Circuit board soldering and resistor colour coding

Objectives: At the end of this lesson you shall be able to
- **distinguish between eyelet board, lug board and PCB**
- **explain the preparation of components for mounting and method of soldering on boards**
- **explain the inspection of solder joints and defects in soldered joints**
- **explain construction, types, function, colour coding and application of resistors in circuits.**

In assembling of electronic circuits using components, it is required to layout (arrange), mount and wire the components in a systematic manner. In wiring the electronic circuits depending upon the circuit, different types of boards are used.

Type of boards

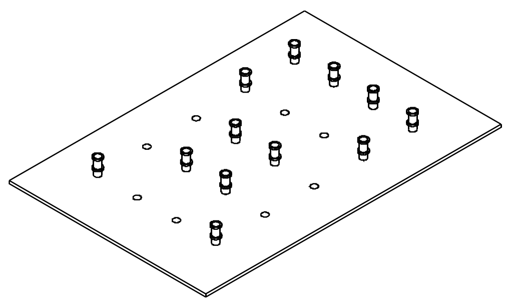
1 Eyelet board

2 Lug or tag board

3 Printed Circuit Boards (PCB's)

Eyelet Board (Fig 1) : In this, eyelets are riveted on perforated bakelite boards. Refer Fig 1. In this type of board, eyelets can be riveted only to a limited number, depending on the lay-out of the circuits.

Fig 1

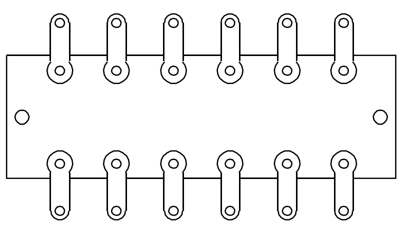


EYELET BOARD

ELN4116011

Lug or tag board (Fig 2) : In this type of boards, brass lugs are riveted in rows on insulated board like bakelite. In this type, components are to be arranged, and circuits are to be made without altering the lug position.

Fig 2



LUG BOARD

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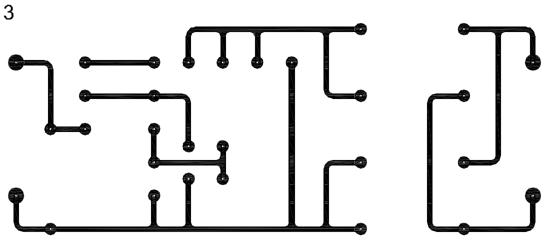
PCB (Printed circuit board) : A printed circuit board in which inter connecting wires are replaced by a thin conducting surface called copper on silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phenolic (or) paper or fibre glass or epoxy.

The required circuit pattern on the laminated board is made by process called "etching". Etching is the process of removing the portion of the metal foil, leaving behind only the required portion refer Fig 3.

Fig 3

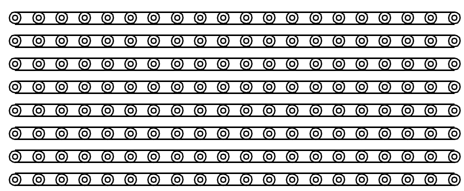


PRINTED CIRCUIT BOARD

ELN4116013

For general purpose, printed circuit boards are readily available to design and develop electronic circuits. They are also called as matrix boards. A strip type matrix board is shown in Fig 4.

Fig 4



GENERAL PURPOSE PCB

ELN4116014

Securing and fixing of components: Mounting of components on eyelet board / lug board / tag board or PCB involves 4 main activities, namely,

1 Preparation of component leads and surfaces to be soldered.

2 Shaping the components leads.

3 Bending and trimming the excess length before soldering.

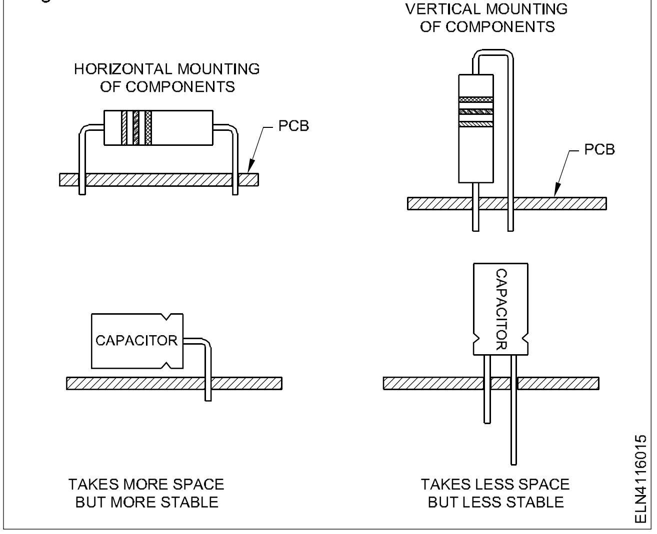
4 The order of mounting and soldering.

1 Preparation of components leads and surfaces etc.: Dust, oil, oxide layer paint or any protective coating on the component leads and surfaces must be removed at places where soldering has to be done.

2 Shaping the components: The shape to which the components leads are to be bent depends up on the manner in which the component is to be mounted. Care should be taken to reduce the thrust on the component.

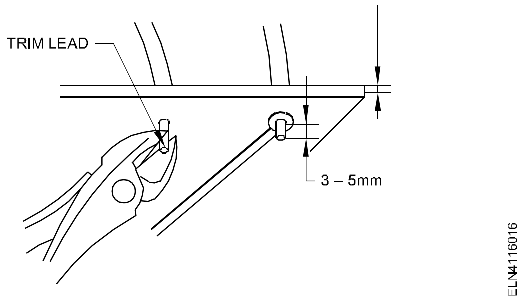
Depending on the type of component lead, and the space available on the PCB, component can be mounted either vertically (or) horizontally as in Fig 5.

Fig 5



3 Bending and trimming : Once the components leads are inserted into the holes of PCB, lead length in excess (0.5 mm to 3 mm), from the PCB surface should be trimmed, using side cutting pliers as in Fig 6.

Fig 6



After cutting the excess lead length, the component lead must be bend and terminated, on PCB.

4 **Order of mounting:** Mount the components in the order as per layout, and should be easy to trace the circuit, as per connection diagram.

The technique used for soldering is explained in subsequent lesson.

Soldering technique

Objectives : At the end of this lesson you shall be able to
- **list the critical factors and stages in soldering**
- **list the steps involved in selecting and preparing the materials**
- **list the different shapes of tips and inspection of soldering iron**
- **state the functions of soldering iron stand and inspection of soldering iron**
- **state the technique of soldering electronic components and effect of residual flux**
- **state the defects in soldering joints.**

Soldering

Soldering is the process of joining two metals for a permanent joint/connections. The bonding of two metals done by using alloy of two metals-lead and tin called solder in different ratios to solder electronic component like resistors, capacitor, transistor etc.

Soldering a joint: Selection and preparation of the soldering materials and cleaning the surfaces to be soldered are the most time consuming phase of making a solder joint. Heating the joint and applying solder is the least time consuming but, all these steps contribute heavily for the good soldered joint.

Critical factor during soldering

1 Controlling the temperature of the workpiece.

2 Limiting the time that a workpiece is to be held at soldering temperature.

These factors are specially critical while soldering electronic components like resistors, capacitors, transistors, ICs etc., Failure of correct time and coordinate the heating of the joint and add solder, will result in a poor quality joint and may even damage the components.

Stage in soldering: The soldering process can be divided into several distinct stage or phases as given below:

1 Selection and preparation of materials

2 Cleaning the surfaces to be soldered

3 Heating the joint and adding solder

4 Cooling the joint

5 Cleaning the joint

6 Inspecting the joint.

1 Selection and preparation of materials

Selection of soldering iron wattage : Soldering irons are available in different wattage ratings starting from 10 watts to several 100 watts. The wattage of a soldering iron specifies the amount of heat it can produce. As a thumb rule, higher the physical dimension of the workpiece, higher should be the wattage rating of the soldering iron. Some of the suggested wattage of soldering iron are given below:

i) For soldering, less temperature sensitive component such as, resistors on lug boards or tag boards, use 25 to 60W iron. For soldering on printed circuit boards, use 10 to 25 W iron.

ii) For soldering highly temperature sensitive components such as, diodes, transistors and integrated circuits, use 10 to 25 watts iron.

Selection of soldering iron tip: To ensure that the joint is heated to the required temperature ideally,

– the area of the tip face should be approximately equal to the area of the joint to be soldered

– the tip should be long enough to allow easy access to the joint.

- the tip should not be too long, as this may result in the low temperature at the tips working face.

In most soldering irons, the tip can be easily removed and can be replaced.

Selection of tip shape: Suggested soldering tip shapes and their application are given below;

Type of soldering tip shape	Application
Wires, resistor and the passive components on lug boards	CHISEL TIP
All miniature electronic components except ICs on to lug boards and printed circuit boards (PCB)	BEVEL TIP
Integrated circuits (ICs) on to printed circuit boards (PCBs)	CONICAL TIP

Selection of solder and flux: For electronic soldering applications, solder of tin and lead of 60/40 proportion is used. This solder proportion has a melting point of 200°C which is the required temperature for general purpose soldering irons.

For electrical purpose, resin core solders are used.

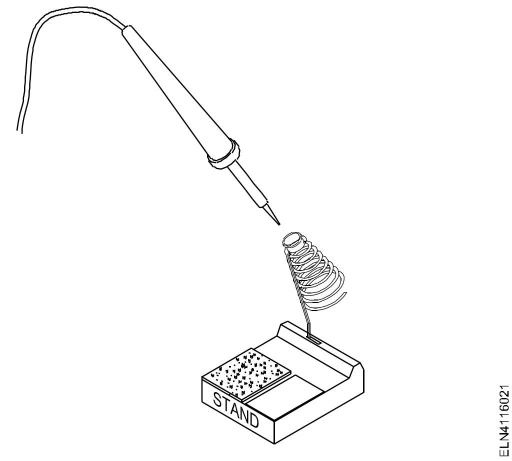
For ease of application, the flux used in addition to the cored flux in solder, should be in paste form.

Flux is a chemical substance which has acidic properties. Therefore, it is advised not to touch the flux by hand. Use a stick or a thin stiff brush to apply flux on the work pieces. Hands should be washed after soldering work.

Soldering stand: Soldering stand plays an important role of retaining the soldering iron tip temperature around the required soldering temperature. The soldering stand should not allow the external temperature to cool the bit. At the same time the stand should not contain all the heat generated.

Soldering stands are specially designed as in Fig 1 to fulfill the above requirements. Such a design also prevents accidental burn injuries to the user of the soldering iron and the stand remains stable mechanically.

Fig 1



Inspection of soldering iron: Most soldering irons are powered by AC main voltage. This voltage level is high and can give shock if one is careless. Soldering irons will generally have lengthy mains cable. While using the iron, the mains cable gets twisted and will have to bear physical stain. Because of this strain, the insulation of cable may get cut. This may lead to live wires protruding out. The live wires give severe electrical shocks if it touches the user.

Hence, a thorough inspection of the soldering iron cable is a must before using it.

Preparation of soldering iron for soldering: The soldering bit tip should be cleaned, heated and tinned before starting the soldering work.

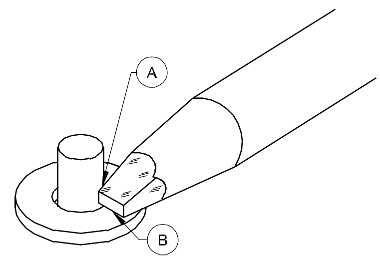
Cleaning the surfaces to be soldered: Before joining two pieces of metal by soldering, the joining surfaces should be cleaned to remove foreign matters over the surface. Also the jointing surfaces should be free from grease grit or oil. this could be achieved by using either a knife or by a sand paper and cloth.

2 Heating the joint and adding solder: Tips for heating and applying solder to a joint to be soldered are given below:

– Do not apply too much flux on a joint in one place. Apply a small amount of flux around the joint. Do not allow the flux to flow outside the area to be soldered.

– Place the iron tip at the joint such that the tip gets maximum contact with parts to be joined as in Fig 2

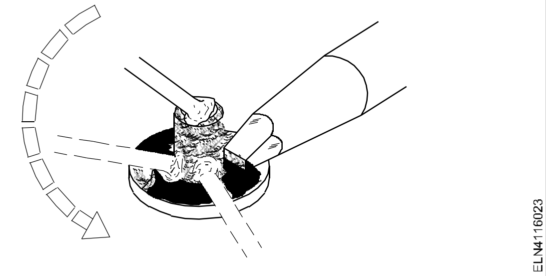
Fig 2



A. COMPONENT LEAD TO IRON CONTACT AREA
B. IRON TO LUG / TERMINAL / PCB CONTACT AREA

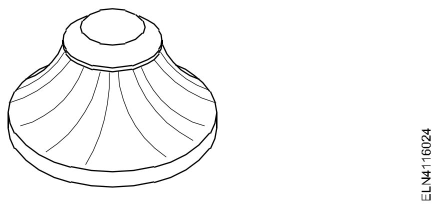
Slowly feed the solder into the joint starting close to the soldering tip and moving towards the edge of the joint as in Fig 3

Fig 3



Continue applying the solder to the joint until complete wetting of the joint has been achieved and the joint has a concave fillet as in Fig 4

Fig 4



After enough solder has been applied and solder wire removed, keep the soldering iron tip on the joint for a moment to ensure that all the flux on the joint has reached the soldering temperature. This will allow majority of the acids within the joint to break down, which otherwise will corrode the joint after a period of time.

Generally the time taken to make a good soldered joint is between 3 to 7 seconds from applying the soldering iron to and removing the soldering iron.

3 Cooling the joint: Tips for cooling a solder joint are given below:

- Allow the joint to cool without assistance, do not blow air from your mouth or from any other source to cool the joint. Forced cooling, cools the joint much earlier than it has to, resulting in a dry and brittle solder joint which will lead to mechanical and electrical defects of the joint.
- Do not move any part of the joint while it is cooling. This disturbs the chemical bonding taking place. Movement of the joint while it is cooling results in a dry joint.

4 Cleaning the joint : When a solder joint is made, the amount of flux applied should be just sufficient to make a good joint. But, quite often, there will be a brown waxy substance left on the joint. This is nothing but the flux residue. In its original state this residue is corrosive. Hence, the flux residue or excess flux must be removed from the joint before soldering can be considered as complete.

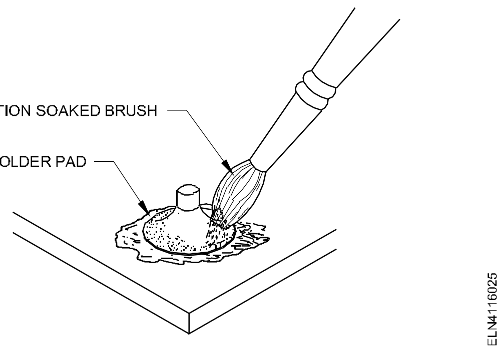
If the flux residue and excess flux are not properly removed, their corrosive nature of the flux will gradually destroy the component leads and the circuit board. The flux residue is also sticky and, if not removed, will collect dust and debris leading to circuit failure.

Removal of flux residue requires the use of solvents. The type of solvent depends on the flux used.

Iso Propyl Alcohol (IPA) is one of the solvents used for removing residual flux. It is available either undiluted or pre-mixed with water and can be obtained in pump sprays, aerosols, cans and drums depending on the quantity and style of use.

Cleaning using water/IPA solution: Determine the right method of application. (spray or liquid). Apply the solvent to the soldered joint. Use a clean brush, or some other type of stiff brush, to gently scrub the joint as in Fig 5, to help dissolve the residue, taking care to avoid splashing the mixture.

Fig 5



When the residue has been dissolved, dry the joint with a lint-free cloth to remove as much of the dissolved residue as possible.

Inspection of soldered joints: Soon after making a solder joint, as a quick check, the following features of the solder joint should be checked:

1 Soldered joint must be bright and shiny.

2 Soldered joint must be smooth and symmetrical.

Surface colour - The surface of a correctly soldered joint will be glossy, silvery and uniform in colour.

Surface texture - The surface texture of a correctly soldered joint will be smooth, even and non-grainy. There shall be no signs of pitting on the surface of the solder.

Common soldering defects: Defects in solder joints can be grouped as follows:

1 Temperature defects

2 Wetting defects

3 Solder quantity defects

4 Mechanical defects.

Temperature defects: Temperature defects are caused by excessive or insufficient heating of the joint during the soldering process.

Defects due to excessive heating: The solder on an overheated joint will have grainy tenure, dull grey colour and pitted.

Too much heat can lead to one or more of the following defects:

– Overheating of the resin flux, causes the flux to char and lose its ability to remove oxides. Lumps of charred flux gets trapped in the solder forming pits and voids.

– Overheating of the solder, causes excessive alloying between the copper parts of the connection and the tin content of the solder. This in turn causes localized depletion of the tin and results in a brittle joint.

– Excessive oxidisation of the solder. The oxidised solder forms a poor bond with the other parts of the joint.

Defects due to insufficient heating: Too little heat can lead to one or more of the following defects:

A defect known as a cold joint. A cold joint occurs when the flux is unable to remove the tarnish from the joint. At low soldering temperature the flux is only partly activated. Therefore, it is less effective in removing tarnish.

Insufficiently heated solder joint results in,

– poor wetting of the joint

– a course solder fillet

– solder steps at the edges

The effects of a cold joint are,

– high electrical resistance

– low mechanical strength

– dry solder joint

A defect known as a dry joint occurs when the solder is too viscous to push the flux away from the component lead. A layer of the flux becomes trapped around the lead. This layer of flux causes a weak bond and hence a poor electrical connection.

Causes of incorrect soldering temperatures

A common indicator of incorrect soldering temperature is the formation of small peaks at the tip of the joint as the iron is pulled away. These peaks will be formed at either too high or too low soldering temperature.

Incorrect soldering temperature may be due to,

– incorrect wattage of the soldering iron

– incorrect soldering tip selection

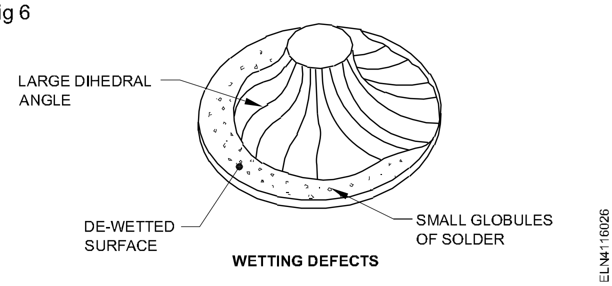
– insufficient heating of the soldering iron

– poor soldering technique, leading to poor heat transfer from the tip of the iron to the joint.

Wetting defects (Refer Fig 6)

The degree of wetting of a joint depends greatly on the cleanliness of the parts to be joined.

Fig 6



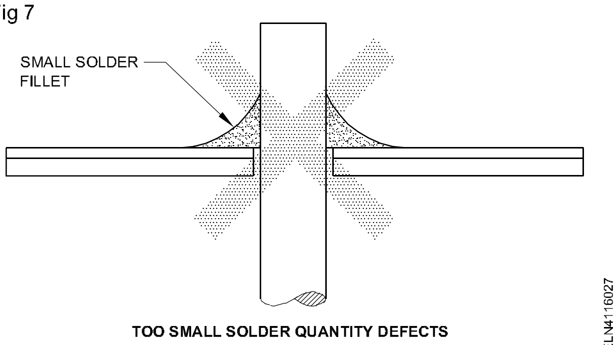
Wetting defects are easily recognised by the inability of the solder to cover all the metal surfaces at the joint and the formation of a large dihedral angles as in Fig 6.

On severely tarnished surfaces, the solder will not flow over the tarnished surface(non-wetting) or the solder initially flows over the tarnished surface, but then retreats leaving small globules of solder on the surface (de-wetting) as in Fig 6.

Solder quantity defects(Refer Fig 7 and 8)**:** Solder quantity defects are due to either too little or too much solder applied to a connection.

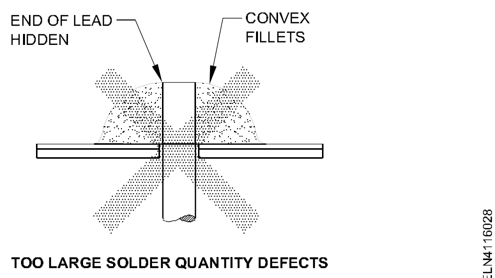
Too little solder results in a small size of the solder fillet as in Fig 7. The small solder fillets makes a joint weak.

Fig 7



Too much solder results in convex solder fillets as in Fig 8. This defect is recognised by the large size and the convex shape of the fillets.

Fig 8



Mechanical defects: Mechanical defects of a solder joint are caused by;

– the movement of parts of a joint while the solder is cooling.

Movement during cooling causes severe dislocation of the crystalline structure of the solder. This results in a weak joint which may fracture later and cause high electrical resistance or an intermittent fault when the circuit is in use. A joint moved before cooling will have a frosted appearance with fractures.

– stresses imposed on the joint as it cools.

Stresses on the joint are usually as a result of inadequate stress relief bends in the leads of components. A stressed joint usually breaks due to the expansion and contraction of components while in use, due to temperature variations.

Blowing on the soldered joint to attempt to speed up cooling will introduce several additional cooling stresses.

Connections that have been disturbed as they cool usually have a frosted appearance.

Never forget the rule, if the quality or reliability of the joint is in doubt, de-solder the joint and re-solder it fresh.

Resistors: These are the most common passive component used in electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from 0.1 W. to hundreds of Watts.

There are four types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

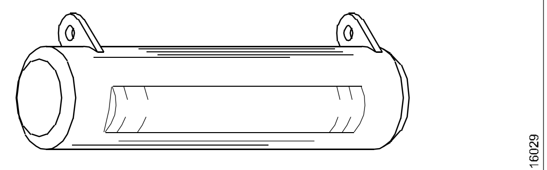
3 Metal film resistors

4 Carbon film resistors

1 Wire-wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc.Fig 9, shows this type of resistor.The bare wire used in the unit is generally enclosed in insulating material. Wire wound resistors are used for high current application. They are available in wattage ratings from one watt to 100 watts or more. The resistance can be less than 1 ohm and go up to several thousand ohms. They are also used where accurate resistance values are required.

Fig 9



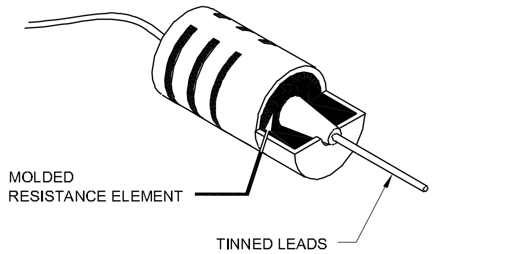
WIRE-WOUND FIXED RESISTOR

One type of Wire-wound resistor is called as fusible resistor enclosed in a porcelain case. The resistance is designed to open the circuit when the current through it exceeds certain limit.

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 10 shows the construction of carbon composition resistor.

Fig 10

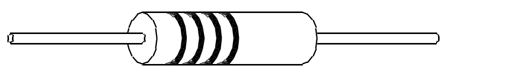


CARBON COMPOSITION RESISTOR

Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5 and 2 watts.

3 Metal film resistors (Fig 11)

Fig 11



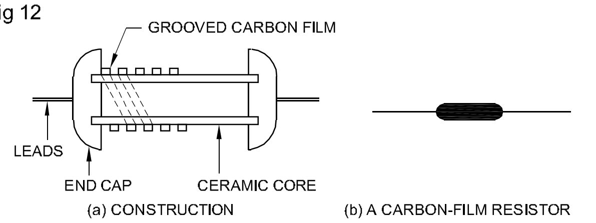
METAL FILM RESISTOR

Metal film resistors are manufactured by two processes. Thick film resistors are pasted with metal compound and powdered glass which are spread on the ceramic base and then backed.

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MΩ, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 12)

Fig 12



CARBON – FILM RESISTOR

In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Carbon film resistors are available from 1 ohm to few Meg ohm and up to 2W and can work from 85°C to 155°C.

All the above four types of resistors are coated with synthetic resin to protect them against mechanical damages and climatic influences, It is therefore, difficult to distinguish them from each other externally.

Specification of resistors: Resistors are specified normally with the four important parameters

1 Type of resistor

2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.

3 Tolerance limit for the resistance value in percentage.

4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90 Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

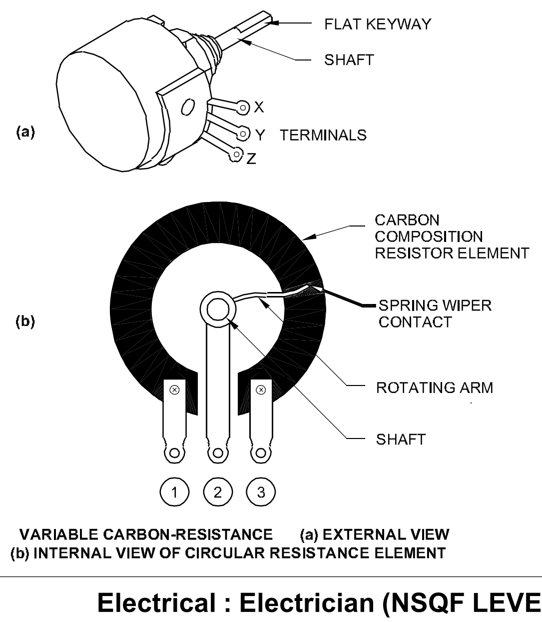
1 Fixed resistors

2 Variable resistors

Fixed resistors : The fixed resistors is one in which the nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 10 to 12)

Variable resistors (Fig 13) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentiometer resistors or simply as a potentiometers.

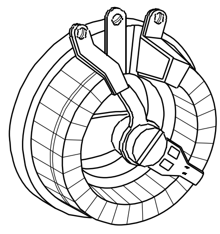
Fig 13



VARIABLE CARBON-RESISTANCE (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT

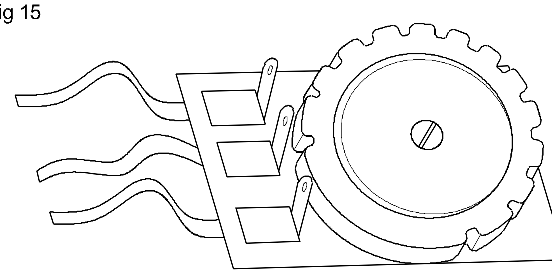
It is provided with 3 terminals as shown in Fig 13 and 14. They are available with carbon tracks (Fig 13) and wire wound (Fig 14) types. Trimmer potentiometers (or) resistor which can be adjusted with the help of a small screw driver. (Fig 15).

Fig 14



WIRE-WOUND VARIABLE RESISTOR

Fig 15



TRIMMER RESISTOR

Resistance depends upon temperature, voltage, light: Special resistors are also produced whose resistance varies with temperature, voltage, and light.

PTC resistors (Sensistors) : Since, different materials have different crystal structure, the rate at which resistance increases with raising temperature varies from material to material. In PTC resistor (positive temperature coefficient resistor), as the temperature increases, the resistance increases non linearly. For example, the resistance of PTC at room temperature may be of nominal value 100 Ω when the temperature rises say 10°C, it may increase to 150 Ω and with further increase of another 10°C, it may increases to 500 Ω.

NTC Resistors (Thermistors) : In case of NTC resistors (Negative temperature co-efficient resistors) as the temperature increases, the value of resistance decreases non-linearly, For example, NTC resistor, which has nominal value of resistance is 500 Ω at room temperature may decrease to 400 Ω with the rise of 10°C temperature and further decrease to 150 Ω when the temperature rises to another 10°C.

The PTC and NTC resistors can perform switching operation at specific temperature. They are also used for measurements and temperature compensators.

VDR (Varistors) : The VDR (Voltage dependent resistor) resistance falls non-linearly with increasing voltage. For example, a VDR, may have 100 Ω resistance at 10 V, and it may decrease to 90 Ω at rise in 5V. By further increasing the voltage to another 5V, the resistance may fall to 50 Ω. The VDRS are used in voltage stabilisation, arc quenching and over voltage protection.

Light dependent resistor (LDR): The LDRs are also known as photo-conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Marking codes for resistors

Commercially, the value of resistance and tolerance value are marked over the resistors by colour codes (or) letter and digital codes.

Resistance and tolerance value of colour coded resistors.

The colour codes for indicating the values to two significant figure and tolerances are given in Table 1 as per IS:8186.

Table 1

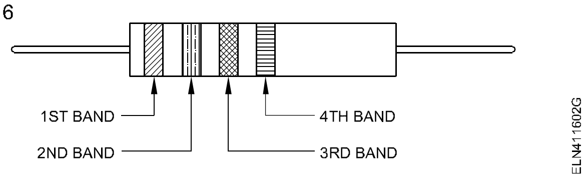
Values to two significant figures and tolerances corresponding to colours

Colour	First Band/ Dot	Second Band/ Dot	Third Band/ Dot	Fourth Band/ Dot
	First Figure	Second Figure	Multiplier	Tolerance
Silver	—	—	10^{-2}	± 10 %
Gold	—	—	10^{-1}	± 5 %
Black	—	0	1	—
Brown	1	1	10	± 1 %
Red	2	2	10^2	± 2 %
Orange	3	3	10^3	—
Yellow	4	4	10^4	—
Green	5	5	10^5	—
Blue	6	6	10^6	—
Violet	7	7	10^7	—
Grey	8	8	10^8	—
White	9	9	10^9	—
None	—	—	—	± 20 %

The two significant figures and tolerances colour coded resistors have 4 bands of colours coated on the body as in Fig 16.

The first band shall be the one nearest to one end of the component resistor. The second, third and four colourbands are shown in Fig 16.

Fig 16



The first two colour bands indicate the first two digits in the numeric value of resistance. The third colour band indicates the multiplier. The first two digits are multiplied by the multiplier to obtain the actual resistance value. The forth colour band indicates the tolerance in percentage.

Example

Resistance value : If the colour band on a resistor are in the order- Red, Violet, Orange and Gold, then the value of the resistor is 27,000 ohms with +5% tolerance.

First colour	Second colour	Third colour	Fourth colour
Red	Violet	Orange	Gold
2	7	1000(10^3)	±5%

Tolerance value: The fourth band (tolerance) indicates the resistance range within which is the actual value falls. In the above example, the tolerance is ±5%. ±5% of 27000 is 1350 ohms. Therefore, the value of the resistor is any value between 25650 ohms and 28350 ohms. The resistors with lower value of tolerance (precision) are costlier than normal value of resistors.

For less than ten ohms, the third band will be either golden or silver.

The colours are,

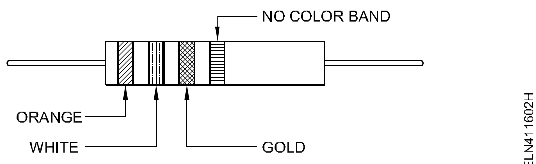
Gold -	10^{-1}	=	1/10 = 0.1
Silver -	10^{-2}	=	1/100 = 0.01

Example (Refer Fig 17)

Colour of Ist Band	Colour of 2nd Band	Colour of 3rd Band
Orange	White	Gold
3	9	1/10

thus, the value of resistor is 39/10 or 3.9 ohms.

Fig 17



Large value resistances are expressed in kilo ohms and megohms. Letter 'k' stands for kilo and M stands for mega. One kilo equals 1000 (10^3) and one mega equals 1000000 (10^6). The resistance values are expressed as

1000 ohms	=	1 k
1800 ohms	=	1k 8
100 ohms	=	0.1 k
10000 ohms	=	0.1 M
1500000 ohms	=	1 M 5.

Preferred values for resistors: It is not possible to manufacture all values of resistors right from one ohm to a million ohms. So only a set of preferred values of resistors are generally made. Also in the manufacturing process, in which thousands of resistors are made in a day, it is not possible to adjust every ordinary resistor to an exact value. The term 'tolerance' denotes the acceptable deviation in the resistance value of a resistor.The usual specified tolerances are ±5%, ±10% and ±20% for the ordinary resistors. The precision resistors may have selected tolerances as close as ±0.1%. In each tolerance range, a set of preferred values are available refer Table 2.

Table 2

Preferred series of values for resistors with ordinary tolerances

E 24 Series Tolerance ±5 percent	E12 Series Tolerance ± 10 percent	E 6 Series Tolerance ±20 percent
1.0	1.0	1.0
1.1	—	—
1.2	1.2	—
1.3	—	—
1.5	1.5	1.5
1.6	—	—
1.8	1.8	—
2.0	—	—
2.2	2.2	2.2
2.4	—	—
2.7	2.7	—
3.0	—	—
3.3	3.3	3.3
3.6	—	—
3.9	3.9	—
4.3	—	—
4.7	4.7	4.7
5.1	—	—
5.6	5.6	—
6.2	—	—
6.8	6.8	6.8
7.5	—	—
8.2	8.2	—
9.1	—	—

Letter and digit code for resistance values: In this system of coding, numbers and letter are used. Generally three or four, or five characters consisting of

1 Two figures and letters

2 Three figures and letter,

3 Four figures and letters are used as the case may be.

The letter R.K. and M. shall be used for multipliers of the resistance values expressed in ohms R = $(10^{\circ}) = 1$, k = 10^3 = 1000, M = 10^6 = 1 000000

For example (Fig 18)

0.1Ω is coded as R10 and 1200 Ω or 1.2k Ω is coded as 1.2 kΩ similarly 1500000 Ω or 1.5 M Ω is coded as 1 M 5.

For symmetrical tolerance in percentage the following letter shall be used for indicating tolerance of the resistance ±5% = J, ±10% = K, ±20% = M

For example (Refer Fig 18)

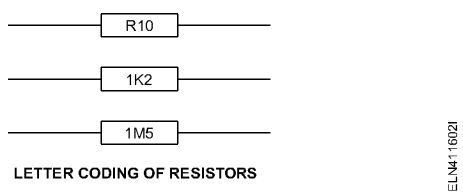
1 1.5 Ω ±10% 1 W is letter coded as K 1R51W

2 330 Ω ±20% 0.5 W is letter coded as M 330R 0.5W

3 2.7 K Ω ±5% 2W is letter coded as J 2K72W

4 1M Ω ±20% 1 W is letter coded as M 1M1W

Fig 18



LETTER CODING OF RESISTORS

Semiconductor theory-Active and passive components

Objectives: At the end of this lesson you shall be able to
- **explain atom conductor, semiconductor, insulator and atomic structure**
- **state the function of N and P type semiconductor, PN junction, depletion region**
- **state the coding of semiconductor devices and its meaning**
- **explain active and passive components, symbols - uses.**

Atom

The very tiny fundamental unit of an element which is capable of independent existence is the atom. An atom of any element consists of a central core called Nucleus. A number of small particles called electrons move around the central core.

The nucleus contains protons and neutrons. A proton in the nucleus possess a positive electrical charge. An electron in an atom possess negative electrical charge. In normal state, the atom is electrically neutral, that is the number of electrons is equal to the number of protons in the nucleus.

For stability of materials (solids), the valence (outer most) shell of an atom should contain either 8 or more number of electrons, if it is to be complete.The above stability keeps the atoms and the molecules together in a solid state.

There are three important kinds of bonding amongst the atoms and the molecules of a solid. They are i) ionic ii) covalent and iii) metallic bonds.

Examples of solids under different bondings are,

Ionic bond	:	sodium chloride
Covalent bond	:	silicon and germanium
Metallic bond	:	metals like copper

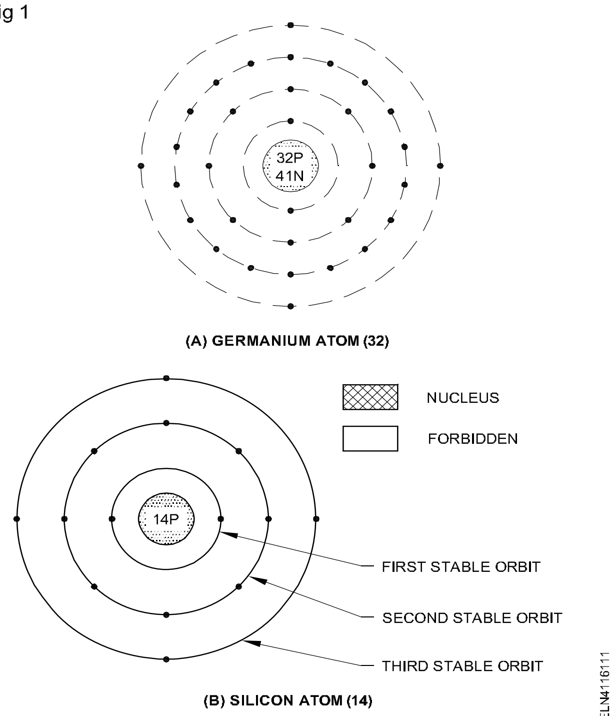
Difference between conductors insulators and semi conductors: We are familiar with conducting and insulating materials. Conducting materials are good conductors of electricity. Insulating materials are bad conductors of electricity. There is another group of materials called as semiconductors, such as germanium and silicon. These are neither good conductors nor good insulators.

The conductors on valence electrons are always free. In an insulator the valence electrons are always bound. Whereas in semi conductors the valence electrons are normally bound but can be set free by supplying a small amount of energy. Several electronic devices are made using semi conductor materials.

Semi conductors - Atomic structure: Germanium (Ge) and silicon (Si) are examples of semi conductors. Fig 1a shows a germanium atom. In the centre is a nucleus with 32 protons. 32 revolving electrons are distributed themselves in different orbits. There are 2 electrons in the first orbit, 8 electrons in the second orbit, and 18 electrons in the third orbit. The fourth orbit is the outer or valence orbit which contains 4 electrons.

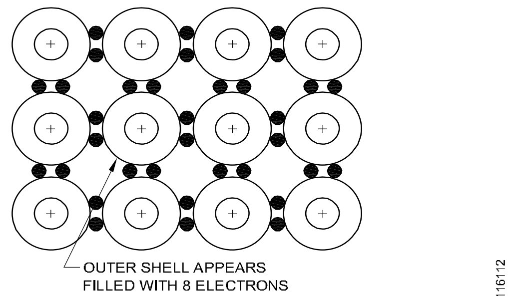
Fig 1b shows a silicon atom. It has 14 protons in the nucleus and 14 electrons in 3 orbits. There are 2 electrons in the first orbit and 8 in the second orbit. The remaining 4 electrons are in the outer or valence orbit.

Fig 1



In semiconductor materials, the atoms are arranged in an orderly pattern called a crystal lattice structure. If a pure silicon crystal is examined we find that the four electrons in the outer (valence) shell of an atom is shared by the neighbouring atoms as in Fig 2.

Fig 2



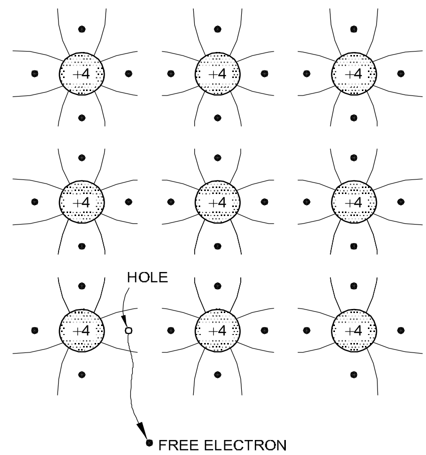
CRYSTAL LATTICE STRUCTURE OF SILICON ATOMS

The union of atoms sharing the valence electrons is called a **covalent band**.That means a valence electron being shared by two adjacent atoms. Each atom appears to have a full outer shell of eight electrons.

Types of semiconductors : A pure semiconductor is called an intrinsic semiconductor. For example, a silicon crystal is an intrinsic semiconductor because every atom in the crystal is a silicon atom. One way to increase conductivity in a semiconductor is by **'doping'**. This means adding impurity atoms to an intrinsic semiconductor. The doped semi-conductor is known as an extrinsic semiconductor.

The residual heat at room temperature (300K) is sufficient to make a valence electron of an intrinsic semiconductor to move away from the covalent bond and then the covalent bond is broken, and the electron becomes a free electron to move in the crystal. This is shown in Fig 3.

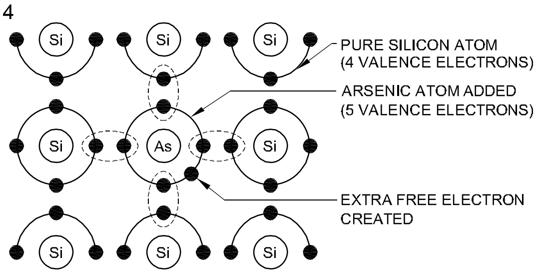
Fig 3



When an electron breaks a covalent bond and moves away, a vacancy is created in the broken covalent bond. This vacancy is called a 'hole'. A hole has a positive charge. When a free electron is liberated, a hole is created.

N - type semiconductor : A semiconductor with excess of electrons is called N-type. To obtain excess free electrons the element doped with the semiconductor material is arsenic, or antimony or phosphorus. Each of these atoms has five electrons in its outer orbit. (Fig 4)

Fig 4



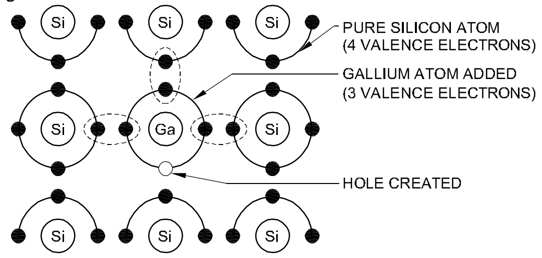
FORMATION OF 'N' TYPE SEMICONDUCTOR

Because the outer orbits of the atoms can hold eight electrons, no hole is available for the fifth electron in the arsenic atoms to move into. It, therefore, becomes a free electron. The number of such free electrons is controlled by the amount of arsenic added to the crystals.

In N-type, the free electrons are called the **majority** carriers, and the holes **minority** carriers.

P-type semiconductor : To obtain more holes, a pure silicon crystal is doped with elements such as aluminum or boron or gallium. The atoms of each of these elements have three electrons only in their outer orbit. Adding gallium to pure silicon crystals allows the atoms of the two elements to share seven electrons. (Fig 5)

Fig 5

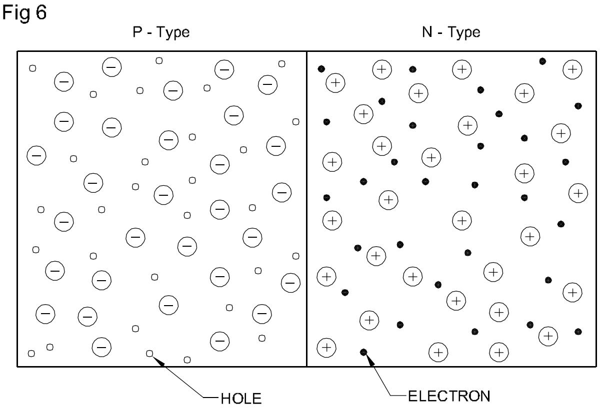


FORMATION OF 'P' TYPE SEMICONDUCTOR

A hole is created in the place of the eighth electron. Now that the number of holes exceeds the number of free electrons the substance becomes 'P' type material. The holes in P-type are the **majority** carriers, and the free electrons are the minority carriers.

PN Junction : A PN junction is formed by combining P and N type materials. The surface where they meet is called the PN junction. A PN junction is illustrated in Fig 6.

Fig 6



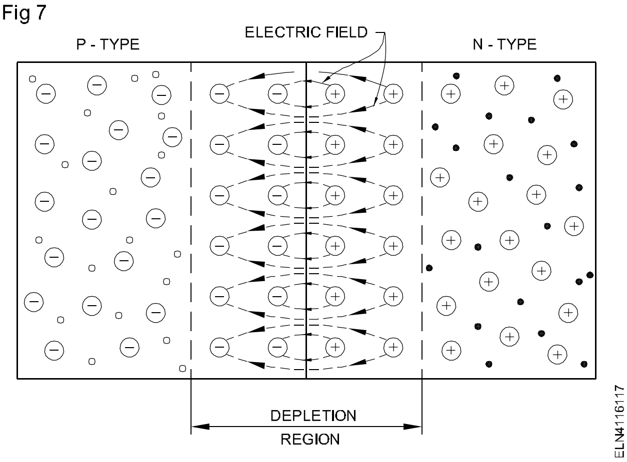
P – N JUNCTION

The free electrons in the N-regions diffuse across the junctions into the P-region. The free electrons lose energy and recombine with the holes in the P-regions.This recombination eliminates a free electron and a hole. When the electron moved from the N-region and diffused across the junction, it leaves the atom to be a positive ion.

The positive ion is not balanced by a negative charge in the N-region. The hole is eliminated in the P-region by recombination. The elimination of the hole and its positive charge leaves the atom to be a negative ion in the P-region.

The ions in the crystal structure are fixed and cannot move. Thus, a layer of fixed charges is formed on the two sides of the junctions. This is shown in Fig 7.

Fig 7



There is a layer of positively charged ions on the N-side and on the P-side of the junction there is a layer of negatively charged ions. An electric field is created across the junction between the oppositely charged ions. This is called a junction field. The junction field is also known as 'barrier'. The distance between the sides of the barrier is the 'width' of the barrier.

Depletion region : The carrier in the vicinity of the junction are involved in forming the junction. Once the junction field is established, no carriers can move through the junction. Hence the junction field is called 'depletion region' or 'space charge region'. This layer is called the depletion layer, because there are neither free electrons nor holes present. This depletion region prevents further movement of electrons from the N-material to the P-material and thus an equilibrium is reached.

The intensity of the field is known as 'barrier height' or 'potential' hill'. The internal voltage set up due to positive and negative ions at the junction is called barrier potential. If any more electrons have to go over from the N-side to P-side, they have to over come this barrier potential. This means, only when the electrons on the N-side are supplied with energy to overcome the barrier potential they can go over to the P-side.

In order to cancel the barrier potential and the electrons to cross over a potential difference of 0.7 V is required for a silicon diode and 0.3 V for a germanium diode. The barrier voltage is more for silicon because its lower atomic number allows more stability in the covalent bonds. The barrier potential decreases at higher temperatures.

Old system : Some earlier semiconductor diodes and transistors have type numbers, consisting of two or three letters followed by group of one, two or three figures. The first letter is always 'O', indicating a semi-conductor device.

The second (and third) letter(s) indicate the general class of the device.

A – diode or rectifier

AP – photo-diode

AZ – voltage regulator diode

C – transistor

CP – phototransistor

The group of figures in a serial number indicating a particular design or development.

Present system : This system consists of two letters followed by a serial number. The serial number may consists of three figures of one letter and two figures depending on the main application of the device.

The first letter indicates the semiconductor material used.

A Germanium

B Silicon

C Compound materials such as gallium arsenide

R Compound materials such as cadmium sulphide

The second letter indicates the general function of the device.

A detection diode, high speed diode, mixer diode

B variable capacitance diode

C transistor for I.F. applications (not power types)

D power transistor for A.F. applications (not power types)

E tunnel diode

F transistor for A.F. applications (not power types)

G multiple of dissimilar devices, miscellaneous devices

L power transistor for a.f. applications

N photo-coupler

P radiation sensitive device such as photo-diode, photo-transistor, photo-conducive cell, or radiation detector diode

Q radiation generating device such as light-emitting diode

R controlling and switching devices (e.g. thyristor) having a specified breakdown characteristic (not power types)

S transistor for switching applications (not power types)

T controlling and switching power device (e.g. thyristor) having a specified breakdown characteristic.

U power transistor for switching applications

X multiplier diode such as varactor or step recovery diode

Y rectifier diode, booster diode, efficiency diode

Z voltage reference or voltage regulator diode, transient suppressor diode.

The remainder of the type number is a serial number indicating a particular design or development, and is in one of the following two groups.

a Devices intended primarily for use in consumer applications (radio and television receivers, audio-amplifiers, tape recorders, domestic appliances, etc.) The **serial number** consists of three figures.

b Devices intended mainly for applications other than (a) e.g. industrial, professional and transmitting equipments.

The serial number consists of one letter (Z,Y,X,W etc) followed by two numbers (digits)

The International System follows letters 1N, 2N, 3N etc followed by four numbers.

1N indicates single junction

2N indicates two junction

3N indicates three junctions.

The number indicates internationally agreed manufacturer's code e.g. 1N 4007, 2N 3055, 3N 2000.

Again, manufacturers use their own codes for semiconductor devices. Manufacturers in Japan use 2SA, 2SB, 2SC, 2SD etc. followed by a group of numbers e.g. 2SC 1061, 2SA 934, 2SB 77. Indian manufacturers have their own codes too.

Passive and active electronic components

Introduction: The Components used in electronic circuits can broadly grouped under two headings.

– passive components

– active components

Passive components: Components like resistors, capacitors, and inductors used in electronic circuit are called as passive components. These components by themselves are not capable of amplifying or processing an electrical signal. However these components are equally important in electronic circuit as that of active components, without the aid of passive components, a transistor (active components) cannot be made to amplify electrical signal.

Circuits formed with passive components obey the electrical circuits laws such as ohm's law, Kirchoff's Laws etc.,

Resistors: The components whose purpose to introduce resistance in the circuit is called as resistors. Other details of resistors are dealt in earlier lessons.

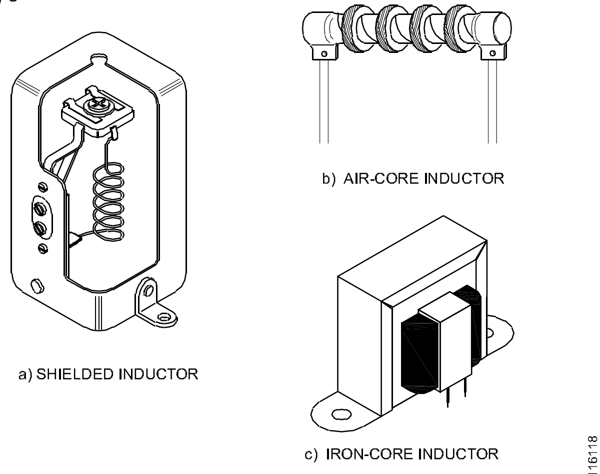
Capacitor: The components whose purpose to introduce capacitance in the circuit is called as capacitor. The unit of capacitance is 'FARAD'. Commercially capacitors are available in Microfarad (μF), Nanofarad (nF) and Picofarads (pF).

The colour coding of capacitors and resistors are same. Where as, in the case of fixed capacitors, the colour coded unit shall be in Picofarads.

For letter coding, incase of capacitor, the letter 'p', 'n', 'μ' shall be used as multipliers. Where $p = 10^{-12}$, $n = 10^{-9}$ and $\mu = 10^{-6}$ farads, and letter code for tolerance on capacitor is the same as in resistor.

Inductor: The ability of the conductor to induce voltage in itself, when the current changes in it is called as self inductance (or) simply inductance. A coil introduced in a circuit to have inductance is called as inductor. Different type of inductors are shown in Fig 8. The unit of inductance is "Henry". Commercially a coil may have inductance in Millihenry (10^{-3}H), or in Microhenry (10^{-6}H).

Fig 8



TYPES OF INDUCTORS

While specifying the inductance the following factors to be considered

- nominal value of inductance in Henry / Millihenry / Microhenry.
- tolerance in percentage (±5/10/20%)
- type of winding like single layer, double layer, multilayer and pie (p) etc.
- type of core like air core, iron core, ferrite core
- type of application like audio frequency (AF), Radio frequency (RF) coupling coil, filter coil etc.,

In an electronic circuit some time, it is also required to vary the inductance.

The inductance of a coil can be varied by:-

- providing tapped inductive coil, as in Fig 9 or
- adjusting the core of a coil as in Fig 10.

However, all inductor coils have inherent resistance due to the resistance of the winding wire in the coil. Further the maximum current that can be safely carried by an inductor depends upon the size of the winding wire used.

Fig 9

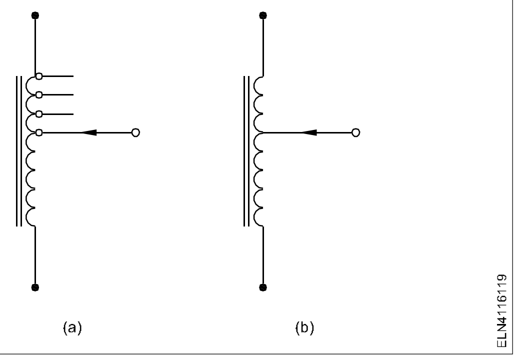
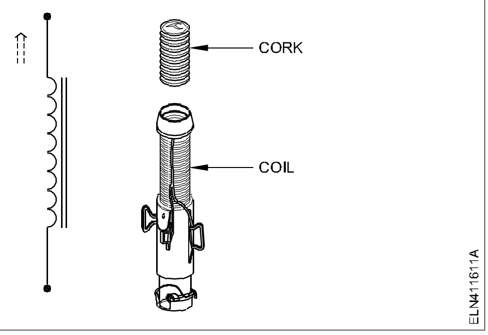


Fig 10



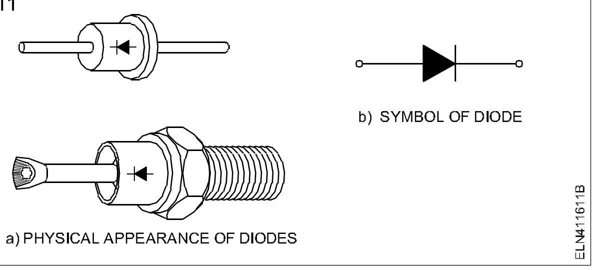
Active components

In electronic circuit, the components, other than passive are known as active components. Namely, transistors, diodes, SCRs Vacuum tubes etc.,

Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely, transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode (Fig 11) etc. The application of electrical circuit laws (Ohm's law etc.) in the circuit containing the above components will not give correct results. i.e. these components do not obey. Ohm's law, Kirchoff's law etc. These components are called active components.

The different active components and the method of representing them by symbols in the circuit diagram are given below (Fig 11)

Fig 11



The different types of diodes (Fig 12) used for specific purposes are represented by the symbols given.

Transistor : Figure 13a shows the physical appearance of transistors. There are two symbols to represent a transistor. (Fig 13b). The selection of a symbol is based on either the NPN or the PNP type of transistor.

Fig 12

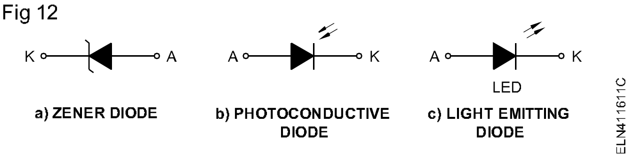
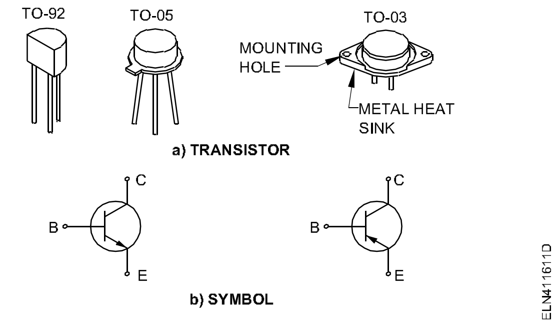
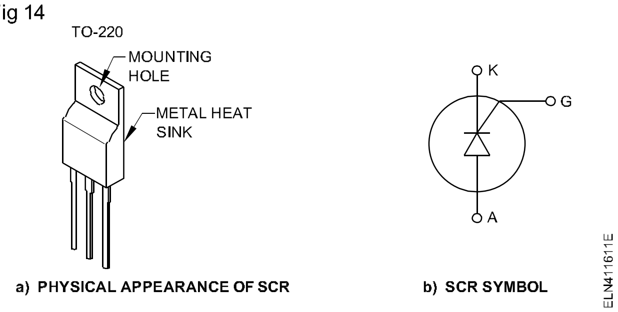


Fig 13



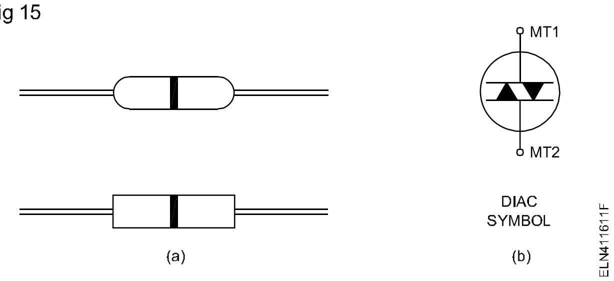
SCR (Silicon controlled rectifier) : Figure 14a shows the physical appearance of one type of SCR and the symbol is shown in Fig 14b. SCRs are also called thyristors and used as switching devices.

Fig 14



Diac : A diac (Fig 15a) is a two-lead device like a diode. It is a bidirectional switching device. Its symbol is shown in Fig 15b.

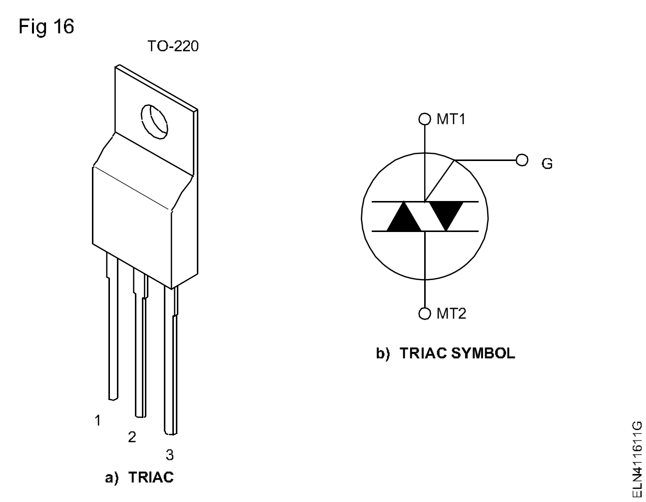
Fig 15

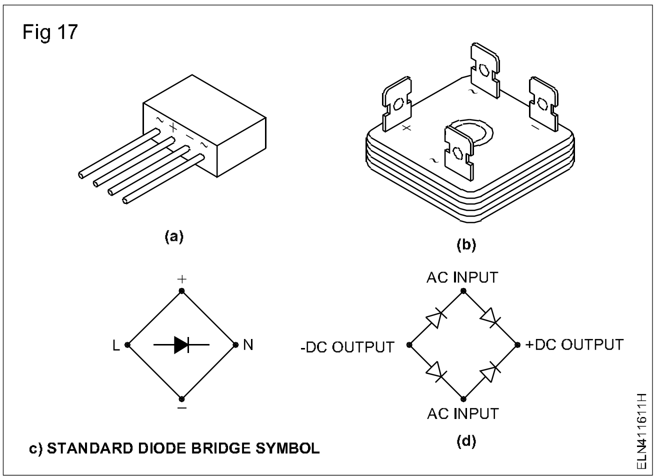


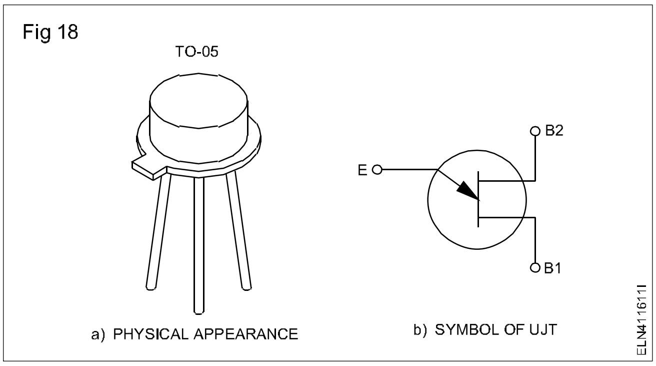
Triac : A triac is also a semiconductor device with three leads like two SCRs in parallel. The triac can control the circuit in either direction. (Fig 16)

Bridge rectifier or diode bridge : It is a single package of four semiconductor diodes connected in bridge circuit. The input AC and the output DC leads are marked and terminated as shown in the Figure 17.

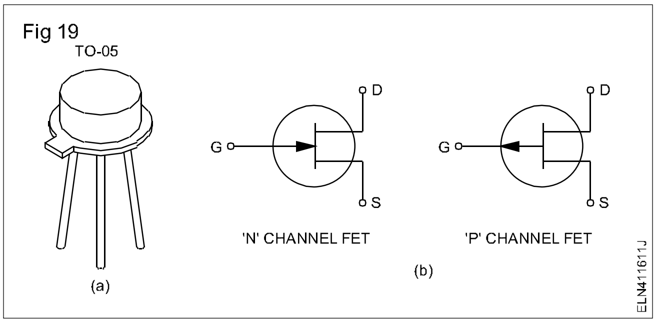
UJT (Uni-junction transistor) : It has two doped regions with three leads and has one emitter and two bases (Fig 18).







FET (Field effect transistor) : Fig 19a give a pictorial view of the component, and the related symbol to represent the field effect transistor is shown in Fig 19b. The selection of the symbol is based on whether the FET is a 'N' channel or a 'P' channel one.



In the active components few basic components discussed have and many more advanced components associated with modern circuits are in use.