Resistors, Colour code, types and characteristics

Objectives: At the end of this lesson you shall be able to
- **explain construction, types, colour coding and application of resistors in circuits.**

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 1 shows this type of resistor.

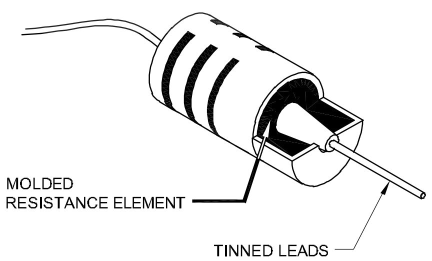
Fig 1

WIRE-WOUND FIXED RESISTOR

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 2 shows the construction of carbon composition resistor.

Fig 2

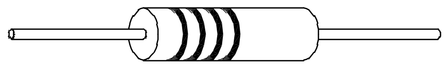


CARBON COMPOSITION RESISTOR

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 3)

Fig 3

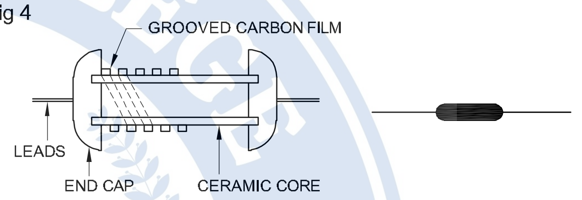


METAL FILM RESISTOR

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 4)

Fig 4



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.

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.

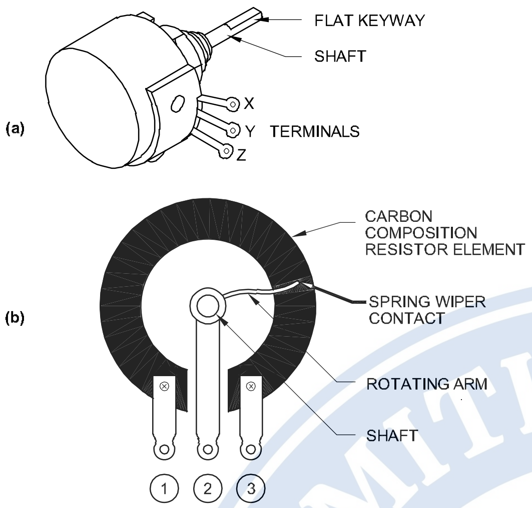
The resistors can also be classified with respect to their function as

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 2 to 4)

Variable resistors (Fig 5) : 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.

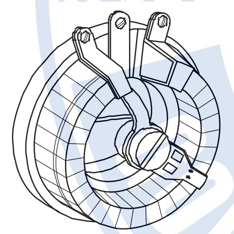
Fig 5



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

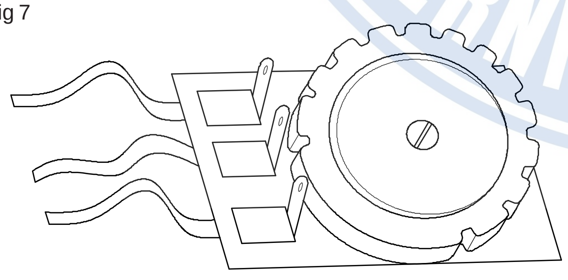
It is provided with 3 terminals as shown in Fig 5 and 6. They are available with carbon tracks (Fig 6) and wire wound (Fig 6) types. Trimmer potentiometers (or) resistor which can be adjusted with the help of a small screw driver. (Fig 7).

Fig 6



WIRE-WOUND VARIABLE RESISTOR

Fig 7



TRIMMER RESISTOR

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

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.

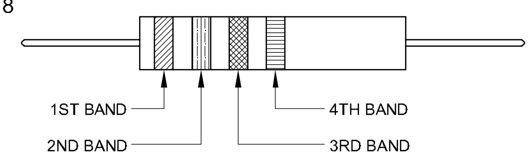
Table 1

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 8.

Fig 8



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 8.

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.

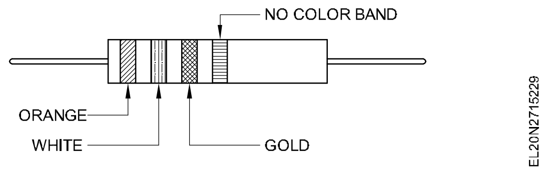
For less than ten ohms, the third band will be either golden or silver.

The colours are,

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

Example (Refer Fig 9)

Fig 9



Colour of 1st 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.

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.

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.

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.

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.

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.

Fig 1

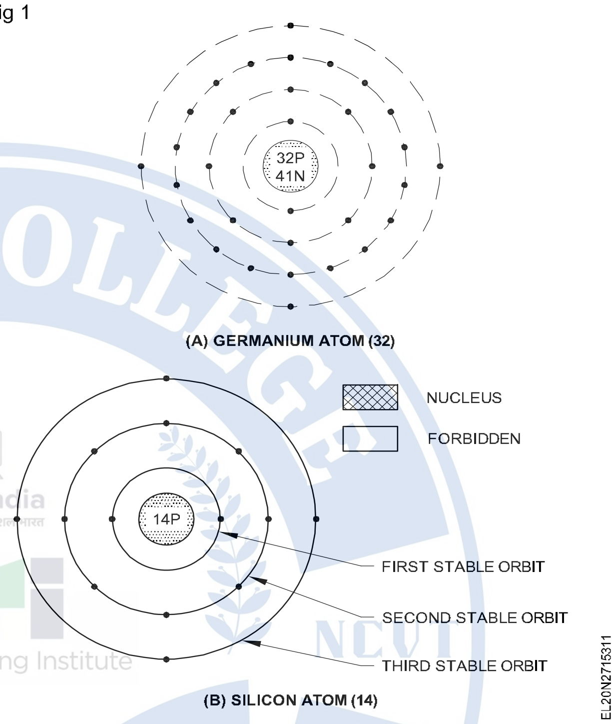
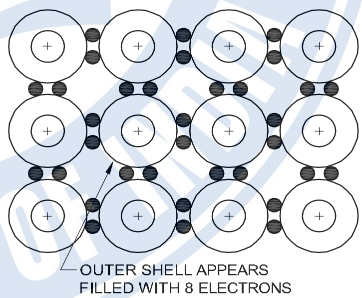


Fig 2

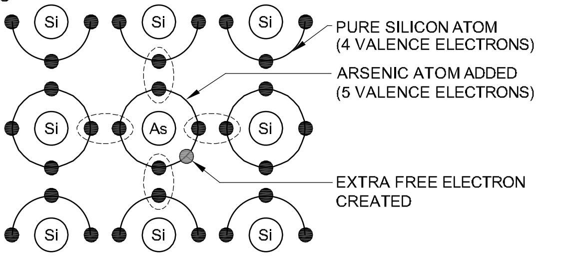


CRYSTAL LATTICE STRUCTURE OF SILICON ATOMS

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.

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 3)

Fig 3



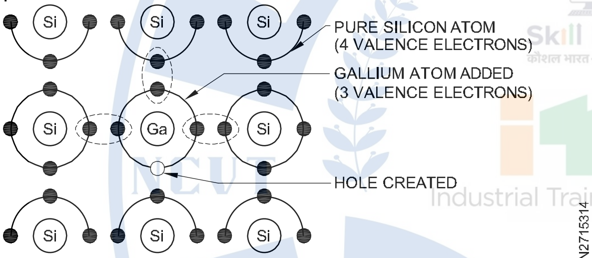
FORMATION OF 'N' TYPE SEMICONDUCTOR

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 4)

Fig 4

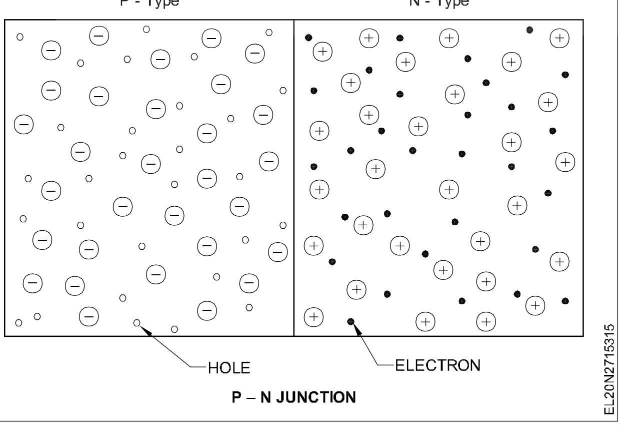


FORMATION OF 'P' TYPE SEMICONDUCTOR

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 5.

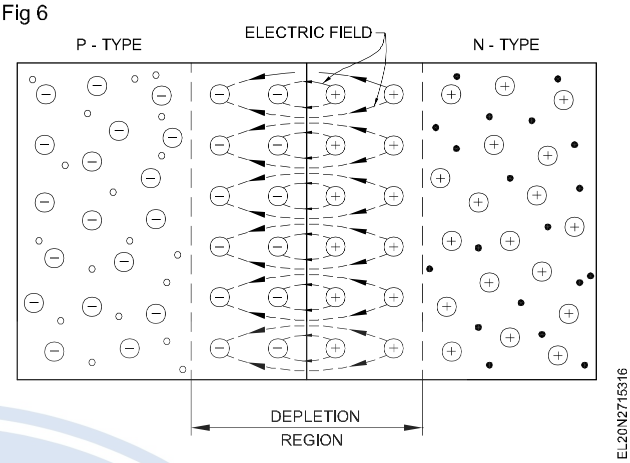
Fig 5



P – N JUNCTION

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 6.

Fig 6



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.

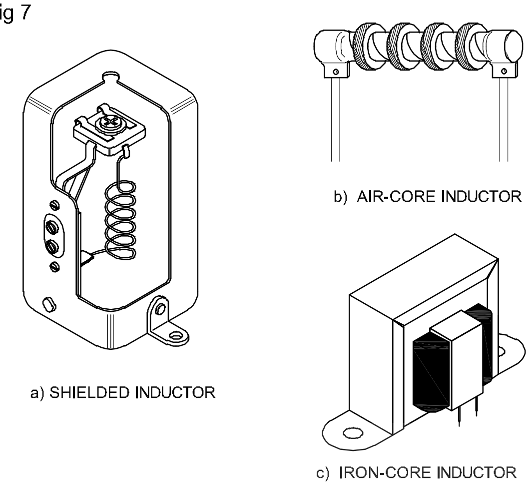
Capacitor: The components whose purpose to introduce capacitance in the circuit is called as capacitor. The unit of capacitance is 'FARAD'. Commercially capacitors are available in Microfarad (μF), Nanofarad (nF) and Picofarads (pF).

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 7. The unit of inductance is "Henry". Commercially a coil may have inductance in Millihenry (10^{-3}H), or in Microhenry (10^{-6}H).

Fig 7



TYPES OF INDUCTORS

While specifying the inductance the following factors to be considered

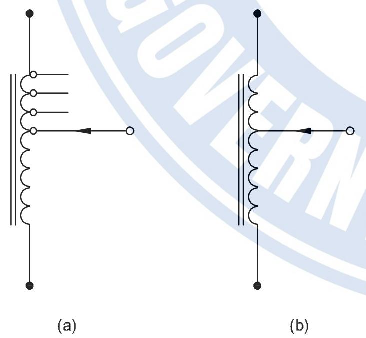
- nominal value of inductance in Henry / Millihenry / Microhenry.
- tolerance in percentage (±5/10/20%)
- type of winding like single layer, double layer, multilayer and pie (p) etc.
- type of core like air core, iron core, ferrite core
- type of application like audio frequency (AF), Radio frequency (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 8 or

Fig 8



- adjusting the core of a coil as in Fig 9.

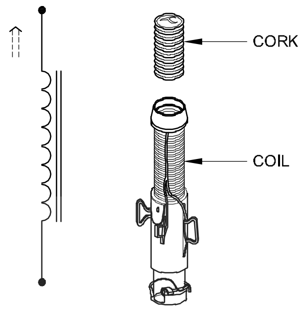
However, all inductor coils have inherent resistance due to the resistance of the winding wire in the coil. Further the maximum current that can be safely carried by an inductor depends upon the size of the winding wire used.

Active components

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

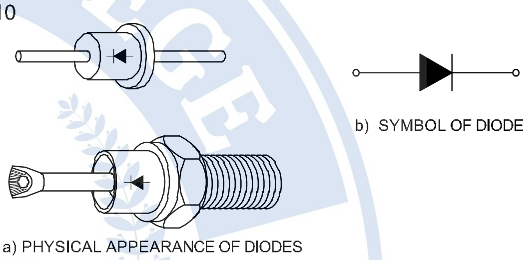
Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely, transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode (Fig 10) etc. The application of electrical circuit laws (Ohm's law etc.) in the circuit containing the above components 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.

Fig 9



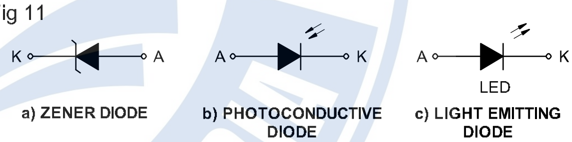
The different active components and the method of representing them by symbols in the circuit diagram are given below (Fig 10)

Fig 10



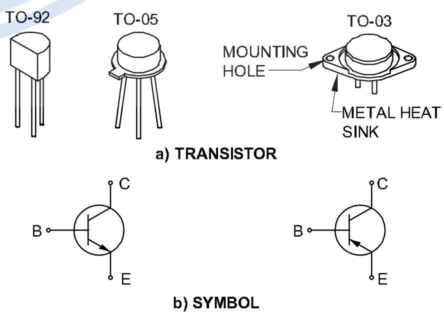
The different types of diodes (Fig 11) used for specific purposes are represented by the symbols given.

Fig 11



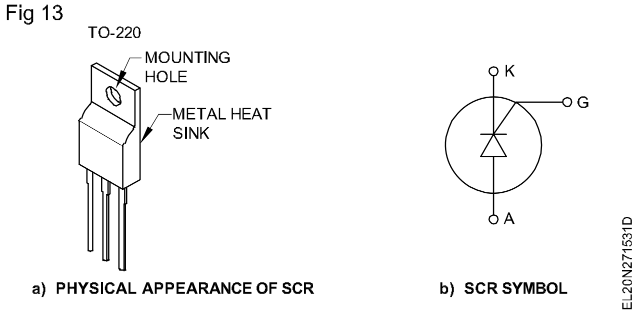
Transistor : Figure 12a shows the physical appearance of transistors. There are two symbols to represent a transistor. (Fig 12b). The selection of a symbol is based on either the NPN or the PNP type of transistor.

Fig 12



SCR (Silicon controlled rectifier) : Figure 14a shows the physical appearance of one type of SCR and the symbol is shown in Fig 13b. SCRs are also called thyristors and used as switching devices.

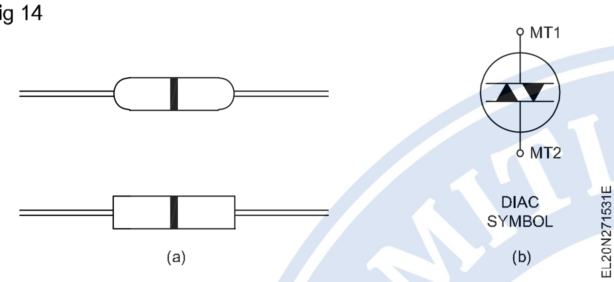
Fig 13



a) PHYSICAL APPEARANCE OF SCR b) SCR SYMBOL

Diac : A diac (Fig 14a) is a two-lead device like a diode. It is a bidirectional switching device. Its symbol is shown in Fig 14b.

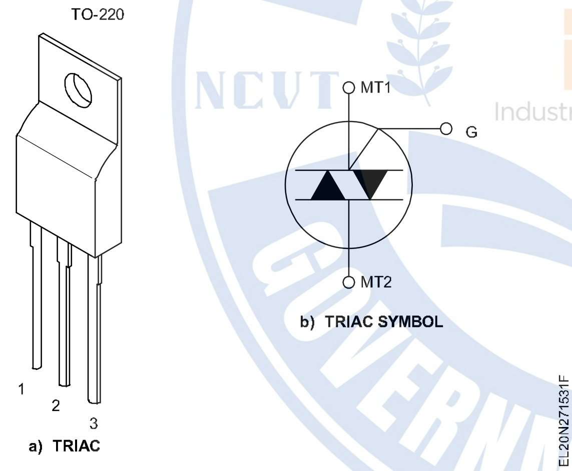
Fig 14



(a) (b)

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 15)

Fig 15

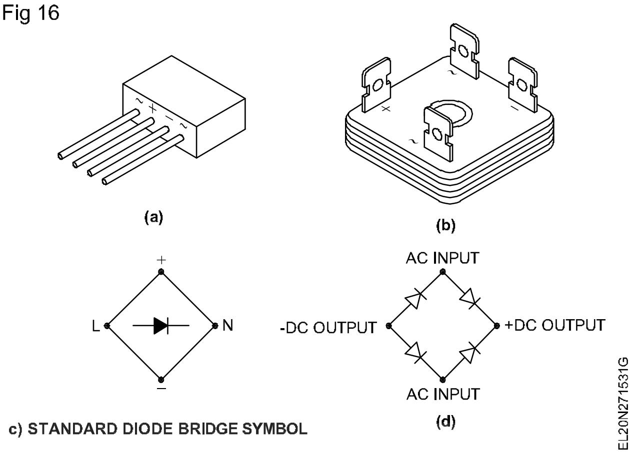


a) TRIAC b) TRIAC SYMBOL

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 16.

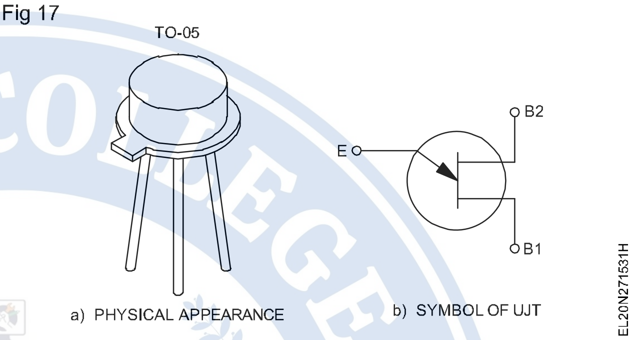
UJT (Uni-junction transistor) : It has two doped regions with three leads and has one emitter and two bases (Fig 17).

Fig 16



c) STANDARD DIODE BRIDGE SYMBOL (d)

Fig 17

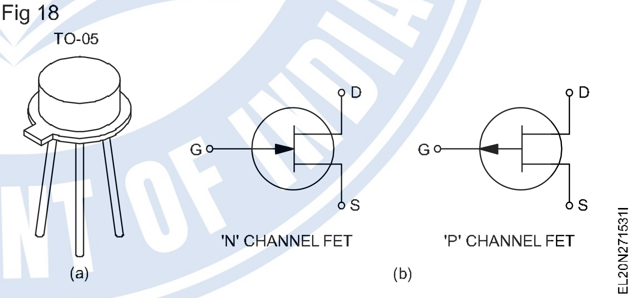


a) PHYSICAL APPEARANCE b) SYMBOL OF UJT

FET (Field effect transistor) : Fig 18a give a pictorial view of the component, and the related symbol to represent the field effect transistor is shown in Fig 18b. 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.

Fig 18



(a) (b)

PN Junction - semi conductor diodes

Objectives: At the end of this lesson you shall be able to
- **explain diffusion in PN junction and barrier potential**
- **explain forward and reverse biasing of PN junction and semi conductor diodes and its VI characteristics**
- **state the applications specifications and classification of diodes**
- **state the method of testing diode and identifying the polarity**
- **state special diodes and their functions and PIV.**

PN junction: A diode is made by combining P and N materials. The surface at which these materials meet is the PN junction.

Diffusion occurs when P and N materials are joined together.(Fig 1) some electrons in the N material, near the junction, are attracted to the holes in the P material, thus leaving holes in the N material. The diffusion of electrical charges produces a potential difference in a small area near the junction (Fig 2).As a result, the material will conduct in one direction but not in the opposite direction. For this reason, the area in which this emf exists is called a barrier.

Fig 1

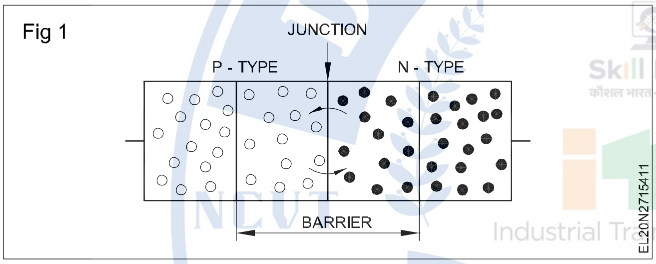
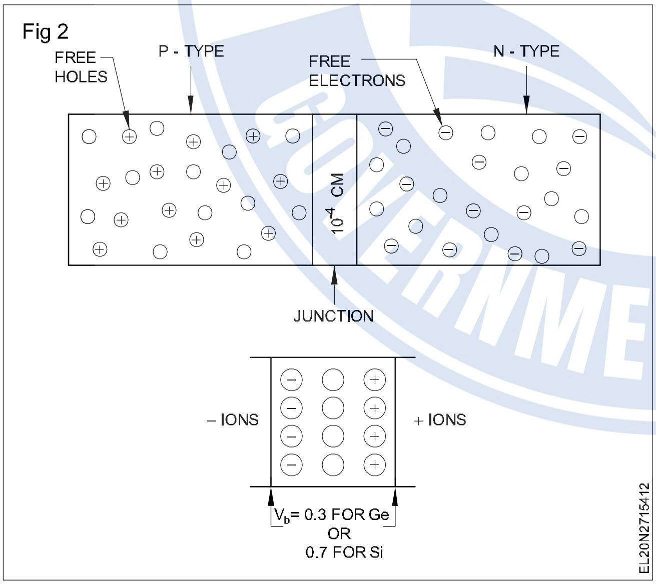


Fig 2

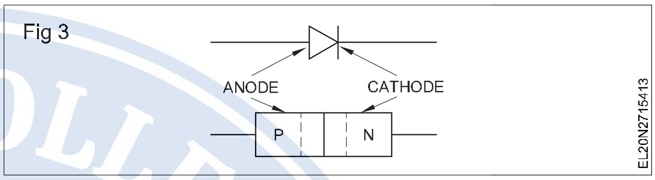


The internal barrier potential (V_b) : Although it is an internal contact potential that cannot be measured directly, the effect can be overcome by 0.3V for a **Ge** junction or 0.7 V for **Si**. The barrier voltage is more for **Si** because its lower atomic number allows more stability in the covalent bonds as already stated.

The PN junction, with the depletion zone magnified, shows the iron that has +ve and -ve charges produce the internal contact potential V_b at the barrier. (Fig 2)

A PN device is knows as a diode. The diode and its symbol are in Fig 3. This type of construction permits the current to flow in one direction but not in the opposite direction.

Fig 3

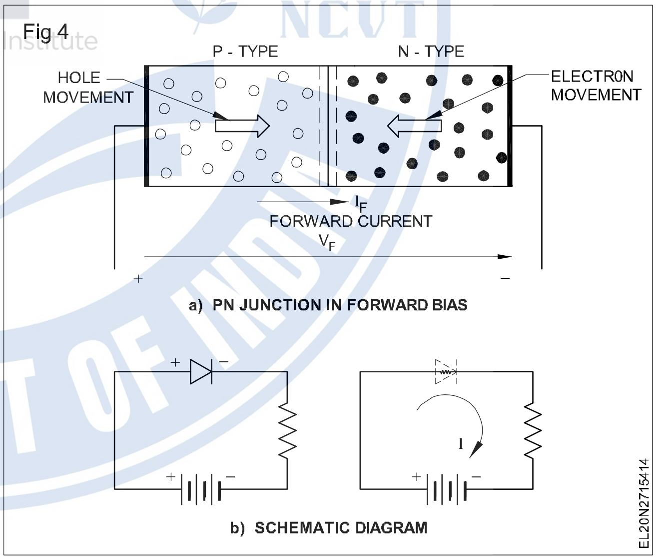


Biasing the PN junction

Forward Bias : A forward-biased PN junction is in Fig 4 The positive terminal is connected to the P-side and the negative terminal of the DC supply is connected to the N-side of the junction.

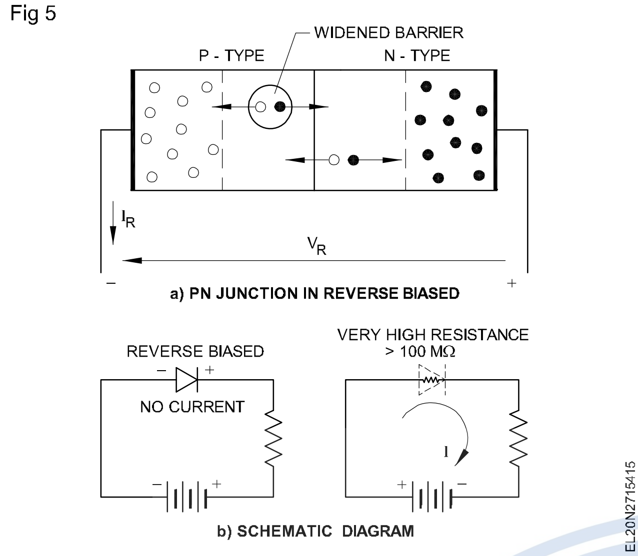
A current will flow through the diode as in the Fig 4.

Fig 4



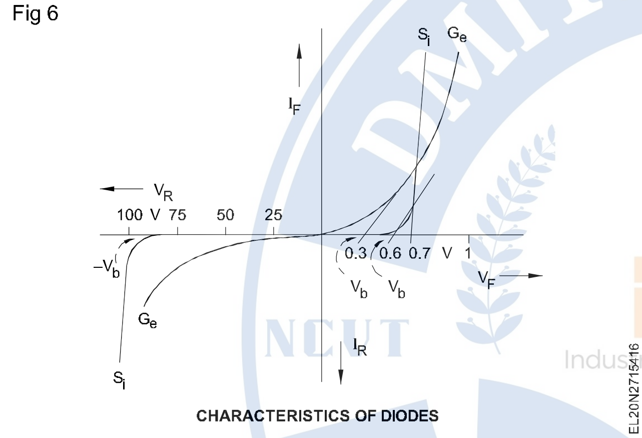
Reverse Bias: If the polarities of the DC supply are as shown in Fig 5, the PN junction is said to be reverse-biased. That is, the P side is connected to the negative and the N-side is connected to the positive terminals of the supply. Fig 5 shows the battery connection reversed (reverse bias). At the same instant, a shift in electrons in the P material causes the positive holes to appear further away from the junction near the end for the diode, which is connected to the negative terminal of the battery. This action produces a wider barrier at the PN junction through which the electrons cannot flow. (A very small current leakage may however occur).

Fig 5



V-I characteristic of PN junction : The static current voltage characteristic is in Fig 6.

Fig 6



The current in the forward direction increases rapidly upon reaching the forward voltage V_b which is known as the barrier potential or the junction potential and the barrier potential for germanium is 0.3 V and for silicon it is 0.7 V.

The behaviour of the PN junction is limited by the maximum forward current, as too much of current may destroy a diode due to the excess heat generation.

The current in the reverse direction of the junction is very small. Upon reaching —V_b in the reverse direction, the reverse current suddenly increases. —V_b in the reverse direction where the current starts increasing is called the knee potential or breakdown voltage. Normally the diode should not be operated in this region. The knee voltage depends on the type of diode which varies from 3V to 20 kV or more.

Application of diodes : Semi conductor diodes are used for various applications. Some of the major areas of application are listed below.

- Modulation and demodulation in communication receivers.
- Switching high speed digital circuits
- Low power and high power rectification
- As surge protectors in EM relay and other circuits.
- For clipping, clamping wave-forms.

For different applications, diodes of different current carrying capacity, different PIV capacity and so on are required. Therefore, manufacturers make diodes to cater to varied applications with different specifications. Before using a diode for a particular application, it is a must to find out whether the voltage, current, and temperature characteristics of the given diode match the requirement or not.

Important specifications of a diodes

The material : The diode is made-of doped semi-conductor material. This could be Silicon or Germanium or Selenium.This is important because the cut-in voltage depends upon the material the diode is made-of. For example, in Ge diodes the cut-in voltage is around 0.3V, whereas in Si diodes the cut-in voltage is around 0.7V.

Maximum safe reverse voltage : Denoted as V_R or V_r that can be applied across the diode. This is known as peak-inverse-voltage or PIV. If a higher reverse voltage than the rated PIV is applied across the diode, it will become defective permanently.

Maximum average forward current : I_f or I_F that a diode can allow to flow through it without getting damaged.

Forward voltage drop : V_F or V_f that appears across the diode when the maximum average current, I_f flows through it continuously

Maximum reverse current : I_{vr} that flows through the diode when the maximum reverse voltage, PIV is applied.

Maximum forward surge current : I_s that can flow through the diode for a defined short period of time.

The maximum junction temperature: The temperature upto which the diode junction can withstand without mal functioning or getting damaged.

Testing diodes using ohmmeter: A simple ohmmeter can be used to quickly test the condition of diodes. In this testing method, the resistance of the diode in forward and reverse bias condition is checked to confirm its condition.

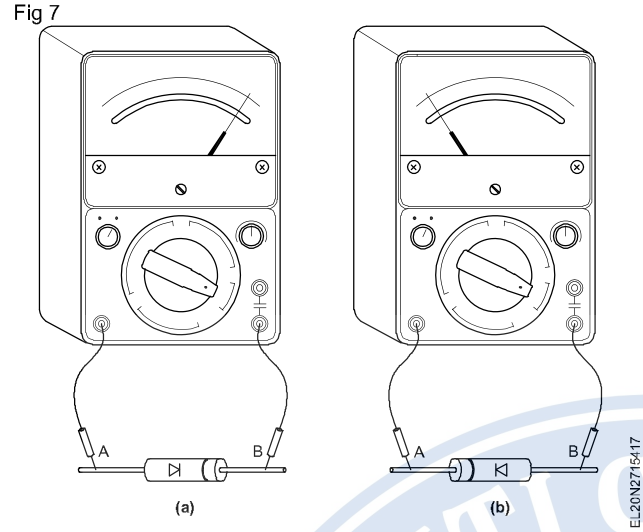
Recall that there will be a battery inside an ohmmeter or a multimeter in the resistance range. This battery voltage comes in series with the leads of the meter terminals as in Fig 7.In Fig 7 the lead A is positive, lead B negative.

> **If the polarity of the meter leads are not known at first, the polarity of the meter leads can be determined by using a voltmeter across the ohm meter terminals.**

If the positive lead of the ohmmeter, lead A in the Fig 7 is connected to the anode of a diode, and the negative (lead B) to the cathode, the diode will be forward-biased. Current will flow, and the meter will indicate low resistance.

On the other hand, if the meter leads are reversed, the diode will be reverse-biased. Very little current will flow because a good diode will have very high resistance when reverse biased, and the meter will indicate a very high resistance.

Fig 7



While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions, then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward and reverse biased conditions.

Polarity marking on the diodes: The cathode end of a diode is usually marked by a circular band or by a dot or by plus (+) sign. In some diodes the symbol of the diode, which itself indicates the polarities, is printed on the body of the diode.

Special diodes: All diodes are basically PN junction diodes and are made according to the application. There are many special purpose diodes are in use in which zener diodes widely used for voltage regulation.

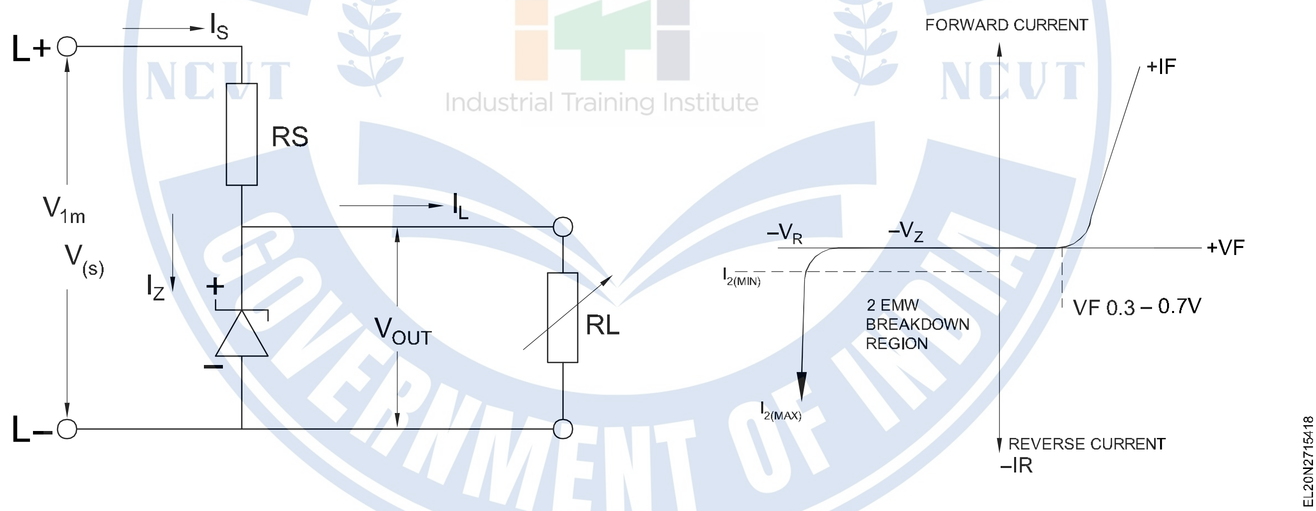
Zener diode: This diode specially designed for voltage regulation. A wide range of voltage regulated zener diodes are available.

It is a PN junction diode doped heavily for regulation purpose. It has a normal VI characteristic when it is forward biased. But the characteristic are changed abruptly when it is connected in reverse bias.

In the reverse bias condition a leakage current in the order of Microamps will flow. When the reverse voltage reaches to a particular designed voltage a sudden breakdown known as avalanche breakdown happens.

When a heavy current flows at constant voltage, the voltage continue to remain constant. Further increase in voltage, the current suddenly increases. Fig 8 shows the reverse characterises of zener diode.

Fig 8



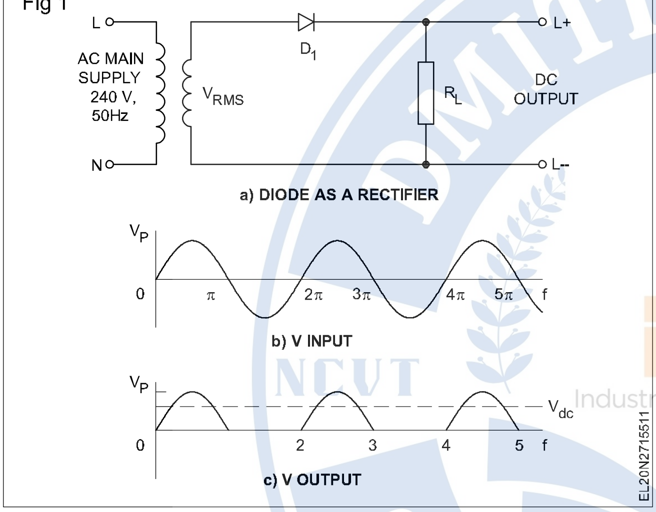
Rectifiers

Objectives: At the end of this lesson you shall be able to
- **state the purpose of rectifier in power supply circuit**
- **explain the working of half-wave, full-wave and bridge rectifier circuit**
- **state the need of filter circuit to rectifier circuits**
- **state the different types filter circuit for rectifiers.**

Most of the electronic equipment, both entertainment and professional, need DC voltage for operation. The power supply converts AC supply voltage into DC. Diodes are used as rectifier in a power supply circuit.

Half wave rectifier: This simplest form of AC to DC converter is by using one diode such an AC to DC converter is known as half-wave rectifier as in Fig 1.

Fig 1



A diode D_1 and a load resistance R_L in series are connected across the secondary of a step down transformer (Fig 1(a). The transformer steps up or steps down the supply voltage as needed. Further the transformer isolates the power line and reduces the risk of electrical shock. During the positive half-cycle of the input line frequency, (Fig 1b) the diode anode is made positive with respect to the cathode. The diode D_1 conducts because it is forward-biased. Current flows from the positive end of the supply through diode D_1 and R_L to the negative terminal of the input. During this period of time, a voltage is developed across R_L. The polarity of the voltage is as indicated in Fig 1C.

During the negative half cycle of AC input line frequency, the diode is reverse-biased. Practically no current flows through the diode and the load R_L and there is no voltage output.

DC output: The voltage drop across the forward biased diode is low, because the resistance of the forward-biased diode is very low. Ge diode drops 0.3V and Si diode drops 0.7V. Ignoring the small voltage drop across the diode. We can find the relationship between AC input and DC output voltage.

The AC input wave-form is shown in Fig 1b.

$V_{rms} = 0.707\ V_p$

$$V_p = \frac{V_{rms}}{0.707}$$

In Fig 1C, the DC output is shown. The diode produces only half cycle of the Ac input. The average value of this half wave is the DC output voltage.

$$V_{dc} = 0.318\ V_p$$

$$= 0.318 \times \frac{V_{rms}}{0.707}$$

$$= 0.45\ V_{rms}$$

For example if the input AC voltage is 24 volts the output DC of the half wave rectifier will be V_{dc} = 0.45 x 24= 10.8 V

The DC load current is $I_{dc} = \frac{V_{dc}}{R_L}$

Ripple frequency: From Fig 1 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

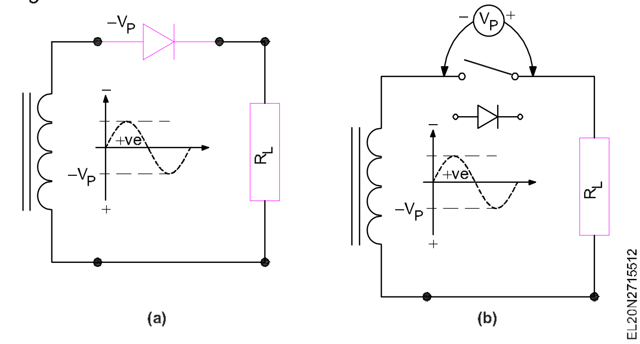
Peak inverse voltage: Fig 1(a) shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as in Fig 2b. Since the diode is reverse biased, there is no voltage across the load R_L. Therefore, from Kirchhoff's Voltage law, all the secondary voltage appears across the diode as shown in Fig 2a. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the peak inverse voltage (PIV). Therefore, in a half-wave rectifier the peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage $V_{s(peak)}$. Since the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a halfwave rectifier can be taken as a $V_{s(peak)}$.

In the example considered earlier, the PIV across the diode will be,

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 = 34 \text{ volts}$$

Fig 2

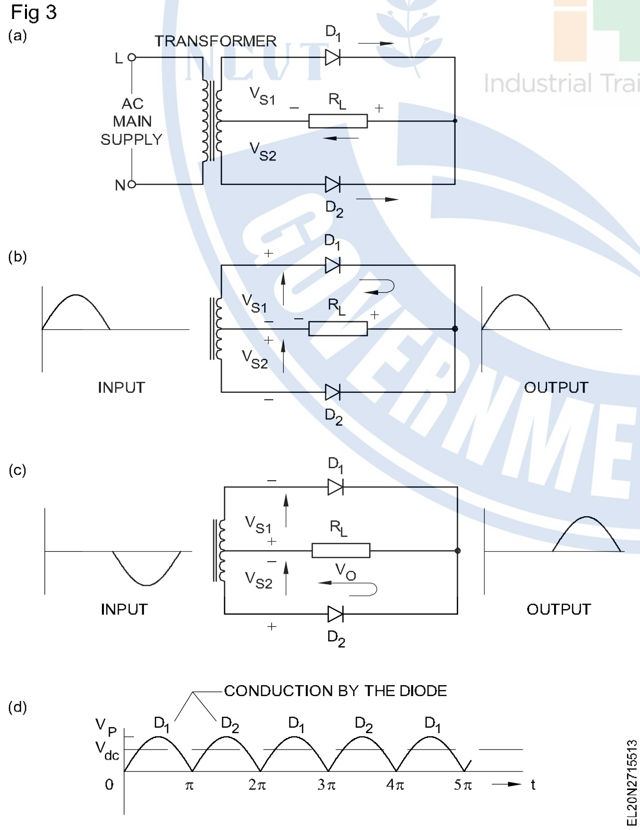


To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

However this condition changes when a filter capacitor is used in the output DC circuit.

Full wave rectifier (FW): A full wave rectifier circuit is in Fig 3. The secondary winding of the transformer is centre-tapped. The secondary voltage is divided equally into two halves, one end of the load R_L is connected to the centre tap and the other end of R_L to the diodes.

Fig 3



It is seen that two half-wave rectifiers are conducting on alternate half cycles of the input Ac.

During the positive half cycle of the secondary voltage, diode D_1 is forward-biased and diode D_2 is reverse-biased. (Fig 3b) The current flows through the load resistor R_L, diode D_1 and the upper half of the secondary winding.

During the negative half cycle of secondary voltage, diode D_2 is forward-biased and diode D_1 is reverse-biased. Therefore, current flows through the load resistor RL diode D_2 and the lower half of the secondary winding. (Fig 3c)

The load current is in the same direction during both the half-cycles of the AC input. The output of the full-wave rectifier is shown in Fig 3d.

DC output : Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a full wave rectifier is naturally twice the output of a half wave rectifier driven by the same secondary voltage.

From Fig 3 it i s evident that the average of DC value of a full wave rectified output is

$V_{dc} = 0.318\ V_{s(peak)} + 0.318\ V_{s(peak)}$

$V_{dc} = 0.636\ V_{s(peak)}$

where, $V_{s(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{s(rms)}$ V_{dc} of full wave rectifier is given by,

$Vs_{(rms)} = 0.707\ V_{s(peak)}$

$$\text{Therefore, } V_{dc} = 0.636 = \frac{V_{s\,(rms)}}{0.707} = 0.9\ V_{s\,(rms)}$$

Example

Suppose the secondary voltage of the transformer is 24-0-24V(rms), the Dc output voltage of a full wave rectifier using this transformer will be,

For a two diode full wave rectifier

$V_{dc} = 0.9\ V_{s(rms)}$

Therefore, in the given example

$V_{dc} = 0.9 \times V_{s(rms)} = 0.9 \times 24 = 21.6$ volts

Ripple frequency in a full wave rectifier: From Fig 3c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half cycle of the input voltage. As a result, the output of a full wave rectifier has frequency double the input AC frequency. If mains AC supply is used as input to a full wave rectifier, the mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

Note: This increased ripple frequency has certain advantages when the pulsating DC is smoothed. This will be dealt with in further lesson.

Peak inverse voltage: Fig 4 shows the full wave rectifier at the instant the secondary voltage reaches its maximum positive value.

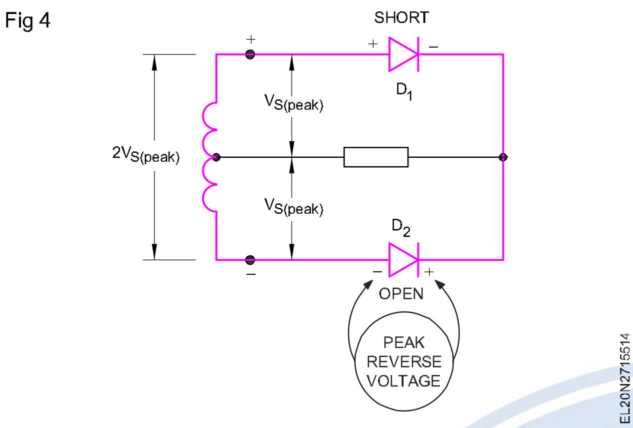
Applying Kirchhoff's law around the outside loop, we get, $2V_{s(peak)}$ - Reverse voltage(PIV)

across D_2 + Forward voltage across $D_1 = 0$

Neglecting the small forward voltage across D_1 we have, $2V_{s(peak)}$ = PIV across D_2 + 0 = 0

or PIV across $D_2 = 2V_{s(peak)}$

Fig 4



From the above it can be seen that each diode in a fullwave rectifier must have PIV rating greater than the peak value of the full secondary voltage. $2V_{s(peak)}$

In the example considered earlier, the PIV of diodes should be 2 $V_{s(peak)}$.

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} \qquad = \qquad 2\,V_{s(peak)} = \frac{2 \times V_{s(rms)}}{0.707}$$

$$= \frac{2 \times 24}{0.707} = 68 \text{ volts (approx.)}$$

Current rating of diodes in a full wave rectifier : If the load, R_L connected in the fullwave rectifier is, say 10Ω the DC current through it will be,

$$I_{dc} = \frac{V_{dc}}{10\,\Omega}$$

In the example considered above, V_{dc} = 21.6 volts

$$\text{Therefore,} \quad I_{dc} = \frac{21.6}{10} = 2.16 \text{ amps.}$$

It is interesting to note this current I_{dc} is shared by the two diodes D_1 and D_2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current I_{dc}. Hence, the maximum current through each diode with 10Ω load will be 2.16/2 = 1.08 amps. From this it follows that the current rating (If(max)) of each diode need only be half the maximum/rated load current.

NOTE: In a halfwave rectifier, since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a full wave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode full wave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode full wave rectifier, the current rating of each diode should be = 1/2 the total load current.

Therefore I_f(max) of diodes should be = 1.8 amps/2 = 0.9 amps.

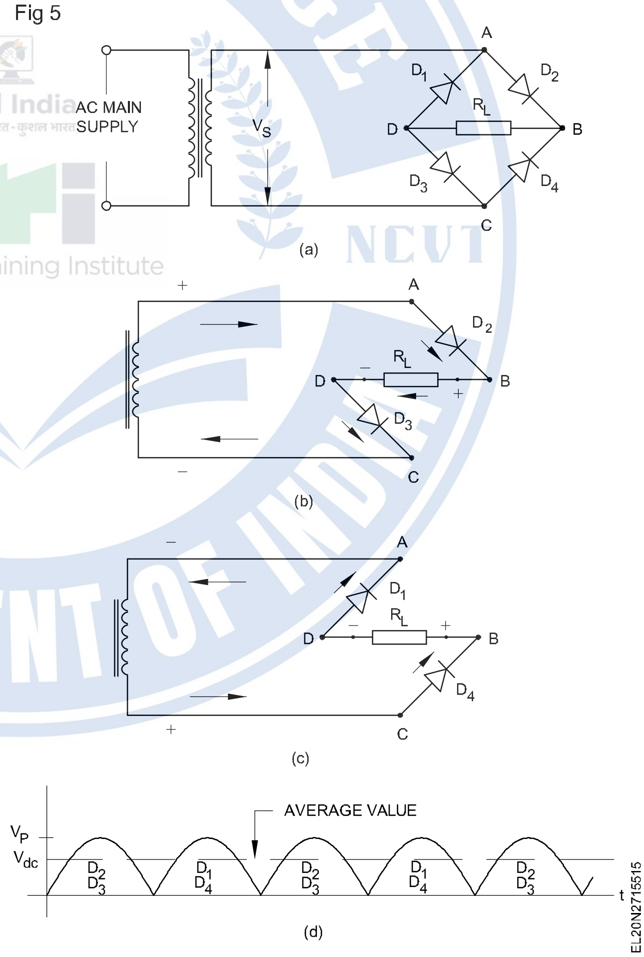
It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

Disadvantages of TWO DIODE full wave rectifier : The full wave rectifier using two diodes and centre tap transformer has the following disadvantages

- A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacturer and, hence, expensive.
- Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.
- In a two diode full wave rectifier, only half of the secondary voltage is made use at a time although it works in both +ve and -ve half cycles.

Bridge rectifier : It is a full-wave rectifier. The circuit is in Fig 5a. In the bridge rectifier four diodes are used. There is no centre tap on the secondary of the transformer.

Fig 5



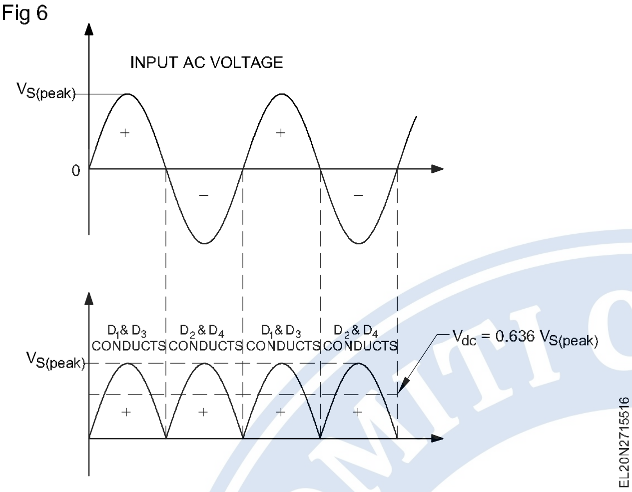
During the positive half of the secondary voltage, diodes D_2 and D_3 are forward-biased. Hence current flows through diode D_2 load resistance R_L and D_3 to the other end of the secondary. This is illustrated in Fig 5b. During the negative half of the secondary voltage, diodes D_1 and D_4 are conducting . The current flows through diode D_4, resistor

R_L and diode D_1 to the other end of the secondary. This is illustrated in Fig 5c.

In both cases the current flows through the load resistor in the same direction. Hence, a fluctuating DC is developed across the load resistor RL. This is shown in Fig 5d.

DC output: Fig 6 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

Fig 6



This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

$V_{dc} = 0,636\ V_{s(peak)}$

or $V_{dc} = 0.9\ V_{s(rms)}$

where, Vs(rms) is the full secondary AC rms voltage.

> **NOTE: In a two -diode full wave rectifier $V_{s(rms)}$ refers to only half for the total secondary voltage whereas in a bridge rectifier $V_{s(rms)}$ refers to full secondary voltage.**

Example: In Fig 5, if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load R_L will be,

From equation ....2, V_{dc} for a bridge rectifier is given by, $V_{dc} = 0.9\ V_{s(rms)}$

In the given example, $V_{s(rms)}$ = 24 volts

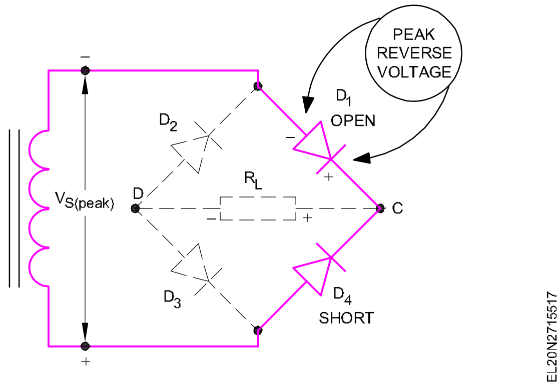
Therefore, V_{dc} = 0.9 x 24 = 21.6 volts

> **NOTE: Using the same transformer, a two-diode full wave rectifier would have given only 10.8 volts which is half of that of bridge rectifier output.**

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode full wave. Hence as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 7 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Fig 7



Diode D_4 is ideally short (as it is conducting) and D_1 is ideally open. summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{s(peak)}$ - PIV across D_1 + 0 = 0

or PIV across $D_1 = V_{s(peak)}$

Therefore, the peak inverse voltage across D_1 is equal to the peak secondary voltage $V_{s(peak)}$

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{s(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{s(peak)}$

Example

In Fig 7 if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, find the minimum PIV of diodes used. In a bridge rectifier PIV across the diodes is same and is equal to $V_{s(peak)}$

Therefore, in the given example,

$$PIV = V_{sd(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts}$$

Current rating of diodes in bridge rectifiers : As in the case of a two diode fullwave rectifier even in a bridge rectifier is in Fig 5, diode pairs D_1, D_3 and D_2 D_4 carry half the total load current1. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, D_1, D_3 and D_2, D_4 is that, this circuit uses four diodes for full wave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

Encapsulated bridge rectifiers are available as a single pack with two terminals for AC input and two terminals for DC output.

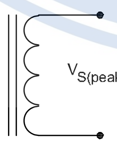
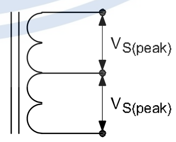
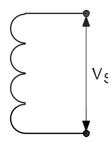
The following table provides data for a normally used diode having the current rating of one ampere.

Maximum ratings

Rating	Symbol	Type Number							Unit
		IN 4001	IN 4002	IN 4003	IN 4004	IN 4005	IN 4006	IN 4007	
Peak repetitive reverse voltage Working peak reverse voltage DC blocking voltage	$V_{RM(rep)}$ $V_{RM(wkg)}$ V_R	50	100	200	400	600	800	1000	Volts
Non-repetitive peak reverse voltage (half wave, single phase, 50 Hz peak)	$V_{RM\ (nonrep)}$	75	150	300	600	900	1200	1500	Volts
RMS reverse voltage	Vr	35	70	140	280	420	560	700	Volts
Average rectified forward current (Single phase, resistive load, 50Hz, $T_A = 75°C$)	Io			1.0					Amp
Non-repetitive (Half sine wave t=10m sec)	IFM			30					
Maximum thermal resistance junction temperature to ambient (lead length = 25 mm)	TJA			85					
Maximum Operating and storage junction temperature range	$T_j T_{stg}$			-65 to 175					

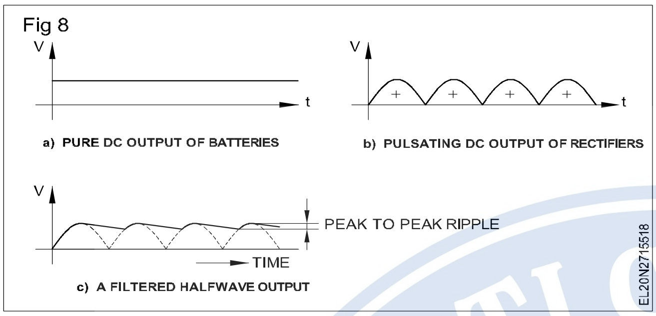
Other diode specifications can be obtained from the data book).

A comparison of half-wave, fullwave and bridge rectifier is given below in a tabular form

	Half wave	Full wave	Bridge
Number of diodes required	1	2	4
Transformers peak output voltage			
DC output voltage in terms of $V_{s(peak)}$	0.318 $Y_{s(peak)}$	0.636V $V_{s(peak)}$	0.636V $V_{s(peak)}$
DC output voltage in terms of $V_{s(rms)}$	0.45 $V_{s(rms)}$	0.9 $V_{s(rms)}$	0.9$V_{s(rms)}$
Diode current rating	$I_{L(max)}$	0.5 $I_{L(max)}$	0.5$I_{L(max)}$

Peak inverse voltage	$V_{s(peak)}$	$2V_{s(peak)}$	$V_{s(peak)}$
Ripple frequency	f_{input}	$2f_{input}$	2_{finput}

Filter circuits : Alternating current is rectified to provide a steady DC voltage similar to the output of a battery as shown in Fig 9a. But the output of rectifiers in a pulsating DC as in Fig 9b.



Pulsating DC voltages cannot be used in most of the electronic circuits. For example a buzzing sound will be obtained from a radio if these pulsations are not removed in the output of the rectifiers. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or popularly as Ripple filters.

Ripple : The small voltage fluctuations in the output of a filter like those shown in figure 9c are called Ripple.

Filter circuit components : Filter circuits are normally combinations of capacitors, inductors and resistors.

Types of filter circuits : The different filter circuits in use are

1 Capacitor input filter.
2 RC filter
3 Series inductor filter
4 Choke input LC filter
5 π filter.

The rate at which the capacitor discharges between points B and C in Fig 10b depends upon the time constant R_LC. longer this time constant is, the steadier is the output voltage.

Calculation of Ripple : While designing a filter circuit the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit.

Method 1

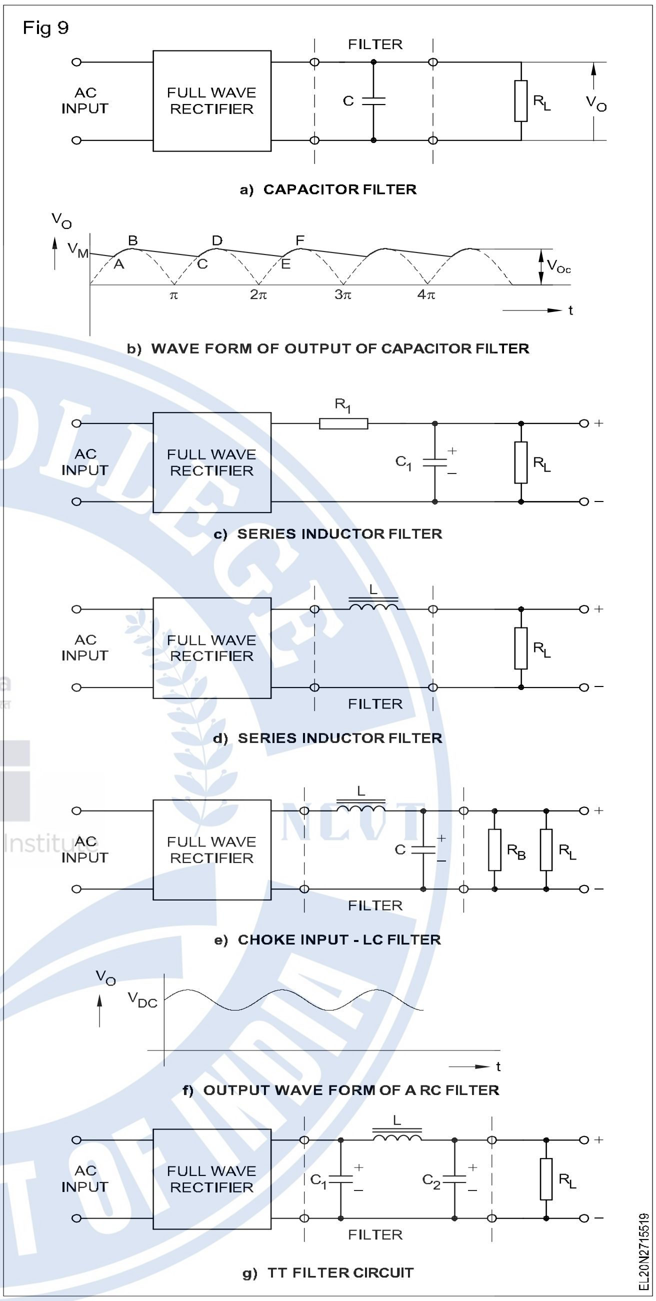
Knowing the required load current, I_L, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

$$V_{rip(p-p)} = \frac{I_L}{F_r C} \text{ .... (2)}$$

Where

$V_{r(p-p)}$ = peak-to-peak ripple voltage in volts
I_L = required Dc load current, in Amps
F_r = ripple frequency, in Hz
C = capacitance in Farads

Fixing the permissible $V_{r(p-p)}$ and knowing f and I_L the required value for C can also be found using this formula



Method 2

Another method of expressing the ripple in the output DC is by ripple factor r defined as,

$$\text{Ripple factor, } r = \frac{V_{r(rms)}}{V_{dc}}$$

where,

r = ripple factor (dimension less)

$V_{r\,(rms)}$ = rms value for ripple voltages.

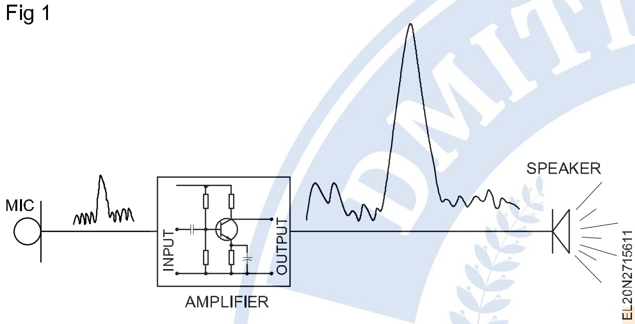
V_{dc} is the measured dc voltage at the output.

Transistors

Objectives: At the end of this lesson you shall be able to
- **explain the construction of bipolar transistors**
- **explain the classification and working of PNP and NPN transistors**
- **state the important packages and type number systems of transistor**
- **explain the methods of testing transistor.**

Introduction: Transistor is an active device which can be compared to the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1



Before the transistors were invented (1947), certain devices are used known as vaccum tubes or valves which were used in amplifiers.

Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vaccum tubes became obsolete as soon as transistors came to market.

Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

- Very small in size
- Light in weight
- Minimum power loss in the form of heat
- Low operating voltage
- Rugged in construction
- Long life and cheap.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in Transistor data books.

Transistor are available as bi polar, field effect and unijunction etc.,

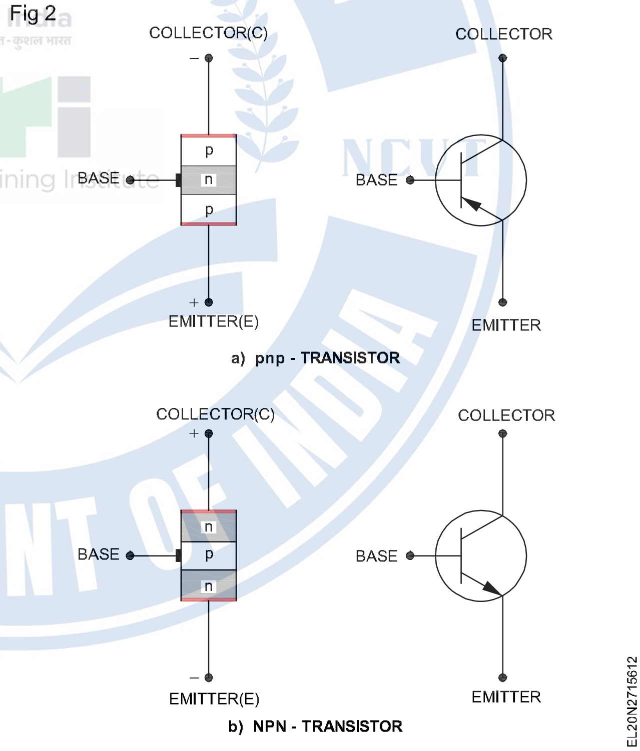
A bipolar junction transistor uses two opposite polarity of doped semiconductor i.e. 'N' type and 'P' type.

A field-effect transistor uses electrostatic field of charged carriers for its working.

An unijunction transistor uses a single junction of 'P' and 'N' type semiconductor.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2



A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In most of the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

Classification of transistors

1 Based on the semiconductor used

- Germanium transistors
- Silicon transistors

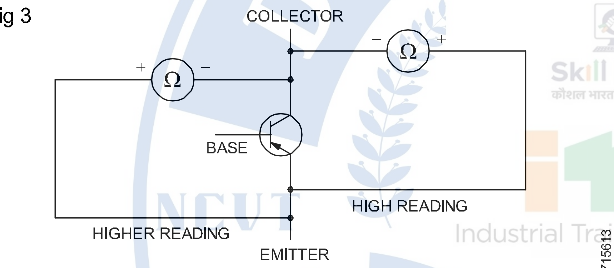
Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor in Fig 3 first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Fig 3



OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON

Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

2 Based on the way the P and N junctions are organised as in Fig 4

- NPN transistor
- PNP transistor

Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Operation of NPN transistor : During the normal operation of the transistor for amplifications the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as in Fig 5.

If V_{EB} is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of V_{EB} and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of V_{EB}, producing base current I_B. Many electrons in the base and collector are attracted by the high potential of V_{CB}, producing collector current I_c. Emitter current I_E is equal to base and collector currents.

Fig 4

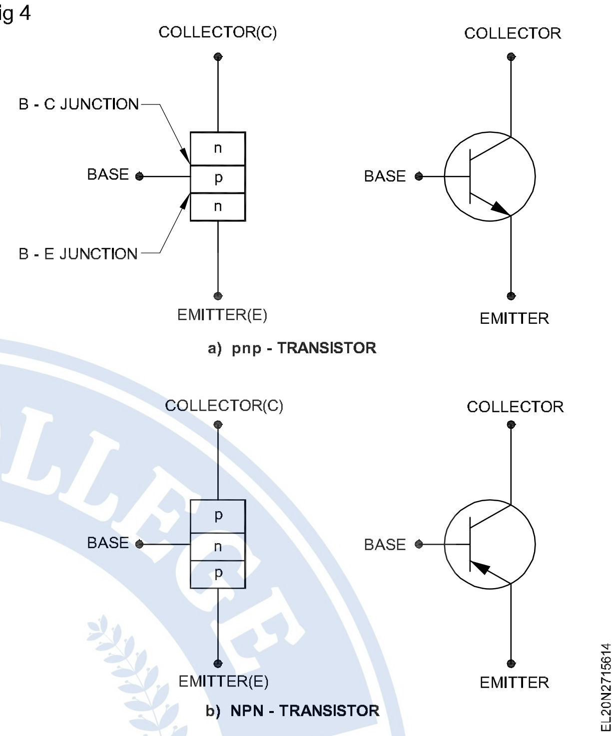
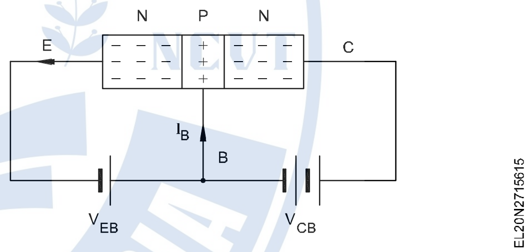


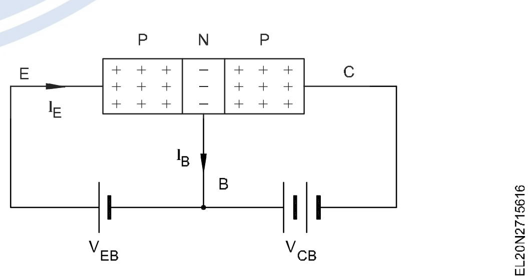
Fig 5



$I_E = I_B + I_c$

Working of PNP transistor: For proper operation of a PNP transistors as amplifier the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as in Fig 6.

Fig 6



Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

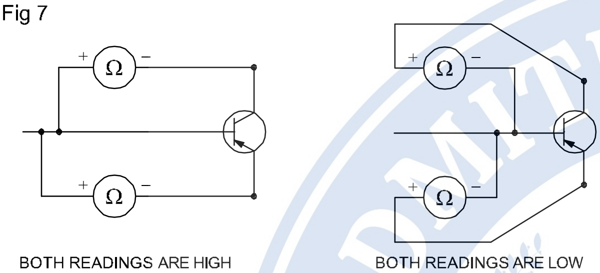
In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1 Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7

Fig 7



RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE PNP TYPE

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

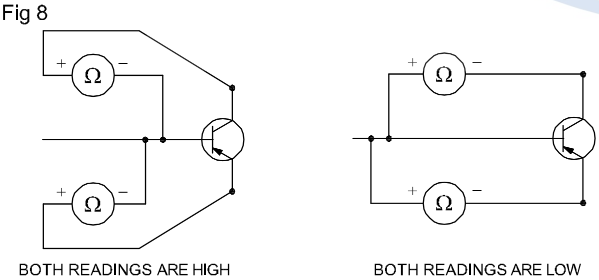
3 If both readings shows high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)

4 Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.

5 If both readings show low resistance, then it is a PNP transistor.

NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.

Fig 8



RESULTS OF THESE OHMMETER TESTS PROVE THAT TRANSISTOR IS THE NPN TYPE

Continue testing as follows:

1 Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.

2 Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3 If the readings show low resistance, then it is a NPN transistor.

3 Based on the power handling capacity of transistors, they are classified as

1 Low power transistors less than 2 watts

2 Medium power transistors is 2 to 10 watts

3 High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to the surrounding air.

Transistor data books give information about the power handling capacity of different transistor.

4 Based on the frequency of application

- Low frequency transistor (Audio Frequency of A/F transistors)
- High frequency transistor (Radio frequency of R/F transistors)

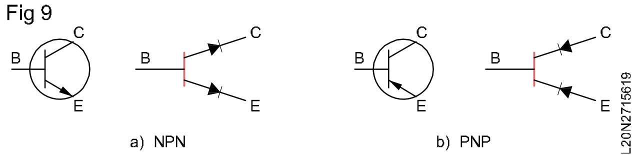
Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)

Fig 9



An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms, in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings.

Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohm-meter/ multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1 When the ratio of reverse to forward R is very high, the junction is good.

2 When both the forward and reverse R are very low, close to zero, the junction is short-circuited.

3 When both the forward and reverse R are very high, close to infinity, the junction is open.

4 When both junctions are good transistor is good.

5 For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

Normally for any power transistor, collector is connected to the metallic part/case to dissipate excess heat generated.

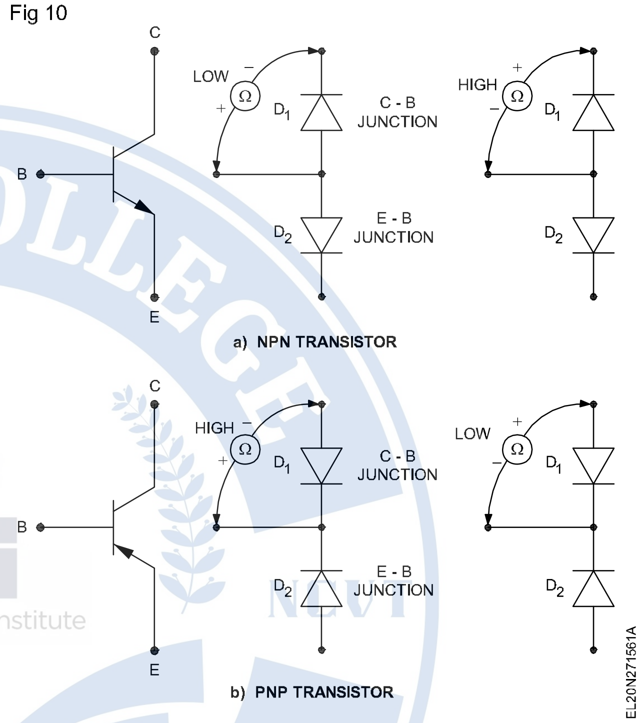
6 With a high voltage multimeter (MOTWANE multimeter with 9 V cell in Ω x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as similar to testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

Fig 10



Transistor biasing and characteristics

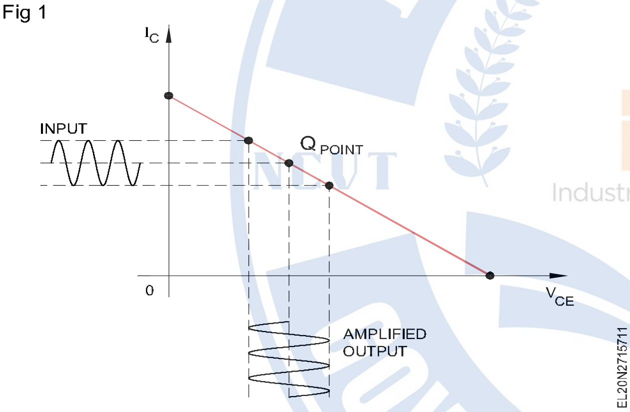
Objectives: At the end of this lesson you shall be able to
- **state the need and type of transistors biasing**
- **state the reason for shifting Q point due to temperature and β_{dc} changes**
- **state the necessity and importance of transistor characteristics**
- **state the importance of DC load line and meaning of Q point in transistors characteristics.**

Need of biasing of transistor

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by driving the car.

Before an AC signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming AC signals can produce fluctuations above and below this Q point as in Fig 1.

Fig 1



For the normal operation of a transistor amplifier circuit, it is essential that there should be

a) a forward bias on the emitter-base junction and

b) reverse-bias on the collector-base junction

In addition, the amount of bias required is important for establishing the Q point which is dictated by the mode of operation desired.

If the transistor is not biased correctly, it would

1) work inefficiently and

2) produce distortion in the output signal.

It is desirable, that once selected, the Q point should remain stable i.e. should not shift its position due to temperature rise which cause variation in β (V_{BE}) or leakage currents.

Further the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation of cut off.

Stable Q point: A set Q point of a transistor amplifier may shift due to increased temperature and transistor β value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

The Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of I_B, I_C and V_{CE}. Further , the collector current I_C depends both on I_B and β of the transistor. If I_B changes, I_c also changes, and hence, the Q point changes. If β changes, again I_C changes, and hence, the Q point gets shifted.

Shifting of Q point due to temperature: Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. this increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q point due to β_{dc} changes: Practically two transistors of the same type number may have different value of β. this is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different β of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the β of the transistor changes.

Different methods for transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line.

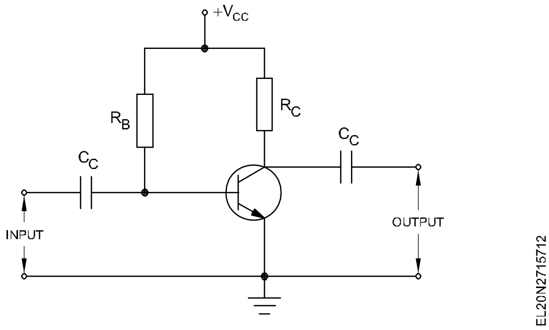
The methods used for providing a bias for transistors are 1 fixed bias or base bias

2 self-bias or emitter bias or emitter feed back bias

3 voltage divider bias

Fixed bias or base bias: The circuit in Fig 2 provides a fixed bias by means of the power source V_{cc} and the base resistor R_B

Fig 2



Self-bias arrangements are not practicable for small values of current because the DC Q point changes due to

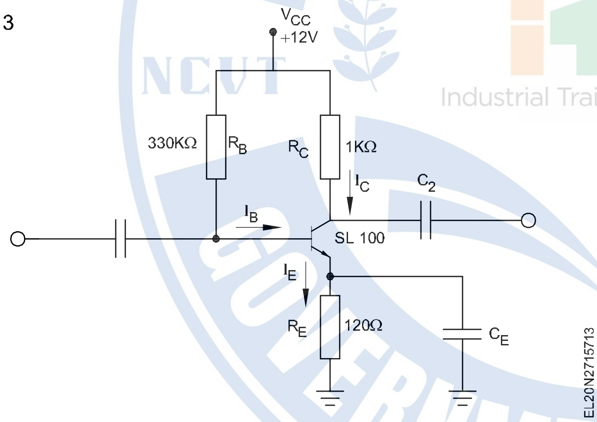
– poor Beta sensitivity

– bias voltages and current do not remain constant during transistor operation due to temperature variation.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistor are used as a switch and not as a linear amplifier.

2 SELF BIAS or EMITTER BIAS or emitter feedback bias: Fig 3 shows a emitter-biased transistor. This type of biasing compensates for the variations in temperature and keeps the Q point fairly stable.

Fig 3



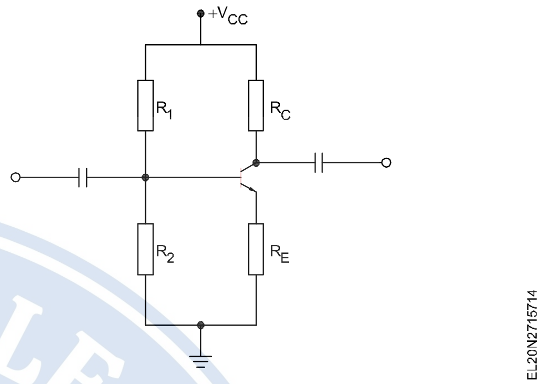
Let the temperature rise-causing rise in I_c and consequently rise in I_c. Then the current in R_E increases. The increased current in R_E increases the DC voltage drop across R_E, reduces the net emitter to the base bias, and the base current, and hence reduces the collector current. Thus the presence of the self-biasing resistor R_E reduces the increase in Ic and improves the operating point stability.

However if β_{dc} increases, the collector current increase. This inturn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in I_c due to increase β_{dc}.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

3 **VOLTAGE-DIVIDER bias: Collector to base bias**: Fig 4 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 4



This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R_1 and R_2. The voltage drop across R_2 should be such that it forward biases the emitter diode.

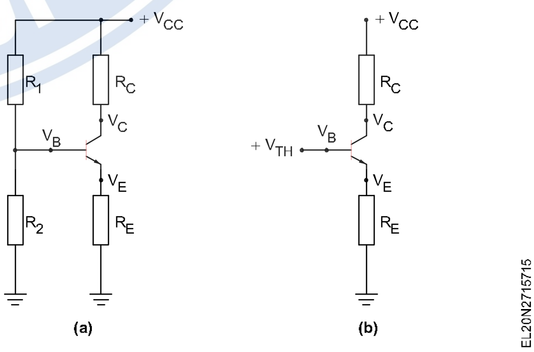
Emitter current in voltage divider bias : Assume that the base lead is open as shown in Fig 5b. Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} = V_{CC}.$$

NOTE: V_{TH} is known as the Thevenin's voltage. Refer reference books for Thevenin's theorem.

Now assume that, the base lead is connected back to the voltage divider as in Fig 5a. then, voltage V_{TH} drives the base of the transistor. In other words, the circuit simplifies to Fig 5a and the transistor acts like the controlled current source.

Fig 5



Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}$$

The collector current I_c will be approximately equal to I_E.

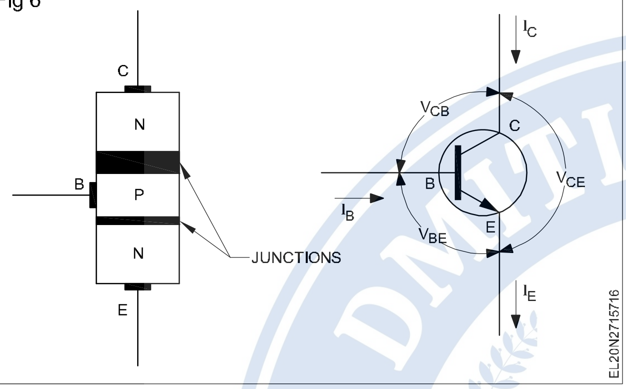
Notice that β_{dc} does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in β_{dc}. This means that the divider-biased transistor has a stable Q point.

Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Transistor characteristics

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E is in Fig 6.

Fig 6



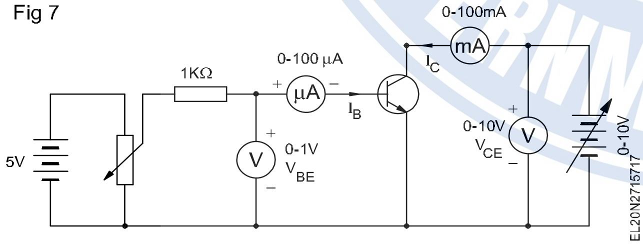
Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

– Input characteristics

– Output characteristics

For simplicity in understanding, consider a common-emitter amplifiers circuit (Fig 7). The two characteristics graphs are in Fig 8.

Fig 7

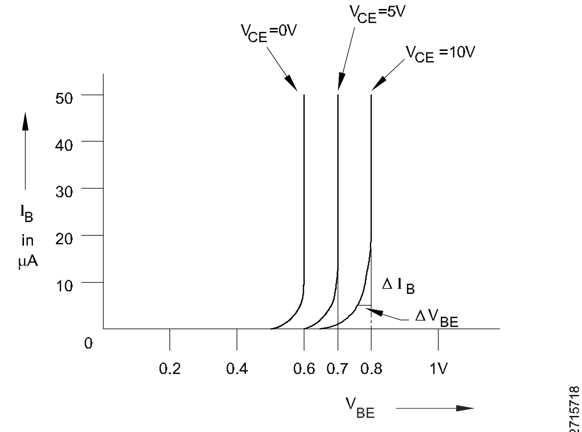


The graph at Fig 8 shows the relationship between the input voltage V_{BE} and input current I_B for different values of V_{CE}

To find the input characteristics from the circuit as in Fig 7 keep $V_{CE} = 0$ constant; increase V_{BE} at regular steps of 0.1V and note the value of I_B at each step. Repeat the above procedure for different value of V_{CE} say $V_{CE} = 5V$ and 10V.

Input characteristic curves can be obtained by plotting I_B on the Y axis against V_{BE} on the X axis. A typical input characteristic is in Fig 9.

Fig 8



INPUT CHARACTERISTICS OF A COMMON EMITTER AMPLIFIER

The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of V_{CE} the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\,\mu A - 10\,\mu A} = \frac{0.02}{10\,\mu A} = 2k\Omega$$

(μ = micro)

The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\,V - 5\,V}{0.15\,\mu A - 0.65\,\mu A} = \frac{5\,V}{0.1\,\mu A} = 50$$

Output CE characteristics: To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1V and note the value of I_B at each step. Repeat the above procedure for I_B = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting I_c on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 9.

It is seen that as V_{CE} increases from zero, I_c rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B=0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\,mA - 2\,mA} = \frac{6}{0.15\,mA} = 40\text{ k ohms.}$$

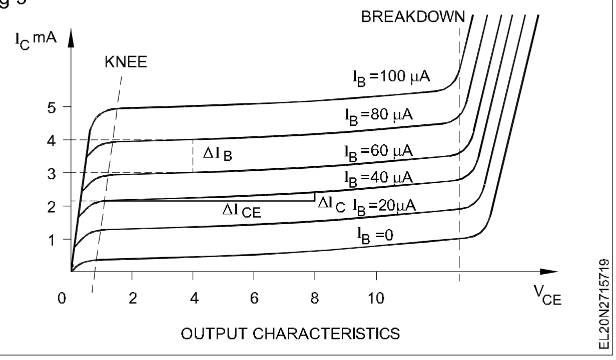
Current gain can be calculated by the formula

$$\text{Beta } \beta = \frac{I_C}{I_B} = \frac{4mA - 3\,mA}{80\,\mu A - 60\,\mu A} = \frac{1\,mA}{20\,\mu A} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$\text{Alpha } \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

Fig 9

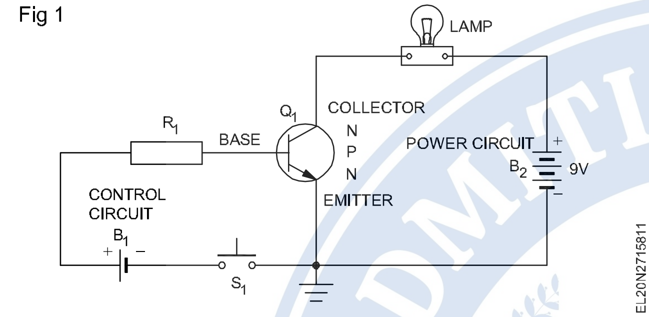


Transistor as a switch, series voltage regulator and amplifiers

Objectives: At the end of this lesson you shall be able to
- **explain the function of the transistor at cut-off and saturation condition**
- **explain the operation of a transistor as a switch and its application**
- **state the working of series voltage regulator using transistor**
- **state the classification of amplifiers.**

The operation of transistor as switch: The switching action for Q_1 in Fig 1 illustrates how the output current can be controlled at the input. Note the following important operating characteristics.

Fig 1



- The transistor is normally off, without any output current unless forward voltage is applied in the base-emitter circuit.
- The forward voltage controlling the base current determines the amount of output current.

In Fig 2 the control circuit of the input determines the base current. For the power circuit, the output is the collector current. An NPN transistor is used for Q_1. This type requires positive V_{BE} forward voltage. The emitter is common to both (a) the control circuit at the input and (b) the power output circuit.

The base emitter junction of Q_1, in Fig 1 can be forward biased by the battery B_1. Switch S_1 must be closed to apply the forward voltage. Reverse voltage for the collector of Q_1 is supplied by B_2. The reverse polarity means that the N collector is more positive than the base. With switch S_1 open, no current flows in the base-emitter (or control) circuit.

The reason is that the forward voltage is not applied. Therefore, the resistance from the emitter to the collector of the transistor is very high. No current flows in the power circuit, and the lamp does not light.

Next, assume that switch S_1 is closed. This causes a small current to flow in the control circuit. R_1 is a current limiting resistor for the base circuit. Therefore, the resistance from the emitter to the collector of the transistor drops. Consequently, a large current flows in the power circuit, causing the lamp to light.

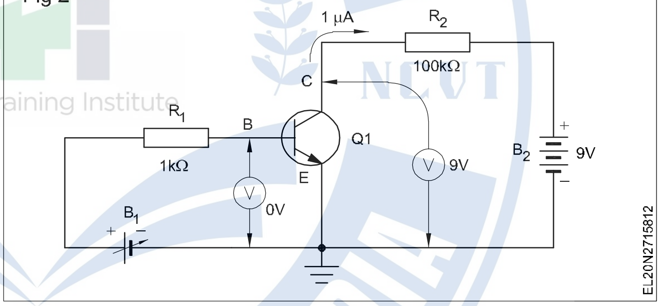
Finally, the opening of the switch S_1 in the control circuit cause the lamp in the power circuit to go out. This is because the resistance from the emitter(E) to the collector (C) of Q_1 has again increased to near infinity.

In summary, a small current in the control circuit causes a large current to flow in the power circuit. With no current in the control circuit, the transistor acts like an open switch. With some current in the control circuit, the transistor acts like a closed switch.

Operation of transistor switching circuit: The schematic circuit in Fig 2 shows the measured voltages and collector current I_c in the 'transistor off' circuit. Note that only a tiny leakage current of 1micro amp flows from the emitter to the collector. The resistance from E to C is calculated as

$$R = \frac{V}{I} = \frac{9\,V}{0.000001\,A} = 9 \text{ megohm}$$

Fig 2



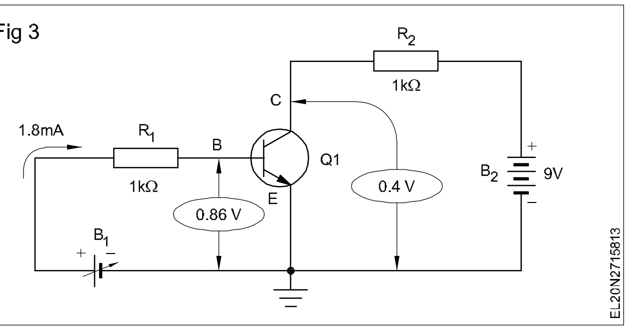
The transistor has a resistance of 9 Megohm, which is like the open or off condition of a switch.

The schematic in Fig 3, shows the measured voltages and currents in the 'transistor on' circuit. First, the voltage from the emitter to the base has been increased by adjusting B_1. The forward-biased voltage of 0,86V at the emitter-base junction of the transistor causes 1.8 mA to flow in the control circuit. This current in turn causes the resistance of the transistor from E to C to drop. The effect is that a large current of 85mA flows from the collector of the transistor. The resistance from E to C in Fig 4 is calculated as

$$R = \frac{V}{I} = \frac{0.4\,V}{0.085A} = 4.7 \text{ ohm}$$

The resistance of the transistor from E to C has dropped from its previous high value of 9 megohm to a low value of 4.7 ohm. As a result, the transistor is acting like a closed switch.

Fig 3



The transistor in Fig 2 is said to be at cut off position. It has reached its maximum resistance from E to C and has cut off the current. The very tiny current still flowing is due to minority current carriers in the transistor, which is the leakage current.

The transistor in Fig 3 is said to be at saturation. It has reached its minimum resistance from E to C, which produces the maximum collector current. When used as a switch, the transistor is driven to cut off or to saturation by the base current caused by the emitter-base voltage.

Transistor switching times : Now let us pay attention to the behaviour of the transistor as it makes a transition from one state to the other. Consider the transistor circuit in Fig 4a, driven by the pulse wave-form in Fig 4b. This wave-form makes transitions between the voltage levels V_2 and V_1. At V_2 the transistor is at cut off, and at V_1 is applied between the base and the emitter through a resistor R_1 which may be included explicitly in the circuit or may represent the output impedance of the source in the wave-form Fig 4b.

The response of the collector current I_c to the input wave-form, together with its time relationship to that waveform, is in Fig 4c. The current does not immediately respond to the input signal. Instead, there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10 percent of its maximum (saturation) value $I_{CS} = V_{cc}/R_L$, is called the delay time t_d. The current waveform has a nonzero rise time tr which is the time required for the current to rise from 10 to 90 percent of I_{CS}. The total turn-on time t_{ON} is the sum of the delay and rise time,

$$t_{ON} = t_d + t_r$$

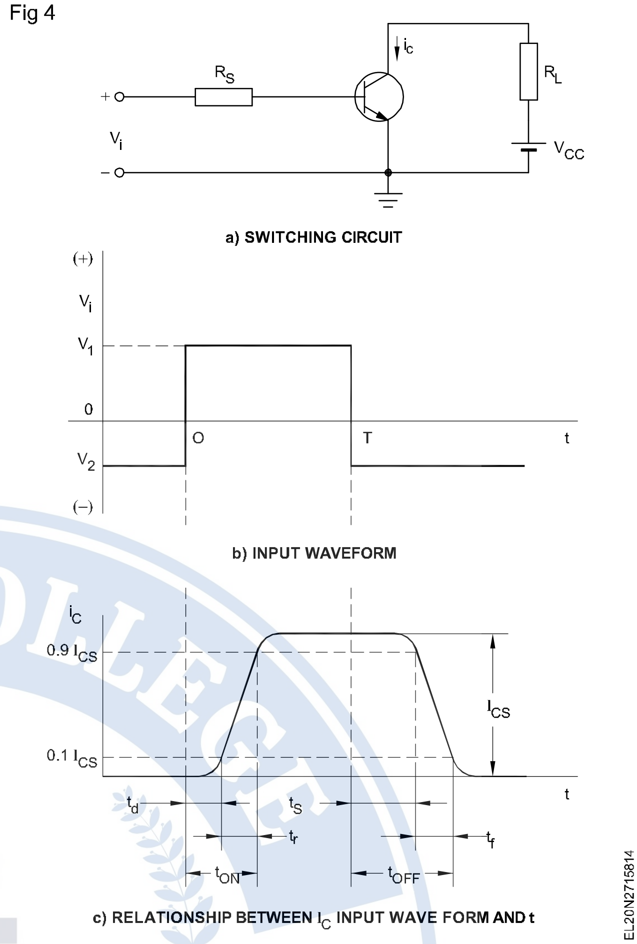
When the input signal returns to its initial state at t = T (Fig 4b), the current again fails to respond immediately. The interval which elapses between the transition of the input waveform and the time when i_c has dropped to 90 percent of ICS is called the storage time t_s. The storage interval is followed by the fall time tt, which is the time required for i_c to fall from 90 to 10 percent of I_{CS}. The turn off time to t_{OFF} is defined as the sum of the storage and fall times,

$$t_{OFF} = t_s + t_F$$

The application of transistor switch: The transistor switch is used

- as an electronic ON and OFF switch

Fig 4



- in the stable, mono-stable and bi-stable or filp-flop multi-vibrator circuits
- in the counter and pulse generator circuit
- in the clipping circuits
- as a sweep starting switch in the cathode ray oscilloscope equipment
- as a relay, but unlike the mechanical relay, the transistor has no moving mechanical parts.

Series voltage regulator

Voltage regulated power supply using zener diode is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

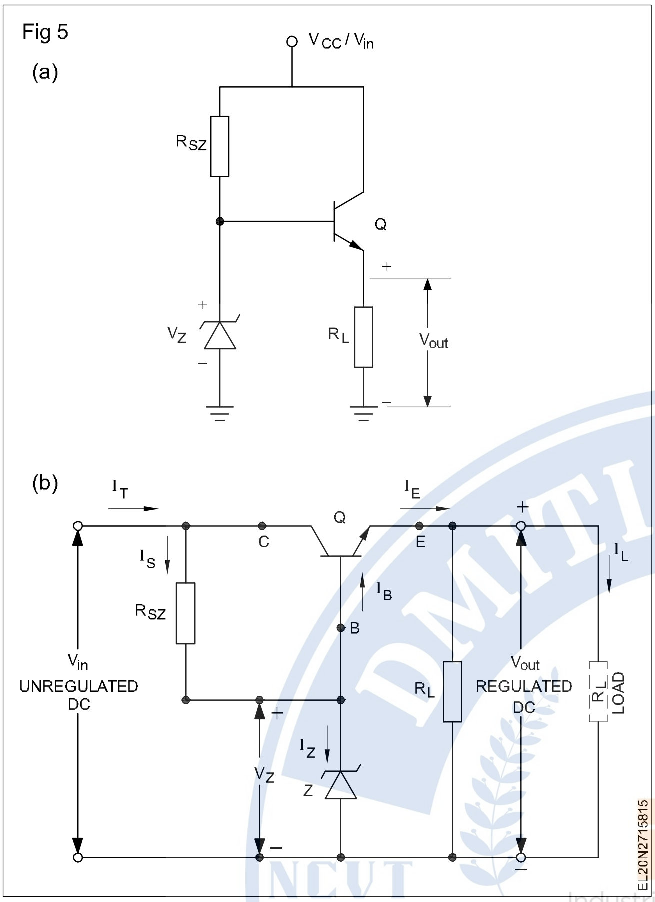
1 When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.

2 In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance, R_Z which ranges from a few ohms to a few tens of ohms (typically 5Ω to 25Ω). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 5.

The simple series regulator is in Fig 5a, redrawn in Fig 5b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.

Fig 5



Classifications of amplifiers : An amplifier is an electronic circuit which is used to amplify or increase the level of weak input signals into very high output signals. Transistors are used as amplifiers in most circuits. In addition, resistors, capacitors and a biasing battery are required to form complete amplifier circuits.

Almost all electronic systems work with amplifiers. We are able to hear the news or other programmes on our radio, simply because the amplifier in the radio amplifiers the weak signals received by its antenna.

Classification of amplifiers: Linear amplifiers are classified according to their mode of operation, i.e. the way they operate according to a predetermined set of values. Various amplifier descriptions are based on the following factors.

1 Based on the transistor configuration
   - a common emitter (CE) amplifier
   - b common collector (CC) amplifier
   - c common Base (CB) amplifier

2 Based on the output
   - a voltage amplifier
   - b current amplifier
   - c power amplifier

3 Based on the input
   - a small signal amplifier
   - b large signal amplifier

4 Based on the coupling
   - a RC coupled amplifier
   - b transformer coupled amplifier
   - c impedance coupled amplifier
   - d direct coupled amplifier

5 Based on the frequency response
   - a audio frequency (AF) amplifier
   - b intermediate frequency (IF) amplifier
   - c radio frequency (RF) amplifier
   - d VHF and UHF amplifiers

6 Based on the feedback
   - a current series feedback amplifier
   - b current parallel feedback amplifier
   - c voltage series feedback amplifier
   - d voltage parallel feedback amplifier

7 Based on the biasing conditions
   - a Class A power amplifier
   - b Class B power amplifier
   - c Class AB power amplifier
   - d Class C power amplifier

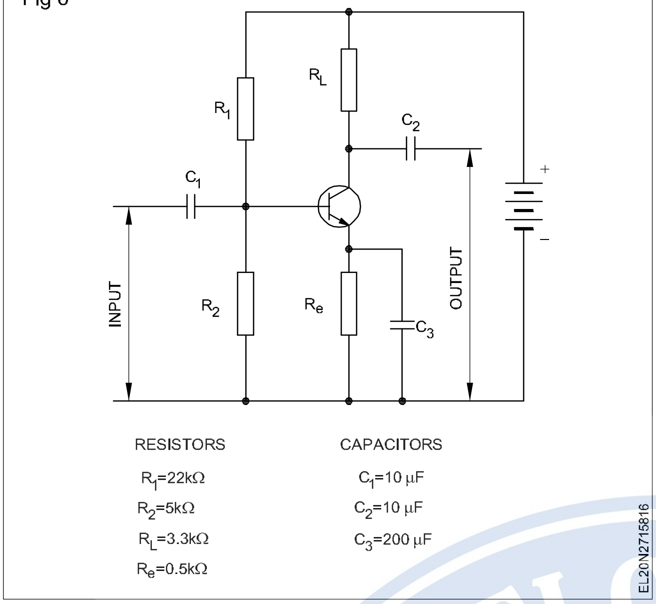
Of the above mentioned, serial numbers one and two are explained at this state. Some of the amplifiers dealt in this book for detailed study the students can refer to any standard books for the remaining portions depending on their special interest.

Common-emitter amplifier: This type of circuit is by far the most frequently used. It has the greatest power gain, substantial current and voltage gains, and is specially advantageous in multistage application when a high gain is a primary requirement. A common-emitter amplifier stage with biasing from a single D.C supply battery is in Fig 6.

The A.C. signal is applied between the base and the emitter and the output is taken from the collector. For the transistor to operate, the emitter base junction must be forward-biased, the resistors R_1 and R_2 setting the base voltage so that the emitter is forward-biased. The collector current flows through the load resistors R_L and R_e and the voltage developed by R_L at the collector is the output.

The voltage gain of a transistor is largely determined by the value of this particular resistor since the voltage developed across it due to change in the collector current is far greater than that developed across the base resistor from the input signal.

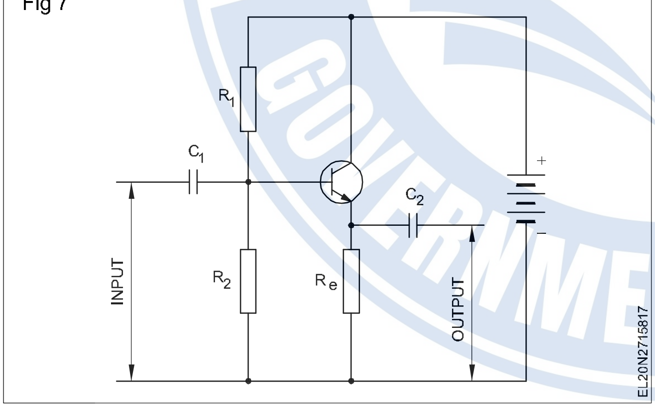
Fig 6



Resistor R_e is included to minimise the effect of temperature changes in the collector current. To prevent R_e from reducing the signal gain by current feedback, a capacitor C_3 may be included in parallel with R_e.

Common-collector amplifier : In this configuration, the collector is the common point for the input and output circuits, the input signal being applied between the base and collector and taken off between the emitter and collector, Fig 7. The notable feature is the large input impedance virtually equal to that of the parallel circuit of R_1 and R_2. The output resistance is, however, low and, hence it follows that the voltage gain is low, but a high current amplification can be obtained.

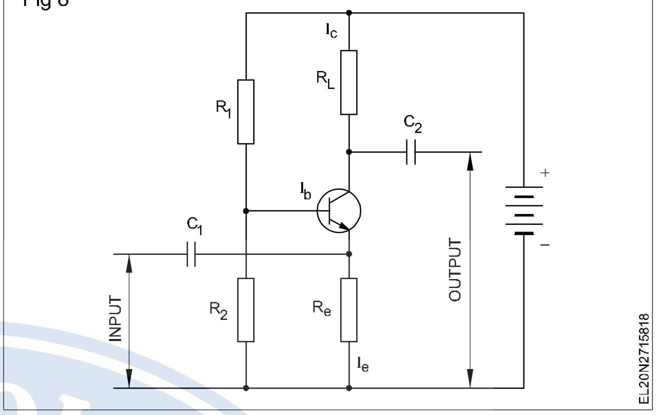
Fig 7



The functions of the capacitors C_1 and C_2 are the same as for the common-emitter stage, as the potential networks R_1 and R_2 which provide forward bias for the emitter-base junction. The main advantage of the common-collector circuit is the readiness with which it may be directly coupled to any point in a circuit regardless of voltage.

Common-base amplifier: In this circuit the base is the common terminal between the emitter terminal and the collector terminal. The emitter current I_e is the input current and the collector current I_c is the output current. (Fig 8) Since $I_e = I_b + I_c$ and since in this circuit Ie is greater than I_c, by the value of I_b, the current gain I_c/I_e will always be slightly less than one. Therefore, there can be no current gain in a common-base circuit. However, because of the low impedance of the forward-biased emitter-base junction and the high impedance of the reverse-biased collector-base junction a sizable voltage gain is obtained.

Fig 8



For instance, if we assume that input resistance of 200Ω, a load resistance of 50K and a current gain of 0.98, the voltage gain is 0.98 x 50k/200 = 245

Voltage amplifier: An amplifier is a circuit that incorporates one or more transistors and is designed to increase an alternating signal applied to the input terminals. It is called a voltage amplifier. If the size or magnitude of the output voltage is considerably greater than the input voltage, it is called the voltage gain of the amplifier.

The main function of a voltage amplifier is to produce a given gain with the minimum of distortion, i.e. the output voltages should have the same wave-form as the input wave-form, but should of course be much higher in magnitude. Examples for the voltage amplifier are the common base and the common emitter amplifiers.

Current amplifier: The function of the current amplifier is when the current injected in the base, load can influence to much greater current to flow in the emitter-collector circuit.

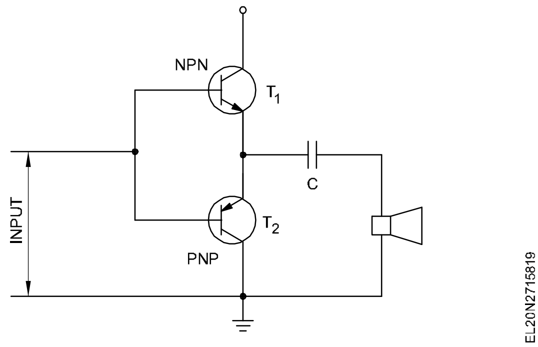
The remarkable result is that, if the base current is increased by a certain proportion, the base current in the collector current gives rise to a corresponding, but much larger changes in the collector current. We have achieved current amplification. The ratio of the output current to the input current is called the current gain of the amplifier.

An example for the current amplifier is the common-emitter, common-collector amplifier. The current gain of common-emitter amplifier is 50 to 300 and that of the common-collector amplifier is 50 to 500.

Power amplifier : Power amplifiers are used to drive the output mechanism, e.g. a loudspeaker, a pair of earphones, a moving coil meter or some other type of indicating device. The main function of a power amplifier is to deliver a good deal of undistorted power into the output device or load circuit. Examples for the power amplifiers are class A, class B, class AB and class C.

Fig 9 shows the complementary symmetry Class B push-pull power amplifier circuit. In a complementary pair of power amplifiers, one of them is an NPN type and the other a PNP type. With no input signal, neither transistor conducts and the output is zero. When the input signal is positive going, the NPN transistor T_1 conducts and the PNP transistor T_2 is cut off. When the signal is negative going, T_1 is tuned of while T_2 conductors. The maximum efficiency of this circuit is about 78%.

Fig 9



Function generator and cathode ray oscilloscope (CRO)

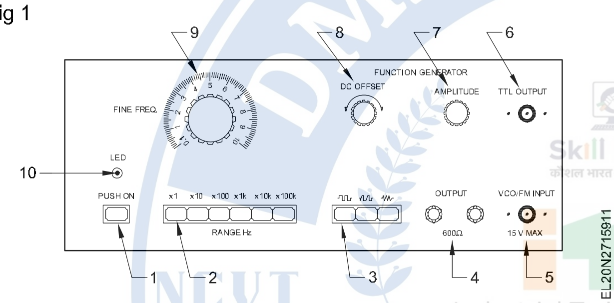
Objectives: At the end of this lesson you shall be able to
- **explain the use and control of function and AF (audio frequency) generator**
- **explain the function of CRO with block diagram**
- **state the functions of various controls in CRO**
- **state the use of CRO in electronic circuits.**

Introduction: A function generator is an equipment capable of providing sine, square and triangular wave outputs at different frequencies and amplitude. It has a maximum of 20 volts peak to peak single amplitude. A function generator finds applications in frequency modulations, tone control, Audio electronic, other laboratory and research work.

Panel controls and features of function generator

The front panel controls of function generator. (Fig 1)

Fig 1



1 **Power ON-OFF switch:** To turn on the function generator this button should be depressed. To turn off the same button should be pressed to release.

2 **Range selectors:** The range selection is of decade frequency type. The output frequency is given by the product of range selected and frequency dial indication. For example if the 10 K range button in depressed and frequency dial is at 2, then the output frequency is 20 KHz.

3 **Function selectors:** These selectors select the desired output waveform. (square, sine or Triangle)

4 **Output jack:** The wave forms selected by the function switches are available at this jack.

5 **VCO input jack:** An external voltage (not exceeding ± 20V peak) input will vary the output frequency. The change in frequency is directly proportional to the input voltages.

6 **TTL JACK:** A TTL (Transistor, Transistor logic) square wave is available at this jack. This output is independent of the Amplitude.

7 **Amplitude control:** This controls the amplitudes of the output signal.

8 **Offset control:** This controls the DC offset of the output.

9 **Fine frequency dial:** The output frequency of the wave forms is given by the product of the setting of this dial and the range selected.

Operating information: The function generator is powered by 240V. AC mains. When the power ON switch is depressed the LED will glow.

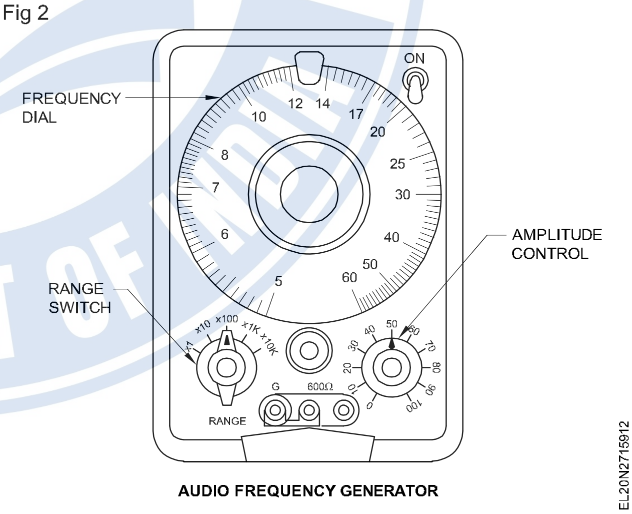
The desired frequency is set by depressing the frequency range switch an positioning the fine frequency dial.

The desired wave from is selected by depressing the appropriate function button from sine, square or triangle.

The amplitude of the selected output signal is adjusted by Amplitude control knob. A variation of the display amplitude from 0-20 V peak is possible. The TTL output is not affected by the amplitude control.

Audio Frequency (AF) Generator (Fig 2): Audio frequency generators produce sine wave signals from 20 Hz to 20 kHZ. Certain type of AF generators produce sine wave upto 100 kHZ. In addition to sine wave there may be provision to produce square waves too.

Fig 2



These generators contain a variable amplitude control which changes the signal amplitude from 10 mv to 20V. With the help of this generator the audio amplifier stages in radio, TV recorders and audio amplifier could be tested.

While the frequency range switch selects the desired frequency range switch selects the desired frequency range, the frequency dial is used to select the frequency within the desired range.

Cathode ray oscilloscope (CRO)

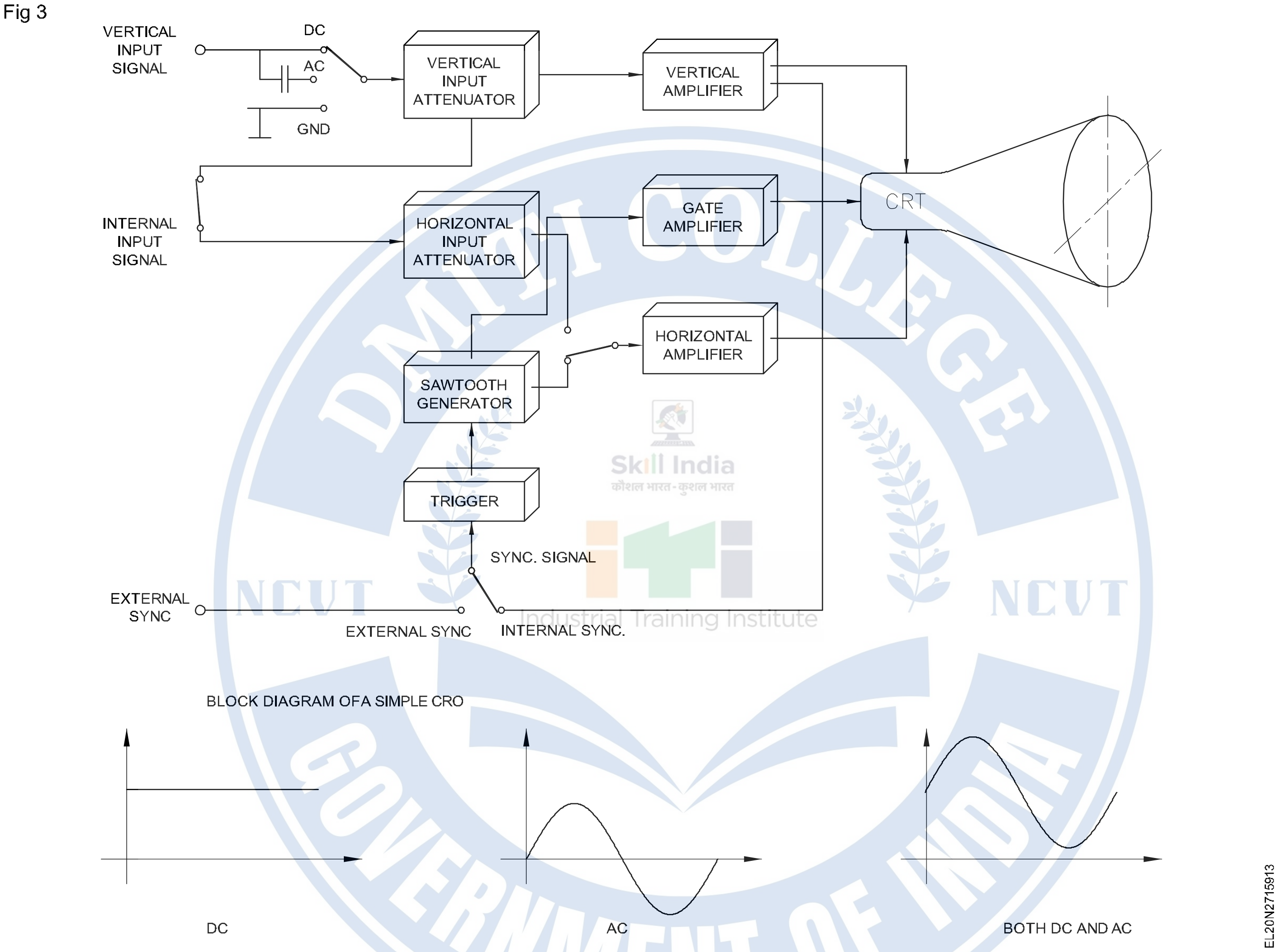
Introduction: The oscilloscope is an electronic measuring device which provides a visual presentation of any wave form applied to the input terminals. Cathode ray tube (CRT) like a television tube provides the visual display of the signal applied as a wave form on the front screen. An electron beam is deflected as it sweeps across the tube face, leaving a display of the input signal.

An oscilloscope usually consists of:

- Attenuator
- amplifiers
- saw-tooth generator
- gate amplifiers or Z-amplifier
- Trigger
- CRT (cathode ray tube)
- power supply

The block diagram of a simple cathode ray oscilloscope is shown in Fig 3.

Fig 3



BLOCK DIAGRAM OFA SIMPLE CRO

Attenuator : The input signal should be attenuated to a suitable magnitude before it is applied to the amplifier. The attenuators are employed at the input of both vertical and horizontal amplifiers.

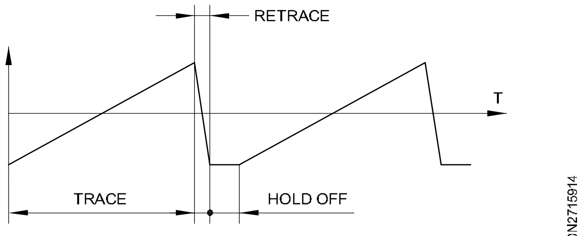
Amplifier : The amplifiers of an oscilloscope consist of a vertical amplifier and a horizontal amplifier. The vertical amplifiers amplify the vertical input signal before it is applied to the Y-plates. The horizontal amplifier amplifies the signal, before it is connected to the X-plates.

Saw-tooth generator: The measuring signal of any shape is connected to the Y-input(plates) and then it appears on the screen. The signal on X-plates should be such that the image on the screen is similar to that on the Y-plates. Hence a saw-tooth signal is required to be connected to the X-plates which makes the image on the screen like the signal connected at the vertical plate. The saw-tooth signal is called the time base signal, and is produced by the saw-tooth generator. The shape of the saw-tooth signal is shown in Fig 4. The time-base signal consists of trace, retrace and hold off period.

Gate amplifier or Z-amplifier: It is desirable that the image seen on the screen of the CRT must be continuous, that is, the electron beam is desired to appear only in the trace period of the time-base signal. The retrace period of the electron beam must not be visible on the screen. Therefore, the gate amplifier is required to control the electron beam in order that it appears only in the trace period.

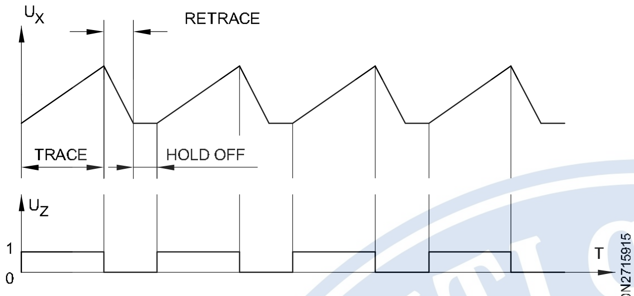
The signal from the gate amplifier is a square wave and is related to the time-base signal. This is illustrated in Fig 5.

Fig 4



OUTPUT OF SAW TOOTH GENERATOR

Fig 5



OUTPUT OF GATE AMPLIFIER

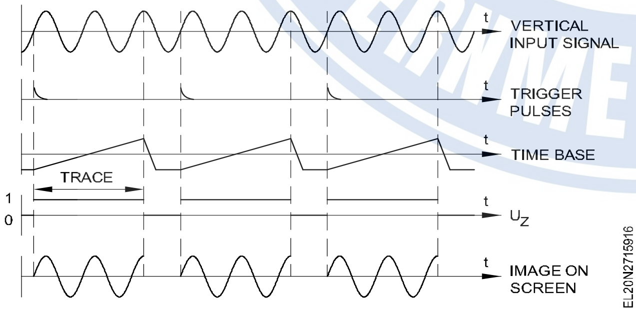
Trigger (Gate amplifier output) : As mentioned earlier, the measuring signal-wave form is connected to Y-input, which appears on the screen. In order to make the wave-form stationary on the screen, it is required that the starting point of the time base signal has to be fixed related to the signal connected to the Y-input. This is known s 'synchronization'. The functional stage which performs synchronization is the trigger.

The trigger will produce a pulse or impulse for triggering the time-base. Every time the time-base is triggered, one saw-tooth wave-form is produced.

There are three forms of triggering in an oscilloscope.

Internal triggering : The signal which is supplied to the trigger is the internal signal of the CRO produced by using the signal from the vertical input signal. The sequence of signal processing is shown in Fig 6.

Fig 6



External triggering : The signal which is supplied to the trigger is the external signal, produced by using the signal from the external, sync.

Line triggering : The signal which is supplied to the trigger is the signal from the power supply of CRO. (Not shown in the block diagram)

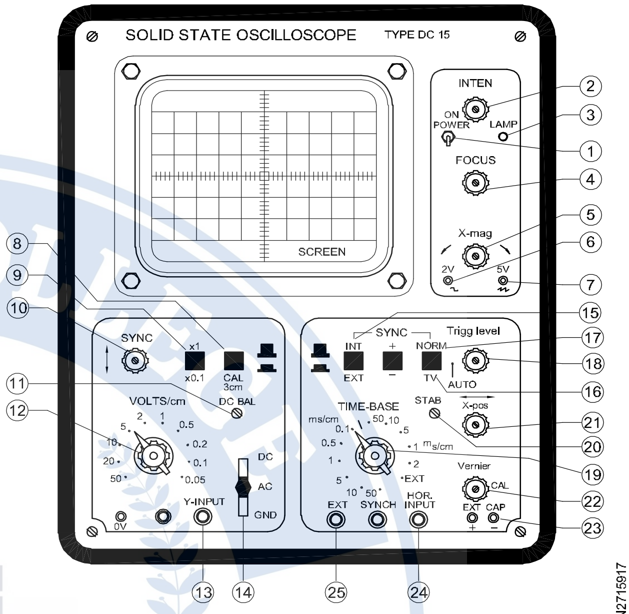
Switches are provided to select the form of triggers as required. In a CRO, suitable timing can be selected that causes the image on the screen to be stationary.

CRO (The Cathode ray tube): The constructional features are explained later in this text.

Power supply: Low voltage and high voltage DC supplies which are required for the oscilloscope function are produced by rectifier filters and switch mode power supply circuits.

Controls and their functions in a CRO: The operating controls on the front panel of a general purpose oscilloscope is shown in Fig 7. The names of the controls and their functions are listed below.

Fig 7



CATHODE RAY OSCILLOSCOPE

General

Power-on (1): It is toggle switch meant for switching on power. In the ON position, power is supplied to the instrument and the neon lamp (3) glows.

Intensity (2): It controls the trace intensity from zero to maximum.

It controls the sharpness of the trace. A slight readjustment of this control may be necessary after changing the intensity of the trace.

X-Magnification (5): It expands length of the time-based from 1 to 5 times continuously, and makes the maximum time-base to 40ns/cm.

Square wave (6): This provides a square wave of 2 V (p-p) amplitude to enable the user of the scope to check the Y-calibration of the scope.

Saw-tooth wave (7): This provides a saw-tooth, wave-form output coincident to the sweep-speed switch with an output of 5V (p-p). The load resistance should not be less than 10 k ohms.

Vertical section

Y (10) : This control enables the movement of the display along the y-axis.

Y (13) : It connects the input signal to the vertical amplifier through the AC-DC-GND coupling switch (14)

AC-DC-GND coupling switch (14): It selects coupling to the vertical amplifier, in DC mode, it directly couples the signal to the input; in AC mode, it couples the signal to the input through a 0.1 MF, 400-V capacitor. In GND position, the input to the attenuator (12) is grounded, whereas the Y-input is isolated.

Volts/cm (Attenuator) (12): It is a 10-position attenuator switch. It adjusts the sensitivity of the vertical amplifier from 50 m V/cm to 50 V/cm in 1,2,5,10 sequence. The attenuator accuracy is ±3%.

x1 or x 0.1 switch (9)

When switched in x 0.1 or position, it magnifies the basic sensitivity to 5 m V/cm from 50 m V/ cm

CAL switch (8): When pressed, a DC signal of 15 m V or 150 m V is applied to a vertical amplifier depending upon the position of x1-x0.1 switch (9) position.

DC bal (11): It is a preset control on the panel. It is adjusted for no movement of the trace when either x1 - x0.1 switch (9) is pressed, or the position of AC-DC-GND coupling switch (14) is changed.

X-Position (21): This control enables the movement of display along the X-axis.

Trigger level (18): It selects the mode of triggering. In AUTO position, the time-base line is displayed in the absence of the input signal. When the input signal is present, the display is automatically triggered. The span of the control enables the trigger point to be manually selected.

Time-base (19): This sector switch selects sweep speeds from 50 ms/cm to 0.2Ms/cm in 11 steps. The position marked EXT is used when an external signal to be applied to the horizontal input (24)

Vernier (22): This control is a fine adjustment associated with the time-based sweep-selector switch (19). It extends the range of sweep by a factor of 5. It should be turned fully clockwise to the CAL position for calibrated sweep speeds.

Sync. selector (15, 16, 17): The INT/EXT switch (15) selects internal or external trigger signal. The +ve or -ve switch (16) selects whether the wave-form is to be triggered on +ve or -ve step. NORM/TV switch (17) permits normal or TV (line frequency) frame.

Stab (20): It is a preset control on the panel. It should be adjusted so that you just get the base line in the AUTO position of the trigger level control (18). In any other position of the trigger level control, you should not get the base line.

Ext. Cap (23): This pair of connectors enables the time-base range to be extended beyond 50 ms/cm by connecting a capacitor at these connectors.

Hor. input (24): In connects the external signal to the horizontal amplifier.

Ext. sync. (25): It connects the external signal to the trigger circuit for synchronization.

Application of CRO

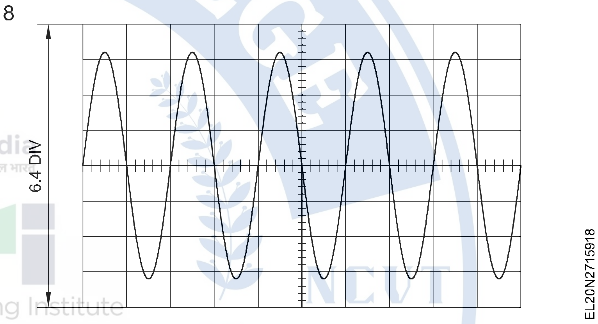
AC voltage measurement: The screen of the cathode ray oscilloscope usually has a plastic gratitude overlay, marked in centimeter divisions. The vertical amplitude of any wave form indicates peak-to-peak voltage.

To measure unknown AC voltages the main supply AC should be isolated through a isolation transformer and the attenuator is set to 50 V/ div. The AC-DC switch is set to AC position (out). Voltage to be measured is connected to the input and common terminal. Set the time base switch to display several cycles of the wave form. Adjust the V/div switch to get a wave form at a convenient height such that the positive and negative peaks appears with-in the screen.

Measure the vertical amplitude (no. of divisions peak-to-peak) of the voltage on the screen. Now multiply the amplitude by the volts/div setting to find the peak-to-peak voltage value.

Example : Assume a vertical deflection of 6.4 divisions as in Fig 8 and a volt/div setting of 5 volts.

Fig 8



Peak-to-peak voltage	= 6.4 x 5 = 32 V
therefore peak voltage	= 16 V
therefore RMS voltage	= 16 x 0.707 = 11.31 V

$$\text{or RMS voltage} = \frac{\text{Peak to peak voltage}}{2.83} = \frac{V_{PP}}{2 \times \sqrt{2}}$$

$$= \frac{32}{2 \times \sqrt{2}} = 11.31\text{v}$$

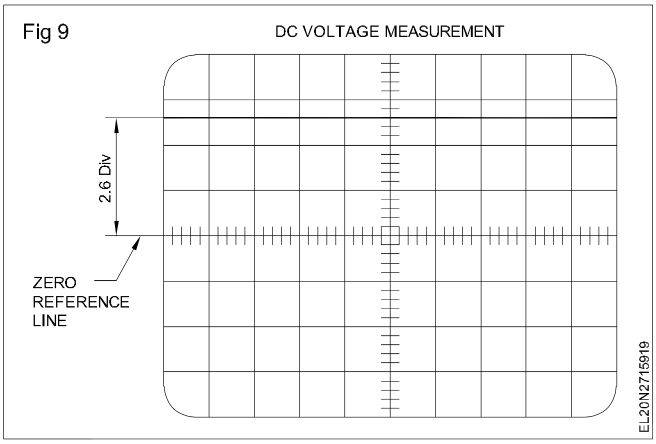
DC voltage measurement : The input selector switch is set to DC position. Adjust the Y shift position to get the trace at the centre of the screen. This line represents zero DC volts. Connect the +ve of the DC voltage to be measured to input terminal and the -ve to the common terminal. Now the horizontal line will move up. (Down for reverse polarity) the volts/div switch is set as required.

Now measure the vertical distance in divisions form the zero reference line.

The DC voltage can be found by multiplying the vertical distance (division) with VOLT/DIV setting.

An example is worked out with reference to Fig 9

Assume a vertical deflection of 2.6 division and a Volts/Div setting of 20 V.



DC voltage = 2.6 x 20 = 52V.

Measurement of time and frequency : The wave-form to be measured is connected to the V input. The volts/Div switch is set to display a suitable vertical amplitude of the wave-form. The Time/Div switch is set to display approximately two cycles of the wave-form to be measured. Adjust the Y-SHIFT control to move the trace so that the measurement points are on the horizontal centre line. The X-SHIFT control is adjusted to move the start of the measurement points to a convenient reference line.

The distance (divisions) between the points of one cycle is measured as in Fig 10.

The product of the divisions of one cycle and the setting of time/div switch gives the period of one cycle.

The frequency can be determined by the formula

$$\text{Frequency} = \frac{1}{\text{Time period}}$$

where frequency is in hertz and time in seconds.

Example

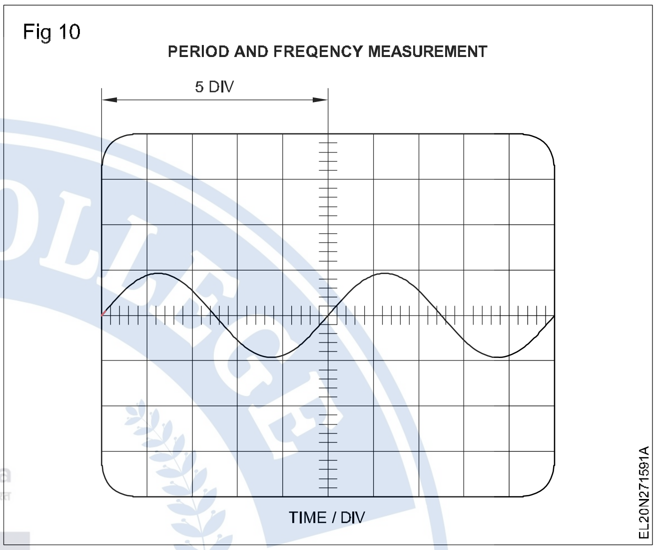
Time = Div x time base setting

= 5 x 0.2 ms

= 1 ms

$$\text{therefore frequency} = \frac{1}{T} = \frac{1}{1 \times 10^{-3}} = 1000\,\text{Hz}$$

Frequency = 1 kHz.



Printed circuit boards (PCB)

Objectives : At the end of this lesson you shall be able to
- **state the types of etchants used for etching and preparation of etchant solution**
- **state the reasons for agitating the etchant solution while etching**
- **list the important points while drilling holes on PCBs**
- **list the advantages of marking component positions on PCBs.**

Introduction

Printed circuit board in which the connecting wires are replaced by a thin conducting path called copper or silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phonetic, paper or fibre glass or epoxy.

The moulded conducting path generally known as tracks size depend on the power of the circuit. The width of tracks are varied few millimeters to less than one millimeter depend on the circuit.

The thin tracks less than one millimeter made up with silver tracks where IC circuits and micro controller circuits are to be made. Several process moulded to make PCB and it is explained below.

Etching

Once the required portions on the copper foil side of the laminate is painted/masked and dried, the next step is to remove the copper present in the unmasked portions of the laminate. This process is known as etching.

Only after etching the unwanted areas of the copper foil, the metal side of the laminate gets the actual shape of the circuit connection required.

Etching is done using any one of the following chemicals;

– Alkaline ammonia

– Sulpuric-hydrogen peroxide

– Ferric chloride

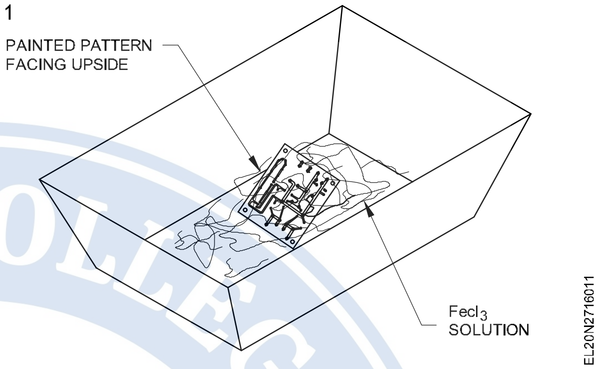
– Cupric chloride

The ratio of ferric chloride and water decides the rate of etching. The typical ratio is, 100mg of concentrated ferric chloride powder/liquid for one litre of water. This $Fecl_3$ is prepared in a plastic tray of suitable size such that the painted laminate to be etched can be fully immersed as shown in Fig 1.

Since ferric chloride is an acid solution, although diluted, it is harmful to the skin. Hence, rubber gloves are to be used while working with this solution.

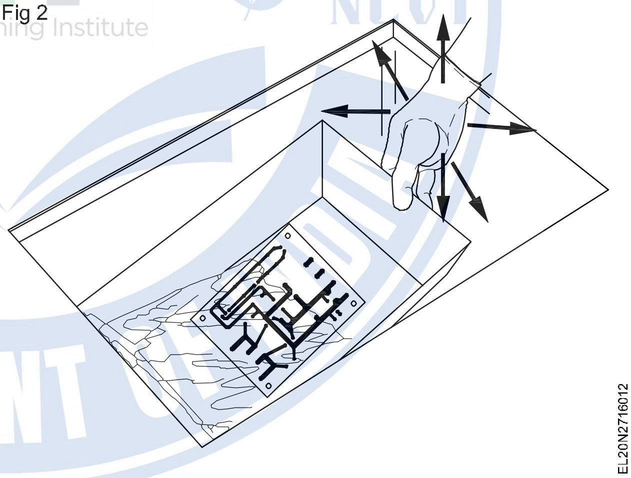
The painted laminate to be etched is slid into the $Fecl_3$ solution of required quantity, with the painted surface of the laminate facing the top as in Fig 1, such that, as the process of etching progresses, the extent of etching is visible.

Fig 1



To ensure speedy and uniform etching, the etchant solution is agitated lightly by shaking and tilting the tray as shown in Fig 2. Too much of agitation of the solution should be avoided, as this may peel off the ends of the painted tracks and remove those portions which were not intended to be etched.

Fig 2

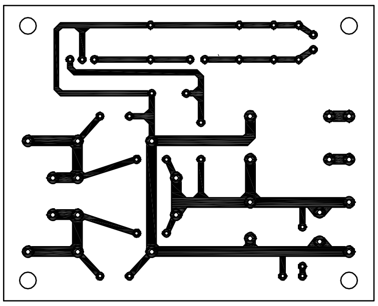


As the etching progresses, the copper in the unwanted portion is gradually removed. When the etching is complete, all the copper in the unwanted portion disappears and the etched portion will have the colour of the insulator of the laminate board.

Once the unwanted portions of copper are completely etched, the board is taken out of the solution and is cleaned using fresh water to remove the remaining $Fecl_3$ solution. This stops any further etching process.

After cleaning the board using water and drying, the etch-resistant ink/paint on the lay out pattern is removed using solvents, such as, thinner or petrol. The cleaned board will then have bright copper stripes and pads, only in the required portions representing the circuit as in Fig 3.

Fig 3



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Drilling holes on PCBs

The next step after etching and removing the mask/paint is to drill holes of required diameter at the pad centers for inserting the components, input/output and V_{cc} & ground(Gnd) connections. Extra care is to be taken while drilling holes because carelessness while drilling may peel off the pad area of the copper. Some hints for drilling on PCB's are given below;

– If the point where drilling is to be made is not clear, punch the point again such that the drill bit sits at the punched point before starting the drilling.

– Use a high speed drill gun/machine.

– Use drill bits of the required size. If an exact size drill bit is not available, use a drill bit one size smaller but never one size larger.

– Fix the PCB firmly on a vice using a wooden block so that the PCB does not become loose while drilling and peel of the pad area copper.

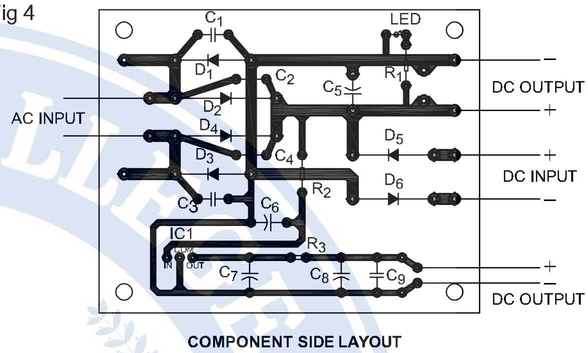
– Ensure that all the points required are drilled because, once the components are mounted, drilling holes on the PCB may damage the mounted components due to vibration.

After drilling holes, clean the PCB such that it is free from burr and dust. Apply varnish on the layout pattern, to protect the copper pattern from corrosion.

Preparing and marking component lay out

A typical component side of a PCB with the components marked on it is in Fig 4.

Fig 4



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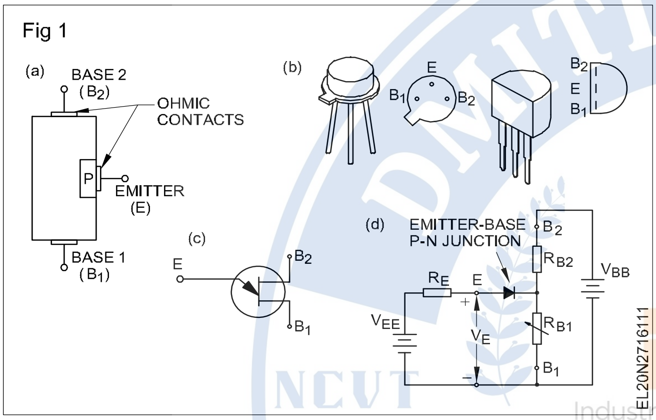
Unijunction transistor (UJT) and FET and its application

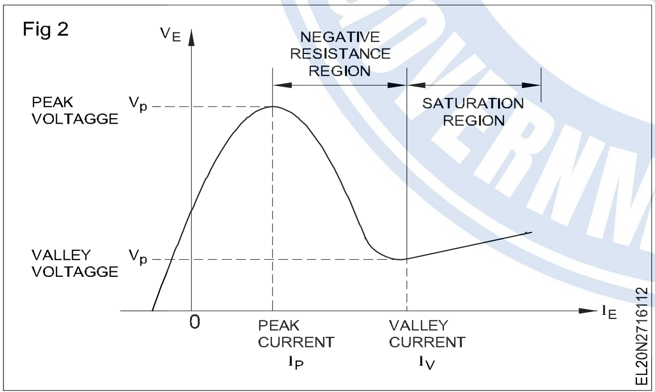
Objectives: At the end of this lesson you shall be able to
- **explain the construction and working principle of UJT**
- **make a quick test of UJT**
- **state the FET, JEFT principle, working biasing application as an amplifier**
- **list and explain the application of UJTs**

Unijunction transistor(UJT) is a three terminal semiconductor device as shown in fig 1a. In its appearance it looks like a transistor as shown in Fig 1b. As shown in Fig 1a, it consists of two layers(a P-layer and a N-layer) and therefore it has only one junction(hence its name, uni-junction).

The symbol of UJT and its electrical equivalent circuit is shown in Fig 1c and 1d.



UJT is a special semiconductor device because it exhibits negative resistance characteristics as shown in Fig 2. The details of the characteristics are discussed in subsequent paragraphs.



Construction of UJT

2646 and 2N 2647 UJT's are available in the modified TO-18 case style as shown in Fig 1b.

Equivalent circuit of UJT

The electrical equivalent circuit of UJT is shown in fig 1d. The resistance between the B_1 and B_2 terminals is called the inter-base resistance R_{BB}. The N-type silicon bar serves as a resistance divided into two parts R_{B1} and R_{B2} by the PN junction. The total of the internal R_{B1} and R_{B2} is the interbase resistance R_{BB}. Value of R_{BB} is typically in the range of 4 to 10 K ohms. Also r_{B1} usually a little greater than r_{B2} because the emitter is a little closer to B_2.

The interbase resistance R_{BB} is measured with the emitter open.

$$R_{BB} = R_{B1} + R_{B2} \text{ at } I_E=0.$$

Operation of UJT

The DC supply polarities for a UJT to function is shown in Fig 3. As can be seen from fig 3, B_2 is connected to +ve and B_1 to ground. As a result current(conventional) flows from B_2 to B_1. This conduction results in a voltage gradient along the N-type silicon bar. Therefore there is a voltage in the region of the emitter junction(V_E) which is positive with respect to ground. The magnitude of this voltage is given by the simple voltage divider action between R_{B1} and R_{B2}.

$$V_E \text{ or } (V_{RB!}) = \frac{R_{B1}}{R_{B1}+R_{B2}} V_{BB} = \eta V_{BB} \qquad ....[1]$$

The Greek letter η (eta) is called the intrinsic stand-off ratio. This is an important data of any UJT and is invariably mentioned in all UJT data sheets. From the above equation, intrinsic stand-off ration η (eta) is given by,

$$\eta = \frac{R_{B1}}{R_{B1}+R_{B2}} \qquad ....[2]$$

UJT and its applications of triggering circuits

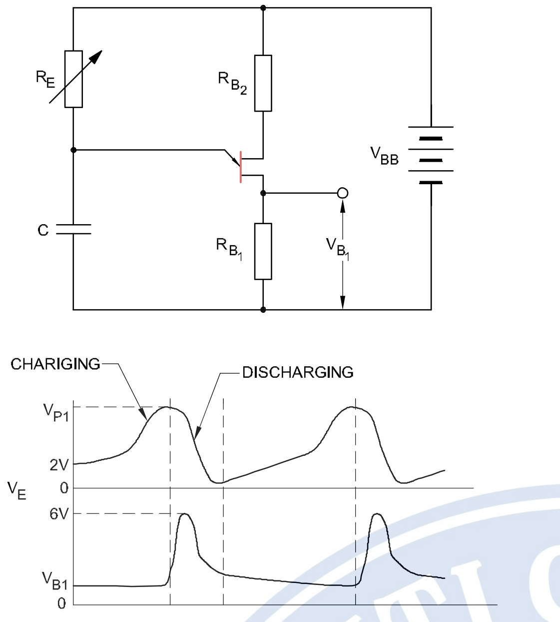
UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include

- triggers for thyristors
- as oscillators
- as pulse and saw tooth generators
- timing circuits
- regulated power supplies
- bistable circuits and so on.

Let us analyse the waveform generated across the capacitor and R_1 with respect to the relaxation oscillator or free running oscillator as in Fig 3.

The negative - resistance portion of the UJT characteristic is used in the circuit shown in Fig 3 to develop a relaxation oscillator.

Fig 3



UJT AS RELAXATION OSCILLATOR

The wave form developed across the capacitor is shown in Fig 3 as V_E, whereas the waveform produced across the resistor R_{B1} is shown as a pulse V_{B1}.

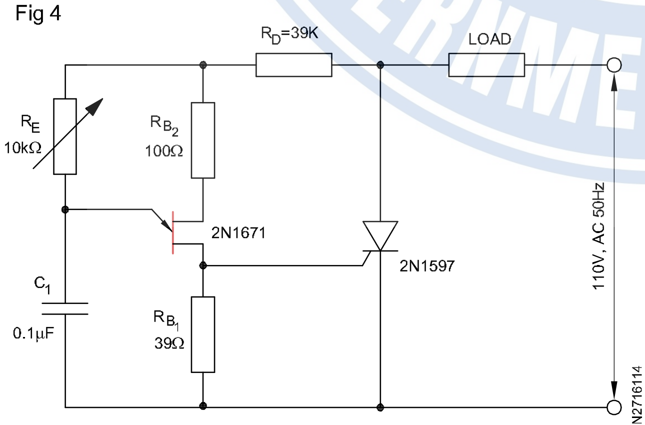
The frequency of oscillation

f =

Where R_E is the value of variable resistor in ohms and C is the value of the capacitor in farad.

By varying the value of R_E, the frequency of the oscillator can be varied. Although such an oscillator using a DC supply voltage could be used to trigger a SCR, there would be trouble in synchronizing the pulses with the cycles of alternating current. Fig 4 shows a stable triggering circuit for an SCR in which the firing angle can be varied from 0° to 180°.

Fig 4



UJT RELAXATION OSCILLATOR USED FOR TRIGGERING THE SCR

Field-effect transistor (FET)

The main difference between a Bi-polar transistor and a field effect transistor is that,

Bi-polar transistor is a current controlled device

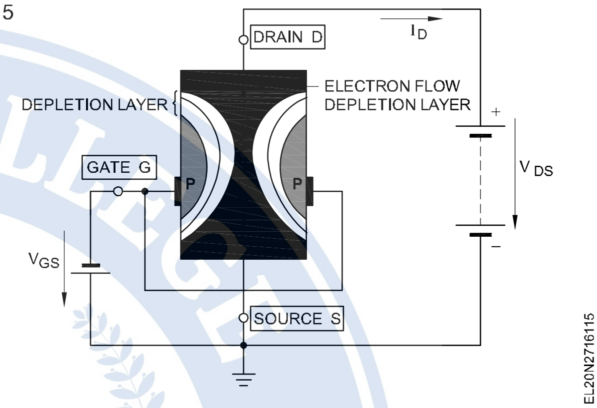
In simple terms, this means that the main current in a bi-polar transistor (collector current) is controlled by the base current.

Filed effect transistor is a voltage controlled device

This means that the voltage at the gate(similar to base of a bi-polar transistor) controls the main current.

In addition to the above, in a bi-polar trasistor (NPN or PNP), the main current always flows through N-doped and P-doped semiconductor materials. Whereas, in a Field effect transistor the main current flows either only through the N-doped semiconductor or only through the P-doped semiconductor as in Fig 5.

Fig 5



If the main current flow is only through the N-doped material, then such a FET is referred as a N-channel or N-type FET. The current through the N-doped material in the N-type FET is only by electrons.

If the main current flow is only through the P-doped material, then such a FET is referred as a P-channel or P-type FET. The current through the P-doped material in the P-type FET is only by Holes.

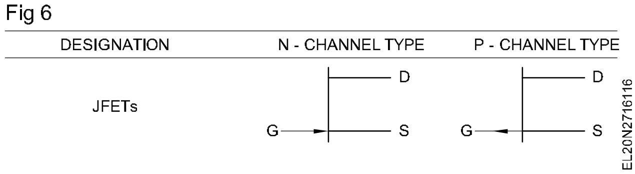
Unlike in bipolar transistors in which the main current is both by electrons and holes, in contrast in FETs depending on the type(P or N type) the main current is either by electrons or by holes and never both. For this reason FETs are also known as Unipolar transistors or Unipolar device.

There are a wide variety of FETs. In this lesson one of the fundamental types called as Junction Field Effect Trasistor (JFET) is discussed.

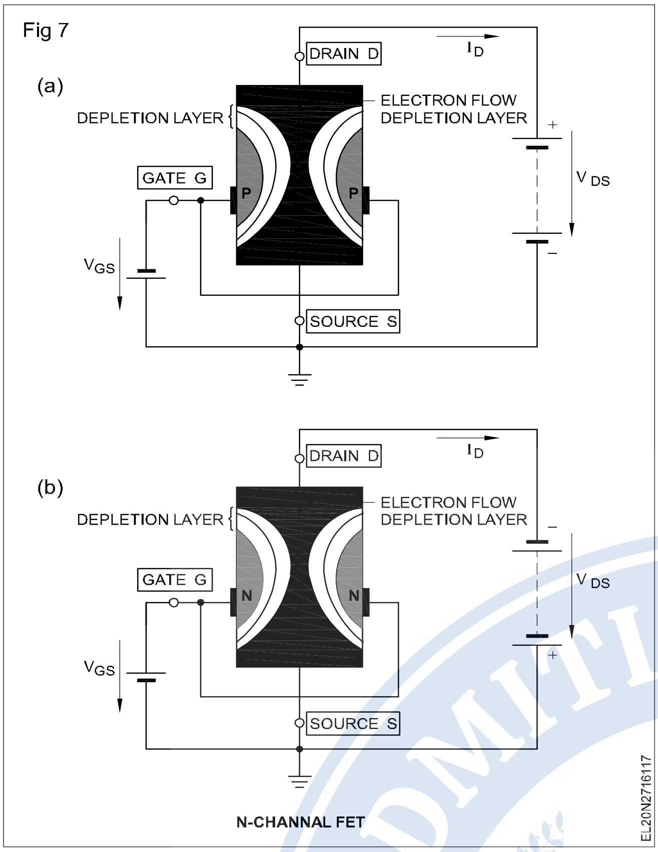
Junction Field effect Transistor(JFET)

It is a three terminal device and looks similar to a bi-polar transistor. The standard circuit symbols of N-channel and P-channel type FETs are shown in Fig 6.

Fig 6



The internal diagram of a N-channel FET is shown in Fig 7.



FET notation listed below are essential and worth memorizing,

1 **Source terminal:** It is the terminal through which majority carriers enter the bar(N or P bar depending upon the type of FET).

2 **Drain terminal:** It is the terminal through which majority carriers come out of the bar.

3 **Gate terminal:** These are two internally connected heavily doped regions which form two P-N junctions.

4 **Channel:** It is the space between the two gates through which majority carriers pass from source to drain when FET is working(on).

Working of FET

Similar to Biploar transistors, the working point of adjustment and stabilization are also required for FETs.

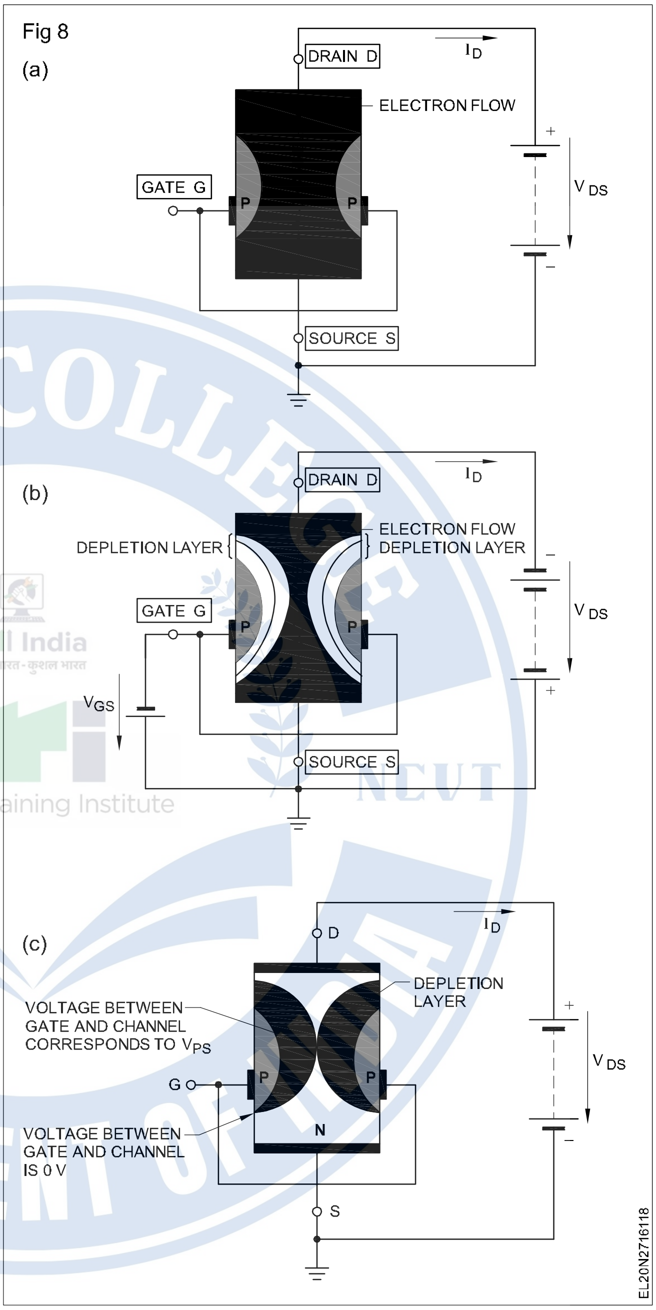
Biasing a JFET

- Gates are always reverse biased. Therefore the gate current I_G is practically zero.

- The source terminal is always connected to that end of the supply which provides the necessary charge carriers. For instance, in an N-channel JFET source terminal S is connected to the negative of the DC power supply. And, the posive of the DC power supply is connected to the drain terminal of the JFET.

Whereas in a P channel JFET, Source is connected to the positive end of the power supply and the drain is connected to the negative end of the power supply for the drain to get the holes from the P-channel where the holes are the charge carriers.

Let us now consider an N channel JFET, the drain is made positive with respect to source by voltage V_{DS} as shown in Fig 8a. When gate to source voltage V_{GS} is zero, there is no control voltage and maximum electron current flows from source(S) - through the channel - to the drain(D). This electron current from source to drain is referred to as Drain current, I_D.



When gate is reverse biased with a negative voltage(V_{GS} negative) as shown in Fig 8b, the static field established at the gate causes depletion region to occur in the channel as shown in Fig 8b.

This depletion region decreases the width of the channel causing the drain current to decrease.

If V_{GS} is made more and more negative, the channel width decreases further resulting in further decrease in drain current. When the negative gate voltage is sufficiently high, the two depletion layers meet and block the channel cutting off the flow of drain current as in Fig 8c. This voltage at which this effect occurs is referred to as the Pinch off voltage, V_P.

Thus, by varying the reverse bias voltage between gate and source($-V_{GS}$), the drain current can be varied between maximum current (with $-V_{GS}=0$) and zero current(with $-V_{GS}$=pinch off voltage). So, JFET can be referred as a voltage controlled devices.

P channel JFET operates in the same way as explained above except that bias voltages are reversed and the majority carrier of channel are holes.

Advantages of FET

1 Since they are voltage controlled amplifier this makes their input impedence very high

2 They have a low noise output. This makes them useful as preamplifiers where the noise must be very low because of high gain in the following stages.

3 They have better linearity

4 they have low inter electrode capacity.

Typical applications of JFET

One very important characteristic of JFET is its very high input impedence of the order of 10^9 ohms. This characteristic of FET, has made it very popular at the input stage of a majority of electronic circuits.

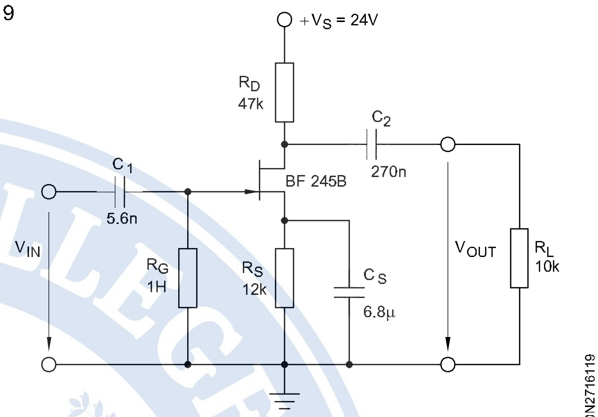
As discrete components FETS are mainly used in,

- DC voltage amplifiers
- AC voltage amplifiers(input stage amplifiers in HF and LF ranges)
- Constant current sources
- Integrated circuits of both analog and especially in Digital technology.

1 FET AC voltage amplifier

In the circuit at Fig 9, the amplification is determined by the design. it can be varied within certain limits of the drain resistance and the source resistance are made variable. Potentiometer can be connected in series for this purpose.

Fig 9



CIRCUIT DIAGRAM OF THE CALCULATED A.C VOLTAGE AMPLIFIER

Power supplies-troubleshooting

Objectives: At the end of this lesson you shall be able to
- **list the initial activities involved in troubleshooting**
- **list the three general steps involved in troubleshooting**
- **list and explain the two popular methods of troubleshooting**
- **list the possible defects in a power supply.**

Introduction

Troubleshooting in any equipment or in a circuit involves the following activities:

– To identify the exact nature of the problem.

– To identify the section causing the problem.

– To isolate and arrive at the exact cause(s).

– To confirm the causes by necessary tests.

– To replace the problem-causing parts.

– To re-test and confirm the satisfactory working.

The following are the general steps involved in troubleshooting.

i Physical and sensory tests

– Look for the most common physical faults, such as broken wires, cracked circuit boards, dry solders and burnt out components.

– Smell for hot or burning components.

– Feel with the fingers for unduly hot components.

ii Symptom diagnosis

Learn the operation of the system to be repaired with the help of its block diagram and its input and output specifications.

Observe the symptoms produced by the defective system, and determine which section or function would produce the symptoms.

iii Testing and replacing defective components

When the probable defective section has been diagnosed, check the probable components in that section of the circuit that are most likely to go defective in the order given below:

Components should be checked in the order given below because that is the order in which they fall in most cases.

– **Active high power components:** For example, components such as transistors, ICs, and diodes. High power devices are physically large in size and are used for handling the high power, generally in output circuits.

– **Active low power components:** These are the same as in (a) but are physically small and can handle smaller amounts of power.

– **High voltage/power passive components:** Such components are resistors, capacitors, transformers, coils, etc. which handle large amounts of voltage/ power. They are found in power supplies and output circuits.

– **Low power passive components:** These are the same as in (c) but are physically smaller and handle comparatively less power and are low in value (ohm, microfarad, microhenry, etc.)

> **Note: This procedure may not turn out to be true always. Hence, do not attempt to replace common sense and meter measurements with the procedure.**

While troubleshooting any electronic system, two main methods are generally adopted. They are:

Step-by-step method of troubleshooting: This approach is preferred by the beginners. In this approach, the problem causing part or section is identified by testing the parts or sections from the beginning to the end as shown in Fig 1.

Although this approach may take more time, this is the most suited approach for the beginners.

Shortcut or logical approach method of troubleshooting: This method is used by the experienced servicing people. In this method, the problem causing part or section is identified from the nature of the problem symptom. Divide and conquer procedure is adopted to arrive at the exact cause. This method takes less time comparatively.

Troubleshooting power supplies: All electronic systems can be broken down into blocks, generally based on their function. Fig 1 shows the various blocks of a simple power supply. Each block has a particular function to perform.

Before carrying out the troubleshooting of power supplies, the first thing to be done is to isolate the load connected to the power supply. This is because the connected load itself may be the cause of the problem as shown in the Fig 2.

Once it is confirmed that the power supply has the same defect even with the load disconnected, you can follow either the step-by-step approach or the logical approach to troubleshoot the power supply.

Step-by-step approach to troubleshoot power supply: In the step-by-step approach of troubleshooting, the various blocks of the power supply is in Fig 1 and the components of the blocks are checked one by one, starting with block 1 and in steps as given below.

Fig 1

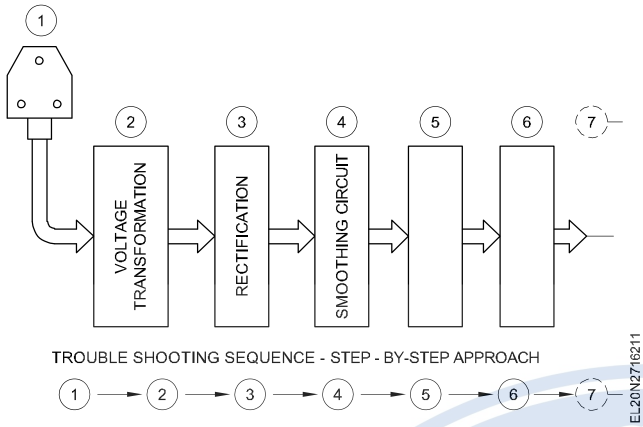
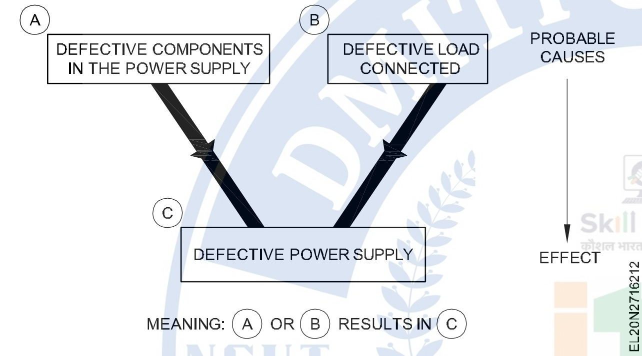


Fig 2



Step 1: Confirm the presence and satisfactory level of the mains supply from which the power supply is powered.

Step 2: Switch the power ON and test and note down the exact nature of the problem. Although the nature of the problem has been already told, it is essential to confirm the exact nature of the problem. This is because, in a real life situation, the customer may not be a technical person to inform the exact nature of the problem.

Step 3: Carry out physical and sensory tests.

Step 4: Trace the circuit to identify any wrong polarity connections.

Step 5: Remove the power cord of the power supply from the mains and test the power cord.

Step 6: Test the transformer.

Step 7: Test the diode(s) of the rectifier section.

Step 8: Test the capacitor(s) of the filter section.

Step 9: Test the bleeder resistor, surge resistor and other resistors, if any.

Step 10: Test the output indicator lamps/LEDs.

After completing all the above steps, from the defective components identified, analyze the root cause for the problem and confirm that the cause will not reoccur if the identified components are replaced.

Step 11: Replace the identified defective component(s).

Step 12: Switch the power ON and test the power supply, first without load, and then connecting it to the load.

Power control circuit using SCR,DIAC,TRIAC & IGBT

Objectives : At the end of this lesson you shall be able to
- **explain the construction and working of SCR,DIAC,TRIAC & IGBT**
- **explain power control circuits using SCR**
- **explain power control circuit using DIAC & TRIAC**
- **explain the construction and using of IGBT.**

Introduction to power electronics devices

Industrial electronics is concerned primarily with electronics applied to industries such as industrial equipments, controls and processes. An important application of electronics in industries is in controlling of machinery.

In communication electronics, domestic & entertainment electronics, generally, the electronic devices operate with currents in the order of Microampere to Milliampere. For industrial applications, most frequently, devices are required to handle currents in the range of ampere to several thousands of ampere. This, therefore calls for high power electronic devices. One such high power electronic device frequently used in industrial electronic application is the SCR,TRIAC,IGBT and DIAC for associate triggering circuits.

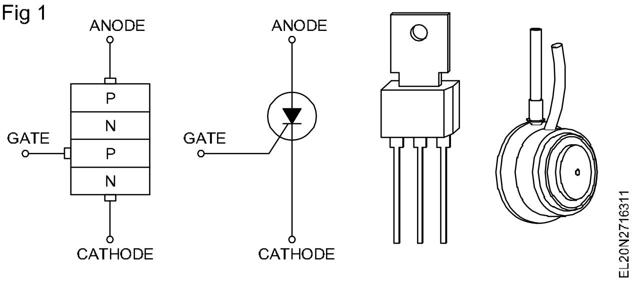
This devices can be used to run, dc motors from an ac power source, control power tool speed,also to control motor speeds of small appliances like, mixers and food blenders, illumination control, temperature control and so on.

Silicon Controlled Rectifier (SCR)

Before Silicon controlled rectifiers were invented(1956), a glass tube device called Thyratron was used for high power applications. Silicon Controlled Rectifier (SCR) is the first device of the thyristor family. The term thyristor is coined from the expression Thyratron-transistor. SCR is a semiconductor device. SCR does the function of controlled rectification. Unlike a rectifier diode, SCR has an additional terminal called the gate which controls the rectification(gated silicon rectifier).

The basic principle application of SCRs is to control the amount of power delivered to a load(motor, lamp, etc.,).A rectifier diode will have one PN junction. SCRs on the other hand will have two PN junctions (P-N-P-N layers). Fig 1 shows the electrical symbol, basic construction and a typical SCR packages.

Fig 1



Basic operation of SCR

When a gate direct current is applied to the gate terminal, forward current conduction commences in the SCR(latched into conduction). When the gate current is removed, the forward current through the SCR **does not cut-off**. This means, once the SCR is latched into conduction, the gate loses control over the conduction. The current through the SCR can be turned off only by reducing the current through it(load current) below a critical value called the **Holding current**.

Fig 2 shows how an SCR can be gated into conduction or turned off.

In Fig 2a, with switched S1 open the SCR is in OFF state and no current is flowing through the load.

In Fig 2b, when S_1 is closed, a small gate current(around 1/1000 or less compared to load current) turns-ON (fires) the SCR. A heavy load current starts flowing through the SCR and load R_L.

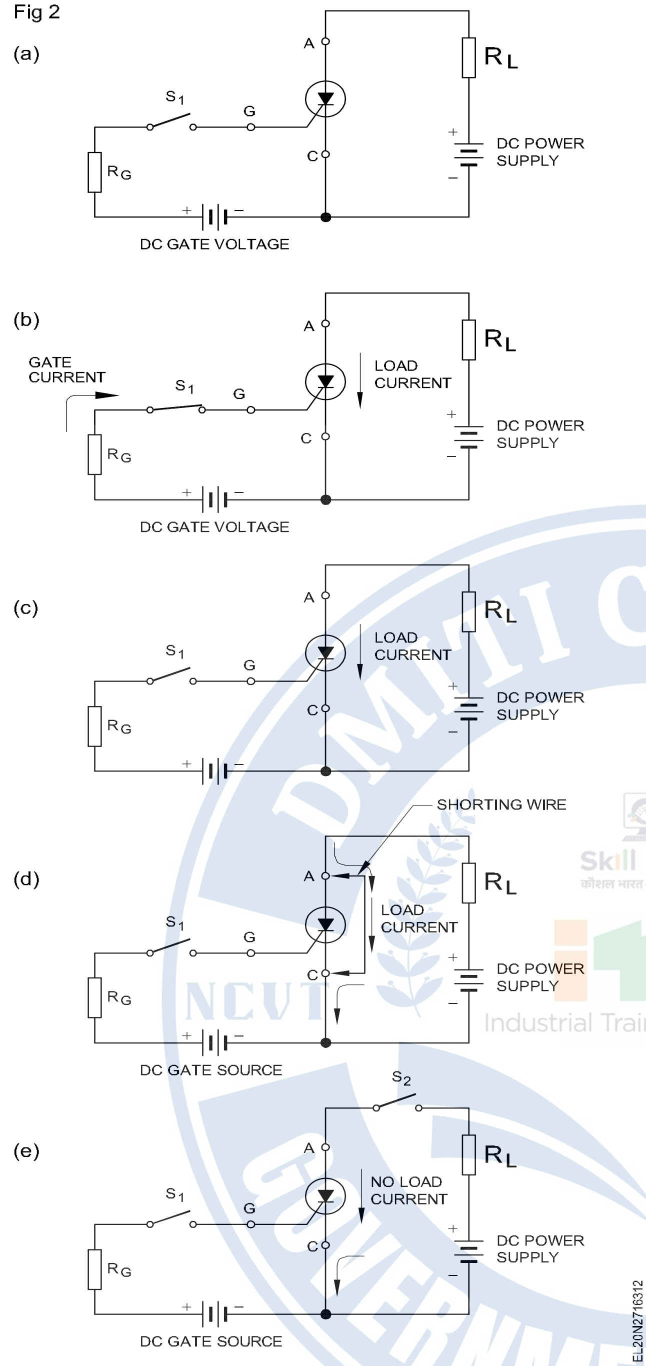
In Fig 2c, when S_1 is opened, gate current becomes zero. This will have no effect on the current through the SCR and the heavy load current continues to flow through the SCR in the DC gate supply.

In Fig 2d, if a shorting wire is placed across the anode and the cathode terminals, the current though the SCR gets by-passed and all the current starts flowing through the shorted wire instead through the SCR. This means the current through the SCR is reduced below the rated holding current(minimum current required through SCR to keep it latched). This turns-OFF the SCR. Even when the shorting wire is removed the SCR remains to be in OFF state.

Fig 2e shows an alternative method of turning-OFF the SCR. In this instead of shorting the anode and cathode terminals of the SCR, the load current is cut-off by opening the Switch S_2. This reduced current through the SCR below the holding current and thus turns- OFF the SCR. Once the SCR is turned_OFF, the SCR does not turn-ON even if the switch S_2 is closed. To make the SCR fire again, with the switch S_2 closed, the gate current should be made to flow by closing the switch S_1.

Since the SCR does not conduct in the reverse direction, the anode of the SCR should always be positive with respect to cathode for conduction.

Fig 2



Important features of SCR,

- A very small gate current will control the switching OFF a large load current.

SCR operation with AC supply

Operation of SCR with AC circuit is similar to SCR operation . Fig 3 illustrates working of SCR in AC control circuits.

The SCR gate circuit consists of resistor R_1, potentiometer R_2 and silicon diode D_1. Resistors R_1 and R_2 act as a variable voltage divider. By adjusting the value of R_2 the gate current I_G can be suitably modified. Diode D_1 prevents negative voltage being applied to the gate when the ac supply is in the negative half cycle.

[X] During the +ve half cycle of the AC power source, as the positive half cycle voltage increases, the gate current I_G increases. When I_G reaches the trigger level, SCR fires and allows current I_L to flow through the load.

From this point onwards the SCR impedance is low and current I_L continues to flow throughout the +ve half cycle even though the gate current reduces below the trigger value(recall: once SCR is fired it continues to conduct even if the gate trigger is decreased or removed).

[Y] At the end of the +ve half cycle of AC power source, the +ve voltage drops to zero and SCR ceases to conduct(recall: one method of turning off SCR is to reduce the current through the SCR to below the holding current. This can be done by either opening the load circuit or reducing the supply to zero). Thus the SCR remains in off state throughout the negative half cycle.

Cycle [X] and [Y] repeats and current through the load flows in pulses as in Fig 3d.

Fig 3b,3c shows the voltage wave forms of source and gate voltage.

If the value of R_2 is varied, the point at which SCR triggers also varies changing the firing point shown in Fig 3d. In the circuit shown in Fig 3a, the firing of SCR can be adjusted any where between almost 180 degrees(maximum) to 90 degrees(minimum).

This simple AC control circuit shown in Fig 3a using SCR can be used to control the current through the load during the +ve half cycle of AC. During the -ve half cycle the SCR remains turned off. Thus, SCR can be used as an excellent switching device in AC control circuits.

The circuit in Fig 3 is useful only in limited applications such as temperature control of soldering iron etc.,

Power control using SCR

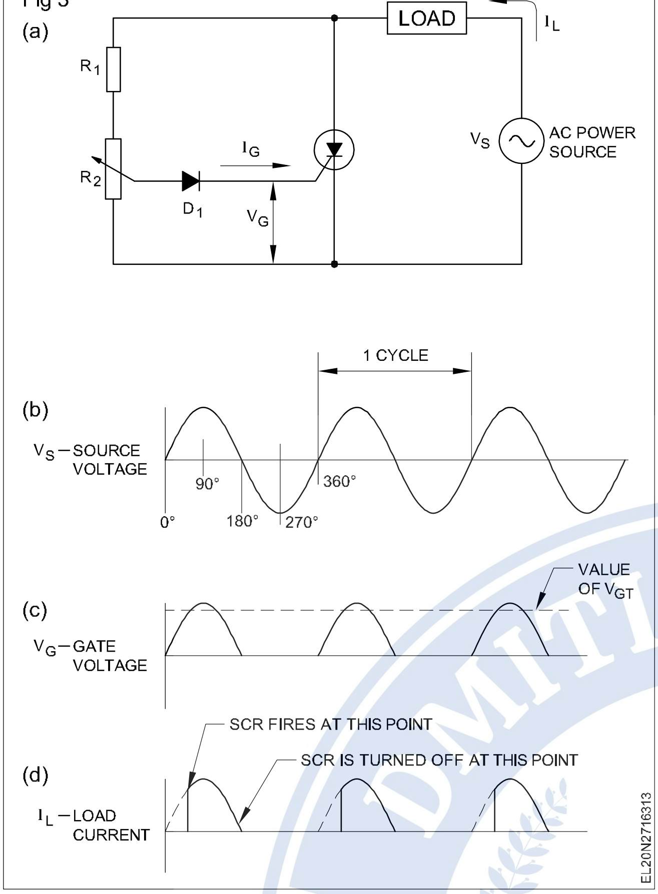
- DC Motor speed control
- AC Motor speed control
- Regulated DC power supplies
- Power control
- Circuit breakers
- Time delay circuits
- Soft start circuits
- Pulse, logic and digital circuits and so on.

Speed control of DC motors: In this Related Theory information only brief outline of power circuits is discussed. Due variation of motor load currents, inductance effect in winding, the practical circuit should be modified to suit the requirement. DC motors consists of field winding and armature winding. The speed of DC motors can be varied by two methods,

1 controlling the field current

2 controlling the armature voltage

Fig 3



The first method is used for controlling the motor speed above the rated speed of the motor. The second method is used for controlling the motor speed below the rated speed of the motor.

Power circuit using TRIAC and DIAC

TRIAC or SCR for speed control of AC motors: Compared to SCR, Triac is most popular and works satisfactorily for lamp dimmer circuits and speed control of universal motors. Although both SCR and TRIAC can be used to phase control and vary the current through the lamp or motor, TRIAC being a full wave device, symmetrically controls the phase of both half cycles of the applied AC.

The resultant full wave current format then produces smooth lamp or motor operation that can be attained from the half wave rectification using SCRs. This is particularly noticeable during low/dim light requirement or low speed for motors.

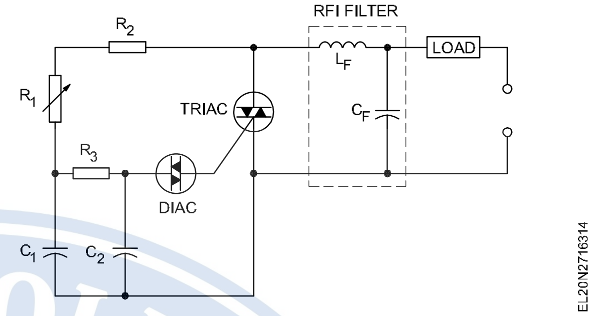
The circuit at Fig 4 shows a TRIAC phase control circuit for controlling the brightness of the lamp or speed of universal motors.

The load shown in circuit at Fig 4 is a general load rather than a motor symbol because, this circuit can also be used for light dimmers and for the control of heaters.

This circuit features a double time constant phase-shift network. This reduces hysteresis in firing of the triac, thereby making the manual adjustment of dimmer operation or control off speed more repeatable.

The DIAC used as trigger device, adds to the reliability of the circuit. The elemental low-pass filter comprising L_F and C_F attenuates much of the radio-frequency interference (RFI) that gets generated and tries to get into the power line. This high frequency RF1 energy is generated by the extremely rapid turn-on time of the TRIAC. Which should be eliminated to avoid radio interference due to higher frequency content of the rectified wave form Otherwise, the frequency may interfere with reception at nearby places or in the main line circuit elsewhere.

Fig 4



Lamp dimmers: Lamp dimmer is a circuit which controls as AC power supplied to an incandescent lamp thereby controlling the intensity of light emitted by the lamp from almost zero to full brilliance.

Conventional and soft-start dimming of incandescent lights: Advantage of semi-conductor based light dimmers over the auto transformer connected light dimmers

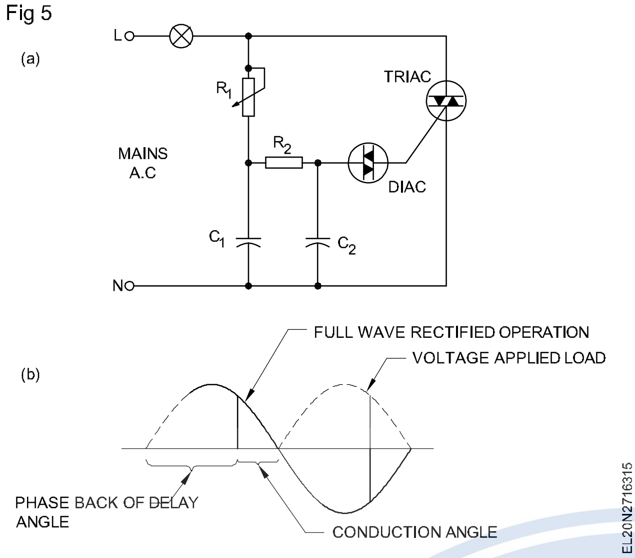
Old technology light dimmers used high wattage rheostats adjustable auto-transformers or saturable reactors, which were large, expensive generated considerable heat and power loss. Present day semi-conductor light dimmers have overcome these difficiencies and have therefore become very popular for many applications.

Modern semi-conductor dimmers are inexpensive, reliable, small generate little heat, and are easy to control remotely. These properties have not only permitted semi-conductor dimmers to supersede older types in theatres and auditoriums with excellent results, but have made dimmers practical for built-in home lighting, table and floor lamps, projection equipment and other uses.

Semi-conductor based light dimmers: Two light dimmers for incandescent light bulbs are discussed below. Both these dimmer circuits control light intensity by adjusting the angle of conduction of a triac connected in series with the bulb. The first dimmer uses a very simple circuit that is ideal for highly compact applications requiring minimum cost. The second dimmer features soft starting for low in rush current and consequent long lamp life. Soft start lamp dimmers are especially useful with expensive lights with short lives, such as projection lamps and photographic bulbs.

Simple light dimmer: The circuit shown in Fig 5 is a wide range light dimmer using very few parts. The circuit can be operated using any mains supply source (240V, 50Hz) by choosing appropriate value of circuit components. The circuit can control upto 1000watts of power to incandescent bulbs.

Fig 5

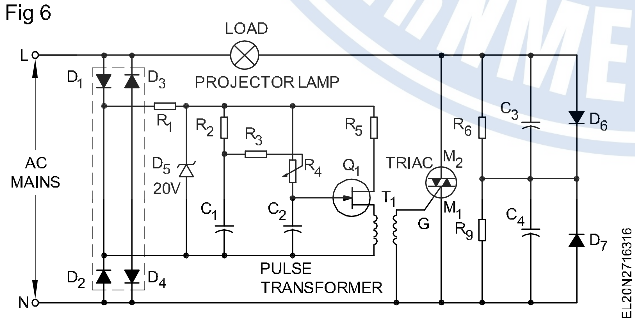


The power to the bulbs is varied by controlling the conduction angle of Triac. Many circuits can be used for phase control, but the single Triac circuit used is the simplest and is therefore chosen for this particular application.

The control circuit for this Triac must function as shown in Fig 5b. The control circuit must create a delay between the time voltage is applied to the circuit and the time it is applied to the load. The Triac is triggered after this delay and conducts current through the load for the remaining part of each alteration. This circuit can control the conduction angle from 0° to about 170° and provides better than 97% of full power control.

Light dimmer with soft-start option: The circuit at Fig 6 is a light dimmer with soft start option. Soft starting is desirable because of the very low resistance of a cold lamp filament compared to its hot resistance. At the time of initial switching ON, the low resistance of the lamp causes very high inrush currents which leads to short filament/ lamp life. Lamp failures caused by high inrush currents is eliminated by the soft start feature, which applies current to the bulb slowly enough to eliminate high surges.

Fig 6



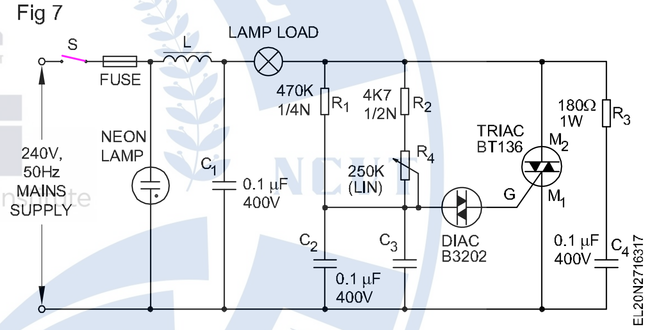
Operation of the circuit at Fig 6 begins when voltage is applied to the diode bridge consisting of D_1 through D_4. The bridge rectifies the input and applies a DC voltage to resistor R_1 and zener diode D_5. The zener provides a constant voltage of 20volts to unijunction transistor Q_1, except at the end of each alternation when the line voltage drops to zero. Initially the voltage across capacitor C_1 is zero and capacitor C_2 cannot charge to trigger Q_1. C_1 will begin to charge, but because the voltage is low, C_2 will have adequate voltage to trigger Q_1 only near the end of the half cycle. Although the lamp resistance is low at this time, the voltage applied to the lamp is low and the inrush current is small. Then the voltage on C_1 rises, allowing C_2 to trigger Q_1 earlier in the cycle.

At the same time the lamp is being heated by slowly increasing applied voltage and by the time the peak voltage applied to the lamp has its maximum value, the bulb has been heated sufficiently so that the peak inrush current is kept to a reasonable value.

Resistor R_4 controls the charging rate of C_2 and provides the means to dim the lamp. Power to the load can be adjusted manually by varying the resistance of R_4. T1 is a pulse transformer. In addition to supplying the trigger to Triac, this transformer isolates the high current load circuit from the low power triggering circuit (gate isolation methods for Triac is discussed in further paragraphs).

A simple lamp dimmer cum Universal motor speed controller: In the lamp dimmer cum universal speed controller circuit is in Fig 7, a Triac is used as control device. Phase control technique is used to control conduction angle of the triac which inturn control the power fed to the lamp.

Fig 7



A lamp L is connected in series with AC mains supply to the Triac. The trigger pulses to Triac gate is given through Diac. The Diac is triggered at the same breakover voltage level (30V) during both positive and negative half cycles.

Potentiometer R_4 provides the facility for varying the intensity of light or speed of a universal motor.

Snubber circuit: One problem with the Triac control is the sudden application of reverse voltage across the triac immediately after it has stopped conduction. This is a serious problem when the load is a highly inductive as in motors. This reapplied voltage denoted by dv/dt can trigger-on (unwanted or false triggering) the device losing the phase control.

To avoid this false triggering, an R and C series network is placed across the circuit R_4 and C_4 as shown in Fig 7. This RC network slows down the rate of rise of voltage applied across the Triac. This RC circuit connected across the Triac circuit is called snubber circuit.

The inductance L and capacitor C_1 forms a low pass filter to substantially reduce the radio frequency interference (RF) generated by the rapid turn-on and turn-off the triac.

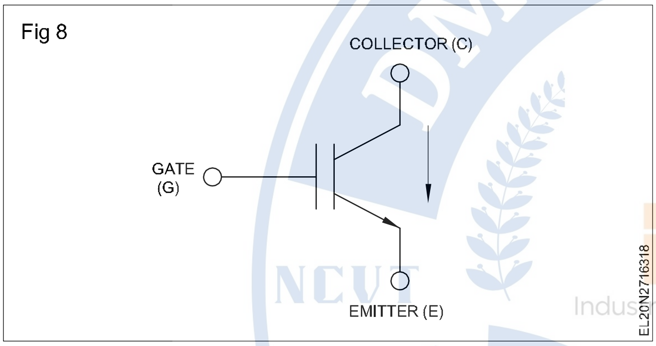
Fan speed regulator: The lamp dimmer circuit at Fig 7 can be used equally well as a fan speed regulator. The only change to be made is to connect a fan in place of the lamp shown in the circuit at Fig 7. The speed can be varied from almost zero to full speed by just rotating POT R_3.

IGBT (Insulated Gate Bipolar Transistor)

The insulated Gate Bipolar Transistor (IGBT) is the latest device is power electronics. It is obtained by combining the properties of BJT and MOSFET. We know that BJT has lower on - state losses for high values of collector current. But the drive requirement of BJT is little complicated. The drive of MOSFET is very simple (i.e only voltage is to be applied between gate and source). But MOSFET has high on - state losses.

The gate circuit of MOSFET and collector emitter circuits of BJT are combined together to form a new device. This device is called IGBT. Thus IGBT has advantages of both the BJT and MOSFETs. Fig 8 shows the symbol of IGBT. Observer that the symbol clearly indicates combination of MOSFET and BJT.

Fig 8



The IGBT has three terminals : Gate (G), collector (C) and emitter (E), Current flows from collector to emitter whenever a voltage between gate and emitter is applied. The IGBT is said to have turned 'ON'. When gate emitter voltage is removed, IGBT turns - off. Thus gate has full control over the conduction of IGBT. When the gate to emitter voltage is applied, very small (negligible) current flows. This is similar to the gate circuit of MOSFET. The on - state collector to emitter drop is very small like BJT.

Structure of IGBT

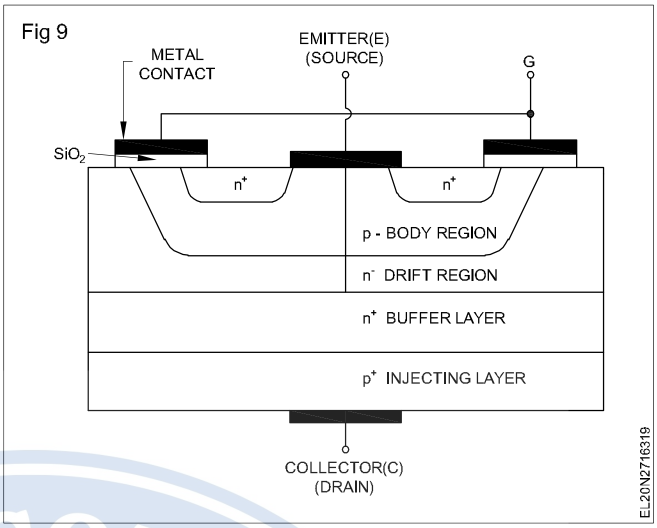
The structure of IGBT is similar to that of MOSFET. Fig 9 show the vertical cross section of IGBT . In this structure observe that there is additional P+ layer. This layer is collector (Drain) of IGBT.

This P+ injection layer is heavily doped. It has the doping intensity of 10^{19} per cm^3. The doping of other layer is similar to that of MOSFET. n+ layers have 10^{19} per cm^3. P-type body region has doping level of 10^{16} per cm^3. The n- drift region is lightly doped (10^{14} per cm^3).

Punch through IGBT

The n+ buffer layer is not necessary for the operation of IGBT. The IGBTs which have n+ buffer layer are called punch through IGBTs. Such IGBTs have asymmetric voltage blocking capabilities. Punch through IGBTs have faster turn-off times. Hence they are used for inverter and chopper circuits.

Fig 9



Non - punch through IGBT

The IGBTs without n+ buffer layer are called non-punch through IGBTs. These IGBTs have symmetric voltage blocking capabilities. These IGBTs are used for rectifier type applications.

Operation of IGBT

When $V_{GS} > V_{GS}$(threshold), then the channel of electrons is formed beneath the gate as in Fig 10. These electrons attract holes from p+ layer. Hence, holes are injected from p+ layer into n- drift region. Thus hole / electron current starts flowing from collector to emitter. When holes enter p-type body region, they attract more electrons from n+ layer. This action is exactly similar to MOSFET.

Fig 10

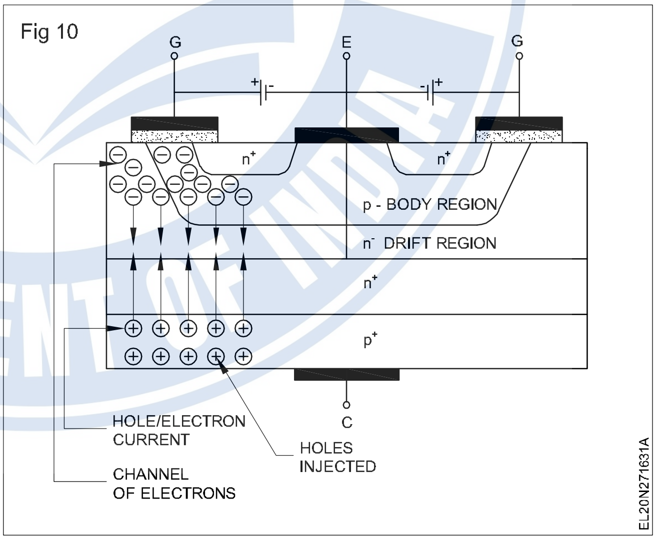
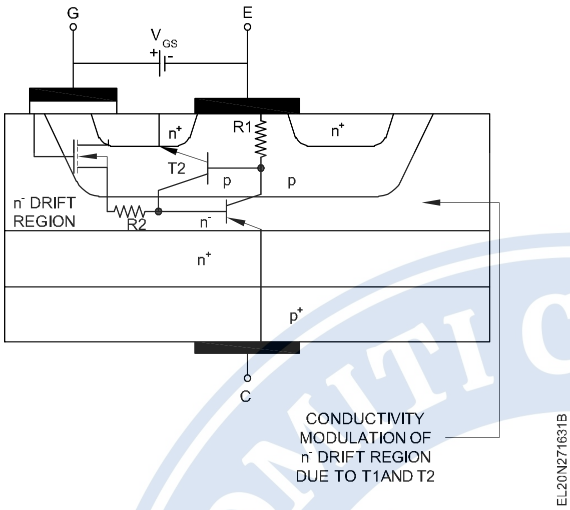


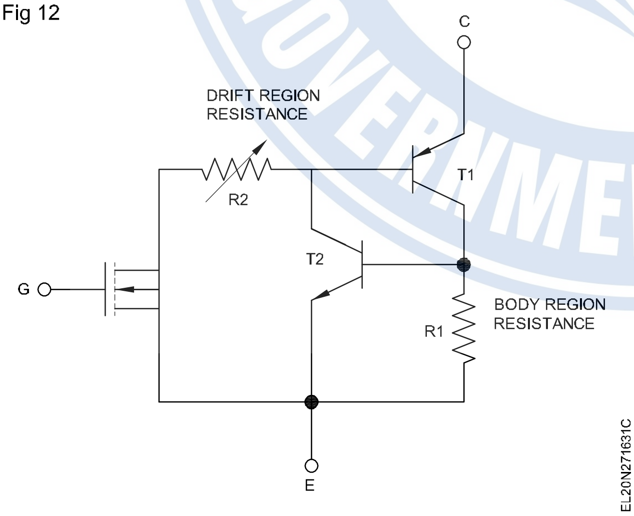
Fig 11 shows the structure of IGBT showing how internal MOSFETs and transistors are formed. The MOSFET is formed with input gate, emitter as source and n- drift region as drain. The two transistors T_1 and T_2 are formed as in Fig 11. The holes injected by the P+ injecting layer go to the n- drift region. This n- drift region is base of T_1 and collector of T_2. The holes in the n- drift region further go to the p - type body region, which is connected to the emitter. The electrons from n+ region (which is emitter) pass through the transistor T_2 and further in the n- drift region. Thus holes and electrons are injected in large amounts in n- drift region. This reduces the resistance of the n- drift region. This is called conductivity modulation of n- drift region. Note that such conductivity modulation does not exist in MOSFET. The connection of T_1 and T_2 is such that large amount of hole/electrons are injected in n- drift region.

Fig 11



The action of T_1 and T_2 is like SCR which is regenerative. The gate serves as trigger for T_1 through internally formed MOSFET. Fig 12 shows the equivalent circuit. In this figure observe that when gate is applied ($V_{GS} > V_{GS}(th)$), the internal equivalent MOSFET turns ON. This gives base drive to T_1. Hence T_1 starts conducting. The collector of T_1 is base of T_2. Therefore T_2 also turns ON. The collector of T_2 is base of T_1. Thus the regenerative loop begins and large number of carriers are injected in n- drift region. This reduces the on- state loss of the IGBT just like BJT. This happens due to conductivity modulation of n- drift region.

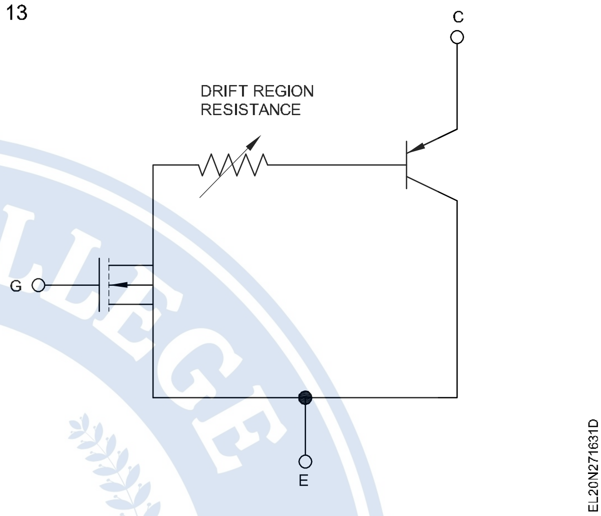
Fig 12



When the gate drive is removed, the IGBT should turn-OFF. When gate is removed, the induced channel will be vanished and internal equivalent MOSFET will turn-OFF. Hence T_1 will turn -OFF if T_2 turns-OFF T_2 will turn - OFF if the p- type body region resistance R_1 is very very small. Under such situation, its base and emitter will be virtually shorted. Hence T_2 turns - OFF. Therefore T_1 will also turn - OFF. Hence structure of IGBT is organizes such that body region resistance (R_1) is very very small.

If R_1 is very very small, than T_2 will never conduct and the equivalent circuit of IGBT will be as in Fig 13. IGBTs are thus different than MOSFETs because of conduction of current from collector to emitter. For MOSFETs, on state losses are high since resistance of drift region remains same. But in IGBTs, resistance of drift region reduces when gate drive is applied. This resistance reduces because of P+ injecting region. Hence, on state loss of IGBT is very small.

Fig 13



Merits, Demerits and Applications of IGBT

Merits of IGBT

1 Voltage controlled device. Hence drive circuit is very simple.

2 On - state losses are reduced.

3 Switching frequencies are higher than thyristors.

4 No commutation circuits are required.

5 Gate have full control over the operation of IGBT

6 IGBTs have approximately flat temperature coefficient.

Demerits of IGBT

1 IGBTs have static charge problems.

2 IGBTs are costlier than BJTs and MOSFETs.

Applications of IGBTs

1 AC motor drives, i.e. inverters.

2 DC to DC power supplies, i.e choppers

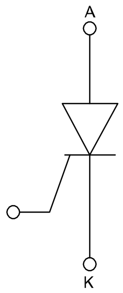
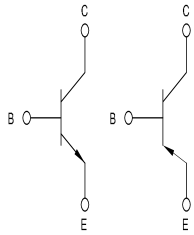
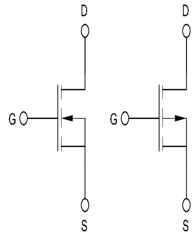
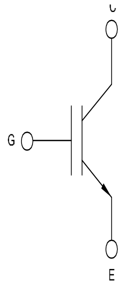
3 UPS systems.

4 Harmonic compensators.

Comparison of Power Devices

The power devices can be compared on the basis of switching frequency, gate drive circuit, power handling capacity etc. Table 1 shows the comparison of SCR, BJT, MOSFET and IGBT.

Table 1

S.No.	Parameter	SCR	BJT	MOSFET	IGBT
1	Symbol				
2	Triggered i.e latching or linear	Triggered or latching device	Linear trigger	Linear trigger	Linear trigger
3	Type of carriers in device	Majority carrier device	Bipolar device	Majority carrier device	Majority carrier device
4	Control of gate or base	Gate has no control once turned on	Base has full control control	Gate has full control	Gate has full control
5	On-state drop	< 2 Volts	< 2 Volts	< 4-6 Volts	< 3.3 Volts
6	Switching frequency	500 Hz	10 kHz	up to 100 kHz	20 kHz
7	Gate drive	Current	Current	Voltage	Voltage
8	Snubber	Unpolarized	Polarized	Not essential	Not essential
9	Temperature coefficient	Negative	Negative	Positive	Approximately flat, but positive at high current
10	Voltage and current ratings	10 kV/4kA	2 kV/4kA	1 kV/50 A	1.5 kV/400 A
11	Voltage blocking capability	Symmetric and	Asymmetric	Asymmetric	Asymmetric
12	Application	AC to DC converters, AC voltage controllers, electronic circuit breakers	DC to AC converters, induction motor drives, UPS, SMPS, Choppers	DC choppers, low powers, UPS, SMPS, brushless DC motor drives	DC to AC converters, AC motor drivers, UPS choppers, SMPS etc,.

Integrated circuit voltage regulators

Objectives: At the end of this lesson you shall be able to
- **explain integrated circuit**
- **state the classification of integrated circuit**
- **state the types of IC voltage regulators**
- **design voltage regulator for a required output voltage**
- **modify fixed voltage regulator to variable output regulator, circuit.**

IC introduction

Integrated circuit

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consists of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator. If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very small. although small, this will do the same job as that of the circuit wired using discrete components. Such miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as Integrated circuits or ICs. Integrated circuits (ICs) can consists of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way, say as voltage regulators or amplifiers or oscillators and so on.

Classification of Integrated circuits: Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry

i Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.

ii Digital ICs - Example: Digital gates, flip-flops, address etc.

2 Based on the number of transistors built into IC

i Small scale integration (SSI) - consists of 1 to 10 transistors.

ii Medium scale integration (MSI) - consists of 10 to 100 transistors.

iii Large scale integration (LSI) - 100 to 1000 transistors.

iv Very large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used

i Bipolar - carries both electron and hole current.

ii Metal oxide semiconductor (MOS) - electron or hole current.

iii Complementary metal oxide semiconductor (CMOS) - electron or hole current.

> **Note: The terms MOS and CMOS are another type of transistor and the trainees are requested to refer any standard electronic book for further reference.**

ICs are available in different packages and shapes. The usual packages are:

– dual in the packages DIP

– single in line package SIP and

– metal can packages.

ICs handling power more than IW are provided with heat sinks.

Advantages of integrated circuits over discrete circuit (Refer Table 1)

Table 1

Integrated circuits	Discrete circuits
1 All in a single chip	All are separate discrete components
2 Requires less space due to smaller size	Requires more space
3 Cheaper due to mass manufacture	Costlier due to individual components
4 More reliable due to specific construction	Less reliable
5 Easy for servicing and repairs	Difficult for servicing and repairs
1 ICs are manufactured for specific applications having specific circuits	Discrete devices can be used for any circuit
2 If any part of IC is defective, the entire IC is to be replaced	Only particular defective component requires replacement

When the advantages are considered, the disadvantages of IC are negligible. They are widely used for different applications such as voltage regulators, audio amplifiers, TV circuits, computers, industrial amplifiers etc. ICs are available in different pin configurations in different outlines suitable for different circuits.

Integrated circuit (IC) voltage regulators: The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

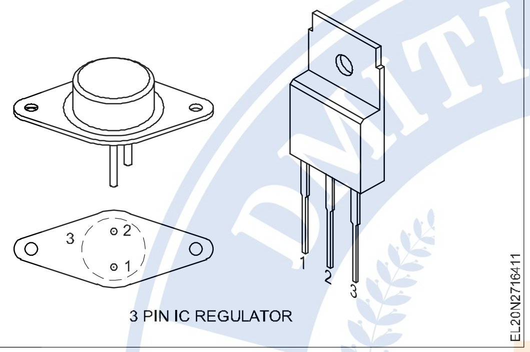
There are two types of voltage regulator ICs. They are,

– Fixed output voltage regulator ICs

– Adjustable output voltage regulator ICs.

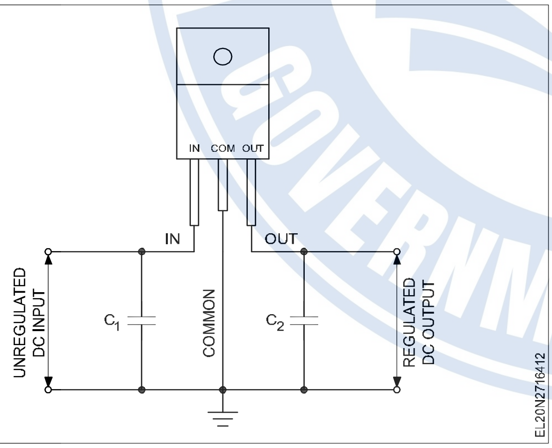
Fixed output voltage regulator ICs: The latest generation of fixed output voltage regulator ICs have only three pins as in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

Fig 1



These ICs consist of all those components and even more in the small packages in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as in Fig 2.

Fig 2



The reason behind using capacitor C_1 is when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC. Capacitor C_1 prevents setting up of such oscillations. Typical value of bypass capacitor C_1 range from 0.220μF to 1μF. It is important to note that C_1 should be connected as close to the IC as possible.

The capacitor C_2 is used to improve the transient response of the regulated output voltage. C_2 bypasses these transients produced during the ON/OFF time. Typical values of C_2 range from 0.1μF to 10μF.

Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9v, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

The most popular three terminal IC regulators are,

1 LMXXX-X series

Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series

Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in IC data book.

Specifications of three terminal IC regulators: For simplicity in understanding, let us consider the specification of a three terminal IC μA7812. The table 2 given below lists the specifications of μA7812.

Table 2

Parameter	Min.	Type.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current			350	mA
Drop out voltage			2.0	V
Ripple rejection	55	71		dB
Peak output current		2.2		A

Identification of output voltage and rated maximum load current from IC type number

– 78XX and 79XX series are 3 Terminal voltage regulators.

– All 78XX series are positive output voltage regulators

– All 79XX series are negative output voltage regulators

The term XX indicates the rated output regulated voltage.

Example

7805

Indicates positive output regulator — Indicates output voltage is +5V

7912

Indicates negative output regulator — Indicates output voltage is –12V

It is important to note that, different manufacturers of 78 XX/ 79XX series such as Fair Child (MA/Mpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated. ICs. One such scheme is given below.

78LXX - L indicates rated maximum load current as 100mA.

78MXX - M indicates rated a maximum load current as 500mA

78XX - Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.

78SXX - S indicates rated maximum load current is 2amp.

Example

μPC 78 M 15H

- μPC: Indicates positive Fair Child (Manufacturer's code)
- 78: Positive regulator
- M: Rated maximum load current is 500mA
- 15H: Indicates Regulated output voltage is 15V

LM 3XX series of 3 terminal voltage regulators: In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX → Fixed –ve voltage regulators.

LM340-X or LM340-XX → Fixed +ve voltage regulators.

Examples

LM 320 - 5

- LM: RCA (Manufacturer)
- 320: Fixed negative voltage regulator
- 5: Output voltage -5V

LM 340 - 15

- LM: RCA
- 340: Fixed positive voltage regulator
- 15: Output

Binary numbers, logic gates and combinational circuits

Objectives : At the end this lesson you shall be able to
- **explain the digital electronics principle and positional notation and weightage**
- **explain decimal to binary conversion, binary odometer**
- **explain hexadecimal number system**
- **convert decimal to hexa, hexa to decimal and BCD system**
- **explain logic gates principle - NOT, OR and AND gates with truth table**
- **explain combinational gates - NAND, NOR with truth table and logic pulser.**

Introduction

When we hear the word 'number' immediately we recall the decimal digits 0,1,2....9 and their combinations. Digital circuits do not process decimal numbers. Instead, they work with binary numbers which use the digits '0' and '1' only. The binary number system and digital codes are fundamental to digital electronics. But people do not like working with binary numbers because they are very long when representing larger decimal quantities. Therefore digital codes like octal, hexadecimal and binary coded decimal are widely used to compress long strings of binary numbers.

Binary number systems consists of 1s and 0s. Hence this number system is well suited for adopting it to the digital electronics.

The decimal number system is the most commonly used number system in the world. It uses 10 different characters to show the values of numbers. Because this number system uses 10 different characters it is called base-10 system. The base of a number system tells you how many different characters are used. The mathematical term for the base of a number system is radix.

The 10 characters used in the decimal number systems are 0,1,2,3,4,5,6,7,8,9.

Positional notation and weightage

A decimal integer value can be expressed in units, tens, hundreds, thousands and so on. For example decimal number 1967 can be written as 1967 = 1000 + 900 + 60 + 7. In powers of 10, this becomes.

				$1 \times 10^3 = 1000$
10^3	10^2	10^1	10^0	$9 \times 10^2 = 900$
				$6 \times 10^1 = 60$
1	9	6	7	$7 \times 10^0 = 7$
				1967

i.e. $[1967]_{10} = 1(10^3) + 9(10^2) + 6(10^1) + 7(10^0)$

This decimal number system is an example of positional notation. Each digit position has a weightage. The positional weightage for each digit varies in the sequence 10^0, 10^1, 10^2, 10^3 etc starting from the least significant digit.

The sum of the digits multiplied by their weightage gives the total amount being represented as shown above.

In a similar way, binary number can be written in terms of weightage.

To get the decimal equivalent, then the positional weightage should be written as follows.

$[1010]_2 = 1(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$

$= 8 + 0 + 2 + 0$

$[1010]_2 = [10]_{10}$

Any binary number can be converted into decimal number by the above said positional weightage method.

Decimal to Binary conversion

Divide the given decimal number by 2 as shown below and note down the remainder till you get the quotient - zero.

Example

	0		
2	1	1	→ MSB
2	2	0	
2	4	0	
2	8	0	
2	17	1	
2	34	0	→ LSB

The remainder generated by each division form the binary number. The first remainder becomes the LSB and the last remainder becomes the MSB of binary number.

Therefore, $[34]_{10} = [100010]_2$

Counting binary number

To understand how to count with binary numbers, let us see how an odometer (KM indicator of a car) counts with decimal numbers,

The odometer of a new car starts with the reading 0000.

After traveling 1KM , reading becomes 0001.

Successive KM produces 0002, 0003 and so on upto 0009

At the end of 10th KM , the units wheel turns back from 9 to 0, a tab on this wheel forces the tens wheel to advance by 1. That is why the number changed from 0009 to 0010.

That is, the units wheel is reset to 0 and sent a carry to the tens wheel. Let us call this familiar action as reset and carry. The other wheels of odometer also reset and carry. For instance, after covering 999KM , the odometer shows 0999.

After the next KM , the unit wheel resets and carries, the tens wheel resets and carries, the hundreds wheel resets and carries and the thousands wheel advances by 1 to get the reading 01000.

Binary odometer

Visualize a binary odometer, a device whose wheels have only two digits 0 and 1. When each wheel turns, it displays 0 then 1 and then back to 0 and the cycle repeats. A four digit binary odometer starts with 0000.

After 1km, it indicates - 0001.

The next km forces the units wheel to reset and sends carry. So the number changes to 0010.

The third km results in 0011.

After 4km, the units wheel resets and sends carry, the second wheel resets and sends carry and the third wheel advances by 1. Hence it indicates 0100.

Table below shows all the binary numbers from 0000 to 1111 equivalent to decimal 0 to 15.

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Addition of binary numbers

Sum	Carry
0 + 0 = 0	0
1 + 0 = 1	0
0 + 1 = 1	0
1 + 1 = 0	1 (one plus one is equal to zero with carry one)

Ex: 1

```
  1 0
+ 1 1
-----
1 0 1
```

Ex: 2

```
1 + 1 + 1 =  1
            + 1   (One plus one plus one is equal to one with carry one)
             10
            + 1
             11
```

Hexadecimal number system: In hexadecimal system there are 16 characters. They are 0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F where A=10, B=11, C=12, D=13, E=14, F=15 in decimal. In this system, the base is 16. This system is mainly used to develop programmes for computers.

For Example

$[23]_{16} = [35]_{10}$; $16^1 \times 2 + 16^0 \times 3 = 32 + 3 = 35$;

$[2C]_{16} = [44]_{10}$; $16^1 \times 2 + 16^0 \times 12 = 32 + 12 = 44$;

Decimal to hexadecimal conversions

The conversion of decimal to hexadecimal is similar to binary conversion. Only difference is that divide the decimal number successively by 16, and note down the remainder.

	Quotient	Remainder	
	0		
16	1	1	⟶ MSB
16	27	11 or B	
16	432	0	⟶ LSB

$[432]_{10} = [1B0]_{16}$

Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

Ex: $223A_{16} = 2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0$

$= 2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1$

$= 8192 + 512 + 48 + 10$

$= 8762_{10}$

BCD (Binary Coded Decimal)

Binary Coded Decimal (BCD) is a way to express each of the decimal digits with a binary code, since there are only ten code groups in the BCD system, it is very easy to convert between decimal and BCD. Because decimal system is used for read and write, BCD code provides an excellent interface to binary systems. Examples of such interfaces are keypad inputs and digital readouts.

8421 code

The 8421 code is a type of binary coded decimal (BCD), binary coded decimal means that each decimal digit, 0 through 9 is represented by a binary code of four bits. The designation 8421 indicates the binary weights of the four bits (2^3, 2^2, 2^1, 2^0). The ease of conversion between 8421 code numbers and the familiar decimal numbers is the main advantage of this code. All you have to remember are the ten binary combinations that represents the ten decimal digits as shown in the Table.

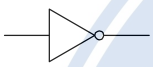
Decimal digit	0	1	2	3	4
BCD	0000	0001	0010	0011	0100
Decimal digit	5	6	7	8	9
BCD	0101	0110	0111	1000	1001

The 8421 code is the pre-dominant BCD code, and when we refer to BCD, we always mean the 8421 code unless otherwise stated.

Inverters (NOT Gate)

An inverter is a gate with only one input signal and one output signal. The output state is always the opposite of the input state. Logic symbol is shown in Fig 1.

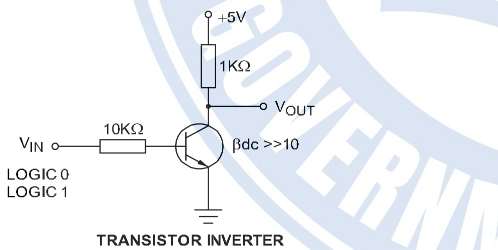
Fig 1



Transistor inverter

The Fig 2 shows the transistor inverter circuit. The circuit is a common emitter amplifier which works in saturation or in cut off region depending upon the input voltage. When V_{in} is in low level, say less than the transistor cut in voltage 0.6V in silicon type, the transistor goes to cut off condition and the collector current is zero. Therefore, V_{out} = +5V which is taken as high logic level. On the other hand, when V_{in} is in high level, the transistor saturates and $V_{out} = V_{sat}$ = 0.3V i.e low level.

Fig 2



The table summarizes the operation

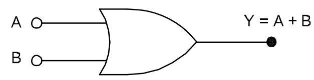
V_{in}	V_{out}
Low(0)	High(1)
High(1)	Low(0)

The logic expression for the inverter is as follows: Let the input variable be 'A' and the output variable be Y, then the output Y = .

OR and AND gate circuits

OR Gate : The output of an OR will be in 1 state if one or more of the inputs is in 1 state. Only when all the inputs are in 0-state, the output will go to 0-state. Fig 3 shows the schematic Symbol of an OR Gate :

Fig 3



The boolean expression for OR gate is Y=A+B.

The equation is to be read as Y equals A ORed B. Two-input truth table given below is equivalent to the definition of the OR operation.

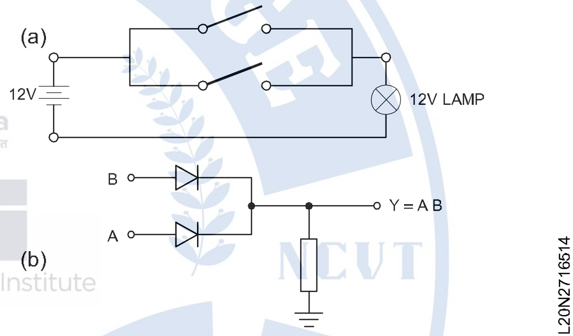
Truth table for OR gate

A	B	Y=A + B
0	0	0
1	0	1
0	1	1
1	1	1

Electrical equivalent circuit

The Fig 4a shows the electrical equivalent circuit of an OR gate. It is evident that if any one of the switch is closed, there will be output.

Fig 4



2 in-put OR gate using diode

The Fig 4b shows one way to build a 2-input OR gate, using diodes. The inputs are labeled as A and B, while the output is Y.

Assume logic 0 = 0V (low)

logic 1 = +5V (high)

Since this is a 2 input OR gate, there are only four possible cases,

Case 1: A is low and B is low. With both the input voltage low, both the diodes are not conducting. Therefore the output Y is in low level.

Case 2: A is low and B is high, The high B input voltage (+5V) forward biases the lower diode, producing an output voltage that is ideally +5V (actually +4.3V taking the diode voltage drop 0.7V into consideration). That is, the output is in high level. During this condition, the diode connected to input A is under reverse bias or OFF condition.

Case 3: A is high and B is low, the condition is similar to case 2. Input A diode is ON and Input B diode is OFF and Y is in high level.

Case 4: A is high, B is high. With both the inputs at +5V, both diodes are forward biased, since the input voltages are in parallel, the output voltage is +5V ideally [+4.3V to a second approximation]. That is, the output Y-is in high level.

OR gates are available in the IC form. IC7432 is a T.T.L OR gate IC having 4 OR gates inside it.

Simple application of OR gate

Intrusion detection

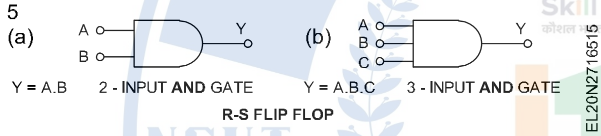
Simplified portion of an intrusion detection and alarm system is two windows and a door. The sensors are magnetic switches that produce a high(1) output when windows and doors are opened and a low(0) output when closed. As long as the windows and the door are secured, the switches are closed and all three of the OR gate inputs are in low(0). When one of the windows or the door is opened, a high(1) output is produced on that input of the OR gate and the gate output goes high. It then activities an alarm circuit to warn of the intrusion.

AND gates

The AND gate has two or more inputs but only one output. All input signals must be held high to get a high output. Even if one of the inputs is low, the output becomes low.

AND gate symbols for 2 input and 3 input gates are shown in Fig 5a and 5b.

Fig 5



Truth table

Two input AND gate

A	B	Y=AB
0	0	0
0	1	0
1	0	0
1	1	1

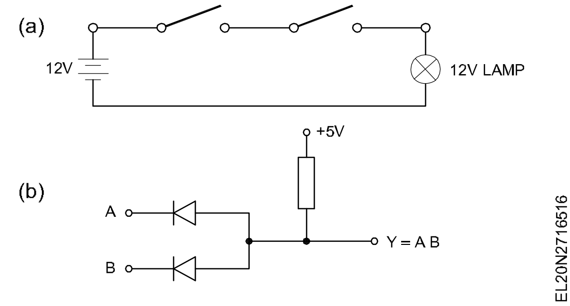
Three input AND GATE

A	B	C	Y=ABC
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Electrical equivalent circuit of an AND gate

The output is available only when both the switches are closed. IC7408 is a T.T.L quad AND gate IC. (Refer data book for pin diagram). The electrical equivalent of AND gate and AND gate using diodes are shown in Fig 6a and 6b.

Fig 6

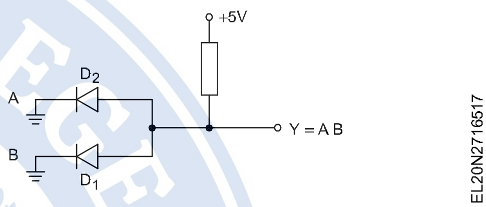


Two input AND gate using diode

I condition

A=0, B=0, Y=0 as in Fig 7.

Fig 7

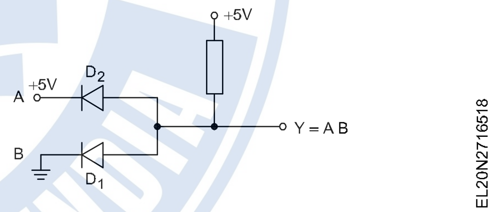


During the above condition I/P A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the O/P Y to logic-0.

II condition

A=0, B=1, Y=0 as in Fig 8.

Fig 8

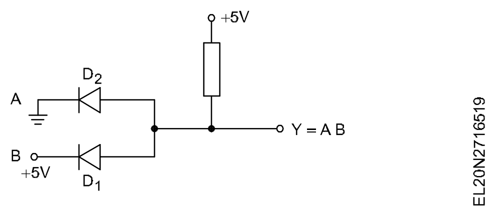


In the II condition shown in the figure above, diode D_1 is connected logic-0 input and diode D_2 is connected to +5V [Logic high]. Diode D_1 is in forward bias and conducts. Diode D_2 is having equal potential (+5V) at anode and cathode. So potential difference between anode and cathode is 0. Hence diode D2 does not conduct. The output Y is pulled down to logic zero, since D_1 is conducting.

III condition

A=1, B=0, Y=0 as in Fig 9.

Fig 9

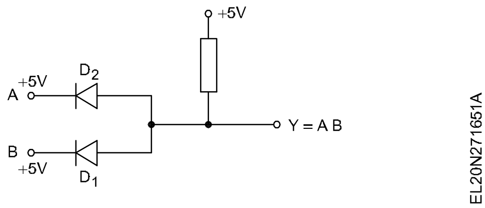


The III condition is similar to the II condition. D_2 is forward biased. D_1 is reverse biased. Hence output Y is pulled to logic-0.

IV condition

A=1, B=1, Y=1 as in Fig 10.

Fig 10



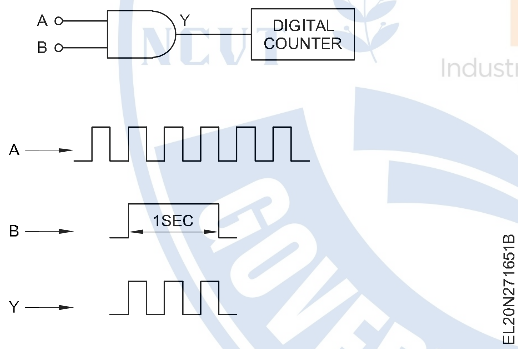
In this condition both the diodes are reverse biased. So both the diodes act as open circuit. Therefore output y is +5V i.e y is in logic-1 condition.

AND gate as an Enable/Inhibit device

A common application of the AND gate is to enable (i.e to allow) the passage of a signal (pulse waveform) from one point to another at certain times and to inhibit (prevent) the passage at other times.

In Fig 11a AND gate controls the passage of a signal (waveform A) to a digital counter. The purpose of this circuit is to measure the frequency of waveform 'A'. The enable pulse has a width of precisely 1 second. When the enable pulse applied at B is high, waveform A passes through the gate to the counter, and when the enabled pulse is low, the signal is prevented (inhibited) from passing through. Refer Fig 11b for the waveforms of the above process.

Fig 11



During the 1 second interval of the enabled pulse, a certain number of pulses in waveform A pass through the AND gate to the counter. The number of pulses counted by the counter is equal to the frequency of the waveform A. For example, if 1000 pulses pass through the gate in the 1 second interval of the enabled pulse, there are 1000 pulses/sec. That is, frequency is 1000Hz.

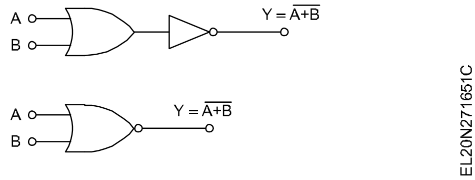
Combinational gate circuits - NOR and NAND

NOR Gate

In Fig 12a the output y of the circuit equals to the complement of A OR B, because the circuit is an OR gate followed by a NOT gate. To obtain high output [Logic-1], both the inputs should be tied to low input [Logic-0]. For the rest of the other three possibilities, output will be zero, the combination of this OR and NOT gate is called as NOR gate.

Symbol (Fig 12b) :

Fig 12



We can define a NOR gate as follows:

The output of a NOR gate is 0, even if one of the inputs is in logic-1. Only when both the inputs are in logic-0, the output is in logic-1.

Truth table

A	B	A + B
0	0	1
0	1	0
1	0	0
1	1	0

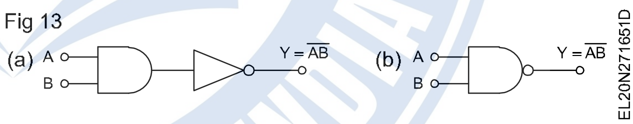
IC7402 is a T.T.L NOR gate IC. It contains 4 NOR gates. For pin details, refer data book.

NAND gate

An AND gate followed by a NOT gate forms the NAND gate as in Fig 13a. In this gate to get a low output (logic=0), all the inputs must be in high state and to get high output state, any one of the inputs or both inputs must be in low state.

Fig 13b is the standard symbol for a NAND gate. The inverter triangle has been deleted and the bubble is moved to the AND-gate output.

Fig 13



Truth table for NAND gate

A	B	
0	0	1
0	1	1
1	0	1
1	1	0

Pulsed operation

Output waveform Y is low only for the time intervals when both inputs A and B are high as shown in the timing diagram Fig 14.

Logic pulser

Fig 15 shows the circuit diagram of logic pulser, the circuit essentially consists of NAND gates connected debouncer circuit and its output is Double inverted. The LED indicates, pulses ON or OFF status.

Fig 14

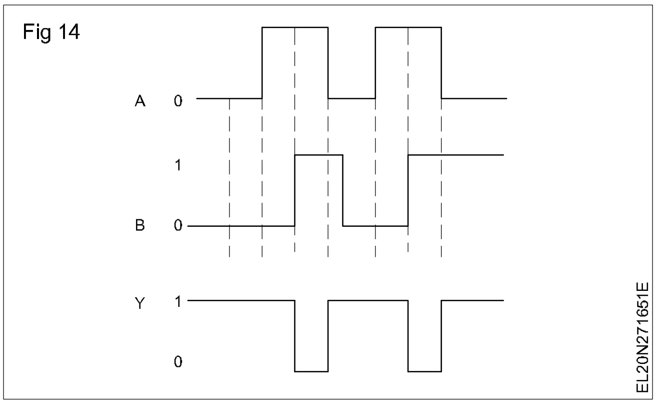
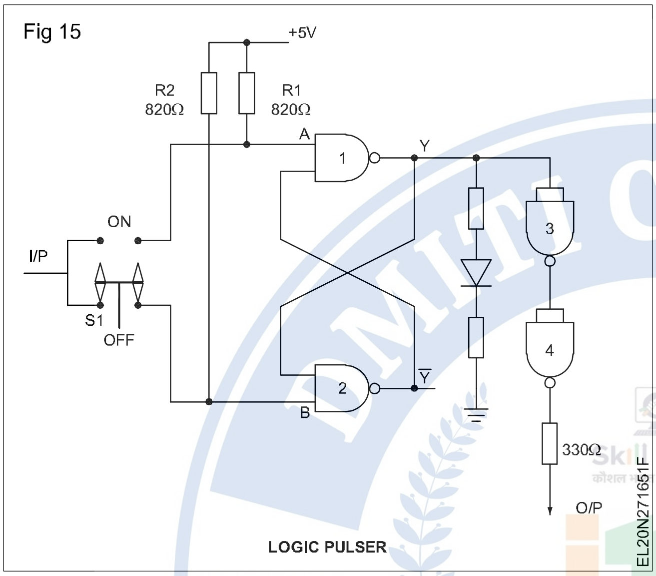


Fig 15



When switch S_1 is not pressed, (OFF position) B input of NAND gate No.2 is grounded, hence its output $\overline{Y}$ is forced to go logic HIGH. This HIGH output is feedback to NAND gate 1, A input of NAND gate 1 is also held HIGH through R_1 resistor (820Ω) and thus the output of NAND gate-1 'Y' is at low. This logic low output keeps LED in OFF condition and this logic low is again double inverted at the logic pulser tip through NAND gate 3 and 4 to get logic low level at pulser tip.

When S_1 is pressed to ON, A input of NAND gate is forced to go logic-low. Hence the output of this NAND gate is forced to go logic-HIGH. Therefore the 'Y' output is at logic-1, so LED glows and a logic-HIGH appears at probe tip. Also note that with HIGH at Y output, the inputs of NAND gate 2 are also at logic-HIGH and the output of NAND gate-2 is forced to go low. As long as switch S_1 is at ON position the probe tip is HIGH. When it is released it springs back to OFF position, and the output returns to a logic-LOW condition.

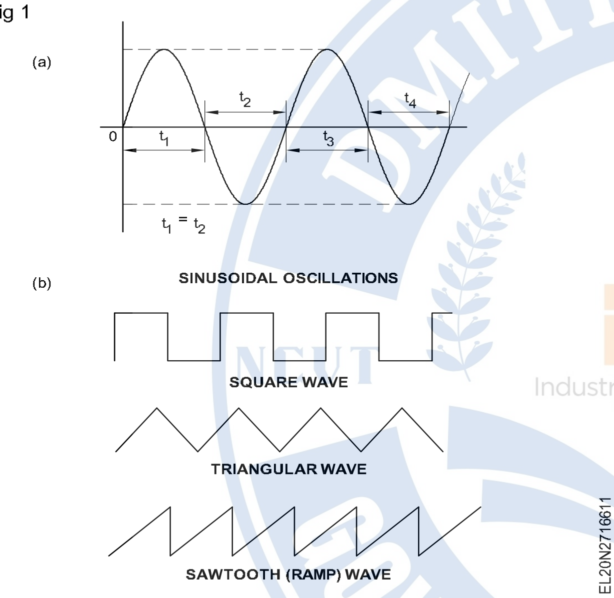
Wave shapes - Oscillators

Objectives: At the end of this lesson you shall be able to
- **state the working principle and gain of oscillator**
- **explain the RC phase-shift oscillator and frequency calculation**
- **state the features, gain and frequency of Hartley, colpitts and crystal oscillators**
- **state the working principle and frequency calculation of bistable and monostable multivibrator using CRO.**

Oscillator: An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as in Fig 1a and Fig 1b.

The output wave-form of an oscillator may be sinusoidal as in Fig 1a. Such oscillators are known as sine wave oscillators or harmonic oscillators.

Fig 1



The output of oscillators may be square, triangular or saw-tooth wave forms as in Fig 1b. Such oscillators are known as non-sinusoidal oscillators or relaxation oscillators.

It was discussed earlier that positive feedback results in converting an amplifier into an oscillator. To provide positive feedback the feedback signal should be inphase with the input signal such that it adds up with the input signal.

In practice, an oscillator will have no input AC signal at all, but it still generates AC signal. An oscillator will have only a DC supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of dc supply and sustains the oscillations.

To build an oscillator, the following are essential;

– An amplifier

– A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_V}{1 - kA_V}$$

kA_v is known as the loop gain of the amplifier. In the case of the amplifiers when the sign associated with kA_v is negative, the denominator has value more than 1. And, hence the value of Avt will always be less than A_v (negative feedback). But, if the value of kA_v is made larger, such that, it approaches unity, and, if the sign associated with kA_v is negative then the value of the denominator decreases to less than 1, and hence, A_{vf} will be larger than A_v.

In case of oscillators, if the loop gain kA_v is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example

An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

i k = 0.01

ii k = 0.02

iii k = 0.025

Solution

i $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.01 \times 40} = \frac{40}{0.6} = 66.7$

ii $A_{vf} = \frac{A_V}{1 - kA_V} = \frac{40}{1 - 0.02 \times 40} = \frac{40}{0.2} = 200$

iii A_{vf} =

In (iii) the gain of the amplifier become infinite when the loop gain $kA_v = +1$. This is known as the critical value of the loop gain kA_v. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of $kA_v = 1$ can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

There are 3 types of oscillators.

1 Hartley oscillator

2 Colpitts oscillator

3 Crystal oscillator

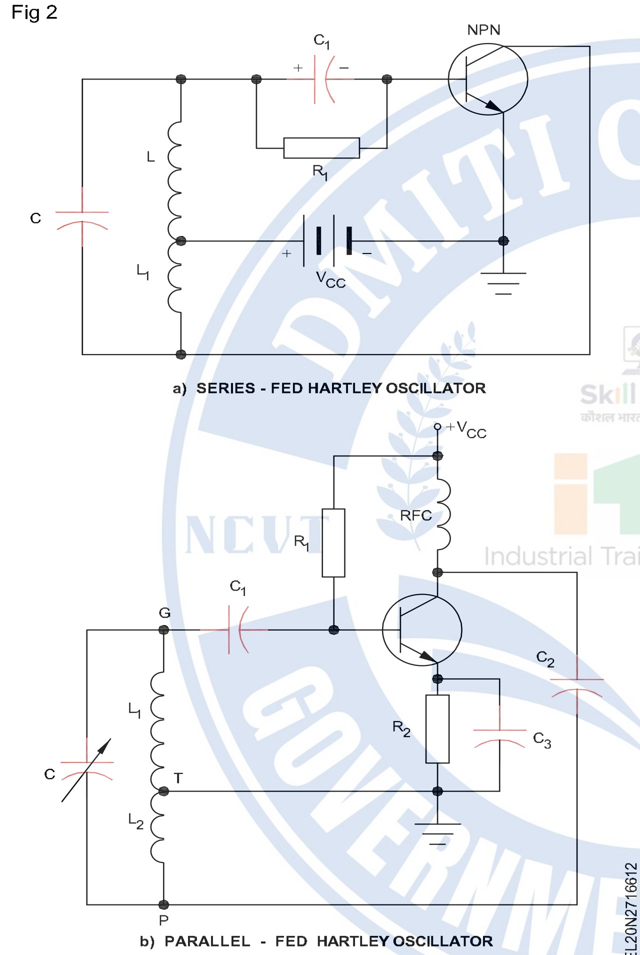
Out of three Hartley oscillator only discussed.

Hartley oscillator: One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 2a and 2b.

As in Fig 2a is a series fed Hartley oscillator. This circuit is similar to the tickler coil oscillator, but the tickler circuit coil L_1 is physically connected to L, and is hence a part of L (like an auto-transformer). This oscillator is called series-fed because, the high frequency oscillations generated and the DC paths are the same, just as they would be in a series circuit. Series fed Hartley oscillators are not preferred due to their poor stability of oscillations.

Fig 2b is parallel fed Hartley oscillator commonly used in radio receivers. Parallel fed Hartley oscillators are known for their high stability of oscillations.

Fig 2



The circuit at Fig 2b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations.

The capacitor C_2 and inductor L_2 form the path for RF current in the collector to ground circuit.

RF current through L_2 induces a voltage in L_1 in proper phase and amplitude to sustain oscillations.

The position of the tap at the junction of L_1 and L_2 determines how much signal is fed back to the base circuit.

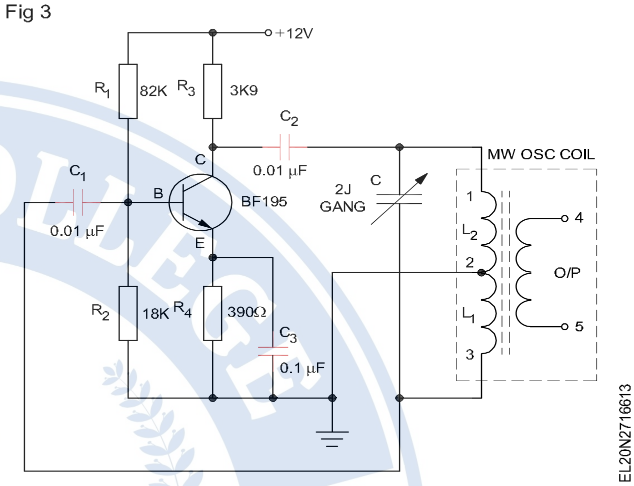
The capacitor C and the inductors $L_1 + L_2$ forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor C can be made variable capacitor for tuning the oscillator to different frequencies. C_1 and R_1 form the RC circuit which develops the bias voltage at the base.

The RF choke at the collector keeps the high frequency ac signal out of the V_{cc} supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

Resistor R_2 connected in the emitter provides DC stabilization. R_2 is by-passed by C_3 to prevent AC degeneration.

The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as in Fig 3, is small compared with the resistance between T and G., If the coil connections are not made properly, the oscillator will not work.

Fig 3



Checking oscillator frequency: The frequency of an oscillator can be computed if the values of L ($L = L_1 + L_2$) and C are known using the formula,

f =

where, f is in hertz, L in henry, and C in farad.

The frequency of an oscillator may be measured in two ways,

- Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.
- Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, 'T' frequency is calculated using the formula

f =

where, f is the frequency in Hz and 'T' the time period in seconds.

A practical Hartley oscillator circuit using medium-wave oscillator coil as L is shown in Fig 3.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.