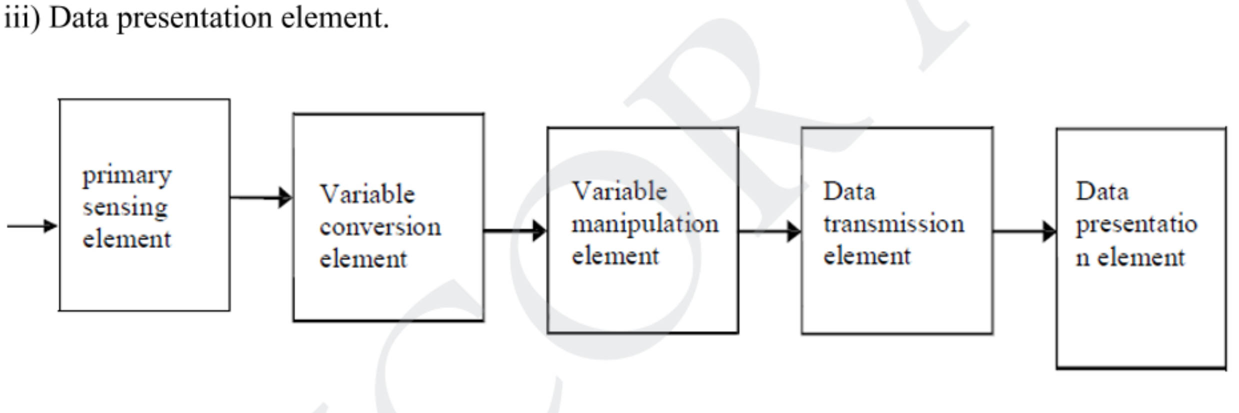
EE8403- MEASUREMENTS AND INSTRUMENTATION
UNIT I INTRODUCTION

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.
BASIC REQUIREMENTS OF MEASUREMENT:
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.
MEASURING INSTRUMENT:
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.



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

Data presentation element:

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'**

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- Xn-Xn(bar)/ Xn

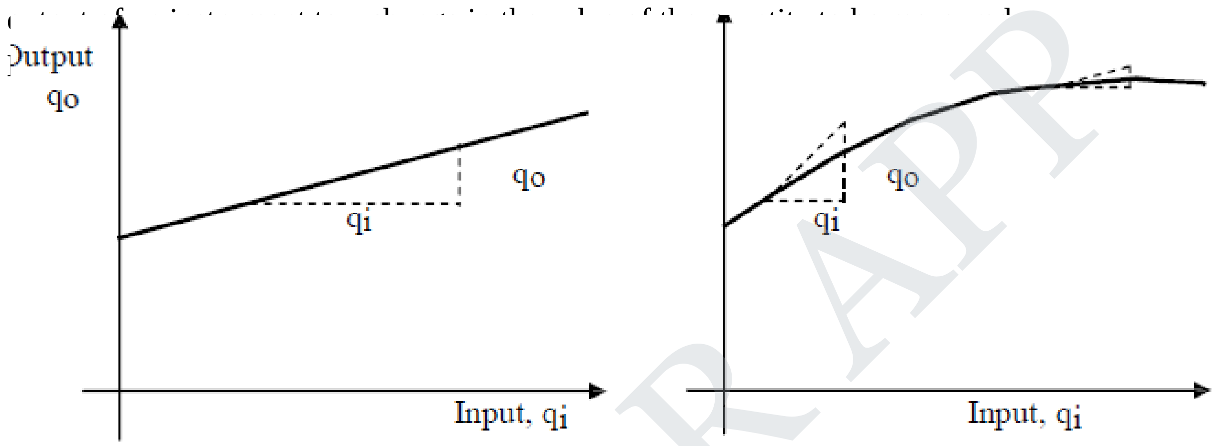
Where, P = precision

Xn = Value of nth measurement

Xn(bar) = 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



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

$$= \frac{\text{ǻqo}}{\text{ǻqi}}$$

if the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve. If the calibration c urve 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

Linearity:

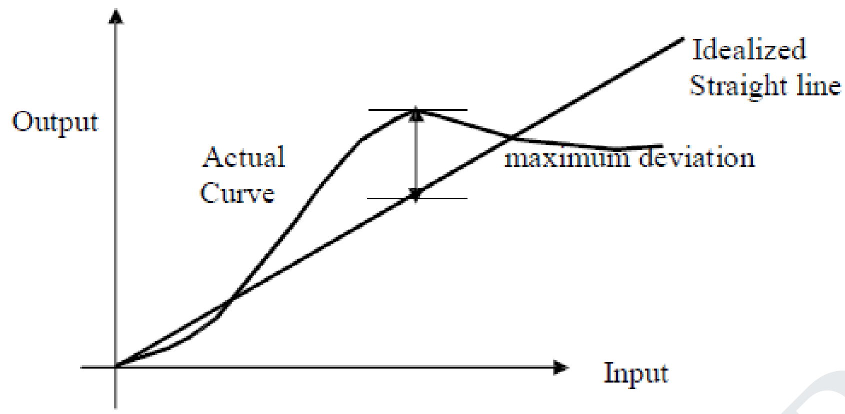
ǻqi

=

ǻqo

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

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

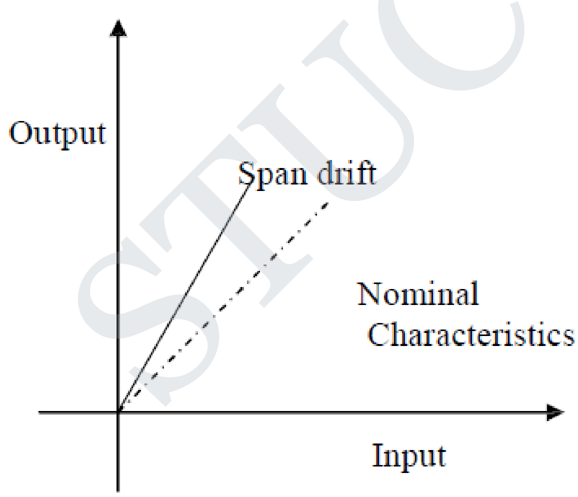


$$\% \text{ non-linearity} = \frac{\text{Max. deviation of output from idealized straight line}}{\text{Full scale reading}}$$

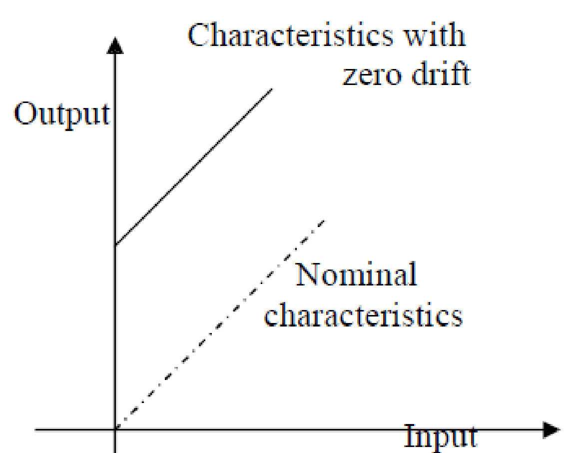
Reproducibility:
It is the degree of closeness with which a given value may be repeatedly measured. It is specified in terms of scale readings over a given period of time.

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

Drift:
Drift may be classified into three categories:
a) zero drift:
If the whole calibration gradually shifts due to slippage, permanent set, or due to undue warming up of electronic tube circuits, zero drift sets in.



(Fig) span drift



(fig) zero drif

b) span drift or sensitivity drift

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

c) Zonal drift:

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

Resolution:

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

Threshold:

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

Stability:

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

Tolerance:

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

Range or span:

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

Speed of response:

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

Measuring lag:

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.

Dynamic error:

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.

ERRORS IN MEASUREMENT
The types of errors are follows
i) Gross errors
ii) Systematic errors
iii) Random errors
Gross Errors:
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'.**
Ways to minimize gross errors:
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.
Systematic errors:
A constant uniform deviation of the operation of an instrument is known as a Systematic error
The Systematic errors are mainly due to the short comings of the instrument & the characteristics of the material use d in the instrument, such a s defective or worn parts, ageing effects, env iron metal effects, etc.
Types of Systematic errors:
There are three types of Systematic errors as:
i) Instrumental errors
ii) Environmental errors iii) Observational errors
Instrumental errors:
These errors can be mainly due to the following three reasons:
a) Short comings of instruments:
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 .,
Ways to minimize this error:
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) Misuse of instruments:
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) Loading effects
Loading effects due to im proper way of using the instrument cause the serious errors. The best ex ample of such loading effect error is connecting a w ell calibrated volt meter across the two points of high resistance circuit. The same volt meter connected in a low resistance circuit gives accurate reading..
to minimize this error:
Thus the err ors due to the loading effect can be avoided by using an instrument intelligently and correctly.
Environmental errors:

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, and ageing of equipment and frequency sensitivity of an instrument.

Ways to minimize this error:

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.

Observational errors:

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.
Ways to minimize this error
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.

Random errors:

Some errors still result, though the systematic and instrumental errors are reduced or at least accounted for. The causes of such errors are unknown and hence the errors are called random errors.
Ways to minimize this error 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.

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, g generally u sing different observers, different instruments & by different ways of measurement. The statistical analysis helps to determine analytically t he uncertainty of the final test results.
Arithmetic mean & median:
When the n umber 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,

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

This mean is very close to true value, if number of readings is very large.
But when the number of readings is large, calculation of mean value is complicated. In such a case, a median value is obtained which is obtained which is a close approximation to the arithmetic mean value. For a set of µ 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
Average deviation:

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

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

Where
di=xi- X
di = deviation of ith reading
Xi= value of ith reading
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

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.
Types of calibration methodologies:
There are two methodologies for obtaining the comparison between test instrument & standard instrument. These methodologies are
i) Direct comparisons
ii) Indirect comparisons

Direct comparisons:

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.

Indirect comparisons:

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 is classified as i) International standards
ii) Primary standards

iii) Secondary standards IV) Working standards

International standards

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.

Primary standards

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.

Secondary standards

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.

Working standards

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

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.

Ammeters & Multimeters

Ammeters are connected in series

current to be measured and R is the resistance of ammeter. Therefore, ammeters should have a low

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

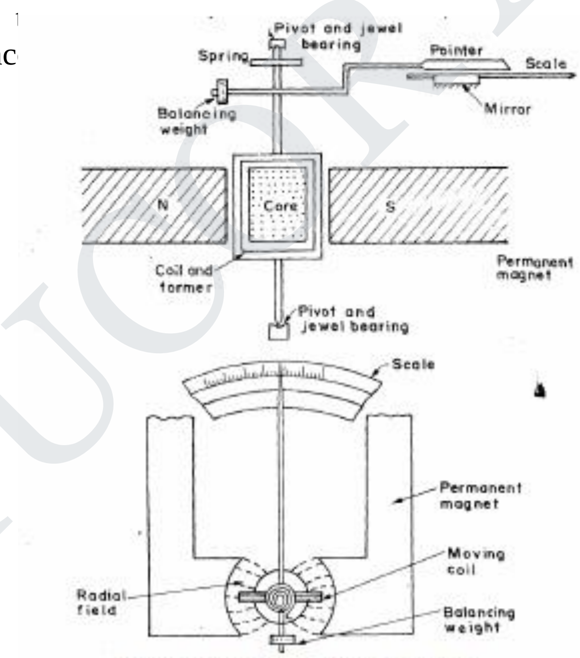
(vi) Induction

(vii) Electrostatic

viii) Rectifier.

Permanent Magnet Moving Coil Instrument (PMMC)

The permanent magnet moving coil instrument is the most accurate type for **d.c. measur ements**. The working principle of f the d' Arsonval type of galvanometers, the differenc rovided with a pointer and a scale.



(Fig) Permanent magnet moving coil instrument

Construction of PMMC Instruments

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

Magnet Systems

Ø Old style magnet system consisted of relatively long U shaped permanent magnets having soft iron pole pieces.

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

lengths and high field intensities.

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

Control

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

Ø These springs also serve to lead current in and out of the coil. The control torque is provided by the ribbon suspension as shown. Ø This method i s comparatively new and is claimed to be advantageous as it eliminates earing friction.

. Damping

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

Pointer and Scale

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

Ø The pointer is of light-weight construction and, apart from those used i n some inexpensive instruments has the section over the scale twisted to form a fine blade.

Ø This helps to reduce parallax err ors i n the reading of the scale.

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

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

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

where G = a constant = $NB\ ld$

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

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

and G being constants) we get a uniform (linear) scale for the instrument.

Errors in PMMC Instruments

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

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

Ø Weakening of springs due to ageing and temperature effects.

Ø Change of resistance of the moving coil with temperature.

Advantages and Disadvantages of PMMC Instruments

The main advantages of PMMC instruments are

Ø The scale is uniformly divided.

Ø The power consumption is very low

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

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

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

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

The chief disadvantages are

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

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

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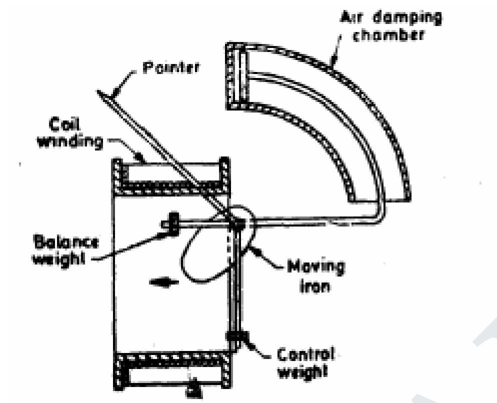
Moving Iron Instruments

Classification of Moving Iron Instruments

Moving iron instruments are of two types

(i) Attraction type. (ii) Repulsion type.

Attraction Type



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

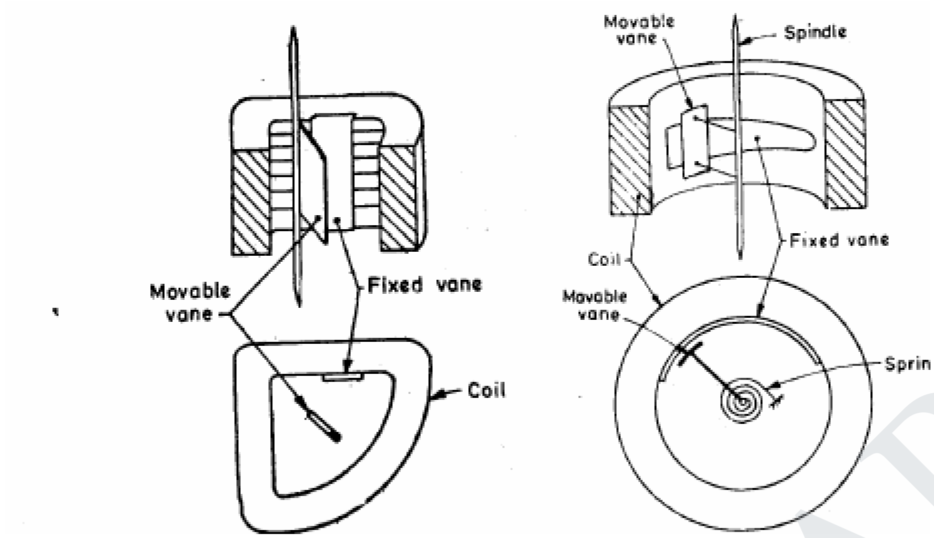
(I) Radial Vane Type

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 be 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 dș a mechanical work will be done. Let Td be the deflecting torque.

Mechanical work done = Td. d ș

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

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

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

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

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

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

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

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

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 y the controlling torque $T_c = K\theta$

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

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

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

operating current. The deflecting torque is, therefore, uni- directional (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

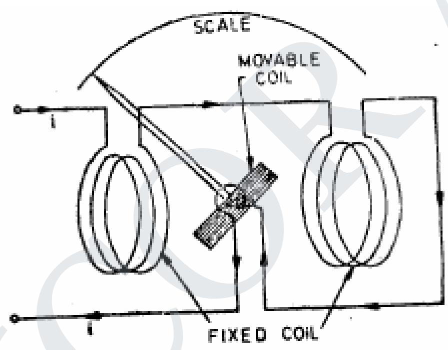
Frequency errors

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 on alternating 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 instruments 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

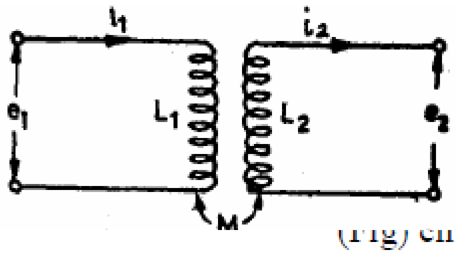
Let i1 = instantaneous value of current in the fixed coils: A.

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, ɀ1 = L1 i1 + Mi2

Flux linkages f coil 2, ɀ2 = 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.

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

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

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

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.

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

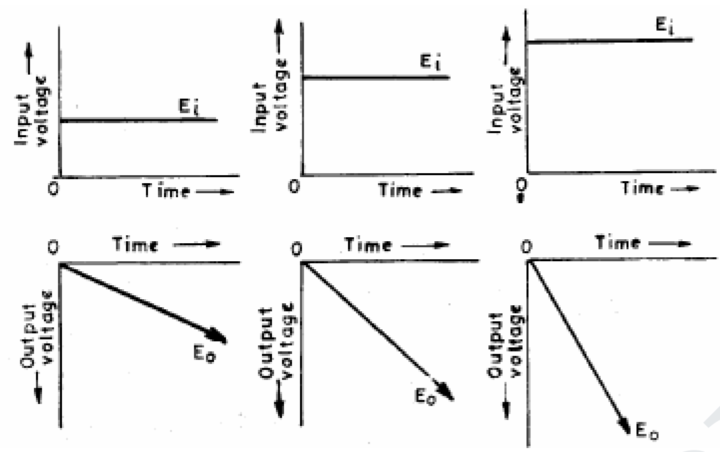
(iv) Successive approximation type DVM (v) Continuous balance type DVM

Ramp type Digital Voltmeter

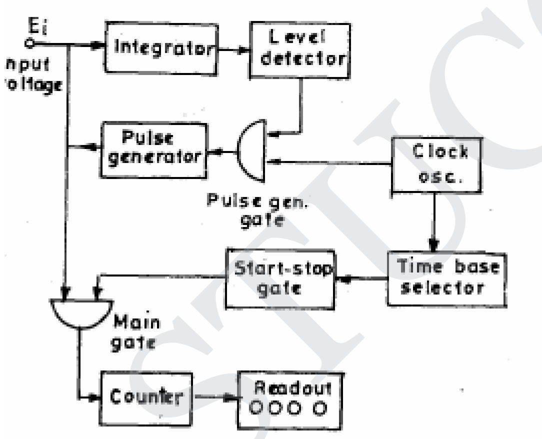
The operating principle of a ramp type digital voltmeter is to measure the time that a linear ramp voltage takes to change from level of input voltage to zero voltage (or vice versa).This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits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

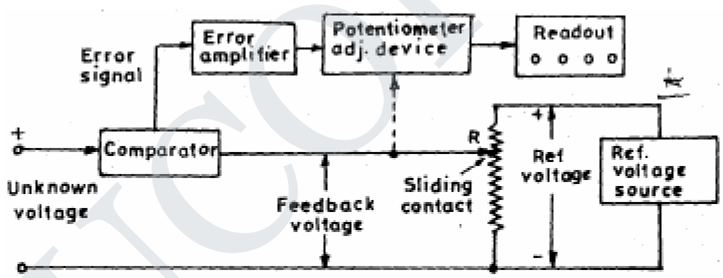


The unknown voltage is applied to the input of the integrator, and the output voltage starts to rise. The slope of output voltage is determined by the value of input voltage This voltage is fed a level detector, and when voltage reaches a certain reference level, the detector sends a pulse to the pulse 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.



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 adjustment device which moves the sliding contact of the potentiometer. This magnitude by which the sliding contact moves depends upon the magnitude of the error signal.

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

PRINCIPLE AND TYPES OF MULTI METERS – SINGLE AND THREE PHASE WATT METERS AND ENERGY METERS – MAGNETIC MEASUREMENTS – DETERMINATION OF B-H CURVE AND MEASUREMENTS OF IRON LOSS – INSTRUMENT TRANSFORMERS – INSTRUMENTS FOR MEASUREMENT OF FREQUENCY AND PHASE.

SINGLE 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

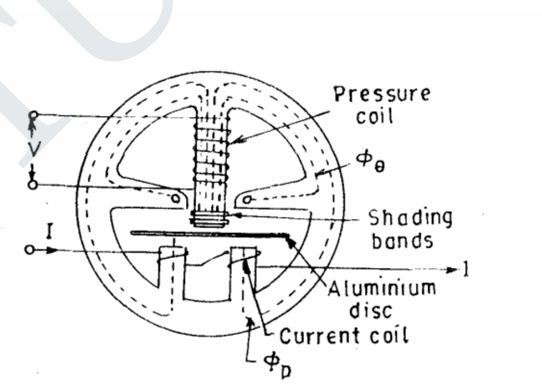
(i) Driving system (ii) Moving system (iii) Braking system (iv) Registering system

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

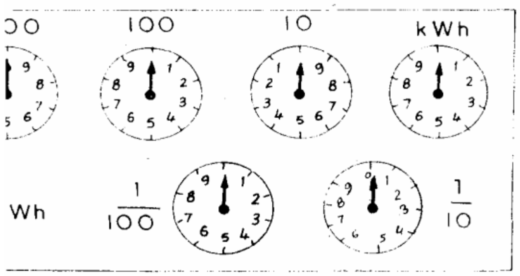
This consists of an aluminum disc mounted on a light alloy shaft. This disc is positioned in the air gap between series and shunt magnets. The upper bearing of the rotor (moving system) is a steel pin located in a hole in the bearing cap fixed to the top of the shaft. The rotor runs on a hardened steel 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.



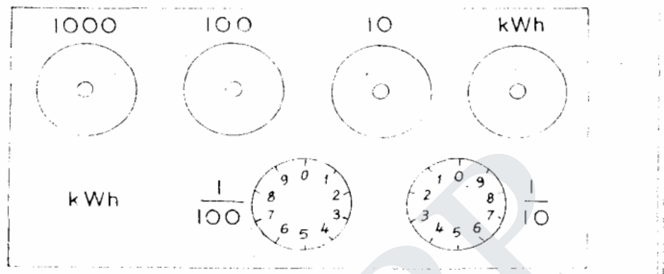
SINGLE PHASE ENERGY METER

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.



POINTER TYPE



CYCLOMETER REGISTER

REGISTERING (COUNTING) MECHANISM

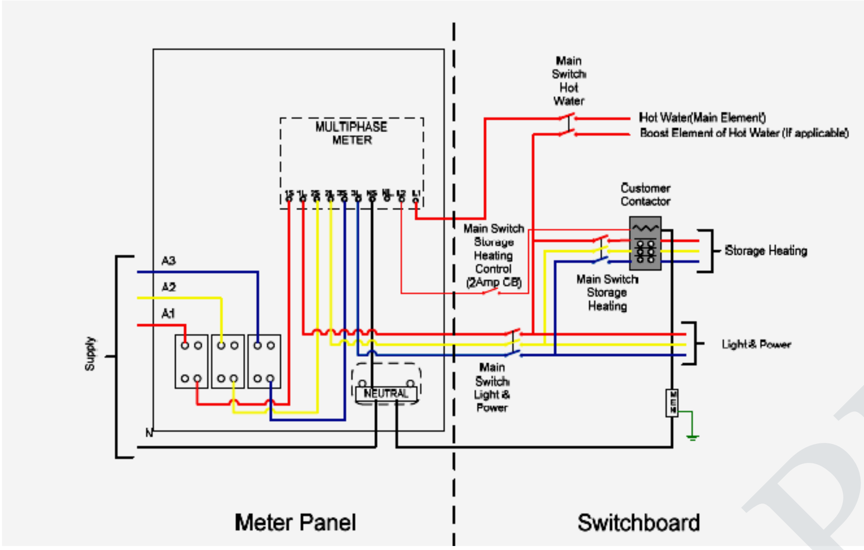
The function of a registering or counting mechanism is to record continuously a number which is proportional to the revolutions made by the moving system. By a suitable system, a train of reduction gears the pinion on the rotor shaft drives a series of five or six pointers. These rotate on round dials 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)
- 2.5mm^2 with 7 strands for conductors to control customer contactor
- Load carrying conductors not less than 4mm^2 or greater than 35mm^2
- All metering neutrals to be black colour 4mm^2 or 6 mm^2 with minimum 7 stranded conductors.
- Not less than 18 strand for 25 & 35mm^2 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

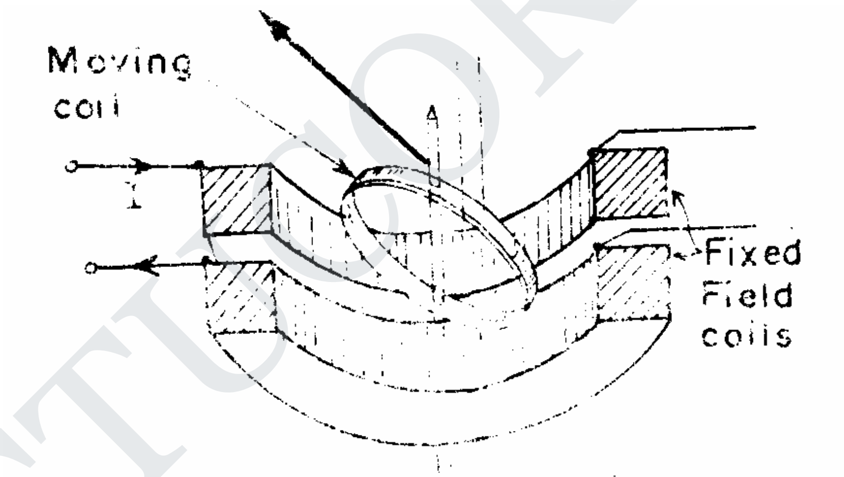
- These instruments are similar in design and construction to electrodynamometer type ammeters and voltmeters.
- The two coils are connected in different circuits for measurement of power.
- The fixed coils or " field coils" arc connected in series with the load and so carry the current in the circuit.
- 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.



DYNAMOMETER WATTMETER

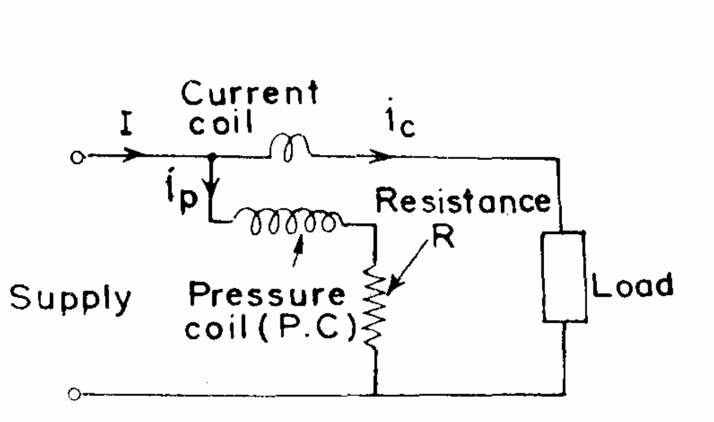
Damping

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



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 2 Ȧt).
Average deflecting torque,

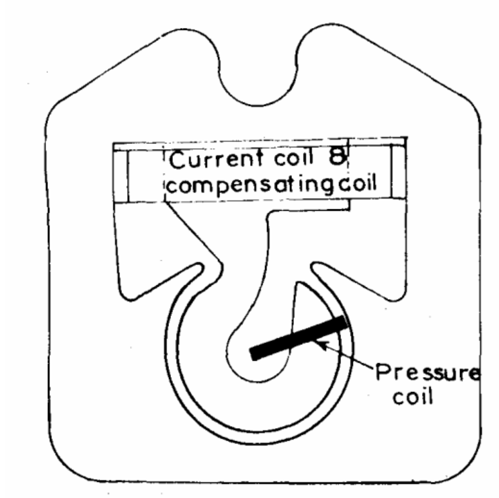
$$T_d = \frac{1}{T}\int_0^T T_i \, d(\omega t) = \frac{1}{T}\int_0^T I_p \, I \, [\cos\phi - \cos(2\omega t - \phi)] \, \frac{dM}{d\theta} \, . \, d(\omega t)$$
$$= I_p \, I \cos\phi \, . \, dM/d\theta$$
$$= (VI/R_p) \cos\phi \, . \, dM/d\theta$$

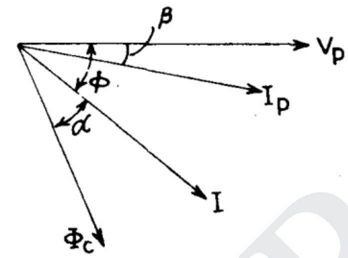
Controlling torque exerted by springs Tc= Kș
Where, K = spring constant; ș= final steady deflection.

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.

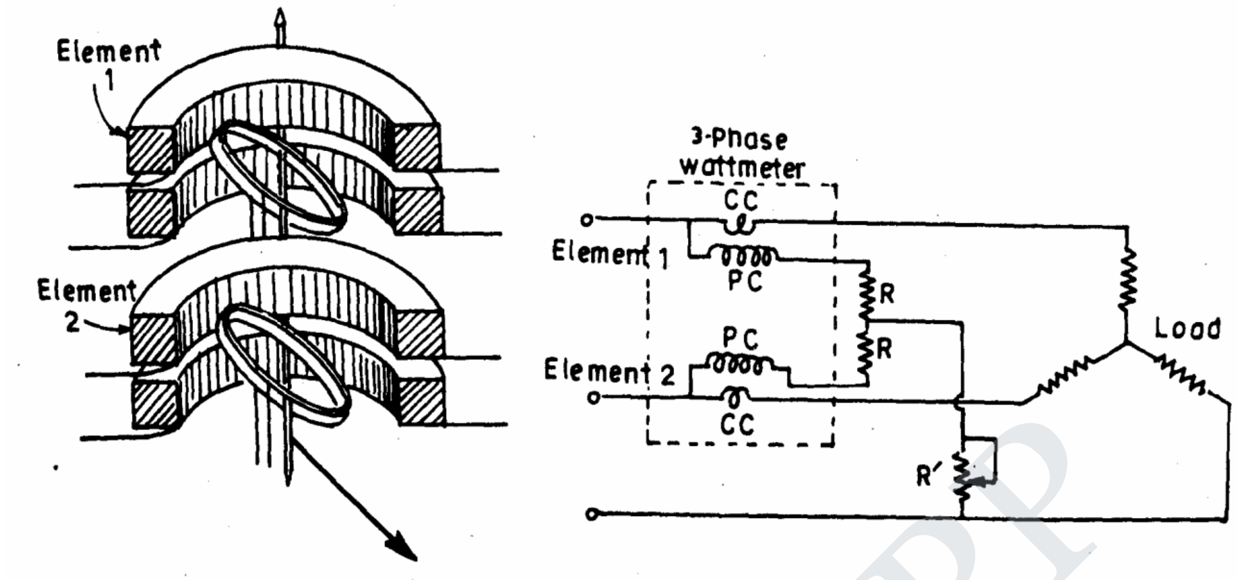




The use of ferromagnetic core makes it possible to employ a robust construction for the moving element. Also the Instrument is less sensitive to external magnetic fields. On the other hand, this construction introduces non-linearity of magnetization curve and introduction of large eddy current & hysteresis losses in the core.

THREE PHASE WATTMETERS

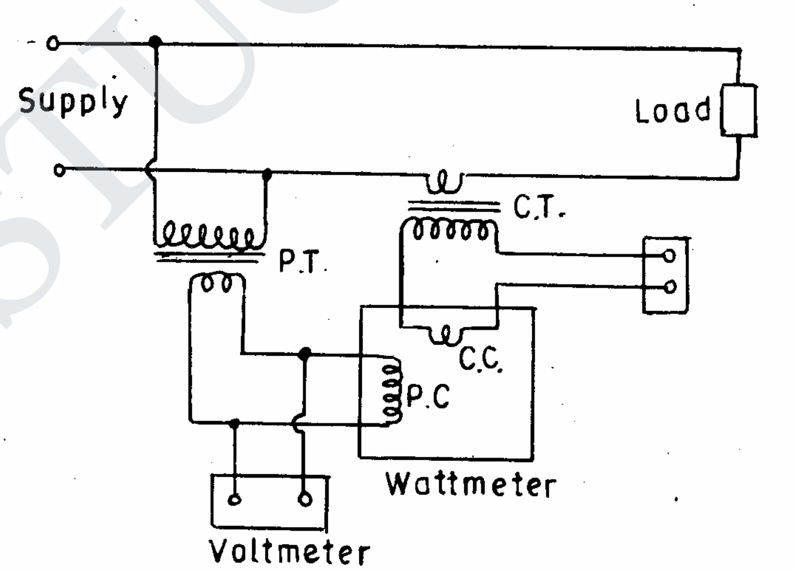
A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle. The arrangement is shown in Fig. There are two current coils and two pressure coils. A current coil together with its pressure coil 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.



THREE PHASE WATTMETER

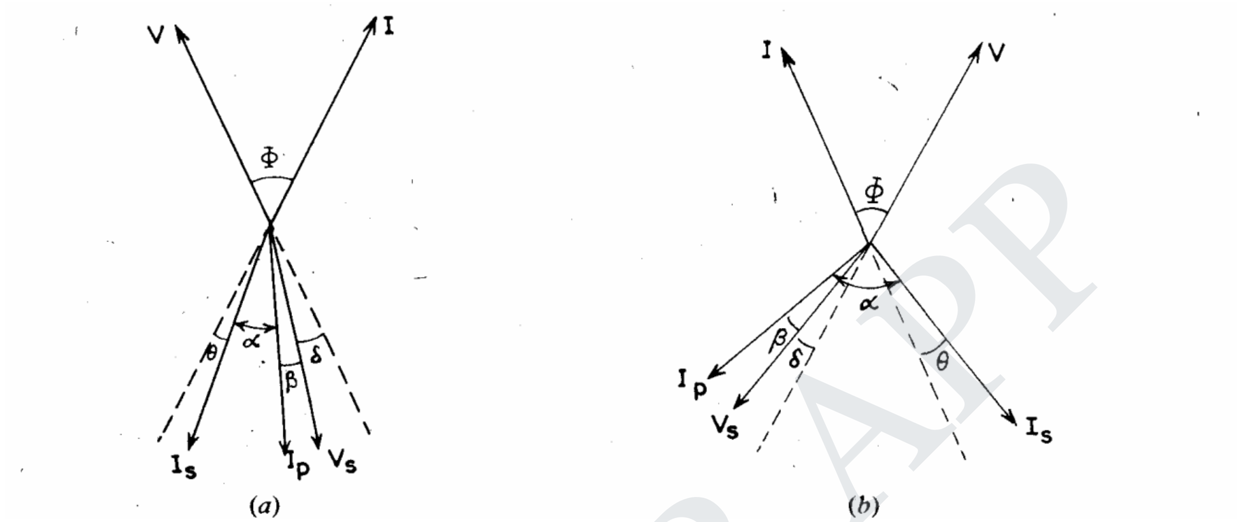
INSTRUMENT TRANSFORMERS

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 affected 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



of Ferro-magnetic materials used for their construction. Therefore, magnetic measurements and a thorough knowledge of characteristics of magnetic materials are of utmost importance in designing and manufacturing electrical equipment.

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

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

Types of Tests

Many methods of testing magnetic materials have been devised wherein attempts have been made to eliminate the inaccuracies. However, attention will be confined to a few basic methods of ‘ Testing Ferro-magnetic materials. They are:

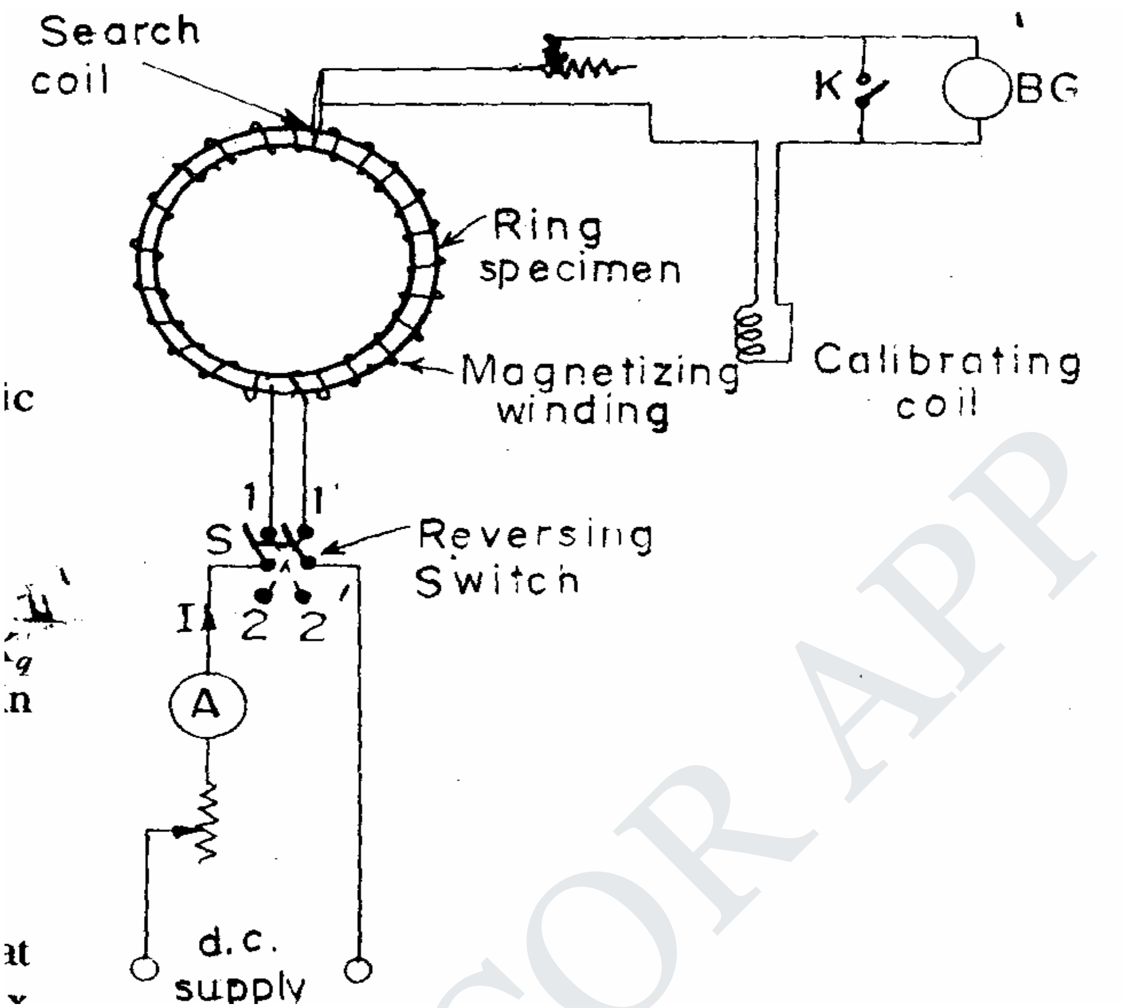
(i) Ballistic Tests: These tests are generally employed for the determination of B- H curves and hysteresis loops of Ferro-magnetic materials.
(ii) A. C. Testing. These tests may be carried at power, audio or radio frequencies. They give information about eddy current and hysteresis losses in magnetic materials.
(iii) Steady State Tests. These are performed to obtain the steady value of flux density existing in the air gap of a magnetic circuit.

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

MEASUREMENT OF FLUX DENSITY

The measurement of flux density inside a specimen can be done by winding a search coil over the specimen. This search coil is known as a " B coil" . This search coil is then connected to a ballistic galvanometer or to a flux meter.

Let us consider that we have to measure the flux density in a ring specimen shown in Fig. The ring specimen is wound with a magnetizing winding which carries a current I. A search coil of convenient number of turns is wound on the specimen and connected through a resistance and calibrating coil, to a ballistic galvanometer as shown. The current through the magnetizing coil is reversed and therefore the flux linkages of the search coil change inducing an emf in it. Thus emf sends a current through the ballistic galvanometer causing it to deflect.

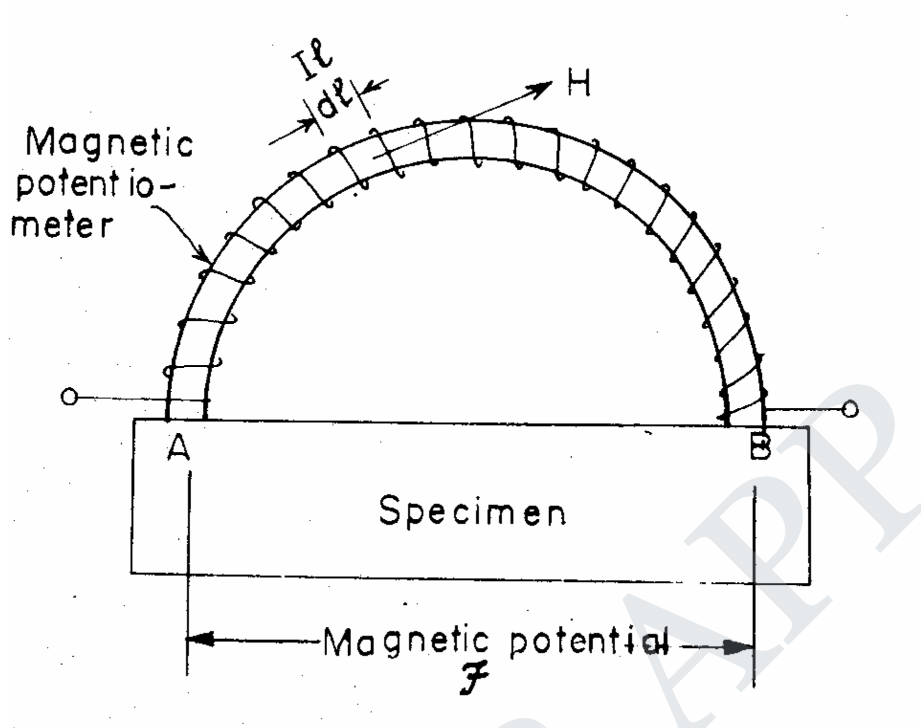


MAGNETIC POTENTIOMETER

This is a device for measurement of magnetic potential difference between two points. It can be shown that the line integral of magnetizing force H produced by a coil of N concentrated turns carrying a current I is:

$$\int H dl = NI$$

around any closed path linking the coil.



Magnetic potentiometer

This is the circuital law of the magnetic field and forms the basis of magnetic potentiometer. A magnetic potentiometer may be used to determine the mmf around a closed path, or the magnetic potential difference between two points in a magnetic circuit. A magnetic potentiometer consists of a one metre long flat and uniform coil made of two or four layers of thin wire wound unidirectional on a strip of flexible non-magnetic material. The coil ends are brought out at the middle of the strip as shown in Fig. and connected to a ballistic galvanometer. The magnetic potential difference between points A and B of the field is measured by placing the ends of the strip at these points and observing the throw of the ballistic galvanometer when the flux through the specimen is changed.

DETERMINATION OF B-H CURVE

Method of reversals

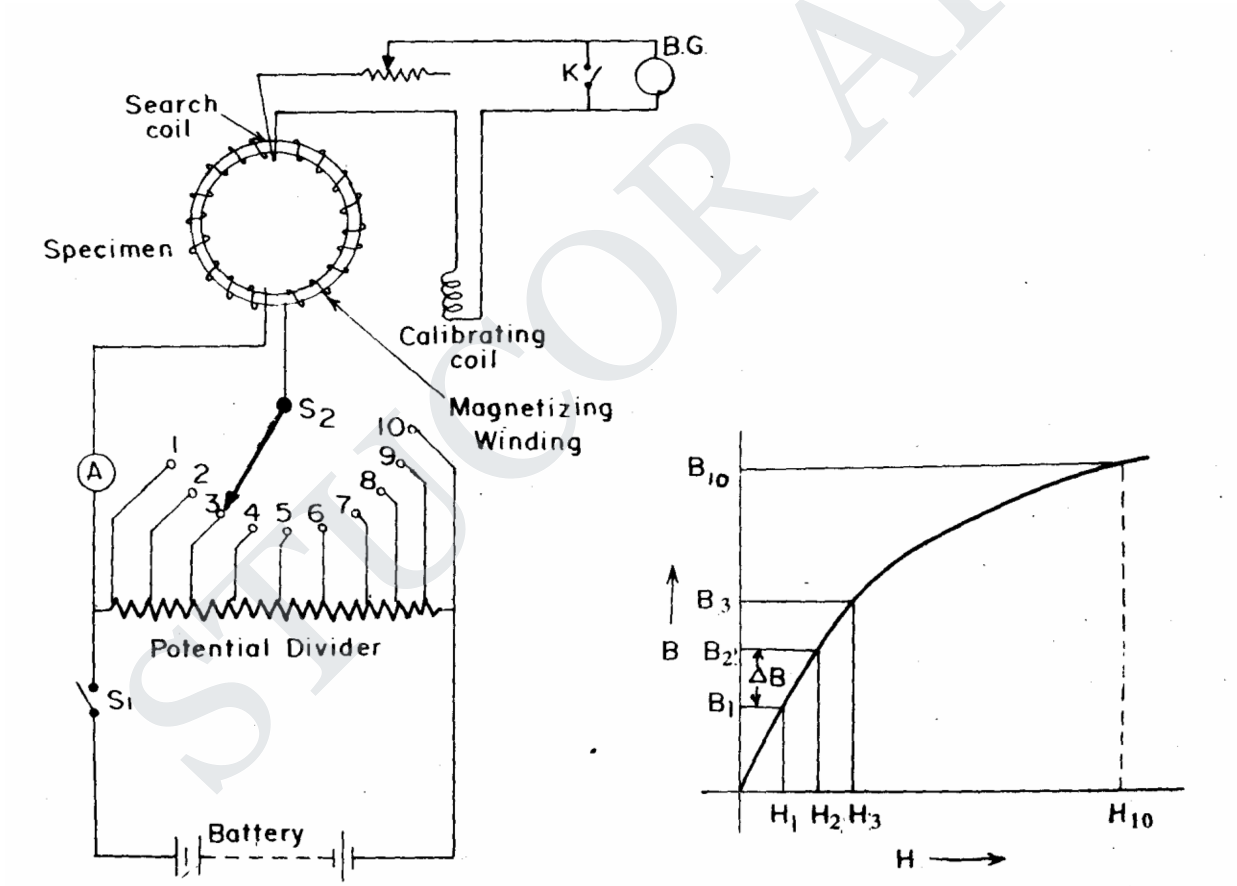
A ring shaped specimen whose dimensions are known is used for the purpose After demagnetizing the test is started by setting the magnetising current to its lowest test vlane. With galvanometer key K closed, the iron specimen is brought into a ‘ reproducible cyclic magnetic state’ by throwing the reversing switch S backward and forward about twenty times.
Key K is now opened and the value of flux corresponding to this value of H is measured by reversing the switch S and noting the throw of galvanometer. The value of flux density corresponding to this H can be calculated by dividing the flux by the area of the specimen.
The above procedure is repeated for various values of H up to the maximum testing point.
The B-H curve may be plotted from the measured values of B corresponding to the various values of H.

Step by step method

The circuit for this test is shown in Fig. The magnetizing winding is supplied through a potential divider having a large number of tapping. The tappings are arranged so that the magnetizing force H may be increased, in a number of suitable steps, up to the desired maximum value. The specimen before being tested is demagnetized. The tapping switch S is set on tapping I and the switch S is closed. The throw of the galvanometer corresponding to this increase in flux density in the specimen, form zero to some value B, is observed.

Step by step method

After reaching the point of maximum H i.e... when switch S is at tapping 10, the magnetizing current is next reduced, in steps to zero by moving switch 2 down through the tapping points 9, 8, 7 3, 2, 1. After reduction of magnetizing force to zero, negative values of H are obtained by reversing the supply to potential divider and then moving the switch S up again in order 1, 2, 3 7, 8. 9, 10.

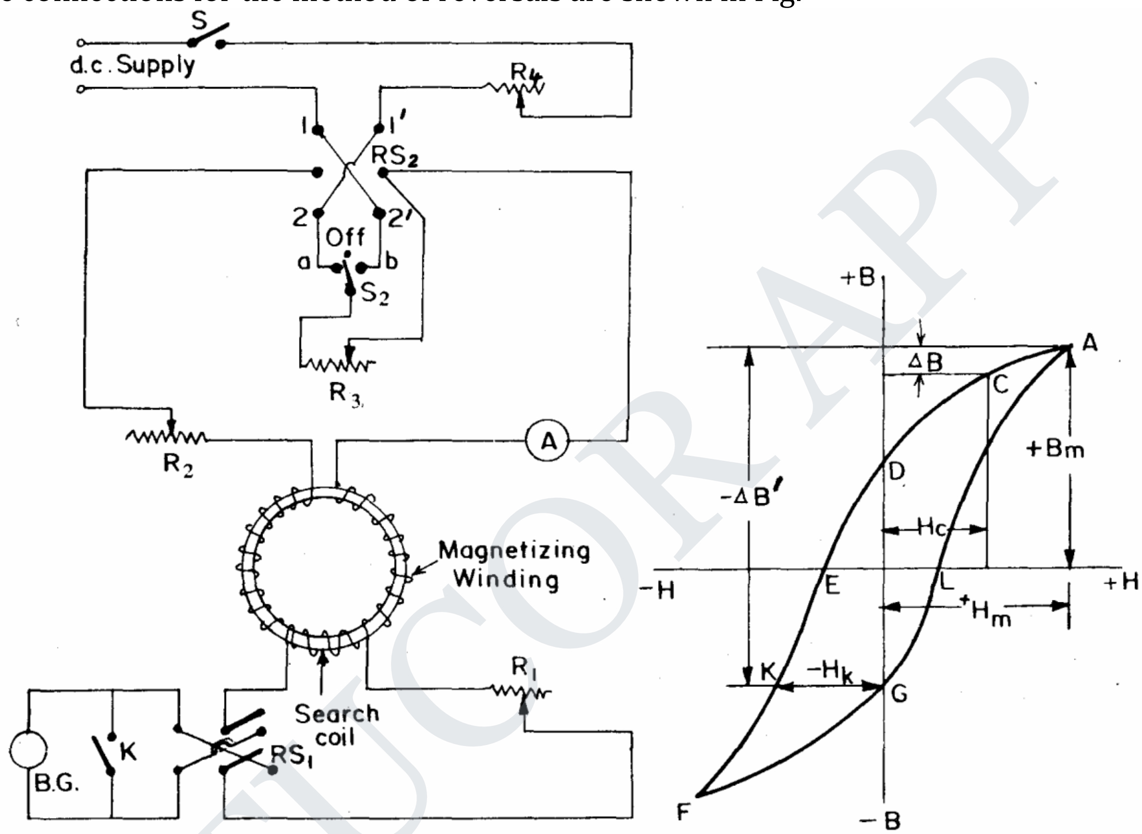


DETERMINATION OF HYSTERESIS LOOP

Method of reversals

This test is done by means of a number of steps, but the change in flux density measured at each step is the change from the maximum value + Bm down to some lower value. But before the next step is commenced the iron specimen is passed through the remainder of the cycle of magnetization back to the flux density + Bm. Thus the cyclic state of magnetization is preserved.

The connections for the method of reversals are shown in Fig.



Method of reversal

MEASUREMENT OF FREQUENCY :

A frequency meter is an instrument that displays the frequency of a periodic electrical signal.

Various types of frequency meters are used. Many are instruments of the deflection type, ordinarily used for measuring low frequencies but capable of being used for frequencies as high as 900 Hz. These operate by balancing two opposing forces. Changes in the frequency to be measured cause a change in this balance that can be measured by the deflection of a pointer on a scale. Deflection-type meters are of two types, electrically resonant circuits and ratiometers.

An example of a simple electrically resonant circuit is a moving-coil meter. In one version, this device has two coils tuned to different frequencies and connected at right angles to one another in such a way that the whole element, with attached pointer, can move. Frequencies in the middle of the meter's range cause the currents in the two coils to be approximately equal and the pointer to indicate the midpoint of a scale. Changes in frequency cause an imbalance in the currents in the two coils, causing them, and the pointer, to move.

Another type of frequency meter, Weston Frequency meter is not of the deflection type, is the resonant reed type, ordinarily used in ranges from 10 to 1,000 Hz, although special designs can operate at lower or higher frequencies.

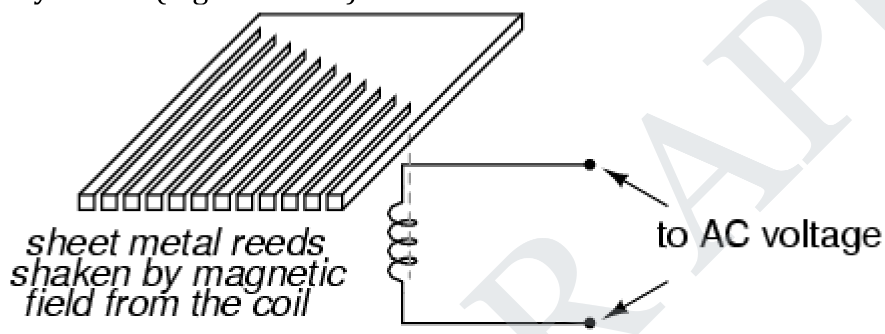
The main principle of working of weston type frequency meter is that "when an current flows through the two coils which are perpendicular to each other, due to these currents some magnetic fields will produce and thus the magnetic needle will deflects towards the stronger magnetic field showing the measurement of frequency on the meter". Construction of weston frequency is as compared to ferrodynamic type of frequency meter. In order to construct a circuit diagram we need two coils, three inductors and two resistors. Axis of both coils are marked as shown. Scale of the meter is calibrated such that at standard frequency the pointer will take position at 45o. Coil 1 contains a series resistor marked R1 and reactance coil marked as L1, while the coil 2 has a series reactance coil marked as L2 and parallel resistor marked as R2. The inductor which is marked as L0 is connected in series with the supply voltage in order to reduce the higher harmonic means here this inductor is working as a filter circuit. Let us look at the working of this meter.

Now when we apply voltage at standard frequency then the pointer will take normal position, if there increase the frequency of the applied voltage then we will see that the pointer will moves towards left marked as higher side as shown in the circuit diagram. Again we reduce the frequency the pointer will start moving towards the right side, if lower the frequency below the normal frequency then it cross the normal position to move towards left side marked lower side as shown in the figure. Now let us look at the internal working of this meter. Voltage drop across an inductor is directly proportion to frequency of the source voltage, as we increase the frequency of the applied voltage the voltage drop across the inductor L1 increase that means the voltage impressed between the coil 1 is increased hence the current through the coil 1 increase while the current through the coil 2 decreases. Since the current through the coil 1 increases the magnetic field also increases and the magnetic needle attracts more towards the left side showing the increment in the frequency. Similar action will takes if decrease the frequency but in this the pointer will moves towards the left side.

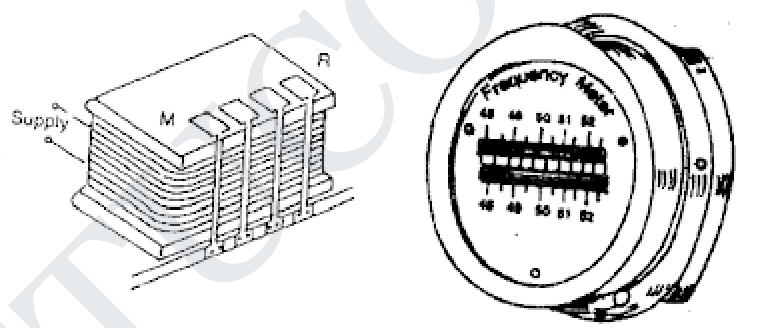
- Weston frequency meter
- Electrical resonance type frequency meter
- Mechanical resonance type frequency meter
- Digital frequency meter

An important electrical quantity with no equivalent in DC circuits is *frequency*. Frequency measurement is very important in many applications of alternating current, especially in AC power systems designed to run efficiently at one frequency and one frequency only. If an electromechanical alternator is generating the AC, the frequency will be directly proportional to the shaft speed of the machine, and frequency could be measured simply by measuring the speed of the shaft. If frequency needs to be measured at some distance from the alternator, though, other means of measurement will be necessary.

One simple but crude method of frequency measurement in power systems utilizes the principle of mechanical resonance. Every physical object possessing the property of elasticity (springiness) has an inherent frequency at which it will prefer to vibrate. The tuning fork is a great example of this: strike it once and it will continue to vibrate at a tone specific to its length. Longer tuning forks have lower resonant frequencies: their tones will be lower on the musical scale than shorter forks. Imagine a row of progressively sized tuning forks arranged side-by-side. They are all mounted on a common base, and that base is vibrated at the frequency of the measured AC voltage (or current) by means of an electromagnet. Whichever tuning fork is closest in resonant frequency to the frequency of that vibration will tend to shake the most (or the loudest). If the forks' tines were flimsy enough, we could see the relative motion of each by the length of the blur we would see as we inspected each one from an end-view perspective. Well, make a collection of "tuning forks" out of a strip of sheet metal cut in a pattern akin to a rake, and you have the *vibrating reed* frequency meter: (Figure below)

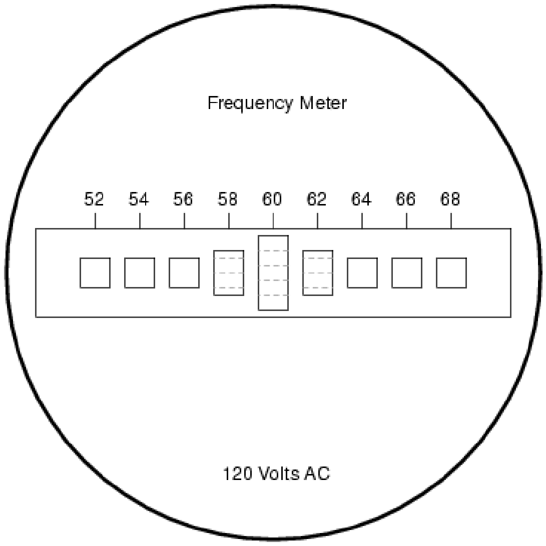


Vibrating reed frequency meter diagram.



Vibrating Reed Frequency Meter.

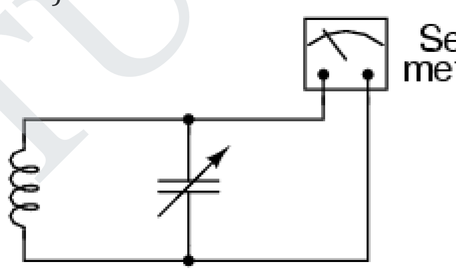
The user of this meter views the ends of all those unequal length reeds as they are collectively shaken at the frequency of the applied AC voltage to the coil. The one closest in resonant frequency to the applied AC will vibrate the most, looking something like Figure below.



Vibrating reed frequency meter front panel

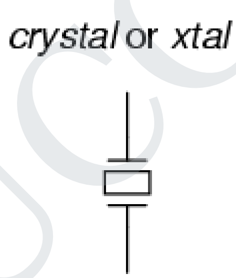
Vibrating reed meters, obviously, are not precision instruments, but they are very simple and therefore easy to manufacture to be rugged. They are often found on small engine-driven generator sets for the purpose of setting engine speed so that the frequency is somewhat close to 60 (50 in Europe) Hertz.

While reed-type meters are imprecise, their operational principle is not. In lieu of mechanical resonance, we may substitute electrical resonance and design a frequency meter using an inductor and capacitor in the form of a tank circuit (parallel inductor and capacitor). See Figure below. One or both components are made adjustable, and a meter is placed in the circuit to indicate maximum amplitude of voltage across the two components. The adjustment knob(s) are calibrated to show resonant frequency for any given setting, and the frequency is read from them after the device has been adjusted for maximum indication on the meter. Essentially, this is a tunable filter circuit, which is adjusted and then read in a manner similar to a bridge circuit (which must be balanced for a “null” condition and then read).



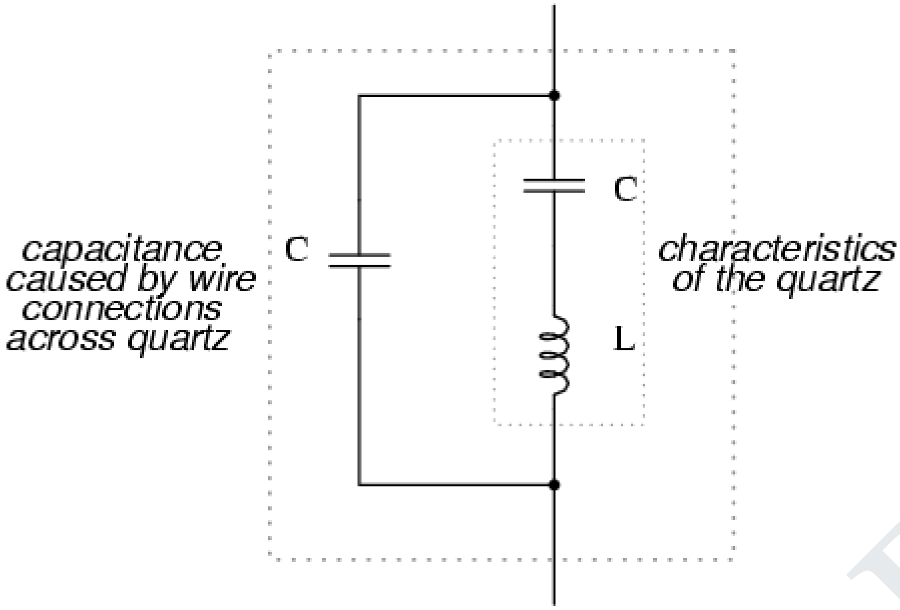
This technique is a popular one for amateur radio operators (or at least it was before the advent of inexpensive digital frequency instruments called *counters*), especially because it doesn't require direct connection to the circuit. So long as the inductor and/or capacitor can intercept enough stray field (magnetic or electric, respectively) from the circuit under test to cause the meter to indicate, it will work. In frequency as in other types of electrical measurement, the most accurate means of measurement are usually those where an unknown quantity is compared against a known *standard*, the basic instrument doing nothing more than indicating when the two quantities are equal to each other. This is the basic principle behind the DC (Wheatstone) bridge circuit and it is a sound metrological principle applied throughout the sciences. If we have access to an accurate frequency standard (a source of AC voltage holding very precisely to a single frequency), then measurement of any unknown frequency by comparison should be relatively easy. For that frequency standard, we turn our attention back to the tuning fork, or at least a more modern variation of it called the *quartz crystal*. Quartz is a naturally occurring mineral possessing a very interesting property called *piezoelectricity*. Piezoelectric materials produce a voltage across their length when physically stressed, and will physically deform when an external voltage is applied across their lengths. This deformation is very, very slight in most cases, but it does exist. Quartz rock is elastic (springy) within that small range of bending which an external voltage would produce, which means that it will have a mechanical resonant frequency of its own capable of being manifested as an electrical voltage signal. In other words, if a chip of quartz is struck, it will “ring” with its own unique frequency determined by the length of the chip, and that resonant oscillation will produce an equivalent voltage across multiple points of the quartz chip which can be tapped into by wires fixed to the surface of the chip. In reciprocal manner, the quartz chip will tend to vibrate most when it is “excited” by an applied AC voltage at precisely the right frequency, just like the reeds on a vibrating-reed frequency meter.

Chips of quartz rock can be precisely cut for desired resonant frequencies, and that chip mounted securely inside a protective shell with wires extending for connection to an external electric circuit. When packaged as such, the resulting device is simply called a *crystal* (or sometimes “*xtal*”). The schematic symbol is shown in Figure below.



Crystal (frequency determing element) schematic symbol.

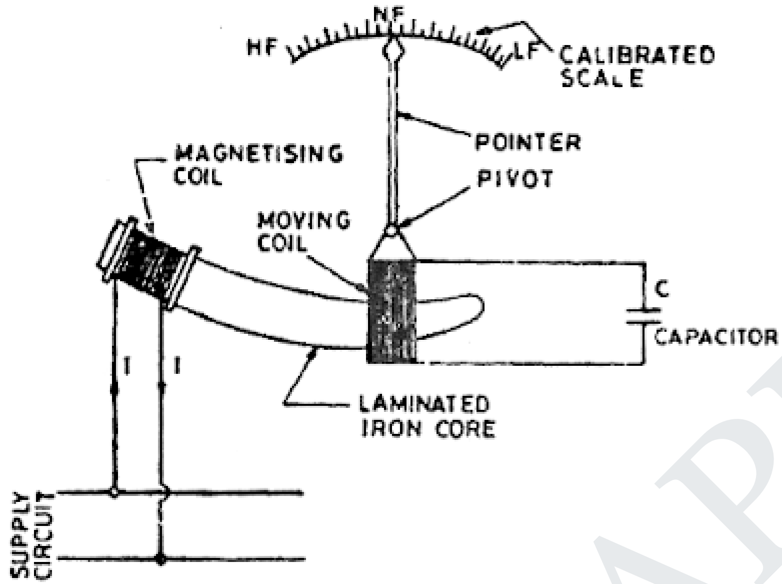
Electrically, that quartz chip is equivalent to a series LC resonant circuit. (Figure below) The dielectric properties of quartz contribute an additional capacitive element to the equivalent circuit.



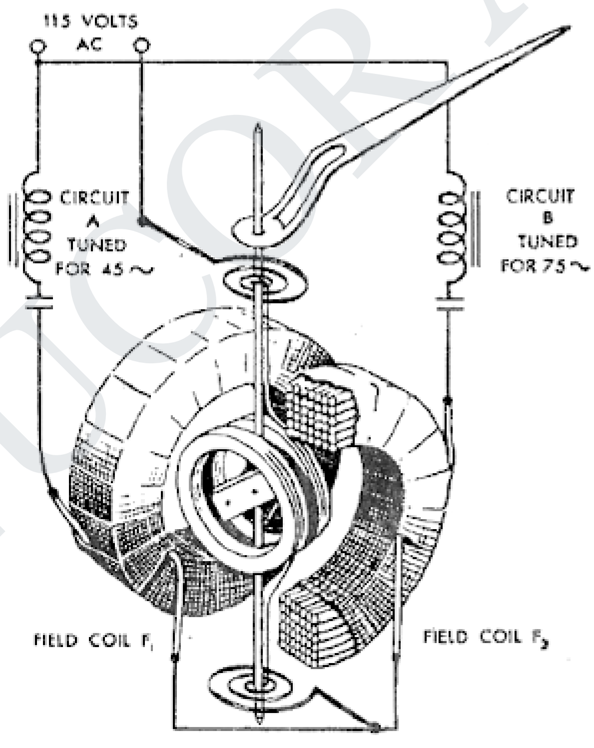
Quartz crystal equivalent circuit

The “capacitance” and “inductance” shown in series are merely electrical equivalents of the mechanical resonance properties: they do not exist as discrete components within the crystal. The capacitance shown in parallel due to the wire connections across the dielectric (insulating) quartz body is real, and it has an effect on the resonant response of the whole system. A full discussion on crystal dynamics is not necessary here, but what needs to be understood about crystals is this resonant circuit equivalence and how it can be exploited within an oscillator circuit to achieve an output voltage with a stable, known frequency. Crystals, as resonant elements, typically have much higher “Q” (*quality*) values than tank circuits built from inductors and capacitors, principally due to the relative absence of stray resistance, making their resonant frequencies very definite and precise. Because the resonant frequency is solely dependent on the physical properties of quartz (a very stable substance, mechanically), the resonant frequency variation over time with a quartz crystal is very, very low. This is how *quartz movement* watches obtain their high accuracy: by means of an electronic oscillator stabilized by the resonant action of a quartz crystal. For laboratory applications, though, even greater frequency stability may be desired. To achieve this, the crystal in question may be placed in a temperature stabilized environment (usually an oven), thus eliminating frequency errors due to thermal expansion and contraction of the quartz. For the ultimate in a frequency standard though, nothing discovered thus far surpasses the accuracy of a single resonating atom. This is the principle of the so-called *atomic clock*, which uses an atom of mercury (or cesium) suspended in a vacuum, excited by outside energy to resonate at its own unique frequency. The resulting frequency is detected as a radio-wave signal and that forms the basis for the most accurate clocks known to humanity. National standards laboratories around the world maintain a few of these hyper-accurate clocks, and broadcast frequency signals based on those atoms' vibrations for scientists and technicians to tune in and use for frequency calibration purposes.

ELECTRICAL RESONANCE TYPE FREQUENCY METER

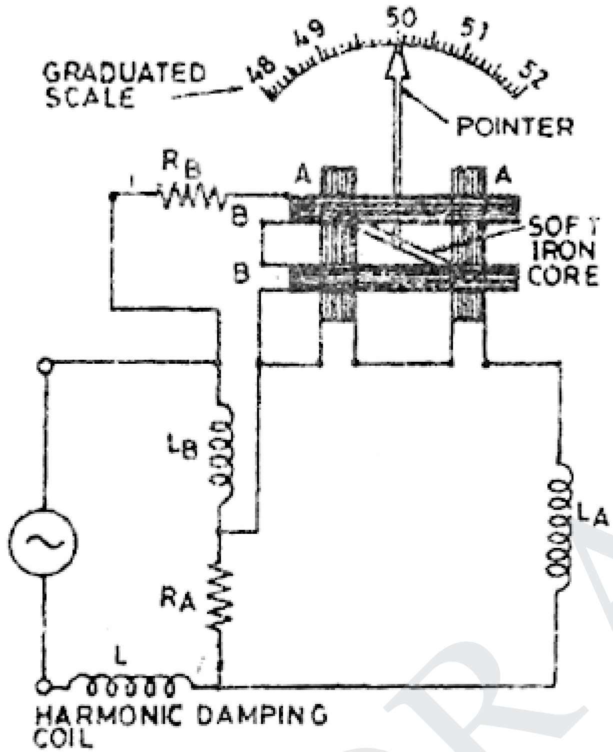


Electrical Resonance Frequency Meter.



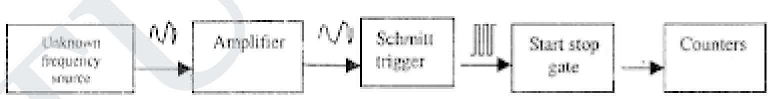
Resonant-circuit Frequency Meter.

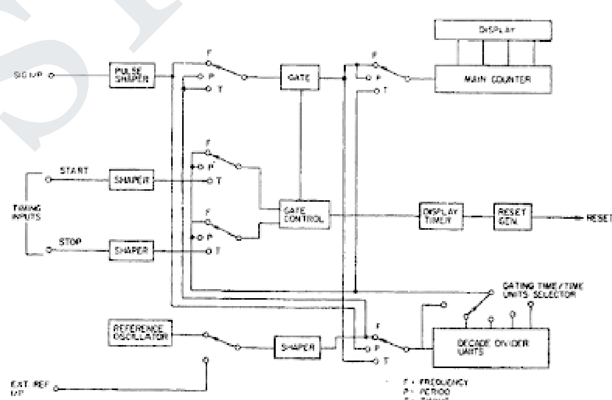
WESTON FREQUENCY METER:



Weston Frequency Meter

DIGITAL FREQUENCY METER:



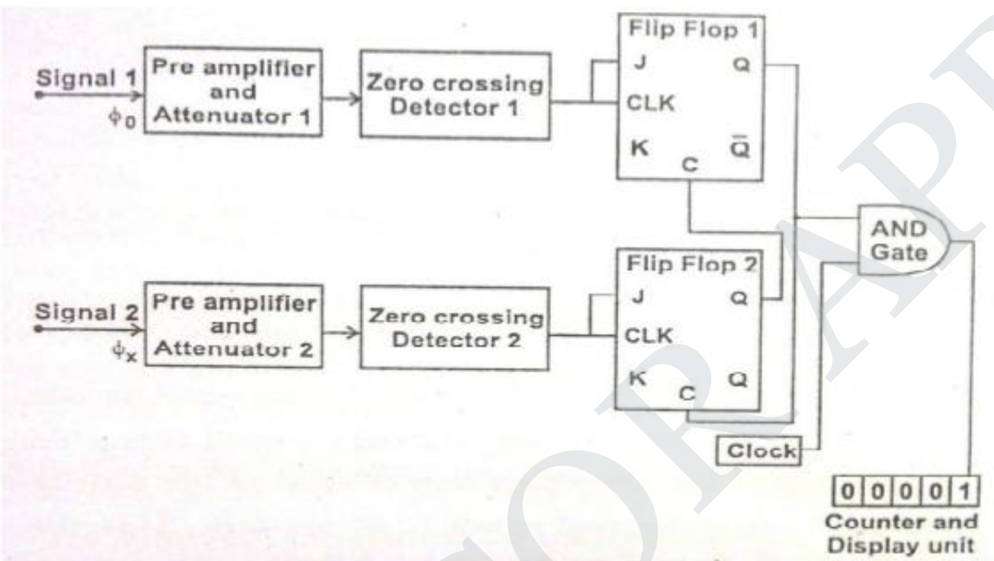


Block diagram of counter-timer or Frequency Meter.

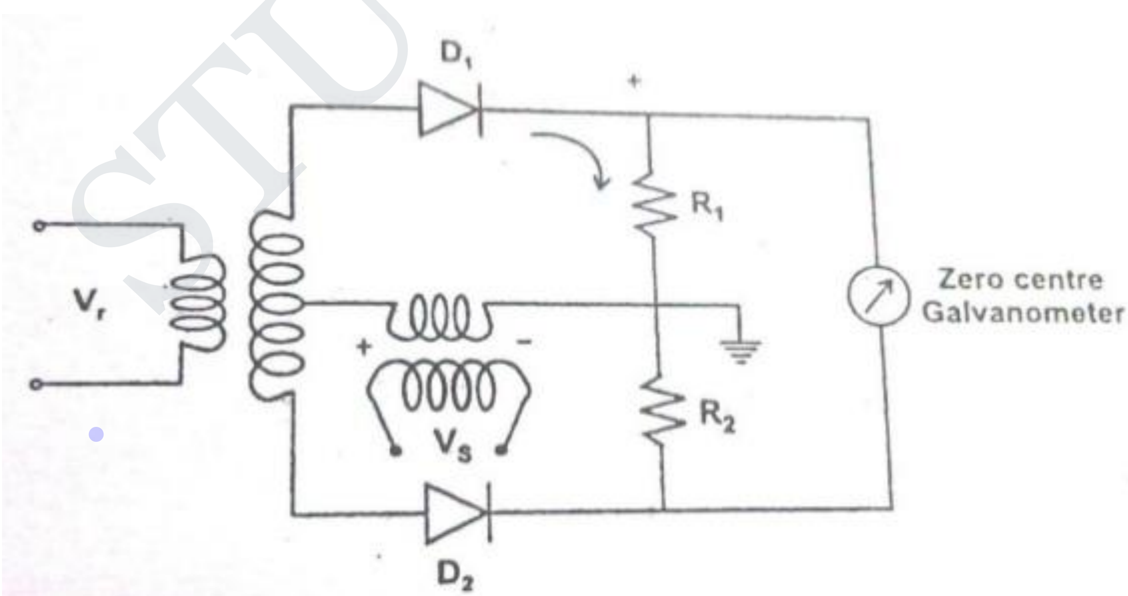
MEASUREMENT OF PHASE:

A device for measuring the difference in phase of two alternating currents of electromotive forces.

- Analog phase meter
- Digital phase meter

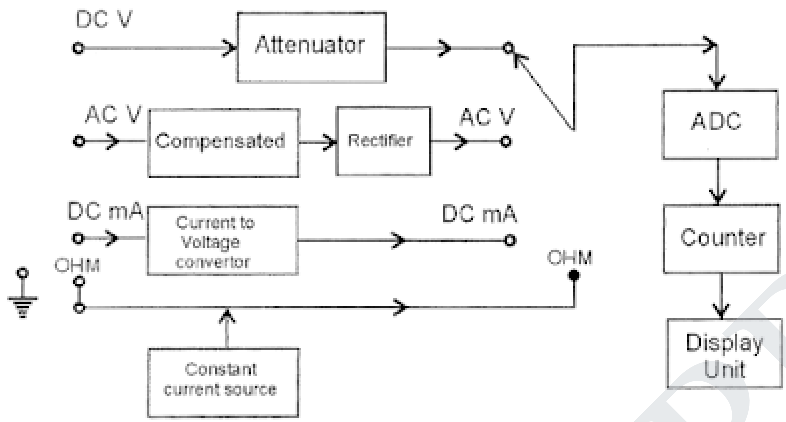


DIGITAL PHASE METER



ANALOG PHASE METER

DIGITAL MULTIMETER:



Block Diagram of Digital Multimeter

D.C potentiometers, D.C (Wheat stone, Kelvin and Kelvin Double bridge) & A.C bridges (Maxwell, Anderson and Schering bridges), transformer ratio bridges, self-balancing bridges. Interference & screening – Multiple earth and earth loops – Electrostatic and electromagnetic Interference – Grounding techniques.

UNIT-3

COMPARISON METHODS OF MEASUREMENTS

Prepared by :U.NAGABALAN., AP/EEE ., M.VENKATESWARAN., AP/EEE ., R.VANITHA., AP/EEE

DC Potentiometer

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: 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, 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.

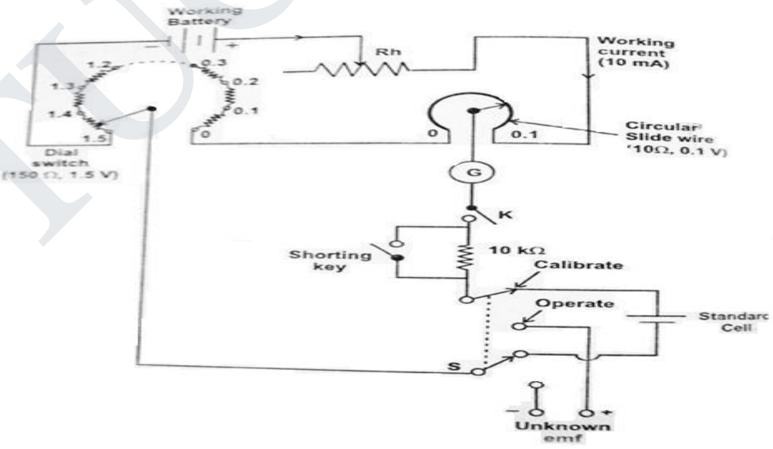


Figure 3.1 DC Potentiometer

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:

a slide-wire and phase-adjustable supply; separate in-phase and quadrature adjustments on Slide wires supplied from sources that have a 90° phase difference. Such potentiometers have limited use in magnetic testing.

An instrument that precisely measures an electromotive force (emf) or a voltage by opposing to it a known potential drop established by passing a definite current through a resistor of known characteristics. (A three-terminal resistive voltage divider is sometimes also called a potentiometer.) There are two ways of accomplishing this balance 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; 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.

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Balance in opposing an unknown voltage is achieved in one of two ways: a slide-wire and phase-adjustable supply; separate in-phase and quadrature adjustments on slide wires supplied from sources that have a 90° phase difference. Such potentiometers have limited use in magnetic testing an 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 quantities; when used with the appropriate measuring transducer, it can be used to gauge various nonelectrical quantities, such as temperature, pressure, and the composition of gases.

A 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 10^4 to 10^5 ohms (Ω) and a current ranging from 10^{-1} to 10^{-9} amperes (A), or low-resistance, with a slide-wire resistance below 2×10^3 ohms and a current ranging from 10^{-1} to 10^{-3} A.

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.

BRIDGES

Bridge circuits are mainly used to measure unknown quantities such as resistance, inductance, capacitance, Impedance and admittance. Bridge circuit consists of 4 resistance arms forming a closed circuit with dc source of current applied to two opposite junctions and a current detector connected to the other two junctions.

Types of bridges

- A.C Bridges
- D.C Bridges

DC Bridges

Wheatstone bridge

A Wheatstone bridge is an electrical circuit invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. Its operation is similar to the original potentiometer.

Operation

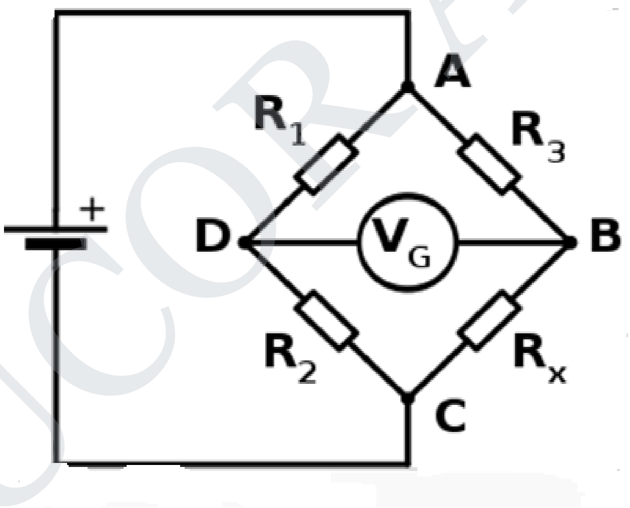


Figure 3.2 Wheatstone Bridge

In the figure 3.2, R_x is the unknown resistance to be measured; R_1, R_2 and R_3 are resistors of known resistance and the resistance of R_2 is adjustable. If the ratio of the two resistances in the known leg(R_2 / R_1) is equal to the ratio of the two in the unknown leg (R_x / R_3), then the voltage between the two midpoints (**B** and **D**) will be zero and no current will flow through the galvanometer V_g. If the bridge is unbalanced, the direction of the current indicates whether R_2 is too high or too low. R_2 is varied until there is no current through the galvanometer, which then reads zero. Detecting zero current with a galvanometer can be done to extremely high accuracy. Therefore, if R_1, R_2 and R_3 are known to high precision, then R_x can be measured to high precision. Very small changes in R_x disrupt the balance and are readily detected.

At the point of balance, the ratio of $R_2 / R_1 = R_x / R_3$

$$I_1 - I_2 - I_g = 0$$

$$I_3 - I_x + I_g = 0$$

Alternatively, if R_1, R_2, and R_3 are known, but R_2 is not adjustable, the voltage difference across or current flow through the meter can be used to calculate the value of R_x, using Kirchhoff's circuit laws (also known as Kirchhoff's rules). This setup is frequently used in strain gauge and resistance thermometer measurements as it is usually faster to read a voltage level off a meter than to adjust a resistance to zero the voltage.

Derivation

First, Kirchhoff's first rule is used to find the currents in junctions B and D: Then, Kirchhoff's second rule is used for finding the voltage in the loops ABD and BCD:

$$R_x = \frac{R_2 . I_2 . I_3 . R_3}{R_1 . I_1 . I_x}$$

$$R_x = \frac{R_3 . R_2}{R_1}$$

The bridge is balanced and $I_g = 0$, so the second set of equations can be rewritten as:

$$(I_3 . R_3) - (I_g . R_g) - (I_1 . R_1) = 0$$

Then, the equations are divided and rearranged, giving:

$$(I_3 . R_3) - (I_g . R_g) - (I_1 . R_1) = 0$$

$$(I_x . R_x) - (I_2 . R_2) + (I_g . R_g) = 0$$

From the first rule, $I_3 = I_x$ and $I_1 = I_2$. The desired value of R_x is now known to be given as:

$$I_3 . R_3 = I_1 . R_1$$

$$I_x . R_x = I_2 . R_2$$

If all four resistor values and the supply voltage (V_S) are known, and the resistance of the galvanometer is high enough that I_g is negligible, the voltage across the bridge (V_G) can be found by working out the voltage from each potential divider and subtracting one from the other. The equation for this is:

$$V_G = \frac{R_x}{R_3 + R_x} V_S - \frac{R_2}{R_1 + R_2} V_S$$

This can be simplified to:

$$V_G = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_S$$

with an explosimeter. The Kelvin bridge was specially adapted from the Wheatstone bridge for measuring very low resistances. In many cases, the significance of measuring the unknown resistance is related to measuring the impact of some physical phenomenon - such as force, temperature, pressure, etc. which thereby allows the use of Wheatstone bridge in measuring those elements indirectly.

KELVIN BRIDGE

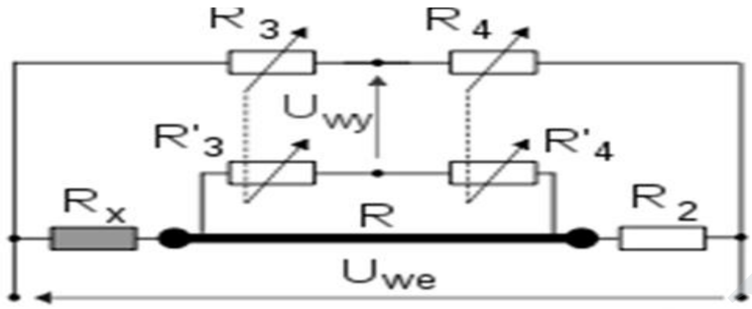


Figure 3.3 Kelvin Bridge

A Kelvin bridge (also called a Kelvin double bridge and some countries Thomson bridge) is a measuring instrument invented by William Thomson, 1st Baron Kelvin. It is used to measure an unknown electrical resistance below 1 Ω. Its operation is similar to the Wheatstone bridge except for presence of additional resistors. These additional low value resistors and the internal configuration of the bridge are arranged to substantially reduce measurement errors introduced by voltage drops in the high current (low resistance) arm of the bridge

Accuracy

There are some commercial the devices reaching accuracies of 2% for resistance ranges from 0.000001 to 25 Ω. Often, ohmmeters include Kelvin bridges, amongst other measuring instruments, in order to obtain large measure ranges, for example, the Valhalla 4100 ATC Low-Range Ohmmeter.

The instruments for measuring sub-ohm values are often referred to as low-resistance ohmmeters, milli-ohmmeters, micro-ohmmeters, etc

Principle of operation

The measurement is made by adjusting some resistors in the bridge, and the balance is achieved when: in 1865 and further improved by Alan Bulletin in about 1926.

Resistance *R* should be as low as possible (much lower than the measured value) and for that reason is usually made as a short thick rod of solid copper. If the condition $R_3R_4' = R_3'R_4$ met (and value of *R* is low), then the last component in the equation can be neglected and it can be assumed that:

$$R_x = R_2 . \frac{R_3}{R_4} + \text{R}. \frac{(R_3 R\prime_4) - (R\prime_3 . R_4)}{R_4 . (\text{R} + R'_3 + R'_4)}$$

AC BRIDGES

Schering Bridge

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. Figure3.4 below shows a diagram of the Schering Bridge.

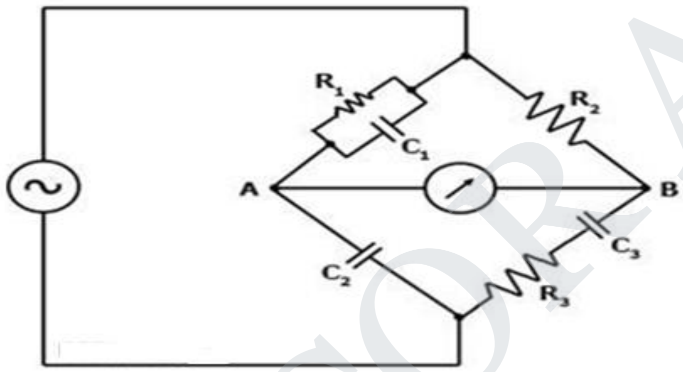


Figure 3.4 Schering Bridge

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. The capacitive reactance of a capacitor C is 1/2πfC.

As such, Z1 = R1/[2πfC1((1/2πfC1) + R1)] = R1/(1 + 2πfC1R1) while Z3 = 1/2πfC3 + R3.

Thus, when the bridge is balanced:

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

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

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

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

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

$$R3 = C1R2 / C2.$$

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

$$C2/C3 = R2/R1\text{ or}$$

$$C3 = R1C2 / R2.$$

Maxwell's Bridge

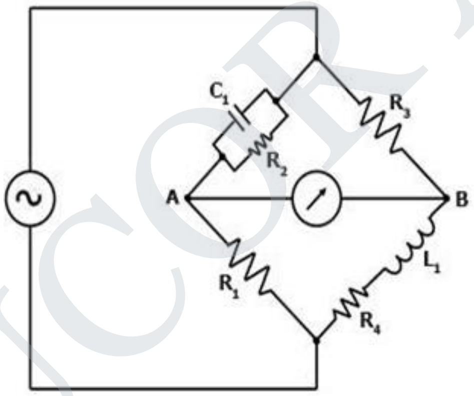


Figure 3.5 Maxwell's Bridge

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. Because the phase shifts of inductors and capacitors are exactly opposite each other, a capacitive impedance can balance out an inductive impedance if they are located in opposite legs of a bridge, as they are here.

Another advantage of using a Maxwell bridge to measure inductance rather than a symmetrical inductance bridge is the elimination of measurement error due to mutual inductance between two inductors. Magnetic fields can be difficult to shield, and even a small amount of coupling between coils in a bridge can introduce substantial errors in certain conditions. With no second inductor to react with in the Maxwell bridge, this problem is eliminated.

Anderson Bridge

It is a modified version of Maxwell's inductance capacitance bridge. In this method, the self inductance is measured in terms of a standard capacitance. It is applicable for precise measurement of self-inductance over a wide range of values.

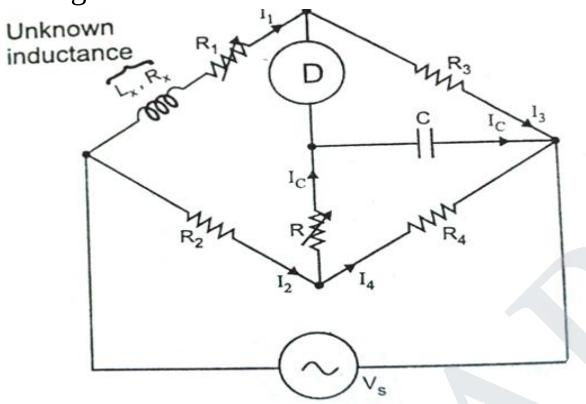


Figure 3.6 Anderson's Bridge

Let L_X be the selfinductance to be measured

R_X be the resistance of self-inductor.

r_1 be the resistance connected in series with selfinductor .

r,R_2 ,R_3,R_4 be the known non-inductive resistances,and C be the fixed standard capacitance

At balance

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

$$I_1 R_3 = I_C \times \frac{1}{j\omega c}$$

$$I_C = I_1 j\omega c R_3$$

Writing the other balance equations

$$I_1(r_1 + R_X + j\omega L_X) = I_2 R_2 + I_e$$

Sub the value of I_C In the above equation,

$$I_1(r + R_X + j\omega L_1 - j\omega c R_3 \text{ r}) = I_2 r_4$$

From the above equations, $R_X = \frac{R_2 R_3}{R_4} - r_1$

$$L_X = C\frac{R_3}{R_4}[r(R_4 + R_2) + R_2 R_4]$$

Advantages

- A fixed capacitor can be used instead of a variable capacitors in the case of Maxwell's bridge.
- This bridge may be used for accurate determination of capacitance in terms of inductance.
- It is much easier to obtain balance in case of Anderson's bridge than in Maxwell's bridge for low Q coils.

Disadvantages

- The Anderson's bridge is more complex than its prototype Maxwell's bridge.
- An additional junction point increases the difficulty of shielding the bridge.

TRANSFORMER RATIO BRIDGES

The transformer ratio bridges are popular one. These bridges are mainly used for wide range of applications. The transformer ratio bridges are replacing the conventional arc. bridges.

This bridge consists of voltage transformer whose performance approaches that of an ideal transformer. But the ideal transformer has no resistance, no core loss and no leakage flux.

The ratio transformer consists of number tapings in order to obtain voltage division. Voltage across the windings of the transformer is

$V = 4.44\ f\ \phi_m N$ volt

Where

N=number of turns

F=frequency in hertz

ϕ_m=maximum value of flux in wb

For a given value of ϕ_m and f, $V = K_1 N$

Fig shows an auto transformer with tapings. V is the input voltage to the winding. Here, we assume that the auto transformer is ideal one, the division of input voltage V into output voltages V_1 and V_2.

Different values of V_1 and V_2 may be had by changing the sliding contact on the tapings.

The construction of ideal transform we is impossible. But the ideals of zero winding resistance, zero core loss and perfect coupling can be closely achieved by using special design similar to those for instrument transformers.

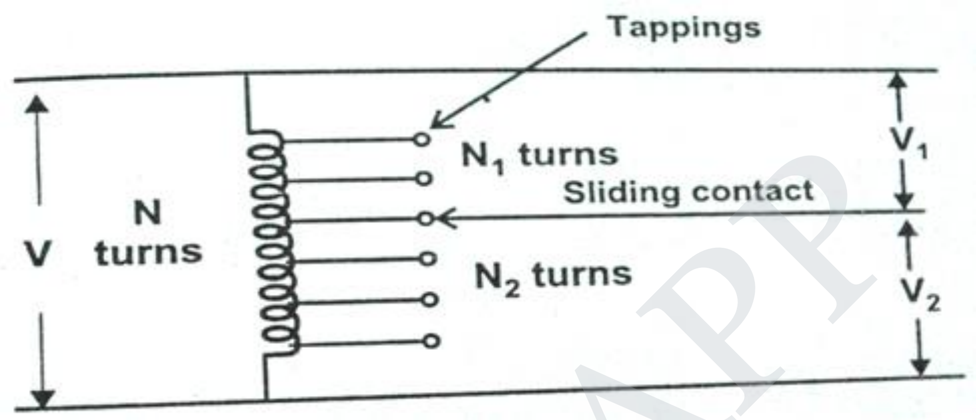


Figure 3.8 Transformer ratio Bridge

The material used for construction of core should be such that it gives the very less core losses at the desired operating frequency. The magnetizing current is minimised by using a Toroidal core.

The main advantage of toroidal core is minimum leakage reactance. It gives almost perfect magnetic coupling. The leakage reactance can be reduced by using a special type of construction for the winding as shown in figure 3.9.

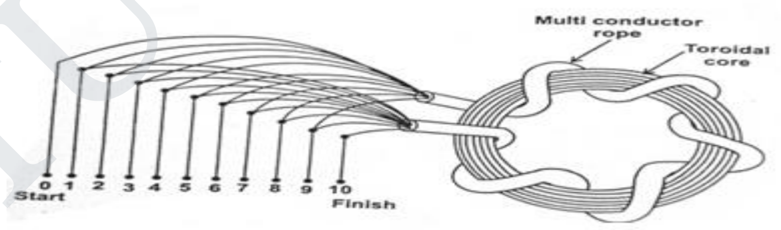


Figure 3.9 Multiconductor Rope

This type of winding takes the form of multi-conductor rope. By using multi-conductor rope, we can get a decade of voltage division, and ten wires with successive seeks of turns connected in series and a tapping is taken from each joint.

The resistance of the windings can be minimized by copper wire of heavy cross-section. Fig shows a 4-decode ratio transformer. This type of arrangement gives a ratio error of less than 1 part in 10^4.

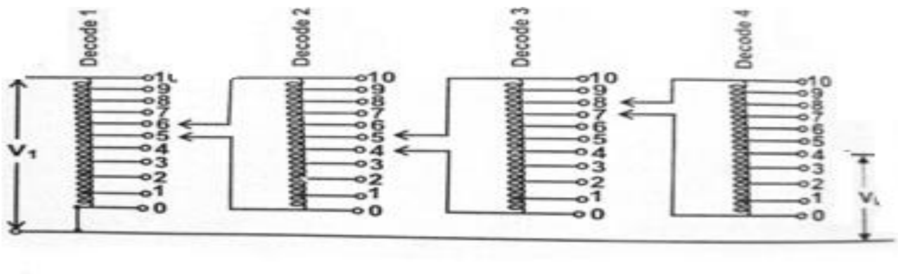


Figure 3.10 4-Decode Ratio Transformer

Applications

- It can be used for measurement of resistance, capacitance and inductance in comparison with standard resistance, standard capacitance and standard inductance respectively.
- It can be used for amplifier gain and phase shift.
- It is also used for measurement of transformer ratios.

Features

- It can be used only in a.c.
- It gives very small ratio errors.
- This ratio transformer has high input impedance and low output impedance. Due to this, loading effect is very small.
- The frequency range is from 50 Hz to 50 Khz.

Measurement of resistance

In the unknown resistance R is in comparison with a standard resistance R_s. The position of the wiper is adjusted till the detector D shows null position. Current through the unknown resistance

$I_1=V_1/R= K_1 N_1/R$

Current through the standard resistance $I_2=V_2/R_s= K_1 N_2/R_s$

Under balance conditions, the current through the detector D is zero ie$I_1=I_2$

Hence $K_1 N_1/R = K_1 N_2/R_s$

Or $R= N_1/ N_2 R_s$

Measurement of Capacitance

The measurement of capacitance by using ratio transformer. Here, unknown capacitance C is measured in comparison with a standard capacitance C_s. A resistance R is connected across the unknown capacitor C. This resistance represents the loss of the capacitor. Under balance position, the magnitude and phase of the currents passing through detector should be the same; a variable standard resistance is connected in parallel with the standard capacitor.

At balance position,

$C = N_2/ N_1 C_s$

$R = N_1/ N_2 R_s$

Dissipation factor D

$D = 1/\omega CR=1/ _{\omega}C_sR_s$

Measurement of phase angle

Figure 3.11 shows the measurement of phase angle by using ratio transformer.

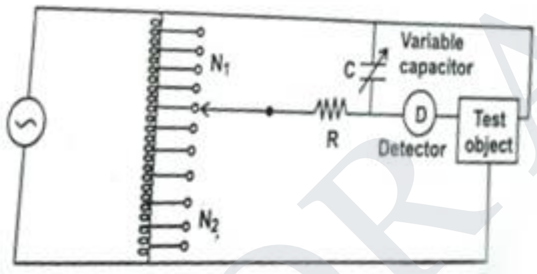


Figure 3.11 Ratio Transformer

Here, R and C are used. By varying the capacitance we can get phase shift. The value of resistance should be larger in order that there are no loading effects on the ratio transformer. The detector D is indicated zero by adjusting the capacitor value.

Phase angle $\phi = \tan^{-1}(-\omega RC)$

The magnitude of in-phase component is

$\Phi_1 = (N_2/N_1+ N_2)\cos^2 \phi$

SELF BALANCING BRIDGE

The term self balancing is used to describe bridges which are automatically re-balanced. Here, we can discuss some self balancing bridges. These are

1. Self balancing bridge by using bolometer
2. Self balancing bridge as a resistance to current converter.
3. Self balancing bridge for fluid flow rate measurement.

Self balancing bridge by using bolometer

Figure 3.12 shows self balancing bridge by using bolometer. Here, the bolometer is used as the coupling network between the output and input of a high gain frequency elective audio amplifier. Bolometer measurements are based on the dissipation of the RF power in a small temperature sensitive resistive element, called a Bolometer.

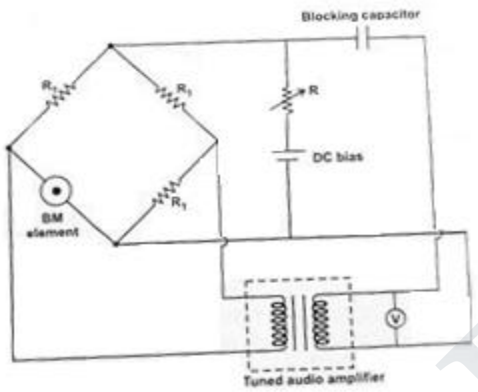


Figure 3.12 Bolometer

Here, the feedback is in proper phase to produce sustained oscillations of such amplitude as well maintain the resistance of the bolometer at a fixed value which nearly balances the bridge. When the supply is switched ON, the bridge is unbalanced. The gain of the amplifier is large, so that the oscillations are allowed to build up until the bridge is balanced. By increasing the gain of the amplifier, the bridge should be accurately balanced.

The test radio frequency is now dissipated into the bolometer element, which causes an unbalance in the bridge circuit. The audio frequency output voltage automatically adjusts itself to restore the bolometer resistance to its original value. The amount by which the AF power level in the bolometer is reduced equals the applied RF power. Here, the voltmeter reads the AF voltage.

Most of the DC and AC bridges that can be balanced by adjusting the element utilize the servo meter to balance the bridge circuit. The system thus serves as resistance-to-displacement converter. The scale is calibrated in terms of the quantities to which the resistance transducer of the bridge network responds. Where an output element related to the resistance of a transducer in the bridge is desired, electronic self-balancing is adopted.

INTERFERENCE AND SCREENING

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

However, it should be considered, that interference is always present. All technical remedies only aim at reducing the effect of interference to such a degree, that it is neither audible nor disturbing. This is mainly achieved by different ways of screening.

This paper will explain the technical background of interference and provides some common rules and hints which may help you to reduce the problems.

Types of Interference

Theoretically, the effects and mechanism of a single interference can well be calculated. But in practice, the complex coupling systems between pieces of equipment prevent precise prediction of interference. The following picture shows the different types of interference coupling.

If we consider all possible coupling paths in the diagram above we will find 10 different paths. This means a variety of 1024 different combinations. It should be noted, that not only the number of paths, but also their intensity is important.

Symmetrical and Asymmetrical Interference

Having a closer look at the interference of cable, we find that high frequency-interference currents cause measurable levels on signal (audio) lines and on supply lines.

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

Galvanic Coupling of Interference

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

Capacitive Coupling of Interference

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

Principle of capacitive coupling of interference

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

Inductive Coupling of Interference

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

The interference voltage induced by inductive coupling is

- increasing the distance between conductors
- mounting conductors close to conductive surfaces
- using short conductors
- avoiding parallel conductors
- screening
- using twisted cable

Note that by the same means the capacitive as well as the inductive coupling of interference will be reduced.

Interference by Radiation

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

Interference by Electrostatic Charge

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

Screening

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

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

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

MULTIPLE EARTH AND EARTH LOOPS

Earth loop forms a distinct part of the guarding system of electrical equipments.

An example of such an earth loop formed between a grounded transducer and a grounded measuring instrument which are connected by relatively long cables; R_1 and R_2 represent the cable resistances.

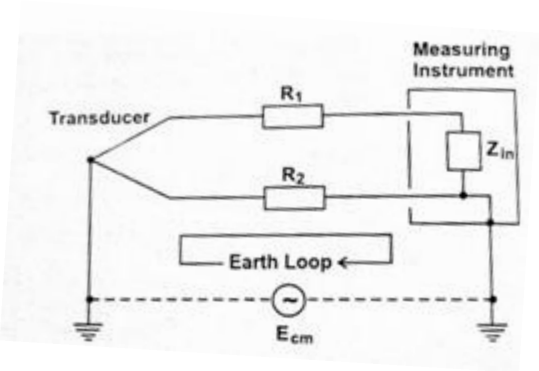


Figure 3.13 Earth Loop

Different methods to obtain ground connection

- ➢ If one rod does not give a sufficiently low ground spread resistance, a system of rods connected by a copper ground bus can be used.

- In some cases, the iron rods of a reinforced and concrete structure are welded together and connected to special conducting rods to give the required low ground spread resistance.

- A metallic underground water piping system also provides good contact with ground and is the best solution for grounding of measurements.

Earth current

- Considerable earth currents may be expected as a result of the discharge of current from power systems to ground. It is very difficult to evaluate these currents and no satisfactory methods of measurement has been developed.
- Most of the data available are average values taken over a period of time because of the complexity of parameters such as soil resistivity, soil moisture, depth of the electrodes, weather conditions etc.

ELECTROMAGNETIC INTERFERENCE

Definition

If the parameter to be measured is at the place at which a measurement is to be displayed or used for control purposes is at some distance from the point of measurement, then it can lead to various problems. The main one is electrical noise or interference being superimposed on the measurement signal. This is called electromagnetic interference.

Sources Of Electromagnetic Interference

Sources of noise and interference include

- Ac power circuits, solenoids switching fluorescent lightning, radio frequency transmitters.
- Welding equipment.
- Inductive or capacitive coupling.
- By having earths of slightly different potentials.

Effects of electromagnetic interference

Electromagnetic interference often affects instrument signals, particularly when operating with very sensitive instruments which are close to equipment that produces a log of electrical noise.

Example: Some of the instruments which are close to the measuring instrument include thyristor drives for AC motors which produce high-frequency spikes. Drives for DC motors also produce noise, but at lower frequencies than AC drives, as do solid state relays and other equipment with high inductance or capacitance, such as induction heating. **Electromagnetic compatibility**

The electromagnetic compatibility regulations are designed to eliminate radio frequency interference emissions from electrical machines and to ensure that these machines are immune to such radiation from external sources.

Limiting Interference Problems

To limit interference problems, the following steps are being taken:

- Signal and power cables are routed as far as possible from one another.
- Sensors such as load beams are electrically insulated from other equipment.
- Shielding is used where necessary and appropriate earthing is done.
- Low pass filters are used to reduce high frequency noise in signals and the signals themselves are amplified as near to the sensor as possible to reduce the signal-to-noise ratio on the cabling.
- Sometimes the problem itself can be reduced by using, for example DC , instead of AC motors and drives.
- ‘Molybdenum’ metal is useful for mechanical shielding of electrically ‘noisy’ components.

ELECTROSTATIC INTERFERENCE AND SCREENING

The Basics of Balancing

Balanced connections in an audio system are designed to reject both external noise, from power wiring etc., and also internal cross talk from adjacent signal cables. The basic principle of balanced interconnection is to get the signal you want by subtraction, using a three wire connection. In Many cases, one signal wire (the hot or in-phase) senses the actual output of the sending unit, while the other (the cold or phase-inverted)senses the unit’s output –socket ground, and the difference between them gives the wanted signal. Are in theory completely cancelled by the subtraction. In real life the subtraction falls short of perfection, as the gains via the hot and cold inputs will not be precisely the same, and the degree of discrimination Actually achieved is called the Common-Mode Rejection Ratio, or CMRR.

Screening

While two wires carry the signal , the third is the ground wire which has the dual of both joining the grounds of the interconnected equipment, and electrostaticallly screening the two signal wires by being in some way wrapped around them. The ‘wrapping around’ can mean.

- A lapped screen with wires laid parallel to the central signal conductor. The screening converge is not perfect, and can be badly degraded as it tends to open up on the outside of cable bends.
- A braided screen around the central signal wires. This is more expensive, but opens up less on bends. Screening is not 100%, but certainly better than screen.
- An overlapping foil screen, with the ground wire running down the inside of the foil and in electrical contact with it. This is usually the most effective as the foil cannot open up on the outside of bends, and should give perfect electrostatic screening, However, the higher resistance of aluminium foil compared with Copper braid means that RF screening may be worse.

Advantages of Balancing

- ➢ It discriminates against noise and crosstalk.
- ➢ Balanced interconnect aloes 6 dB more signal level on the line.

Electrical Noise

Noise gets into signal cables in three major ways:

Electrostatic coupling

An interfering signal with significant voltage amplitude couples directly to the inner signal line, through stray capacitance.

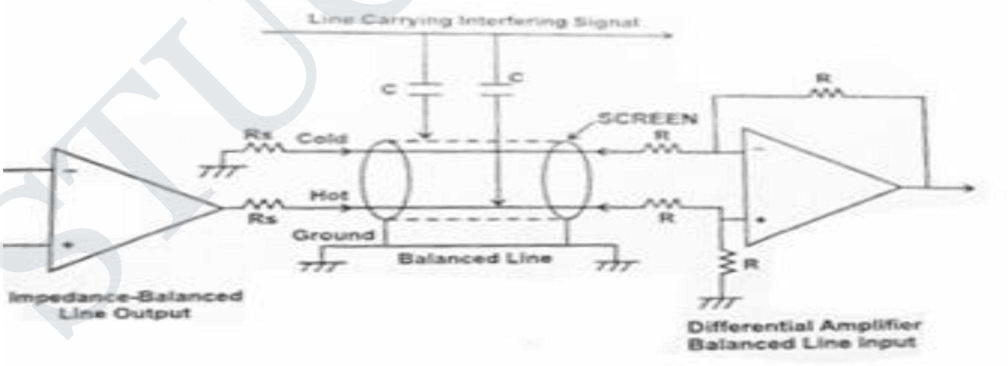


Figure3.14 Electrostatic Coupling

The situation is shown in Figure 3.14 with C.C representing the stray capacitance between imperfectly-screened conductors: this will be a fraction of a Pf in most circumstances. This coupling can be serious in studio installations with unrelated signals going down the same ducting.

The two main lines of defence against electrostatic coupling are effective screening and low impedance drive.

An overlapping foil screen provides complete protection. Driving the line from a low impedance, of the order of 100 Ohms or less, means that the interesting signal, having passed through a very small capacitance, is a very small current and cannot develop much voltage across such a low impedance. For the best effectiveness the impedance must remain low up to as high a frequency as possible: this can be a problem as op[-amps invariably have a frequency, and this makes the output impedance side with frequency possible.

This can be a problem as op-amps invariably have a feedback factor that begins to fall from a low, and possibly sub-audio frequency, and this makes the output impedance rise with frequency. From the point of view of electrostatic screening alone, the screen does not need tube grounded at some point. Electrostatic coupling falls off with the square of distance. Rearranging the cable-run away from the source of interference is more effective than trying to rely on very good common-mode rejection.

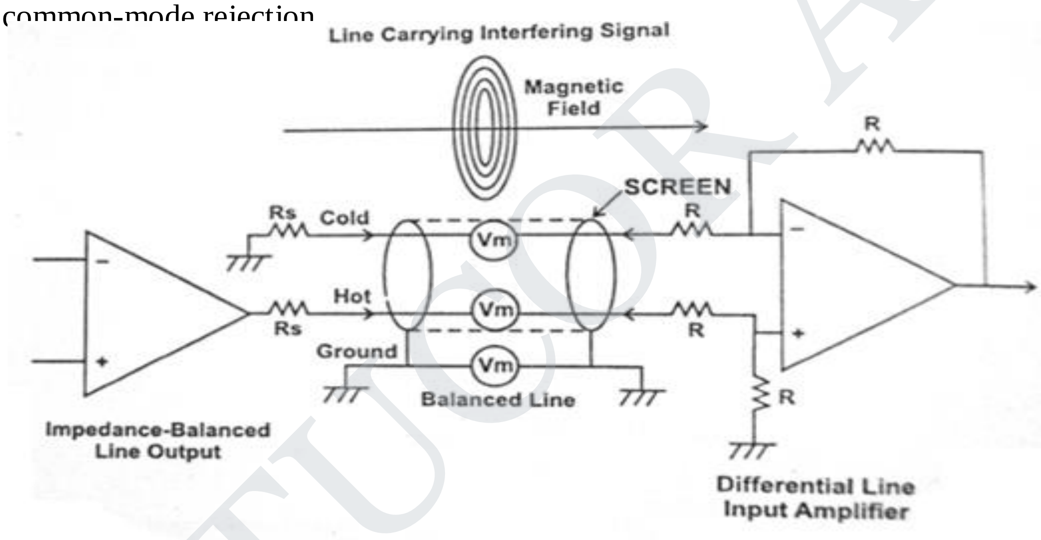


Figure 3.15 Magnetic Coupling

An EMF V_m is induced in both signal conductors and the screen, and according to some writers, the screen current must be allowed to flow freely or its magnetic field will not cancel out the field acting on the signal conductors, and therefore the screen should be grounded at both ends, to form a circuit. In practice on the common-mode rejection of the balanced system, to cancel out the hopefully equal voltages V_m induced in the two signal wires. The need to ground both ends for magnetic rejection is not a restriction, as it will emerge that there are other good reasons why the screens should be grounded at both ends of a cable.

In critical situations the equality of these voltage is maximised by minimising the loop area between the two signal wires, usually by twisting them tightly together. In practice most audio cables have parallel rather than twisted signal conductors, and this seems adequate most of the time. Magnetic coupling falls off with the square of distance, so rearranging the cable-run away from the source of magnetic field is usually all that is required. It is unusual for it to present serious difficulties in a domestic environment.

- **Ground voltages coupled in through the common ground impedance**

  This is the root of most ground loop problems. In the equipment safety ground causes a loop ABCD; the more existence of a loop in itself does no harm, but it is invariably immersed in a 50 Hz magnetic field that will induce mains frequency current plus odd harmonics into it.

  This current produces a voltage drop down the non- negligible ground-wire resistance, and this once again effectively appears as a voltage source in each of the to signal lines. Since the CMRR is finite , a proportion of this voltage will appear to be differential signal, and will be reproduced as such.

GROUNDING TECHNIQUES

Grounding (or)Earthling

This is one of the simplest but most efficient methods to reduce interference.

Grounding can be used for three different purposes:

- **Protection Ground**

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

- **Function Ground**

The ground is used as a conductive path for signals.

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

- **Screening Ground**

Used to provide a neutral electrical path for the interference, to prevent that the interfering voltages or currents from entering the circuit.

In this chapter we will only consider the third aspect. Grounding of equipment is often required for the cases 1 or 2 anyhow, so that the screening ground is available "free of charge".

Sometimes the grounding potential, provided by the mains connection, is very "polluted". This means that the ground potential itself already carries an interfering signal.

This is especially likely if there are big power consumers in the neighbourhood or even in the same building. Using such a ground might do more harm than good. The quality of the ground line can be tested by measuring it with a storage scope against some other ground connection, e.g. a metal water pipe or some metal parts of the construction. Never use the Neutral (N) of the mains as ground. It might contain strong interference, Because it carries the load current of all electrical consumers.

The grounding can be done by single-point grounding or by multi-point grounding. Each method has advantages which depend on the frequency range of the signal frequencies. All parts to be grounded are connected to one central point. This results in no "ground loops" being produced. This means the grounding conductors do not form any closed conductive path in which magnetic interference could induce currents. Furthermore, conductive lines between the equipment are avoided, which could produce galvanic coupling of interference. Central grounding requires consistent arrangement of the grounding circuit and requires insulation of the individual parts of the circuit. This is sometimes very difficult to achieve. A system using the single-point grounding.

Multi-Point Grounding

In multi-point grounding all parts are connected to ground at as many points as possible. This requires that the ground potential itself is as widely spread as possible.

In practice, all conductive parts of the chassis, the cases, the shielding, the room and the installation are included in the network. The interconnection of these parts should be done at as many point possible.

Screening

When considering the effect of electrical and magnetic fields, we have to distinguish between low and high frequencies. At high frequencies the skin effect plays an important roll for the screening. The penetration describes the depth from the surface of the conductor, where the current density has decayed to 37% compared to the surface of the conductor. the interference and never fully prevent it. This means there will never be a system which is 100% safe from interference. Because the efforts and the cost will rise with the degree of reduction of interference, a compromise has to be found between the effort and the result.

The requirement for the reduction of interference will depend on:

- the strength of the interference source

- the sensitivity of the interference sink
- the problems caused by interference
- the costs of the equipment

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

- **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 bus bars.

- **Ventilation**

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

- **Earthling**

Proper earthling bus bar 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. Schering Bridge is independent of frequency.

3.11 QUESTION BANK

PART – A

1. Draw Maxwell's AC bridge and give the balance equation In terms of resistance.
2. Explain any two technical parameters to be consider in grounding
3. Give some applications of Whetstone's bridge.
4. What is a potentiometer?
5. List the applications of dc and ac potentiometer.
6. Differentiate the principle of dc potentiometer and Ac potentiometer.
7. What is meant by transformer ratio bridge
8. What are the features of ratio transformer? List its applications.
9. What is meant by electromagnetic interference?
10. List the sources of electromagnetic interference.
11. What are the ways of minimizing the electro magnetic interference?
12. Define electromagnetic compatibility.(EMC)
13. What are the main causes of group loop currents?
14. What are the limitations of single point grounding method?
15. What is the necessity of grounding and state is advantages.
16. What is meant by ground loop? How it is created? 17. What are the sources of errors in bridge measurement?
18. Define standardization.
19. Give the relationship between the bridge balance equation of DC bridge and AC bridge.
20. What does a bridge circuit consists of?

PART – B

1. a) Explain in detail about the laboratory type DC potentiometer.(1 2)

   b) Give the applications of AC potentiometers. (4)

2. a)Describe about the multiple earth and earth loops.(8)

   b) Explain the different techniques of grounding. (8)

3. Explain voltage sensitive self balancing bridge, and derive the bridge sensitivity of voltage sensitive bridge with fundamentals.(1 6)

4. a) With fundamentals distinguish between DC and AC Potentiometers, and give any two specific applications for each.(8)

   b) Discuss the advantages and limitations of electromagnetic Interference in measurements.(8)

5. a) Explain Kelvin's double bridge method for the measurement of low resistance.(8)

   b) Explain how inductance in measured by using Maxwell's bridge. (8)

6. a)Explain the working principle of Anderson's bridge and also derive its balance equations. (8)

   b) Explain the working principle of Schering bridge and also derive its balance equations. (8)

MAGNETIC DISK AND TAPE – RECORDERS, DIGITAL PLOTTERS AND PRINTERS, CRT DISPLAY, DIGITAL CRO,LED, LCD & DOT MATRIX DISPLAY – DATA LOGGERS.

4.1 Recorders

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

Electronic recorders may be classified as:

1. Analogrecorders
2. Digitalrecorders

Analog recorders dealing with analog systems can be classified as

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

Digital recorders dealing with digital output can be classified as

1. Incremental digitalrecorders
2. Synchronous digital recorders

4.2 Magnetic Disk AndTape

Magnetic Tape Recorder

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

Basic Components of Tape Recorder

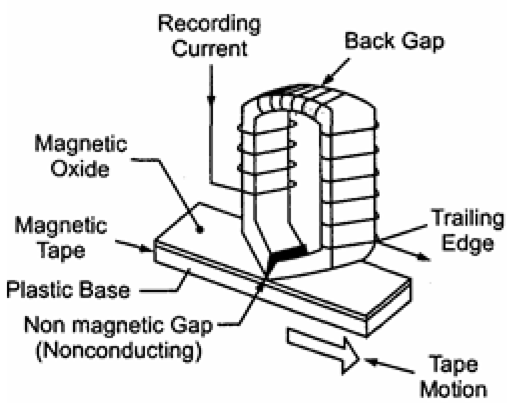
Following are the basic components of magnetic tape recorder

1. RecordingHead
2. MagneticTape
3. ReproducingHead
4. Tape TransportMechanism
5. ConditioningDevices

Recording Head

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

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



(Fig) Magnetic tape recording head

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

Ø The magnetic tape is having iron oxide particles.

Ø When the tape is passing the head, the flux produced due to recording current gets linked with iron oxide particles on the magnetic tape and these particles get magnetized.

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

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

Ø Any signal is recorded in the form of thepatterns.

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

Magnetic Tape

- The magnetic tape is made of thin sheet of tough and dimensionally stable plastic ribbon.
- One side of this plastic ribbon is coated by powdered iron oxide particles (Fe2O3) thick.
- The magnetic tape is wound around a reel.
- This tape is transferred from one reel to another.
- When the tape passes across air gap magnetic pattern is created in accordance with variation of recording current.
- To reproduce this pattern, the same tape with some recorded pattern is passed across another magnetic head in which voltage isinduced.
- This voltage induced is in accordance with the magnetic pattern.

Reproducing Head

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

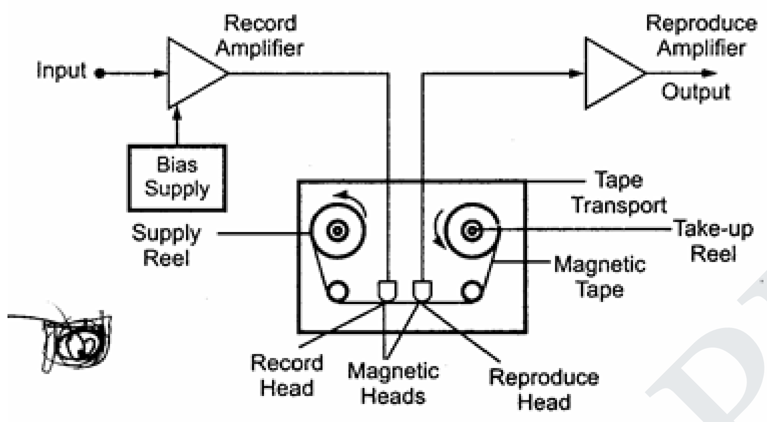
Ø The working of the reproducing head is exactly opposite to that of the recording head.

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

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

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

Tape Transport Mechanism



(Fig) Basic tape transport mechanism

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

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

Ø The magnetic tape is wound on reel.

Ø There are two reels; one is called as supply & other is called as take-upreel. Ø Both the reels rotate in samedirection.

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

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

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

Conditioning Devices

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

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

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

Principle of Tape Recorders

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

Ø This magnetic pattern is in accordance with the variations of original recording current. The recorded signal can be reproduced back by passing the same tape through a reproducing head where the voltage is induced corresponding to the magnetic pattern on the tape.

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

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

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

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

Where N = number of turns of the winding on reproducing head Æ = magnetic flux produced.

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

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

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

Ø It is given by e= k2 ŬVm cos wt

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

Methods of Recording

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

i) DirectRecording
ii) Frequency ModulationRecording
iii) Pulse Duration ModulationRecording

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

4.3 Digital Plotters AndPrinters

PRINTERS

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

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

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

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

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

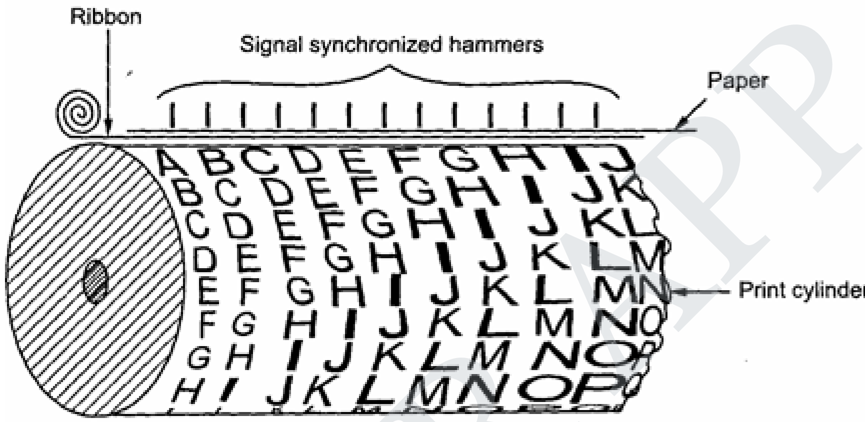
Line Printers

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

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

Drum Printers

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

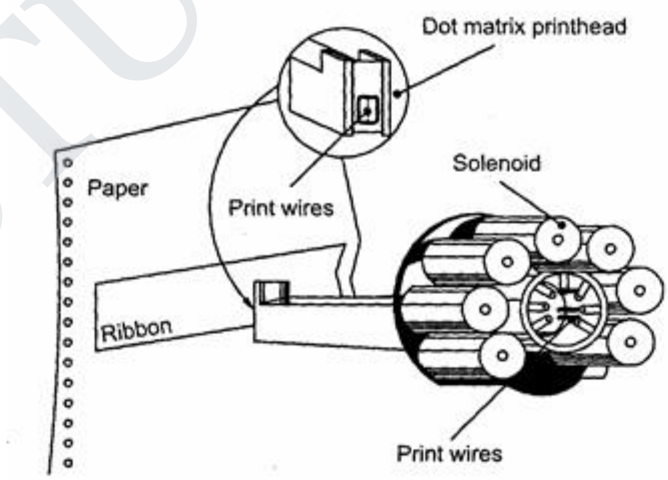


Chain Printers

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

Dot Matrix Printers

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



Laser Printer

Ø The li ne, do t matrix, and ink jet printers need a head movement on a ribbon to print characters.

Ø This mechanical movement is relatively slow due to the high inertia of mechanical elements.

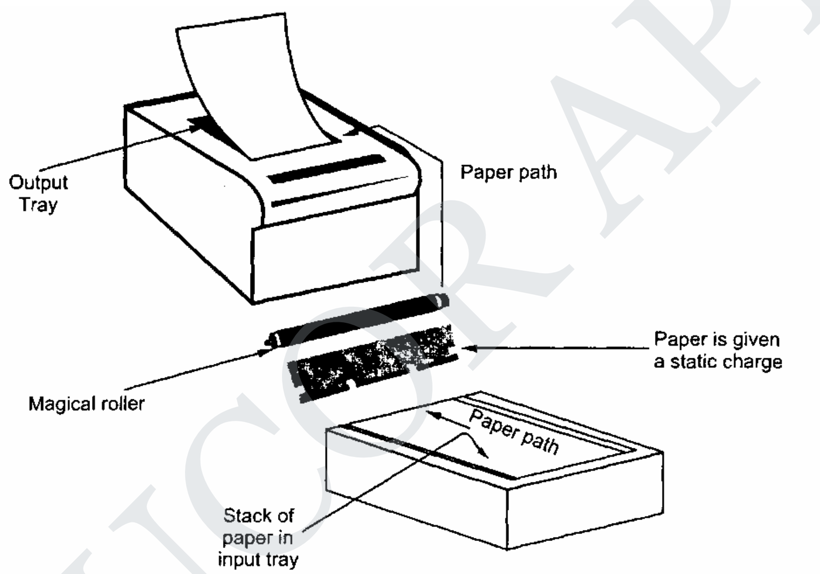
Ø In laser printers these mechanical movements are avoided. In these printers, an electronically controlled lase r beam traces out the desired character to be printed on a photoconductive drum.

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

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

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

Ø When charge is more, more ink is attracted and we get a dark print.



A colour laser printer works like a single colour laser printer, except that the process is repeated four times with four different ink colours: Cyan, magenta, yellow andblack.

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

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

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

Advantages of Laser printer

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

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

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

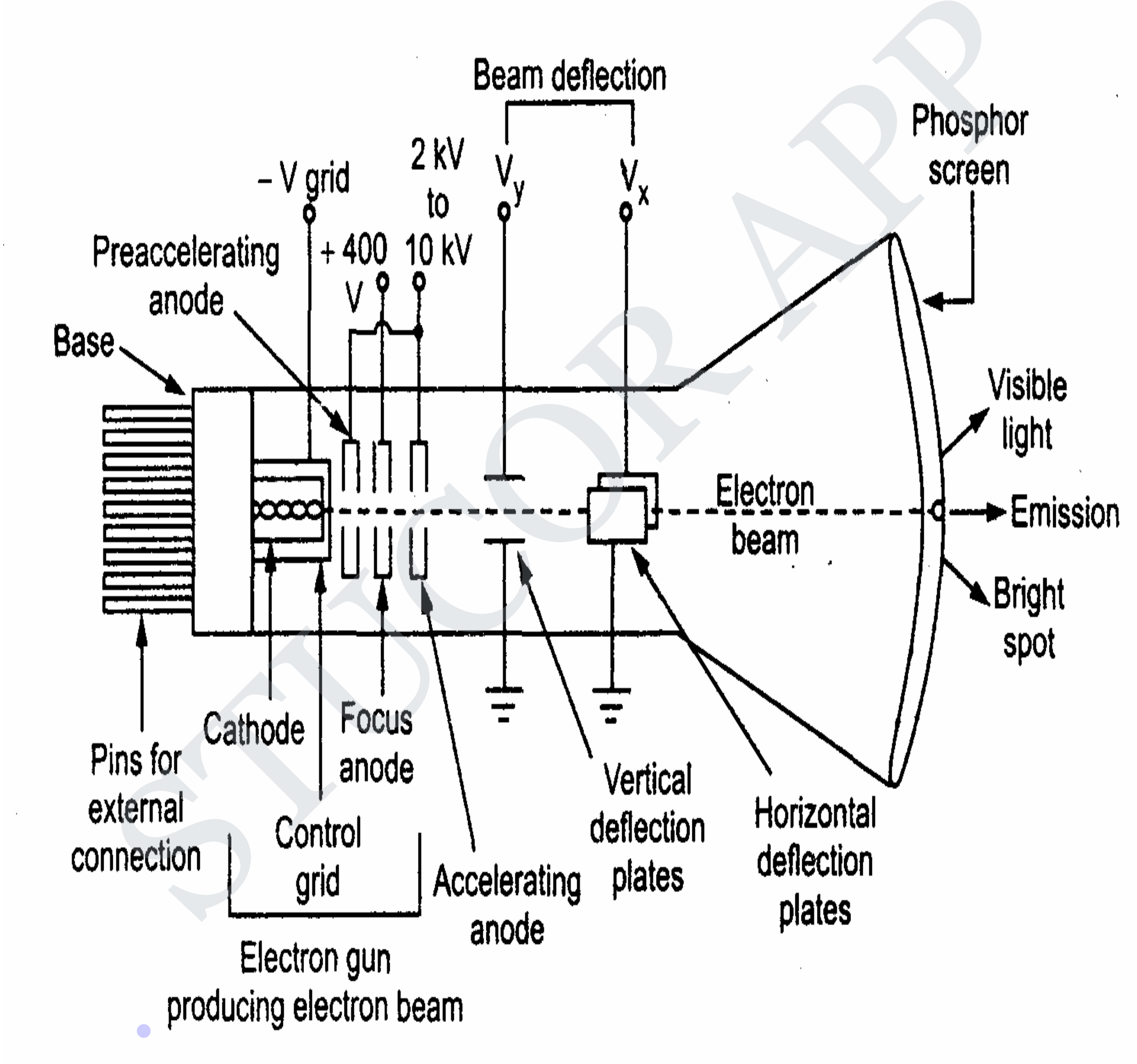
Ø Laser printers tend to be more expensive than ink-jet printers, but it doesn’t cost as much to keep them running.

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

4.4 CRT Display

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

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



Electron gun

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

Ø This section starts from thermally heated cathode, emitting the electrons. Ø The control grid is given negative potential with respect to cathode.

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

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

Ø The light emitted is usually of the green colour.

Deflection System

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

Fluorescent Screen

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

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

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

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

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

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

Glass Tube

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

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

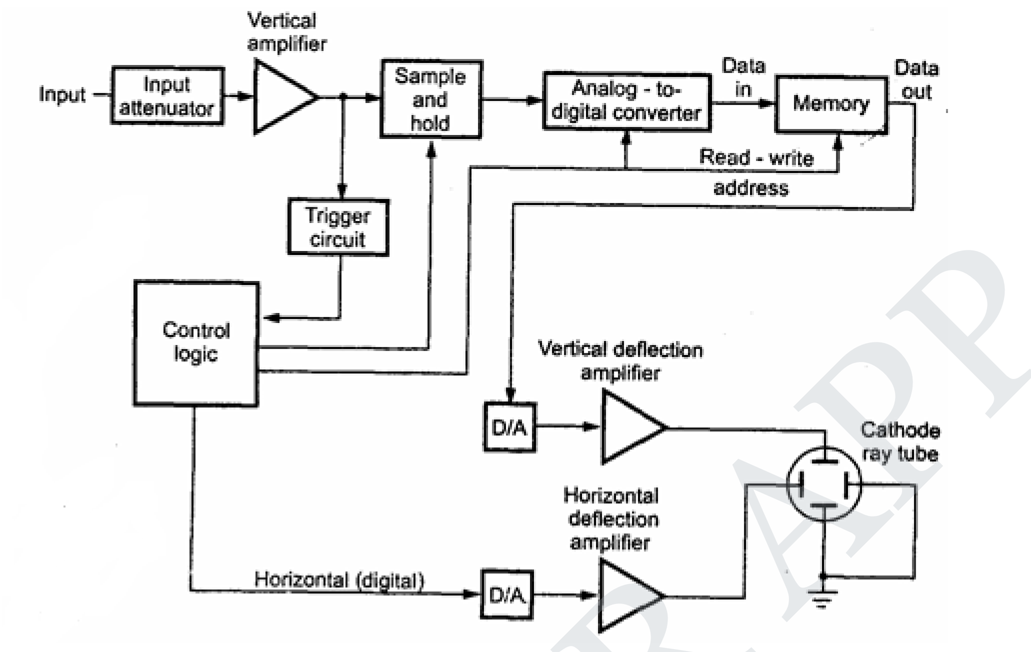
Base

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 attenuatorsection.
- 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 beingerased.

Ø The digital storage oscilloscope has three modes:

1. Rollmode
2. Storemode
3. Hold or savemode.

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 thememory.

iv) The cursor measurement ispossible.

v) The characters can be displayed on screen along with thewaveformwhich can indicate waveform information such as minimum, maximum, frequency, amplitudeetc.

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

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

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

ix) Signal processing is possible which includes translating the raw data into finishedinformation

e.g. computing parameters of a captured signal like r.m.s. value, energy stored etc.

4.6 DATALOGGER

Definition

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

Components

Ø Pulse inputs

Counts circuit closing

Ø Control ports

Digital in and out.

Most commonly used to turn things on and off Can be programmed as a digital input

Ø Excitation outputs

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

Examples

Examples of where these devices are used abound.

A few of these examples are shown below:

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

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

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

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

Ø Monitoring environmental parameters in temperature and environmental chambers and test facilities. Ø A data logger is a self-contained unit that does not require a host to operate.

Ø It can be installed in almost any location, and left to operate unattended.

Ø This data can be immediately analyzed for trends, or stored for historical archive purposes.

Ø Data loggers can also monitor for alarm conditions, while recording a minimum number of samples, for economy.

Ø If the recording is of a steady-state nature, without rapid changes, the user may go through rolls of paper, without seeing a single change in the input.

Ø A data logger can record at very long intervals, saving paper, and can note when an alarm condition is occurring. When this happens, the event will be recorded and any outputs will be activated, even if the event occurs in between sample times.

Ø A record of all significant conditions and events is generated using a minimum of recording hardcopy

Ø The differences between various data loggers are based on the way that data is recorded and stored.

Ø The basic difference between the two data logger types is that one type allows the data to be stored in a memory, to be retrieved at a later time, while the other type automatically records the data on paper, for immediate viewing and analysis.

Ø Many data loggers combine these two functions, usually unequally, with the emphasis on either the ability to transfer the data or to provide a printout of it

Advantages

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

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

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

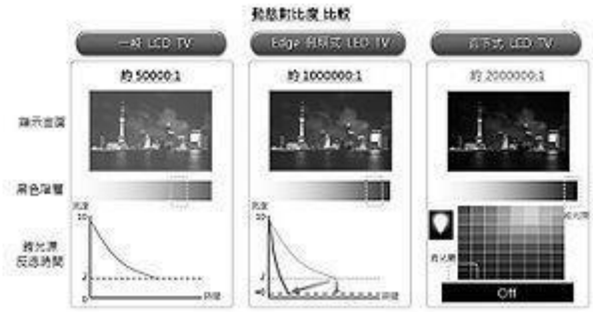
Ø No other external or peripheral equipment is required for operation,

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

Applications

Ø Temperature sensor
Ø Pressure sensor

4.7 LED-BACKLIT LCDTELEVISION (for reference)



Comparison of LCD, edge lit LED and LED TV

LED-backlight LCD television (incorrectly called LED TV by (CCFLs) used in traditional LCDtelevisions.Thishasadramaticimpactresultinginathinnerpanelandlesspower consumption, brighter display with better contrast levels. It also generates less heat than regular LCD TVs. The LEDs can come in three forms: dynamic RGB LEDs which are positioned behind the panel, white Edge-LEDs positioned around the rim of the screen which use a special diffusion panel to spread the light evenly behind the screen (the most common) and full-array which are arranged behind the screen but they are incapable of dimming or brightening individually

LED backlighting techniques RGB dynamic LEDs

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

Edge-LEDs

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

Full Array LEDs

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

Differences between LED-backlit and CCFL-backlit LCD displays

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

The variations of LED backlighting do offer different benefits. The first commercial LED backlit LCD TV was the SonyQualia005 (introduced in 2004). This featured RGB LED arrays to offer a color gamut around twice that of a conventional CCFL LCD television (the combined light output from red, green and blue LEDs produces a more pure white light than is possible with a single white light LED). RGB LED technology continues to be used on selected Sony BRAVIA LCD models, with the addition of 'local dimming' which enables excellent on- screen contrast through selectively turning off the LEDs behind dark parts of a pictureframe.

Edge LED lighting was also first introduced by Sony (September 2008) on the 40 inch BRAVIA KLV-40ZX1M (referred to as the ZX1 in Europe). The principal benefit of Edge-LED lighting forLCDtelevisionsistheabilitytobuildthinnerhousings(theBRAVIAKLV-40ZX1Misas

thin as 9.9mm). Samsung has also introduced a range of Edge-LED lit LCD televisions with extremely thin housings.

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

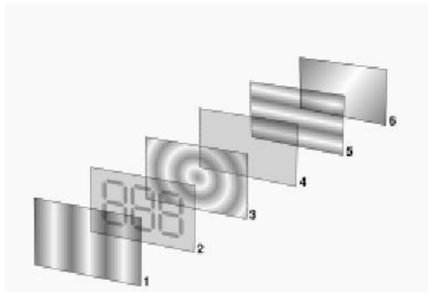
energy efficiency than plasmas and conventional LCD TVs.[10] Unlike CCFL backlights, LEDs also use no mercury in their manufacture. However, other elements such as gallium and arsenic are used in the manufacture of the LED emitters themselves, meaning there is some debate over whether they are a significantly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

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

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

4.8 LCD & Dot MatrixDisplay

LIQUID CRYSTAL DISPLAY



Reflective twisted nematic liquid crystal display.

1. Polarizingfilterfilmwithaverticalaxistopolarizelightasitenters.
2. Glass substrate with ITO electrodes. The shapes of these electrodes will determine the shapes that will appear when the LCD is turned ON. Vertical ridges etched on the surface aresmooth.
3. Twisted nematic liquid crystal.
4. Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontalfilter.
5. Polarizing filter film with a horizontal axis to block/passlight.
6. Reflective surface to send light back to viewer. (In a backlit LCD, this layer is replaced with a lightsource.)

A liquid crystal display (LCD) is a thin, flat electronic visual display that uses the light modulating properties of liquid crystals (LCs). LCs do not emit light directly.
They are used in a wide range of applications including: computer monitors, television, instrument panels, aircraft cockpit displays, signage, etc. They are common in consumer devices such as video players, gaming devices, clocks, watches, calculators, and telephones. LCDs have displaced cathode ray tube (CRT) displays in most applications. They are usually more compact, lightweight, portable, less expensive, more reliable, and easier on the eyes. They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they cannot suffer image burn-in. LCDs are more energy efficient and offer safer disposal thanCRTs.

Overview

LCD alarm clock

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

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

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

the rotation of the polarization of the incident light, and the device appears grey. If the applied

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

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

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

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

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

ILLUMINATION

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

Passive-matrix and active-matrix addressed LCDs

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

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

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

ACTIVE MATRIX TECHNOLOGIES

A Casio1.8 in colour TFT liquid crystal display which equips the SonyCyber-shot DSC-P93A

Twisted nematic (TN)

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

In-plane switching (IPS)

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

Known as fringe field switching (FFS) until 2003, advanced fringe field switching is a technology similar to IPS or S-IPS offering superior performance and colour gamut withhighluminosity. AFFS is developed by HYDIS TECHNOLOGIES CO.,LTD, Korea (formally Hyundai Electronics, LCD Task Force). AFFS-applied notebook applications minimize colour

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

Vertical alignment (VA)

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

Blue Phase mode

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

Military use of LCD monitors

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

Quality control

Some LCD panels have defective transistors, causing permanently lit or unlit pixels which are commonly referred to as stuck pixels or dead pixels respectively. Unlike integrated circuits (ICs), LCD panels with a few defective transistors are usually still usable. It is claimed that it is economically prohibitive to discard a panel with just a few defective pixels because LCD panels are much larger than ICs, but this has never been proven. Manufacturers' policies for theacceptable number of defective pixels vary greatly. At one point, Samsung held a zero-tolerance policy for LCD monitors sold in Korea. Currently, though, Samsung adheres to the less restrictive ISO 13406-2 standard. Other companies have been known to tolerate as many as 11 dead pixels in their policies. Dead pixel policies are often hotly debated between manufacturers and customers. To regulate the acceptability of defects and to protect the end user, ISO released the ISO 13406-2 standard. However, not every LCD manufacturer conforms to the ISO standard and the ISO standard is quite often interpreted in different ways. LCD panels are more likely to have defects than most ICs due to their larger size. For example, a 300 mm SVGA LCD has 8 defects and a 150 mm wafer has only 3 defects. However, 134 of the 137 dies on the wafer will be acceptable, whereas rejection of the LCD panel would be a 0% yield. Due to competition between manufacturers quality control has been improved. An SVGA LCD panel with 4 defective pixels is usually considered defective and customers can request an exchange for a new one. Some manufacturers, notably in South Korea where some of the largest LCD panel manufacturers, such as LG, are located, now have "zero defective pixel guarantee", which is an extra screening process which can then determine "A" and "B" grade panels. Many manufacturers would replace a product even with one defective pixel. Even where such guarantees do not exist, the location of defective pixels is important. A display with only a few defective pixels may be unacceptable if the defective pixels are near each other. Manufacturers may also relax their replacement criteria when defective pixels are in the center of the viewing area. LCD panels also have defects known as *clouding* (or less commonly *mura*), which describes the uneven patches of changesin luminance.Itismostvisibleindarkorblackareasofdisplayed scenes

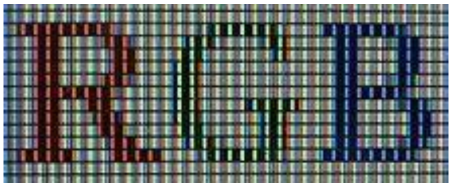
ZERO-POWER (BISTABLE) DISPLAYS

The zenithal bistable device (ZBD), developed by QinetiQ(formerly DERA), can retain an image without power. The crystals may exist in one of two stable orientations ("Black" and "White") and power is only required to change the image. ZBD Displays is a spin-off company from QinetiQ who manufacture both grayscale and colourZBD devices. A French company, Nemoptic, has developed the BiNem zero-power, paper-like LCD technology which has been mass-produced in partnership with Seiko since2007.

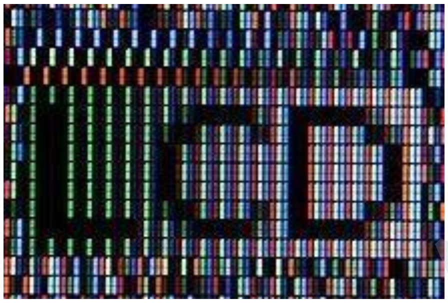
This technology is intended for use in applications such as Electronic Shelf Labels, E-books, E- documents, E-newspapers, E-dictionaries, Industrial sensors, Ultra-Mobile PCs, etc.

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

Comparison of the OLPC XO-1 display (left) with a typical colour LCD. The images show 1×1 mm of each screen. A typical LCD addresses groups of 3 locations as pixels. The XO-1 display addresses each location as a separatepixel.



Example of how the colours are generated (R-red, G-green and B-blue)

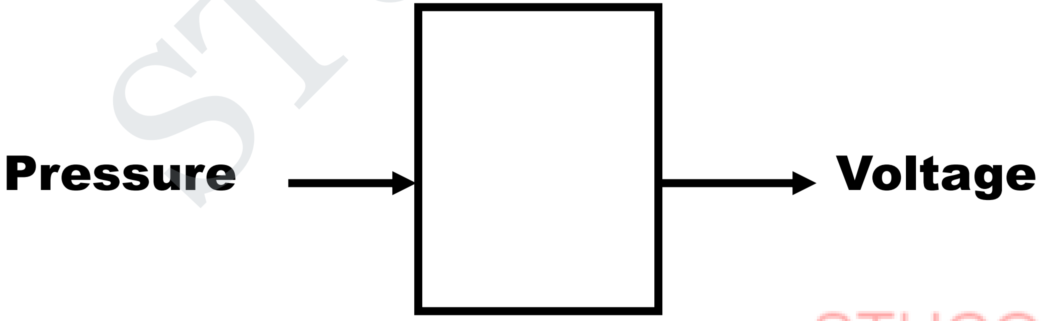


In colour LCDs each individual pixel is divided into three cells, or subpixels, which are coloured red, green, and blue, respectively, by additional filters (pigment filters, dye filters and metal oxide filters). Each subpixel can be controlled independently to yield thousands or millions of possible colours for each pixel. CRT monitors employ a similar 'subpixel' structures *via* phosphors, although the electron beam employed in CRTs do not hit exact subpixels. The figure at the left shows the twisted nematic (TN) type of LCD.

TRANSDUCERS

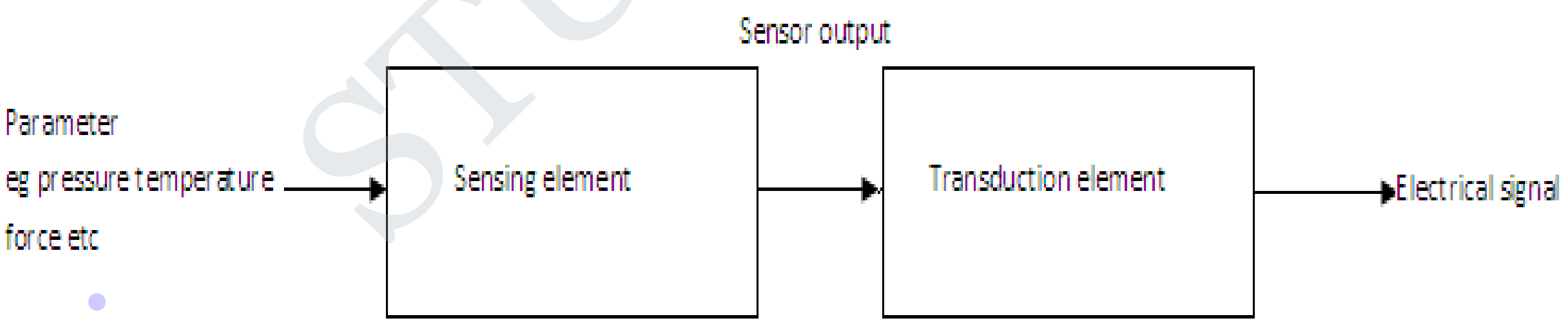
INTRODUCTION OF TRANSDUCERS

- A transducer is a device that convert one form of energy to other form. It converts the measurand to a usable electrical signal.
- In other word it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.



BLOCK DIAGRAM OF TRANSDUCERS

- Transducer contains two parts that are closely related to each other i.e. the sensing element and transduction element.
- The sensing element is called as the sensor. It is device producing measurable response to change in physical conditions.
- The transduction element convert the sensor output to suitable electrical form.



CHARACTERISTICS OF TRANSDUCERS

1. Ruggedness
2. Linearity
3. Repeatability
4. Accuracy
5. High stability and reliability
6. Speed of response
7. Sensitivity
8. Small size

TRANSDUCERS SELECTION FACTORS

1. **Operating Principle:** The transducer are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive , optoelectronic, piezo electric etc.
2. **Sensitivity:** The transducer must be sensitive enough to produce detectable output.
3. **Operating Range:** The transducer should maintain the range requirement and have a good resolution over the entire range.
4. **Accuracy:** High accuracy is assured.
5. **Cross sensitivity:** It has to be taken into account when measuring mechanical quantities. There are situation where the actual quantity is being measured is in one plane and the transducer is subjected to variation in another plan.
6. **Errors:** The transducer should maintain the expected input-output relationship as described by the transfer function so as to avoid errors.

Contd.

7. **Transient and frequency response :** The transducer should meet the desired time domain specification like peak overshoot, rise time, setting time and small dynamic error.
8. **Loading Effects:** The transducer should have a high input impedance and low output impedance to avoid loading effects.
9. **Environmental Compatibility:** It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.
10. **Insensitivity to unwanted signals:** The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.

CLASSIFICATION OF TRANSDUCERS

The transducers can be classified as:

I. Active and passive transducers.
II. Analog and digital transducers.
III. On the basis of transduction principle used.
IV. Primary and secondary transducer
V. Transducers and inverse transducers.

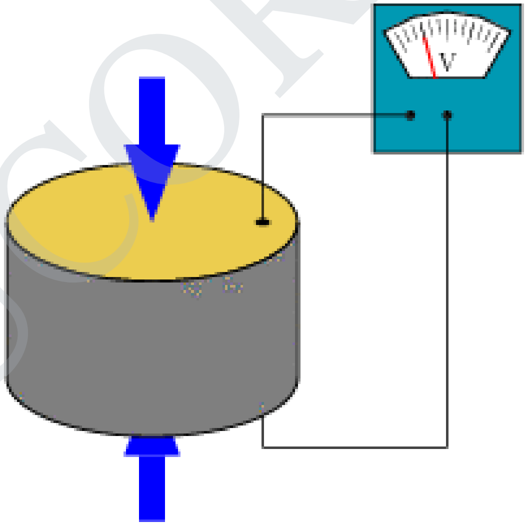
ACTIVE AND PASSIVE TRANSDUCERS

- **Active transducers :**
- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

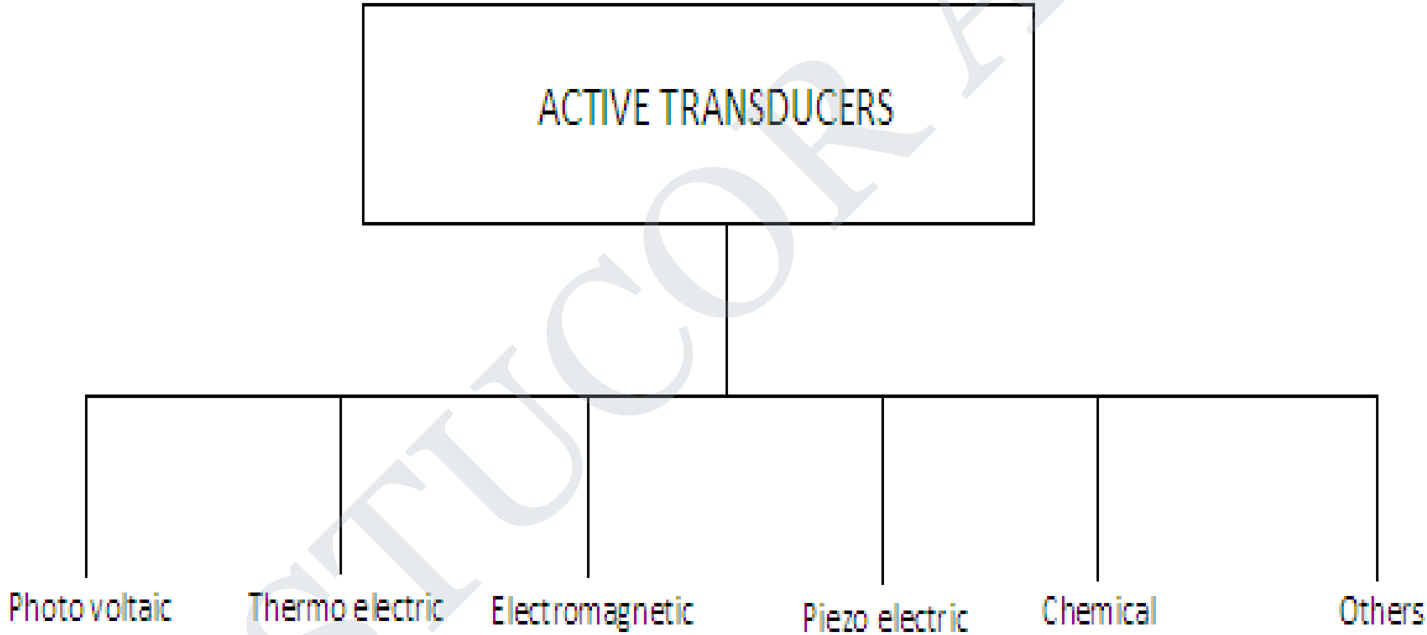
I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used.

Piezoelectric Transducer



CLASSIFICATION OF ACTIVE TRANSDUCERS



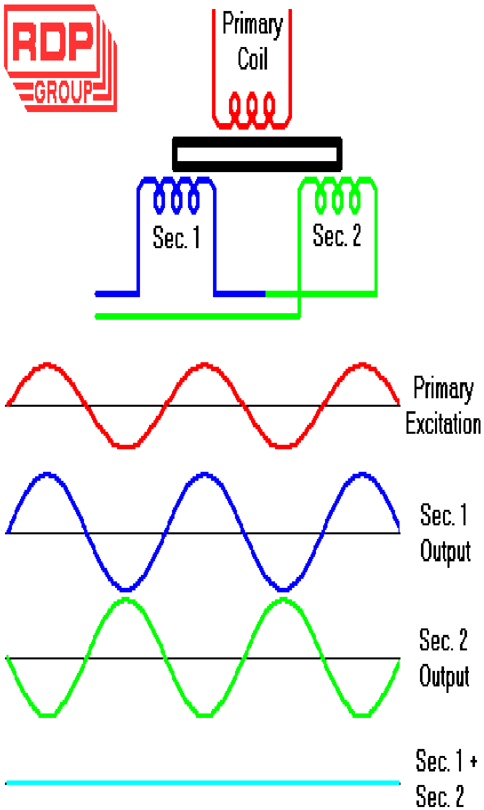
ACTIVE AND PASSIVE TRANSDUCERS

- **Passive Transducers :**

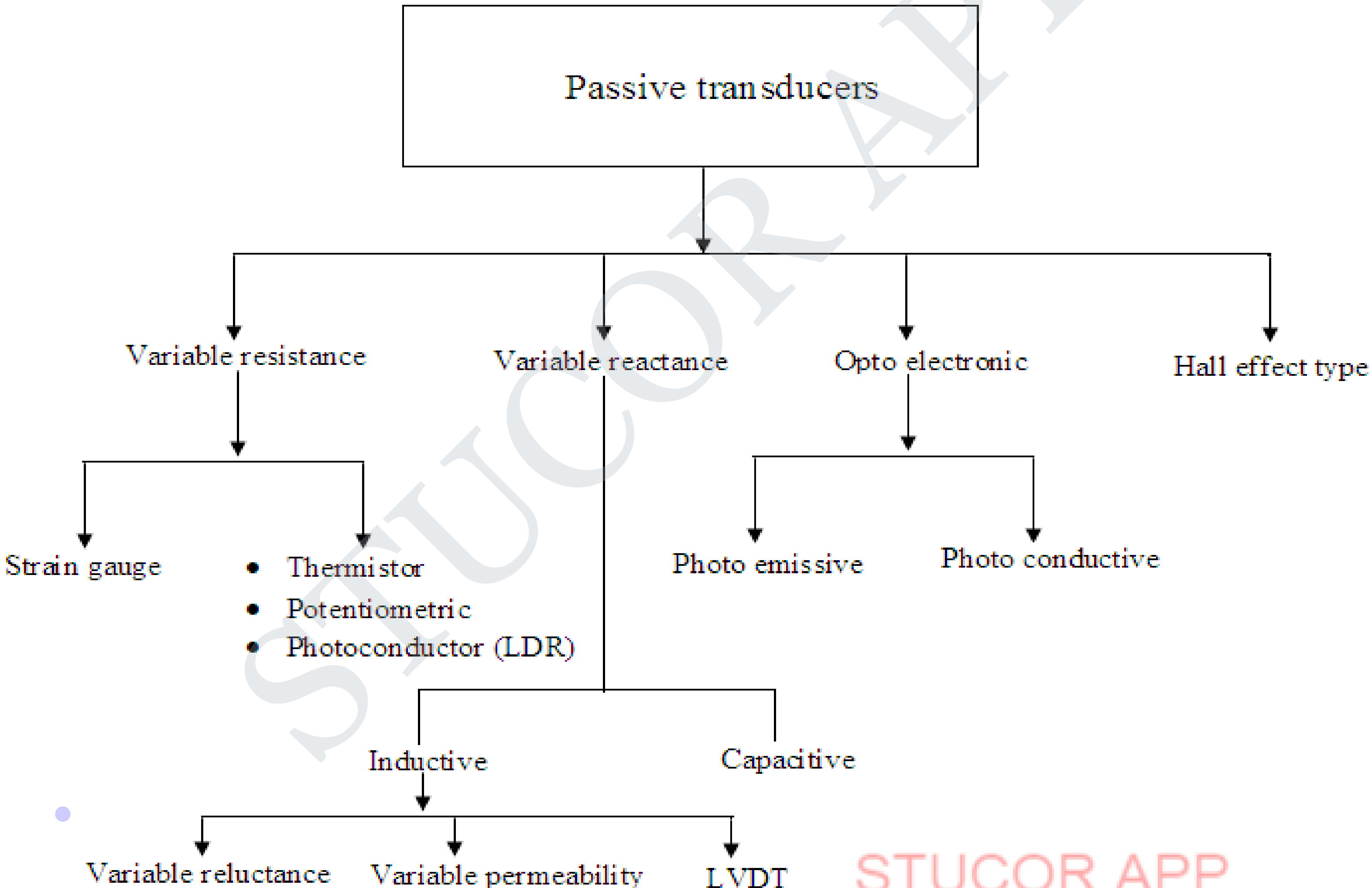
I. These transducers need external source of power for their operation. So they are not self generating type transducers.

II. A DC power supply or an audio frequency generator is used as an external power source.

III. These transducers produce the output signal in the form of variation in resistance, capacitance, inductance or some other electrical parameter in response to the quantity to be measured.



CLASSIFICATION OF PASSIVE TRANSDUCERS



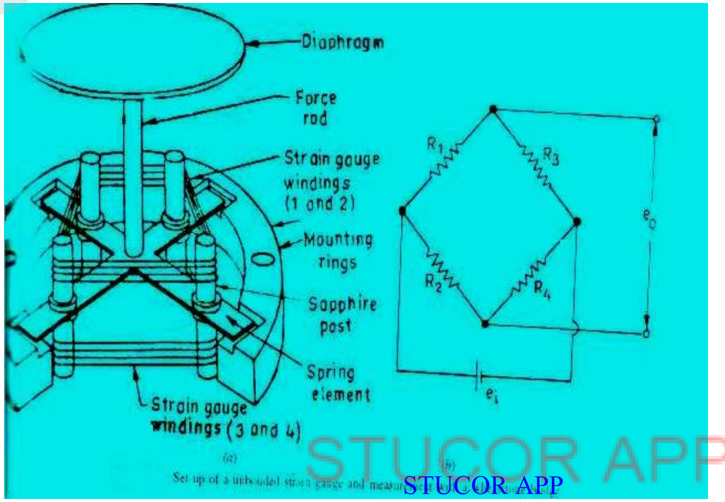
PRIMARY AND SECONDARY TRANSDUCERS

- Some transducers contain the mechanical as well as electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical device are called as the primary transducers, because they deal with the physical quantity to be measured.

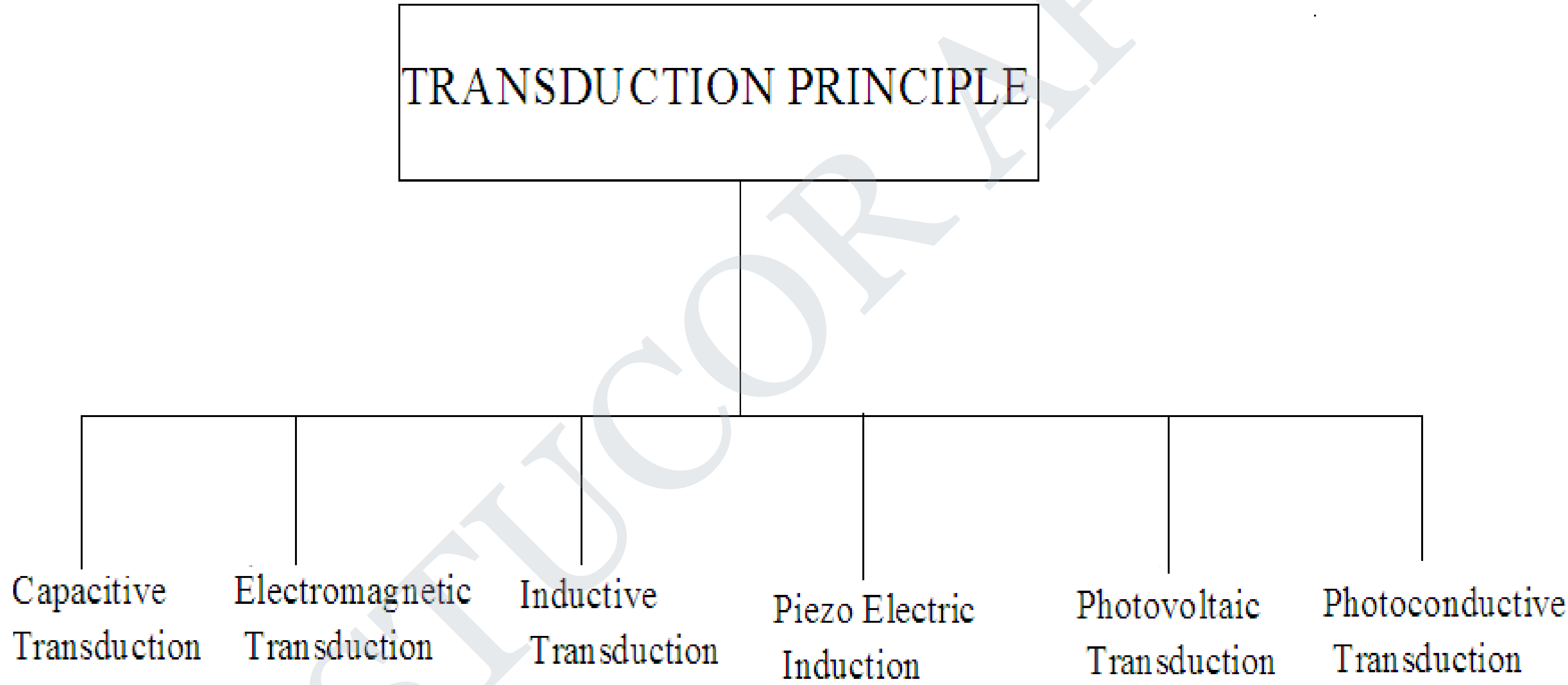
- The electrical device then convert this mechanical signal into a corresponding electrical signal. Such electrical device are known as secondary transducers.

CONTD

- Ref fig in which the diaphragm act as primary transducer. It convert pressure (the quantity to be measured) into displacement(the mechanical signal).
- The displacement is then converted into change in resistance using strain gauge. Hence strain gauge acts as the secondary transducer.



CLASSIFICATION OF TRANSDUCERS According to Transduction Principle



CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

CAPACITIVE TRANSDUCER:

•In capacitive transduction transducers the measurand is converted to a change in the capacitance.

• A typical capacitor is comprised of two parallel plates of conducting material separated by an electrical insulating material called a dielectric. The plates and the dielectric may be either flattened or rolled.

• The purpose of the dielectric is to help the two parallel plates maintain their stored electrical charges.

• The relationship between the capacitance and the size of capacitor plate, amount of plate separation, and the dielectric is given by

$C = \varepsilon_0 \varepsilon_r A / d$

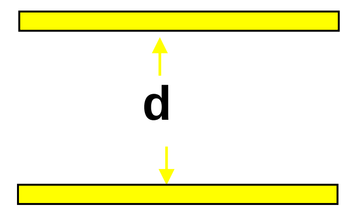
d is the separation distance of plates (m)

C is the capacitance (F, Farad)

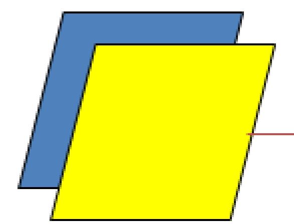
ε_0 : absolute permittivity of vacuum

ε_r : relative permittivity

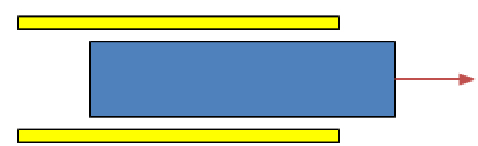
A is the effective (overlapping) area of capacitor plates (m2)



Area=A



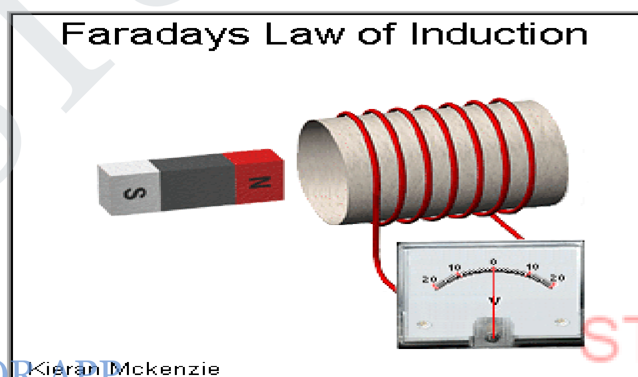
Either A, d or ε can be varied.

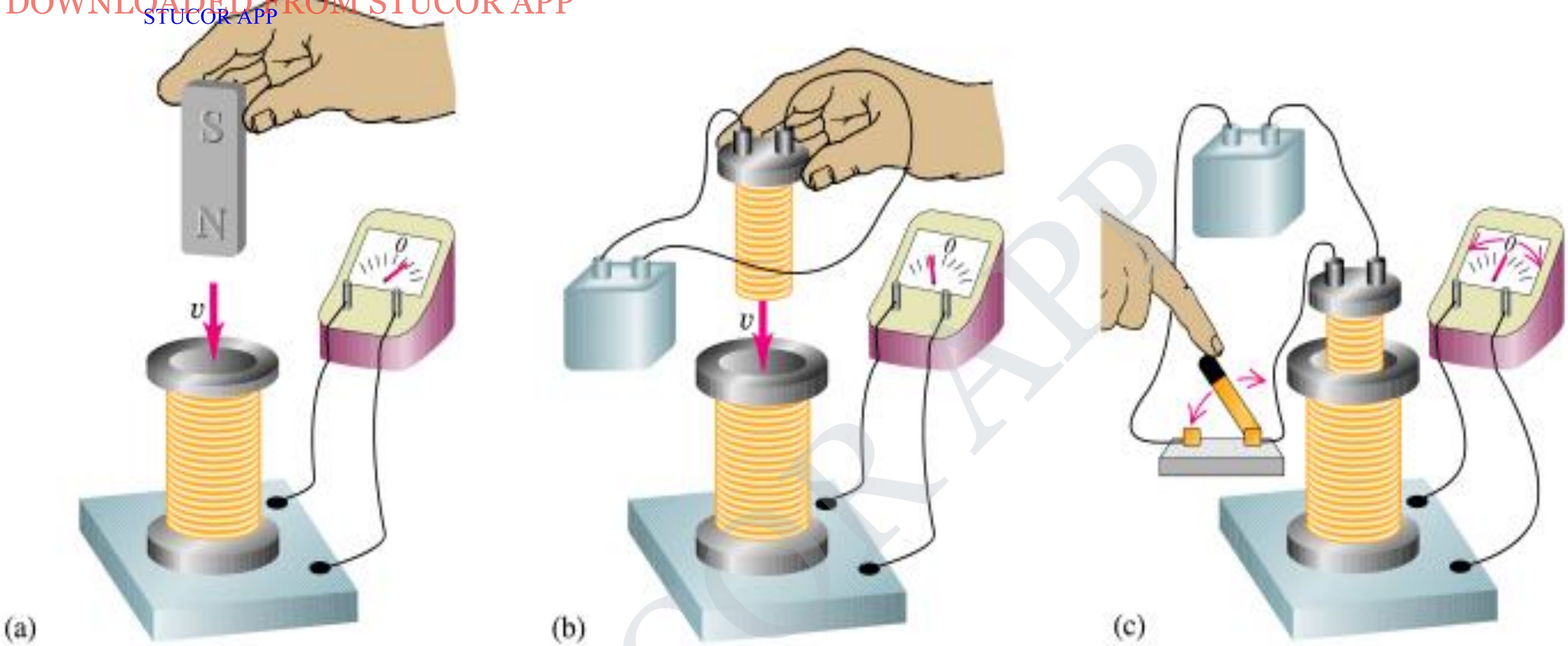


CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

ELECTROMAGNETIC TRANSDUCTION:

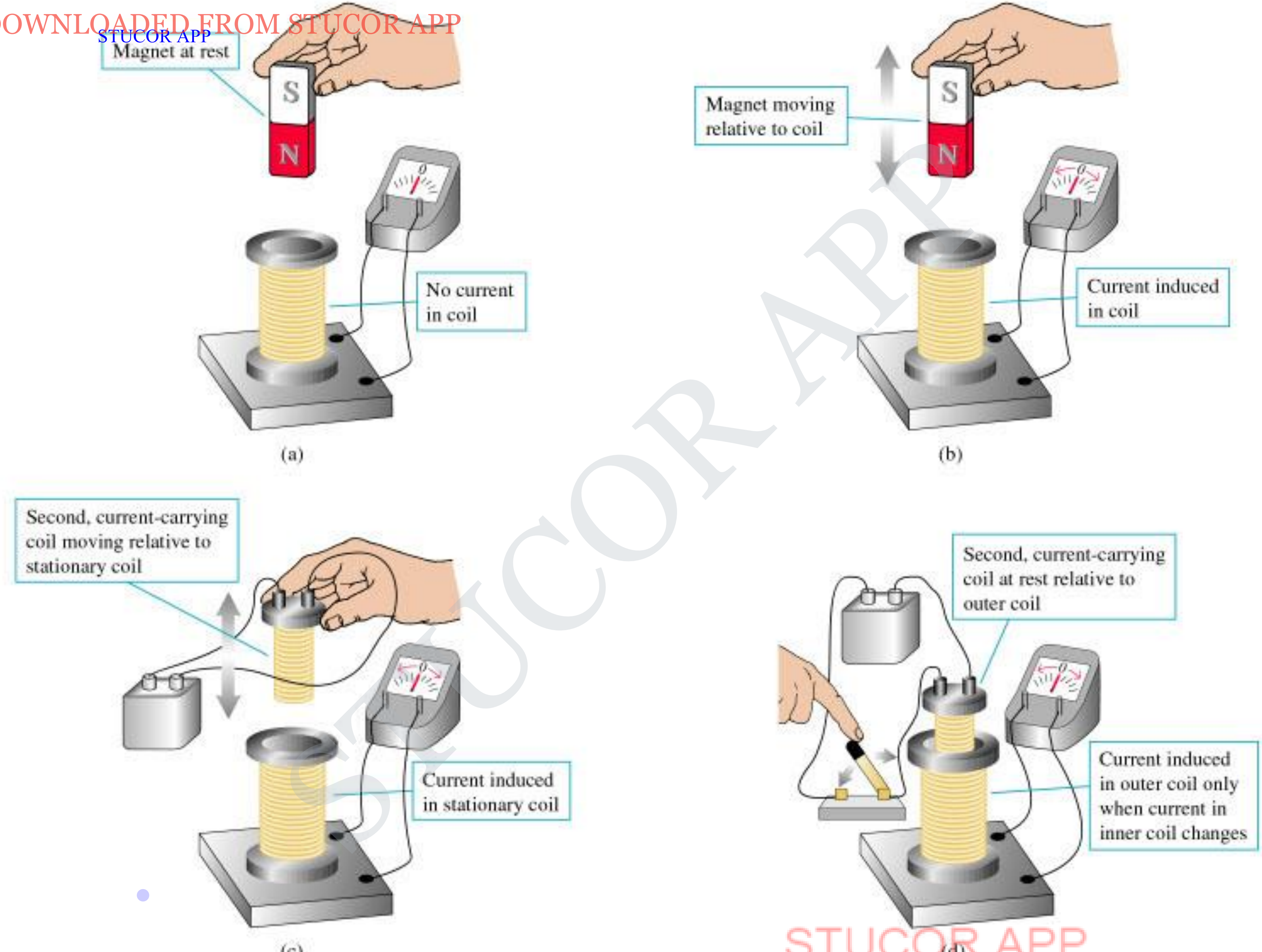
- In electromagnetic transduction, the measurand is converted to voltage induced in conductor by change in the magnetic flux, in absence of excitation.
- The electromagnetic transducer are self generating active transducers
- The motion between a piece of magnet and an electromagnet is responsible for the change in flux





Current induced in a coil.

STUCOR APP


Magnet at rest
S
N
No current in coil
(a)
Magnet moving relative to coil
S
N
Current induced in coil
(b)
Second, current-carrying coil moving relative to stationary coil
Current induced in stationary coil
(c)
Second, current-carrying coil at rest relative to outer coil
Current induced in outer coil only when current in inner coil changes
(d)

CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

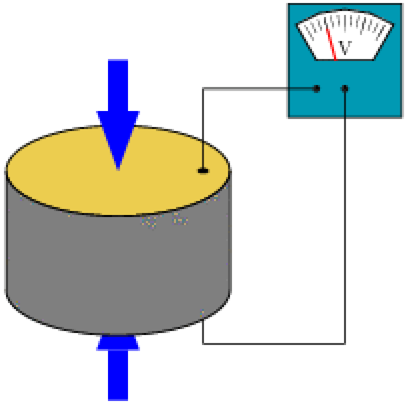
INDUCTIVE TRANSDUCER:

- In inductive transduction, the measurand is converted into a change in the self inductance of a single coil. It is achieved by displacing the core of the coil that is attached to a mechanical sensing element

CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

PIEZO ELECTRIC INDUCTION :

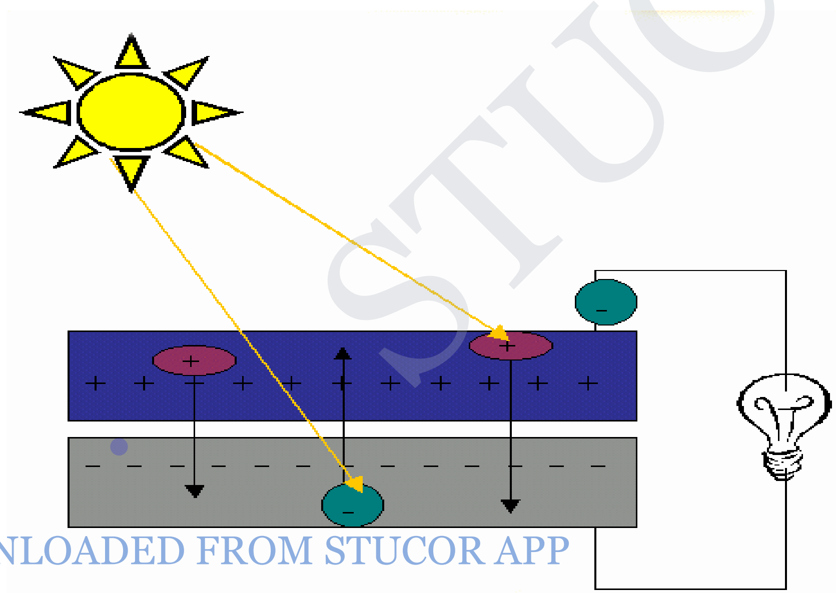
•In piezoelectric induction the measurand is converted into a change in electrostatic charge q or voltage V generated by crystals when mechanically it is stressed as shown in fig.

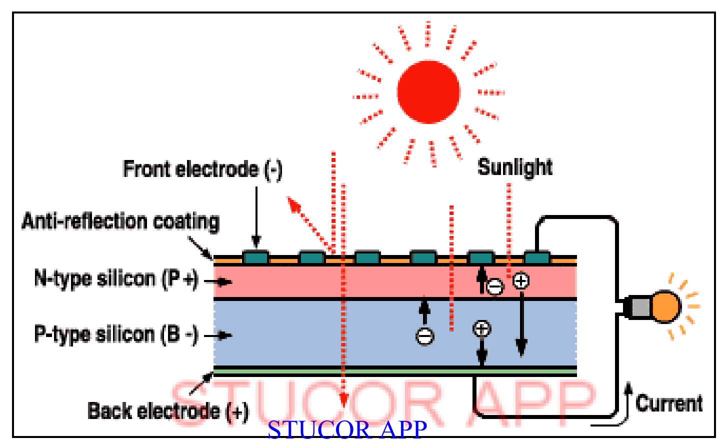


CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

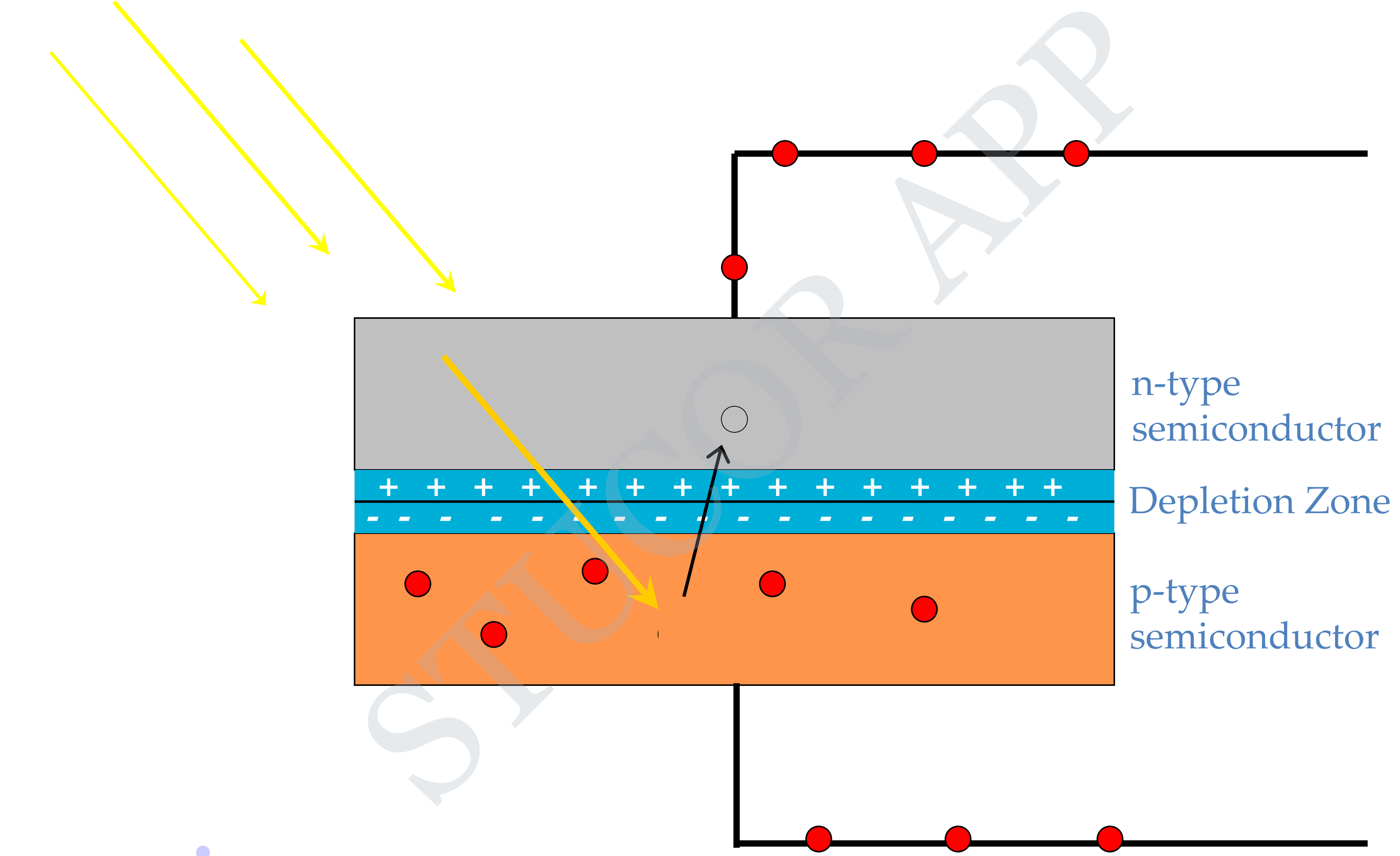
PHOTOVOLTAIC TRANSDUCTION :

•In photovoltaic transduction the measurand is converted to voltage generated when the junction between dissimilar material is illuminated as shown in fig.





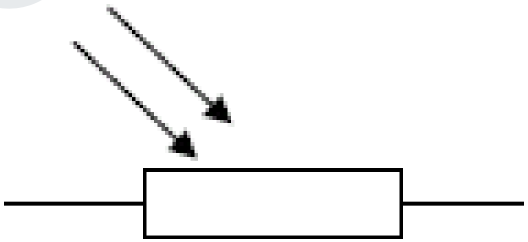
Physics of Photovoltaic Generation



CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

PHOTO CONDUCTIVE TRANSDUCTION :

- In photoconductive transduction the measurand is converted to change in resistance of semiconductor material by the change in light incident on the material.



CLASSIFICATION OF TRANSDUCERS
Transducer and Inverse Transducer

TRANSDUCER:

- Transducers convert non electrical quantity to electrical quantity.

INVERSE TRANSDUCER:

- Inverse transducers convert electrical quantity to a non electrical quantity

PASSIVE TRANSDUCERS

- **Resistive transducers** :
  - Resistive transducers are those transducers in which the resistance change due to the change in some physical phenomenon.
  - The resistance of a metal conductor is expressed by a simple equation.
  - $R = \rho L/A$
  - Where R = resistance of conductor in Ω

    L = length of conductor in m

    A = cross sectional area of conductor in m^2

    ρ = resistivity of conductor material in Ω-m.

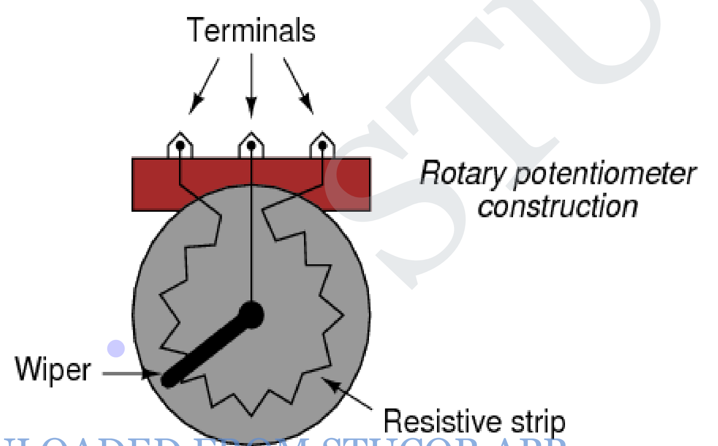
RESISTIVE TRANSDUCER

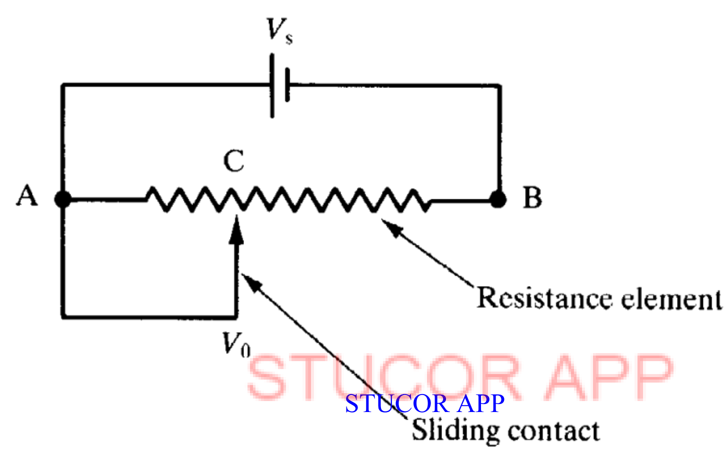
There are 4 type of resistive transducers.

1. Potentiometers (POT)
2. Strain gauge
3. Thermistors
4. Resistance thermometer

POTENTIOMETER

- The potentiometer are used for voltage division. They consist of a resistive element provided with a sliding contact. The sliding contact is called as wiper.
- The contact motion may be linear or rotational or combination of the two. The combinational potentiometer have their resistive element in helix form and are called helipots.
- Fig shows a linear pot and a rotary pot.





STRAIN GAUGE

- The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change.
- This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.

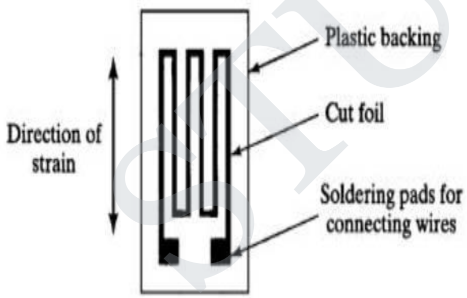
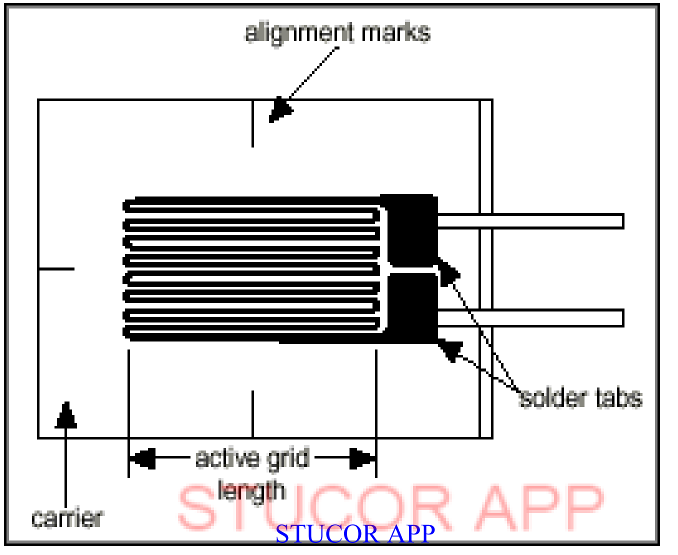


FIGURE 8.2
Foil strain gage.



TYPES OF STRAIN GAUGE

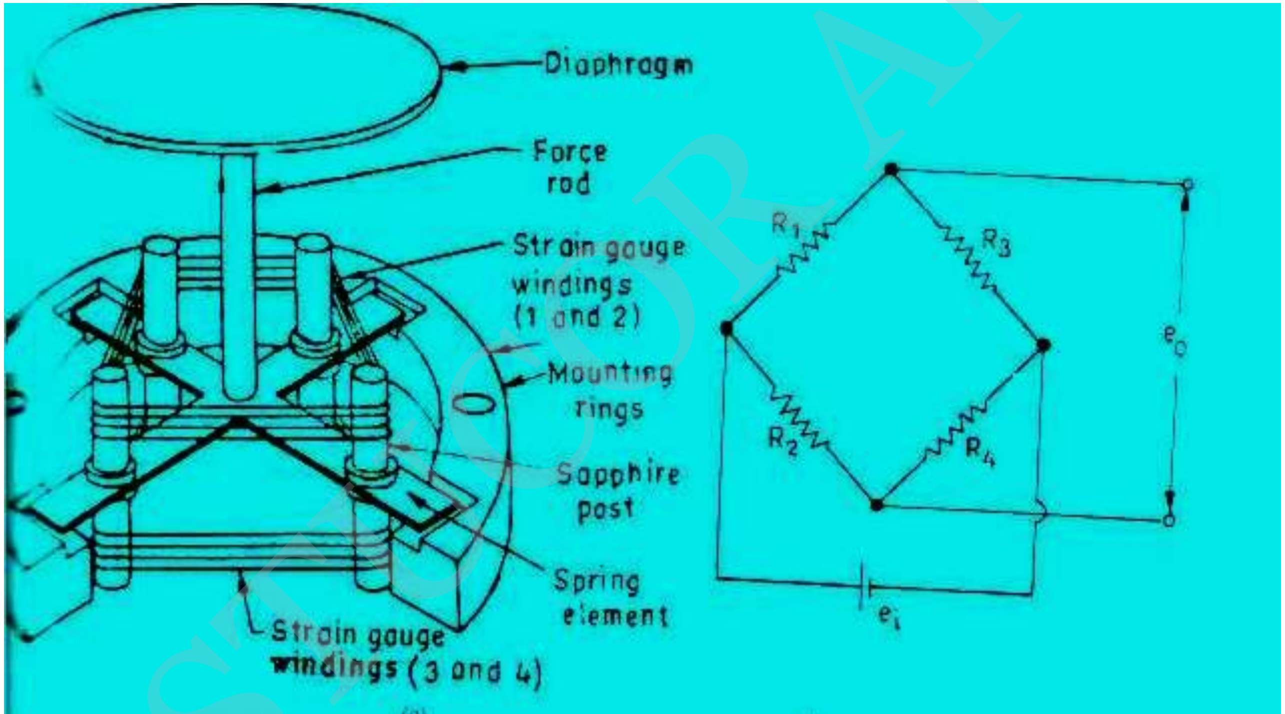
- The type of strain gauge are as

1. Wire gauge
   a) Unbonded
   b) Bonded
   c) Foil type
2. Semiconductor gauge

UNBONDED STRAIN GAUGE

- An unbonded meter strain gauge is shown in fig
- This gauge consist of a wire stretched between two point in an insulating medium such as air. The wires may be made of various copper, nickel, crome nickle or nickle iron alloys.
- In fig the element is connected via a rod to diaphragm which is used for sensing the pressure. The wire are tensioned to avoid buckling when they experience the compressive force.

- The unbounded meter wire gauges used almost exclusively in transducer application employ preloaded resistance wire connected in Wheatstone bridge as shown in fig.
- At initial preload the strain and resistance of the four arms are nominally equal with the result the output voltage of the bridge is equal to zero.
- Application of pressure produces a small displacement , the displacement increases a tension in two wire and decreases it in the other two thereby increase the resistance of two wire which are in tension and decreasing the resistance of the remaining two wire .
- This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure .

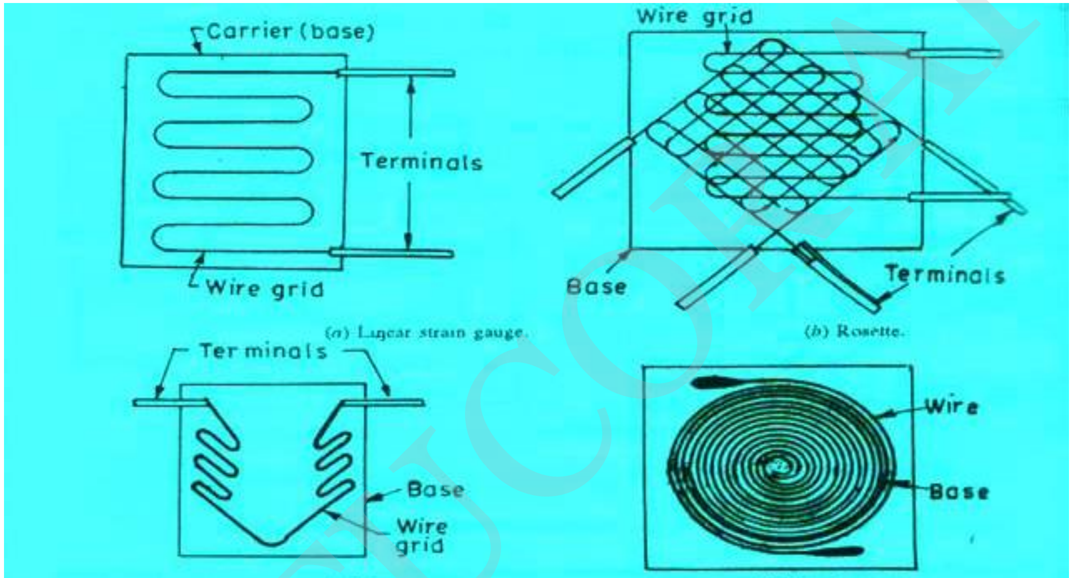


(a) (b)

Set up of a unbonded strain gauge and measurement with a wheatstone bridge

BONDED STRAIN GAUGE

- The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer.
- A resistance wire strain gauge consist of a grid of fine resistance wire. The grid is cemented to carrier which may be a thin sheet of paper bakelite or teflon.
- The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical demage.
- The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires.



(a) Linear strain gauge. (b) Rosette. (c) Torque gauge. (d) Helical gauge.

Resistance wire strain gauge.

BONDED METAL FOIL STRAIN GAUGE

- It consist of following parts:

1. **Base (carrier) Materials:** several types of base material are used to support the wires. Impregnated paper is used for room temp. applications.
2. **Adhesive:** The adhesive acts as bonding materials. Like other bonding operation, successful starain gauge bonding depends upon careful surface preparation and use of the correct bonding agent.

   In order that the strain be faithfully transferred on to the strain gauge, the bond has to be formed between the surface to be strained and the plastic backing material on which the gauge is mounted .

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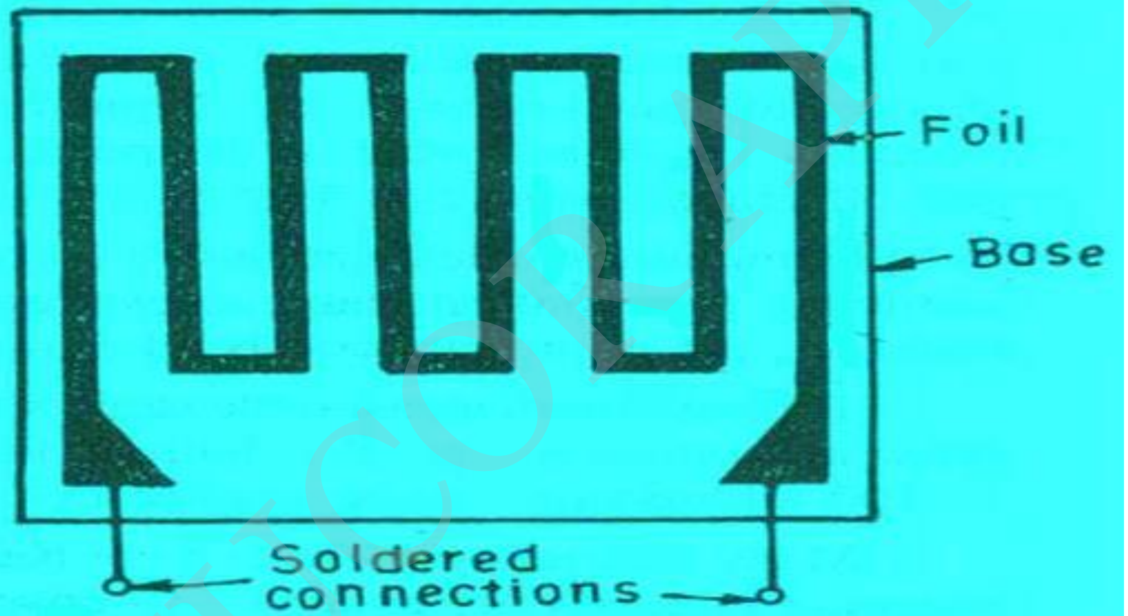


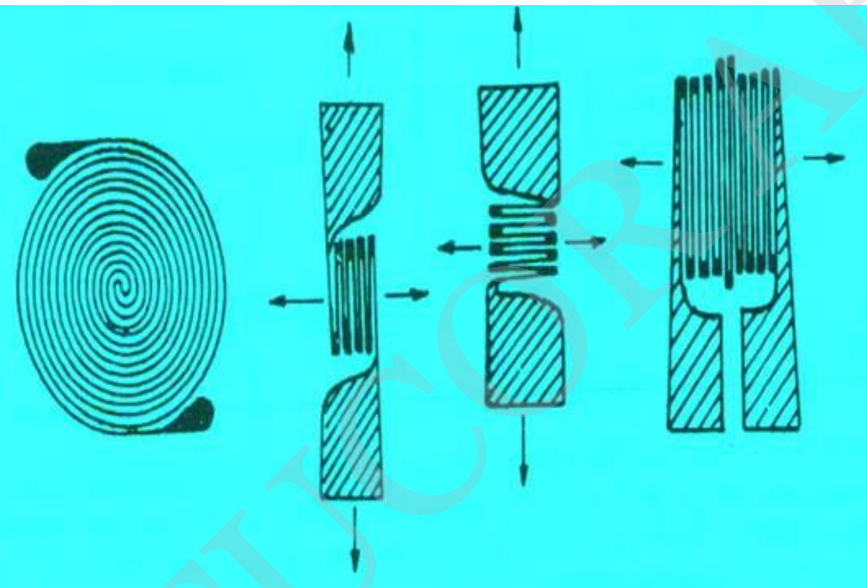
Bonded metal foil gauge.

It is important that the adhesive should be suited to this backing and adhesive material should be quick drying type and also insensitive to moisture.

3. **Leads:** The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficent

Contd.

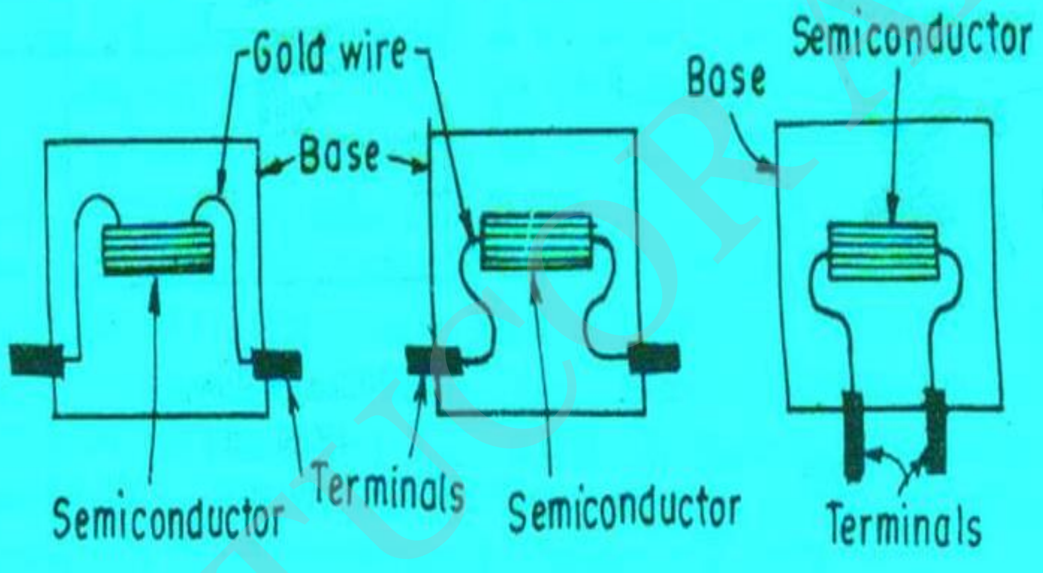
- This class of strain gauge is only an extension of the bonded metal wire strain gauges.
- The bonded metal wire starin gauge have been completely superseded by bonded metal foil strain gauges.
- Metal foil strain gauge use identical material to wire strain gauge and are used for most general purpose stress analysis application and for many transducers.



Metal foil strain gauges.

SEMICONDUCTOR GAUGE

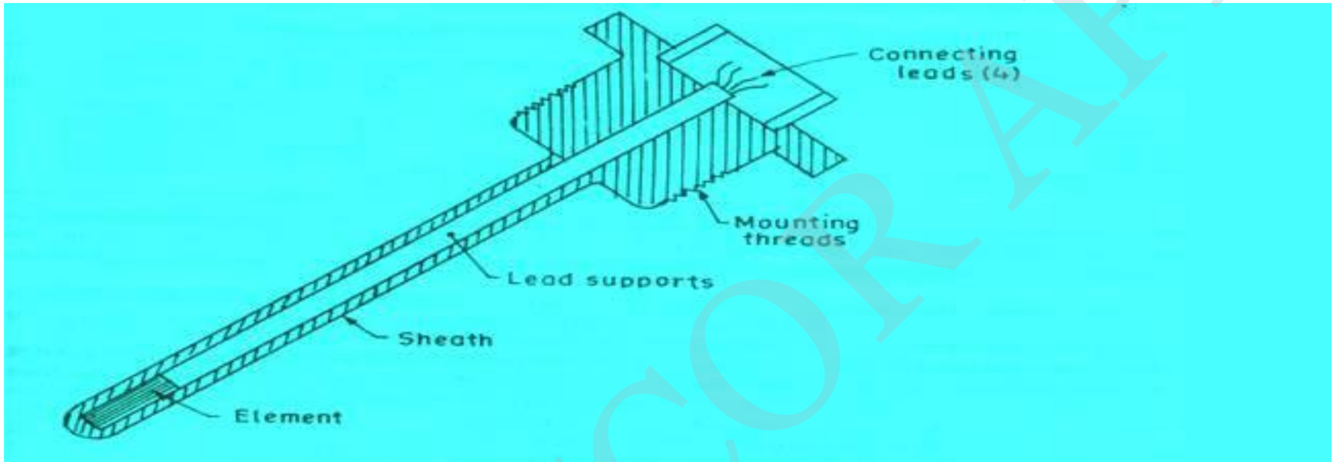
- Semiconductor gauge are used in application where a high gauge factor is desired. A high gauge factor means relatively higher change in resistance that can be measured with good accuracy.
- The resistance of the semiconductor gauge change as strain is applied to it. The semiconductor gauge depends for their action upon the piezo-resistive effect i.e. change in value of resistance due to change in resistivity.
- Silicon and germanium are used as resistive material for semiconductor gauges.



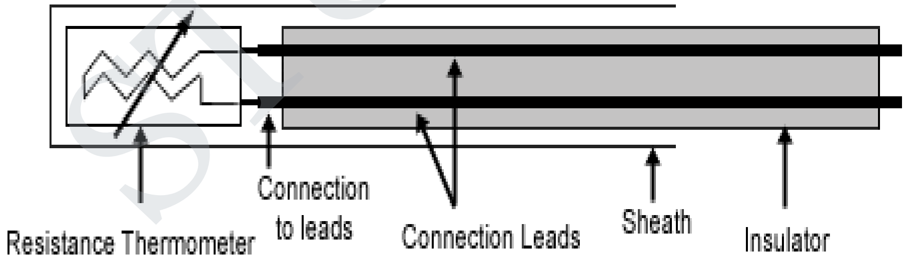
Semi-conductor strain gauge.

RESISTANCE THERMOMETER

- Resistance of metal increase with increases in temperature. Therefore metals are said to have a positive temperature coefficient of resistivity.
- Fig shows the simplest type of open wire construction of platinum résistance thermometer. The platinum wire is wound in the form of spirals on an insulating material such as mica or ceramic.
- This assembly is then placed at the tip of probe
- This wire is in direct contact with the gas or liquid whose temperature is to be measured.



Industrial platinum resistance thermometer.

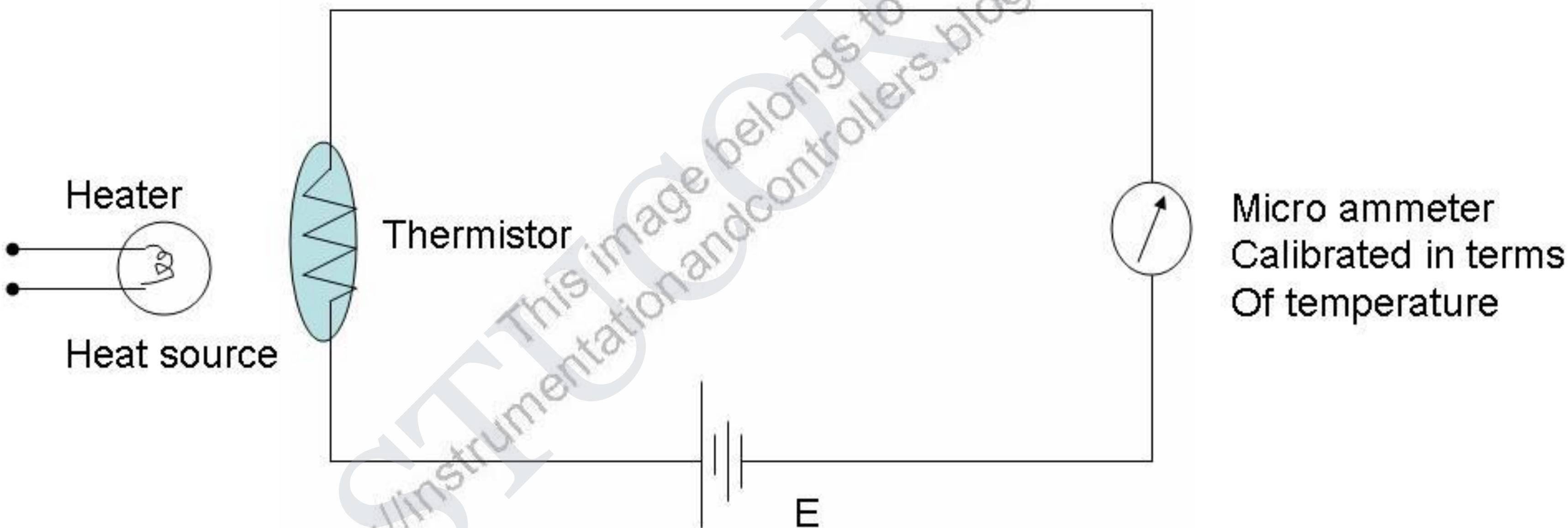


- The resistance of the platinum wire changes with the change in temperature of the gas or liquid
- This type of sensor have a positive temperature coefficient of resistivity as they are made from metals they are also known as resistance temperature detector
- Resistance thermometer are generally of probe type for immersion in medium whose temperature is to be measured or controlled.

THERMISTOR

- Thermistor is a contraction of a term "thermal resistor".
- Thermistor are temperature dependent resistors. They are made of semiconductor material which have negative temperature coefficient of resistivity i.e. their resistance decreases with increase of temperature.
- Thermistor are widely used in application which involve measurement in the range of 0-60^{o} Thermistor are composed of sintered mixture of metallic oxides such as magnese, nickle, cobalt, copper, iron and uranium

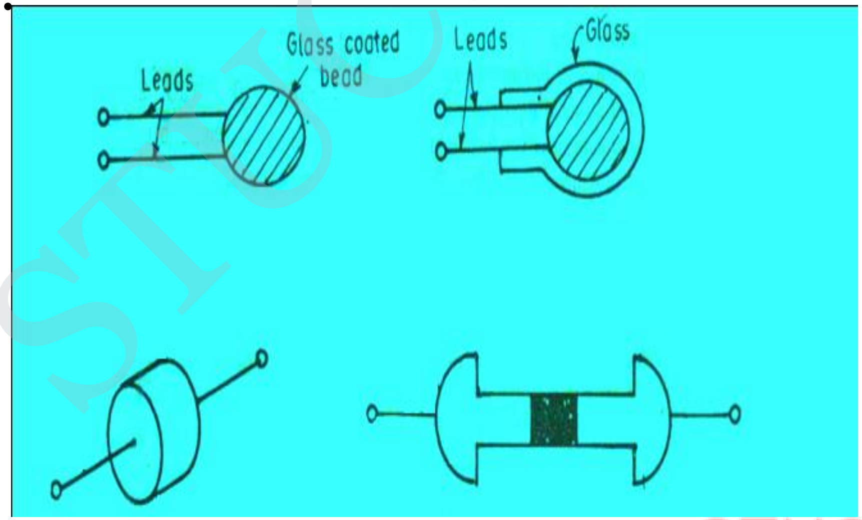
Temperature measurement using thermistor



Contd.

•The thermistor may be in the form of beads, rods and discs.

•The thermistor provide a large change in resistance for small change in temperature. In some cases the resistance of themistor at room temperature may decreases as much as 6% for each 1ºC rise in temperature.

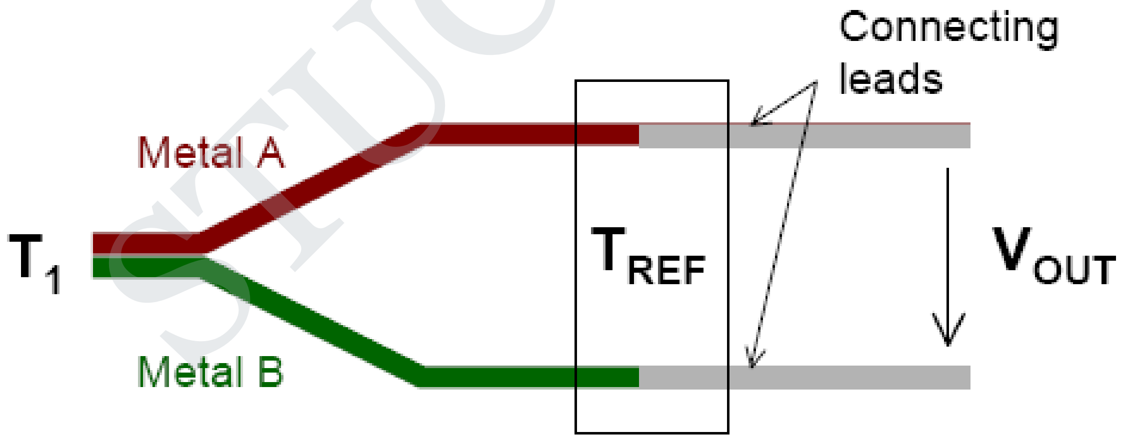


Thermocouples

See beck Effect

When a pair of dissimilar metals are joined at one end, and there is a temperature difference between the joined ends and the open ends, thermal emf is generated, which can be measured in the open ends.

This forms the basis of thermocouples.



VARIABLE-INDUCTANCE TRANSDUCERS

- An inductive electromechanical transducer is a transducer which converts the physical motion into the change in inductance.

- Inductive transducers are mainly used for displacement measurement.

- The inductive transducers are of the self generating or the passive type. The self generating inductive transducers use the basic generator principle i.e. the motion between a conductor and magnetic field induces a voltage in the conductor.
- The variable inductance transducers work on the following principles.
- Variation in self inductance
- Variation in mutual inductance

PRINCIPLE OF VARIATION OF SELF INDUCTANCE

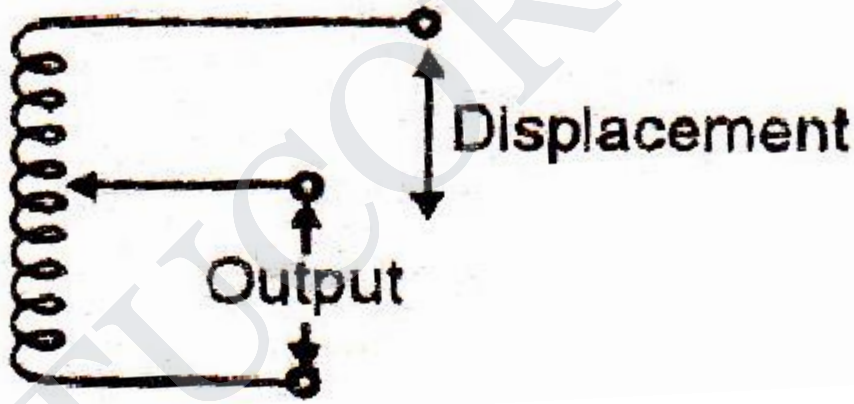
- Let us consider an inductive transducer having N turns and reluctance R. when current I is passed through the transducer, the flux produced is
- $\Phi = Ni / R$
- Differentiating w.r.t. to t,
- $d\Phi/dt = N/R * di/dt$
- The e.m.f. induced in a coil is given by
- $e = N * d\Phi/dt$

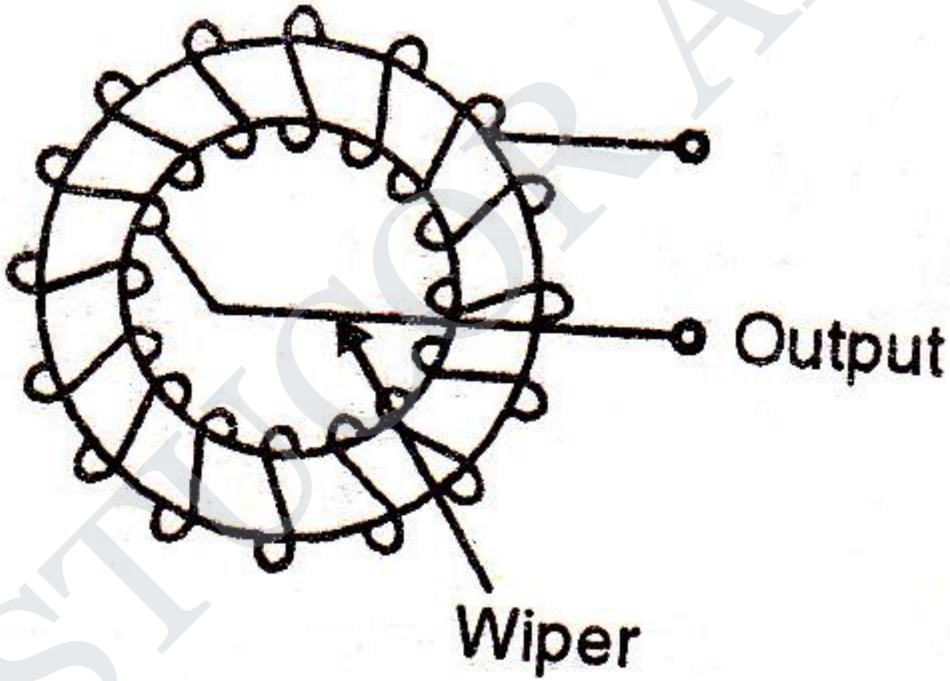
- $e = N * N/R * di/dt$
- $e = N^2 / R * di/dt$
- Self inductance is given by
- $L = e/di/dt = N^2 / R$
- The reluctance of the magnetic circuit is $R = l/\mu A$
- Therefore $L = N^2 / l/\mu A = N^2 \mu A / l$
- From eqn we can see that the self inductance may vary due to

i. Change in number of turns N
ii. Change in geometric configuration
iii. Change in permeability of magnetic circuit

CHANGE IN SELF INDUCTANCE WITH CHANGE IN NUMBER OF TURNS N

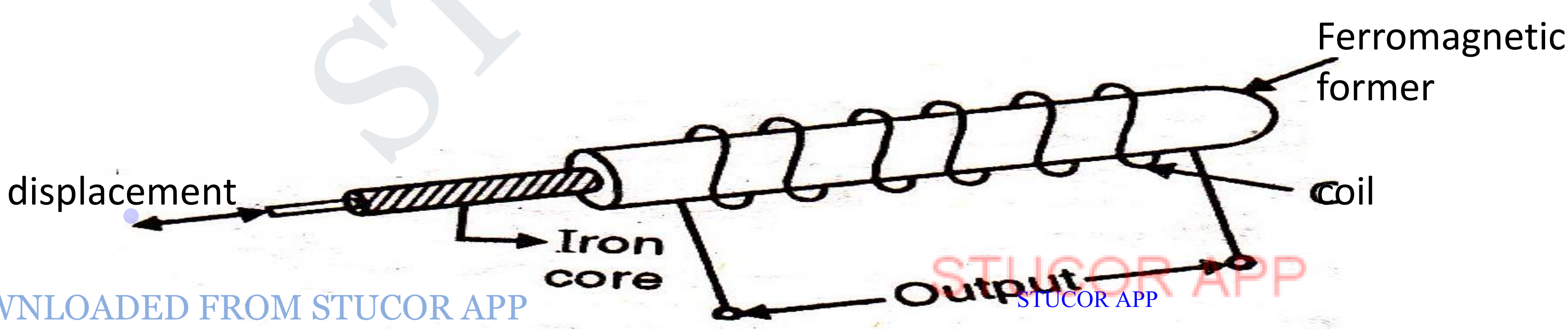
- From eqn we can see the output may vary with the variation in the number of turns. As inductive transducers are mainly used for displacement measurement, with change in number of turns the self inductance of the coil changes in-turn changing the displacement
- Fig shows transducers used for linear and angular displacement fig a shows an air cored transducer for the measurement of linear displacement and fig b shows an iron cored transducer used for angular displacement measurement.


Displacement
Output


Output
Wiper

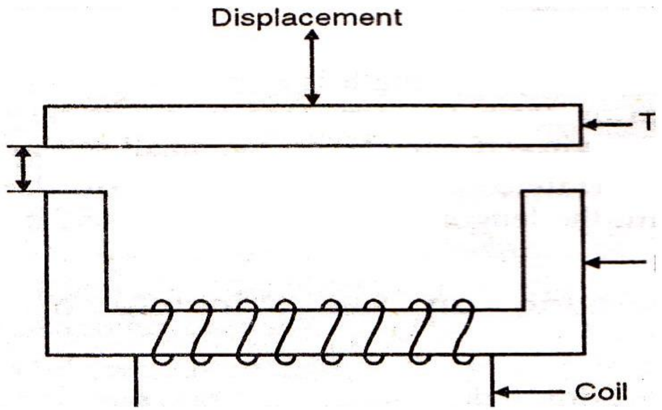
CHANGE IN SELF INDUCTANCE WITH CHANGE IN PERMEABILITY

- An inductive transducer that works on the principle of change in self inductance of coil due to change in the permeability is shown in fig
- As shown in fig the iron core is surrounded by a winding. If the iron core is inside the winding then the permeability increases otherwise permeability decreases. This cause the self inductance of the coil to increase or decrease depending on the permeability.
- The displacement can be measured using this transducer



VARIABLE RELUCTANCE INDUCTIVE TRANSDUCER

- Fig shows a variable reluctance inductive transducer.
- As shown in fig the coil is wound on the ferromagnetic iron. The target and core are not in direct contact with each other. They are separated by an air gap.
- The displacement has to be measured is applied to the ferromagnetic core
- The reluctance of the magnetic path is found by the size of the air gap.
- The self inductance of coil is given by
- $L = N^2 / R = N^2 / Ri + Ra$
- N : number of turns
- R : reluctance of coil
- Ri : reluctance of iron path
- Ra : reluctance of air gap



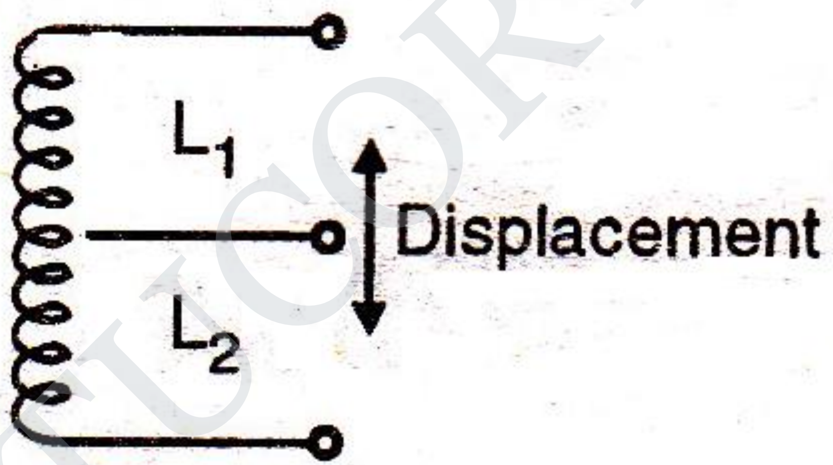
STUCOR APP

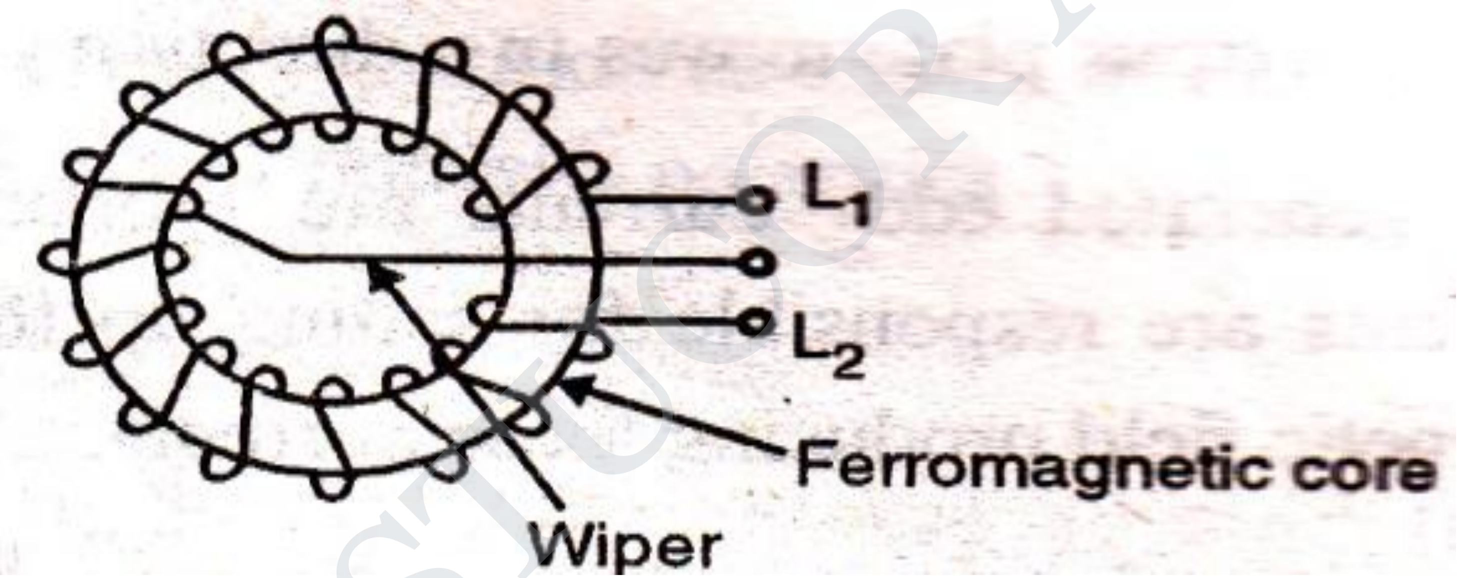
CONTD.

- The reluctance of iron path is negligible
- $L = N^2 / Ra$
- $Ra = la / \mu_0 A$
- Therefore L œ 1 / la i.e. self inductance of the coil is inversely proportional to the air gap la.
- When the target is near the core, the length is small. Hence the self inductance is large. But when the target is away from the core, the length is large. So reluctance is also large. This result in decrease in self inductance i.e. small self inductance.
- Thus inductance is function of the distance of the target from the core. Displacement changes with the length of the air gap, the self inductance is a function of the displacement.

PRINCIPLE OF CHANGE IN MUTUAL INDUCTANCE

- Multiple coils are required for inductive transducers that operate on the principle of change in mutual inductance.
- The mutual inductance between two coils is given by
- M = KsqrtL1L2
- Where M : mutual inductance
- K : coefficient of coupling
- L1:self inductance of coil 1
- L2 : self inductance of coil 2
- By varying the self inductance or the coefficient of coupling the mutual inductance can be varied

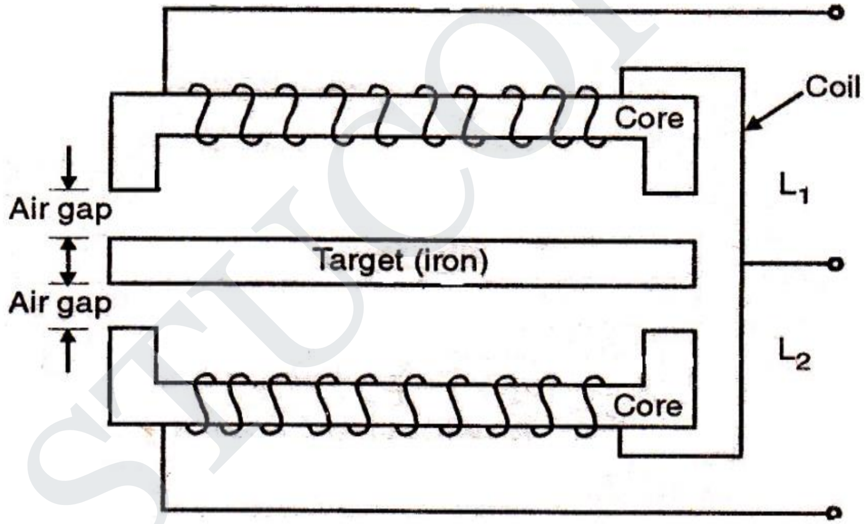

L1
L2
Displacement


L1
L2
Ferromagnetic core
Wiper

DIFFERENTIAL OUTPUT TRANSDUCERS

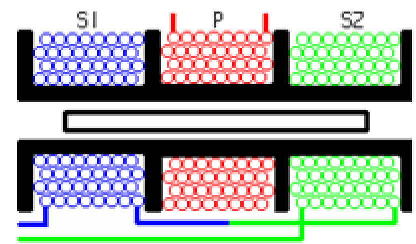
- Usually the change in self inductance ΔL for inductive transducers is insufficient for the detection of stages of an instrumentation system.
- The differential arrangement comprises of a coil that is divided in two parts as shown in fig a and b.
- In response to displacement, the inductance of one part increases from L to L+ΔL while the inductance of the other part decreases from L to L- ΔL. The difference of two is measured so to get output 2 ΔL. This will increase the sensitivity and minimize error.
- .

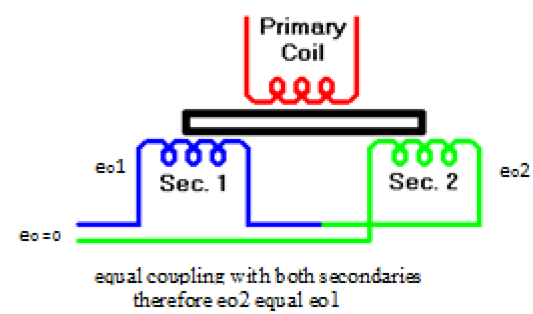
- Fig c shows an inductive transducer that provides differential output. Due to variation in the reluctance, the self inductance of the coil changes. This is the principle of operation of differential output inductive transducer


Coil
Core
L1
Air gap
Target (iron)
Air gap
L2
Core

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER(LVDT)

- AN LVDT transducer comprises a coil former on to which three coils are wound.
- The primary coil is excited with an AC current, the secondary coils are wound such that when a ferrite core is in the central linear position, an equal voltage is induced in to each coil.
- The secondary are connected in opposite so that in the central position the outputs of the secondary cancels out.





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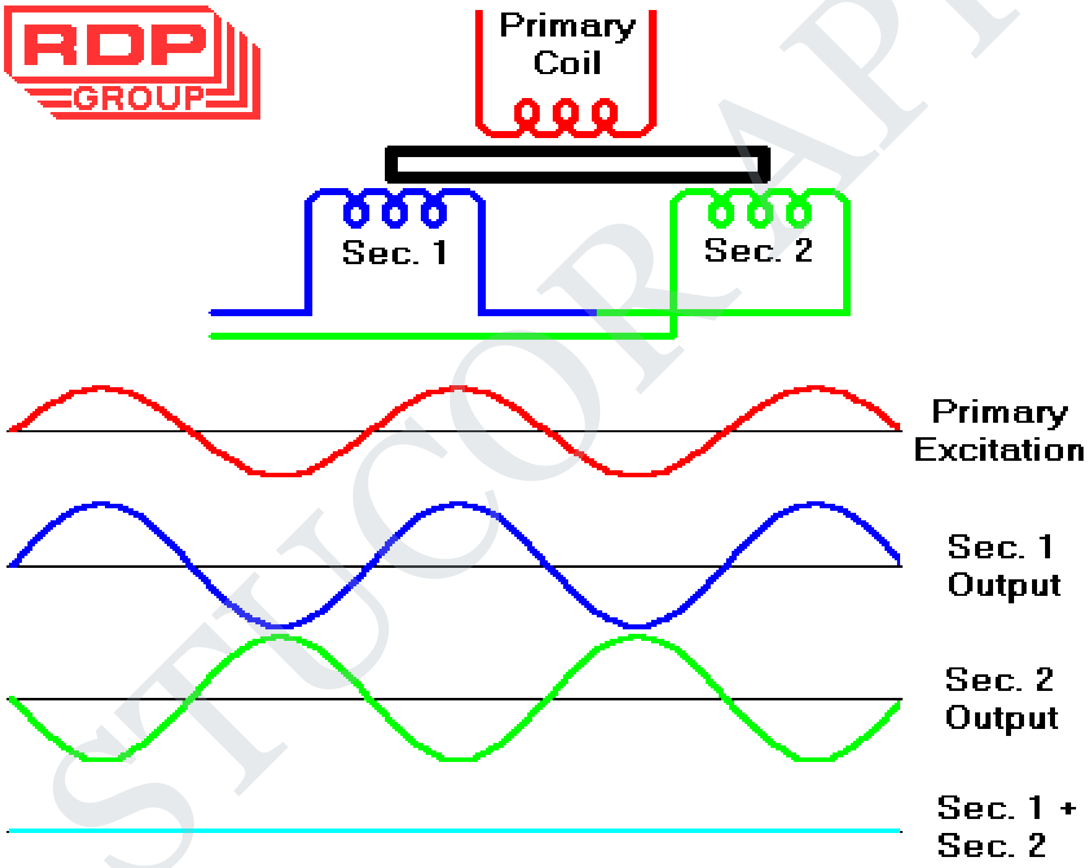
LVDT contd…

- The excitation is applied to the primary winding and the armature assists the induction of current in to secondary coils.
- When the core is exactly at the center of the coil then the flux linked to both the secondary winding will be equal. Due to equal flux linkage the secondary induced voltages (eo1 & eo2) are equal but they have opposite polarities. Output voltage eo is therefore zero. This position is called "null position"


RDP
GROUP
Primary
Coil
Sec. 1
Sec. 2
Primary
Excitation
Sec. 1
Output
Sec. 2
Output
Sec. 1 +
Sec. 2

- Now if the core is displaced from its null position toward sec1 then flux linked to sec1 increases and flux linked to sec2 decreases. Therefore eo1 > eo2 and the output voltage of LVDT eo will be positive
- Similarly if the core is displaced toward sec2 then the eo2 > eo1 and the output voltage of LVDT eo will be negative.