

Electronic Components

Generally electronic components are classified into

- **Passive components**

Passive components are the components, they themselves are not capable of processing an electrical signal such as amplification, oscillation, modulation etc. But these components aid the active components in functioning. The behavior of passive components is linear.

Examples: resistor, capacitor, inductor and transformer.

- **Active components**

Active components are those, they actually processing, when signal passes through it. This process may be amplification, modulation, frequency conversion etc. The behavior of active components is nonlinear.

Examples: transistors and diodes.

An electric circuit becomes an electronic circuit when it has one or more active component(s). However, an active component all alone cannot perform any useful function.

Resistors

A resistor is a device which provides a force opposing the charge-flow (or current) in a circuit. This opposing force is called resistance (R). It is measured in ohms (symbol is Ω). All resistors have power ratings. It is the maximum power that can be dissipated without raising the temperature too high. In electronic circuits, the common standard power ratings are $\frac{1}{4}$ W, $\frac{1}{2}$ W, 1 W and 2 W.

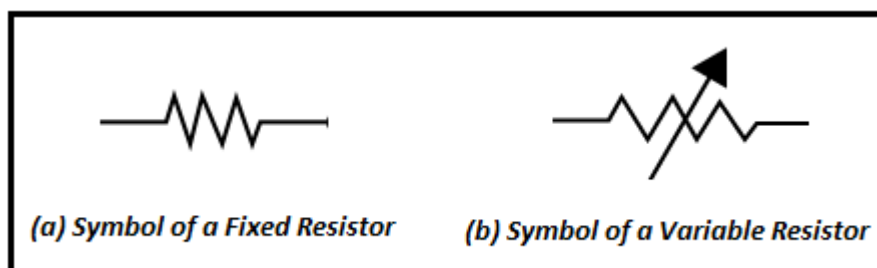


Fig: Resistor Symbols

There are two basic types of resistors.

1. **Linear Resistors**
2. **Non Linear Resistors**

1. Linear Resistors

Those resistors, which values change with the applied voltage and temperature, are called linear resistors. In other words, a resistor, which current value is directly proportional to the applied voltage is known as linear resistors.

Generally, there are two types of resistors which have linear properties.

a) Fixed Resistors b) Variable Resistors.

a) Fixed Resistors

As the name tells everything, fixed resistor is a resistor which has a specific value and we can't change the value of fixed resistors.

Types of Fixed resistors.

1. **Carbon Composition Resistors**
2. **Wire Wound Resistors**
3. **Thin Film Resistors**
4. **Thick Film Resistors**

Carbon Composition Resistor

These **types of** resistor are very commonly used low cost **resistor**. The construction of **carbon composition** resistor is very simple. It is also commonly referred as **carbon** resistor. It is mainly made of carbon clay composition covered with a plastic case. The lead of the resistor is made of tinned copper. The main advantages of these **resistors** are that they are easily available in local market in very low cost and they are very durable too. But the main disadvantage is that they are very much temperature sensitive. These resistors are available in wide range of values. It is available in as low as 1 Ω value and it is also available in as high as 22 Mega Ω value. The tolerance range in resistance of **carbon composition** resistor is of ± 5 to ± 20 %. Such **resistor** has a tendency of electric noise due to passage of electrical current from one carbon particle to other. Where low cost is the main criteria of designing a circuit rather than its performance, these resistors are normally used.

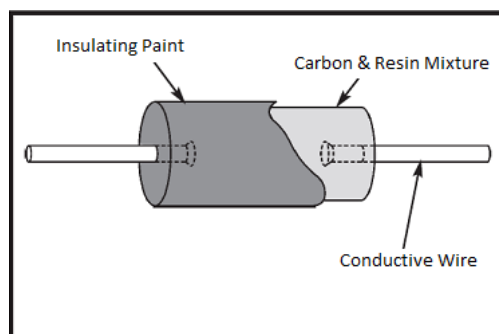


Fig: Carbon Composition Resistor

Wire Wound Resistor

The first commercial resistors made were formed by wrapping a resistive wire around a non-conducting rod. The rod was usually made of some form of ceramic that had the desired heat properties since the wires could become quite hot during use. End caps with leads attached were then placed over the ends of the rod making contact to the resistive wire, usually a nickel chromium alloy. The value of wirewound resistors remains fairly flat with increasing temperature, but change greatly with frequency. It is also difficult to precisely control the value of the resistor during construction so they must be measured and sorted after they are built. Different sizes and ratings of **wire wound resistor** can easily be achieved by using different lengths and diameters of the wire. These resistors are easily available for wide range of ratings. The range of resistance values varies from $1\ \Omega$ to $1\ \text{M}\Omega$. Typical tolerance limit of these resistors varies from 0.01 % to 1 %. They can be used for high power applications of 5 to 200 W dissipation ratings. The cost of these resistors is much higher than carbon resistor. Normally wire wound resistor is used where carbon composition resistor cannot meet the purpose because of its limitations.

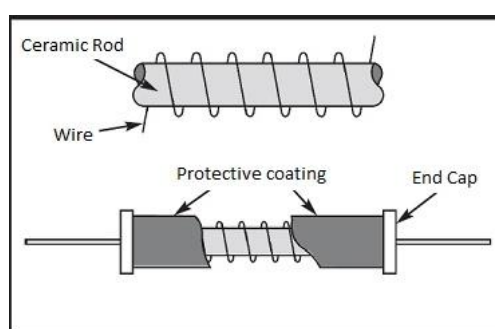


Fig: Wirewound Resistor

Thin Film Resistors

Basically, all thin film resistors are made of from high grid ceramic rod and a resistive material. A very thin conducting material layer overlaid on insulating rod, plate or tube which is made from high quality ceramic material or glass.

Thick Film Resistors

The production method of Thick film resistors is same like thin film resistors, but the difference is that there is a thick film instead of a thin film or layer of resistive material around. That's why it is called Thick film resistors. b) **Variable Resistors**

When a resistor is constructed so its value can be adjusted, it is called a variable resistor. Figure below shows the basic elements present in all variable resistors. First a resistive material is deposited on a non-conducting base. Next, stationary contacts are connected to each end of the resistive material. Finally, a moving contact or wiper is constructed to move along the resistive material and tap off the desired resistance. There are many methods for constructing variable resistors, but they all contain these three basic principles.

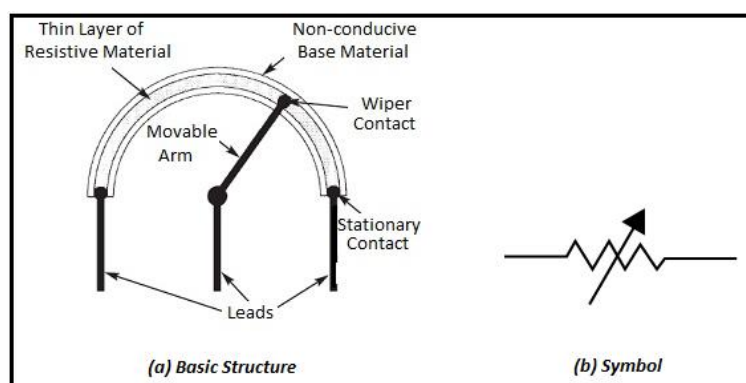


Fig: Variable Resistor

2. Non Linear Resistors

We know that, nonlinear resistors are those resistors, where the current flowing through it does not change according to Ohm's Law but, changes with change in temperature or applied voltage.

In addition, if the flowing current through a resistor changes with change in body temperature, then these kinds of resistors are called Thermistors. If the flowing current through a resistor change with the applied voltages, then it is called a Varistors or VDR (Voltage Dependent Resistors).

Following are the different types of Non Linear Resistors.

1. Thermistors

2. Varistors(VDR)

3. Photo Resistor or Photo Conductive Cell or LDR

Thermistors

Thermistors are thermally sensitive resistors whose prime function is to exhibit a large, predictable and precise change in electrical resistance when subjected to a corresponding change in body temperature. Thermistors are made from the cobalt, Nickel, Strontium and the metal oxides of Manganese. Negative Temperature Coefficient (NTC) thermistors exhibit a decrease in electrical resistance when subjected to an increase in body temperature and Positive Temperature Coefficient (PTC) thermistors exhibit an increase in electrical resistance when subjected to an increase in body temperature.

When thermistor is subjected to a temperature change, the resistance of the thermistor changes. This change in resistance becomes a measure of the change in temperature when calibrated.



Fig: Thermistor Symbol

Varistors

Varistors are voltage dependent Resistors (VDR) which is used to eliminate the high voltage transients. In other words, a special type of variable resistors used to protect circuits from destructive voltage spikes is called varistors. When voltage increases (due to lightning or line faults) across a connected sensitive device or system, then it reduces the level of voltage to a secure level i.e. it changes the level of voltages.

Photo Resistor or Photo Conductive Cell or LDR (Light Dependent Resistors)

Photo Resistor or LDR (Light Dependent Resistors) is a resistor which terminal value of resistance changes with light intensity. In other words, those resistors, which resistance values changes with the falling light on their surface is called Photo Resistor or Photo Conductive Cell or LDR (Light Dependent Resistor). The material which is used to make these kinds of resistors is called photo conductors, e.g. cadmium sulfide, lead sulfide etc.

When light falls on the photoconductive cells (LDR or Photo resistor), then there is an increase in the free carriers (electron hole pairs) due to light energy, which reduce the resistance of

semiconductor material (i.e. the quantity of light energy is inversely proportional to the semiconductor material). It means photo resistors have a negative temperature coefficient.

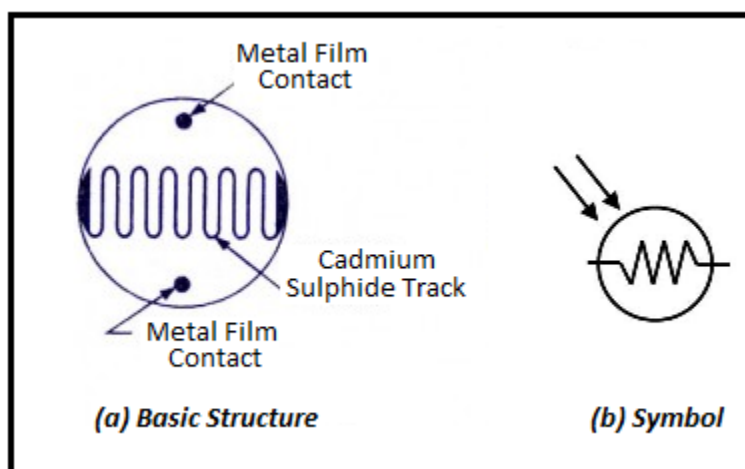


Fig: Light Dependent Resistor (LDR)

Resistor Marking

Markings on resistors can vary. Larger resistors have printed resistance values, while smaller resistors have color-coded bands. The correspondence between the digits and the colors of the bands is named **resistor color code**. This code is used to determine the value of a resistor or indicate its values by using a color code. It is defined by the international standard "IEC 60062" entitled 'Marking codes for resistors and capacitors'. To determine the resistance of a colour-coded resistor, start from the end opposite the silver or gold band. Use the colour code chart shown in table to determine the resistance values.

There are **three types of resistors** depending on the number of bands: 4-band, 5-band and 6-band resistors.

4-band resistors

In 4-band resistors, the first two bands identify the first and second digits of the resistance value, and the third band indicates the number of zeroes. The fourth determines the **tolerance** of the resistor that indicates the incertitude on the effective value of the resistor given by the manufacturer. The selling price of the resistor is inversely proportional to its precision.

Band colour	Value	Band colour & its tolerance
Black	0	Gold = $\pm 5\%$
Brown	1	Silver = $\pm 10\%$
Red	2	No colour means 20 %
Orange	3	
Yellow	4	
Green	5	
Blue	6	
Violet	7	
Grey	8	
White	9	

Table: Colour Code Chart

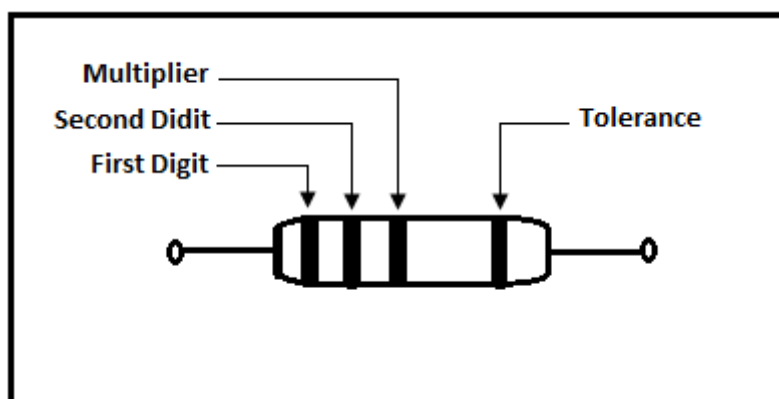


Figure: Four Band Resistor

For example, refer the four band resistor shown below. Where, brown = 1, black = 0, red = $2(10^2)$ and silver = 10 % tolerance. Hence its value is $10 \times 10^2 \Omega = 1000 \Omega = 1 \text{ k}\Omega$.

Capacitors

The **Capacitor**, sometimes referred to as Condenser, is a simple passive element that is used to 'store electricity'. The capacitor is a component which has the ability or 'capacity' to store energy in the form of an electrical charge producing a potential difference across its plates, much like a small rechargeable battery.

A Capacitor consists of two or more parallel conductive (metal) plates which are not connected or touching each other, but are electrically separated either by air or by some form of a good insulating material such as waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors. The insulating layer between capacitor plates is commonly called the **Dielectric**.

By applying a voltage to a capacitor and measuring the charge on the plates, the ratio of the charge Q to the voltage V will give the capacitance value of the capacitor and is therefore given as: $C = Q/V$. This equation can also be re-arranged to give the more familiar formula for the quantity of charge on the plates as; $Q = C \times V$. The property of a capacitor to store charge on its plates in the form of an electrostatic field is called the **Capacitance** of the capacitor. The capacitance is given by $C = \epsilon_0 \epsilon_r A / d$, where A is the area of plates, d is the plates separation, ϵ_0 is the permittivity of free space ($8.84 \times 10^{-12} \text{ F/m}$) and ϵ_r is the relative permittivity of the material being used as the dielectric .

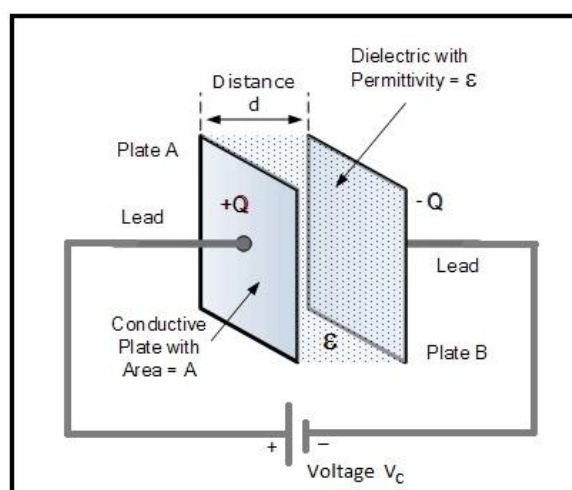


Fig: Operational Diagram of a Capacitor

The conductive plates of a capacitor are generally made of a metal foil or a metal film allowing for the flow of electrons and charge, but the dielectric material used is always an insulator. The various insulating materials used as the dielectric in a capacitor differ in their ability to block or pass an electrical charge.

This dielectric material can be made from a number of insulating materials or combinations of these materials with the most common types used being: air, paper, polyester, polypropylene, Mylar, ceramic, glass, oil, or a variety of other materials.

Capacitance is defined as being that a capacitor has the capacitance of **One Farad** when a charge of **One Coulomb** is stored on the plates by a voltage of **One volt**. Capacitance, C is always positive and has no negative units. However, the Farad is a very large unit of measurement to use on its own so sub-multiples of the Farad are generally used such as micro-farads, nano-farads and pico-farads.

- Microfarad (μF) $1\mu\text{F} = 10^{-6} \text{ F}$
- Nanofarad (nF) $1\text{nF} = 10^{-9} \text{ F}$
- Picofarad (pF) $1\text{pF} = 10^{-12} \text{ F}$

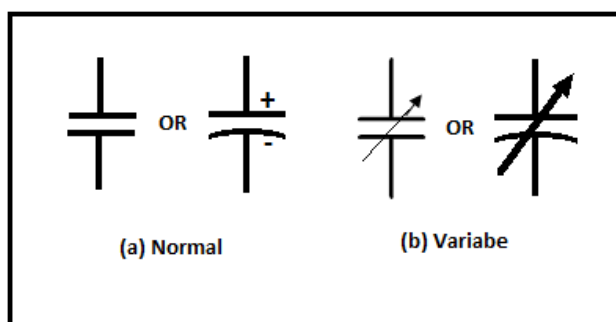


Fig: Capacitor Symbols

There are three main classes of capacitors: (i) Non electrolytic or normal capacitors and (ii) electrolytic capacitors and (iii) variable capacitors.

(i) Non electrolytic capacitors

Non electrolytic capacitors are mostly of parallel plate type and can have mica, paper, ceramic or polymer as dielectric.

Mica Capacitors

Mica capacitors are made from plates of Aluminium foil separated by sheets of mica. The plates are connected to two electrodes. The mica capacitors have excellent characteristics under stress of temperature variations and high voltage applications ($\sim 500 \text{ V}$). Available capacitances range from 5 to 10,000 pF. Its leakage current is very small (R_{leakage} is about 1000 MW).

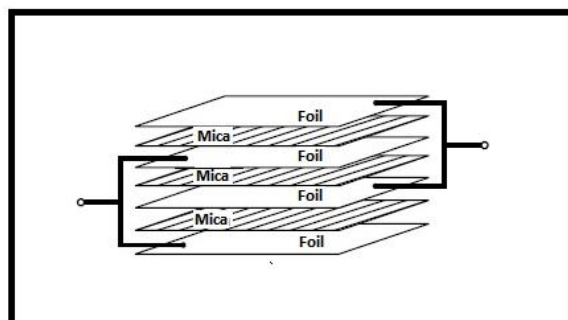


Fig: Construction of a Mica Capacitor

Ceramic Capacitors

Ceramic capacitors are made in many shapes and sizes. A ceramic disc is coated on two sides with a metal, such as copper or silver. These coatings act as two plates. After attaching tinned-wire leads, the entire unit is coated with plastic and marked with its capacitance value—either using numerals or colour code. The colour coding is similar to that used for resistances. Ceramic capacitors are very versatile. Their working voltage ranges from 3 V (for use in transistors) up to 6000 V. The capacitance value ranges from 3 pF to about 3 mF. Ceramic capacitors have a very low leakage current (R_{leakage} is about 1000 MW) and can be used in both dc and ac circuits.

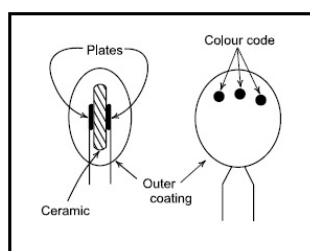


Fig: construction of a Ceramic Capacitor

Paper Capacitors

This capacitor consists of two metal foils separated by strips of paper. This paper is impregnated with a dielectric material such as wax, plastic or oil. Since paper can be rolled between two metal foils, it is possible to concentrate a large plate area in a small volume. Paper capacitors have capacitances ranging from 0.0005 mF to several mF, and are rated from about 100 V to several thousand volts. They can be used for both dc and ac circuits. Its leakage resistance is of the order of 100 MW.

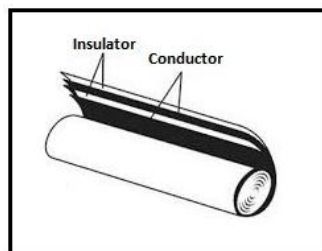


Fig: Construction of a Paper Capacitor

(ii) Electrolytic Capacitors

An electrolytic capacitor consists of an aluminium-foil electrode which has an aluminium-oxide film covering on one side. The aluminium plate serves as the positive plate and the oxide as the dielectric. The oxide is in contact with a paper or gauze saturated with an electrolyte. The electrolyte forms the second plate (negative) of the capacitor. Another layer of aluminium without the oxide coating is also provided for making electrical contact between one of the terminals and the electrolyte. In most cases, the negative plate is directly connected to the metallic container of the capacitor. The container then serves as the negative terminal for external connections.

The aluminium oxide layer is very thin. Therefore, the capacitor has a large capacitance in a small volume. It has high capacitance-to-size ratio. It is primarily designed for use in circuits where only dc voltages are applied across the capacitor. The terminals are marked +ve and -ve. Ordinary electrolytic capacitors cannot be used with alternating currents. However, there are capacitors available that can be used in ac circuits (for starting motors) and in cases where the polarity of the dc voltage reverses for short periods of time. The capacitance value may range from 1 mF to several thousand microfarads. The voltage ratings may range from 1 V to 500 V, or more.

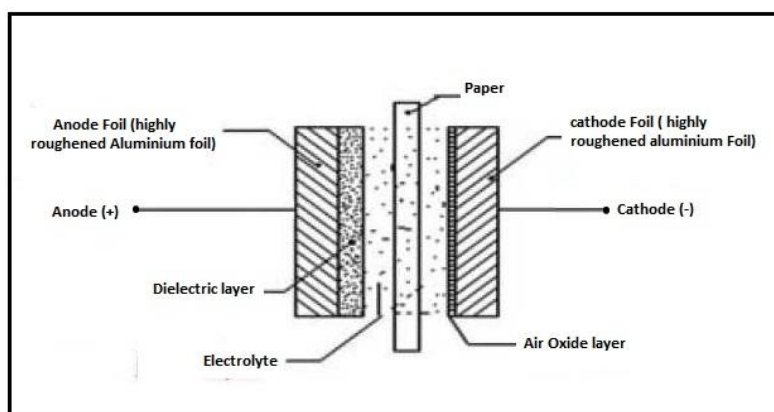


Fig: Construction of Electrolytic Capacitor

Electrolytic Capacitors are generally used in DC power supply circuits due to their large capacitance's and small size to help reduce the ripple voltage or for coupling and decoupling applications. One main disadvantage of electrolytic capacitors is their relatively low voltage rating and due to the polarisation of electrolytic capacitors, it follows then that they must not be used on AC supplies. Electrolytic's generally come in two basic forms; **Aluminium Electrolytic Capacitors** and **Tantalum Electrolytic Capacitors**.

(iii) Variable Capacitors

A Variable Capacitor is one whose capacitance may be intentionally and repeatedly changed mechanically. Variable capacitors are often used in L/C circuits to set the resonance frequency, for example, to tune a radio (therefore they are sometimes called tuning capacitors), or as a variable reactance for impedance matching in antenna tuners. The most common variable capacitor is the air-gang capacitor. The dielectric for this capacitor is air. By rotating the shaft at one end, we can change the common area between the movable and fixed set of plates. The greater the common area, the larger the capacitance.

In some applications, the need for variation in the capacitance is not frequent. One setting is sufficient for all normal operations. In such situations, we use a variable capacitor called a trimmer (sometimes called padder). Both mica and ceramic are used as the dielectric for trimmer capacitors.

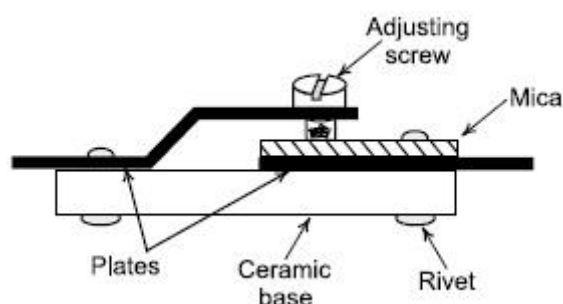


Fig: Construction of a Mica Trimmer

Colour and Number code of capacitors

Different marking schemes are used for electrolytic and non-electrolytic capacitors. Temperature coefficient is of minor importance in an electrolytic filter capacitor, but it is very important in ceramic trimmers for attenuator use. One never finds temperature coefficient on an electrolytic label, but it is always present on ceramic trimmers.

(i) Electrolytic Capacitors

There are two designs of electrolytic capacitors: (i) Axial where the leads are attached to each end (220 μ F in picture) and (ii) Radial where both leads are at the same end (10 μ F in picture).

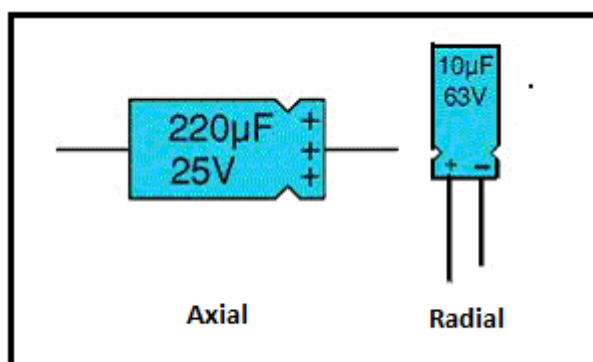


Fig: Axial and Radial Electrolytic Capacitors

(ii) Non-polarised capacitors (< 1 μ F)

Small value capacitors have their values printed but without a multiplier. For example 0.1 means 0.1 μ F = 100nF. Sometimes the unit is placed in between 2 digits indicating a decimal point. For example: 4n7 means 4.7nF.

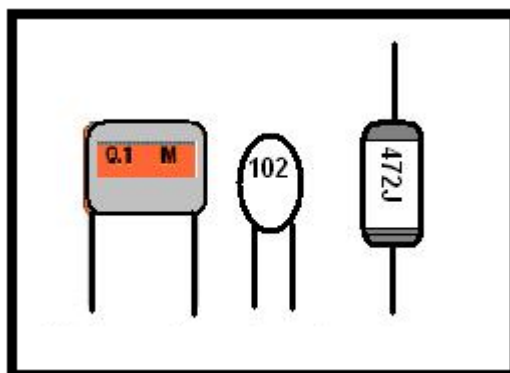


Fig: Examples of Number Coded Capacitors

Inductors

Inductors are the passive components consisting of coils of insulated copper wire wound around a former that will have some type of core at its centre. This core might be a metal such as iron that can be easily magnetised; or in high frequency inductors, it will more likely be just air.

Inductors resist or oppose changes of current but will easily pass a steady state DC current. This ability of an inductor to resist changes in current and which also relates current, i with its

magnetic flux linkage, $N\Phi$ as a constant of proportionality is called **Inductance** which is given the symbol L . Inductance of a coil is measured in Henry's. This name comes from an outstanding scientist by the name of Joseph Henry who studied coils and their properties in the early days of electronics. One Henry is the amount of inductance required to produce an e.m.f. of 1 volt in a conductor when the current in the conductor changes at the rate of 1 Ampere per second. Typically, milli Henry's or even micro Henry's are used to measure inductance. Large power transformers in power substation may have 1000 Henry's or more of inductance.

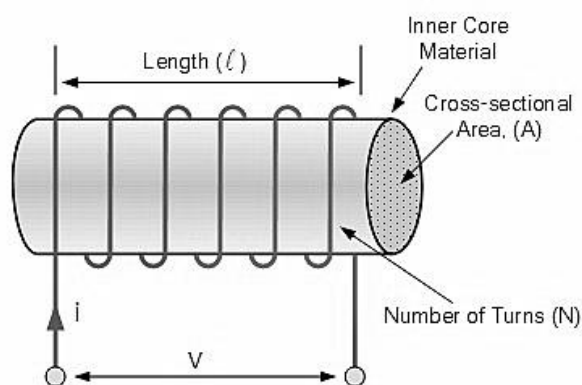


Fig: Inductor Basics

Transformers

Transformer is a static device which transforms electrical energy from one circuit to another without any direct electrical connection and with the help of mutual induction between two windings. It transforms power from one circuit to another without changing its frequency but may be in different voltage level. Transformers are commonly used in applications which require the conversion of AC voltage from one voltage level to another.

There are two broad categories of transformers: *electronic* transformers, which operate at very low power levels, and *power* transformers, which process thousands of watts of power. Electronic transformers are used in consumer electronic equipment like television sets, CD players, personal computers, and many other devices, to reduce the level of voltage from 220V (available from the AC mains) to the desired level at which the device operates. Power transformers are used in power generation, transmission and distribution systems to raise or lower the level of voltage to the desired levels. The basic principle of operation of both types of transformers is the same.

Working Principle of Transformer

Transformer works on the principle of mutual induction of two coils or Faraday Law's Of Electromagnetic induction. Faraday's law states that a voltage appears across the terminals of an electric coil when the flux linkages associated with the same changes. This emf is proportional to the rate of change of flux linkages.

$$e = d\phi/dt \quad \dots\dots\dots (1)$$

Where, e is the induced emf in volt and ϕ is the flux linkages in Weber turn.

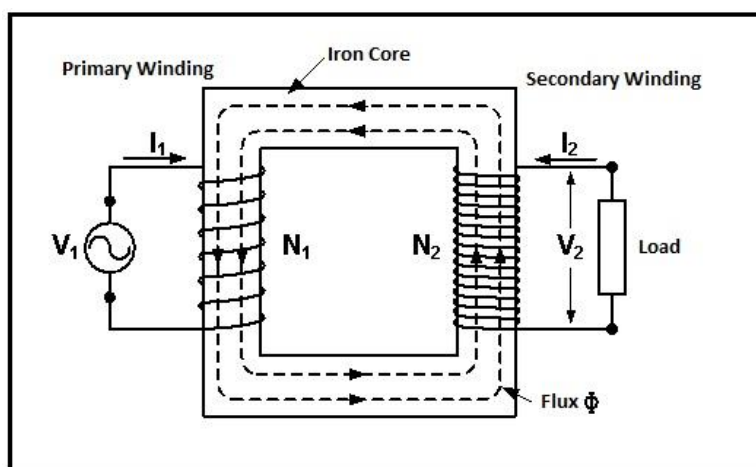


Fig:Basic Structure of a Transformer

The figure shows the simplest form of a transformer. Basically a transformer consists of two inductive coils; primary winding and secondary winding. The coils are electrically separated but magnetically linked to each other. When, primary winding is connected to a source of alternating voltage, alternating magnetic flux is produced around the winding.

The core provides magnetic path for the flux, to get linked with the secondary winding. Most of the flux gets linked with the secondary winding. As the flux produced is alternating, emf gets induced in the secondary winding according to Faraday's law of electromagnetic induction. This emf is called 'mutually induced emf', and the frequency of mutually induced emf is same as that of supplied emf. If the secondary winding is closed circuit, then mutually induced current flows through it, and hence the electrical energy is transferred from one circuit (primary) to another circuit (secondary).

Types of Transformers

The transformers are classified based on voltage levels, design, Core medium used, winding arrangements and the type of cooling employed.

Transformers based on voltage levels

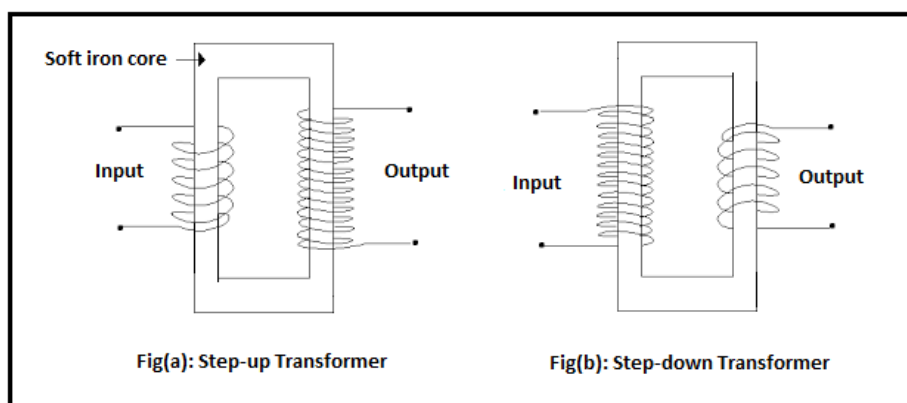
The transformers are classified as step-up and step-down transformers as the voltage ratios from primary to secondary. These are widely used transformer types for all the applications. Here the important thing to remember is that there will not be any difference in primary power and secondary power. That means if the voltage is high at secondary side then the current drawn from the secondary will low so that the power will be same. Same as in the reverse case when the voltage is low the current drawn will be high.

Step-up transformer

As the name specifies the secondary voltage is stepped up with a ratio compared to primary voltage. This is achieved by increasing the number of coil turns in the secondary as shown in figure. In power plant this transformer is used as connecting transformer of Generator to Grid. The Generated low voltage should be suitably stepped up to connect to high voltage grid.

Step-down transformer

In this transformer the voltage is stepped down at the secondary from high voltage primary so that it is called as step-down transformer. The winding turns will be high at primary side where as it will less at secondary side. In power plant the use of this transformer are very high where the grid power supply stepped down and given to corresponding plant auxiliaries during starting of the power plant. Once the plant has started then the voltage stepping down is necessary where the plant auxiliaries will operate at low voltage compared to its generated voltage. In distribution also the step down transformer is widely used to convert the high grid voltage to the low voltage which can be used at house purposes.



PN Junction Diode

Diode is a two terminal device consisting of a PN junction formed either in Ge or Si crystal. Here the terminal on the P-side is called the **anode** and the terminal on the N-side is called the **cathode**. In the symbol of the diode anode is identified by large arrow. The forward current direction in the diode is in the direction of the arrow (ie, from P to N). The PN junction conducts the current only when it is in forward biased and no current flows through it when it is in reverse biased (i.e., current flows in only one direction). Thus the diode is called **uni directional device**.

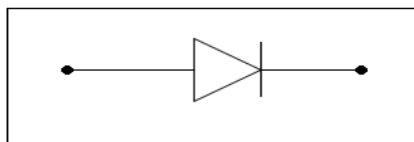


Fig: Symbol

Types of diodes

We can distinguish the following types of diodes:

- **Rectifier diodes** are typically used for power supply applications. Within the power supply, you will see diodes as elements that convert AC power to DC power.
- **Switching diodes** have lower power ratings than rectifier diodes, but can function better in high frequency application and in clipping and clamping operations that deal with short-duration pulse waveforms.

A number of **special purpose diodes** for specific applications in this fast developing world. Some of the more common special-purpose diodes are (a) Zener diode (b) Light-emitting diode (LED) (c) Photo-diode (d) Tunnel diode (e) Varactor diode and solar cells.

Zener Diodes

Zener diodes are also called *breakdown diodes*. These are specially doped PN junction diodes to produce controlled break down characteristics without damage and are operated in the break down region. The break down in zener diode is influenced by two phenomenon, zener *effect* and *avalanche effect*. Here zener effect is predominant for break down voltages less than about 4V and avalanche break down is predominant for voltages greater than 6V. Between 4V and 6V, both effects are present. Because of high temperature and current capability, Silicon is usually preferred for the manufacture of zener diodes. The break down voltage V_z and resistance R_z of zener diode is controlled by varying the doping level of the PN junction. Increasing the impurity will decrease both break down voltage and resistance.

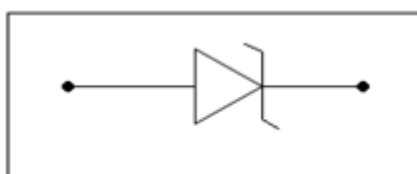


Fig: Zener Diode Symbol

Light Emitting Diode (LED):

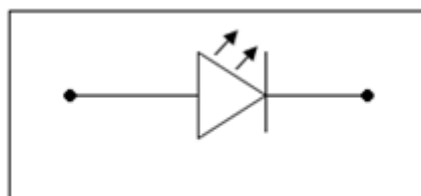
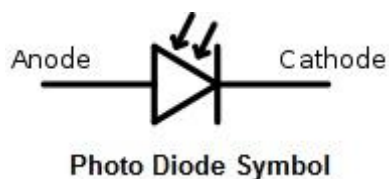


Fig: LED Symbol

Light emitting diode is a PN junction that emits optical radiation generated by the recombination of electrons and holes, when the junction is forward biased. Most of the commercial LEDs are realized using a highly doped N and a P Junction.

Photo-diode

A **photo-diode** is a reverse-biased silicon or germanium pn junction in which reverse current increases when the junction is exposed to light. The reverse current in a photo-diode is directly proportional to the intensity of light falling on its pn junction. This means that greater the intensity of light falling on the pn junction of photo-diode, the greater will be the reverse current.



Varactor Diode

These are also known as Varicap diodes. It acts like the variable capacitor. Operations are performed mainly at reverse bias state only. These diodes are very famous due to its capability of changing the capacitance ranges within the circuit in the presence of constant voltage flow. They can able to vary capacitance up to high values. In varactor diode by changing the reverse bias voltage we can decrease or increase the depletion layer. These diodes have many applications as voltage controlled oscillator for cell phones, satellite pre-filters etc. The symbol of varactor diode is given below.



Fig: Symbol of a Varactor Diode

Transistors

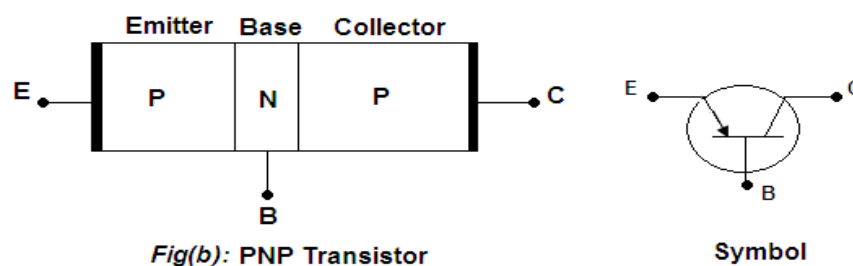
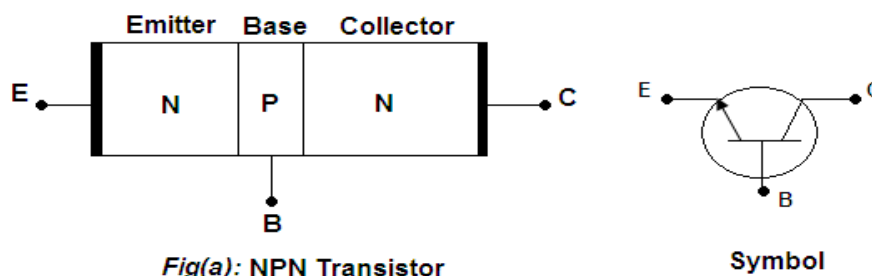
The transistor is the main building block “element” of electronics. It is a semiconductor device and it comes in two general types: the Bipolar Junction Transistor (BJT) and the Field Effect Transistor (FET).

Bipolar Junction Transistor (BJT)

Bipolar Junction Transistor is a three terminal active device which transforms current flow from low resistance path to high resistance path. This transfer of current through resistance path, given the name to the device ‘*transfer resistor*’ as **transistor**. Transistors consists of junctions within it, are called junction transistors. The *bipolar junction transistor* (BJT) is a three terminal device consists of two P-N junctions connected back to back. Current carries inside is by two opposite polarities of charge carriers (electrons and holes), hence the name *bipolar* junction transistor.

If a P-type material is sandwiched between two N-type materials as shown in fig (a), the resulting structure is called *NPN transistor*. Similarly when N-type material is sandwiched between the two P-type materials as shown in fig (b), the resulting structure is called *PNP transistor*. In both

cases, the first layer where the emission or injection of the carriers starts is called **emitter**. The second layer through which carriers pass is called the **base** and the third layer which collects the injected carriers is called **collector**. In the symbol, the emitter has an arrowed head; it points the direction of the conventional emitter current (from P to N region).



Although the emitter and collector are same type of material, they have different physical and electrical properties. The collector section is physically larger than the emitter section, since it has to collect all injected carriers and to withstand the large reverse bias voltage. The base is very thin and lightly doped. The size of the emitter falls between the base and collector region and is heavily doped. The doping level of collector region is between heavily doped emitter and lightly doped base.

Field Effect Transistor (FET)

Field Effect Transistor (FET) is a three terminal semiconductor device in which the output current is controlled by an electric field (voltage). The conduction of current in the device is only by majority carriers (either holes or electrons) and hence it is said to be a *unipolar device*.

FETs are used for a variety of applications that match, to a large extent, those of the BJT transistors. Although there are important differences between the two types of devices, there are also many similarities. The primary difference between the two types of transistors is the fact that the BJT transistor is a *current-controlled* device, while the JFET transistor is a *voltage-controlled* device. In other words, the current I_C in is a direct function of the level of I_B . For the FET the current I will be a function of the voltage V_{GS} applied to the input circuit. In each case the current of the

output circuit is being controlled by a parameter of the input circuit—in one case a current level and in the other an applied voltage. Just as there are *npn* and *pnp* bipolar transistors, there are *n-channel* and *p-channel* field-effect transistors. BJTs have two main drawbacks namely low input impedance because of forward biased emitter junction and considerable noise level. Both of these drawbacks have been overcome, to a great extent in the field effect transistor (FET).

The family tree of FET devices may be divided into two main branches, Junction FETs (JFETs) and Insulated Gate FETs (or MOSFETs, metal-oxide- semiconductor FETs). Junction FETs are inherently depletion-mode devices, and are available in both n- and p-channel configurations. MOSFETs are available in both enhancement and depletion modes, and also exist as both n- and p-channel devices.



Fig: JFET Symbols

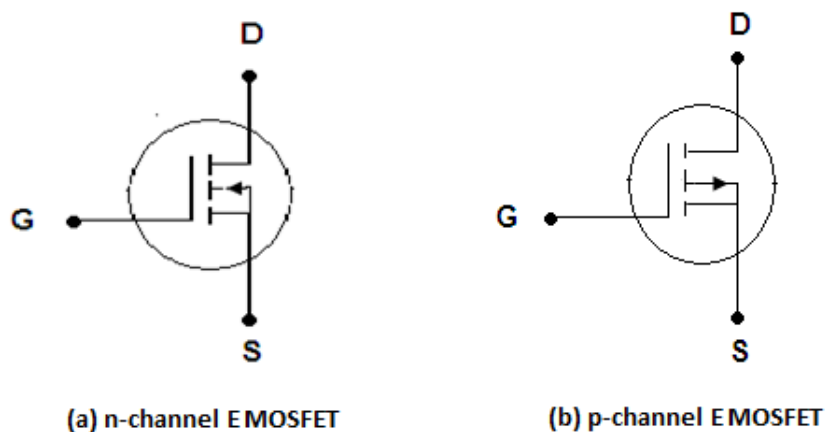


Fig: E MOSFET Symbols

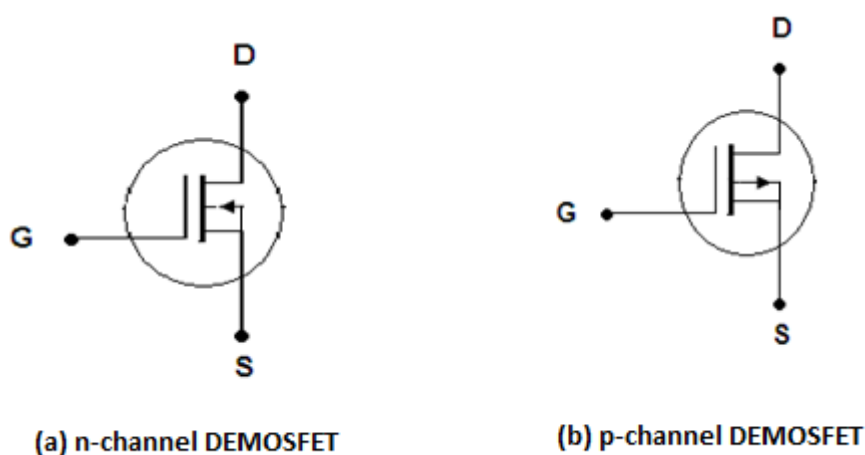


Fig: DEMOSFET Symbols

Electronic Instruments

Electronic instruments are built to accurately detect and display an electrical quantity in a form readable by a human being. Usually this "readable form" is visual: motion of a pointer on a scale, a series of lights arranged to form a "bargraph," or some sort of display composed of numerical figures. In the analysis and testing of circuits, there are instruments designed to accurately measure the basic quantities of voltage, current, and resistance.

Cathode Ray Oscilloscope (CRO)

An oscilloscope is easily the most useful instrument available for testing circuits because it allows you to see the signals at different points in the circuit. The best way of investigating an electronic system is to monitor signals at the input and output of each system block, checking that each block is operating as expected and is correctly linked to the next. CRO is an instrument which is used to measure voltages that change with time and to display the waveforms in real time mode. There is a graphical scale present on the screen which is used to calculate the voltage or frequency value. A very important specification of a CRO is its bandwidth which gives the maximum frequency of a signal which a CRO can measure. A front panel view of a CRO is shown in figure.

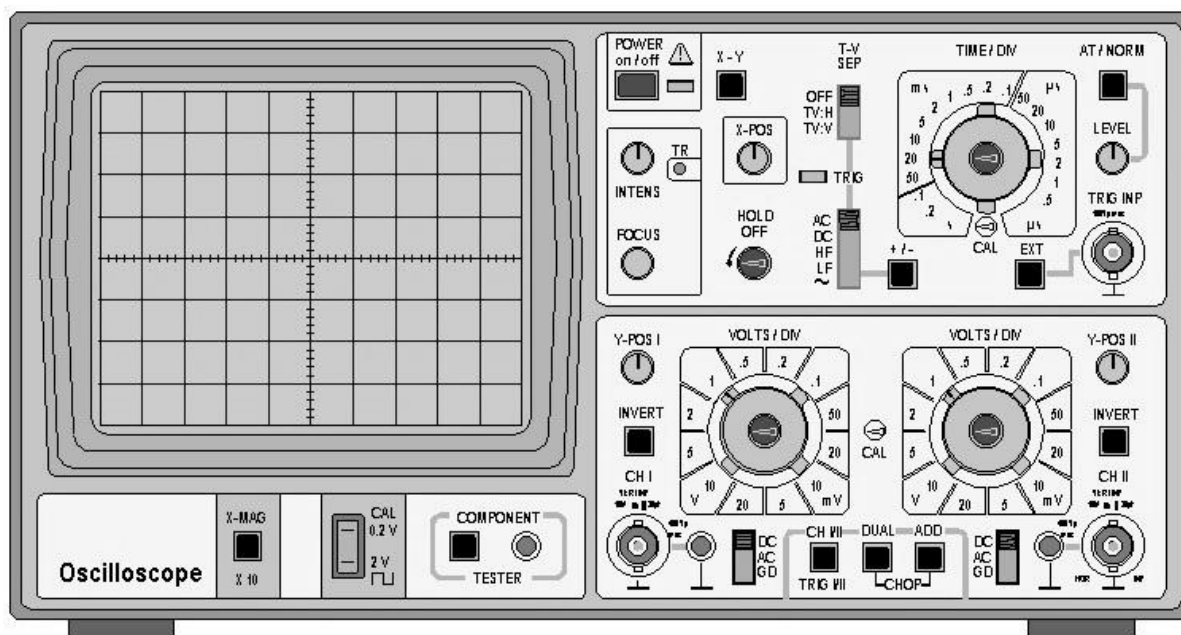


Fig: Front Panel of a CRO

The function of an oscilloscope is extremely simple: it draws a V/t graph, a graph of voltage against time, voltage on the vertical or Y-axis, and time on the horizontal or X-axis.

As you can see, the screen of this oscilloscope has 8 squares or divisions on the vertical axis, and 10 squares or divisions on the horizontal axis. Usually, these squares are 1 cm in each direction:

Working of a CRO :

An outline explanation of how an oscilloscope works can be given using the block diagram shown below:

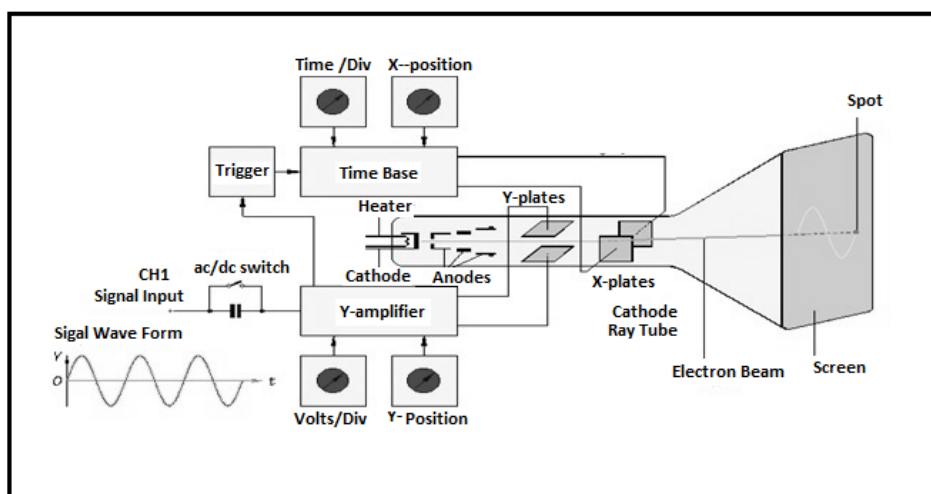


Fig: Block Diagram of CRO

A simple cathode ray oscilloscope consists of a cathode ray tube, a vertical amplifier, a time base, a horizontal amplifier, a trigger circuit and a power supply.

Like a television screen, the screen of an oscilloscope consists of a cathode ray tube. Although the size and shape are different, the operating principle is the same. Inside the tube is a vacuum. The electron beam emitted by the heated cathode at the rear end of the tube is accelerated and focused by one or more anodes, and strikes the front of the tube, producing a bright spot on the phosphorescent screen.

The electron beam is bent, or deflected, by voltages applied to two sets of plates fixed in the tube. The horizontal deflection plates, or X-plates produce side to side movement. As you can see, they are linked to a system block called the time base. This produces a sawtooth waveform. During the rising phase of the sawtooth, the spot is driven at a uniform rate from left to right across the front of the screen. During the falling phase, the electron beam returns rapidly from right to left, but the spot is 'blanked out' so that nothing appears on the screen. In this way, the time base generates the X-axis of the V/t graph.

The slope of the rising phase varies with the frequency of the sawtooth and can be adjusted, using the TIME/DIV control, to change the scale of the X-axis. Dividing the oscilloscope screen into squares allows the horizontal scale to be expressed in seconds, milliseconds or microseconds per division (s/DIV, ms/DIV, μ s/DIV). Alternatively, if the squares are 1 cm apart, the scale may be given as s/cm, ms/cm or μ s/cm.

The signal to be displayed is connected to the input. The AC/DC switch is usually kept in the DC position (switch closed) so that there is a direct connection to the Y-amplifier. In the AC position (switch open) a capacitor is placed in the signal path. The capacitor blocks DC signals but allows AC signals to pass.

The Y-amplifier is linked in turn to a pair of Y-plates so that it provides the Y-axis of the V/t graph. The overall gain of the Y-amplifier can be adjusted, using the VOLTS/DIV control, so that the resulting display is neither too small or too large, but fits the screen and can be seen clearly. The vertical scale is usually given in V/DIV or mV/DIV.

The trigger circuit is used to delay the time base waveform so that the same section of the input signal is displayed on the screen each time the spot moves across. The effect of this is to give a stable picture on the oscilloscope screen, making it easier to measure and interpret the signal.

Changing the scales of the X-axis and Y-axis allows many different signals to be displayed. Sometimes, it is also useful to be able to change the *positions* of the axes. This is possible using the X-POS and Y-POS controls. For example, with no signal applied, the normal trace is a straight line across the centre of the screen. Adjusting Y-POS allows the zero level on the Y-axis to be changed, moving the whole trace up or down on the screen to give an effective display of signals like pulse waveforms which do not alternate between positive and negative values.

Front-panel controls

Intensity. This knob controls the brightness of the trace by adjusting the number of electrons emerging from the gun.

Focus. This control is for making the trace on the screen sharper. It is connected to the anode of the electron gun whose voltage collimates the electron beam.

Vertical Position & Horizontal Position. Through these controls the beam can be positioned at variable vertical or horizontal positions as desired. These knobs apply a dc voltage to the vertical and horizontal deflection plates.

Volt / Division. This control is used to control the voltage sensitivity. This is internally connected to an attenuator of the vertical system. It determines the voltage required by the vertical plates to deflect the beam vertically by one division.

Time / Division. This determines the time taken for the spot to move horizontally across one division of the screen when the sweep is generated by triggering process. The signal which is fed to the vertical deflection plates provides the triggering to the waveform. Each position of the time/ div knob is applicable for a particular frequency. This determines the horizontal sensitivity of the observed signal.

Trigger Source. This selects the source of the trigger to be applied to the saw tooth waveform. There are usually three possible sources (i) Internal: This is mostly used for all applications. The vertical signal applies the triggering signal. (ii) Line: This is generally used when the voltage to be measured is related to the line voltage. This selects the 50Hz line voltage. (iii) Ext. In this case an external signal is applied to trigger the saw tooth waveform.

Slope. This determines whether the time base circuit responds to the positive or negative slope of the triggering waveform.

Level. This determines the amplitude level on the triggering waveform which can start the sweep

AC, DC and GND. This selects the coupling mechanism for the input signal to the CRO. In dc mode the vertical amplifier receives both ac and dc components of the input signal. In ac mode the coupling capacitor blocks all dc components and displays only pure ac waveform. In gnd configuration, the input signal is grounded and one gets a straight line. To measure the dc component of any signal (ac or dc), one has to switch from ac to dc mode and observe the vertical shift of the waveform. The amount of vertical shift in volts gives the corresponding dc component.

X-Y mode. In this mode of operation. two signals are superimposed at right angles on each other. The saw tooth time base circuit is disconnected from the horizontal deflection plates and the external signal which is fed to channel two is given to time base instead. Hence if two sine waves are fed to two channels respectively then the electron beam will undergo deflection according to right angle superposition of two sine waves. It will trace lissajous figures.

Measurements Using CRO

In general a scope can measure both time-based and voltage-based characteristics:

- **Timing characteristics:**
 - **Frequency and period** – Frequency is defined as the number of times per second a waveform repeats. And the period is the reciprocal of that (number of seconds each repeating waveform takes). The maximum frequency a scope can measure varies, but it's often in the 100's of MHz range.
 - **Duty cycle** – The percentage of a period that a wave is either positive or negative (there are both positive and negative duty cycles). The duty cycle is a ratio that tells you how long a signal is "on" versus how long it's "off" each period.
 - **Rise and fall time** – Signals can't instantaneously go from 0V to 5V, they have to smoothly rise. The duration of a wave going from a low point to a high point is called the rise time, and fall time measures the opposite. These characteristics are important when considering how fast a circuit can respond to signals.
- **Voltage characteristics:**
 - **Amplitude** – Amplitude is a measure of the magnitude of a signal. There are a variety of amplitude measurements including peak-to-peak amplitude, which measures the absolute difference between a high and low voltage point of a signal.

Peak amplitude, on the other hand, only measures how high or low a signal is past 0V.

- **Maximum and minimum voltages** – The scope can tell you exactly how high and low the voltage of your signal gets.
- **Mean and average voltages** – Oscilloscopes can calculate the average or mean of your signal, and it can also tell you the average of your signal's minimum and maximum voltage.

Measurement of frequency of a signal

Initially, the unknown frequency signal is applied to the vertical inputs of the CRO. Now the horizontal sweep is turned ON and the display appearing on the screen is adjusted by varying different control knobs provided on the front panel of CRO, till the signal is suitably displayed on the screen. After obtaining the display of good deflection, count the number of horizontal division for a complete cycle. From the counted horizontal divisions, the time period is computed as, $T = m \cdot n$.

Where m = Number of division in one complete cycle

n = Setting of time base = Time/Division

From the measured time period of the signal, the unknown frequency is calculated as, $f = 1/T$

Measurement of A.C voltage

To measure the alternating voltage of sinusoidal waveform, The A.C. signal, from the signal generator, is applied across the y – plates. The voltage(deflection) sensitivity band switch (Y-plates) and time base band switch (X-plates) are adjusted such that a steady picture of the waveform is obtained on the screen. The vertical height (l) i.e. peak-to-peak height is measured. When this peak-to-peak height is multiplied by the voltage(deflection) sensitivity i.e. volt/div, we get the peak-to-peak voltage ($2V_o$). From this we get the peak voltage (V_o). The rms voltage V_{rms} is equal to $V_o/\sqrt{2}$. This rms voltage V_{rms} is verified with rms voltage value, measured by the multi-meter.

Measurement of D.C Voltage

Deflection on a CRO screen is directly proportional to the voltage applied to the deflecting plates. Therefore, if the screen is first calibrated in terms of known voltage. i.e. the deflection sensitivity is determined, the direct voltage can be measured by applying it between a pair of deflecting plates. The amount of deflection so produced multiplied by the deflection sensitivity, gives the value of direct voltage.

Example: Measure voltage and frequency of an ac signal using CRO as shown in the figure below.

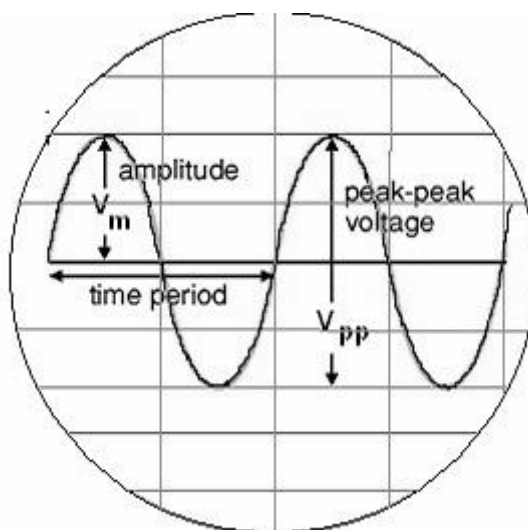


Fig: A Sine Wave Defining Amplitude and Frequency

Function Generator

A function generator is a signal source that has the capability of producing different types of waveforms as its output signal. The most common output waveforms are sine-waves, triangular waves, square waves, and sawtooth waves. The frequencies of such waveforms may be adjusted from a fraction of a hertz to several hundred kHz.

These wave forms are used to test the response of circuits to common input signals. The electrical leads from the device are attached to the ground and signal input terminals of the device under test. Function Generators are instruments capable of generating an ac signal of any frequency ($\sim 100\text{Hz}$ – hundreds of kHz), voltage ($\sim 1\text{ mV}$ – 20V) and various forms (e.g. sine wave, Square pulse, Saw tooth wave, Triangular wave or noise waveform). They also provide a continuously variable dc offset, variable duty cycle. The figure shows the front panel view of a function generator.

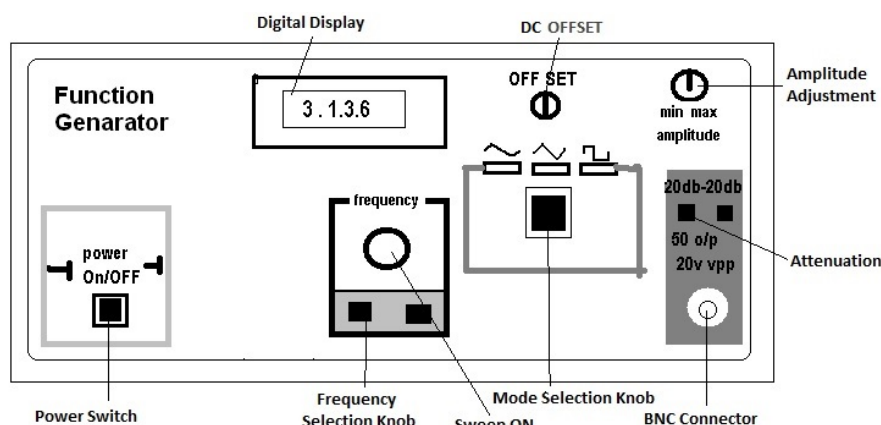


Fig: Front Panel View of a Function Generator

Features and controls

Most function generators allow the user to choose the shape of the output from a small number of options.

- Square wave - The signal goes directly from high to low voltage.
- Sine wave - The signal curves like a sinusoid from high to low voltage.
- Triangle wave - The signal goes from high to low voltage at a fixed rate.

Power Switch. Power switch indicates a power on condition.

Amplitude Control. This variable control, depending on the position of the VOLTS OUT button, determines the level of the signal at the MAIN output connector.

Digital Display. This is a 4 digit frequency meter used for displaying amplitude and frequency.

DC Offset. The DC OFFSET control sets the DC level and polarity of the signal at the MAIN output. The direct current (DC) offset control varies the average voltage of a signal relative to the ground. When the control is pressed in, the signal is centered at zero VDC.

Frequency Selection Knob and Frequency Control. These buttons determine the frequency range of the signal at the MAIN output connector. Frequency control determines the frequency of the signal at the MAIN output connector within the range set by the selection button.

Mode Selection. The sine, square or saw tooth buttons select the type of signal provided at the MAIN output connector(BNC connector) .

BNC Connector. BNC output connector for sine wave, square wave and sawtooth wave signals.

Duty Cycle Control. Activated by the DUTY CYCLE Switch. Rotation from center position adjusts the duty cycle of the main OUTPUT signal. The duty cycle of a signal refers to the ratio of high voltage to low voltage time in a square wave signal.

Attenuation Knob(-20 dB,-40 dB). This button is used to obtain the signals in mV range. In -20dB position the signal at the OUTPUT jack is attenuated by 20dB. In the -40 dB position, the amplitude of the output signal is attenuated by 40dB(to a few millivolt). Such small signals are used for testing amplifier circuits.

Using of function generator

After powering on the function generator, the output signal needs to be configured to the desired shape. Typically, this means connecting the signal and ground leads to an oscilloscope to check the controls. Adjust the function generator until the output signal is correct, then attach the signal and ground leads from the function generator to the input and ground of the device under test. For some applications, the negative lead of the function generator should attach to a negative input of the device, but usually attaching to ground is sufficient.

Power supply basics

The aim of a DC power supply is to provide the required level of DC power to the load using an AC supply at the input. Different applications require different attributes, but more often than not these days DC power supplies provide an accurate output voltage - this is regulated using electronic circuitry so that it provides a constant output voltage over a wide range of output loads.

In most power supplies there are number of different elements. These may not all be present in every design.

- **Input transformer:** The input transformer is used to transform the incoming line voltage down to the required level for the power supply. Typically the input transformer provides a step down function. It also isolates the output circuit from the line supply.
- **Rectifier:** The power supply rectifier converts the incoming signal from an AC format into raw DC. Either half wave or more commonly full wave rectifiers may be used as they make use of both halves of the incoming AC signal.
- **Smoothing:** The raw DC from the rectifier is far from constant falling to zero when the AC waveform crossed the zero axis, and then rising to its peak. The addition of a reservoir

capacitor here fills in the troughs in the waveform, enabling the next stage of the power supply to operate. Large value capacitors are normally used within this stage.

- **Regulator:** This stage of the power supply takes the smoothed voltage and uses a regulator circuit to provide a constant output virtually regardless of the output current and any minor fluctuations in the input level.

Power supply regulation

There are two basic forms of power supply used in electronics equipment:

- **Unregulated:** This form of power supply was the only type used many years ago. It simply consisted of a rectifier section and this was followed by capacitor or capacitor and inductor smoothing. There was no regulation to steady the voltage. If a large current was drawn the voltage would fall as a result of the resistive losses, and also the smoothing would not be as effective and the level of hum would rise.
- **Voltage regulated:** As transistor circuitry became more commonplace, regulated power supplies became more common. Today they are almost universally used. They typically incorporate a voltage reference, and the output voltage is compared to this and altered accordingly by control circuitry within the regulated power supply.

Multimeter

Multimeter or a multimeter is a measurement instrument used in electronics, which is designed to perform tasks of several measuring instruments. The voltage, current, and resistance measurements can be made using different options available in a common Multimeter. Therefore, it is also called VOM (Volt Ohm meter). In more expensive and advanced models, capacitance and inductance can also be measured and can be used to detect pins of semiconductor elements like transistors and diodes.

There are two types of multimeters ;analog and digital based on their measurement and display method.

In **Analog Multimeter** continuous deflection of a pointer over a scale represents the value of quantity being measured. Analog meters require no power supply,they give a better visual indication of changes and suffer less from electrical noise and isolation problems. These meters are simple and inexpensive.

Digital multimeters display a numerical value as the output which has a higher accuracy than the analog multimeters. Also, advanced digital multimeters offer automatic ranging features so that the user do not have to select the range of the measurement manually. Additionally, this becomes a safety feature too. Since no moving parts are inside, the digital multimeters are unaffected by shocks such as the impact with a solid surface.

Digital multimeter is basically a digital voltmeter and may be used for the measurement of voltage ,current (D.C or A.C) and resistance.All quantities other than D.C voltage are first converted into an equivalent D.C voltage by some device. Digital multimeters obtain several samples of the signal during a short period of time and average the signals to provide better accuracy. The analog signal is converted into a digital signal by the analog to digital converter, which is the most important component of the multimeter circuit.

Block Diagram of a Digital Multimeter:

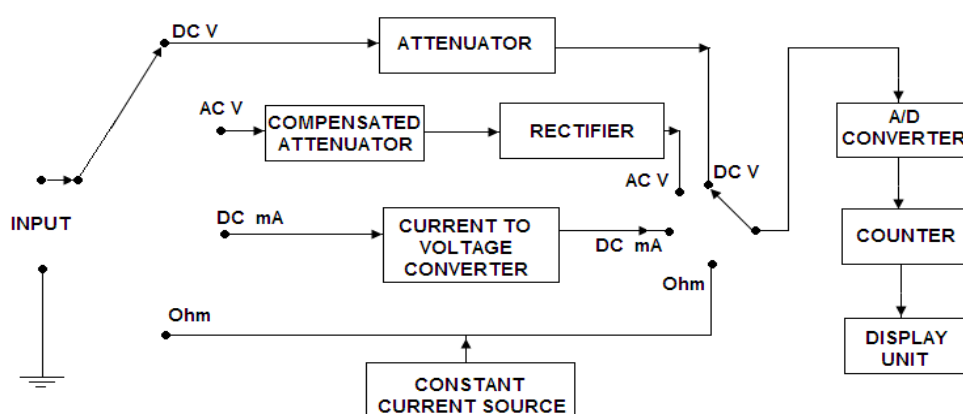


Fig: Digital Multimeter

For measurement of ac voltage the input voltage is converted in to a dc voltage by means of attenuator and rectifier.

For measurement of resistance a constant current,depending on the range,supplied from a battery or a constant current source is passed through the resistance under measurement and voltage developed across it is measured.The resistance value is displayed in ohms.

For measurement of current,the unknown current is passed through a precision resistor in many commercial digital multimeters and the voltage developed across the precision resistor is measured.the current value is displayed in mA. A current to voltage converter can also be used for current measurement as shown in block diagram.

The current under measurement is applied to the summing junction at the input of the operational amplifier. The current in the feedback resistor I_R is equal to the input current I_i because of very high input impedance of the op-amp. The current I_R causes a voltage drop across one of the resistors, which is proportional to the input current I_i . Different resistors are employed for different ranges. The voltage drop is the input to the A/D converter, thereby providing a reading that is proportional to the unknown current.

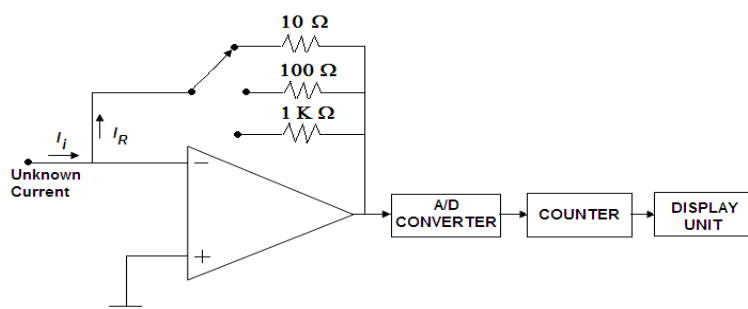


Fig: Current to Voltage Converter

Symbols & Functions in Digital Multimeter

-))) Continuity
- ▶ Diode test
- m milli (volts, amps)
- k kilo (ohms)
- Ω ohms
- VDC volts direct current
- VAC volts alternating current
- ADC amps direct current
- AAC amps alternating current

Measurements using digital multimeter

Dc voltage measurements

1. Set the function switch to the highest V DC position.
2. Insert the black test lead banana plug into the negative (COM) jack. Insert the red test lead banana plug into the positive (V) jack.
3. Touch the black test probe tip to the negative side of the circuit. Touch the red test probe tip to the positive side of the circuit.

4. Read the voltage in the display. Reset the function switch to successively lower V DC positions to obtain a higher resolution reading. The display will indicate the proper decimal point and value. If the polarity is reversed, the display will show (-) minus before the value.

AC Voltage Measurements

1. Set the function switch to the highest V AC position.
2. Insert the black test lead banana plug into the negative (COM) jack. Insert red test lead banana plug into the positive (V) jack.
3. Touch the black test probe tip to the negative side of the circuit. Touch the red test probe tip to the positive side of the circuit.
4. Read the voltage in the display. Reset the function switch to successively lower V AC positions to obtain a higher resolution reading. The display will indicate the proper decimal point and value.

DC Current Measurements

1. Insert the black test lead banana plug into the negative (COM) jack.
2. For current measurements up to 200mA DC, set the function switch to the 200mA DC position and insert the red test lead banana plug into the (mA) jack.
3. For current measurements up to 10A DC, set the function switch to the 10A range and insert the red test lead banana plug into the (10A) jack.
4. Remove power from the circuit under test, then open up the circuit at the point where you wish to measure current.
5. Touch the black test probe tip to the negative side of the circuit. Touch the red test probe tip to the positive side of the circuit.
6. Apply power to the circuit.
7. Read the current in the display. The display will indicate the proper decimal point and value.

AC Current Measurements


1. Insert the black test lead banana plug into the negative (COM) jack.
2. For current measurements up to 200mA AC, set the function switch to the 200m AAC position and insert the red test lead banana plug into the (mA) jack.
3. For current measurements up to 10A AC, set the function switch to the 10A range and insert the red test lead banana plug into the (10A) jack.
4. Remove power from the circuit under test, then open up the circuit at the point where you wish to measure current.
5. Touch the black test probe tip to the negative side of the circuit. Touch the red test probe tip to the positive side of the circuit.

6. Apply power to the circuit.
7. Read the current in the display. The display will indicate the proper decimal point and value.


RESISTANCE MEASUREMENTS

1. Set the function switch to the highest Ω position.
2. Insert the black test lead banana plug into the negative (COM) jack Insert the red test lead banana plug into the positive Ω jack.
3. Touch the test probe tips across the circuit or part under test. It is best to disconnect one side of the part under test so the rest of the circuit will not interfere with the resistance reading.
4. Read the resistance in the display and then set the function switch to the lowest Ω position that is greater than the actual or any anticipated resistance. The display will indicate the proper decimal point and value.

CONTINUITY CHECK

1. Set the function switch to the  position.
2. Insert the black lead banana plug into the negative (COM) jack Insert the red test lead banana plug into the positive (Ω) jack.
3. Touch the test probe tips to the circuit or wire you wish to check.
4. If the resistance is less than approximately 30Ω , the audible signal will sound. If the circuit is open, the display will indicate "1".

Diode Test

1. Insert the black test lead banana plug into the negative **COM** jack and the red test lead banana plug into the positive diode jack.
2. Turn the function switch to the  position.
3. Touch the test probes to the diode under test. Forward voltage will indicate .4 to .5V. Reverse voltage will indicate "1". Shorted devices will indicate near 0mV. Shorted devices will indicate near 0mV and an open device will indicate "1" in both polarities. A **Zener diode** can be verified like a normal diode as described above. **LED diodes** usually have a *forward voltage drop* too high to test with most multimeters.

Testing Of Bipolar Transistors

The assumption made when testing **transistors** is that a transistor is just a pair of connected diodes. Therefore it can be tested for shorts, opens or leakage with a simple analog or digital

multimeter. Gain, frequency response, etc. tests can be made only with expensive specialized instruments.

To test a bipolar transistor with a digital multimeter, take it out of circuit and make the following measurements using the diode test mode:

- Connect the red (positive) lead to the base of the transistor. Connect the black (negative) lead to the emitter. A good NPN transistor will read a **junction drop voltage** of 0.4V to 0.9V. A good PNP transistor will read **open**.
- Leave the red meter lead on the base and move the black meter lead to the collector - the reading should be *almost the same as the previous test*, open for PNP and a *slightly lower voltage drop* for NPN transistors.
- Reverse the meter leads and repeat the test. This time, connect the black meter lead to the base of the transistor and the red lead to the emitter. A good PNP transistor will read a **junction drop voltage** of 0.4V to 0.9V. A good NPN transistor will read **open**.
- Leave the black meter lead on the base and move the red lead to the collector - the reading should be *almost the same as the previous test*, open for NPN and a *slightly lower voltage drop* for PNP transistors.
- Place one meter lead on the collector, the other on the emitter, then reverse. Both tests should read **open** for both NPN and PNP transistors.

Identifying the leads and polarity of unknown bipolar transistors

- The type (**PNP** or **NPN**) and the **lead arrangement** of unmarked transistors can be determined easily using a digital, if the transistor is seen as a pair of connected diodes. The collector and emitter can be identified knowing the fact that the doping for the B-E junction is always much higher than for the B-C junction, therefore, the forward voltage drop will be slightly higher. This will show up as a couple of millivolts difference on a digital multimeter's diode test scale or a slightly higher resistance on an analog VoltOhmMeter.
- First *make the a few measurements between various leads*. Soon you'll identify a lead (the **Base**) that will show a forward voltage drop combined with two other leads (the Emitter and Collector). Now that the Base is identified, observe carefully the voltage drops across B-E and B-C. The **B-C** junction will have a slightly less voltage drop.

If you arrived at this point, you already know the **polarity** of the transistor under test. If the negative lead is placed on the Base when measuring the B-C and B-E voltage drops, you have a **PNP transistor**. Similarly, if the positive meter lead is placed on the base, you have a **NPN transistor**.

Transistor hfe Measurement

- Set the range switch to the desired h_{FE} position.
- Determine the transistor is NPN or PNP type and locate the emitter, base, collector leads. Insert the leads of the transistor into the proper holes of the hFE socket on the front panel.
- Read the displayed transistor H_{FE} .

Testing Of JFET

JFET can be considered as one PN junction and measured the resistance between gate and source or between gate and drain. The meter shows low resistance if the positive lead is on gate and high resistance if the negative lead is on gate. Then it is an N-channel JFET. Since the JFET is a single, uninterrupted piece of semiconductor material, there is usually no difference between the source and drain terminals. A resistance check from source to drain should yield the same value as a check from drain to source. This resistance should be relatively low (a few 100 ohms at most) when the gate-source PN junction voltage is zero.