward biased and allows electric current through it. However, when the AC current reverses its direction to negative half cycle, **the diode is reverse biased and does not allow electric current through it.** In simple words, during the positive half cycle, the diode allows current and during the negative half cycle, the diode blocks current. Thus, electric current flows through the diode only during the positive half cycle of the AC current. This current which flows across the diode is nothing but a DC current. Thus, the P-N junction diode acts like a rectifier by converting the AC current into DC current.

Types of rectifiers: 1. Half wave rectifier. 2. Full wave rectifier

Half wave rectifier
It rectifier which converts half of the AC input signal (positive half cycle) into pulsating DC output signal and the remaining half signal (negative half cycle) is blocked or lost. In half wave rectifier circuit, we use only a single diode. The half wave rectifier is made up of an AC source, transformer (step-down), diode, and resistor (load). The diode is placed between the transformer and resistor (load).

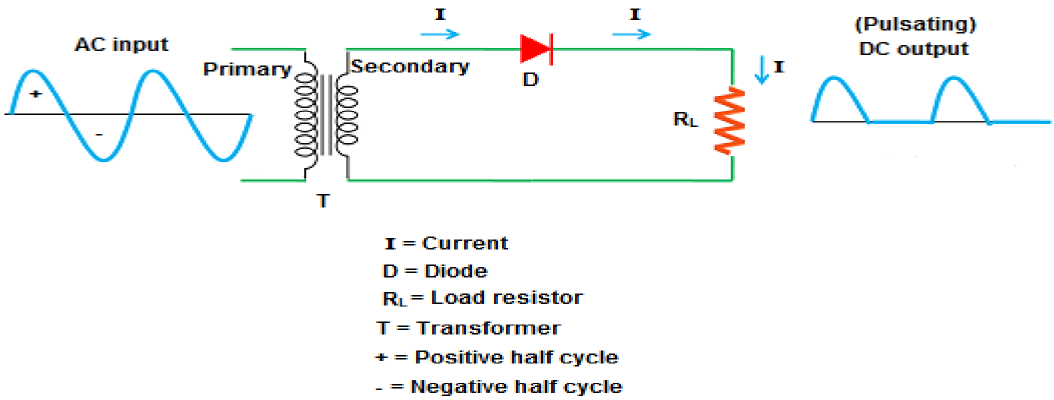


Half wave rectifier

Half wave rectifier operation
Positive half wave rectifier

When high AC voltage (60 Hz) is applied, the step-down transformer reduces this high voltage into low voltage. Thus, a low voltage is produced at the secondary winding of the transformer. The low voltage produced at the secondary winding of the transformer is called **secondary voltage (VS).** The AC voltage or AC signal applied to the transformer is nothing but an input AC signal or input AC voltage.

The low AC voltage produced by the step-down transformer is directly applied to the diode.



Positive half wave rectifier

When low AC voltage is applied to the diode (D), during the positive half cycle of the signal, the diode is **forward biased** and allows electric current whereas, during the negative half cycle, the diode is **reverse biased** and blocks electric current. In simple words, the diode allows the positive half-cycle of the input AC signal and blocks the negative half-cycle of the input AC signal.

The positive half-cycle of the input AC signal or AC voltage applied to the diode is analogous to the forward DC voltage applied to the p-n junction diode similarly the negative half-cycle of the input AC signal applied to the diode is analogous to the reverse DC voltage applied to the p-n junction diode.

The positive half wave rectifier does not completely block the negative half cycles. It allows a small portion of negative half cycles or small negative current. This current is produced by the minority carriers in the diode.
The current produced by the minority carriers is very small. So it is neglected. We can’t visually see the small portion of negative half cycles at the output.

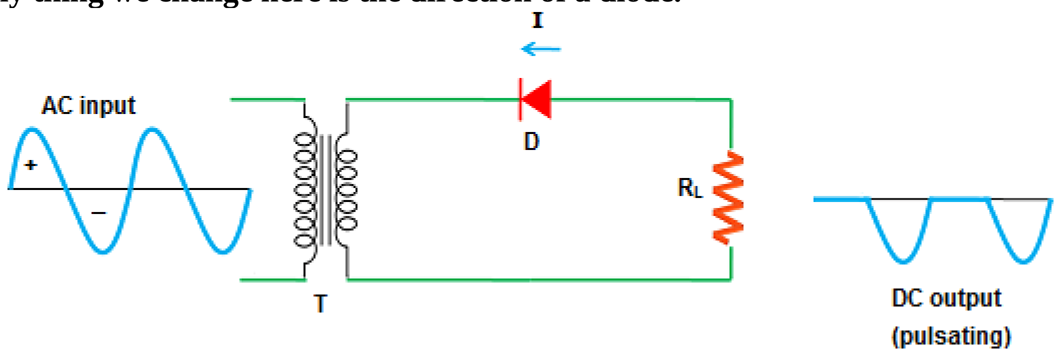
In an ideal diode, the negative half cycles or negative current is zero.
The resistor placed at the output consumes the DC current generated by the diode. Hence, the resistor is also known as an **electrical load**. The output DC voltage/ current is measured across the load resistor R_L.

Load
The electrical load is a electrical component of a circuit that consumes electric current. In half wave rectifier, the resistor consumes the DC current generated by the diode. So the resistor in half wave rectifier is known as a load.

Load =It is the power consumed by the circuit.
The load resistors are used in half wave rectifiers to restrict or block the unusual excess DC current produced by the diode.

Thus, the half wave rectifier allows positive half cycles and blocks negative half cycles. The half wave rectifier which allows positive half cycles and blocks negative half cycles is called a **positive half wave rectifier**. The output DC current or DC signal produced by a positive half wave rectifier is a series of positive half cycles or positive sinusoidal pulses. Now let's take a look at the negative half wave rectifier.

Negative half wave rectifier
The only thing we change here is the direction of a diode.



Negative half wave rectifier

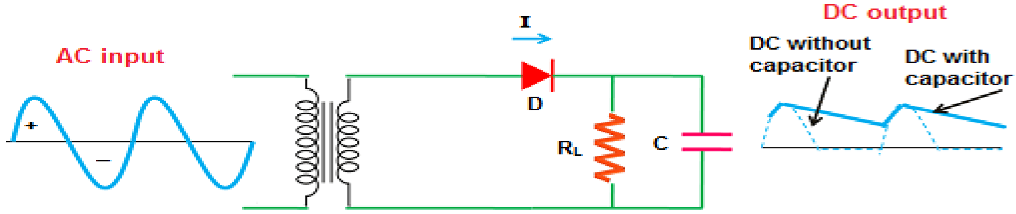
In an ideal diode, the positive half cycle or positive current is zero.
The DC current or DC voltage produced by the negative half wave rectifier is measured across the load resistor R_L. The output DC current or DC signal produced by a negative half wave rectifier is a series of negative half cycles or negative sinusoidal pulses.
Thus, a negative half wave rectifier produces a series of negative sinusoidal pulses.
In a perfect or ideal diode, the positive half cycle or negative half cycle at the output is exactly same as the input positive half cycle or negative half cycle. However, in practice, the positive half cycle or negative half cycle at the output is slightly different from the input positive half cycle or negative half cycle. But this difference is negligible. So we can't see the difference with our eyes.

Thus, the half wave rectifier produces a series of positive sinusoidal pulses or negative sinusoidal pulses. This series of positive pulses or negative pulses is not a pure direct current. It is a pulsating direct current. The pulsating direct current changes its value over a short period of time. But our aim is to produce a direct current which does not change its value over a short period of time. Therefore, the pulsating direct current is not much useful.

Half wave rectifier with capacitor filter
A filter converts the **pulsating direct current into pure direct current**. In half wave rectifiers, a capacitor or inductor is used as a filter to convert the **pulsating DC to pure DC.**

The output voltage produced by a half wave rectifier is not constant; it varies with respect to time. In practical applications, a constant DC supply voltage is needed.

In order to produce a constant DC voltage, we need to suppress the ripples of a DC voltage. This can be achieved by using either a capacitor filter or inductor filter at the output side. In the below circuit, we are using the capacitor filter. The capacitor placed at the output side smoothen the pulsating DC to pure DC.



D = Diode
C = Capacitor (Filter)
R_L = Load resistor
I = Current

Half wave rectifier with filter capacitor

Characteristics of half wave rectifier

Ripple factor

The direct current (DC) produced by a half wave rectifier is not a pure DC but a pulsating DC. In the output pulsating DC signal, **we find ripples.** These ripples in the output DC signal can be reduced by using filter such **capacitors and inductors.**

In order to **measure how much ripples** are there in the **output DC signal** we use a factor known as **ripple factor.** The ripple factor tells us the amount of ripples present in the output DC signal and is denoted by γ. A large ripple factor indicates a high pulsating DC signal while a **low ripple factor indicates a low pulsating DC signal.**

If the ripple factor is very low then it indicates that the output DC current is closer to the pure DC current. In simple words, the lower the ripple factor the smoother the output DC signal. Ripple factor can be mathematically defined as the ratio of rms value of AC component of the output voltage to the DC component of the output voltage.

Ripples factor = (RMS value of AC component / DC component) of the output voltage.
Where, rms = root mean square   Or

Ripple factor = Ratio of ripple voltage / DC voltage

The ripple factor should be kept as **minimum** as possible to construct a good rectifier.
The ripple factor is given as

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

γ = 1.21
The unwanted ripple present in the output along with the DC voltage is 121% of the DC magnitude. This indicates that the half wave rectifier is not an efficient AC to DC converter. The high ripples in the half wave rectifier can be reduced by using filters.

DC current (I_{DC}) I_{max} = maximum DC load current	**I_{DC}= Imax/π**
Output DC voltage (V_{DC}) It is the voltage appeared at the load resistor (R_L).	**V_{DC} == I_{DC} R_L**
Output voltage VDC V_{Smax} = Maximum secondary voltage	**VDC=V_{Smax}/ π**

Peak inverse voltage (PIV)
It is the **maximum reverse bias voltage** up to which a **diode can withstand**. If the applied voltage is greater than the peak inverse voltage, the **diode will be destroyed**.
During the **positive half cycle**, the diode is **forward biased** and allows **electric current**. This current is dropped at the resistor load (RL). However, during the negative half cycle, the diode is reverse biased and does not allows electric current, so the input AC current or AC voltage is dropped at the diode.
The maximum voltage dropped at the diode is nothing but an input voltage.
Therefore, peak inverse voltage (PIV) of diode = V_{Smax}

Rectifier efficiency = output DC power / the input AC power.
The rectifier efficiency of a half wave rectifier is 40.6%

Root mean square (RMS) value of load current (I_{RMS}) =I_M/2

Root mean square (RMS) value of output load voltage V_{RMS}
The root mean square (RMS) value of output load voltage in a half wave rectifier is

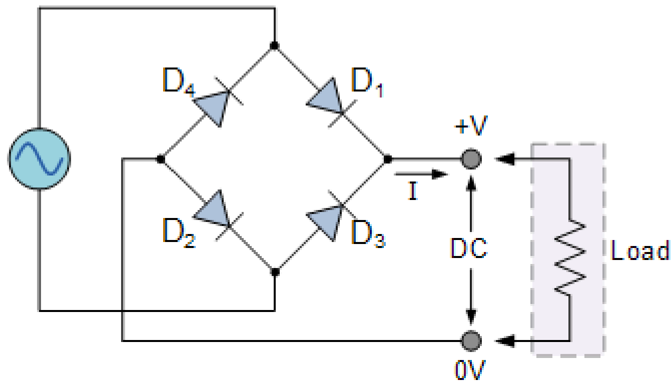
$$V_{RMS} = I_{RMS}\, R_L = \frac{I_m}{2}\, R_L$$

Form factor = RMS value / DC value. It of half wave rectifier is F.F = 1.57
Advantages of half wave rectifier
Few components, very low and easy to construct

Disadvantages of half wave rectifier
1. **Power loss**: The half wave rectifier either allows the positive half cycle or negative half cycle. So the remaining **half cycle is wasted**. Approximately half of the **applied voltage is wasted in half wave rectifier.**
2. **Pulsating direct current**: The direct current produced by the half wave rectifier **is not a pure direct current;** it is a pulsating direct current which is not much useful.
3. **Produces low output voltage**.

Full wave rectifier

It which converts the full **AC input signal (positive half cycle and negative half cycle) to pulsating DC output signal.** Unlike the half wave rectifier, the input signal is not wasted in full wave rectifier.



Rectifier practical example

In our houses the electronic appliances use AC current. Electronic appliances such as laptops or notebook computers **convert this AC current into DC current before they consume the power.**

The **AC adapters** consist of all the essential components needed for **AC to DC conversion**. These components are a **transformer, capacitor, and several diodes.** Out of these components, the main key component is a diode which converts the alternating current into direct current. The transformer in the AC adapter reduces the high AC voltage to a low AC voltage. The rectifier (made up of diodes) converts this low AC voltage or AC current into low DC voltage or DC current. However, the converted current is not pure DC current. It is a pulsating DC current. The capacitor filters this pulsating DC current to pure DC current.

DYNAMOMETER TYPE METERS FOR MEASUREMENT OF VOLTAGE

Power Factor = Actual electrical power dissipated by an AC circuit / the product of the r.m.s. values of current and voltage. The difference between the two is caused by reactance in the circuit and represents power that does no useful work.

In power transmission system and **distribution system we measure power factor** at every station and **electrical substation** using these **power factor meters**. Power factor measurement provides us the knowledge of type of loads that we are using and helps in calculation of losses happening during the **power transmission system** and distribution.

Hence we need a separate device for calculating the power factor **accurately and more precisely.** General construction of any **power factor meter** circuit include **two coils namely**

pressure coil and current coil. Pressure coil is connected across the circuit while current coil is connected such that it can carry circuit current or a definite fraction of current. **By measuring the phase difference between the voltage and current the electrical power factor can be calculated on suitable calibrated scale.** Usually the pressure coil is splits into two parts namely inductive and non-inductive part or pure resistive part. There is no requirement of controlling system because at equilibrium there exist two opposite forces which balance the movement of pointer without any requirement of controlling force.

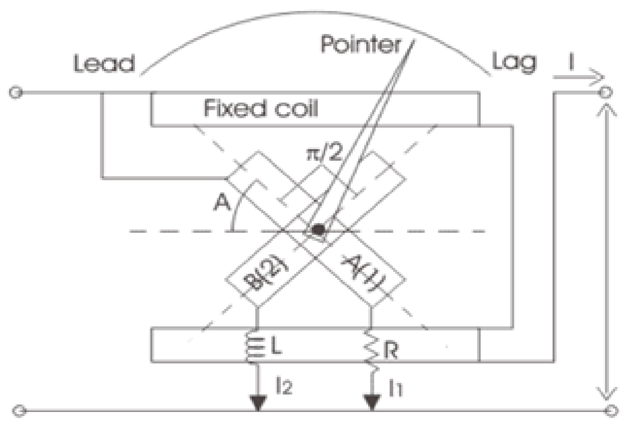
Types of power factor meters

1. Electrodynamometer type. 2. Moving iron type.

Electrodynamometer Type Power Factor Meter

Here there are **2 types of supply voltage**. 1. Single phase. 2. Three phase.

The general circuit diagram of single phase electrodynamometer power factor meter is given below.



Pressure Coil
1. NOn Inductive Part
2. Pure Resistive Part

PFM--->Pressure Coil

Now the **pressure coil is split into two parts** one is purely inductive another is purely resistive as shown in the diagram by **resistor** and **inductor**. At present the reference plane is making an angle A with coil 1. And the angle between both the coils 1 and 2 is 90°. Thus the coil 2 is making an angle (90° + A) with the reference plane. Scale of the meter is properly calibrated as shown the value values of cosine of angle A. Let us mark the electrical **resistance** connected to **coil 1 be R** and **inductor** connected to **coil 2 be L**. Now during measurement of power factor the values of R and L are adjusted such that R = wL so that both coils carry equal magnitude of current.

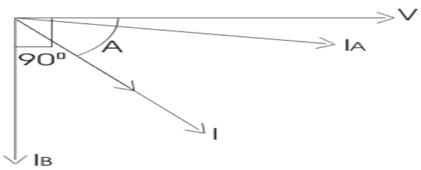
Therefore the current passing through the coil 2 is lags by 90° with reference to current in **coil 1** as coil 2 path is highly inductive in nature. Let us derive an expression for deflecting torque for this **power factor meter**. Now there are two deflecting torques one is acting on the coil 1 and another is acting on the coil 2. The coil winding are arranged such that the two torques produced, are opposite to each other and therefore pointer will take a position where the two torques are equal. Let us write a mathematical expression for the deflecting torque for coil 1-

$$T_1 = KVIM \cos A \sin B$$

Where M is the maximum value of **mutual inductance** between the two coils, B is the angular deflection of the plane of reference. Now the mathematical expression for the deflecting torque for coil 2 is-

$$T_2 = KVIM\cos(90 - A)\sin(90 + B) = KVIM\sin A\cos B$$

At equilibrium we have both the torque as equal thus on equating $T_1 = T_2$ we have A = B. From here we can see that the deflection angle is the measure of phase angle of the given circuit. The phasor diagram is also shown for the circuit such that the current in the coil 1 is approximately at an angle of 90^o to current in the coil 2.



Advantages of Electrodynamic Type Power Factor Meters

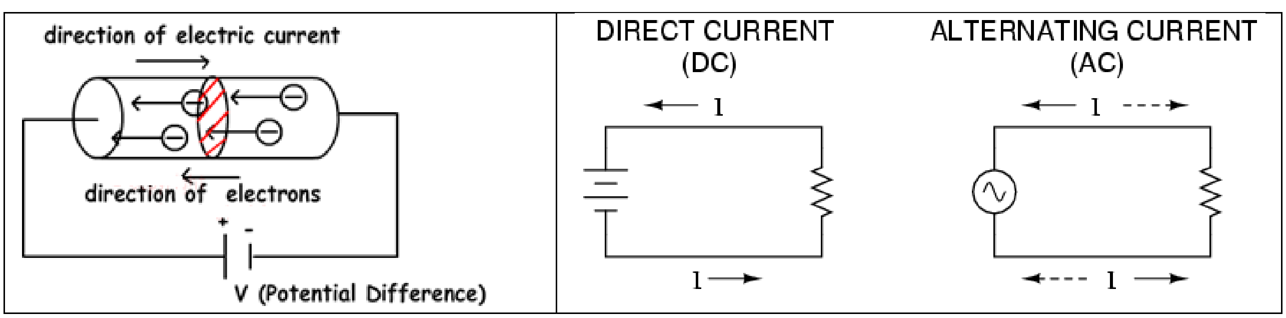
1. Losses are less because of **minimum use of iron part**s and also **give less error over a small range of frequency as compared to moving iron type instruments.**
2. they high **torque is to weight ratio.**

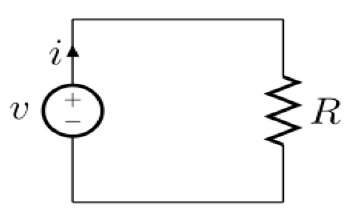
Disadvantages of Electrodynamics Type Power Factor Meters

1. **Working forces are small** as compared to **moving iron type instruments.**
2. The scale is not extended over 360^o.
3. Calibration of electrodynamometer type instruments are highly affected by the changing the **supply voltage frequency.**
4. They are **quite costly** as compared to other instruments.

CURRENT

An electric current is a flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire. Ampere is unit of electric current.





Electronics and Instrumentation

Voltmeter
It is used to measure the voltage b/w the two nodes and the unit of potential difference is volts.

Working Principle of Voltmeter
The main **principle of voltmeter** is that it must be connected in parallel in which we want to measure the **voltage**. Parallel connection is used because a **voltmeter** is constructed in such a way that it has a very **high value of resistance**. So if that high resistance is connected in series than the current flow will be **almost zero** which means the circuit has become open.

If it is connected in parallel, than the **load impedance comes parallel** with the high resistance of the voltmeter and hence the combination will give almost the same the impedance that the load had. Also in parallel circuit we know that the **voltage is same so the voltage between the voltmeter and the load is almost same** and hence voltmeter measures the voltage. For an ideal voltmeter, we have the resistance is to be infinity and hence **the current drawn to be zero** so there will be no power loss in the instrument. But this is not achievable practically as we cannot have a material which has infinite resistance. **(Ideal Voltmeter-→Resistance=Infinity→I=0)**

Voltmeter Types

1. Permanent Magnet moving coil (PMMC) Voltmeter.	DC voltages	Measures **(PERIMED)**
2. Moving Iron (MI) Voltmeter.	AC and DC voltages	
3. Electro Dynamometer Type Voltmeter.	AC and DC voltages	
4. Rectifier Type Voltmeter	AC and DC voltages	
5. Induction Type Voltmeter.	AC and DC voltages	
6. Electrostatic Type Voltmeter.	AC and DC voltages	
7. Digital Voltmeter (DVM).	`AC and DC voltages	

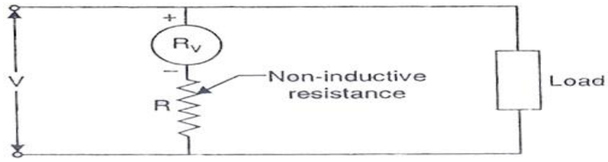
Types of measurement we do: 1. DC Voltmeter. 2. AC Voltmeter.

PMMC Voltmeter/ D Arnsonval type instrument
When current carrying conductor **placed in a magnetic field**, a **mechanical force acts on the conductor,** if it is attached to a moving system, with the coil movement, the pointer moves over the scale. PMMC instruments have permanent magnets. It is suited for DC measurement because here **deflection is proportional to the voltage** because resistance is constant for a material of the meter and hence if voltage polarity is reversed, deflection of the pointer will also be reversed so it is used only for DC measurement. **Advantages** of having linear scale, power consumption is low, high accuracy. Major **disadvantages** are - It only measures DC quantity, higher cost etc.

$$Deflecting\ torque,\ T = BiNlb\ \ Nm$$

Where, B = Flux density in Wb/m², i = V/R where V =voltage, R = resistance of the load. l = Length of the coil in m. b = Breadth of the coil in m. N = No of turns in the coil.

Extension of Range in a PMMC Voltmeter
In the PMMC voltmeters we have the facility of **extending the range of measurement of voltage** also. Just connecting a resistance in series with the meter we can extend the range of measurement.



Let, V is the supply voltage in volts. R_v is the voltmeter resistance in Ohm. R is the external resistance connected in series in ohm. V_1 is the voltage across the voltmeter. Then the external resistance to be connected in series is given by $R = \frac{V - V_1}{V_1} \times R_V$

MI Voltmeter (Moving Iron Instrument)
It shows directional deflection, classified into 2 : **1. Attraction type. 2. Repulsion type.**

$$Its\ Torque\ equation\ is:\ T = \frac{1}{2} \times I^2 \frac{dL}{d\theta}$$

Where, I = total current flowing in the circuit in Amp. I = V/Z Where, V = voltage and Z = impedance of the load. L is the **self inductance** of the coil in Henry. θ is the deflection in Radian.

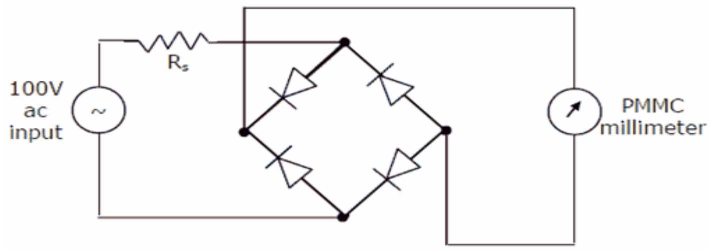
Attraction type MI Instrument Principle
If an unmagnified soft iron is placed in the magnetic field, **it is attracted towards the coil**, if a pointer is attached to the systems and **current is passed through a coil** as a result of the applied voltage, it creates a **magnetic field which attracts iron piece and creates deflecting torque as a result of which pointer moves over the scale.**

Repulsion type MI Instrument Principle
When two iron pieces are magnetized with the same polarity by passing a current which done by applying a voltage across the **voltmeter than repulsion between them occurs and that repulsion produces a deflecting torque due to which the pointer moves.** The advantages are it measure both AC and DC, it is cheap, low friction errors, Robust etc. It is mainly used in AC measurement because in DC measurement error will be more due to hysteresis.

Electrodynamometer Type Voltmeter
We have two coils, fixed and moving coils. If a voltage is applied at the two coils as a result of which current flows two coils it will stay in the zero position due to the development of equal and opposite torque. If the direction of one torque is reversed as the current in the coil reverses, an undirectional torque is produced. For voltmeter, the connection is a parallel one and both fixed and moving coils are connected in series with non-inductive resistance. φ = 0 where φ is the phase angle. $T = I^2 \times \frac{dM}{d\theta}$ Where, I is the amount of current flowing in the circuit in Amp = V/Z V and Z are the applied voltages and impedance of the coil respectively. M = <u>Mutual inductance</u> of the coil. They have no hysteresis error, can be used for both AC and DC measurement, the main disadvantages are having low torque/weight ratio, high friction loss, expensive than other instruments etc.

Electronics and Instrumentation

Rectifier Voltmeter



For DC measurement we have to connect a **PMMC meter** which measures pulsating DC voltage which measures rectified voltage which is connected across the **bridge rectifier.**

Advantages of Rectifier Voltmeter
1. Can be used in high frequency.
2. It has uniform scale for most of the ranges.

Digital Voltmeters (DVM) Principle
It can **give the output voltage** not by deflection but directly indicating the value. It measure voltage and eliminates error due to parallax, approximation in measurement, high-speed reading can be done and it can also be stored in memory for further analysis.

Electrostatic Instruments
When **electric field** created by the **charged particles are allowed to act on the conductors which is charged by the current**, a deflecting torque is produced. This can be done by using-

1. Two electrodes which are oppositely charged in which one of them is fixed and the other is movable.
2. Force between two electrodes which causes rotary motion of the moving electrode.

$$Torque\ equation\ is\ T_D = \frac{1}{2} \times V^2 \frac{dC}{d\theta}$$

Where, V is the voltage to be measured in volts, C is the value of **capacitance** in farad and θ is the deflection in radians. Advantages of the **electrostatic meter** having low power consumption can be used for **both** AC and DC quantities, no **hysteresis loss**, no stray magnetic field error. Disadvantages are it has non uniform scale, low operating force, it has expansive and the size is large also its construction is not robust.

RESISTANCE AND POWER'S
It is the rate, per unit time, **at which electrical energy is transferred by an electric circuit.** The SI unit of power is the watt, one joule per second.

Power=VI=I^2R=V^2/R	P=VI
V=IR	V=IR→I=V/R
P= (IR) I=I^2R	P= V (V/R)=V^2R

INTEGRATION METERS (E1+E2+……En)
Instrument that totalizes electric energy or some other quantity consumed over a period of time.

ELECTRONIC VOLTMETER

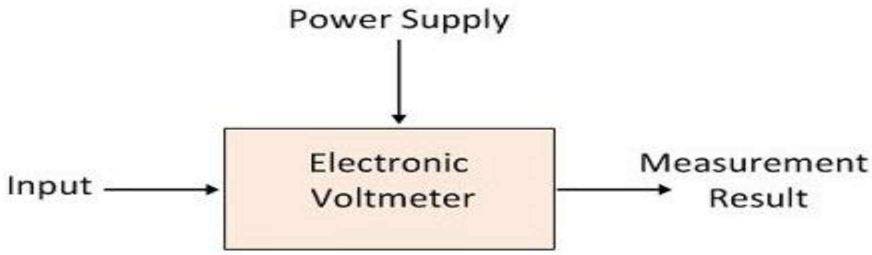
The **voltmeter which uses the amplifier** for **increases their sensitivity** is known as the electronic voltmeter. It is used for measuring the voltages of both the AC and DC devices.

The **electronic voltmeter has high input impedance because of which it detects the signals of very weak strength**, hence gives the accurate reading. The high impedance means the circuit opposes the input supply.

The electronic voltmeter uses the **transistor / vacuum tube**. The transistor type voltmeter (TVM) has **resistance** because of which it cannot measure the current. And the vacuum voltmeter (VVM) has low resistance. Hence it is used for measuring the current.

Working of Electronic Voltmeter

In moving coil voltmeter the large power is drawn from the measure circuit because of which the error occurs in their reading. This problem is overcome in the electronic voltmeter.



Electronic Voltmeter

In electronic voltmeter, **the pointer is deflected by taking the supply from the auxiliary amplifier circuit.** The output voltages of the amplifier circuit are similar to the voltage of the test circuit. The extra power is not passing through the deflector because of which the meter gives the accurate reading.

Electronic Voltmeter Types

1. Analog Electronic Voltmeter.
2. Digital Electronic Voltmeter.

Analog Electronic Voltmeter – The meter whose output is obtained by the deflection of the pointer on the calibrated scale is known as the analogue electronic measurement. It is a voltage measuring instrument which has high circuit impedance. The meter uses the electronic amplifier for controlling the input signals. The analogue electronic voltmeter is further classified into AC and DC analogue electronic voltmeter.

Digital Electronic Voltmeter – The voltmeter which gives the **digital output reading of the measures voltage** is known as the electronic voltmeter. The output of the digital electronic voltmeter is in the form of the numerical value. The digital electronic instruments reduce the human and the parallax error because the reading is directly shown in the numeric form.

Electronic Voltmeter Advantages

1. **Detection of Low-level signals** – **It uses the amplifier** which avoids the load error. The amplifier detects the very small signals which produce the current of approximately 50μA. The detection of low-level signals is essential for determining the true value of the measurement.
2. **Low Power Consumption** – The electronic voltmeter has vacuum tubes and the transistor which has the amplifying properties. It uses the **auxiliary source for the deflection of the pointer.** The measure and voltage controls the deflection of the sensing element. Thus, the circuit of the electronic voltmeter consumes very less power.
3. **High-Frequency Range** – The working of the electronic voltmeter is free from frequency range because of the transistor. Along with the voltage, the signal of very high and low frequency can also be measured through it.

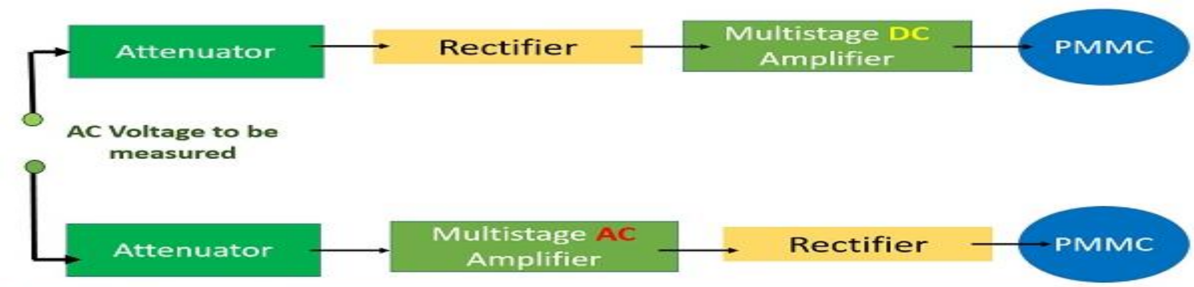
The electronics voltmeter measures the power only when they have the closed circuit, i.e., the current flows through their meter.

AC Voltmeter

AC voltmeters measure the AC voltage.

Block Diagram of AC Voltmeter

The **input to be measured** is given to the **attenuator circuit** which **performs the operation of selection of a particular range of voltage.** The **output of attenuator is given to rectifier** which converts the **AC voltage into pulsating DC voltage**. Then the final output of DC amplifier is given to the PMMC meter.

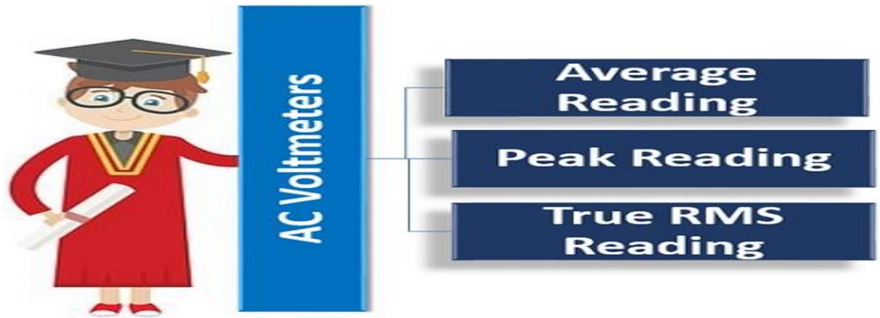


Block Diagram of AC Voltmeter

The rectifier can be used before the **multistage amplifier** or after the amplifier. This depends on the type of amplifier used in AC voltmeter. If we are using multistage AC amplifier, then the rectifier circuit will be used after the amplifier. On the contrary, if the multistage amplifier used is DC, then the rectifier should be used before it.

AC voltmeters Classification

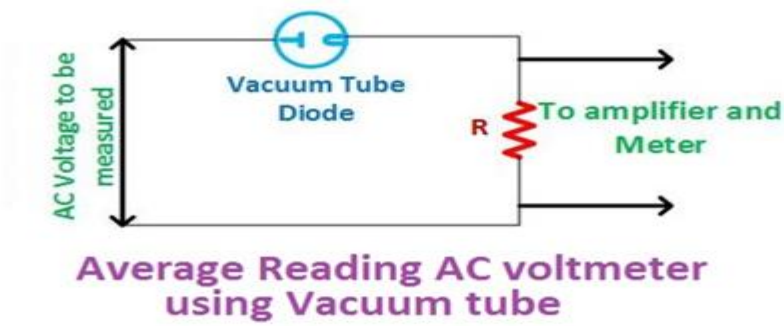
It’s based on the type of measurement it provides. These are average reading, peak reading and true RMS reading AC voltmeter.



Average Reading AC Voltmeter

The **average reading voltmeter** measures the **average value of the AC voltage**. The scale calibrated in average reading voltmeter is in terms of RMS value.

Average reading voltmeters can be designed in various manners such as by using vacuum diode, semiconductor diode or a full wave rectifier. In this, the **voltage-current characteristics** must be linear, because the **change in voltage is measured by the change in current.**
Let’s understand first the basic construction of AC voltmeters using vacuum diode.

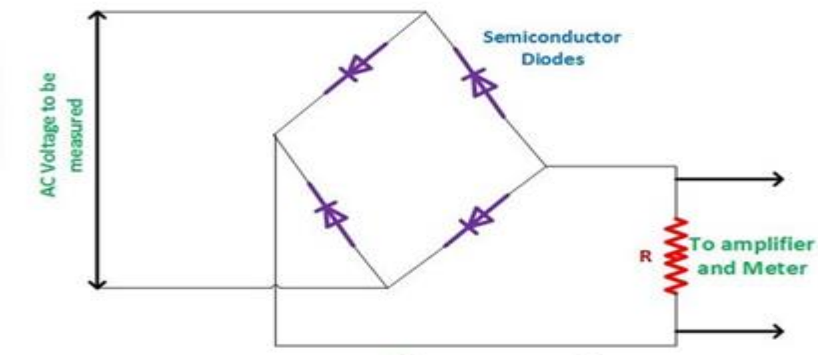


The requisite factor in such voltmeters is that the resistance of plates of vacuum tube should be low so that it does not create variation in linear characteristics of plate voltage and current.

The average current through the diode can be given by the below equation. The value of 1.11 represents the **form factor.** The multiplying factor of 2 represents the half wave rectification phenomenon.

$$I_{avg} = \frac{V_{avg}}{2R} = \frac{V_{rms}}{2\times1.11\times R} = 0.45\frac{V_{rms}}{R}$$

The average voltmeter can also be designed with the help of full wave rectifier. The average current in case of full wave rectifier will be double to that of half wave rectifier.



Average reading AC voltmeter using Full wave Rectifier

Advantages of Average Reading AC voltmeter

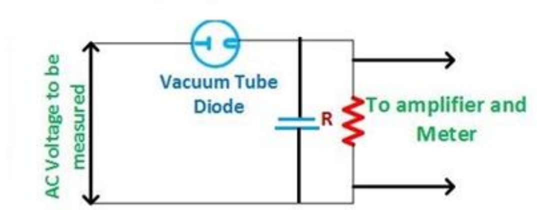
1. Low Power Consumption.
2. High input impedance.
2. Simple Construction.
4. Uniform scaling.

Disadvantages of Average Reading AC Voltmeter

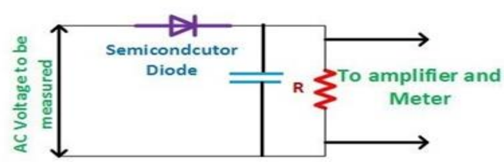
1. The circuit under measurement should possess low resistance otherwise it will load the circuit.
2. The linear characteristics should be strictly maintained because non-linear characteristics will create issue during measurement of low voltages.
3. It is appropriate only in audio-frequency range because, in radio frequency range, errors occur due to distributed capacitance.

Peak Reading AC Voltmeter

The peak reading voltmeter can also be **designed in two ways**. One is by using **vacuum tube** and another with the help of **semiconductor diode.** The difference between the peak reading and average reading circuit arrangement is only that the capacitor is not used in case of average reading while it is used in case of peak reading voltmeter.



Peak Reading AC Voltmeter using Vacuum tube diode

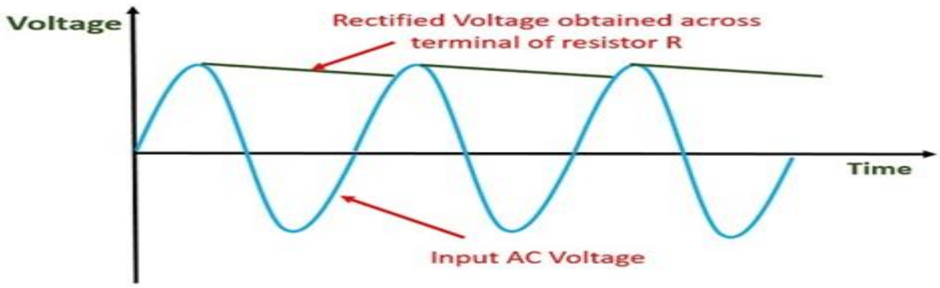


Peak Reading AC Voltmeter using diode

The above circuit shows the **AC voltmeter using vacuum tube**. The capacitor is connected in parallel to the resistance of high magnitude. The resistance is connected in parallel to the amplifier and the PMMC meter.

In the same way, it can be designed with the help of **semiconductor diode**. In place of the vacuum tube, we need to connect semiconductor diode in this case.

The working of the peak reading voltmeter can be easily understood with the help of above two circuits. When **the input voltage is applied the capacitor** starts charging until it attains its peak value. When the capacitor attains peak voltage, it starts **getting discharged through the resistor.**



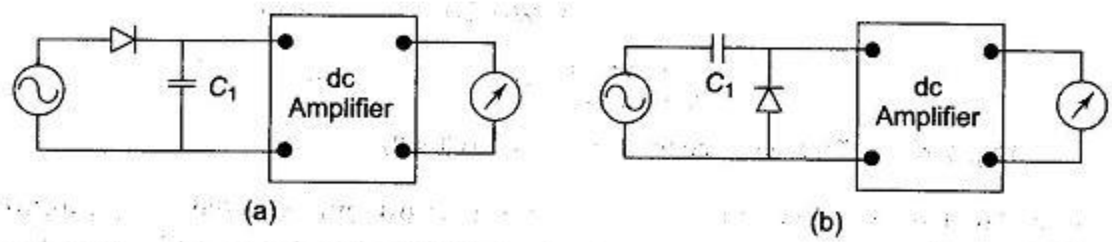


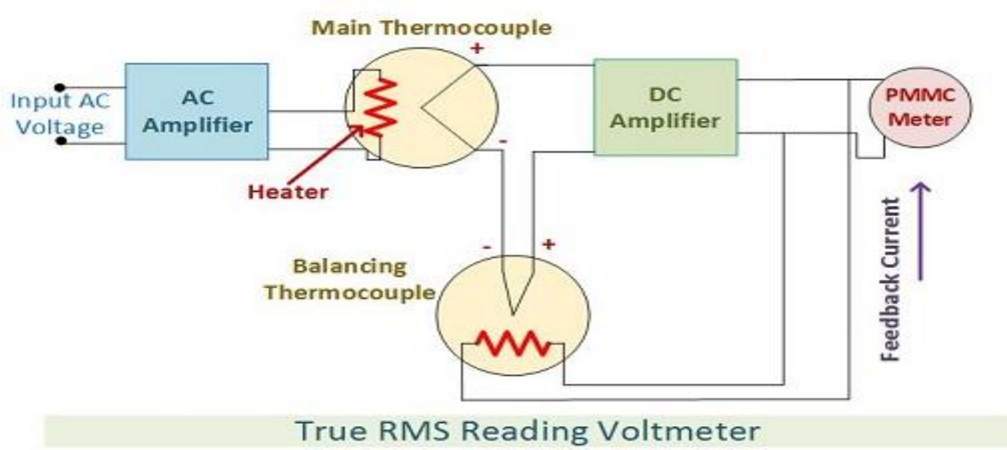
Fig. 4.24 Peak Responding Voltmeter

The main disadvantage of using **peak reading AC voltmeter is that it is not suitable for the measurement of a low voltage signal.** This is because, in case of the low input voltage, the electrons at high velocity still contribute to current flow in the circuit which produces errors in the measurement.

True RMS reading AC Voltmeter

The average reading voltmeter is economical and provides RMS value of sinusoidal waveforms then **what is the need for true RMS reading AC voltmeters?**

And that too when the cost of true RMS reading voltmeter is higher than that of average reading AC voltmeters. This is because in case of non-sinusoidal waveforms we need to calculate true **RMS voltage which is not possible** with the **help of average reading AC voltmeter. In such case, we need true RMS reading voltmeter.**



Principle of True RMS reading AC voltmeter

The **heating power associated with the waveform** varies **directly with the square of the RMS value of the voltage.** Thus, if by some means we succeed in **measuring the heating power of the waveform we can easily measure the RMS value associated with the input waveforms.**

For this purpose, a **thermocouple** is utilized. The thermocouple is an instrument which is used for measuring **heating power of waveforms.**

Voltage (RMS) ^{2} directly proportional to heating power.

Working

The thermocouple used here will fetch input voltage from AC amplifier. This is because the magnitude of the signal should be sufficiently high in order to provide correct measurements. The thermocouple will receive the input waveforms through its input terminal. This thermocouple is called **main thermocouple.**

Wave Form------------→Thermo Couple----------------→Heating Power

The non-linearity associated with the main thermocouple needs to cancel out. Otherwise, it will create errors in the final measurements. For this purpose, the **balancing thermocouple** is used. The non-linearity produced by balancing thermocouple and the non-linearity produced by the main thermocouple cancel out each other.

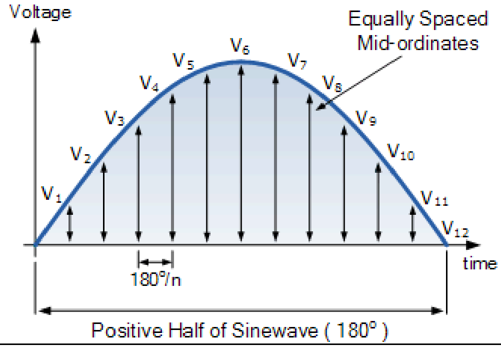
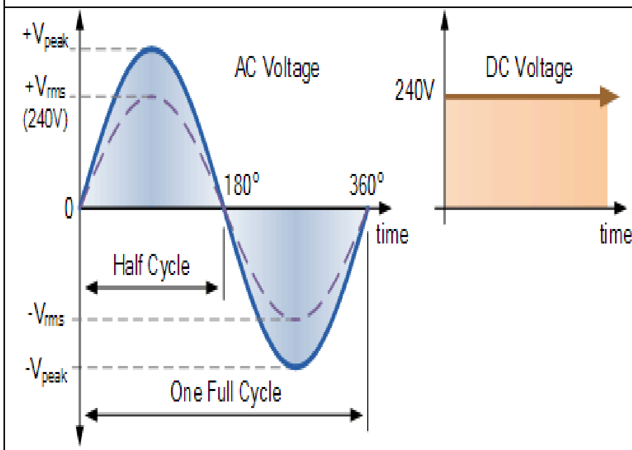
In this way, it acts as a balancing bridge circuit. The feedback current supplied by the AC amplifier is used for balancing in case of any error signal produced. When the input is not applied to the main thermocouple, then the output of both thermocouples will be equal and will produce zero voltage signal. Thus, **true RMS reading AC voltmeter** provides an aid to measure the RMS value of the non-sinusoidal waveform. It must be kept in mind that dynamic range of AC amplifier should be sufficiently high so that peak excursion created by input waveform does not exceed the range of AC amplifier.

RMS (Root Mean Square)

It refers to the most common mathematical method of defining the **effective voltage / current of an AC wave.** The RMS (Root-Mean-Square) value is the effective value of the total waveform. It is equal to the level of the DC signal that would provide the same average power as the periodic signal.

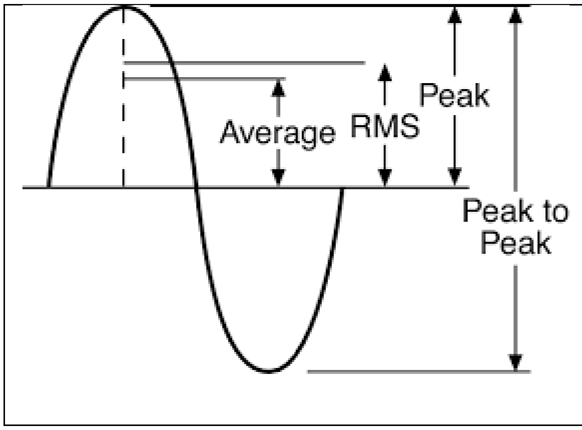
Methods of finding RMS voltage of a sinusoid or complex waveform

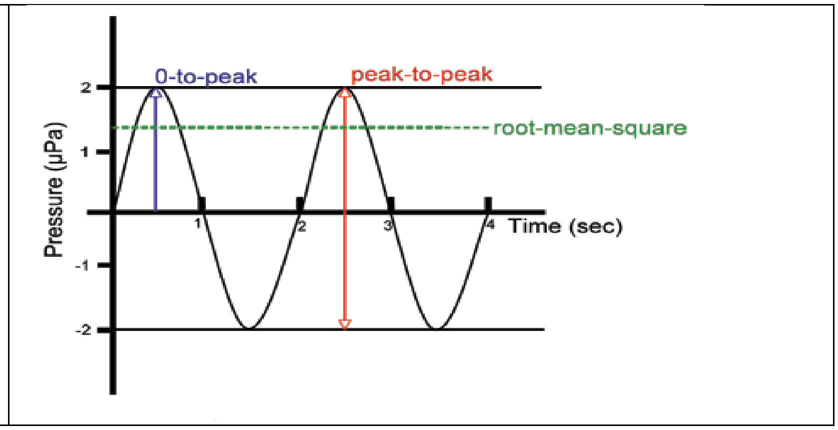
Graphical Method	**RMS Voltage Graphical Method**
Which can be used to find the RMS value of any non-sinusoidal time-varying waveform by drawing a number of mid-ordinates onto the waveform.	$V_{RMS} = \sqrt{\dfrac{\text{sum of mid-ordinate (voltages)}^2}{\text{number of mid-ordinates}}}$

	
Analytical Method It is a mathematical procedure for finding the effective or RMS value of any periodic voltage or current using calculus.	$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T V_m^2 \cos^2(\omega t)\, dt}$
RMS Voltage Equation **Peak voltage=V_{PK}** **Peak voltage=V_{PP}**	$V_{RMS} = V_{pk}\frac{1}{\sqrt{2}} = V_{pk} \times 0.7071$
	**Sinusoidal RMS Values** $V_{RMS} = \frac{1}{\sqrt{2}} \times V_{pk} = 0.7071 \times V_{pk}$ $V_{RMS} = \frac{1}{2\sqrt{2}} \times V_{p\text{-}p} = 0.3536 \times V_{p\text{-}p}$ $V_{RMS} = \frac{\pi}{2\sqrt{2}} \times V_{avg} = 1.11 \times V_{avg}$

Peak
A peak meter is a type of visual measuring instrument that indicates the instantaneous level of an audio signal that is passing through it (a sound level meter).

The **peak value** is the **highest voltage that the waveform will ever reach**, like the peak is the highest point on a mountain.





CRO (CATHODE RAY OSCILLOSCOPE)/ OSCILLOGRAPH

It contains into 4 sections.

1. Display. 2. Vertical controllers. 3. Horizontal controllers. 4. Triggers.

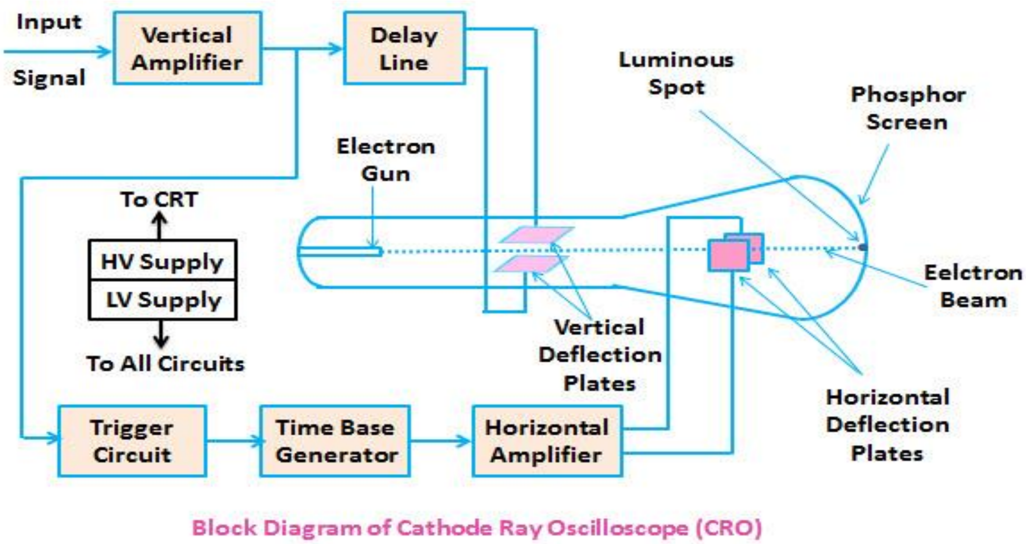
Most of the **oscilloscopes** are **used** the **probes** and they are used **for the input of any instrument.** We can analyze the waveform by plotting amplitude along with the x-axis and y-axis.

It **is an electronic test instrument**; it is used to obtain waveforms when the different input signals are given. The oscilloscope observes the changes in the electrical signals over time, thus the voltage and time describe a shape and it is continuously graphed beside a scale. By seeing the waveform, we can analyze some properties like **amplitude, frequency, rise time, distortion, time interval and etc.**

Cathode Ray Oscilloscope

CRO Block Diagram

The **CRO recruit** the **cathode ray tube** and acts as a **heat of the oscilloscope**. In an oscilloscope, the **CRT produces the electron beam** which is **accelerated to a high velocity** and brings to the focal point on a **fluorescent screen**. Thus, the screen **produces a visible spot** where the electron beam strikes with it. By detecting the beam above the screen in reply to the electrical signal, the electrons can act as an electrical pencil of light which produces a light where it strikes.



Block Diagram of CRO

Here we will use high voltage and low voltage. The low voltage is used for the heater of the electron gun to generate the electron beam. The high voltage is required for the cathode ray tube to speed up the beam. The normal voltage supply is necessary for other control units of the oscilloscope.
The horizontal and vertical plates are placed between the electron gun and the screen, thus it can detect the beam according to the input signal.
If the electron beam is detected in the X-axis and the Y- axis a **trigger circuit is given for the synchronizing these two types detections.** Hence the horizontal deflection starts at the same point of the input signal.

Vertical Deflection System (*amplifier)*
It is to amplify the weak signal so that the amplified signal can produce the desired signal. To examine the input signals are penetrated to the vertical deflection plates through the input attenuator and number of amplifier stages.

Horizontal Deflection System
The **vertical and horizontal system** consists of horizontal **amplifiers to amplify the weak input signals**, but it is different to the vertical deflection system. The **horizontal deflection plates are penetrated by a sweep voltage** that gives a time base. By seeing the circuit diagram the sawtooth sweep generator is triggered by the synchronizing amplifier while the sweep selector switches in the internal position. So the trigger saw tooth generator gives the input to the horizontal amplifier by following the mechanism. Here we will discuss the four types of sweeps.

Recurrent Sweep: Itself says that the saw tooth is respective.
Triggered Sweep: Sometimes the waveform should be observed that it may not be predicted, thus the desired that the sweep circuit remains inoperative and the sweep should be initiated by the waveform under the examination. In these cases, we will use the triggered sweep.
Driven Sweep: In general, the drive sweep is used when the sweep is a free running but it is a triggered by the signal under the test.
Non-Saw Tooth Sweep: This sweep is used to find the difference between the two voltages. By using the non-saw tooth sweep we can compare the frequency of the input voltages.
Synchronization: It produces the stationary pattern.
Internal: In this the signal is measured by the vertical amplifier.
External: In the external trigger, the external trigger should be present.
Line: The line trigger is produced by the power supply.
Intensity Modulation: It is produced by inserting the signal between the ground and cathode. This modulation causes by brightening the display.
Positioning Control
By applying the small independent internal direct voltage source to the detecting plates through the potentiometer the position can be controlled and also we can control the position of the signal.
Intensity Control: It has a difference by changing the grid potential with respect to the cathode.
Applications of CRO:
Voltage, Current measurement, Examination of waveform and Measurement of phase and frequency

Uses of CRO
1. Display different types of waveforms
2. Measure short time interval
3. Used as a voltmeter.

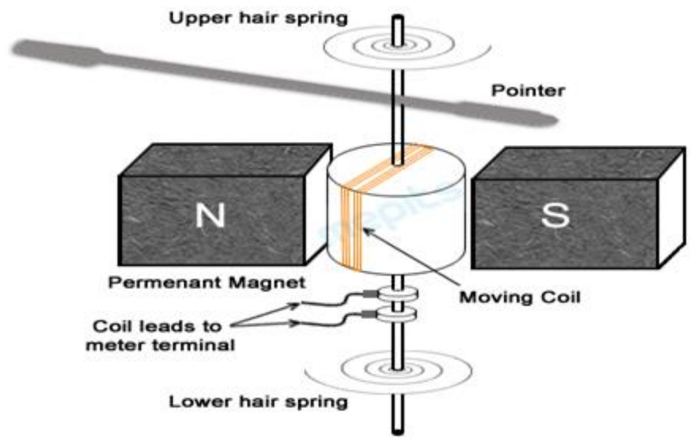
Electronic Instruments Used Commonly in Electronics Lab
Ammeter
It is an **electronic instruments** device **used to determine the electric current flowing through a circuit.** Ammeters measuring current in **milli-ampere** range is known as milli-ammeters.

Types of ammeters
1. Moving-coil ammeter.
2. Moving-iron ammeter.
Ammeters are connected in series to the circuit whose current is to be measured. Hence these electronic instruments are designed to have as minimum resistance/ loading as possible. It is used commonly in electronics lab.

Ammeter- Electronic Instruments

Moving Coil Ammeter

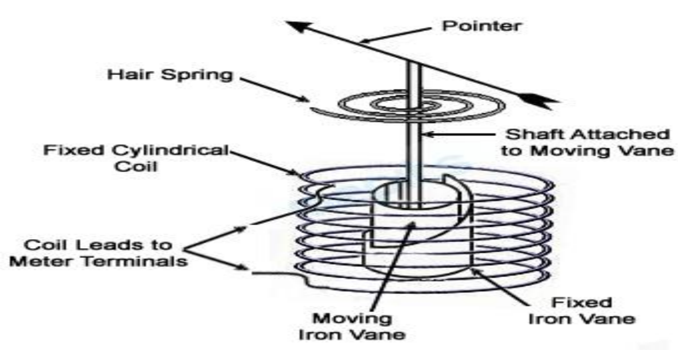
It is used to measure DC Currents in electronics lab. This electronic instrument consists of a **coil suspended by two hair springs.** This coil is placed in a magnetic field created by a fixed permanent magnet. **A torque is experienced when current passes through this coil which is proportional to the current.** When the coil turns, the springs will exert a **restoring force proportional to the angle turned.** By these two forces, the coil will stop at some point and the angular deflection will be proportional to the current.



Moving coil ammeter - Electronic Instruments

Moving Iron Ammeter

It as electronic instruments can be **used for measuring both direct and alternating currents in electronics lab.** It contain a piece of soft iron is used. This iron piece constitutes of a **moving vane and a fixed vane.** Current to be checked flows through a fixed coil placed around the iron piece. **This coil produces a magnetic field proportional to the current.** So the iron pieces will get magnetized with the same polarity. The movable vane turns away from the fixed vane due to magnetic repulsion. As the **iron turns**, **the spring of the electronic instruments will exert a restoring force** and **stop the vane**, when both the forces become equal. The pointer of the ammeter is attached to the movable vane, which will point to the proper current reading using a calibrated scale.



Moving Iron Ammeter - Electronic Instruments

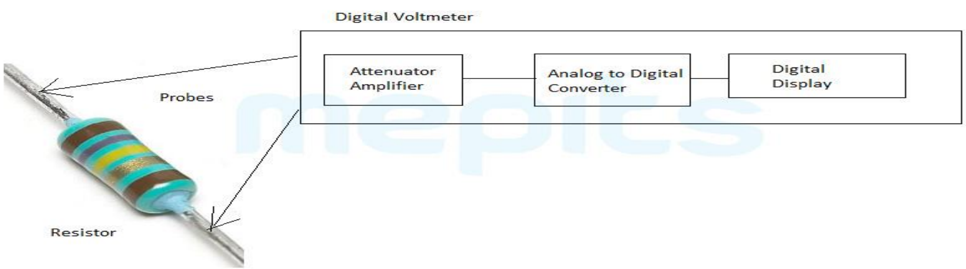
Voltmeter

It determines the potential difference or voltage between two different points. Digital and analog voltmeters are available in electronics lab. They are usually **connected in parallel (shunt) to the circuit.** Hence they are designed to have maximum resistance as possible to reduce the loading effect.

Analog Voltmeter

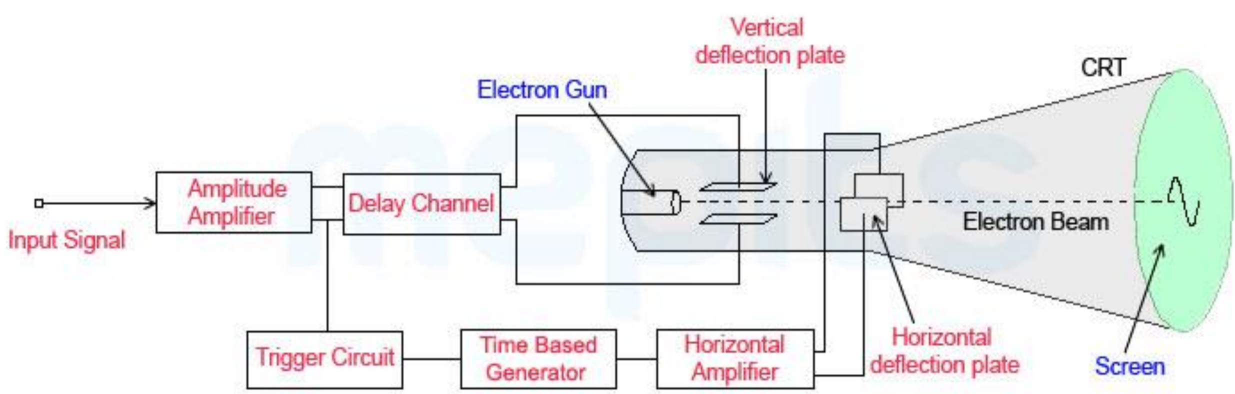
It is a type of voltmeter and electronic instruments with an extra connection of a series resistor (high resistance). **It consists of a movable coil placed in a magnetic field.** The coil ends are connected to the measuring terminals. As current flows across the coil, it will start turning due to magnetic force excreted on the coil and thus the hair spring will stop the coil by an equal and opposite restoring force. Angular rotation will be proportional to the voltage in this electronic instruments.

Digital Voltmeter



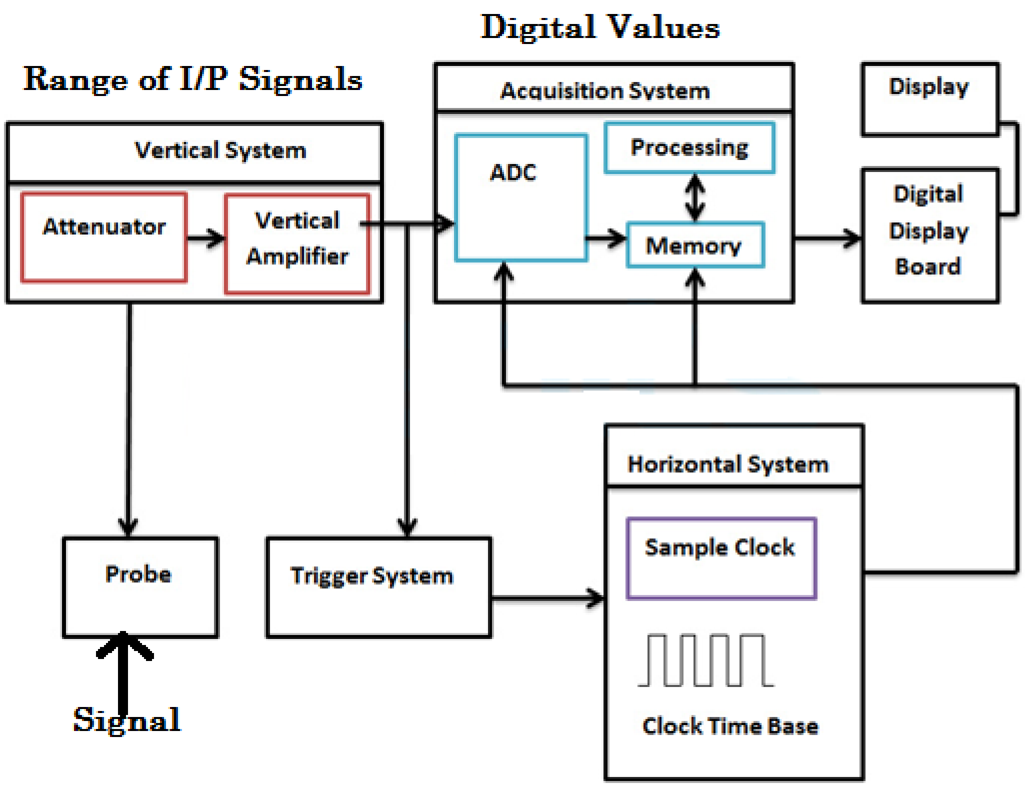
Digital voltmeters can measure both AC and DC measurements with high accuracy as an electronics instrument. It can measure a high voltage up to 1 kV. Main component of a digital voltmeter is an **Analog to Digital Converter (ADC)**. Voltage to be measured is amplified or attenuated properly by the circuit and the output is sent to an Analog to Digital Converter (ADC) IC. This IC will convert the analog signal input to digital signal output. A digital display driven by this **IC** will display the proper voltage value.

Oscilloscope

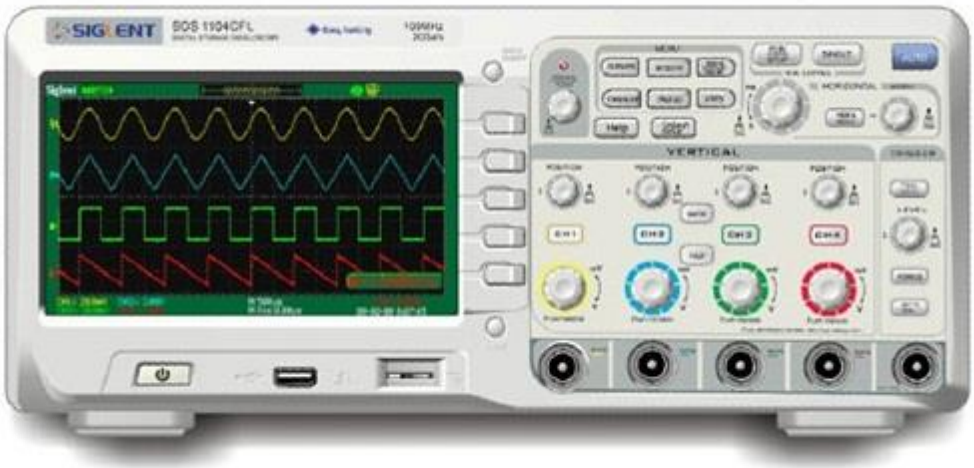


Oscilloscope used to **measure constantly varying signal voltages.** The input signal is not directly applied to the vertical plates it is delayed for a period of time by the delay channel. **Time based generator signal moves the glowing dot across the screen from left to right within a specific time interval.** Due to the **rapid sequence by many sweeps,** the glowing dot will blend into a solid line. In each second the dot may sweep across the screen up to 4-5 lakh times. The combined effect of the vertical deflection and the horizontal sweeping, traces a graph of the input signal on the screen.

Digital Storage Oscilloscope (DSO)
Used to **measure, store and display the input signal.** DSO will record the signal digitally into its memory and display it whenever needed.



DSO has 4 sections: vertical section, horizontal section, data acquisition section and display section. Vertical section takes the input signal from the **selected range.** Amplitude adjustments of the signal can be done in this section. From vertical section, the signal is fed to the acquisition section, in which the signal is sampled to digital values using an ADC. **The sampling rate is according to the clock generated by the horizontal section.** More than one sample points are stored in the memory as waveform points. **All the waveform points together make a waveform record.** The start and stop points of the record is determined by the trigger system. Display section will fetch the data from the memory to display it on the screen.

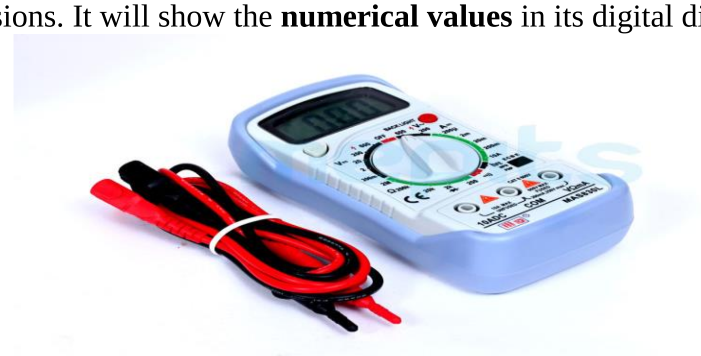


DSO - Electronic Instruments

In addition to the display functions, various mathematical operations such as **addition, subtraction, multiplication etc can be performed in a DSO.**

Multimeter

Used to measure different electrical parameters such as voltage, current, resistance etc. It is the common electronic instruments used to troubleshoot the faults in all electrical and electronic devices. **Digital multimeters** offer better **precision** and **accuracy** and are **cheaper** compared to the analog versions. It will show the **numerical values** in its digital display.



Multimeter

To measure the value of a **resistor**, probes of the multimeter are connected across the resistor. The multimeter is switched to **resistance measurement mode (position 1).** Then current from the constant current source **will flow through the resistor and a potential difference is created across the resistor.** According to **ohm's law,** this potential difference is proportional to its resistance. A buffer amplifier will amplify this voltage and feed it to an analog to digital converter (ADC). The digital display will show the value in ohms based on the output from the microprocessor. V=IR

For measuring AC current, the probes of the multimeter are connected in series to the circuit. The multimeter is switched to AC current measurement mode (position 2). In this case, it is to be ensured that the positive probe is connected to the current measurement plug on the multimeter.

The current to be measured is converted into proportional voltage by current to voltage converter. AC voltage is rectified by a rectifier circuit. The **rectifier** output voltage is converted into proportional digital signal by Analog to Digital Converter (ADC). Then, Digital display will show the value in amperes.

For measuring AC voltage, connect the AC voltage across the probes. Switch the multimeter to AC measuring mode (position 3). The AC voltage passes through an attenuator which attenuates the signal, if it is above the selected range. The rectifier circuit will rectify AC voltage into DC. Analog to Digital Converter will produce a digital signal proportional to the DC voltage, to get the digital display in volts.

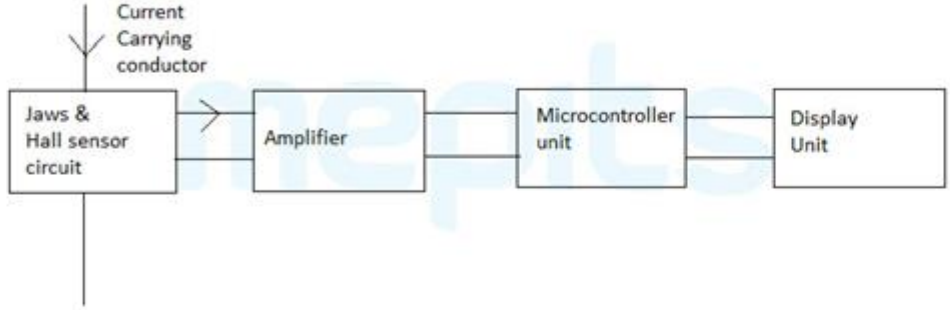
To measure DC current connect the current to multimeter probes. Switch multimeter to DC current measuring mode (position 4). Here also it is to be ensured that the positive probe is connected to the current measurement plug on the multimeter. By the use of a current to voltage converter, the input signal is converted into a proportional voltage. Using this voltage, analog to digital converter produces a digital signal to display the value in amperes.

If DC voltage is given as input, then we have to switch the multimeter to DC voltage measuring mode (position 5). If the input is above the selected range, then the attenuator will attenuate the signal. The voltage is then given as the input of an Analog to Digital Converter. It will generate a digital signal and display the value in volts.

Clamp on meter
Used to measure current flowing through a conductor. By this type of meter we can conveniently measure the current in a live wire without any interruption to the circuit. **Using this meter, large currents can be measured without shutting off or interrupting the circuit.**

AC clamp meter consists of a bar current transformer in its jaws. **When this jaws are clamped on a conductor, that conductor will act as primary. Magnetic flux due to the alternating current in the conductor will cut the secondary of current transformer.** A current to voltage converter will convert the current in the secondary of a current transformer to its proportional voltage. An Analog to digital converter will make the signal digital. The microcontroller used will drive the display unit to show the reading.

DC current is flowing through the conductor in a fixed polarity. So magnetic field around the conductor is fixed and will not change. **Due to this, for measuring DC current some changes in the AC clamp meter is needed.**



Hall Effect is the main principle behind the working of a DC clamp meter. It is the production of a potential difference across a material, when a magnetic field is applied in a direction perpendicular to that of the flow of current. In this meter a sensor known as hall element is used. The Hall element responds to the magnetic field due to direct current in the conductor by producing a **voltage across the element.** This voltage is proportional to the current. It is then **amplified and converted to digital value.** With the help of a microcontroller value of current is displayed.

LC / LCR Meter

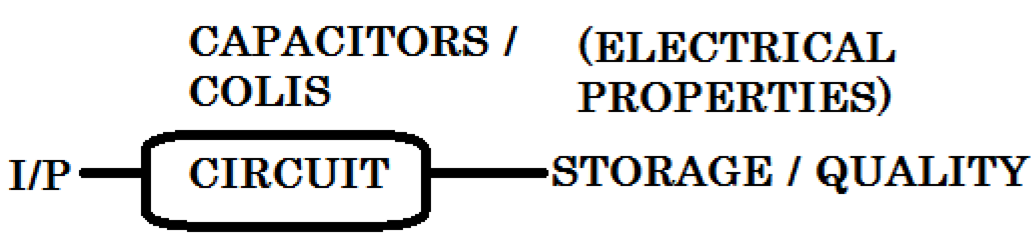
Used to measure inductance and capacitance. In this meter, the impedance of the object is measured and from its impedance values the inductance and capacitance is measured. An AC voltage is given to the device under test. **The circuit measures the voltage across the device and the current flowing through the device.** From the ratio of these values its impedance is calculated.

Q meter

It is used in electronics lab. It is used to **measure the electric properties of the capacitors and coils.** This process is done by measuring the Q value of the circuit.

The basic principle used is the resonant rise of the voltage across the capacitor in the circuit.

If XL=Xc and E=IR Q= (XL/R) = (XC/R)	

Q Meter Uses

- Coefficient of coupling
- Measure inductance and capacitance
- Find bandwidth
- Measure Q of the coil.

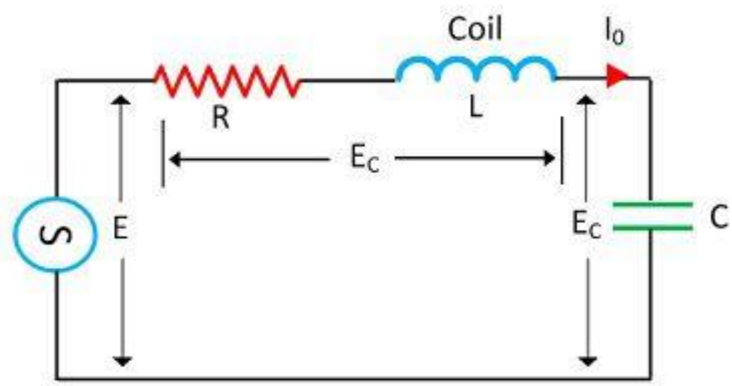
Q Meter

It measures the **storage / quality factor** of the electrical **circuit** at **radio frequencies**, such type of device is known as the Q-meter. The **quality factor** is one of the **parameters** of the **oscillatory system**, which shows the **relation** between the **storage and dissipated energy**.

The Q meter measures the quality factor of the circuit which **shows the total energy dissipated by it.** It also explains the properties of the coil and capacitor. The Q meter uses in a laboratory for testing the radio frequency of the coils.

Working Principle of Q meter

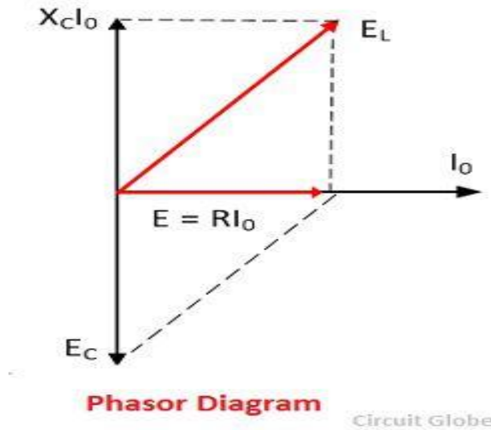
The Q meter works on series resonant. The resonance is the condition exists in the circuit when their inductance and capacitance reactance are of equal magnitude. They induce energy which is oscillating between the electric and magnetic field of the capacitor and inductor respectively. The Q-meter is based on the characteristic of the **resistance**, **inductance** and **capacitance** of the resonant series circuit. The figure below shows a coil of resistance, inductance and capacitance connected in series with the circuit.



Resonant RLC Series Circuit

At resonant frequency f_0, $X_C = X_L$ the value of capacitance reactance is $X_C = \frac{1}{2}\pi f_0 C = \frac{1}{\omega_0 C}$ at inductive reactance, $X_L = \frac{1}{2}\pi f_0 L = \frac{1}{\omega_0 L}$

At the resonant frequency, $f_0 = \frac{1}{2\pi\sqrt{LC}}$ and current at resonance becomes $I_0 = \frac{E}{R}$ The



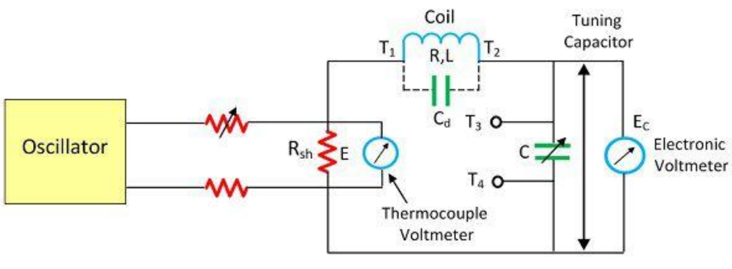
phasor diagram of the resonance is shown in the figure

The voltage across the capacitor is expressed as $E_C = I_0 X_C = I_0 X_L = I_0 \omega_0 L$ Input voltage $E = I_0 r$ $\frac{E_C}{E} = \frac{I_0 \omega_0 L}{I_0 R} = \frac{\omega_0 L}{R} = Q$ $E_0 = QE$ The above equation shows that the input voltage E is Q times the voltage appears across the capacitor. The voltmeter is calibrated for finding the value of Q factor.

Applications of the Q-meter

1. Measurement of Q	$Q_{true} = Q_{meas}\left(1 + \frac{C_d}{C}\right)$ $Q_{max} = \frac{\omega_0 L}{R}$	$Q_{max} = \frac{\omega_0 L}{R}$ $Q_{true} = Q_{meas}\left(1 + \frac{R_{sh}}{R}\right)$
2. **Measurement of Inductance**		$L = {}^{1}/_{4\pi^2 f_0^2 C}$
3. **Measurement of Effective resistance**		$R = \frac{\omega_0 L}{Q_{true}}$
4. **Measurement of Self-Capacitance**	distributed capacitance The self-capacitance is determined by measuring the two capacitance at different frequencies. The capacitor is adjusted to the high value, and the circuit is resonated by adjusting the oscillator frequency.	$C_d = \frac{C_1 - 4C_2}{3}$

5. **Measurement of Bandwidth**		$$Q_{max} = \frac{\omega_0 L}{R}$$
6. **Measurement of Capacitance**	The capacitance is determined by connecting the dummy coil across the terminal T_1 and T_2. Let the capacitor under test is connected across the terminal T_3 and T_4. The circuit is again resonated by varying the value of tuning capacitor C_2. The value of testing capacitance is determined by subtracting the C_1 and C_2.	



Circuit of Q meter

The oscillator and tuning capacitor adjust to the desired frequency for obtaining the maximum value of E_0. Under this condition, the value of the quality factor is expressed asTrue value is given as The value of the quality factor is obtained by the voltmeter which is connected across the capacitor. The measured value is the Q factor of the whole circuit and not only of the coil. Thus, errors occur in the reading because of the shunt resistance and distributed capacitance.

Distortion Meter
Used to **determine specific frequencies** that **cause distortion in electronic devices.** The device is primarily **used in audio related equipment.**

What is a distortion meter used for? Now distortion meter is such a device which measures detects the frequencies which are responsible for producing harmonic distortion in our signal. So the first question that needs to be answered is that what is harmonic distortion?

Harmonic distortion
It is the distortion in our signal that is **produced by the additional frequencies generated in the signal.** These frequencies are nothing but multiples of the original frequency of our signal. Harmonic distortion occurs not only in sound waves, as that is the most commonly used example.

It also occurs in electrical signals, that is, **when a current is passing through a circuit, it can induce vibrations in the circuit** and the **vibrations produced would obviously be some multiple of the current signal frequency.** Hence these **vibrations can cause distortion in our original signal.** This distortion in current can lead to **many problems like voltage fluctuation etc.**

How to use a distortion meter?
Used for the detection and measurement of such frequencies, what lies next?

So once the frequencies are detected, the distortion meter now acts such that it works to **eliminate the effect of such frequencies.** For this purpose it has the option to set certain predefined parameters, so that any **frequencies which lie outside these set of parameters are eliminated and not allowed** to pass along **with the original signal.** The original signal can then be produced at the output in whatever way it is required.

A typical distortion meter looks something like this:

Applications of Distortion Meter

1. Distortion meters are being widely used now a days especially in **music industry**. For eliminating the unwanted frequencies we use a distortion meter.

2. Distortion meters also find extensive uses in electrical circuits now a days. As mentioned earlier they are used to **eliminate the distortions in the currents and voltages** which can also prove fatal in some cases.
3. Many advance electrical machines use distortion meters to compensate for the current distortions so that the expensive appliance can be **saved from damage due to these distortions.**

Spectrum analyzer

It displays signal amplitude (strength) as it varies by signal frequency. The frequency appears on the horizontal axis, and the amplitude is displayed on the vertical axis. To the casual observer, a spectrum analyzer looks like an oscilloscope, and in fact, some devices can function either as **oscilloscopes or spectrum analyzers.**

The electronics industry uses spectrum analyzers to examine the **frequency spectrum of radio frequency (RF) and audio signals.** These devices display the individual elements of these signals, as well as the performance of the circuits producing them.

How spectrum analyzers work

Most spectrum analyzers offer users the opportunity to set a **start, stop and center frequency.**

Features

Able to do analog-to-digital conversion and sample a significant input signal and frequency range. A modern spectrum analyzer may be **able to show displayed average noise level,**

calculating the average noise level detected by the device. These detectors are typically capable of sample detection, peak detection or average detection.

Uses for spectrum analyzers

A spectrum analyzer can be used to determine **whether or not a wireless transmitter** is working according to federally defined standards for purity of emissions. **Used to determine, by direct observation, the bandwidth of a digital or analog signal.**

Types of spectrum analyzers

Swept or superheterodyne

A swept-tuned, or superheterodyne, spectrum analyzer down-**converts part of the input signal to the center frequency of a band-pass filter by running a voltage-controlled oscillator across a range of frequencies.**

Fast Fourier transform, FFT

Some digital spectrum analyzers use Fourier transforms -- a way of **decomposing a signal into its individual frequencies.**

Real-time

Real-time analyzers collect real-time bandwidth and sample the incoming RF spectrum in a limited span of time, **converting the information using the fast Fourier transform (FFT) algorithm.**

Audio

Spectrum analyzers can also be used in the **audio spectrum, displaying volume levels of frequency bands audible to humans.**

Spectrum analyzer interface

It can be connected to a **wireless receiver or a personal computer to allow visual detection and analysis of electromagnetic signals over a defined band of frequencies.** This is called panoramic reception, and it can be used to determine the frequencies of sources of interference to wireless networking equipment, such as Wi-Fi and wireless routers.

Continue Reading about spectrum analyzer

- Tools to manage wireless network connections
- Wireless LAN troubleshooting strategies for BYOD
- Checklist for troubleshooting Wi-Fi issues

Spectrum analyzers are an invaluable item of electronic test equipment **used in the design, test and maintenance of radio frequency circuitry and equipment.** Spectrum analysers, like oscilloscopes are a basic tool used for observing signals. However, where oscilloscopes look at signals in the time domain, spectrum analyzers look at signals in the frequency domain. Thus a spectrum analyser will display the amplitude of signals on the vertical scale, and the frequency of the signals on the horizontal scale.

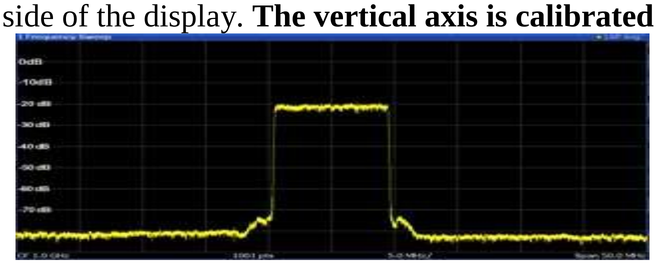
How to use a Spectrum Analyzer
How to use it to make radio frequency tests and measurements.

SPECTRUM ANALYZER TUTORIAL INCLUDES

Using spectrum analysers it is possible to **make measurements of the bandwidth of modulated signals can be checked to discover whether they fall within the required mask.** Another way of using a spectrum analyzer is in **checking and testing the response of filters and networks.** By using a tracking generator - a signal generator that tracks the instantaneous frequency being monitored by the spectrum analyser, it is possible to see the loss at any given frequency. In this way the spectrum analyser makes a plot of the frequency response of the network.

Spectrum analyser display
A key element of using a spectrum analyser is in understand in the display. The purpose of a spectrum analyzer is to **provide a plot or trace of signal amplitude against frequency.**

The **horizontal axis** of the analyzer is linearly calibrated in **frequency** with the higher frequency being at the right hand side of the display. **The vertical axis is calibrated in amplitude.**



Typical spectrum analyser display

Setting the spectrum analyzer frequency
When using a spectrum analyser, one of the first settings is that of the frequency.
Dependent upon the spectrum analyser in use, there are various ways in which this can be done:
1. Using centre frequency
2. Using upper and lower frequencies: Another option that is available on most spectrum analysers is to set the start and stop frequencies of the scan. This is another way of expressing the span as the difference between the start and stop frequencies is equal to the span

Adjusting the gain
RF Attenuator: as the name implies this control provides RF attenuation in the RF section. It is actually placed before the RF mixer and serves to control the signal level entering the mixer.
IF Gain: The IF Gain control controls the level of the gain within the IF stages of the spectrum analyser after the mixer. It enables the level of gain to be controlled to allow the signal to be positioned correctly on the vertical scale on the display.

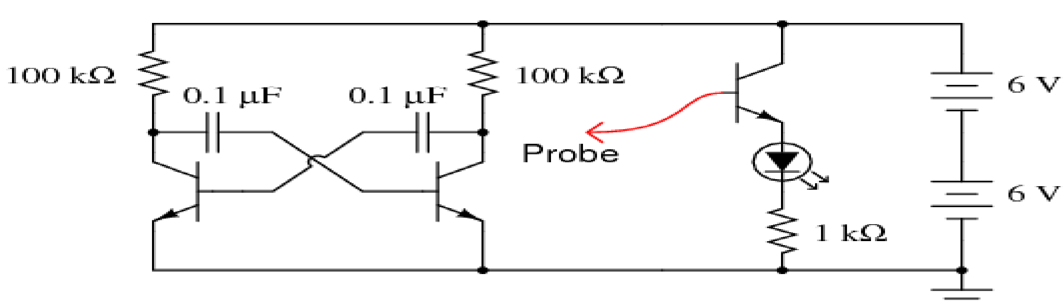
Filter bandwidths
Other controls on the spectrum analyzer determine the bandwidth of the unit. There are two main controls that are used:
IF bandwidth: The IF filter, sometimes labelled as the resolution bandwidth **adjusts the resolution of the spectrum analyzer in terms of the frequency.**
Video bandwidth: Te video filters enable a form of averaging to be applied to the signal. This has the effect of reducing the variations caused by noise and this can help average the signal and thereby reveal signals that may not otherwise be seen.

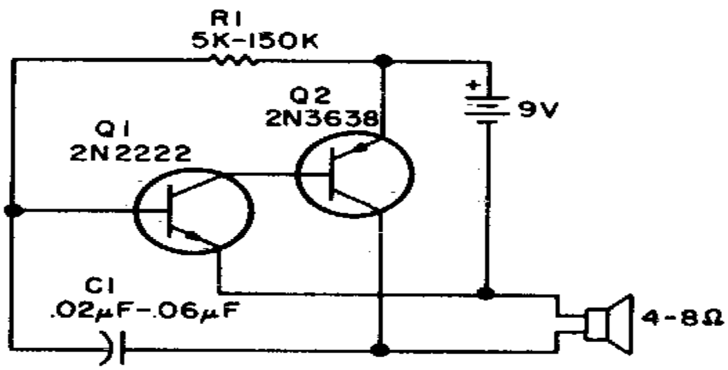
Scan rate
The spectrum analyser operates by scanning the required frequency span from the low to the high end of the required range. The speed at which it does this is important. The slower the scan, obviously the longer it takes for the measurements to be made. As a result, there is always the need to ensure that the scans are made as fast as reasonably possible.

Audio Oscillators
It is an electronic device that generates a periodic (i.e. repetitive) waveform. This waveform has it's fundamental frequency (the "loudest") between the human hearing range.

What is audio frequency?
The range of frequencies that **human beings are capable of hearing directly as sound;** it is generally taken to mean the range from approx. 20 Hz to 20 kHz, although many people can hear somewhat beyond this, and in most humans the upper limit to the audible range falls off significantly starting around age 30 or so.

SCHEMATIC DIAGRAM





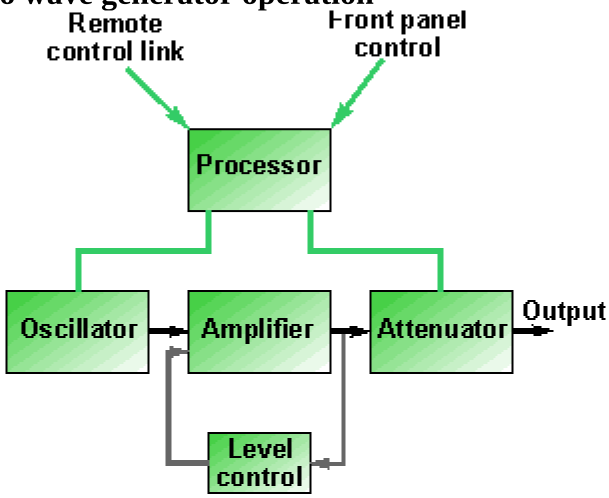
RF signal generator
It is useful to test equipment widely used in RF microwave design and test applications.
These microwave and RF signal generators come in a variety of forms and with a host of facilities and capabilities.

In order to gain the most from any RF signal generator or microwave signal generator, it is necessary to have an understanding of its operation and the capabilities it possesses.

Types of RF signal generator
1. Free running RF signal generators: These signal generators are rarely used these days as their frequency tends to drift. However they do have the advantage that the signal produced is very clean and does not have the level of noise (phase noise) either side of the main signal that is present on some other radio frequency signal generators.
Some signal generators used a form of frequency locked loop to provide a means of adding some frequency stability while still retaining the very low levels of phase noise. Again, these are not common these days because the performance of RF signal generators using frequency synthesizer technology has considerably improved.
2. Synthesized radio frequency signal generators: Virtually all radio frequency signal generators used today **employ frequency synthesizers**. Using this technique enables frequencies to be entered directly from a keypad, or via remote control and it also enables the output signal to be determined very accurately.

There are two main techniques that are used within **synthesized RF signal generators:**
1. Phase locked loop synthesizer: Phase locked loop synthesizers are used within most RF signal generators as they enable signals to be generated over a wide range of frequencies with a relatively low level of spurious signals.
2. Direct Digital Synthesizer, DDS

RF signal/Generic micro wave generator operation



Block diagram for a generic RF signal generator

The diagram shows a very simplified block diagram for an RF / Microwave signal generator.

From this, it can be seen that the generator has a few major blocks within it:
Oscillator: It would take commands from the controller and be set to the required frequency.
Amplifier
Attenuator: An attenuator is placed on the output of the signal generator. **This serves to ensure accurate source impedance is maintained as well as allowing the generator level to be adjusted very accurately.**
Control: Advanced processors are used to ensure that the RF and **microwave signal generator** is easy to **control** and is also able to **take remote control commands.** The processor will control all aspects of the operation of the test equipment.

RF signal generator functions
Frequency range
Output level
Modulation
Sweep
Control: There are many options for controlling RF and microwave signal generators these days.

RADIO-FREQUENCY (RF) SIGNAL GENERATORS
In addition to the necessary power supply, a typical rf signal generator contains three other mainsections: an **OSCILLATOR CIRCUIT**, a MODULATOR, and an OUTPUT CONTROL CIRCUIT. **Oscillator circuit used depends on the range of frequencies for which thegenerator is designed.**
INTERNAL MODULATION.
EXTERNAL MODULATION.

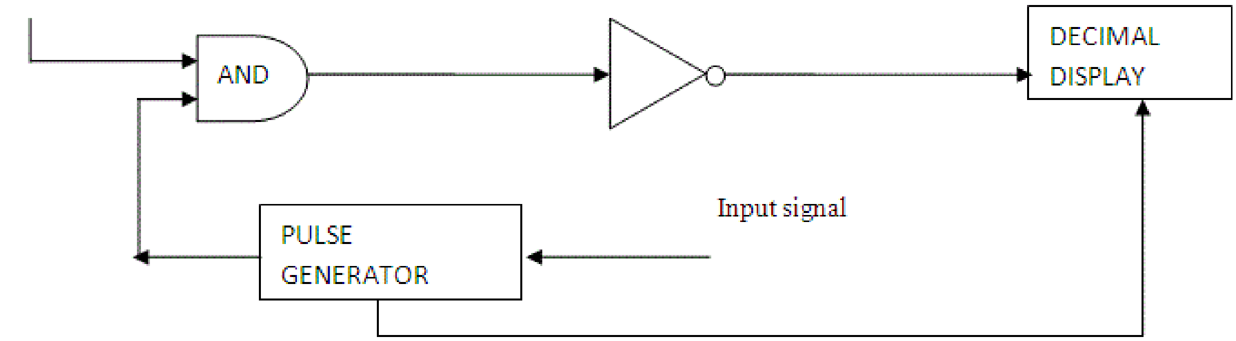
Introduction to Digital Voltmeter
Used to measure potential difference between two points. The **voltage** to be measured may be AC or DC. **Two types of voltmeters** are available for the purpose of voltage measurement i.e.

analog and digital. Analog voltmeters generally contain a dial with a needle moving over it according to the measure and hence displaying the value of the same. With the passage of time analog voltmeters are replaced by **digital voltmeters**

Advantages Associated with Digital Voltmeters

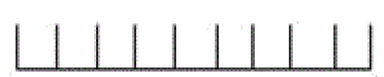
- Read out of **DVMs** is easy as it eliminates observational **errors in measurement** committed by operators.
- Error on account of parallax and approximation is entirely eliminated.
- Reading can be taken very fast.
- Output can be fed to memory devices for storage and future computations.
- Versatile and accurate
- Compact and cheap
- Low power requirements
- Portability increased

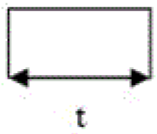
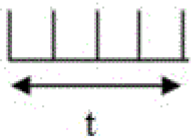
Working Principle of Digital Voltmeter



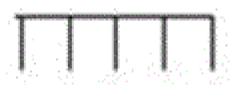
The **block diagram of a simple digital voltmeter** is shown in the figure. **Explanation of various blocks Input signal:** It is basically the signal i.e. **voltage** to be measured. **Pulse generator:** Actually it is a **voltage source**. It uses digital, analog or both techniques to generate a rectangular pulse. The width and frequency of the rectangular pulse is controlled by the digital circuitry inside the generator while amplitude and rise and fall time is controlled by analog circuitry.

AND gate: It gives high output only when both the inputs are high. When a train pulse is fed to it along with rectangular pulse, it provides us an output having train pulses with duration as same as the rectangular pulse from the pulse generator.

	Train pulse

	Rectangular pulse
	Output of AND gate

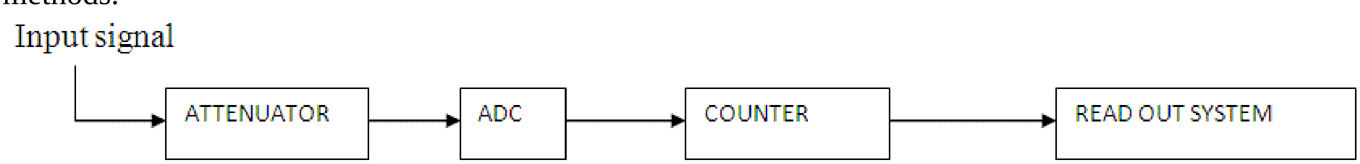
NOT gate: It inverts the output of AND gate.

	Output of NOT gate

Decimal Display: It counts the numbers of impulses and hence the duration and display the value of voltage on LED or LCD display after calibrating it. Now we are in situation to understand the **working of a digital voltmeter** as follows:

- Unknown voltage signal is fed to the pulse generator which generates a pulse whose width is proportional to the input signal.
- Output of pulse generator is fed to one leg of the AND gate.
- The input signal to the other leg of the **AND gate** is a train of pulses.
- Output of AND gate is positive triggered train of duration same as the width of the pulse generated by the pulse generator.
- This positive triggered train is fed to the inverter which converts it into a negative triggered train.
- Output of the inverter is fed to a counter which counts the number of triggers in the duration which is proportional to the input signal i.e. voltage under measurement.
- Thus, counter can be calibrated to indicate voltage in volts directly.

We can see the working of digital voltmeter that it is nothing but an analog to digital converter which converts an analog signal into a train of pulses, the number of which is proportional to the input signal. So a **digital voltmeter** can be made by using any one of the A/D conversion methods.



Digital voltmeters can be classified as:

- Ramp type digital voltmeter
- Integrating type voltmeter
- Potentiometric type digital voltmeters
- Successive approximation type digital voltmeter

- Continuous balance type digital voltmeter

Now-a-days **digital voltmeters** are also replaced by digital millimeters due to its multitasking feature i.e. it can be **used for measuring current, voltage and resistance.** But still there are some fields where separated digital voltmeters are being used.

Digital Display Devices

Types:
CRT
LCD
It contains the liquid crystals and these displays do not contain the tubes. So, there isn't any electronic gun as well and one doesn't have to worry about the electrons painting the display. Instead, there is a back light that always keeps the liquid crystal display on.
LED
Plasma: This is another new invention and it is named as the plasma display since there are some really small sized cells are present there. These cells are of the Nobel gases and when the voltage is provided to them, the ultra-violate ray is generated and the each light is brightened and hence the light is emitted through the display. Now, the phosphorus is being used instead of these cells and hence the colour quality has been improved a lot.

Projector
OLED: This technology is the new technology. It stands for the Organic Light emitting Diodes. This technology is the flat light emission one and it is made through some thin films which are organic and they are placed between two conductors. Whenever it gets hit by the electricity, the bright light comes out of it. These displays do not require some backlight and they are pretty thinner. So, they are better than all the LED and the LCD since they don't use the backlight to project an image.

Refresh Rates
Refresh rate is actually important when one talks about the CRT displays. The rate was the measurement to tell how fast and efficient a CRT display is. The rate describes that how fast an electrons gun can throw electrons on the screen and how fast the display can be shown. The refresh rates for the devices, which were considered good, were between 65 and 75. Also, sometimes they reach 85 hertz as well. It meant that the screen could be refreshed around 85 times in just one second. But the thing is, the when the screens got bigger, it became a problem since the electrons has to cover the wider areas and the number of screen updates got reduced dramatically. When the refresh rate turned to 72 Hz or near it, that used to be a big problem since at the rate, the human eye started flickering. Also, it became so annoying while watching the display. Also, the important thing is that the display which could support some resolution desired by the people was shown at above 72 Hz. But the modern technology has allowed the LED and the LCD displays to update every single pixel on the screen instantly and hence one doesn't have to face the flickering or any other problem in viewing the display.

Resolution
Native Resolution
Brightness/Lumens

When we talk about seeing some clear displays, we also talk about having the clear brightness. The brightness can be increased and decreased. The measurement of brightness is done through the luminance. It is also measures as the candela that is per square meter.

Analog vs. Digital
The video signals that are sending to the display from the computers vary in their nature.

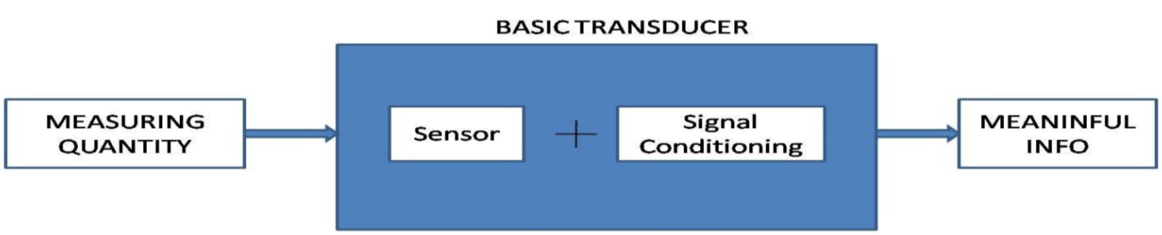
Privacy/Antiglare Filters
Filters are added to the displays by the people and they have become pretty common.

Multiple Displays
If one is using a workstation, he might **need more than one display** so that the information can be seen all at once and it becomes easier for the user to work on it. One can put some various applications at the various places in the multiple screens. One can have the different things grouped up and shown on the other screens. Also, these **displays can be used as the mirror as well and they can be shown to the other people who can know what one is doing on the computer.**

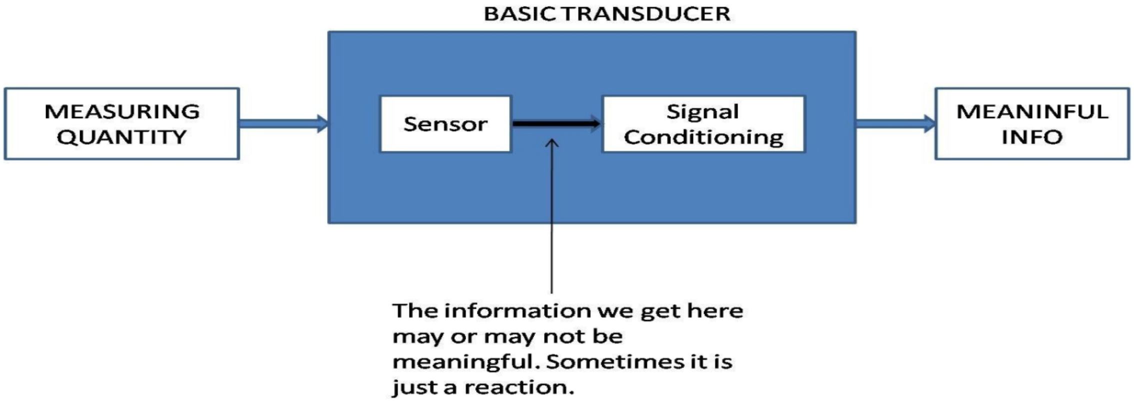
Sensor and Transducers
Sensor - It is a body which **reacts** to a **physical, chemical or biological condition.** It **senses**. It can be considered as a detector.

Transducer - The conversion of energy from one form to another is known as Transduction. A transducer serves for this purpose.
A Sensor can sense in any form (usually electronic) i.e. due to some mechanical change, it can react in electrical form. Thus there is a conversion, similar to that of a transducer.
A classic example would be a **thermocouple. / Pressure** sensor which might detect pressure and convert it into electric current (3-15psi to 4-20ma)

A Transducer is more than a sensor. It consists of a sensor/actuator along with signal conditioning circuits.
A signal conditioning circuit **which conditions the signal so that it is strong enough for further processing.** A system might contain many **stages before the signal** finally reaches its destination to derive meaningful information.



So one way to define is that the output from a sensor may or may not be meaningful i.e most of the times it needs to be conditioned and converted into various other forms. The transducer output is always meaningful.



The output of a **motor** is meaningful. The output of a **loudspeaker** is meaningful. They are transducers. A sensor is nothing but just a primary element which senses any physical phenomenon or it **gives an indication** in any **change of the physical phenomenon.**

We can say that **every transducer is also (or has) a sensor but every sensor need not be a transducer**. Sometimes it is. A compass is a simple sensor of magnetic north, wherein the magnetic element in the compass is the transducer.
Thermocouple etc where the temperature is sensed and the measurement is made in terms of voltage.

Resistive inductive and capacitive pickups for non electrical quantities
Transducer is defined as a device which converts **energy / information** from one form to another. Transducer may be mechanical, electrical, magnetic, optical, chemical, and thermal or combination of two or more of these

Electrical Transducers
Most **quantities** to be measured are **nonelectrical** such as temperature, pressure, displacement, humidity, fluid flow, speed, pH, etc., but these quantities **cannot be measured directly.** Hence such **quantities are required to be sensed and changed into some other form of quantities.** Therefore, for measurement of nonelectrical quantities these are to be converted into electrical quantities (because these are easily measurable). This conversion is done by device called Electrical Transducer

Classification of transducers
1. Based on principle of transduction
2. Active & passive
3. Analog & digital
4. Inverse transducer

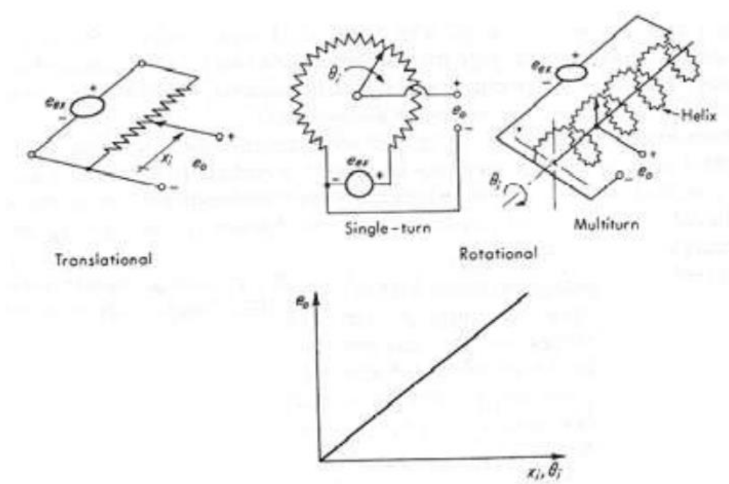
Based on principle used
• Thermo electric • Magneto resistive • Electro kinetic • Optical

Passive transducer
Device which need **external power for transduction** from auxiliary power source Eg : resistive, inductive, capacitive Without power they will not work

Active transducer
• No extra power required.
• Self generating
• Draw power from input applied
• Eg. Piezo electric x'tal used for acceleration measurement

Resistive Transducer
In this transducer, the **resistance of the output terminal** of the transducer gets varied according to the measured. Some resistive transducers are:-
Potentiometer
Strain gauge
Resistance Thermometer

RESISTIVITE POTENTIOMETERS
A resistance element **provided with a movable contact.** This is very simple and cheap form of transducer and is widely used. It converts linear or **rotational displacement into a voltage.** The contact motion can be **Linear, rotation and combination of the two such as helical**



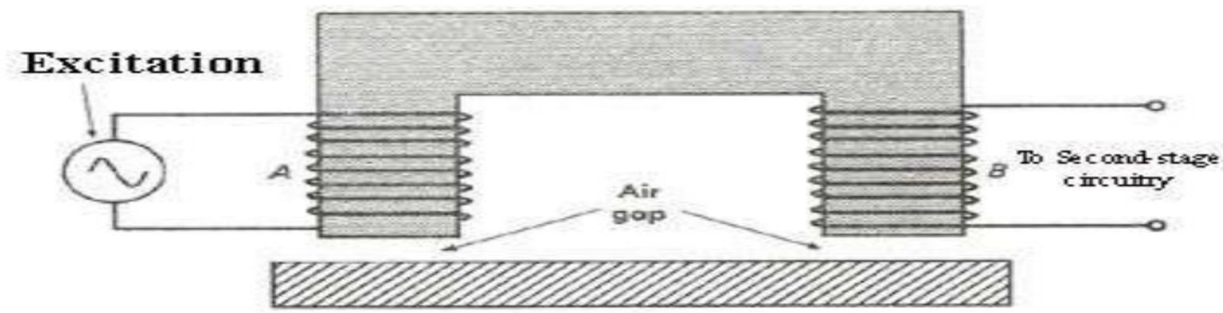
Strain Gauges
Used for measuring **mechanical surface strain** and one of the most extensively used electrical transducer. It can detect and convert force or small mechanical displacement into electrical signal. Many other quantities such as torque, pressure, weight and tension etc, which involve the effect of force or displacement, can be measured with string gauge.

Gauge Factor (G) = Change in resistance per unit strain.

Strain Gauge can be of four types:-
1. Wire strain gauge.
2. Foil strain gauge.
3. Thin film strain gauge.
4. Semiconductor strain gauge.

Inductive transducers are those in which SELF INDUCTANCE of a coil or the MUTUAL INDUCTANCE of a pair of coil is altered due to variation in the measure and. Change in inductance ΔL is measured.

The self inductance of a coil refers to the flux linkage within the coil due to current in the same coil. Mutual inductance refers to the flux linkages in a coil due to current in adjacent coil.



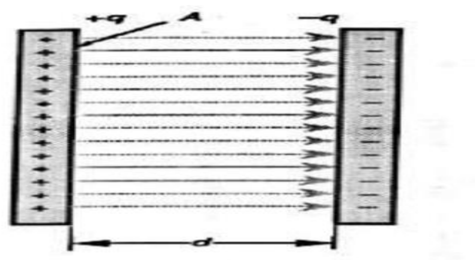
CAPACITIVE TRANSDUCERS

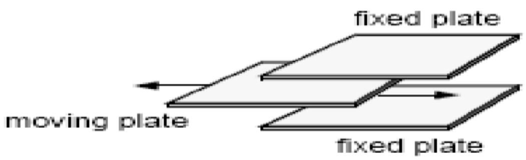
A capacitor is an electrical component which essentially consists of two plates separated by an insulator. The property of a capacitor to store an electric charge when its plates are at different potential is referred to as capacitance.

$$\text{Capacitance } C = \frac{Q}{V}$$

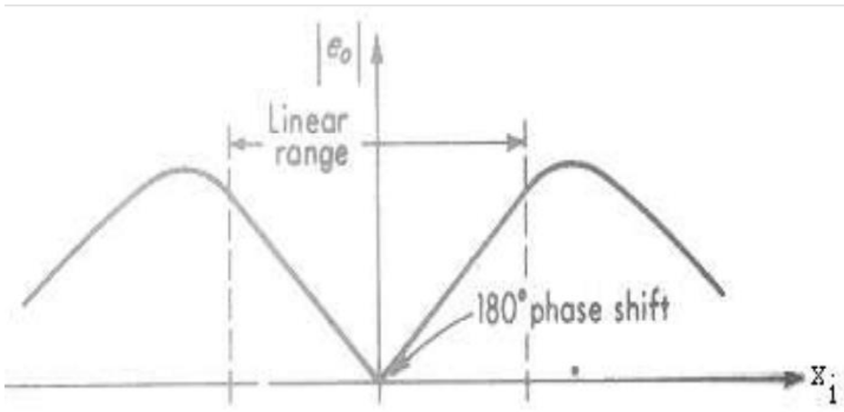
If the capacitance is large, more charge is needed to establish a given voltage difference. The capacitance between two parallel metallic plates of area

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \qquad \left(\varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{m}\right)$$





- There is one primary winding connected to an ac source (50 Hz – 20 kHz), excitation 3 – 15 V_{rms}.
- Core is made of high permeability soft iron or nickel iron.
- Two secondary windings are connected in series opposition



Geometric centre of coil arrangement is called the NULL position. The output voltage at the null position is ideally zero.

¬ However it is small but nonzero (null voltage). Why?

1. Harmonics in the excitation voltage and stray capacitance coupling between the primary and the secondary
2. Manufacturing defects.

Advantages

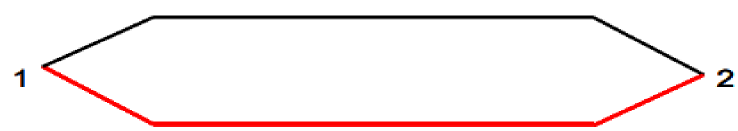
1. Wide range of displacement from µm to cm.

2. Frictionless and electrical isolation.
3. High output.
4. High sensitivity [sensitivity is expressed in mV (output voltage)/ mm (input core displacement)]

Disadvantages
1. Sensitive to stray magnetic fields.
2. Affected by vibrations.
3. Dynamic response is limited mechanically by the mass of core and electrically by frequency of excitation voltage.

Pressure Measurement
The measurement of force or pressure can be done by converting the applied force or pressure into displacement by elastic element (such as diaphragm, capsule, bellows or bourdon tube) which act as primary transducer. This displacement, which is function of pressure is measured by transducer which act as secondary transducer (these may be potentiometer, strain gauge, LVDT, piezoelectric,etc.).

Thermo-couple

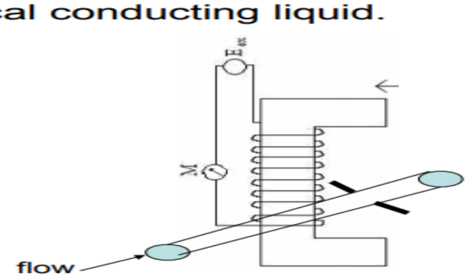


The thermocouple is one of the most commonly used method for measuring the process temperature. The operation is based on seebeck effect.

Thermo-couple consists of two dissimilar metals joined together as shown. It forms two junctions 1 and 2 in which one junction is hot and other is cold. Due to this difference in temperature, an e.m.f. is generated and electric current flow in circuit.

Flow Measurement

- Electromagnetic Flow meter:-
  This is suitable for measurement of slurries, sludge and any electrical conducting liquid.

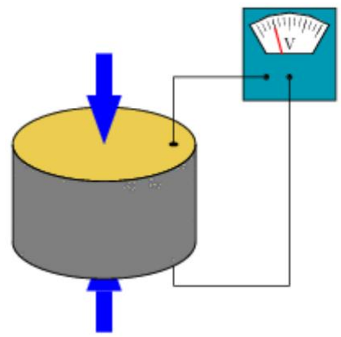


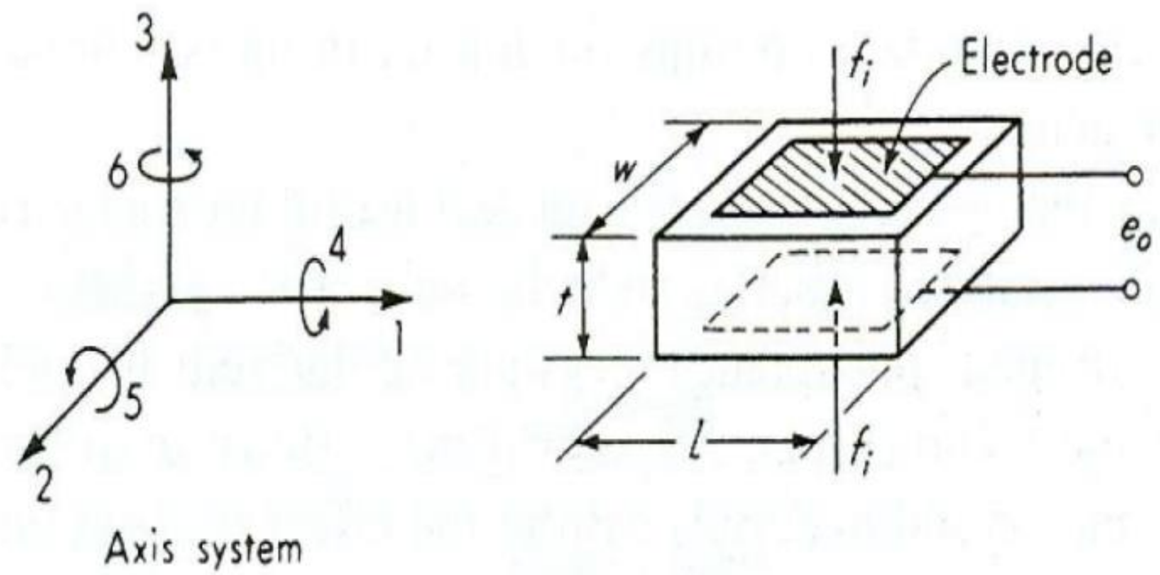
Electromagnetic flow meter consists of insulated electrodes pair buried in opposite sides of non conducting pipe placed in magnetic field of electromagnet. The voltage induced across electrodes is E=Blv volts

PIEZOELECTRIC AND HALL EFFECT TRANSDUCERS

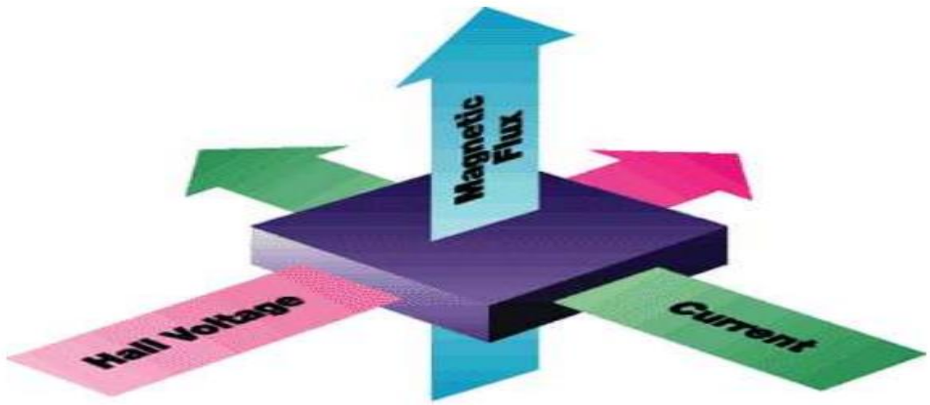
Piezoelectricity Phenomenon of **generating an electric charge in a material** when subjecting it to a mechanical stress (direct effect). and Generating a mechanical strain in response to an applied electric field (converse effect).

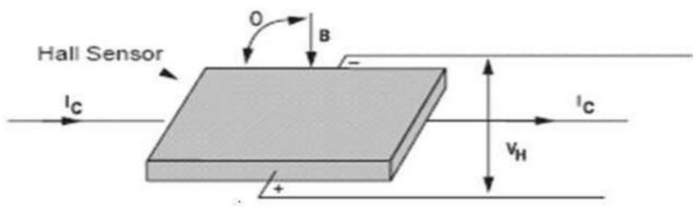
Piezoelectric materials are Anisotropic – Electrical and mechanical properties differ along different directions





There are two families of constants: 'g' constants and 'd' constants. In the constants the first subscript refers to the direction of electrical effect and the second to that of the mechanical effect according to the axis systems.

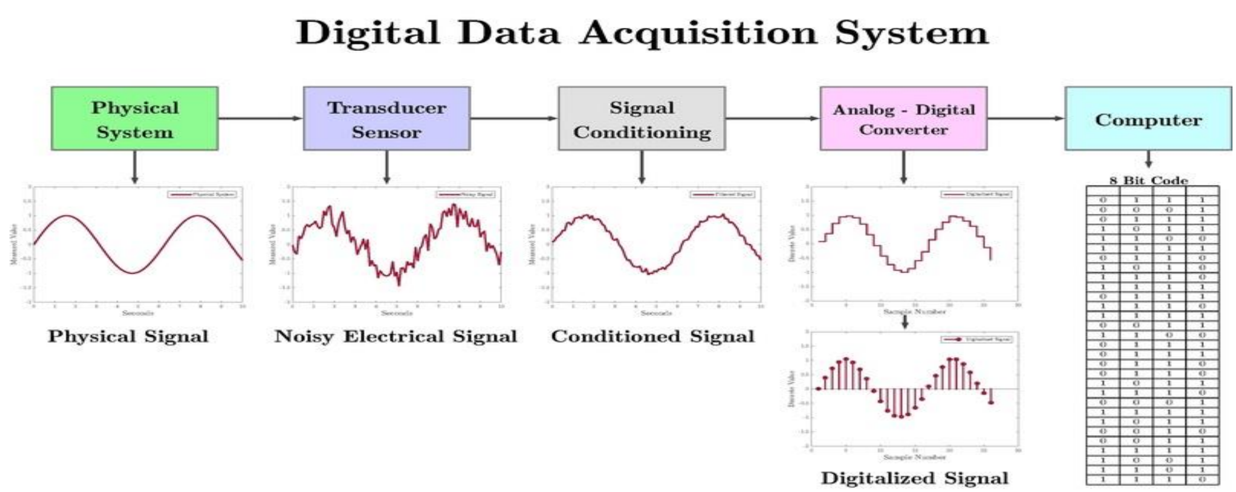




Hall generators made of:
Bulk Indium Arsenide (InAs) ,•Thin Film InAs , Gallium Arsenide (GaAs) , Indium Antimonide (InSb).

Analog and digital acquisition and transmission system
Data acquisition is the process of **sampling signals** that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems, abbreviated by the acronyms **DAS / DAQ**, typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors, to convert physical parameters to electrical signals.
- Signal conditioning circuitry, to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, to convert conditioned sensor signals to digital values.



Data acquisition applications are usually **controlled by software programs developed using various general purpose programming languages** such as Assembly, BASIC, C, C++, C#, Fortran, Java, LabVIEW, Lisp, Pascal, etc. Stand-alone data acquisition systems are often called **data loggers.**

Sources and systems

Data acquisition begins with the **physical phenomenon** or **property** to be measured. Examples of this **include temperature, light intensity, gas pressure, fluid flow, and force. Regardless of the type of physical property to be measured**, the physical state that is to be measured must first be transformed into a unified form that can be sampled by a data acquisition system. The task of performing such transformations falls on **devices called sensors.** A data acquisition system is a collection of software and hardware that lets you measure or control physical characteristics of something in the real world. A complete data acquisition system consists of DAQ hardware, sensors and actuators, signal conditioning hardware, and a computer running DAQ software.

A **sensor**, which is a type of **transducer**, is a device that **converts a physical property into a corresponding electrical signal** (e.g., **strain gauge**, thermistor). An acquisition system to measure different properties depends on the sensors that are suited to detect those properties. Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used. The signal may need to be filtered or amplified in most cases. Various other examples of signal conditioning might be bridge completion, providing current or voltage excitation to the sensor, isolation, and linearization. For transmission purposes, **single ended analog signals**, which are more susceptible to noise, can be converted to differential signals. Once digitized, the signal can be encoded to reduce and correct transmission errors. **Data acquisition involves gathering signals from measurement sources and digitizing the signals for storage, analysis, and presentation on a PC. Data acquisition systems (a.k.a. DAS or DAQ) convert analog waveforms into digital values for processing.** The device we will be using utilizes this process. Once connected to the computer via the shielded cable, we will be able to either send analog signals into the device (using a Wavtek generator) which can then be viewed on the PC itself, or generate a signal from the device itself and manipulate the values through the use of the Measurement & Automation Explorer.

DAQ hardware

DAQ hardware is what usually interfaces between the signal and a PC.[6] It is a set of modules that can be connected to the computer's ports (**parallel, serial, USB**, etc.) or cards connected to slots (S-100 bus, Apple Bus, ISA, MCA, PCI, PCI-E, etc.) in the **motherboard**. Usually the space on the back of a PCI card is too small for all the connections needed, so an external **breakout box** is required.

DAQ cards often contain multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a Busby a **microcontroller**, which can run small programs. A controller is more flexible than a hard wired logic, yet cheaper than a CPU so that it is permissible to block it with simple polling loops. For example: Waiting for a trigger, starting the ADC, looking up the time, waiting for the ADC to finish, move value to RAM, switch multiplexer, get TTL input, let DAC proceed with voltage ramp.

Electronics and Instrumentation

DAQ device drivers

DAQ device drivers are **needed in order for the DAQ hardware to work with a PC. The device driver performs low-level register writes and reads on the hardware, while exposing API for** developing user applications in a variety of pro

Input devices

3D scanner, Analog-to-digital converter and Time-to-digital converter

Hardware

- Computer Automated Measurement and Control (CAMAC)
- Industrial Ethernet
- Industrial USB
- LAN eXtensions for Instrumentation
- NIM
- PowerLab
- PCI eXtensions for Instrumentation
- VMEbus
- VXI

DAQ software

Specialized DAQ software may be delivered with the DAQ hardware. Software tools used for building large-scale data acquisition systems include EPICS. Other programming environments that are used to build DAQ applications include ladder logic, Visual C++, Visual Basic, LabVIEW, and MATLAB. See also: LabChart, MIDAS and BioChart