## UNIT V

## TRANSDUCERS

**Introduction:**

The primary objective of process control is to control the physical parameters such as temperature, pressure, flow rate, force, level etc. The system used to maintain these parameters constant, close to some desired specific value is called **process control system.**

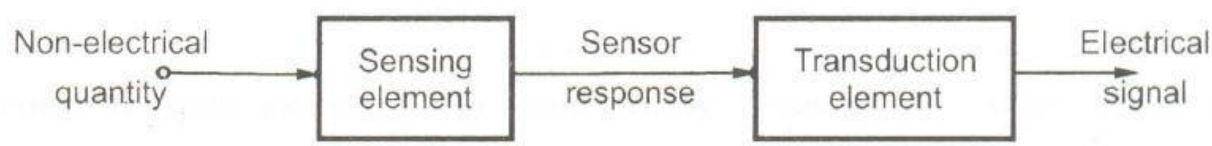
These parameters may change because of internal and external disturbances hence a constant corrective action is required to keep these parameters constant or within the specified range.It consists of four elements,

1. Process 2. Measurement 3. Controller 4. Controlelement.

A device which converts a physical quantity into the proportional electrical signal is called a transducer.

The electrical signal produced may be a voltage, current or frequency. A transducer uses many effects to produce such conversion. The process of transforming signal from one form to other is called transduction. A transducer is also called pick up.

The transduction element transforms the output of the sensor to an electrical output, as shown in theFig.




Transducer elements in cascade

The common range of an electrical signal used to represent analog signal in the industrial environment is 0 to 5 V or 4 to 20 mA. In industrial applications, nowadays, 4 to 20 mA range is most commonly used to represent analog signal. A current of 4 Ma represents a zero output and current of 20 mA represents a full scale value i.e. 5 V in case of voltage representation. The zero current condition represents open circuit in the signal transmission line. Hence the standard range is offset fromzero.

Many a times, the transducer is a part of a circuit and works with other elements of that circuit

In electrical circuits, there are combinations of three passive elements : resistor, inductor and capacitor. These three passive elements are described with the help of the primary parameters such as resistance, self or mutual inductance and capacitance respectively. Any change in these parameters can be observed only if they are externally powered. We have studied that the passive transducers do not generate any electrical signal by themselves and they require some external power to generate an electrical signal.

The transducers based on variation of parameters such as resistance, self or mutual inductance capacitance, due to an external power are known as passive transducers. Hence resistive transducer, inductive transducer and capacitive transducer are the basic passivetransducers.

**Resistive transducer:**

In general, the resistance of a metal conductor is given

$$R = \frac{\rho L}{A}$$

where $\rho$ = Resistivity of conductor ($\Omega$ m)

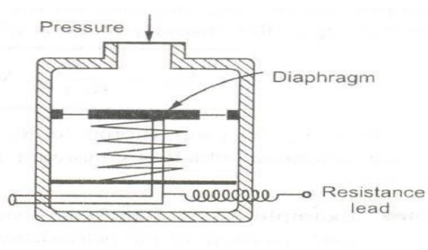
$L$ = Length of conductor (m)

$A$ = Area of cross-section of conductor ($m^2$)

by,

The electrical resistive transducers are designed on the basis of the methods of "arintioll of anyone of the qnantities in above equation; such as change in length, change in iueil of cross-section and change in resistivity.

The sensing element which is resistive in nature, may be in different forms depending upon the mechanical arrangement. The change in pressure can be sensed by Llsing ~nsitive resistive elements. The resistance pressure transducers may use Bellow, Diaphragm or Bourdon tube.

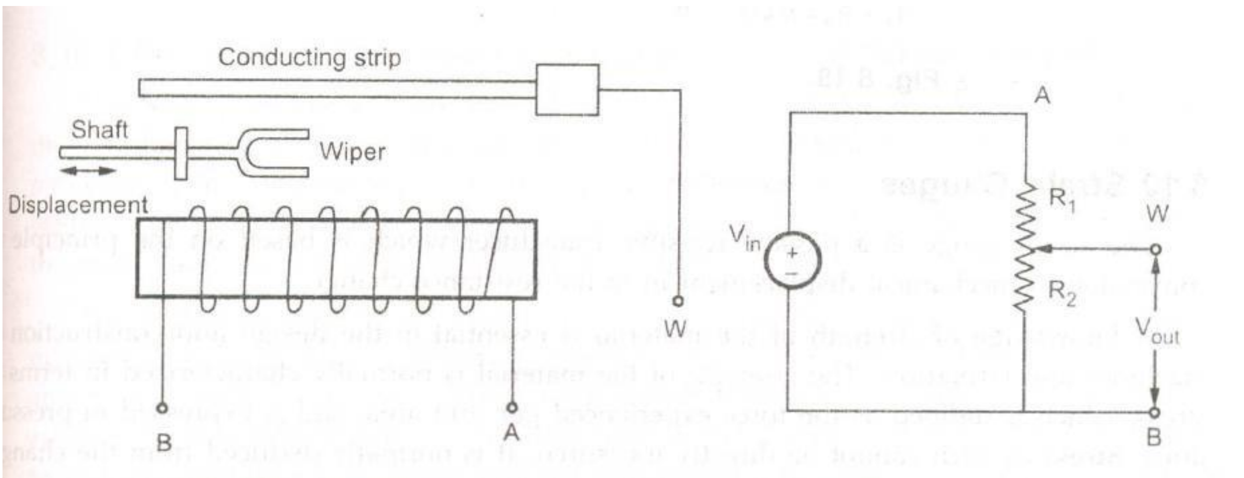



(b) Diaphragm type

In many industrial measurements and control applications, it is necessary to sense position of the object or the distance that object travels. For such applications, simple resi~tanceposition transducer is very useful.

It works on the principle that resistance of the sensing element changes due to the wiations in physical quantity being measured.

A simple resistance position transducer is as shown in the Fig.




(a) Resistance position transducer (b) Equivalent circuit

The transducer consists a sliding contact or wiper. A resistive element is mounted with the sliding contact which is linked with the object whose position is to be monitored.

Depending upon the position of the object, the resistance between slider and the one end of resistive element varies. The equivalent circuit is as shown in the Fig. 8.18 (b). *The* output voltage Vout depends on the position of the wiper. Thus depending upon position of the wiper, the output voltage is givenby,

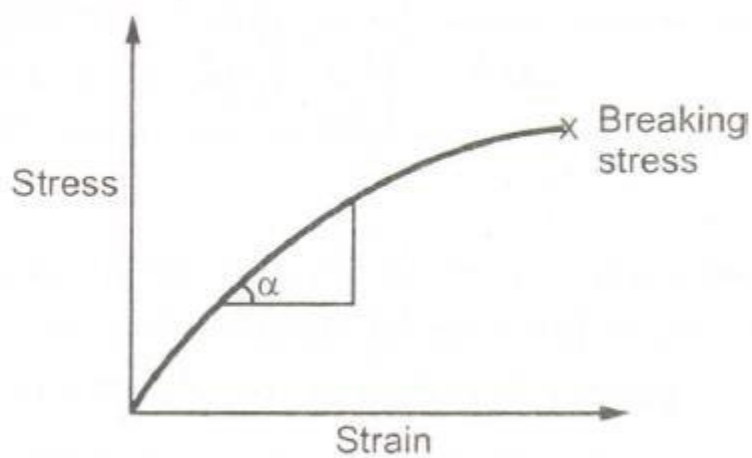
$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

Thus You I is proportional to R2 i.e. wiper position. The output voltage is measured using voltmeter which is calibrated in centimeters and allows direct readout of the object position.

**Strain gauges:**

The strain gauge is a passive resistive transducer which is based on the principle of

A knowledge of strength of the material is essential in the design and construction of machines and structures. The strength of the material is normally characterized in terms of stress, which is defined as the force experienced per unit area, and is expressed in pressure units. **Stress** as such cannot be directly measured. It is normally deduced from the changes in mechanical dimensions and the applied load. The mechanical deformation is measured with strain-gauge elements. The **strain** is defined as the change, *(td),* in length, *(I),* per unit length and is expressed as *t:.;{* inmicrostrains.




**Stress-strain curves for typical metals specimen**

The most common materials used for wire strain gauges are constantan alloys containing 45% Nickel and 55% Copper, as they exhibit high specific resistance, constant gauge factor over a wide strain range, and good stability over a reasonably large temperature range (from O°C to 300°C). For dynamic strain measurements, Nichrome alloys, containing 80% Nickel and 20% Chromium are used. They can be compensated for temperature with platinum.

Bonding cements are adhesives used to fix the strain gauge onto the test specimen. This cement serves the important function of transmitting the strain from the specimen to the gauge-sensing element. Improper bonding of the gauge can cause many errors.

Basically, the cement can be classified under two categories, viz, solvent-setting cement and chemically-reacting cement. Duco cement is an example of solvent-setting cements which is cured by solvent evaporation. Epoxies and phenolic bakelite cement are chemically-reacting almost instantaneously. The proper functioning of a strain gauge is wholly dependent on the quality of bonding which holds the gauge to the surface of the structure undergoing the test.

**Derivation of Gauge Factor:**

The gauge factor is defined as the unit change in resistance per unit change in length. It is denoted as K or S. It is also called sensitivity of the strain gauge.

$$S = \frac{\Delta R/R}{\Delta l/l}$$

S = Gauge factor or sensitivity

R = Gauge wire resistance

$\Delta R$ = Change in wire resistance

$l$ = Length of the gauge wire in unstressed condition

$\Delta l$ = Change in length in stressed condition.

Derivation: Consider that the resistance wire is under tensile stress and it is deformed by ~*l*as shown in the Fig.

When uniform stress (J is applied to th.is wire along the length, the resistance R

Let $\rho$ = Specific resistance of wire material in $\Omega$-m

$l$ = Length of the wire in m

A = Cross-section of the wire in $m^2$

changes to R + ~R because of change in length and cross-sectional area.

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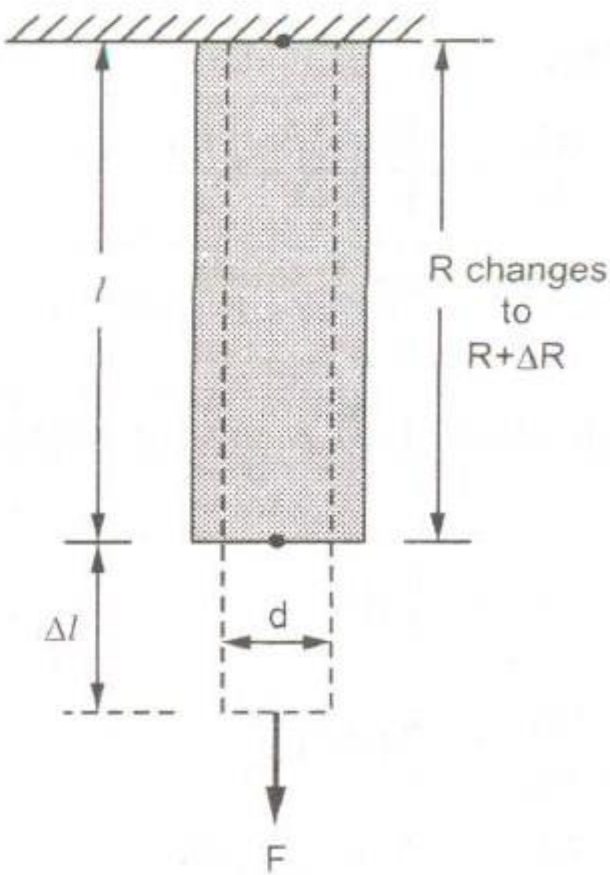



$$\sigma = \text{Stress} = \frac{\Delta l}{l}$$

$\Delta l/l$ = Per unit change in length

$\Delta A/A$ = Per unit change in area

$\Delta \rho/\rho$ = Per unit change in resistivity (specific resistance)

$$R = \frac{\rho l}{A}$$

$$\therefore \quad \frac{dR}{d\sigma} = \frac{d\left(\frac{\rho l}{A}\right)}{d\sigma} = \frac{\rho}{A}\frac{\partial l}{\partial \sigma} - \frac{\rho l}{A^2}\frac{\partial A}{\partial \sigma} + \frac{l}{A}\frac{\partial \rho}{\partial \sigma}$$

Note that $\frac{\partial}{\partial \sigma}\left(\frac{1}{A}\right) = -\frac{1}{A^2}\frac{\partial A}{\partial \sigma}$

Multiply both sides by $\frac{1}{R}$,

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{\rho}{RA}\frac{\partial l}{\partial \sigma} - \frac{1}{R}\frac{\rho l}{A^2}\frac{\partial A}{\partial \sigma} + \frac{l}{RA}\frac{\partial \rho}{\partial \sigma}$$

Using $R = \frac{\rho l}{A}$ on right hand side,

$$\frac{1}{R}\frac{dR}{d\sigma} = \frac{1}{l}\frac{\partial l}{\partial \sigma} - \frac{1}{A}\frac{\partial A}{\partial \sigma} + \frac{1}{\rho}\frac{\partial \rho}{\partial \sigma}$$

Canceling $\partial\sigma$ from both sides,

$$\frac{dR}{R} = \frac{dl}{l} - \frac{dA}{A} + \frac{\partial \rho}{\rho}$$

i.e. $$\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho}$$

**Types of Strain Gauges:**

Depending upon the principle of operation and their constructional features, strain gauges are classified as mechanical, optical, or electrical. Of these, the electrical strain gauges are most commonly used.

1. Mechanical Gauges : In these gauges, the change in length, *t:.l,* is magnified mechanically using levers or gears. These gauges are comparatively larger in size, and as such can be used in applications where sufficient area is available on the specimen for fixing the gauge. These gauges are employed for static strain measurementsonly.

2. Optical Gauges: These gauges are similar to mechanical strain gauges except that the magnification is achieved with multiple reflectors using mirrors or prisms. In one type a plain mirror is rigidly fixed to a movable knife-edge. When stress is applied, the mirror rotates through an angle, and the reflected light beam from the mirror subtends an angle twice that of the incident light. The measurement accuracy is high and independent of temperaturevariations.

3. Electrical Strain Gauges : The electrical strain gauges measure the changes that occur in resistance, capacitance, or inductance due to the strain transferred from the specimen to the basic gauge element. The most commonly used strain gauge is the bonded resistance type of strain gauge. The other two, viz., capacitance and inductance type are used only in special types of applications.

**Basic Forms of Resistance Wire Strain Gauges:**

The resistance wire strian gauges of metallic type are available in two basic forms; *bo,r/ded and lInbonded type Tire banded metallic* strain gauges are furtnercIassified as fiat grid, helical grid and thin foil type straingauges.

**Resistance temperature detector (RTD):**

Resistance temperature detector is a primary electrical transducer which is used to measure the change in the temperature. It is commonly known as resistance thermometer. The resistance thermometers are based on the principle that the resistance of the conductor changes when ~he temperature changes. Basically the resistance thermometer determines the' change in the electrical resistance of the conductor subjected to the temperature changes.

The temperature sensing element used in this thermometer should exhibit a relatively large change in resistance for a given change in temperature. Also the sensing element should not undergo permanent change with use or age. Another desirable characteristic for the sensing element is the linear change in resistance with change in temperature. When the sensing element is smaller in size, less heat is required to raise its temperature. This is suitable for me~surement of rapid variations in temperature. Platinum, nickel, and copper are the metals most commonly used to measure temperature. The relationship between temperature and resistance of conductor is given This is suitable for me~surement of rapid variations in temperature. Platinum, nickel, and copper are the metals most commonly used to measure temperature. The relationship between temperature and resistance of conductor is given .

Almost all metallic conductors have a *positive temperature coefficient* so that their resistance increases with an increase in temperature. A high value of a is desirable in a temperature sensing element so that a substantial change in resistance occurs for a relatively small change in temperature. This change in resistance *[L* R] can be measured with a Wheatstone bridge, the output of which can be directly calibrated to indicate the temperature which caused the change isresistance.

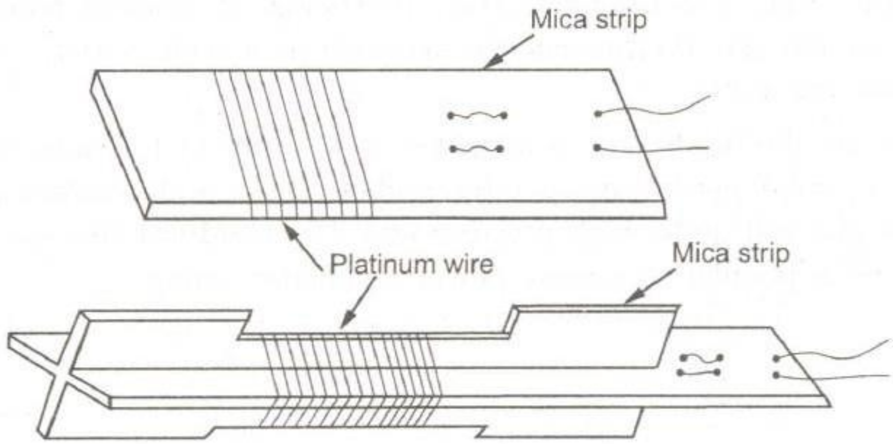
Most of the metals show an increase in resistivity with temperature, which is first linear and then increases in an accelerated fashion. The metals that exhibit good sensitivity and reproducibility for temperature measurement purposes are copper, nickel, and platinum. Among these, copper has the highest temperature coefficient with the most linear dependence. However, copper is generally not used due to certain practical problems. Because of its low resistivity, the size of the resistance element increases to get reasonable sensitivity. In the range below 400 K, a gold silver alloy can be used whichhas
the same characteristicb as platinum.

**Construction of RTD:**

The wire resistance thermometer usually consists of a coil wound on a mica or ceramic former, as shown in the Fig. The coil is wound in bifilar form so as to make it non-inductive. Such coils are available in different sizes and with different resistance values ranging from 10 ohms to 25,000 ohms.

To avoid corrosion of resistive element, usually elements are enclosed in a protective tube of pyrex glass, porcelain, quartz or nickel, depending on the range of temperature and the nature of the fluid whose temperature is to be measured. The tube is evacuated and sealed or filled with air or any other inert gas and kept around atmospheric pressure or in some cases at a higherpressure.

The wire resistance thermometer usually consists of a coil wound on a mica or ceramic former, as shown in the Fig. The coil is wound in bifilar form so as to make it non-inductive. Such coils are available in different sizes and with different resistance values ranging from 10 ohms to 25,000 ohms.

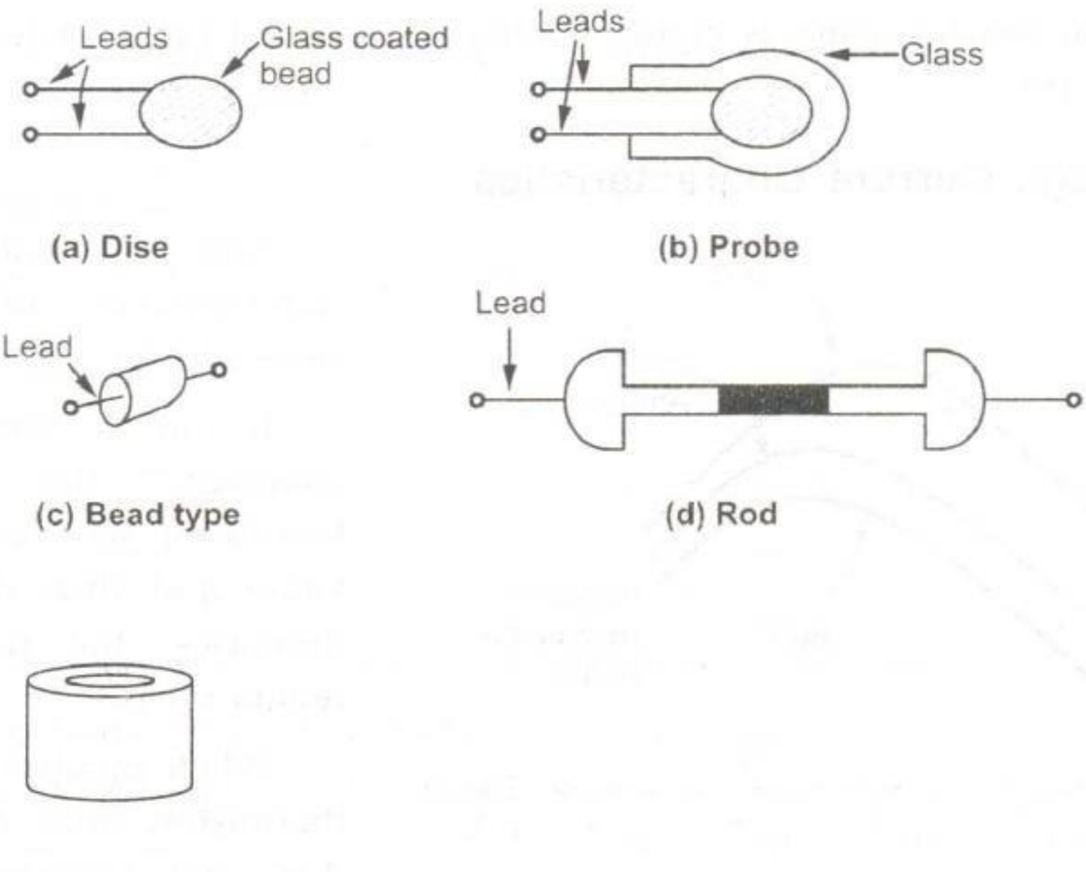



**Thermistors**:

Basically thermistor is a contraction of a word 'thermal resistors', The resistors depending on temperature are thermal resistors. Thus resistance thermometers are also thermistors having positive - temperature coefficients. But generally the resistors having negative temperature coefficients (NTC) are called thermistors. The resistance of a thermistor decreases as temperature increases. The NTC of thermistors can be as large as few percent per degree celcius change in temperature. Thus the thermistors are very sensitive and can detect very small changes in temperature too.

**Construction of thermistor:**

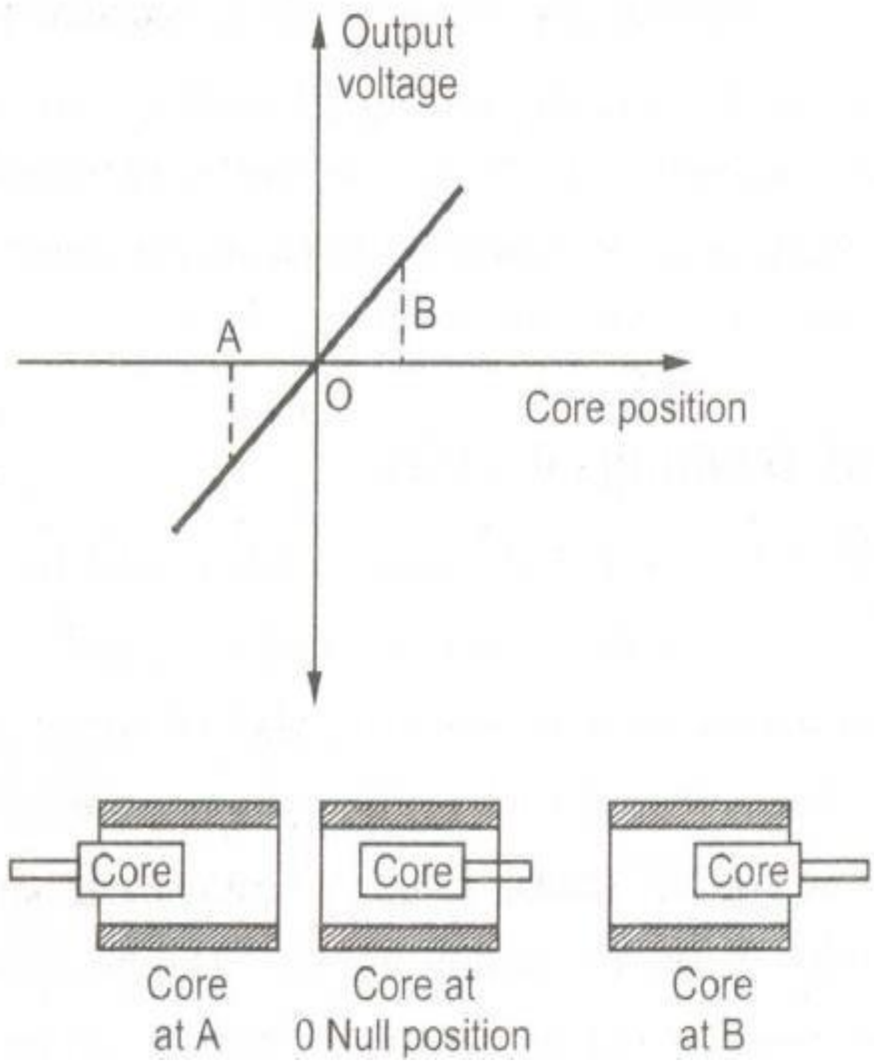
Thermistors are composed of a sintered mixture of metallic oxides, such as manganese, nickel, cobalt, copper, iron, and uranium. Their resistances at ambient temperature may range from 100 n to 100 ill. Thermistors are available in a wide variety of shapes and sizes as shown in the Fig. 8.29. Smallest in size are the beads with a diameter of 0.15 mm to 1.25 mm. Beads may be sealed in the tips of solid glass rods to form probes. Disks and washers are made by pressing thermistor materia~ under high pressure into Hat cylindrical shapes. Washers can be placed in series or in parallel to increase power dissipationrating.



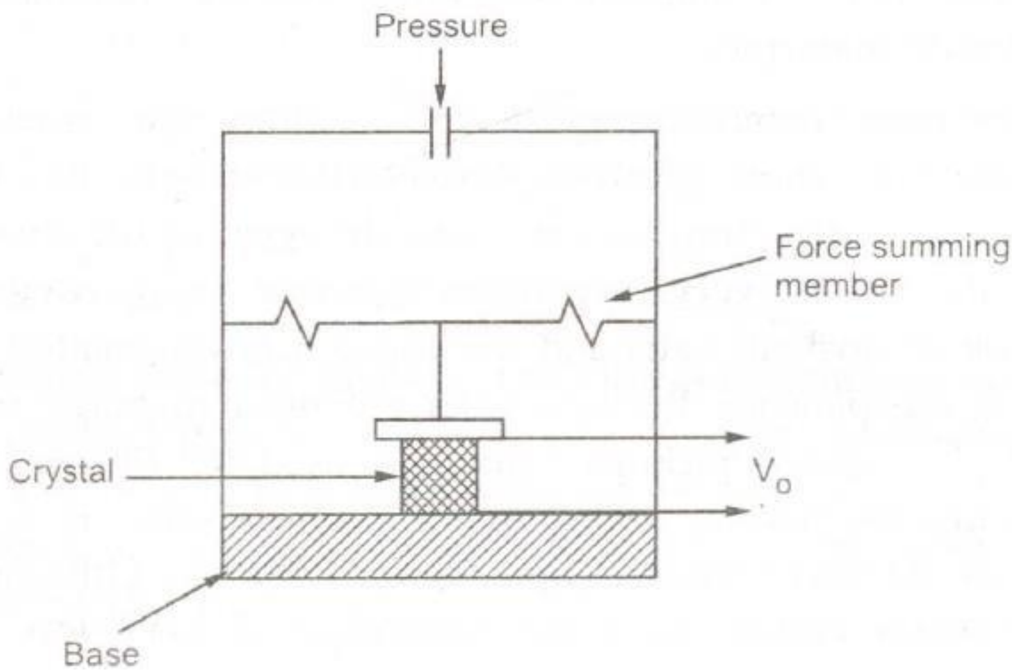

(a) Dise (b) Probe (c) Bead type (d) Rod (e) Washer type

Thermistors are well suited for precision temperature measurement, temperature control, and temperature compensation, because of their. *very*large change in resistance with temperature. They are widely used for measurements in the temperature range -1000 C to +2000 C. The measurement of the change in resistance with temperature is carried out with a Wheatstone bridge. **Linear variable differential transformer (LVDT)**

When an externally applied force moves the core to the left-hand position, more magnetic flux links the left-hand coil than the right-hand coil. The emf induced in the left-hand coil, ES], is therefore larger than the induced emf of the right-hand [oil, Es2' The magnitude of the output voltage is then equal to the difference between the two secondary voltages and it is in phase with the voltage of the left-hand coil.




**Output voltage of LVDT at different core positions**

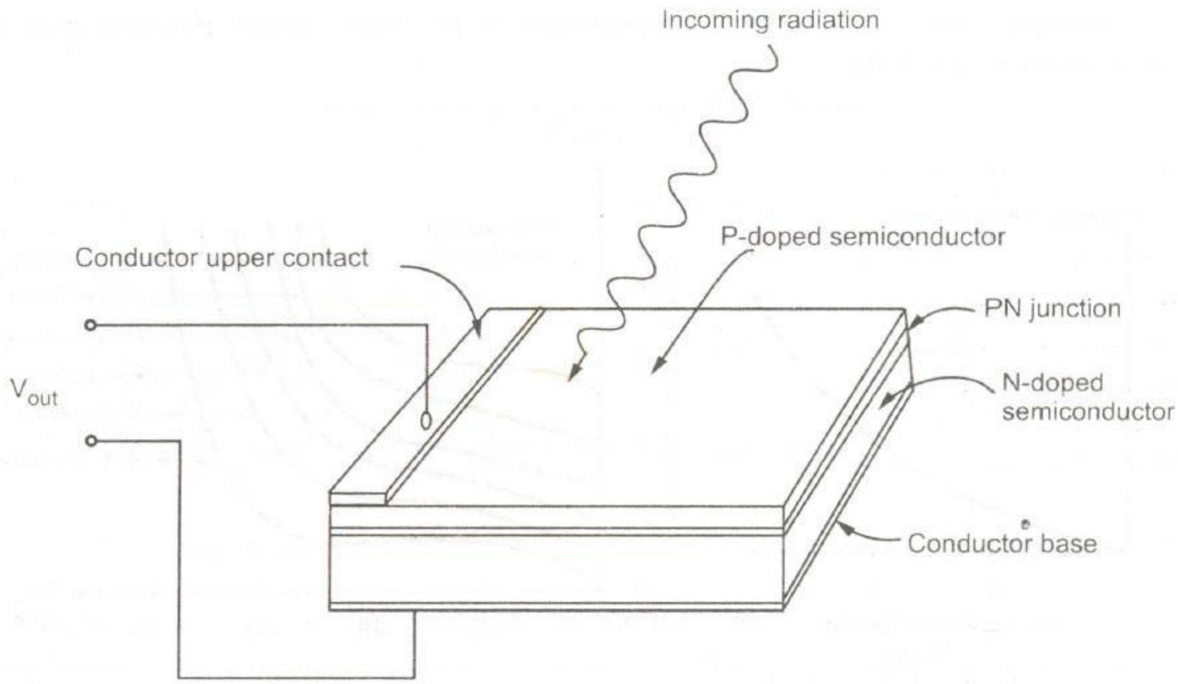



Piezoelectric transducer

A piezoelectric quartz crystal is hexagonal prism shaped crystal, which has pyramids Jt both ends. This is shown in the Fig. (a). The marking of co-ordinate axes are fixed for such crystals. The axis passing through the end points of pyramids is called optic axis or z axis. The axis passing through corners is called electrical axis or x axis while the aXIs passing through midpoints of opposite sides is called mechanical axis or y axis. The axes are shown in the

**Photovoltaic cell:**

Fig shows structure of photovoltaic cell. It shows that cell is actually a PN-junction diode with appropriately doped semiconductors. When photons strike on the thin p-doped upper layer, they are absorbed by the electrons in the n-layer; which causes formation of conduction electrons and holes. These conduction electrons and holes are separated by depletion region potential of the pn junction. When il load is connected across the cell, the depletion region potential causes the photocurrent to flow through the load N



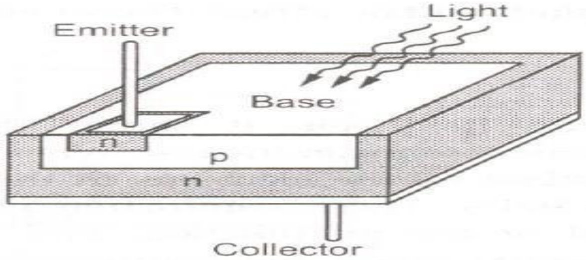

**Phototransistor:**

The photo transistor has a light sensitive collector to base junction. A lens is used in a transistor package to expose base to an incident light. When no light is incident, a small leakage current flows from collector to emitter called IeEO, due to small thermal generation. This is very small current, of the order of nA. This is called a **dark current.**

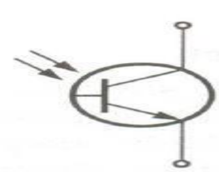
When the base is exposed to the light, the base current is produced which is proportional to the light intensity. Such photoinduced base current is denoted as I)...The resulting collector current is given by,

$$I_C \approx h_{fe} I_\lambda$$

The structure of a phototransistor is shown in the Fig. 9.15 (a) while the symbol is shown in the Fig.

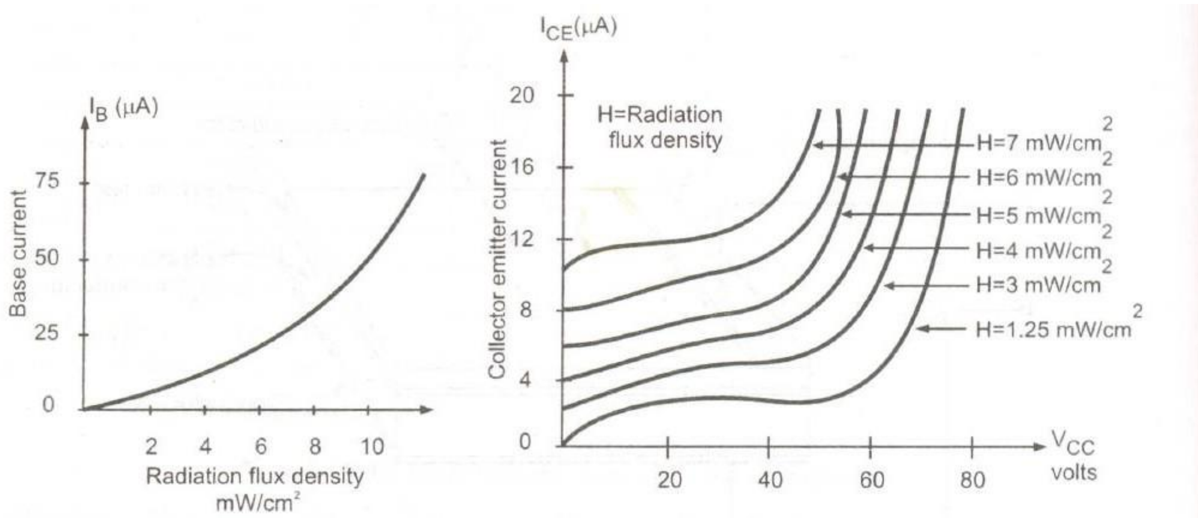



(a) Construction



(b) Symbol

To generate more base current proportional to the light, larger physical area of the base is exposed to thelight.

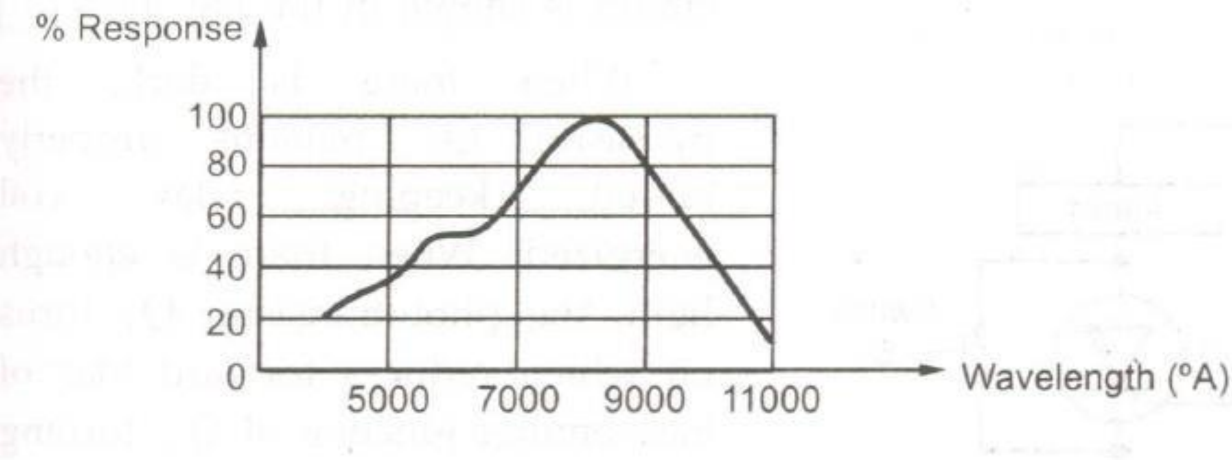



The fig .shows the graph of base current against· the radiation flux density measured in mW/ cm2. The Fig. (b) shows the collector characteristics of a phototransistor. As light intensity increases, the base current increases exponentially.

Similarly the collector current also increases corresponding to the increase in the light intensity.

A phototransistor can be either a two lead or a three lead device. In a three lead device, the base lead is brought out so that it can be used as a conventional BJT with or without the light sensitivity feature.

In a two lead device, the base is not electrically available and the device use is totally light dependent. The use of phototransistor as a two lead device is shown in the Fig. (a) while the Fig. (b) shows the typical collector characteristic curves.




Spectral response

Each curve on the characteristic graph is related to specific light intensity. The collector current level increases corresponding to increase in the light intensity. In most of the applications the phototransistor is used as a two lead device.

The phototransistor is not sensitive to all the light but sensitive to light within a certain range. The graph of response against wavelength is called **spectral** response. A typical spectral response is shown in the Fig

**Display devices:**

**Introduction :**

In digital instruments, the output device of the instrument indicate the value of measured quantity using the digital display device. This digital display device may receive the digital information in any form but it converts the information in decimal form. Thus the digital display device indicates the value in decimal digits directly. The basic element in a digital display is the display for a single digit. By grouping such displays for single digits, we can get multiple digit display. In general, digital display is classified as planar and non-planar display. A planar display is a display in which entire characters are displayed in one plane. A non-planar display is a display in which characters are displayed in different planes. In this chapter we will discuss different display dl:\'ices. In general, LED's are most commmonly used in the digital displays. The LED's have advantages such as low voltage, long life, high reliability, low cost, fast swi~ching characteristics.

**Classification of display:**

In the digital electronic field, the most commonly used displays include cathode ray tube (CRT), light emitting diode (LED) and liquid crystal display (LCD), gas discharge plasma displays, electro-luminescent displays, incandescent displays.. liquidvapour displaysetc.

**A] Classification on the basis of conversion of electrical signal into the visible light :**

There are two types of such displays.

a) **Active Displays** - CRT, gas discharge plasma display, LED

b) **Passive Displays** - LCD, electrophoretic image displays

**B] Classification on the basis of applications :**

a) **Analog Displays** - Bar graph display, CRT

b) **Digital Displays** - Nixie tubes, alphanumeric display, LED.

**C] Classification on the basis of physical dimensions and sizes :**

a) **Symbolic Displays** - Alphanumeric, Nixie tube, LED

b) **Console Displays** - LED, CRT

c) **Large Screen Displays** - Enlarged projectors

**D] Classification on the basis of display format**

a) **Direct View Type (Flat Panel)** - Segmental display, dot matrix

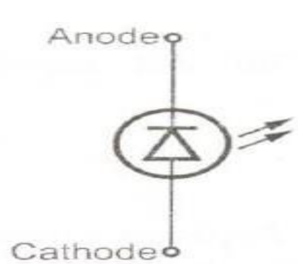
b) **Stacked Non-planar Type** - Nixie tube

**E] Classification on the basis of resolution**

a) Simple single element indicator

b) Multielement displays

## Light Emitting Diodes (LED)

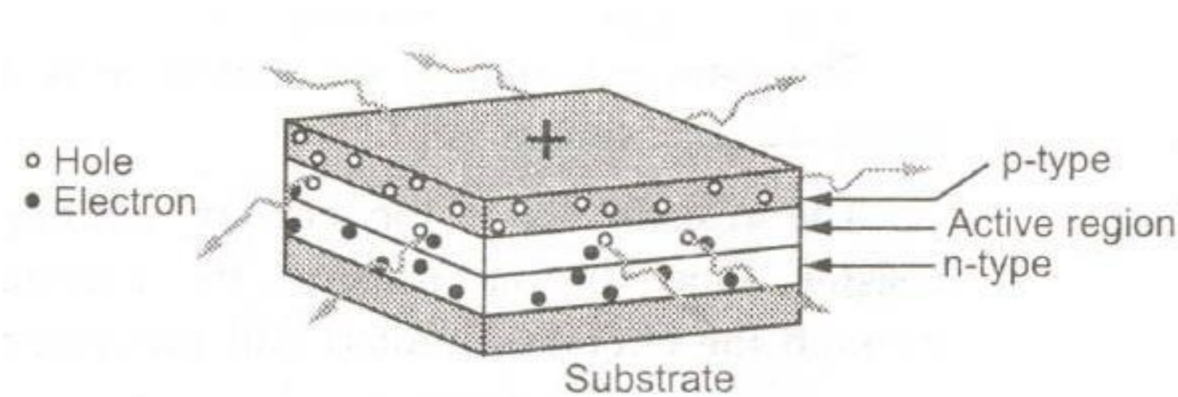


The LED is an optical diode, which emits light when forward biased. The Fig. shows the symbol of LED which is similar to p-n junction diode apart from the two arrows indicating that the device emits the light energy.

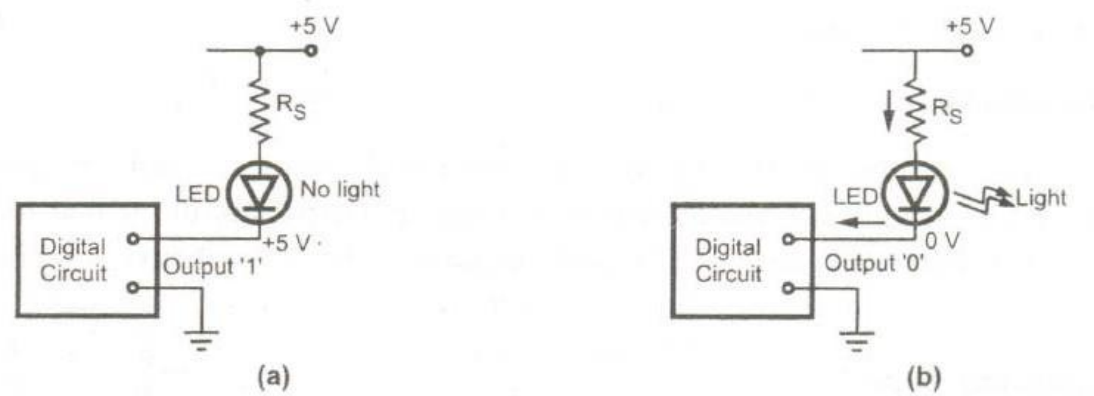
**Basic Operation:**

VVhenevL'r ,1 p-n junction is forward biased, the electrons cross the p-n junction from
till' 11 type semiconductor material c1nd recombine with the holes in the p type "ellliconductor material. The free electrons are in the conduction band while the holes are prl"'ent in the valence bcllld. Thus the free electrons are at higher energy level with respect to the holes. When a free electron recombines with hole, it falls from conduction band to a valence band. Thus the energy level associated with it changes from higher value to lower value. The energy corresponding to the difference between higher level and lower level is released by an electron while travelling from the conduction band to the valence band. In *flormif} diodes, this* energy released is in *the* form of neat. 5ut LED j·s made up some special material which release this energy in the form of photons which emit the light energy. Hence such diodes are called light emitting diodes.

**Construction of LEDs:**




One of the methods used for the LED construction is to deposite three semiconductor layers on the substrate as shown in the Fig In between p type and n type, there exists an active region. **LED Driver Circuit:**




The output of a digital circuit is logical i.e. either'O' or '1'. The '0' means low while '1' means high. In the high state the output voltage is nearly 5 V while in low state, it is almost 0 V. If LED is to be driven by such digital circuit, it can be connected as shown in the Fig. 10.10. When output of digital circuit is high, both ends of LED are at 5 V and it can not be forward biased hence will not give light. While when output of digital circuit is *!nw*, then high current will flow through LED as it becomes forward biased, and it will give light.

To improve the brightness of display, a dynamic display system is used. In thIS, the LEOs are not lit continuously but are sequentially lit by scanning in a "vertical strobe" or "horizontal strobe" mode. This is similar to "running lights" used Jl1 modern advertisements.

In the vertical strobe mode, a single row is selected at a time, the appropnatp LEOs are energized in that row, and then the signal is applied to next row. On the contrary, in horizontal strobe mode, a single column is selected at a time.

Alphanumenc displays using LEOs employ a number of square and oblong emitting areas, arriJnged either as dot matrix or segmented bar matrix.Alphanumeric LEOs are normally laid out on a single slice of semiconductor material, all the chips being enclosed in a package, similar to an IC, except that the packaging compound is transparent, and notopaque,

**Liquid Crystal Displays (LCDs):**

The liquid crystals are one of the most fascinating material systems in nature, having properties of liquids as well as of a solid crystal. The terms liquid crystal refers to the fact that these compounds have a crystalline arrangement of molecules, yet they flow like a liquid. Liquid crystal displays do not emit or generate light, but rather alter externally generated illumination. Their ability to modulate light when electrical signal is applied has made them very useful in flat panel display technology.

The crystal is made up of organic molecules which are rod-like in shape with a length of -20 A ° - 100 A 0. The orientation of the rod like molecule defines the "director" of the liquid crystal. The different arrangements of these rod-like 'molecules leads t( three main categories of liquid crystals.

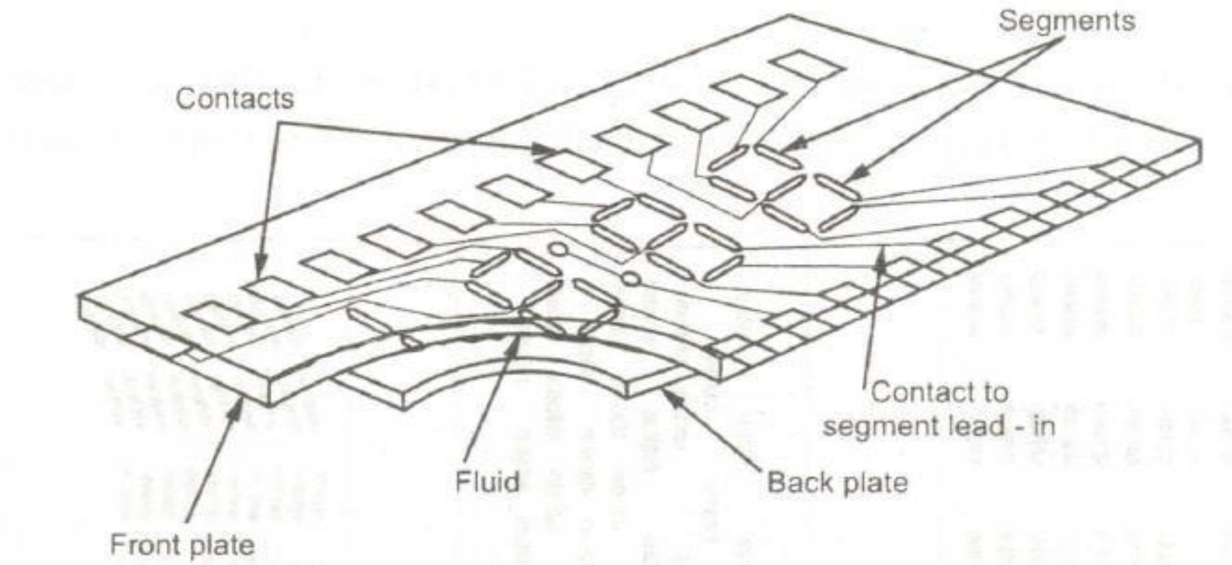
1. Smectic 2. Nematic 3.Cholesteric

**Types of LCDs:**

There are two types of liquid crystal displays (LCDs) according to the theory of operation: 1. Dynamic scattering 2. Field effect.

**Dynamic Scattering Type LCD:**

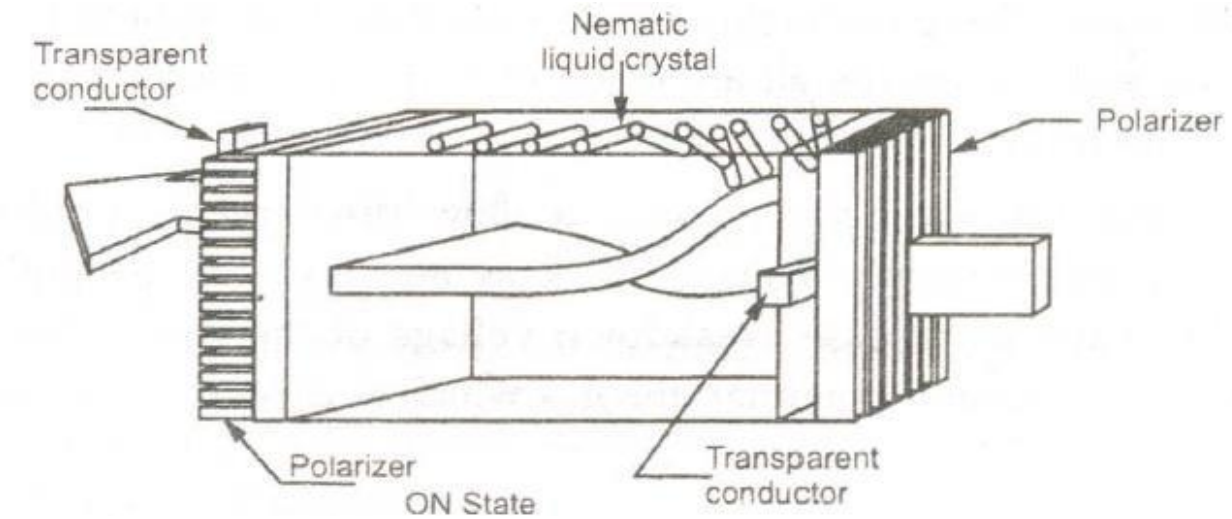
Fig. shows the construction of a typical liquid crystal display. It consists of two glass plates with a liquid crystal fluid in between. The back plate is coated with thin transparent layer of conductive material,where as front plate has a photoetched conductive coating with seven segment pattern as shown in Fig



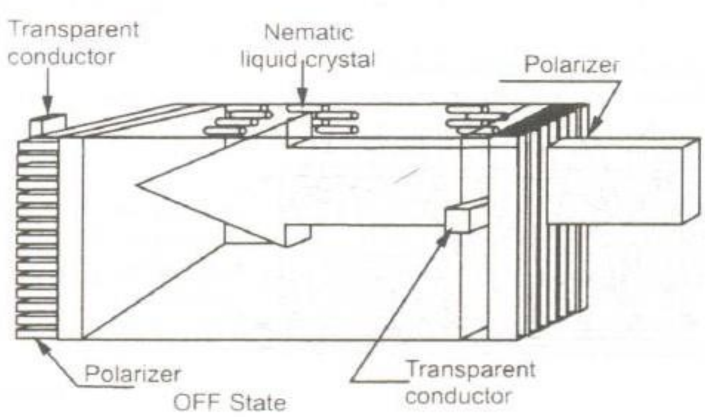

**Field Effect Display:**

In these displays nematic liquid crystals are used. Figshows operation of field effect liquid crystal display with nematic crystals. It consists of two glass plates, a liquid crystal fluid, polarizers and transparent conductors. The liquid crystal fluid is sandwiched between two glass plates. Each glass plate is associated with light polarizer. The light polarizers are placed at right angle to each other. In the absence of electrical excitation, the light coming through the front polarizer is rotated through/-O" in the fluid and passed through the rear polarizer. It is then reflected to the viewer by the back mirror as shown in Fig. (a).

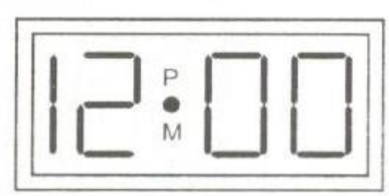
On the application of electrostatic field, the liquid crystal fluid molecules get aligned and therefore light through the molecules is not rotated by 90° and it is absorbed by the rear polarizer as shown in Fig. (b). This causes the appearance of dark digit on a light background as shown in Fig. (c).




(a) Field effect display "ON state"




(b)




(c)

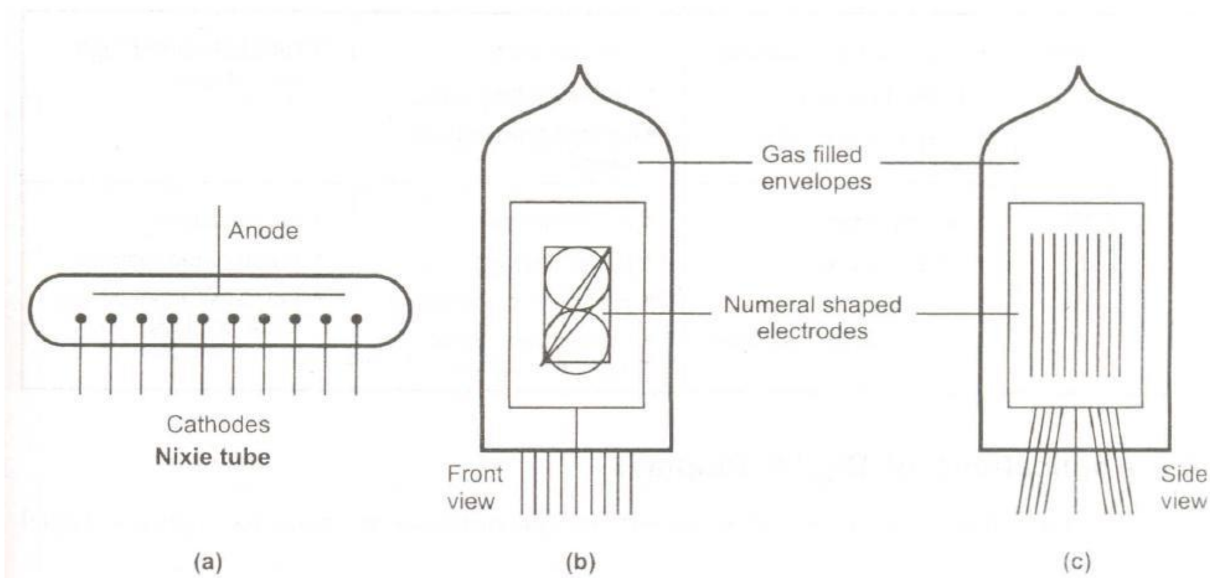
**Advantages of LCDs:**

1. Low cost
2. Uniform brightness with goodcontrast

**Nixie tubes:**

The operation of this display is based on the principle that under breakdown condition, a gas near cold cathode gas filled tube emits light. The cold cathode indicators <Ire called Nixie Tubes. These are based on the principle of glow discharge in a cold cathode gas filled tubes. The construction of the nixie tube is as shown in the Fig..It consists 10 cathode and one anode, all are made of thin wires. But only difference is anode is in the form of thinframe.

When a gas near cathode breaks down, a glow discharge is produced. The guaze electrodes with a positive supply voltage work as an anode. In generaL this voltage is selected greater than the worst case breakdown voltage of the gas within tube. When the cathode is connected to ground potential, the gas which is close to a cathodeglows.




**Bolometer and RF power measurement using Bolometer: Introduction:**

In many industrial applications, the measurement of power is very important aspect.The considerations for the measurement of power are different for different frequency ranges. The direct measurement of power is very difficult in A.F. and RF. ranges. But it is convenient to measure voltage or current in A.F. and RF. ranges. Hence indirectly power is obtained by using relation,

$$P = \frac{V^2}{R} = I^2 \cdot R$$

If we consider a frequency range well above RF. range, then it is a microwave frequency range. In the microwave ranges, the parameters such as voltage, current, impedances are distributed throughout the length of the circuit. Moreover these parameters change their values with the variation in geometry of the circuit. So it is difficult to measure voltage and current at microwave frequency ranges, but the power can be measured accurately. Thus the direct measurement of power is possible with actual load replaced by dummyload

**Power measurement at audio frequency:**

The power measurement at audio frequencies (upto 20 kHz) is carried out using a substitute load for the actual load. This is called dummy load. The dummy load is generally a resistance whose value is known. The dummy load is connected at the output of the device under test. The voltage across the dummy load or current through the dummy load is measured using instruments like rectifier, thermocouple type meters which can work at high frequencies. As the resistance of dummy load is known, the output power can be measured as,

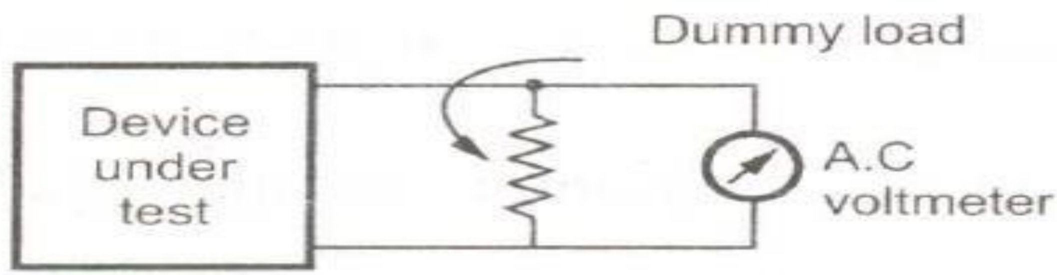
$$P = \frac{V^2}{R} = I^2 R$$

where $P$ = Output power to be measured

$V$ = Voltage across dummy load

$I$ = Current through dummy load

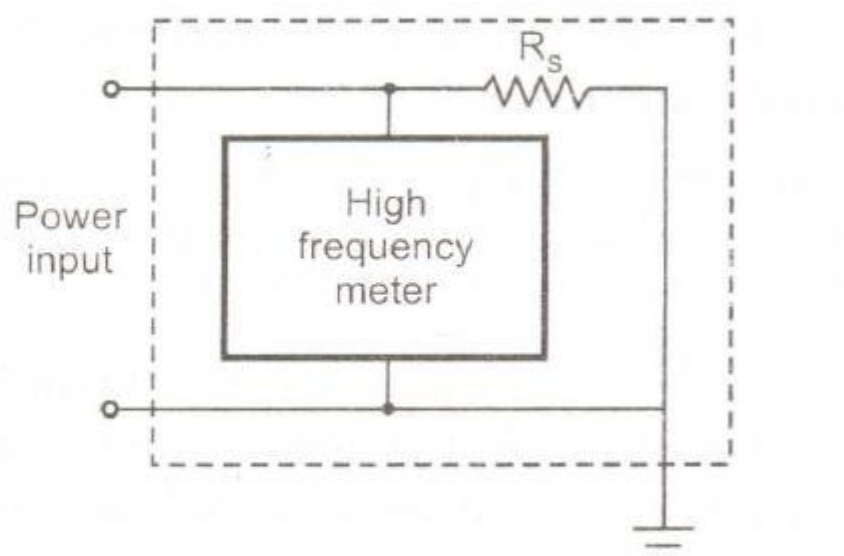
$R$ = Resistance of dummy load




The resistance of dummy load is approximately equal to the output impedance of the device under test. It is connected across the device under test. The resistance R should be able to dissipate the power applied to it. The 3.C. voltmeter which is a high resistance rectifier type instrument is used to measure voltage across the dummy load. As the dummy load resistance R is fixed and known then power is V2 / R where V is voltage measured by a.c. voltmeter. In such a case the scale of the a.c. voltmeter can be calibrated to measure the power output of the device under test. This scale is calibrated in decibels as the power measured at audio frequency range is generally specified in decibels(dB).

**Power measurement at radio frequency:**

The method of using a dummy load and a voltmeter can be used at radio frequencies upto 500 MHz also. In such a case, the voltmeter and load resistor are usually combined into a sirtgle absorption type power meter as shown in the Fig.



The resistance Rs is so designed that its value remains constant over the entire range of frequencies of interest. The voltmeter is a high "requency meter which is capable of responding to high frequency signals with high accuracy. The power is calculated by using the basic relationship as,

$$P = \frac{V_s^2}{R_s}$$

where $V_s$ = Voltmeter reading

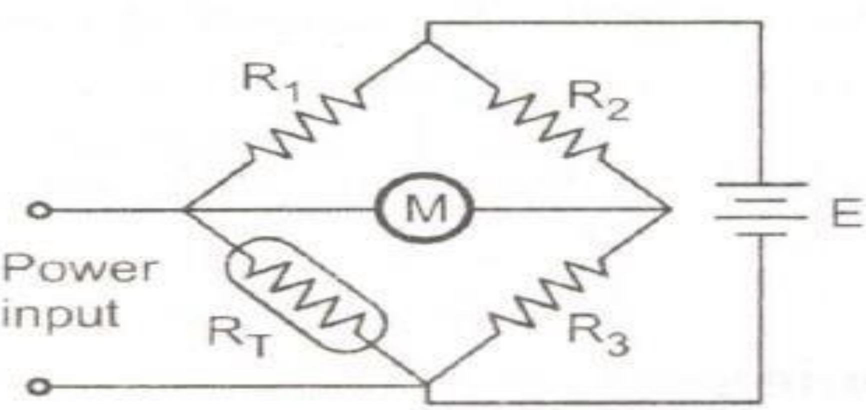
In practice the standard resistors are available which have constant value for frequencies ranging from d.c. to 4 GHz. This type of power meter is used to measure power below 500 MHz only.

To measure power at high frequencies from 500 MHz to 40 GHz two special type of absorption meters are popularly used. These meters are,

1. Calorimeter powermeter
2. Bolometer powermeter

Both these meters use the sensing of heating effects caused by the power signal to be measured.

**Introduction to Bolometer power meter:**




The Bolometer power meter basically consists of a bridge called Bolometer bridge. One of the arms of this bridge consists of a temperature sensitive resistor. The basic bridge used in Bolometer power meter is shown in the Fig.The high frequency power input is applied to the temperature sensitive resistor RT. The power is absorbed by the resistor and gets heated due to the high frequency power input signal.

This heat generated causes change in the resistance RT. This change in resistance is measured with the help of bridge circuit which is proportional to the power to be measured.

The most common type of temperature sensitive resistors are the thermistor and barretter. The thermistor is a resistor that has large but negative temperature coefficient. It is made up of a semiconductor material. Thus its resistance decreases as the temperature increases. The barretter consists of short length of fine wire or thin film having positive temperature coefficient. Thus its resistance increases as the temperature increases. The barretters are very deli<::ate while thermistors are rugged. The bolometer power meters are llsed to measure radio frequency power in the range 0.1 to 10 mW.

In modern bolometer power meter set up uses the differential amplifier und bridge [orl11 an oscillator which oscillates at a particular amplitude when bridge is unbalanced. The modern bolometer power meter circuit is shown in the Fig.

Initially when temperature sensitive resistor is cold, bridge is almost balance. With d.c. bias, exact balance is achieved. When power input at high frequency is applied to RT, it absorbs power and gets heated. Due to this its resistance changes causing bridge unbalance. This unbalance is in the direction opposite to that of initial cold resistance. Due to this, output from the oscillator decreases to achieve bridgebalance.

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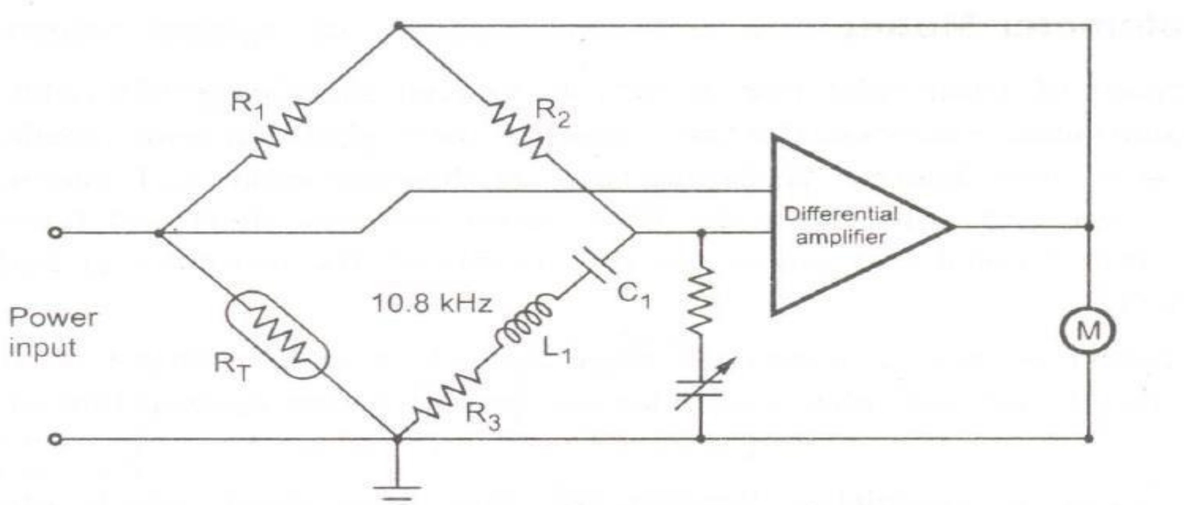


## BOLOMETER ELEMENTS :

Basically a bolometer is very short thin wire. A wire with positive temperature coefficient of resistance is called Baretter. Similarly a wire with negative temperature coefficient of resistance is called thermistor. Both are able to measure small power of the order of microwatts.

A metal wire bolometer i.e. barreter has a positive temperature coefficient of resistance (PTC). It is operated at powers which heat wire upto 100 - 200°C. The metal wire bolometer consists a short length of Wollaston wire. Its external sheath is etched away so that its thin metal core consisting platinum alloy is exposed. The length of such wires IS extremely small (typically 2.5 mm). The diameter of such wires range from 1 to 3 micron.For perfect match with the R.F. line, resistance of the depleted region is adjusted suitably for bias with low powers. This value is generally equal to the characteristicimpedance.

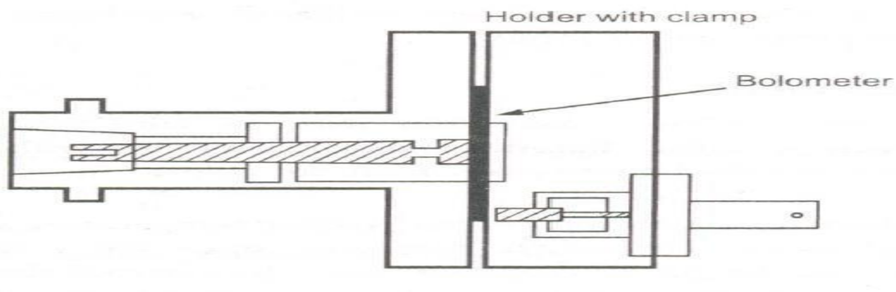
For R.F. measurements, the minute beads of ceramic such as semiconductor mixtures of metal oxides with large negative temperature coefficient of resistance (NTC) are used as thermistors. Such beads consists two platinum alloy wires. Then the bead is sintered and coated with glass film. The beads are capsuled in glass envelope.

line, the bolometer element is made of very small size. Such element responses equally well to low frequency and R.F. power.

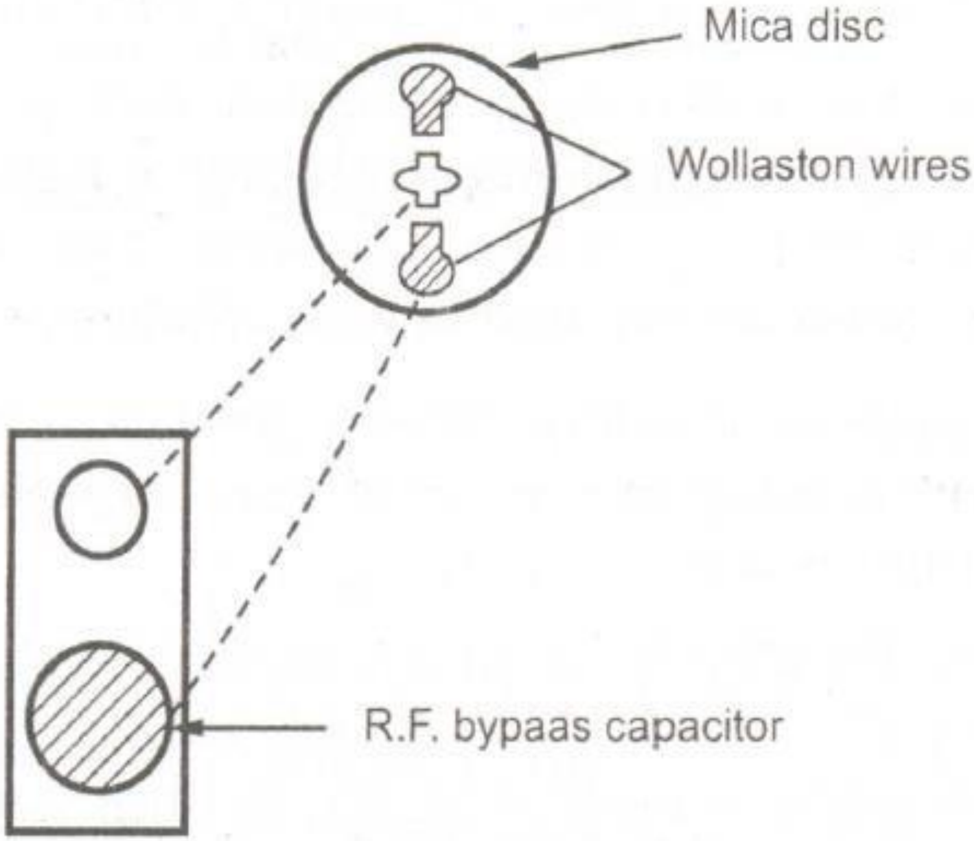
In most of the elements, the diameter of wire is selected equal to the skin depth of R.F.current at highest frequency of operation. Typically d.c. and R.F. resistivities of the element are same. The reactive component *is* made negligible for such elements. As the maximumcross-section area of the bolometer wire is inversely proportional to the highest frequency of 0rerahon and conductivity of the bolometer material, the wires of the bolometer are ultra 'hin at microwavefrequency.

**Bolometer mount:**

It consists of a thin mica disc. It consists sprayed silver electrodes. There are through silver plated holes which enables the contact of outer electrode with circular electrode on opposite side. Two depleted Wollatone wires of diameter equal to 1 micron are mounted between centre and outer electrode. These wires are very short and typically of length 1 - 2 mm. With normal bias power, for d.c. conditions, the resistance of both the wires is about 100 D. The holder is used to clamp the mica disc which makes contact of upper electrode with the metal case andother electrodes are insulated from co-axial line as shown in the Fig. The circuit is completed through the thin mica sheet which provides bypass capacitance.



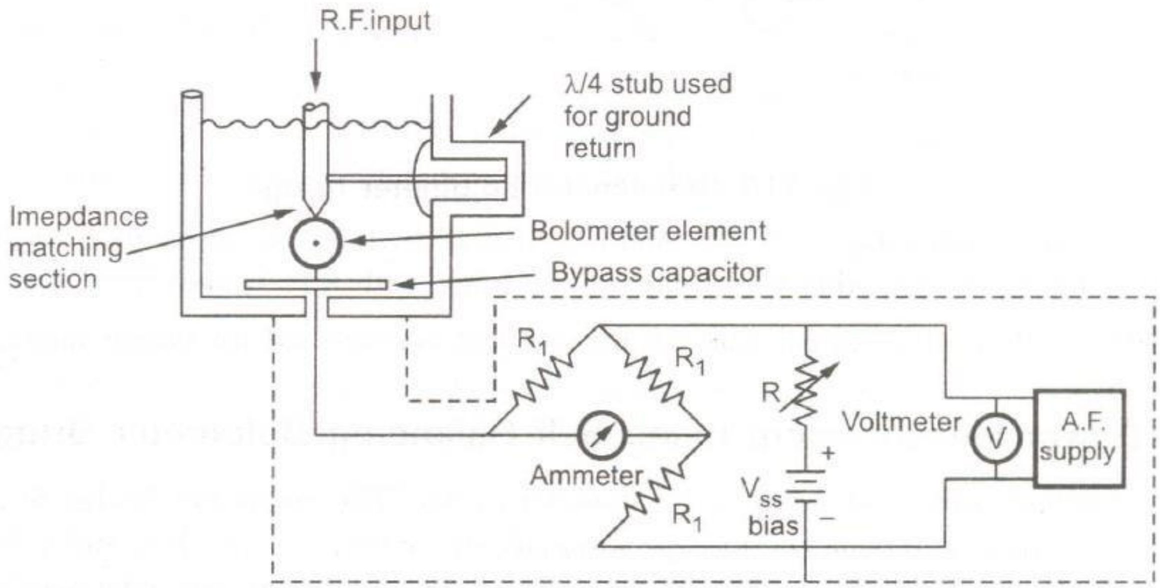

(a) Bolometer mount




(b) Bolometer element

# Bolometer Bridge for Measurement of Power

The measurement of unknown RF. power is done by using bolometer bridge in which a known A.F. power is superimposed on unknown RF. power. The schematic of power measurement using bolometer bridge is as shown in the Fig.



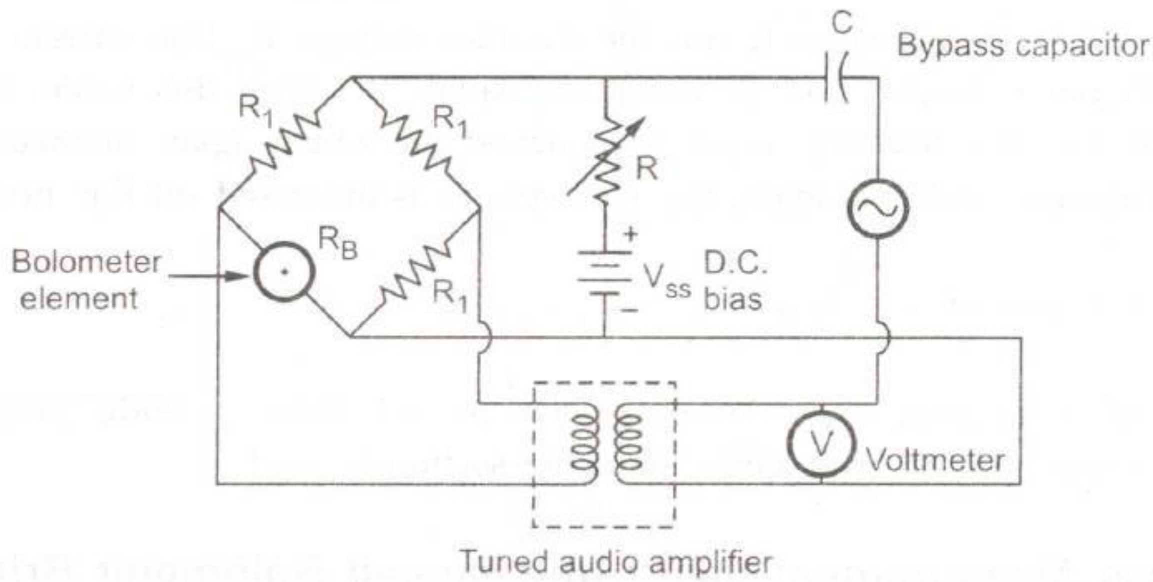

Using the variable resistance R and the d.c. bias voltage Yss, the current is adjusted till bolometer element is heated and its resistance equals R1. With this value, bridge achieves balance condition. The test RF. input is switched off which again unbalances bridge. To achieve the balance condition again, the A.F. voltage is increased till RF. power equals

When the KF. powe~ is dissipated in the bolometer element, the bridge again becomes unblanced. But again the output voltage of amplifier readjusts the balancing condition automatically by restoring the value of bolometer resistance. Note that the amount of A.F. power level reduces in the bolometer isequal to the unknown C applied KF.power.The voltmeter V measures A.F. voltage

$$\text{R.F. power} = \frac{V_2^2 - V_1^2}{4R_1}$$

**Power measurement using self balancing bolometer**

This method uses a self balancing bolometer bridge. The bolometer bridge is called self bal,lIlcing because it rebalances bridge automatically whenever the bolometer element is supplied with unknown KF. power. A typical circuit diagram for self balancing bolometer bridge is as shown in the Fig.




This method uses an audio amplifier which is high gain frequency selective amplifier.The input and output terminals of the amplifier are coupled through bolometer bridge. The feedback used in amplifier produces sustained A.F. oscillations and also maintains the resistance of the bolometer at a fixed value required for balanced condition.

When the supply is switched ON, the bolometer bridge becomes unbalance. But due to the oscillations produced with a proper phase, the bridge becomes almost balanced. The gain of the tuned audio amplifier plays important role. That means if the gain of the amplifier is higher then the bolometer bridge balancesclosely.

When the KF. power is dissipated in the bolometer element, the bridge again becomes unblanced. But again the output voltage of amplifier readjusts the balancing condition automatically by restoring the value of bolometer resistance. Note that the amount of A.F. power level reduces in thebolometerisequaltotheunknownappliedKF.power.ThevoltmeterVmeasuresA.F.voltage and it is calibrated in such a way that the magnitude of the KF. power is read directly.A typical self balancing bolometer bridge circuit can be used for measurement of several power ranges from 0.1 mW to 100 mW. In such circuit, the bolometer used has a resistance with five selected values form 50 n to 250 n within + 10 % range.

**Introduction to Signal conditioning: Introduction:**

The primary objective of industrial process control is to control physical parameters such as temperature, pressure, flow rate, level, force, light intensity, and so on. The process control system is designed to maintain these parameters near some desired specific value.

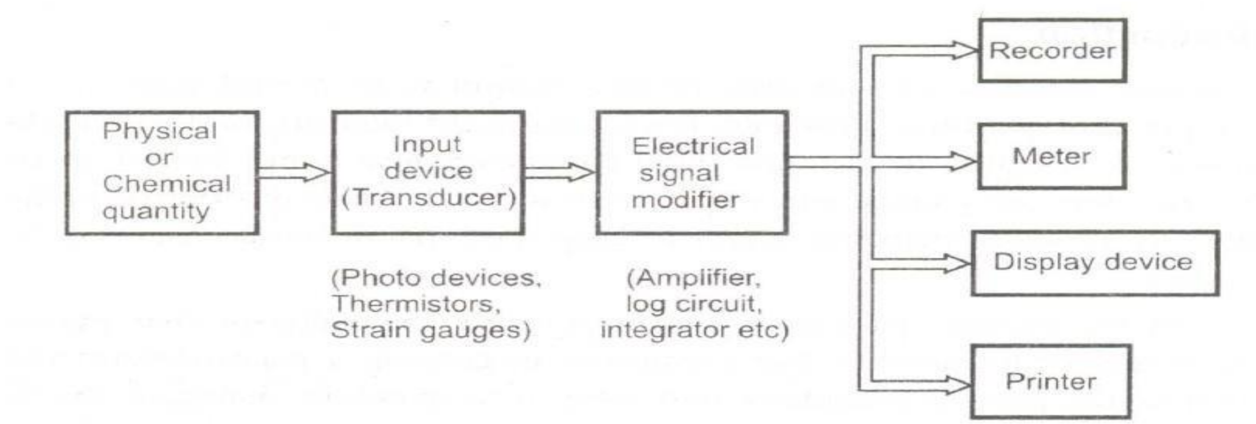
As these parameters can change either spontaneously or because of external influences, we must constantly provide corrective action to keep these parameters constant or within the specified range.

To control the process parameter, we must know the value of that parameter and hence it is necessary to measure that parameter. **In** general, a measurement refers to the transduction of the process parameter into some corresponding analog of the parameter, such as a pneumatic pressure, an electric voltage, or current. A **transducer** is a device that performs the initial measurement and energy conversion of a process parameter into analogous electrical or pneumatic information. Many times further transformation or signal enhancement may be required to complete the measurement function. Such processing is known as **signalconditioning.**

**Electronic aided measurement:**

For any measurement system., the first stage detects the physical quantity to be measured this is done with the help of suitable transducer. The next stage converts this signal into an electrical form. The second stage is used to amplify the converted signal such that it becomes usable and suitable for the last stage which is signal conditioning stage. The last stage includes various elements used for different purposes such as indicating, recording, displaying, data processing and controlelements.

typical electronic aided measurement system is as shown in the Fig



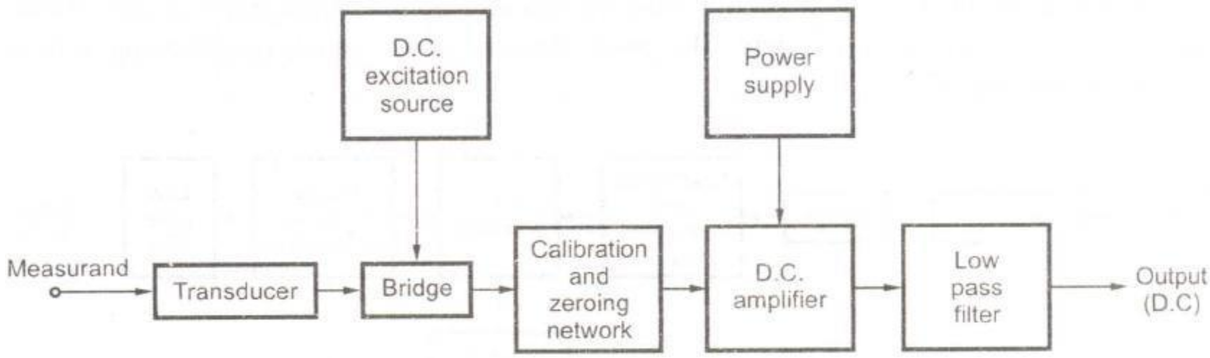

The first stage is the input device which is nothing but a transducer which converts measurand into an usable form i.e. electrical signal. In other words, the quantity measured is encoded as an electrical signal. The next stage modifies the electrical signal in the form suitable for the output or read-out devices. Generally the most frequently used electronic circuits are amplifiers, with parameter adjustments and automatic compensation circuits specially used for temperature variation. of the input device and non-linearities of the input device. The output is obtained from read-out devices such as meter, recorder, printer,display unitsetc.

In general, the quantity which is measured by using transducer can be encoded in different ways. For example, as a physical or chemical quantity or property, as a characteristics of the electrical signal, as a number. The property or different characteristics used to represent a data is called **data** domain.

The electronic aided measurement system represents the measurement of physical quantity faithfully in the analog or digital form of it obtained from the signal conditioning circuits. For passive transducers, the signal conditioning circuit mainly' includes excitation and amplification circuitry, while for active transducers, only amplification circuitry is needed and the excitation is not needed. Depending on the type of the excitation either a.c. or d.c. source, we have a.c. signal conditioning system and d.c. signal conditioning system.

**D.C. Signal Conditioning System:**

The block diagram of d.c. signal conditioning system is shown in the Fig




The resistance transducers are commonly used for the d.c. systems. The resistance transducers like strain gauge forms one or more arms of a wheatstone bridge circuit. A separate d.c. supply is required for the bridge. The bridge is balanced using potentiometer and can be calibrated for unbalanced conditions. This is the function of Cdlibration and zeroing network. Then there is d.c. amplifier which also reqUIresi..l separate d.c. supply.

The d.c. amplifier must have following characteristics:

1. Balanced differentialinputs.
2. High common mode rejection ratio.(CMRR)
3. Hlgh inputimpedance.
4. Good thermal and long term stability. The d.c. system has followingadvantages:

1. It is easy to calibrate at lowfrequencies.
2. It is able to recover from an overload condition.

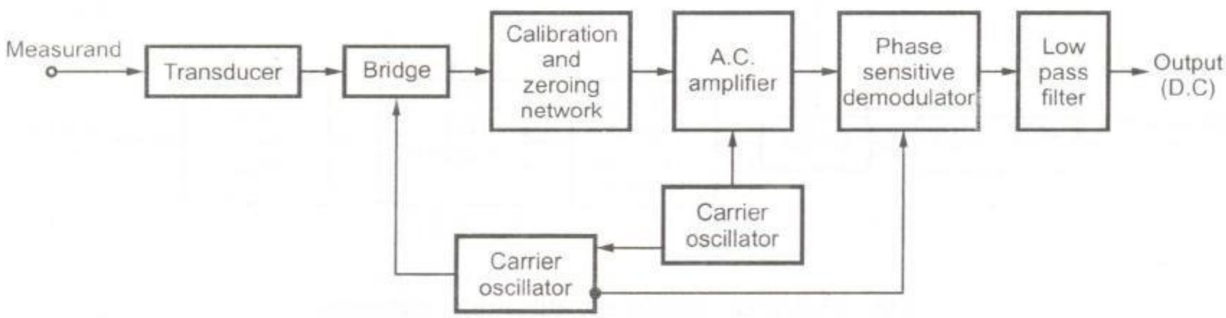
But the main disadvantage of d.c. system is that it suffers from the problems of drift.The low frequency spurious unwanted signals are available alongwith the required data signal. For overcoming this, low drift d.c. amplifiers are required.

The output of d.c. amplifier is given to a low pass filter. The function of low pass filter is to elliminate unwanted high frequency components or noise from the required data signzd. Thus the output of low pass filter is the required data signal. Thus the output of low pass filter is the required d.c. output from the d.c. signal conditioningsystem.

The applications of such system are in use with common resistance transducers such as potentiometers and resistance straingauges.

**A.C. Signal ConditioningSystem:**

The limitation of d.c. signal conditioning system can be overcome upto certain extent, using a.c. signal conditioning system. The block diagram of a.c. signal conditioning system is shown in the Fig




This is carrier type a.c. signal conditioning system. The transducer used is variable resistance or variable inductance transducer. The carrier oscillator generates a carrier signal of the frequency of about 50 Hz to 200 kHz. The carrier frequencies are higher and are <ltleast5 to 10 times the signal frequencies.

The bridge output is amplitude modulated carrier frequency signal. The a.c. amplifier is used to amplify this signal. A separate power supply is required for the a.c. amplifier.

The amplified signal is demodulated using phase sensitive demodulator. The advantage of using phase sensitive demodulator is that the polarity of d.c. output indicates the direction of the parameter change in the bridge output.

Unless and until spurious and noise signals modulate the carrier, they will not affect the data signal quality and till then are not important. Active filters are used to reject mains frequency pick up. This prevents the overloading of a.c. amplifier. Filtering out of carrier frequency components of the data signal is done by phase sensitivedemodulator.

The applications of such system are in use with variable reactance transducers and for the systems where signals are required to be transmitted through long cables, to connect the transducers to the signal conditioningsystem.

**Introduction:**

The digital voltmeters generally referred as DVM, convert the analog signals into digital and display the voltages to be measured as discrete numericals instead of pointer deflection, on the digital displays. Such voltmeters can be used to measure a.c. and d.c. voltages and also to measure the quantities like pressure, temperature, stress etc. using proper transducer and signal conditioning circuit. The transducer converts the quantity into the proportional voltage signal and signal conditioning circuit brings the signal into the proper limits which can be easily measured by the digital voltmeter. The output voltage is displayed on the digital display on the front panel. Such a digital output reduces the human reading and interpolation errors and parallax errors. The DVMs have various features and the advantages, over the conventional analog voltmeters having pointer deflection on the continuous scale.

**Performance parameters of digital voltmeters:**

1. **Number of measurementranges:**

The basic range of any DVM is either 1V or 10 V. With the help of attenuator at the input, the range can be extended from few microvolts to kilovolts.

2. **Number of digits in readout:** The number of digits of DVMs vary from 3 to 6. More the number of digits, more is theresolution.

3. **Accuracy:** The accuracy depends on resolution and resolution on number of digits. Hence more number of digits means more accuracy. The accuracy is as high upto ± 0.005% of thereading.

4. **Speed of the reading:** In the digital voltmeters, it is necessary to convert analog signal into digital signal. The various techniques are used to achieve this conversion. The circuits which are used to achieve such conversion are called digitizing circuits and the process is called digitizing. The time required for this conversion is called digitizing period. The maximum speed of reading and the digitizing period are interrelated. The instrument user must wait, till a stable reading is obtained as it is impossible to follow the visual readout at high readingspeeds.

5. **Normal mode noise rejection:** This is usually obtained through the input filtering or by use of the integration techniques. The noise present at the input, if passed to the analog to digital converting circuit then it can produce the error, especially when meter is used for low voltage measurement. Hence noise is required to befiltered.

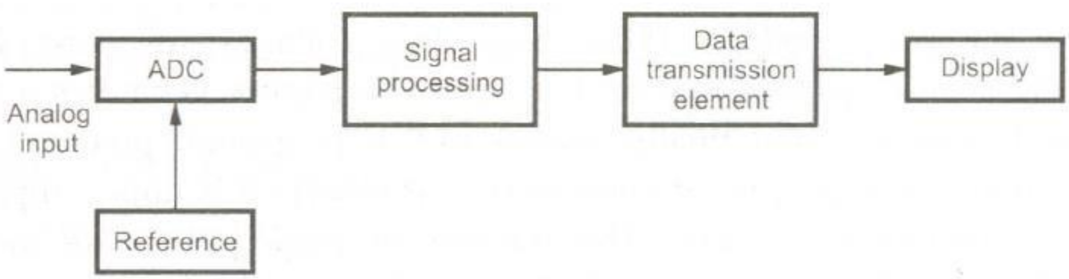
6. **Common mode noise rejection :**This is usually obtained by guarding. A guard is a sheet metal box sourrounding the circuitry. A terminal at the front panel makes this 'box' available to the circuit undermeasurement.

7. **Digital output of several types:** The digital readout of the instrument may be 4 line BCD, single line serial output etc. Thus the type of digital output also determines the variety of the digitalvoltmeter.

8. **Input impedance :**The input impedance of DVM must be as high as possible which red l1ces the loading effects. Typically it is of the order of 10:M.ohm.

**Block diagram of DVM:**

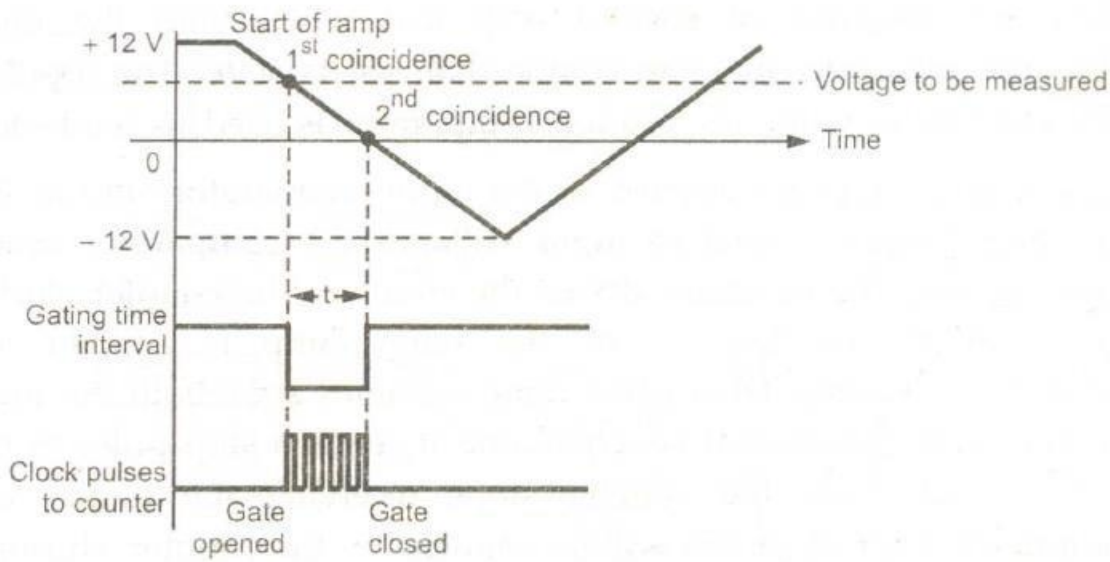
Any digital instrument requires analog to digital converter at its input. Hence first block in a general DVM is ADC as shown in the Fig.




Every ADC requires a reference. The reference is generated internally and reference generator circuitry depends on the type of ADC technique used. The output of ADC is decoded and signal is processed in the decoding stage. Such a decoding is necessary to drive the seven segment display. The data from decoder is then transmitted to the display. The data transmission element may be a latches, counters etc. as per the requirement. A digital display shows the necessary digital result of the measurement.

**Ramp type DVM: Linear ramp technique:**

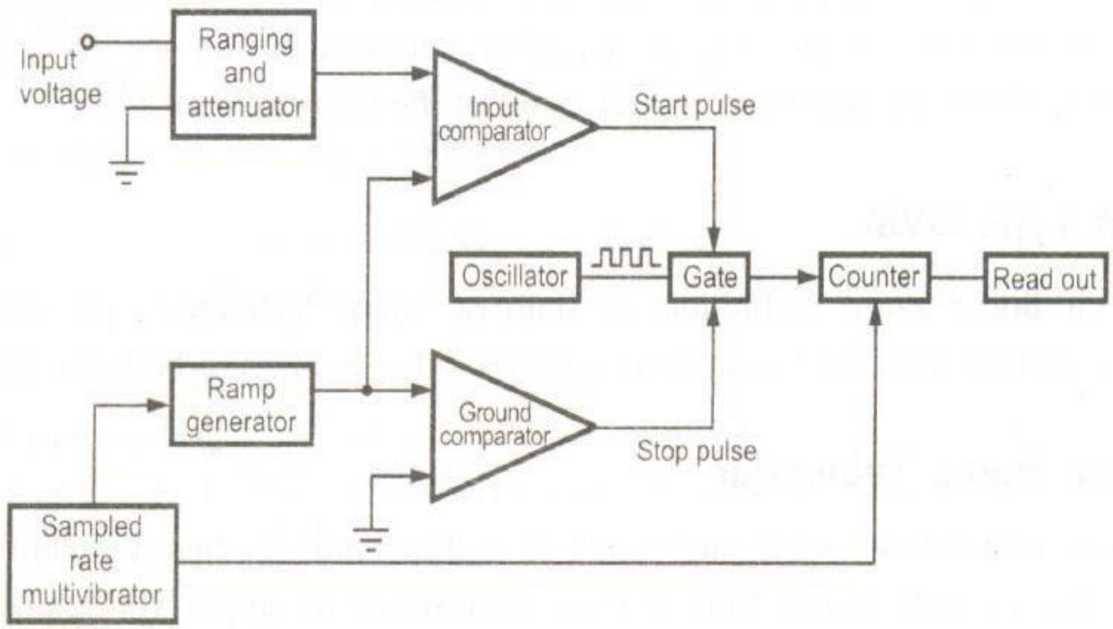
The basic principle of such measurement is based on the measurement of the time taken by l1 linear ramp to rise from a V to the level of the input voltage or to decrease from the level of the input voltage to zero. This time is measured with the help of electronic time interval counter and the count is displayed in the numeric form with the help of a digitaldisplay.




Basically it consists of a linear ramp which is positive going or negative going. The range of the ramp is ± 12 V while the base range is ± 10 V. The conversion from a *voltage* to c1 time interval is shown in the fig

At the start of measurement, a ramp *voltage* is initiated which is continuously compared with the input voltage. When these two voltages are same, the comparator generates a pulse which opens a gate i.e. the input comparator generates a start pulse. The ramp continues to decrease and finally reaches to 0 V or ground potential. This is sensed by the second comparator or ground comparator. At exactly 0 V, this comparator produces a stop pulse which closes the gate. The number of clock pulses are measured by the counter. Thus the time duration for which the gate is opened, is proportional to the input voltage. fn the time interval between start and stop pulses, the gate remains open and the oscillator circuit drives the counter. The magnitude of the count indicates the magnitude of the input voltage, which is displayed by the display. The block diagram of linear ramp DVM is shown in the Fig.

Thus the time duration for which the gate is opened, is proportional to the input voltage. fn the time interval between start and stop pulses, the gate remains open and the oscillator circuit drives the counter. The magnitude of the count indicates the magnitude of the input voltage, which is displayed by the display. The block diagram of linear ramp DVM is shown in the Fig




Properly attenuated input signal is applied as one input to the input comparator. The ramp generator generates the proper linear ramp signal which is applied to both tne comparators. Initially the logic circuit sends a reset signal to the counter and the readout. The comparators are designed in such a way that when both the input signals of comparator are equal then only the comparator changes its state. The input comparator is used to send the start pulse while the ground comparator is used to send the stoppulse.

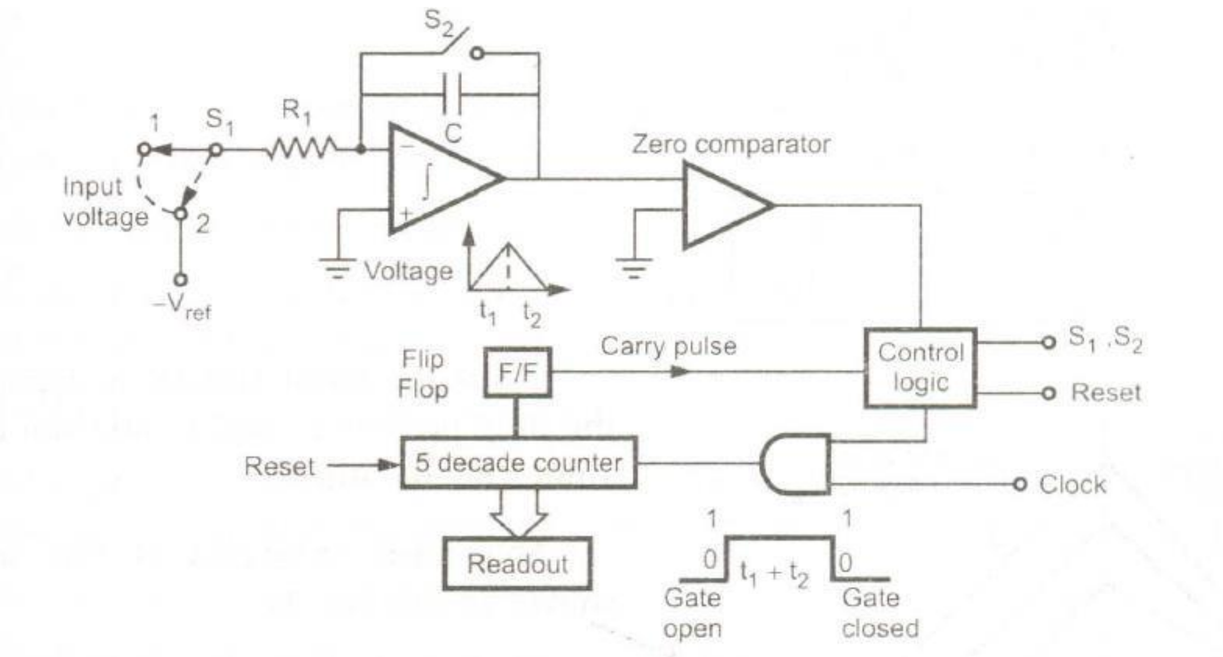
When the input and ramp are applied to the input comparator, and at the point when negative going ramp becomes equal to input voltages the comparator sends start pulse, due to which gate opens. The oscillator drives the counter. The counter starts counting the pulses *received* from the oscillator. Now the same ramp is applied to the ground comparator and it is decreasing. Thus when ramp becomes zero, both the inputs of ground compaotor becomes zero (grounded) i.e. equal and it sends a stop pulse to the gate due to which gate gets closed. Thus the counter stops receiving the pulses from the local oscillator. A definite number of pulses will be counted by the counter, during the start and stop pulses which is measure of the input voltage. This is displayed by the digital readout.'

he sample rate multivibrator determines the rate at which the measurement cycles are initiated. The oscillation of this multivibrator is usually adjusted by a front panel control named rate, from few measuring cycles/second with an accuracy of ± 0.005% of the reading. The sample rate provides an initiating pulse to the ramp generator to start its next ramp voltage. At the same time, a reset pulse is also generated which resets the counter to the zerostate.

**Dual slope integrating type DVM:**

This is the most popular method of analog to digital conversion. In the ramp techniques, the noise can cause large errors but in dual slope method the noise is averaged out by the positive and negative ramps using the process of integration. The basic principle of this method is that the input signal is integrated for a fixed interval of time. And then the same integrator is used to integrate the reference voltage with reverse slope. Hence the name given to the technique is **dual** slope integration technique.

The block diagram of dual slope integrating type DVM is shown in the Fig. It consists of five blocks, an op-amp used as an integrator, a zero comparator, clock pulse generator, a set of decimal counters and a block of control logic.




When the switch Sl is in position 1, the capacitor C starts charging from zero level. The rate of charging is proportional to the input voltage level. The output of the op-amp is given by,

$$V_{out} = -\frac{1}{R_1 C}\int_0^{t_1} V_{in}\, dt$$

$$\therefore \quad \boxed{V_{out} = -\frac{V_{in}\, t_1}{R_1\, C}}$$

where $t_1$ = Time for which capacitor is charged

$V_{in}$ = Input voltage

$R_1$ = Series resistance

$C$ = Capacitor in feedback path

After the interval t I, the input voltage is disconnected and a negative voltage -Vref is connected by throwing the switch S1 in position 2. In this position, the output of the op-ilmp is given by,

$$V_{out} = \frac{1}{R_1 C}\int_0^{t_2} -V_{ref}\, dt$$

$$\boxed{V_{out} = -\frac{V_{ref}\, t_2}{R_1\, C}}$$

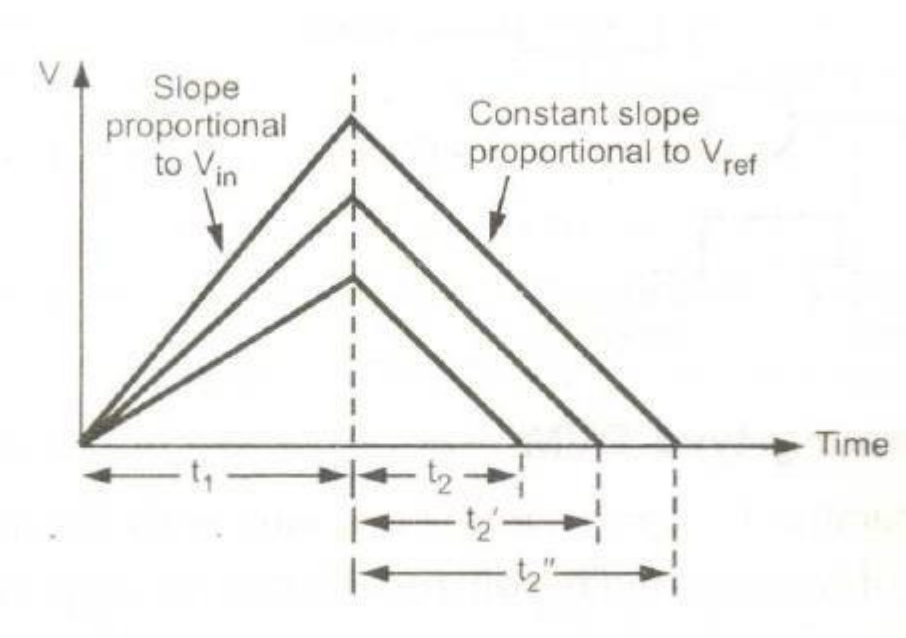
Subtracting (1) from (2),

$$V_{out} - V_{out} = 0 = \frac{-V_{ref}\, t_2}{R_1\, C} - \left(\frac{-V_{in}\, t_1}{R_1\, C}\right)$$

$$\therefore \quad \frac{V_{ref}\, t_2}{R_1\, C} = \frac{V_{in}\, t_1}{R_1\, C}$$

$$\therefore \quad V_{ref}\, t_2 = V_{in}\, t_1$$

$$\therefore \quad \boxed{V_{in} = V_{ref} \cdot \frac{t_2}{t_1}}$$




Thus the input voltage is dependent on the time periods t] and t2 and not on the values of R] and C. This basic principle of this method is shown in the Fig.

At the start of the measurement, the counter is resetted to zero. The output of the flip-flop is also zero. This is given to the control logic. This control sends a signal so as to close an electronic switch to position 1 and integration of the input voltage starts. It continues till the time period t.

As the output of the integrator changes from its zero value, the zero comparator output changes its state. This provides a signal to control logic which inturn opens the gate and the counting of the clock pulses starts.

The counter counts the pulses and when it reaches to 9999, it generates a carry pulse and all digits go to zero. The flip flop output gets activated to the logic level T. This activates the control logic. This sends a signal which changes the switch 5\ position from 1 to 2 Thus -Vref gets connected to op-amp. As Vref polarity is opposite, the capacitor starts discharging. The integrator output will have constant negative slope as shown in th Fig. 3.5"1. The output decreases linearly and after the interval t2, attains zero value, when the capacitor C gets fully discharged.

From equation (3) we can write,

$$V_{in} = V_{ref} \cdot \frac{t_2}{t_1}$$

Let time period of clock oscillator be T and digital counter has counted the counts n1 and n2 during the period t] and t2respectively.

$$V_{in} = V_{ref} \cdot \frac{n_2 T}{n_1 T} = V_{ref} \cdot \frac{n_2}{n_1}$$

Thus the unknown voltage measurement is not dependent on the clock frequency, but dependent on the counts measured by thecounter.

The advantages of this technique are:

i) Excellent noise rejection as noise and superimposed a.c. are averaged out during the process of integration.

ii) The RC time constant does not affect the input voltagemeasurement.

iii) The capacitor is connected via an electronic switch. This capacitor is an auto zero capacitor and avoids the effects of offsetvoltage.

iv) The integrator responds to the average value of the input hence sample and hold circuit is not necessary.

v) The accuracy is high and can be readily varied according to the specificrequirements.

The only disadvantage of this type of DVM is its slow speed.

**V – F converter type integrating DVM**:

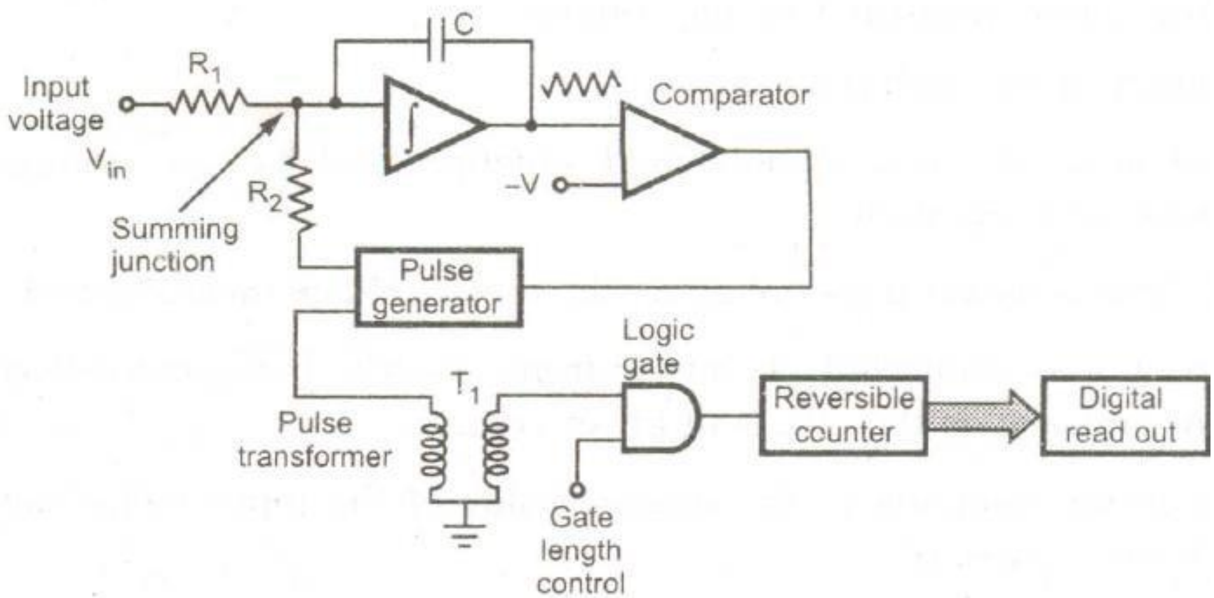
In case of ramp type DVM, the voltage is converted to time. The time and frequency are related to each other. Thus the voltage can be converted to frequency for the measurement purpose. A train of pulses, whose frequency depends upon the voltage being measured, is generated. Then the number of pulses appearing in a definite interval of time is counted . Since the frequency of these pulses is a function of the unknown voltage, the number of pulses counted in that period of time is the indication of the unknown input voltage.

The heart of such integrating type of DVM is the operational amplifier used as an integrator. The input voltage is integrated for a fixed interval. An integration of a constant input voltage results a ramp at the output, the slope of which is proportional to the input voltage. If the inputispositive,theoutputofop-ampisnegativegoingramp.Aftersometime,thecapacitoris discharged to 0, thus output returns back to zero and the next cycle begins. Hence the waveform at the output is a sawtooth waveform as shown in the Fig.


If the input signal is doubled, the number of teeth in the output signal per unit time will be also doubled. Thus the frequency of the output will be doubled. Thus the frequency of the output is proportional to the input voltage. This is nothing but the voltage to frequency conversion.

The sawtooth pulses are finally enter into a reversible counter. The measured value by the reversible counter is finally displayed with the help of digital readout.

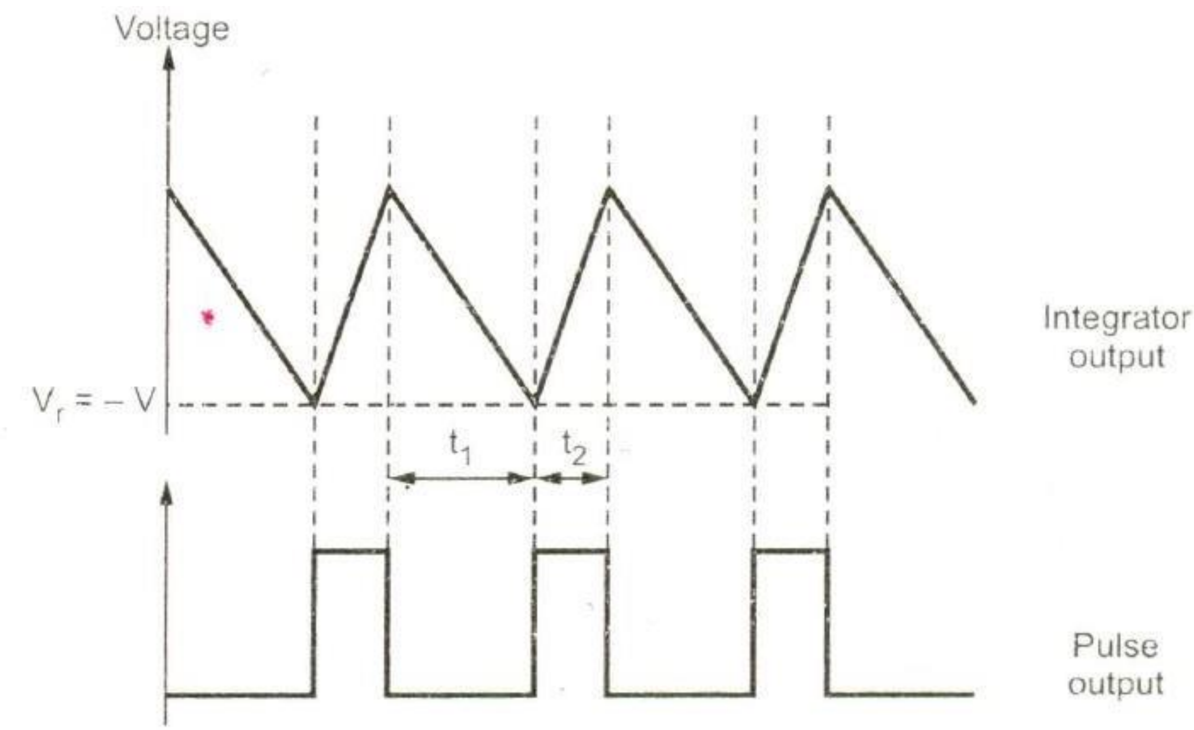
The block diagram of voltage to frequency converter type integrating DVM is shown in the Fig.




Initially output of an integrator is adjusted to zero volts. When the input voltage Vi" is applied, the charging current Vin /Rj flows, which starts the charging of the capacitor C. This produces a ramp at the output. When input voltage is positive, the output ramp is negative going. This ramp is given as one input of a comparator. A -V volts is given as a reference to the second input terminal of a comparator. The negative going ramp and – V volts reference are compared by the comparator. When the ramp reaches to -V volts, the comparator output changes its state. This signal triggers the pulse generator. The function of the pulse generator is to produce a pulse of precision charge content. The polarity of this charge is opposite to that of capacitor charge. Thus the pulse generated by the pulse generator rapidly discharges the capacitor. Hence the output of the op-amp again becomes zero. This process continues so as to get a sawtooth waveform at the output of op-amp. The frequency of such waveform is directly proportional to the applied input voltage. Thus if the input voltage increases, the number of teeth per unit time in the sawtooth waveform also increases i.e. the frequencyincreases.

Each teeth produces a pulse at the output of the pulse generator so number of pulses is directly related to the number of teeth i.e. the frequency. These pulses are allowed to pass through the pulse transformer. These are applied at one input of the gate. Gate length control signal is applied at the other input. The gate length' may be 0.1 sec, Isec, 20 msec etc. The gate remains open for this much timeperiod.

The wavefoms of integrator output and output of a pulse generator are shown In the Fig




From the analysis of dual slope technique, we can write,

$$V_{in} = V_r \frac{t_2}{t_1}$$

But in this type, both V1 and t2 are constants.

$$K_2 = V_r t_2$$

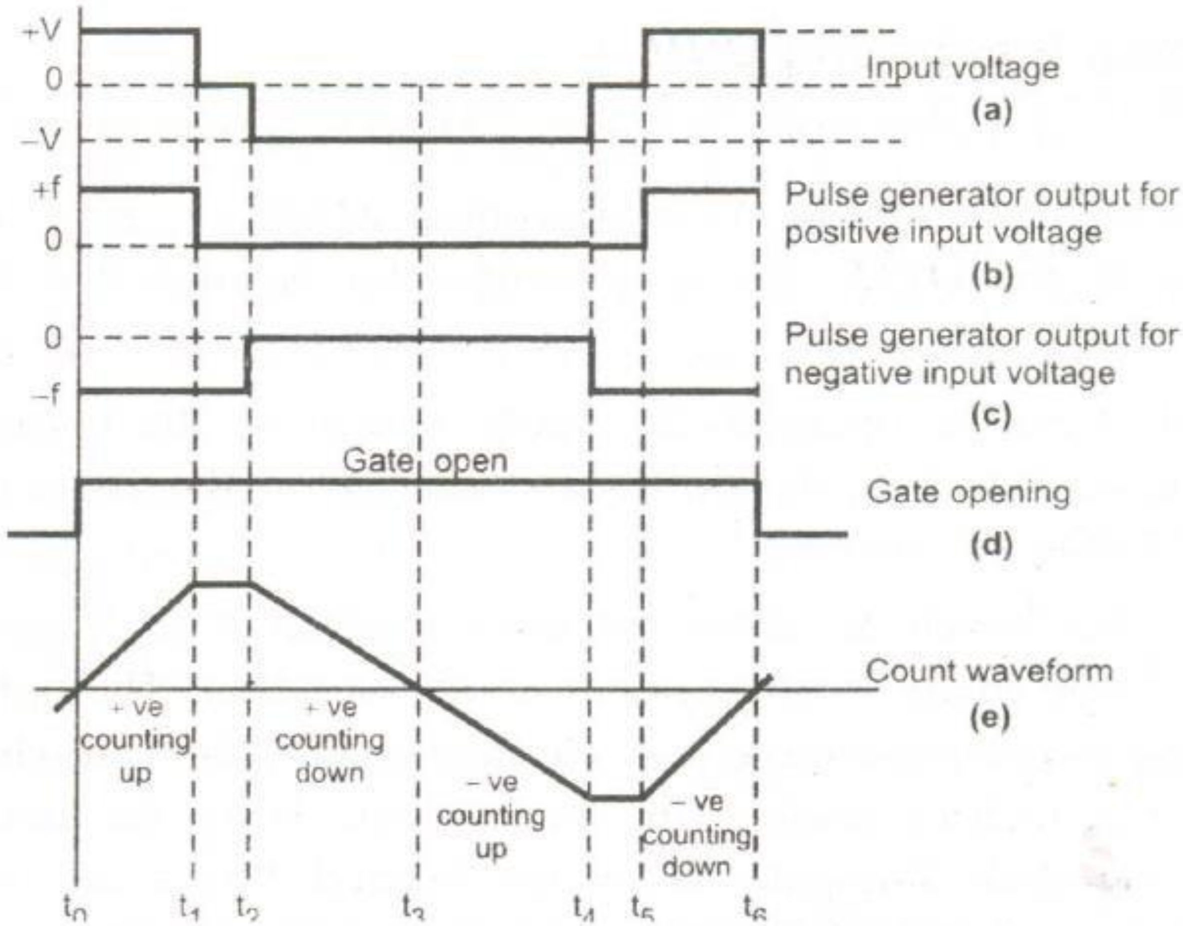
$$\boxed{V_{in} = K_2\left(\frac{1}{t_1}\right) = K_2(f_o)}$$

Accuracy: The accuracy of voltage to frequency conversion technique depends on the magnitude and stability of the charge produced by the pulse generator. Thus the, accuracy depends on the precision of the charge fedback in every pulse and also on the linearity, between voltage and frequency.
To obtain the better accuracy the rate of pulses generated by the pulse generator is kept equal to,

i) the voltage time integration of the input signal ii) the total voltage time areas of the feedbackpulses.

When input voltage polarity is positive i.e. for the periods t (t0 to t1 and t5 to t6 the output of the pulse generator is high. For other time period it is low. This is shown in the Fig . When the input voltage polarity is negative i.e. for the period t 1 to t 4 the output of the pulse generator is high. This is due to other pulse generator used for the bipolar voltages. This is shown in the Fig. For the period t0 to t1, it is positive counting up. For the period t2 to t3 it is positive counting down. For t 3 to t 4 negative counting up while for the period t 5 to t6, it is negative countingdown.

**Transfer characteristics :**The transfer characteristics show the relation between the input voltage and the output frequency. This should be as linear as possible. It remains linear upto a frequency called **saturation frequency.** This is shown in the Fig. The slope of both the positive and negative voltage characteristics must be same.

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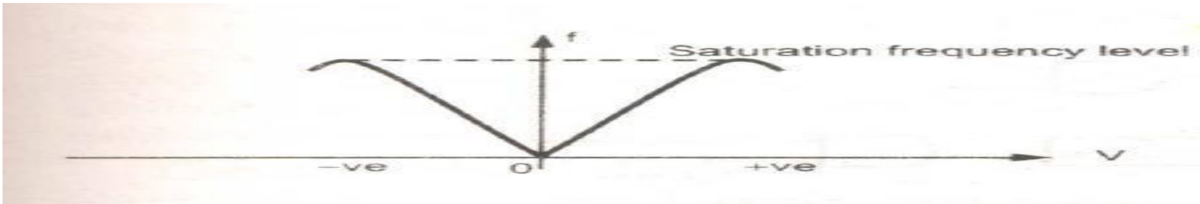


To increase the operating speed of this type of DVM, the upper frequency can be increased i.e. increasing V*I* f conversion rate. But this results into reduced accuracy and design cost of such circuit is also very high. Hence another method in which 5 digit resolution is available, is used to increase the speed of operation. This is the modified version of V*I* f integrating type DVM and is called interpolating integrating DVM.

**Interpolating Integrating DVM:**

The block diagram of interpolating integrating DVM is shown in the Fig.

This is a modified version of V*If* integrating DVM. A zero comparator is the additional circuitry in the DVM. The zero comparator ensures that the charge on the capacitor is zero. During first 20 msec, the operation is exactly similar to the normal V*If* integrating DVM. However during this time the pulses are directed to the 100 s decade. Here each pulse is equivalent to the 100counts.

After 20 msec, the switch SI is moved from position 1 to 2 and Vrer of opposite polarity is offered. Some charge is still present on the capacitor. The opposite polarity Vrer helps to remove the remaining charge at a constant rate. When the charge reaches zero, the zero comparator provides a pulse to the control logic. When the switch is moved from position 1 to 2, at the same time gate G2 is also opened. Hence the pulses from 50 kHz oscillator can reach to Is decade. When the zero comparator provides a pulse, the gate G1 is closed. This completes the reading operation.

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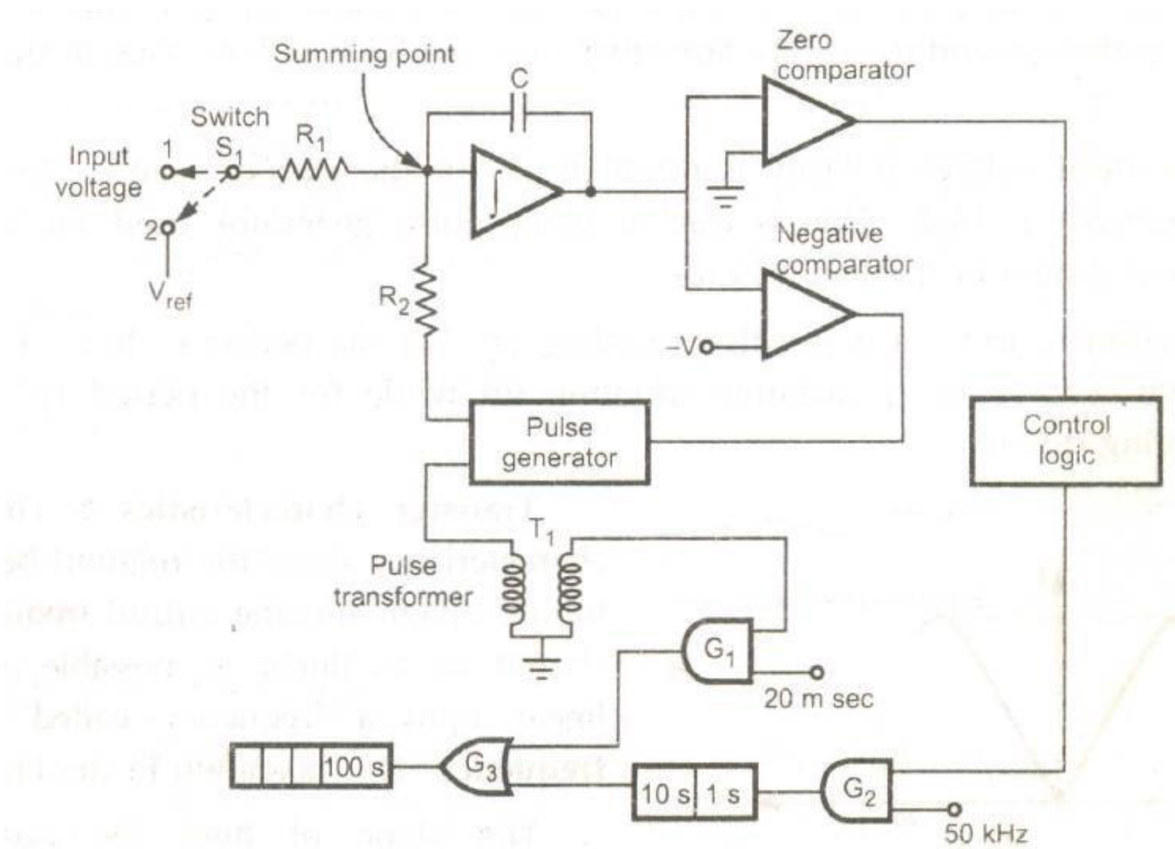
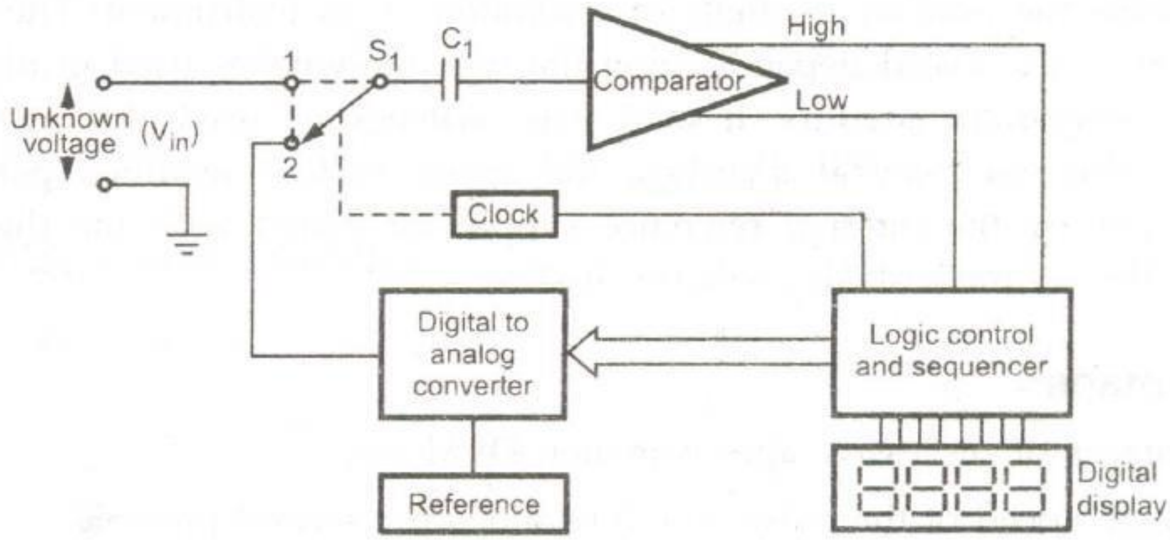



**Successive approximation type DVM:**

In successive approximation type DVM, the comparator compares the output of digital to analog converter with the unknown voltage. Accordingly, the comparator provides logic high or low signals. The digital to analog converter successively generates the set pattern of signals. The procedure continues till the output of the digital to analog converter becomes equal to the unknown voltage.

After 20 msec, the switch SI is moved from position 1 to 2 and Vrer of opposite polarity is offered. Some charge is still present on the capacitor. The opposite polarity Vrer helps to remove the remaining charge at a constant rate. When the charge reaches zero, the zero comparator provides a pulse to the control logic. When the switch is moved from position 1 to 2, at the same time gate G2 is also opened. Hence the pulses from 50 kHz oscillator can reach to Is decade. When the zero comparator provides a pulse, the gate G1 is closed. This completes the reading operation.




The capacitor is connected at the input of the comparator. The output of the digital to analog converter is compared with the unknown voltage, by the comparator. The output of the comparator is given to the logic control and sequencer. This unit generates the sequence of code which is applied to digital to analog converter. The position 2 of the switch 51 receives the output from digital to analog converter. The unknown voltage is available at the position 1 of the switch S1. The logic control also drives the clock which is used to alternate the switch S1 between the positions 1 and 2, as per therequirement.

**Resolution and sensitivity:**

If n is the number of full digits then the resolution of a DVM is given by,

$$R = \frac{1}{10^n}$$

where R = Resolution

Thus for 3 digit display, n = 3

$$\therefore \quad R = \frac{1}{10^3} = 10^{-3} = 0.001 \text{ or } 0.1\%$$

The sensitivity is the smallest change in the input which a digital meter should be able to detect. Hence, it is the full scale value of the lowest range multiplied by the resolution of the meter.

$$S = (fs)_{min} \times R$$

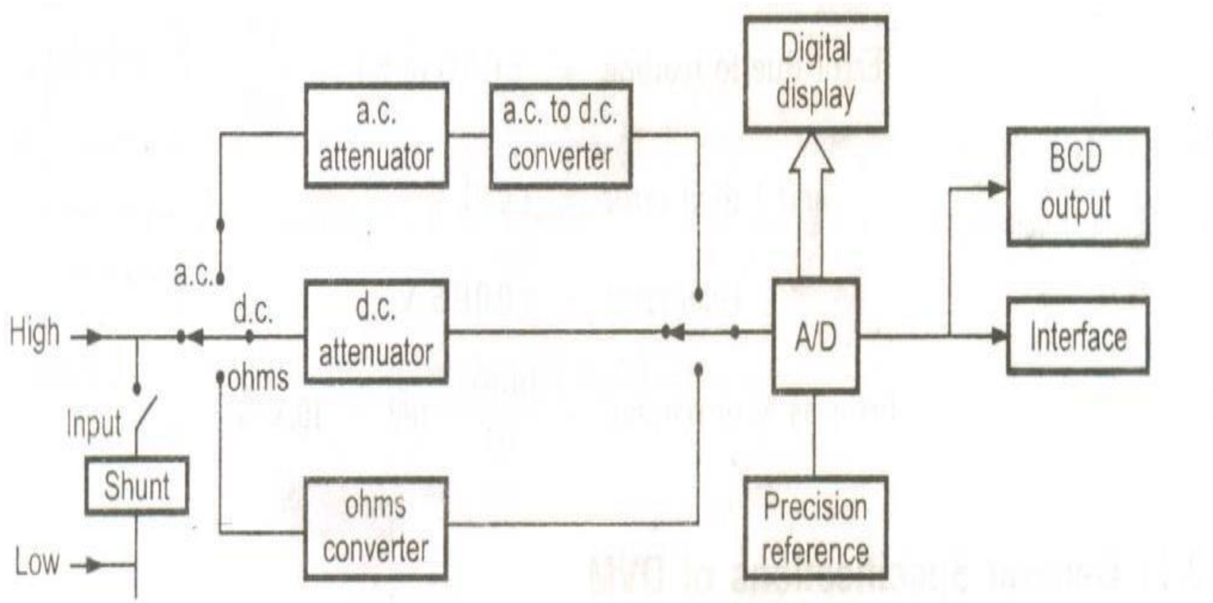
where $S$ = Sensitivity

$(fs)_{min}$ = Full scale value on minimum range.

$R$ = Resolution expressed as decimal.

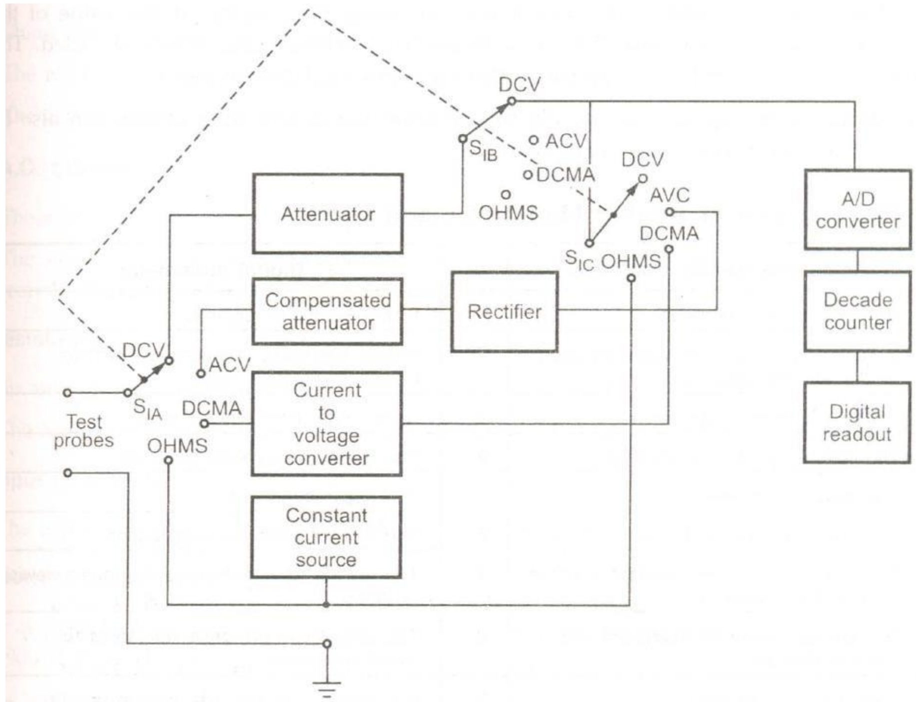
**Digital multimeters:**

The digital multimeter is an instrument which is capable of measuring a.c. voltages, d.c. voltages, a.c. and d.c. currents and resistances *over* several ranges. The basic circuit of a digital multimeter is always a d.c. voltmeter as shown in the Fig

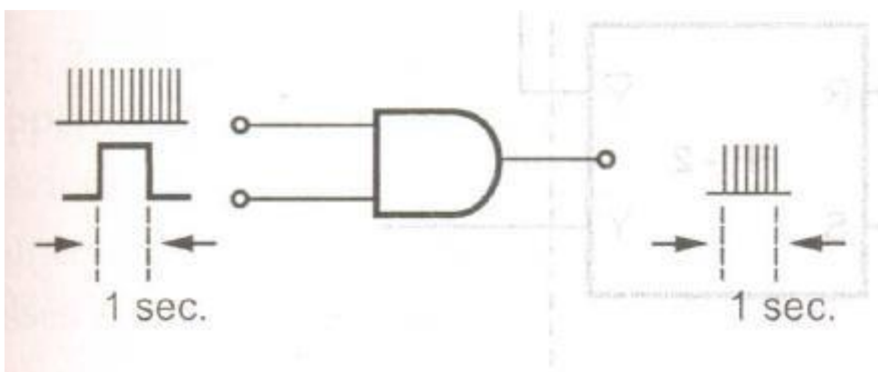



The current is converted to voltage by passing it through low shunt resistance. The a.c. quantities are *converted* to d.c. by employing various rectifier and filtering circuits. While for the resistance measurements the meter consists of a precision low current source that is applied across the unknown resistance while gives d.c. voltage. All the quantities are digitized using analog to digital converter and displayed in the digital form on the display.

The basic building blocks of digital multimeter are several *AID* converters, counting circuitry and an attenuation circuit. Generally dual slope integration type ADC is prefprred in the multimeters. The single attenuator circuit is used for both a.c. and d.c. measurements in many commercial multimeters. The block diagram of a digital multimeter is shown in the Fig.

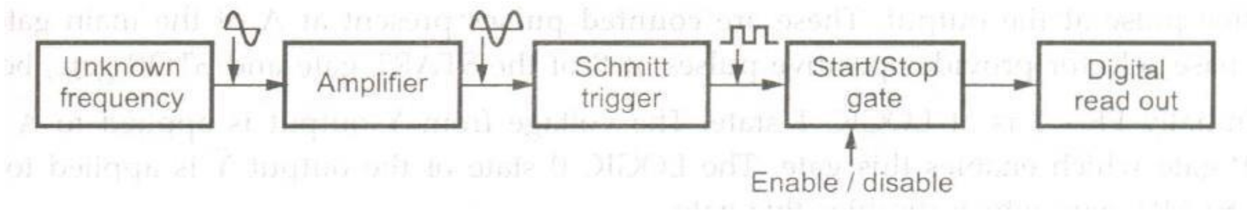



**Digital Frequency meter: Principle:**



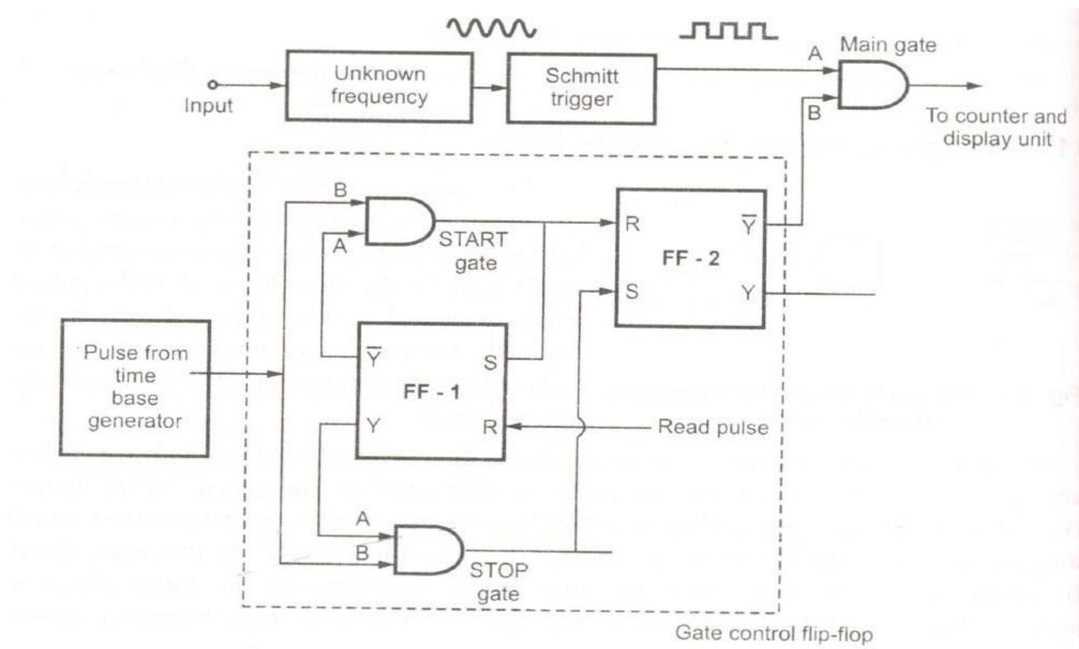

The signal waveform whose frequency is to be measured is converted into tngger pulses and applied continuously to one terminal of an AND gate. To the other terminal of the gate, a pulse of 1 sec is applied as shown in the Fig. The number of pulses counted at the output terminal during period of 1 sec indicates thefrequency.

The signal whose frequency is to be measured is converted to trigger pulses which is nothing but train of pulses with one pulse for each cycle of the signal. At the output terminal of AND gate, the number of pulses in a particular interval of time are counted using an electronic counter. Since each pulse represents the cycle of the unknown signal, the number of counts is a direct indication of the frequency of the signal which is unknown. Since electronic counter has a high speed of operation, high frequency signals can be measured.




**Block diagram of digital frequency meter**

The signal waveform whose frequency is to be measured is first amplified. Then the amplified signal is applied to the schmitt trigger which converts input signal into a square wave with fast rise and fall times. This square wave is then differentiated and clipped. As a result, the output from the schmitt trigger is the train of pulses for each cycle of the signal. The output pulses from the schmitt trigger are fed to a START/STOP gate. When this gate is enabled, the input pulses pass through this gate and are fed directly to the electronic counter, which counts the number of pulses. When this gate is disabled, the counter stops counting the incoming pulses. The counter displays the number of pulses that have passed through it in the time interval between start and stop. If this interval is known, the unknown frequency can be measured.




The output of unknown frequency is applied to the Schmitt trigger which produces positive pulse at the output. These are **counted pulses** present at A of the t11<lingate. The time base

selector provides positive pulses at B of the START gate and STOP gate, both. Initially FF - 1 is at LOGIC 1 state. The voltage from Y output is applied to A of the STOP gate which enables this gate. The LOGIC a state of the output Y is applied to input A of START gate which disables this gate. When STOP gate enables, positive pulses from the time base pass through STOP gate to S input of FF - 2, setting FF - 2 to LOGIC 1 state. The LOGIC a level of Y of **FF - 2** is connected to B of main gate, which confirms that pulses from unknown frequency source can't pass through the main gate. By applying a positive pulse to R input of FF - I, the operation is started. This changes states of the FF - 1 to Y = 1 and Y = O. Due to this, STOP gate gets disabled, while START gate gets enabled. The same pulse is simultaneously applied to all decade counters to reset all of them, to start new counting.

With the next pulse from the time base passes through START gate reseting FF - 2 and it changes state from LOGIC a to LOGIC 1. As Y changes from a to 1, the gating signal is applied to input B of the main gate which enables the main gate.

Now the pulses from source can pass, through the main gate to the counter. The counter counts pulses. The state of FF - 1 changes from a to 1 by applying same pulse fromSTART gate to S input of FF - 1. Now the START gate gets disabled, while STOP gategets enabled. It is important that the pulses of unknown frequency pass through the maingate to counter till the main gate is enabled.

The next pulse from the time base generator passes through STOP Gate to S input of FF -

2. This sets output back to 1 and Y =*0* O. Now main gate gets disabled. The source supplying pulses of unknown frequency gets disconnected. In between this pulse and previous pulse from the time base selector, the number of pulses are counted by the counter. When the interval of time between two pulses is 1 second, then the count of pulses indicates the frequency of the unknown frequency source.

1. **Input signal conditioning circuit:**

   In this circuit, an amplifier and schmitt trigger are included. The threshold voltage 01 the schmitt trigger can be controlled by sensitivity control on the control panel. First of all the input signal of unknown frequency is fed into input signal conditioning circuit. There the signal is amplified and then it is converted into square wave by schmitt trigger circuit.

2. **Time basegenerator:**

The crystal oscillator produces a signal of 1 MHz or 100 MHz depending upon the requirement. In general, the accuracy of the digital frequency counter depends on the accuracy of the time base signals produced, thus the temperature compensated crystal oscillator is used. rhen output of the oscillator is passed through another schmitt trigger circuit producing square wave output. Then it is fed to frequency dividers connected in cascade. Thus a train of pulses are obtained after each frequency divider section. Using time base selector switch 5 the Gate **Time** can be adjusted. The gating circuit consists of AND gate. When the enable signal is provided to the A D gate, it allows a train of pulses to pass through the gate for the time period selected by the time base circuit. The pulses are counted and then the second pulse generated from the time base generator disables AND gate and thus closes it.

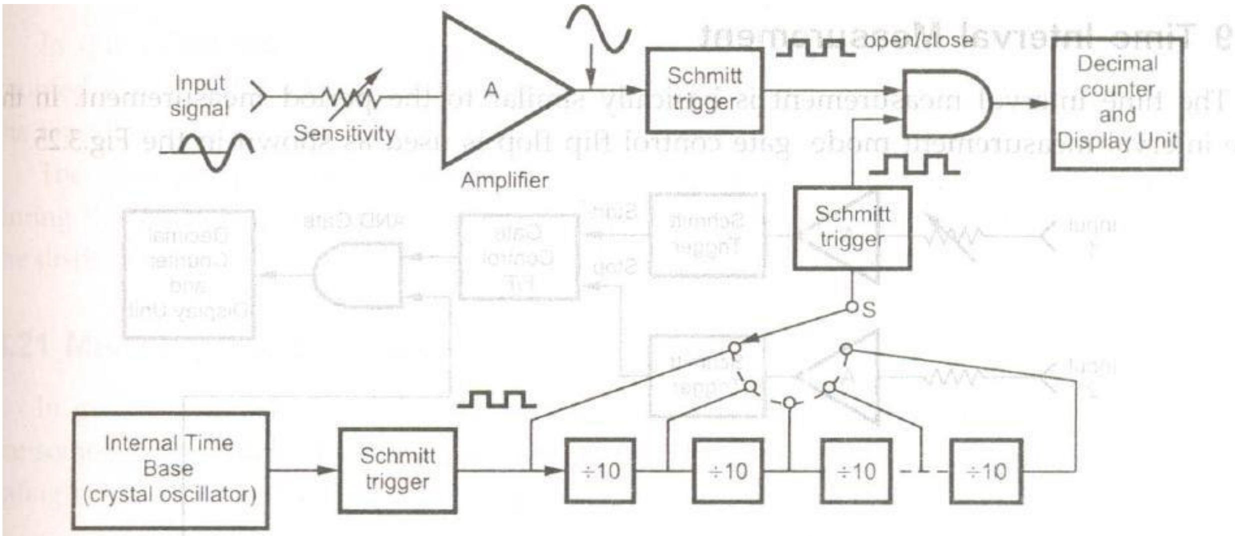
Tn this unit, decade counters are connected in the cascade. The output of the A TD gate
is connected to the clock input of the first decade counter. Then the output of this counter to the clock inpllt of next and so on. Using these counters the number of pulses are counted and are displayed by the display unit. As the number of pulses counted are proportional to the input signal frequency, the final display is proportional to the unknown frequency of the input signal.

**Period measurement:**

Using the frequency counter, the period measurement is possible. As we know, time period T == 1/ f. 50 if the frequency to be measured is low, then the accuracy of the frequency counter decreases as less number of pulses are connected to the gatingcircuit.

Thus in low frequency region it is better to measure period rather than frequency. The block diagram of the period mode of the digital frequency counter is as shown in the Fig.

Now the pulses from source can pass, through the main gate to the counter. The counter counts pulses. The state of FF - 1 changes from a to 1 by applying same pulse fromSTART gate to S input of FF - 1. Now the START gate gets disabled, while STOP gategets enabled. It is important that the pulses of unknown frequency pass through the maingate to counter till the main gate is enabled.

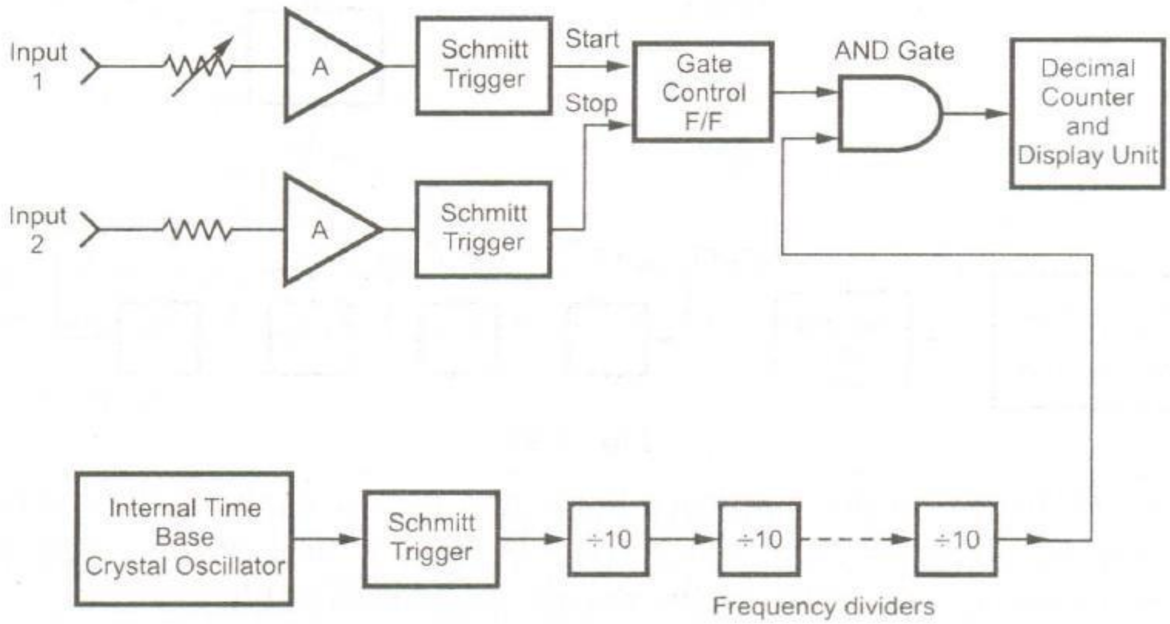



The main difference in the frequency mode and period mode of the digital frequency counter is that the unknown input signal controls the gate time of the gating circuit while the time base frequency is counted in the decade counter assembly. Note that in the period mode, the input signal conditioning circuit produces a train of pulses. So the positive going zero crossing pulses are used as trigger pulses for opening and closing of AND gate in the gating circuit. The main advantage of the period mode is that the accuracy is grealer for the low frequency input signals.

**Time interval measurement:**

The time interval measurement is basically similar to the period measurement. In the time interval measurement mode, gate control flip flop is used as shown in the Fig

In this measurement mode, two inputs are used to start and stop the counting. Here similar to the period measurement, the internal frequency pulses generated by time base generator circuit are counted. The start and stop signals are derived from two inputs. The AND gate is enabled with the external input 1 applied. The counting of the pulses starts at this instant. The AND gate is disabled with the input 2 applied. Thus pulses are counted in the time interval which is proportional to the time interval between application of inputs 1 and2.

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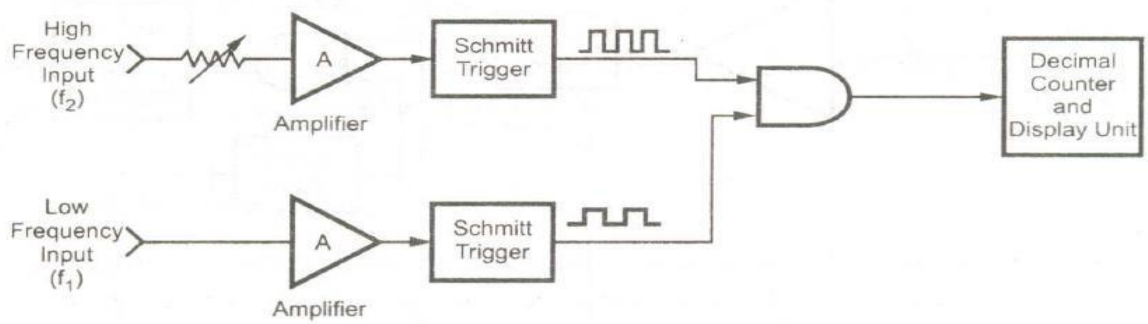
**Frequency ratio measurement:**

By using the frequency counter, the ratio of two frequencies can be measured. It is again similar to period measurement. The block diagram is as shown in the Fig.




In this mode, the low frequency signal is used as gating signal, while the pulses are counted for the high frequency signal. Hence it is clear that the low frequency represents the time base.