ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE 3403 - MEASUREMENTS AND INSTRUMENTATION

IV SEMESTER

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UNIT I CONCEPTS OF MEASUREMENTS

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.

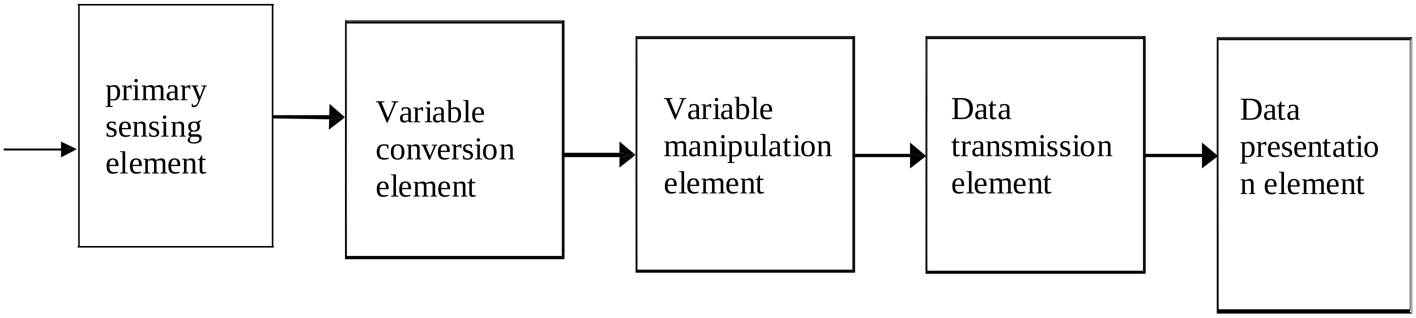
MEASURINGINSTRUMENT:

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 measurement 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 ‖ **signal conditioning'**
The term signal conditioning includes many other functions in addition to Variable conversion & Variable manipulation In fact the element that follows the primary sensing element 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 personnel 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

Accuracy:

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.

Precision:

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-

$$\left| \frac{X_n - \overline{X_n}}{\overline{X_n}} \right|$$

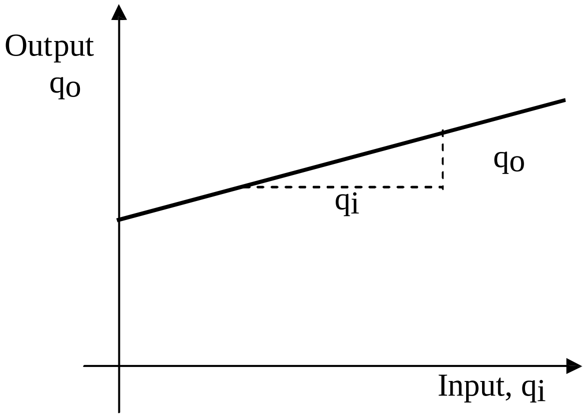
Where, P = precision

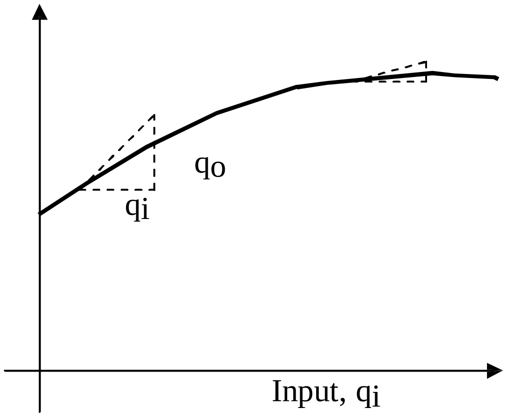
X_n = Value of n^{th} measurement

$\overline{X_n}$ = Average value the set of measurement values

Sensitivity:

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,





$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$= \frac{\text{ắqo}}{\text{ắqi}}$$

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.

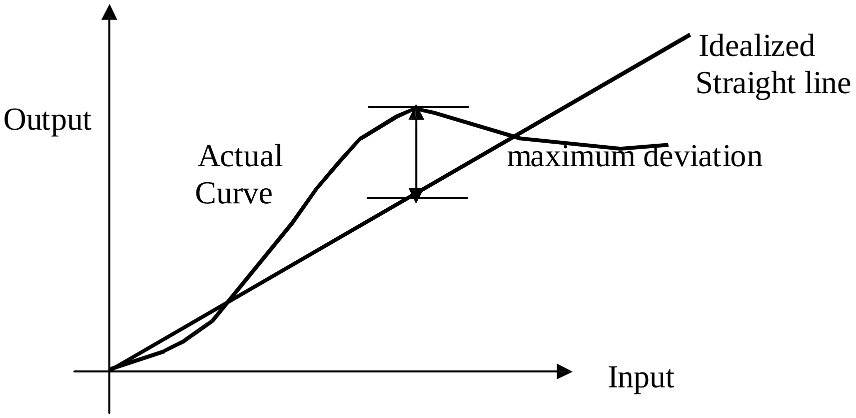
Inverse sensitivity or deflection factor = 1/ sensitivity

$$= \frac{\text{ắqi}}{\text{ắqo}}$$

Linearity:

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

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



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

<u>Reproducibility:</u>

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.

<u>Repeatability:</u>

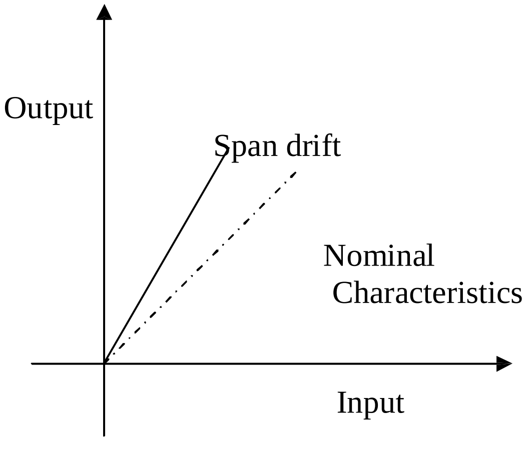
It is defined as the variation of scale reading & random in nature.

<u>Drift:</u>

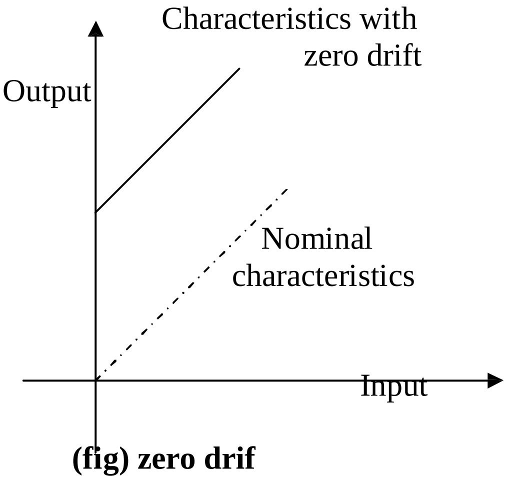
Drift may be classified into three categories:

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 gross errors is not possible but one can minimize them by the following ways:

Taking great care while taking the reading, recording the reading & 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 and applying the 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 example of such loading effect error is connecting a well calibrated volt meter across the two points of high resistance circuit. The same volt meter connected in a low resistance circuit gives accurate reading.

Waystominimizethiserror:

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

Environmentalerrors:

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.

Waystominimizethiserror:

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 fields can be minimized by using the magnetic or electro static shields or screens
v) Using the equipment which is immune to such environmental effects.

Observationalerrors:

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.

Waystominimizethiserror

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 the instrument not responding fast enough to follow the changes in the variable to be measured.

Randomerrors:

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.

Waystominimizethiserror

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.

Arithmeticmean&median:

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 ofµ Q measurements X1, X2, X3.Xn written down in the ascending order of magnitudes, the median value is given by,

Xmedian=X (n+1)/2

Averagedeviation:

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

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

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

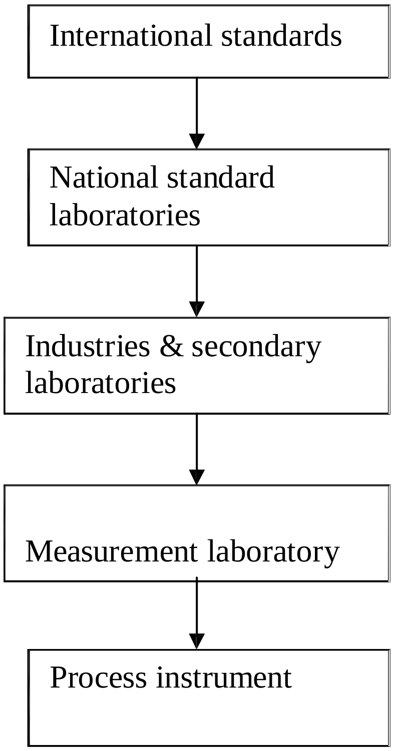
As mentioned above, the primary standards are not available for use outside the national laboratories.

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.



UNIT II MEASUREMENT OF PARAMETERS IN ELECTRICAL SYSTEMS

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.

1.2Ammeters & 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

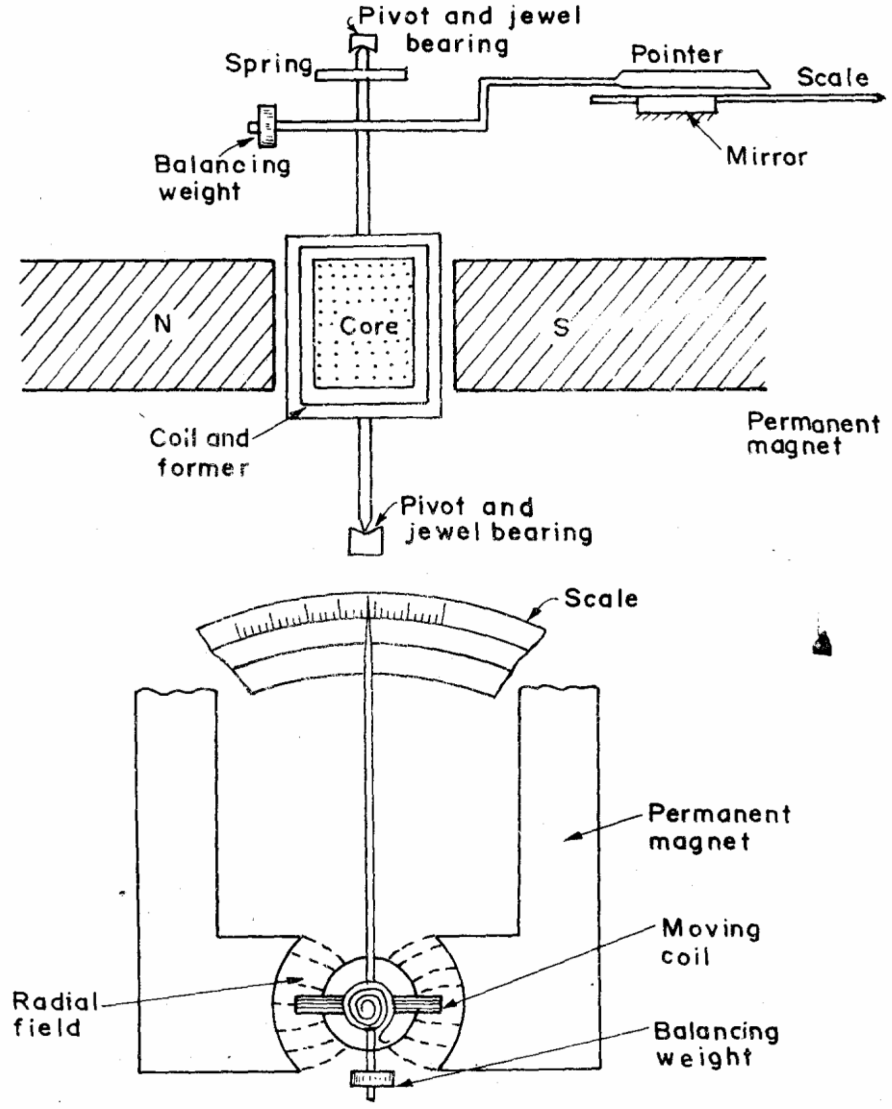
The main types of instruments used as an ammeters and voltmeters are

(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

- The constructional features of this instrument are shown in Fig.
- The moving coil is wound with many turns of enameled or silk covered copper wire.
- The coil is mounted on a rectangular aluminium former which is pivoted on jewelled bearings.
- The coils move freely in the field of a permanent magnet.
- Most voltmeter coils are wound on metal frames to provide the required electro-magnetic damping.
- Most ammeter coils, however, are wound on non-magnetic formers, because coil turns are effectively shorted by the ammeter shunt.
- The coil itself, therefore, provides electro magnetic damping.

Magnet Systems

- Old style magnet system consisted of relatively long U shaped permanent magnets having soft iron pole pieces.
- Owing to development of materials like Alcomax and Alnico, which have a high co-ercive force, it is possible to use smaller magnet lengths and high field intensities.
- The flux densities used in PMIMC instruments vary from 0.1 Wb/m to 1 Wb/m.

Control

- When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs.
- These springs also serve to lead current in and out of the coil. The control torque is provided by the ribbon suspension as shown.
- This method is comparatively new and is claimed to be advantageous as it eliminates bearing friction.

Damping

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

Pointer and Scale

- The pointer is carried by the spindle and moves over a graduated scale.
- The pointer is of light-weight construction and, apart from those used in some inexpensive instruments has the section over the scale twisted to form a fine blade.
- This helps to reduce parallax errors in the reading of the scale. When the coil is supported between two jewel bearings the control torque is provided by two phosphor bronze hair springs.
- 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 $GI = K\theta$

$\therefore$ 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

- Weakening of permanent magnets due to ageing at temperature effects.
- Weakening of springs due to ageing and temperature effects.
- Change of resistance of the moving coil with temperature.

Advantages and Disadvantages of PMMC Instruments

The main advantages of PMMC instruments are

- The scale is uniformly divided.
- The power consumption is very low
- 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.
- A single instrument may be used for many different current and voltage ranges by using different values for shunts and multipliers.
- 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.
- Self-shielding magnets make the core magnet mechanism particularly useful in aircraft and aerospace applications.

The chief disadvantages are

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

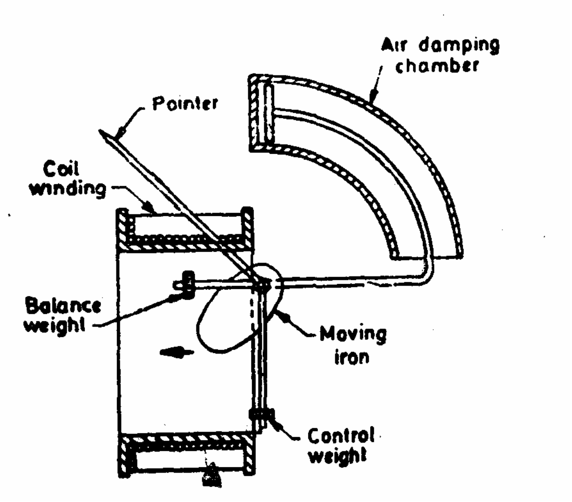
Moving Iron Instruments

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.

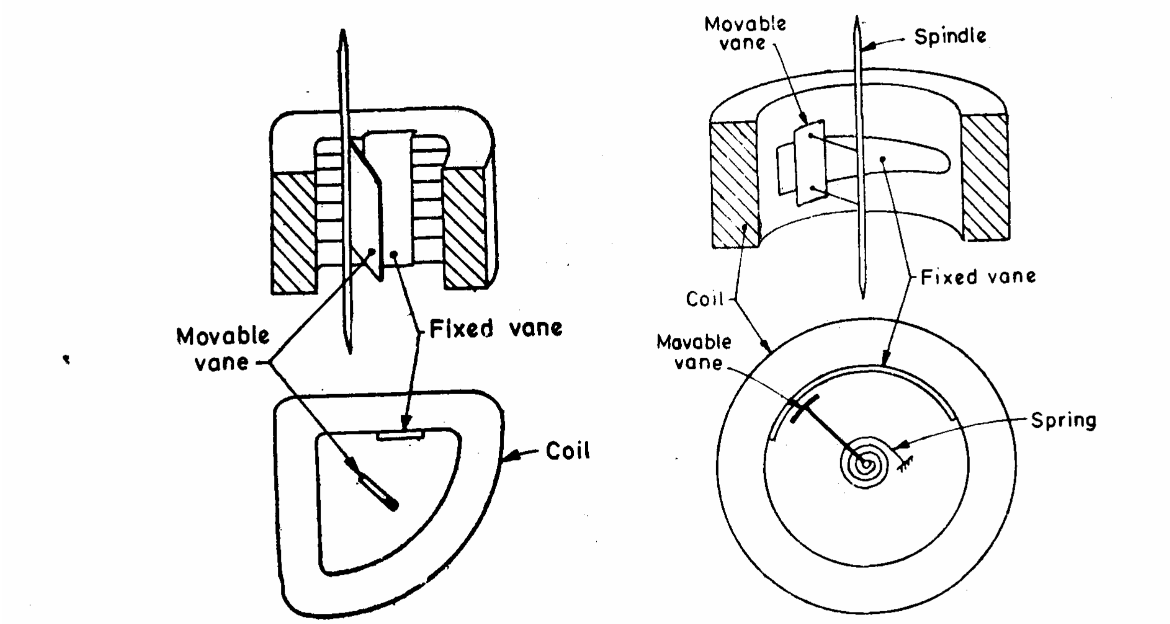
Repulsion Type

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.



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

(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 considering the energy relations when there is a small increment in current supplied to the instrument. When this happens there will be a small deflection dş a mechanical work will be done. Let Td be the deflecting torque.

Mechanical work done = Td. dş

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 ş. If the current is increased by di then the deflection changes by d ş and the inductance by dL. In order to affect an 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 $ILdI + \frac{1}{2} I^2 d$

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

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

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 K = control spring constant ; Nm/rad, θ = deflection ; rad.

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

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

Hence the deflection is proportional to square of the rms value of the operating current. The deflecting torque is, therefore, unidirectional (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

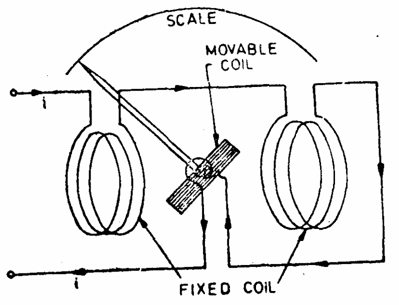
Advantages & Disadvantages

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.

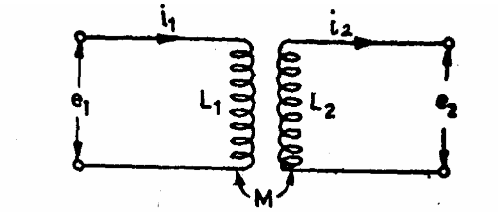
A spirit level is also provided to ensure proper leveling.

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

$$= i_1L_1di_1 + i_1^2dL_1 + i_1i_2dM + i_1Mdi_2 + i_2L_2di_2 + i_2^2dL_2 + i_1i_2dM + i_2Mdi_1$$

Energy stored in the magnetic field $= \frac{1}{2}i_1^2L_1 + \frac{1}{2}i_2^2L_2 + i_1i_2M$

Change in energy stored $= d(\frac{1}{2}i_1^2L_1 + \frac{1}{2}i_2^2L_2 + i_1i_2M)$

$$= i_1L_1di_1 + (i_1^2/2)dL_1 + i_2L_2di_2 + (i_2^2/2)dL_2 + i_1Mdi_2 + i_2Mdi_1 + i_1i_2dM$$

From principle of conservation of energy,

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

$\therefore$ **Mechanical energy** $= \frac{1}{2}i_1^2dL_1 + \frac{1}{2}i_2^2dL_2 + i_1i_2dM.$

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

$$T_id\theta = i_1i_2dM \text{ or } T_i = i_1i_2\, dM/d\theta$$

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

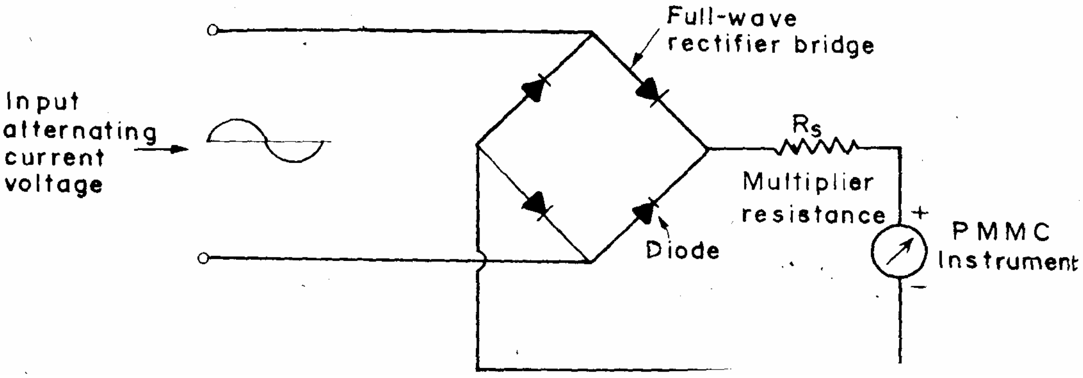
(vi) They have a non-uniform scale.

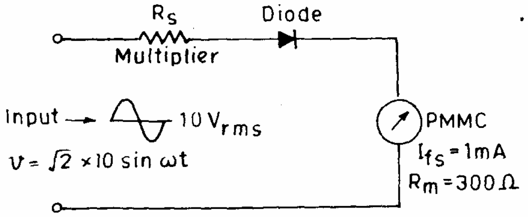
Rectifier Type Instruments

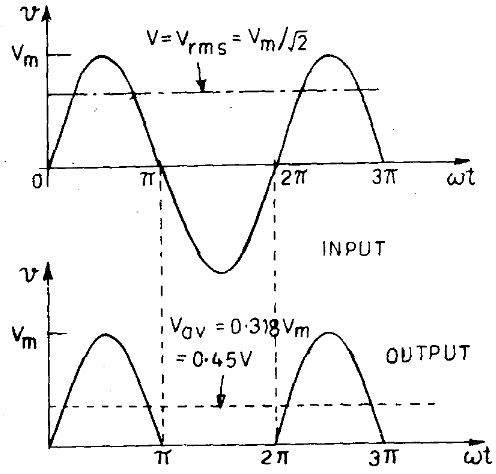
Rectifier type instruments are used for measurement of ac. voltages and currents by employing a rectifier element which converts a.c. to a unidirectional d.c. and then using a meter responsive to d.c. to indicate the value of rectified a.c.

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.







(Fig) voltmeter using full wave rectifier

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

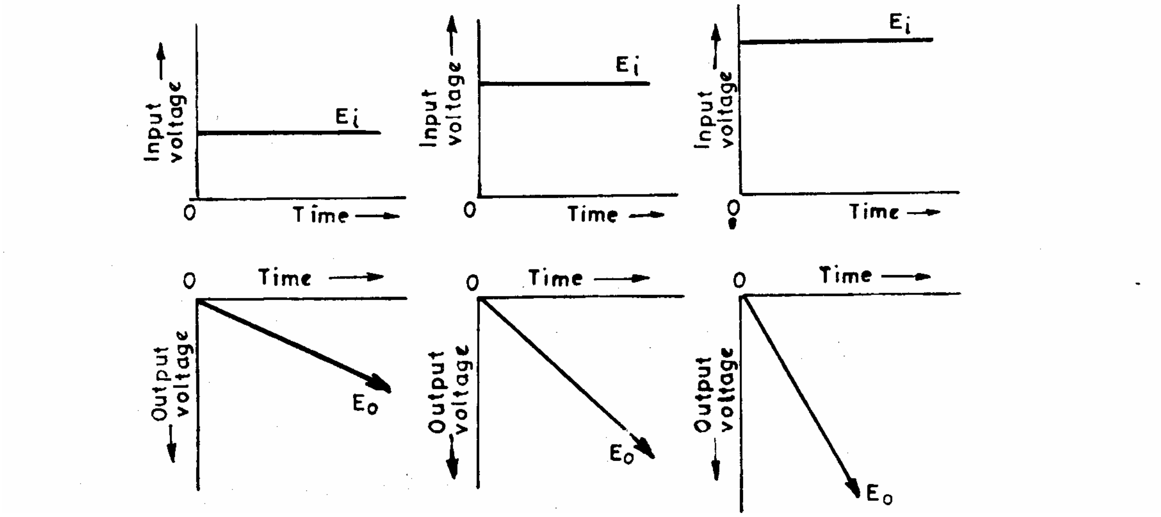
The operating principle of a ramp type digital voltmeter is to measure the time that a linear ramp voltage takes to change from level of input voltage to zero voltage (or vice versa).This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits 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.

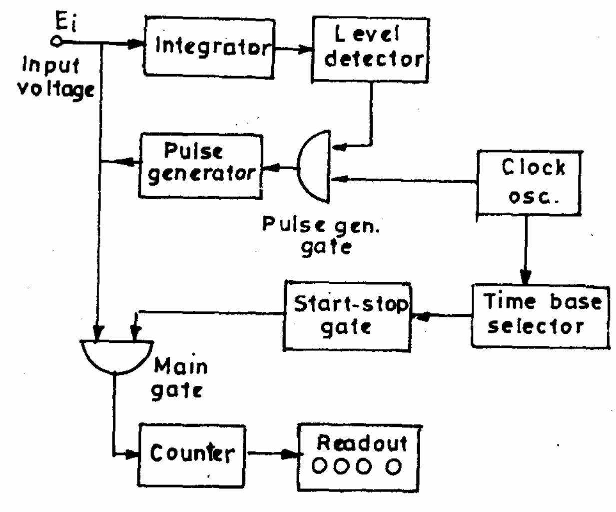
The heart of this technique is the operational amplifier acting as an Integrator.

Output voltage of integrator E = -Ei / 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



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.

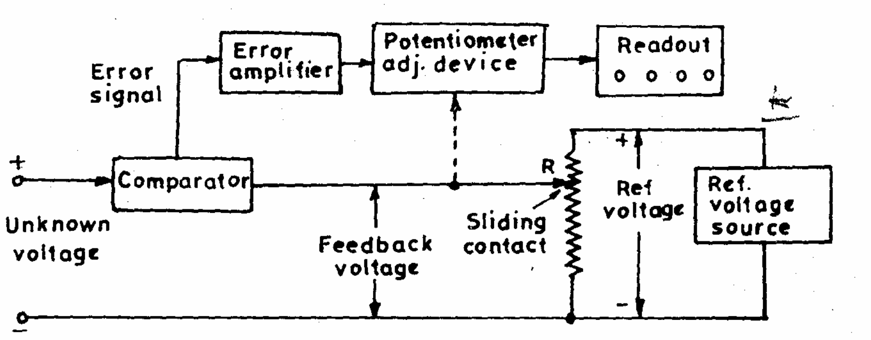
The potentiometer setting is changed to obtain balance (i.e. null conditions).

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 contact 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.

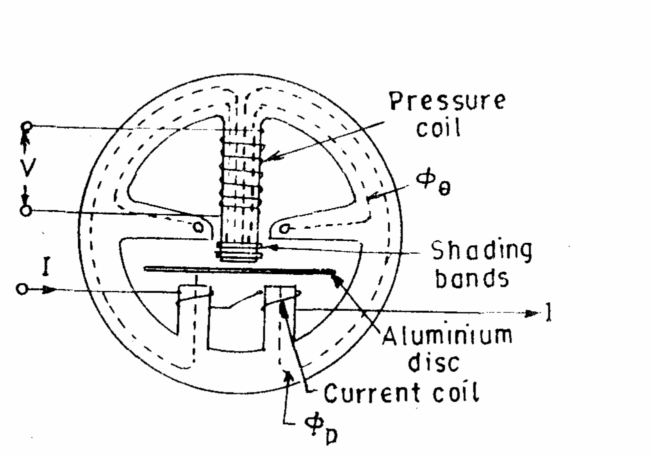
Moving System

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.

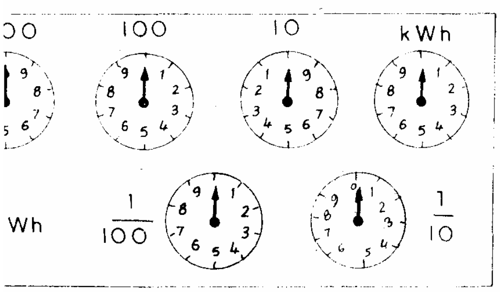


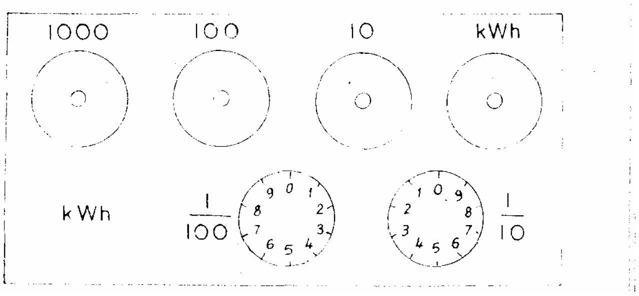
(Fig) single phase energy meter

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.

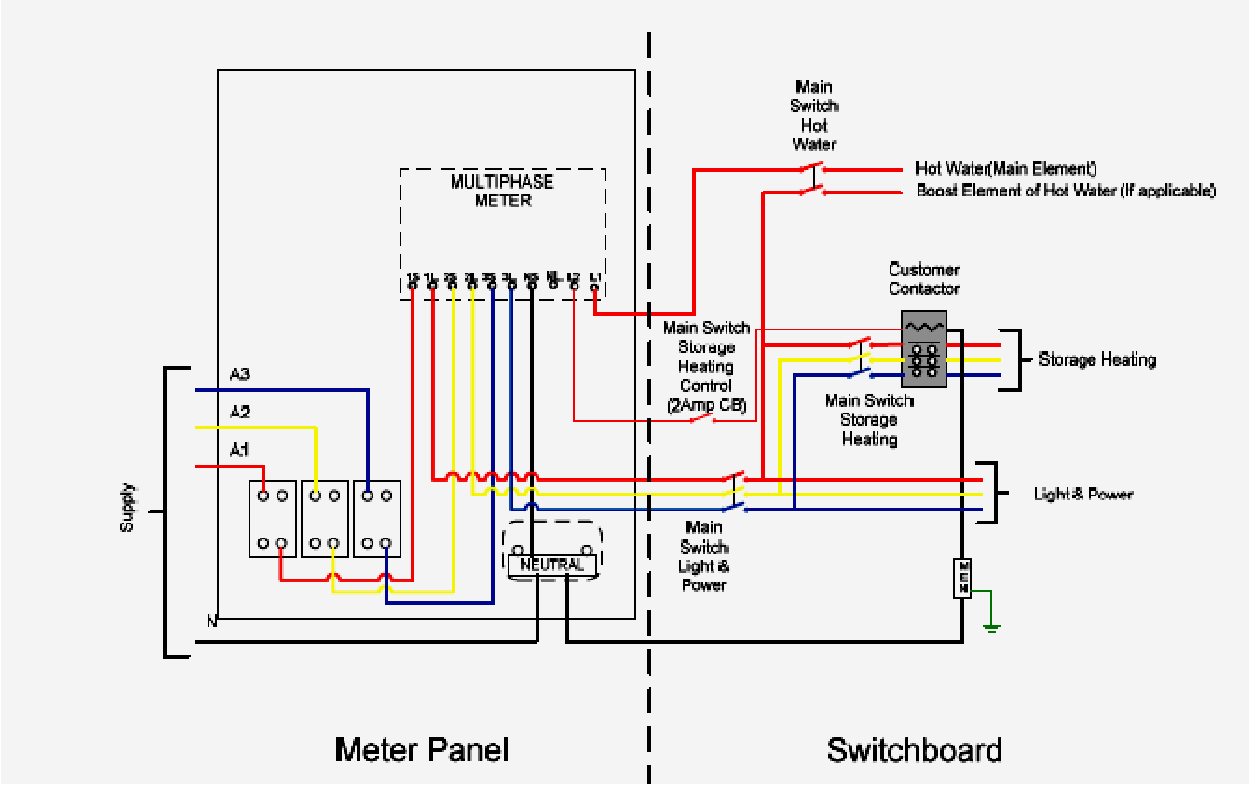
(ii) Incorrect phase angles.

(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



- 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

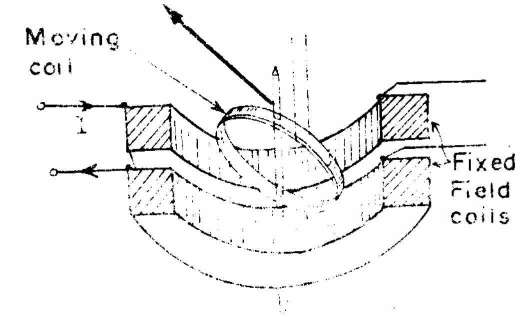
Fixed Coils

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

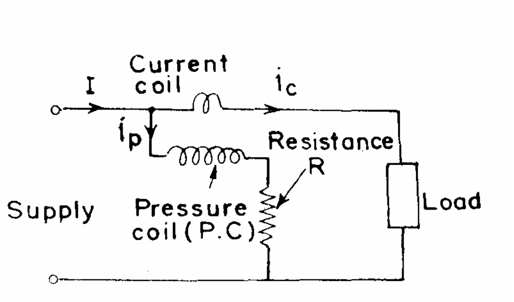
Damping

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 2At).

Average deflecting torque

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

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

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

Controlling torque exerted by springs Tc= Kș
Where, K = spring constant; ș= 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.

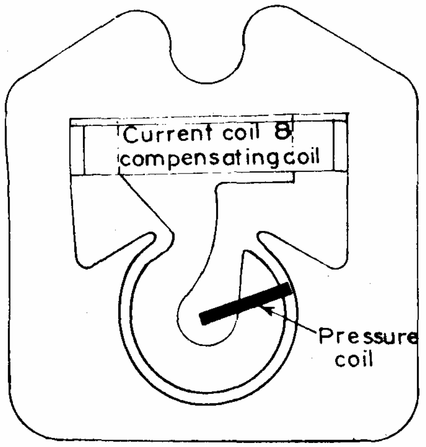
The fixed coil is wound on a laminated core having pole pieces designed to give a uniform radial field throughout the air gap.

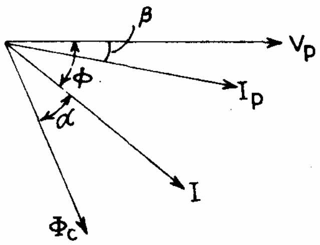
The moving coil is asymmetrically pivoted and is placed over a hook shaped pole piece.

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.

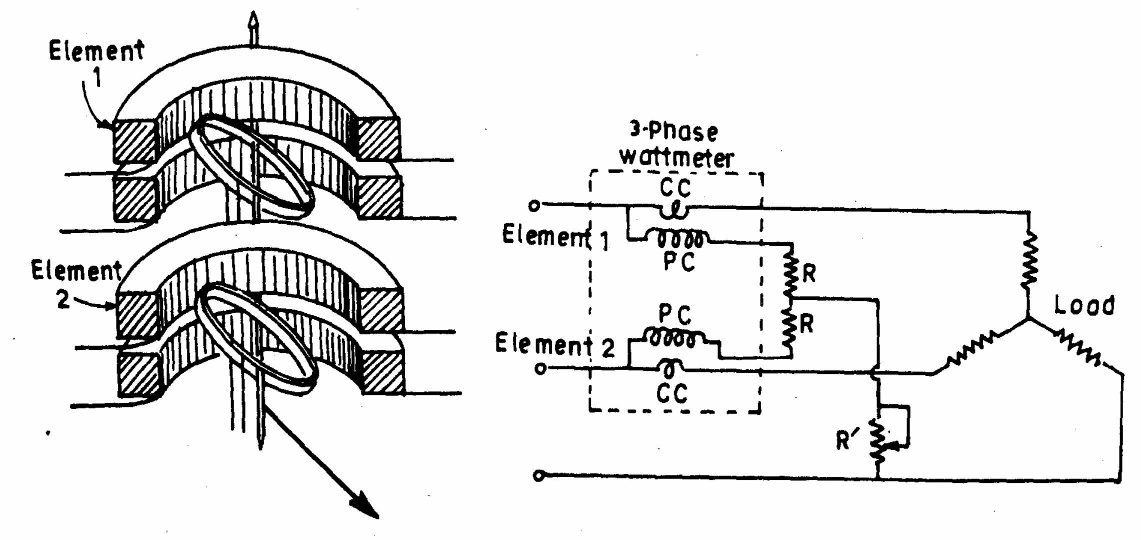
The torque on each element is proportional to the power being measured by it.

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.



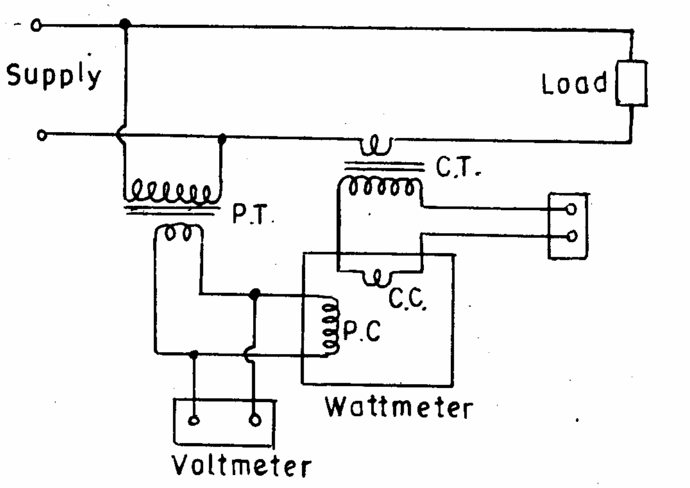
(fig) three phase wattmeter

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.

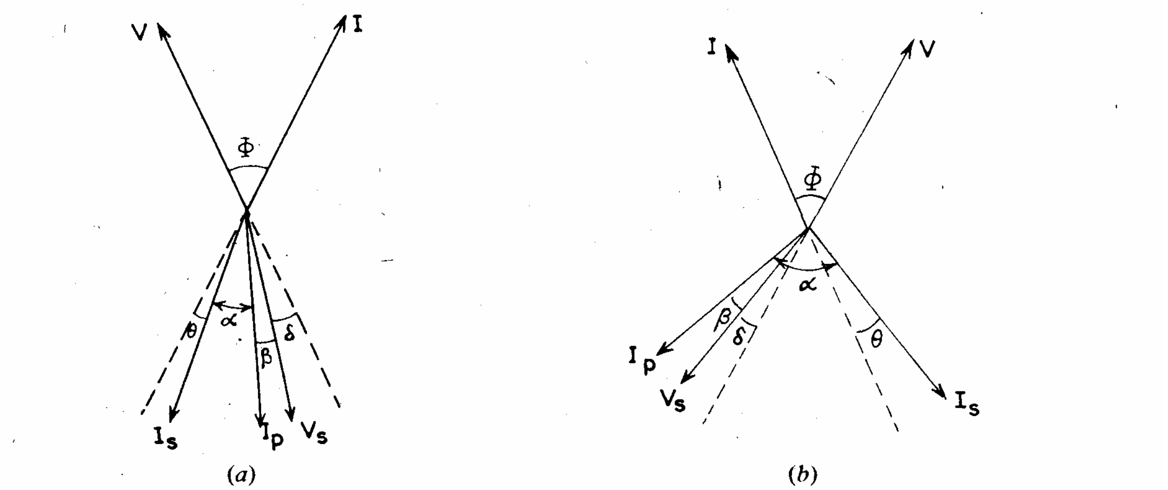


The errors in good modem instrument transformers are small and may be ignored for many purposes.

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.



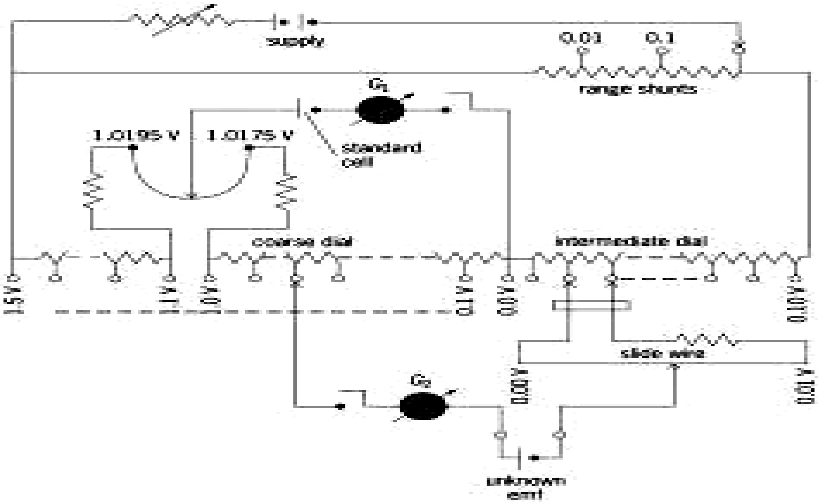
(a) (b)

UNIT III AC/DC BRIDGES AND INSTRUMENTATION AMPLIFIERS

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 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.

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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

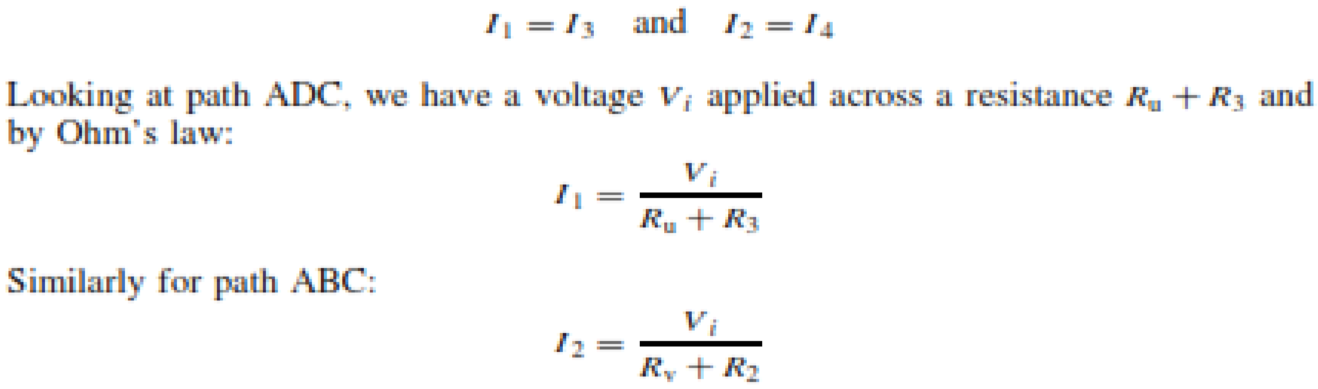
Bridge circuits are used very commonly as a variable conversion element in measurement systems and produce an output in the form of a voltage level that changes as the measured physical quantity changes. They provide an accurate method of measuring resistance, inductance and capacitance values, and enable 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:

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



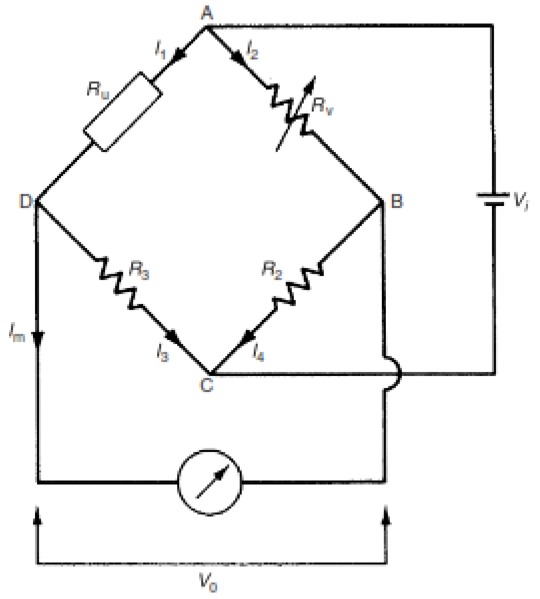
$$I_1 = I_3 \quad \text{and} \quad I_2 = I_4$$

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:

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

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

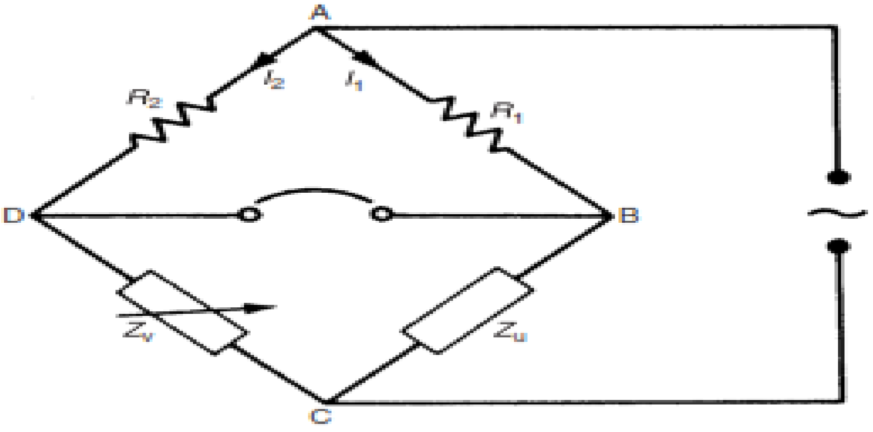
Bridges with a.c. excitation are used to measure unknown impedances. As for d.c. bridges, both null and deflection types exist, with null types being generally reserved for calibration duties.

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.

$$I_1R_1 = I_2R_2; \quad I_1Z_u = I_2Z_v$$

$$Z_u = \frac{Z_vR_1}{R_2}$$



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

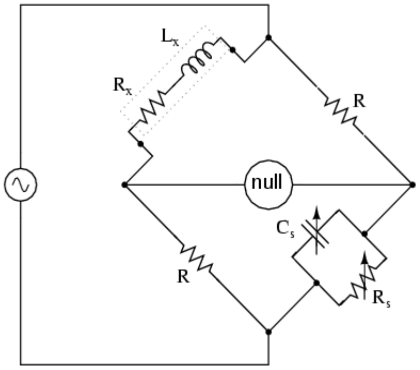


Figure 1.7.1. Maxwell Bridge

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

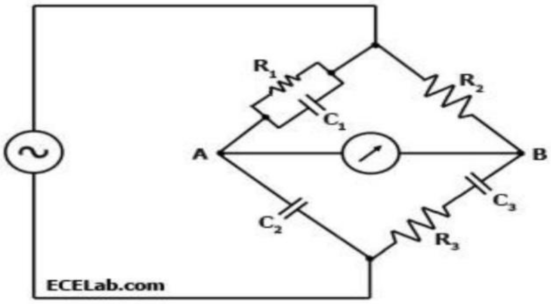


Figure 1.7.2. Schering Bridge

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.

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

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

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

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

- 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,

so $C2/C3 = R2/R1$ or $C3 = R1C2 / R2$.

- 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

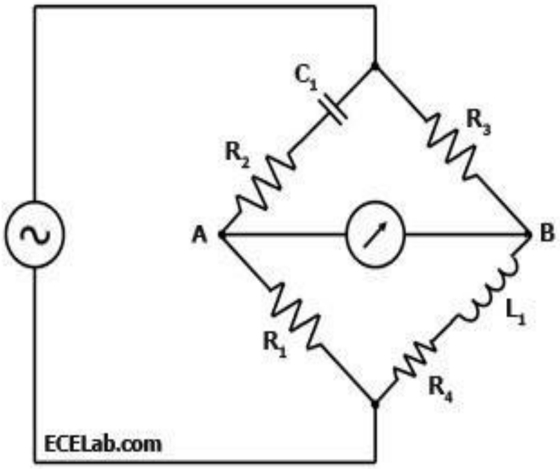


Figure 1.7.3. Hay Bridge

- 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
  $2\pi fL1R2 = R4/2\pi fC1$, 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

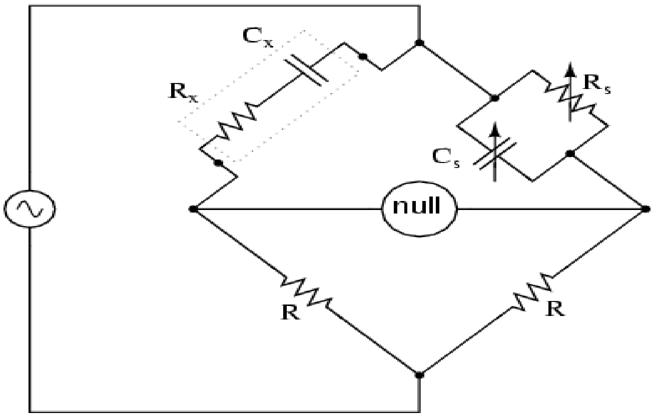


Figure 1.7.4 Wein bridge

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:

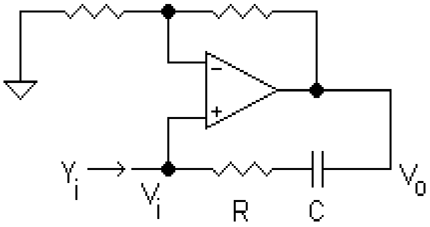


Figure 1.7.4 Input analysis

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:
- And the input admittance is defined as:
- Input admittance can be rewritten as:
- 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.

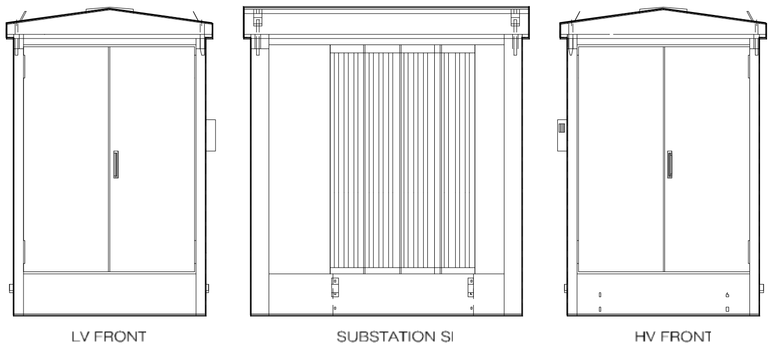
We would in particular stress the importance of care in:

- 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



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

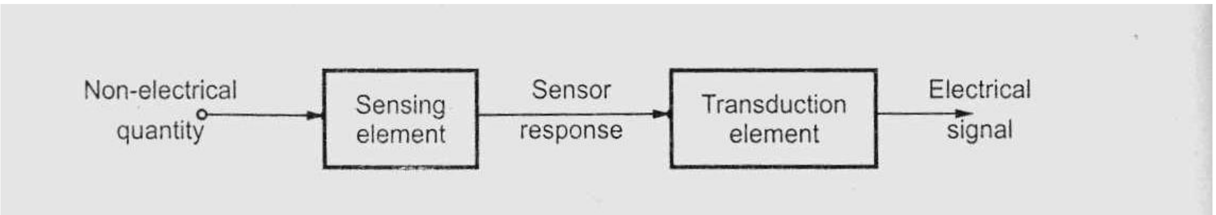
After the Package Compact Substation has been found to be in good condition and the protective equipment is operational, the substation may be connected to the network. However, it is recommended that the transformer to be left to settle for 1 or 2 days after installation so those air bubbles in the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

UNIT IV TRANSDUCERS FOR MEASUREMENTS OF NON-ELECTRICAL PARAMETERS

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

4.1 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

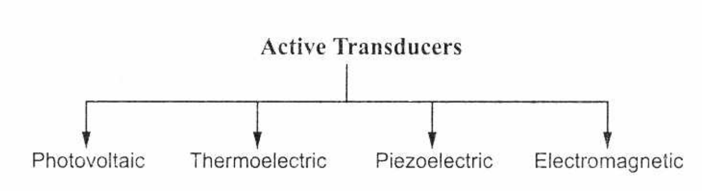
- As active and passive transducer
- According to transduction principle
- As analog and digital transducer
- As primary and secondary transducer
- As transducer and inverse transducer

Active and Passive Transducer

Active Transducers

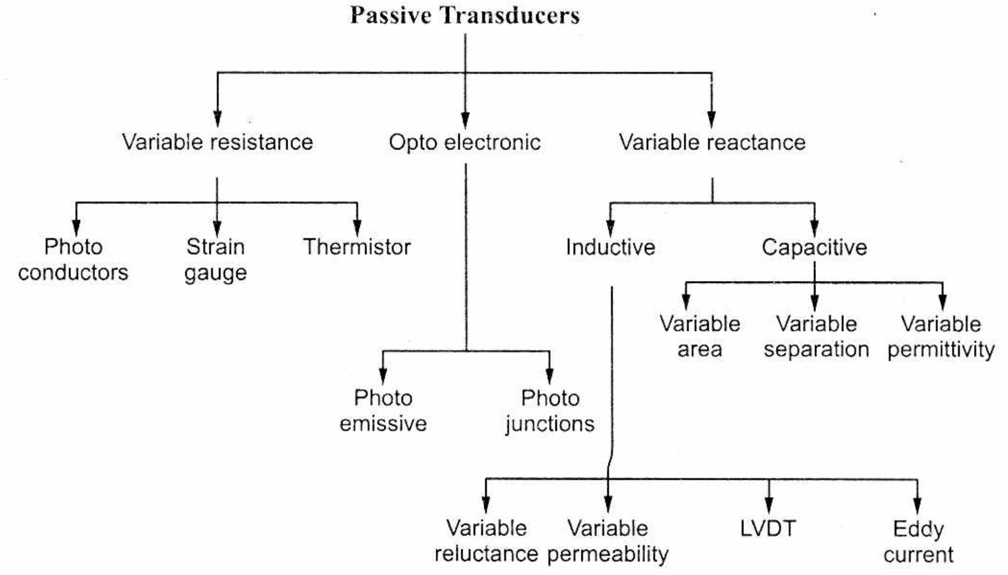
- Ø Active transducers are self-generating type of transducers.
- Ø These transducers develop an electrical parameter (i.e. voltage or current) which is proportional to the quantity under measurement.
- Ø These transducers do not require any external source or power for their operation.

Ø They can be subdivided into the following commonly used types



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.



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

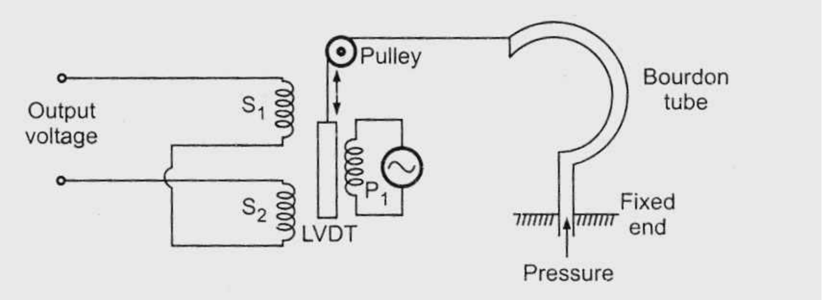
which is a continuous function of time.

Digital Transducers

- Digital transducers produce an electrical output in the form of pulses which forms an unique code.
- Unique code is generated for each discrete value sensed.

Primary or Secondary

- Some transducers consist of mechanical device along with the electrical device.
  - In such transducers mechanical device acts as a primary transducer and converts physical quantity into mechanical signal.
- The electrical device then converts mechanical signal produced by primary transducer into an electrical signal.
- Therefore, electrical device acts as a secondary transducer.
- 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

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

- The electrical transducer is sometimes less reliable than mechanical type because of the ageing and drift of the active components.
- Also, the sensing elements and the associated signal processing circuitry are comparatively expensive.
- With the use of better materials, improved technology and circuitry, the range of accuracy and stability have been increased for electrical transducers.
- 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.

4.2 Transducer Selection Factors

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

4.3 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.

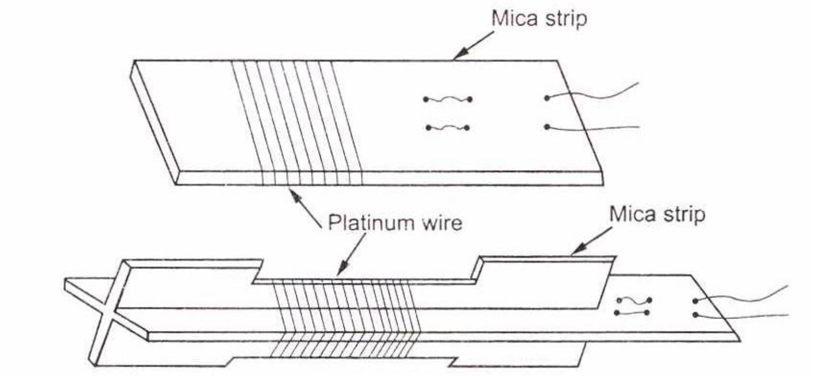
One of these effects can be employed for temperature measurement purposes. Electrical methods are the most convenient and accurate methods of temperature measurement. These methods are based on change in resistance with temperature and generation of thermal e.m.f. The change in resistance with temperature 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

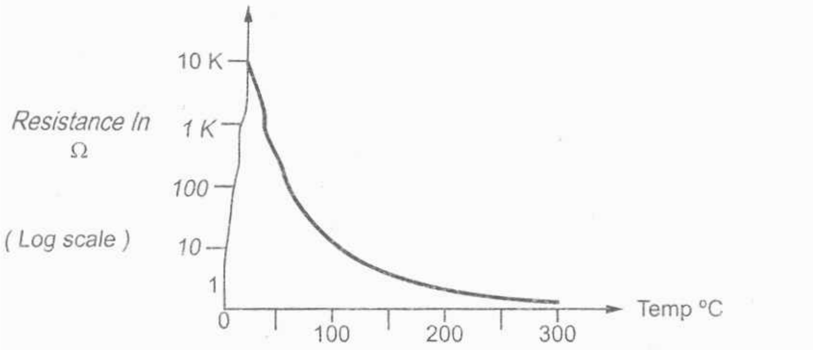
1. A bridge circuit with external power source is necessary for their operation.
2. They are comparatively costly.

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.

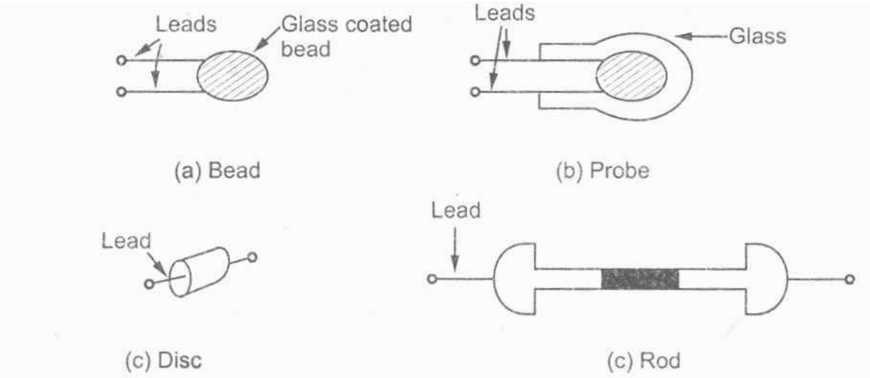


Construction of Thermistor

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.



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.

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

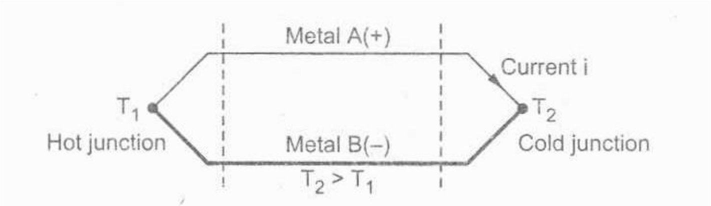
1. The thermistors relatively large resistance change per degree change in temperature [known as sensitivity] makes it useful as temperature transducer.
2. The high sensitivity, together with the relatively high thermistor resistance that may be selected [e.g. 100k .], makes the thermistor ideal for 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.

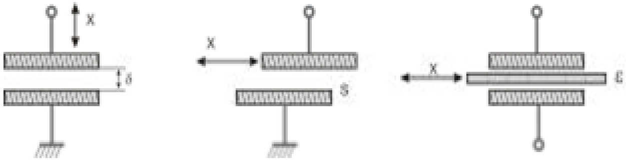
4.4 Capacitive Transducers

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

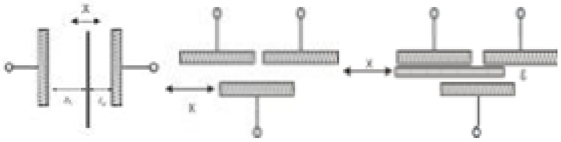
$$C=\varepsilon_0 \varepsilon s/d$$

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

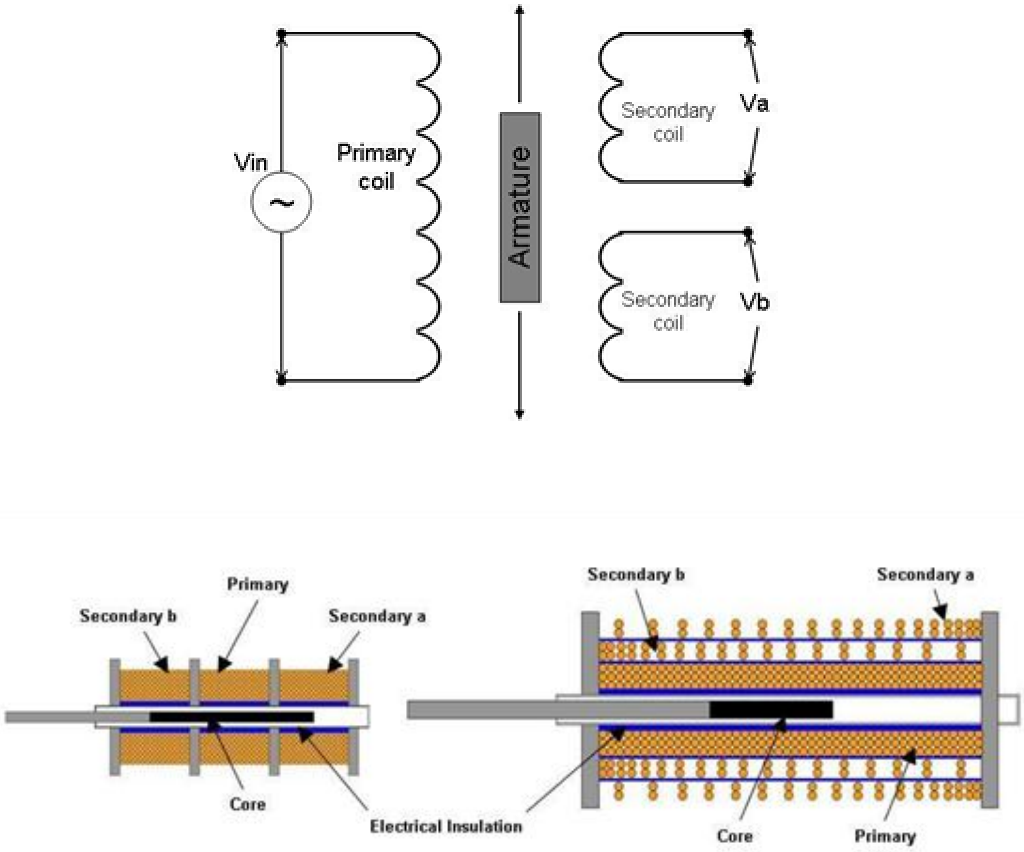
Application of capacitive transducers

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.

4.5 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.

4.6 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

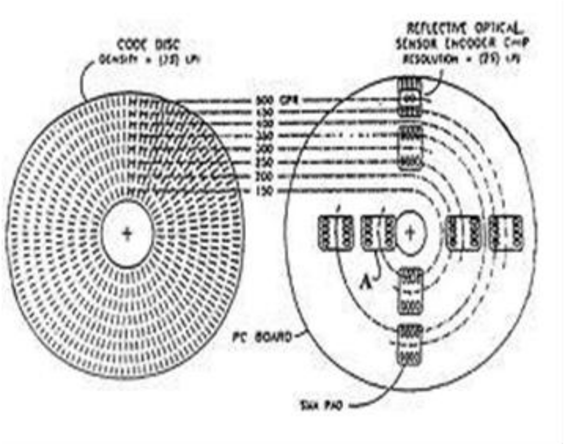
Shaft Encoders:

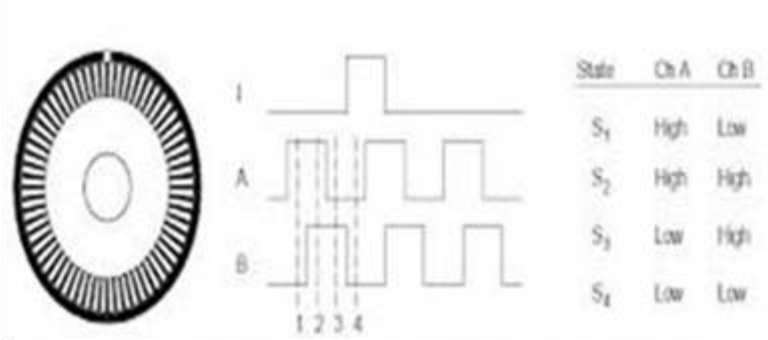
An encoder is a device that provides a coded reading of a measurement. A Shaft encoders can be one of the encoder that provide digital output measurements of angular position and velocity. This shaft encoders are excessively applicable in robotics, machine tools, mirror positioning systems, rotating 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

4.7 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.

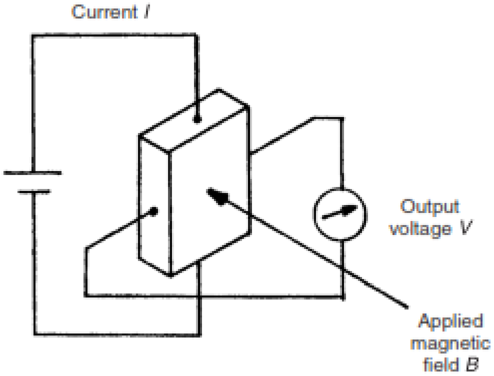
Where **F** is the applied force in g, A is the area of the material in mm, d is the thickness of the material and k is the piezoelectric constant. The polarity of the induced voltage depends on whether the material is compressed or stretched.

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.

4.8 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.

4.9 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.

4.10 Optical Transducer

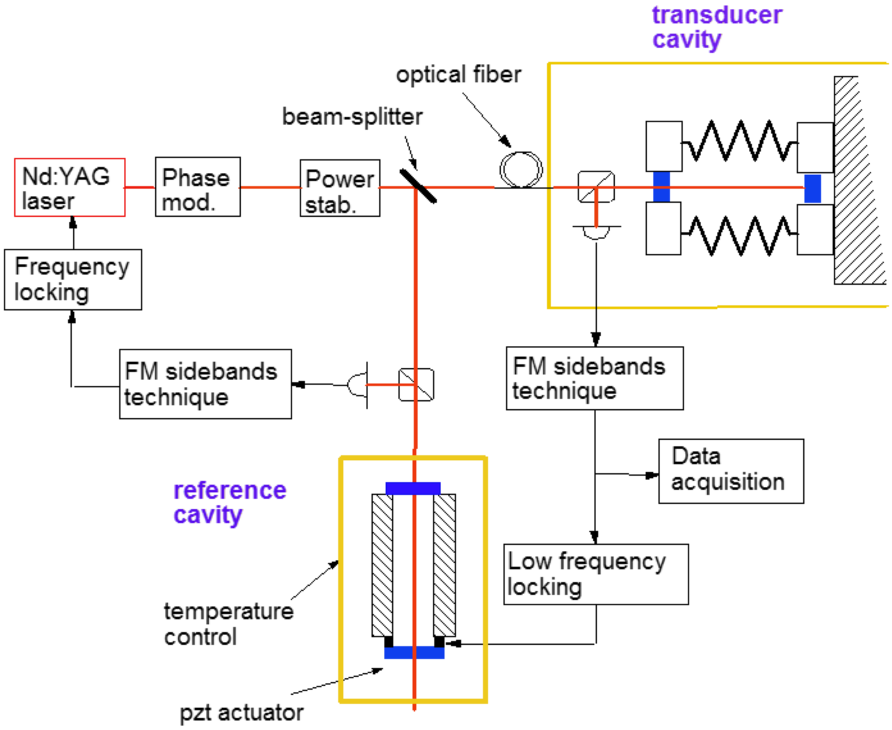
Transducer cavity:

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



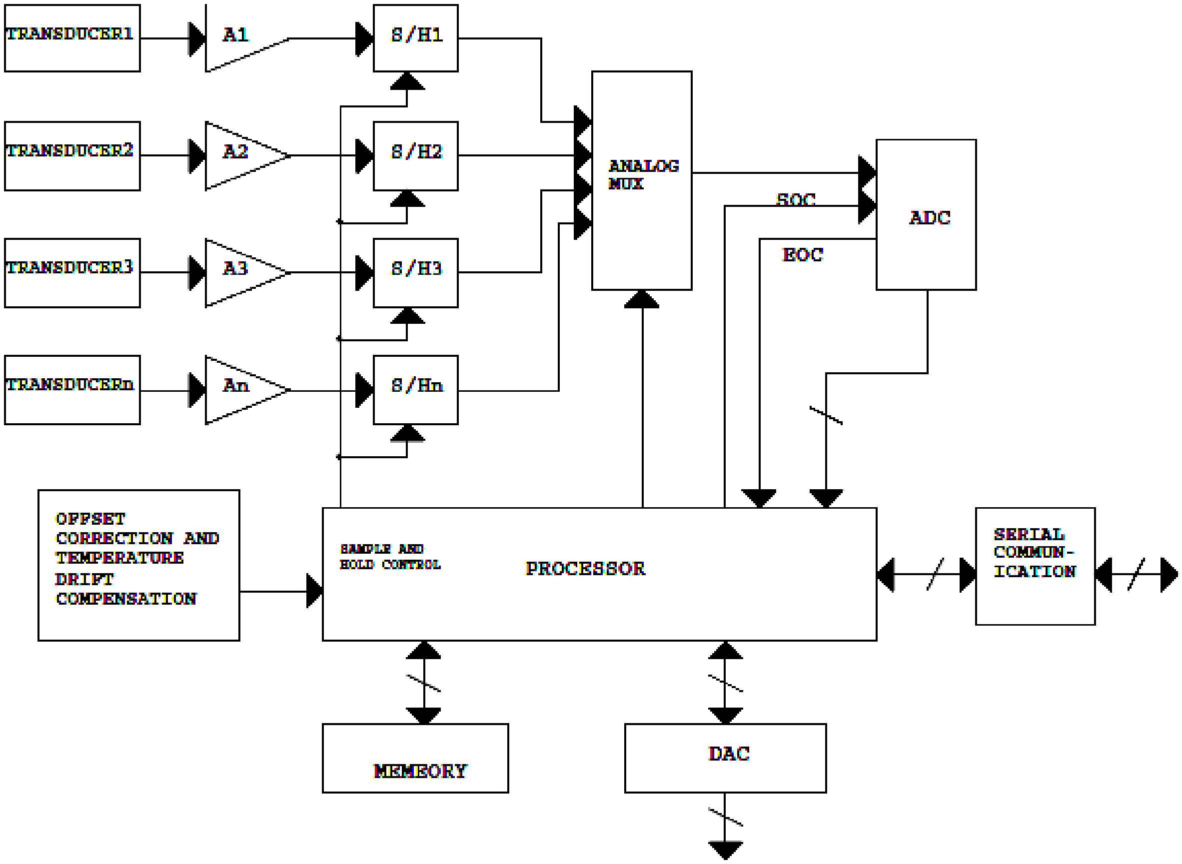
General Architecture of smart sensor:

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.

UNIT V DITIAL INSTRUMENTATION

5.1 ADC AND DAC SPECIFICATIONS

Resolution:

The resolution of a DAC is the smallest change in the output of the DAC for any change in digital input.i.e. if a input to DAC changes one bit, how much analog output has changed in full scale deflection.

% resolution = [Step size / Full scale output (FSO)] * 100

In other way the resolution is the number of states into which the full scale output is divided. i.e if a 8 bit DAC can resolve the FSO up to 255 levels. Each level of output is called step size and for higher number of bits the resolution will be better.

% resolution = $[1/(2^N-1) *100]$

Normally the resolution will be in milli volts.

Accuracy

The Accuracy of a DAC is the difference between output practical analog output to the ideal expected output for a given digital input. The DAC is contains electronic components where the gain plays a major role which can introduce gain error in the output. Due to the the full scale output may differ compared to ideal one. For an example if a DAC of 10 V is said to have an accuracy of 0.01% there will be 10mv output deviation. The another factor which implicates the accuracy is the zero offset error i.e for a zero input the output of DAC reflects some offset value.

Conversion Speed

The conversion speed of the DAC is output analog value settling time period for a change in the digital input. This is also called settling time period of DAC. Normally it will be micro seconds and in some advanced micro controller DAC it may be nano seconds.

Monotonicity

The Digital to Analog Converter is said to be monotonic if its analog value is either increasing or equal to previous value for an LSB change in input digital signal.

Offset/ Zero scale error:

An input code of zero may be expected to give 0V output. A small offset may be present and the transfer characteristic does not pass through the origin.

Linearity:

The input-output characteristic of a D/A converter. zero offset and gain develop in the characteristic which passes through the origin and full scale points. But it is not sure that the intermediate points will always lie in the straight line. Avery small error in the weighting factor for a fraction LSB will cause non-linearity. Linearity can be expressed by deviation from the ideal line as a percentage or fraction of LSB. It is specified as ±LSB or ±1/2 LSB.

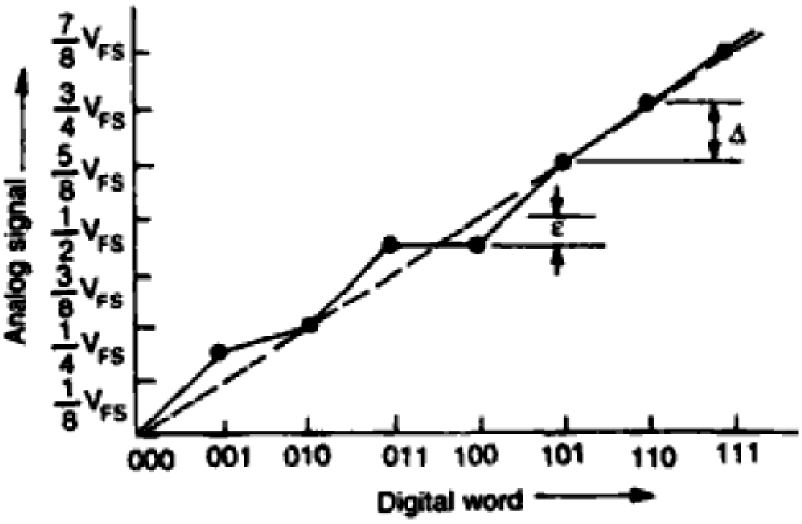


Fig.1: Linearity error for a 3-bit ADC

Settling time:

This is usually expressed as the time taken to settle within half LSB. Generally settling time will be 500ns.

Stability:

The ability of a DAC to produce a stable output all the time is called as Stability. The performance
of a converter changes with drift in temperature, aging and power supply variations. So all the parameters such as offset, gain, linearity error & monotonicity may change from the values specified in the datasheet. Temperature sensitivity defines the stability of a D/A converter.

Quantization error

Quantization is representing the sampled values of the amplitude by a finite set of levels, which means converting a continuous-amplitude sample into a discrete-time signal.

For any system, during its functioning, there is always a difference in the values of its input and output. The processing of the system results in an error, which is the difference of those values.

The difference between an input value and its quantized value is called a Quantization Error. A Quantizer is a logarithmic function that performs Quantization (rounding off the value). An analog-to-digital converter (ADC) works as a quantizer.

The following figure illustrates an example for a quantization error, indicating the difference between the original signal and the quantized signal.

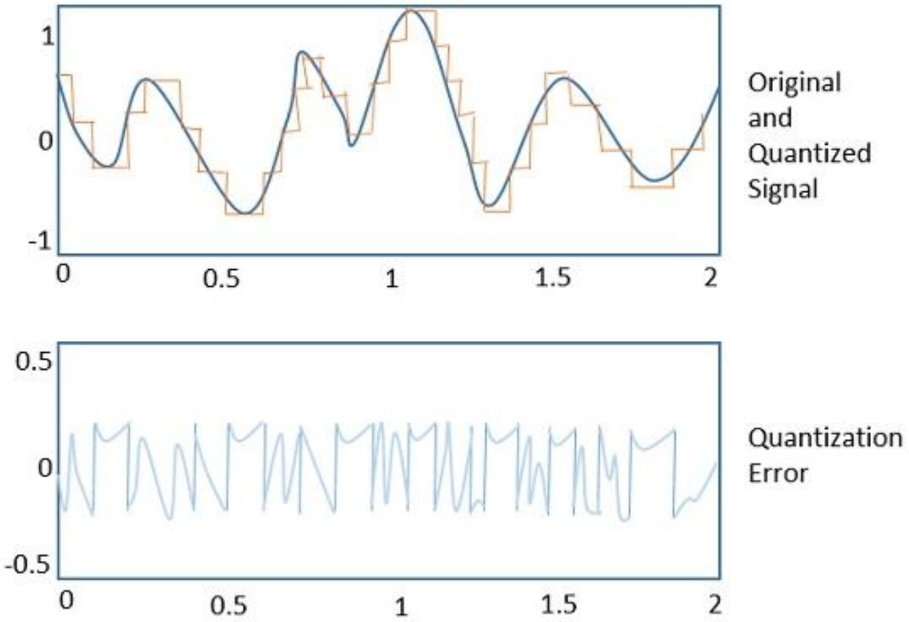
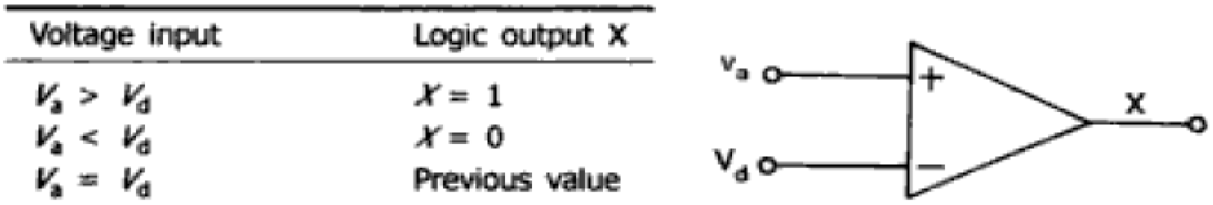


Fig.2 Quantization error.

5.2.TYPES OF ADC

2.1 FLASH TYPE ADC:

This is the simplest possible A/D converter. It is at the same time, the fastest and most expensive technique. Figure shows a 3 bit A/D converter. The circuit consists of a resistive divider network, 8 op-amp comparators and a 8-1ine to 3-1ine encoder (3-bit priority encoder). The Comparator and its truth table are shown in Figure below



Voltage input	Logic output X
$V_a > V_d$	$X = 1$
$V_a < V_d$	$X = 0$
$V_a = V_d$	Previous value

Fig.3 A comparator and its truth table

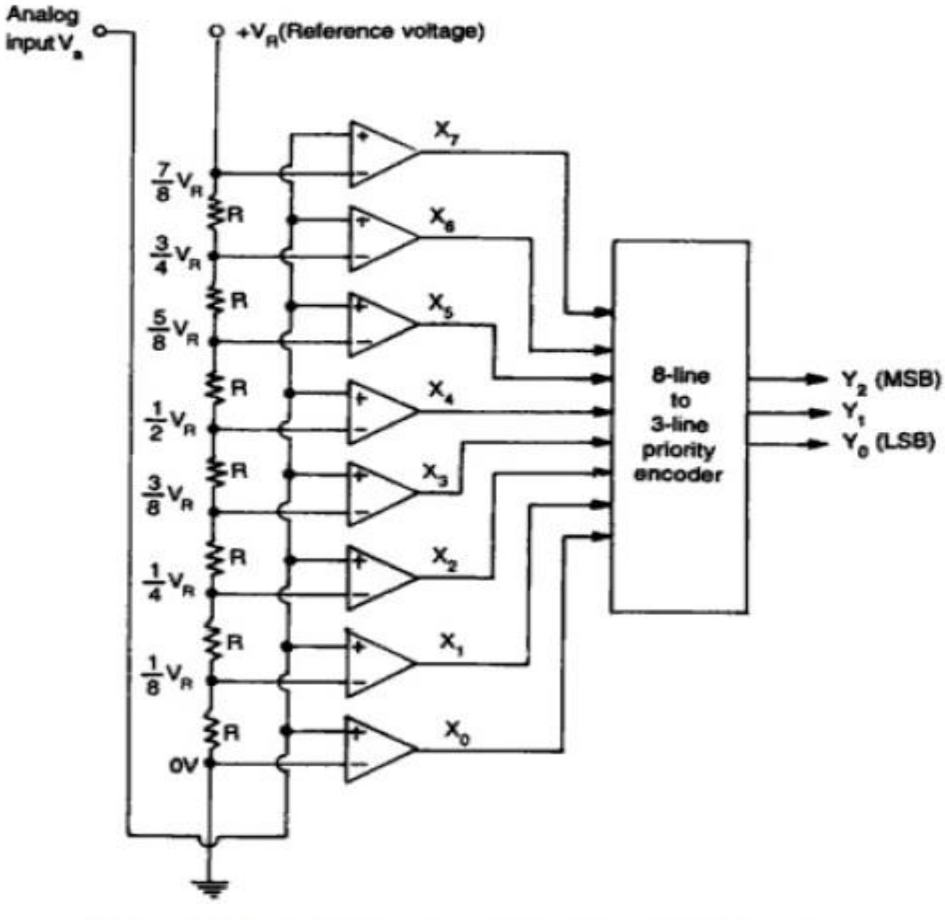


Fig.4 Flash type A-D converter

Table 1:Truth table for Flash type ADC

Input voltage V_a	X_7	X_6	X_5	X_4	X_3	X_2	X_1	X_0	Y_2	Y_1	Y_0
0 to $V_R/8$	0	0	0	0	0	0	0	1	0	0	0
$V_R/8$ to $V_R/4$	0	0	0	0	0	0	1	1	0	0	1
$V_R/4$ to 3 $V_R/8$	0	0	0	0	0	1	1	1	0	1	0
3 $V_R/8$ to $V_R/2$	0	0	0	0	1	1	1	1	0	1	1
$V_R/2$ to 5 $V_R/8$	0	0	0	1	1	1	1	1	1	0	0
5 $V_R/8$ to 3 $V_R/4$	0	0	1	1	1	1	1	1	1	0	1
3 $V_R/4$ to 7 $V_R/8$	0	1	1	1	1	1	1	1	1	1	0
7 $V_R/8$ to V_R	1	1	1	1	1	1	1	1	1	1	1

A small amount of hysteresis is built into the comparator to resolve any problems that might occur if both inputs were of equal voltage as shown in the truth table. From the Figure, at each node of the resistive divider, a comparison voltage is available. Since all the resistors are of equal value, the voltage levels available at the nodes are equally divided between the reference voltage V_R and the ground. The purpose of the circuit is to compare the analog input voltage V_a with each of the node voltages. The truth table for the flash type A/D converter is shown above.

Advantages of flash type A/D converter

- High speed simultaneous conversion
- Typical conversion time is 100 ns or less.

Disadvantages of flash type A/D converter

- The number of comparators required almost doubles for each added bit.
- Larger the value of n (number of bits), the more complex is the priority encoder.

2.2 COUNTER TYPE ADC

The counter type ADC is the basic form of ADC which is also called as ramp type ADC or stair case approximation ADC. This circuit consists of N-bit counter, DAC and comparator

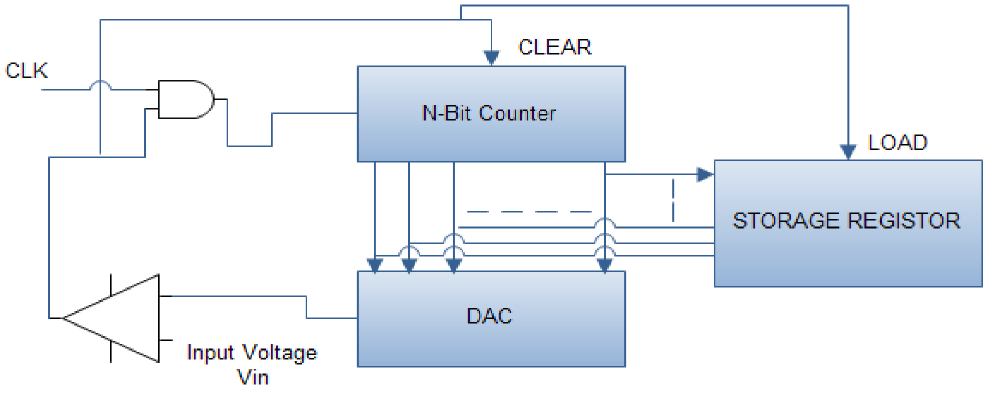


Fig.5 Counter type ADC

The N bit counter generates an n bit digital output which is applied as an input to the DAC. The analog output corresponding to the digital input from DAC is compared with the input analog voltage using an op-amp comparator. The op-amp compares the two voltages and if the generated DAC voltage is less, it generates a high pulse to the N-bit counter as a clock pulse to increment the counter. The same process will be repeated until the DAC output equals to the input analog voltage.

If the DAC output voltage is equal to the input analog voltage, then it generates low clock pulse and it also generates a clear signal to the counter and load signal to the storage resistor to store the corresponding digital bits. These digital values are closely matched with the input analog values with small quantization error. For every sampling interval the DAC output follows a ramp fashion so that it is called as Digital ramp type ADC. And this ramp looks like stair cases for every sampling time so that it is also called as staircase approximation type ADC.

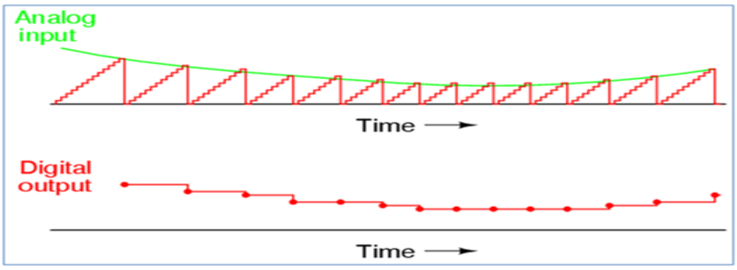


Fig.6 Digital output and analog input for a counter type ADC

Conversion time of ADC is the time taken by the ADC to convert the input sampled analog value to digital value. Here the maximum conversion of high input voltage for a N bit ADC is the clock pulses required to the counter to count its maximum count value. So

The maximum conversion of Counter type ADC is = (2^N-1) T

Where, T is the time period of clock pulse.

If N=2 bit then the $T_{max} = 3T$.

By observing the above conversion time of Counter type ADC it is illustrated that the sampling period of Counter type ADC should be as shown below.

$Ts >= (2^N-1) T$

Advantages of Counter type ADC:

- Simple to understand and operate.
- Cost is less because of less complexity in design.

Disadvantages or limitations of Counter type of ADC:

- Speed is less because every time the counter has to start from ZERO.
- There may be clash or aliasing effect if the next input is sampled before completion of one operation.

2.3 SUCCESSIVE APPROXIMATION TYPE ADC

- A Successive Approximation Register (SAR) is added to the circuit
- Instead of counting up in binary sequence, this register counts by trying all values of bits starting with the MSB and finishing at the LSB.
- The register monitors the comparators output to see if the binary count is greater or less than the analog signal input and adjusts the bits accordingly

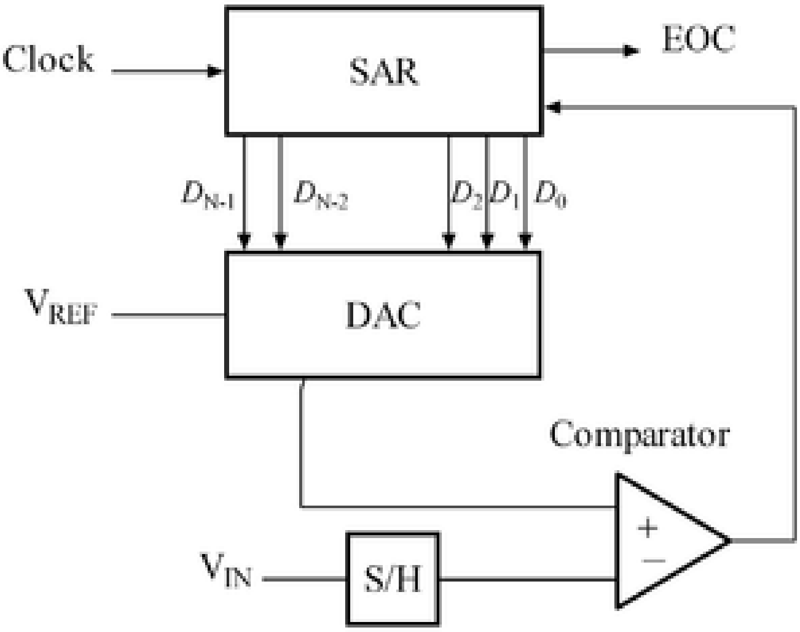


Fig.7 Successive Approximation ADC Circuit

Elements:

- DAC = Digital to Analog Converter
- EOC = End of Conversion
- SAR = Successive Approximation Register
- S/H = Sample and Hold Circuit
- V_{in} = Input Voltage
- Comparator
- V_{ref} = Reference Voltage

Algorithm

- Uses an n-bit DAC and original analog results
- Performs a binary comparison of V_{DAC} and V_{in}
- MSB is initialized at 1 for DAC
- If $V_{in} < V_{DAC}$ $(V_{REF} / 2^{\wedge n=1})$ then MSB is reset to 0
- If $V_{in} > V_{DAC}$ $(V_{REF} / 2^{\wedge n})$ Successive Bits set to 1 otherwise 0
- Algorithm is repeated up to LSB
- At end DAC in = ADC out

- N-bit conversion requires N comparison cycles

Example 1:

5-bit ADC, V_{in}=0.6V, V_{ref}=1V

Cycle 1 => MSB=1

SAR = $\underline{1}$ 0 0 0 0

$V_{DAC} = V_{ref}/2^{\wedge 1} = .5$ $V_{in} > V_{DAC}$ SAR unchanged = 1 0 0 0 0

- Cycle 2

SAR = 1 $\underline{1}$ 0 0 0

$V_{DAC} = .5 + .25 = .75$ $V_{in} < V_{DAC}$ SAR bit3 reset to 0 = 1 0 0 0 0

- Cycle 3

SAR = 1 0 $\underline{1}$ 0 0

$V_{DAC} = .5 + .125 = .625$ $V_{in} < V_{DAC}$ SAR bit2 reset to 0 = 1 0 0 0 0

- Cycle 4

SAR = 1 0 0 $\underline{1}$ 0

$V_{DAC} = .5+.0625=.5625$ $V_{in} > V_{DAC}$ SAR unchanged = 1 0 0 1 0

- Cycle 5

SAR = 1 0 0 1 $\underline{1}$

$V_{DAC} = .5+.0625+.03125= \underline{.59375}$

Table 2:Input vs Voltage

Bit	4	3	2	1	0
Voltage	.5	.25	.125	.0625	.03125

Advantages

- Capable of high speed and reliable
- Medium accuracy compared to other ADC types
- Good tradeoff between speed and cost
- Capable of output the binary number in serial (one bit at a time) format.
- High resolution

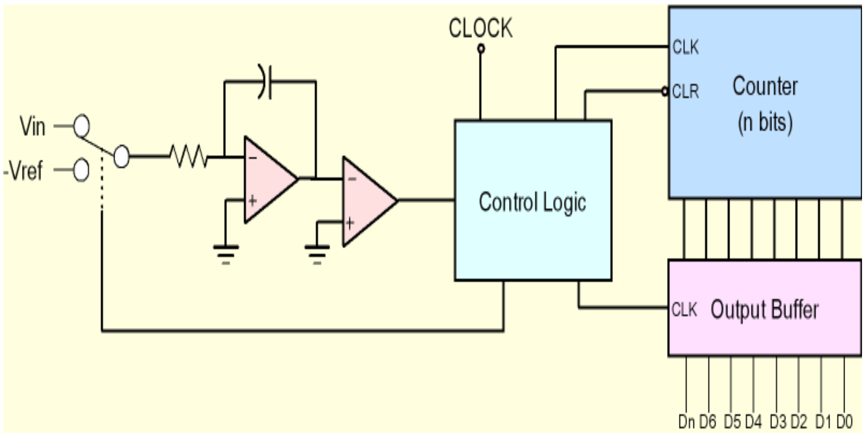
- No precision external components needed

Disadvantages

- Higher resolution successive approximation ADC’s will be slower
- Speed limited.

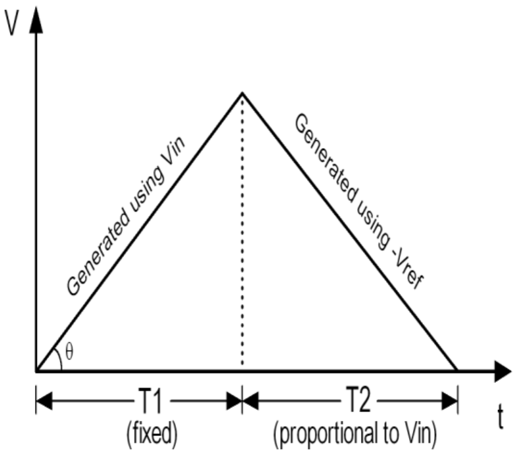
2.4 DUAL SLOPE ADC

- An unknown input voltage is applied to the input of the integrator and allowed to ramp for a fixed time period (t_u)
- Then, a known reference voltage of opposite polarity is applied to the integrator and is allowed to ramp until the integrator output returns to zero (t_d)
- The input voltage is computed as a function of the reference voltage, the constant run-up time period, and the measured run-down time period.
- The run-down time measurement is usually made in units of the converter's clock, so longer integration times allow for higher resolutions.
- The speed of the converter can be improved by sacrificing resolution



$$V_{in} = -V_{ref}\frac{t_d}{t_u}$$

Fig.8 Dual Slope ADC



$$\left(V(t) = V(0) + \frac{V_{in}\,t}{RC}\right)^{*}$$

Fig.9 Graph

Table 3:Comparison

Type	**Speed (relative)**	**Cost (relative)**
Dual Slope	Slow	Med
Flash	Very Fast	High
Successive Appox	Medium – Fast	Low
Sigma-Delta	Slow	Low

2.5 INTRODUCTION TO DELTA-SIGMA

A Delta Sigma (SD-ADC) has a modulator and a digital filter (also known as decimation filter) as shown in figure below. A modulator converts the input analog signal into digital bit streams (1s and 0s). One can observe a bit, either 1’b1 or 1’b0 coming at every clock edge of the modulator.
The decimation filter receives the input bit streams and, depending on the over sampling ratio (OSR) value, it gives one N-bit digital output per OSR clock edge. For example, if we consider OSR to be 64, then the Filter gives one N-bit output for every 64 clock edges (64 data outputs of the modulator). Here N is the resolution of the SD ADC.

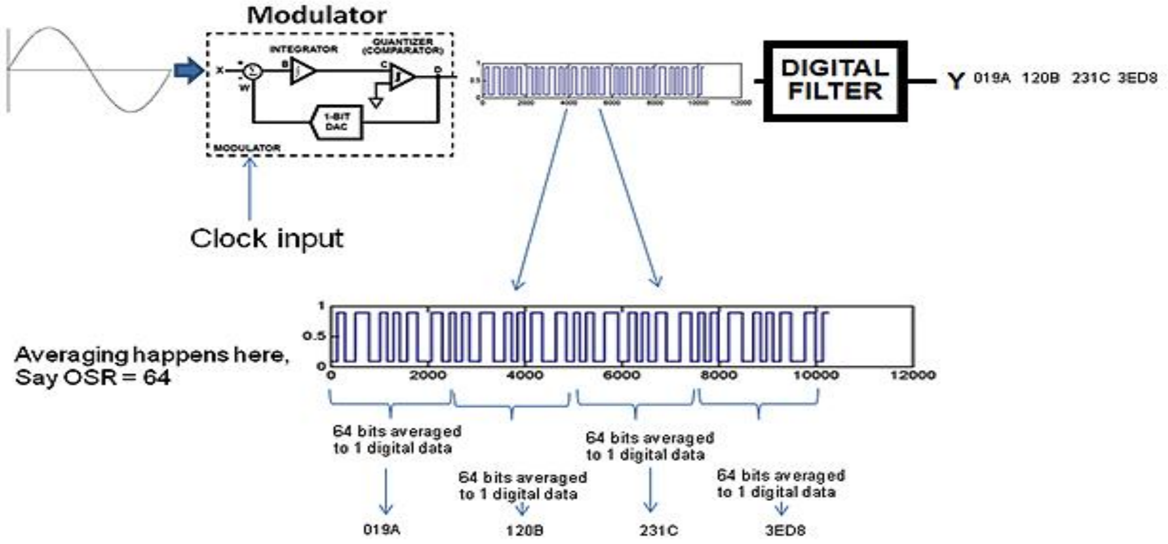


Fig.10 Delta Sigma ADC

In a conventional ADC, an analog signal is integrated, or sampled, with a sampling frequency and subsequently quantized in a multi-level quantizer into a digital signal. This process introduces quantization error noise. The first step in a delta-sigma modulation is delta modulation. In delta modulation the change in the signal (its delta) is encoded, rather than the absolute value. The result is a stream of pulses, as opposed to a stream of numbers as is the case with PCM. In delta-sigma modulation, the accuracy of the modulation is improved by passing the digital output through a 1-bit DAC and adding (sigma) the resulting analog signal to the input signal, thereby reducing the error introduced by the delta-modulation. Primarily because of its cost efficiency and reduced circuit complexity, this technique has found increasing use in modern electronic components such as DACs, ADCs, frequency synthesizers, switched-mode power supplies and motor controllers. Both ADCs and DACs can employ delta-sigma modulation. A delta-sigma ADC first encodes an analog signal using high-frequency delta-sigma modulation, and then applies a digital filter to form a higher-resolution but lower sample-frequency digital output. On the other hand, a delta-sigma DAC encodes a high-resolution digital input signal into a lower-resolution but higher sample-frequency signal that is mapped to voltages, and then smoothed with an analog filter. In both cases, the temporary use of a lower-resolution signal simplifies circuit design and improves efficiency.

In brief, because it is very easy to regenerate pulses at the receiver into the ideal form transmitted. The only part of the transmitted waveform required at the receiver is the time at which the pulse occurred. Given the timing information the transmitted waveform can be reconstructed electronically with great precision. In contrast, without conversion to a pulse stream but simply transmitting the analog signal directly, all noise in the system is added to the analog signal, permanently reducing its quality. Each pulse is made up of a step up followed after a short interval by a step down. It is possible, even in the presence of electronic noise, to recover the timing of these steps and from that regenerate the transmitted pulse stream almost noiselessly. Then the accuracy of the transmission process reduces to the accuracy with which the transmitted pulse stream represents the input waveform.

Delta-sigma modulation converts the analog voltage into a pulse frequency and is alternatively known as Pulse Density modulation or Pulse Frequency modulation. In general, frequency may vary smoothly in infinitesimal steps, as may voltage, and both may serve as an analog of an infinitesimally varying physical variable such as acoustic pressure, light intensity, etc. The substitution of frequency for voltage is thus entirely natural and carries in its train the transmission advantages of a pulse stream. The different names for the modulation method are the result of pulse frequency modulation by different electronic implementations, which all produce similar transmitted waveforms.

The ADC converts the mean of an analog voltage into the mean of an analog pulse frequency and counts the pulses in a known interval so that the pulse count divided by the interval gives an accurate digital representation of the mean analog voltage during the interval. This interval can be chosen to give any desired resolution or accuracy. The method is cheaply produced by modern methods; and it is widely used.

5.3.TYPES OF DAC

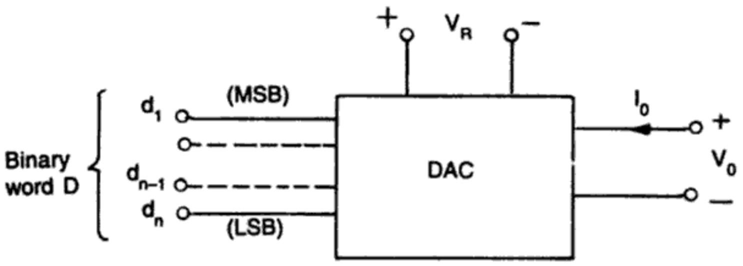


Fig 11: DAC

The input in the digital to analog converter is an n-bit binary word D and is combined with a reference voltage V_r to give an analog output signal. The output of a DAC can be either a voltage or current. For a voltage output DAC, the D/A converter is mathematically described as

$$V_o = K\ V_{FS}\ (d_1 2^{-1} + d_2 2^{-2} + \ldots + d_n 2^{-n}) \quad \text{------ (1)}$$

Where,

V_o = output voltage

V_{FS} = full scale output voltage

K = scaling factor usually adjusted to unity

$d_1\ d_2 \ldots\ldots d_n$ = n-bit binary fractional word with the decimal point located at the left
d_1 = most significant bit (MSB) with a weight of $V_{FS}/2$

d_n = most significant bit (MSB) with a weight of $V_{FS}/2^n$

There are various ways of implementing DAC

- Weighted-Resistor DAC

- 2R ladder DAC
- PWM type DAC

3.1 WEIGHTED RESISTOR DAC

One of the simplest circuits is shown in Figure uses a summing amplifier with a binary weighted resistor network. It has n- electronic switches $d_1\, d_2 \ldots\ldots d_n$ controlled by binary input word. These switches are single pole double throw (SPDT) type. If the binary input to a particular switch is 1, it connects the resistance to the reference voltage (-V_R). And if the input bit is 0, the switch connects the resistor to the ground. From Figure (a) the output current I_o for an ideal op-amp can be written as

$$\begin{aligned} I_o &= I_1 + I_2 + \ldots + I_n \\ &= \frac{V_R}{2R} d_1 + \frac{V_R}{2^2 R} d_2 + \ldots + \frac{V_R}{2^n R} d_n \\ &= \frac{V_R}{R} (d_1 2^{-1} + d_2 2^{-2} + \ldots + d_n 2^{-n}) \end{aligned}$$

The output voltage

$$V_o = I_o R_f = V_R \frac{R_f}{R} (d_1 2^{-1} + d_2 2^{-2} + \ldots + d_n 2^{-n}) \qquad \text{----- (2)}$$

Comparing equation (1) with (2) it can be seen that if R_f = R then K = 1 and V_{FS}= V_R .

The circuit shown in Figure uses a negative reference voltage. The analog output voltage is therefore positive staircase as shown in Figure for a 3-bit weighted resistor DAC. It may be noted that

- ✓ Although the op-amp in Figure is connected in inverting mode, it can also be connected in non-inverting mode.
- ✓ The op-amp is simply working as a current to voltage converter.
- ✓ The polarity of the reference voltage is chosen in accordance with the type of the switch used. For example, for TTL compatible switches, the reference voltage should be = 5 V and the output will be negative.

The accuracy and stability of a DAC depends upon the accuracy of the resistors and the tracking of each other with temperature. There are however a number of problems associated with this type of DAC. One of the disadvantages of binary weighted type DAC is the wide range of resistor values required. It may be observed that for better resolution, the input binary word length has to be increased. Thus, as the number of bit increases, the range of resistance value increases. For 8-bit DAC, the resistors required are 2^0R, 2^1 R, 2^2 R… 2^7 R. the largest resistor is 128 times the smallest one for only 8-bit DAC. For a 12-bit DAC, the largest resistance required is 5.12 MΩ if the smallest is 2.5 kΩ. The fabrication of such a large resistance is IC is not practical. Also the voltage drop across such a large resistor due to the bias current would also affect the accuracy. The choice of smallest resistor value as 2.5 kΩ is reasonable; otherwise loading effect will be there. The difficulty of achieving and maintaining accurate ratios over such a wide range especially in monolithic form restricts the use of weighted resistor DACs to below 8-bits.

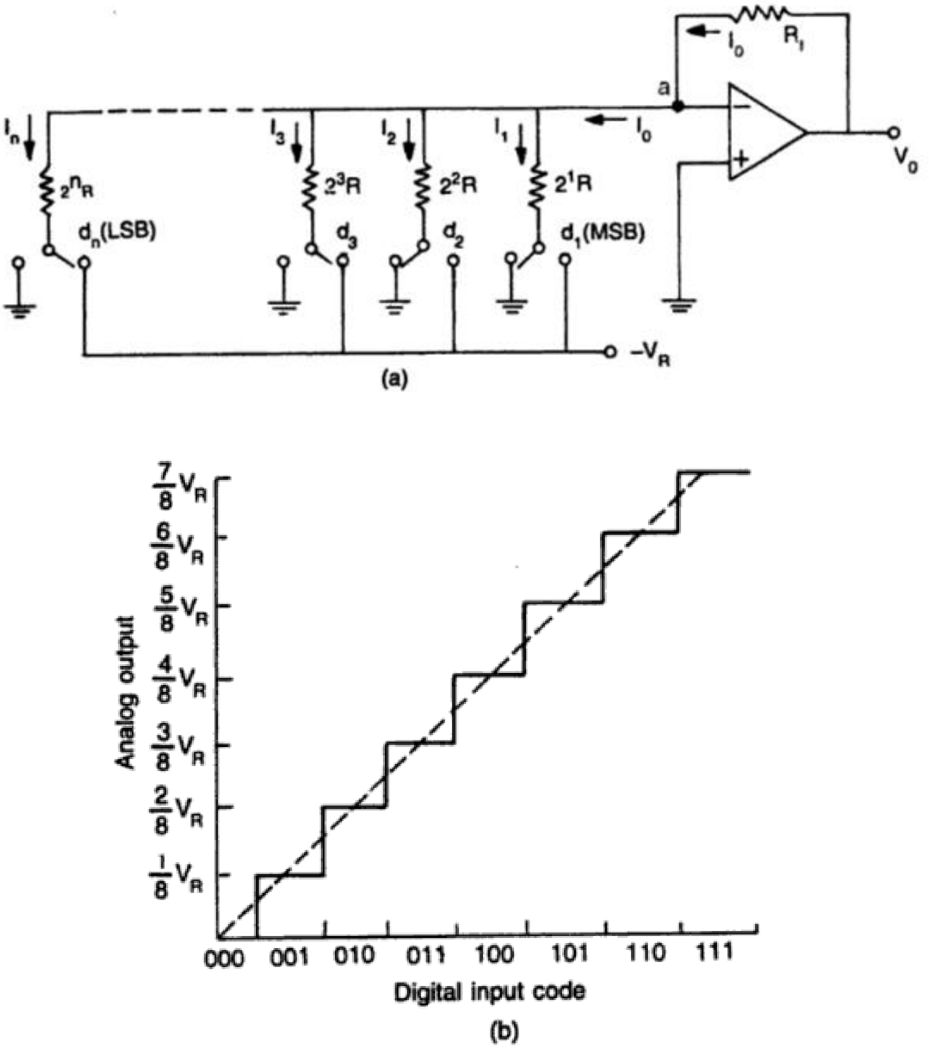


Fig.12 (a)A simple weighted resistor DAC (b) Transfer characteristics of a 3-bit DAC

3.2 R-2R LADDER DAC

Wide range of resistors are required in binary weighted resistor type DAC. This can be avoided by using R-2R ladder type DAC where only two values of resistors are required. It is well suited for integrated circuit realization. The typical value of resistor ranges from 2.5kΩ to 10kΩ.

For simplicity, consider a 3-bit DAC as shown in Figure, where the switch position $d_1\ d_2\ d_3$ corresponds to the binary word 100. The circuit can be simplified to the equivalent form of Figure (b) and finally to Figure (c). then, voltage at node C can be easily calculated by the set procedure of network analysis as

$$\frac{-V_R\left(\frac{2}{3}R\right)}{2R+\frac{2}{3}R} = -\frac{V_R}{4}$$

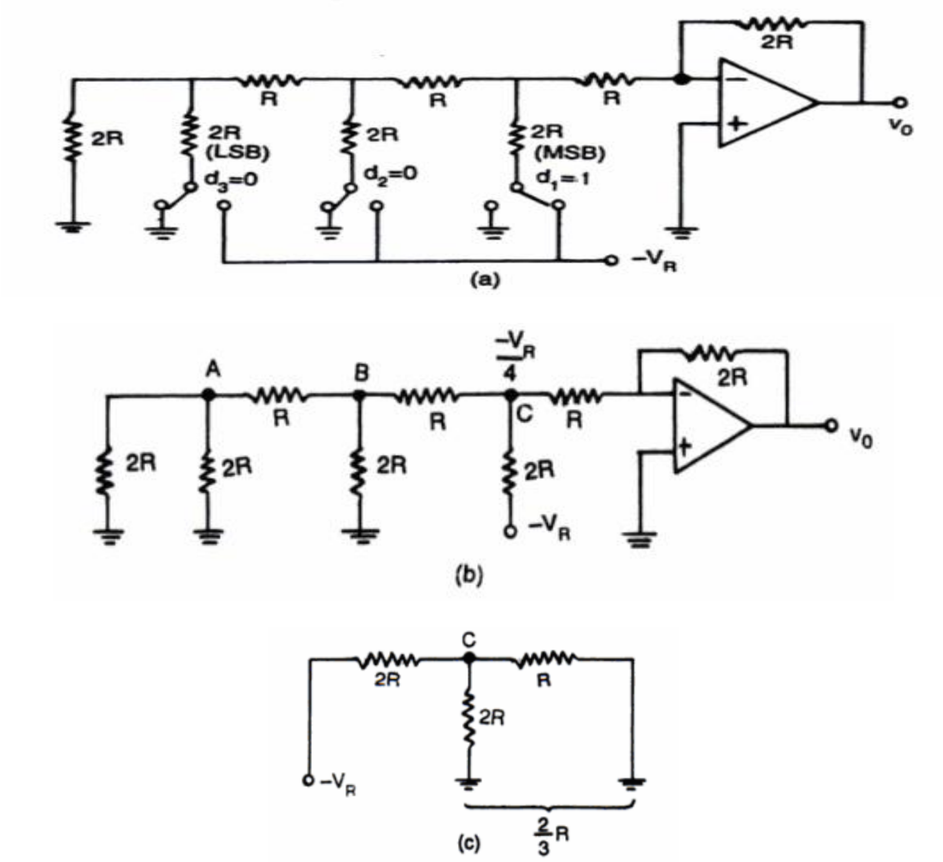


Fig.13 (a) R-2R ladder DAC (b) Equivalent circuit of (a), (c) Equivalent circuit of (b)

The output voltage

$$V_o = \frac{-2R}{R}\left(-\frac{V_R}{4}\right) = \frac{V_R}{2} = \frac{V_{FS}}{2}$$

The switch position corresponding to the binary word 001 in 3 bit DAC is shown in Figure (a). The circuit can be simplified to the equivalent form of Fig(b). The voltages at the nodes (A,B,C) formed by resistor branches are easily calculated in a similar fashion and the output voltage becomes

$$V_o = \left(-\frac{2R}{R}\right)\left(-\frac{V_R}{16}\right) = \frac{V_R}{8} = \frac{V_{FS}}{8}$$

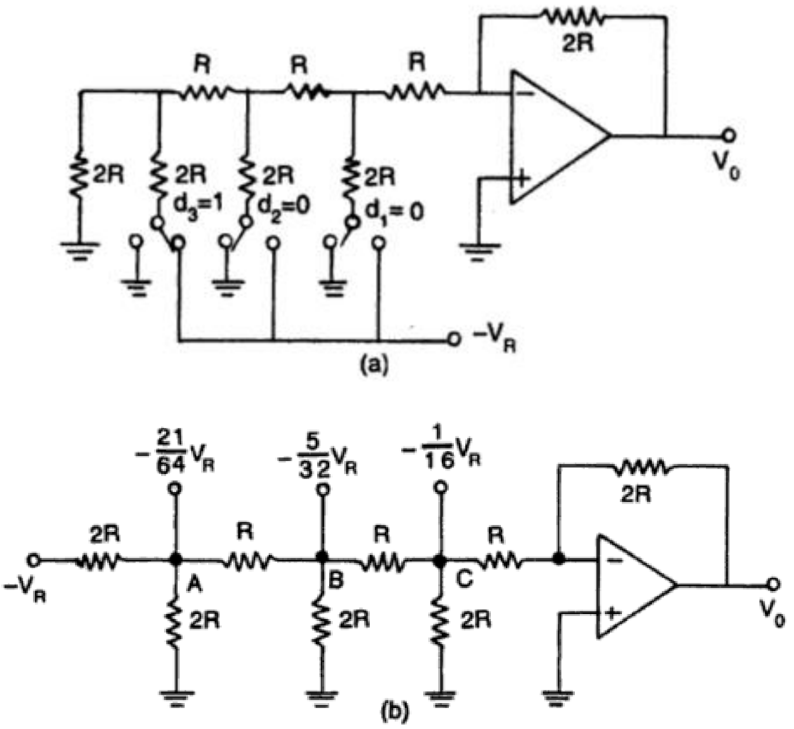
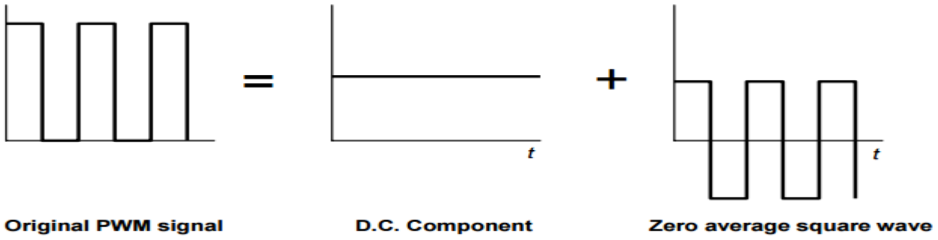


Fig.14 (a) R-2R ladder DAC for switch positons 001 (b) Equivalent circuit

In a similar fashion, the output voltage for R-2R ladder type DAC corresponding to other 3-bit binary words can be calculated.

3.3 PWM TYPE DAC

The PWM signal outputs on a device are variable duty cycle square-waves with 3.3 volt amplitude. These signals can each be decomposed into a D.C. component plus a new square-wave of identical duty-cycle but with a time-average amplitude of zero. Figure below depicts this graphically.



Original PWM signal D.C. Component Zero average square wave

Fig.15 Decomposition of PWM signal

The idea behind realizing digital-to-analog (D/A) output from a PWM signal is to analog low-pass filter the PWM output to remove most of the high frequency components, ideally leaving only the D.C. component. This is depicted in Figure below. The bandwidth of the low-pass filter will essentially determine the bandwidth of the digital-to-analog converter. A frequency analysis of the PWM signal is given in the next section in order to provide a theoretical basis for the filtering strategy.

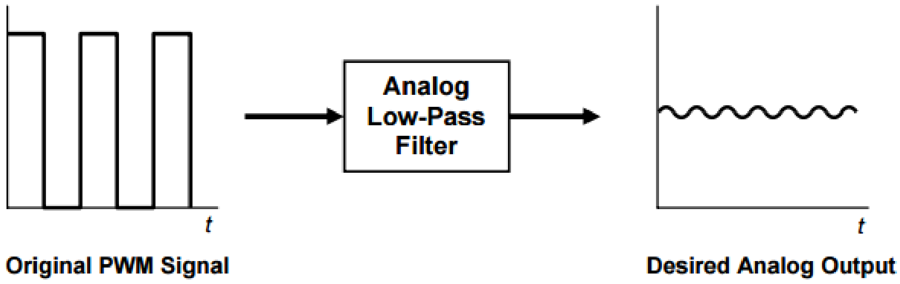


Fig.16 Analog filtering of PWM signal

The PWM/DAC approach is not new, but performance limitations have historically confined its use to low-resolution, low-bandwidth applications. The performance of the method relates directly to the ability of the low-pass filter to remove the high-frequency components of the PWM signal. Use a filter with too low a cut-off frequency, and DAC bandwidth suffers. Use a filter with too high a cut-off frequency or with slow stop-band roll-off, and DAC resolution suffers, but one way to alleviate both of these problems is to increase the frequency of the PWM. However, as PWM frequency increases on conventional microprocessor generated PWM, digital resolution problems begin to manifest.

3.4 ADC/DAC PROBLEMS

1)

The basic step of a 9-bit DAC is 10.3 mV. If 000000000 represents 0 V, what output is produced if the input is 101101111?

Solution

The output voltage for input 101101111 is

$$= 10.3\ \text{mV}\ (1 \times 2^8 + 0 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0)$$

$$= 10.3\ \text{mV}\ (367)$$

$$= 3.78\ \text{V}$$

2) Calculate the values of the LSB, MSB and full scale output for an 8-bit DAC for the 0 to 10 V range.

Solution

$$\text{LSB} = \frac{1}{2^8} = \frac{1}{256}$$

For 10 V range, $\text{LSB} = \dfrac{10\ \text{V}}{256} = 39\ \text{mV}$

and $\text{MSB} = \left(\dfrac{1}{2}\right)\ \text{full scale} = 5\ \text{V}$

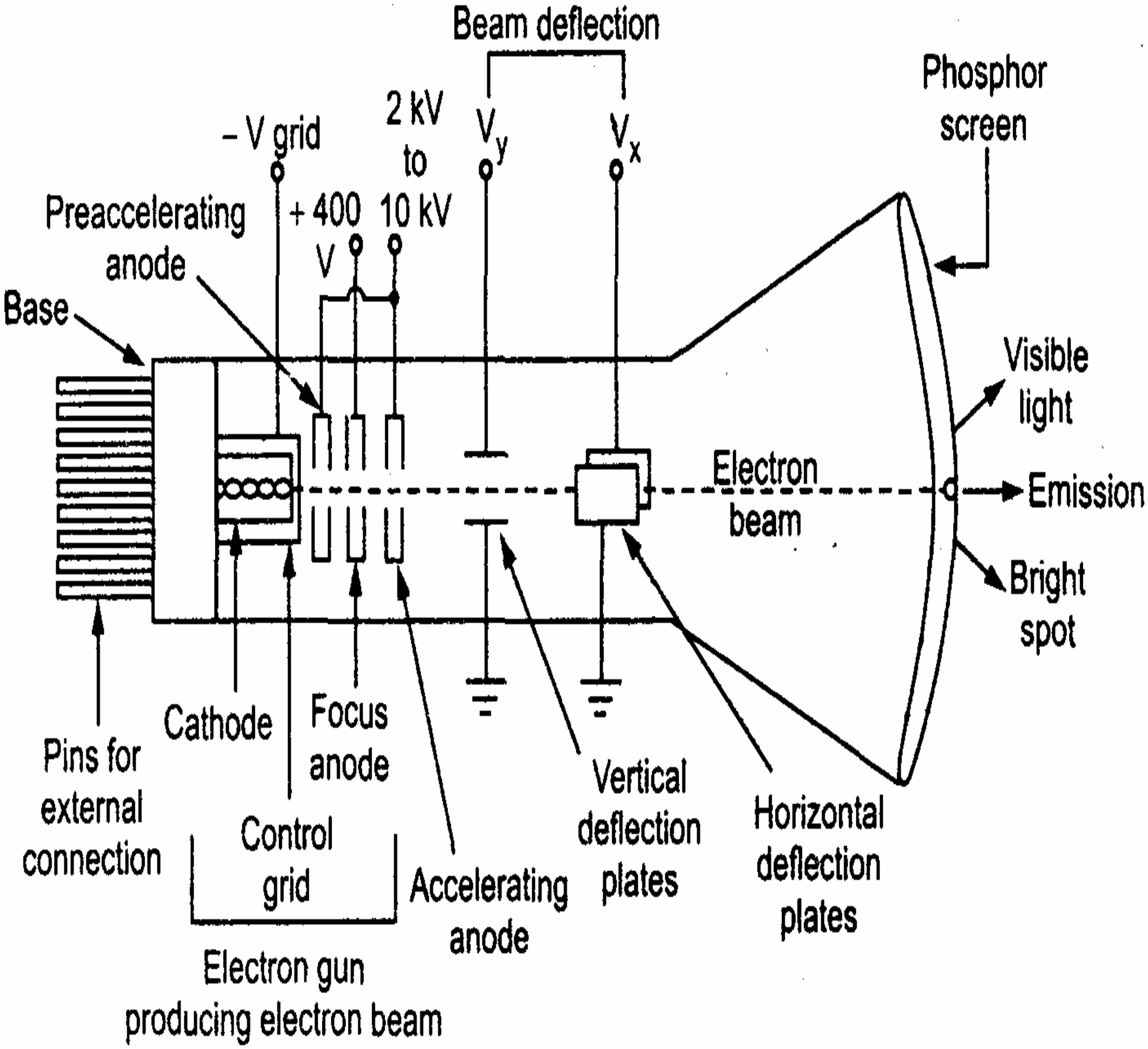
$$\text{Full scale output} = (\text{Full scale voltage} - 1\ \text{LSB})$$

$$= 10\ \text{V} - 0.039\ \text{V} = 9.961\ \text{V}$$

5.4 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

- The electron gun section of the cathode ray tube provides a sharply focused, electron beam directed towards the fluorescent-coated screen.
- This section starts from thermally heated cathode, emitting the electrons.
- The control grid is given negative potential with respect to cathode.
- This grid controls the number of electrons in t beam, going to the screen.
- 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.
- The light emitted is usually of the green colour.

Deflection System

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

Fluorescent Screen

- The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero.
- The time period for which the trace remains on the screen after the signal becomes zero is known as “persistence or fluorescence”.
- The persistence may be as short as a few microsecond, or as long as tens of seconds or even minutes.
- Medium persistence traces are mostly used for general purpose applications.
  - Long persistence traces are used in the study of transients.
- Long persistence helps in the study of transients since the trace is still seen on the screen after the transient has disappeared.

Glass Tube

- All the components of a CRT are enclosed in an evacuated glass tube called envelope.
- This allows the emitted electrons to move about freely from one end of the tube to the other end.

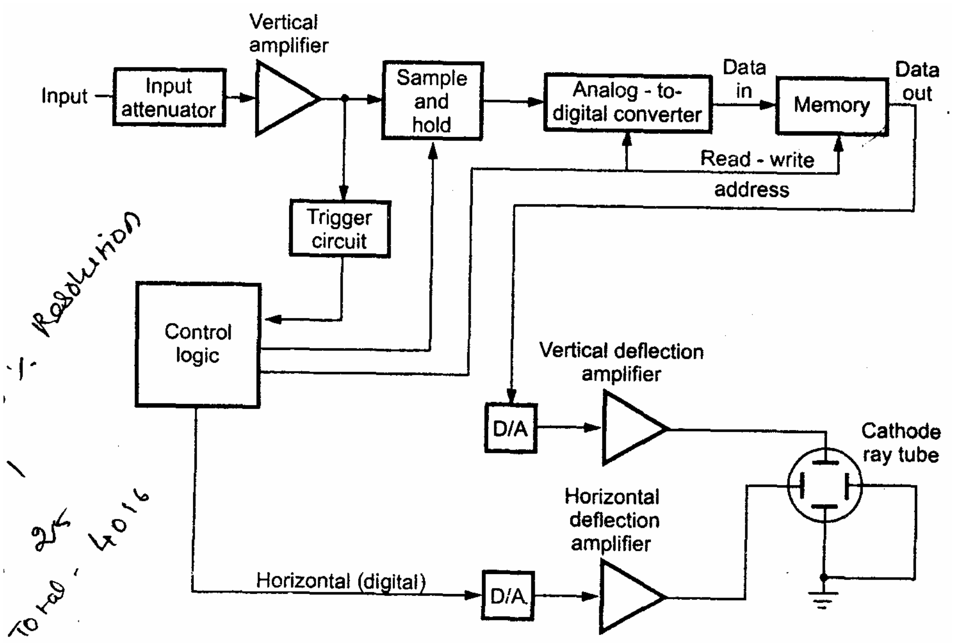
Base

- 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.

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

5.5 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

- Pulse inputs
  - Counts circuit closing
- Control ports
  - Digital in and out
  - Most commonly used to turn things on and off
  - Can be programmed as a digital input
- 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