



Sheikh Hasina University, Netrokona
Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-4: Basic Electronics

Md. Ariful Islam
Assistant Professor
Dept. of Robotics and Mechatronics Engineering
University of Dhaka
&
Adjunct Faculty
Sheikh Hasina University, Netrokona
Department of Computer Science and Engineering

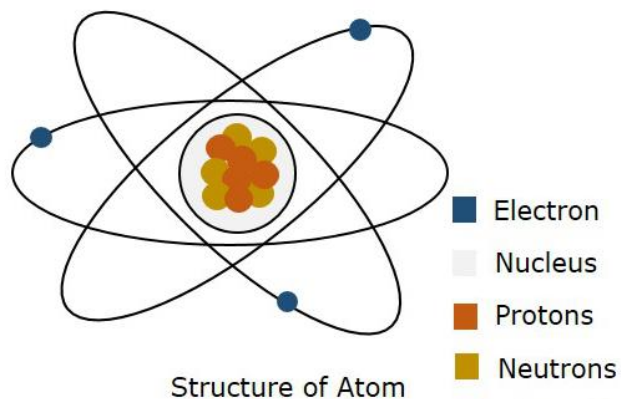
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Structure of an Atom

Matter is made up of molecules which consists of atoms. According to Bohr’s theory, “the atom consists of positively charged nucleus and a number of negatively charged electrons which revolve round the nucleus in various orbits”. When an electron is raised from a lower state to a higher state, it is said to be **excited**. While exciting, if the electron is completely removed from the nucleus, the atom is said to be ionized. So, the process of raising the atom from normal state to this ionized state is called as **ionization**.

The following figure shows the structure of an atom.



Structure of Atom

According to Bohr's model, an electron is said to be moved in a particular **Orbit**, whereas according to quantum mechanics, an electron is said to be somewhere in free space of the atom, called as **Orbital**. This theory of quantum mechanics was proven to be right. Hence, a three dimensional boundary where an electron is probable to found is called as **Atomic Orbital**.

Quantum Numbers:

Each orbital, where an electron moves, differs in its energy and shape. The energy levels of orbitals can be represented using discrete set of integrals and half-integrals known as quantum numbers. There are four quantum numbers used to define a wave function.

What is Charge in Physics and Electronics: Electric Charge

What is Charge?

Electric Charge may be defined as the quantity of unbalanced electricity in a body (*either positive or negative*) and construed as an excess or deficiency of electrons.

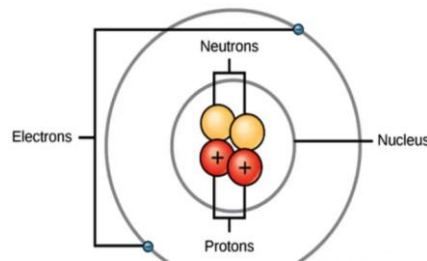
It comes in two forms, positive (+), and negative (−) .

Properties

Charge is conserved. This means that you cannot create or destroy it. It can just change its "Form".

How is Electric Charge Generated?

In Physics and Chemistry, we all studied Structure of an Atom that has equal Number of Electrons, Protons and Neutrons. Electrons are Negatively Charged, Protons are Positively Charged and Neutrons are Neutrally Charged.



If by any means, some electrons from one atom of a body moves to another atom of another body then there is Deficiency of Electrons (*Negatively Charged*) in the Donor Atom and Excess of Protons (*Positively Charged*) in the Receiver Atom.

Thus the Donor Body becomes Negatively Charged (*because of Excess Electrons*) and the Receiver becomes Positively Charged (*Because of Excess Protons*). This is how Electric Charge is Generated.

Unit of Charge

The unit of charge is the Coulomb, **C**. The symbol is **Q**.

$$1 \text{ Coulomb} = 6.28 \times 10^{18} \text{ Electrons}$$

All about Semiconductor

A **semiconductor** can be defined as a substance with properties of a conductor and insulator both.

It can conduct electricity under certain circumstances but not always. This physics and property of a semiconductor makes it a good medium to use electricity in a controlled manner as and where required. Conductance of a semiconductor depends on several factors such as current or voltage applied to a control electrode, or on the intensity of irradiation by infrared (*IR*), visible light, ultraviolet (*UV*), or X rays.

So, we can say that a **semiconductor** is a material that has electrical conductivity greater than an insulator but less than a conductor.

Examples: *Diodes, transistors, and many photovoltaic cells.*

Energy Bands

In gaseous substances, the arrangement of molecules is not close. In liquids, the molecular arrangement is moderate. But, in solids, the molecules are so closely arranged, that the electrons in the atoms of molecules tend to move into the orbitals of neighboring atoms. Hence the electron orbitals overlap when the atoms come together.

Due to the intermixing of atoms in solids, instead of single energy levels, there will be bands of energy levels formed. These set of energy levels, which are closely packed are called as **Energy bands**.

Valance Band

The electrons move in the atoms in certain energy levels but the energy of the electrons in the innermost shell is higher than the outermost shell electrons. The electrons that are present in the outermost shell are called as **Valance Electrons**.

These valance electrons, containing a series of energy levels, form an energy band which is called as Valance Band. The **valence band** is the *band having the highest occupied energy*.

Conduction Band

The valence electrons are so loosely attached to the nucleus that even at room temperature, few of the valence electrons leave the band to be free. These are called as **free electrons** as they tend to move towards the neighboring atoms.

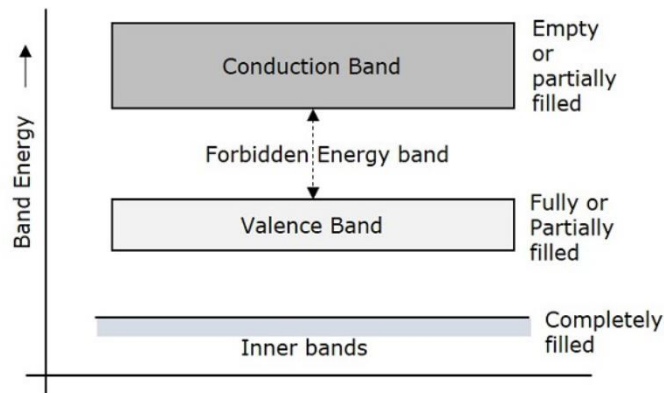
These free electrons are the ones which conduct the current in a conductor and hence called as **Conduction Electrons**. The band which contains conduction electrons is called as **Conduction Band**. The conduction band is the *band having the lowest occupied energy*.

Forbidden gap

The gap between valence band and conduction band is called as **forbidden energy gap**. As the name implies, this band is the forbidden one without energy. Hence no electron stays in this band. The valence electrons, while going to the conduction band, pass through this.

The forbidden energy gap if greater, means that the valence band electrons are tightly bound to the nucleus. Now, in order to push the electrons out of the valence band, some external energy is required, which would be equal to the forbidden energy gap.

The following figure shows the valence band, conduction band, and the forbidden gap.

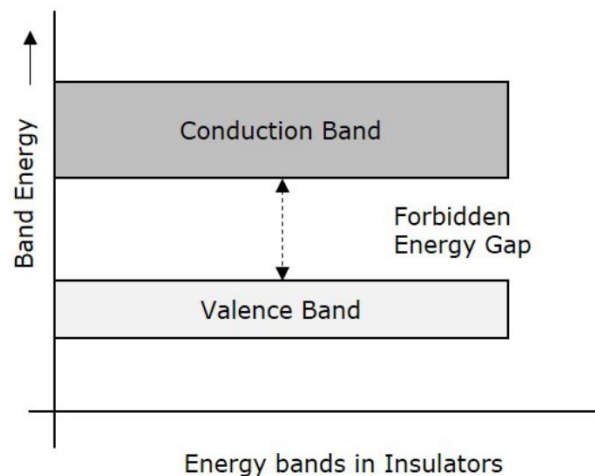


Types of Materials

Depending upon the size of the forbidden gap, the Insulators, the Semiconductors and the Conductors are formed.

Insulators

Insulators are such materials in which the conduction cannot take place, due to the large forbidden gap. Examples: Wood, Rubber. The structure of energy bands in Insulators is as shown in the following figure.



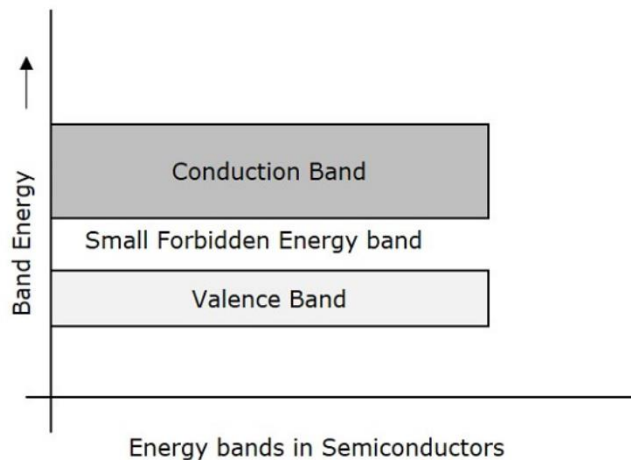
Characteristics

The following are the characteristics of Insulators.

- The Forbidden energy gap is very large.
- Valance band electrons are bound tightly to atoms.
- The value of forbidden energy gap for an insulator will be of 10eV.
- For some insulators, as the temperature increases, they might show some conduction.
- The resistivity of an insulator will be in the order of 10^7 ohm-meter.

Semiconductors

Semiconductors are such materials in which the forbidden energy gap is small and the conduction takes place if some external energy is applied. Examples: Silicon, Germanium. The following figure shows the structure of energy bands in semiconductors.



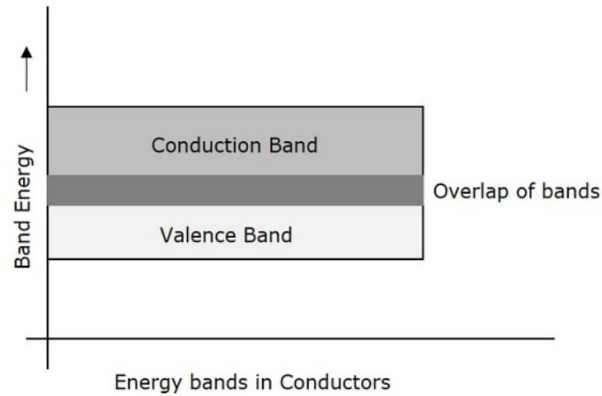
Characteristics

The following are the characteristics of Semiconductors.

- The Forbidden energy gap is very small.
- The forbidden gap for Ge is 0.7eV whereas for Si is 1.1eV.
- A Semiconductor actually is neither an insulator, nor a good conductor.
- As the temperature increases, the conductivity of a semiconductor increases.
- The conductivity of a semiconductor will be in the order of 10^2 mho-meter.

Conductors

Conductors are such materials in which the forbidden energy gap disappears as the valence band and conduction band become very close that they overlap. Examples: Copper, Aluminum. The following figure shows the structure of energy bands in conductors.



Characteristics

The following are the characteristics of Conductors.

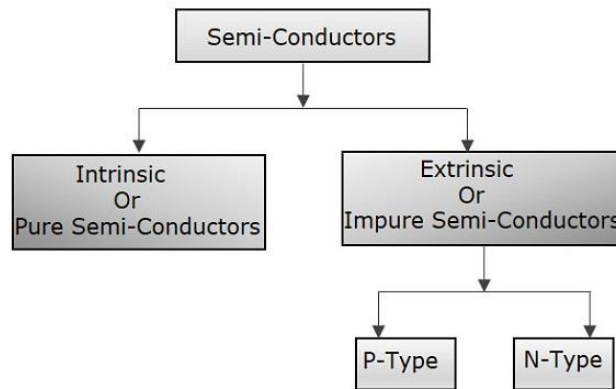
- There exists no forbidden gap in a conductor.
- The valance band and the conduction band gets overlapped.
- The free electrons available for conduction are plenty.
- A slight increase in voltage, increases the conduction.
- There is no concept of hole formation, as a continuous flow of electrons contribute the current.

Semiconductor

A **semiconductor** is a substance whose resistivity lies between the conductors and insulators. The property of resistivity is not the only one that decides a material as a semiconductor, but it has few properties as follows.

- Semiconductors have the resistivity which is less than insulators and more than conductors.
- Semiconductors have negative temperature co-efficient. The resistance in semiconductors, increases with the decrease in temperature and vice versa.
- The Conducting properties of a Semiconductor changes, when a suitable metallic impurity is added to it, which is a very important property.

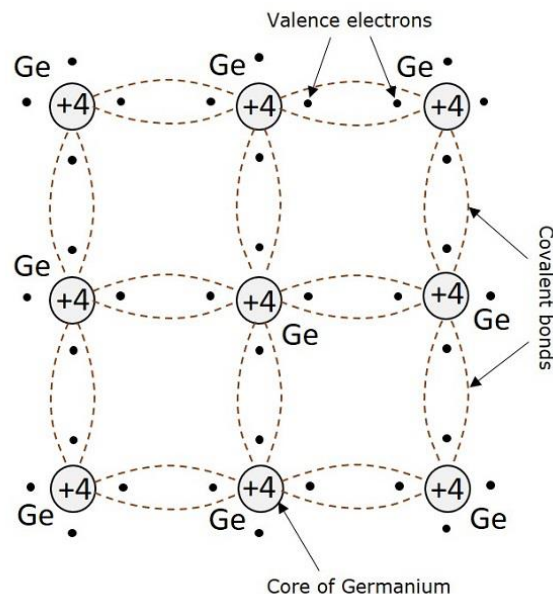
Semiconductor devices are extensively used in the field of electronics. The transistor has replaced the bulky vacuum tubes, from which the size and cost of the devices got decreased and this revolution has kept on increasing its pace leading to the new inventions like integrated electronics. The following illustration shows the classification of semiconductors.



Conduction in Semiconductors

After having some knowledge on the electrons, we came to know that the outermost shell has the **valence electrons** which are loosely attached to the nucleus. Such an atom, having valence electrons when brought close to the other atom, the valence electrons of both these atoms combine to form “**Electron pairs**”. This bonding is not so very strong and hence it is a **Covalent bond**.

For example, a germanium atom has 32 electrons. 2 electrons in first orbit, 8 in second orbit, 18 in third orbit, while 4 in last orbit. These 4 electrons are valence electrons of germanium atom. These electrons tend to combine with valence electrons of adjoining atoms, to form the electron pairs, as shown in the following figure.



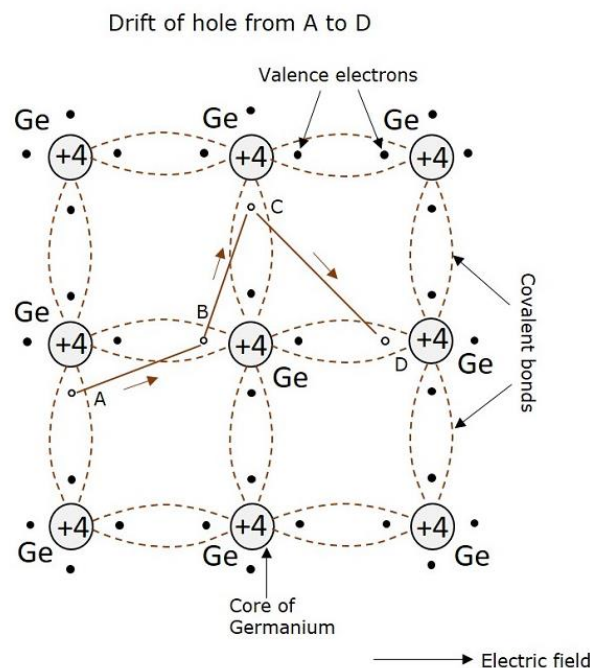
Creation of Hole

Due to the thermal energy supplied to the crystal, some electrons tend to move out of their place and break the covalent bonds. These broken covalent bonds, result in free electrons which wander randomly. But the **moved away electrons** creates an empty space or valence behind, which is called as a **hole**.

This hole which represents a missing electron can be considered as a unit positive charge while the electron is considered as a unit negative charge. The liberated electrons move randomly but when some external electric field is applied, these electrons move in opposite direction to the applied field. But the holes created due to absence of electrons, move in the direction of applied field.

Hole Current

It is already understood that when a covalent bond is broken, a hole is created. Actually, there is a strong tendency of semiconductor crystal to form a covalent bond. So, a hole doesn't tend to exist in a crystal. This can be better understood by the following figure, showing a semiconductor crystal lattice.



An electron, when gets shifted from a place A, a hole is formed. Due to the tendency for the formation of covalent bond, an electron from B gets shifted to A. Now, again to balance the covalent bond at B, an electron gets shifted from C to B. This continues to build a path. This movement of hole in the absence of an applied field is random. But when electric field is applied, the hole drifts along the applied field, which constitutes the **hole current**. This is called as hole current but not electron current because, the movement of holes contribute the current flow.

Electrons and holes while in random motion, may encounter with each other, to form pairs. This recombination results in the release of heat, which breaks another covalent bond. When the temperature increases, the rate of generation of electrons and holes increase, thus rate of recombination increases, which results in the increase of densities of electrons and holes. As a result, conductivity of semiconductor increases and resistivity decreases, which means the negative temperature coefficient.

Intrinsic Semiconductors

A Semiconductor in its extremely pure form is said to be an **intrinsic semiconductor**. The properties of this pure semiconductor are as follows –

- The electrons and holes are solely created by thermal excitation.
- The number of free electrons is equal to the number of holes.
- The conduction capability is small at room temperature.

In order to increase the conduction capability of intrinsic semiconductor, it is better to add some impurities. This process of adding impurities is called as **Doping**. Now, this doped intrinsic semiconductor is called as an Extrinsic Semiconductor.

Doping

The process of adding impurities to the semiconductor materials is termed as doping. The impurities added, are generally pentavalent and trivalent impurities.

Pentavalent Impurities

- The **pentavalent** impurities are the ones which has five valence electrons in the outer most orbit.
Example: Bismuth, Antimony, Arsenic, Phosphorus
- The pentavalent atom is called as a **donor atom** because it donates one electron to the conduction band of pure semiconductor atom.

Trivalent Impurities

- The **trivalent** impurities are the ones which has three valence electrons in the outer most orbit.
Example: Gallium, Indium, Aluminum, Boron
- The trivalent atom is called as an **acceptor atom** because it accepts one electron from the semiconductor atom.

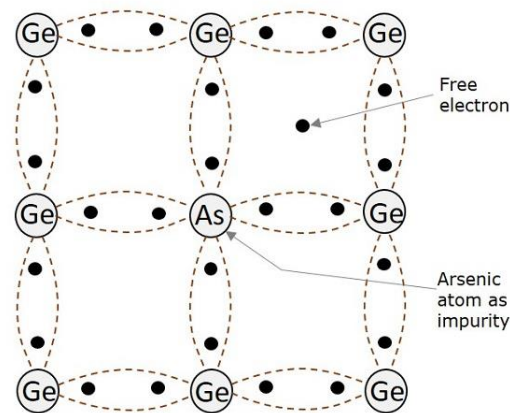
Extrinsic Semiconductor

An impure semiconductor, which is formed by doping a pure semiconductor is called as an **extrinsic semiconductor**. There are two types of extrinsic semiconductors depending upon the type of impurity added. They are N-type extrinsic semiconductor and P-Type extrinsic semiconductor.

N-Type Extrinsic Semiconductor

A small amount of pentavalent impurity is added to a pure semiconductor to result in Ntype extrinsic semiconductor. The added impurity has 5 valence electrons.

For example, if Arsenic atom is added to the germanium atom, four of the valence electrons get attached with the Ge atoms while one electron remains as a free electron. This is as shown in the following figure.

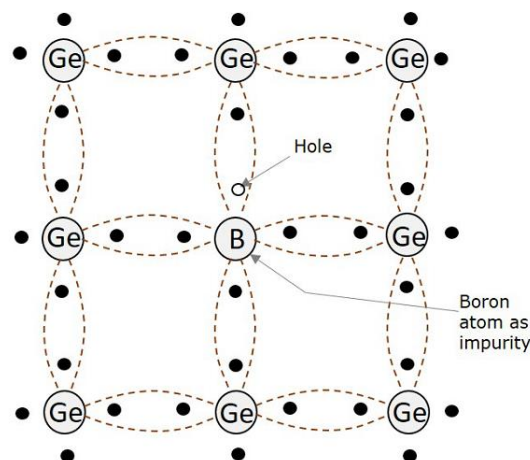


All of these free electrons constitute electron current. Hence, the impurity when added to pure semiconductor, provides electrons for conduction.

- In N-type extrinsic semiconductor, as the conduction takes place through electrons, the electrons are majority carriers and the holes are minority carriers.
- As there is no addition of positive or negative charges, the electrons are electrically neutral.
- When an electric field is applied to an N-type semiconductor, to which a pentavalent impurity is added, the free electrons travel towards positive electrode. This is called as negative or N-type conductivity.

P-Type Extrinsic Semiconductor

A small amount of trivalent impurity is added to a pure semiconductor to result in P-type extrinsic semiconductor. The added impurity has 3 valence electrons. For example, if Boron atom is added to the germanium atom, three of the valence electrons get attached with the Ge atoms, to form three covalent bonds. But, one more electron in germanium remains without forming any bond. As there is no electron in boron remaining to form a covalent bond, the space is treated as a hole. This is as shown in the following figure.



The boron impurity when added in a small amount, provides a number of holes which helps in the conduction. All of these holes constitute hole current.

- In P-type extrinsic semiconductor, as the conduction takes place through holes, the holes are majority carriers while the electrons are minority carriers.
- The impurity added here provides holes which are called as **acceptors**, because they accept electrons from the germanium atoms.
- As the number of mobile holes remains equal to the number of acceptors, the P-type semiconductor remains electrically neutral.
- When an electric field is applied to a P-type semiconductor, to which a trivalent impurity is added, the holes travel towards negative electrode, but with a slow pace than electrons. This is called as P-type conductivity.
- In this P-type conductivity, the valence electrons move from one covalent bond to another, unlike N-type.

Why Silicon is Preferred in Semiconductors?

Among the semiconductor materials like germanium and silicon, the extensively used material for manufacturing various electronic components is **Silicon** Si. Silicon is preferred over germanium for many reasons such as –

- The energy band gap is 0.7eV, whereas it is 0.2eV for germanium.
- The thermal pair generation is smaller.
- The formation of SiO₂ layer is easy for silicon, which helps in the manufacture of many components along with integration technology.
- Si is easily found in nature than Ge.
- Noise is less in components made up of Si than in Ge.

Hence, Silicon is used in the manufacture of many electronic components, which are used to make different circuits for various purposes. These components have individual properties and particular uses.

The main electronic components include — Resistors, variable resistors, Capacitors, variable capacitors, Inductors, diodes, Tunnel diodes, Varactor diodes, Transistors, BJTs, UJT, FETs, MOSFETs, LDR, LED, Solar cells, Thermistor, Varistor, Transformer, switches, relays, etc.

Types of Currents

Coming to the types of currents in semiconductors, there are two terms need to be discussed. They are **Diffusion Current** and **Drift Current**.

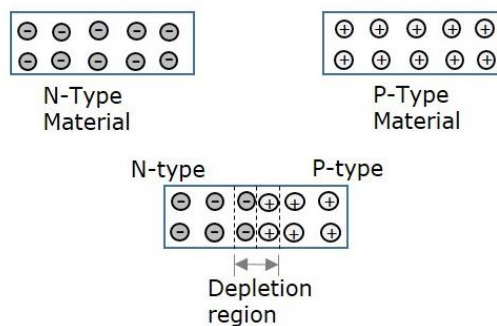
Diffusion current

When doping is done, there occurs a difference in the concentration of electrons and holes. These electrons and holes tend to diffuse from higher concentration of charge density, to lower concentration level. As these are charge carriers, they constitute a current called **diffusion current**.

To know about this in detail, let us consider an N-type material and a P-type material.

- N-type material has electrons as majority carriers and few holes as minority carriers.
- P-type material has holes as majority carriers and few electrons as minority carriers.

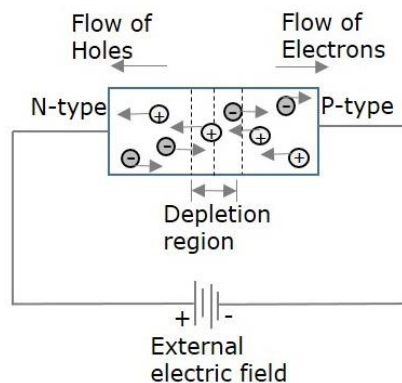
If these two materials are brought too close to each other to join, then few electrons from valence band of N-type material, tend to move towards P-type material and few holes from valence band of P-type material, tend to move towards N-type material. The region between these two materials where this diffusion takes place, is called as **Depletion region**.



Hence, the current formed due to the diffusion of these electrons and holes, without the application of any kind of external energy, can be termed as **Diffusion Current**.

Drift Current

The current formed due to the drift movement of charged particles electrons or holes due to the applied electric field, is called as **Drift Current**. The following figure explains the drift current, whether how the applied electric field, makes the difference.



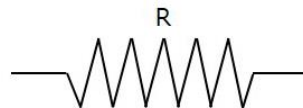
The amount of current flow depends upon the charge applied. The width of depletion region also gets affected, by this drift current. To make a component function in an active circuit, this drift current plays an important role.

Resistor

Resist is the word which means “to oppose”. **Resistance** is the property of opposing the flow of electrons, in a conductor or a semiconductor. A Resistor is an electronic component which has the property of resistance.

Symbol and Units

The symbol for a Resistor is as shown below.



Symbol for a resistor

The units of resistance is **Ohms**, which is indicated by Ω omega.

The formula for resistance is

$$R = V/I$$

Where **V** is Voltage and **I** is Current. It would really be difficult to manufacture the resistors with each and every value. Hence, few values are chosen and the resistors of such values are only manufactured. These are called as “**Preferred Values**”. In practice, the resistors with near values are chosen to match the required applications. This is how a practical resistor looks like –



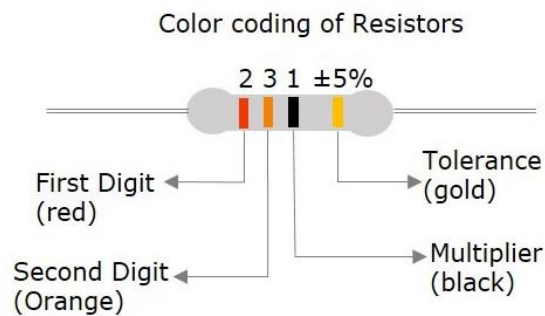
Color Coding

A process called **color coding** is used to determine the value of resistance for a resistor, just as shown in the above figure. A resistor is coated with four color bands where each color determines a particular value. The below table shows a list of values which each color indicates.

COLOUR	DIGIT	MULTIPLIER	TOLERANCE
Black	0	$10^0 = 1$	
Brown	1	$10^1 = 10$	1
Red	2	$10^2 = 100$	2
Orange	3	$10^3 = 1000$	
Yellow	4	$10^4 = 10000$	
Green	5	$10^5 = 100000$	0.5
Blue	6	$10^6 = 1000000$	0.25
Violet	7	$10^7 = 10000000$	0.1
Gray	8	$10^8 = 100000000$	
White	9	$10^9 = 1000000000$	
Gold		$10^{-1} = 0.1$	5
Silver		$10^{-2} = 0.01$	10
none			20

The first two colored bands indicate the first and second digit of the value and the third color band represents the multiplier number of zeroes added. The fourth color band indicates the tolerance value.

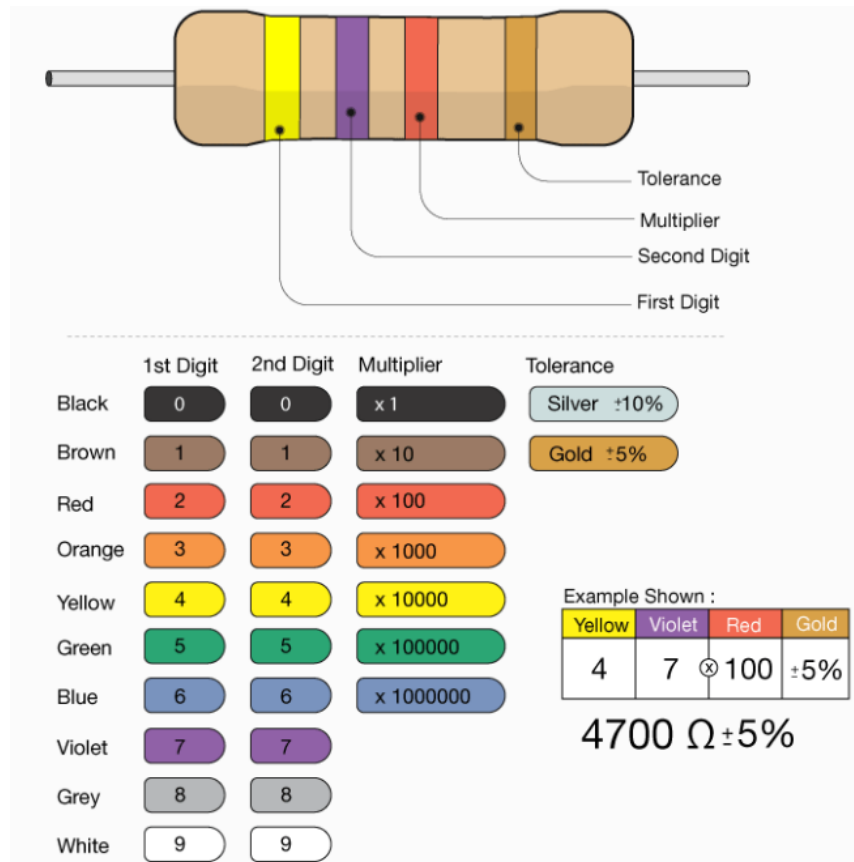
Tolerance is the range of value up to which a resistor can withstand without getting destroyed. This is an important factor. The following figure shows how the value of a resistor is determined by color code.



A 23Ω resistor

23×1 ohms with a tolerance rating of $\pm 5\%$

The five color band resistors are manufactured with tolerance of 2% and 1% and also for other high accuracy resistors. In these five band resistors, the first three bands represent digits, fourth one indicates multiplier and the fifth represents tolerance.



Let us look at an example to understand the color coding process.

Example 1 – Determine the value of a resistor with a color code yellow, blue, orange and silver.

Solution – The value of yellow is 4, blue is 6, orange is 3 which represents multiplier. Silver is ±10 which is the tolerance value.

Hence the value of the resistor is $46 \times 10^3 = 46\text{k}\Omega$

The maximum resistance value for this resistor is

$46\text{k}\Omega$ or $46000\Omega + 10\% = 46000 + 4600 = 50600\Omega = 50.6\text{k}\Omega$

The minimum resistance value for this resistor is

$46\text{k}\Omega$ or $46000\Omega - 10\% = 46000 - 4600 = 41400\Omega = 41.4\text{k}\Omega$

After having gone through different details regarding resistors, we have some terms to learn. Also we have to deal with different behaviors of a resistor for few types of connections.

Important Terms

There are a few terms which we need to discuss before going into the type of resistors we have. One needs to get introduced to these terms at this stage and can understand them as we progress further.

Resistance

Resistance is the property of a resistor that opposes the flow of current. When alternating current goes through a resistance, a voltage drop is produced that is in-phase with the current.

- Indication – **R**
- Units – **Ohms**
- Symbol – Ω

Along with resistance, there are other important terms, called as reactance and impedance.

Reactance

The resistance offered to the alternating current because of the capacitances and inductances present in the circuit, can be understood as reactance. When alternating current goes through a pure reactance, a voltage drop is produced that is 90° out of phase with the current.

Depending upon the phase i.e., +90° or -90° the reactance can be termed as inductive reactance or capacitive reactance.

- Indication – **X**
- Units – **Ohms**
- Symbol – Ω

Impedance

Impedance is the effective resistance to alternating current arising from the combined effects of ohmic resistance and reactance. When alternating current goes through an impedance, a voltage drop is produced which is somewhere between 0° to 90° out of phase with the current.

- Indication – **I**
- Units – **Ohms**
- Symbol – Ω

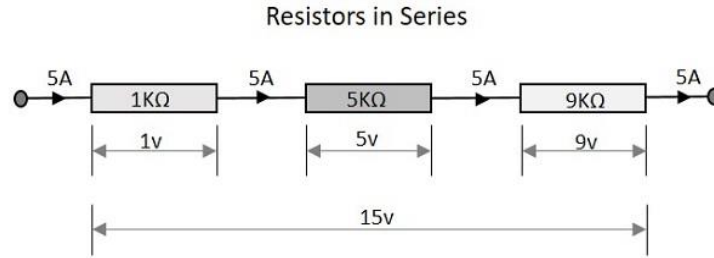
Conductance

This is the ability of a material to conduct electricity. It is the reciprocal of resistance.

- Indication – **G**
- Units – **Mhos**
- Symbol – \mathcal{U}

Resistors in Series

Let us observe what happens, when few resistors are connected in Series. Let us consider three resistors with different values, as shown in the figure below.



Resistance

The total resistance of a circuit having series resistors is equal to the sum of the individual resistances. That means, in the above figure there are three resistors having the values 1KΩ, 5KΩ and 9KΩ respectively.

Total resistance value of the resistor network is –

$$R = R_1 + R_2 + R_3$$

Which means $1 + 5 + 9 = 15\text{K}\Omega$ is the total resistance.

Where R_1 is the resistance of 1st resistor, R_2 is the resistance of 2nd resistor and R_3 is the resistance of 3rd resistor in the above resistor network.

Voltage

The total voltage that appears across a series resistors network is the addition of voltage drops at each individual resistance. In the above figure we have three different resistors which have three different values of voltage drops at each stage.

Total voltage that appears across the circuit –

$$V = V_1 + V_2 + V_3$$

Which means $1\text{v} + 5\text{v} + 9\text{v} = 15\text{v}$ is the total voltage.

Where V_1 is the voltage drop of 1st resistor, V_2 is the voltage drop of 2nd resistor and V_3 is the voltage drop of 3rd resistor in the above resistor network.

Current

The total amount of Current that flows through a set of resistors connected in series is the same at all the points throughout the resistor network. Hence the current is same 5A when measured at the input or at any point between the resistors or even at the output.

Current through the network –

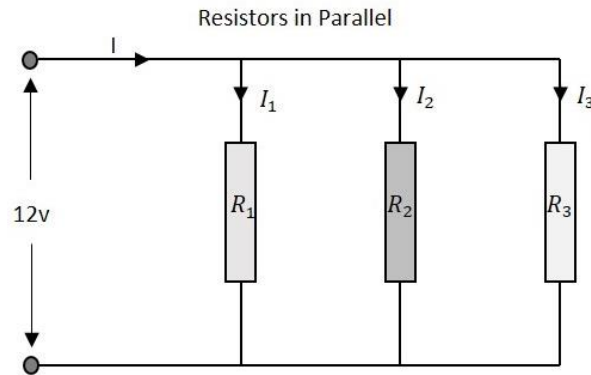
$$I = I_1 = I_2 = I_3$$

Which means that current at all points is 5A.

Where I_1 is the current through the 1st resistor, I_2 is the current through the 2nd resistor and I_3 is the current through the 3rd resistor in the above resistor network.

Resistors in Parallel

Let us observe what happens, when few resistors are connected in Parallel. Let us consider three resistors with different values, as shown in the figure below.



Resistance

The total resistance of a circuit having Parallel resistors is calculated differently from the series resistor network method. Here, the reciprocal $1/R$ value of individual resistances are added with the inverse of algebraic sum to get the total resistance value.

Total resistance value of the resistor network is –

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Where R_1 is the resistance of 1st resistor, R_2 is the resistance of 2nd resistor and R_3 is the resistance of 3rd resistor in the above resistor network.

For example, if the resistance values of previous example are considered, which means $R_1 = 1K\Omega$, $R_2 = 5K\Omega$ and $R_3 = 9K\Omega$. The total resistance of parallel resistor network will be –

$$\begin{aligned} \frac{1}{R} &= \frac{1}{1} + \frac{1}{5} + \frac{1}{9} \\ &= \frac{45 + 9 + 5}{45} = \frac{59}{45} \\ R &= \frac{45}{59} = 0.762K\Omega = 76.2\Omega \end{aligned}$$

From the method we have for calculating parallel resistance, we can derive a simple equation for two-resistor parallel network. It is –

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

Voltage

The total voltage that appears across a Parallel resistors network is same as the voltage drops at each individual resistance.

The Voltage that appears across the circuit –

$$V = V_1 = V_2 = V_3$$

Where V_1 is the voltage drop of 1st resistor, V_2 is the voltage drop of 2nd resistor and V_3 is the voltage drop of 3rd resistor in the above resistor network. Hence the voltage is same at all the points of a parallel resistor network.

Current

The total amount of current entering a Parallel resistive network is the sum of all individual currents flowing in all the Parallel branches. The resistance value of each branch determines the value of current that flows through it. The total current through the network is

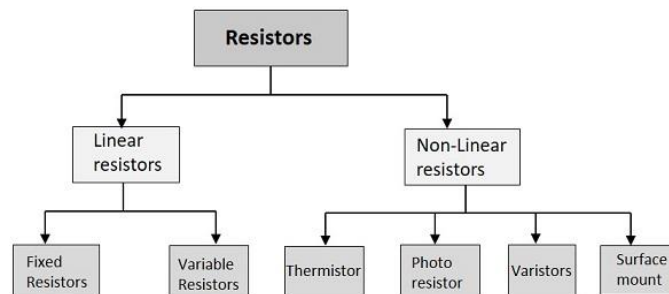
$$I = I_1 + I_2 + I_3$$

Where I_1 is the current through the 1st resistor, I_2 is the current through the 2nd resistor and I_3 is the current through the 3rd resistor in the above resistor network. Hence the sum of individual currents in different branches obtain the total current in a parallel resistive network.

A Resistor is particularly used as a load in the output of many circuits. If at all the resistive load is not used, a resistor is placed before a load. Resistor is usually a basic component in any circuit.

Non linear Resistors

There are many types of resistors according to the type of material used, the manufacturing procedure and their applications. The classification is as shown below.



Linear resistors have linear VI characteristics and non-linear resistors has non-linear VI characteristics. Non-linear resistors are the resistors whose voltage and current characteristics vary non-linearly. The voltage and current values vary depending upon other factors like temperature and light, but they may not be linear.

Thermistor

Thermal means temperature. In this resistor, the resistance varies with temperature. If heat increases, the resistance decreases and vice versa. This is used for measurement and control purposes.

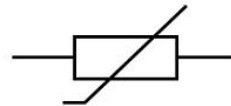
The main types of thermistors are **NTC** and **PTC**.

- NTC is **Negative Temperature Coefficient** and in such devices, the resistance decreases as the temperature increases. These are used to protect the devices from over-voltage conditions.
- PTC is **Positive Temperature Coefficient** and in such devices, the resistance increases as the temperature increases. These are used to protect the devices from over current conditions.

The following figure shows an NTC thermistor, along with its symbol.



Image of a Thermistor (NTC)



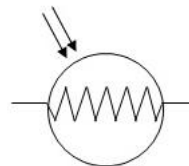
Symbol for Thermistor

Photo Resistor

Photo means light. In this resistor, the resistance varies with light. As light increases resistance decreases and vice versa. This is also used for measurement and control purposes. It is also called as **LDR** Light Dependent Resistor



Image of LDR or
Photo resistor



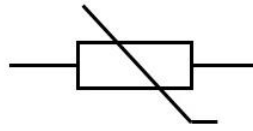
Symbol for LDR or
Photo resistor

Varistors

The resistance of a varistor, varies with the applied voltage. As the voltage increases, the resistance decreases and if the voltage decreases, the resistance increases. It is also called as **VDR** Voltage Dependent Resistor.



Image of a Varistor



Symbol for Varistor

Surface Mount

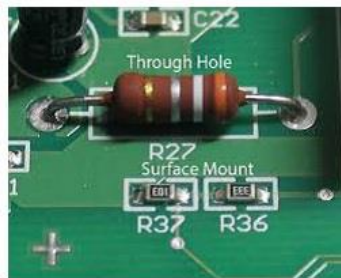
These are being highly used since the introduction of surface mount technology. These can be termed as **chip resistors**, which means a resistive layer integrated on a ceramic chip.

These surface mount resistors are very small when compared to the normal resistors and hence occupy less space. They are effective and dissipate less heat. The invention of these resistors has changed the look of a PCB Printed Circuit Board and reduced its size greatly.

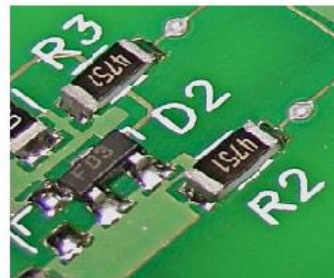
The advantages of surface mount resistors are –

- These are compact in size.
- These are very stable.
- They have good tolerance.
- They are effective in reducing heat dissipation.

The following figure shows the images of surface mount resistors.



Surface mount resistor when compared to the size of a normal resistor



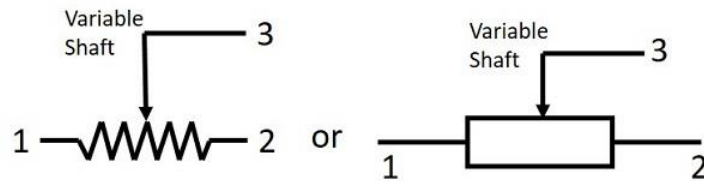
Surface mount resistors mounted on a PCB

Linear Resistors

A Linear resistor is one whose resistance doesn't vary with the flow of current through it. The current through it, will always be proportional to the voltage applied across it. Linear resistors are further classified as **Fixed and Variable resistors**.

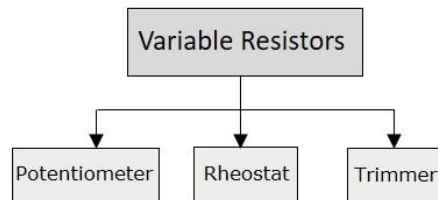
Variable Resistors

Variable resistors are those whose values can be varied manually, according to the requirement. A particular value of resistance is chosen from a range of resistance values, with the help of a shaft connected. The symbol of a variable resistor is as shown below.



Symbol for a Variable resistor

These resistors are better understood with the help of the classification we have. Variable resistors are further divided into Potentiometers, Rheostats and Trimmers.



Potentiometer

A Potentiometer is simply called as a **Pot**. This is a three-terminal resistor having a shaft which slides or rotates. This shaft when operated forms an adjustable voltage divider. The following figure shows an image of a Potentiometer.

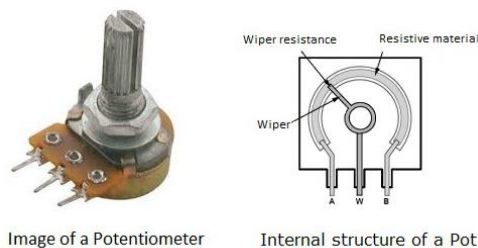


Image of a Potentiometer

Internal structure of a Pot

A potentiometer also measures the **potential difference** voltage in a circuit. A path of resistive material with resistance of low to high value is laid internally and a wiper is placed so that it connects the resistive material to the circuit. This is mostly used as a volume controller in TV sets and Music systems.

Rheostat

A Rheostat can be simply called as a Wire wound resistor. A **Resistive wire** is wound around an insulating ceramic core tightly. A **Wiper** slides over these windings. One connection is made to one end of the resistive wire and the second connection is made to the wiper or the sliding contact, to obtain the desired resistance.

The Rheostat is used to **control current**. These are mostly used in the speed control of heavy motors. The resistance obtained by these is in the order of **kilo ohms**. Rheostats are mostly available as single tube and double tube rheostats, as shown in the following figure.



Single tube Rheostat

Double tube Rheostat

As a variable resistance they are often used for tuning and calibration in circuits. Now-a-days, the usage of rheostats was replaced by switching electronic devices, as rheostats have lower efficiency.

Trimmer

Trimmer is both a variable resistor and a potentiometer measures potential difference. This Trimmer Potentiometer is, in short called as **Trim Pot**. If these are used as variable resistors, then they are called as Preset Resistors.

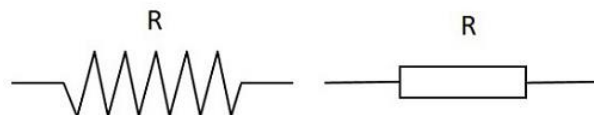


Images showing different types of Trim Pots

These trim pots are of different types such as single turn or multi turn. These are small variable resistors used for tuning and calibration. Their life span is shorter than other variable resistors.

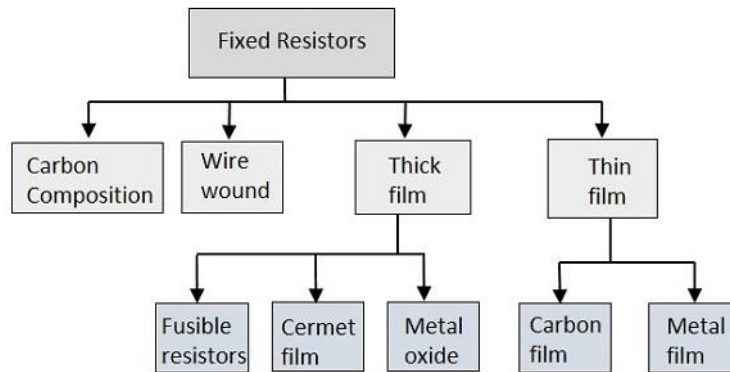
Fixed Resistors

Fixed resistors are one type of linear resistors. A resistor is said to be a fixed resistor, if its value is fixed. The value of fixed resistor can't be varied like a variable resistor as its value is determined at the time of manufacturing itself. The following figures represent the symbol of a fixed resistor.



Symbol for a fixed resistor

The fixed resistors are classified into different types, depending upon their manufacturing processes and the materials used in their manufacturing. The classification is as follows.



Carbon composition

The Carbon composition resistors are a blend of carbon particles, graphite and ceramic dust mixed with a binder substance like clay. This mixture is treated with high pressure and temperature. After the whole thing is molded in a case, the leads are fixed.

- Thermal mass of the carbon composition resistor is higher so as to withstand high energy pulses.
- These resistors have low stability and high noise which is a disadvantage.

The following figure shows an image of carbon composition resistor.

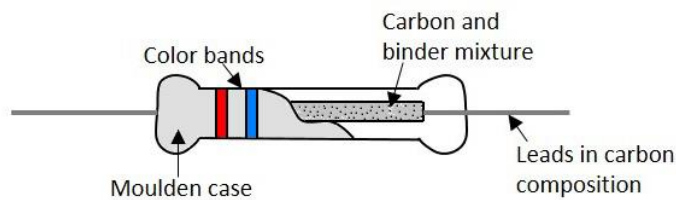
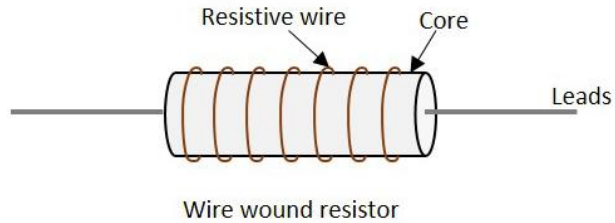


Image of a Carbon composition resistor

Carbon composition resistors are used in Surge protection, Current limiting, and High voltage power supplies.

Wire wound

A Wire wound resistor is formed by winding a wire made up of a resistive material around a core. The metallic core acts as a non-conductive material while the resistive wire conducts, but with some resistance. The image of a wire wound resistor is as shown below.



Usually a nichrome wire or a manganin wire is used to wind the core because they offer high resistance. Whereas plastic, ceramic or glass is used for core.

- Wire wound resistors are very accurate.
- They work excellently for low resistance values and high power ratings.

These are the oldest type of fixed resistors, but are being used even now.

Thick Film

The film resistors have a resistive layer on a ceramic base, whose thickness defines the type they belong to. The thickness of resistive layer on thick film resistors is much higher than thin film resistors. Thick film resistors are produced by firing a special paste, which is a mixture of glass and metal oxides, onto the substrate.

There are three main types in thick film resistors like Fusible resistors, Cermet film resistors, and Metal oxide film resistors.

Fusible Resistors

The Fusible resistors are similar to wire wound resistors. But these resistors along with providing resistance, act as a fuse. The image of a fusible resistor is as shown below.



Images of Fusible resistors

In this resistor, the current flows through a spring loaded connection, which is placed closely to the body of the resistor. The blob that is attached to the spring wire of the resistor takes the heat generated by the resistor due to the current flow. If this heat is increased, the attachment to the blob gets melted up and opens the connection.

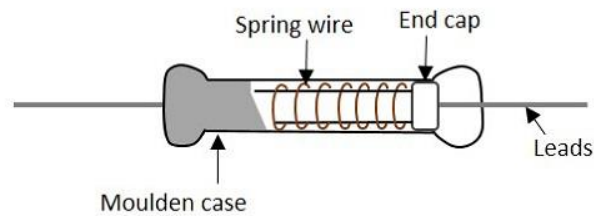


Image of a Fusible resistor

Hence we can say that, these resistors limit the current, but if the circuit power rating exceeds a specified value, these resistors act as a fuse to open or break the circuit. The value of these resistors is usually of less than 10 Ohms. These resistors are generally used in TV sets, amplifiers and other expensive electronic circuits.

Cermet Film Resistors

The Cermet film resistors are the film resistors made up of a special material called **Cermet**. Cermet is a composite alloy made by combining **Ceramic** and **Metal**. This combination provides the advantages in both of these materials like high temperature resistance and wear resistance of ceramic along with flexibility and electrical conductivity of a metal.

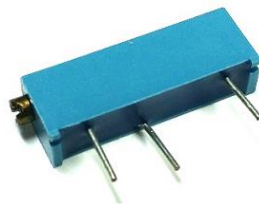
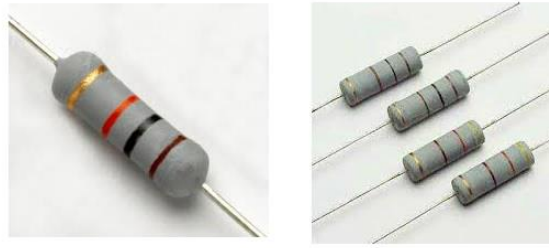


Image of a Cermet resistor

A metal film layer is wrapped around a resistive material and is fixed in a ceramic metal or cermet substrate. Leads are taken to make the connections easy while fixing on a PCB. They offer high stability as temperature cannot affect their performance.

Metal Oxide film resistors

A Metal oxide film resistor is formed by oxidizing a thick film of Tin chloride on a heated glass rod, which is a substrate. They have high temperature stability and can be used at high voltages. These resistors have low operating noise.



Images showing Metal oxide film resistors

Metal oxide film resistors differ with metal film ones only regarding the type of film coated. **Metal oxide** is a metallic compound like tin with oxygen to form tin oxide, which is coated as a film on the resistor. The resistivity of this resistor depends upon the amount of antimony oxide added to the **tin oxide**.

Thin Film

Thin film resistors have a resistive layer of width 0.1 micrometer or smaller on the ceramic base. Thin film resistors have a metallic film that is vacuum deposited on an insulating substrate.

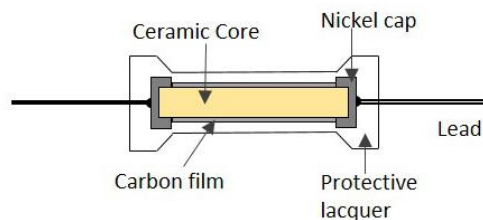
Thin film resistors are more accurate and have better temperature coefficient and is more stable. The thin film resistors are further divided into two types such as –

- Carbon film resistors
- Metal film resistors

Carbon film resistor

A Carbon film resistor is made by depositing a carbon film layer on a ceramic substrate. The carbon film acts as the resistive material to the current and the ceramic substance acts as an insulating substance. Metallic caps are fixed at both the ends and copper leads are drawn out.

The following figure shows the construction of a carbon film resistor.



The main advantages of these resistors are their high stability, wide operating range, low noise, and low cost. The carbon film resistors are the most preferred ones over carbon composition resistors due to their low noise.

Metal Film Resistors

The film coating makes the difference between metal oxide film resistors and metal film resistors. A thin film of metallic substance such as nickel chromium is used to coat the resistor in a metal film resistor whereas a film of metal oxide like tin oxide is used to coat the resistor in a metal oxide resistor.



Images of Metal film resistors

Metal film resistors have low temperature coefficient of resistance, which means the resistance is less affected by the temperature.

Wattage

While using a resistor, if the flow of current increases, the resistor dissipates some heat. If this value crosses a certain critical value, the resistor may get damaged. The wattage rating of a resistor is printed on some higher value resistors in order to avoid such situation.

Wattage is the amount of electric power expressed in watts. Electric power is the rate of transfer of electrical energy.

Power $P = VI = I^2R$

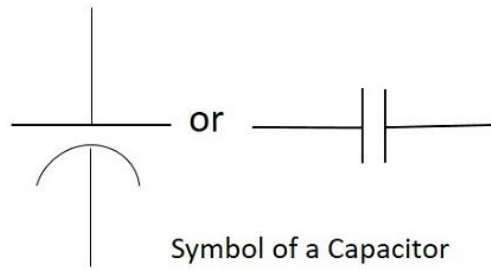
Capacitors

A Capacitor is a passive component that has the ability to store the energy in the form of potential difference between its plates. It resists a sudden change in voltage. The charge is stored in the form of potential difference between two plates, which form to be positive and negative depending upon the direction of charge storage.

A non-conducting region is present between these two plates which is called as **dielectric**. This dielectric can be vacuum, air, mica, paper, ceramic, aluminum etc. The name of the capacitor is given by the dielectric used.

Symbol and Units

The standard units for capacitance is Farads. Generally, the values of capacitors available will be in the order of micro-farads, pico-farads and nano-farads. The symbol of a capacitor is as shown below.



The Capacitance of a capacitor is proportional to the distance between the plates and is inversely proportional to the area of the plates. Also, the higher the permittivity of a material, the higher will be the capacitance. The **permittivity** of a medium describes how much electric flux is being generated per unit charge in that medium. The following image shows some practical capacitors.



When two plates having same area A , and equal width are placed parallel to each other with a separation of distance d , and if some energy is applied to the plates, then the capacitance of that parallel plate capacitor can be termed as –

$$C = \frac{\epsilon_0 \epsilon_r d}{A}$$

Where

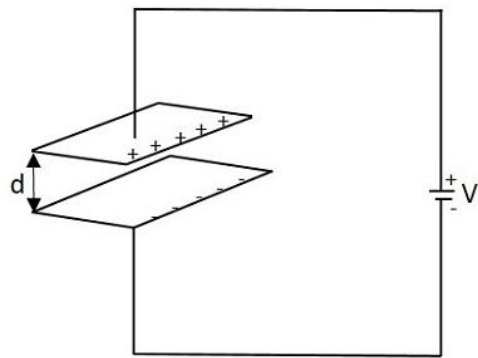
C = Capacitance of a capacitor

ϵ_0 = permittivity of free space

ϵ_r = permittivity of dielectric medium

d = distance between the plates

A = area of the two conducting plates



Parallel plate capacitor

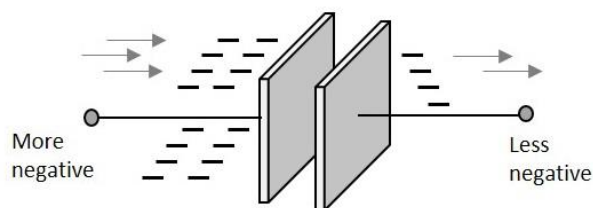
With some voltage applied, the charge deposits on the two parallel plates of the capacitor. This charge deposition occurs slowly and when the voltage across the capacitor equals the voltage applied, the charging stops, as the voltage entering equals the voltage leaving.

The rate of charging depends upon the value of capacitance. The greater the value of capacitance, the slower the rate of change of voltage in the plates.

Working of a Capacitor

A Capacitor can be understood as a two-terminal passive component which stores electrical energy. This electrical energy is stored in electrostatic field.

Initially, the negative and positive charges on two plates of the capacitor are in equilibrium. There is no tendency for a capacitor to get charged or discharged. The negative charge is formed by the accumulation of electrons, while the positive charge is formed by the depletion of electrons. As this happens without any external charge given, this state is **electrostatic** condition. The figure below shows the capacitor with static charges.



The accumulation and depletion of electrons according to the varying positive and negative cycles of the AC supply, can be understood as “current flow”. This is called as **Displacement Current**. The direction of this current flow keeps on changing as this is AC.

Charging of a Capacitor

When an external voltage is given, the electric charge gets converted into electrostatic charge. This happens while the capacitor is charging. The positive potential of the supply, attracts the electrons from the positive plate of the capacitor, making it more positive. While the negative potential of the supply,

forces the electrons to the negative plate of the capacitor, making it more negative. The figure below explains this.

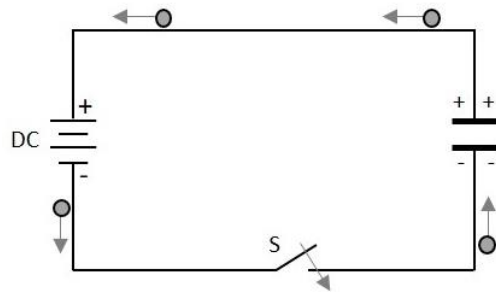
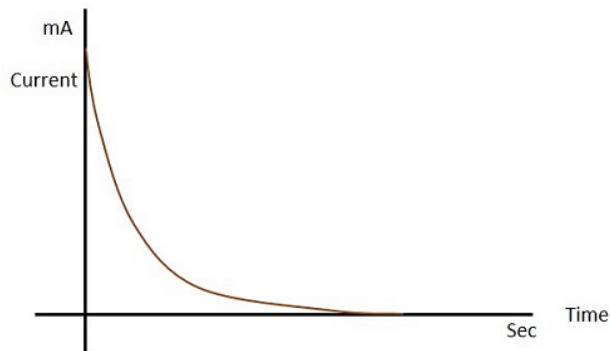


Figure showing the electrons from positive plate to deposit on negative plate of a capacitor

During this process of charging, the electrons move through the DC supply but not through the **dielectric** which is an **insulator**. This displacement is large, when the capacitor starts to charge but reduces as it charges. The capacitor stops charging when the voltage across capacitor equals the supply voltage.

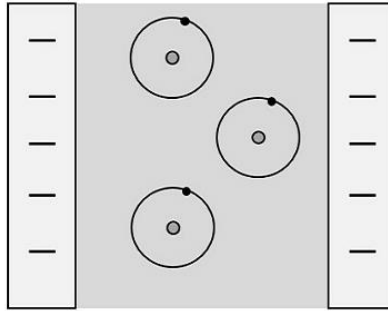


Let us see what happens to the dielectric when the capacitor begins to charge.

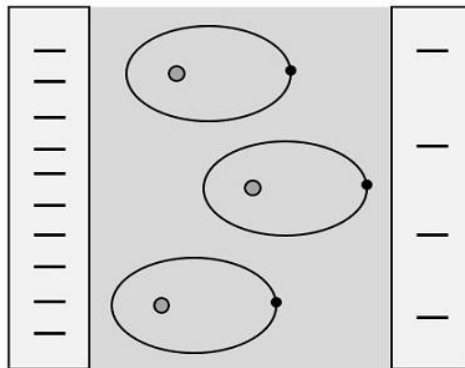
Dielectric behavior

As the charges deposit on the plates of the capacitor, an electrostatic field is formed. The strength of this electrostatic field depends upon the magnitude of charge on the plate and the permittivity of the dielectric material. **Permittivity** is the measure of dielectric whether how far it allows the electrostatic lines to pass through it.

The dielectric is actually an insulator. It has electrons in the outer most orbit of the atoms. Let us observe how they get affected. When there is no charge on the plates, the electrons in the dielectric move in circular orbit. This is as shown in the figure below.



When charge deposition takes place, the electrons tend to move towards the positive charged plate, but still they keep on revolving as shown in the figure.



If the charge increases further, the orbits expand more. But if it still increases, the dielectric **breaks down** shorting the capacitor. Now, the capacitor being fully charged, it's ready to get discharged. It is enough if we provide a path for them to travel from negative to positive plate. The electrons flow without any external supply as there are too many number of electrons on one side and barely any electrons on the other. This imbalance is adjusted by the **discharge** of the capacitor.

Also, when a discharge path is found, the atoms in the dielectric material tend to get to their normal **circular orbit** and hence forces the electrons to get discharged. This kind of discharge enables capacitors to deliver high currents in a short period of time, just as in a camera flash.

Color Coding

To know the value of a capacitor, it is usually labelled as below –

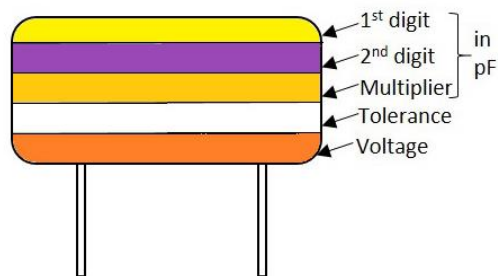
$n35 = 0.35\text{nF}$ or $3n5 = 3.5\text{nF}$ or $35n = 35\text{nF}$ and so on.

Sometimes the markings will be like 100K which means, $k = 1000\text{pF}$. Then the value will be $100 \times 1000\text{pF} = 100\text{nF}$.

Though these number markings are being used now-a-days, an International color coding scheme was developed long ago, to understand the values of capacitors. The color coding indications are just as given below.

Band colour	Digit A and B	Multiplier	Tolerance t > 10pf	Tolerance t < 10pf	Temperature coefficient
Black	0	$\times 1$	$\pm 20\%$	$\pm 2.0\text{pF}$	
Brown	1	$\times 10$	$\pm 1\%$	$\pm 0.1\text{pF}$	-33×10^{-6}
Red	2	$\times 100$	$\pm 2\%$	$\pm 0.25\text{pF}$	-75×10^{-6}
Orange	3	$\times 1,000$	$\pm 3\%$		-150×10^{-6}
Yellow	4	$\times 10,000$	$\pm 4\%$		-220×10^{-6}
Green	5	$\times 100,000$	$\pm 5\%$	$\pm 0.5\text{pF}$	-330×10^{-6}
Blue	6	$\times 1,000,000$			-470×10^{-6}
Violet	7				-750×10^{-6}
Gray	8	$\times 0.01$	$+80\%, -20\%$		
White	9	$\times 0.1$	$\pm 10\%$	$\pm 1.0\text{pF}$	
Gold		$\times 0.1$	$\pm 5\%$		
Silver		$\times 0.01$	$\pm 10\%$		

These indications were used to identify the value of capacitors.



Color coding in capacitors

In these five band capacitors, the first two bands represent digits, third one indicates multiplier, fourth for tolerance and the fifth represents voltage. Let us look at an example to understand the color coding process.

Example 1 – Determine the value of a capacitor with a color code yellow, violet, orange, white and red.

Solution – The value of yellow is 4, violet is 7, orange is 3 which represents multiplier. White is ± 10 which is the tolerance value. Red represents the voltage. But to know the voltage rating, we have got another table, from which the particular band to which this capacitor belongs, has to be known.

Hence the value of the capacitor is 47nF, 10% 250v voltage for V band

The following table shows how voltage is determined depending upon the bands the capacitors belong to.

With the help of this table, the voltage rating for each band of capacitors is known according to the color given. The type of voltage ratings also indicates the type of capacitors. For example, TYPE J ones are Dipped Tantalum Capacitors, TYPE K ones are Mica Capacitors, TYPE L ones are Polystyrene Capacitors, TYPE M ones are Electrolytic Band 4 Capacitors and TYPE N ones are Electrolytic Band 3 Capacitors. These days, the color coding has been replaced by simple printing of value of the capacitors as mentioned previously.

Capacitive Reactance

This is an important term. Capacitive Reactance is the opposition offered by a capacitor to the alternating current flow, or simply AC current. A capacitor resists the change in the flow of current and hence it shows some opposition which can be termed as **reactance**, as the frequency of the input current should also be considered along with the resistance it offers.

Symbol: X_C

In a purely capacitive circuit, the current I_C **leads** the applied voltage by 90°

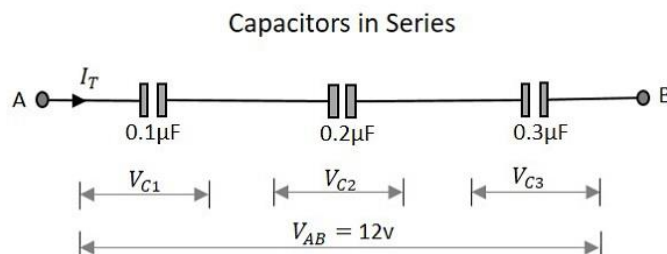
Temperature Coefficient of Capacitors

The maximum change in **Capacitance** of a capacitor, over a specified temperature range, can be known by the temperature coefficient of a capacitor. It states that when the temperature exceeds a certain point, the change in capacitance of a capacitor that might occur is understood as the **temperature coefficient of capacitors**.

All the capacitors are usually manufactured considering a reference temperature of 25°C . Hence the temperature coefficient of capacitors is considered for the values of temperatures that are above and below this value.

Capacitors in Series

Let us observe what happens, when few Capacitors are connected in Series. Let us consider three capacitors with different values, as shown in the figure below.



Capacitance

When the capacitance of a network whose capacitors are in series is considered, the reciprocal of the capacitances of all capacitors, is added to get the reciprocal of the total capacitance. To get this more clearly,

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Following the same formula, if simply two capacitors are connected in series, then

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

Where C_1 is the capacitance across the 1st capacitor, C_2 is the capacitance across the 2nd capacitor and C_3 is the capacitance across the 3rd capacitor in the above network.

Voltage

The voltage across each capacitor depends upon the value of individual capacitances. Which means

$$V_{C1} = \frac{Q_T}{C_1} \quad V_{C2} = \frac{Q_T}{C_2} \quad V_{C3} = \frac{Q_T}{C_3}$$

The total voltage across the series capacitors circuit,

$$V_T = V_{C1} + V_{C2} + V_{C3}$$

Where V_{C1} is the voltage across the 1st capacitor, V_{C2} is the voltage across the 2nd capacitor and V_{C3} is the voltage across the 3rd capacitor in the above network.

Current

The total amount of Current that flows through a set of Capacitors connected in series is the same at all the points. Therefore, the capacitors will store the same amount of charge regardless of their capacitance value.

Current through the network,

$$I = I_1 = I_2 = I_3$$

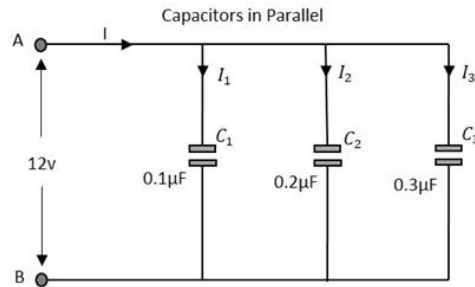
Where I_1 is the current through the 1st capacitor, I_2 is the current through the 2nd capacitor and I_3 is the current through the 3rd capacitor in the above network.

As the current is same, the storage of charge is same because any plate of a capacitor gets its charge from the adjacent capacitor and hence capacitors in series will have the same charge.

$$Q_T = Q_1 = Q_2 = Q_3$$

Capacitors in Parallel

Let us observe what happens, when few capacitors are connected in Parallel. Let us consider three capacitors with different values, as shown in the figure below.



Capacitance

The total Capacitance of the circuit is the equivalent to the sum of the individual capacitances of the capacitors in the network.

$$C_T = C_1 + C_2 + C_3$$

Where C₁ is the capacitance across the 1st capacitor, C₂ is the capacitance across the 2nd capacitor and C₃ is the capacitance across the 3rd capacitor in the above network.

Voltage

The voltage measured at the end of the circuit is **same** as the voltage across all the capacitors that are connected in a parallel circuit.

$$V_T = V_1 = V_2 = V_3$$

Where V_{c1} is the voltage across the 1st capacitor, V_{c2} is the voltage across the 2nd capacitor and V_{c3} is the voltage across the 3rd capacitor in the above network.

Current

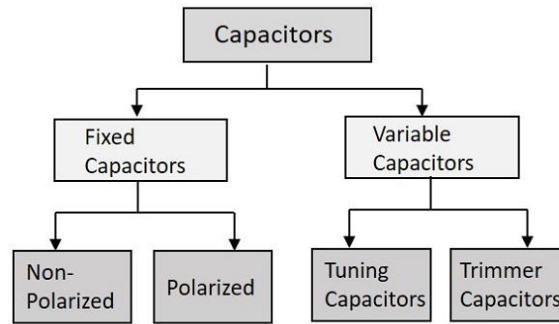
The total current flowing is equal to the sum of the currents flowing through each capacitor connected in the parallel network.

$$I_T = I_1 + I_2 + I_3$$

Where I₁ is the current through the 1st capacitor, I₂ is the current through the 2nd capacitor and I₃ is the current through the 3rd capacitor in the above network.

Types of Capacitors

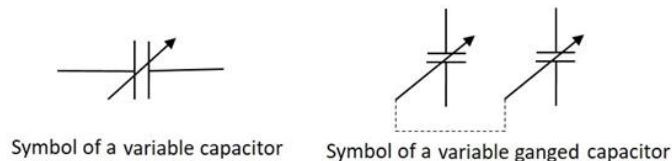
The classification is as shown in the following figure.



The main classification is just like the above one. The fixed capacitors are the ones whose value is fixed at the time of manufacturing itself and the variable ones provide us with an option to vary the value of capacitance.

Variable Capacitors

Let us know something about the variable capacitors whose value alters when you vary, either **electrically** or **mechanically**. Variable capacitors in general consists of interwoven sets of metallic plates in which one is fixed and the other is variable. These capacitors provide the capacitance values so as to vary between **10 to 500pF**.

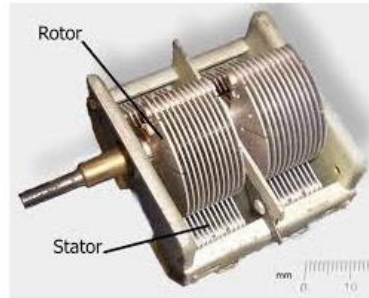


The ganged capacitor shown here is a combination of two capacitors connected together. A single shaft is used to rotate the variable ends of these capacitors which are combined as one. The dotted line indicates that they are connected internally.

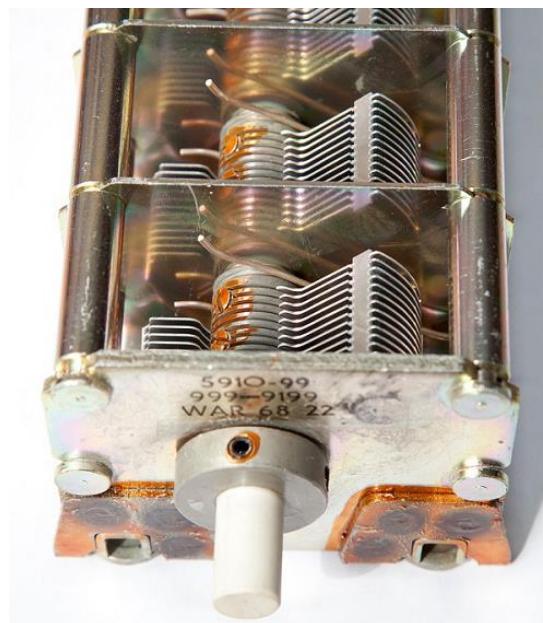
There are many uses of these variable resistors such as for tuning in LC circuits of radio receivers, for impedance matching in antennas etc. The main types of variable capacitors are Tuning capacitors and Trimmer capacitors.

Tuning Capacitors

Tuning capacitors are popular type of variable capacitors. They contain a stator, a rotor, a frame to support the stator and a mica capacitor. The constructional details of a tuning capacitor are shown in the following figure.



The stator is a stationary part and rotor rotates by the movement of a movable shaft. The rotor plates when moved into the slots of stator, they come close to form plates of a capacitor. When the rotor plates sit completely in the slots of the stator then the capacitance value is maximum and when they don't, the capacitance value is minimum.



The above figure shows a **ganged tuning capacitor** having two tuning capacitors connected in a gang. This is how a tuning capacitor works. These capacitors generally have capacitance values from few Pico Farads to few tens of Pico Farads. These are mostly used in LC circuits in radio receivers. These are also called as **Tuning Condensers**.

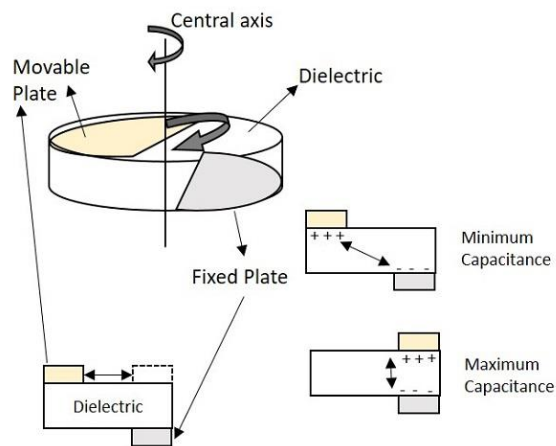
Trimmer Capacitors

Trimmer capacitors are varied using a screwdriver. Trimmer capacitors are usually fixed in such a place where there is no need to change the value of capacitance, once fixed.

There are three leads of a trimmer capacitor, one connected to stationary plate, one to rotary and the other one is common. The movable disc is a semi-circular shaped one. A trimmer capacitor would look like the ones in the following figure.



There are two parallel conducting plates present with a dielectric in the middle. Depending upon this dielectric used, there are air trimmer capacitors and ceramic trimmer capacitors. The constructional details of a trimmer capacitor are as shown below.



One of the two plates is movable, while the other is fixed. The dielectric material is fixed. When the movable plate is moved, opposite to the area between movable and fixed electrode, then the capacitance can be changed. The capacitance will be higher if the opposite area gets bigger, as both the electrodes act as two plates of a capacitor.

The Trimmer Capacitors are easily fixed on a PCB Printed Circuit Board and they are mostly used for calibration of equipment.

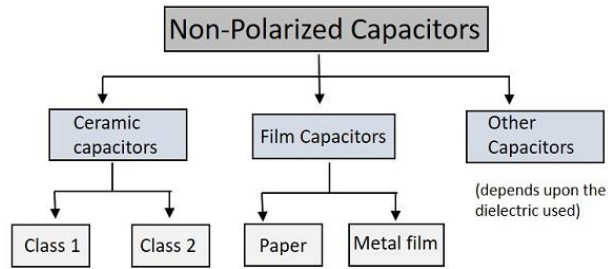
Fixed Capacitors

The Capacitors whose value is fixed while manufacturing and cannot be altered later are called as **Fixed Capacitors**. The main classification of fixed capacitors is done as polarized and non-polarized. Let us have a look at Non-polarized capacitors.

Non-Polarized Capacitors

These are the capacitors that have **no specific polarities**, which means that they can be connected in a circuit, either way without bothering about the placement of right lead and left lead. These capacitors are also called as **Non-Electrolytic Capacitors**.

The main classification of Non-Polarized capacitors is done as shown in the following figure.



Among the types of capacitors, let us first go through the Ceramic Capacitors.

Ceramic Capacitors

The common capacitors used among fixed type are Ceramic Capacitors. The Ceramic capacitors are fixed capacitors that have **ceramic material** as a dielectric.

These ceramic capacitors are further classified as class1 and class2 depending upon their applications. For instance, **Class1** has high stability and works best for resonant circuit applications, while **class2** has high efficiency and gives its best for coupling applications.



Images of different Ceramic Capacitors

A hollow tubular or plate like ceramic material such as **titanium dioxide** and **barium titanate** is coated with a deposition of silver compound on both walls, so that both sides act as two capacitor plates and ceramic acts as a dielectric. Leads are drawn from these two surfaces and this whole assembly is encapsulated in a moisture-proof coating.

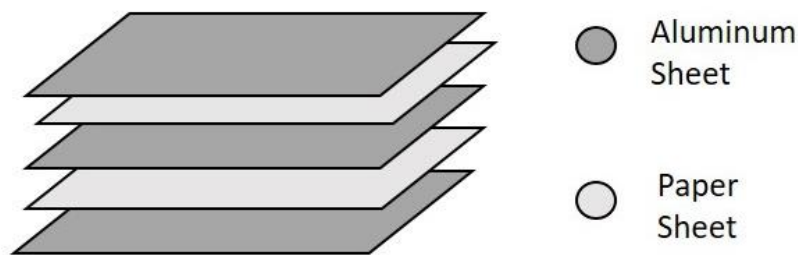
The most often used modern ceramic capacitors are **Multi-Layer Chip Capacitors (MLCC)**. These capacitors are made in surface mounted technology and are mostly used due to their small size. These are available in the order of 1nF to $100\mu\text{F}$.

Film Capacitors

The Film Capacitors are the ones which have a film substance as a dielectric material. Depending upon the type of film used, these are classified as **Paper** and **Metal film** capacitors.

These film capacitors are both paper dielectric capacitors whereas a paper capacitor uses a **waxed** paper while a metallic film capacitor uses a **metallized** paper. The arrangement is almost same as shown below.

Construction of a Film Capacitor



Paper Capacitors

Paper capacitors use Paper as a dielectric material. Two thin tin foil sheets are taken and placed between thin waxed or oiled paper sheets. This paper acts as a dielectric. Now-a-days paper is being replaced by plastic.

These sheets are sandwiched and are rolled into a cylindrical shape and encapsulated in a plastic enclosure. Leads are drawn out. The following figure shows an example of Paper Capacitors.



Image of a Paper Capacitor

Paper capacitors are available in the order of $0.001\mu\text{F}$ to $2\mu\text{F}$ and the voltage rating can be as high as 2000volts. These capacitors are useful in high voltage and current applications.

Metal Film Capacitors

Metal Film capacitors are another type of film capacitors. These are also called as Metal Foil Capacitors or Metallized Paper Capacitors as the dielectric used here is a paper coated with metallic film.

Unlike in paper capacitors, a film of Aluminum or Zinc is coated on a paper to form a dielectric in this metallic film capacitors. Instead of Aluminum sheets placing between papers, the paper itself is directly coated here. This reduces the size of the capacitor.



Image of Metallic Paper Capacitors

The Aluminum coating is preferred over zinc coating so as **to avoid destruction** of capacitor due to chemical reduction. The Aluminum coated sheets are rolled in the form of a cylinder and leads are taken. This whole thing is encapsulated with wax or plastic resin to protect the capacitor. These capacitors are useful in **high voltage and current** applications.

Other Capacitors

These are the miscellaneous capacitors that are named after the dielectric materials used. This group includes Mica Capacitors, Air Capacitors, Vacuum Capacitors and Glass Capacitors etc.

Mica Capacitors

The Mica Capacitors are made by using thin Mica sheets as dielectric materials. Just like paper capacitors, thin metal sheets are sandwiched with mica sheets in between. Finally the layers of metal sheets are connected at both ends and two leads are formed. Then the whole assembly is enclosed in plastic Bakelite capsule. The following image shows how a Mica capacitor looks like.



Mica Capacitors are available in the range of 50pF to 500pF. The Mica capacitors have high working voltage up to 500volts. These are most commonly used capacitors for electronic circuits such as ripple filters, Resonant circuits, Coupling circuits and high power, high current RF broadcast transmitters.

Air Capacitors

The Air Capacitors are the ones with **air as dielectric**. The simplest air capacitors are the ones with conducting plates having air in between. This construction is exactly the same as the **variable tuning capacitor** discussed above. These capacitors can be fixed and variable also but fixed are very rarely used as there are others with superior characteristics.

Vacuum Capacitors

The Vacuum Capacitors uses **high vacuum as dielectric** instead of air or some other material. These are also available in fixed and variable modes. The construction of these capacitors is similar to vacuum tubes. They are mostly seen in the form of a glass cylinder which contain inter-meshed concentric cylinders.

The following image shows a variable vacuum capacitor.



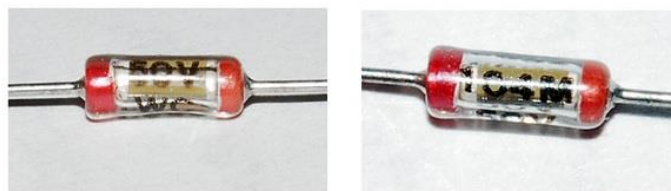
The following image shows how a fixed vacuum capacitor looks like –



Variable vacuum capacitors are available at a range of 12pF to 5000pF and they are used for high voltage applications such as 5kV to 60kV. They are used in main equipment such as **high power broadcast transmitters, RF amplifiers** and large **antenna tuners**.

Glass Capacitors

Glass capacitors are very exclusive ones with many advantages and applications. As all of the above types, here **glass** is the dielectric substance. Along with glass dielectric, Aluminum electrodes are also present in these capacitors. Plastic encapsulation is done after taking out the leads. The leads can be axial leads or tubular leads.



Images of Glass Capacitors

There are many advantages of a glass capacitor such as –

- The temperature coefficient is low.
- These are Noise-free capacitors.
- They produce high quality output with low loss.
- They have the capability of handling high operating temperatures.

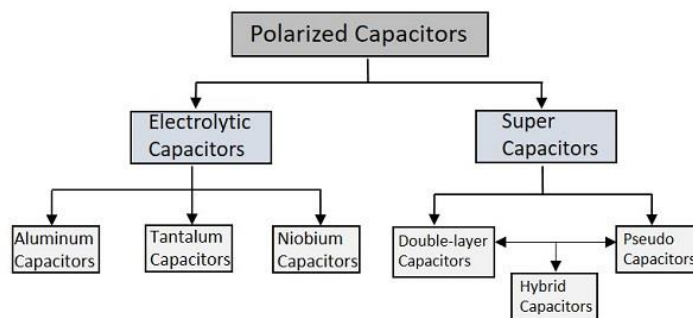
- These capacitors can handle large RF currents.

There are many applications for these glass capacitors such as –

- Used in circuits that need to be at high temperature zones.
- Used in circuits that need high Q.
- Used in high power handling circuits.
- Used for circuits that need high tolerances.

Polarized Capacitors

Polarized Capacitors are the ones that have specific positive and negative polarities. While using these capacitors in circuits, it should always be taken care that they are connected in **perfect polarities**. The following image shows the classification of polarized capacitors.



Let's start the discussion with Electrolytic Capacitors.

Electrolytic Capacitors

The Electrolytic Capacitors are the capacitors which indicate by the name that some electrolyte is used in it. They are polarized capacitors which have anode ++ and cathode -- with particular polarities.

A metal on which **insulating oxide layer** forms by anodizing is called as an **Anode**. A solid or non-solid **electrolyte** which covers the surface of the oxide layer, functions as a **cathode**. The Electrolytic Capacitors have much higher **Capacitance-Voltage CV value** than the others, due to their larger anode surface and thin dielectric oxide layer.

Aluminum Electrolytic Capacitors

Aluminum Electrolytic Capacitors are the most common types among the Electrolytic capacitors. In these ones, a pure **Aluminum foil** with an etched surface acts as an **Anode**. A thin layer of metal, which has a thickness of few micrometers acts as a **diffusion barrier**, which is placed between two metals to separate electrically. Hence the diffusion barrier acts as a **dielectric**. The **electrolyte** acts as a **cathode** which covers the rough surface of oxide layer.

The following figure shows an image of different sizes of Aluminum Electrolytic Capacitors available.



Depending upon the electrolyte there are three types of Aluminum Electrolytic Capacitors. They are –

- Wet Aluminum Electrolytic capacitors non-solid
- Manganese dioxide Aluminum Electrolytic capacitors solid
- Polymer Aluminum Electrolytic capacitors solid

The main advantage with these Aluminum Electrolytic capacitors is that, they have **low impedance** values even at mains frequency and they are cheaper. These are mostly used in **Power supply circuits**, **SMPS** Switched Mode Power Supply and **DC-DC Converters**.

Tantalum Electrolytic capacitors

These are another type of Electrolytic capacitors whose **anode** is made up of **tantalum** on which a very thin insulating **oxide layer** is formed. This layer acts as a **dielectric** and the **electrolyte** acts as a cathode which covers the surface of oxide layer.

The following figure shows how tantalum capacitors look like.

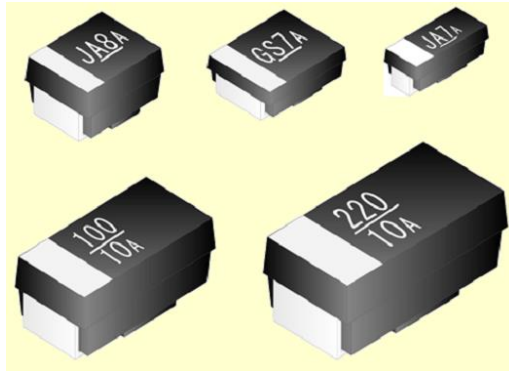


Tantalum provides high permittivity dielectric layer. Tantalum has high capacitance per volume and lower weight. But these ones are costlier than Aluminum Electrolytic capacitors, due to the frequent unavailability of tantalum.

Niobium Electrolytic Capacitors

A Niobium Electrolytic Capacitor is the other type of Electrolytic Capacitors in which a passivated niobium metal or niobium monoxide is considered as anode and an insulating niobium pentoxide layer is added on

to the anode, so that it acts as a dielectric. A solid electrolyte is laid on the surface of the oxide layer which acts as a cathode. The following figure shows how Niobium capacitors look like.



The Niobium Capacitors are commonly available as SMD Surface Mount Devices chip capacitors. These are easily fitted in a PCB. These capacitors should be operated in perfect polarities. Any kind of reverse voltage or ripple current higher than the specified will eventually **destroy the dielectric** and the capacitor as well.

Super Capacitors

The high capacity electrochemical capacitors with capacitance values much higher than the other capacitors, are called as **Super Capacitors**. These can be categorized as a group that lies between electrolytic capacitors and rechargeable batteries. These are also called as **Ultra Capacitors**.

There are many advantages with these capacitors such as –

- They have high capacitance value.
- They can store and deliver charge much faster.
- They can handle more charge and discharge cycles.

These capacitors have many applications such as –

- They are used in cars, buses, trains, elevators and cranes.
- They are used in regenerative braking.
- They are used for memory backup.

The types of super capacitors are Double-layered, Pseudo and Hybrid ones.

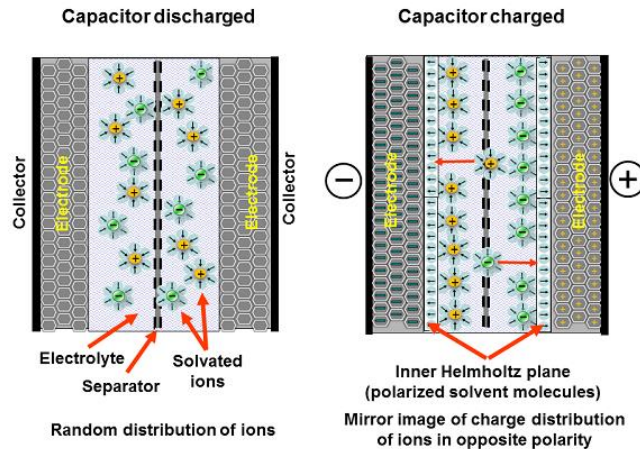
Double-layered Capacitors

Double-layered capacitors are electrostatic capacitors. The charge deposition is done in these capacitors according to the principle of Double-layer.

- All solid substances have negative charge on the surface layer when disposed into a liquid.
- This is due to the high dielectric coefficient of liquid.
- All the positive ions come near the surface of the solid material to make a skin.

- The deposition of positive ions near the solid material get looser with the distance.
- The charge created at this surface due to the deposition of anions and cations leads to some capacitance value.

This double-layer phenomenon is also termed as Helmholtz double layer. The figure below explains the procedure of double-layer phenomenon, when the capacitor is charged and when it is discharged.



These capacitors are simply called as Electric Double Layered Capacitors EDLC. They use carbon electrodes to achieve separation of charge between the surface of conductive electrode and the electrolyte. The carbon acts as dielectric and the other two as anode and cathode. The separation of charge is much smaller than in a conventional capacitor.

Pseudo Capacitors

These capacitors follow the **electrochemical** process for the deposition of charge. This is also called as **faradaic process**. At an electrode, when some chemical substance reduces or oxidizes, some current is generated. During such process, these capacitors store the electric charge by electron transfer between electrode and electrolyte. This is the working principle of Pseudo capacitors.



Image showing Pseudo Capacitors

They get charged much faster and store the charge as much as a battery does. They are operated at a faster rate. These are used in tandem with batteries to improve life. These are used in grid applications to handle power fluctuations.

Hybrid Capacitors

A Hybrid Capacitor is a combination of EDLC and Pseudo Capacitor. In the Hybrid capacitors, activated carbon is used as cathode and the pre-doped carbon material acts as anode. Li ion capacitor is the common example of this type. The following figure shows different types of Hybrid Capacitors.



They have high tolerance in a wide range of temperature variations from -55°C to 200°C . Hybrid capacitors are also used in airborne applications. Though cost is high, these capacitors are highly reliable and compact. These are rugged and can tolerate extreme shock, vibration and pressure from environment. Hybrid capacitors have higher energy density and higher specific power than any electrolytic capacitor.