ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

(Approved by AICTE, New Delhi. Affiliated to Anna University, Chennai)

ANGUCHETTYPALAYAM, PANRUTI – 607 106.

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE 8403 - MEASUREMENTS AND INSTRUMENTATION

IV SEMESTER

Prepared by

Mrs. J. Arul Martinal, AP/EEE

MEASUREMENTS:

The measurement of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) & a predefined standard. Since two quantities are compared, the result is expressed in numerical values.

BASICREQUIREMENTSOFMEASUREMENT:

i)   The standard used for comparison purposes must be accurately defined & should be commonly accepted

ii)   The apparatus used & the method adopted must be provable.

MEASURINGINSTRUMENT:

It may be defined as a device for determining the value or magnitude of a quantity or variable.

1.1 FUNCTIONAL ELEMENTS OF AN INSTRUMENT:

Most of the measurement systems contain three main functional elements. They are:

i)   Primary sensing element

ii)   Variable conversion element &

iii)   Data presentation element.
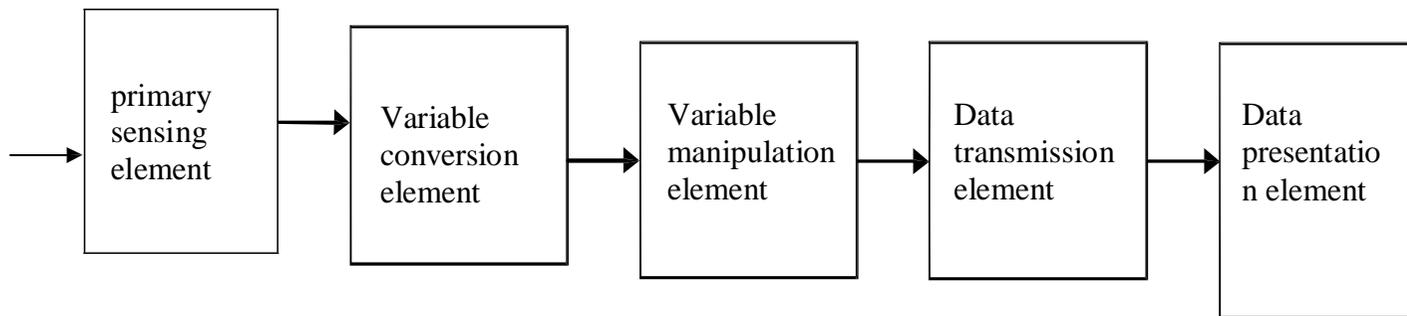
Primarysensingelement:

The quantity under measurement makes its first contact with the primary sensing element of a measurement system. i.e., the measurand- (the unknown quantity which is to be measured) is first detected by primary sensor which gives the output in a different analogous form This output is then converted into an eelectrical signal by a transducer - (which converts energy from one form to another). The first stage of a m e a s u r e m e n t system is known as a **detector transducer stage'.**

Variableconversionelement:

The output of the primary sensing element may be electrical signal of any form , it may be voltage, a frequency or some other electrical parameter
For the instrument to perform the desired function, it may be necessary to convert this output to some other suitable form.

Variablemanipulationelement:

The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. It is not necessary that a variable manipulation element should follow the variable conversion element Some non -linear processes like modulation, detection, sampling , filtering, chopping etc.,are performed on the signal to bring it to the desired form to be accepted by the next stage of measurement system This process of conversion is called μ **signal conditioning'**
The term signal conditioning includes many other functions in addition to Variable conversion & Variable manipulation In fact the element that follows the p r i m a r y sensing e l e m e n t in any instrument or measurement system is called **conditioning element'**

NOTE: When the elements of an instrument are actually physically separated, it becomes necessary to transmit data from one to another. The element that performs this function is called a **data transmission element'.**

Datapresentationelement:

The information about the quantity under measurement has to be conveyed to the p e r s o n n e l handling the instrument or the system for monitoring, control, or analysis purposes. This function is done by data presentation element
In case data is to be monitored, visual display devices are needed These devices may be analog or digital indicating instruments like ammeters, voltmeters etc. In case data is to be recorded, recorders like magnetic tapes, high speed camera & TV equipment, CRT, printers may be used. For control & analysis is purpose microprocessor or computers may be used. The final stage in a measurement system is known as **terminating stage'**

1.2 STATIC & DYNAMIC CHARACTERISTICS

The performance characteristics of an instrument are mainly divided into two categories:
    i)   Static characteristics
    ii) Dynamic characteristics

Static characteristics:

The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called **'static characteristics'.**

The various static characteristics are:
    i)   Accuracy
    ii)   Precision
    iii)   Sensitivity
    iv)   Linearity
    v)   Reproducibility
    vi)   Repeatability
    vii)   Resolution
    viii) Threshold
    ix)   Drift
    x)   Stability
    xi)   Tolerance
    xii)   Range or span

<u>Accuracy:</u>
It is the degree of closeness with which the reading approaches the true value of the quantity to be measured. The accuracy can be expressed in following ways:

a) Point accuracy:
Such an accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other point on the scale.

b) Accuracy as percentage of scale span:
When an instrument as uniform scale, its accuracy may be expressed in terms of scale range.

c) Accuracy as percentage of true value:
The best way to conceive the idea of accuracy is to specify it in terms of the true value of the quantity being measured.

<u>Precision:</u>
It is the measure of reproducibility i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements. The precision is composed of two characteristics:

a) Conformity:
Consider a resistor having true value as 2385692　　　, which is being measured by an ohmmeter. But the reader can read consistently, a value as 2.4 M　　　due to the nonavailability of proper scale. The error created due to the limitation of the scale reading is a precision error.

b) Number of significant figures:
The precision of the measurement is obtained from the number of significant figures, in which the reading is expressed. The significant figures convey the actual information about the magnitude & the measurement precision of the quantity.

The precision can be mathematically expressed as: $P = 1 - \left| \dfrac{X_n - \overline{X_n}}{\overline{X_n}} \right|$

Where, P = precision
X_n = Value of nth measurement
$\overline{X_n}$ = Average value the set of measurement values

<u>Sensitivity:</u>

The sensitivity denotes the smallest change in the measured variable to which the instrument responds. It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured. Mathematically it is expressed as,
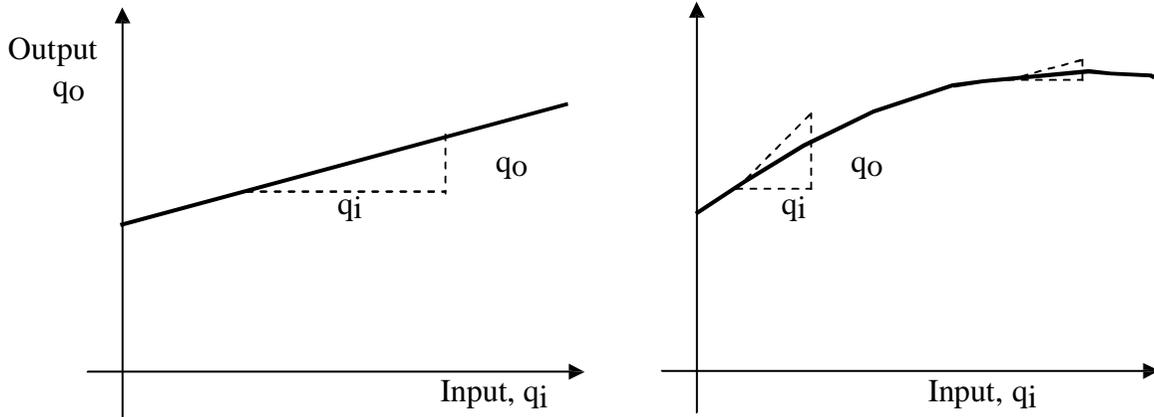
$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$= \frac{\delta q_o}{\delta q_i}$$

Thus, if the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve.

If the calibration curve is not linear as shown, then the sensitivity varies with the input.

Inverse sensitivity or deflection factor is defined as the reciprocal of sensitivity.
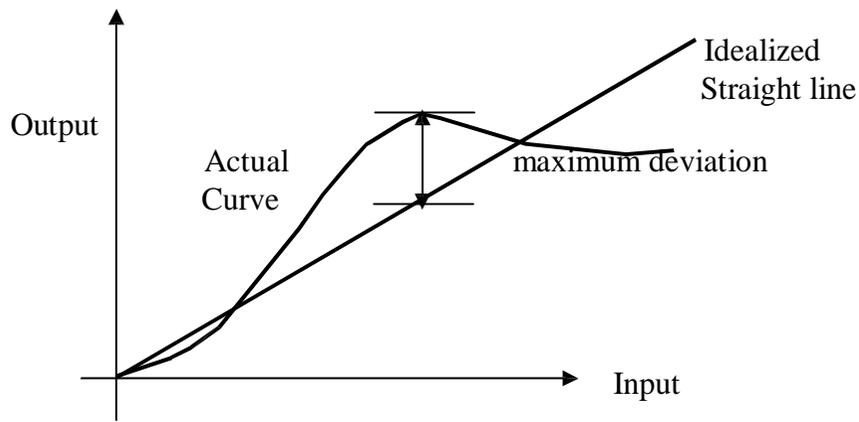
Inverse sensitivity or deflection factor = 1/ sensitivity

$$= \frac{\delta q_i}{\delta q_o}$$

<u>Linearity:</u>

The linearity is defined as the ability to reproduce the input characteristics symmetrically & linearly.

The curve shows the actual calibration curve & idealized straight line.

$$\% \text{ non-linearity} = \frac{\text{Max. deviation of output from idealized straight line}}{\text{Full scale reading}}$$

Reproducibility:

It is the degree of closeness with which a given value may be repeatedly measured. It is specified in terms of scale readings over a given period of time.
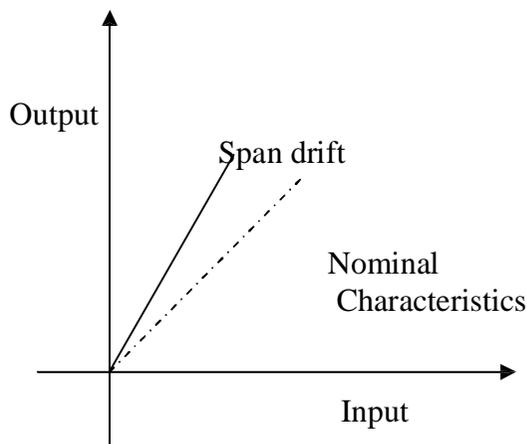
Repeatability:

It is defined as the variation of scale reading & random in nature.
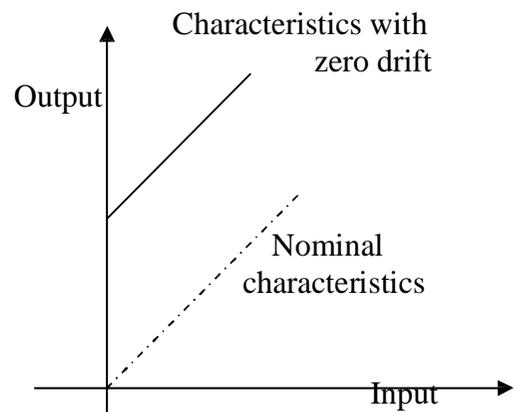
Drift:

Drift may be classified into three categories:

a) zero drift:

If the whole calibration gradually shifts due to slippage, permanent set, or due to undue warming up of electronic tube circuits, zero drift sets in.

(Fig) span drift

(fig) zero drif

b) span drift or sensitivity drift

   If there is proportional change in the indication all along the upward scale, the drifts is called span drift or sensitivity drift.

c) Zonal drift:

   In case the drift occurs only a portion of span of an instrument, it is called zonal drift.

Resolution:

If the input is slowly increased from some arbitrary input value, it will again be found that output does not change at all until a certain increment is exceeded.
This increment is called resolution.

Threshold:

If the instrument input is increased very gradually from zero there will be some minimum value below which no output change can be detected. This
minimum value defines the threshold of the instrument.

Stability:

It is the ability of an instrument to retain its performance throughout is specified operating life.

Tolerance:

The maximum allowable error in the measurement is specified in terms of some value which is called tolerance.

Rangeorspan:

The minimum & maximum values of a quantity for which an instrument is designed to measure is called its range or span.

Dynamic characteristics:

The set of criteria defined for the instruments, which are changes rapidly with time, is called **'dynamic characteristics'.**

The various static characteristics are:
   i) Speed of response ii)Measuring lag
   iii) Fidelity
   iv) Dynamic error

Speedofresponse:

It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.

Measuringlag:

It is the retardation or delay in the response of a measurement system to changes in the measured quantity. The measuring lags are of two types:

a) Retardation type:
In this case the response of the measurement system begins immediately after the change in measured quantity has occurred.

b) Time delay lag:
In this case the response of the measurement system begins after a dead time after the application of the input.

Fidelity:

It is defined as the degree to which a measurement system indicates changes in the measurand quantity without dynamic error.

Dynamicerror:

It is the difference between the true value of the quantity changing with time & the value indicated by the measurement system if no static error is assumed. It is also called measurement error.

1.3 ERRORS IN MEASUREMENT

The types of errors are follows
i) Gross errors
ii) Systematic errors
iii) Random errors

GrossErrors:

The gross errors mainly occur due to carelessness or lack of experience of a human begin
These errors also occur due to incorrect adjustments of instruments
These errors cannot be treated mathematically
These errors are also called **personal errors'.**

Waystominimizegrosserrors:

The complete elimination of g r o s s errors is not possible but one c a n minimize them by the following ways:

Taking great care while taking the reading, recording the r e a d i n g &
calculating the result
Without depending on only one reading, at least three or more readings must be taken *
preferably by different persons.

Systematicerrors:

A constant uniform deviation of the operation of an instrument is known as a Systematic error

The Systematic errors are mainlydue to the short comings of the instrument & the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc.

TypesofSystematicerrors:

There are three types of Systematic errors as:
   i)   Instrumental errors
   ii)   Environmental errors iii)
            Observational errors

Instrumentalerrors:
These errors can be mainly due to the following three reasons:

a) Shortcomingsofinstruments:

These are because of the mechanical structure of the instruments. For example friction in the bearings of various moving parts; irregular spring tensions,   reductions   in   due   to improper handling , hysteresis, gear backlash, stretching of spring, variations in air gap, etc .,

Waystominimizethiserror:

These errors can be avoided by the following methods:

Selecting a proper instrument and planning the proper procedure for the measurement recognizing the effect of such   errors a n d applying t h e proper correction factors calibrating the instrument carefully against a standard

b) Misuseofinstruments:

A good instrument if used in abnormal way gives misleading results. Poor initial adjustment, Improper zero setting, using leads of high resistance etc., are the examples of misusing a good instrument. Such things do not cause the permanent damage to the instruments but definitely cause the serious errors.

C) Loadingeffects

Loading effects due to improper way of using the instrument cause the serious errors. The best ex ample of such loading effect error is connecting a w ell calibrated volt meter across the two points of high resistance circuit. The same volt meter connected in a low resistance circuit gives accurate reading.

<u>Waystominimizethiserror:</u>

Thus the errors due to the loading effect can be avoided by using an instrument intelligently and correctly.

<u>Environmentalerrors</u>:

These errors are due to the conditions external to the measuring instrument. The various factors resulting these environmental errors are temperature changes, pressure changes, thermal emf, ageing of equipment and frequency sensitivity of an instrument.

<u>Waystominimizethiserror:</u>

The various methods which can be used to reduce these errors are:

i)   Using the proper correction factors and using the information supplied by the manufacturer of the instrument
ii) Using the arrangement which will keep the surrounding conditions
     Constant
iii) Reducing the effect of dust ,humidity on the components by hermetically sealing the components in the instruments
iv) The effects of external f i e l d s can be minimized by using the magnetic or electro static shields or screens
v)   Using the equipment which is immune to such environmental effects.

<u>Observationalerrors</u>:

These are the errors introduced by the observer.
These are many sources of observational errors such as parallax error while reading a meter, wrong scale selection, etc.

<u>Waystominimizethiserror</u>

To eliminate such errors one should use the instruments with mirrors, knife edged pointers, etc.,

The systematic errors can be subdivided as static and dynamic errors. The static errors are caused by the limitations of the measuring device while the dynamic errors are caused by t h e instrument not responding fast enough to follow the changes in the variable to be measured.

<u>Randomerrors:</u>
Some errors still result, though the systematic and instrumental errors are reduced or atleast accounted for.The causes of such errors are unknown and hence the errors are called random errors.

<u>Waystominimizethiserror</u>

The only way to reduce these errors is by increasing the number of observations and using the statistical methods to obtain the best approximation of the reading.

1.4 STATISTICAL EVALUATION OF MEASUREMENT DATA

Out of the various possible errors, the random errors cannot be determined in the ordinary process of measurements. Such errors are treated mathematically

The mathematical analysis of the various measurements is called **statistical analysis of the data'.**

For such statistical analysis, the same reading is taken number of times, generally using different observers, different instruments & by different ways of measurement. The statistial a alysis helps to determine analytically the uncertainty of the final test results.

<u>Arithmeticmean&median:</u>

When the number of readings of the same measurement are taken, the most likely value from the set of measured value is the arithmetic mean of the number of readings taken.

The arithmetic mean value can be mathematically obtained as,

$$\overline{X} = \frac{X_1 \quad X_2 \quad .... \quad Xn}{n} =$$

This mean is very close to true value, if number of readings is very large.

But when the number of readings is large, calculation of mean value is complicated. In such a case, a median value is obtained which is obtained which is a close approximation to the arithmetic mean value. For a set of measurements X1, X2, X3.Xn written down in the ascending order of magnitudes, the median value is given by,

$$Xmedian=X (n+1)/2$$

<u>Averagedeviation:</u>

The deviation tells us about the departure of a given reading from the arithmetic mean of the data set

$$di=xi-\overline{X}$$

Where

di = deviation of ith reading
Xi= value of ith reading
$\overline{X}$ = arithmetic mean

The average deviation is defined as the sum of the absolute values of deviations divided by the number of readings. This is also called mean deviation

1.5 STANDARD & CALIBRATION

CALIBRATION

Calibration is the process of making an adjustment or marking a scale so that the readings of an instrument agree with the accepted & the certified standard.

In other words, it is the procedure for determining the correct values of measurand by comparison with the measured or standard ones.

The calibration offers a guarantee to the device or instrument that it is operating with required accuracy, under stipulated environmental conditions.

The calibration procedure involves the steps like visual inspection for various defects, installation according to the specifications, zero adjustment etc.,

The calibration is the procedure for determining the correct values of measurand by comparison with standard ones. The standard of device with which comparison is made is called a **standard instrument**. The instrument which is unknown & is to be calibrated is called **test instrument.** Thus in calibration, test instrument is compared with standard instrument.

Typesofcalibrationmethodologies:

There are two methodologies for obtaining the comparison between test instrument & standard instrument. These methodologies are

      i)   Direct comparisons
      ii)   Indirect comparisons

Directcomparisons:

In a direct comparison, a source or generator applies a known input to the meter under test. The ratio of what meter is indicating & the known generator values gives the meter s error. In such case the meter is the test instrument while the generator is the standard instrument. The deviation of meter from the standard value is compared with the allowable performance limit.
With the help of direct comparison a generator or source also can be calibrated.

Indirectcomparisons:

In the indirect comparison, the test instrument is compared with the response standard instrument of same type i .e., if test instrument is meter, standard instrument is also meter, if test instrument is generator; the standard instrument is also generator & so on.

If the test instrument is a meter then the same input is applied to the test meter as well a standard meter.

In case of generator calibration, the output of the generator tester as well as standard, or set to same nominal levels.

Then the transfer meter is used which measures the outputs of both standard and test generator.

Standard

All the instruments are calibrated at the time of manufacturer against measurement standards.

A standard of measurement is a physical representation of a unit of measurement.

A standard means known accurate measure of physical quantity.

The different size of standards of measurement are classified as i) International standards

ii)   Primary standards
iii)   Secondary standards
iv)   Working standards

Internationalstandards

International standards are defined as the international agreement. These standards,as mentioned above are maintained at the international bureau of weights an d measures and are periodically evaluated and checked by absolute measurements in term s of fundamental units of physics.

These international standards are not available to the ordinary users for the calibration purpose.

For the improvements in the accuracy of absolute measurements the international units are replaced by the absolute units in 1948.

Absolute units are more accurate than the international units.

Primarystandards

These are highly accurate absolute standards, which can be used as ultimate reference standards.These primary standards are maintained at national

standard laboratories in different countries.

These standards representing fundamental units as well as some electrical and mechanical derived units are calibrated independently by absolute measurements at each of the national laboratories.

These are not available for use, outside the national laboratories.

The main function of the primary standards is the calibration and verification of secondary standards.

Secondarystandards

As mentioned above, the primary standards are not available for use outside the national laboratories.

The various industries need some reference standards. So, to protect highly accurate primary standards the secondary standards are maintained, which are designed and constructed from the absolute standards.

These are used by the measurement and calibration laboratories in industries and are maintained by the particular industry to which they belong. Each industry has its own standards.

Workingstandards

These are the basic tools of a measurement laboratory and are used to check and calibrate the instruments used in laboratory for accuracy and the performance.

.

```
┌─────────────────────────┐
│ International standards  │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ National standard       │
│ laboratories            │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Industries & secondary  │
│ laboratories            │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Measurement laboratory  │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Process instrument      │
└─────────────────────────┘
```
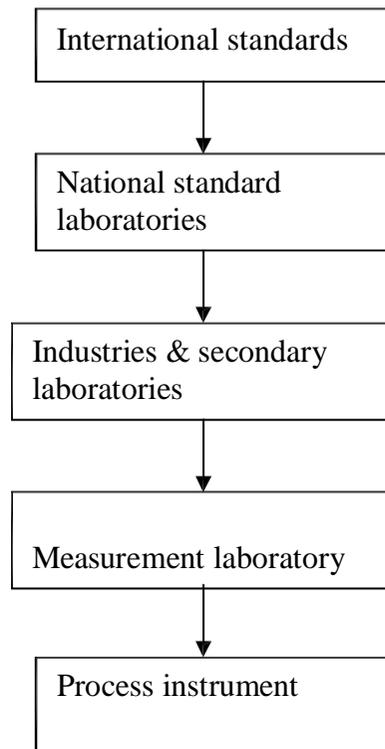
UNIT II ELECTRICAL AND ELECTRONICS INSTRUMENTS

2.1 Principle And Types Of Analog And Digital Voltmeters

Ø Basically an electrical indicating instrument is divided into two types. They are i) Analog instruments
      ii) Digital Instruments.

Ø Analog instruments are nothing but its output is the deflection of pointer, which is proportional to its input.

Ø Digital Instruments are its output is in decimal form.

Ø Analog ammeters and voltmeters are classed together as there are no fundamental differences in their operating principles.

Ø The action of all ammeters and voltmeters, with the exception of electrostatic type of instruments, depends upon a deflecting torque produced by an electric current.

Ø In an ammeter this torque is produced by a current to be measured or by a definite fraction of it.

Ø In a voltmeter this torque is produced by a current which is proportional to the voltage to be measured.

Ø Thus all analog voltmeters and ammeters are essentially current measuring devices.

The essential requirements of a measuring instrument are

(i)   That its introduction into the circuit, where measurements are to be made, does not alter the circuit conditions ;

(ii)   The power consumed by them for their operation is small.

1.2 Ammeters & Multimeters

Ammeters are connected in series

In the circuit whose current is to be measured. The power loss in an ammeter is I^2Ra where I is the current to be measured and R is the resistance of ammeter. Therefore, ammeters should have a low electrical resistance so that they cause a small voltage drop and consequently absorb small power.

Voltmeters are connected in parallel with the circuit whose voltage is to be measured. The power loss in voltmeters is V where V is the voltage U) be measured and R is the resistance of voltmeter. The voltmeters should have a high electrical resistance, in order that the current drawn by them is small and consequently the power consumed is small.
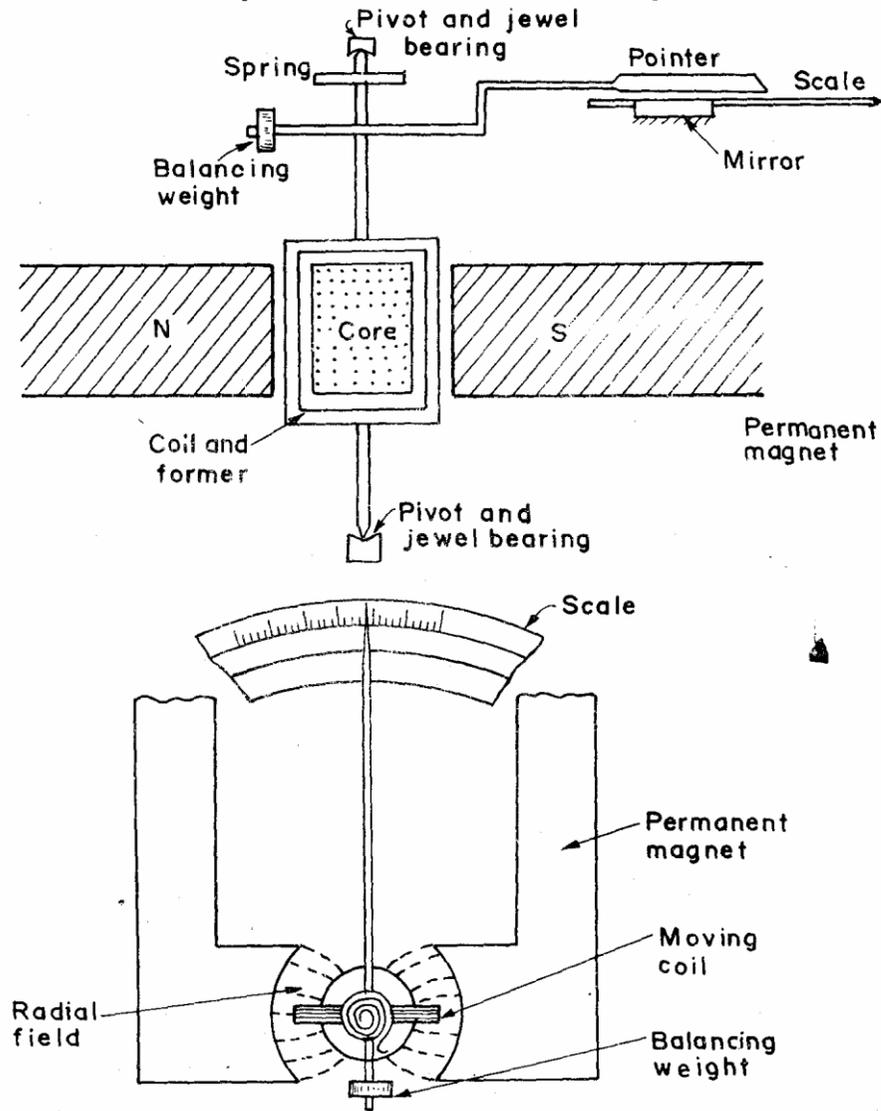
Types of instruments

The main types of instruments used as an ammeters and voltmeters are

(i)   Permanent magnet moving coil (PMMC)

(ii)   Moving iron

(iii)   Electro-dynamometer

(iv)   Hot wire

(iv)   Thermocouple

(vi)   Induction

(vii)   Electrostatic

(viii)   Rectifier.

Permanent Magnet Moving Coil Instrument (PMMC)

The permanent magnet moving coil instrument is the most accurate type for **d.c. measurements**. The working principle of these instruments is the same as that of the d' Arsonval type of galvanometers, the difference being that a direct reading instrument is provided with a pointer and a scale.

(Fig) Permanent magnet moving coil instrument

Construction of PMMC Instruments

Ø The constructional features of this instrument are shown in Fig.

Ø The moving coil is wound with m any turns of enameled or silk covered copper wire.

Ø The coil is mounted on a rectangular aluminium former which is pivoted on jewelled bearings.

Ø The coils move freely in the field of a permanent magnet.

Ø Most vol tmeter coils are w ound on m etal frames to provide the re quired electro-magnetic damping.

Ø Most a mmeter coi ls, however, are wound on non -magnetic formers, because coil turns are effectively shorted by the ammeter shunt.

Ø The coil itself, therefore, provides electro magnetic damping.

Magnet Systems

Ø Old style m agnet syste m consisted of relatively long U shaped permanent magnets having soft iron pole pieces.

Ø Owing to development of materials like Alcomax and Alnico, which have a h igh co-ercive force, i t is possible to use smaller magnet lengths and high field intensities.

Ø The flux densities used in PMIMC instruments vary from 0.1 W b/m to 1 Wb/m.

Control

Ø When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs.

Ø These springs also serve to lead current in and out of the coil. The control torque is provided by the ribbon suspension as shown.

Ø This m ethod i s com paratively new and is c laimed to be advantageous as it eliminates bearing friction.

Damping

Ø Damping torque is produced by movement of the aluminium former moving in the magnetic field of the permanent magnet.

Pointer and Scale

Ø The pointer is carried by the spindle and moves over a graduated scale.

Ø The poin ter is of lig ht-weight constructi on and, apar t f rom those used i n some inexpensive instruments has the section over the scale twisted to form a fine blade.

Ø This helps to reduce parallax err ors i n the r eading of the scale.
When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs.

Ø These springs also serve to lead current in and out of the coil.

Torque Equation.

The torque equation of a moving coil instrument is given by

Deflecting torque $T_d = NB\ l\ dI = GI$

where G = a constant = $NB\ ld$

The spring control provides a restoring (controlling) torque $T_c = K\theta$

where K = spring constant.

For final steady deflection $T_c = T_d$ or $GI = K\theta$

∴ Final steady deflection $\theta = (G/K)\ I$

or current $I = (K/G)\ \theta$

As the deflection is directly proportional to the current passing through the meter (K and G being constants) we get a uniform (linear) scale for the instrument.

Errors in PMMC Instruments

The main sources of errors in moving coil instruments are due to

Ø Weakening of permanent magnets due to ageing at temperature effects.

Ø Weakening of springs due to ageing and temperature effects.

Ø Change of resistance of the moving coil with temperature.

Advantages and Disadvantages of PMMC Instruments

The main advantages of PMMC instruments are

Ø The scale is uniformly divided.

Ø The power consumption is very low

Ø The torque-weight ratio is high which gives a high accuracy. The accuracy is of the order of generally 2 percent of full scale deflection.

Ø A single instrument may be used for many different current and voltage ranges by using different values for shunts and multipliers.

Ø Since the operating forces are large on account of large flux densities which may be as high as 0.5 Wb/m the errors due to stray magnetic fields are small.

Ø Self-shielding magnets make the core magnet mechanism particularly useful in aircraft and aerospace applications.

The chief disadvantages are

Ø These instruments are useful only for d.c. The torque reverses if the current reverses. If the instrument is connected to a.c., the pointer cannot follow the rapid reversals and the deflection corresponds to mean torque, which is zero. Hence these instruments cannot be used for a.c.

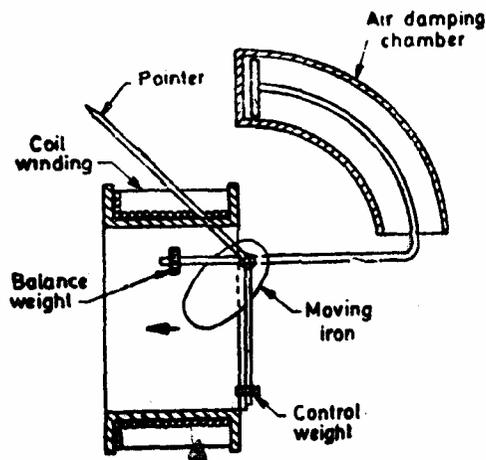Ø The cost of these instruments is higher than that of moving iron instruments.

Moving Iron Instruments

Classification of Moving Iron Instruments

Moving iron instruments are of two types
(i) Attraction   type.
(ii) Repulsion type.

Attraction Type

Ø The coil is flat and has a narrow slot like opening.
Ø The moving iron is a flat disc or a sector eccentrically mounted.
Ø   When the current flows through the coil, a magnetic field is produced and the moving iron moves from the weaker field outside the coil to the
Stronger field inside it or in other words the moving iron is attracted in.
Ø   The controlling torque is provide by springs hut gravity control can be used for panel type of instruments which are vertically mounted.
Ø   Damping is provided by air friction with the help of a light aluminium piston (attached to the moving system) which move in a fixed chamber closed at one end as shown in Fig. or with the help of a vane (attached to the moving system) which moves in a fixed sector shaped chamber a shown.

Repulsion Type

In the repulsion type, there are two vanes inside the coil one fixed and other movable. These are similarly magnetized when the current flows through the coil and there is a force of repulsion between the two vane s resulting in the movement of the moving vane. Two different designs are in common use
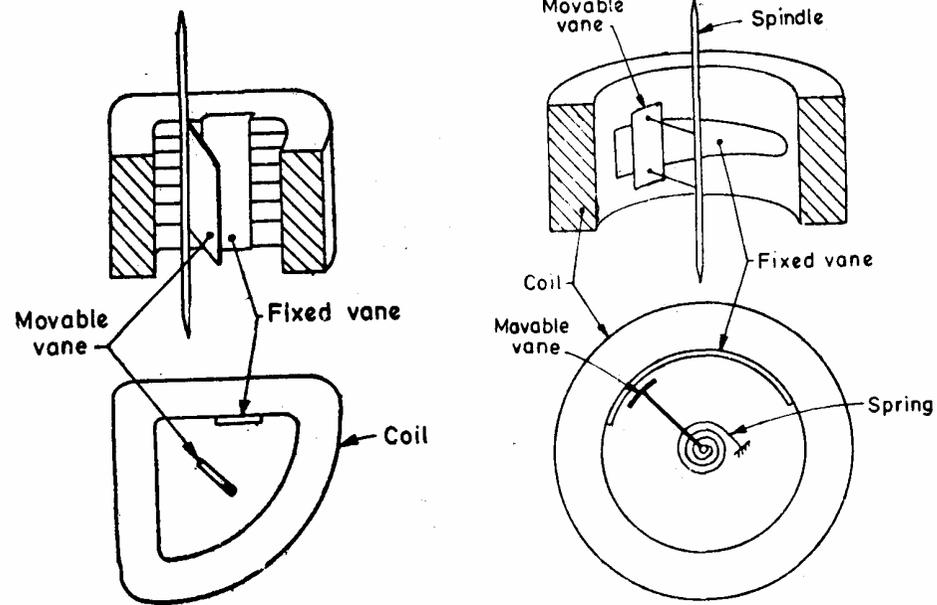
(I) Radial Vane Type

In this type, the vanes are radial strips of iron.
The strips are placed within the coil as shown in Fig.

The fixed vane is attached to the coil and the movable one to the spindle of the instrument.

<div style="text-align:center">

(a) Radial vane type.   **(b) Co-axial vane type**

</div>

(ii) Co-axial Vane Type

Ø In this type of instrument, the fixed and moving vanes are sections of co axial cylinders as shown in Fig.

Ø The controlling torque is provided by springs. Gravity control can also he used in vertically mounted instruments.

Ø The damping torque is produced by air friction as in attraction type instruments.

Ø The operating magnetic field in moving iron instruments is very weak and therefore eddy current damping is not used in them as introduction of a permanent magnet required for eddy current damping would destroy the operating magnetic field.

Ø It is clear that whatever may be the direction of the current in the coil of the instrument, the iron vanes are so magnetized that there is always a force of attraction in the attraction type and repulsion in the repulsion type of instruments.

Ø Thus moving iron instruments are unpolarised instruments i.e., they are independent of the direction in which the current passes.

Ø Therefore, these instruments **can be used on both ac. and d.c.**

Torque Equation of Moving Iron Instrument:

An expression for the torque moving iron instrument may be derived by consid ring the energy relations when there is a small increment in current supplied to the instrument. When this happens there will be a small deflection dș a mechanical work will be done. Let Td be the deflecting torque.

Mechanical work done = Td. dș

Alongside there will be a change in the energy stored in the magnetic field owing to change in inductance.

Suppose the initial current is I, the instrument inductance L and the deflection ș. If the curr ent is increased by di then the defle ction chan ges by d ș and the inductance by dL. In order to affect a n increment the current there must be an increase in the applied voltage given by

$$e = \frac{d}{dt}(LI) = I\frac{dL}{dt} + L\frac{dI}{dt}.$$

The electrical energy supplied $eIdt = I^2dL + ILdI$

The stored energy changes from $= \frac{1}{2}I^2 L$ to $\frac{1}{2}(I + dI)^2 (L + dL)$.

Hence the change in stored energy $\frac{1}{2}(I^2 + 2IdI + dI^2)(L + dL) - \frac{1}{2}I^2L$.

Neglecting second and higher order terms in small quantities this becomes $ILdI + \frac{1}{2}I^2d$

From the principle of the conservation of energy,

Electrical energy supplied = increase in stored energy + mechanical work done

$$I^2dL + ILdI = ILdI = \frac{1}{2}I^2dL + T_d d\theta$$

Thus $\qquad T_d\ d\theta = \frac{1}{2}I^2dL$

or   Deflecting torque $\qquad T_d = \frac{1}{2}I^2\frac{dL}{d\theta}$

T is in newton-metre, I in ampere, L in henry, and θ in radian.

The moving system is provided with control springs and it turns the deflecting torque T_d is balanced by the controlling torque $T_c = K\theta$

where $\qquad K$ = control spring constant ; Nm/rad, $\qquad \theta$ = deflection ; rad.

At equilibrium (or final steady) position, $T_c = T_d$ or $K\theta = \frac{1}{2}I^2\frac{dL}{d\theta}$

$\therefore$ Deflection $\qquad\qquad \theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}$

Hence the deflection is proportional to square of the r ms value of the operating cur rent. The deflecting torq ue is, t herefore, unidir ectional (acts in the same direction) whatever may be the polarity of the current.

Comparison between Attraction and Repulsion Types of Instruments

In general it may be said that attraction-type instruments possess the same advantages, and are subject to the limitations, described for the repulsion type.

An attraction type instrument will usually have a lower inductance than the corresponding repulsion type instrument, and voltmeters will therefore be accurate over a wider range of frequency and there is a greater possibility of using shunts with ammeters.

On the other hand, repulsion instruments are more suitable for economical production in manufacture, and a nearly uniform scale is more easily obtained; they are, therefore, much more common than the attraction type.

Errors in Moving Iron Instruments

There are two types of errors which occur in moving iron instruments — errors which occur with both a.c. and d.c. and the other which occur only with ac. only.

Errors with both D.C. and A.C

i)   Hysteresis Error
ii)   Temperature error
iii)   Stray magnetic field

■■

Errors with only A.C

Frequency errors

## Advantages & Disadvantages

1) Universal use
 (2) Less Friction Errors
(3) Cheapness
(4)   Robustness
(5) Accuracy
(6) Scale
(7) Errors
(8) Waveform errors.

Electrodynamometer (Eelectrodynamic) Type Instruments

The necessity for the a.c. calibration of moving iron instruments as well as other types of instruments which cannot be correctly calibrated requires the use of a transfer type of instrument. A transfer instrument is one that may be calibrated with a d.c. source and then used without modification to measure a.c. This requires the transfer type instrument to have same accuracy for both d.c. and a.c., which the electrodynamometer instruments have.

These standards are precision resistors and the Weston standard cell (which is a d.c. cell).It is obvious, therefore, that it would be impossible to calibrate an a.c. instrument directly against the fundamental standards.The calibration of an a.c. instrument may be performed as follows. The transfer instrument is first calibrated on d.c.This calibration is then transferred to the a.c. instrument onalternating current, using operating conditions under which the latter operates properly. Electrodynamic instruments are capable of service as transfer instruments.Indeed, their principal use as ammeters and voltmeters in laboratory and measurement work is for the transfer calibration of working instruments and as standards for calibration of other nstruments as their accuracy is very high.Electrodynamometer types of instruments are used as a.c. voltmeters and ammeters both in the range of power frequencies and lower part of the audio power frequency range. They are used as watt-meters, and with some modification as power factor meters and frequency meters.
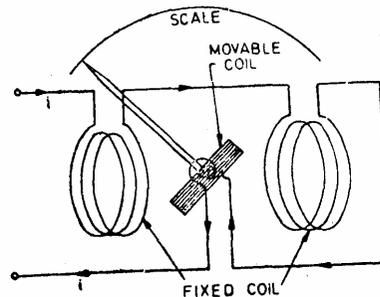
Operating Principle of Electrodynamometer Type Instrument

It would have a torque in one direction during one half of the cycle and an equal effect in the opposite direction during the other half of the cycle.If the frequency were very low, the pointer would swing back and forth around the zero point. However, for an ordinary meter, the inertia is so great that on power frequencies the pointer does not go very far in either direction but merely stays (vibrates slightly) around zero. If, however, we were to reverse the direction of the flux each time the current through the movable coil reverses, a unidirectional torque would be produced for both positive and negative halves of the cycle.

In electrodynamometer instruments the field can be made to reverse simultaneously with the current in the movable coil if the field (fixed) coil is connected in series with the movable coil.

Construction of Electrodynamometer type instrument
Fixed Coils
> The field is produced by a fixed coil.
> This coil is divided into two sections to give a more uniform field near the centre and to allow passage of the instrument shaft.

Moving Coil
> A single element instrument has one moving coil.
> The moving coil is wound either as a self-sustaining coil or else on a non-metallic former.
> A metallic former cannot be used as eddy current would be induced in it by the alternating field.
> Light but rigid construction is used for the moving coil.

It should be noted that both fixed and moving coils are air cored.

Control

The controlling torque is provided by two control springs.

These springs act as leads to the moving coil.

Moving System

The moving coil is mounted on an aluminum spindle.

The moving system also carries the counter weights and truss type pointer.

Sometimes a suspension may be used in case a high sensitivity is desired.

Damping

Air friction damping is employed for these instruments and is provided by a pair of aluminum vanes, attached to the spindle at the bottom.

These vanes move in sector shaped chambers.

Eddy current damping cannot be used in these instruments as the operating field is very weak (on account of the fact that the coils are air cored) and any introduction of a permanent magnet required for eddy current damping would distort the operating magnetic field of the instrument.

Shielding

The field produced by the fixed coils is somewhat weaker than in other types of instruments

It is nearly 0.005 to 0.006 Wb/m

In d.c. measurements even the earth magnetic field may affect the readings.

Thus it is necessary to shield an electrodynamometer type instrument from the effect of stray magnetic fields.

Air cored electrodynamometer type instruments are protected against external magnetic fields by enclosing them in a casing of high permeability alloy.

This shunts external magnetic fields around the instrument mechanism and minimizes their effects on the indication.

Cases and Scales

Laboratory standard instruments are usually contained in highly polished wooden cases.

These cases are so constructed as to remain dimensionally stable over long periods of time.

The glass is coated with some conducting material to completely remove the electrostatic effects.

The case is supported by adjustable leveling screws.

A spirit level is also provided to ensure proper leveling.

The scales are hand drawn, using machine sub-dividing equipment. Diagonal lines for fine sub-division are usually drawn for main markings on the scale.

Most of the high-precision instruments have a 300 mr scale with 100, 120 or 150 divisions.

Torque Equation

Let i1 = instantaneous value of current in the fixed coils: A.

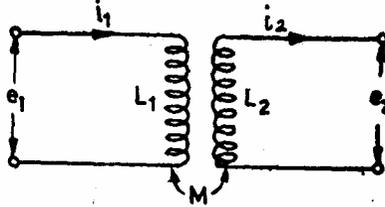i2 = instantaneous value of current in the moving coil: A. L1 = self-inductance of fixed coils: H.

L2 = self-inductance of moving coils H,

M = mutual inductance between fixed and moving coils:

Flux linkages of coil 1, z_1 = L1 i1 + Mi2

Flux linkages f coil 2, z_2 = L2 i2 + Mi1

Electrical input energy = e1i1dt+e2i2dt

(Fig) circuit representation

$$= i_1 L_1 di_1 + i_1{}^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + i_2{}^2 dL_2 + i_1 i_2 dM + i_2 M di_1$$

Energy stored in the magnetic field $= \frac{1}{2} i_1{}^2 L_1 + \frac{1}{2} i_2{}^2 L_2 + i_1 i_2 M$

Change in energy stored $= d(\frac{1}{2} i_1{}^2 L_1 + \frac{1}{2} i_2{}^2 L_2 + i_1 i_2 M)$

$= i_1 L_1 di_1 + (i_1{}^2/2) dL_1 + i_2 L_2 di_2 + (i_2{}^2/2) dL_2 + i_1 M di_2 + i_2 M di_1 + i_1 i_2 dM$

From principle of conservation of energy,

Total electrical input energy = change in energy stored + mechanical energy.

$\therefore$ Mechanical energy $= \frac{1}{2} i_1{}^2 dL_1 + \frac{1}{2} i_2{}^2 dL_2 + i_1 i_2 dM.$

Now the self-inductances L and L are constant and therefore dL and dL are both equal to zero. Thus we have

$$T_i d\theta = i_1 i_2 dM \text{ or } T_i = i_1 i_2 \, dM/d\theta$$

Errors in Electrodynamometer Instruments

i) Frequency error
ii) Eddy current error
iii) External magnetic field
iv) Temperature changes

Advantages

i) These instruments can be used on both a.c & d.c
ii) Accurate rms value

Disadvantages

(i) They have a low torque/weight ratio and hence have a low sensitivity. (ii) Low torque/weight ratio gives increased frictional losses.
(iii) They are more expensive than either the PMMC or the moving iron type instruments.

(iv) These instruments are sensitive to overloads and mechanical impacts. Therefore, they must be handled with great care.

(v) The operating current of these instruments is large owing to the fact that they have weak magnetic field. The flux density is about 0.006 Wb/m as against 0.1 to
0.5 Wb/m in PMCC instruments

(vi) They have a non-uniform scale.

Rectifier Type Instruments

Rectifier type instruments are used for measurement of ac. voltages and currents by employing a rectifier e l e m e n t which converts a.c. to a unidirectional d.c. and then using a meter responsive to d.c. to indicate the value of rectified a.c.

The indicating instrument is PM MC instrument which uses a d 'Arsonval movement.

This method is very attractive since PM MC instruments have a higher sensitivity than the electrodynamometer or the moving iron instruments. The arrangement which employs a full wave.
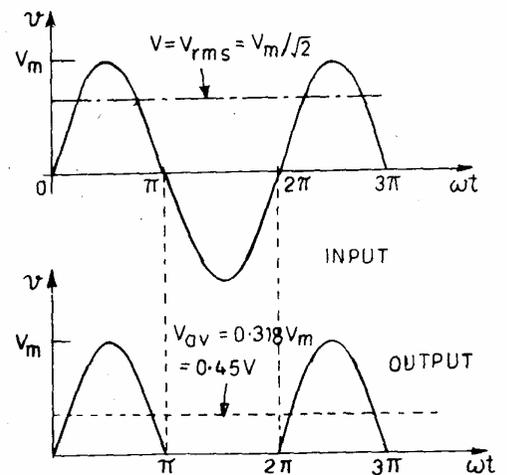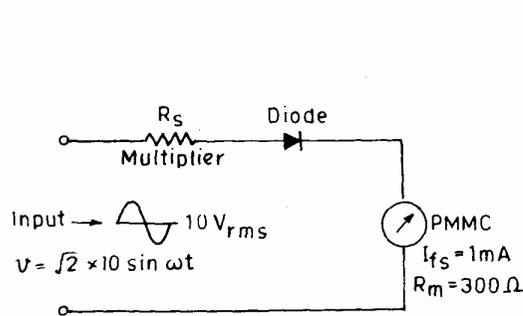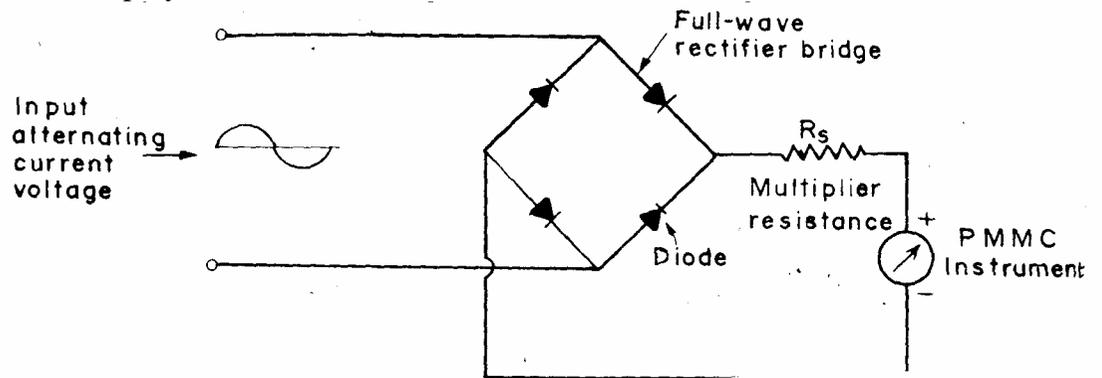
Digital Voltmeter

A digital voltmeter (DVM) displays the value of a.c. or d.c. voltage being measured directly as discrete numerals in the decimal number system. Numerical readout of DVMs is advantageous since it eliminates observational errors committed by operators.

The errors on account of parallax and approximations are entirely eliminated.

The use of digital voltmeters increases tile speed with which readings can be taken.

A digital voltmeter is a versatile and accurate voltmeter which has many laboratory applications.

On account of developments in the integrated circuit (IC) technology, it has been possible to reduce the size, power requirements and cost of digital voltmeters.

In fact, for the same accuracy, a digital voltmeter now is less costly than its analog counterpart.

The decrease in size of DVMs on account of use of ICs, the portability of the instruments has increased.

Types of DVMs

The increasing popularity of DVMs has brought forth a wide number of types employing different circuits. The various types of DVMs in general use are

      (i)   Ramp type DVM
      (ii)   Integrating type DVM
      (iii)   Potentiometric type DVM
      (iv)   Successive approximation type DVM
      (v)   Continuous balance type DVM

Ramp type Digital Voltmeter

The operating principle of a ramp type digital voltmeter is to measure the time that a linear ramp voltage takes to change from level of input voltage to zero voltage (or vice versa).This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits on electronic indicating tubes of the output readout of the voltmeter.The conversion of a voltage value of a time interval is shown in the timing diagram .A negative going ramp is shown in Fig. but a positive going ramp may also be used.The ramp voltage value is continuously compared with the voltage being measured (unknown voltage).At the instant the value of ramp voltage is equal to that of unknown voltage.The ramp voltage continues to decrease till it reaches ground level (zero voltage).At this instant another comparator called ground comparator generates. a pulse and closes the gate.The time elapsed between opening and closing of the gate is t as indicated in Fig.During this time interval pulses from a clock pulse generator pass through the gate and are counted and displayed.The decimal number as indicated by the readout

is a measure of the value of input voltage.The sample rate multivibrator determines the rate at which the measurement cycles are initiated.The sample rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage.

At the same time it sends a pulse to the counters which set all of them to 0.

This momentarily removes the digital display of the readout.

Integrating Type Digital Voltmeter

The voltmeter measures the true average value of the input voltage over a fixed measuring period.In contrast the ramp type DVM samples the voltage at the end of the measuring period.This voltmeter employs an integration technique which uses a voltage to frequency conversion.The voltage to frequency (VIF) converter functions as a feedback control system which governs the rate of pulse generation in proportion to the magnitude of input voltage.
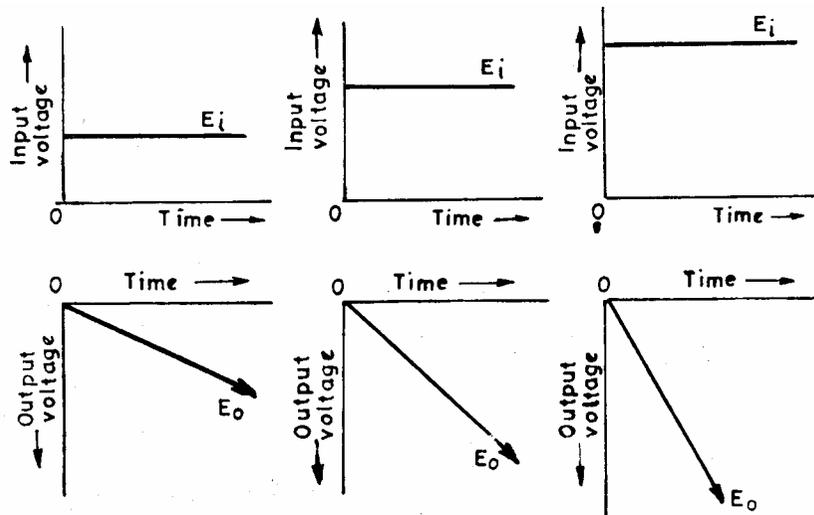
Actually when we employ the voltage to frequency conversion techniques, a train of pulses, whose frequency depends upon the voltage being measured, is generated.

Then the number of pulses appearing in a definite interval of time is counted.

Since the frequency of these pulses is a function of unknown voltage, the number of pulses counted in that period of time is an indication of the input (unknown) voltage.
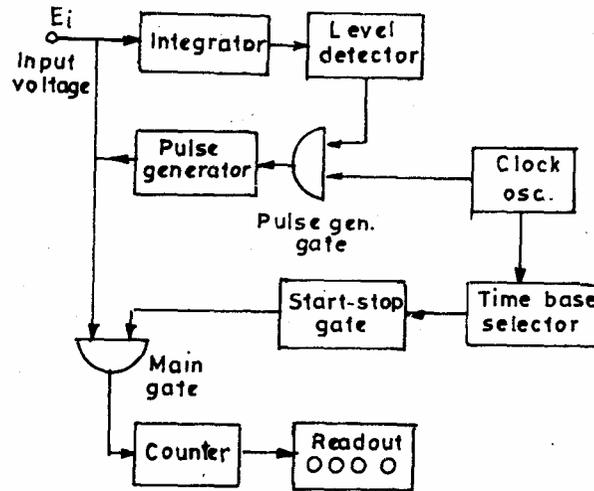
The heart of this technique is the operational amplifier acting as an Integrator.

Output voltage of integrator $E = -E_i / RC*t$

Thus if a constant input voltage E is applied, an output voltage E is produced which rises at a uniform rate and has a polarity opposite to that input voltage.

In other words, it is clear from the above relationship that for a constant input voltage the integrator produces a ramp output voltage of opposite polarity.

The basic block diagram of a typical integrating type of DVM is shown in

Ei

Input voltage

Integrator → Level detector

Pulse generator

Pulse gen. gate

Clock osc.

Start-stop gate

Time base selector

Main gate

Counter → Readout O O O O

The unknown voltage is applied to the input of the integrator, and the output voltage starts to rise.The slope of output voltage is determined by the value of input voltage This voltage is fed a level detector, and when voltage reaches a certain reference level, the detector sends a pulse to the pulse generator gate. The level detector is a device similar to a voltage comparator. The output voltage from integrator is compared with the fixed voltage of an internal reference source, and, when voltage reaches that level, the detector produces an output pulse.

It is evident that greater then value of input voltage the sharper will be the slope of output voltage and quicker the output voltage will reach its reference level.
The output pulse of the level detector opens the pulse level gate, permitting pulses from a fixed frequency clock oscillator to pass through pulse generator.
The generator is a device such as a Schmitt trigger that produces an output pulse of fixed amplitude and width for every pulse it receives. This output pulse, whose polarity is opposite to that of and has greater amplitude, is fedback of the input of the integrator.Thus no more pulses from the clock oscillator can pass through to trigger the pulse generator.When the output voltage pulse from the pulse generator has passed, is restored to its original value and starts its rise again.When it reaches the level of reference voltage again, the pulse generator gate is opened.The pulse generator is trigger by a pulse from the clock generator and the entire cycle is repeated again.
Thus, the waveform of is a saw tooth wave whose rise time is dependent upon the value of output voltage and the fail time is determined by the width of the output pulse from the pulse generator.Thus the frequency of the saw tooth wave is a function of the value of the voltage being measured.Since one pulse from the pulse generator is produced for each cycle of the saw tooth wave, the number of pulses produced in a

given time interval and hence the frequency of saw tooth wave is an indication of the voltage being measured.

Potentiometric Type Digital Voltmeter

A potentiometric type of DVM employs voltage comparison technique. In this DVM the unknown voltage is compared with reference voltage whose value is fixed by the setting of the calibrated potentiometer.

The potentiometer setting is changed to obtain balance (i.e. null conditions).

When null conditions are obtained the value of the unknown voltage, is indicated by the dial setting of the potentiometer.

In potentiometric type DVMs, the balance is not obtained manually but is arrived at automatically.

Thus, this DVM is in fact a self- balancing potentiometer.

The potentiometric DVM is provided with a readout which displays the voltage being measured.
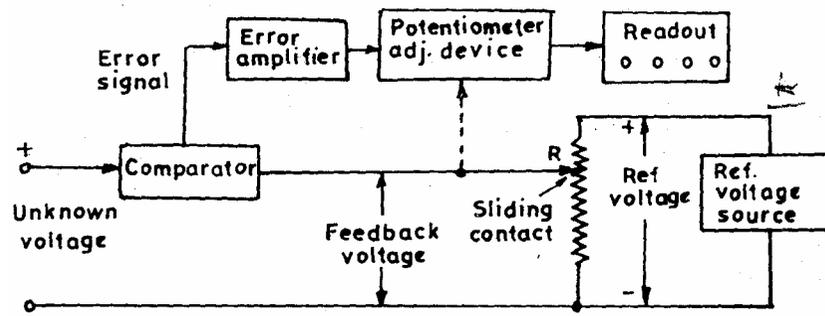
(Fig.) Basic block diagram of a potentiometric DVM.

The block diagram of basic circuit of a potentiometric DVM is shown. The unknown voltage is filtered and attenuated to suitable level. This input voltage is applied to a comparator (also known as error detector).This error detector may be chopper.The reference voltage is obtained from a fixed voltage source. This voltage is applied to a potentiometer.The value of the feedback voltage depends up the position of the sliding contact.The feedback voltage is also applied to the comparator.The unknown voltage and the feedback voltages are compared in the comparator.The output voltage of the comparator is the difference of the above two voltages.The difference of voltage is called the error signal.The error signal is amplified and is fed to a potentiometer djustment device which moves the sliding contact of the potentiometer.This magnitude by which the sliding contact moves depends upon the magnitude of the error signal.

The direction of movement of slider depends upon whether the feedback voltage is larger or the input voltage is larger.The sliding contact moves to such a place where the feedback voltage equals the unknown voltage.In that case, there will not be any error voltage and hence there will be no input to the device adjusting the position of the sliding cont act and therefore it (sliding contact) will come to rest.The position of the potentiometer adjustment device at this point is indicated in numerical form on the digital readout device associated with it.

2.3Single And Three Phase Wattmeters And Energy Meters

Single Phase Induction Type Meters

The construction and principle of operation of Single Phase Energy Meters is explained below

Construction of Induction Type Energy Meters

There are four main parts of the operating mechanism
  (i)   Driving   system
  (ii)   Moving   system
  (iii)   Braking system
  (iv)   Registering system

Driving system

The driving system of the meter consists of two electro-magnets.

The core of these electromagnets is made up of silicon steel laminations. The coil of one of the electromagnets is excited by the load current. This coil is called the current coil.

The coil of second electromagnet is connected across the supply and, therefore, carries a current proportional to the supply voltage. This coil is called the pressure coil.

Consequently the two electromagnets are known as series and shunt magnets respectively.

Copper shading bands are provided on the central limb. The position of these bands is adjustable.

The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.
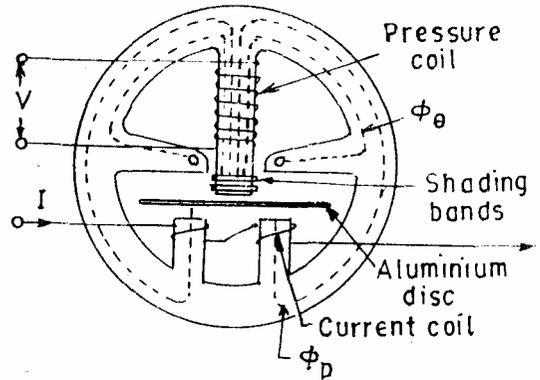
Moving System

This consists of an aluminum disc mounted on a light alloy shaft.

This disc is positioned in the air gap between series and shunt magnets. The upper bearing of the rotor (moving system) is a steel pin located in a hole in the bearing cap fixed to the top of the shaft.

The rotor runs on a hardened steel pivot, screwed to the foot of the shaft. The pivot is supported by a jewel bearing.

 A pinion engages the shaft with the counting or registering mechanism.

(Fig) single phase energy meter

Braking System

A permanent magnet positioned near the edge of the aluminium disc forms the braking system. The aluminium disc moves in the field of this magnet and thus provides a braking torque.

The position of the permanent magnet is adjustable, and therefore braking torque can be adjusted by shifting the permanent magnet to different radial positions as explained earlier.
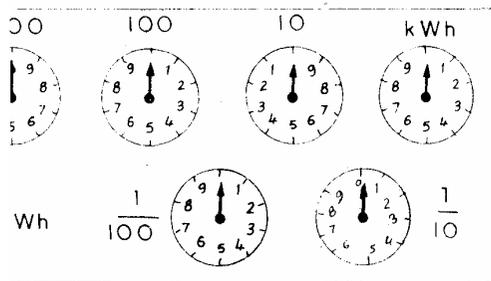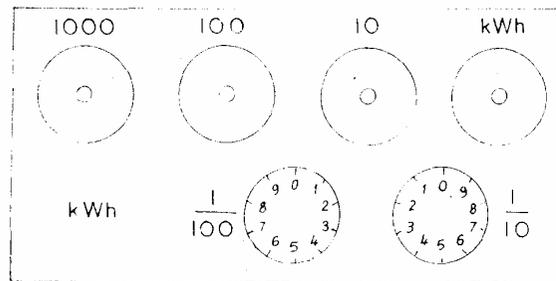
(fig) Pointer type   (fig) cyclometer register

Registering (counting) Mechanism

The function of a registering or counting mechanism is to record continuously a number which is proportional to the revolutions made by the moving system.

By a suitable system, a train of reduction gears the pinion on the rotor shaft drives a series of five or six pointers.

These rotate on round dials which are marked with ten equal divisions.

The pointer type of register is shown in Fig. Cyclo-meter register as shown in Fig can also he used.

Errors in Single Phase Energy Meters

The errors caused by the driving system are

(i)   Incorrect magnitude of fluxes.

(ii)   Incorrect phase angles.

(iii)   Lack of Symmetry in magnetic circuit.

The errors caused by the braking system are
i)   changes in strength of brake magnet
ii)   changes in disc resistance
iii)   abnormal   friction
iv)   self braking effect

Three Phase General Supply with Controlled Load

Meter Panel | Switchboard
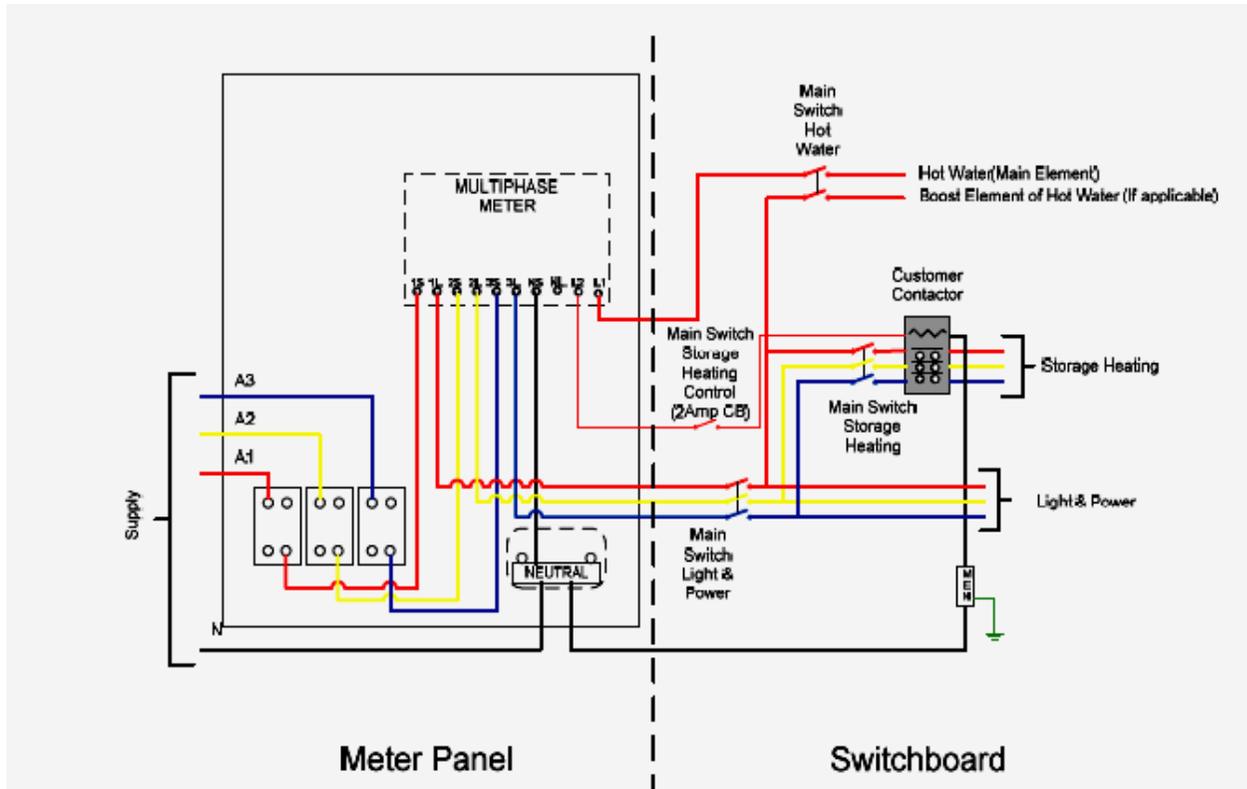
- L1 – 30A Load Control (Hot Water)
- L2 – Maximum 2A Load Control (Storage Heating)
- 2.5mm² with 7 strands for conductors to control customer contactor
- Load carrying conductors not less than 4mm² or greater than 35mm²
- All metering neutrals to be black colour 4mm² or 6 mm² with minimum 7 stranded conductors.
- Not less than 18 strand for 25 & 35mm² conductors
- Refer to SIR's for metering obligations
- Comply with Electrical Safety (Installations) Regulations 2009 and AS/NZS 3000
- Customer needs to provide 2A circuit breaker as a Main Switch and their load control contactor
- Within customer's switchboard
- Meter panel fuse not required for an overhead supply.
- Off Peak controlled load only includes single phase hot water & single or multi-phase storage heating
- Wiring diagram applicable for Solar

- Metering diagram is applicable for 2 or 3 phase load.
  For 2 phase loads – Red and Blue phase is preferred.

  WATTMETER

  Electrodynamometer Wattmeters

  These instruments are similar in design and construction to electrodynamometer type ammeters and voltmeters.

  The two coils are connected in different circuits for measurement of power.

  The fixed coils or "field coils" arc connected in series with the load and so carry the current in the circuit.

  The fixed coils, therefore, form the current coil or simply C.C. of the wattmeter.

  The moving coil is connected across the voltage and, therefore, carries a current proportional to the voltage.

  A high non-inductive resistance is connected in series with the moving coil to limit the current to a small value.

  Since the moving coil carries a current proportional to the voltage, it is called the "pressure coil" or "voltage coil" or simply called P.C. of the wattmeter.

  Construction of Electrodynamometer Wattmeter

  Fixed Coils

  The fixed coils carry the current of the circuit.

  They are divided into two halves.

  The reason for using fixed coils as current coils is that they can be made more massive and can be easily constructed to carry considerable current since they present no problem of leading the current in or out.

  The fixed coils are wound with heavy wire. This wire is stranded or laminated especially when carrying heavy currents in order to avoid eddy current losses in conductors. The fixed coils of earlier wattmeters were designed to carry a current of 100 A but modem designs usually limit the maximum current ranges of wattmeters to about 20 A. For power measurements involving large load currents, it is usually better to use a 5 A wattmeter in conjunction with a current transformer of suitable range.
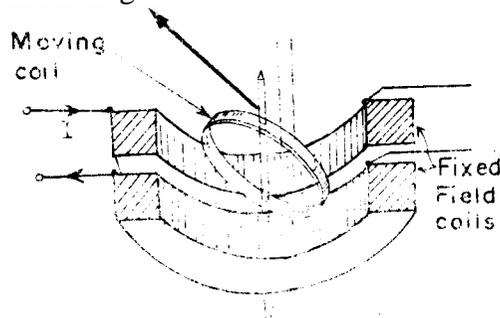
(Fig) Dynamometer wattmeter

Damping

Air friction damping is used.

The moving system carries a light aluminium vane which moves in a sector shaped box. Electromagnetic or eddy current damping is not used as introduction of a permanent magnet (for damping purposes) will greatly distort the weak operating magnetic field.

Scales and Pointers

They are equipped with mirror type scales and knife edge pointers to remove reading errors due to parallax.

Theory of Electrodynamometer Watt-meters
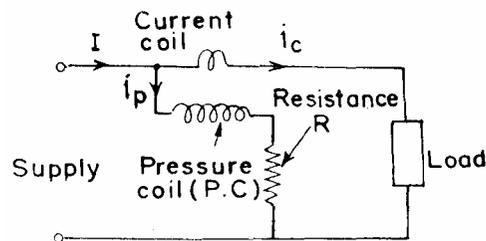
(Fig) circuit of electrodynamometer

It is clear from above that there is a component of power which varies as twice the frequency of current and voltage (mark the term containing 2ωt).

Average deflecting torque

$$T_d = \frac{1}{T}\int_0^T T_i \, d(\omega t) = \frac{1}{T}\int_0^T I_p \, I \, [\cos\phi - \cos(2\omega t - \phi)]\frac{dM}{d\theta} \cdot d(\omega t)$$

$$= I_p \, I \cos\phi \cdot dM/d\theta$$

$$= (VI/R_p) \cos\phi \cdot dM/d\theta$$

Controlling torque exerted by springs Tc= Kş

Where, K = spring constant; ş= final steady deflection.

Errors in electrodynamometer

   i) Errors due to inductance effects ii) Stray magnetic field errors

   iii) Eddy current errors

   iv) Temperature error

Ferrodynamic Wattmeters

The operating torque can be considerably increased by using iron cores for the coils.

Ferrodynamic wattmeters employ cores of low loss iron so that there is a large increase in the flux density and consequently an increase in operating torque with little loss in accuracy.

The fixed coil is wound on a laminated core having pole pieces designed to give a uniform radial field throughout the air gap.

The moving coil is asymmetrically pivoted and is placed over a hook shaped pole piece.

This type of construction permits the use of a long scale up to about 270° and gives a deflecting torque which is almost proportional to the average power.

With this construction there is a tendency on the part of the pressure coil to creep (move further on the hook) when only the pressure coil is energized.

This is due to the fact that a coil tries to take up a position where it links with maximum flux. The creep causes errors and a compensating coil is put to compensate for this voltage creep.
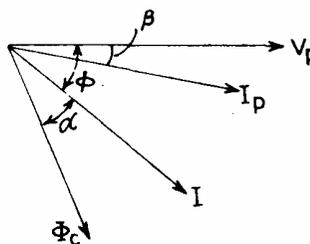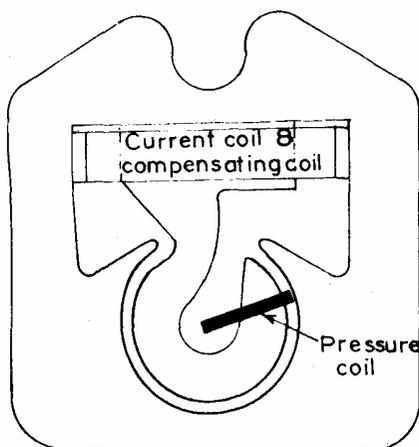
The use of ferromagnetic core makes it possible to employ a robust construction for the moving element.

Also the Instrument is less sensitive to external magnetic fields. On the other hand, this construction introduces non-linearity of magnetization curve and introduction of large eddy current & hysteresis losses in the core.

Three Phase Wattmeters

A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle.

The arrangement is shown in Fig.

There are two current coils and two pressure coils.

A current coil together with its pressure coil is known as an element.

Therefore, a three phase wattmeter has two elements.

The connections of two elements of a 3 phase wattmeter are the same as that for two wattmeter method using two single phase wattmeter.

The torque on each element is proportional to the power being measured by it.

The total torque deflecting the moving system is the sum of the deflecting torque of the two elements.

Hence the total deflecting torque on the moving system is proportional to the total Power.

In order that a 3 phase wattmeter read correctly, there should not be any mutual interference between the two elements.

A laminated iron shield may be placed between the two elements to eliminate the mutual effects.
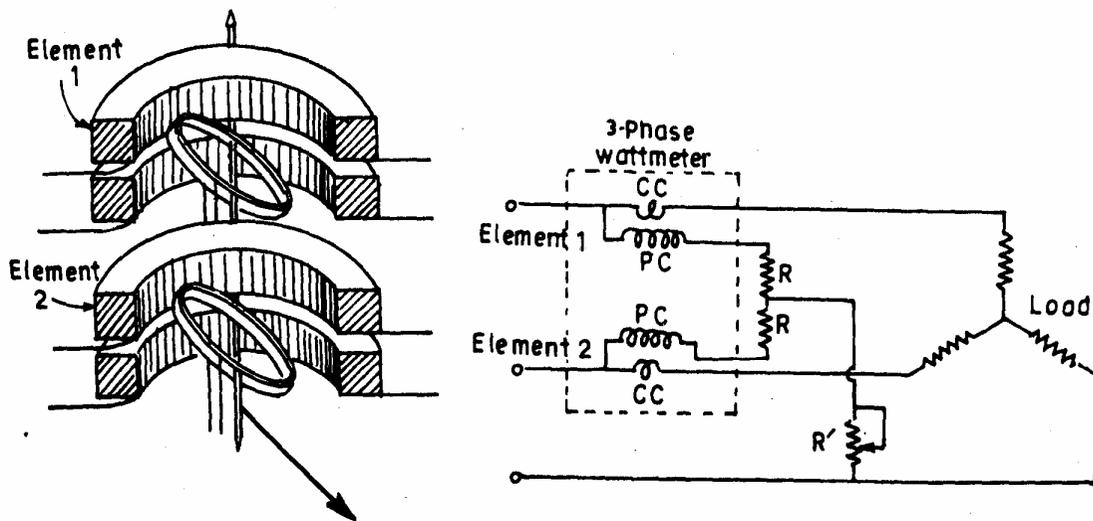

(fig) three phase wattmeter

2.4 InstrumentTransformers

Power measurements are made in high voltage circuits connecting the wattmeter to the circuit through current and potential transformers as shown.

The primary winding of the C.T. is connected in series with the load and the secondary winding is connected in series with an ammeter and the current coil of a wattmeter.

The primary winding of the potential transformer is connected across the supply lines and a voltmeter and the potential coil circuit of the wattmeter are connected in parallel with the secondary winding of the transformer. One secondary terminal of each transformer and the casings are earthed.
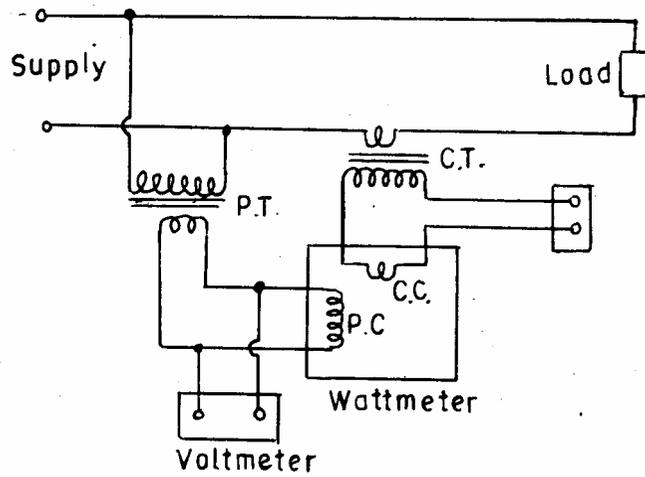
The errors in good modem instrument transformers are small and may be ignored for many purposes.

However, they must be considered in precision work. Also in some power measurements these errors, if not taken into account, may lead to very inaccurate results.

Voltmeters and ammeters are effected by only ratio errors while wattmeters are influenced in addition by phase angle errors. Corrections can be made for these errors if test information is available about the instrument transformers and their burdens.

Phasor diagrams for the current and voltages of load, and in the wattmeter coils.

(a)   (b)
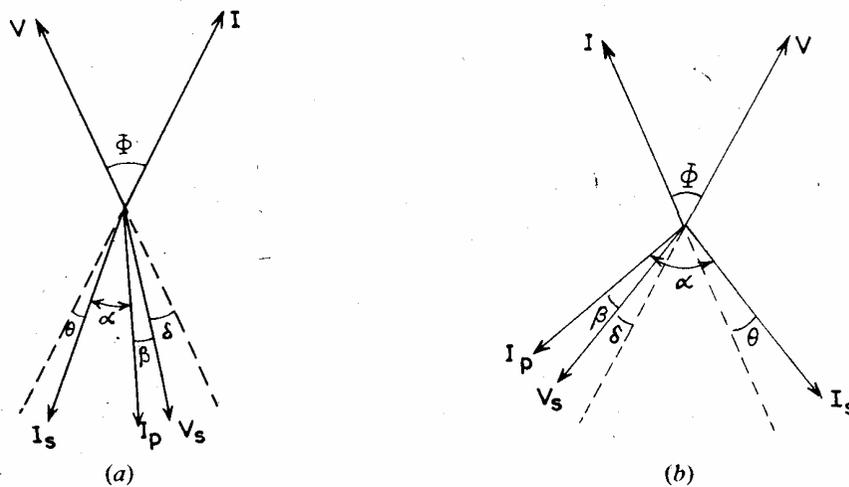
2.5 MAGNETICMEASUREMENTS

The operating characteristics of electrical machines, apparatus and instruments are greatly influenced by the properties of Ferro-magnetic materials used for their construction. Therefore, magnetic measurements and a thorough knowledge of characteristics of magnetic materials are of utmost importance in designing and manufacturing electrical equipment.

The principal requirements in magnetic measurements are
(i) The measurement of magnetic field strength in air.
(ii) The determination of B-H curve and hysteresis loop for soft Ferro-magnetic materials.
(iii) The determination of eddy current and hysteresis losses of soft Ferro-magnetic materials subjected to alternating magnetic fields.

(iv) The testing of permanent magnets.
Magnetic measurements have some inherent inaccuracies due to which the measured values depart considerably from the true values. The inaccuracies are due to the following reasons
(i) The conditions in the magnetic specimen under test are different from those assumed in calculations;
(ii) The magnetic materials are not homogeneous
(iv)There is no uniformity between different batches of test specimens even if such batches are of the same composition.

Types of Tests
Many methods of testing magnetic materials have been devised wherein attempts have been made to eliminate the inaccuracies. However, attention will be confined to a few basic methods of' Testing Ferro-magnetic materials. They are:
(i) Ballistic Tests: These tests are generally employed for the determination of B- H curves and hysteresis loops of Ferro-magnetic materials.
(ii) A. C. Testing. These tests may be carried at power, audio or radio frequencies. They give information about eddy current and hysteresis losses in magnetic materials.
(iii) Steady State Tests. These are performed to obtain the steady value of flux density existing in the air gap of a magnetic circuit.

Ballistic Tests: These tests are used for determination of flux density in a specimen, **determination of B-H curves and plotting of hysteresis loop**.

Measurement of Flux Density
The measurement of flux density inside a specimen can be done by winding a search coil over the specimen.
This search coil is known as a "B coil".
This search coil is then connected to a ballistic galvanometer or to a flux meter.
Let us consider that we have to measure the flux density in a ring specimen shown in Fig.
The ring specimen is wound with a magnetizing winding which carries a

current I.

A search coil of convenient number of turns is wound on the specimen and connected through a resistance and calibrating coil, to a ballistic galvanometer as shown.

The current through the magnetizing coil is reversed and therefore the flux linkages of the search coil change inducing an emf in it.

 Thus emf sends a current through the ballistic galvanometer causing it to deflect.
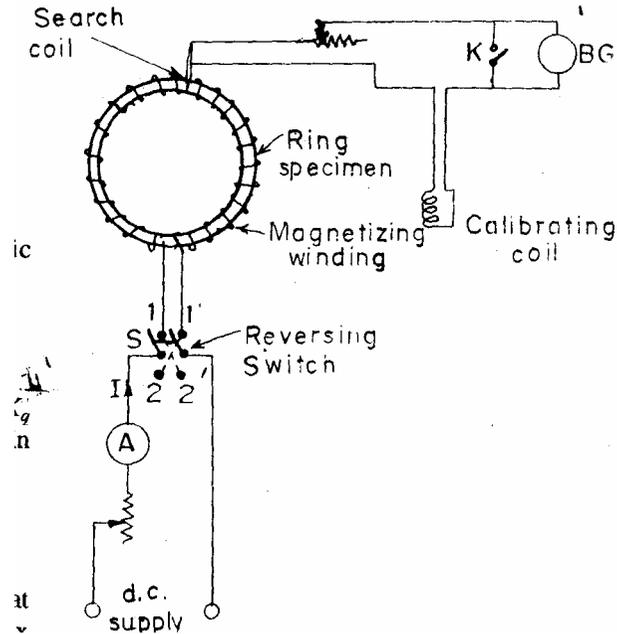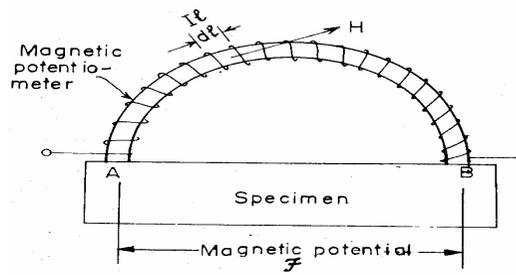

Magnetic Potentiometer

This is a device for measurement of magnetic potential difference between two points.

It can be shown that the line integral of magnetizing force H produced by a coil of N concentrated turns carrying a current I is:

$$\int H dl = NI$$

around any closed path linking the coil.

(Fig) Magnetic potentiometer

This is the circuital law of the magnetic field and forms the basis of magnetic potentiometer.

A magnetic potentiometer may be used to determine the mmf around a closed path, or the magnetic potential difference between two points in a magnetic circuit.

A magnetic potentiometer consists of a one metre long flat and uniform coil made of two or four layers of thin wire wound unidirectional on a strip of flexible non-magnetic material.

The coil ends are brought out at the middle of the strip as shown in Fig. and connected to a ballistic galvanometer.

The magnetic potential difference between points A and B of the field is measured by placing the ends of the strip at these points and observing the throw of the ballistic galvanometer when the flux through the specimen is changed.

2.6 Determination of B-H curve

Method of reversals

A ring shaped specimen whose dimensions are known is used for the purpose

After demagnetizing the test is started by setting the magnetising current to its lowest test vlane.

With galvanometer key K closed, the iron specimen is brought into a ' reproducible cyclic magnetic state' by throwing the reversing switch S backward and forward about twenty times.

Key K is now opened and the value of flux corresponding to this value of H is measured by reversing the switch S and noting the throw of galvanometer.

The value of flux density corresponding to this H can be calculated by dividing the flux by the area of the specimen.

The above procedure is repeated for various values of H up to the maximum testing point.

The B-H curve may be plotted from the measured values of B corresponding to the various values of H.

Step by step method

The circuit for this test is shown in Fig.

The magnetizing winding is supplied through a potential divider having a large number of tapping.

The tappings are arranged so that the magnetizing force H may be increased, in a number of suitable steps, up to the desired maximum value.

The specimen before being tested is demagnetized.

The tapping switch S is set on tapping I and the switch S is closed.

The throw of the galvanometer corresponding to this increase in flux density in the specimen, form zero to some value B, is observed.

Step by step method

After reaching the point of maximum H i.e... when switch S is at tapping 10, the magnetizing current is next reduced, in steps to zero by moving switch 2 down through the tapping points 9, 8, 7 3, 2, 1.

After reduction of magnetizing force to zero, negative values of H are obtained by reversing the supply to potential divider and then moving the switch S up again in order 1, 2, 3 7, 8. 9, 1O.

(Fig) Determination of B-H curve step by step method
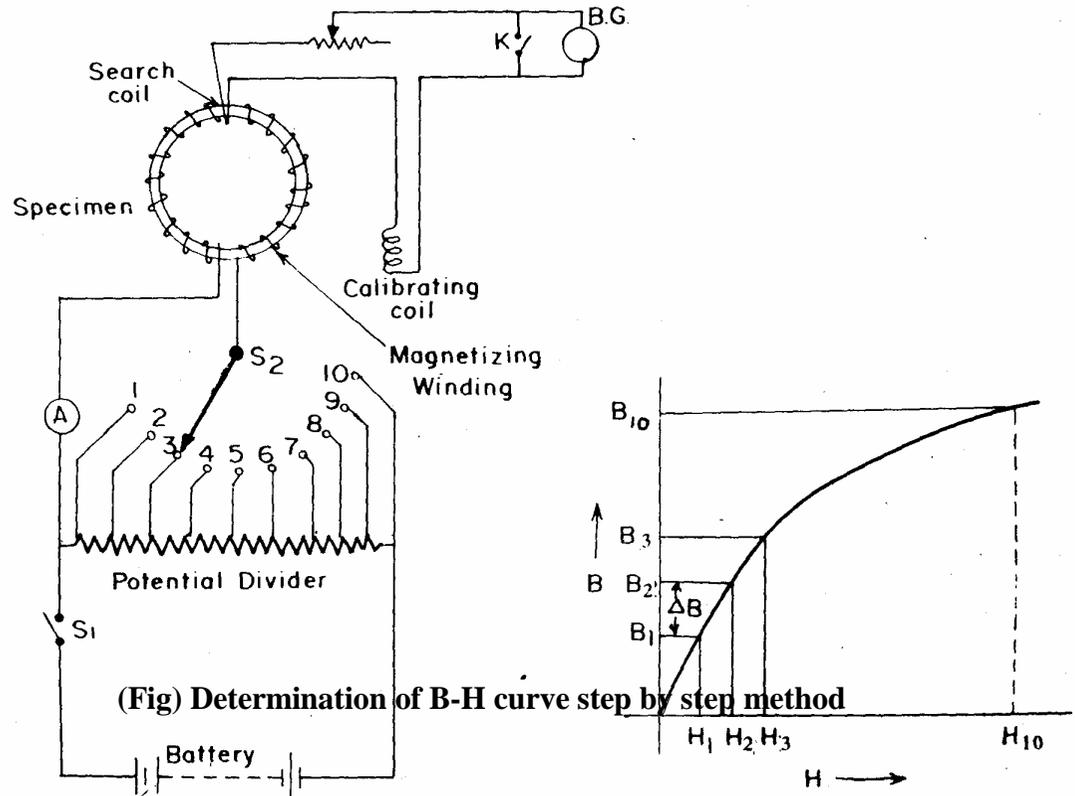
Determination of Hysteresis Loop

Method of reversals

This test is done by means of a number of steps, but the change in flux density measured at each step is the change from the maximum value + Bm down to some lower value.

 But before the next step is commenced the iron specimen is passed through the remainder of the cycle of magnetization back to the flux density + Bm.

Thus the cyclic state of magnetization is preserved.

The connections for the method of reversals are shown in Fig.
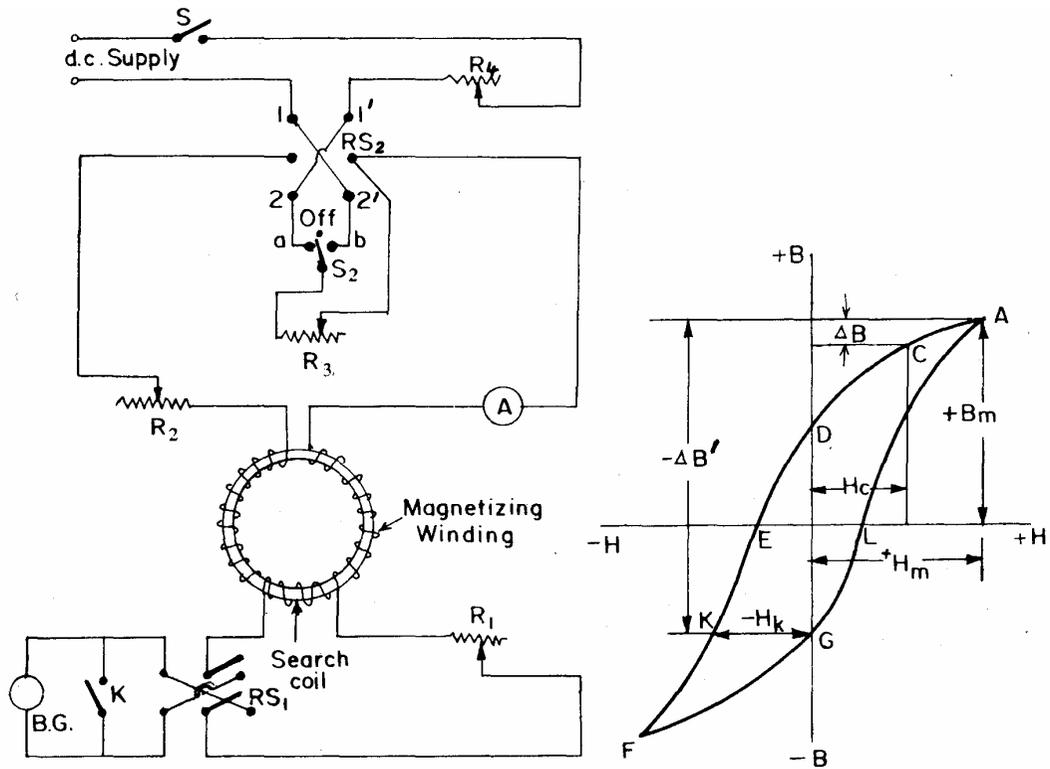
(fig) Method of reversal

UNIT III COMPARISON METHODS OF MEASUREMENTS

D.C & A.C Potentiometers

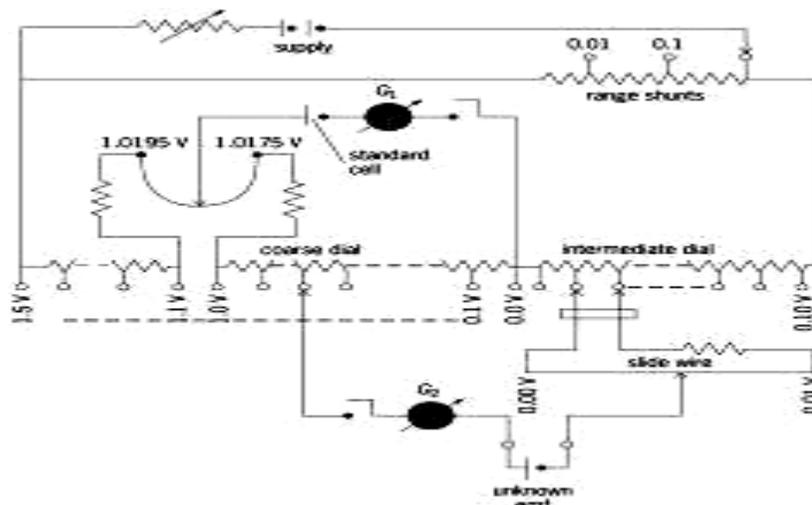An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance: (1) the current I may be held at a fixed value and the resistance R across which the IR drop is opposed to the unknown may be varied; (2) current may be varied across a fixed resistance to achieve the needed IR drop.

The essential features of a general-purpose constant-current instrument are shown in the illustration. The value of the current is first fixed to match an IR drop to the emf of a reference standard cell. With the standard-cell dial set to read the emf of the reference cell, and the galvanometer (balance detector) in position G_1, the resistance of the supply branch of the circuit is adjusted until the IR drop in 10 steps of the coarse dial plus the set portion of the standard-cell dial balances the known reference emf, indicated by a null reading of the galvanometer. This adjustment permits the potentiometer to be read directly in volts. Then, with the galvanometer in position G_2, the coarse, intermediate, and slide-wire dials are adjusted until the galvanometer again reads null. If the potentiometer current has not changed, the emf of the unknown can be read directly from the dial settings. There is usually a switching arrangement so that the galvanometer can be quickly shifted between positions 1 and 2 to check that the current has not drifted from its set value.

  Circuit diagram of a general-purpose constant-current potentiometer, showing essential features
Potentiometer techniques may also be used for current measurement, the unknown current being sent through a known resistance and the IR drop opposed by balancing it at the voltage terminals of the potentiometer. Here, of course, internal heating and consequent resistance change of the current-carrying resistor (shunt) may be a critical factor in measurement accuracy; and the shunt

design may require attention to dissipation of heat resulting from its I^2R power consumption.

Potentiometer t e c h n i q u e s h a v e been extended to alternating-voltage measurements,   but generally at a reduced accuracy level (usually 0.1% or so). Current is set on an ammeter which must have the same response on ac as on dc, where it may be calibrated with a potentiometer and shunt combination. Balance in opposing an unknown voltage is achieved in one of two ways: (1) a slide-wire and phase-adjustable supply; (2) separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have limited use in magnetic testing.

An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance: (1) the current I may be held at a fixed value and the resistance R across which the IR drop is opposed to the unknown may be varied; (2) current may be varied across a fixed resistance to achieve the needed IR drop.

The essential features of a general-purpose constant-current instrument are shown in the illustration. The value of the current is first fixed to match an IR drop to the emf of a reference standard cell. With the standard-cell dial set to read the emf of the reference cell, and the galvanometer (balance detector) in position G_1, the resistance of the supply branch of the circuit is adjusted until the IR drop in 10 steps of the coarse dial plus the set portion of the standard-cell dial balances the known reference emf, indicated by a null reading of the galvanometer. This adjustment permits the potentiometer to be read directly in volts. Then, with the galvanometer in position G_2, the coarse, intermediate, and slide-wire dials are adjusted until the galvanometer again reads null. If the potentiometer current has not changed, the emf of the unknown can be read directly from the dial settings. There is usually a switching arrangement so that the galvanometer can be quickly shifted between positions 1 and 2 to check that the current has not drifted from its set value.

Potentiometer techniques may also be used for current measurement, the unknown current being sent through a known resistance and the IR drop opposed by balancing it at the voltage terminals of the potentiometer. Here, of course, internal heating and consequent resistance change of the current-carrying resistor (shunt) may be a critical factor in measurement accuracy
Potentiometer techniques have been extended to alternating-voltage measurements, but generally at a reduced accuracy level (usually 0.1% or so). Current is set on an ammeter which must have the same response on ac as on dc, where it may be calibrated with a potentiometer and shunt combination. Balance in opposing an unknown voltage is achieved in one of two ways: (1) a slide-wire and phase-adjustable supply; (2) separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have

limited use in magnetic testing

 (1) An electrical measuring device used in determining the electromotive force (emf) or voltage by means of the compensation method. When used with calibrated standard resistors, a potentiometer can be employed to measure current, power, and other electrical quantites; when used with the appropriate measuring transducer, it can be used to gauge various non-electrical quantities, such as temperature, pressure, and the composition of gases.
 distinction is made between DC and AC potentiometers. In DC potentiometers, the voltage being measured is compared to the emf of a standard cell. Since at the instant of compensation the current in the circuit of the voltage being measured equals zero, measurements can be made without reductions in this voltage. For this type of potentiometer, accuracy can exceed 0.01 percent. DC potentiometers are categorized as either high-resistance, with a slide-wire resistance ranging from The higher resistance class can measure up to 2 volts (V) and is used in testing highly accurate apparatus. The low-resistance class is used in measuring voltage up to 100 mV. To measure higher voltages, up to 600 V, and to test voltmeters, voltage dividers are connected to potentiometers. Here the voltage drop across one of the resistances of the voltage divider is compensated; this constitutes a known fraction of the total voltage being measured.

In AC potentiometers, the unknown voltage is compared with the voltage drop produced by a current of the same frequency across a known resistance. The voltage being measured is then adjusted both for amplitude and phase. The accuracy of AC potentiometers is of the order of 0.2 percent. In electronic automatic DC and AC potentiometers, the measurements of voltage are carried out automatically. In this case, the compensation of the unknown voltage is achieved with the aid of a servomechanism that moves the slide along the resistor, or rheostat. The servomechanism is actuated by the imbalance of the two voltages, that is, by the difference between the compensating voltage and the voltage that is being compensated. In electronic automatic potentiometers, the results of measurements are read on dial indicators, traced on recorder charts or received as numerical data. The last method makes it possible to input the data directly into a computer. In addition to measurement, electronic automatic potentiometers are also capable of regulating various parameters of industrial processes. In this case, the slide of the rheostat is set in a position that predetermines, for instance, the temperature of the object to be regulated. The voltage imbalance of the potentiometer drives the servomechanism, which then increases or decreases the electric heating or regulates the fuel supply.

A voltage divider with a uniform variation of resistance, a device that allows some fraction of a given voltage to be applied to an electric circuit. In the simplest case, the device consists of a conductor of high resistance equipped with a sliding contact. Such dividers are used in electrical engineering, radio engineering, and measurement technology. They can also be utilized in analog computers and in automation systems, where, for example, they function as sensors for linear or angular displacement

3.2 D.C & A.C Bridges
  Bridge circuits are used very commonly as a variable conversion element in measurement systems and produce an output in the form of a voltage level that changes as the measured physical quantity changes. They provide an accurate method of measuring resistance,

inductance and capacitance values, and enable the detection of very small changes in these quantities about a nominal value. They are of immense importance in measurement system technology because so many transducers measuring physical quantities have an output that is expressed as a change in resistance, inductance or capacitance. The displacement-measuring strain gauge, which has a varying resistance output, is but one example of this class of transducers. Normally, excitation of the bridge is by a d.c. voltage for resistance measurement and by an a.c. voltage for inductance or capacitance measurement. Both null and deflection types of bridge exist, and, in a like manner to instruments in general, null types are mainly employed for calibration purposes and deflection types are used within closed-loop automatic control schemes.

Null-type, d.c. bridge (Wheatstone bridge)

A null-type bridge with d.c. excitation, commonly known as a Wheatstone bridge, has the form shown in Figure 7.1. The four arms of the bridge consist of the unknown resistance R_u, two equal value resistors R_2 and R_3 and a variable resistor R_v (usually a decade resistance box). A d.c. voltage V_i is applied across the points AC and the resistance R_v is varied until the voltage measured across points BD is zero. This null point is usually measured with a high sensitivity galvanometer.

To analyses the Whetstone bridge, define the current flowing in each arm to be $I_1 \ldots I_4$ as shown in Figure 7.1. Normally, if a high impedance voltage-measuring instrument is used, the current I_m drawn by the measuring instrument will be very small and can be approximated to zero. If this assumption is made, then, for I_m D 0:

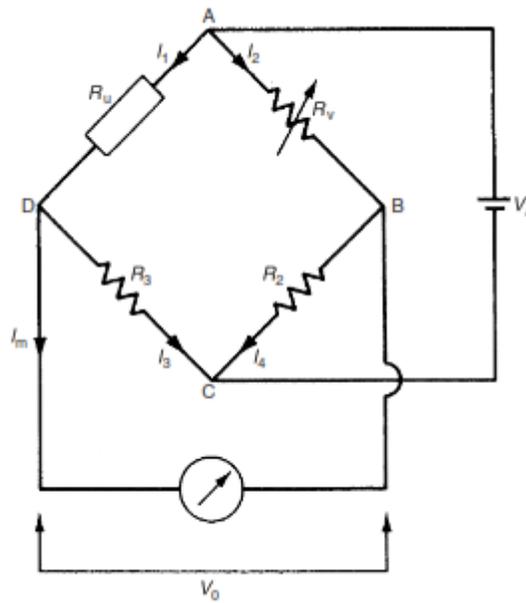$$I_1 = I_3 \text{ and } I_2 = I_4$$

$$I_1 = I_3 \quad \text{and} \quad I_2 = I_4$$

Looking at path ADC, we have a voltage V_i applied across a resistance $R_u + R_3$ and by Ohm's law:

$$I_1 = \frac{V_i}{R_u + R_3}$$

Similarly for path ABC:

$$I_2 = \frac{V_i}{R_v + R_2}$$

Now we can calculate the voltage drop across AD and AB:

$$V_{AD} = I_1 R_v = \frac{V_i R_u}{R_u + R_3}; \quad V_{AB} = I_2 R_v = \frac{V_i R_v}{R_v + R_2}$$

By the principle of superposition,

$$V_0 = V_{BD} = V_{BA} + V_{AD} = -V_{AB} + V_{AD}$$

Thus:

$$V_0 = -\frac{V_i R_v}{R_v + R_2} + \frac{V_i R_u}{R_u + R_3}$$

At the null point $V_0 = 0$, so:

$$\frac{R_u}{R_u + R_3} = \frac{R_v}{R_v + R_2}$$

Inverting both sides:

$$\frac{R_u + R_3}{R_u} = \frac{R_v + R_2}{R_v} \quad \text{i.e.} \quad \frac{R_3}{R_u} = \frac{R_2}{R_v} \quad \text{or} \quad R_u = \frac{R_3 R_v}{R_2}$$

Thus, if $R_2 = R_3$, then $R_u = R_v$. As R_v is an accurately known value because it is derived from a variable decade resistance box, this means that R_u is also accurately known.

Deflection-type d.c. bridge

A deflection-type bridge with d.c. excitation is shown in Figure 7.2. This differs from the Wheatstone bridge mainly in that the variable resistance R_v is replaced by a fixed resistance R_1 of the same value as the nominal value of the unknown resistance R_u. As the resistance R_u changes, so the output voltage V_0 varies, and this relationship between V_0 and R_u must be calculated.

This relationship is simplified if we again assume that a high impedance voltage measuring instrument is used and the current drawn by it, I_m, can be approximated to zero. (The case when this assumption does not hold is covered later in this section.) The analysis is then exactly the same as for the preceding example of the Wheatstone bridge, except that R_v is replaced by R_1. Thus, from equation (7.1), we have:

$$V_0 = V_i * (R_u / R_u + R_3) - (R_1 / R_1 + R_2)$$

When R_u is at its nominal value, i.e. for R_u D R_1, it is clear that V_0 D 0 (since R_2 D R_3). For other values of R_u, V_0 has negative and positive values that vary in a non-linear way with R_u.

A.C bridges

Bridges with a.c. excitation are used to measure unknown impedances. As for d.c. bridges, both null and deflection types exist, with null types being generally reserved for calibration duties.

Null-type impedance bridge

A typical null-type impedance bridge is shown in Figure 7.7. The null point can be conveniently detected by monitoring the output with a pair of headphones connected via an operational amplifier across the points BD. This is a much cheaper method of null detection than the application of an expensive galvanometer that is required for a d.c. Wheatstone bridge.

$$I_1 R_1 = I_2 R_2; \qquad I_1 Z_u = I_2 Z_v$$

$$Z_u = \frac{Z_v R_1}{R_2}$$
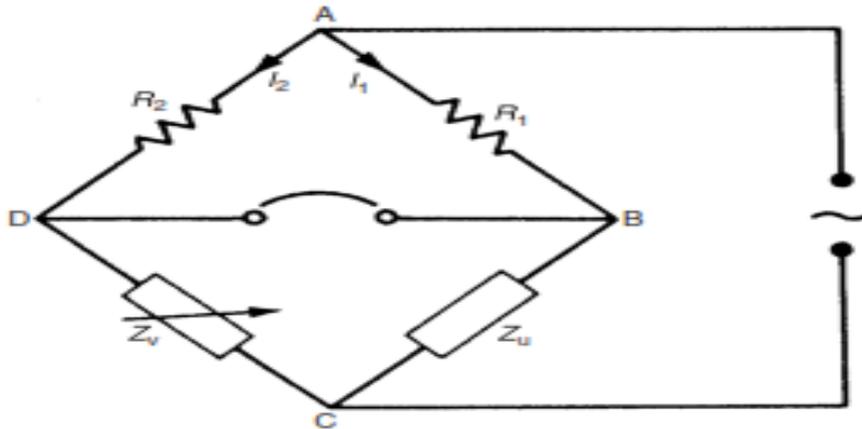
If Z_u is capacitive, i.e. Z_u D $1/j\omega C_u$, then Z_v must consist of a variable capacitance box, which is readily available. If Z_u is inductive, then Z_u D R_u C $j\omega L_u$.

Notice that the expression for Z_u as an inductive impedance has a resistive term in it because it is impossible to realize a pure inductor. An inductor coil always has a resistive component, though this is made as small as possible by designing the coil to have a high Q factor (Q factor is the ratio inductance/resistance). Therefore, Z_v must consist of a variable-resistance box and a variable-inductance box. However, the latter are not readily available because it is difficult and hence expensive to manufacture a set of fixed value inductors to make up a variable-inductance box. For this reason, an alternative kind of null-type bridge circuit, known as the *Maxwell Bridge*, is commonly used to measure unknown inductances.

Maxwell bridge

Definition

A Maxwell bridge (in long form, a Maxwell-Wien bridge) is a type of Wheatstone bridge used to measure an unknown inductance (usually of low Q value) in terms of calibrated resistance and capacitance. It is a real product bridge.

The maxwell bridge is used to measure unknown inductance in terms of calibrated resistance and capacitance. Calibration-grade inductors are more difficult to manufacture than capacitors of similar precision, and so the use of a simple "symmetrical" inductance bridge is not always practical.
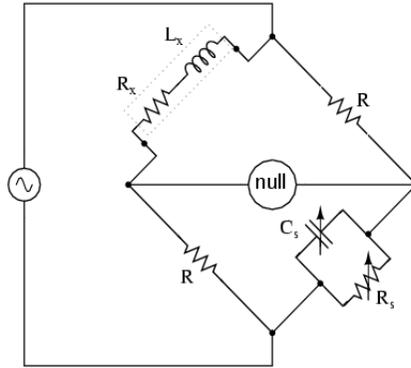
Circuit Diagram

Figure 1.7.1. Maxwell Bridge

Explanation

- With reference to the picture, in a typical application R1 and R4 are known fixed entities, and R2 and C2 are known variable entities.
- R2 and C2 are adjusted until the bridge is balanced.R3 and L3 can then be calculated based on the values of the other components:
- As shown in Figure, one arm of the Maxwell bridge consists of a capacitor in parallel with a resistor (C1 and R2) and another arm consists of an inductor L1 in series with a resistor (L1 and R4). The other two arms just consist of a resistor each (R1 and R3).
- The values of R1 and R3 are known, and R2 and C1 are both adjustable. The unknown values are those of L1 and R4.
- Like other bridge circuits, the measuring ability of a Maxwell Bridge depends on 'Balancing' the circuit.
- Balancing the circuit in Figure 1 means adjusting C1 and R2 until the current through the bridge between points A and B becomes zero. This happens when the voltages at points A and B are equal.
- Mathematically,
  $Z1 = R2 + 1/ (2\pi fC1)$; while $Z2 = R4 + 2\pi fL1$.
  $(R2 + 1/ (2\pi fC1)) / R1 = R3 / [R4 + 2\pi fL1]$;

                  or

  $R1R3 = [R2 + 1/ (2\pi fC1)] [R4 + 2\pi fL1]$
- To avoid the difficulties associated with determining the precise value of a variable capacitance, sometimes a fixed-value capacitor will be installed and more than one resistor will be made variable.
- The additional complexity of using a Maxwell bridge over simpler bridge types is warranted in circumstances where either the mutual inductance between the load and the known bridge entities, or stray electromagnetic interference, distorts the measurement results.
- The capacitive reactance in the bridge will exactly oppose the inductive reactance of the load when the bridge is balanced, allowing the load's resistance and reactance to be

reliably determined.

Advantages:

- The frequency does not appear
- Wide range of inductance

Disadvantages:

- Limited measurement
- It requires variable standard capacitor

SCHERING BRIDGE

Definition

A **Schering Bridge** is a bridge circuit used for measuring an unknown electrical capacitance and its dissipation factor. The dissipation factor of a capacitor is the the ratio of its resistance to its capacitive reactance. The Schering Bridge is basically a four-arm alternating-current (AC) bridge circuit whose measurement depends on balancing the loads on its arms. Figure 1 below shows a diagram of the Schering Bridge.

Diagram

ECELab.com
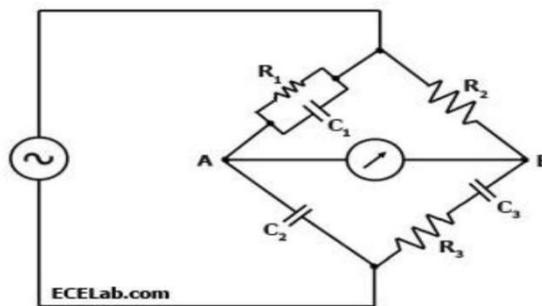
Figure 1.7.2. Schering Bridge

Explanation

- In the Schering Bridge above, the resistance values of resistors R1 and R2 are known, while the resistance value of resistor R3 is unknown.
- The capacitance values of C1 and C2 are also known, while the capacitance of C3 is the value being measured.
- To measure R3 and C3, the values of C2 and R2 are fixed, while the values of R1 and C1 are adjusted until the current through the ammeter between points A and B becomes zero.
- This happens when the voltages at points A and B are equal, in which case the bridge is

said to be 'balanced'.

- When the bridge is balanced, Z1/C2 = R2/Z3, where Z1 is the impedance of R1 in parallel with C1 and Z3 is the impedance of R3 in series with C3.
- In an AC circuit that has a capacitor, the capacitor contributes a capacitive reactance to the impedance.

$$Z1 = R1/[2\pi fC1((1/2\pi fC1) + R1)] = R1/(1 + 2\pi fC1R1)$$

$$\text{while } Z3 = 1/2\pi fC3 + R3. \ 2\pi fC2R1/ (1+2\pi fC1R1) = R2/(1/2\pi fC3 + R3); \text{ or}$$

$$2\pi fC2 \ (1/2\pi fC3 + R3) = (R2/R1) \ (1+2\pi fC1R1); \text{ or}$$

$$C2/C3 + 2\pi fC2R3 = R2/R1 + 2\pi fC1R2.$$

- When the bridge is balanced, the negative and positive reactive components are equal and cancel out, so

$$2\pi fC2R3 = 2\pi fC1R2 \text{ or}$$

$$R3 = C1R2 / C2.$$

- Similarly, when the bridge is balanced, the purely resistive components are equal,

$$\text{so} \quad C2/C3 = R2/R1 \text{ or} \quad C3 = R1C2 / R2.$$

- Note that the balancing of a Schering Bridge is independent of frequency.

Advantages:

- Balance equation is independent of frequency
- Used for measuring the insulating properties of electrical cables and equipment's

HAY BRIDGE

Definition

A Hay Bridge is an AC bridge circuit used for measuring an unknown inductance by balancing the loads of its four arms, one of which contains the unknown inductance. One of the arms of a Hay Bridge has a capacitor of known characteristics, which is the principal component used for determining the unknown inductance value. Figure 1 below shows a diagram of the Hay Bridge.

Explanation

- As shown in Figure 1, one arm of the Hay bridge consists of a capacitor in series with a resistor (C1 and R2) and another arm consists of an inductor L1 in series with a resistor (L1 and R4).
- The other two arms simply contain a resistor each (R1 and R3). The values of R1and R3 are known, and R2 and C1 are both adjustable.
- The unknown values are those of L1 and R4.
- Like other bridge circuits, the measuring ability of a Hay Bridge depends on 'balancing' the circuit.
- Balancing the circuit in Figure 1 means adjusting R2 and C1 until the current through the ammeter between points A and B becomes zero. This happens when the voltages at points A and B are equal.
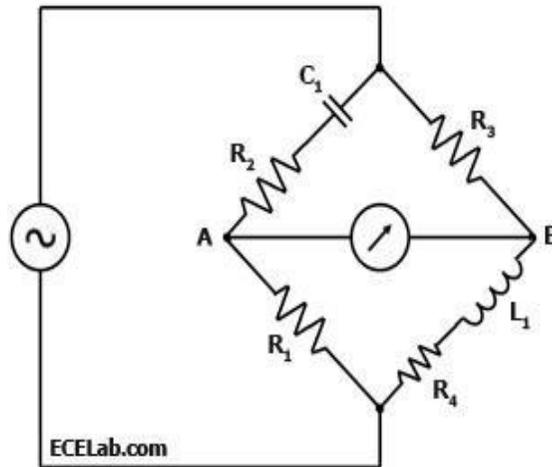
Diagram

Figure 1.7.3. Hay Bridge

- When the Hay Bridge is balanced, it follows that $Z1/R1 = R3/Z2$ wherein $Z1$ is the impedance of the arm containing C1 and R2 while $Z2$ is the impedance of the arm containing L1 and R4.

$$\text{Thus, } Z1 = R2 + 1/(2\pi fC) \text{ while } Z2 = R4 + 2\pi fL1.$$

$$[R2 + 1/(2\pi fC1)] \ / \ R1 = R3 \ / \ [R4 + 2\pi fL1]; \text{ or}$$

$$[R4 + 2\pi fL1] = R3R1 \ / \ [R2 + 1/(2\pi fC1)]; \text{ or}$$

$$R3R1 = R2R4 + 2\pi fL1R2 + R4/2\pi fC1 + L1/C1.$$

- When the bridge is balanced, the reactive components are equal, so

$$2\pi fL1R2 = R4/2\pi fC1, \text{ or } R4 = (2\pi f) \, 2L1R2C1.$$

- Substituting R4, one comes up with the following equation:

$$R3R1 = (R2+1/2\pi fC1) \, ((2\pi f) \, 2L1R2C1) + 2\pi fL1R2 + L1/C1; \text{ or}$$

$$L1 = R3R1C1 \ / \ (2\pi f) \, 2R22C12 + 4\pi fC1R2 + 1);$$

$$L1 = R3R1C1 \ / \ [1 + (2\pi fR2C1)2]$$

- After dropping the reactive components of the equation since the bridge is

- Thus, the equations for L1 and R4 for the Hay Bridge in Figure 1 when it is balanced are:

$$L1 = R3R1C1 \ / \ [1 + (2\pi fR2C1)2]; \text{ and}$$

$$R4 = (2\pi fC1)2R2R3R1 \ / \ [1 + (2\pi fR2C1)2]$$

Advantages:
- Simple expression

Disadvantages:
- It is not suited for measurement of coil

WIEN BRIDGE:

Definition

      A Wien bridge oscillator is a type of electronic oscillator that generates sine waves. It can generate a large range of frequencies. The circuit is based on an electrical network originally developed by Max Wien in 1891. Wien did not have a means of developing electronic gain so a workable oscillator could not be realized. The modern circuit is derived from William Hewlett's 1939 Stanford University master's degree thesis. Hewlett, along with David Packard co-founded Hewlett-Packard. Their first product was the HP 200A, a precision sine wave oscillator based on the Wien bridge. The 200A was one of the first instruments to produce such low distortion.

Diagram
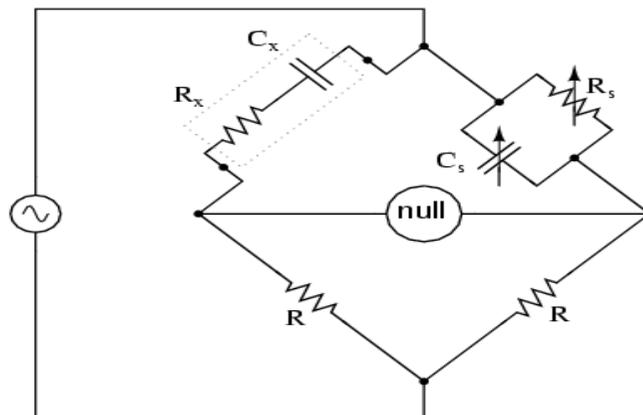
Figure 1.7.4 Wein bridge

Amplitude stabilization:
- The key to Hewlett's low distortion oscillator is effective amplitude stabilization.
- The amplitude of electronic oscillators tends to increase until clipping or other gain limitation is reached. This leads to high harmonic distortion, which is often undesirable.
- Hewlett used an incandescent bulb as a positive temperature coefficient (PTC) thermistor in the oscillator feedback path to limit the gain.
- The resistance of light bulbs and similar heating elements increases as their temperature increases.

- If the oscillation frequency is significantly higher than the thermal time constant of the heating element, the radiated power is proportional to the oscillator power.
- Since heating elements are close to black body radiators, they follow the Stefan-Boltzmann law.
- The radiated power is proportional to T4, so resistance increases at a greater rate than amplitude.
- If the gain is inversely proportional to the oscillation amplitude, the oscillator gain stage reaches a steady state and operates as a near ideal class A amplifier, achieving very low distortion at the frequency of interest.
- At lower frequencies the time period of the oscillator approaches the thermal time constant of the thermistor element and the output distortion starts to rise significantly.
- Light bulbs have their disadvantages when used as gain control elements in Wien bridge oscillators, most notably a very high sensitivity to vibration due to the bulb's micro phonic nature amplitude modulating the oscillator output, and a limitation in high frequency response due to the inductive nature of the coiled filament.
- Modern Distortion as low as 0.0008% (-100 dB) can be achieved with only modest improvements to Hewlett's original circuit.
- Wien bridge oscillators that use thermistors also exhibit "amplitude bounce" when the oscillator frequency is changed. This is due to the low damping factor and long time constant of the crude control loop, and disturbances cause the output amplitude to exhibit a decaying sinusoidal response.
- This can be used as a rough figure of merit, as the greater the amplitude bounce after a disturbance, the lower the output distortion under steady state conditions.
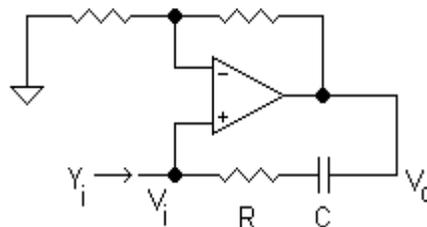
Analysis:

Figure 1.7.4 Input analysis

Input admittance analysis
- If a voltage source is applied directly to the input of an ideal amplifier with feedback, the input current will be:

- Where vin is the input voltage, vout is the output voltage, and Zf is the feedback impedance. If the voltage gain of the amplifier is defined as:

$$\overline{}$$

- And the input admittance is defined as:

$$\overline{}$$

- Input admittance can be rewritten as:

$$\overline{}$$

- If Av is greater than 1, the input admittance is a negative resistance in parallel with an inductance.
- If a resistor is placed in parallel with the amplifier input, it will cancel some of the negative resistance. If the net resistance is negative, amplitude will grow until clipping occurs.
- If a resistance is added in parallel with exactly the value of R, the net resistance will be infinite and the circuit can sustain stable oscillation at any amplitude allowed by the amplifier.

Advantages:
- Frequency sensitive
- Supply voltage is purely sinusoidal

3.3 Transformer Ratio Bridges & Self-Balancing Bridges

TRNSFORMER RATIO BRIDGES

INTRODUCTION

The product to which this manual refers should be installed, commissioned, operated and maintained under the supervision of a competent *Electrical Engineer* in accordance with relevant statutory requirements and good engineering practice, including Codes of Practice where applicable, and properly used within the terms of the specification.

The instructions in this manual should familiarize qualified personal with the proper procedures to keep all new unit(s) in proper operating condition. These instructions for installation, operation and maintenance of Package Compact Substation should be read carefully and used as a guide during installation and initial operation.

These instructions do not propose to cover all details or variations in equipment, nor to provide for every contingency to be met in connection with installation, operation, or maintenance. Should further information be desired, or particular problems arise which are not covered, please contact the nearest ABB office.

We would in particular stress the importance of care in:

- Site selection and design, embodying features that provide adequate ventilation, protection and security and which have taken account of appropriate fire, moisture and explosion hazards.
- Jointing.
- Earthing.
- Selection and setting of electrical protection in primary and secondary, against overload, overvoltage and short-circuit.
- Carrying out regular inspection and electrical and mechanical maintenance.

The Package Compact Substation(s) covered by these instructions have been repeatedly inspected and tested to meet all applicable standards of IEC, to ensure you of a first-rate quality product, which should give many years of satisfactory performance.
The specific ratings of each Package Compact Substation are shown on the drawings.

File these instructions in a readily accessible place together with drawings and descriptive data of the Package Compact Substation. These instructions will be a guide to proper maintenance of the equipment and prolong its life and usefulness

GENERAL

LV FRONT   SUBSTATION SI   HV FRONT
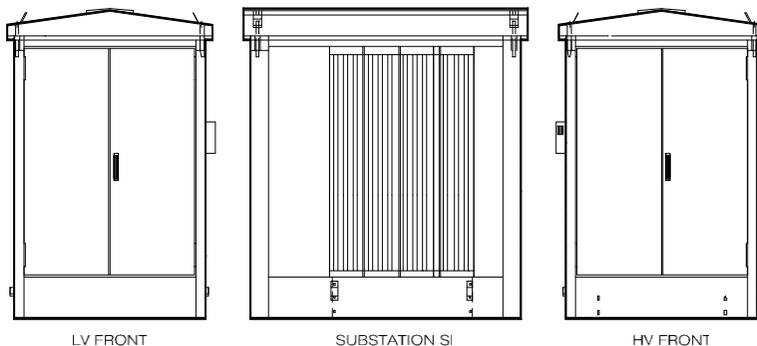
The Package Compact Substations are completely self-contained, mounted on an integral base, factory assembled in a totally enclosed, aesthetically and acceptable cladding, vandal-proof, vermin-proof and weather-proof housing ready for installation into position on a concrete base pad or pier. The base frame is of welded structural steel and been hot-dipped galvanized after fabrication to assure affective corrosion resistance in service.Housing of the Package Compact Substation is made of special material called ALUZINK, a sheet steel with a metallic alloy

coating. The alloy consists of 55% aluminum and 43.4% zinc. This provides optimum corrosion protection.The housing has three compartments, separated with ALUZINK sheet. The transformer compartment is completely separated from the medium voltage and low voltage compartments.

RECEIVING / INSPECTION / STORAGE

The Package Compact Substation is shipped from the factory ready for installation on site. It has been submitted to all normal routine tests before being shipped, and it is not required to do any voltage testing before putting it into service, provided the substation has not sustained any damage during transportation.

Immediately upon receipt of the Package Compact Substation, examine them to determine if any damage or loss was sustained during transit. If abuse or rough handling is evident, file a damage claim with carrier and promptly notify the nearest ABB office. ABB ELECTRICAL INDUSTRIES CO. LTD. is not responsible for damage of goods after delivery to the carrier; however, we will lend assistance if notified of claims.

PERSONNEL SAFETY

The first and most important requirements are the protection against contact with live parts during normal service as well as maintenance or modifications.

This is the reason why all live parts have been metal enclosed, so that when the parts are live and the Package Compact Substation doors are open, no one can be able to touch them.

Also, it is safe in case any short-circuiting or sparking occurs at the busbars.

VENTILATION

Transformer compartment has been provided with sand trap louvers, to prevent ingress of sand and that proper air circulation should take place.

EARTHING

Proper earthing busbar has been provided.

HANDLING

Lifting lugs has been provided on top of four corners of the housing for lifting the DPS by crane and chains as a single unit, otherwise this can be done by a forklift of sufficient capacity, but the lifting fork must be positioned under the transformer portion.

INSTALLATIONS

A clean, flat surface capable of supporting the Package Compact Substation unit weight is the only requirement for a foundation. It is, however, important that adequate accessibility, ventilation and ease of inspection of the unit must be provided.

In all installation work, the safety regulations for electrical installations have to be observed.

Each Package Compact Substation must be permanently grounded or earthed by connecting an affective recognised ground or earth as prescribed by the latest applicable edition of IEC or ANSI requirements.The Package Compact Substation is designed to operate with a solidly grounded neutral system. The neutral connection should be solidly and permanently grounded.

Tap connections

All units have taps located in the High Voltage winding. The tap arrangement is shown on the nameplate of the transformer. These taps are provided to furnish rated output voltage when the input voltage differs from the rated voltage.

To change tap connections, do the following steps:

1. De-energized the unit, short-circuit both the high and low voltage connections and ground both sides.
2. Unlock the tap changer handle, and then move the taps changer handle to the desired tap, then locked the tap changer handle.
3. Remove safety shorts and ground connections from the high voltage and low voltage buses.

After ensuring that no tools or hardware was left in the enclosure, and the enclosures are closed properly, you may then re-energize the Package Compact Substation. Make sure that the tap connections are proper for the required voltage as listed on the nameplate. The transformer is normally shipped with the tap changer for the rated voltage.

Cable connections

When making outside cable connections, conductors suitable for at least 85°C should be used. All connections should be made without placing undue stress on the terminals. Conductors should be securely fastened in place and adequately supported with allowances for expansion and contraction.

FINAL INSPECTION PRIOR TO ENERGIZATION

After the Package Compact Substation has been found to be in good condition and the protective equipment is operational, the substation may be connected to the network. However, it is recommended that the transformer to be left to settle for 1 or 2 days after installation so those air bubbles in the oil have time to dissolve before connecting the voltage.

Before energizing the unit, a complete electrical inspection should be made. The following checklist should be used as a minimum requirement.

Electrical Inspection

All external connections have been made properly (phasing of connections to terminals, etc.).

All connections are tight and secure.

All accessory circuits are operational. Check the transformer protective equipment and test

the function of their electrical circuits:
Thermometers (alarms, tripping)

Pressure relay (tripping)
Oil level indicator

Ensure that all fuses are inserted and in the correct position

All tap connections are properly positioned.

The neutral and ground connections have been properly made.

Mechanical Inspection

All shipping members have been removed.

There is no obstructions in or near the openings for ventilation.
No tools or other articles are left inside the enclosures.
All protective covers are in place or closed and bolted tight.

MAINTENANCE AND PERIODIC INSPECTION

In order to assure a long lifetime and correct and reliable operation of equipment delivered for this facility it is of utmost importance to perform maintenance regularly.
Following general rules should always be considered before starting maintenance activity.
1. Authority from responsible engineer shall always be obtained before starting any maintenance.
2. Follow safety procedure established in carrying out the work.

Realize that no set of safety *or maintenance instructions* will ever be written that can adequately cover all accident possibilities.
Therefore **"SAFETY"** as dictated by actual current conditions, always takes precedence over any previously prepared safety or maintenance instructions. Assume nothing. Take the precautions that you personally deem necessary in addition to those included in standard practice.
• Be familiar with the drawings and previous test records before starting activity.
• Scrutinize maintenance instructions given for the equipment to be maintained.
Maintenance information is given in the Operation and Maintenance Manual for each type of equipment.
The main dangers of such process are:

• Inaccessible lubrication points (greased for life) cannot be lubricated and may seize up.
• Areas not lubricated may be subject to corrosion.
• The high-pressure spray may damage equipment.
• Especially protective coatings may be removed.

Bolt Tightness

All connections should be tight and secure. Bolts and nuts on busbar and terminal lugs should be

torqued and marked properly.

Inspection and Testing

The need for preventive maintenance will vary on operating conditions. Where heavy dust conditions exist, an accumulation of dust on the equipment may effect the operation of unit substation and its protective apparatus.

When normal maintenance inspection and cleaning of bus connections, relays, lug connections, and other part of the distribution system is being made, it is advisable to operate and check circuit breakeror switch-disconnector   operation.

Routine Field Testing

Routine field testing of the electrical equipment is intended to enable maintenance personal to determine, without laboratory conditions or complicated equipment, that a particular electrical equipment is able to perform its basic circuit functions.

The following constitutes a guide to tests that might be performed during routine maintenance.

1. **Insulation Resistance Test**
    Extreme atmospheres and conditions may reduce the dielectric withstandability of any insulating material. An instrument commonly known as "megger" is used to perform this test.

    The voltage recommended for this test should be at least 50 percent greater than the circuit rating; however, a minimum of 500 volts is permissible. Tests should be made between phases of opposite polarity as well as from current carrying parts of the circuit protective device to ground. Also, a test should be made between the line-and-load terminals with the circuit protective device in the "OFF" position.

    Resistance values below one megaohm are considered unsafe and should be investigated for possible contamination on the surfaces.

    NOTE: For individual circuit protective device's resistance readings, load and line conductors should be disconnected. If not disconnected, the test measurements will also include the characteristics of the attached circuits.
    A temperature and humidity reading are recommended and recorded during the testing period.

    Insulation resistivity is markedly effected by temperature and humidity conditions. Based condition of one (1) megaohm per kV assumes a 20°C wet bulb reading. The following table shall be used to adjust readings to the 20°C constant.

2. **Connection Test**
    Connections to the circuit protective device should be inspected to determine that a proper electrical joint is present. If overheating in these connections is evident by discoloration or signs of arcing, the connections should be removed and the connecting surfaces clean before re-connections. It is essential that electrical connections be made properly to prevent and reduce overheating.

3.   **Mechanical Operation**

During routine tests, mechanical operation of the circuit protective devices or disconnects should be checked by turning it "ON" and "OFF" at least three times.

3.5 INTERFERENCE AND SCREENING

Interference is one of the most serious as well as most common problems in audio electronics. We encounter interference when it produces effects like noise, hiss, hum or cross-talk. If a radio engineer faces such problems, good theoretical knowledge as well as experience is required to overcome them.

However, it should be considered, that interference is always present. All technical remedies only aim at reducing the effect of interference to such a degree, that it is neither audible nor disturbing. This is mainly achieved by different ways of screening. This paper will explain the technical background of interference and provides some common rules and hints which may help you to reduce the problems.

TYPES OF INTERFERENCE.

Theoretically, the effects and mechanism of a single interference can well be calculated. But in practice, the complex coupling systems between pieces of equipment prevent precise prediction of interference. The following picture shows the different types of interference coupling.The different types of interference between the components of an electric system. If we consider all possible coupling paths in the diagram above we will find 10 different paths. This means a variety of 1024 different combinations. It should be noted, that not only the number of paths, but also their intensity is important.

SYMMETRICAL AND ASYMMETRICAL INTERFERENCE.

Having a closer look at the interference of cable, we find that hf-interference currents cause measurable levels on signal (audio) lines and on supply lines. A ground-free interference source would produce signals on a cable which spread along the line. These voltages and currents can be called symmetrical interference. In practice this rarely occurs.

Through interference, asymmetrical signals are produced in respect to the ground. The asymmetrical interference current flows along the two wires of the symmetrical line to the sink and via the ground back to the source. These interference signals are cancelled at the symmetrical input.

GALVANIC COUPLING OF INTERFERENCE.

Galvanic coupling of interference occurs if the source and the sink of interference are coupled by a conductive path.As can be seen from the equivalent circuit diagram, the source impedance of the interference consists of the resistance RC and the inductance LC of the conductor, which are common to the two parts of the circuit. From these elements the interference source voltage can be calculated.

CAPACITIVE COUPLING OF INTERFERENCE.

The capacitive coupling of interference occurs due to any capacitance between the source and sink of interference.

Principle of capacitive coupling of interference.

The current in the interference sink can be calculated as
The interference voltage in the sink is proportional to its impedance. Systems of high impedance are therefore more sensitive to interference than those of low impedance. The coupled interference current depends on the rate of change of the interference and on the coupling capacitance CC.

INDUCTIVE COUPLING OF INTERFERENCE.

Inductive coupling of interference occurs if the interference sink is in the magnetic
field of the interference source (e.g. coils, cables, etc.)
Principle of the inductive coupling of interference.

The interference voltage induced by inductive coupling is
- **increasing the distance between conductors**
- **mounting conductors close to conductive surfaces**
- **using short conductors**
- **avoiding parallel conductors**
- **screening**
- **using twisted cable**
Note that by the same means the capacitive as well as the inductive coupling of
interference will be reduced.
3.5 Electrostatic And Electromagnetic Interference

INTERFERENCE BY RADIATION.
Interference by electromagnetic radiation becomes important at cable lengths greater than 1/7 of the wavelength of the signals. At frequencies beyond 30Mhz, most of the interference occurs by e.m. radiation

Principle of the coupling by e.m. Interference.

INTERFERENCE BY ELECTROSTATIC CHARGE.
Charged persons and objects can store electrical charges of up to several micro- Coulombs, which means voltages of some 10kV in respect to ground. Dry air, artificial fabrics and friction favour these conditions.When touching grounded equipment, an instantaneous discharge produces arcing with short, high current pulses and associated strong changes of the e.m. field.
REDUCTION OF INTERFERENCE

There are a number of methods to prevent interference. But all of them only **reduce**

the interference and never fully prevent it. This means there will never be a system which is 100% safe from interference. Because the efforts and the cost will rise with the degree of reduction of interference, a compromise has to be found between the effort and the result.
The requirement for the reduction of interference will depend on:

- The strength of the interference source
- The sensitivity of the interference sink
- The problems caused by interference

- The costs of the equipment
We will discuss ways of preventing interference, their effect, and the main aspects for the optimum efficiency of each method.

3.6 GROUNDING (OR EARTHING).

This is one of the simplest but most efficient methods to reduce interference.
Grounding can be used for three different purposes:
1. Protection Ground

Provides protection for the operators from dangerous voltages. Widely used on mains-operated equipment.
2. Function Ground

The ground is used as a conductive path for signals.

Example: in asymmetrical cables screen, which is one conductor for the signal, is connected to the ground.

3. Screening Ground

Used to provide a neutral electrical path for the interference, to prevent that the interfering voltages or currents from entering the circuit. In this chapter we will only consider the third aspect. Grounding of equipment is often required for the cases 1 or 2 anyhow, so that the screening ground is available "free
of charge". Sometimes the grounding potential, provided by the mains connection, is very "polluted". This means that the ground potential itself already carries an interfering signal. This is especially likely if there are big power consumers in the neighbourhood or even in the same building. Using such a ground might do more harm than good.
The quality of the ground line can be tested by measuring it with a storage scope against some other ground connection, e.g. a metal water pipe or some metal parts of the construction.

Never use the Neutral (N) of the mains as ground.

It might contain strong interference, Because it carries the load current of all electrical consumers.The grounding can be done by single-point grounding or by multi-point grounding. Each method has advantages which depend on the frequency range of the signal frequencies. All parts to be grounded are connected to one central point. This resultsin no "ground loops" being produced. This means the groundingconductors do not form any closed conductive path in which magneticinterference could induce currents. Furthermore, conductive linesbetween the equipment are avoided, which could produce galvanic coupling of interference.Central grounding requires consistent arrangement of the groundingcircuit and requires insulation of the individual parts of the circuit. This is sometimes very difficult to achieve.A system using the single-point grounding.

MULTI-POINT GROUNDING:

In multi-point grounding all parts are connected to ground at as many points as possible. This

requires that the ground potential itself is as widely spread as possible. In practice, all conductive parts of the chassis, the cases, the shielding, the room and the installation are included in the network.

SCREENING.

When considering the effect of electrical and magnetic fields, we have to distinguish between low and high frequencies. At high frequencies the skin effect plays an important roll for the screening. The penetration describes the depth from the surface of the conductor, where the current density has decayed to 37% compared to the surface of the conductor.

SCREENING OF CABLES.

When signal lines run close to interference sources or when the signal circuit is very sensitive to interference, screening of signal lines will give an improvement. There are different ways of connecting the cable screen:

Three different ways of connecting the cable screen.Cable screen not connected. This screen will not prevent any interference, because the charge on the screen, produced by interference, will remain and will effect the central signal line. Also, the current induced by interference in the linewill flow through the sink, effecting the signal.Cable screen grounded on one side only.This screen will only prevent interference at low frequency signals. Forelectromagnetic interference, where the wavelength is short comparedto the length of the cable, the screening efficiency is poor.Cable screen grounded on either sidet is effective for all kinds of interference. Any current induced in thescreen by magnetic interference will flow to ground. The inner of thecable is not affected. Only the voltage drop on the screen will affect thesignal in the screen. type of grounding is
- Ensure proper and careful connection of the screens.
- Use suitable plugs in connection with the cable screen.

3.7 MULTIPLE EARTH AND EARTH LOOPS

SIMPLE TWO SYNODIC PERIOD CYCLER (CASE 1)
The simple two Earth-Mars synodic period cycler. In the circular coplanar model it has a period P=l.348 years, a radius of aphelion R~ = 1 .15 A U and the V, at Earth is 5.6 *M s* . For the "Up" transfer, the Earth-Mars transfer is Type I or I1 and the Mars-Earth leg is Type VI. The trajectory departs the Earth with the V, inward of the Earth's velocity vector taking it through a perihelion of about 0.93 AU, crossing the Earth's orbit ahead of the Earth and outward to Mars' orbit. As seen from Figure 1 the transfer to Mars is about 225 degrees and takes a little over nine months. The trajectory continues onward making three complete orbits about the Sun without coming near either the Earth or Mars again until passing through its original starting point on the Earth's orbit for the third time, somewhat behind the Earth and

finally encountering the Earth 2/7 of a revolution about the Sun (102.9 deg.) from the starting point. The cycler has made 3 2/7 complete orbits about the Sun while Earth has made 4 2/7. The Earth flyby must now rotate the incoming V, vector, which is outward, to the symmetrically inward orientation to begin the next cycle. Unfortunately, the rotation angle required is approximately 135 degrees and with a V, of 5.65 km/s the Earth can only rotate the V, vector about 82 degrees. Now in the actual Solar System, the orbit of Mars is elliptical with a semi-major axis of 1.524 AU, a perihelion of 1.381 AU and **an** aphelion of 1.666 AU. Thus the simple Case 1 cycler does not quite reach Mars' average distance from the Sun. It is thus clear that a real world version of the Case 1 cycler would require **AV** to make up for the inability of the Earth to rotate the V, vector, as well as for the fact that over the course of seven cycles, of two synodic periods each, the Case 1 cycler will not make it to Mars' orbit more than one half of the time. The real value of Case 1 is as a basis for variations that can address these deficiencies.

TWO SYNODIC PERIOD CYCLER WITH "BACKFLIP" (CASE 2)

Modifylng Case 1 by introducing another Earth flyby, approximately six months and 180 degrees after the first, changes the situation somewhat. This six month, 180 degree
transfer, or "backflip" trajectory, was first introduced for lunar trajectories by U p h ~ f f . ~
The "Up" trajectory for this version leaves the Earth with a Type I or I1 short transfer to Mars and a Type V transfer back to Earth. This transfer to the first Earth encounter makes
2 11/14 revolutions about the Sun in 3 11/14 years. The Earth flyby then puts the vehicle onto a heliocentric orbit with a period of one year which re-encounters the Earth approximately six months and 180 degrees later, completing the **3** 217 revolutions in 4 2/7 years. This second Earth flyby then sends the vehicle on to the next Mars encounter, continuing the cycle. Figure 2 shows this cycler trajectory. Note that the first Earth encounter is in the lower portion of the plot. The backflip trajectory is not shown since its difference from the Earth's orbit is primarily in the z-direction. The second Earth flyby
and departure point for the second cycle is indicated slightly left of straight up on the Earth's orbit. In the circular co-planar model the Earth-Mars-Earth trajectory has a period P=l.325 years, a radius of aphelion R~ z l . 4A5 U and the V, at Earth is 4.15 *MS*F.or Case 2, the transfer does not reach Mars' orbit in the circular co-planar model, but in the real world does reach Mars when Mars is near its perihelion.
The lower V, for Case 2 enables the Earth to rotate the V, vector as much as about 102 degrees, thus easily enabling the first Earth flyby to rotate the incoming V, to the required near polar orientation required for the backflip trajectory outgoing V, as well as the second earth flyby to rotate the near polar incoming V, to the outgoing V, required

for the transfer to the next Mars, Thus, although Case 2 has many desirable characteristics, it cannot be used for an entire seven cycles. If fact it will reach Mars for at most two of the seven cycles without propulsive AVto augment the gravity assists.

TWO SYNODIC PERIOD CYCLER WITH "BACKFLIP" PLUS 1-YEAR LOOP (CASE 3)
Modifying Case 2 to introduce a third Earth flyby in addition to the "backflip" adds additional flexibility. This is accomplished by adding a one year Earth-Earth loop either before or after the backflip. The order of the one year loop and the "backflip" can be chosen to best

advantage in the real world. The **TJp''** trajectory for this version leaves the Earth with a Type I short transfer to Mars and a Type I11 or IV transfer back to Earth. This transfer to the first Earth encounter makes 1 11/14 revolutions about the Sun in 2

11/14 years. The Earth flyby the puts the vehicle onto a heliocentric orbit with a period of one year which re-encounters the Earth approximately six months and 180 degrees later and then re-encounters the Earth one year later, or vice versa. The final Earth flyby then sends the vehicle on to the next Mars encounter. Figure 3 shows this cycler trajectory. Again as in Case 2, the backflip trajectory is not seen. The one year Earth-Earth loop is also not shown. In the circular co-planar model the Earth-Mars-Earth trajectory has a period **P=l.484** years, a radius of aphelion R~=l .65A U and the V, at Earth is **5.4** km/s.

In this case the transfer reaches an aphelion approximately equal to Mars' aphelion and will thus always cross Mars orbit in the real world. Analysis of Case 3 with the actual ephemerides of Earth and Mars is considered in more detail below.

1-YEAR LOOP (CASE 3)

TWO SYNODIC PERIOD CYCLER WITH ONE OR TWO 1-YEAR LOOPS
Modifying Case 1 to introduce one or two one year Earth-Earth loops or even a two year

Earth-Earth loop without a backflip is also possible, it leads however, to much higher

V,'s less desirable characteristics that any of Cases 1,2 or 3, or the Aldrin Cycler for that matter.

DETAILED ANALYSIS OF CASE 3

A detailed analysis of Case 3 was performed using the actual ephemerides of the Earth and Mars. The trajectories were modeled as Sun-centered point-to-point conics connecting the Earth and Mars flybys. The flybys were modeled as instantaneous V m rotations. This – V m -matching‖ model gives excellent insight into both the heliocentric and planetocentric trajectories and sufficient accuracy for developing long term trajectory scenarios that can be closely reproduced with fully numerically integrated trajectory models. The Table shows data for a full cycle of seven two-synodic period cyclers (30 years). This should approximately repeat since the Earth and Mars are very nearly at the same inertial positions every 15 years.The choice of one year loop or backflip and whether the backflip is –north‖ or –south‖ needs to be made in each case to make best use of the arrival and departure V,'s to minimize the required bending by the Earth and potential required **AV.** The Mars flybys (given to the nearest 1000 km) are all at reasonably high altitudes. Whereas in the circular co-planar analysis the Mars flybys are arbitrarily high, in the real world the Mars gravity assist must control the inclination of the heliocentric orbit as well as adjust the energy slightly to properly phase for the next encounter. The Mars V,'s vary between about 3 km/s and **8** km/s which compares to the value of 5.3 km/s in the circular coplanar case. The Earth V,'s vary between about **4** km/s and 7.5 km/s which compares to 5.4 km/s.

UNIT IV STORAGE AND DISPLAY DEVICES

4.1 Recorders

A recorder is a measuring instrument which records time varying quantity, even after the quantity or variable to be measured has stopped. The electrical quantities such as voltage & current are measured directly. The non- electrical quantities are recorded using indirect methods. The non- electrical quantities are first converted to their equivalent voltages or currents, using various transducers.

Electronic recorders may be classified as:

1. Analog recorders
2. Digital recorders

Analog recorders dealing with analog systems can be classified as

1. Graphic recorders
2. Oscillographic recorders
3. Magnetic Tape recorders

Digital recorders dealing with digital output can be classified as

1. Incremental digital recorders
2. Synchronous digital recorders

4.2 Magnetic Disk And Tape

MagneticTapeRecorder

- Ø The magnetic tape recorders are used for high frequency signal recording.
- Ø In these recorders, the data is recorded in a way that it can be reproduced in electrical form any time.
- Ø Also main advantage of these recorders is that the recorded data can be replayed for almost infinite times.
- Ø Because of good higher frequency response, these are used in Instrumentation systems extensively.
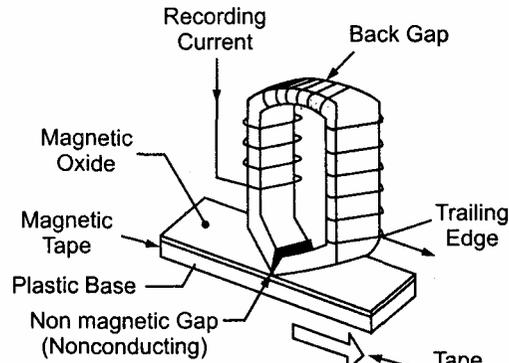
Basic Components of Tape Recorder

Following are the basic components of magnetic tape recorder

1. Recording Head
2. Magnetic Tape
3. Reproducing Head
4. Tape Transport Mechanism
5. Conditioning Devices

Recording Head

- Ø The construction of the magnetic recording head is very much similar to the construction of a Transformer having a toroidal core with coil.

Ø There is a uniform fine air gap of 5µ m to 15µ m between the head and the magnetic tape.

Recording Current   Back Gap

Magnetic Oxide

Magnetic Tape   Trailing Edge

Plastic Base

Non magnetic Gap (Nonconducting)   Tape

(Fig) Magnetic tape recording head

Ø   When the current used for recording is passed through coil wound around magnetic core, it produces magnetic flux.

Ø The magnetic tape is having iron oxide particles.

Ø   When th e tape is passing the head, the flux pr oduced due to recording current gets linked with iron oxide part ices on th e magnetic tape and these particles get magnetized.

Ø This magnetization particle remain as it is, e vent Hough the magnetic tape leaves the gap.

Ø The actual recording takes place at the trailing edge of the   air gap.

Ø Any signal is recorded in the form of the patterns.

Ø   These magnetic patterns are dispersed anywhere along the length of mag netictape in accordance with the variation in recording current with respect to time.
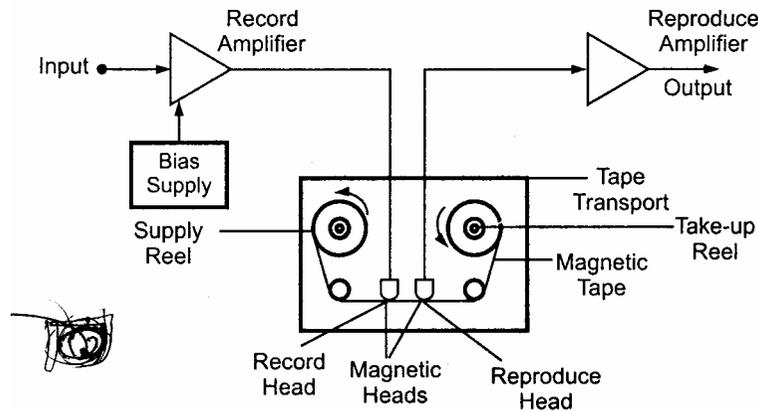
Magnetic Tape

Ø The magnetic tape is made of thin sheet of tough and dimensionally stable plastic ribbon.

Ø One side of this plastic ribbon is coated by powdered iron oxide particles (Fe_2O_3) thick.

Ø The magnetic tape is wound around a reel.

Ø This tape is transferred from one reel to another.

Ø   When the tape passes across air gap magnetic pattern is created in accordance with variation of recording current.

Ø   To reproduce this pattern, the same tape with some recorded pattern is passed across another magnetic head in which voltage is induced.

Ø This voltage induced is in accordance with the magnetic pattern.

Reproducing Head

Ø The use of the reproducing head is to get the recorded data played back.

Ø   The working of the reproducing head is exactly opposite to that of the recording head.

Ø The reproducing head detects the magnetic pattern recorded on the tape.

Ø The head converts the magnetic pattern back to the original electrical signal.

Ø In appearance, both recording and reproducing heads are very much similar.

Tape Transport Mechanism

(Fig) Basic tape transport mechanism

Ø   The tape transport mechanism moves the magnetic tape along the recording head or reproducing head with a constant speed

Ø The tape transport mechanism must perform following tasks.
    It must handle the tape without straining and wearing it.
    It must guide the tape across magnetic heads with great precision.
     It must maintain proper tension of magnetic tape.
     It must maintain uniform and sufficient gap between the tape and heads.

Ø The magnetic tape is wound on reel.

Ø   There are two reels; one is called as supply & other is called as take-up reel.

Ø Both the reels rotate in same direction.

Ø The transportation of the tape is done by using supply reel and take-up reel.

Ø   The fast winding of the tape or the reversing of the tape is done by using special arrangements.

Ø The rollers are used to drive and guide the tape.

Conditioning Devices

Ø   These devices consist of amplifiers and fitters to modify signal to be recorded.

Ø The conditioning devices allow the signals to be recorded on the magnetic tape with proper format.

Ø   Amplifiers allow amplification of signal to be recorded and filters removes unwanted ripple quantities.

Principle of Tape Recorders

Ø When a magnetic tape is passed through a recording head, the signal to be recorded appears as some magnetic pattern on the tape.

Ø This magnetic pattern is in accordance with the variations of original recording current.

Ø   The recorded signal can be reproduced back by passing the same tape through a reproducing head where the voltage is induced corresponding to the magnetic pattern on the tape.

Ø   When the tape is passed through the reproducing head, the head detects the changes in the magnetic pattern i.e. magnetization.

Ø   The change in magnetization of particles produces change in the reluctance of the magnetic circuit of the reproducing head, inducing a voltage in its winding.

Ø   The induced voltage depends on the direction of magnetisation and its magnitude on the tape.

Ø   The emf, thus induced is proportional to the rate of change of magnitude of magnetisation i.e. e N (dφ / dt)

   Where N = number of turns of the winding on reproducing head

   Ǽ = magnetic flux produced.

   Suppose the signal to be recorded is Vm sin Ŭt. Thus, the current in the recording head and flux induced will be proportional to this voltage.

Ø   It is given by e= k 1. Vm sin wt, where k1 = constant.

Ø   Above pattern of flux is recorded on the tape. Now, when this tape is passed through the reproducing head, above pattern is regenerated by inducing voltage in the reproducing head winding.

Ø   It is given by e= k2 ŬVm cos wt

Ø   Thus the reproducing signal is equal to derivative of input signal
   & it is proportional to flux recorded & frequency of recorded signal.

Methods of Recording

The methods used for magnetic tape recording used for instrumentation purposes are as follows:

   i) Direct Recording
   ii) Frequency Modulation Recording
   iii) Pulse Duration Modulation Recording

For instrumentation purposes mostly frequency modulation recording is used. The pulse duration modulation recording is generally used in the systems for special applications where large number of slowly changing variables has to be recorded simultaneously.

4.3 Digital Plotters And Printers

PRINTERS

Ø   Printers can be classified according to their printing methodology **Impact printers** and **Non-impact printers**.

Ø   Impact printers press formed character faces against an inked ribbon onto the paper.

Ø   A line printer and dot matrix printer are the examples of an impact printer.

Ø   Non impact printer and plotters use laser techniques, inkjet sprays, xerographic processes, electrostatic methods and e1ectrothermal methods to get images onto the paper.

Ø   A ink-jet printer and laser printer are the examples of non- impact printers.
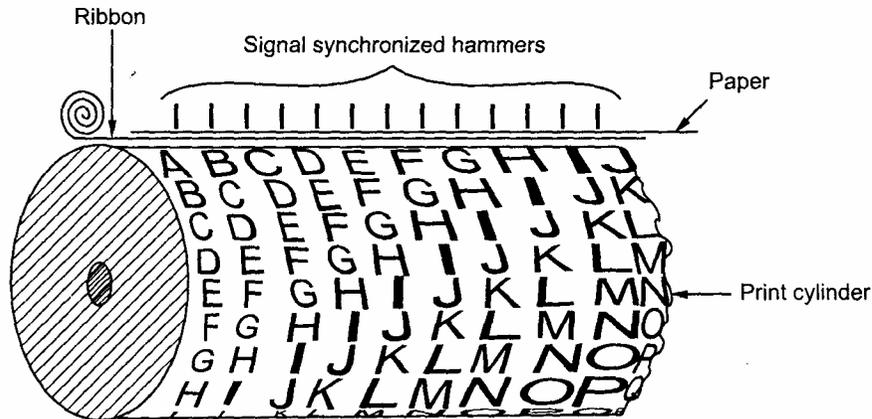
Line Printers

A line printer prints a complete line at a time. The printing speed of line printer varies from 150 lines to

2500 lines per minute with 96 to 100 characters on one line. The line printers are divided into two categories Drum printers and chain printer.

Drum Printers

Drum printer consists of a cylindrical drum. One complete set of characters is embossed on all the print positions on a line, as shown in the Fig. The character to be printed is adjusted by rotating drum.
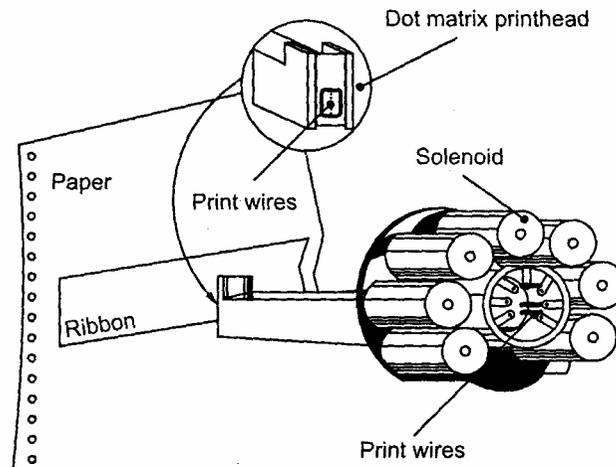

Chain Printers

In these printers chain with embossed character set is used, instead of drum. Here, the character to be printed is adjusted by rotating chain.

Dot Matrix Printers

Dot matrix printers are also called serial printers as they print one character at a time, with printing head moving across a line.

Laser Printer

- Ø The line, dot matrix, and ink jet printers need a head movement on a ribbon to print characters.
- Ø This mechanical movement is relatively slow due to the high inertia of mechanical elements.
- Ø In laser printers these mechanical movements are avoided.

Ø In these printers, an electronically controlled laser beam traces out the desired character to be printed on a photoconductive drum.

Ø The exposed areas of the drum gets charged, which attracts an oppositely charged ink from the ink toner on to the exposed areas.

Ø This image is then transferred to the paper which comes in contact with the drum with pressure and heat.

Ø The charge on the drum decides the darkness of the print.

Ø When charge is more, more ink is attracted and we get a dark print.
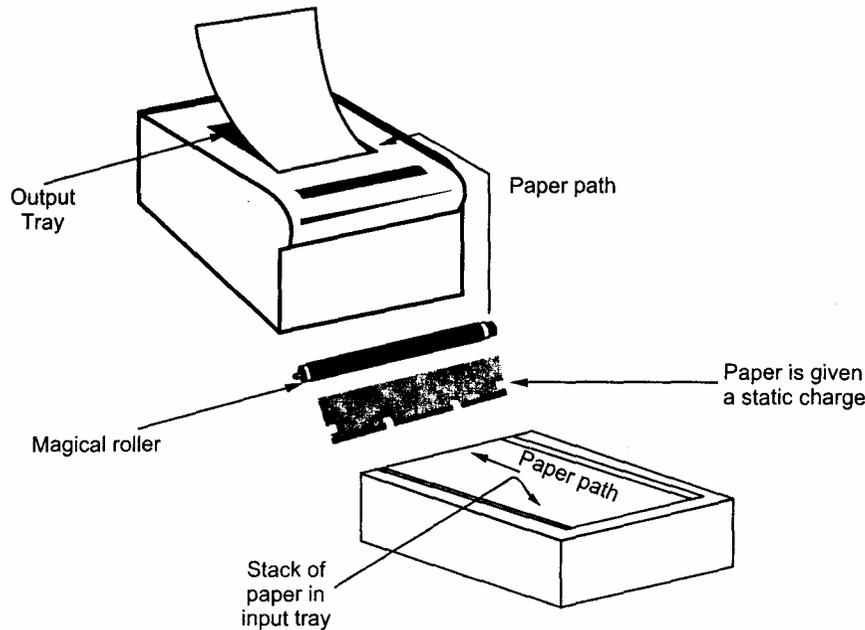
Ø A colour laser printer works like a single colour laser printer, except that the process is repeated four times with four different ink colours: Cyan, magenta, yellow and black.

Ø Laser printers have high resolution from 600 dots per inch upto 1200 per inch.

Ø These printers print 4 to 16 page of text per minute.

Ø The high quality and speed of laser printers make them ideal for office environment.

Advantages of Laser printer

Ø The main advantages of laser printers are speed, precision and economy.

Ø A laser can move very quickly, so it can "write" with much greater speed than an inket.

Ø Because the laser beam has an unvarying diameter, it can draw more precisely, without spilling any excess ink.

Ø Laser printers tend to be more expensive than ink-jet printers, but it doesn't cost as much to keep them running.

Ø Its toner power is cheap and lasts for longer time.

4.4 CRT Display

The device which allows, the amplitude of such signals, to be displayed primarily as a function of time, is called cathode ray oscilloscope. The cathode ray tube (CRT) is the heart of the C.R.O. The CRT generates the electron beam, accelerates the beam, deflects the beam and also has a screen where beam becomes visible as a spot. The main parts of the CRT are

       i)   Electron gun
      ii)   Deflection system
     iii)   Fluorescent screen
      iv)   Glass tube or envelope
      v) Base
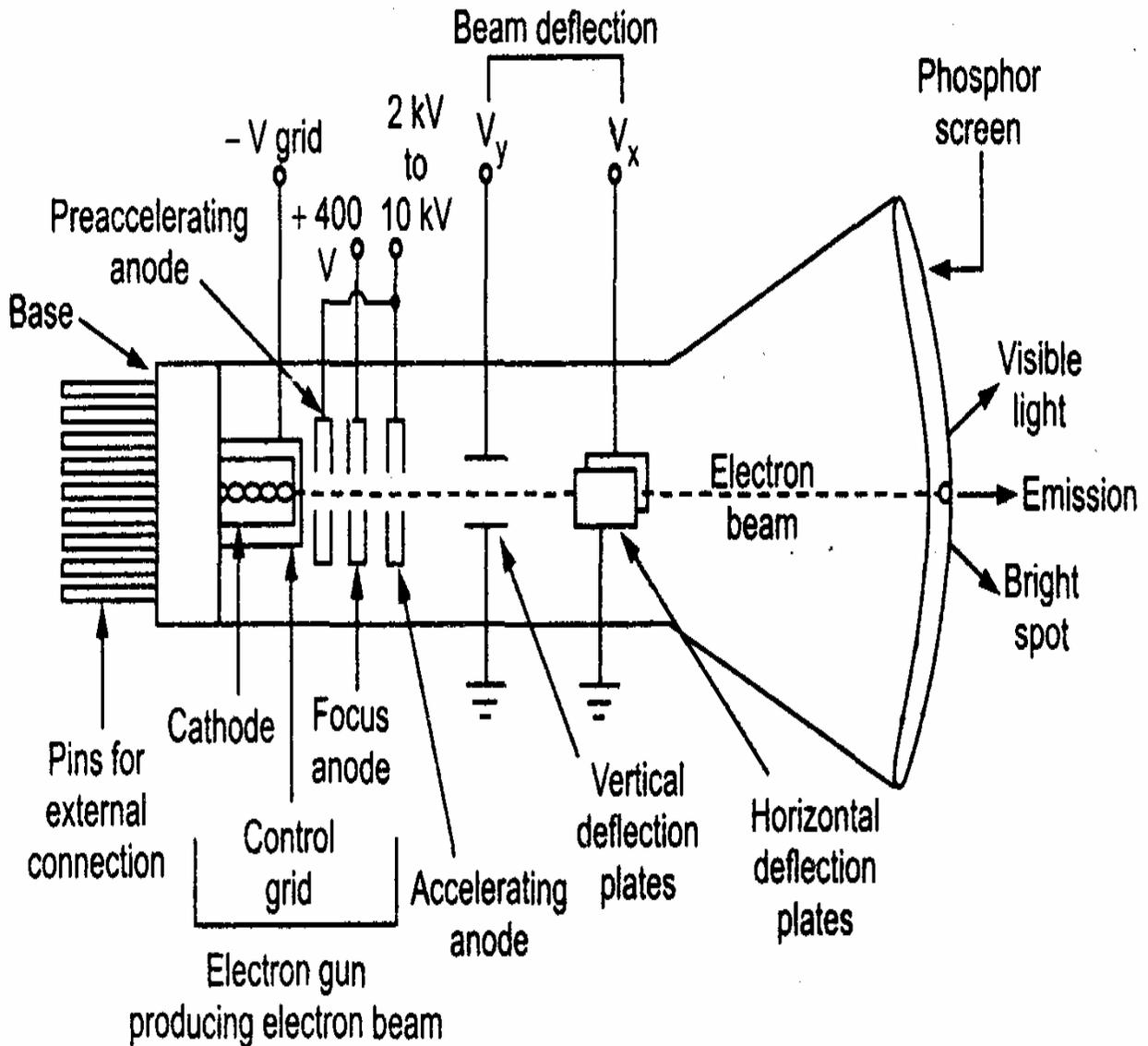
Electron gun

Ø The electron gun section of the cathode ray tube provides a sharply focused, electron beam directed towards the fluorescent-coated screen.

Ø This section starts from thermally heated cathode, emitting the electrons.

Ø The control grid is given negative potential with respect to cathode.

Ø This grid controls the number of electrons in t beam, going to the screen.

Ø The momentum of the electrons (their number x their speed) determines the intensity, or brightness, of the light emitted from the fluorescent screen due to the electron bombardment.

Ø The light emitted is usually of the green colour.

Deflection System

Ø When the electron beam is accelerated it passes through the deflection system, with which beam can be positioned anywhere on the screen.

Fluorescent Screen

Ø The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero.

Ø The time period for which the trace remains on the screen after the signal becomes zero is known as "persistence or fluorescence".

Ø The persistence may be as short as a few microsecond, or as long as tens of seconds or even minutes.

Ø Medium persistence traces are mostly used for general purpose applications.

    Ø Long persistence traces are used in the study of transients.

Ø Long persistence helps in the study of transients since the trace is still seen on the screen after the transient has disappeared.

Glass Tube

Ø All the components of a CRT are enclosed in an evacuated glass tube called envelope.

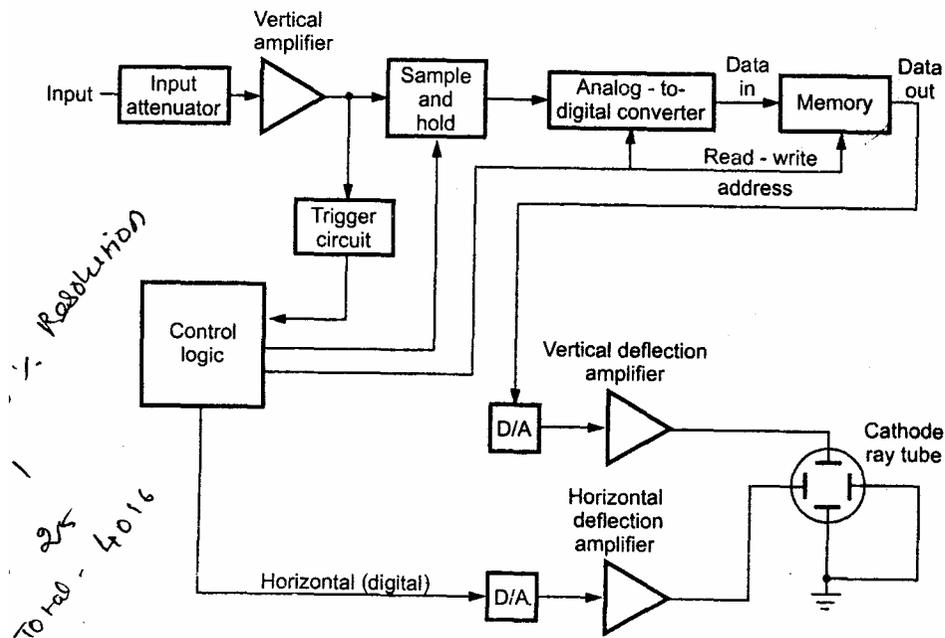Ø This allows the emitted electrons to move about freely from one end of the tube to the other end.

Base

Ø   The base is provided to the CRT through which the connections are made to the various parts.

Digital Storage Oscilloscope

Block Diagram

The block diagram of digital storage oscilloscope is shown in the Fig.

Ø   The input signal is applied to the amplifier and attenuator section.
Ø   The oscilloscope uses same type of amplifier and attenuator circuitry as used in the conventional oscilloscopes.
Ø   The attenuated signal is then applied to the vertical amplifier.
Ø   To digitize the analog signal, analog to digital (A/D) converter is used.
Ø   The output of the vertical amplifier is applied to the A/D converter section.
Ø   The successive approximation type of A/D converter is most oftenly used in the digital storage oscilloscopes.
Ø   The sampling rate and memory size are selected depending upon the duration & the waveform to be recorded.
Ø   Once the input signal is sampled, the A/D converter digitizes it.
Ø   The signal is then captured in the memory.

Ø Once it is stored in the memory, many manipulations are possible as memory can be readout without being erased.

Ø The digital storage oscilloscope has three modes:

1. Roll mode
2. Store mode
3. Hold or save mode.

Advantages

i) It is easier to operate and has more capability. ii) The storage time is infinite.

iii) The display flexibility is available. The number of traces that can be stored and recalled depends on the size of the memory.

iv) The cursor measurement is possible.

v) The characters can be displayed on screen along with the waveform which   can   indicate waveform information such as minimum, maximum, frequency, amplitude etc.

vi) The X-Y plots, B-H curve, P-V diagrams can be displayed.

vii) The pretrigger viewing feature allows to display the waveform before trigger pulse.

viii) Keeping the records is possible by transmitting the data to computer system where the further processing is possible

ix) Signal processing is possible which includes translating the raw data into finished information e.g. computing parameters of a captured signal like r.m.s. value, energy stored etc.

4.6 DATA LOGGER

Definition

Data logger is an electronic device that records data over time or in relation to location either with a built in instrument or sensor.

Components

Ø Pulse inputs

Counts circuit closing

Ø Control ports

Digital in and out

Most commonly used to turn things on and off

Can be programmed as a digital input

Ø Excitation outputs

Though they can be deployed while connected to a host PC over an Ethernet or serial port a data logger is more typically deployed as standalone devices. The term data logger (also sometimes referred to as a data recorder) is commonly used to describe a self-contained, standalone data acquisition system or device. These products are comprised of a number of analog and digital inputs that are monitored, and the results or conditions of these inputs is then stored on some type of local memory (e.g. SD Card, Hard Drive).

Examples

Examples of where these devices are used abound. A few of these examples are shown below:

Ø monitoring temperature, pressure, strain and other physical phenomena in aircraft flight tests (even including logging info from Arinc 429 or other serial communications buses)

Ø Monitoring temperature, pressure, strain and other physical phenomena in automotive and in-vehicle tests including monitoring traffic and data transmitted on the vehicles CAN bus.

Ø Environmental monitoring for quality control in food processing, food storage, pharmaceutical manufacturing, and even monitoring the environment during various stages of contract assembly or semiconductor fabrication

Ø Monitoring stress and strain in large mechanical structures such as bridges, steel framed buildings, towers, launch pads etc.

Ø Monitoring environmental parameters in temperature and environmental chambers and test facilities.

Ø A data logger is a self-contained unit that does not require a host to operate.

Ø It can be installed in almost any location, and left to operate unattended.
Ø This data can be immediately analyzed for trends, or stored for historical archive purposes.
Ø Data loggers can also monitor for alarm conditions, while recording a minimum number of samples, for economy.
Ø If the recording is of a steady-state nature, without rapid changes, the user may go through rolls of paper, without seeing a single change in the input.
Ø A data logger can record at very long intervals, saving paper, and can note when an alarm condition is occurring. When this happens, the event will be recorded and any outputs will be activated, even if the event occurs in between sample times.
Ø A record of all significant conditions and events is generated using a minimum of recording hardcopy
Ø The differences between various data loggers are based on the way that data is recorded and stored.
Ø The basic difference between the two data logger types is that one type allows the data to be stored in a memory, to be retrieved at a later time, while the other type automatically records the data on paper, for immediate viewing and analysis.
Ø Many data loggers combine these two functions, usually unequally, with the emphasis on either the ability to transfer the data or to provide a printout of it

Advantages

Ø A data logger is an attractive alternative to either a recorder or data acquisition system in many applications. When compared to a recorder, data loggers have the ability to accept a greater number of input channels, with better resolution and accuracy.

Ø Also, data loggers usually have some form of on-board intelligence, which provides the user with diverse capabilities.

Ø For example, raw data can be analyzed to give flow rates, differential temperatures, and other interpreted data that otherwise would require manual analysis by the operator the operator has a permanent recording on paper,

Ø No other external or peripheral equipment is required for operation, and

Ø Many data loggers of this type also have the ability to record data trends, in addition to simple digital data recording

Applications

Ø Temperature sensor
Ø Pressure sensor

4.7 LED-BACKLIT LCD TELEVISION
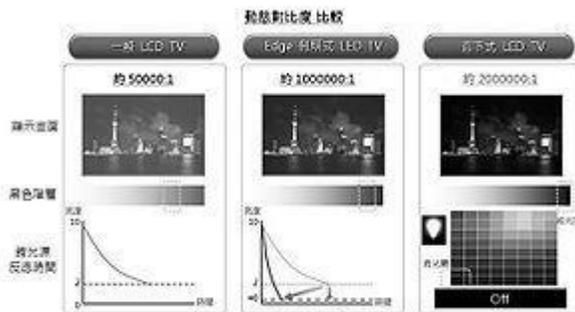
Comparison of LCD, edge lit LED and LED TV

LED-backlight LCD television (incorrectly called LED TV by (CCFLs) used in traditional LCD televisions. This has a dramatic impact resulting in a thinner panel and less power consumption, brighter display with better contrast levels. It also generates less heat than regular LCD TVs. The LEDs can come in three forms: dynamic RGB LEDs which are positioned behind

the panel, white Edge-LEDs positioned around the rim of the screen which use a special diffusion panel to spread the light evenly behind the screen (the most common) and full-array which are arranged behind the screen but they are incapable of dimming or brightening individually

LED backlighting techniques

RGB dynamic LEDs

This method of backlighting allows dimming to occur in locally specific areas of darkness on the screen. This can show truer blacks, whites and PRs[clarification needed] at much higher dynamic contrast ratios, at the cost of less detail in small bright objects on a dark background, such as star fields

Edge-LEDs

This method of backlighting allows for LED-backlit TVs to become extremely thin. The light is diffused across the screen by a special panel which produces a uniform color range across the screen.

Full Array LEDs

Sharp, and now other brands, also have LED backlighting technology that aligns the LEDs on back of the TV like the RGB Dynamic LED backlight, but it lacks the local dimming of other sets.[6] The main benefit of its LED backlight is simply reduced energy consumption and may not improve quality over non-LED LCD TVs.[7]

Differences between LED-backlit and CCFL-backlit LCD displays

An LED backlight offers several general benefits over regular CCFL backlight TVs, typically higher brightness. Compared to regular CCFL backlighting, there may also be benefits to color gamut. However advancements in CCFL technology mean wide color gamuts and lower power consumption are also possible. The principal barrier to wide use of LED backlighting on LCD televisions is cost.

The variations of LED backlighting do offer different benefits. The first commercial LED backlit LCD TV was the Sony Qualia 005 (introduced in 2004). This featured RGB LED arrays to offer a color gamut around twice that of a conventional CCFL LCD television (the combined light output from red, green and blue LEDs produces a more pure white light than is possible with a single white light LED). RGB LED technology continues to be used on selected Sony BRAVIA LCD models, with the addition of 'local dimming' which enables excellent on-screen contrast through selectively turning off the LEDs behind dark parts of a picture frame.

Edge LED lighting was also first introduced by Sony (September 2008) on the 40 inch BRAVIA KLV-40ZX1M (referred to as the ZX1 in Europe). The principal benefit of Edge-LED lighting for LCD televisions is the ability to build thinner housings (the BRAVIA KLV-40ZX1M is as thin as 9.9mm). Samsung has also introduced a range of Edge-LED lit LCD televisions with extremely thin housings.

LED-backlit LCD TVs are considered a more sustainable choice, with a longer life and better

energy efficiency than plasmas and conventional LCD TVs.[10] Unlike CCFL backlights, LEDs also use no mercury in their manufacture. However, other elements such as gallium and arsenic are used in the manufacture of the LED emitters themselves, meaning there is some debate over whether they are a significantly better long term solution to the problem of TV disposal.

Because LEDs are able to be switched on and off more quickly than CCFL displays and can offer a higher light output, it is theoretically possible to offer very high contrast ratios. They can produce deep blacks (LEDs off) and a high brightness (LEDs on), however care should be taken with measurements made from pure black and pure white outputs, as technologies like Edge-LED lighting do not allow these outputs to be reproduced simultaneously on-screen.

In September 2009 Nanoco Group announced that it has signed a joint development agreement with a major Japanese electronics company under which it will design and develop quantum dots for LED Backlights in LCD televisions.[11] Quantum dots are valued for displays, because they emit light in very specific gaussian distributions. This can result in a display that more accurately renders the colors than the human eye can perceive. Quantum dots also require very little power since they are not color filtered. In September 2010, LG Electronics revealed their new product which claimed as the world's slimmest full LED 3D TV at the IFA consumer electronics trade show in Berlin

4.8 LCD & Dot Matrix Display

LIQUID CRYSTAL DISPLAY
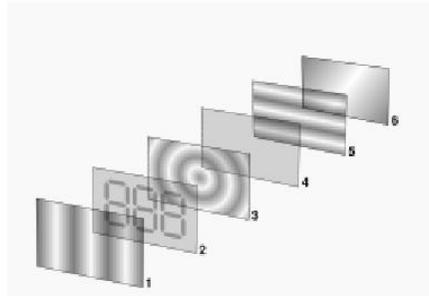
Reflective twisted nematic liquid crystal display.

1. Polarizing filter film with a vertical axis to polarize light as it enters.

2. Glass substrate with ITO electrodes. The shapes of these electrodes will determine the shapes that will appear when the LCD is turned ON. Vertical ridges etched on the surface are smooth.
3. Twisted nematic liquid crystal.

4. Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontal filter.
5. Polarizing filter film with a horizontal axis to block/pass light.
6. Reflective surface to send light back to viewer. (In a backlit LCD, this layer is replaced with a light source.)

A liquid crystal display (LCD) is a thin, flat electronic visual display that uses the light modulating properties of liquid crystals (LCs). LCs do not emit light directly.

They are used in a wide range of applications including: computer monitors, television, instrument panels, aircraft cockpit displays, signage, etc. They are common in consumer devices such as video players, gaming devices, clocks, watches, calculators, and telephones. LCDs have displaced cathode ray tube (CRT) displays in most applications. They are usually more compact, lightweight, portable, less expensive, more reliable, and easier on the eyes.They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they cannot suffer image burn-in. LCDs are more energy efficient and offer safer disposal than CRTs.

Overview

LCD alarm clock

Each pixel of an LCD typically consists of a layer of molecules aligned between two transparent electrodes, and two polarizing filters, the axes of transmission of which are (in most of the cases) perpendicular to each other. With no actual liquid crystal between the polarizing filters, light passing through the first filter would be blocked by the second (crossed) polarizer. In most of the cases the liquid crystal has double refraction.

The surface of the electrodes that are in contact with the liquid crystal material are treated so as to align the liquid crystal molecules in a particular direction. This treatment typically consists of a thin polymer layer that is unidirectionally rubbed using, for example, a cloth. The direction of the liquid crystal alignment is then defined by the direction of rubbing. Electrodes are made of a transparent conductor called Indium Tin Oxide (ITO).

Before applying an electric field, the orientation of the liquid crystal molecules is determined by the alignment at the surfaces of electrodes. In a twisted nematic device (still the most common liquid crystal device), the surface alignment directions at the two electrodes are perpendicular to each other, and so the molecules arrange themselves in a helical structure, or twist. This reduces

the rotation of the polarization of the incident light, and the device appears grey. If the applied voltage is large enough, the liquid crystal molecules in the center of the layer are almost completely untwisted and the polarization of the incident light is not rotated as it passes through the liquid crystal layer. This light will then be mainly polarized perpendicular to the second filter, and thus be blocked and the pixel will appear black. By controlling the voltage applied across the liquid crystal layer in each pixel, light can be allowed to pass through in varying amounts thus constituting different levels of gray. This electric field also controls (reduces) the double refraction properties of the liquid crystal.

LCD with top polarizer removed from device and placed on top, such that the top and bottom polarizers are parallel.

The optical effect of a twisted nematic device in the voltage-on state is far less dependent on variations in the device thickness than that in the voltage-off state. Because of this, these devices are usually operated between crossed polarizers such that they appear bright with no voltage (the eye is much more sensitive to variations in the dark state than the bright state). These devices can also be operated between parallel polarizers, in which case the bright and dark states are reversed. The voltage-off dark state in this configuration appears blotchy, however, because of small variations of thickness across the device.

Both the liquid crystal material and the alignment layer material contain ionic compounds. If an electric field of one particular polarity is applied for a long period of time, this ionic material is attracted to the surfaces and degrades the device performance. This is avoided either by applying an alternating current or by reversing the polarity of the electric field as the device is addressed (the response of the liquid crystal layer is identical, regardless of the polarity of the applied field).

When a large number of pixels are needed in a display, it is not technically possible to drive each directly since then each pixel would require independent electrodes. Instead, the display is multiplexed. In a multiplexed display, electrodes on one side of the display are grouped and wired together (typically in columns), and each group gets its own voltage source. On the other side, the electrodes are also grouped (typically in rows), with each group getting a voltage sink. The groups are designed so each pixel has a unique, unshared combination of source and sink. The electronics, or the software driving the electronics then turns on sinks in sequence, and drives sources for the pixels of each sink.

ILLUMINATION

LCD panels produce no light of their own, they require an external lighting mechanism to be easily visible. On most displays, this consists of a cold cathode fluorescent lamp that is situated behind the LCD panel. Passive-matrix displays are usually not backlit, but active-matrix displays almost always are, with a few exceptions such as the display in the original Gameboy Advance. Recently, two types of LED backlit LCD displays have appeared in some televisions as an alternative to conventional backlit LCDs. In one scheme, the LEDs are used to backlight the entire LCD panel. In another scheme, a set of green red and blue LEDs is used to illuminate a small cluster of pixels, which can improve contrast and black level in some situations. For example, the LEDs in one section of the screen can be dimmed to produce a dark section of the image while the LEDs in another section are kept bright. Both schemes also allows for a slimmer panel than on conventional displays.

Passive-matrix and active-matrix addressed LCDs
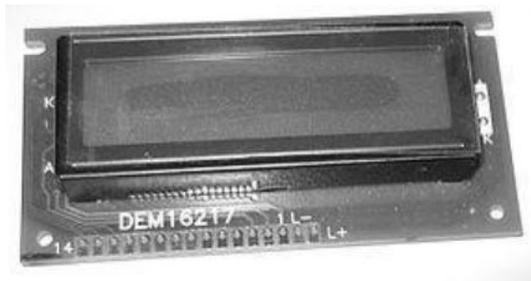
 A general purpose alphanumeric LCD, with two lines of 16 characters. LCDs with a small number of segments, such as those used in digital watches and pocket calculators, have individual electrical contacts for each segment. A external dedicated circuit supplies an electric charge to control each segment. This display structure is unwieldy for more than a few display elements.

Small monochrome displays such as those found in personal organizers, electronic weighing scales, older laptop screens, and the originalGameboy have a passive-matrix structure employing super-twisted nematic (STN) or double-layer STN (DSTN) technology (the latter of which addresses a colour-shifting problem with the former), and colour-STN (CSTN) in which colour is added by using an internal filter. Each row or column of the display has a single electrical circuit. The pixels are addressed one at a time by row and column addresses. This type of display is called passive-matrix addressed because the pixel must retain its state between refreshes without the benefit of a steady electrical charge. As the number of pixels (and, correspondingly, columns and rows) increases, this type of display becomes less feasible. Very slow response times and poor contrast are typical of passive-matrix addressed LCDs.
Monochrome passive-matrix LCDs were standard in most early laptops (although a few used plasma displays). The commercially unsuccessful Macintosh Portable (released in 1989) was one of the first to use an active-matrix display (though still monochrome), but passive-matrix was the norm until the mid-1990s, when colour active-matrix became standard on all laptops.

High-resolution colour displays such as modern LCD computer monitors and televisions use an active matrix structure. A matrix of thin-film transistors (TFTs) is added to the polarizing and colour filters. Each pixel has its own dedicated transistor, allowing each column line to access one pixel. When a row line is activated, all of the column lines are connected to a row of pixels and the correct voltage is driven onto all of the column lines. The row line is then deactivated and the next row line is activated. All of the row lines are activated in sequence during a refresh operation. Active-matrix addressed displays look "brighter" and "sharper" than passive-matrix addressed displays of the same size, and generally have quicker response times, producing much better images.

ACTIVE MATRIX TECHNOLOGIES

A Casio 1.8 in colour TFT liquid crystal display which equips the SonyCyber-shot DSC-P93A

Twisted nematic (TN)

Twisted nematic displays contain liquid crystal elements which twist and untwist at varying degrees to allow light to pass through. When no voltage is applied to a TN liquid crystal cell, the light is polarized to pass through the cell. In proportion to the voltage applied, the LC cells twist up to 90 degrees changing the polarization and blocking the light's path. By properly adjusting the level of the voltage almost any grey level or transmission can be achieved.

In-plane switching (IPS)

In-plane switching is an LCD technology which aligns the liquid crystal cells in a horizontal direction. In this method, the electrical field is applied through each end of the crystal, but this requires two transistors for each pixel instead of the single transistor needed for a standard thin-film transistor (TFT) display. Before LGEnhanced IPS was introduced in 2009, the additional transistors resulted in blocking more transmission area, thus requiring a brighter backlight, which consumed more power, and made this type of display less desirable for notebook computers. This newer, lower power technology can be found in the AppleiMac, iPad, and iPhone 4, as well as the Hewlett-Packard EliteBook 8740w. Currently Panasonic is using an enhanced version eIPS for their large size LCD-TV products.Advanced fringe field switching (AFFS)
Known as fringe field switching (FFS) until 2003, advanced fringe field switching is a technology similar to IPS or S-IPS offering superior performance and colour gamut with high

luminosity. AFFS is developed by HYDIS TECHNOLOGIES CO.,LTD, Korea (formally Hyundai Electronics, LCD Task Force). AFFS-applied notebook applications minimize colour

In 2004, HYDIS TECHNOLOGIES CO.,LTD licenses AFFS patent to Japan's Hitachi Displays. Hitachi is using AFFS to manufacture high end panels in their product line. In 2006, HYDIS also licenses AFFS to Sanyo Epson Imaging Devices Corporation.
HYDIS introduced AFFS+ which improved outdoor readability in 2007.

Vertical alignment (VA)

Vertical alignment displays are a form of LCDs in which the liquid crystal material naturally exists in a vertical state removing the need for extra transistors (as in IPS). When no voltage is applied, the liquid crystal cell remains perpendicular to the substrate creating a black display. When voltage is applied, the liquid crystal cells shift to a horizontal position, parallel to the substrate, allowing light to pass through and create a white display. VA liquid crystal displays provide some of the same advantages as IPS panels, particularly an improved viewing angle and improved black level

Blue Phase mode

Blue phase LCDs do not require a liquid crystal top layer. Blue phase LCDs are relatively new to the market, and very expensive because of the low volume of production. They provide a higher refresh rate than normal LCDs, but normal LCDs are still cheaper to make and actually provide better colours and a sharper image

Military use of LCD monitors

LCD monitors have been adopted by the United States of America military instead of CRT displays because they are smaller, lighter and more efficient, although monochrome plasma displays are also used, notably for their M1 Abrams tanks. For use with night vision imaging systems a US military LCD monitor must be compliant with MIL-L-3009 (formerly MIL-L-85762A). These LCD monitors go through extensive certification so that they pass the standards for the military. These include MIL-STD-901D - High Shock (Sea Vessels), MIL-STD-167B - Vibration (Sea Vessels), MIL-STD-810F – Field Environmental Conditions (Ground Vehicles and Systems),MIL-STD-461E/F –EMI/RFI(Electromagnetic nterference/Radio Frequency Interference), MIL-STD-740B – Airborne/Structureborne Noise, and TEMPEST - Telecommunications Electronics Material Protected from Emanating Spurious Transmissions

Quality control

Some LCD panels have defective transistors, causing permanently lit or unlit pixels which are commonly referred to as stuck pixels or dead pixels respectively. Unlike integrated circuits (ICs), LCD panels with a few defective transistors are usually still usable. It is claimed that it is economically prohibitive to discard a panel with just a few defective pixels because LCD panels are much larger than ICs, but this has never been proven. Manufacturers' policies for the

acceptable number of defective pixels vary greatly. At one point, Samsung held a zero-tolerance policy for LCD monitors sold in Korea. Currently, though, Samsung adheres to the less restrictive ISO 13406-2 standard. Other companies have been known to tolerate as many as 11 dead pixels in their policies. Dead pixel policies are often hotly debated between manufacturers and customers. To regulate the acceptability of defects and to protect the end user, ISO released the ISO 13406-2 standard. However, not every LCD manufacturer conforms to the ISO standard and the ISO standard is quite often interpreted in different ways. LCD panels are more likely to have defects than most ICs due to their larger size. For example, a 300 mm SVGA LCD has 8 defects and a 150 mm wafer has only 3 defects. However, 134 of the 137 dies on the wafer will be acceptable, whereas rejection of the LCD panel would be a 0% yield. Due to competition between manufacturers quality control has been improved. An SVGA LCD panel with 4 defective pixels is usually considered defective and customers can request an exchange for a new one. Some manufacturers, notably in South Korea where some of the largest LCD panel manufacturers, such as LG, are located, now have "zero defective pixel guarantee", which is an extra screening process which can then determine "A" and "B" grade panels. Many manufacturers would replace a product even with one defective pixel. Even where such guarantees do not exist, the location of defective pixels is important. A display with only a few defective pixels may be unacceptable if the defective pixels are near each other. Manufacturers may also relax their replacement criteria when defective pixels are in the center of the viewing area. LCD panels also have defects known as *clouding* (or less commonly *mura*), which describes the uneven patches of changes in luminance. It is most visible in dark or black areas of displayed scenes

ZERO-POWER (BISTABLE) DISPLAYS

The zenithal bistable device (ZBD), developed by QinetiQ (formerly DERA), can retain an image without power. The crystals may exist in one of two stable orientations ("Black" and "White") and power is only required to change the image. ZBD Displays is a spin-off company from QinetiQ who manufacture both grayscale and colour ZBD devices. A French company, Nemoptic, has developed the BiNem zero-power, paper-like LCD technology which has been mass-produced in partnership with Seiko since 2007.

This technology is intended for use in applications such as Electronic Shelf Labels, E-books, E-documents, E-newspapers, E-dictionaries, Industrial sensors, Ultra-Mobile PCs, etc.

Kent Displays has also developed a "no power" display that uses Polymer Stabilized Cholesteric Liquid Crystals (ChLCD). A major drawback of ChLCD screens are their slow refresh rate, especially at low temperatures. Kent has recently demonstrated the use of a ChLCD to cover the entire surface of a mobile phone, allowing it to change colours, and keep that colour even when power is cut off. In 2004 researchers at the University of Oxford demonstrated two new types of zero-power bistable LCDs based on Zenithal bistable techniques. Several bistable technologies, like the 360° BTN and the bistable cholesteric, depend mainly on the bulk properties of the liquid crystal (LC) and use standard strong anchoring, with alignment films and LC mixtures similar to the traditional monostable materials. Other bistable technologies (i.e. Binem Technology) are based mainly on the surface properties and need specific weak anchoring materials. distortion while maintaining its superior wide viewing angle for a professional display. Colour shift and deviation caused by light leakage is corrected by optimizing the white gamut which also enhances white/grey reproduction.

Comparison of the OLPC XO-1 display (left) with a typical colour LCD. The images show 1×1 mm of each screen. A typical LCD addresses groups of 3 locations as pixels. The XO-1 display addresses each location as a separate pixel.
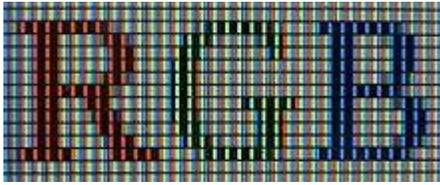
Example of how the colours are generated (R-red, G-green and B-blue)
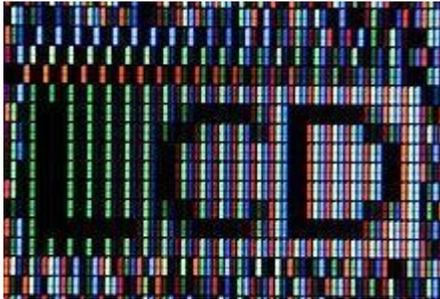
In colour LCDs each individual <u>pixel</u> is divided into three cells, or subpixels, which are coloured red, green, and blue, respectively, by additional filters (pigment filters, dye filters and metal oxide filters). Each subpixel can be controlled independently to yield thousands or millions of possible colours for each pixel. CRT monitors employ a similar 'subpixel' structures *via* phosphors, although the electron beam employed in CRTs do not hit exact subpixels. The figure at the left shows the twisted nematic (TN) type of LCD.

UNIT V TRANSDUCERS AND DATA ACQUISITION SYSTEMS

TRANSDUCERS

Ø The input quantity for most instrumentation systems is nonelectrical. In order to use electrical methods and techniques for measurement, the nonelectrical quantity is converted into a proportional electrical signal by a device called transducer.

Ø Another definition states that transducer is a device which when actuated by energy in one system, supplies energy in the same form or in another form to a second system.

Ø When transducer gives output in electrical form it is known as electrical transducer.
Actually, electrical transducer consists of two parts which are very closely related to
Each other.

Ø These two parts are sensing or detecting element and transduction element. The sensing or detecting element is commonly known as sensor.

Ø Definition states that sensor is a device that produces a measurable response to a
Change in a physical condition.

Ø The transduction element transforms the output of the sensor to an electrical output, as shown in the Fig.
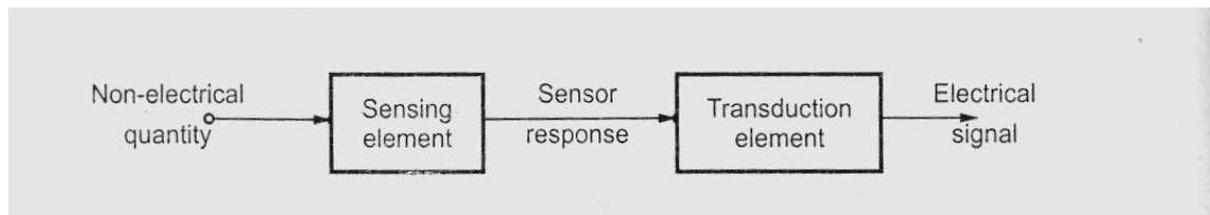
(Fig)Transducer elements in cascade

5.1 Classification of Electrical Transducers

Transducers may be classified according to their structure, method of energy conversion and   application.
Thus we can say that transducers are classified
• As active and passive transducer
• According to transduction principle
• As analog and digital transducer
• As primary and secondary transducer
• As transducer and inverse transducer
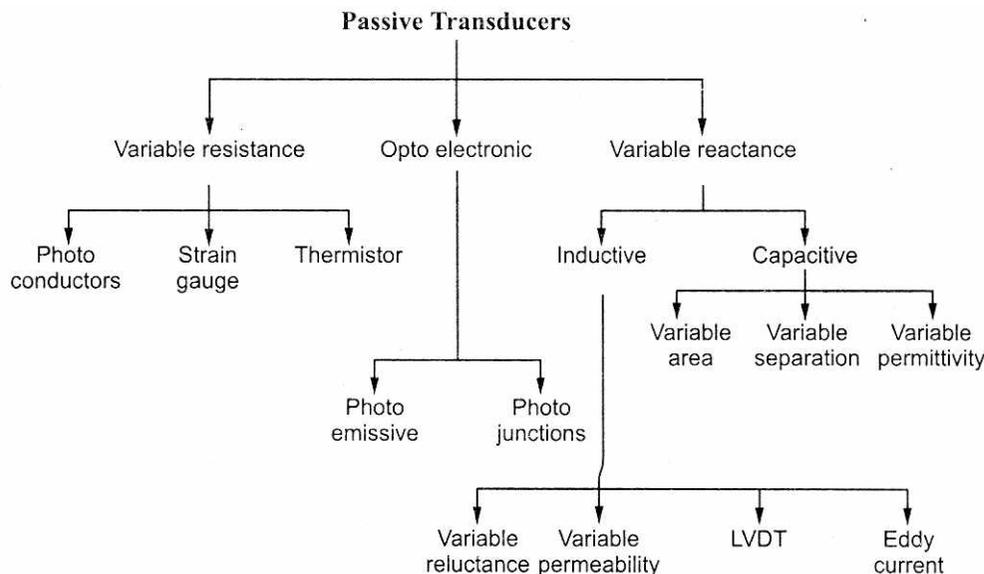
Active and Passive Transducer
Active Transducers

Ø Active transducers are self-generating type of transducers.

Ø These transducers develop an electrical parameter (i.e. voltage or current) which is proportional to the quantity under measurement.

Ø These transducers do not require any external source or power for their operation.

Ø   They can be subdivided into the following commonly used types

Active Transducers — Photovoltaic, Thermoelectric, Piezoelectric, Electromagnetic
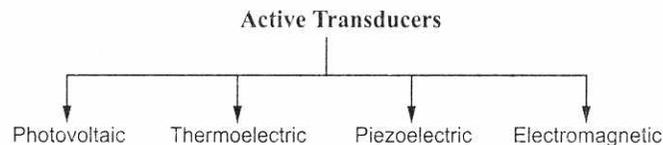
Passive Transducers
Ø   Passive transducers do not generate any electrical signal by themselves.
Ø   To obtain an electrical signal from such transducers, an external source of power is essential.
Ø   Passive transducers depend upon the change in an electrical parameter (R, L, or C).
Ø   They are also known as externally power driven transducers.
Ø   They can be subdivided into the following commonly used types.

Passive Transducers — Variable resistance (Photo conductors, Strain gauge, Thermistor), Opto electronic (Photo emissive, Photo junctions), Variable reactance — Inductive (Variable reluctance, Variable permeability, LVDT, Eddy current), Capacitive (Variable area, Variable separation, Variable permittivity)

According to Transduction Principle
   The transducers can be classified according to principle used in transduction.
   • Capacitive transduction
   • Electromagnetic transduction
   • Inductive transduction
   • Piezoelectric transduction
   • Photovoltaic transduction
   • Photoconductive transduction

Analog and Digital Transducers
   The transducers can be classified on the basis of the output which may be a continuous function of time or the output may be in discrete steps.

Analog Transducers

Ø   These transducers convert the input quantity into an analog output which is a continuous function   of time.
Ø   A strain gauge, LVDT, thermocouples or thermistors are called analog transducers as they produce an outpu

which is a continuous function of time.

Digital Transducers

Ø Digital transducers produce an electrical output in the form of pulses which forms an unique code.

Ø Unique code is generated for each discrete value sensed.

Primary or Secondary

Ø Some transducers consist of mechanical device along with the electrical device.

Ø In such transducers mechanical device acts as a primary transducer and converts physical quantity into mechanical signal.

Ø The electrical device then converts mechanical signal produced by primary transducer into an electrical signal.

Ø Therefore, electrical device acts as a secondary transducer.

Ø For an example, in pressure measurement Bourdons tube acts as a primary transducer which converts a pressure into displacement and LVDT acts as a secondary transducer which converts this displacement into an equivalent electrical signal.
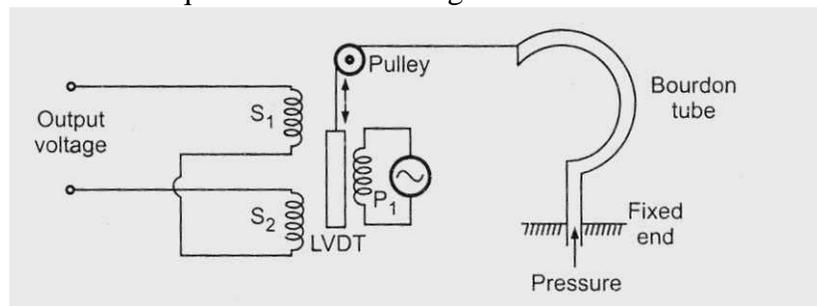
(Fig) pressure Measurement

Transducer and Inverse Transducer

Ø Transducers convert non-electrical quantity into electrical quantity whereas inverse transducer converts electrical quantity into non-electrical quantity.

Ø For example, microphone is a transducer which converts sound signal into an electrical signal whereas loudspeaker is an inverse transducer which converts electrical signal into sound signal.

Advantages of Electrical Transducers

1. Electrical signal obtained from electrical transducer can be easily processed (mainly amplified) and brought to a level suitable for output device which may be an indicator or recorder.

2. The electrical systems can be controlled with a very small level of power

3. The electrical output can be easily used, transmitted, and processed for the purpose of measurement.

4. With the advent of IC technology, the electronic systems have become extremely small in size, requiring small space for their operation.

5. No moving mechanical parts are involved in the electrical systems. Therefore there is no question of mechanical wear and tear and no possibility of mechanical failure.

Electrical transducer is almost a must in this modem world. Apart from the merits described above, some disadvantages do exist in electrical sensors.

Disadvantages of Electrical Transducers
- Ø The electrical transducer is sometimes less reliable than mechanical type because of the ageing and drift of the active components.
- Ø Also, the sensing elements and the associated signal processing circuitry are comparatively expensive.
- Ø With the use of better materials, improved technology and circuitry, the range of accuracy and stability have been increased for electrical transducers.
- Ø Using negative feedback technique, the accuracy of measurement and the stability of the system are improved, but all at the expense of increased circuit complexity, more space, and obviously, more cost.

Characteristics of Transducer
1. **Accuracy**: It is defined as the closeness with which the reading approaches an accepted standard value or ideal value or true value, of the variable being measured.
2. **Ruggedness**: The transducer should be mechanically rugged to withstand overloads. It should have overload protection.
3. **Linearity**: The output of the transducer should be linearly proportional to the input quantity under measurement. It should have linear input - output characteristic. -
4. **Repeatability:** The output of the transducer must be exactly the same, under same environmental conditions, when the same quantity is applied at the input repeatedly.
5. **High output**: The transducer should give reasonably high output signal so that it can be easily processed and measured. The output must be much larger than noise. Now-a-days, digital output is preferred in many applications;
6. **High Stability and Reliability:** The output of the transducer should be highly stable and reliable so that there will be minimum error in measurement. The output must remain unaffected by environmental conditions such as change in temperature, pressure, etc.
7. **Sensitivity**: The sensitivity of the electrical transducer is defined as the electrical output obtained per unit change in the physical parameter of the input quantity. For example, for a transducer used for temperature measurement, sensitivity will be expressed in mV/° C. A high sensitivity is always desirable for a given transducer.
8. **Dynamic Range:** For a transducer, the operating range should be wide, so that it can be used over a wide range of measurement conditions.
9. **Size:** The transducer should have smallest possible size and shape with minimal weight and volume. This will make the measurement system very compact.
10. **Speed of Response:** It is the rapidity with which the transducer responds to changes in the measured quantity. The speed of response of the transducer should be as high as practicable.

5.2 Transducer Selection Factors

1. Nature of measurement
2. Loading effect
3. Environmental considerations
4. Measuring system
5. Cost & Availability

5.3 Resistance Transducers

Temperature Sensors

Temperature is one of the fundamental parameters indicating the physical condition of matter, i.e. expressing its degree of hotness or coldness. Whenever a body is heat' various effects are observed. They include

• Change in the physical or chemical state, (freezing, melting, boiling etc.)
• Change in physical dimensions,
• Changes in electrical properties, mainly the change in resistance,
• Generation of an emf at the junction of two dissimilar metals.

One of these effects can be employed for temperature measurement purposes. Electrical methods are the most convenient and accurate methods of temperature measurement. These methods are based on change in resistance with temperature and generation of thermal e.m.f. The change in resistance with temperature may be positive or negative. According to that there are two types

• Resistance Thermometers —Positive temperature coefficient
• Thermistors —Negative temperature coefficient

Construction of Resistance Thermometers

Ø The wire resistance thermometer usually consists of a coil wound on a mica or ceramic former,   as shown in the Fig.

Ø The coil is wound in bifilar form so as to make it no inductive. Such coils are available in different sizes and with different resistance values ranging from 10 ohms to 25,000 ohms.
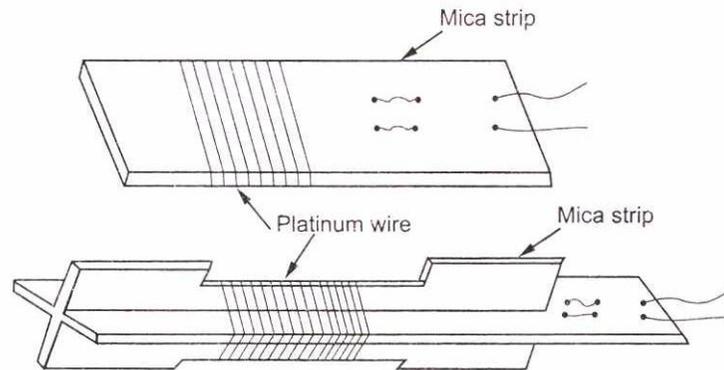
(Fig) Resistance Thermometer

### Advantages of Resistance Thermometers

1. The measurement is accurate.
2. Indicators, recorders can be directly operated.
3. The temperature sensor can be easily installed and replaced.
4. Measurement of differential temperature is possible.
5. Resistance thermometers can work over a wide range of temperature from
    -20' C to + 650° C.
6. They are suitable for remote indication.
7. They are smaller in size
8. They have stability over long periods of time.

Limitations of Resistance Thermometers

1. A bridge circuit with external power source is necessary for their operation.
2. They are comparatively costly.

Thermistors
- Ø Thermistor is a contraction of a term 'thermal-resistors'.
- Ø Thermistors are semiconductor device which behave as thermal resistors having negative temperature coefficient [i.e. their resistance decreases as temperature increases.
- Ø The below Fig. shows this characteristic.
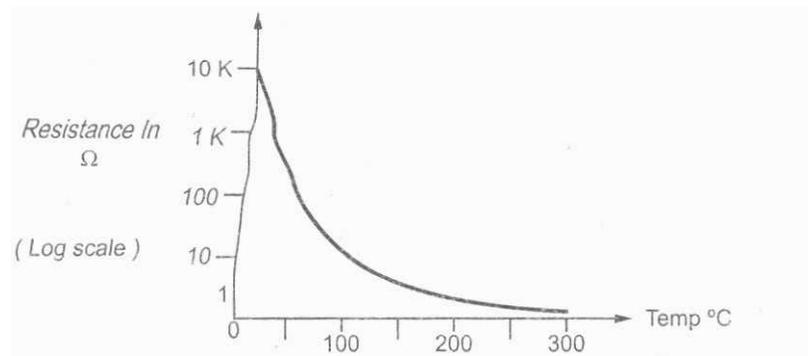
Construction of Thermistor
- Ø Thermistors are composed of a sintered mixture of metallic oxides, manganese, nickel, cobalt, copper, iron, and uranium.
- Ø Their resistances at temperature may range from 100 to 100k .
- Ø Thermistors are available in variety of shapes and sizes as shown in the Fig.

(a) Bead   (b) Probe

(c) Disc   (c) Rod
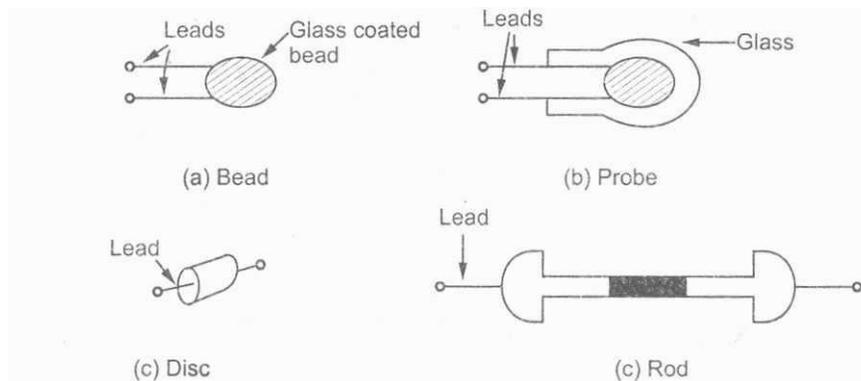
- Ø Smallest in size are the beads with a diameter of 0.15 mm to 1.25 mm.
- Ø Beads may be sealed in the tips of solid glass rods to form probes.
- Ø Disks and washers are made by pressing thermistor material under high pressure into flat cylindrical shapes.
- Ø Washers can be placed in series or in parallel to increase power dissipation rating.
- Ø Thermistors are well suited for precision temperature measurement, temperature control, and temperature compensation, because of their very large change in resistance with temperature.
- Ø They are widely used for measurements in the temperature range -100   C to +100 C

Advantages of Thermistor
1. Small size and low cost.

101

2. Comparatively large change in resistance for a given change in temperature
3. Fast response over a narrow temperature range.

Limitations of Thermistor
1. The resistance versus temperature characteristic is highly non-linear.
2. Not suitable over a wide temperature range.
3. Because of high resistance of thermistor, shielded cables have to be used to minimize interference.
**Applications of Thermistor**
1. The thermistors relatively large resistance change per degree change in temperature
[known as sensitivity] makes it useful as temperature transducer.
2. The high sensitivity, together with the relatively high thermistor resistance that
may be selected [e.g. 100k   .], makes the thermistor ideal for remote measurement or control. Thermistor control systems are inherently sensitive, stable, and fast acting, and they require relatively simple circuitry.
3. Because thermistors have a negative temperature coefficient of resistance,
thermistors are widely used to compensate for the effects of temperature on circuit performance.
4. Measurement of conductivity.

Temperature Transducers
They are also called thermo-electric transducers. Two commonly used temperature transducers are
• Resistance Temperature Detectors
• Thermocouples.

Thermocouples
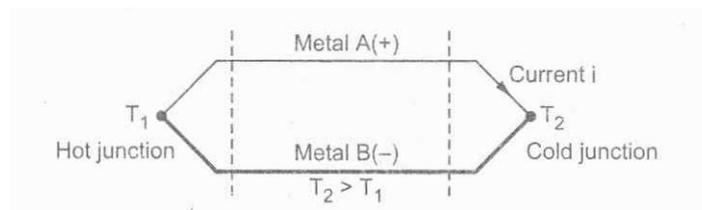
(Fig) Basic circuit
Ø   The thermocouple is one of the simplest and most commonly used methods of measuring process temperatures.
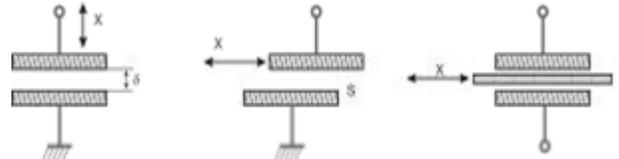
5.4 Capacitive Transducers

Capacitive transducers are capacitors that change their capacity under the influence of the input magnitude, which can be linear or angular movement. The capacity of a flat capacitor, composed of two electrodes with sizes **a ͡b**, with area of overlapping **s**, located at a distance **δ** from each other (in **d** << **a**/10 and **d** << **b**/10) is defined by the formula

$$C = \varepsilon_0 \, \varepsilon \, s/d$$

where: $\varepsilon_0 = 8{,}854.10^{-12}$ F/m is the dielectric permittivity of vacuum;
ε - permittivity of the area between the electrodes (for air **e**= 1,0005);
S=a.b – overlapping cross-sectional area of the electrodes. The
capacity can be influenced by changing the air gap **d**, the active area
of overlapping of the electrodes **s** and the dielectric properties of

the environment

Single capacitive transducers
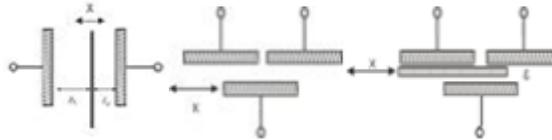
Differential capacitive transducers

Application of capacitive transducers

Capacitive sensors have found wide application in automated systems that require precise determination of the placement of theobjects, processes in microelectronics, assembly of precise equipment associated with spindles for high speed drilling machines, ultrasonic welding machines and inequipment for vibration measurement. They can be used not only to measure displacements (large and small), but also the level of fluids, fuel bulk materials, humidity environment, concentration of substances and others Capacitive sensors are often used for non-contact measurement of the thickness of various materials, such as silicon wafers, brake discs and plates of hard discs. Among the possibilities of the capacitive sensors is the measurement of density, thickness and location of dielectrics.

5.5 Inductive Transducers

An LVDT, or Linear Variable Differential Transformer, is a transducer that converts a linear displacement or position from a mechanical reference (or zero) into a proportional electrical signal containing phase (for direction) and amplitude information (for distance). The LVDT operation does not require electrical contact between the moving part (probe or core rod assembly) and the transformer, but rather relies on electromagnetic coupling; this and the fact that they operate without any built-in electronic circuitry are the primary reasons why LVDTs have been widely used in applications where long life and high reliability under severe environments are a required, such Military/Aerospace applications.

The LVDT consists of a primary coil (of magnet wire) wound over the whole length of a non-ferromagnetic bore liner (or spool tube) or a cylindrical coil form. Two secondary coils are wound on top of the primary coil for "long stroke" LVDTs (i.e. for actuator main RAM) or each side of the primary coil for "Short stroke" LVDTs (i.e. for electro-hydraulic servo-valve or EHSV). The two secondary windings are typically connected in "opposite series" (or wound in opposite rotational directions). A ferromagnetic core, which length is a fraction of the bore liner length, magnetically couples the primary to the secondary winding turns that are located above the length of the core.
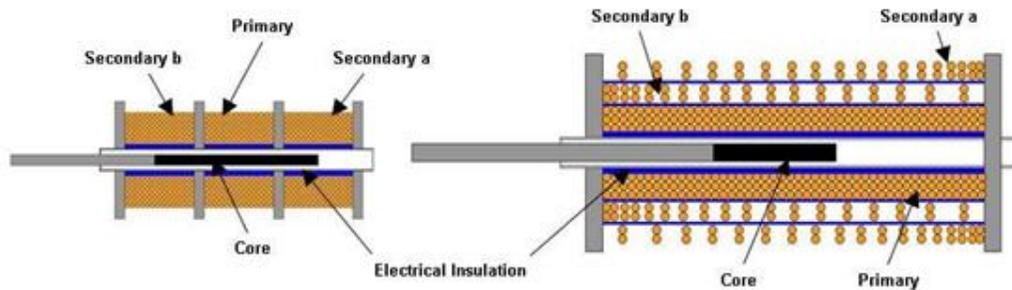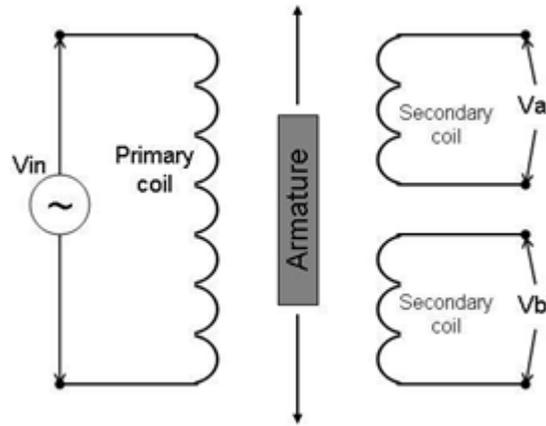
The LVDT: construction and principle of operation

When the primary coil is excited with a sine wave voltage (Vin), it generate a variable magnetic field which, concentrated by the core, induces the secondary voltages (also sine waves). While the secondary windings are designed so that the differential output voltage (Va-Vb) is proportional to the core position from null, the phase angle (close to 0 degree or close to 180 degrees depending of direction) determines the direction away from the mechanical zero. The zero is defined as the core position where the phase angle of the (Va-Vb) differential output is 90 degrees.

The differential output between the two secondary outputs (Va-Vb) when the core is at the mechanical zero (or "Null Position") is called the Null Voltage; as the phase angle at null position is 90 degrees, the Null Voltage is a "quadrature" voltage. This residual voltage is due to the complex nature of the LVDT electrical model, which includes the parasitic capacitances of the windings.

5.6 Digital Transducers

A transducer measures physical quantities and transmits the information as coded digital signals rather than as continuously varying currents or voltages. Any transducer that presents information as discrete samples and that does not introduce a quantization error when the reading is represented in the digital form may be classified as a digital transducer. Most transducers used in digital systems are primarily analogue in nature and incorporate some form of conversion to provide the digital output. Many special techniques have been developed to avoid the necessity to use a conventional analogue- to-digital conversion technique to produce the digital signal. This article describes some of the direct methods which are in current use of producing digital outputs from transducers.

Some of the techniques used in transducers which are particularly adaptable for use in digital systems are introduced. The uses of encoder discs for absolute and incremental position measurement and to provide measurement of angul ar speed are outlined. The application of linear gratings for measurement of translational displacement is compared with the use of Moire fringe techniques used for similar purposes. Synchro devices are briefly explained and the various techniques used to produce a digital output from synchro resolvers are described. Brief descriptions of devices which develop a digital output from the natural frequency of vibration of some part of the transducer are presented. Digital techniques including vortex flowmeters and instruments using laser beams are also briefly dealt with. Some of them are as follows:

1. Shaft Encoders
2. Digital Resolvers
3. Digital Tachometers
4. Hall Effect Sensors
5. Limit Switches

Shaft Encoders:

An encoder is a device that provides a coded reading of a measurement. A Shaft encoders can be one of the encoder that provide digital output measurements of angular position and velocity. This shaft encoders are excessively applicable in robotics, machine tools, mirror positioning systems, rotating machinery controls (fluid and electric), etc. Shaft encoders are basically of two types-Absolute and Incremental encoders.

An "absolute" encoder maintains position information when power is removed from the system. The position of the encoder is available immediately on applying power. The relationship between the encoder value and the physical position of the controlled machinery is set at assembly; the system does not need to return to a calibration point to maintain position accuracy. An "incremental" encoder accurately records changes in position, but does not power up with a fixed relation between encoder state and physical position. Devices controlled by incremental encoders may have to "go home" to a fixed reference point to initialize the position measurement. A multi-turn absolute rotary encoder includes additional code wheels and gears. A high-resolution wheel measures the fractional rotation, and lower-resolution geared code wheels record the number of whole revolutions of the shaft.

An absolute encoder has multiple code rings with various binary weightings which provide a data word representing the absolute position of the encoder within one

revolution. This type of encoder is often referred to as a parallel absolute encoder.

An incremental encoder works differently by providing an A and a B pulse output that provide no usable count information in their own right. Rather, the counting is done in the external electronics. The point where the counting begins depends on the counter in the external electronics and not on the position of the encoder. To provide useful position information, the encoder position must be referenced to the device to which it is attached, generally using an index pulse. The distinguishing feature of the incremental encoder is that it reports an incremental change in position of the encoder to the counting electronics.

State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low
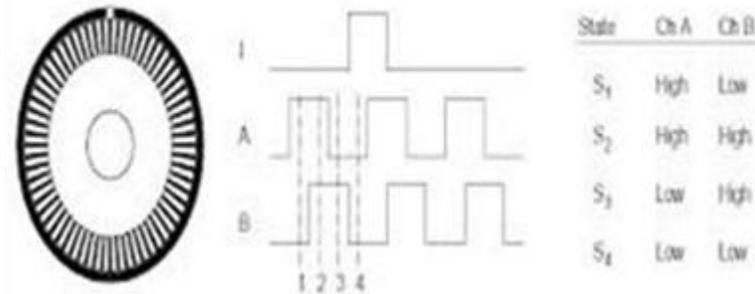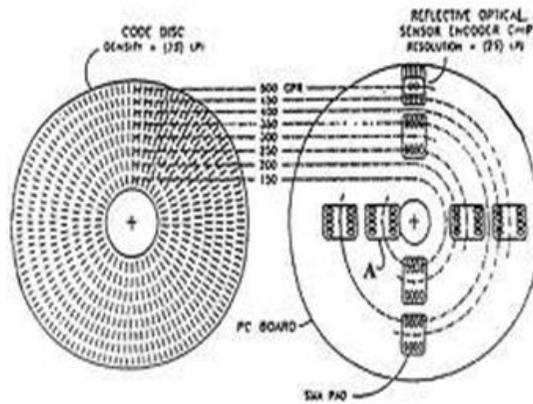
5.7 Piezoelectric Transducers

Piezoelectric transducers produce an output voltage when a force is applied to them. They are frequently used as ultrasonic receivers and also as displacement transducers, particularly as part of devices measuring acceleration, force and pressure. In ultra- sonic receivers, the sinusoidal amplitude variations in the ultrasound wave received are translated into sinusoidal changes in the amplitude of the force applied to the piezoelectric transducer. In a similar way, the translational movement in a displacement transducer is caused by mechanical means to apply a force to the piezoelectric transducer. Piezoelectric transducers are made from piezoelectric materials. These have an asymmetrical lattice of molecules that distorts when a mechanical force is applied to it. This distortion causes a reorientation of electric charges within the material, resulting in a relative displacement of positive and negative charges. The charge displacement induces surface charges on the material of opposite polarity between the two sides. By implanting electrodes into the surface of the material, these surface charges can be measured as an output voltage. For a rectangular block of material, the induced voltage is given by:

$$V = \frac{kFd}{A}$$

Where F is the applied force in g, A is the area of the material in mm, d is the thickness of the material and k is the piezoelectric constant. The polarity of the induced voltage depends on whether the material is compressed or stretched.

Where F is the applied force in g, A is the area of the material in mm, d is the thickness of the material and k is the piezoelectric constant. The polarity of the induced voltage depends on whether the material is compressed or stretched.

Materials exhibiting piezoelectric behaviour include natural ones such as quartz, synthetic ones such as lithiumsulphate andferroelectric ceramics such as barium titanate. The piezoelectric constant varies widely between different materials. Typical values of k are 2.3 for quartz and 140 for barium titanate. Applying equation (13.1) for a force of 1 g applied to a crystal of area 100 mm^2 and thickness 1 mm gives an output of 23 μV for quartz and 1.4 mV for barium titanate.

The piezoelectric principle is invertible, and therefore distortion in a piezoelectric material can be caused by applying a voltage to it. This is commonly used in ultrasonic transmitters, where the application of a sinusoidal voltage at a frequency in the ultra- sound range causes a sinusoidal variation in the thickness of the material and results in a sound wave being emitted at the chosen frequency. This is considered further in the section below on ultrasonic

transducers.

5.8 Hall-effect transducers

Basically, a Hall-effect sensor is a device that is used to measure the magnitude of a magnetic field. It consists of a conductor carrying a current that is aligned orthogonally with the magnetic field, as shown in Figure 13.4. This produces a transverse voltage difference across the device that is directly proportional to the magnetic field strength. For an excitation current I and magnetic field strength B, the output voltage is given by V D KIB, where K is known as the Hall constant
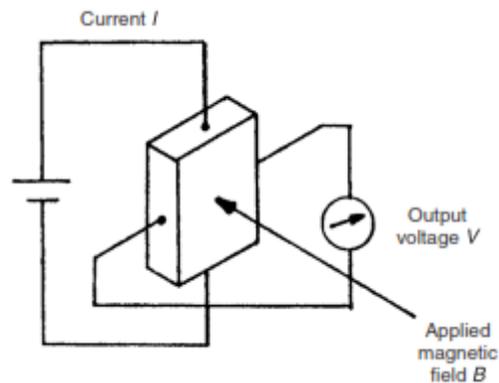
The conductor in Hall-effect sensors is usually made from a semiconductor material as opposed to a metal, because a larger voltage output is produced for a magnetic field of a given size. In one common use of the device as a proximity sensor, the magnetic field is provided by a permanent magnet that is built into the device. The magnitude of this field changes when the device becomes close to any ferrous metal object or boundary. The Hall Effect is also commonly used in keyboard pushbuttons, in which a magnet is attached underneath the button. When the button is depressed, the magnet moves past a Hall-effect sensor. The induced voltage is then converted by a trigger circuit into a digital output. Such pushbutton switches can operate at high frequencies without contact bounce.

5.9 DATA ACQUISITION SYSTEMS
Definition

Data acquisition is the process of real world physical conditions and conversion of the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition and data acquisition systems (abbreviated with the acronym **DAS**) typically involves the conversion of analog waveforms into digital values for processing.

The components of data acquisition systems include:

i) Sensors that convert physical parameters to electrical signals.

ii) Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.

iii) Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Diagram

Fundamental elements of data acquisition system

Explanation

- Data acquisition is the process of extracting, transforming, and transporting data from the source systems and external data sources to the data processing system to be displayed, analyzed, and stored.

- A data acquisition system (DAQ) typically consist of transducers for asserting and measuring electrical signals, signal conditioning logic to perform amplification, isolation, and filtering, and other hardware for receiving analog signals and providing them to a processing system, such as a personal computer.

- Data acquisition systems are used to perform a variety of functions, including laboratory research, process monitoring and control, data logging, analytical chemistry, tests and analysis of physical phenomena, and control of mechanical or electrical machinery.

- Data recorders are used in a wide variety of applications for imprinting various types of forms, and documents.

- Data collection systems or data loggers generally include memory chips or strip charts for electronic recording, probes or sensors which measure product environmental parameters and are connected to the data logger.

- Hand-held portable data collection systems permit in field data collection for up-to-date information processing.

Source

- Data acquisition begins with the physical phenomenon or physical property to be measured.

- Examples of this include temperature, light intensity, gas pressure, fluid flow, and force. Regardless of the type of physical property to be measured, the physical state that is to be measured must first be transformed into a unified form that can be sampled by a data acquisition system.

- The task of performing such transformations falls on devices called sensors.

- A sensor, which is a type of transducer, is a device that converts a physical property into a corresponding electrical signal (e.g., a voltage or current) or, in many cases, into

a corresponding electrical characteristic (e.g., resistance or capacitance) that can easily be converted to electrical signal.

- The ability of a data acquisition system to measure differing properties depends on having sensors that are suited to detect the various properties to be measured. There are specific sensors for many different applications.

- DAQ systems also employ various signal conditioning techniques to adequately modify various different electrical signals into voltage that can then be digitized using an Analog-to-digital converter (ADC).

Signals

- Signals may be digital (also called logic signals sometimes) or analog depending on the transducer used. Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used.
- The signal may need to be amplified, filtered or demodulated.
- Various other examples of signal conditioning might be bridge completion, providing current or voltage excitation to the sensor, isolation, and linearization. For transmission purposes, single ended analog signals, which are more susceptible to noise can be converted to differential signals. Once digitized, the signal can be encoded to reduce and correct transmission errors.

DAQ hardware

- DAQ hardware is what usually interfaces between the signal and a PC. It could be in the form of modules that can be connected to the computer's ports (parallel, serial, USB, etc.) or cards connected to slots (S-100 bus, Apple Bus, ISA, MCA, PCI, PCI-E, etc.) in the mother board.
- Usually the space on the back of a PCI card is too small for all the connections needed, so an external breakout box is required. The cable between this box and the PC can be expensive due to the many wires, and the required shielding
- DAQ cards often contain multiple components (multiplexer, ADC, DAC, TTL-IO, high speed timers, RAM). These are accessible via a bus by a microcontroller, which can run small programs.
- A controller is more flexible than a hard wired logic, yet cheaper than a CPU so that it is alright to block it with simple polling loops.
- The fixed connection with the PC allows for comfortable compilation and debugging. Using an external housing a modular design with slots in a bus can grow with the needs of the user.
- Not all DAQ hardware has to run permanently connected to a PC, for example intelligent stand-alone loggers and oscilloscopes, which can be operated from a PC, yet they can operate completely independent of the PC.

DAQ software

- DAQ software is needed in order for the DAQ hardware to work with a PC. The device driver performs low-level register writes and reads on the hardware, while exposing a standard API for developing user applications.
A standard API such as COMEDI allows the same user applications to run on
- different operating systems, e.g. a user application that runs on Windows will also run on Linux and BSD.

Advantages

- Reduced data redundancy
- Reduced updating errors and increased consistency
- Greater data integrity and independence from applications programs
- Improved data access to users through use of host and query languages
- Improved data security
- Reduced data entry, storage, and retrieval costs
- Facilitated development of new applications program
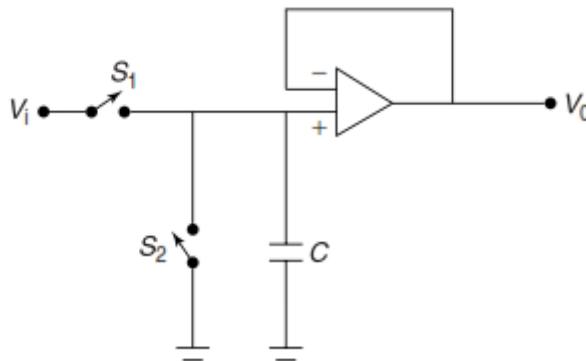
Disadvantages

- Database systems are complex, difficult, and time-consuming to design
- Substantial hardware and software start-up costs
- Damage to database affects virtually all applications programs
- Extensive conversion costs in moving form a file-based system to a database system
- Initial training required for all programmers and users

Applications

- Temperature measurement
- Recommended application software packages and necessary toolkit
- Prewritten Lab VIEW example code, available for download
- Sensor recommendations
- Video tutorials for hardware setup and software programming

5.10 Analogue-To-Digital Converters

Important factors in the design of an analogue-to-digital converter are the speed of conversion and the number of digital bits used to represent the analogue signal level. The minimum number of bits used in analogue-to-digital converters is eight.

The use of eight bits means that the analogue signal can be represented to a resolution of 1 part in 256 if the input signal is carefully scaled to make full use of the converter range. However, it is more common to use either 10 bit or 12 bit analogue-to-digital converters, which give resolutions respectively of 1 part in 1024 and 1 part in 4096. Several types of analogue-to-digital converter exist. These differ in the technique used to effect signal conversion, in operational speed, and in cost.

The simplest type of analogue-to-digital converter is the *counter analogue-to-digital converter*, as shown in Figure 5.23. This, like most types of analogue-to-digital converter, does not convert continuously, but in a stop-start mode triggered by special signals on the computer's control bus. At the start of each conversion cycle, the counter is set to zero. The digital counter value is converted to an analogue signal by a digital- to-analogue converter (a discussion of digital-to-analogue converters follows in the next section), and a comparator then compares this analogue counter value with the unknown analogue signal. The output of the comparator forms one of the inputs to an AND logic gate. The other input to the AND gate is a sequence of clock pulses. The comparator acts as a switch that can turn on and off the passage of pulses from the clock through the AND gate. The output of the AND gate is connected to the input of the digital counter. Following reset of the counter at the start of the conversion cycle, clock pulses are applied continuously to the counter through the AND gate, and the analogue signal at the output of the digital-to-analogue converter gradually increases in magnitude. At some point in time, this analogue signal becomes equal in magnitude to the unknown signal at the input to the comparator. The output of the comparator changes state in consequence, closing the AND gate and stopping further increments of the counter. At this point, the value held in the counter is a digital representation of the level of the unknown analogue signal.

output
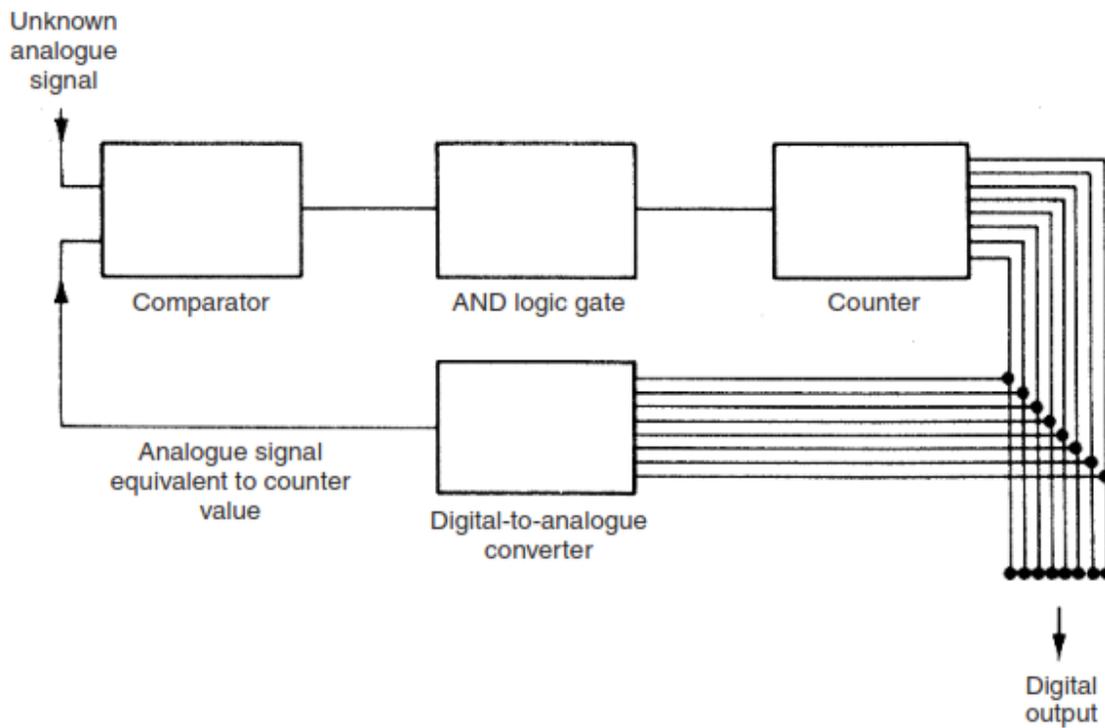
Counter analogue – digital converter circuit.

5.11 Digital-To-Analogue (D/A) Conversion

Digital-to-analogue conversion is much simpler to achieve than analogue-to-digital conversion and the cost of building the necessary hardware circuit is considerably less. It is required wherever a digitally processed signal has to be presented to an analogue control actuator or an analogue signal display device. A common form of digital-to-analogue converter is illustrated in Figure 5.24. This is shown with 8 bits for simplicity of explanation, although in practice 10 and 12 bit D/A converters are used more frequently. This form of D/A converter consists of a resistor-ladder network on the input to an operational amplifier

$$V_A = V_7 + \frac{V_6}{2} + \frac{V_5}{4} + \frac{V_4}{8} + \frac{V_3}{16} + \frac{V_2}{32} + \frac{V_1}{64} + \frac{V_0}{128}$$

V_0 to V_7 are set at either the reference voltage level V_{ref} or at zero volts according to whether an associated switch is open or closed. Each switch is controlled by the logic level of one of the bits 0–7 of the 8 bit binary signal being converted. A particular switch is open if the relevant binary bit has a value of 0 and closed if the value is 1. Consider for example a digital signal with binary value of 11010100. The values of V_7 to V_0 are therefore:

$$V_7 = V_6 = V_4 = V_2 = V_{ref}; \quad V_5 = V_3 = V_1 = V_0 = 0$$

The analogue output from the converter is then given by:

$$V_A = V_{ref} + \frac{V_{ref}}{2} + \frac{V_{ref}}{8} + \frac{V_{ref}}{32}$$
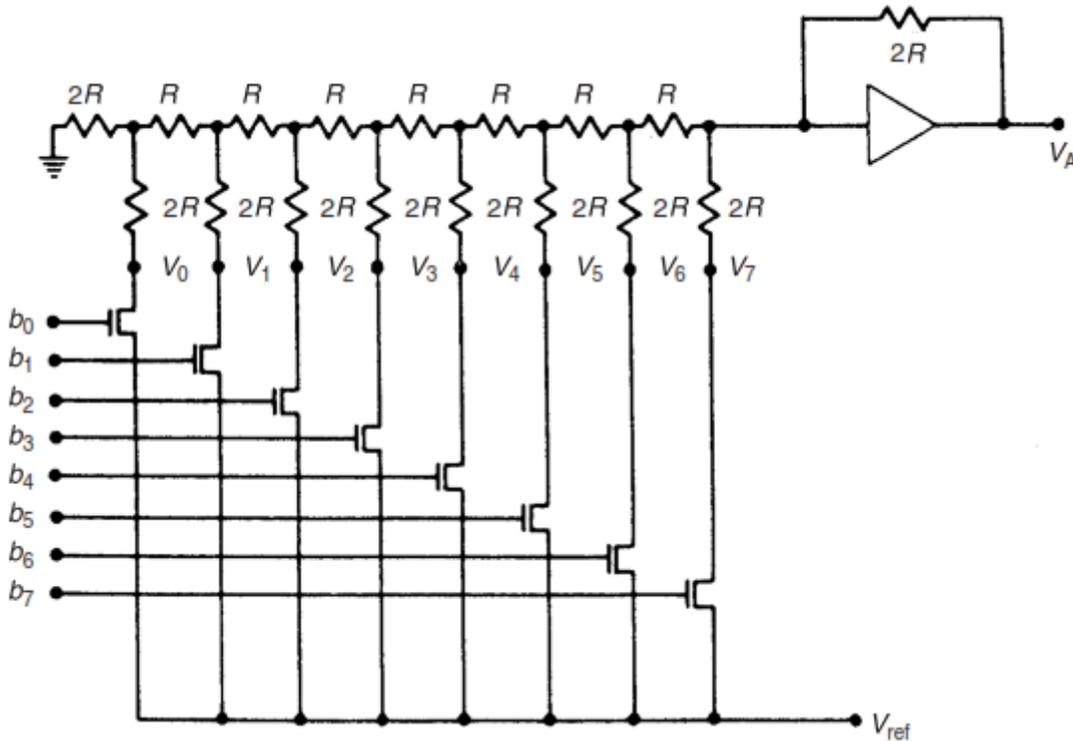
Common form of digital−analogue converter

5.12 Smart Sensors

A smart sensor is a sensor with local processing power that enables it to react to local conditions without having to refer back to a central controller. Smart sensors are usually at least twice as accurate as non-smart devices, have reduced maintenance costs and require less wiring to the site where they are used. In addition, long-term stability is improved, reducing the required calibration frequency.

The functions possessed by smart sensors vary widely, but consist of at least some of the following:

Remote calibration capability   Self-diagnosis of faults   Automatic calculation of measurement accuracy and compensation for random errors   Adjustment for measurement of non-linearity's to produce a linear output   Compensation for the loading effect of the measuring process on the measured system.

Calibration capability

Self-calibration is very simple in some cases. Sensors with an electrical output can use a known reference voltage level to carry out self-calibration. Also, load-cell types of sensor, which are used in weighing systems, can adjust the output reading to zero when there is no applied mass. In the case of other sensors, two methods of self-calibration are possible, use of a look-up table and an interpolation technique. Unfortunately, a *look-up table* requires a large memory capacity to store correction points. Also, a large amount of data has to be gathered from the sensor during calibration. In consequence, the interpolation calibration technique is preferable. This uses an interpolation method to calculate the correction required to any particular measurement and only requires a small matrix of calibration points (van der Horn, 1996).

Self-diagnosis of faults

Smart sensors perform self-diagnosis by monitoring internal signals for evidence of faults. Whilst it is difficult to achieve a sensor that can carry out self-diagnosis of all possible faults that might arise, it is often possible to make simple checks that detect many of the more common faults. One example of self-diagnosis in a sensor is measuring the sheath capacitance and resistance in insulated thermocouples to detect breakdown of the insulation. Usually, a specific code is generated to indicate each type of possible fault (e.g. a failing of insulation in a device).

One difficulty that often arises in self-diagnosis is in differentiating between normal measurement deviations and sensor faults. Some smart sensors overcome this by storing multiple measured values around a set-point, calculating minimum and maximum expected values for the measured quantity.

Uncertainty techniques can be applied to measure the impact of a sensor fault on measurement quality. This makes it possible in certain circumstances to continue to use a sensor after it has developed a fault. A scheme for generating a validity index has been proposed that indicates the validity and quality of a measurement from a sensor (Henry, 1995).

Automatic calculation of measurement accuracy and compensation for random errors

Many smart sensors can calculate measurement accuracy on-line by computing the Mean over a number of measurements and analyzing all factors affecting accuracy. This averaging process also serves to greatly reduce the magnitude of random measurement errors.

Adjustment for measurement non-linearities

In the case of sensors that have a non-linear relationship between the measured quantity and the sensor output, digital processing can convert the output to a linear form, providing that the nature of the non-linearity is known so that an equation describing it can be programmed into the sensor.
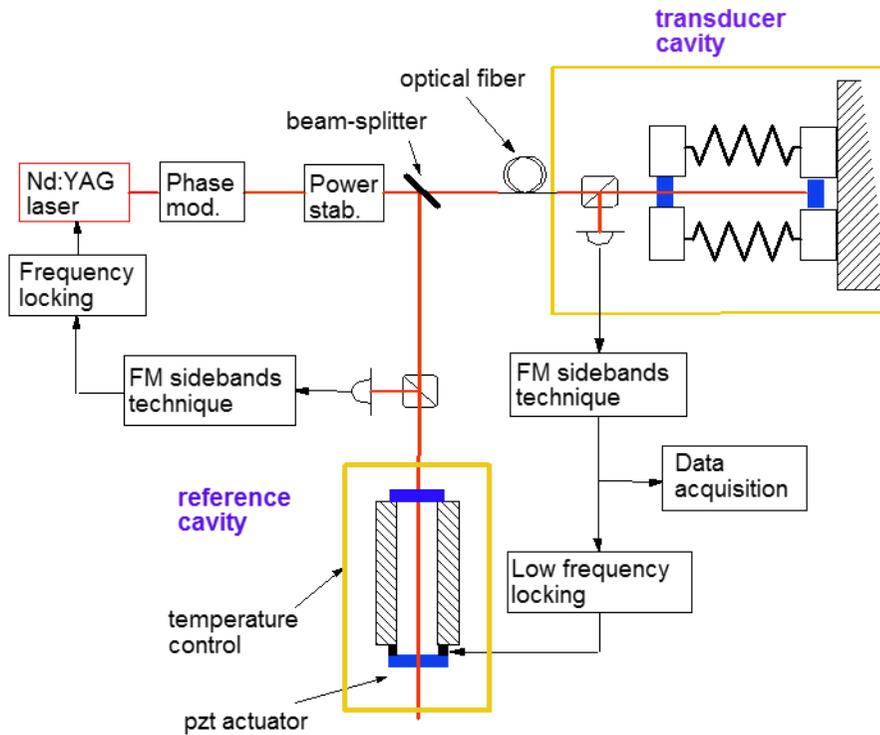
5.13 Optical Transducer

Transducer cavity:

A Fabry-Perot cavity between the bar and the resonant plate

Reference cavity:

A stable Fabry-Perot cavity acting as length reference

Laser source frequency locked to the reference cavity

General Architecture of smart sensor:

One can easily propose a general architecture of smart sensor from its definition, functions. From the definition of smart sensor it seems that it is similar to a data acquisition system, the only difference being the presence of complete system on a single silicon chip. In addition to this it has on–chip offset and temperature compensation. A general architecture of smart sensor consists of following important components:

- Sensing element/transduction element,
- Amplifier,
- Sample and hold,
- Analog multiplexer,
- Analog to digital converter (ADC),
- Offset and temperature compensation,
- Digital to analog converter (DAC),
- Memory,
- Serial communication and

- Processor

The generalized architecture of smart sensor is shown below:

GENERAL ARCHITECTURE OF SMART SENSOR
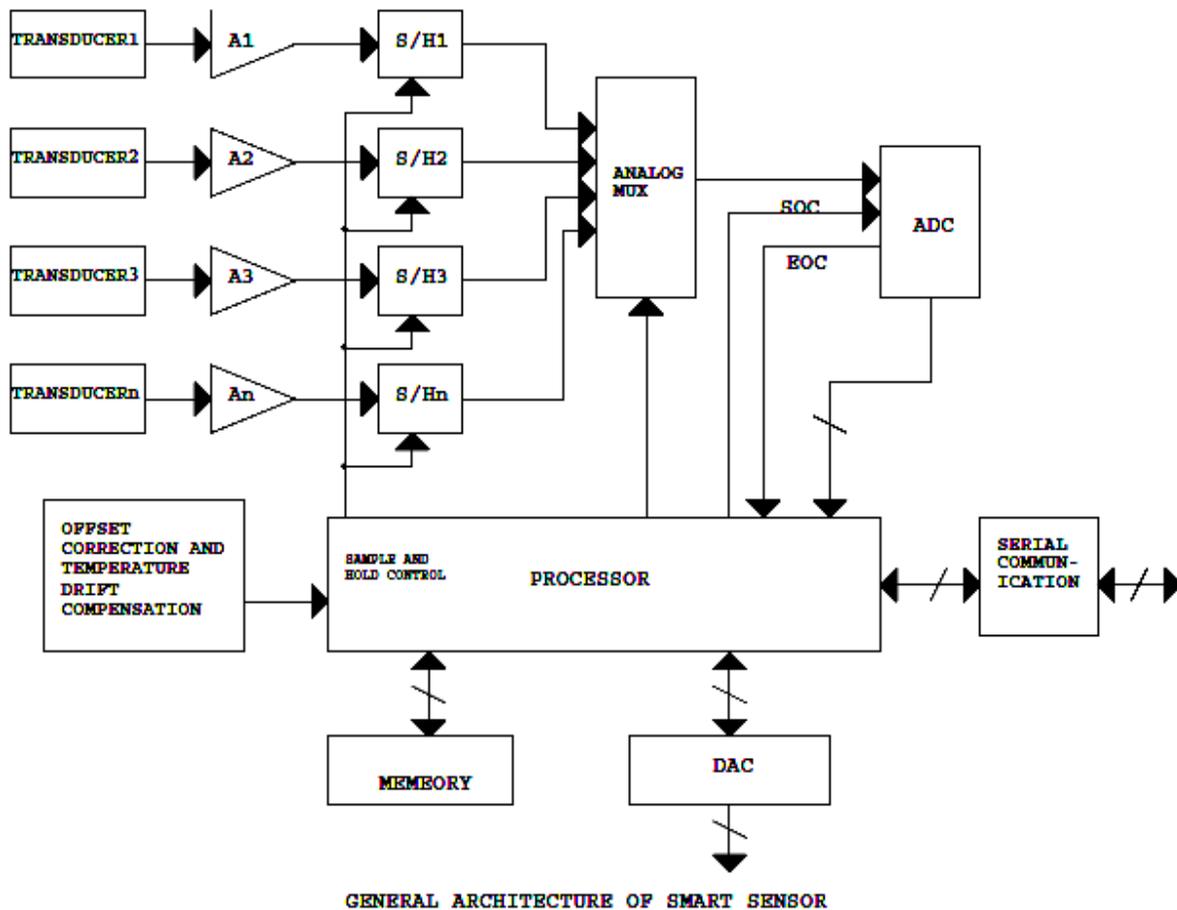
Architecture of smart sensor is shown. In the architecture shown A1, A2…An and S/H1, S/H2…S/Hn are the amplifiers and sample and hold circuit corresponding to different sensing element respectively. So as to get a digital form of an analog signal the analog signal is periodically sampled (its instantaneous value is acquired by circuit), and that constant value is held and is converted into a digital words. Any type of ADC must contain or proceeded by, a circuit that holds the voltage at the input to the ADC converter constant during the entire conversion time. Conversion times vary widely, from nanoseconds (for flash ADCs) to microseconds (successive approximation ADC) to hundreds of microseconds (for dual slope integrator ADCs). ADC starts conversion when it receives start of conversion signal (SOC) from the processor and after conversion is over it gives end of conversion signal to the processor. Outputs of all the sample and hold circuits are multiplexed together so that we can use a single ADC, which will reduce the cost of the chip. Offset compensation and correction comprises of an ADC for measuring a reference voltage and other for the zero. Dedicating two channels of the multiplexer and using only one ADC for whole system can avoid the addition of ADC for this. This is helpful in offset correction and zero compensation of gain due to temperature drifts of acquisition chain. In addition to this smart sensor also include internal memory so that we can store the data and program required.