LITHIUM-ION BATTERY (Li-ion Battery):

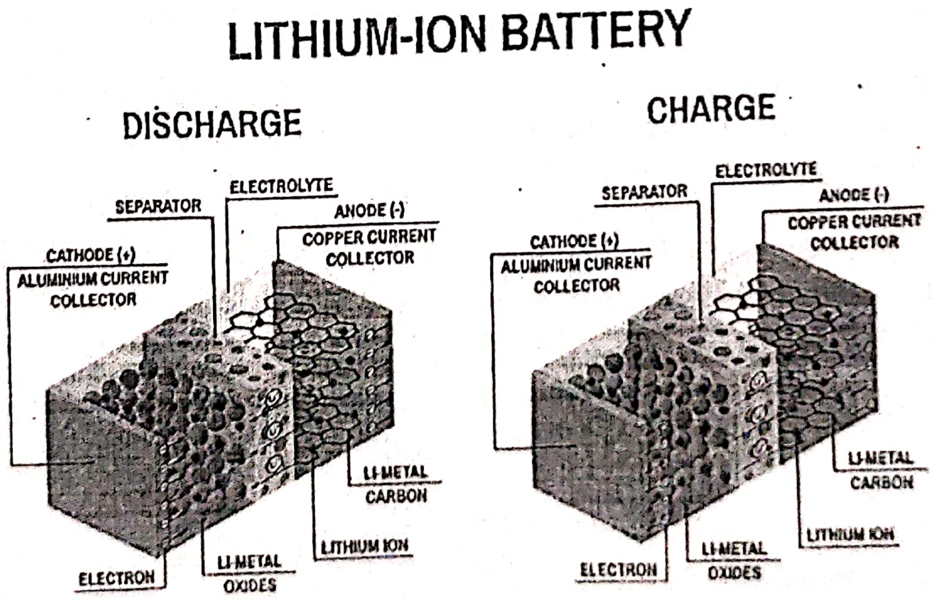
A lithium-ion battery is a type of rechargeable battery that makes use of charged particles of lithium to convert chemical energy into electrical energy. On the basis of the ability of recharging, lithium-ion batteries are classified into two broad categories, namely, primary and secondary. Primary lithium-ion batteries are non-rechargeable, while secondary lithium-ion batteries are rechargeable.

Working Principle of Lithium-ion Battery:

Lithium-ion batteries work on the **rocking chair principle**. Here, the conversion of chemical energy into electrical energy takes place with the help of redox reactions (**A chemical reaction in which electrons are transferred between two reactants participating in it**). Typically, a lithium-ion battery consists of two or more electrically connected electrochemical cells. When the battery is charged, the ions tend to move towards the negative electrode or the anode. When the battery gets completely discharged, the lithium ions return back to the positive electrode i.e., the cathode. This means that during the charging and discharging process. Thus, the lithium ions move back and forth between the two electrodes of the battery, which is why the working principle of a lithium-ion battery is called the **rocking chair principle.**

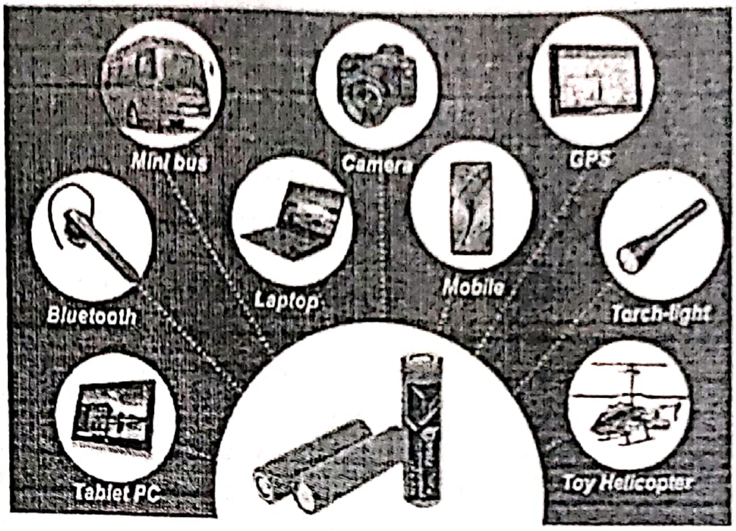
Working of Lithium-ion Battery:

A typically battery consists of two electrodes, namely, anode and cathode. Cathode forms the positive terminal of the battery and anode is the negative terminal. The cathode of a lithium-ion battery is mainly composed of a lithium compound, while the prime element of the anode is graphite. When the battery is plugged in with an electric supply, the lithium ions tend to move from the cathode to the anode, i.e., from the positive electrode to the negative electrode. This is known as charging the battery. During the discharge phase of the battery, the movement of the lithium ions gets reversed from anode to cathode, i.e., from negative electrode to positive electrode, and the electrical energy gets transmitted to the attached load.



Uses of Lithium-ion Battery:

1.Cellular Devices:
2.Power Banks:
3.Electric Vehicles:
4.Medical Devices:
5.Cameras:
6.Uninterrupted Power Supply System (UPS):
7.Robots:



Various Applications of Li-Ion Batteries

Advantages of Lithium-ion Battery:

1. Lithium-ion batteries have a significantly low self-discharge rate as compared to the other type of batteries.
2.They have a high energy density.
3.They require low maintenance.

Disadvantages of Lithium-ion Battery:

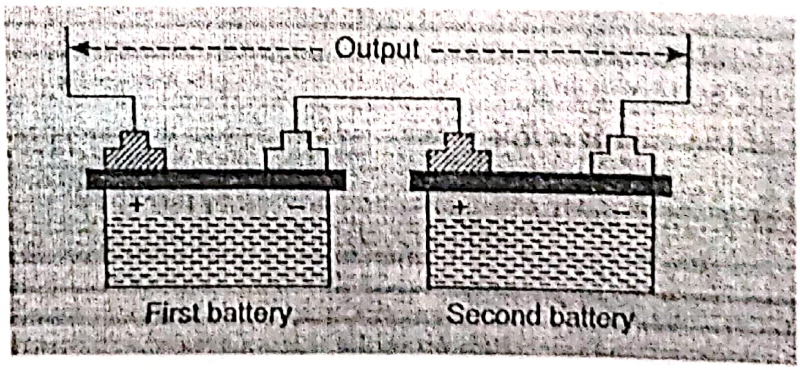
1. If the separator of the lithium-ion batteries gets damaged, they are susceptible to fire hazards.
2.. They are relatively expensive.
3. If the battery runs out of lithium ions, it cannot be replaced. Thus, the battery cannot be used after the tentative life span

COMBINATION OF TWO BATTERIES

Series Configuration of Batteries:

In a series configuration, the negative electrode of first battery is connected to the positive electrode of the second battery. The output is taken from the positive electrode of first battery and negative electrode of second battery. A combination of two batteries in series is

If number of batteries are available, the negative electrode of first battery is connected to the positive electrode of second battery and negative electrode · second battery is connected to the positive electrode of third battery and so on is shown,



Series Combination of Batteries

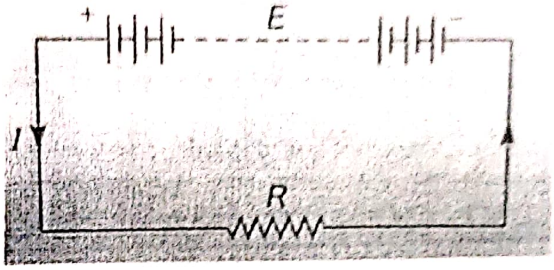
Let, n = number of batteries connected in series
r = internal resistance of a battery
R = external load connected
E = e.m.f. of each cell.

Total e.m.f. of n batteries = nE

Total internal resistance of the batteries = nr

Total circuit resistance = $R + nr$

Current in the circuit $I = \frac{nE}{R + nr}$ --------(1)



(i) If R is negligible as compared to nr, then

Series Combination of n Batteries

$$I' = \frac{nE}{nr} = \frac{E}{r}$$

Therefore, there is ***no increase in the current.***

(ii) If nr is negligible to the load resistance R, then

$$I'' = \frac{nE}{R} = n \times \frac{E}{R} = n\,I'$$

Thus, the ***current*** delivered by the battery has ***increased by n times.***

PARALLEL CONFIGURATION OF BATTERIES:

In parallel configuration, all the positive electrodes are connected to each other to give a positive electrode while all the negative electrodes are connected to each other to give a negative electrode.

Let e.m.f. of each battery = E

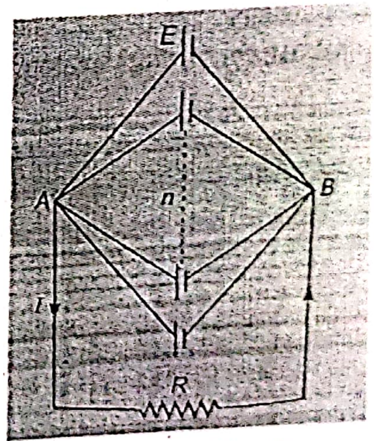
Internal resistance of the battery = $\frac{r}{n}$

Total resistance of the circuit = $R + \frac{r}{n}$

Current in the circuit $I = \frac{E}{R+\frac{r}{n}}$ ------------(1)

(i)If $\frac{r}{n}$ is negligible to R, then current $I' = \frac{E}{R}$ ---------(ii)

This shows that the group is not useful.



Parallel Combination of n Batteries

(ii) If R is negligible in comparison to $\frac{r}{n}$, then $I'' = \frac{nE}{R} = n$ times to I'

Thus, the grouping is useful when external resistance is small as compared to the internal resistance of the battery.

SERIES- PARALLEL COMBINATION OF BATTERIES:

In series-parallel grouping, some batteries are connected in series and then a combination of such series batteries (say m) is connected in parallel.

Let, number of batteries in series = n

Number of series batteries in parallel =m

Resistance of series combination = nr

Let, number of batteries in series = n

Number of series batteries in parallel = m

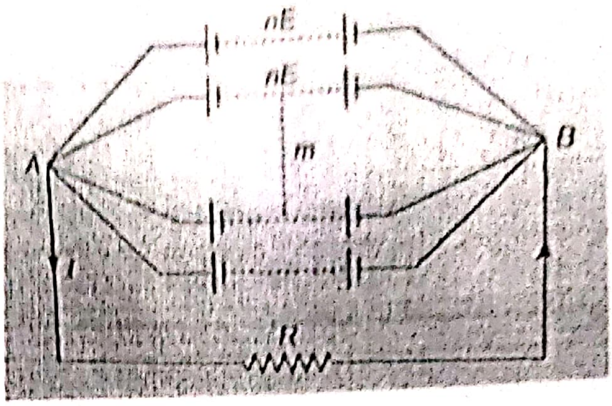
Resistance of series combination = nr

Total resistance connected in the circuit = R

e.m.f. of batteries in one row =

Equivalent resistance of m rows connected in parallel

$= \frac{nr}{m}$



Series- Parallel Combination

$\therefore$ Total circuit resistance = $R + \left(\frac{nr}{m}\right)$

Therefore, current in the circuit $I = \frac{nE}{R + \left(\frac{nr}{m}\right)} = \frac{mnE}{mR+nR}$

$\therefore$ Current in the circuit $I = \frac{NE}{mR+nR}$ ----------(1)

where, N = m x n = total number of batteries.

It is clear from Eq. (1) that the current will be maximum when denominator is minimum, i.e., mR = nr or $R = \left(\frac{nr}{m}\right)$ or the external resistance is equal to internal resistance of battery.

Therefore, series- parallel configuration will give maximum current when load resistance R is equal to the intemal resistance of the battery.

EFFICIENCY OF BATTERY:

The efficiency of a battery is defined as

$$\eta = \frac{output}{input} x\ 100\ \%$$

Let e.m.f. of battery = E, internal resistance = r,

external resistance = R, circuit current = I

$\therefore$ Power developed = I^2 R Watt

Power lost within battery = $I^2 r$ watt.

Total power development = $I^2 R + I^2 r = E\,I$ watt

$$\text{Efficiency, } \eta = \frac{I^2 R}{I^2 R + I^2 r} = \frac{R}{R+r}$$

$$\text{Or Efficiency } \eta = \frac{useful\ power}{total\ power\ produced}$$

Thus, efficiency is higher when R is greater.

DC regulated power supplies are broadly classified into "DC constant voltage power supplies" whose output voltage is stable even when the load changes and "DC constant current power supplies" whose output current is stable.

Constant Voltage:

A constant voltage driver is designed to maintain a constant voltage level during operation regardless of current variations.

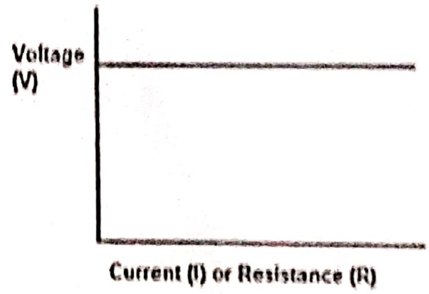
The constant voltage source provides a constant voltage to the load regardless of variations or changes in the load resistance. For this to happen, the source must have an internal resistance which is very low compared to the resistance of the load it is powering.

Some of the characteristics of an ideal constant voltage source is:

1.Zero internal resistance

2.Maintaining the same voltage regardless of variation in the amount of current drawn by load.

3.No current flows when the circuit is not loaded (open circuited).



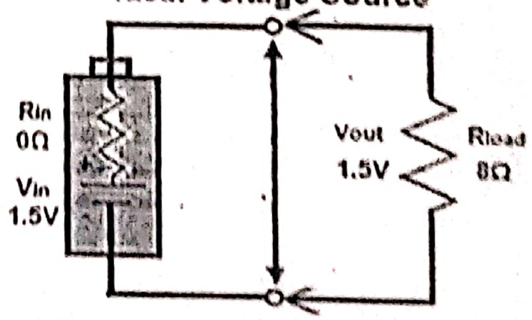
Ideal Constant Voltage Behaviour

Working of A constant voltage source:

For a voltage source to provide a constant voltage, it must have a very low internal resistance, preferably zero When the resistance is very low and using the voltage divider rule, most of the voltage will be dropped across the load, which has a higher resistance. When the internal resistance is much lower compared to the load resistance, the power source output approaches the ideal constant voltage.

In an ideal voltage source, the resistance should be zero and all the voltage is dropped across the load resistance. However, an ideal voltage source is usually practically impossible, and a typical voltage source will still have some form of internal resistance.

Ideal Voltage Source



Ideal voltage source with

zero Impedance Image

The common constant voltage sources are the batteries and regulated power supplies. However, batteries cannot supply the constant voltage for a long time and must be recharged or replaced once exhausted.

There are various ways of getting a constant voltage in power supplies or when the input voltage is higher than the output. Some of the methods of obtaining the constant voltage include using a voltage divider, series transistor, Zener diode or a combination of Zener diode and switching device such as a transistor or thyristor. In addition, a voltage regulator IC may be used to provide a more stable output better than the discrete components.

A constant voltage is usually used in circuits that require a steady voltage supply for their efficient operation. For example, the constant voltage drivers are used for paralleled LED strip lighting due to the circuit design, which produces the most balanced current over the independent output channels.

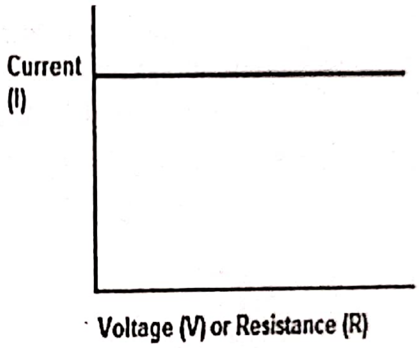
Applications of Voltage Sources:

The output voltage signal is a regulated DC signal. Every power supply in the world uses a **voltage regulator to provide the desired output voltage.** Computers, televisions, laptops and all sorts of devices are powered using this concept.

CONSTANT CURRENT SOURCES:

A constant current source is a **power source which provides a constant current to a load, even despite changes and variance in load resistance.** In other words, the current which a constant current source provides is steady, even if the resistance of the load varies. This comes in use when a circuit needs a steady current supply, without fluctuations.

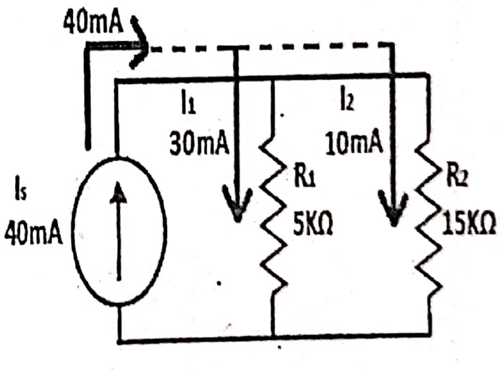
The graph below represents the current which comes from a constant current source.



Working of Constant Current Source:

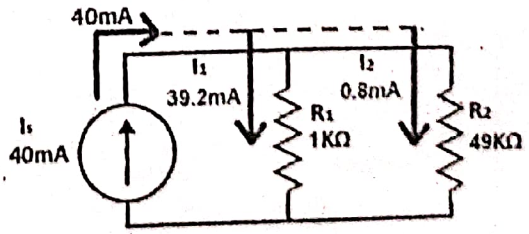
A constant current source is a power generator whose internal resistance is very high compared with the load resistance. As its internal resistance is so high, it can supply a constant current to a load whose resistance value varies, even over a wide range.

Thus, a constant current source follows the rules of current division. Being that it has very high internal resistance and the load resistance is much lower, current takes the path of least resistance, flowing out of the (high internal resistance) current source and into the load resistance, since it is of much lower resistance.



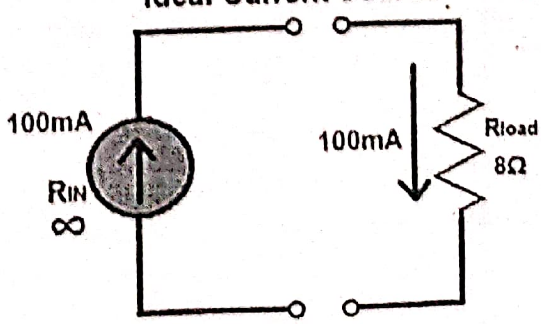
If a current source, supplies 40mA of total current, the majority of this 40mA of current takes the path of least resistance, i.e.,5KΩ resistor, and the other 10mA of current goes through the larger resistance, 15KΩ.

If a resistor of 1KΩ and the other resistor is 49KΩ, the vast majority of the current goes through the 1KΩ resistor. Very little current goes through the 49KΩ, as the resistance is of high value.



The current source represents a current source which has infinite internal resistance.

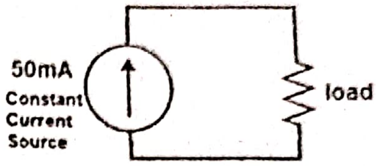
Ideal Current Source



As resistance is infinite and the load is only 8Ω, most of the current goes through the 8Ω resistor, which is the path of least resistance. If the current always take the path of least resistance, the load has infinite internal resistance, current will always seek to escape from it to a lower resistance path.

Constant Current Source Circuit:

A constant current source circuit is just a constant current source connected to the load which it powers. This load above will have a constant current of 50mA supplied to it regardless of whether the load resistance varies.



Applications of Current Sources:

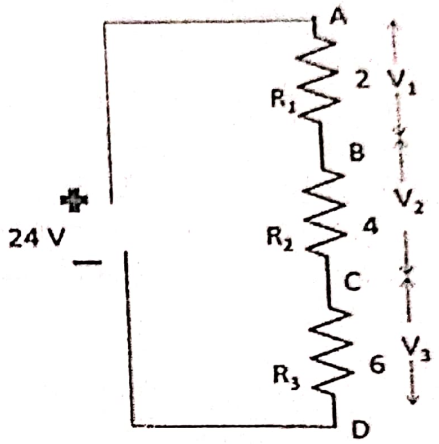
Current sources **can be used to bias transistors and can also be used as active loads for high gain amplifier** stages. They may also be used as the emitter sources for differential amplifiers - for example they may be used in the transistor long tailed pair.

Thus, the reciprocal of the effective resistance in parallel combination is equal to the sum of the reciprocals of the individual resistance.

SERIES COMBINATION (VOLTAGE DIVIDER):

In an electronic equipment it is necessary to supply different voltages to different components from a simple power supply. This can be accomplished by using a voltage divider.

A simple voltage divider consists of two or more resistors connected in series with power supply. Then the current is same through all the resistors. Hence the voltage across each resistor will be proportional to its resistance. If the supply voltage be V and the total series resistance is R then the voltage across a resistance of resistance R is given by



$$V1=\frac{V}{R}\text{ x }R1=\frac{V}{\varepsilon R}R1$$

This equation is known as the voltage divider rule.

Thus, the voltage divider rule states that the voltage across any resistor in a series circuit is equal to the resistance of that resistor times the ratio of the total resistance of all the series resistors.

It is observed that, the series element which has the highest resistance has the largest voltage drop across it.

Advantages:

1.The voltage divider method is that without knowing the value of the current in the circuit, the voltage drop across serval elements can be known.

Parallel Combination (Current Division):

A parallel circuit is often called current divider in which **terminals of all the components are connected in such a way that they share the same two end nodes.** These result in different parallel paths and branches for the current to flow through it

Current Divider circuits have two or more parallel branches for currents to flow through but the voltage is the same for all components in the parallel circuit.

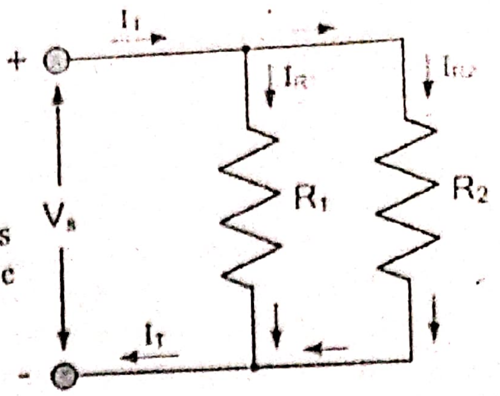
Current Dividers are parallel circuits in which the source or supply current divides into a number of parallel paths. In a parallel connected circuit, all the components have their terminals connected together sharing the same two end nodes. This results in different paths and branches for the current to flow or pass along. However, the currents can have different values through each component.

The main characteristic of parallel circuits is that while they may produce different currents flowing through different branches, the voltage is common to all the connected paths. That is V_{R1} = V_{R2} = V_{R3} ... etc. Therefore, the need to find the individual resistor voltages is eliminated allowing branch currents to be easily found with Kirchhoff's Current Law, (KCL) and of course Ohm's Law.

The basic current divider circuit consists of two resistors: R_1, and R_2 in parallel which splits the supply or source current I_S between them into two separate currents I_{R1} and I_{R2} before joining together again and returning back to the source.

As the source or total current equals the sum of the individual branch currents, then the total current, I_T flowing in the circuit is given by Kirchhoff's current law KCL as being:

$$I_T = I_{R1} + I_{R2}$$



As the two resistors are connected in parallel, from Kirchhoff's Current Law, (KCL) to hold true it must therefore follow that the current flowing through resistor R_1 will be equal to:

$$I_{R1} = I_T - I_{R2}$$

and the current flowing through resistor R_2 will be equal to:

$$I_{R2} = I_T - I_{R1}$$

As the same voltage, (V) is present across each resistive element, we can find the current flowing through each resistor in terms of this common voltage as it is simply V = I*R following Ohm's Law. So, solving for the voltage (V) across the parallel combination gives us:

$$I_T = I_{R_1} + I_{R2}$$

$$I_{R_1} = \frac{V}{R_1} \quad \text{and} \quad I_{R2} = \frac{V}{R_2}$$

$$I_T = \frac{V}{R_1} + \frac{V}{R_2} = V\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

$$\therefore V = I_T\left[\frac{1}{R_1} + \frac{1}{R_2}\right]^{-1} = I_T\left[\frac{R_1R_2}{R_1+R_2}\right]$$

Solving for I_{R1} gives: $I_{R_1} = \frac{V}{R_1} = I_T\left[\frac{\frac{1}{R_1}}{\frac{1}{R_1}+\frac{1}{R_2}}\right]$

$$\therefore I_{R_1} = I_T\left[\frac{R_2}{R_1+R_2}\right]$$

Likewise, solving for I_{R2} gives: $IR_2 = \frac{V}{R_2} = I_T\left[\frac{\frac{1}{R_2}}{\frac{1}{R_1}+\frac{1}{R_2}}\right]$

$$\therefore I_{R_2} = I_T\left[\frac{R_1}{R_1+R_2}\right]$$

Thus, above equations for each branch current has the opposite resistor in its numerator. That is to solve for I_1 we use R_2, and to solve for I_2 we use R_1. This is because each branch current is inversely proportional to its resistance resulting in the smaller resistance having the larger current.

INDUCTORS:

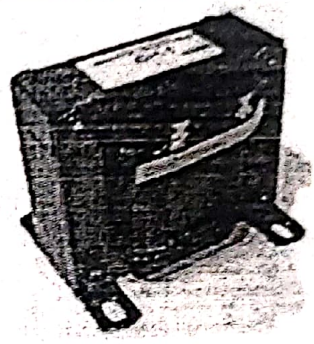
Inductors are often referred to as "**AC resistance**". The main characteristic of an inductor is its ability to resist changes in current and store energy in the form of a magnetic field. The standard unit of inductance is the **Henry**.

Types of Inductors:

Depending on the application there are many types of inductors, they come in various form factors, there are high-frequency inductors, low-frequency power line inductors, and some specially designed inductors for decoupling and filter applications.

Laminated Core Inductor:

The elements of a laminated core inductor consist of a bobbin, a laminated core and a coil which is wrapped around the bobbin.



To make a laminated core inductor, a wire is wrapped around the bobbin of the inductor, then the E and I plates are placed inside the bobbin one by one to form the core, this E and I sheets are made out of steel with high silicon content and its heat-treated to produce high permeability and to lower the hysteresis and eddy current losses.

Applications

1.Onboard charger for Electric Vehicles

2.Line and Noise Filter.

Air Core Inductor:

Construction:

By taking a cylindrical material of specific diameter (like a drill bit) as a template, we can wrap around a length of wire to make an air-core inductor, further the inductance can be stabilized by dipping the inductor in varnish or securing it by wax.

The core material is air, so it has low permeability hence lower inductance so, it can be used for high-frequency applications.

Applications:

1.It is used for constructing RF tuning coils.

2.The air core inductor is used in filter circuits.

3.Snubber Circuit. (*Snubber circuits* are essential for diodes used in switching circuits. It can save a diode from overvoltage spikes).

4.It is used to ensure a lower peak inductance,

5.It is used in high-frequency applications including TV and radio receivers

Ferrite Core Inductor:

By winding a length of wire around a ferrite core will result in a ferrite core inductor.

Mixing Iron oxide (Fe_2O_3) in combination with other metal oxides like (Mn), zinc (Zn) or magnesium (Mg) at a temperature of 1000° C - 1300° C will result in a material called ferrite.

Ferrite core inductors have high permeability, high electrical resistivity and low eddy current losses these characteristics make them suitable for many high-frequency applications.

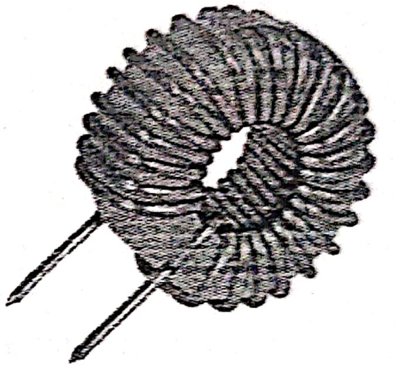
Applications:

1.It can be used at high and medium frequencies

2.It is used in switching circuit

3.Pi Filters

Bobbin Inductor



Construction:

Winding a length of wire in a specially made cylindrical bobbin and securing it with a shrink tube forms a bobbin inductor.

The core material is ferrite so, the properties are also similar to a ferrite core inductor. The small size makes them suitable for power adapter like applications.

Applications:

1.SMPS circuit

2.Input and output filter

3.Pi Filter

Toroidal Core Inductor:

Construction:

A length of wire is wrapped around a donut-shaped core is commonly known as a toroid core inductor. The core material is ferrite so, the material properties resemble a ferrite core inductor.

This type of core contains a magnetic field very well because of its closed-loop nature, thus improving the size and inductance.

Due to the high magnetic field and high inductance value with fewer windings, the impedanc very less which helps to improve the efficiency of the inductor.

Applications:

1.Medical Devices

2.Switching Regulators

3.Industrial Controllers

4.Output Filter (SMPS)

Electronic Components:

An Electric circuit contains many small and large components. All electronic components may be broadly classified into two major classes.

1.Passive Components 2. Active Components

Passive Elements:

The three main passive components used in any circuit are the **Resistor, the Capacitor and the Inductor**. All the three passive components **limit the flow of electrical current** through a circuit but in different ways. Passive element **stores energy** in the form of voltage or current.

Examples: Resistor, Capacitor, Inductor and normal PN junction diode.

Active Element:

An active element is **an element capable of generating electrical energy**. The essential role of the active element is to magnify an input signal to yield a significantly larger output signal. Active element **produces energy** in the form of voltage or current.

Examples: Transistors, Op amps, Logic gates, Tunnel diode and Zener diode.

Resistors:

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements. High-power resistors that can dissipate many watts of electrical power as heat may be used as part of motor controls, in power distribution systems or as test loads for generators.

Types of Resistors:

There are numerous types of resistors that are available and used in electronic circuits. These different types of resistors have different properties depending upon their manufacture and construction. There are different types of resistors available for various applications. The resistors are available in different shapes, size, and materials. Normally, resistors are classified into two types namely linear resistor and non-linear resistor.

Linear Resistors:

The resistors whose value changes with the applied temperature and voltage are called linear resistors. Most types of resistors are linear devices that produce a voltage drop across themselves when a current flow through them. There are two basic types of resistors with linear properties namely fixed resistors and variable resistors.

FIXED RESISTORS:

Fixed resistors are resistors with a specific value. Fixed resistors are used in electronic circuits to set the correct conditions in a circuit.

Types of Fixed Resistors

Wire Wound Resistors:

A resistor that is designed using a conductive wire to limit or restrict the flow of current within a circuit. The designing of the resistor can be done using a conductive wire by wounding around a non-conductive core. Generally, the material of the wire is made with Nichrome (Nickel-chromium alloy) or Manganin (copper-nickel-manganese alloy). These resistors generate very accurately, excellent properties for high power ratings & low resistance values. These resistors are used in industrial and high-power applications like fuses, circuit breakers.

Advantages of Wire Wound Resistor

The advantages are,

1.This resistor is employed in high power circuits
2.It will not affect by the noise
3.It is thermally constant.

Disadvantages of Wire Wound Resistor

The disadvantages are

1.These resistors are used for only low frequencies because it works as an inductor at high frequencies
2.It is expensive as compared with carbon resistor.
3.It is larger in size

Applications

The **applications of the wire-wound** resistors are,

1.Space and Defence
2.Transducer devices. (A ***transducer*** is a ***device*** that converts energy from one form to another).
3.Medical devices
4.Computers
5.Telecommunication
6.Current sensing
7.Telephone switching systems

Thin Film Resistors

Definition:

The resistor which uses a thin film resistive layer is known as the thin-film resistor. This layer is arranged on top of a ceramic base. As compared to the thick film resistor, the thickness of the resistor is very thin approximately 0.1 microns. Generally, these resistors are stable, more accurate and have a better temperature coefficient so they are used in higher precision technologies. Both the thick film and thin film resistors look like same but their manufacturing processing is different.

Advantages:

The advantages of a thin-film resistor are,
1.The electrical performance of these resistors is high.
2.High-frequency response.
3.It provides a high-power rating.
4.It has less noise.

RF = radio frequency

Disadvantages:

The disadvantages of thin-film resistors are,
1.These components are delicate.
2.High cost.
3.Need to handle very carefully.

Applications:

ADC = Analoged digital converter.

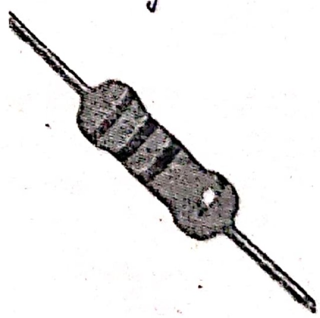
The applications of thin-film resistors are,
1.The function of a thin-film resistor is to use in applications where high accuracy, low noise, and high stability are required. These applications include different equipment like measurement, test, medical, monitoring, instrumentation, precision, and audio applications.
2.These resistors are used in precision applications. measurement (precision)
3.These resistors are used to control the op-amps gain, stable voltage division, ADC or DAC.
4.Thin-film resistors are used where higher precision is necessary like equipment monitoring & measuring in the aerospace & medical fields, audio computer chips, RF applications, telecommunications, power supply converters, etc.

ADC = Analoged digital converter
DAC = digital analoged converter.

CARBON COMPOSITION RESISTORS:

Definition:

Carbon composition resistor is also known as carbon composite This is an old type of resistor but used as a main resistor in many tubes or valve-based devices such as radios, TVs, electronic devices, etc. The Carbon composition resistor is one kind of fixed resistor, used to restrict or reduce the flow of current to a certain stage.

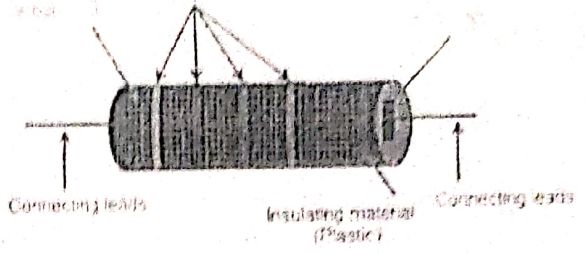


Carbon Composition Resistor

Construction

The carbon composition resistors are made from a solid cylindrical resistive element with embedded wire leads or metal end caps. The cylindrical resistive element of the carbon composition resistor is made from the mixture of carbon or graphite powder and ceramic (made of clay). The carbon powder acts as the good conductor of electric current.

The solid cylindrical resistive element is covered with plastic to protect the resistor from outside heat. The leads made of copper are joined at two ends of the resistive element. The carbon composition resistors are available with different resistance values ranging from one ohm (1Ω) to 22-mega ohms ($22\ M\Omega$).



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Amount of Carbon Added

The resistance of the carbon composition resistor is inversely proportional to the amount of carbon added.

We know that carbon is the good conductor of electricity. Hence, if more amount of carbon is added, more amount of electric current flows and only a small amount of electric current is blocked. Thus, the carbon composition resistor with more carbon has low resistance. If less amount of carbon is added, only a small amount of electric current flows and more amount of electric current is blocked. Thus, the carbon composition resistor with less carbon has more resistance.

Advantages

The **advantages of a carbon composition resistor** are,

1.It can endure high energy pulses.
2.Less cost
3.These are available in small size.

Disadvantages:

The disadvantages of a carbon composition resistor are,
1.The stability of the carbon composition resistor is poor
2.Generates huge noise.
3.Accuracy is less
4.It absorbs the water so it can lead to an increase/decrease in the resistance.

Applications of Carbon Composition Resistor:

The applications of the carbon composition resistor include the following.
1.Used in high-frequency applications
2.It is used to limit the current in the circuits
3.Used in the DC power supplies with high voltage
4.Used in the devices like X-ray, laser, radar & welding technology also.
5.Used in electronic, test equipment, and computers.

4X

VARIABLE RESISTORS:

Variable Resistors consist of a slider which taps onto the main resistor element and a fixed resistor element. Simply we can say that a variable resistor is a potentiometer with only 2 connecting wires instead of 3.

5. **Impedance matching:** To maximize power transmission at high frequencies the impedance of the receive and transmit ends of a circuit need to be the same. Resistors can perform at least part of this requirement.
6. **Current measuring:** Many circuits need to know how much current is flowing. however, it is much easier to measure voltage, so inserting a resistor into the circuit to 'develop' a voltage – remember Ohm's law- is a common technique for measuring current

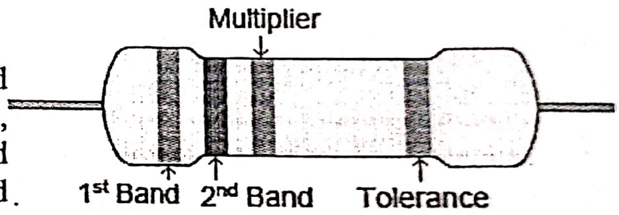
Resistor Colour Code:

An electronic colour code is a code that is used to specify the ratings of certain electrical components, such as the resistance in Ohms of a resistor.

Working:

The resistor colour code shown in the table involves various colour that represent significant figures, multiplier, tolerance, reliability, and temperature coefficient. In a typical four-band resistor, there is a spacing between the third and the fourth band to indicate how the resistor should be read (from left to right, with the lone band after the spacing being the right-most band).

Significant figure component:



In a typical four-band resistor, the first and second bands represent significant figures. For this example, refer to the figure above with a green, red, blue, and gold band. Using the table provided below, the green band represents the number 5 and the red band is 2.

Multiplier:

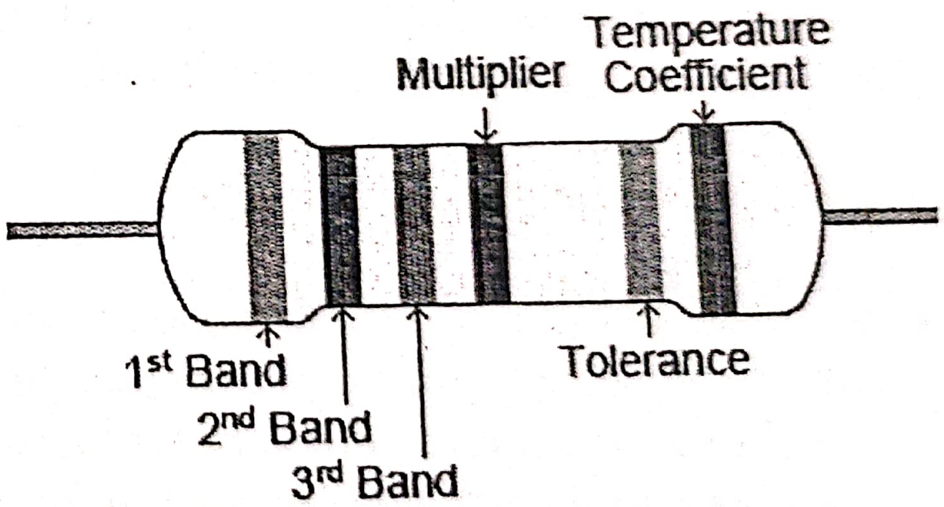
The third, blue band, is the multiplier. Using the table, the multiplier is thus 1,000,000. This multiplier is multiplied by the significant figures determined from the previous bands, in this case 52, resulting in a value of 52,000,000 Ω, or 52 MΩ.

Colour	1st, 2nd, 3rd Band Significant Figures	Multiplier	Tolerance	Temperature Coefficient (Parts per Million per Kelvin)
Black	0	× 1		250 ppm/K (U)
Brown	1	× 10	±1% (F)	100 ppm/K (S)
Red	2	× 100	±2% (G)	50 ppm/K (R)
Orange	3	× 1K	±0.05% (W)	15 ppm/K (P)
Yellow	4	× 10K	±0.02% (P)	25 ppm/K (Q)
Green	5	× 100K	±0.5% (D)	20 ppm/K (Z)
Blue	6	× 1M	±0.25% (C)	10 ppm/K (Z)
Violet	7	× 10M	±0.1% (B)	5 ppm/K (M)
Grey	8	× 100M	±0.01% (L)	1 ppm/K (K)
White	9	× 1G		
		× 0.1	±5% (J)	

Gold				
Silver		× 0.01	±10% (K)	
None			±20% (K)	

On the most precise of resistors, a 6th band may be present. The first three bands would be the significant figure bands, the 4th the multiplier, the 5th the tolerance, and the 6th could be either reliability or temperature coefficient. There are also other possible variations, but these are some of the more common configurations.

Mnemonics were created to easily memorize the sequence as "B B ROY of Great Britain had a Very Good Wife" where the first letter of each word corresponds to the first letter of the colour.



VOLTAGE CURRENT RELATION IN A RESISTOR -THE OHM'S LAW:

The current that flows through a conductor depends upon the potential difference between

Therefore, the energy stored in a capacitor is given by $U = \frac{q^2}{2C}$

Substituting $q=CV$

in the equation above, we get, $U = \frac{1}{2} CV^2$

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APPLICATIONS OF PASSIVE ELEMENTS:

RESISTOR AS A HEATING ELEMENT IN HEATERS:

A heating element is a material or device that directly converts electrical energy into heat or thermal energy through a principle known as Joule heating. Joule heating is the phenomenon where a conductor generates heat due to the flow of electric current. As the electric current flows through the material, electrons or other charge carriers collide with the ions or atoms of the conductor creating friction at an atomic scale. This friction then manifests as heat. Joule's first law (Joule-Lenz law) is used to describe the amount of heat produced from the flow of electricity in a conductor. This is expressed as,

$$P = IV \text{ or } P = I^2R \qquad (\because V=IR)$$

The Joule–Lenz law, also known as Joule's first law, states that Joule heating is proportional to the product of a conductor's electrical resistance and the square of the electrical current flowing through the conductor.

$$P \propto I^2 . R$$

Calculating Resistive Heating:

There are two simple formulas for calculating the amount of heat dissipated in a resistor (i.e., any object with some resistance). The heat is measured in terms of ***power***, which corresponds to energy per unit time. Thus, rate at which energy is being converted into heat inside a conductor is:

$$P = I \times V$$

where P is the power, I is the current through the resistor and V is the voltage drop across the resistor.

Power is measured in units of watts (W), which correspond to amperes x volts. Thus, a current of one ampere flowing through a resistor across a voltage drop of one volt produces one watt of heat. The Unit of watts is also expressed as joules per second.

The relationship P = I x V makes sense if the voltage is a measure of energy per unit charge, while the current is the rate of flow of charge. The product of current and voltage therefore tells us how many electrons are "passing through," multiplied by the amount of energy each electron loses in the form of heat as it goes, giving an overall rate of heat production, i.e.,

$$P = I \times V$$

$$\frac{Charge}{Time} \cdot \frac{Energy}{Charge} = \frac{Energy}{Time}$$

and see that, with the charge cancelling out, units of current multiplied by units of voltage indeed give us unit of power.)

RESISTOR AS A FUSE ELEMENT: