SCHOOL OF ELECTRICAL AND ELECTRONICS

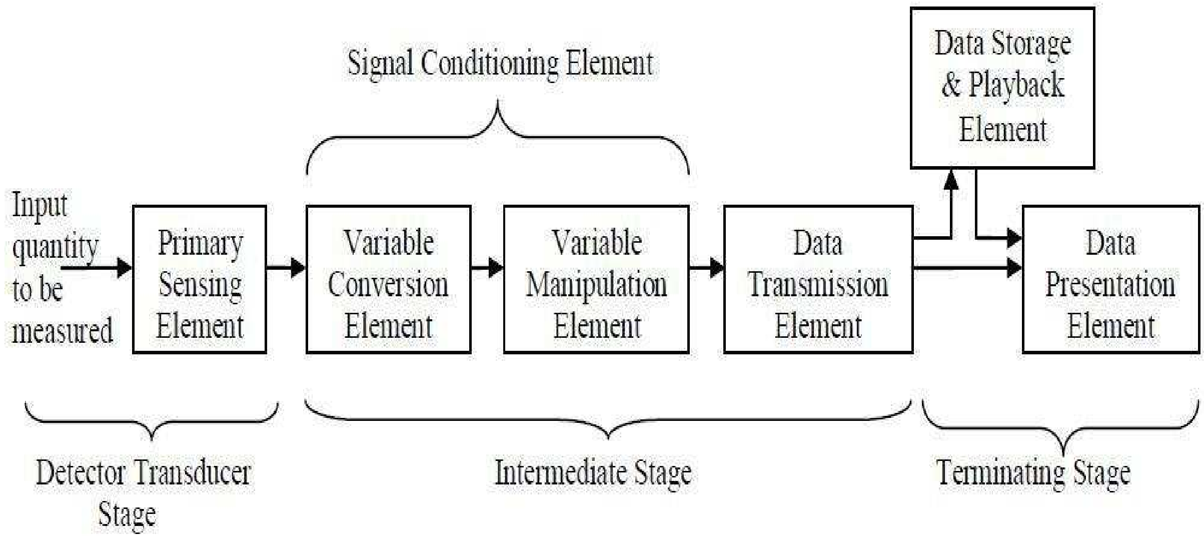
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - I
BASIC MEASUREMENT – SEIA1501

UNIT - I

FUNCTIONAL ELEMENTS OF MEASUREMENT SYSTEM

A systematic organization and analysis are more important for measurement systems. The whole operation system can be described in terms of functional elements. The functional elements of generalized measurement system are shown in figure.



Functional elements of generalized measurement system

Most of the measurement system consists of following functional elements.

1. Primary sensing element
2. Variable conversion element
3. Variable manipulation element
4. Data transmission element
5. Data storage and playback element
6. Data presentation element

1. Primary Sensing Element

The quantity under measurement makes its first contact with primary sensing element of measurement system. The quantity is first sensed or detected by primary sensor. Then detected physical quantity signal is converted into an electrical signal by a transducer.

Transducer is defined as a device which converts a physical quantity into an electrical quantity. Sensor is act as primary element of transducer. In many cases the physical quantity is directlyconverted into an electrical quantity by a transducer. So the first stage of a measurement system is known as a *detector transducer stage.*

Example, Pressure transducer with pressure sensor, Temperature sensor etc.,

2. Variable Conversion Element

The output of primary sensing element is electrical signal of any form like a voltage, a frequency or some other electrical parameter. Sometime this output not suitable for next level of system. So it is necessary to convert the output some other suitable form while maintaining the original signal to perform the desired function the system.

For example the output primary sensing element is in analog form of signal and next stage of system accepts only in digital form of signal. So, we have to convert analog signal into digital form using an A/D converter. Here *A/D converter* is act as variable conversion element.

3. Variable Manipulation Element

The function of variable manipulation element is to manipulate the signal offered but original nature of signal is maintained in same state. Here manipulation means only *change inthe numerical value of signal.*

Examples,

1. *Voltage amplifier* is act as variable manipulation element. Voltage amplifier accepts a smallvoltage signal as input and produces the voltage with greater magnitude .Here numerical value of voltage magnitude is increased.

2. *Attenuator* acts as variable manipulation element. It accepts a high voltage signal andproduces the voltage or power with lower magnitude. Here numerical value of voltage magnitude is decreased.

Linear process manipulation elements: Amplification, attenuation, integration, differentiation, addition and subtraction ect.,

Nonlinear process manipulation elements: Modulation, detection, sampling, filtering, chopping and clipping ect.,

All these elements are performed on the signal to bring it to desired level to be accepted by the next stage of measurement system. This process of conversion is called *signal conditioning*. The combination of variable conversion and variable manipulation elements are called as *SignalConditioning Element.*

4. Data Transmission Element

The elements of measurement system are actually physically separated; it becomes necessary to transmit the data from one to another. The element which is performs this function is called as data transmission element.

Example, Control signals are transmitted from earth station to Space-crafts by a telemetry system using radio signals. Here telemetry system is act as data transmission element.

The combination of Signal conditioning and transmission element is known as *Intermediate Stage* of measurement system.

5. Data storage and playback element

Some applications requires a separate data storage and playback function for easily rebuild the stored data based on the command. The data storage is made in the form of pen/ink and digital recording. Examples, magnetic tape recorder/ reproducer, X-Y recorder, X-t recorder, Optical Disc recording ect.,

6. Data presentation Element

The function of this element in the measurement system is to communicate the information about the measured physical quantity to human observer or to present it in an understandable form for monitoring, control and analysis purposes.

Visual display devices are required for monitoring of measured data. These devices may be analog or digital instruments like ammeter, voltmeter, camera, CRT, printers, analog and digital computers. Computers are used for control and analysis of measured data of measurement system. This

Final stage of measurement system is known as *Terminating stage*.

CHARACTERISTICS OF MEASURING INSTRUMENTS

These performance characteristics of an instrument are very important in their selection.

Static Characteristics: Static characteristics of an instrument are considered forinstruments which are used to measure an unvarying process condition. Performance criteria based upon static relations represent the static Characteristics. (The static characteristics are the value or performance given after the steady state condition has reached).

Dynamic Characteristics: Dynamic characteristics of an instrument are considered forinstruments which are used to measure a varying process condition. Performance criteria based upon dynamic relations represent the dynamic Characteristics.

STATIC CHARACTERISTICS

1) Accuracy

Accuracy is defined as the degree of closeness with which an instrument reading approaches to the true value of the quantity being measured. It determines the closeness to true value of instrument reading.

Accuracy is represented by percentage of full scale reading or in terms of inaccuracy or in terms of error value.

Example, Accuracy of temperature measuring instrument might be specified by ±3ºC. This accuracy means the temperature reading might be within + or -3ºC deviation from the true value.

Accuracy of an instrument is specified by ±5% for the range of 0 to 200ºC in the temperature scale means the reading might be within + or -10ºC of the true reading.

2) Precision

Precision is the degree of repeatability of a series of the measurement. Precision is measures of the degree of closeness of agreement within a group of measurements are repeatedly made under the prescribed condition.

Precision is used in measurements to describe the stability or reliability or the reproducibility of results.

Comparison between accuracy and precision.

S.No	Accuracy	Precision
1.	It refers to degree of closeness of the measured value to the true value.	It refers to the degree of agreement among group of readings
2.	Accuracy gives the maximum error that is maximum departure of the final result from its true value.	Precision of a measuring system gives its capability to reproduce a certain reading with a given accuracy

3) Bias

Bias is quantitative term describing the difference between the average of measured readings made on the same instrument and its true value (It is a characteristic of measuringinstruments to give indications of the value of a measured quantity for which the average value differs from true value).

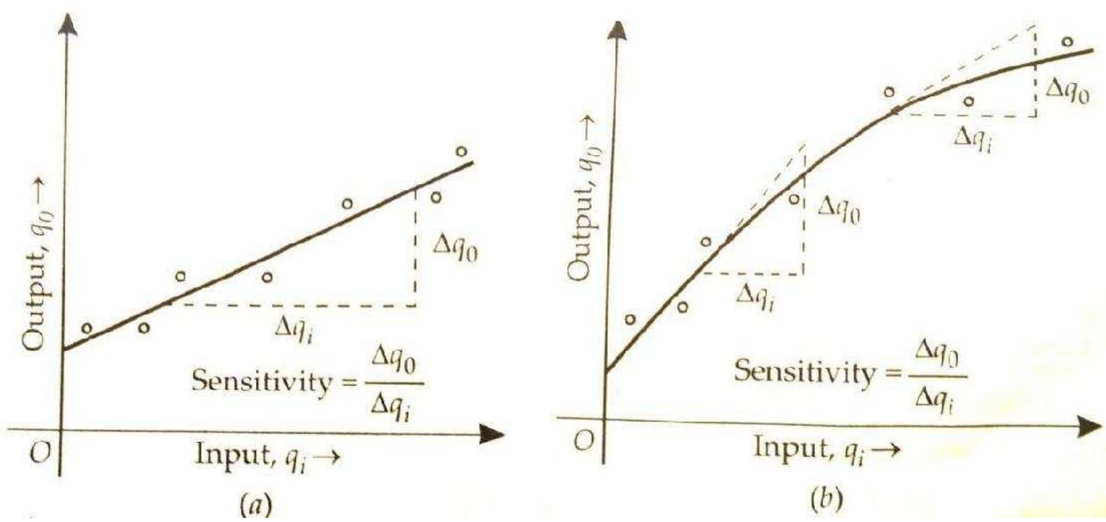
4) Sensitivity

Sensitivity is defined as the ratio of change in output signal (response) to the change in input signal (measurand). It is the relationship indicating how much output changes when input changes.

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

$$\text{Sensitivity} = \frac{\Delta q_o}{\Delta q_i}$$

If the sensitivity is constant then the system is said to be linear system. If the sensitivity is variable then the system is said to be non linear system.

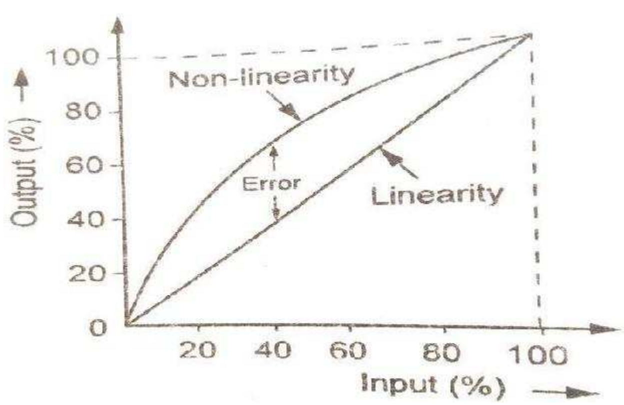


Definition of sensitivity for (a) Linear and (b) Non linear instrument

When the calibration curve is linear as in figure the sensitivity of the instrument can be defined as in slope of the calibration curve. In this case sensitivity is constant over the entire range of instrument. If the curve is not normally straight line or nonlinear instrument sensitivity varies with the input or varies from on range to another as in figure.

4) Linearity

Linearity is the best characteristics of an instrument or measurement system. Linearity of the instrument refers to the output is linearly or directly proportional to input over the entire range of instrument. So the degree of linear (straight line) relationship between the output to input is called as linearity of an instrument.



Representation of Linearity and Non-Linearity of an Instrument

Nonlinearity: The maximum difference or deviation of output curve from the Specifiedidealized straight line as shown in figure. Independent nonlinearity may be defined as

$$\text{Non linearity} = \frac{\text{Maximum deviation of output from the idealized straight line}}{\text{Actual reading or response}} \text{ X } 100$$

5) Resolution

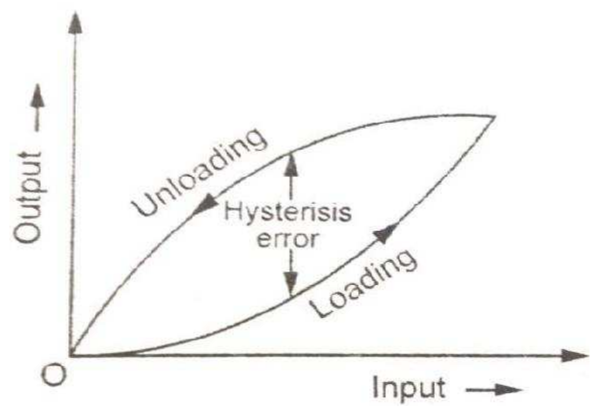
Resolution or Discrimination is the smallest change in the input value that is required to cause an appreciable change in the output. (The smallest increment in input or input change which can be detected by an instrument is called as resolution or discrimination.)

6) Hysteresis

Hysteresis is Non-coincidence of loading and unloading curves on output. Hysteresis effect shows up in any physical, chemical or electrical phenomenon

When input increases, output also increases and calibration curve can be drawn. If input is decreases from maximum value and output also decreases but does not follow the same curve, then there is a residual output when input is zero. This phenomenon is called Hysteresis. The difference between increasing change and decreasing change of output values is known as hysteresis error as shown in figure.

(The different outputs from the same value of quantity being measured are reached by a continuously increasing change or a continuously decreasing change)



Hysteresis Error of an instrument

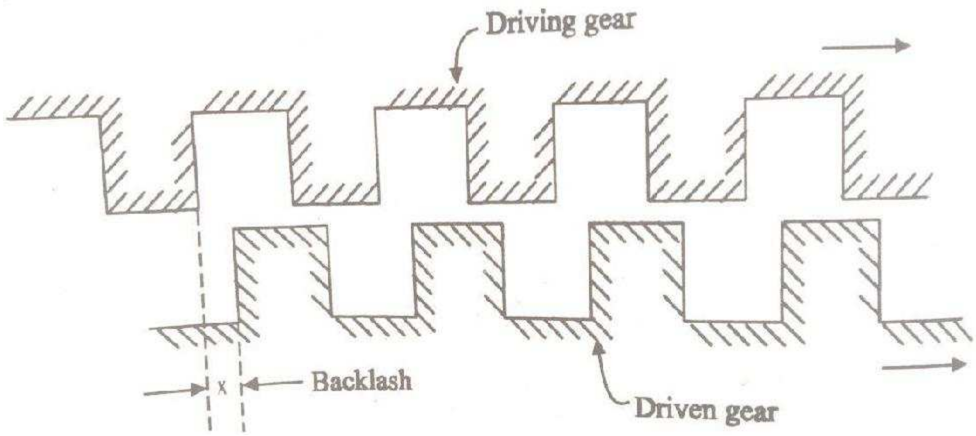
7) Dead Zone

Dead zone or dead band is defined as the largest change of input quantity for which there is no output the instrument due the factors such as friction, backlash and hysteresis within the system.(The region upto which the instrument does not respond for an input change is called dead zone)

Dead time is the time required by an instrument to begin to respond to change in inputquantity.

8) Backlash

The maximum distance through which one part of the instrument is moved without disturbing the other part is called as backlash. (Backlash may be defined as the maximum distance or angle through which any part of the instrument can be moved without causing any motion of next part of the system)



Threshold because of backlash

Reasons for the presence of backlash in an instrument include allowing for lubrication, manufacturing errors, deflection under load, and thermal expansion.

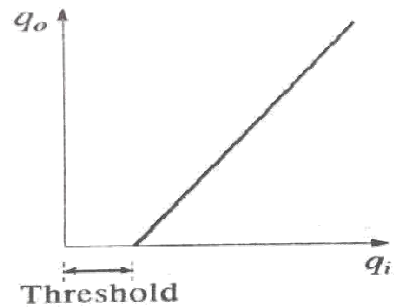
9) Drift

Drift is an undesirable change in output over a period of time that is unrelated to change in input, operating conditions. Drift is occurred in instruments due to internal temperature variations, ageing effects and high stress ect.

Zero drift is used for the changes that occur in output when there is zero output. It is expressed as percentage of full range output.

10) Threshold

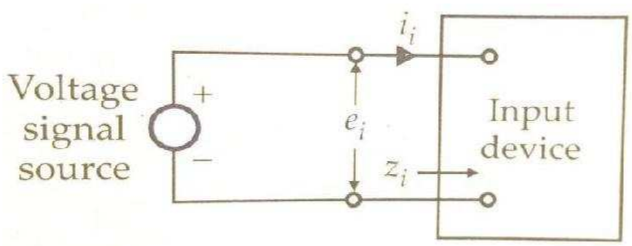
The minimum value of input which is necessary to activate an instrument to produce an output is termed its *threshold* as shown in figure. (Threshold is the minimum value of the input required to cause the pointer to move from zero position).



Threshold effect

11) Input Impedance

The magnitude of the impedance of element connected across the signal source is called Input Impedance. Figure shows a voltage signal source and input device connected across it.



voltage source and input device

The magnitude of the input impedance is given by

$$Z_i = \frac{e_i}{i_i}$$

Power extracted by the input device from the signal source is

$$P = e_i i_i = \frac{e_i^2}{Z_i}$$

From above two expressions it is clear that a low input impedance device connected across the voltage signal source draws more current and more power from signal source than high input impedance device.

12) Loading Effect

Loading effect is the incapability of the system to faith fully measure, record or control the input signal in accurate form.

13) Repeatability

Repeatability is defined as the ability of an instrument to give the same output for repeated applications of same input value under same environmental condition.

14) Reproducibility

Reproducibility is defined as the ability of an instrument to reproduce the same output for repeated applications of same input value under different environment condition.

In case of perfect reproducibility the instrument satisfies no drift condition.

DYNAMIC CHARACTERISTICS

The dynamic behaviour of an instrument is determined by applying some standard form of known and predetermined input to its primary element (sensing element) and then studies the output. Generally dynamic behaviour is determined by applying following three types of inputs.

***l. Step Input*:**Step change in which the primary element is subjected to an instantaneous andfinite change in measured variable.

2. ***Linear Input*:**Linear change, in which the primary element is, follows a measured variable,changing linearly with time.

3. ***Sinusoidal input*:**Sinusoidal change, in which the primary element follows a measuredvariable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude.

The dynamic characteristics of an instrument are

(i) Speed of response,
(ii) Fidelity,
(iii) Lag, and
(iv) Dynamic error.

(i) Speed of Response

It is the rapidity with which an instrument responds to changes in the measured quantity.

(ii) Fidelity

It is the degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction or fidelity of an instrument is the ability of reproducing an input signal faithfully (truly)).

(iii) Lag

It is the retardation or delay in the response of an instrument to changes in the measured variable. The measuring lags are two types:

> ***Retardation type:*** *In this case the response of an instrument begins immediately after achange in measured variable is occurred.*
>
> ***Time delay type:*** *In this case the response of an instrument begins after a dead time afterthe application of the input quantity.*

(iv) Dynamic Error

It is the difference between the true values of a quantity changing with time and the value indicated by the instrument, if no static error is assumed. It is also called as *Measurement Error*.

When measurement problems are concerned with rapidly varying quantities, the dynamic relations between the instruments input and output are generally defined by the use of differential equations.

Errors

The difference between the measured value of quantity and true value (Reference Value) of quantity is called as Error.

Error = Measured value - True Value

$\delta A = A_m - A_t$

Classification of Errors

All measurement can be made without perfect accuracy (degree of error must always be assumed). In reality, no measurement can ever made with 100% accuracy. It is important to find that actual accuracy and different types of errors can be occurred in measuring instruments. Errors may arise from different sources and usually classified as follows, Classification of Error

1. Gross Errors

2. Systematic Errors

a) Instrumental errors

i) Inherent shortcomings of instruments
ii) Misuse of instruments
iii) Loading effects

b) Environmental errors

c) Observational errors

3. Random Errors

1. Gross Errors

The main source of Gross errors is human mistakes in reading or using instruments and in recording and calculating measured quantity. As long as human beings are involved and they may grossly misread the scale reading, then definitely some gross errors will be occurred in measured value.

Example, Due to an oversight, Experimenter may read the temperature as $22.7^{O}C$ while the actual reading may be $32.7^{O}C$ He may transpose the reading while recording. For example, he may read $16.7^{O}C$ and record $27.6^{O}C$ as an alternative.

The complete elimination of gross errors is maybe impossible, one should try to predict and correct them. Some gross errors are easily identified while others may be very difficult to detect. Gross errors can be avoided by using the following two ways.

Great care should be taken in reading and recording the data.

Two, three or even more readings should be taken for the quantity being measured by using different experimenters and different reading point (different environment condition of instrument) to avoid re-reading with same error. So it is suitable to take a large number of readings as a close agreement between readings assures that no gross error has been occurred in measured values.

2. Systematic Errors

Systematic errors are divided into following three categories.

i. Instrumental Errors
ii. Environmental Errors
iii. Observational Errors

a) Instrumental Errors

These errors are arises due to following three reasons (sources of error).

a) Due to inherent shortcoming of instrument
b) Due to misuse of the instruments, and
c) Due to loading effects of instruments

i) Inherent Shortcomings of instruments

These errors are inherent in instruments because of their mechanical structure due to construction, calibration or operation of the instruments or measuring devices.

These errors may cause the instrument to read too low or too high.

Example, if the spring (used for producing controlling torque) of a permanent magnet instrument has become weak, so the instrument will always read high.

Errors may be caused because of friction, hysteresis or even gear backlash.

Elimination or reduction methods of these errors,

- The instrument may be re-calibrated carefully.
- The procedure of measurement must be carefully planned. Substitution methods or calibration against standards may be used for the purpose.
- Correction factors should be applied after determining the instrumental errors.

Ii) Misuse of Instruments

In some cases the errors are occurred in measurement due to the fault of the operator than that of the instrument. A good instrument used in an unintelligent way may give wrong results.

Examples, Misuse of instruments may be failure to do zero adjustment of instrument, poor initial adjustments, using leads of too high a resistance and ill practices of instrument beyond the manufacturer's instruction and specifications ect.

iii) Loading Effects

The errors committed by loading effects due to improper use of an instrument for measurement work. In measurement system, loading effects are identified and corrections should be made or more suitable instruments can be used.

Example, a well calibrated voltmeter may give a misleading (may be false) voltage reading when connected across a high resistance circuit. The same voltmeter, when connected across a low resistance circuit may give a more reliable reading (dependable or steady or true value).

In this example, *voltmeter has a loading effect* on the circuit, altering the actual circuit conditions by measurement process. So errors caused by loading effect of the meters can be avoided by using them intelligently.

b) Environmental Error

Environmental error occurs due to external environmental conditions of the instrument, such as effects of temperature, pressure, humidity, dust, vibration or external magnetic or electrostatic fields.

Elimination or reduction methods of these undesirable errors are

Arrangements should be made to keep the conditions as nearly as constant as possible. Example, temperature can be kept constant by keeping the instrument in the temperature controlled region.

The device which is used against these environmental effects.

Example, variations in resistance with temperature can be minimized by using very low resistance temperature co-efficient of resistive material.

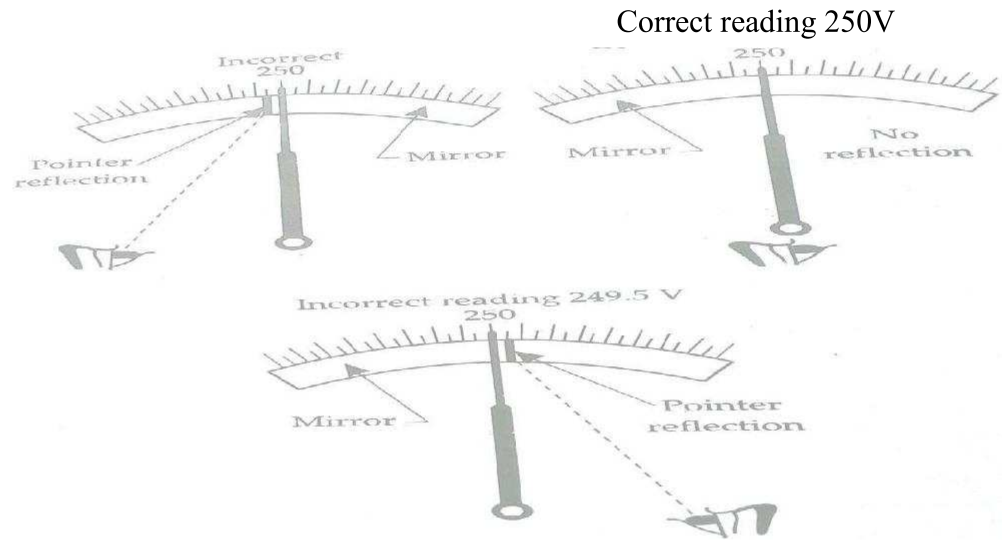
Employing techniques which eliminate the effects of these disturbances. For example, the effect of humidity dust etc., can be entirely eliminated by tightly sealing the equipment.

The external or electrostatic effects can be eliminated by using magnetic or electrostatic shield on the instrument.

Applying computed corrections: Efforts are normally made to avoid the use of application of computed corrections, but where these corrections are needed and are necessary, they are incorporated for the computations of the results

c) Observational Errors

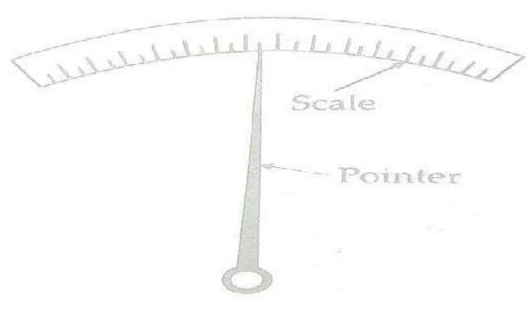
There are many sources of observational errors. As an example, the pointer of a voltmeter rests slightly above the surface of the scale. Thus an error on account of PARALLAX will be acquired unless the line of vision of the observer is exactly above the pointer. To minimize parallax errors, highly accurate meters are provided with mirrored scales as shown in figure.



Errors due to parallax

When the pointer's image appears hidden by the pointer, observer's eye is directly in line with the pointer. Although a mirrored scale minimizes parallax error, an error is necessarily presented through it may be very small.

So we can eliminate this parallax error by having the pointer and scale in the same plane as shown in figure



Arrangements showing scale and pointer in the same plane

The observational errors are also occurs due to involvement of human factors. For example, there are observational errors in measurements involving timing of an event Different observer may produce different results, especially when sound and light measurement are involved.

The complete elimination of this error can be achieved by using digital display of output.

3. Random Errors

These errors are occurred due to unknown causes and are observed when the magnitude and polarity of a measurement fluctuate in changeable (random) manner.

The quantity being measure is affected by many happenings or disturbances and ambient influence about which we are unaware are lumped together and called as *Random* or *Residual*. The errors caused by these disturbances are called *Random Errors*. Since the errors remain even after the systematic errors have been taken care, those errors are called as *Residual (Random)Errors.*

Random errors cannot normally be predicted or corrected, but they can be minimized by skilled observer and using a well maintained quality instrument.

Errors in Measuring Instruments

No measurement is free from error in reality. An intelligent skill in taking measurements is the ability to understand results in terms of possible errors. If the precision of the instrument is sufficient, no matter what its accuracy is, a difference will always be observed between two measured results. So an understanding and careful evaluation of the errors is necessary in measuring instruments. The Accuracy of an instrument is measured in terms of errors.

True value

The true value of quantity being measured is defined as the average of an infinite number of measured values when the average deviation due to the various contributing factors tends to zero.

In ideal situation is not possible to determine the True value of a quantity by experimental way. Normally an experimenter would never know that the quantity being measured by experimental way is the True value of the quantity or not.

In practice the true value would be determined by a “standard method”, that is a method agreed by experts with sufficient accurate.

Static Error

Static error is defined as a difference between the measured value and the true value of the quantity being measured. It is expressed as follows.

$$\delta A = A_m - A_t \text{------------------} \quad (1)$$

Where, δA= Error, A_m =Measured value of quantity and A_t= True value of quantity. δA is also called as absolute static error of quantity A and it is expressed as follows.

$$\varepsilon_0 = \delta A \text{ ------------------------} \quad (2)$$

Where, ε_0 = Absolute static error of quantity A under measurement.

The absolute value of δA does not specify exactly the accuracy of measurement .so the quality of measurement is provided by relative static error.

Relative static error

Relative static error is defined as the ratio between the absolute static errors and true value of quantity being measured. It is expressed as follows.

$$\varepsilon_r = \frac{\text{Absolute Error}}{\text{True Value}} = \frac{\delta A}{A_t} = \frac{\varepsilon_0}{A_t} \text{ --------------------} \quad (3)$$

Percentage static error= % $\varepsilon_r = \varepsilon_r \times 100$

From equation (1), $A_t = A_m - \delta A$

$$A_t = A_m - \varepsilon_0$$

$$A_t = A_m - \varepsilon_r A_t \text{ -------------} \quad (4)$$

$$A_t + \varepsilon_r A_t = A_m$$

$$A_t(1 + \varepsilon_r) = A_m$$

$$A_t = \frac{A_m}{1 + \varepsilon_r}$$

$\varepsilon_0 = \delta A$ is small, which means that the difference between measured value and true values is very small, $A_m - A_t$ = Negligible or small. So Almost

$A_m = A_t$ (that is $\varepsilon_r <<< 1$).

From equation (4), $A_t - A_m \quad \varepsilon_r A_t$

Substitute $A_t = A_m$ in equation (4).

$$A_t = A_m - \varepsilon_r A_m$$

$$A_t = A_m (1 - \varepsilon_r)$$

Static error Correction or method of Correction:

It is the difference between the true value and the measured value of quantity.

$$\delta C = A_t - A_m \text{ ---------------- } (5)$$

* For Detail Error correction (Rectification or Elimination or Reduction) methods of all categories of errors are discussed in the topic of *classification of errors*.

SOURCES OF ERRORS

The sources of error, other than the inability of a piece of hardware to provide a true measurement are listed below,

1) Insufficient knowledge of process parameters and design conditions.
2) Poor design
3) Change in process parameters, irregularities, upsets (disturbances) ect.
4) Poor maintenance
5) Errors caused by people who operate the instrument or equipment.
6) Certain design limitations.

STATISTICAL EVALUATION OF MEASUREMENT DATA

Statistical Evaluation of measured data is obtained in two methods of tests as shown in below.

***Multi Sample Test*:**In multi sample test, repeated measured data have been acquiredby different instruments, different methods of measurement and different observer.

***Single Sample Test*:**measured data have been acquired by identical conditions (sameinstrument, methods and observer) at different times.

Statistical Evaluation methods will give the most probable true value of measured quantity. The mathematical background statistical evaluation methods are Arithmetic Mean, Deviation Average Deviation, Standard Deviation and variance.

Arithmetic Mean

The most probable value of measured reading is the arithmetic mean of the number of reading taken. The best approximation is made when the number of readings of the same quantity is very large. Arithmetic mean or average of measured variables X is calculated by taking the sum of all readings and dividing by the number of reading.

The Average is given by,

$$X = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\Sigma x}{n}$$

Where, X= Arithmetic mean, x_1, x_2....... x_n = Readin readings.

Deviation (Deviation from the Average value)

The Deviation is departure of the observed reading from the arithmetic mean of the group of reading. Let the deviation of reading x_1 be d_1 and that of x_2 be d_2 etc.,

$d_1 = x_1 - X$

$d_2 = x_2 - X$

..

..

..

$d_n = x_n - X$ The algebraic sum deviation is Zero ($d_1 + d_2 + ... + d_n = 0$)

Average Deviation:

Average deviation defined as the average of the modulus (without respect to its sign) of the individual deviations and is given by,

$$D = \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n} = \frac{\Sigma|d|}{n}$$

Where, D= Average Deviation.

The average deviation is used to identify precision of the instruments which is used in making measurements. Highly precise instruments will give a low average deviation between readings.

Standard Deviation

Standard deviation is used to analysis random errors occurred in measurement. The standard Deviation of an infinite number of data is defined as the square root of the sum of individual deviations squared, divided by the number of readings (n).

$$\text{Standard deviation is} \quad S.D = \sigma = \sqrt{\frac{d_1^{\,2}+d_2^{\,2}+d_3^{\,2}+\cdots+d_n^{\,2}}{n}} = \sqrt{\frac{\Sigma d^2}{n}} \text{ ; for n >20}$$

$$\text{Standard deviation is} \quad S.D = s = \sqrt{\frac{d_1^{\,2}+d_2^{\,2}+d_3^{\,2}+\cdots+d_n^{\,2}}{n-1}} = \sqrt{\frac{\Sigma d^2}{n-1}} \text{ ; for n <20}$$

Variance

The variance is the mean square deviation, which is the same as S.D except Square root. Variance is Just the squared standard deviation.

$$\text{Variance} \quad V = (\text{Standard deviation})^2$$

$$\text{Variance} \quad V=\sigma^2 = \frac{d_1^{\,2}+d_2^{\,2}+d_3^{\,2}+\cdots+d_n^{\,2}}{n} = \frac{\Sigma d^2}{n} \text{ ; for n >20}$$

$$\text{Variance} \quad V=s^2 = \frac{d_1^{\,2}+d_2^{\,2}+d_3^{\,2}+\cdots+d_n^{\,2}}{n-1} = \frac{\Sigma d^2}{n-1} \text{ ; for n <20}$$

Histogram:

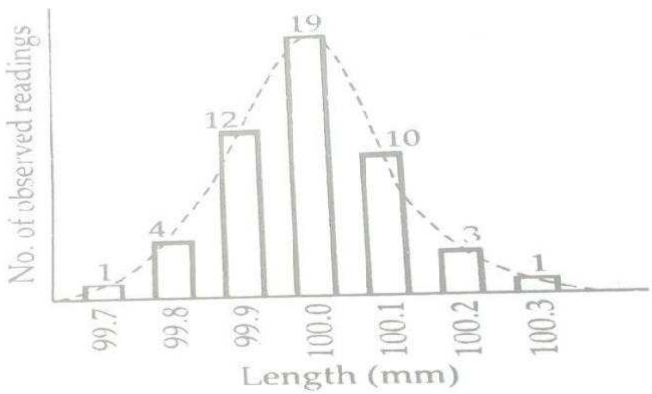
When a number of Multisample observations are taken experimentally there is a scatter of the data about some central value. For representing this results in the form of a *Histogram.* A histogram is also called a *frequency distribution curve.*

Example: Following table3.1 shows a set of 50 readings of length measurement. The most probable or central value of length is 100mm represented as shown in figure Histogram.

Table 3.1

Length (mm)	Number of observed readings (frequency or occurrence)
99.7	1
99.8	4
99.9	12
100.0	19
100.1	10
100.2	3
100.3	1

Total number of readings =50



Histogram

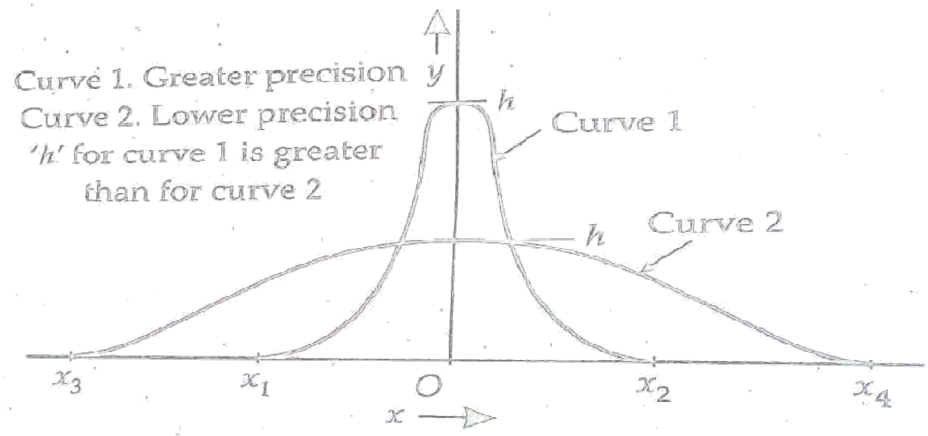
This histogram indicates the number of occurrence of particular value. At the central value of 100mm is occurred 19 times and recorded to the nearest 0.1mm as shown in figure 3.3. Here bell shape dotted line curve is called as normal or Gaussian curve.

Measure of Dispersion from the Mean

The property which denotes the extent to which the values are dispersed about the central value is termed as dispersion. The other name of dispersion is *spread or scatter*.

Measure of dispersion from central value is an indication of the degree of consistency (precision) and regularity of the data.

Example: Figure shows the two sets of data and curve 1 vary from x_1 to x_2 and curve 2 vary from x_3 to x_4. Curve 1 is having smaller dispersion from central value than the curve 2. Therefore curve 1 is having greater precision than the curve 2.



Curves showing different ranges and precision index

Range

The simplest possible measure of dispersion is the range which is the difference between greatest and least values of measured data.
Example: In figure, the range of curve1 is ($x_2 - x_1$) and range of curve 2 is (x_4 - x_3).

Limiting Errors (Guarantee Errors or Limits of errors):

In most of the instruments the accuracy is guaranteed to be within a certain percentage of full scale reading. The manufacturer has to specify the deviations from the *nominal value* of a particular quantity. The limits of these deviations from the specified value are called as *Limiting Errors* or *Guarantee Errors*.

The magnitude of Limiting Error=Accuracy x Full scale reading. In general the actual value of quantity is determined as follows.

Actual Value of Quantity = Nominal value ± Limiting Error

$$A_a = A_n \pm \delta A$$

Where, A_a = Actual value of quantity; A_n = Nominal value of Quantity; ± δA= Limiting error.

For Example, Nominalmagnitude of resister is 1000Ω with a limiting error ±100Ω.Determinethe Actual magnitude of the resistance.
Actual value of quantity A_a =1000±100Ω or $A_a \geq 900\Omega$ and $A_a \leq 1100\Omega$.

Therefore the manufacturer guarantees that the value of resistance of resistor lies between 900Ω and 1100Ω.

Relative (Fractional) Limiting Error

The relative limiting error is defined as the ratio of the error to the specified (nominal) magnitude of the quantity.

Relative Limiting Error ε_r=

Then limiting values calculated as follows,

We know that $A_a = A_n \pm \delta A = A_n \pm \varepsilon_r A_n = A_n (1 \pm \varepsilon_r)$

Percentage limiting error % $\varepsilon_r = \varepsilon_r$ x100

In limiting errors the nominal value A_n is taken as the true value or quantity, the quantity which has the maximum deviation from A_a is taken as the incorrect quantity.

$$\text{Then } \delta A = A_a - A_n$$

$$\text{Therefore Relative Limiting Error } \varepsilon_r = \frac{A_a - A_n}{A_n} = \frac{\text{Actual value} - \text{nominal value}}{\text{nominal value}}$$

For Example, considered $A_n = 100\Omega$ and $\delta A = \pm 10\ \Omega$;

Relative limiting error $\varepsilon_r = \frac{\delta A}{A_n} = \pm \frac{10}{100} = \pm 0.1$

Percentage Limiting error $\%\varepsilon_r = 0.1 \times 100 = \pm 10\%$

Limiting values of resistance are:

$$A_a = A_n(1 \pm \varepsilon_r) = 100\,(1 \pm 0.1) = 100 \pm 10\Omega$$

Probable error

The most probable or best value of a Gaussian distribution is obtained by taking arithmetic mean of the various values of the variety. A convenient measure of precision is achieved by the quantity r. It is called Probable Error of P.E. It is expressed as follows,

$$\text{Probable Error} = \text{P. E} = r = \frac{0.4769}{h}$$

Where r= probable error and h= constant called precision index

Gaussian distribution and Histogram are used to estimate the probable error of anymeasurement.

Histogram **–** Refer the topic of statistical analysis.

Normal or Gaussian curve of errors

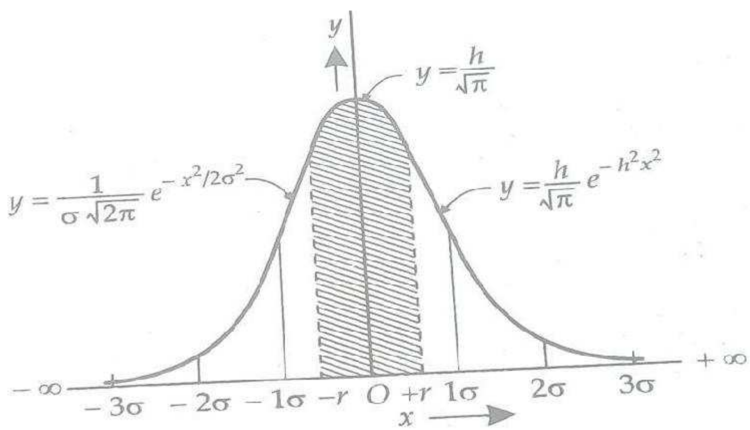
The normal or Gaussian law of errors is the basis for the major part of study of random errors. The law of probability states the normal occurrence of deviations from average value of an infinite number of measurements can be expressed by,

$$y = \frac{h}{\sqrt{\Pi}} \exp(-h^2x^2)$$

Where, x= magnitude deviation from mean

y=Number of readings at any deviation x (the probability of occurrence of deviation x) h= A constant called precision index

The Normal or Gaussian probability curve is shown in figure. In this curve r is the measure of precision quantity (probable error=r). The points –r and +r are locating the area bounded by the Gaussian curve.



The Normal or Gaussian probability curve

Precision index x=0 then, $y = h/\Pi$. The maximum value of y depends upon h. If y is larger, then the corresponding curve is having greater precision. Then the probable is determined using following expression.

$$\text{Probable Error} = r = \frac{0.4769}{h}$$

Calibration

Calibration is the process of checking the accuracy of instrument by comparing the instrument reading with a standard or against a similar meter of known accuracy. So using calibration is used to find the errors and accuracy of the measurement system or an instrument.

Calibration is an essential process to be undertaken for each instrument and measuring system regularly. The instruments which are actually used for measurement work must be calibrated against some reference instruments in which is having higher accuracy. Reference instruments must be calibrated against instrument of still higher accuracy or against primary standard or against other standards of known accuracy.

The calibration is better carried out under the predetermined environmental conditions. All industrial grade instruments can be checked for accuracy in the laboratory by using the working standard.

Certification of an instrument manufactured by an industry is undertaken by National Physical Laboratory and other authorizes laboratories where the secondary standards and working standards are kept.

Process of Calibration

The procedure involved in calibration is called as process of calibration. Calibration procedure involves the comparison of particular instrument with either

A primary standard,

A secondary standard with higher accuracy than the instrument to be calibrated

An instrument of known accuracy.

Procedure of calibration as follows.

Study the construction of the instrument and identify and list all the possible inputs.

Choose, as best as one can, which of the inputs will be significant in the application for which the instrument is to be calibrated.

Standard and secure apparatus that will allow all significant inputs to vary over the ranges considered necessary.

By holding some input constant, varying others and recording the output, develop the desired static input-output relations.

Theory and Principles of Calibration Methods Calibration methods are classified into following two types,

1) Primary or Absolute method of calibration

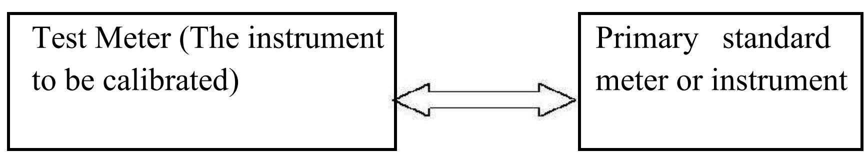
2) Secondary or Comparison method of calibration

    i. Direct comparison method of calibration

    ii. Indirect comparison method of calibration

1) Primary or Absolute method of calibration

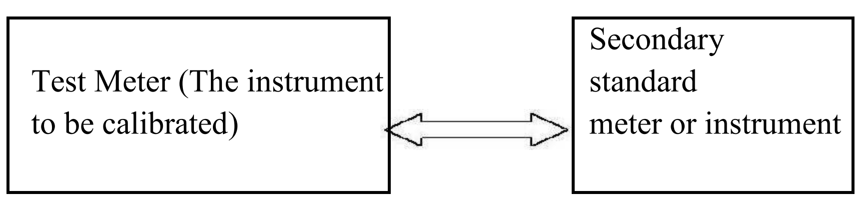
If the particular test instrument (the instrument to be calibrated) is calibrated against primary standard, then the calibration is called as primary or absolute calibration. After the primary calibration, the instrument can be used as a secondary calibration instrument.



Representation of Primary Calibration

2) Secondary or Comparison calibration method

If the instrument is calibrated against secondary standard instrument, then the calibration is called as secondary calibration. This method is used for further calibration of other devices of lesser accuracy. Secondary calibration instruments are used in laboratory practice and also in the industries because they are practical calibration sources.

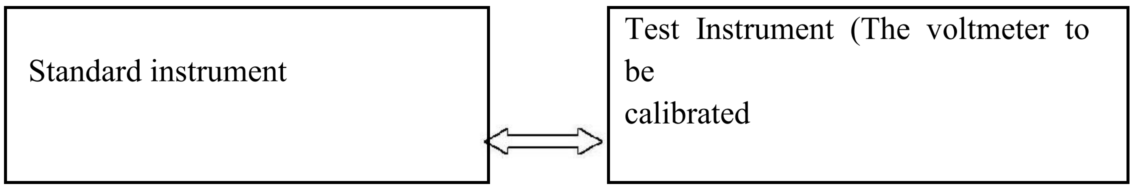


Representation of Secondary Calibration

Secondary calibration can be classified further two
types,

i) Direct comparison method of Calibration

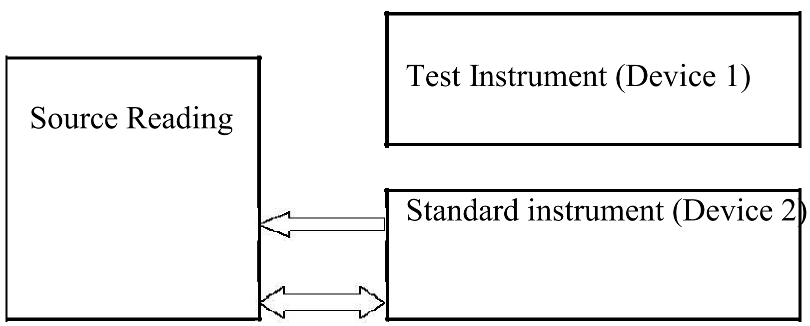
Direct comparison method of calibration with a known input source with same order of accuracy as primary calibration. So the instrument which is calibrated directly is also used as secondary calibration instruments.



Representation of Direct method of Calibration

ii) Indirect comparison method of Calibration

The procedure of indirect method of calibration is based on the equivalence of two different devices with same comparison concept.



Representation of indirect method of Calibration

Standards for calibration

Refer Classification of Standards (4 types).

Standards of measurement:

A standard is a physical representation of a unit of measurement. A known accurate measure of physical quantity is termed as standard. These standards are used to determine the accuracy of other physical quantities by the comparison method.

Example, the fundamental unit of mass in the International System is the Kilogram and defined as the mass of a cubic decimetre of water at its temperature of maximum of density of $4^{o}C$.

Different standards are developed for checking the other units of measurements and all these standards are preserved at the International Bureau of Weight and Measures at Serves, Paris.

Classification of Standards

Standards are classified into four types, based on the functions and applications.

1) International standards
2) Primary standards
3) Secondary standards
4) Working standards

1) International Standard

International standards are defined and established upon internationally. They are maintained at the International Bureau of Weights and measures and are not accessible to ordinary users for measurements and calibration. They are periodically evaluated and checked by absolute measurements in terms of fundamental units of physics.

International Ohms It is defined as the resistance offered by a column of mercuryhaving a mass of 14.4521gms, uniform cross sectional area and length of 106.300cm, to the flow of constant current at the melting point of ice.

2) Primary Standards

Primary standards are maintained by the National Standards Laboratories (NSL) in different parts of the world.

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

They are not available outside the National Laboratory for calibration.

These primary standards are absolute standards of high accuracy that can be used asultimate reference standards.

3) Secondary Standards

These standards are basic reference standards used in industrial laboratories for calibration of instruments.

Each industry has its own secondary standard and maintained by same industry.

Each laboratory periodically sends its secondary standard to the NSL for calibration and comparison against the primary standards.

Certification of measuring accuracy is given by NSL in terms of primary standards.

4) Working Standards

- The working standards are used for day-to-day use in measurement laboratories. So this standard is the primary tool of a measurement laboratory.

- These standards may be lower in accuracy in comparison with secondary standard. It is used to check and calibrate laboratory instruments for accuracy and performance.
- Example, a standard resister for checking of resistance value manufactured.

Current

Current is the rate at which electric charge flows past a point in a circuit. Symbol is I and unit is A or amps

Voltage

Voltage is the electrical force that would drive an electric current between two points. And symbol is v units is volts or voltage

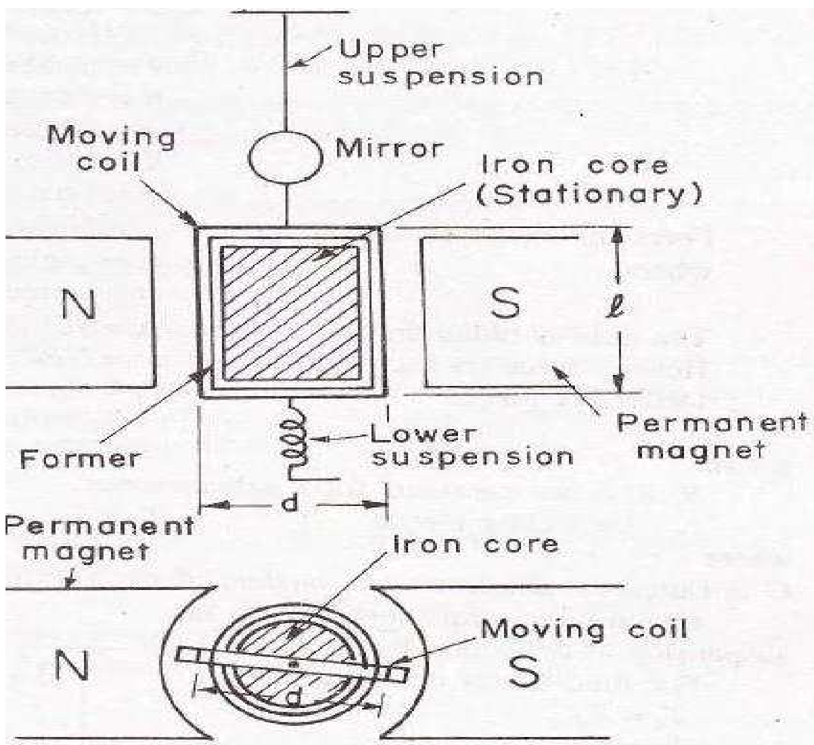
PRINCIPLE OF D'ARSONVAL GALVANOMETER

An action caused by electromagnetic deflection, using a coil of wire and a magnetized field. When current passes through the coil, a needle is deflected.Whenever electrons flow through a conductor, a magnetic field proportional to the current is created. This effect is useful for measuring current and is employed in many practical meters.

Moving Coil:

It is the current carrying element. It is either rectangular or circular in shape and consists of number of turns of fine wire. This coil is suspended so that it is free to turn about its vertical axis of symmetry. It is arranged in a uniform, radial, horizontal magnetic field in the air gap between pole pieces of a permanent magnet and iron core. The iron core is spherical in shape if the coil is circular but is cylindrical if the coil is rectangular. The iron core is used to provide a flux path of low reluctance and therefore to provide strong magnetic field for the coil to move in. this increases the deflecting torque and hence the sensitivity of the galvanometer. The length of air gap is about

1.5mm. In some galvanometers the iron core is omitted resulting in of decreased value of flux density and the coil is made narrower to decrease the air gap. Such a galvanometer is less sensitive, but its moment of inertia is smaller on account of its reduced radius and consequently a short periodic time.



D'Arsonval Galvanometer

2) Damping:

There is a damping torque present owing to production of eddy currents in the metal former on which the coil is mounted. Damping is also obtained by connecting a low resistance across the galvanometer terminals. Damping torque depends upon the resistance and we can obtain critical damping by adjusting the value of resistance.

3) Suspension:

The coil is supported by a flat ribbon suspension which also carries current to the coil. The other current connection in a sensitive galvanometer is a coiled wire. This is called the lower suspension and has a negligible torque effect. This type of galvanometer must be leveled carefully so that the coil hangs straight and centrally without rubbing thepoles or the soft iron cylinder. Some portable galvanometers which do not require exact leveling have ” taut suspensions” consisting of straight flat strips kept under tension for at the both top and at the bottom.

The upper suspension consists of gold or copper wire of nearly 0.012-5 or 0.02-5 mm diameter rolled into the form of a ribbon. This is not very strong mechanically; so that the galvanometers must he handled carefully without jerks. Sensitive galvanometers are provided with coil clamps to the strain from suspension, while the galvanometer is being moved.

4) Indication:

The suspension carries a small mirror upon which a beam of light is cast. The beam of light is reflected on a scale upon which the deflection is measured. This scale is usually about 1 meter away from the instrument, although ½ meter may be used for greater compactness.

5) Zero Setting:

A torsion head is provided for adjusting the position of the coil and also for zero setting.

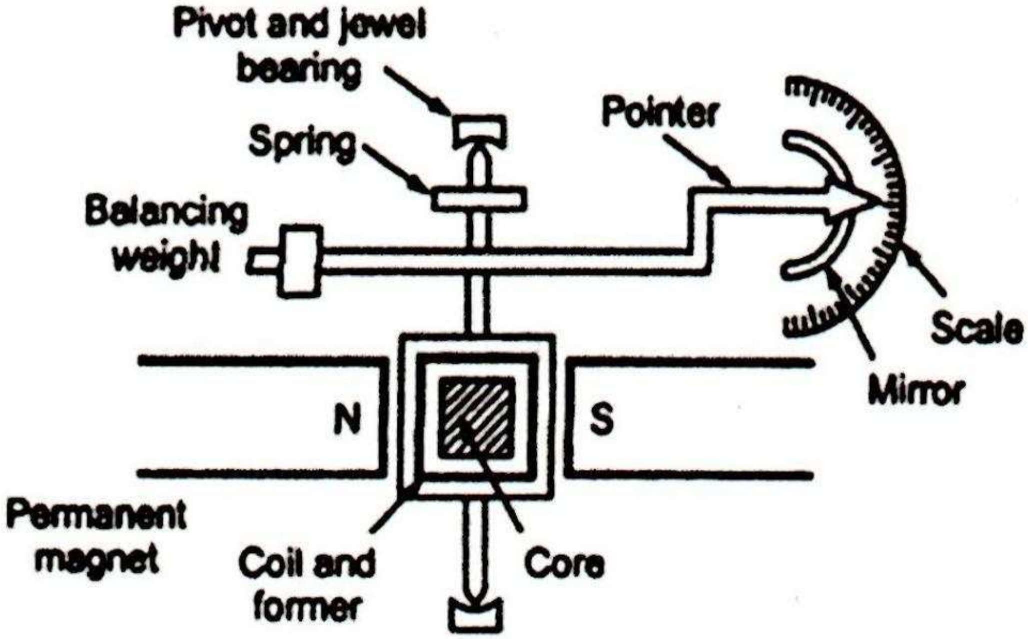
Operation

When a current flows through the coil, the coil generates a magnetic field. This field acts against the permanent magnet. The coil twists, pushing against the spring, and moves the pointer. The hand points at a scale indicating the electric current. Careful design of the pole pieces ensures that the magnetic field is uniform, so that the angular deflection of the pointer is proportional to the current. A useful meter generally contains provision for damping the mechanical resonance of the moving coil and pointer, so that the pointer settles quickly to its position without oscillation

RMANENT MAGNET MOVING COIL INSTRUMENT

Principle of moving coil instrument

Moving coil instrument depends on the principle that when a current carrying conductor is placed on a magnetic field, mechanical force acts on the conductor. The coil placed on the magnetic field and carrying operating current is attached to the moving system. With the movement of the coil the pointer moves over the scale.



Construction of PMMC instrument

Moving coil instrument consists of a powerful permanent magnet with soft iron pieces and light rectangular coil of many turns of fine wire wound on aluminum former inside which is an iron core as shown in the figure. As it uses permanent magnets they are called "***Permanent magnet moving coil instrument***". The purpose of the coil is to make the field uniform. The coil is mounted on the spindle and acts as the moving element. The current is led into and out of the coil by means of the two control hair springs, one above and the other below the coil. The springs also provides the controlling torque. damping torque is provide by eddy current damping.

Working of PMMC instrument

when the moving coil instrument is connected in the circuit, operating current flows through the coil. This current carrying coil is placed in the magnetic field produced by the permanent magnet and therefore, mechanical force acts on the coil. As the coil attached to the moving system, the pointer moves over the scale. It may be noted here that if current direction is reversed the torque will also be reversed since the direction of the field of permanent magnet is same. Hence, the pointer will move in the opposite direction, i.e it will go on the wrong side of zero. In other words, these instruments work only when current in the circuit is passed in a definite direction i.e. for d.c only. So it is called permanent magnet moving coil instruments because a coil moves in the field of a permanent magnet.

Torque Equation for PMMC

The equation for the developed torque of the PMMC can be obtained from the basic law of electromagnetic torque.

The deflecting torque is given by,

$$Td = NBAI$$

Where, Td = deflecting torque in N-m

B = flux density in air gap, Wb/m2

N = Number of turns of the coils

A = effective area of coil m^2

I = current in the moving coil, amperes

Therefore, Td = GI

Where, G = NBA = constant

The controlling torque is provided by the springs and is proportional to the angular deflection of the pointer.

Tc = KØ

Where, Tc = Controlling Torque

K = Spring Constant Nm/rad or Nm/deg

Ø = angular deflection

For the final steady state position,

$Td = Tc$

Therefore $GI = KØ$

So, $Ø = (G/K)I$ or $I = (K/G)\ Ø$

Thus the deflection is directly proportional to the current passing through the coil. The pointer deflection can therefore be used to measure current.

Advantage of PMMC instrument

- Uniform scale.
- Very effective eddy current damping
- Power consumption is low.
- No hysteresis loss.
- They are not affected by stray field.
- Require small operating current.
- Accurate and reliable.

Disadvantage of PMMC instrument

- Only used for D.C measurement.
- Costlier compared to moving iron instrument.
- Some errors are caused due to the aging of the control springs and the permanent magnets.

MOVING IRON INSTRUMENT

There are classified in to two type

4. Attraction type moving iron instrument

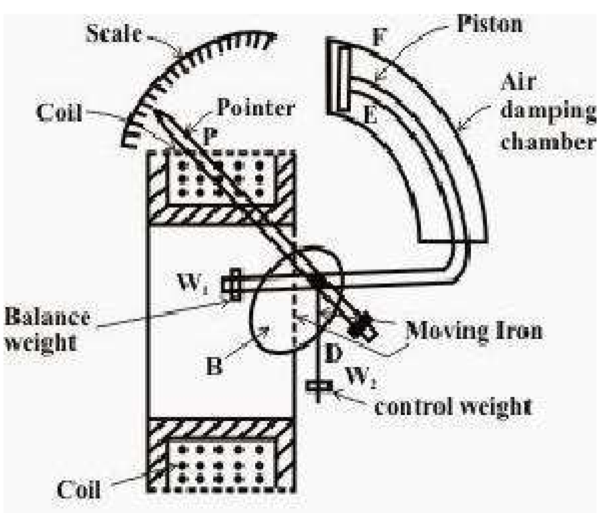
5. Repulsion type moving iron instrument

Attraction type moving iron instrument

Principle of attraction type moving iron instrument

An “attraction type” moving-iron instrument consists of a coil, through which the test current is passed, and a pivoted soft-iron mass attached to the pointer. The resulting magnetic polarity at the end of the coil nearest the iron mass then induces the opposite magnetic polarity into the part of the iron mass nearest the coil, which is then drawn by attraction towards the coil, deflecting the pointer across a scale.

The coil is flat and has a narrow slot like opening. The moving iron is a flat disc or a sector eccentrically mounted. · 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. · The controlling torque is provide by springs hut gravity control can be used for panel type of instruments which are vertically mounted. · Damping is provided by air friction with the help of a light aluminium piston (attached to the moving system) which move in a fixed



Attraction type

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. operation

The current to be measured is passed through the fixed coil. As the current is flow through the fixed coil, a magnetic field is produced. By magnetic induction the moving iron gets magnetized. The north pole of moving coil is attracted by the south pole of fixed coil. Thus the deflecting force is produced due to force of attraction. Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the calibrated scale. But the force of attraction depends on the current flowing through the coil.

The force F, pulling the soft -iron piece towards the coil is directly proportional to;

(v)Field strength H, produced by the coil. b)pole

strength „m‟ developed in the iron piece. F α mH

(v) α mean of i^2 over a cycle

α I^2

Since the deflection is proportional to the square of coil current, the scale of such instruments is non-uniform (being crowded in the beginning and spread out near the finishing end of the scale).

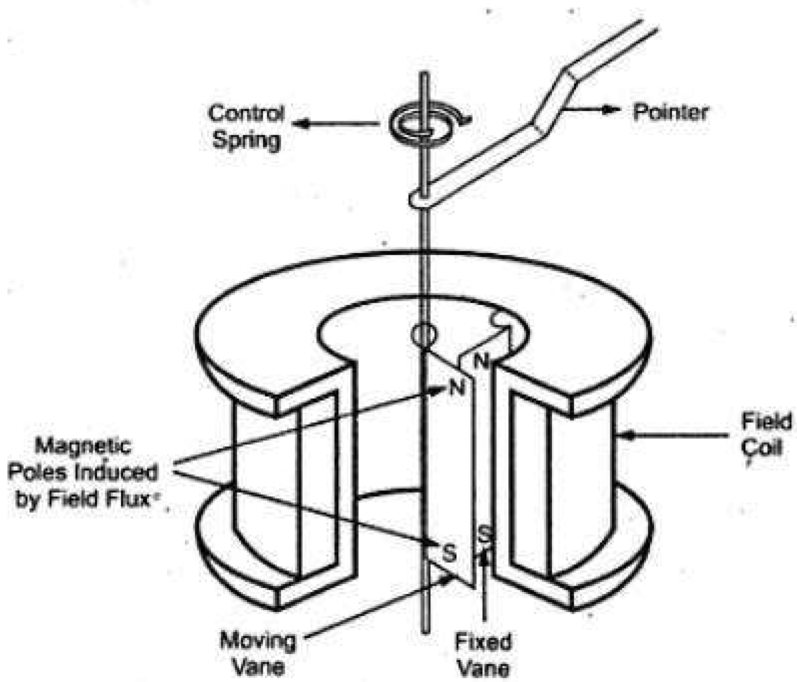
Moving iron repulsion type instrument

These instruments have two vanes inside the coil, the one is fixed and other is movable. When the current flows in the coil, both the vanes are magnetized with like polarities induced on the same side. Hence due to repulsion of like polarities, there is a force of repulsion between the two vanes causing the movement of the moving van. The repulsion type instruments are the most commonly used instruments. The two different designs of repulsion type instruments are:

3. Radial vane type and
4. Co-axial vane type

Radial van repulsion type instrument

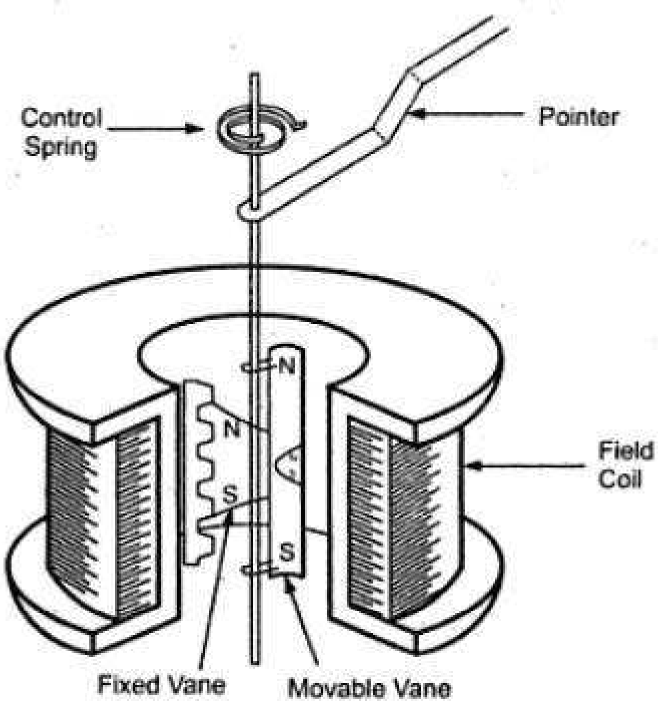
Out of the other moving iron mechanism, this is the most sensitive and has most linear scale. The two vanes are radial strips of iron. The fixed vane is attached to the coil. The movable vane is attached to the spindle and suspended in the induction field of the coil. The needle of the instrument is attached to this vane. Even though the current through the coil is alternating, there is always repulsion between the like poles of the fixed and the movable vane. Hence the deflection of the



pointer is always in the same direction. The deflection is effectively proportional to the actual current and hence the scale is calibrated directly to rad amperes or volts. The calibration is accurate only for the frequency for which it is designed because the impedance is different for different frequencies

Concentric vane repulsion type instrument

The instrument has two concentric vanes. One is attached to the coil frame rigidly while the other can rotate coaxially inside the stationary vane. Both the vanes are magnetized to the same polarity due to the current in the coil. Thus the movable vane rotates under the repulsive force. The movable vane is attached to the pivoted shaft, the repulsion results in a rotation of the shaft. The pointer deflection is proportional to the current in the coil. The concentric vane type instrument is moderately sensitive and the deflection is proportional to the square of the current through coil. Thus the instrument said to have square low response. Thus the scale of the instrument



is non-uniform in nature. Thus whatever may be the direction of the current in the coil, the deflection in the moving iron instruments is in the same direction. Hence moving iron instruments can be used for both a.c. and d.c. measurements. Due to square low response, the scale of the moving iron instrument is non-uniform.

Troque equation

The deflecting torque results due to repulsion between the similarly charged soft- iron pieces or vanes. If the two pieces develop pole strength of m1 and m2 respectively, then;

Instantaneous deflecting torque α $m_1 m_2$ α H^2

If the permeability of iron is assumed constant, then; H α i, where, i is the coil current

Instantaneous deflecting torque α i^2

Average deflecting torque, Td α mean of i^2 over a cycle.

Since the instrument is spring controlled, T_c α θ

In the steady position of deflection, Td = T_c

2 α mean of i^2 over a cycle.

α I^2

Thus, the deflection is proportional to the square of the coil current. The scale of the instrument is non- uniform; being crowded in the beginning and spread out near the finish end of the scale. However, the non- linearity of the scale can be corrected to some extent by the accurate shaping and positioning of the iron vanes in relation to the operating coil.

Advantages

1) The instruments can be used for both a.c. and d.c. measurements.

1 As the torque to weight ratio is high, errors due to the friction are very less.

2 A single type of moving element can cover the wide range hence these instruments are cheaper than other types of if instruments.

3 There are no current carrying parts in the moving system hence these meters are extremely rugged and reliable.

4 These are capable of giving good accuracy. Modern moving iron instruments have a d.c. error of 2% or less.

2. These can withstand large loads and are not damaged even under sever overload conditions.

3. The range of instruments can be extended.

Disadvantages

iv. The scale of moving iron instruments is not uniform and is cramped at the lower end. Hence accurate readings are not possible at this end.

v. There are serious errors due to hysteresis, frequency changes and stray magnetic fields.

vi. The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability and hence affect the reading severely.

vii. Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.

viii. There is a difference between a.c. and d.c. calibration on account of the effect of inductance of the meter. Hence these meters must always be calibrated at the frequency at which they are to be used. The usual commercial moving iron instrument may be used within its specified accuracy from 25 to 125 HZ frequency range.

ix. Power consumption is on higher side.

Errors in moving iron instrument

d) Hysteresis error: Due to hysteresis effect, the flux density for the same currentwhile ascending and descending values is different. While descending, the flux density is higher and while ascending it is lesser. So meter reads higher for descending values of current or voltage. So remedy for this is to use smaller iron parts which can demagnetise quickly or to work with lower flux densities.

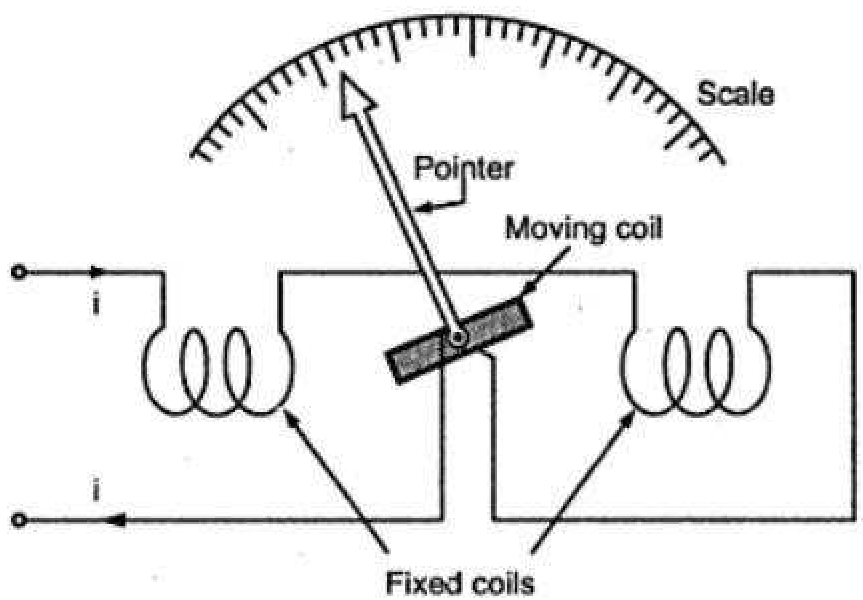
j) Temperature error : The temperature error arises due to the effect of temperatureon the temperature coefficient of the spring. This error is of the order of 0.02 % per oC change in temperature. Errors can cause due to self heating of the coil and due to which change in resistance of the coil. So coil and series resistance must have low temperature coefficient. Hence mangnin is generally used for the series resistance.

k) Stray magnetic Field Error : The operating magnetic field in case of moving ironinstruments is very low. Hence effect of external i.e. stray magnetic field can cause error. This effect depends on the direction of the stray magnetic field with respect to the operating field of the instrument.

p Frequency Error : These are related to a.c. operation of the instrument. The changein frequency affects the reactance of the working coil and also affects the magnitude of the eddy currents. This cause error in the instrument.

q Eddy Current Error : When instrument is used for a.c. measurements the eddycurrents are produced in the iron parts of the instrument. The eddy current affects the instrument current causing the change in the deflection torque. This produce the error in the meter reading. As eddy current are frequency dependent, frequency changes cause eddy current error.

DYNAMAOMETER



Construction

Fixed Coils : The necessary field required for the operation of the instrument isproduced by the fixed coils. A uniform field is obtained near the center of coil due to division of coil in two sections. These coils are air cored. Fixed coils are wound with fine wire for using as voltmeter, while for ammeters and wattmeters it is wound with heavy wire. The coils are usually varnished. They are clamped in place against the coil supports. This makes the construction rigid.

Ceramic is usually used for mounting supports. If metal parts would have been used then it would weaken the field of the fixed coil.

Moving Coil : The moving coil is wound either as a self-sustaining coil or else on a non-metallic former. If metallic former is used, then it would induce eddy currents in it. The construction of moving coil is made light as well as rigid. It is air cored.

Controlling : The controlling torque is provided by springs. These springs act as leadsto the moving coil.

Moving System : The moving coil is mounted on an aluminium spindle. It consists ofcounter weights and pointer. Sometimes a suspension may be used, in case a high accuracy is desired.

Damping : The damping torque is provided by air friction, by a pair of aluminium vaneswhich are attached to the spindle at the bottom. They move in sector shaped chambers. As operating field would be distorted by eddy current damping, it is not employed.

Shielding : The field produced by these instruments is very weak. Even earth'smagnetic field considerably affects the reading. So shielding is done to protect it from stray magnetic fields. It is done by enclosing in a casing high permeability alloy.

Cases and Scales : Laboratory standard instruments are usually contained in polishedwooden or metal cases which are rigid. The case is supported by adjustable levelling screws. A spirit level may be provided to ensure proper levelling.

For using electrodynamometer instrument as ammeter, fixed and moving coils are connected in series and carry the same current. A suitable shunt is connected to these coils to limit current through them upto desired limit.

The electrodynamometer instruments can be used as a voltmeter by connecting the fixed and moving coils in series with a high non-inductive resistance. It is most accurate type of voltmeter.

For using electrodynamometer instrument as a wattmeter to measure the power, the fixed coils acts as a current coil and must be connected in series with the load. The moving coils acts as a voltage coil or pressure oil and must be connected across the supply terminals. The wattmeter indicates the supply power.

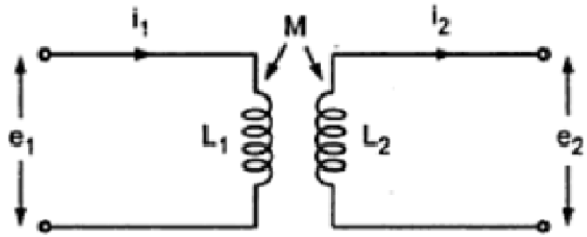
working

When current passes through the fixed and moving coils, both coils produce the magnetic fields. The field produced by fixed coil is proportional to the load current while the field produced by the moving coil is proportional to the voltage. As the deflecting torque is produced due to the interaction of these two fields, the deflection is proportional to the power supplied to the load.

Torque Equation

Let i_1 = Instantaneous value of current in fixed coil i_2 = Instantaneous value of current in moving coil L_1 = Self inductance of fixed coil L_2 = self inductance of moving coil M = Mutual inductance between fixed and moving coils

The electrodynamometer instrument can be represented by an equivalent circuit,



Now $e_1 = \frac{d\phi_1}{dt}$

and $e_2 = \frac{d\phi_2}{dt}$

$$\begin{aligned}
\text{Electrical input energy} &= e_1 i_1 dt + e_2 i_2\, dt \\
&= i_1\, d\,\phi_1 + i_2\, d\,\phi_2 \\
&= i_1\, d\,(L_1 i_1 + M i_2) + i_2\, d\,(L_2 i_2 + M i_1) \\
&= i_1 L_1\, d i_1 + i_1^2\, d L_1 + i_1 i_2\, dM + i_1 M\, d i_2 + \\
&\quad i_2 L_2 d i_2 + i_2^2\, d L_2 + i_1 i_2 d M + i_2 M d i_1 \qquad \ldots(1)
\end{aligned}$$

The energy stored in the magnetic field due to L_1, L_2 and M is given by,

$$\text{Energy stored} = \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M$$

$$\begin{aligned}
\text{Change in stored energy} &= d\left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M\right] \\
&= i_1 L_1\, d i_1 + \frac{1}{2} i_1^2\, d L_1 + i_2 L_2\, d i_2 + \frac{1}{2} i_2^2\, d L_2 + \\
&\quad i_1 M\, d i_2 + i_2 M\, d i_1 + i_1 i_2\, dM \qquad \ldots(2)
\end{aligned}$$

From the principle of conversation of energy,

Energy input=Energy stored + Mechanical energy

Mechanical energy=energy input-energy stored

Subtraction (2) from equation (1),

$$\text{Mechanical energy} = \frac{1}{2} i_1^2 \, d L_1 + \frac{1}{2} i_2^2 \, d L_2 + i_1 \, i_2 \, d M$$

The self inductance L_1 and L_2 are constant and hence dL_1 and dL_2 are zero. Mechanical energy = $i_1 i_2 dM$

If T_i is the instantaneous deflecting torque and $d\theta$ is the change in the deflection then

Mechanical energy = Mechanical work done

$= T_i \, d\theta \; i_1 \, i_2 \, d M = T_i \, d\theta$

$$\boxed{T_i = i_1 \, i_2 \frac{dM}{d\theta}}$$

Advantage of Electrodynamometer instrument

p As the coils are air cored, these instruments are free from hysteresis and eddy current losses.

q They have a precision grade security.

r These instruments can be used on both a.c. and d.c. They are also used as a transfer instruments.

s Electrodynamometer voltmeter are very useful where accurate r.m.s values of voltage, irrespective of waveforms, are required.

t Free from hysteresis errors.

u Low power Consumption.

v Light in weight.

Disadvantage of electrodynamometer instrument

p These instruments have a low sensitivity due to a low torque to weight ratio. Also it introduces increased frictional losses. To get accurate results, these errors must be minimized.

q They are more expensive than other type of instruments.

r These instruments are sensitive to overload and mechanical impacts. Therefore can must be taken while handling them.

s They have a nonuniform scale.

t The operation current of these instruments is large due to the fact that they have weak magnetic field

Error in electrodynamometer instrument

The various errors in electrodynamometer instruments are,

Torque to weight ratio : To have reasonable deflecting torque, mmf of the movingcoil must be large enough. Thus m.m.f. = NI hence current through moving coil should be high or number of turns should be large. The current cannot be made very high because it may cause excessive heating of springs. Large number of turns hence is the only option but it increases weight of the coil. This makes the system heavy reducing torque to weight ratio. This can cause frictional errors in the reading

Frequency errors : The changes in the frequency causes to change self inductancesof moving coil and fixed coil. This causes the error in the reading. The frequency error can be reduced by having equal time constants for both fixed and moving coil circuits.

Eddy current errors : In metal parts of the instrument the eddy current getsproduced. The eddy current interacts with the instrument current, to cause change in the deflecting torque, to cause error. Hnec metal parts should be kept as minimum as possible. Also the resistivity of the metal parts used must be high, to reduce the eddy currents.

Stray magnetic field error : Similar to moving iron instruments the operating field inelectrodynamometer instrument is very weak. Hence external magnetic field can interact with the operation field to cause change in the deflection, causing the error. To reduce the effect of stray magnetic field, the shields must be used for the instruments.

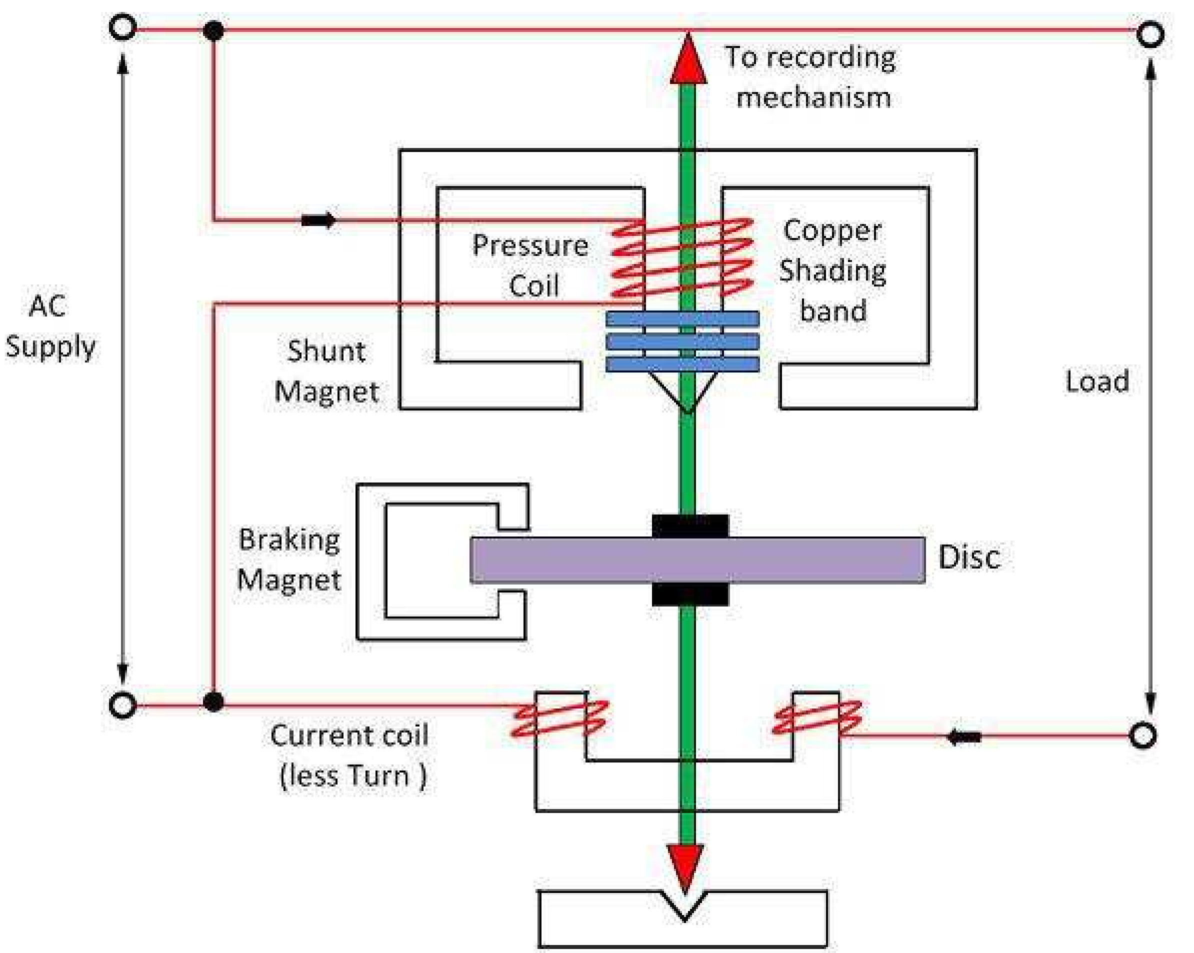
*   **Temperature error** : The temperature errors are caused due to the self heating ofthe coil, which causes change in the resistance of the coil. Thus temperature compensating resistors can be used in the precise instrument to eliminate the temperature errors.

Energy Meter

Definition: The meter which is used for measuring the energy utilises by the electric load is known as the energy meter. The energy is the total power consumed and utilised by the load at a particular interval of time. It is used in domestic and industrial AC circuit for measuring the power consumption. The meter is less expensive and accurate.

Construction of Energy Meter

The construction of the single phase energy meter is shown in the figure below.



Induction Type Energy Meter

The energy meter has four main parts. They are the

i) Driving System
ii) Moving System
iii) Braking System
iv) Registering System

The detail explanation of their parts is written below.

1. Driving System – The electromagnet is the main component of the driving system. It is the temporary magnet which is excited by the current flow through their coil. The core of the electromagnet is made up of silicon steel lamination. The driving system has two electromagnets. The upper one is called the shunt electromagnet, and the lower one is called series electromagnet.

The series electromagnet is excited by the load current flow through the current coil. The coil of the shunt electromagnet is directly connected with the supply and hence carry the current proportional to the shunt voltage. This coil is called the pressure coil.

The centre limb of the magnet has the copper band. These bands are adjustable. The main function of the copper band is to align the flux produced by the shunt magnet in such a way that it is exactly perpendicular to the supplied voltage.

2. Moving System – The moving system is the aluminium disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. This eddy current is cut by the magnetic flux. The interaction of the flux and the disc induces the deflecting torque.

When the devices consume power, the aluminium disc starts rotating, and after some number of rotations, the disc displays the unit used by the load. The number of rotations of the disc is counted at particular interval of time. The disc measured the power consumption in kilowatt hours.

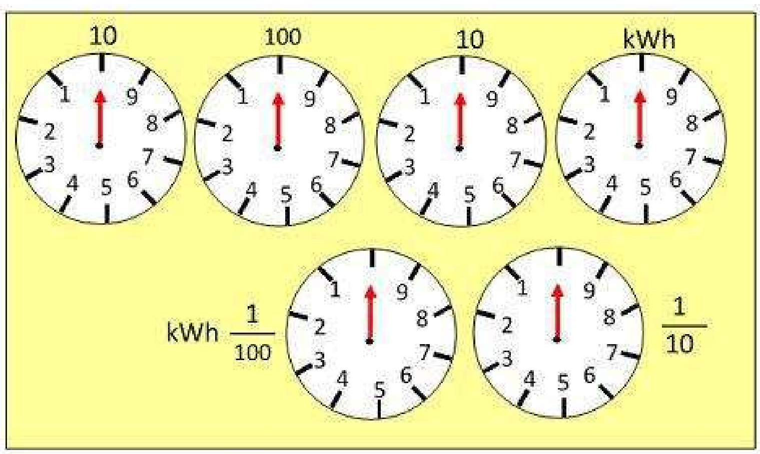
3. Braking system – The permanent magnet is used for reducing the rotation of the aluminium disc. The aluminium disc induces the eddy current because of their

rotation. The eddy current cut the magnetic flux of the permanent magnet and hence produces the braking torque.

This braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

4. Registration (Counting Mechanism) – The main function of the registration or counting mechanism is to record the number of rotations of the aluminium disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour.

The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kWh is obtained by multiply the number of rotations of the disc with the meter constant. The figure of the dial is shown below.



Pointer Type of Register Circuit Globe

Working of the Energy Meter

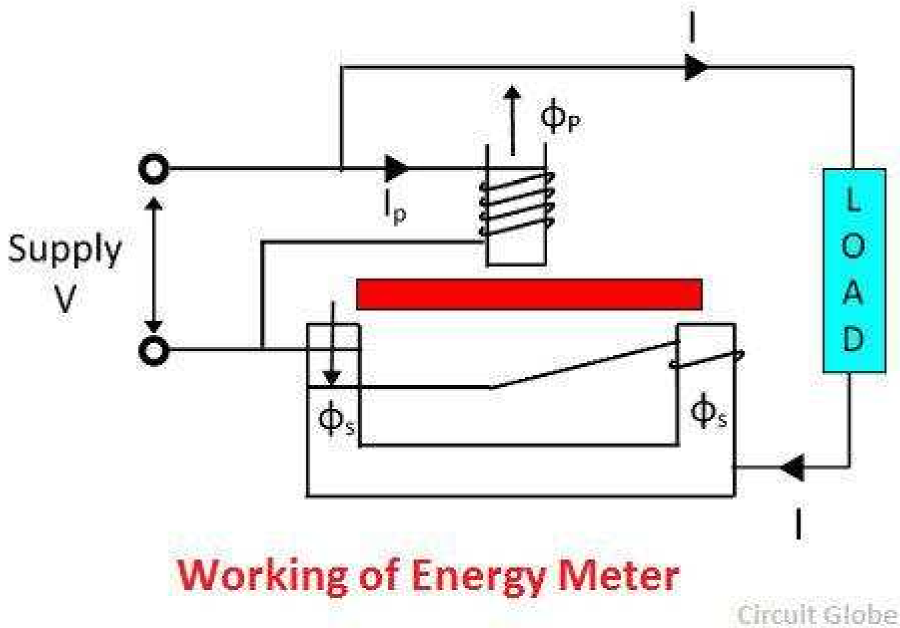
The energy meter has the aluminium disc whose rotation determines the power consumption of the load. The disc is placed between the air gap of the series and shunt electromagnet. The shunt magnet has the pressure coil, and the series magnet has the current coil.

The pressure coil creates the magnetic field because of the supply voltage, and the current coil produces it because of the current.

The field induces by the voltage coil is lagging by 90º on the magnetic field of the current coil because of which eddy current induced in the disc. The interaction of the eddy current and the magnetic field causes torque, which exerts a force on the disc. Thus, the disc starts rotating. The force on the disc is proportional to the current and voltage of the coil. The permanent magnet controls Their rotation. The permanent magnet opposes the movement of the disc and equalises it on the power consumption. The cyclometer counts the rotation of the disc.

Theory of Energy Meter

The pressure coil has the number of turns which makes it more inductive. The reluctance path of their magnetic circuit is very less because of the small length air gap. The current Ip flows through the pressure coil because of the supply voltage, and it lags by 90º.



The Ip produces the two Φp which is again divided into Φp1 and Φp2. The major portion of the flux Φp1 passes through the side gap because of low reluctance. The flux Φp2 goes through the disc and induces the driving torque which rotates the aluminium disc. The flux Φp is proportional to the applied voltage, and it is lagged by an angle of 90º.The flux is alternating and hence induces an eddy current Iep in the disc. The load current passes through the current coil induces the flux Φs. This flux causes the eddy current Ies on the disc. The eddy current Ies interacts with the flux Φp, and the eddy current Iep interacts with Φs to produce the another torque. These torques are opposite in direction, and the net torque is the difference between these two.

CLASSIFICATION OF RESISTANCES

For the purposes of measurements, the resistances are classified into three major groups based on their numerical range of values as under:

• Low resistance (0 to 1 ohm)

• Medium resistance (1 to 100 kilo-ohm) and

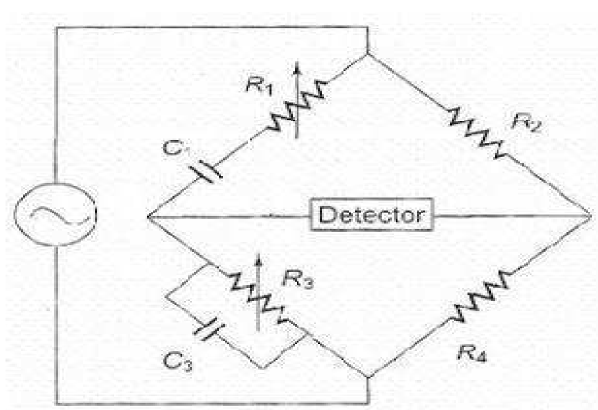
• High resistance (>100 kilo-ohm)

Accordingly, the resistances can be measured by various ways, depending on their range of values, as under:

1. Low resistance (0 to 1 ohm): AV Method, Kelvin Double Bridge, potentiometer, doctor ohmmeter, etc.
2. Medium resistance (1 to 100 kilo-ohm): AV method, wheat stone's bridge, substitution method, etc.
3. High resistance (>100 kilo-ohm): AV method, Fall of potential method, Megger, loss of charge method, substitution method, bridge method, etc.

WIEN'S BRIDGE:

Circuit and derives the expression for the unknown element at balance, Wien Bridge has a series RC combination in one and a parallel combination in the adjoining arm. Wien's bridge is shown in fig. Its basic form is designed to measure frequency. It can also be used for the instrument of an unknown capacitor with great accuracy, The impedance of one arm is



$$Z_1 = R_1 - j/\omega C_1$$

The admittance of the parallelarm is

$$Y_3 = 1/R_3 + j\,\omega\,C_3$$

Using the bridge balance equation,we have

We have $$Z_1\,Z_4 = Z_2\,Z_3$$

Therefore

$$Z_1\,Z_4 = Z_2/Y_3,\text{ i.e. } Z_2 = Z_1\,Z_4\,Y_3$$

$$R_2 = R_4\left(R_1 - \frac{j}{\omega C_1}\right)\left(\frac{1}{R_3} + j\,\omega C_3\right)$$

$$R_2 = \frac{R_1\,R_4}{R_3} - \frac{j\,R_4}{\omega C_1\,R_3} + j\,\omega\,C_3\,R_1\,R_4 + \frac{C_3\,R_4}{C_1}$$

$$R_2 = \left(\frac{R_1\,R_4}{R_3} + \frac{C_3\,R_4}{C_1}\right) - j\left(\frac{R_4}{\omega C_1\,R_3} - \omega\,C_3\,R_1\,R_4\right)$$

Equating the real and imaginary terms we have as,

$$R_2 = \frac{R_1\,R_4}{R_3} + \frac{C_3\,R_4}{C_1} \quad \text{and} \quad \frac{R_4}{\omega\,C_1\,R_3} - \omega\,C_3\,R_1\,R_4 = 0$$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1}$$

$$\frac{1}{\omega C_1\,R_3} = \omega\,C_3\,R_1$$

$$\omega^2 = \frac{1}{C_1\,R_1\,R_3\,C_3}$$

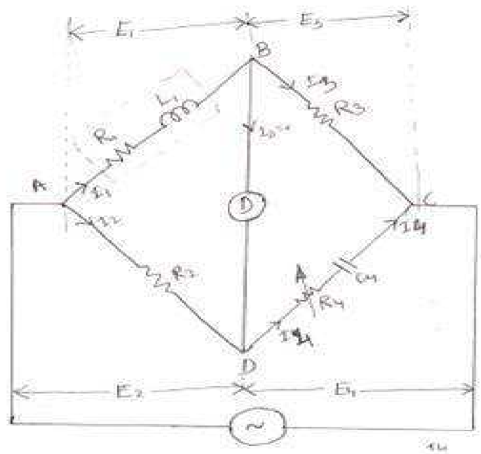
$$\omega = \frac{1}{\sqrt{C_1\,R_1\,C_3\,R_3}}$$

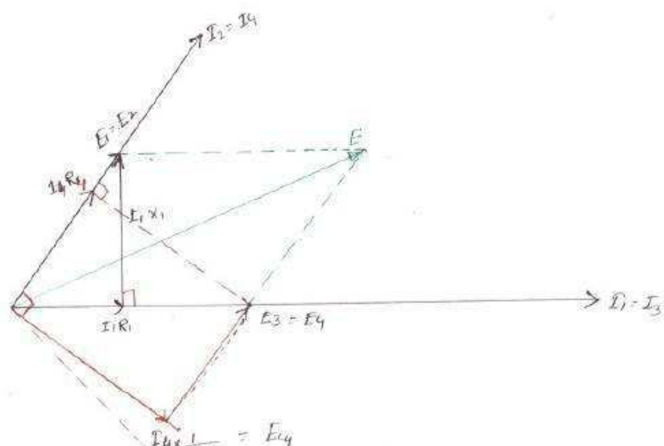
$$\omega = 2\,\pi f$$

$$f = \frac{1}{2\pi\,\sqrt{C_1\,R_1\,C_3\,R_3}}$$

The bridge is used for measuring frequency in the audio range. Resistances R1 and R3 can be ganged together to have identical values. Capacitors C1 and C3 are normally of fixed values. The audio range is normally divided into 20 - 200 - 2 k - 20 kHz range In this case, the resistances can be used for range changing and capacitors, and C3 for fine frequency control within the range. The bridge can also be use for measuring capacitance. In that case, the frequency of operation must be known. The bridge is also used in a harmonic distortion analyzer, as a Notch filter, an in audio frequency and radio frequency oscillators as a frequency determine element. An accuracy of 0.5% - 1% can be readily obtained using this bridge. Because it is frequency sensitive, it is difficult to balance unless the waveform of the applied voltage is purely sinusoidal.

HAY'S BRIDGE





Phasor diagram for hays bridge

- $\dot{E}1 = I_1R_1 + jI_1X_1$
- $\dot{E} = \dot{E}1 + \dot{E}3$
- $\dot{E}4 = \dot{I}_4 R_4 + \frac{I_4}{jwC_4}$
- $\dot{E}3 = I_3R_3$

$$Z_4 = R_4 + \frac{1}{jwC_4} = \frac{1 + jwR_4C_4}{jwC_4}$$

Comparing imaginary part

At balance condition, $Z_1Z_4 = Z_3Z_2$

$$(R_1 + jwL_1)(\frac{1 + jwR_4C_4}{jwC_4}) = R_2R_3$$

$$(R_1 + jwL_1)(1 + jwR_4C_4) = jwR_2C_4R_3$$

$$R_1 + jwC_4R_4R_1 + jwL_1 + j^2w^2L_1C_4R_4 = jwC_4R_2R_3$$

$$(R_1 - w^2L_1C_4R_4) + j(wC_4R_4R_1 + wL_1) = jwC_4R_2R_3$$

Comparing the real term,

$$R_1 - w^2L_1C_4R_4 = 0$$

$$R_1 = w^2L_1C_4R_4$$

$$wC_4R_4R_1 + wL_1 = wC_4R_2R_3$$

$$C_4R_4R_1 + L_1 = C_4R_2R_3$$

$$L_1 = C_4R_2R_3 - C_4R_4R_1$$

Substituting the value of R_1 fro eqn. 2.14 into eqn. 2.15, we have,

$$L_1 = C_4R_2R_3 - C_4R_4 \times w^2L_1C_4R_4$$

$$L_1 = C_4R_2R_3 - w^2L_1C_4^2R_4^2$$

$$L_1(1 + w^2L_1C_4^2R_4^2) = C_4R_2R_3$$

$$L_1 = \frac{C_4R_2R_3}{1 + w^2L_1C_4^2R_4^2}$$

Substituting the value of L_1 in eqn. 2.14 , we have

$$R_1 = \frac{w^2C_4^2R_2R_3R_4}{1 + w^2C_4^2R_4^2}$$

$$Q = \frac{wL_1}{R_1} = \frac{w \times C_4R_2R_3}{1 + w^2C_4^2R_4^2} \times \frac{1 + w^2C_4^2R_4^2}{w^2C_4^2R_4R_2R_3}$$

$$Q = \frac{1}{wC_4R_4}$$

Advantage

Fixed capacitor is cheaper than variable capacitor.

This bridge is best suitable for measuring high value of Q-factor

Disadvantage

Equations of $L_1$and R_1 are complicated.

- Measurements of R_1 and L_1 require the value of frequency.
- This bridge cannot be used for measuring low Q- factor.

MAXWELL'S INDUCTANCE BRIDGE

The choke for which R_1 and L_1 have to measure connected between the points ‗A' and ‗B'. In this method the unknown inductance is measured by comparing it with the standard inductance.

L_2 is adjusted, until the detector indicates zero current.

Let R_1= unknown resistance

L_1= unknown

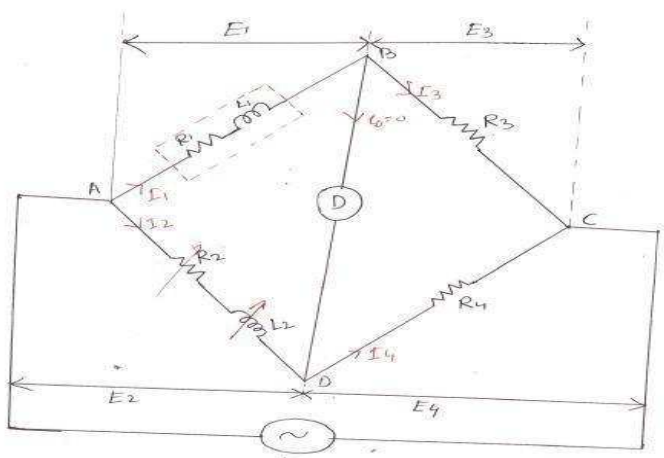
L_2 is adjusted, until the detector indicates zero current.

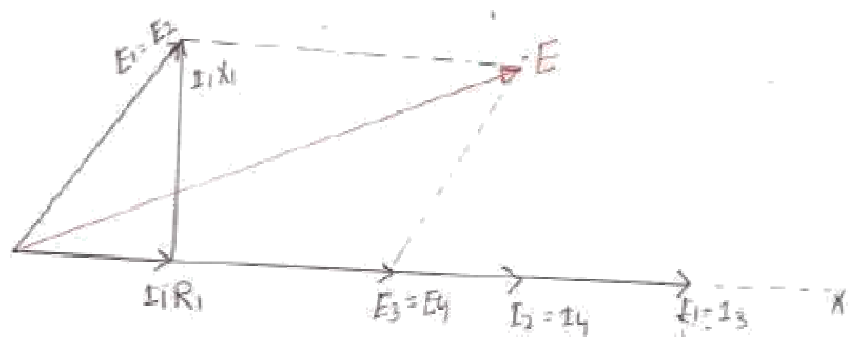
Let R_1= unknown resistance

L_1= unknown inductance of the choke.

L_2= known standard inductance

R_1,R_2,R_4= known resistances





Phasor diagram of maxwell bridge

$(R_1 + jXL_1)R_4 = (R_2 + jXL_2)R_3$

$(R_1 + jwL_1)R_4 = (R_2 + jwL_2)R_3$

$R_1R_4 + jwL_1R_4 = R_2R_3 + jwL_2R_3$

Comparing real part,

$R_1R_4 = R_2R_3$

$\therefore R_1 = \frac{R_2R_3}{R_4}$

Comparing the imaginary parts,

$wL_1R_4 = wL_2R_3$

$L_1 = \frac{L_2R_3}{R_4}$

Q-factor of choke, $Q = \frac{WL_1}{R_1} = \frac{WL_2R_3R_4}{R_4R_2R_3}$

$Q = \frac{WL_2}{R_2}$

Advantage

Expression for R1 and L1 are simple.

Equations area simple

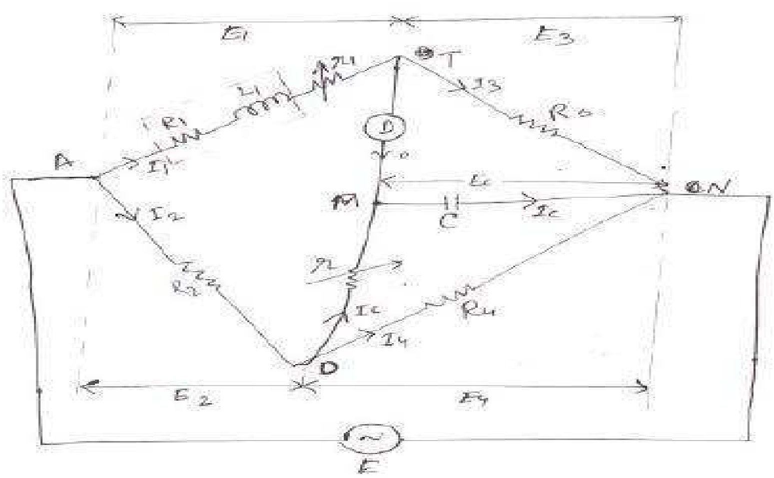
They do not depend on the frequency (as w is cancelled) R1 and L1 are independent of each other

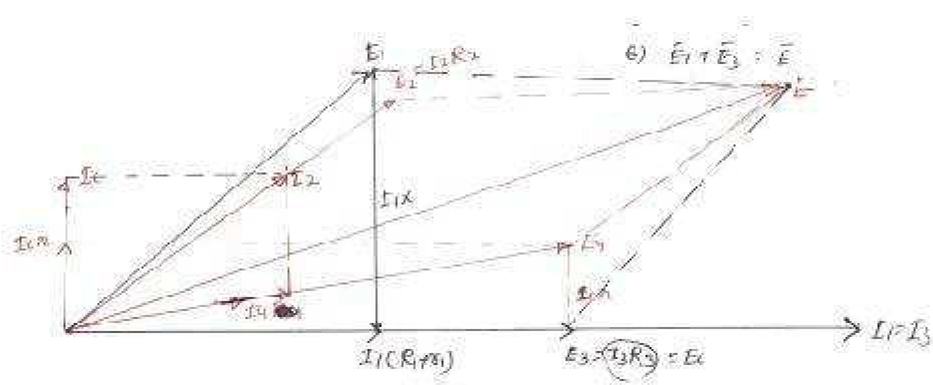
Disadvantage

Variable inductor is costly.

Variable inductor is bulky.

ANDERSON'S BRIDGE





Phasors diagram of Anderson's bridge

Step-1 Take I_1 as references vector .Draw $I_1R_1^|$ in phase with I_1

$R_1^| = (R_1 + r_1)$. I_1X_1 is $\perp_r$ to $I_1R_1^|$

$E_1 = I_1R_1^| + jI_1X_1$

Step-2 $I_1 = I_3$, E_3 is in phase with I_3, From the circuit ,

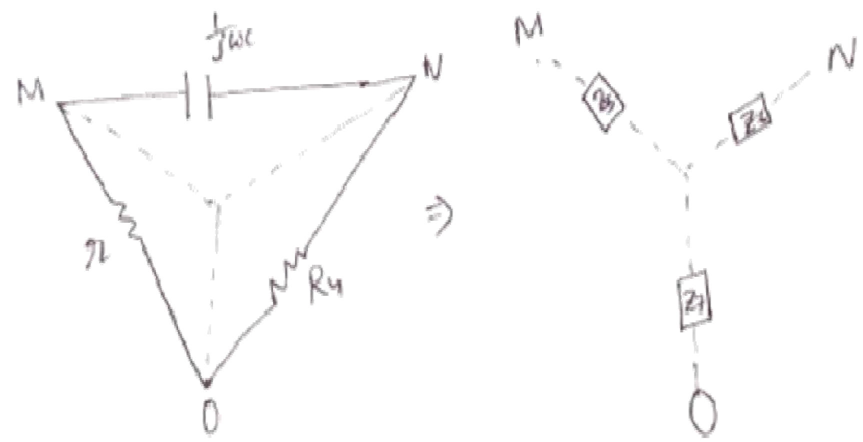
$E_3 = E_C$, I_C leads E_C by 90^0

Step-3 $E_4 = I_C r + E_C$

Step-4 Draw I_4 in phase with E_4 , By KCL , $\bar{I}_2 = \bar{I}_4 + \bar{I}_C$

Step-5 Draw E_2 in phase with I_2

Step-6 By KVL , $\bar{E}_1 + \bar{E}_3 = \bar{E}$ or $\bar{E}_2 + \bar{E}_4 = \bar{E}$



Equivalent delta to star conversion for the loop MON

$$Z_7 = \frac{R_4 \times r}{R_4 + r + \frac{1}{jwc}} = \frac{jwCR_4 r}{1 + jwC(R_4 + r)}$$

$$Z_6 = \frac{R_4 \times \frac{1}{jwC}}{R_4 + r + \frac{1}{jwc}} = \frac{R_4}{1 + jwC(R_4 + r)}$$

$$(R_1^1 + jwL_1) \times \frac{R_4}{1 + jwC(R_4 + r)} = R_3\left(R_2 + \frac{jwCR_4 r}{1 + jwC(R_4 + r)}\right)$$

$$\Rightarrow \frac{(R_1^1 + jwL_1)R_4}{1 + jwC(R_4 + r)} = R_3\left[\frac{R_2(1 + jwC(R_4 + r)) + jwCrR_4}{1 + jwC(R_4 + r)}\right]$$

$$\Rightarrow R_1^1 R_4 + jwL_1 R_4 = R_2 R_3 + jCwR_2 R_3(r + R_4) + jwCrR_4 R_3$$

Comparing Real term

$$R_1^1 R_4 = R_2 R_3$$

$$(R_1 + r_1)R_4 = R_2 R_3$$

$$R_1 = \frac{R_2 R_3}{R_4} - r_1$$

Comparing the imaginary term,

$$wL_1 R_4 = wCR_2 R_3(r + R_4) + wcrR_3 R$$

$$L_1 = \frac{R_2 R_3 C}{R_4}(r + R_4) + R_3 rC$$

$$L_1 = R_3 C\left[\frac{R_2}{R_4}(r + R_4) + r\right]$$

Advantage

Variable capacitor is not required.

Inductance can be measured accurately.

R1 and L1 are independent of frequency.

Accuracy is better than other bridges.

SCHERING BRIDGE

$E1 = I1r1 - jI1X4$

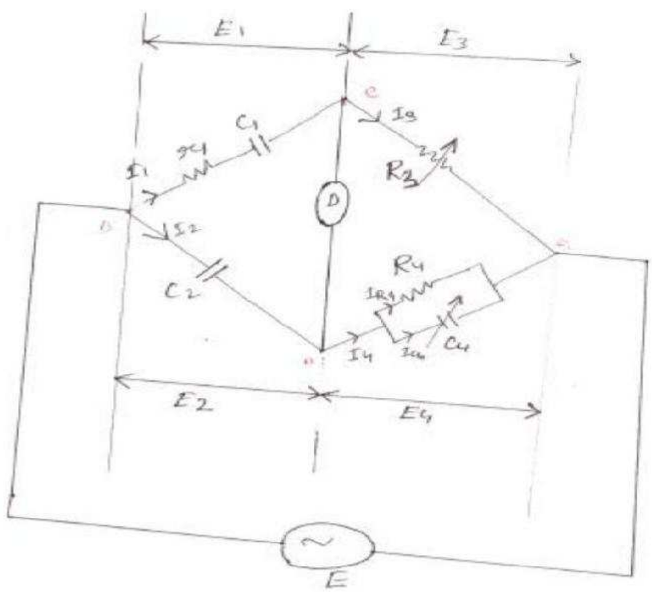
C2 = C4= Standard capacitor (Internal resistance=0)

C4= Variable capacitance.

C1= Unknown capacitance.

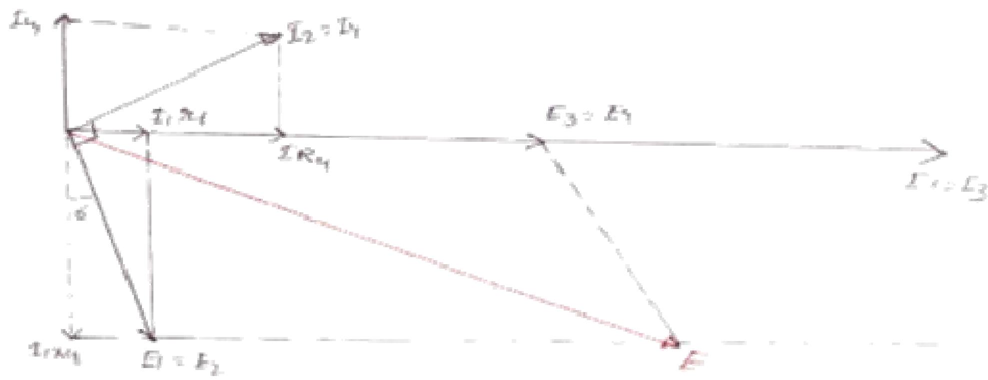
r1= Unknown series equivalent resistance of the capacitor

R3=R4= Known resistor.



$$Z_1 = r_1 + \frac{1}{jwC_1} = \frac{jwC_1 r_1 + 1}{jwC_1}$$

$$Z_4 = \frac{R_4 \times \frac{1}{jwC_4}}{R_4 + \frac{1}{jwC_4}} = \frac{R_4}{1 + jwC_4 R_4}$$



At balance condition, $\dot{Z}_1 \dot{Z}_4 = \dot{Z}_2 \dot{Z}_3$

$$\frac{1+jwC_1r_1}{jwC_1} \times \frac{R_4}{1+jwC_4R_4} = \frac{R_3}{jwC_2}$$

$$(1+jwC_1r_1)R_4C_2 = R_3C_1(1+jwC_4r_4)$$

$$R_2C_2 + jwC_1r_1R_4C_2 = R_3C_1 + jwC_4R_4R_3C_1$$

Comparing the real part,

$$\therefore C_1 = \frac{R_4C_2}{R_3}$$

Comparing the imaginary part,

$$wC_1r_1R_4C_2 = wC_4R_3R_4C_1$$

$$r_1 = \frac{C_4R_3}{C_2}$$

Dissipation factor of capacitor,

$$D = wC_1r_1 = w \times \frac{R_4C_2}{R_3} \times \frac{C_4R_3}{C_2}$$

$$\therefore D = wC_4R_4$$

Advantage

In this type of bridge, the value of capacitance can be measured accurately. It can measure capacitance value over a wide range.

It can measure dissipation factor accurately

Disadvantage

It requires two capacitors. Variable standard capacitor is costly.

TYPES OF DETECTOR

The following types of instruments are used as detector in A.C. bridge.

- Vibration galvanometer
- Head phones (speaker)
- Tuned amplifier

Analog Multimeter:

The Analog Multimeter or VOM (Volt-Ohm-Milliammeter) is constructed using a moving coil meter and a pointer to indicate the reading on the scale. The moving coil meter consists of a coil wound around a drum placed between two permanent magnet. As current passes through the coil, magnetic field is induced in the coil which reacts with the magnetic field of the permanent magnets and the resultant force causes the pointer attached to the drum to deflect on the scale, indicating the current reading. It also consists of springs attached to the drum which provides an opposing force to the motion of the drum to control the deflection of the pointer.

Analog Multimeter

Analog multimeters are electrical test instruments which are used to measure voltage, current, resistance, frequency and signal power.

Analog multimeters use a needle along a scale. Switched range analog multimeters are very cheap but are difficult for beginners to read accurately, especially on resistance scales. Each type of meter has its advantages. Used as a voltmeter, a digital meter is usually better because its resistance is much higher, 1 M or 10 M, compared to 200 for a analog multimeter on a similar range. On the other hand, it is easier to follow a slowly changing voltage by watching the needle on an anlaogue display. Used as an ammeter, nalog multimeters have a very low resistance and is very sensitive. More expensive digital multimeters can equal or better this performance. Most modern multimeters are digital and traditional analog multimters are becoming obsolete.

The basic functionality of an analog multimeter will include measurement of electrical potential in volts, resistance in ohms, and current in amps. Analog multimeters can be used to find electronic and electrical short circuit problems. Advanced analog multimeters come with more features such as capacitor, diode and IC testing modes. Specific measurements made by analog multimeters include DC voltage, AC voltage, DC current, AC current, frequency range for AC currents, and decibel measurement. Analog multimeters that measure current may have a current clamp built-in or configured as a probe. A current clamp is a sensor that clamps around the wire. When searching for analog multimeters it is important to consider the measurement range for whichever value is being measured. An analog multimeter displays these values via a dial, typically a moving pointer or needle. Analog multimeters are generally bench top or hand held. Bench top models can also be portable by use of handles and wheels. Hand held multimeters are specifically designed to be used while holding, i.e, can be operated with one hand.

Analog multimeters have multiple scales on the dial, a moving needle and many manual settings on the function switch. It’s tricky spotting the correct scale to read on the dial, plus you sometimes have to multiply the reading by 10 or 100 to get your final value. Depending on features (make sure it can do continuity testing), prices start at about $15.

For appliance and electronic repairs, it may be better to purchase a digital, not analog, multimeter. This type is much simpler to read and you can change the functions on it more easily. Digital multimeters have LCD readouts, do continuity testing, and cost from $35 on up. Some digital multimeters also feature auto-ranging and overload protection and other advantages analog multimeters lack.

For easier, hands-free viewing, choose an analog multimeter with a stand that will prop it up or hang it on a wall. If an analog multimeter doesn't come equipped with either jumper wires or alligator clips (both about $4 each), buy them. Alligator clips are often used to firmly grip wiring or contacts for hands-free safe and accurate readings. Both types of multimeters and these accessories can be purchased at electronics stores, home centers and hardware stores.

Common features for analog multimeters include battery power, overload protection, temperature compensated, mirrored scale, range switch, diode test, and battery test. Devices with battery power can be operated without plug in power. Multimeters with overload protection have a fuse or other method to protect meter. Temperature compensated devices have programming or electrical devices designed to counteract known errors caused by temperature changes. A mirrored scale makes it easier to read the instrument to a given accuracy by enabling the operator to avoid parallax errors. A range switch is used to select appropriate range of units to be measured. A device with a diode test has methods for testing diode operation. A device with a battery test has methods for testing battery operation. An important environmental parameter to consider when searching for analog multimeters is the operating temperature.

SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - II
BASIC ELECTRONIC MEASUREMENTS – SEIA1501

UNIT 2

BASIC ELECTRONIC MEASUREMENTS

Electronic multimeters – Cathode ray oscilloscopes – block schematic – applications – special oscilloscopes - delayed time base oscilloscopes, analog and digital storageoscilloscope, sampling oscilloscope – Q meters – Vector meters – RF voltage and power measurements – True RMS meters.

thode Ray Oscilloscope

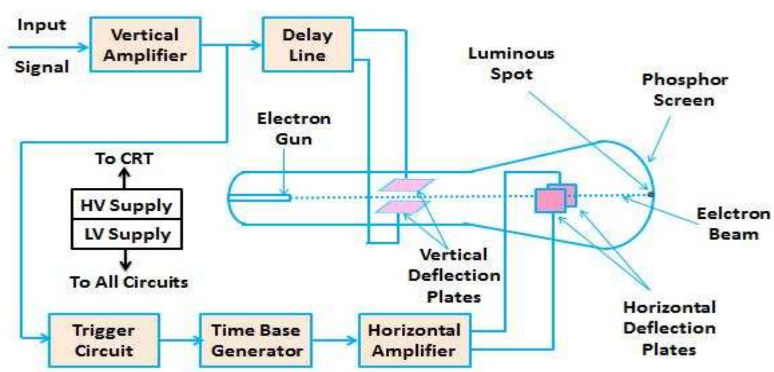
The cathode Ray Oscilloscope or mostly called as CRO is an electronic device used for giving the visual indication of a signal waveform. It is an extremely useful and the most versatile instrument in the electronic industry. CRO is widely used for trouble shooting radio and television receivers as well as for laboratory research and design.

Using a CRO, the wave shapes of alternating currents and voltages can be studied. It can also be used for measuring voltage, current, power, frequency and phase shift.

Different types of oscilloscopes are available for various purposes.

Block Diagram of CRO (Cathode Ray Oscilloscope)

The figure below shows the block diagram of a general purpose CRO.



Block Diagram of Cathode Ray Oscilloscope (CRO)

As we can see from the above figure above, a CRO employs a cathode ray tube (CRT), which acts as the heart of the oscilloscope.

In an oscilloscope, the CRT generates the electron beam which are accelerated to a high velocity and brought to focus on a fluorescent screen. This screen produces a visible spot where the electron beam strikes it. By deflecting the beam over the screen in response to the electrical signal, the electrons can be made to act as an electrical pencil of light which produces a spot of light wherever it strikes.

For accomplishing these tasks various electrical signals and voltages are needed, which are provided by the power supply circuit of the oscilloscope. Low voltage supply is required for the heater of the electron gun to generate the electron beam and high voltage is required for the cathode ray tube to accelerate the beam. Normal voltage supply is required for other control units of the oscilloscope.

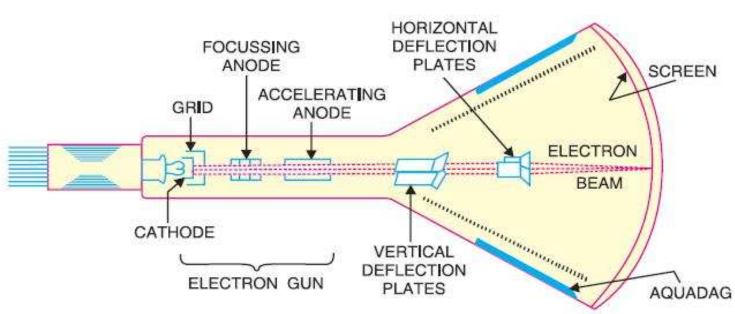
Horizontal and vertical deflection plates are fitted between the electron gun and the screen so that these can deflect the beam according to the input signal. To deflect the electron beam on the screen in horizontal direction i.e. X-axis with constant time dependent rate, a time base generator is provided in the oscilloscope. The signal to be viewed is supplied to the vertical deflection plate through the vertical amplifier, so that it can amplify the signal to a level that will provide usable deflection of the electron beam. As the electron beam is deflected in X-axis as well as Y-axis, a triggering circuit is provided for synchronizing these two types of deflections so that horizontal deflection starts at the same point of the input vertical signal each time it sweeps. Since CRT is the heart of the oscilloscope, we are going to discuss its various components in detail.

Cathode Ray Tube

The cathode ray tube or CRT is a vacuum tube of special geometrical shape which converts an electrical signal into a visual one.

A CRT makes available a large number of electrons which are accelerated to high velocity and are brought to focus on a fluorescent screen where it produces a spot when strikes it. The electron beam is deflected during its journey in response to the applied electrical signal. As a result, the electrical signal waveform is displayed visually.

The figure below shows various parts of a cathode ray tube (CRT).



i) Glass Envelope

It is a conical highly evacuated glass housing which maintains vacuum inside it and supports various electrodes. The inner wall of CRT between the neck and screen are usually coated with a conducting material known as aquadag. This coating is electrically connected to the accelerating anode so that the electrons which accidentally strike the walls are returned to the anode. This prevents the walls from charging to a high negative potential.

(ii) Electron Gun Assembly

The electron gun assembly consists of an indirectly heated cathode, a control grid, a focussing anode and an accelerating anode and it is used to produce a focused beam of electrons. The control grid is held at negative potential w.r.t. cathode. However, the two anodes are held at high positive potential w.r.t. cathode. The cathode consists of a nickel cylinder coated with oxide coating and provides a large number of electrons. The control grid encloses the cathode and consists of a metal cylinder with a tiny circular opening to keep the electron beam small. By controlling the positive potential on it, the focusing anode focuses the electron beam into a sharp pin point. Due to the positive potential of about 10,000 V on the accelerating anode which is much larger than on the focusing diode, the electron beam is accelerated to a high velocity. In this way, the electron gun assembly forms a narrow, accelerated electron beam which produces a spot of light when it strikes the screen.

(iii) Deflection Plate Assembly

It consists of two sets of deflecting plates within the tube beyond the accelerating anode and is used for the deflection of the beam. One set is called as vertical deflection plates and the other set is called horizontal deflection plates. The vertical deflection plates are mounted horizontally in the tube. On application of proper potential to these plates, the electron beam can be made to move up and down vertically on the screen. The horizontal deflection plates are mounted vertically in the tube. On application of proper potential to these plates, the electron beam can be made to move right and left horizontally on the screen.

(iv) Screen

The screen is coated with some fluorescent materials such as zinc orthosilicate, zinc oxide etc and is the inside face of the tube. When high velocity electron beam strikes the screen, a spot of light appears at the point of impact. The colour of the spot depends upon the nature of fluorescent material.

Working of Cathode Ray Tube

As the cathode is heated, it produces a large number of electrons. These electrons pass through the control grid on their way to the screen. The control grid controls the amount of current flow as in standard vacuum tubes. If negative potential on the control grid is high, fewer electrons will pass through it. Hence the electron beam will produce a dim spot of light on striking the screen. Reverse will happen when the negative potential on the control grid is reduced. Therefore, the intensity of the light spot on the screen can be controlled by changing the negative potential on the control grid.

After leaving the control grid, the electron beam comes under the influence of focusing and accelerating anodes. Since, the two anodes are at high positive potential, therefore, they produce a field which acts as electrostatic lens to converge the electron beam at a point on the screen. After leaving the accelerating anode, the electron beam comes under the influence of vertical and horizontal deflection plates. When no voltage is applied to these deflection plates, the electron beam produces a spot of light at the centre as shown by point O in fig below on the screen.

If the voltage is applied to the vertical deflection plates only, the electron beam and so as the spot of light will be deflected upwards i.e. point O1. Ans if the potential on the plates is reversed, the spot of light will be deflected downwards i.e. point O2. Similarly, the spot of light can be deflected horizontally by applying voltage across the horizontal deflection plates.

STORAGE OSCILLOSCOPE

It is sometimes necessary to be able to display a signal for a period of time. One situation where this may be required is for signals that have a very long period and the normal persistence of a display would mean that the trace would decay before the whole waveform was complete. A storage facility could also be required for single shot applications where the single trace would need to be displayed over a period of time to examine the trace. For these and many other situations, it is necessary to have a storage facility on the scope where it can display the trace for longer than would normally be possible.

Analogue storage scopes use a special cathode ray tube with a long persistence facility. A special tube with an arrangement to store charge in the area of the display where the electron beam had struck, thereby enabling the fluorescence to remain for much longer than attainable on normal displays. These cathode ray tubes had the facility to vary the persistence, although if very bright traces were held over long periods of time, they would have the possibility of permanentlyburning the trace onto the screen. Accordingly these storage displays needed to be used with care.

Two storage techniques are used in oscilloscope CRTs as, **-**mesh storage

-phosphor storage.

The Storage targets can be distinguished from standard phosphor targets by their ability to retain a waveform pattern for a long time, independent of phosphor persistence.

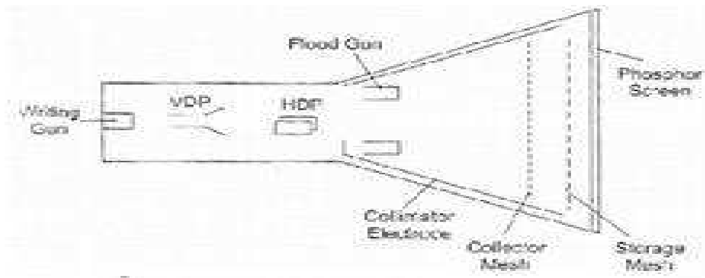
A mesh-storage CRT uses a dielectric material deposited on a storage mesa as the storage target. This mesh is placed between the deflection plates and the standard phosphor target in the CRT.

The writing beam, which is the focused electron beam of the standard CRT,

charges the dielectric material positively e where hit. The storage target is then bombarded with low velocity electrons from a flood gun and the positively charged areas of the storage target allow these electrons to pass through to the standard phosphor target and thereby reproduced the stored image on the screen.

Thus the mesh storage has both a storage target and a phosphor display target. The phosphor storage CRT uses a thin layer of phosphor to serve both as the storage and the display element.

Mesh Storage It is used to display Very Low Frequencies (VLF) signals an: finds many applications in mechanical and biomedical fields. The convention-scope has a display with a phosphor persistence ranging from a few microseconds to a few seconds.



A mesh storage CRT, contains a dielectric material deposed on a storage mesh, a collector mesh, flood guns and a collimator, in addition BO all the elements of a standard CRT

The storage target, a thin deposition of a dielectric material such as Magnesium Fluoride on the storage mesh, makes use of a property known as secondary emission. The writing gun etches a positively charged pattern on the storage mesh or target by knocking off secondary emission electrons.Because of the excellent insulating property of the Magnesium fluoride coating, this positively charged pattern remains exactly in the position where it is deposited. In order to make a pattern visible, a special electron gun, called the flood gun, is switched on (even after many hours).

The electron paths ire adjusted by the collimator electrode, which constitutes a low voltage electrostatic lens system (to focus the electronbeam), Most of the electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen.

The CRT will now display the signal and it will remain visible as long as the flood guns operate. To erase the pattern on the storage mesh, a negative voltage is applied to neutralize the stored positive charge.

Since the storage mesh makes use of secondary emission, between the first and second crossover more electrons are emitted than are absorbed by the material, and hence a net positive charge results. Below the first crossover a net negative charge results, since the impinging electrons do not have sufficient energy to force an equal number to be emitted.

In order to store a trace, assume that the storage surface is uniformly charge; and write gun (beam emission gun) will hit the storage target. Those areas of the storage surface hit by the deflecting beam lose electrons, which are collects by the collector mesh. Hence, the write beam deflection pattern is traced on the storage surface as a positive charge pattern.

Since the insulation of the dielectric material is high enough to prevent any loss of charge for a considerable length of time, the pattern is stored. To view, the stored trace, a flood gun is used when the write gun is turned off. The flood gun, biased very near the storage mesh potential, emits flood of electrons which move towards the collector mesh, since it is biased slightly more positive than the deflection region.

The collimator ,a conductive coating on the CRT envelope with an applied potential, helps to align the flood electrons so that they approach the storage target perpendicularly When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region on the storage surface or a negatively charged region where no trace has been stored.

The positively charged areas allow the electrons to pass through to the post accelerator region and the display target phosphor. The negatively charged region repels the flood electrons back to the collector mesh. Thus the charge pattern on the storage surface appears reproduced on the CRT display phosphor just as though it were being traced with a deflected beam.

DIGITAL STORAGE OSCILLOSCOPE

Storage cathode ray tube has several limitations as follows,

1. There is a short duration of time, in which it can preserve a stored waveform, so the waveform may lose.
2. Trace of storage tube is not as fine as that of a normal CRT.
3. Writing rate of the storage tube is less than that of a conventional CRT which in turn limits the speed of the analog storage oscilloscope.
4. It is more expensive than a conventional CRT and requires additional power supplies.
5. Only one image can be stored. For comparing two traces they are to be superimposed on the same and displayed together.

Digital storage oscilloscope is used to limit these limitations. In DSO, the waveform to be stored is digitized, stored in a digital memory and retrieved for display on the storage oscilloscope. Stored waveform is continuously displayed by repeatedly scanning it. Therefore a conventional CRT can also be used for the display. The stored display can be displayed continuously as long as the power is applied to the memory which can be supplied from a small battery.

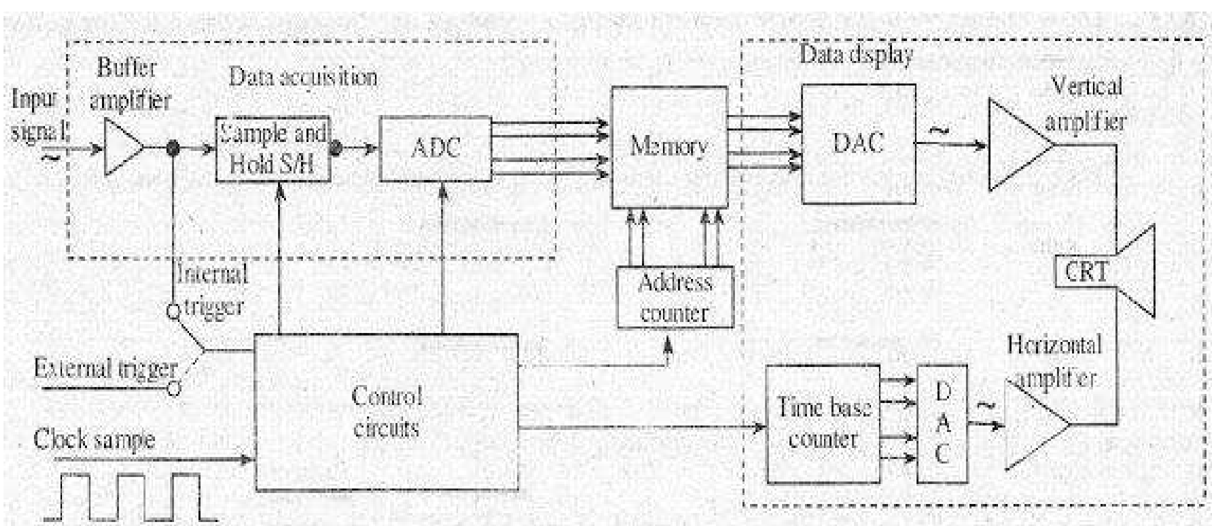


fig 3.1 Block diagram DSO

Digitized waveform can be analyzed by oscilloscope or by reading the contents of the memory into the computer. Display of the stored data is possible in both amplitude versus time and x-y modes. In DSO, fast memory readout is used for CRT display in addition to this a slow readout is also possible which is used for development of hard copy externally.

Figure shows the block diagram of DSO as consists of,

1. Data acquisition
2. Storage
3. Data display.

Data acquisition is earned out with the help of both analog to digital and digital to analog converters, which is used for digitizing, storing and displaying analog waveforms. Overall operation is controlled by control circuit which is usually consists of microprocessor.

Data acquisition portion of the system consist of a Sample-and-Hold (S/H) circuit and an analog to digital converter (ADC) which continuously samples and digitizes the input signal at a rate determined by the sample clock and transmit the digitized data to memory for storage. The control circuit determines whether the successive data points are stored in successive memory location or not, which is done by continuously updating the memories.

When the memory is full, the next data point from the ADC is stored in the first memory location writing over the old data. The data acquisition and the storage process is continues till the control circuit receive a trigger signal from either the input waveform or an external trigger source. When the triggering occurs, the system stops and enters into the display mode of operation in which all or some part of the memory data is repetitively displayed on the cathode ray tube.

In display operation, two DACs are used which gives horizontal and vertical deflection voltage for the CRT Data from the memory gives the vertical deflection of the electron beam, while the time base counter gives the horizontal deflection in the form of staircase sweep signal.

The screen display consist of discrete dots representing the various data points but the number of dot is very large as 1000 or more that they tend to blend together and appear to be a smooth continuous waveform. The display operation ends when the operator presses a front-panel button and commands the digital storage oscilloscope to begin a new data acquisition cycle.

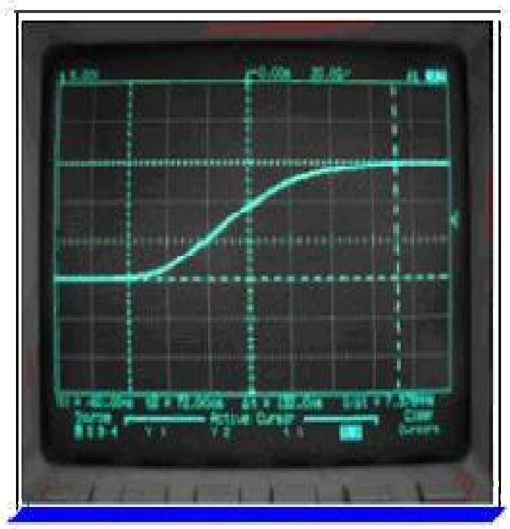


fig : -Screen of Digital Storage Oscilloscope

- DSO use the digital memory. It can store data as required with out degradation.
- DSO also uses for complex processing of the signal with high speed with the hepl of digital signal processing circuits.
- in this A/D converter use to create the data that is stored in microprocessors memory, and data sent to display on screen
- DSO convert analog in to digital form using to A/D convertor, it stores digital data in memory.
- then processes the signals and to be display on screen.
- the wave form is stored in digital ,advantage of using DSO ,that stored data can be used to visualize the signal at any time.

Advantages:-

1. Allows for automation.
2. In this, slow traces l**ike the temperature variation across a day can berecorded**
3. With colour Bigger and brighter display, to distinguish multiple traces
4. peak detection

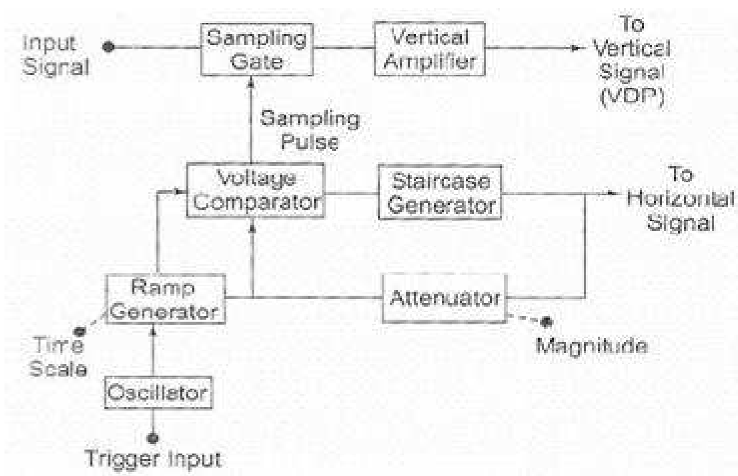
Disadvantage:-

Digital Oscilloscope is the limited refresh rate of the screen.

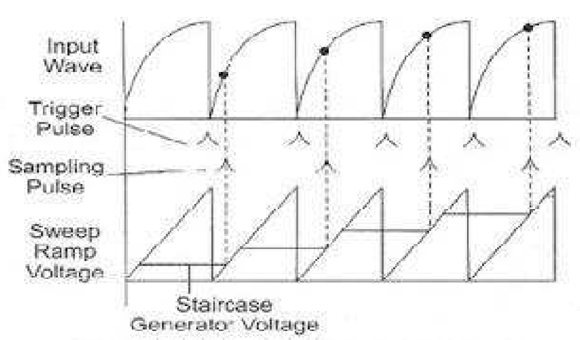
SAMPLING OSCILLOSCOPE

An ordinary oscilloscope has a B.W. of 10 MHz the HF performance can be improved by means of sampling the input waveform and reconstructing its shape from the sample, i.e. the signal to be observed is sampled and after a few cycles sampling point is advanced and another sample is taken. The shape of the wave form is reconstructed by joining the sample levels together. The sampling frequency may be as low as 1/10th of the input signal frequency (if the input signal frequency is 100 MHz, the bandwidth of the CRO vertical amplifier can be as low as 10 MHz).

As many as 1000 samples are used to reconstruct the original waveform.



The input is applied to the sampling gate. The input waveform is sampled whenever a sampling pulse opens the sampling gate. The sampling must be synchronized with the input signal frequency. The signal is delayed in the vertical amplifier, allowing the horizontal sweep to be initiated by the input signal. The waveforms are shown in fig



At the beginning of each sampling cycle, the trigger pulse activates an oscillator anda linear ramp voltage is generated. This ramp voltage is applied to a voltage comparator which compares the ramp voltage to a staircase generate-When the two voltages are equal in amplitude,

the staircase advances one step and a sampling pulse is generated, which opens the sampling gate for a sample of input voltage.
The resolution of the final image depends upon the size of the steps of the staircase generator. The smaller size of the steps, larger the number of samples and higher the resolution of the image**.**

Dual Trace CRO

The block diagram of dual trace oscilloscope which consist of

1. Electronics gun (single)
2. Separate vertical input channels (Two)
3. Attenuators
4. pr-amplifiers
5. Electronic switch.

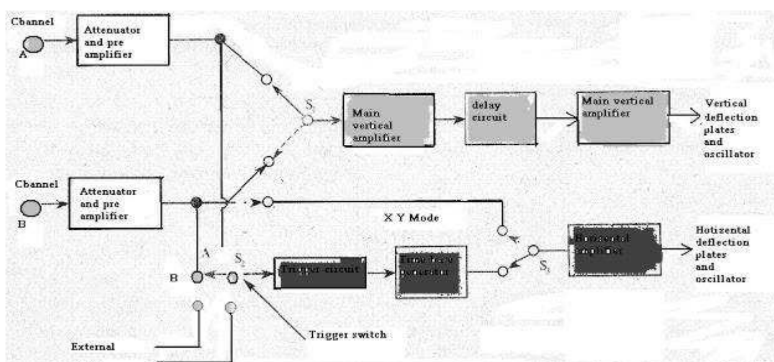


Fig: Block diagram of Dual Trace Oscilloscope

The two separate input signals can be applied to **single electron gun** with the help of **electronic switching** it Produces a dual trace display .Each separate vertical input channel are uses separate **attenuators and pr-amplifier** stages, so the amplitude of each signal can be independently controlled. Output of the pr-amplifiers is given to the electronic switch, which passes one signal at a time into the **main vertical amplifier** of the oscilloscope. The **time base-generator** is similar to that of single input oscilloscope. By using switch S2 the circuit canbe **triggered** on either A or B channel, waveforms, or an external signal, or on line frequency. The **horizontal amplifier** can be fed from sweep generator or from channel B by switching S1. When switch S, is in channel B, its oscilloscope operates in the X-Y mode in which channel A acts as the vertical input signal and channel B as the horizontal input signal.

From the front panel several operating modes can be selected for display, like channel B only, channel A only, channels B and A as two traces, and signals A + B, A - B, B ~ A or - (A + B) as a single trace. Two types of common operating mode are there for the electronic switch, namely, 1. Alternate mode 2. Chop mode.

Q Meter

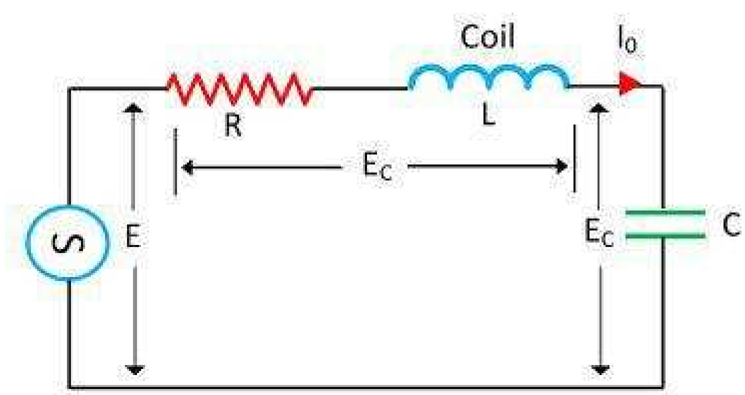
Definition: The instrument which **measures** the **storage factor** or **quality factor** ofthe electrical **circuit** at **radio frequencies**, such type of device is known as the Q-meter. The **quality factor** is one of the **parameters** of the **oscillatory system**, which shows the **relation** between the **storage and dissipated energy**.

The Q meter measures the quality factor of the circuit which shows the total energy dissipated by it. It also explains the properties of the coil and capacitor. The Q meter uses in a laboratory for testing the radio frequency of the coils.

Working Principle of Q meter

The Q meter works on series resonant. The resonance is the condition exists in the circuit when their inductance and capacitancereactance are of equal magnitude. They induce energy which is oscillating between the electric and magnetic field of the capacitor and inductor respectively.

The Q-meter is based on the characteristic of the resistance, inductanceand capacitance of the resonant series circuit. The figure below shows a coil of resistance, inductance and capacitance connected in series with the circuit.



Resonant RLC Series Circuit

At resonant frequency f_0,

$$X_C = X_L$$

The value of capacitance reactance is

$$X_C = \frac{1}{2}\pi f_0 C = \frac{1}{\omega_0 C}$$

At inductive reactance,

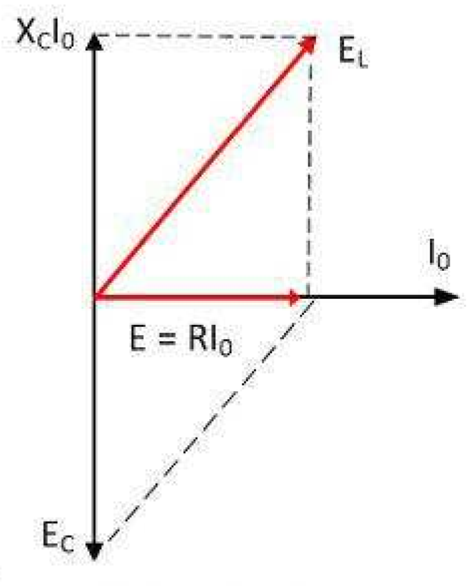
$$X_L = \frac{1}{2}\pi f_0 L = \frac{1}{\omega_0 L}$$

At the resonant frequency,

and current at resonance becomes $$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$I_0 = \frac{E}{R}$$

The phasor diagram of the resonance is shown in the figure



Phasor Diagram

The voltage across the capacitor is expressed as

$$E_C = I_0 X_C = I_0 X_L = I_0 \omega_0 L$$

Input voltage

$$E = I_0 r$$

$$\frac{E_C}{E} = \frac{I_0 \omega_0 L}{I_0 R} = \frac{\omega_0 L}{R} = Q$$

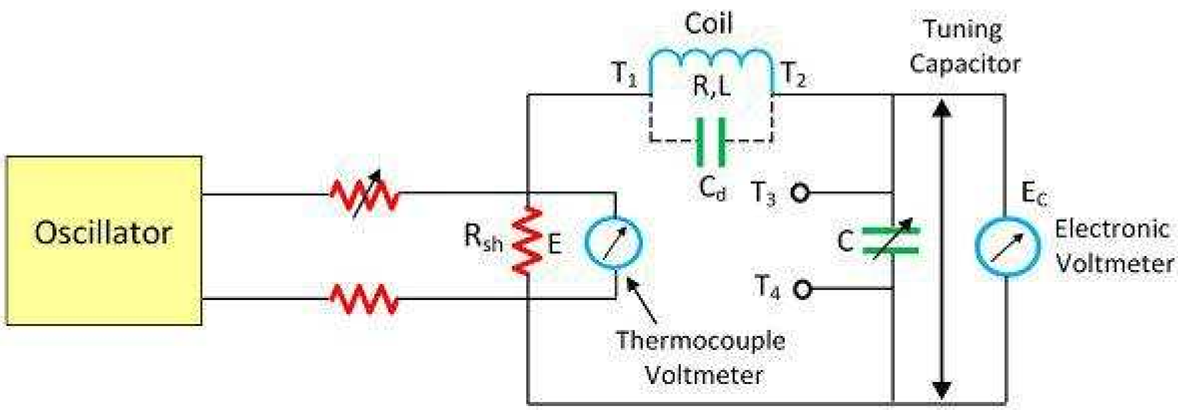
$$E_0 = QE$$

The above equation shows that the input voltage E is Q times the voltage appears across the capacitor. The voltmeter is calibrated for finding the value of Q factor.

Applications of the Q-meter

The following are the applications of the Q-meter.

1. Measurement of Q – The circuit used for measurement of Q is shown in the figure.



Circuit of Q meter

The oscillator and tuning capacitor adjust to the desired frequency for obtaining the maximum value of E_0. Under this condition, the value of the quality factor is expressed as

$$Q_{max} = \frac{\omega_0 L}{R}$$

True value is given as

$$Q_{max} = \frac{\omega_0 L}{R}$$

The value of the quality factor is obtained by the voltmeter which is connected across the capacitor. The measured value is the Q factor of the whole circuit and not only of the coil. Thus, errors occur in the reading because of the shunt resistance and distributed capacitance.

$$Q_{true} = Q_{meas}\left(1 + \frac{C_d}{C}\right)$$

The above equations show that the measured value of the Q is smaller than the true value.

2. **Measurement of Inductance –** The inductance is measured by the equation shownbelow.

$$L = {}^{1}\!/_{4\pi^2 f_0^2 C}$$

The value of f_0& C is required for calculating the value of inductance.

3. **Measurement of Effective resistance –** The equation computes the value ofeffective resistance

$$R = \frac{\omega_0 L}{Q_{true}}$$

4. **Measurement of Self-Capacitance –** The self-capacitance is determined bymeasuring the two capacitance at different frequencies. The capacitor is adjusted to the high value, and the circuit is resonated by adjusting the oscillator frequency. The resonance of the circuit is determined by the Q meter.

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

Thus,

$$f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$$

$$f_2 = 2f_1$$

$$\frac{1}{2\pi\sqrt{L(C_2 + C_d)}} = 2 \times \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

or distributed capacitance

$$Q_{max} = \frac{\omega_0 L}{R}$$

5. **Measurement of Bandwidth – T**he equation below calculates the bandwidth

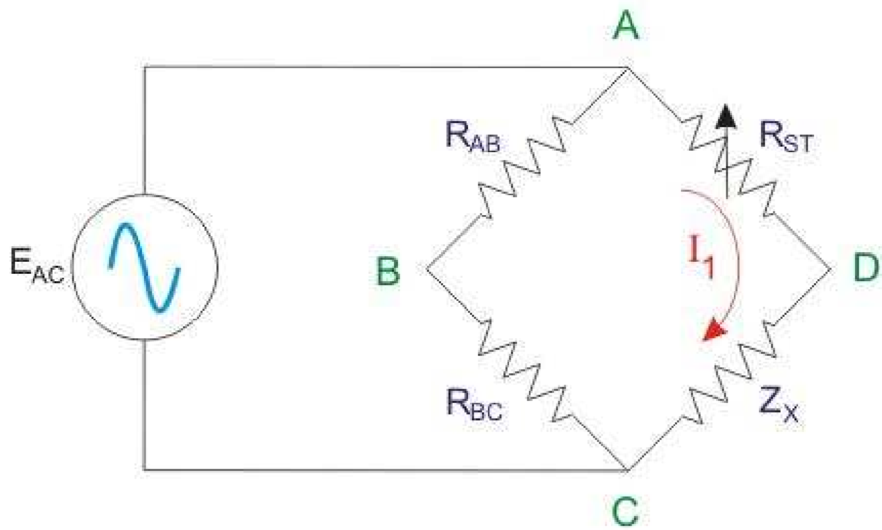
6. **Measurement of Capacitance –** The capacitance is determined by connecting thedummy coil across the terminal T_1 and T_2. Let the capacitor under test is connected across the terminal T_3 and T_4. The circuit is again resonated by varying the value of tuning capacitor C_2. The value of testing capacitance is determined by subtracting the C_1 and

Vector Impedance Meter

Impedance, which is having both magnitude and phase, is truly an opponent to the flow of current inAC circuits with the presence of an appliedvoltage.The**Vector Impedance Meter**is employed for measuring both the amplitude and phase angle of impedance (Z). Normally, in other measuring techniques of impedance, the individual values of resistanceand reactance are obtained in rectangular form. That is

$$Z = R + jX$$

But here, the impedance can be obtained in polar form. That is |Z| and phase angle (θ) of impedance can be acquired by this meter. The circuit is shown below.



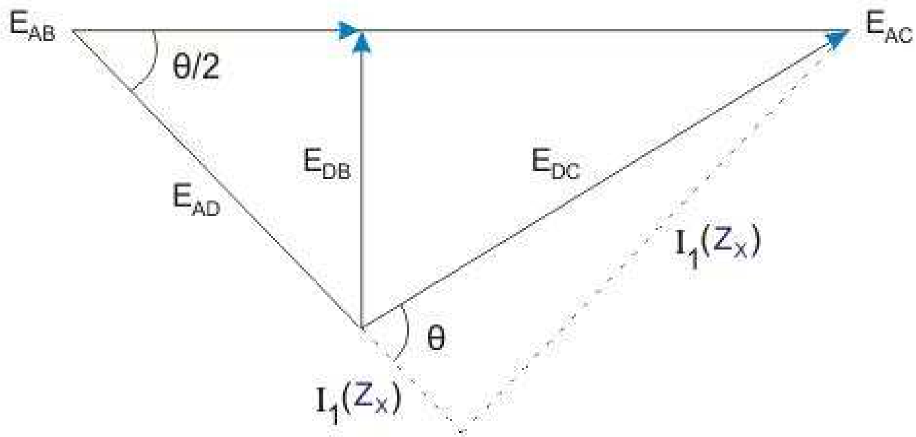
Two resistorswith equal resistancevalue are incorporated here. The voltage dropacross R_{AB}

is E_{AB} and that of R_{BC} is E_{BC}. Both the values are the same and it is equal to half the value of input voltage(E_{AC}).

A variable standard resistance (R_{ST}) is connected in series with the impedance (Z_X) which the value has to be obtained. The equal deflection method is used for the determination of the magnitude of the unknown impedance. This is by achieving the equal voltage drops across the variable resistorand the impedance ($E_{AD} = E_{CD}$) and evaluating the calibrated standard resistor (here it is R_{ST}) which is also necessary for achieving this condition.

The phase angle of the impedance (θ) can be acquired from taking the voltagereading across BD. Here it is E_{BD}. The meter deflection will vary in accordance with the Q factor (quality factor) of the connected unknown impedance. The Vacuum Tube Voltmeter (VTVM) normally reads AC voltage which varies from 0V to maximum value. When the voltage reading is zero, the value of Q will be zero and the phase angle will be 0^{o}. When the voltage reading becomes maximum value, the value of Q will be infinite and the phase angle will be 90^{o}. The angle between E_{AB} and E_{AD} will be equal to $\theta/2$ (half of the phase angle of the unknown impedance). This is because $E_{AD} = E_{DC}$.

We know that the voltage across A and B (E_{AB}) will be equal to half of the voltage across A and C (E_{AC} which is the input voltage). The reading of voltmeter, E_{DB} can be thus obtained in terms of $\theta/2$. Hence, θ (phase angle) can be determined. The vector diagram is shown below.



For obtaining the first approximation of the magnitude and phase angle of the impedance, this method is preferred. For achieving more accuracy in measurement the commercial **vector impedance meter** is preferred.

True R.M.S. Responding Voltmeter

The r.m.s. value means root-mean-square value . As mentioned earlier it is obtained by squaring the input signal and then calculating square root of its average value. The r.m.s. value is also called **effective value**. It compares the heating effect produced by a.c. and d.c.

The true r.m.s. responding voltmeter produces a meter deflection by sensing the heating power of the waveform. This heating power is proportional to the square of the input r.m.s. value. The measurement of heating power is achieved by the use of thermocouple. The input voltage to be measured is applied to the heater. The heating effect of the heater is sensed by a thermocouple attached to the heater. The thermocouple generates the corresponding voltage. The a.c. input is amplified and then given to the heater element to achieve enough heating so that thermocouple can generate enough level of voltage to cause meter deflection.

Key Point: *The output voltage is proportional to the r.m.s. value of the a.c. input.*

For a thermocouple, $$\text{Power} = \frac{E^2_{r.m.s.}}{R_{heater}}$$

$\therefore$ $$E_o \propto \text{Heat} \propto \text{Power}$$

$$\boxed{E_o = \frac{KE^2_{r.m.s.}}{R_{heater}}}$$

where E_{rms} = r.m.s. value of the a.c. input

E_o = Output voltage of thermocouple

K = Constant of proportionality

The value of K depends on the distance between the heater and the thermocouple and so on the materials used in the heater and the thermocouple.

The main difficulty in such a meter is the nonlinear characteristics of a thermocouple. In some instruments this difficulty is ovecome by placing two thermocouples in the same thermal environment. The effect of the nonlinear behaviour of the input thermocouple is cancelled by similar nonlinear effect caused by thermocouple in the feedback path. The input thermocouple is called **measuring thermocouple** while the thermocouple in the feedback path is called **balancing thermocouple**. The true r.m.s responding voltmeter using two thermocouples is shown in the Fig. 1.10.

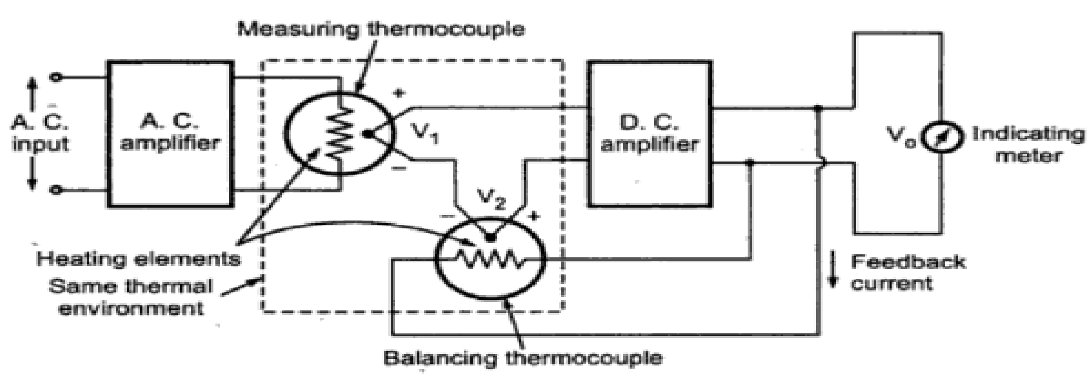


Fig. 1.10 True r.m.s. responding voltmeter

The two thermocouples balancing and measuring, forms a balanced bridge in the input circuit of the d.c. amplifier.

When the a.c. input is applied, the measuring thermocouple produces the voltage V_1 which upsets the balance of the bridge. The d.c. amplifier amplifies the unbalanced voltage. This amplified voltage is feedback to the balancing thermocouple, which heats the heater element to produce V_2 such that the balance of the bridge is re-established.

Thus the d.c. feedback current is the current which is producing same heating effect as that of a.c. input current i.e. the d.c. current is nothing but the r.m.s. value of the input current. The meter deflection is thus proportional to r.m.s or effective value of the a.c. input.

Mathematically we can write,

$$\boxed{V_o = A(V_1 - V_2)}$$

where A = High gain of d.c. amplifier

$$\therefore \quad V_1 - V_2 = \frac{V_o}{A} \approx 0 \qquad \text{... As A is very very high.}$$

In balanced condition of bridge and as A is very high,

$$\boxed{V_1 = V_2}$$

Now V_1 = Output of measuring thermocouple

and V_2 = Output of balancing thermocouple

$$\therefore \quad \boxed{V_1 = KE_{rms}^2}$$

where E_{rms} = r.m.s. value of the input

$$\text{and} \quad \boxed{V_2 = KV_o^2}$$

where V_o = Output d.c. voltage

As K is same due to same thermal environment used for the two thermocouples,

$$E_{rms}^2 = V_o^2$$

$$\boxed{V_o = E_{rms}}$$

Advantages

1) The nonlinear behaviour is avoided by using two thermocouples placed in same thermal environment.
2) The true r.m.s. value measured is independent of the waveform of the a.c. input, if the peak amplitude of a.c. input is within the dynamic range of the a.c. amplifier.
3) Sensitivities in the millivolt region are possible. The voltages throughout a range of 100 μV to 300 V within a frequency range of 10 Hz to 10 MHz can be measured, with good instruments.

However the response of thermocouples is slow hence the overall response of the meter is sluggish. Similarly the crest factor puts the limitation on the meter reading in case of highly nonlinear waveforms. The meter cost is high compared to average and peak responding meters.

A typical laboratory type r.m.s. responding voltmeter provides the accurate r.m.s. reading of complex waveforms having a crest factor (ratio of maximum to r.m.s. value) of 10/1.

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - III
SIGNAL GENERATORS AND ANALYZERS – SEIA1501

UNIT 3
SIGNAL GENERATORS AND ANALYZERS

Function generators – pulse and square wave generators, RF signal generators –Sweep generators – Frequency synthesizer – wave analyzer – Harmonic distortion analyzer–spectrum analyzer :- digital spectrum analyzer, Vector Network Analyzer – Digital L,C,R measurements, Digital RLC meters.

Signal generators

Signal generators can be used to test frequency responses of loudspeakers. They are also a useful way of testing a Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters without the need of an external signal source.

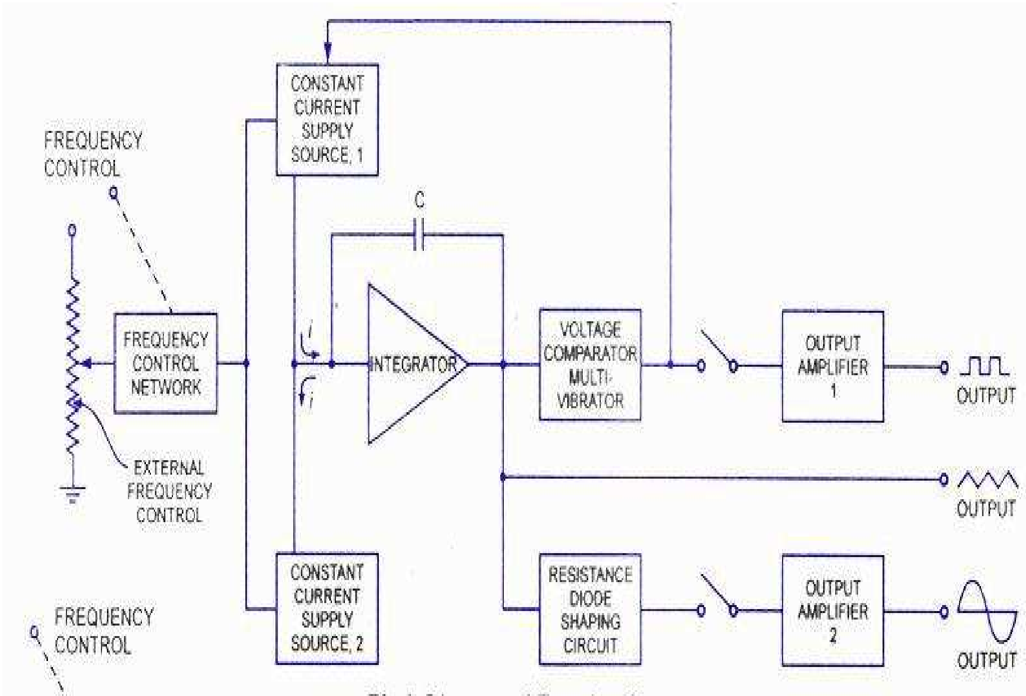
Function Generator

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

Actually the function generators are very versatile instruments as they are capable of producing a wide variety of waveforms and frequencies. In fact, each of the waveform they generate is particularly suitable for a different group of applications. The uses of sinusoidal outputs and square-wave outputs have already been described in the earlier Arts. The triangular-wave and saw tooth wave outputs of function generators are commonly used for those applications which need a signal that increases (or reduces) at a specific linear rate. They are also used in driving sweep oscillators in oscilloscopes and the X-axis of X-Y recorders.

Many function generators are also capable of generating two different waveforms simultaneously (from different output terminals, of course). This can be a useful feature when two generated signals are required for particular application. For instance, by providing a square wave for linearity measurements in an audio-system, a simultaneous saw tooth output may be used to drive the horizontal deflection amplifier of an oscilloscope, providing a visual display of the measurement result. For another example, a triangular-wave and a sine-wave of equal frequencies can be produced simultaneously. If the zero crossings of both the waves are made to occur at the same time, a linearly varying waveform is available which can be started at the point of zero phase of a sine-wave.

Another important feature of some function generators is their capability of phase-locking to an external signal source. One function generator may be used to phase lock a second function generator and the two output signals can be displaced in phase by an adjustable amount. In addition, one function generator may be phase locked to a harmonic of the sine-wave of another function generator. By adjustment of the phase and the amplitude of the harmonics, almost any waveform may be produced by the summation of the fundamental frequency generated by one function generator and the harmonic generated by the other function generator. The function generator can also be phase locked to an accurate frequency standard, and all its output waveforms will have the same frequency, stability, and accuracy as the standard.



Block Diagram of Function Generator

The block diagram of a function generator is given in Figure. In this instrument the frequency is controlled by varying the magnitude of current that drives the integrator. This instrument provides different types of waveforms (such as sinusoidal, triangular and square waves) as its output signal with a frequency range of 0.01 Hz to 100 kHz.

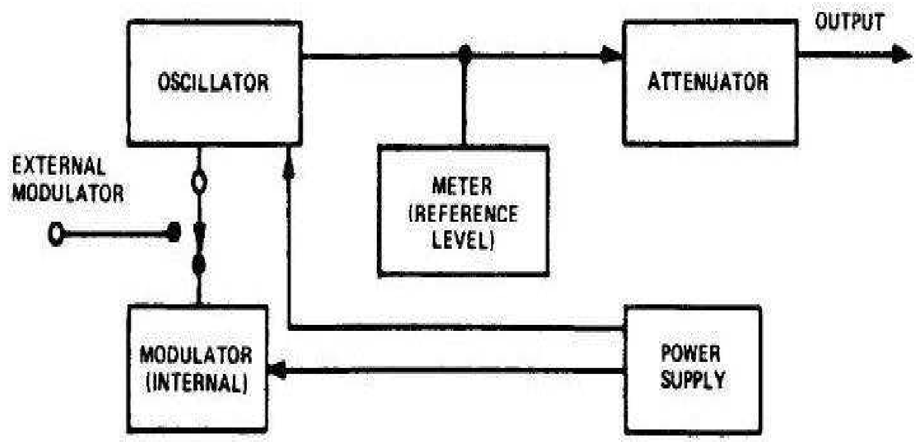
The frequency controlled voltage regulates two current supply sources. Current supply source 1 supplies constant current to the integrator whose output voltage rises linearly with time. An increase or decrease in the current increases or reduces the slope of the output voltage and thus controls the frequency.

The voltage comparator multivibrator changes state at a predetermined maximum level, of the integrator output voltage. This change cuts-off the current supply from supply source 1 and switches to the supply source 2. The current supply source 2 supplies a reverse current to the integrator so that its output drops linearly with time. When the output attains a predetermined level,the voltage comparator again changes state and switches on the current supply source. The output of the integrator is a triangular wave whose frequency depends on the current supplied by the constant current supply sources. The comparator output provides a square wave of the same frequency as output. The resistance diode network changes the slope of the triangular wave as its amplitude changes and produces a sinusoidal wave with less than 1% distortion.

RF signal Generators

A typical radio frequency signal generator contains, in addition to the necessary power supply, three main sections; an oscillator circuit, a modulator, and an output control circuit. The internal modulator modulates the radiofrequency signal of the oscillator. In addition, most RF generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to

prevent the entrance of signals from the oscillator into the circuit under test by means other than through the output circuit of the generator.



Block diagram of RF signal generator

A block diagram of a representative RF signal generator is shown in Figure. The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of the frequencies for which the generator is designed. In low frequency signal generators, the resonating circuit consists of a group of coils combined with a variable capacitor.

One of the coils has a selector switch attached to the capacitor to provide an LC circuit that has the correct range of resonant frequencies. The function of the modulating circuit is to produce audio (or video) voltage which can be superimposed on the RF signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator, or it may be derived from an external source. In some signal generators, either of these methods of modulation may be used. In addition, a means of disabling the modulator section is used whereby the pure un-modulated signal from the oscillator can be used when it is desired.
The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulse of varying duration. In some specialized generators, provision is made for pulse modulation in which the RF signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Sweep Generators

The working of a sweep-frequency generator is explained in the article below. The working and block diagram of an electronically tuned sweep frequency generator and its different parameters are also explained.

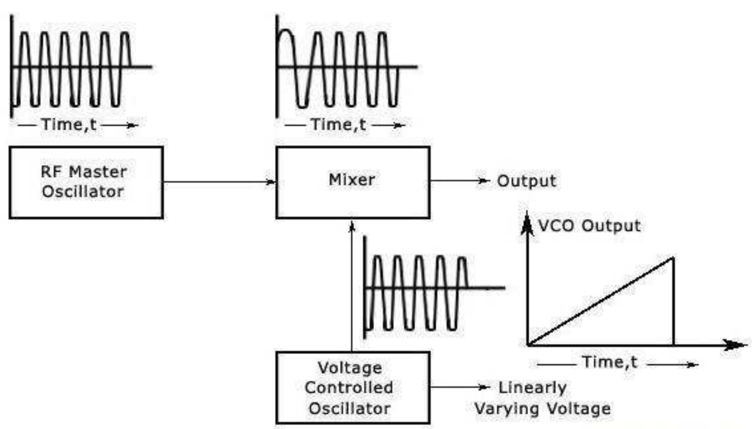
A sweep frequency generator is a type of signal generator that is used to generate a sinusoidal output. Such an output will have its frequency automatically varied or swept between two selected frequencies. One complete cycle of the frequency variation is called a sweep. Depending on the design of a particular instrument, either linear or logarithmic variations can be introduced to the frequency rate. However, over the entire frequency range of the sweep, the amplitude of the signal output is designed to remain constant.

Sweep-frequency generators are primarily used for measuring the responses of amplifiers, filters, and electrical components over various frequency bands. The frequency range of a sweep-frequency generator usually extends over three bands, 0.001 Hz – 100 kHz (low frequency to audio), 100 kHz – 1,500 MHz (RF range), and 1-200 GHz (microwave range). It is really a hectic task to know the performance of measurement of bandwidth over a wide frequency range with a manually tuned oscillator. By using a sweep-frequency generator, a sinusoidal signal that is automatically swept between two chosen frequencies can be applied to the circuit under test and its response against frequency can be displayed on an oscilloscope or X-Y recorder.

Thus the measurement time and effort is considerably reduced. Sweep generators may also be employed for checking and repairing of amplifiers used in TV and radar receivers.

The block diagram of an electronically tuned sweep frequency generator is shown in the

figure.



Electronically Tuned sweep generator

The most important component of a sweep-frequency generator is the master oscillator. It is mostly an RF type and has many operating ranges which are selected by a range switch. Either mechanical or electronic variations can be brought to the frequency of the output signal of the signal generator. In the case of mechanically varied models, a motor driven capacitor is used to tune the of the output signal of the master oscillator.

In the case of electronically tuned models, two frequencies are used. One will be a constant frequency that is produced by the master oscillator. The other will be a varying frequency signal, which is produced by another oscillator, called the voltage controlled oscillator (VCO). The VCO contains an element whose capacitance depends upon the voltage applied across it. This element is used to vary the frequency of the sinusoidal output of the VCO. A special electronic device called a mixer is then used to combine the output of VCO and the output of the master oscillator. When both the signals are combined, the resulting output will be sinusoidal, and its frequency will depend on the difference of frequencies of the output signals of the master oscillator and VCO. For example, if the master oscillator frequency is fixed at 10.00 MHz and the variable frequency is varied between 10.01 MHz to 35 MHz, the mixer will give sinusoidal output whose frequency is swept from 10 KHz to 25 MHz.

Adjustments can be brought to the sweep rates in a sweep frequency generator and it normally can be varied from 100 to 0.01 seconds per sweep. The X-axis of an oscilloscope or X-Y recorder can be easily driven synchronously with a voltage that varies linearly or logarithmically. In the electronically tuned sweep generators, the same voltage which drives the VCO serves as this voltage.

Wave Analyzer

The analysis of electrical signals is used in many applications. The different instruments which are used for signal analysis are wave analyzers, distortion analyzers, spectrum analyzers, audio analyzers and modulation analyzers. All signal analysis instruments measure the basic frequency properties of a signal, but they use different techniques to do so.

A wave analyzer is a voltmeter which can be accurately tuned to measure the amplitude of a single frequency, within a band of about 10 Hz – 40 MHz. It is well known that any periodic waveform can be represented as the sum of a d.c component and a series of sinusoidal harmonics. Analysis of a waveform consists of determination of the values of amplitude, frequency, and sometime phase angle of the harmonic components. Graphical and mathematical methods may be used for the purpose but these methods are quite laborious. The analysis of a complex waveform can be done by electrical means using a band pass filter network to single out the various harmonic components. Networks of these types pass a narrow band of frequency and provide a high degree of attenuation to all other frequencies.

A wave analyzer, in fact, is an instrument designed to measure relative amplitudes of single frequency Components in a complex waveform. Basically, the instrument acts as a frequency selective voltmeter which is tuned to the frequency of one signal while rejecting all other signal components. The desired frequency is selected by a frequency calibrated dial to the point of maximum amplitude. The amplitude is indicated either by a suitable voltmeter or a CRO.

Wave analyzers have very important applications in the following fields

Electrical measurements

Sound measurements and

Vibration measurements.

The wave analyzers are applied industrially in the field of reduction of sound and vibrations generated by rotating electrical machines and apparatus. The source of noise and vibrations is first identified by wave analyzers before it can be reduced or eliminated. A fine spectrum analysis with the wave analyzer shows various discrete frequencies and resonances that can be related to the motion of machines. Once, these sources of sound and vibrations are detected with the help of wave analyzers, ways and means can be found to eliminate them.

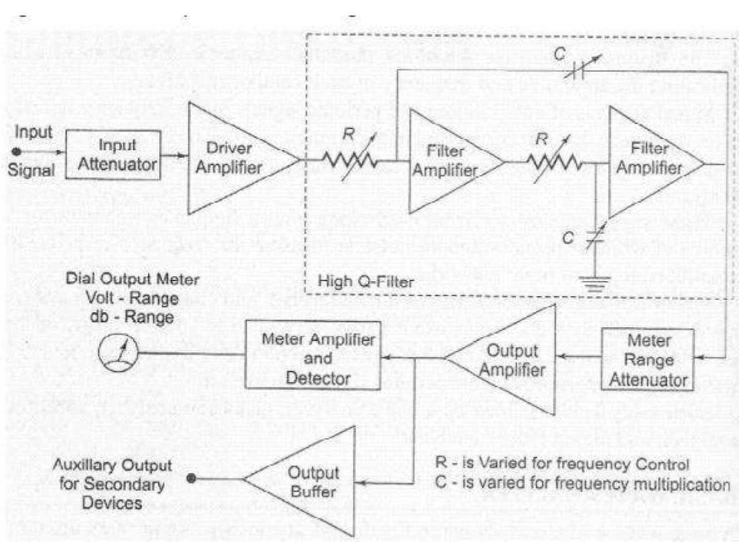
There are two types of wave analysers, depending upon the frequency ranges used,

Frequency Selective wave analyser and

Heterodyne wave analyser.

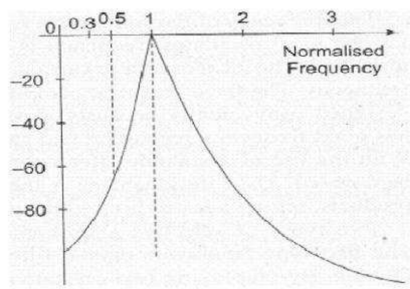
Frequency selective Wave analyzer

The wave analyzer consists of a very narrow pass-band filter section which can Be tuned to a particular frequency within the audible frequency range(20Hz to 20 KHz)). The block diagram of a wave analyzer is as shown in fig.



The complex wave to be analyzed is passed through an adjustable attenuator which serves as a range multiplier and permits a large range of signal amplitudes to be analyzed without loading the amplifier. The output of the attenuator is then fed to a selective amplifier, which amplifies the selected frequency. The driver amplifier applies the attenuated input signal to a high-Q active filter. This high-Q filter is a low pass filter which allows the frequency which is selected to pass and reject all others. The magnitude of this selected frequency is indicated by the meter and the filter section identifies the frequency of the component. The filter circuit consists of a cascaded RC resonant circuit and amplifiers. For selecting the frequency range, the capacitors generally used are of the closed tolerance polystyrene type and the resistances used are precision potentiometers. The capacitors are used for range changing and the potentiometer is used to change the frequency within the selected pass-band, Hence this wave analyzer is also called a Frequency selective voltmeter. The entire AF range is covered in decade steps by switching capacitors in the RC section

The selected signal output from the final amplifier stage is applied to the meter circuit and to an unturned buffer amplifier. The main function of the buffer amplifier is to drive output devices, such as recorders or electronics counters. The meter has several voltage ranges as well as decibel scales marked on it. It is driven by an average reading rectifier type detector. The wave analyzer must have extremely low input distortion, undetectable by the analyzer itself. The band width of the instrument is very narrow typically about 1% of the selective band given by the following response characteristics shows in fig.



Heterodyne Wave Analyzer

Analysis of the waveform means determination of the values of amplitude, frequency and sometime phase angle of the harmonic components. A wave analyser is an instrument designed to measure relative amplitude of signal frequency components in a complex waveform .basically a wave instruments acts as a frequency selective voltmeter which is tuned to the frequency of one signal while rejecting all other signal components.

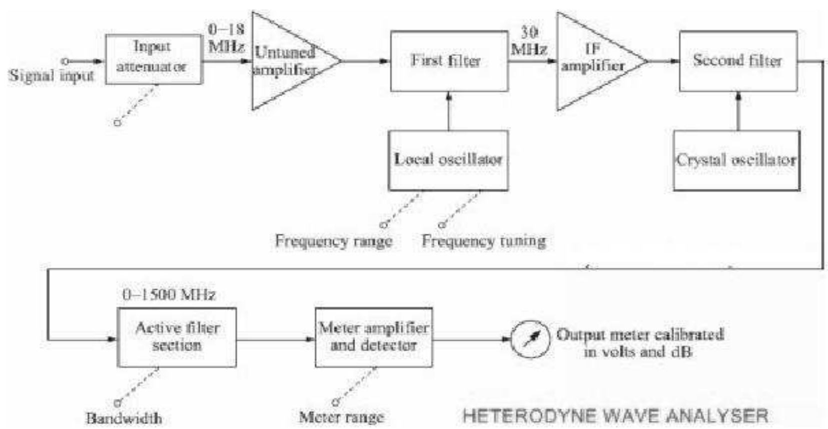
It is well known that any periodic waveform can be represented as the sum of a d.c. component and a series of sinusoidal harmonics. Analysis of a waveform consists of determination of the values of amplitude, frequency, and sometime phase angle of the harmonic components.

Graphical and mathematical methods may be used for the purpose but these methods are quite laborious. The analysis of a complex waveform can be done by electrical means using a band pass filter network to single out the various harmonic components. Networks of these types pass a narrow band of frequency and provide a high degree of attenuation to all other frequencies.

A wave analyzer, in fact, is an instrument designed to measure relative amplitudes of single frequency components in a complex waveform. Basically, the instrument acts as a frequency selective voltmeter which is used to the frequency of one signal while rejecting all other signal components. The desired frequency is selected by a frequency calibrated dial to the point of maximum amplitude. The amplitude is indicated either by a suitable voltmeter or CRO.

This instrument is used in the MHz range. The input signal to be analysed is heterodyned to a higher IF by an internal local oscillator. Tuning the local oscillator shifts various signal frequency components into the pass band of the IF amplifier. The output of the IF amplifier is rectified and is applied to the metering circuit. The instrument using the heterodyning principle is called a *heterodyning tuned voltmeter.*

The block schematic of the wave analyser using the heterodyning principle is shown in fig. above. The operating frequency range of this instrument is from 10 kHz to 18 MHz in 18 overlapping bands selected by the frequency range control of the local oscillator. The bandwidth is controlled by an active filter and can be selected at 200, 1000, and 3000 Hz.



Application of wave analyzer

Electrical measurements

Sound measurements

Vibration measurements.

In industries there are heavy machineries which produce a lot of sound and vibrations, it is very important to determine the amount of sound and vibrations because if it exceeds the permissible level it would create a number of problems. The source of noise and vibrations is first identified by wave analyzer and then it is reduced by further circuitry.

Harmonic Distortion Analyzers

Harmonic Distortion

When we give a sinusoidal signal input to any electronic instrument there should be output in sinusoidal form, but generally the output is not exactly the replica of input, because of various types of distortion that my occur.

Distortion is occur due to inherent non-linear characteristics of different components used in electronic circuit. Nonlinear behavior of electronic component introduces harmonics in the output waveform and the resultant distortion is often referred as harmonic distortion.

Types of Harmonic Distortion

Frequency Distortion

This type of distortion occurs in amplifiers because of amplification factor of amplifier is different for different frequencies.

Amplitude Distortion

It occurs because amplifier introduces harmonic of fundamental of input frequency. Harmonics always generates distortion in amplitude. E.g. when amplifiers are overdriven it clips the waveform.

Phase Distortion

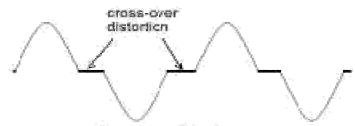
This distortion occurs due to energy storage elements in the system which causes the output signal to be displaced in phase with the input signal. Signals with different frequencies will be shifted by different phase angles.

Intermodulation Distortion

This type of distortion occurs as a consequence of interaction or heterodyning of two frequencies, giving an output which is sum or difference of the two original frequencies.

Cross-Over Distortion

This type of distortion occurs in push-pull amplifiers on account of incorrect boas levels as shown in figure.



Cross-over distortion

Total Harmonic Distortion (THD)

$$THD = \frac{[\Sigma Harmonics^2]^{1/2}}{Fundamental}$$

$$D_2 = \frac{E_2}{E_1}, D_3 = \frac{E_3}{E_1}, D_4 = \frac{E_4}{E_1}, \ldots\ldots$$

$$\text{THD}=\sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots}$$

$$= \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + \cdots}}{E_1}$$

In a measurement system noise is read in addition to harmonics and the total waveform consisting of harmonics, noise and fundamental is measured instead of fundamental alone

$$THD_M = \frac{\{\sum[Harmonics^2 + Noise^2]\}^{1/2}}{\{\Sigma[Fundamental^2 + Harmonic^2 + Noise^2]^{1/2}\}}$$

Distortion analyzer measures the total harmonic power present in the test wave rather than the distortion caused by each component. The simplest method is to suppress the fundamental frequency by means of a high pass filter whose cut off frequency is a little above the fundamental frequency. This high pass allows only the harmonics to pass and the total harmonic distortion can then be measured. Other types of harmonic distortion analyzers based on fundamental suppression are as follows.

Employing a Resonance Bridge

The bridge shown in fig 3.1 is balanced for the fundamental frequency, i.e. L and C are tuned to the fundamental frequency. The bridge is unbalanced for the harmonics, i.e. only harmonic power will be available at the output terminal and can be measured. If the fundamental frequency is changed, the bridge must be balanced again. If L and C are fixed components, then this method is suitable only when the test wave has a fixed frequency. Indicators can be thermocouples or square law VTVMs. This indicates the rms value of all harmonics. When a continuous adjustment of the fundamental frequency is desifrequency is desired a Wien bridge arrangement is used as shown in fig.

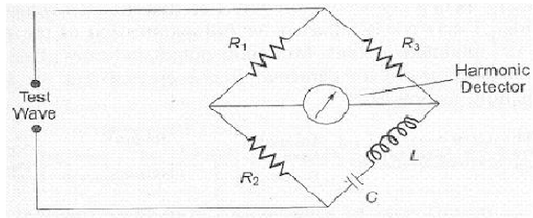


fig 3.1 Resonance Bridge

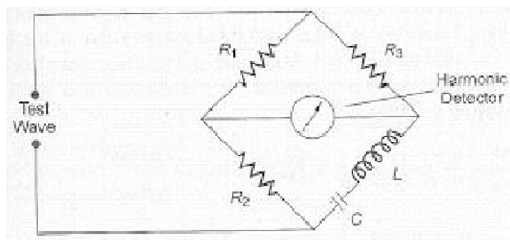


fig 3.1 Resonance Bridge

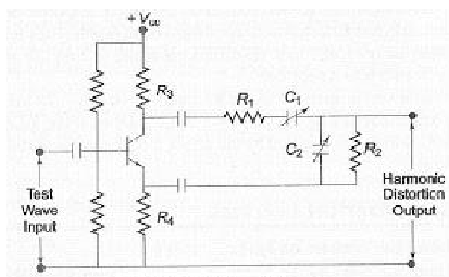


fig 3.2 Wein's bridge method

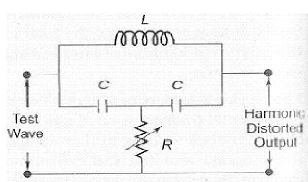


fig 3.3 Bridge T network method

Wien's Bridge Method

The bridge is balanced for the fundamental frequency. The fundamental energy is dissipated in the bridge circuit elements. Only the harmonic components reach the output terminals .The harmonic distortion output can then be measured with a meter. For balance at the fundamental frequency C1=C2=C, R1=R2=R, R3=2R4.

Bridged T-Network Method

Referring to the fig the L and C's are tuned to the fundamental frequency, and R is adjusted to bypass fundamental frequency. The tank circuit being tuned to the fundamental frequency, the fundamental energy will circulate in the tank and is bypassed by the resistance. Only harmonic components will reach the output terminals and the distorted output can be measured by the meter. The Q of the resonant circuit must be at least 3-5. One way of using a bridge T-network is given in Fig. 3.4 The switch S is first connected to point A so that the attenuator is excluded and the bridge T-network is adjusted for full suppression of the fundamental frequency, i.e. Minimum output indicates that the bridged Tnetwork is tuned to the fundamental frequency and that fundamental frequencies is fully suppressed.

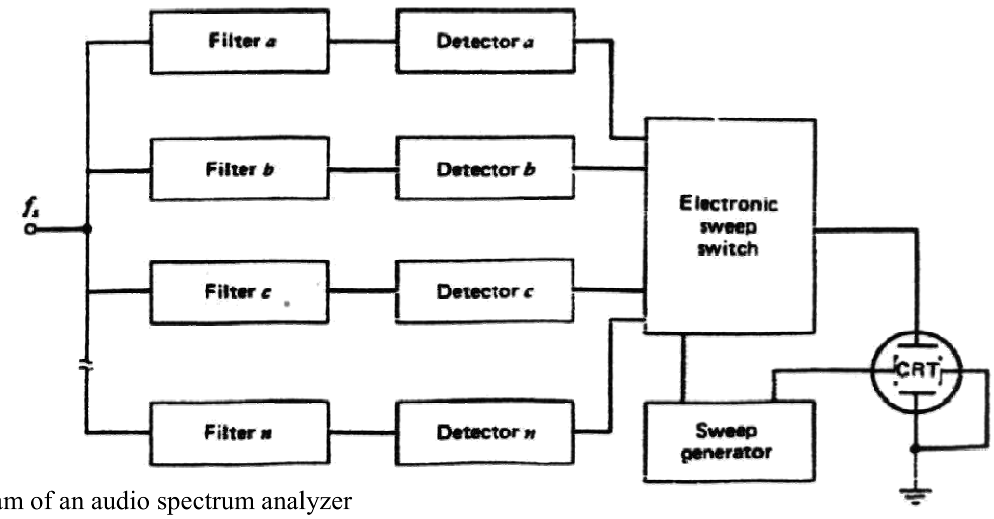
The switch is next connected to terminal B, i.e. the bridge T- network is excluded. Attenuation is adjusted until the same reading is obtained on the meter. The attenuator reading indicates the total rams distortion. Distortion measurement can also be obtained by means of a wave analyzer, knowing the amplitude and the frequency of each component, the harmonic distortion can be calculated. However, distortion meters based on fundamental suppression are simpler to design and less expensive than wave analyzers. The advantage is that give only the total distortion and not the amplitude of individual distortion components.

Spectrum Analyzers

The problems associated with non-real-time analysis in the frequency domain can be eliminated by using a spectrum analyzer. A spectrum analyzer is a real-time analyzer, which means that it simultaneously displays the amplitude of all the signals in the frequency range of the analyzer.

Spectrum analyzers, like wave analyzers, provide information about the voltage or energy of a signal as a function of frequency. Unlike wave analyzers, spectrum analyzers provide a graphical display on a CRT. A block diagram of an audio spectrum analyzer is shown in Fig.

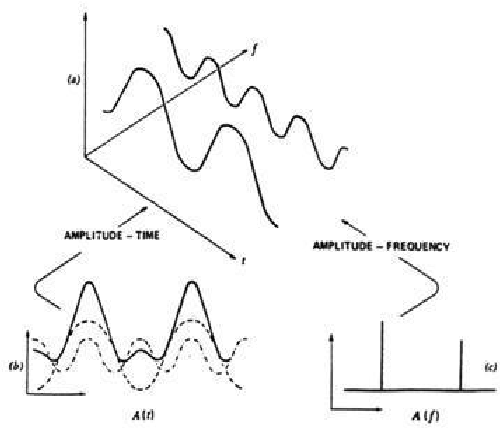
The real-time or multichannel analyzer is basically a set of stagger-tuned band pass filters connected through an electronic scan switch to a CRT. The composite amplitude of the signal within each filters bandwidth is displayed as a function of the overall frequency range of the filter. Therefore, the frequency range of the instrument is limited by the number of filters and their bandwidth. The electronic switch sequentially connects the filter outputs to the CRT. Horizontal deflection is obtained from the scan generator, which has a saw tooth output that is synchronized with the electronic switch.



Block diagram of an audio spectrum analyzer

Such analyzers are usually restricted to audio-frequency applications and may employ as many as 32 filters. The bandwidth of each filter is generally made very narrow for good resolution.

The relationship between a time-domain presentation on the CRT of an oscilloscope and a frequency-domain presentation on the CRT of a spectrum analyzer is shown in the three-dimensional drawing in Fig.



Three dimensional relationships between time, frequency and amplitude

After the waveform is applied to the amplifier, it got amplified further directly to the distortion analyzer which measures the total harmonic distortion. In the field of microwave communications, in which pulsed oscillators are widely used one. Spectrum analyzers are an important tool. They also find wide application in analyzing the performance of AM and FM transmitters. Spectrum analyzers and Fourier analyzers are widely used in applications requiring very low frequencies in the fields of biomedical electronics, geological surveying and oceanography. They are also used in analyzing air and water pollution.

Vector Network Analyzer:-

Vector Network Analyzers are used to test component specifications and verify design simulations to make sure systems and their components work properly together.

Today, the term "network analyzer", is used to describe tools for a variety of "networks". For instance, most people today have a cellular or mobile phone that runs on a 3G or 4G network. In addition, most of our homes, offices and commercial venues all have Wi-Fi, or wireless LAN "networks". Furthermore, many computers and servers are setup in "networks" that are all linked together to the cloud. For each of these "networks", there exists a certain network analyzer tool used to verify performance, map coverage zones and identify problem areas.

From mobile phone networks, to Wi-Fi networks, to computer networks and the to the cloud, all of the most common technological networks of today were made possible using the Vector Network Analyzer that was first invented over 60 years ago.

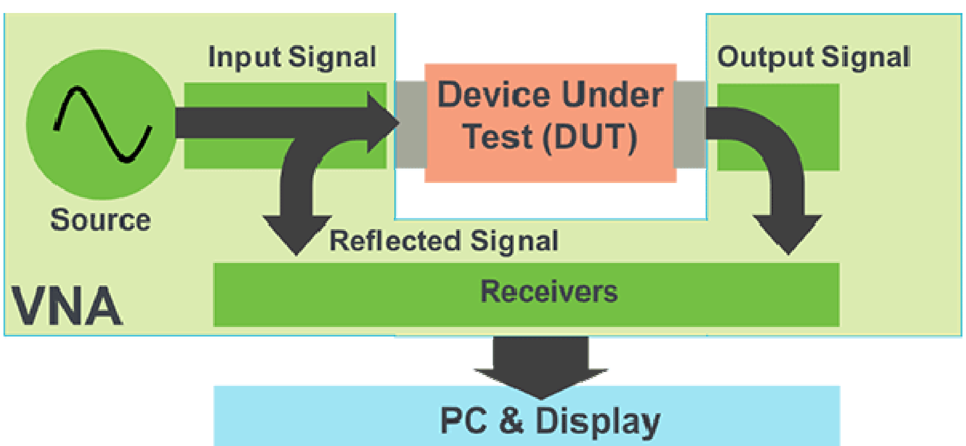
R&D engineers and manufacturing test engineers commonly use VNAs at various stages of product development. Component designers need to verify the performance of their components such as amplifiers, filters, antennas, cables, mixers, etc.

The system designer needs to verify their component specs to ensure that the system performance they're counting on meets their subsystem and system specifications.

Manufacturing lines use Vector Network Analyzers to make sure that all products meet specifications before they're shipped out for use by their customers. In some cases, Vector Network Analyzers are even used in field operations to verify and troubleshoot deployed RF and microwave systems.

How does a Vector Network Analyzer (VNA) work?

A Vector Network Analyzer contains both a source, used to generate a known stimulus signal, and a set of receivers, used to determine changes to this stimulus caused by the device-under-test or DUT.
The stimulus signal is injected into the DUT and the Vector Network Analyzer measures both the signal that's reflected from the input side, as well as the signal that passes through to the output side of the DUT. The Vector Network Analyzer receivers measure the resulting signals and compare them to the known stimulus signal. The measured results are then processed by either an internal or external PC and sent to a display.



What is a Vector Network Analyzer used for?

Vector Network Analyzer's perform two types of measurements – transmission and reflection. Transmission measurements pass the Vector Network Analyzer stimulus signal through the device under test, which is then measured by the Vector Network Analyzer receivers on the other side. The most common transmission S-parameter measurements are S21 and S12 (Sxy for greater than 2-ports). Swept power measurements are a form of transmission measurement. Some other examples of transmission measurements include gain, insertion loss/ phase, electrical length/delay and group delay. Comparatively, reflection measurements measure the part of the VNA stimulus signal that is incident upon the DUT, but does not pass through it. Instead, the reflection measurement measures the signal that travels back towards the source due to reflections.

LCR METER:-

LCR meters or LCR bridges are items of test equipment or test instrumentation used to measure the inductance, capacitance, and resistance of components.

LCR meters tend to be specialist items of test equipment, often used for inspection to ensure that the components arriving are correct. They can also be used in a development laboratory where it is necessary to test and measure the true performance of particular components.

The LCR meter or LCR bridge takes its name from the fact that the inductance, capacitance and resistance are denoted by the letters L, C, and R respectively. Some versions of the LCR meter use a bridge circuit format as the basis of its circuit giving the name that is often used.

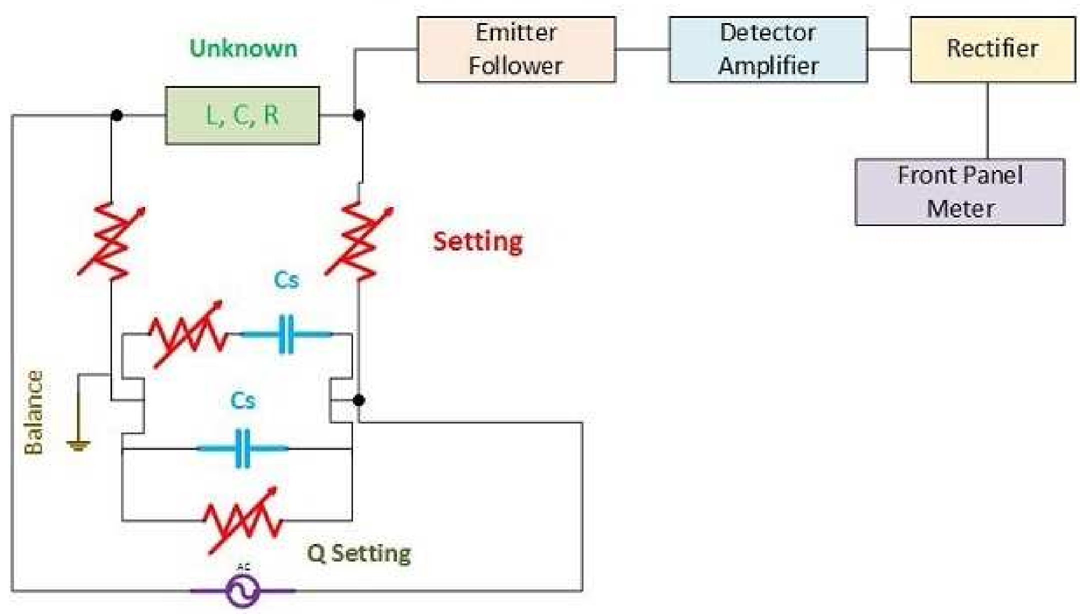
A variety of meters are available. Simpler versions of LCR meters provide indications of the impedance only converting the values to inductance or capacitance.

More sophisticated designs of LCR bridge are able to measure the true inductance or capacitance, and also the equivalent series resistance and tanδ of capacitors and the Q factor of inductive components. This makes them valuable for assessing the overall performance or quality of the component.

LCR meter basics:-

Two main circuit techniques are used to form the basis of an LCR meter.
Bridge method: This method uses the familiar Wheatstone bridge concept as the basis of its operation. The aim is to aim for a condition where the bridge is balanced and no current flows through the meter. At the balance point the bridge component positions can be used to determine the value of the component under test. This method is typically used for lower frequency measurements - often measurement frequencies of up to 100 kHz or so are used.
The significant component of LCR meter is the Wheatstone bridge and RC ratio arm circuits. The component whose value is to be measured is connected in one of the arms of the bridge. There are different provisions for the different type of measurements.

For example, if the value of resistance is to be measured, then Wheatstone bridge comes into picture while the value of inductance and capacitance can be measured by comparing it with standard capacitor present in RC ratio arm circuit.



Block Diagram of LCR meter

The above block diagram clearly defines the connection diagram of the LCR meter. The measurement of DC quantities will be done by exciting the bridge with DC voltage. On the contrary, the AC measurements require excitation of the Wheatstone bridge with AC signal.

For providing AC excitation, the oscillator is used in the circuit. It generates the frequency of 1 kHz.

Working of LCR Meter
The bridge is adjusted in null position in order to balance it completely. Besides, the sensitivity of the meter should also be adjusted along with balancing of the bridge. The output from the bridge is fed to emitter follower circuit. The output from emitter follower circuit is given as an input to detector amplifier.

The significance of detector amplifier can be understood by the fact that if the measuring signal is low in magnitude, it will not be able to move the indicator of PMMC meter. Thus, in order to achieve the sustainable indication we need to have a high magnitude measuring signal.

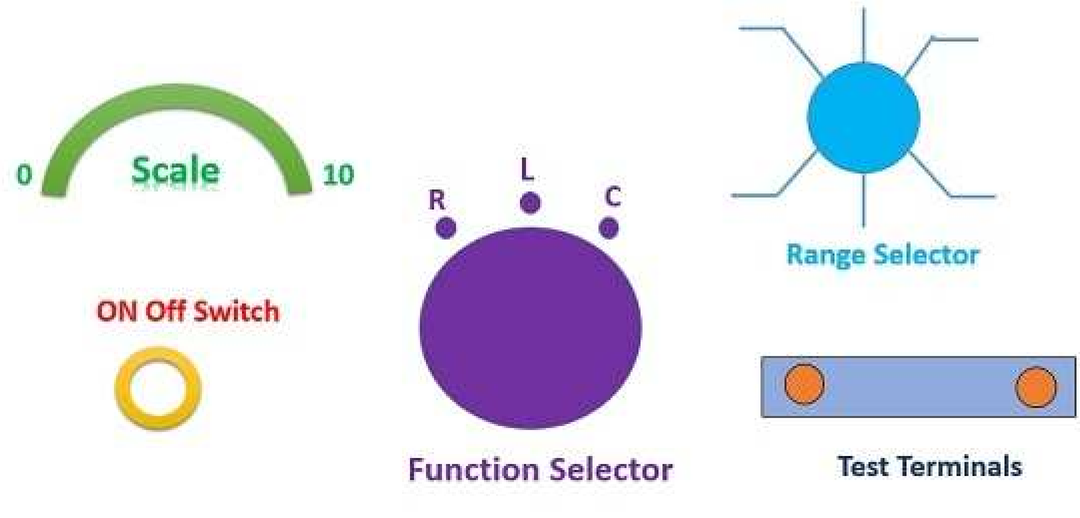
But it is often observed that while dealing with the measurement process, the magnitude of the measuring signal falls down due to attenuation factor. The problem to this solution is to utilize an amplifier.

The rectifier is used in the circuit to convert the AC signal into DC signal. When the bridge is provided with AC excitation then at the output end of the bridge the AC signal needs transformation into DC signal.

Front Panel of LCR meter
The component which is to be measured is placed across the test terminals of LCR meter, after which according to the type of component the measurement is performed. To understand the procedure of measurement by LCR meter, the functional controls on front panel needs to be understood.

Let’s have a look at the controlling terminals of the front panel of LCR meter.

LCR METER FACE PANEL:-



Controls on face panel of LCR meter

ON/OFF Switch: The ON/OFF switch can be used to turn on or off LCR meter. When the switch is positioned to ON state, the main supply is connected with LCR meter. After this, it is crucial to leave the meter for 15 minutes so that it can warm up. The indicator on the front panel will start glowing to indicate that the LCR meter is ON.

Test Terminals: The two points on the front panel are test terminals. The component which is to be measured is connected to this test terminals.

Function Selector: The function selector is used for setting the meter in the mode in order to measure the particular type of the component. If resistance is to be measured, then the function selector is to be set at R mode, if inductance is to be measured it is to be adjusted to L mode and similarly in case of capacitance it is to be adjusted at C mode.

Range Selector: The range selector provides an extent of measuring range so that component of high magnitude or low magnitude values can be measured easily. The range selector should be adjusted properly in order to have correct measurement. For example: if a resistor of 10 mega ohms is under measurement and the range selector is in the range of ohms, then it will not show reliable and accurate results.

The range of instrument can be increased by using multipliers in the circuit. The multipliers should consist of higher precision resistors made up of the metal film. In addition to this, it should possess high-temperature stability.

Scale: The scale calibrated on the LCR meter will show the final values of the measurement. The indicator will move across the calibrated scale to show the measured value.

Use of meter

When we are measuring the unknown value component, select the range of the LCR meter at the highest value. This is because we do not know the range of the component. After this achieve the null deflection in the bridge by adjusting the range, loss factor and sensitivity.

Protection of LCR meters

One should be extremely careful while providing excitation to the bridge of LCR meter. This is because if the value of the voltage applied to the bridge is high the circuit gets burn out. Thus, for the protection of LCR meter, we can also use a circuit of limiting diodes at the end of the circuit of LCR meter. This will provide over-voltage protection.

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - IV
DIGITAL INSTRUMENTS – SEIA1501

UNIT 4
DIGITAL INSTRUMENTS

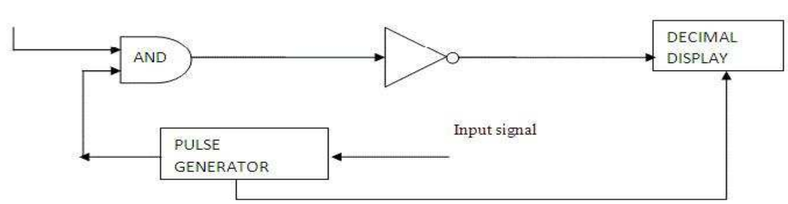
Digital Voltmeters

Voltmeter is an electrical measuring instrument which is used to measure potential difference between two points. The voltage to be measured may be AC or DC. Two types of voltmeters are available for the purpose of voltage measurement i.e. analog and digital. Analog voltmeters generally contain a dial with a needle moving over it according to the measur and hence displaying the value of the same. With the passage of time analog voltmeters are replaced by **digital voltmeters** due to the same advantages associated with digital systems. Although analogvoltmeters are not fully replaced by **digital voltmeters**, still there are many places where analog voltmeters are preferred over digital voltmeters. Digital voltmeters display the value of AC or DC voltage being measured directly as discrete numerical instead of a pointer deflection on a continuous scale as in analog instruments.

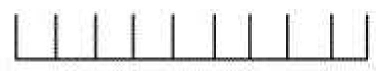
Advantages Associated with Digital Voltmeters

- Read out of DVMs is easy as it eliminates observational errors in measurement committed by operators.
- Error on account of parallax and approximation is entirely eliminated.
- Reading can be taken very fast.
- Output can be fed to memory devices for storage and future computations.
- Versatile and accurate
- Compact and cheap
- Low power requirements
- Portability increased

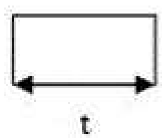
Working Principle of Digital Voltmeter



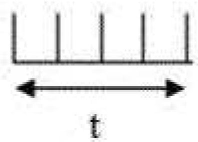
The **block diagram of a simple digital voltmeter** is shown in the figure. Explanation of various blocks Input signal: It is basically the signal i.e. voltage to be measured. Pulse generator: Actually it is a voltage source. It uses digital, analog or both techniques to generate a rectangular pulse. The width and frequency of the rectangular pulse is controlled by the digital circuitry inside the generator while amplitude and rise & fall time is controlled by analog circuitry. AND gate: It gives high output only when both the inputs are high. When a train pulse is fed to it along with rectangular pulse, it provides us an output having train pulses with duration as same as the rectangular pulse from the pulse generator.



Train pulse



Rectangular pulse



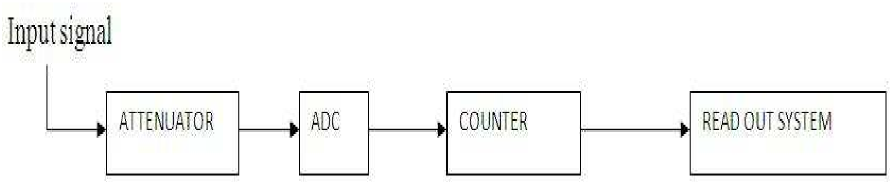
Output of AND gate

Decimal Display: It counts the numbers of impulses and hence the duration and display the valueof voltage on LED or LCD display after calibrating it.

The working of a digital voltmeter as follows:

- Unknown voltage signal is fed to the pulse generator which generates a pulse whose width is proportional to the input signal.
- Output of pulse generator is fed to one leg of the AND gate.
- The input signal to the other leg of the AND gate is a train of pulses.
- Output of AND gate is positive triggered train of duration same as the width of the pulse generated by the pulse generator.
- This positive triggered train is fed to the inverter which converts it into a negative triggered train.
- Output of the inverter is fed to a counter which counts the number of triggers in the duration which is proportional to the input signal i.e. voltage under measurement.
- Thus, counter can be calibrated to indicate voltage in volts directly.

Working of digital voltmeter is nothing but an analog to digital converter which converts an analog signal into a train of pulses, the number of which is proportional to the input signal. So a digital voltmeter can be made by using any one of the A/D conversion methods.



On the basis of A/D conversion method used digital voltmeters can be classified as:

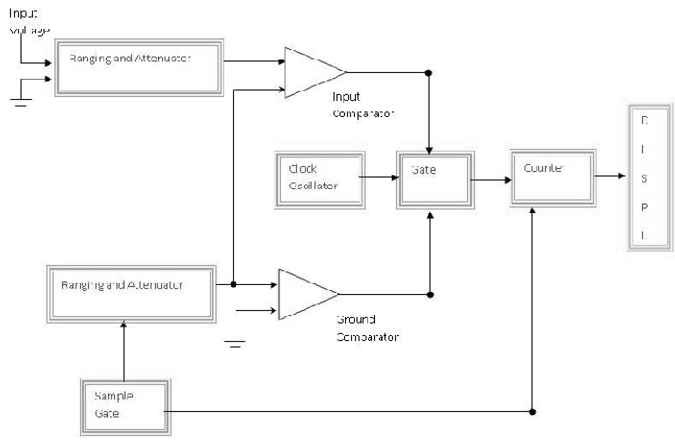
- Ramp type digital voltmeter
- Integrating type voltmeter
- Potentiometric type digital voltmeters
- Successive approximation type digital voltmeter
- Continuous balance type digital voltmeter

Now-a-days digital voltmeters are also replaced by digital millimeters due to its multitasking feature i.e. it can be used for measuring current, voltage and resistance. But still there are some fields where separated digital voltmeters are being used.

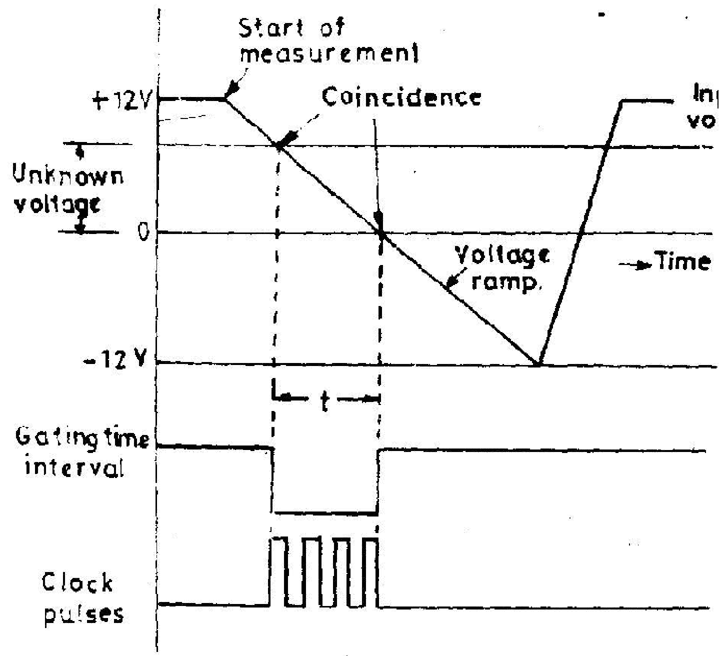
Ramp Type Digital Voltmeter

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 of Fig.



Input
voltage
Ranging and Attenuator
Input
Comparator
Clock
Oscillator
Gate
Counter
D
I
S
P
L
Ranging and Attenuator
Ground
Comparator
Sample
Gate



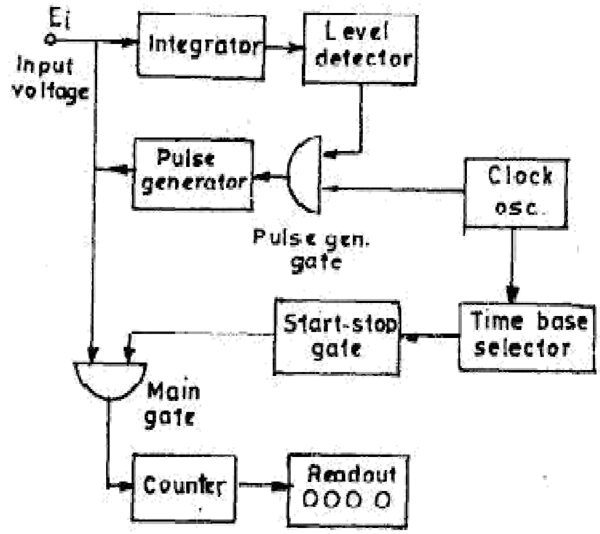
Start of
measurement
+12V
Coincidence
Unknown
voltage
0
Voltage
ramp.
Time
-12 V
t
Gating time
interval
Clock
pulses

At the start of measurement a ramp voltage is initiated.

- 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 voltmeter

This class of voltmeter is used to measure the average value of applied input voltage in a wide range. In opposite of integrating type voltmeter in case of ramp type voltmeter sampling of input voltage in done at the ending of the whole process. As the name suggests an integrating circuit is used in this case that performs the function of converting voltage to its equivalent frequency i.e. it works as voltage to frequency converter. It behaves as a feedback system and tends to decide the rate at which pulses are formed in correspondence to quantity of voltage feed at input section. Voltage to frequency conversion merely means to generate a train of pulses such that it frequency is dependent upon the magnitude of instantaneous voltage applied in this way an parent of variations in voltage is copies into an equivalent pattern of variations in frequency. After formation of a pulse train it is counted that how man pulse the present in fixed interval of time with help of a suitable electronic circuit. As is discussed that thus obtained pulse train has frequency whose value at any instance depends upon the corresponding value of input voltage thus there exists a relation between pulse train and input voltage that is used further to recover the original value of input voltage.



The most important part of this whole system is integrator section which is nothing but an operational amplifier that produces an output voltage whose value can be given by a relation depending upon input voltage Ei. The relation is given by

Eo=-Ei.t/RC.

Where, Eo is output voltage obtained at integrator while Ei is input voltage.

When Ei is made to remain constant Eo tends to change in its magnitude according to time such that Eo is always 180 degree out of phase i.e. having opposite polarity. By the graphical analysis it is seen that if input attains a shape of straight line horizontal to X-axis then its corresponding output comes to have a shape of straight line having declination with X-axis.

As soon as a constant input voltage is applied to integrator circuit a corresponding output is obtained whose value increase with time representing a straight line with a slope depending upon magnitude of input voltage. This rising voltage is applied to a level detector section that further sends a pulse to pulse generator circuit when a particular level of voltage is encountered by it. Functioning of level detector can be understood by considering it as voltage comparator. Integrator and level detector works together in such a way that output voltage from integrator is kept comparing with a fixed reference level, as soon as it reaches that level it generates the massaging pulse. Consequence of this pulse is that it triggers pulse generator gate that make the pulse generated at clock oscillator of fixed frequency to leave from pulse generator. This pulse generator is nothing but a Schmitt trigger.

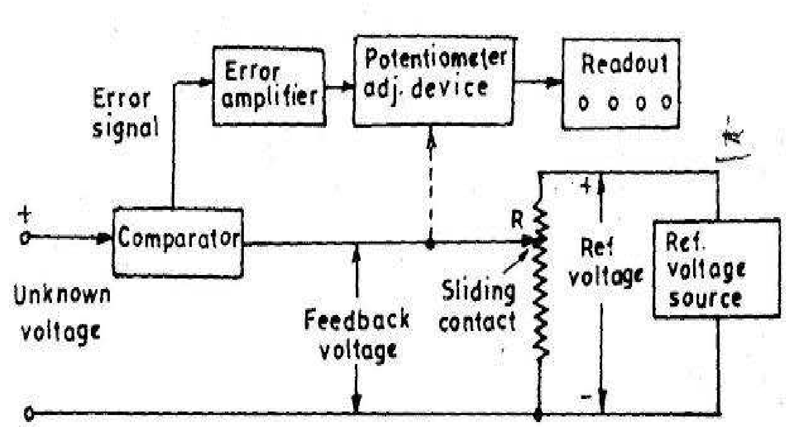
Now this pulse, having polarity opposite to that of input with even greater magnitude which is further applied to integrator. This results into the total input to integrator with reversed polarity.

And consequence of this opposite polarity inputs makes the output of integrator having downward slope. And as soon as output from integrator drops down a level detector circuit switches off the pulse generator gate and now no pulse is generated from clock oscillator. Once after passing of the pulse from pulse generator the input is reset to previous value and also makes output of integrator to increase again and the whole procedure is repeated again and again. This repetition results in formation of a saw tooth waveform whose frequency is function of magnitude of input voltage. Thus frequency of thus produces signal makes it possible to find out the value of input voltage applied.

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.

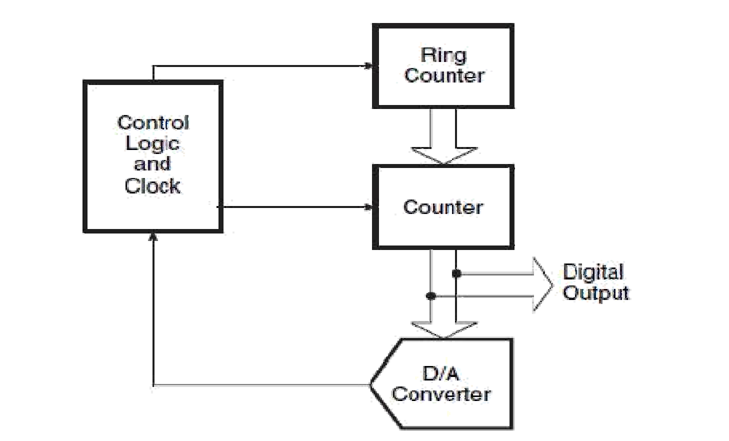
- The unknown voltage is filtered and attenuated to suitable level.
- This input voltage is applied to a comparator (also known as error detector).

- 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 contact and therefore it (sliding contact) will come to rest.
- The position of the potentiometer adjustment device at this point is indicated in numerical form on the digital readout device associated with it.

Since the position at which no voltage appears at potentiometer adjustment device is the one where the unknown voltage equals the feedback voltage, the reading of readout device indicates the value of unknown voltage.

Successive approximation type digital voltmeter

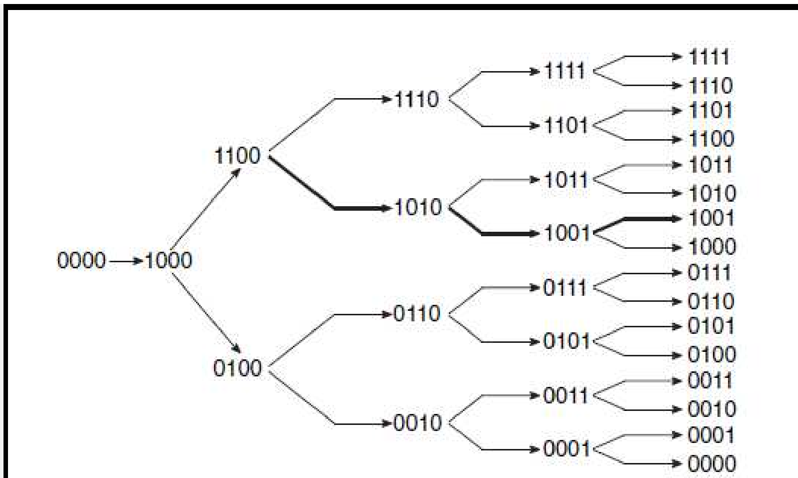
The development of A/D converters has progressed in a quest to reduce the conversion time. The successive approximation type ADC aims at approximating the analogue signal to be digitized by trying only one bit at a time. Work process of Successive Approximation Type ADC is different. The process of A/D conversion by this technique can be illustrated with the help of an example. Let us take a four-bit successive approximation type ADC.



Block schematic representation of a successive-approximation A/D converter.

Initially, the counter is reset to all 0s. The conversion process begins with the MSB being set by the start pulse. That is, the flip-flop representing the MSB is set. The counter output is converted into an equivalent analogue signal and then compared with the analogue signal to be digitized. A decision is then taken as to whether the MSB is to be left in (i.e. the flip-flop representing the MSB is to remain set) or whether it is to be taken out (i.e. the flip-flop is to be reset) when the first clock pulse sets the second MSB. Once the second MSB is set, again a comparison is made and a decision taken as to whether or not the second MSB is to remain set when the subsequent clock pulse sets the third MSB.

The process continues until we go down to the LSB. Note that, every time we make a comparison, we tend to narrow down the difference between the analogue signal to be digitized and the analogue signal representing the counter count. Refer to the operational diagram of Fig. 12.33. It is clear from the diagram that, to reach any count from 0000 to 1111, the converter requires four clock cycles. In general, the number of clock cycles required for each conversion will be n for an n-bit A/D converter of this type.



Conversion process in a successive approximation type A/D converter.

The above Fig shows a block schematic representation of a successive approximation type ADC. Since only one flip-flop (in the counter) is operated upon at one time, a ring counter, which is nothing but a circulating register (a serial shift register with the outputs Q and Q of the last flip-flop connected to the J and K inputs respectively of the first flip-flop), is used to do the job. Referring to Fig the dark lines show the sequence in which the counter arrives at the desired count, assuming that 1001 is the desired count. This type of A/D converter is much faster than the counter-type A/D converter previously discussed. In an n-bit converter, the counter-type A/D converter on average would require 2n−1 clock cycles for each conversion, whereas a successive approximation type converter requires only n clock cycles. That is, an eight-bit A/D converter of this type operating on a 1 MHz clock has a conversion time of 8 s.

Conversion time of Successive Approximation ADC

By observing above 3 bit example it is illustrated for a 3 bit ADC the conversion time will be 3 clock pulses. Then; N bit Successive Approximation ADC conversion time = 3T (T- clock pulse). So to avoid aliasing effect the next sample of input signal should be taken after 3 clock pulses.

Important note on Successive Approximation ADC

In Counter type or digital ramp type ADC the time taken for conversion depends on the magnitude of the input, but in SAR the conversion time is independent of the magnitude of the input sampled value.

Advantages of Successive Approximation ADC

- Speed is high compared to counter type ADC.
- Good ratio of speed to power.
- Compact design compared to Flash Type and it is inexpensive.

Disadvantages of Successive Approximation ADC

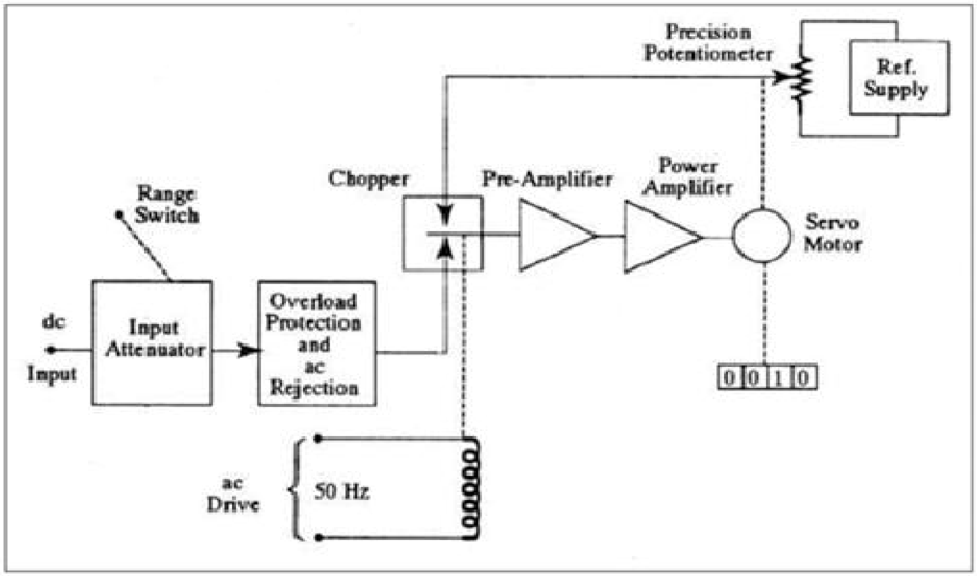
- Cost is high because of SAR
- Complexity in design.

Applications

The SAR ADC will used widely data acquisition techniques at the sampling rates higher than 10KHz.

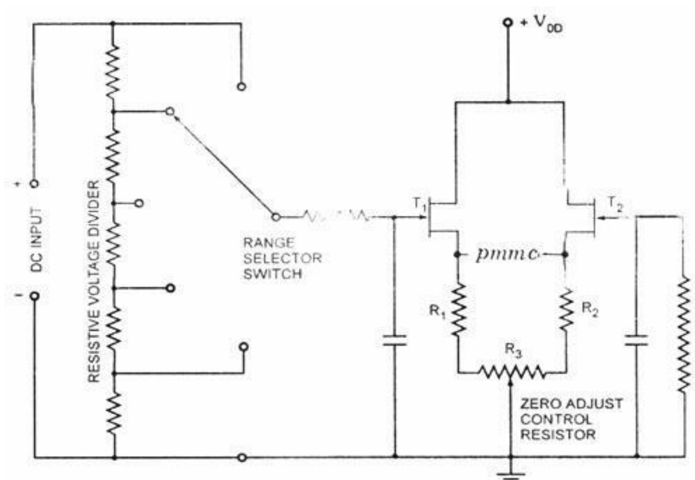
Continuous Balance or servo Balance DVM

The basic Block diagram is shown in figure. The input voltage applied to mechanical chopper comparator, the other side being connected to the variable arm of a precision potentiometer. The output of chopper comparator which is driven by the line voltage at the line frequency rate is a square wave signal whose amplitude is a function of the difference in voltages connected to the opposite side of the chopper. The square wave signal is amplified and fed to a power amplifier and the amplified square wave difference signal drives the arm of the potentiometer in the direction needed to make the difference voltage zero. The servo motor also drives the mechanical readout which is an indication of the magnitude of the input voltage. This DVM uses the principle of balancing instead of sampling because of mechanical movement. The average reading time is 2sec.



Electronic Multimeters

It is one of the most versatile general purpose instruments capable of measuring dc and ac voltages as well as current and resistances. The solid-state electronic multimeter generally consists of the following elements.



Balanced-Bridge DC Amplifier With input Attenuator and Indicating Meter

1. A balanced bridge dc amplifier and a PMMC meter.

2. An attenuator in input stage to select the proper voltage range.

3. A rectifier for converting of an ac input voltage to proportionate dc value.

4. An internal battery and additional circuitry for providing the capability of resistance measurement.

5. A function switch for selecting various measurement functions of the meter such as voltage, current or resistance.

In addition, the instrument is usually provided with a built-in power supply for operation on ac mains and, in most cases, one or more batteries for operation as a portable test instrument.

The schematic diagram of a balanced-bridge dc amplifier using two **field effect transistors** (FETs) is given in figure. It is to be noted that two FETs used in circuit should be reasonably well matched for current gain to ensure circuit thermal stability. The two FETs and the source resistors R_x and R_2, together with zero adjust control resistor R_3, constitute a bridge circuit. The PMMC meter is connected between the source terminals of the FETs, representing two opposite corners of the bridge.

In the absence of input signal, the gate terminals of the FETs are at ground potential and the transistors operate under identical quiescent conditions. Ideally no current should flow through the PMMC movement but in practice, on account of some mismatch between the two FETs and slight tolerance differences in the values of various resistors a current does flow and causes the meter movement to deflect from zero position. This current is reduced zero by the adjust control resistor R_3. Now the bridge is balanced. With a positive input signal applied to the gate of input transistor T_1 its drain current creases causing the voltage at the source terminal to rise. The resulting unbalance between the two transistors T_1 and T_2 source voltages is shown by the meter movement, whose scale is calibrated in terms of the magnitude of the applied input voltage. The maximum voltage that can be applied to the gate of input transistor T_1 is determined by its operating range, which is usually of the order of a few volts. The range of the bridge can easily be extended by employing an input attenuator or a range switch, as illustrated in figure.

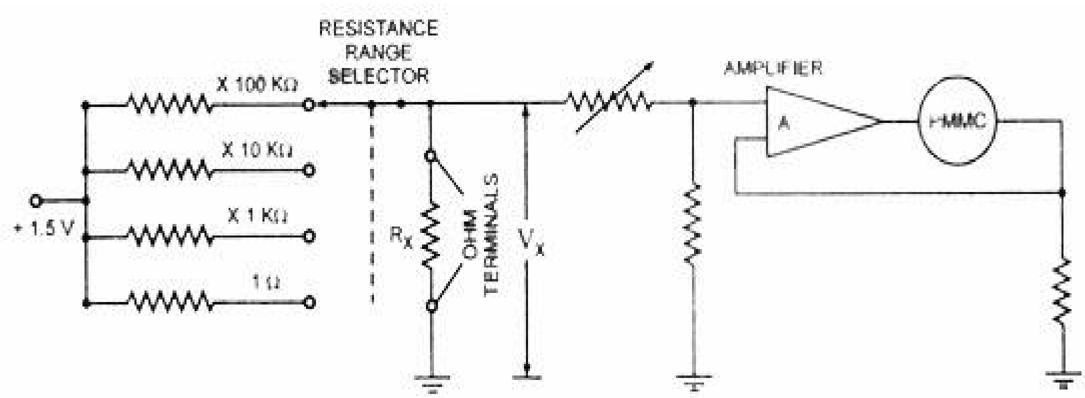
The unknown dc input voltage is applied through a large resistor in the probe body to a resistive voltage divider. Thus, with the range switch in the 3-V position as illustrated, the voltage at the gate of the input transistor T_1 is developed across 8 MQ resistor of the total resistance of 11.3

MQ and the circuit is so arranged that the PMMC meter gives full scale deflection with 3 V applied to the tip of the probe. With the range switch in 1,200 V position, the gate voltage is developed across 20 kilo ohm of the total divider resistance of 11.3 Mega ohms and an input voltage of 1,200 V will he required to cause the full-scale meter deflection.

When the multimeter's function switch is placed in the OHM position, the unknown resistor is connected in series with an internal battery, and the PMMC meter simply measure the voltage drop across it (unknown resistor, R_X).

A typical circuit is given in figure. In the given circuit, a separate divider network, employed only for the measurement of resistance, provides a number of different resistance ranges. With the unknown resistor R_X connected to the OHM terminals of the multimeter, the battery supplies current through one of the range resistors and the unknown resistor to ground. Voltage drop across unknown resistor R_X, V_X is applied to the input of the bridge amplifier and the PMMC movement deflects. Since the voltage drop across R_X is directly proportional to its resistance, the meter scale can be calibrated in terms of Kilo ohm.

The worth noting point is that this instrument indicates increasing resistance from left to right whereas the conventional meter, indicates increasing resistance from right to left. This is because the electronic multimeter reads a large resistance as a higher voltage, whereas the conventional multimeter indicates a higher resistance as a smaller current.



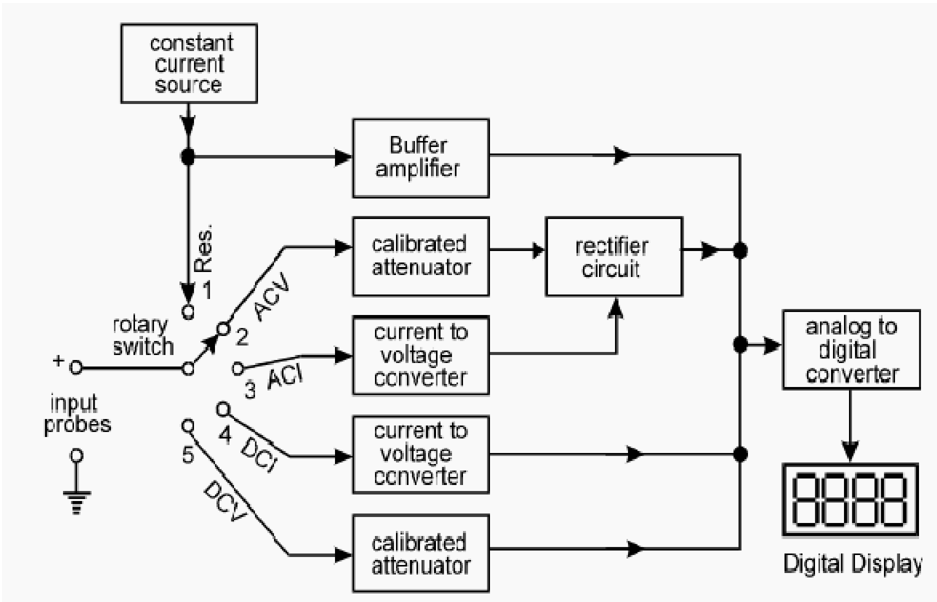
Measurement of Resistance By a Multimeter

DIGITAL MULTIMETER

It is a common & important laboratory instrument. It is used to measure AC/DC voltage, AC/DC current and resistance with digital display. It gives digital display, which is very accurate. It has an advantage of very high input resistance. It also provides over ranging indicator.

How digital multimeter works?

The block diagram of DMM is given below. The working of each block to measure different types of electrical quantities is as follows.



All multimeters on a broad scale use the same process to sample the quantity under measurement

How to measure resistance?

Connect an unknown resistor across its input probes. Keep rotary switch in the position-1 *(refer block diagram above)*. The proportional current flows through the resistor, from constant current source. According to Ohm's law voltage is produced across it. This voltage is directly proportional to its resistance. This voltage is buffered and fed to A-D converter, to get digital display in Ohms.

How to measure AC voltage?

Connect an unknown AC voltage across the input probes. Keep rotary switch in position-2. The voltage is attenuated, if it is above the selected range and then rectified to convert it into proportional DC voltage. It is then fed to A-D converter to get the digital display in Volts.

How to measure AC current?

Current is indirectly measured by converting it into proportional voltage. Connect an unknown AC current across input probes. Keep the switch in position-3. The current is converted into voltage proportionally with the help of I-V converter and then rectified. Now the voltage in terms of AC current is fed to A-D converter to get digital display in Amperes.

How to measure DC current?

The DC current is also measured indirectly. Connect an unknown DC current across input probes. Keep the switch in position-4. The current is converted into voltage proportionally with the help of I-V converter. Now the voltage in terms of DC current is fed to A-D converter to get the digital display in Amperes.

How to measure DC voltage?

Connect an unknown DC voltage across input probes. Keep the switch in position-5. The voltage is attenuated, if it is above the selected range and then directly fed to A-D converter to get the digital display in Volts.

Digital multimeter finds wide range of applications in the measurements of different electrical quantities. Remember that a meter capable of checking for voltage, current, and resistance is called a multimeter.

Remember that while measuring voltage, the DMM is connected in parallel. To measure voltage at a point in the circuit, first confirm the type of voltage, whether it is AC or DC. Also confirm the range of voltage *(it is better to start with higher voltage range)*.

Now connect black probe of DMM to negative terminal of circuit power supply and then connect the RED probe to the point where you want to measure the voltage. Be careful not to touch the bare probe tip anywhere else in the circuit otherwise there may be the problem of short circuit, etc.

Remember that while measuring current, the DMM is connected in series. To measure current flowing through a circuit or wire, first confirm the type of current, whether it is AC or DC. Also confirm the range of current *(it is better to start with higher* current *range)*.

Now connect red and black probes at random in the circuit, to measure the current. Be careful about the connections between the circuit terminals and the probes. They should be tight, otherwise, there will be *"makes" and "breaks"* during measurement, which may lead to produce errors.

To measure the unknown resistance: If you are measuring the unknown value of a resistor already connected in a working circuit, then first of all, switch off the power supply and disconnect the resistor from the circuit.

This is very important, because if you measure the resistance without disconnecting it from the circuit, the voltage drop across it may damage the DMM permanently.

Now connect it across the probes keeping the DMM in *resistance range.* Fix the higher range first, say 10MΩ. Then reduce the range, until you get correct readout.

Remember that the multimeter has practically no resistance between its leads. This is essential during continuity testing, in particular. It is intended to allow electrons to flow through the meter with the *least possible difficulty*.

For example, while checking the continuity of a small piece of copper wire, its practical resistance should be zero. If the probe resistance *were* greater than zero, the meter would add extra resistance in the circuit and would display some errors during continuity testing and would also affect the current.

The elements of DMM

The former topic of DMM covered its fundamental concept. However the commercial DMM is more advanced and packed with many features. It has more precision also. Remember that any DMM internally works as digital voltmeter.

That is, any quantity under measurement is first converted into proportional DC voltage and then measured. For example:

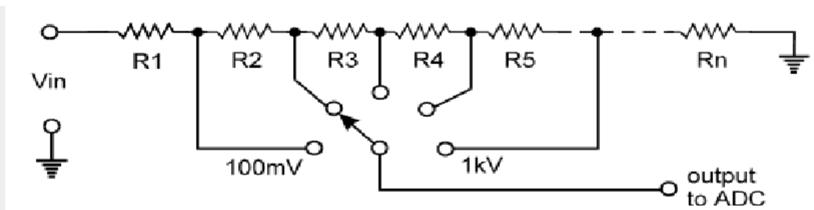
- When we measure resistance, a constant current passes through the unknown resistance and proportional voltage is produced, which is then buffered, sampled and fed to the counter.
- When we measure current, it is converted into proportional voltage first. Then it is sampled and fed to the counter to obtain the equivalent reading in relevant unit.

Thus, every time the DMM converts the quantity under measurement into proportional DC voltage first and then the relevant reading is displayed. Now we shall understand the necessity and basic working of different blocks or elements used in DMM, as follows:

Attenuator: The commercial DMM has a rotary switch used selecting proper range with manysteps in it. Now suppose the DMM is put in voltage range to measure AC or DC voltage. When unknown voltage is connected across its probes, first of all, it is checked for its magnitude within the specified range.

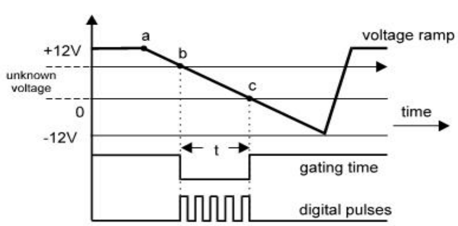
If voltage is high, then it is attenuated proportionally. The attenuator is a ladder of high wattage resistors, as shown in following figure. It has number of steps for attenuation from several volts to kilovolts. To select a particular range for measuring voltage, first switch to higher range.

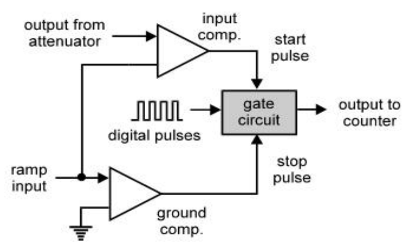
If the resolution of the reading is less, then only you can switch over to successive lower range.



Range selector arrangement using resistor ladder

The process of sampling & gating: Once the input voltage under measurement is converted intoDC voltage, it is further processed and sampled into a series of digital pulses, as shown below.

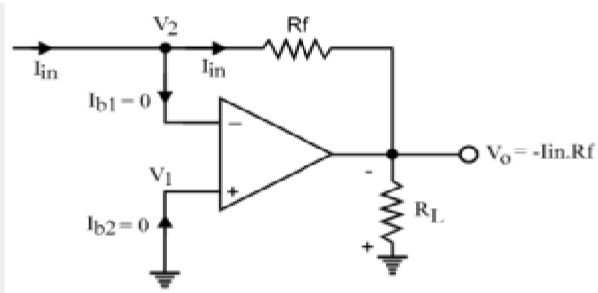




When unknown voltage is connected, at the start of measurement, the ramp voltage is initiated at point „*a*". It is a negative going sawtooth voltage. The ramp voltage is constantly compared with unknown voltage. When magnitude of unknown voltage becomes equal to ramp voltage, at point „*b*", at that instant the input comparator produces START pulse, and the gate is opened.

So digital pulses are fed to the counter and the counting is initiated. During this, the ramp voltage further falls. As it reaches to zero, at point „*c*", the ground comparator produces STOP pulse and the gate is closed. So the digital pulses are disconnected from input of counter. The counting stops and result is displayed.

Current to voltage conversion: This circuit is built around special type of operational amplifier. Atypical circuit of current to voltage converter is given in following circuit. We shall understand how it converts current into proportional voltage.



According to the theory of operational amplifiers, the output voltage of the circuit is given by the equation, as follows:

(Vo/Vi) = -(Rf/Ri) ………… ∴ Vo = -(Vi/R1).Rf

However as V1=0, V1=V2

(Vi/R1) = Iin and ∴ Vo = -(Iin.Rf)

So if we replace the Vi and R1 combination by a current source Iin of as shown in the above circuit, then the output voltage Vo becomes proportional to the input current Iin. Thus, we can say that the input current is converted into proportional output voltage.

In addition to the additional measurement capabilities, DMMs also offer flexibility in the way measurements are made. Again this is achieved because of the additional capabilities provided by the digital electronics circuitry contained within the digital multimeter. Many instruments will offer two additional capabilities:

- ***Auto-range:*** This facility enables the correct range of the digital multimeter to be selectedso that the most significant digits are shown, i.e. a four-digit DMM would automatically select an appropriate range to display 1.234 mV instead of 0.012 V. Additionally it also prevent overloading, by ensuring that a volts range is selected instead of a millivolts range. Digital multimeters that incorporate an auto-range facility usually include a facility to 'freeze' the meter to a particular range. This prevents a measurement that might be on the border between two ranges causing the meter to frequently change its range which can be very distracting.

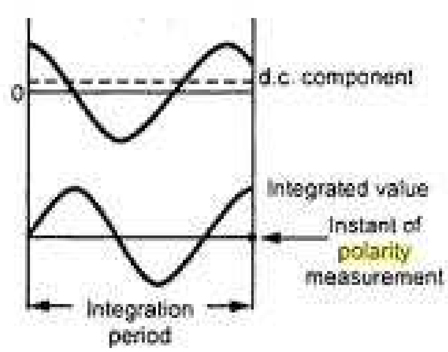
- ***Auto-polarity:*** This is a very convenient facility that comes into action for direct currentand voltage readings. It shows if the voltage of current being measured is positive (i.e. it is in the same sense as the meter connections) or negative (i.e. opposite polarity to meter connections). Analogue meters did not have this facility and the meter would deflect backwards and the meter leads would have to be reversed to correctly take the reading.

Automatic Functions

Various automatic functions in digital instruments are Automatic Polarity Indication, Automatic Ranging and Auto zeroing.

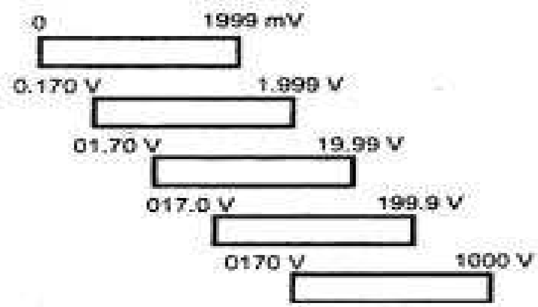
Automatic polarity indication

The information obtained by ADC is responsible for the polarity indication. For the integrating ADCs, only the polarity of the integrated signal is of importance. The polarity should be measured at the end of the integration period as shown in the fig. the integration period is measured by counting the pulses. The last count or some of the last counts can be used to atart the polarity measurement. The output of the integrator is then used to set the polarity flip-flop, the output of which is stored in the memory until the next measurement is done.

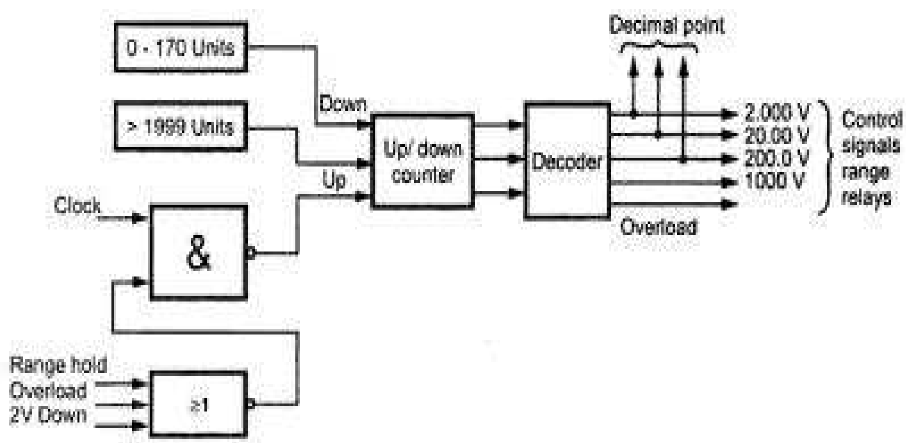


Automatic Ranging

Consider 31/2 digit display on which the maximum reading possible is 1999. i.e the value greater than 1999 have to be reduced by a factor of 10, before it can be displayed. Thus if the display is less than 0200, the instrument should be automatically switched to a range which is more sensitive while if display is higher than 1999 then the next less sensitive range must be automatically selected. Practically the lower limit is taken much lower than 0200. Thus by selecting lower limit much lower than 0200 overlapping of the ranges is achieved. The overlapping ranges make sure that all the values are displayed in the same range. This overlapping range is shown in fig.

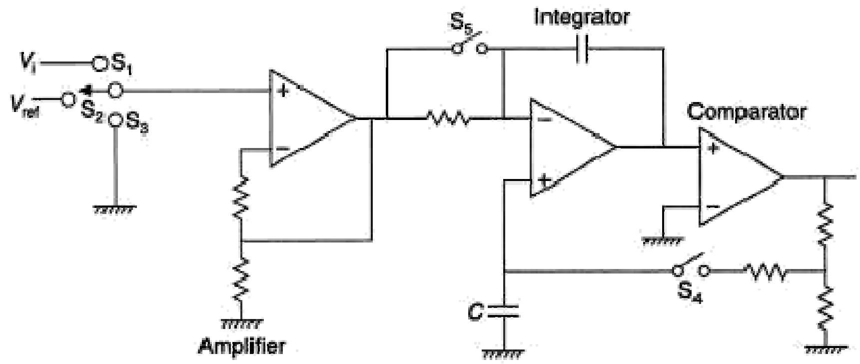


The design of the automatic ranging system is shown in fig. The ADC counter contains some information. If this count is less than 170, a control pulse for down ranging is produced. If this is more than 1999 units, control pulse for up ranging is produced. The up/down counters reacts to this information, at the moment when clock pulse is applied. The new information is used to set the range relays via the decoder. At the same time as per the requirement of new range the decimal point is also changed. If more than one range step is to be made several measuring periods are necessary to reach the final result. The clock pulses and hence automatic ranging can be nhibited by a manual range hold command, by a signal that exceeds the maximum range and by reaching the most sensitive range.



Auto zeroing

Zero had so long been set manually, especially for analog meter. Autozeroing is a facility incorporated with ADC as a part of the instrument. The zero is measured before measurement of each parameter and the zero error stored as an analog signal. An auto zeroing system is shown in figure.



At the start, switches S_3, S_4 and S_5 are closed for a very short period say 0.05 second. Switch S_4 connects output of the comparator to capacitor C switch S_3 grounds the circuit input and switch S_5 puts integrator time constant to effective zero, although a very short time constant does exist. Capacitor C will be charged by the offset voltages of the three stages indicated – amplifier, integrator and comparator. With switches now opened and switch S_1 closed for measurement. The offset voltage stored in the capacitor being the effective zero, the error is algebraically subtracted for the zero error correction.

FREQUENCY COUNTER

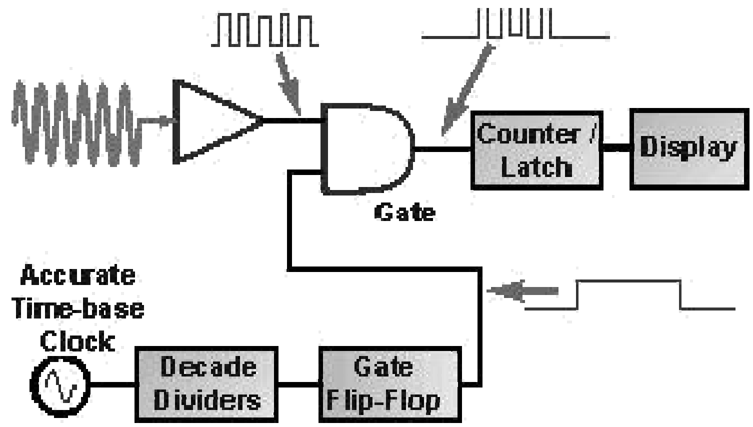
Digital frequency counters are widely used items of test equipment within the electronics industry for measuring the frequency of repetitive signals. In particular, digital frequency counters are used for radio frequency (RF) measurements where it is important to test or measure the precise frequency of a particular signal. These frequency counter is commonly found as general purpose laboratory test equipment.

Frequency counters are test equipment that operate by counting events within a set period or discovering what a period is by counting a number of precisely timed events. The time periods within which events are counted, or the precisely timed events can be generated using a highly stable quartz crystal oscillator. This may even be oven controlled, and in this way a very accurate reference is obtained.

To look at the way in which a frequency counter works, it is necessary to describe the two approaches separately. The two approaches may be termed direct counting and reciprocal counting.

Direct counting

Those digital frequency counters that use a direct counting approach count the number of times the input signal crosses a given trigger voltage (and in a given direction, e.g. moving from negative to positive) in a given time. This time is known as the gate time



Basic frequency counter block diagram

Within the basic counter there are several main blocks:

- ***Input:*** When the signal enters the frequency counter it enters the input amplifier where thesignal is converted into a logic rectangular wave for processing within the digital circuitry in the rest of the counter. Normally this stage contains a Schmitt trigger circuit so that noise does not cause spurious edges that would give rise to additional pulses that would be counted. Trigger levels and sensitivity are controlled within this area of the frequency counter.

- ***Accurate time-base / clock:*** In order to create the various gate / timing signals within thefrequency counter an accurate timebase or clock is required. This is typically is a crystal oscillator and in high quality test instruments it will be an oven controlled crystal oscillator. In many instruments, there will be the capability to use a better quality external oscillator, or to use the frequency counter oscillator for other instruments. This is also beneficial when it is necessary to lock a number of instruments to the same standard.

- ***Decade dividers and flip-flop:*** The clock oscillator is used to provide an accurately timedgate signal that will allow through pulses from the incoming signal. This is generated fromth e clock by dividing the clock signal by decade dividers and then feeding this into a flip flop to give the enabling pulse for the main gate

- ***Gate:*** The precisely timed gate enabling signal from the clock is applied to one input of agate and the other has a train of pulses from the incoming signal. The resultant output from the gate is a series of pulses for a precise amount of time. For example if the incoming signal was at 1 MHz and the gate was opened for 1 second, then 1 million pulses would be allowed through.

- ***Counter/ latch:*** The counter takes the incoming pulses from the gate. It has a set of divide-by-10 stages (number equal to the number of display digits minus 1). Each stage divides by ten and therefore as they are chained the first stage is the input divided by ten, the next is the input divided by 10 x 10, and so forth. These counter outputs are then used to drive the display.

  In order to hold the output in place while the figures are being displayed, the output is latched. Typically the latch will hold the last result while the counter is counting a new reading. In this way the display will remain static until a new result can be displayed at which point the latch will be updated and the new reading presented to the display.

- ***Display:*** The display takes the output from the latch and displays it in a normal readableformat. LCD, or LED displays are the most common. There is a digit for each decade the counter can display. Obviously other relevant information may be displayed on the display as well.

It is important that the gate time is accurately generated. This is done by having a highly accurate frequency source within the frequency counter. Typically these will operate at a frequency of 10 MHz and this needs to be divided to give the required gate time. Figures of 0.01, 0.1, 1, and 10 seconds may be selected. The shorter times obviously enable the display to be refreshed more often, but against this the count accuracy is less.

The reason that the gate time determines the resolution of the frequency counter is that it can normally only count complete cycles, as each crossing represents a cycle. This a gate time of one second will enable frequency resolutions of 1 Hz to be gained, and a ten second gate time will enable resolutions down to 0.1 Hz. It is worth noting that the measurement resolution is a not a percentage of the measurement, but instead it is fixed amount relating only to the gate time.

Reciprocal frequency counters

Another method of measuring the frequency of a signal is to measure the period for one cycle of the waveform and then take the reciprocal of this. Although this approach is slightly more expensive to implement than direct counting and it is not as widely used, it does have some advantages. The main one is that it always will always display the same number of digits of resolution regardless of the input frequency. As a result, reciprocal frequency counters are specified in terms of the number of digits for a given gate time, e.g. 10 digits per second. In view of this it can be seen that reciprocal counters give a higher resolution at low frequencies. At 1 kHz, a direct counter gives a resolution of 1 Hz (4 digits). A 10 digit/second reciprocal counter gives a resolution of 10 digits.The other advantage is that these counters can make very fast readings. A reciprocal counter will give 1 mHz resolution in 1 ms, whereas a direct counter takes a second to give a reading with a resolution of 1 Hz.

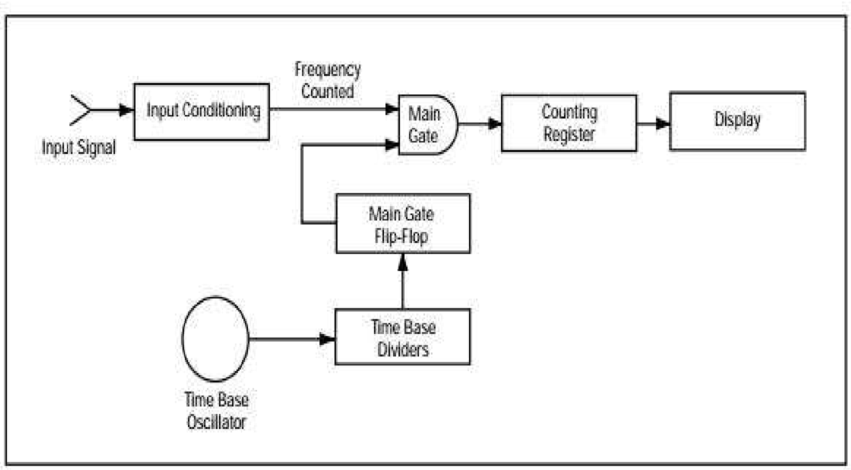
Digital frequency counters are an essential item of test equipment for any accurate measurements of frequency. RF frequency counters may be used in development, production, repair or maintenance. Of the two types, the direct frequency counter is the most common. In fact some digital frequency counters may be bought for a particularly low cost as a result of the high levels of integration that are now available. Even small handheld digital frequency counters are available. However RF frequency counters with much higher levels of performance tend to be contained in larger cases. Often they will require highly accurate crystal oven oscillators to provide the very accurate gate times required. Nevertheless these digital frequency counters still represent very good value.

Measurement of Frequency and Time Intervel

The conventional counter is a digital electronic device which measures the frequency of an input signal. It may also have been designed to perform related basic measurements including the period of the input signal, ratio of the frequency of two input signals, time interval between two events and totalizing a specific group of events.

Frequency Measurement

The frequency, f, of repetitive signals may be defined by the number of cycles of that signal per unit of time. It may be represented by the equation: $f = n / t$ (1) where n is the number of cycles of the repetitive signal that occurs in time interval, t. If t = 1 second, then the frequency is expressed as n cycles per second or n Hertz. As suggested by equation (1), the frequency, f, of a repetitive signal is measured by the conventional counter by counting the number of cycles, n, and dividing it by the time interval, t. The basic block diagram of the counter in its frequency mode of measurement is shown in Figure.

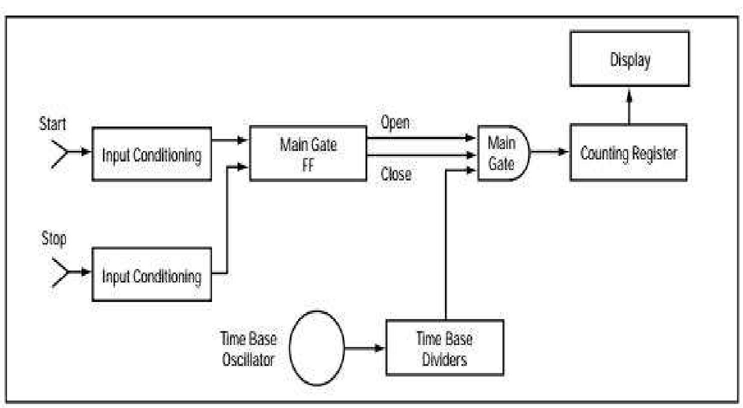


The input signal is initially conditioned to a form that is compatible with the internal circuitry of the counter. The conditioned signal appearing at the door of the main gate is a pulse train where each pulse corresponds to one cycle or event of the input signal. With the main gate open, pulses are allowed to pass through and get totalized by the counting register. The time between the opening to the closing of the main gate or gate time is controlled by the Time Base. From equation (1), it is apparent that the accuracy of the frequency measurement is dependent on the accuracy in which t is determined. Consequently, most counters employ crystal oscillators with frequencies such as 1, 5 or 10 MHz as the basic time base element.

The Time Base Divider takes the time base oscillator signal as its input and provides as an output a pulse train whose frequency is variable in decade steps made selectable by the Gate Time switch. The time, t, of equation (1) or gate time is determined by the period of the selected pulse train emanating from the time base dividers. The number of pulses totaled by the counting register for the selected gate time yields the frequency of the input signal. The frequency counted is displayed on a visual numerical readout. For example, if the number of pulses totaled by the counting register is 50,000, and the selected gate time is one second, the frequency of the input signal is 50,000 Hertz.

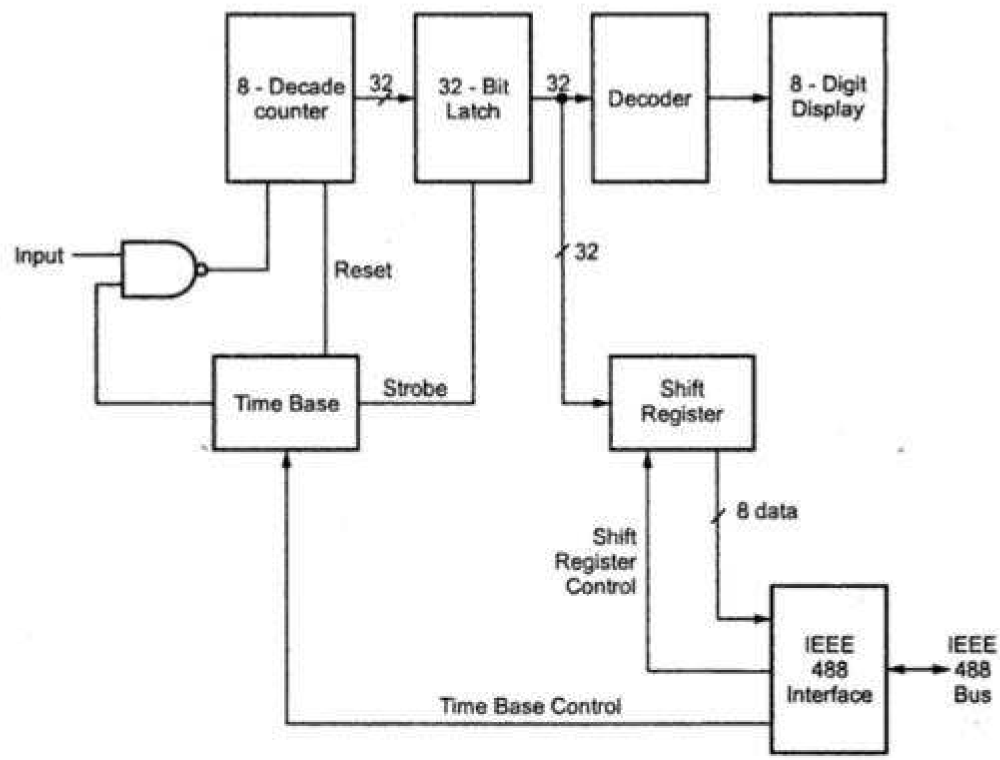
Time Interval Measurement

The basic block diagram of the conventional counter in its time interval mode of measurement is shown in Figure 4. The main gate is now controlled by two independent inputs, the START input, which opens the gate, and the STOP input which closes it. Clock pulses from the dividers are accumulated for the time duration for which the gate is open. The accumulated count gives the time interval between the START event and the STOP event. Sometimes the time interval may be for signal of different voltage levels such as th shown in Figure 5. The input conditioning circuit must be able to generate the START pulse at the 0.5V amplitude point, and the STOP pulse at the 1.5V amplitude point.



Computer controlled instrumentation:

In general, most of the test equipments or test instruments require some sort of modifications in the form of use of some special circuits so as to interface themwith a computer. Depending upon the nature of test equipments, the modifications may be very simple as in case of some equipment or may be very significant in other equipments. For example the measuring instruments using any sort of mechanical device for the effective measurement are not suitable in computer controlled test systems. The meter movement in instruments or resistors and capacitors used in bridge are not suitable for computer controlled measurement systems.



Digital frequency counter with IEEE 488

Such instruments need certain modification such that they can be used in computer controlled measurement system. Generally all the mechanical devices are replaced by purely electronic equivalents. In general, the instruments used in the computer controlled instrumentation are, i) Digital frequency counter ii) Synthesized signal generator iii) Relay switched attenuator iv) Computer controlled spectrum, analyzer v) Adjustable a.c. power supply A digital frequencycounter to, interface with IEEE 488 bus is as shown in the Fig As frequency counter is a digital instrument, it is comparatively simple to interface. The data is placed on a bus a digit at a time. The data is connected to display unit through decoder.

For this either a shift register or multiplexer along with interface circuits are used to fulfill the electrical requirements of the bus. As the frequency counter can be used either as a listener or a talker. In other words it requires appropriate additional circuitry such as data generating circuit and data receiving circuit. In addition to this it requires a correct method of switching between data generating and data receiving circuits. The controlling computer sends messages which are decoded and then accordingly the frequency counter is selected as either a listener or a talker.

What is Virtual Instrumentation?

A virtual instrumentation system is computer software that a user would employ to develop a computerized test and measurement system, for controlling from a computer desktop an external measurement hardware device, and for displaying test or measurement data collected by the external device on instrument-like panels on a computerscreen.

Virtual instrumentation extends also to computerized systems for controlling processes based on data collected and processed by a computerized instrumentation system.

An instrument is a device designed to collect data from an environment, or from a unit under test, and to display information to a user based on the collected data. Such an instrument may employ a transducer to sense changes in a physical parameter, such as temperature or pressure, and to convert the sensed information into electrical signals, such as voltage or frequency variations.

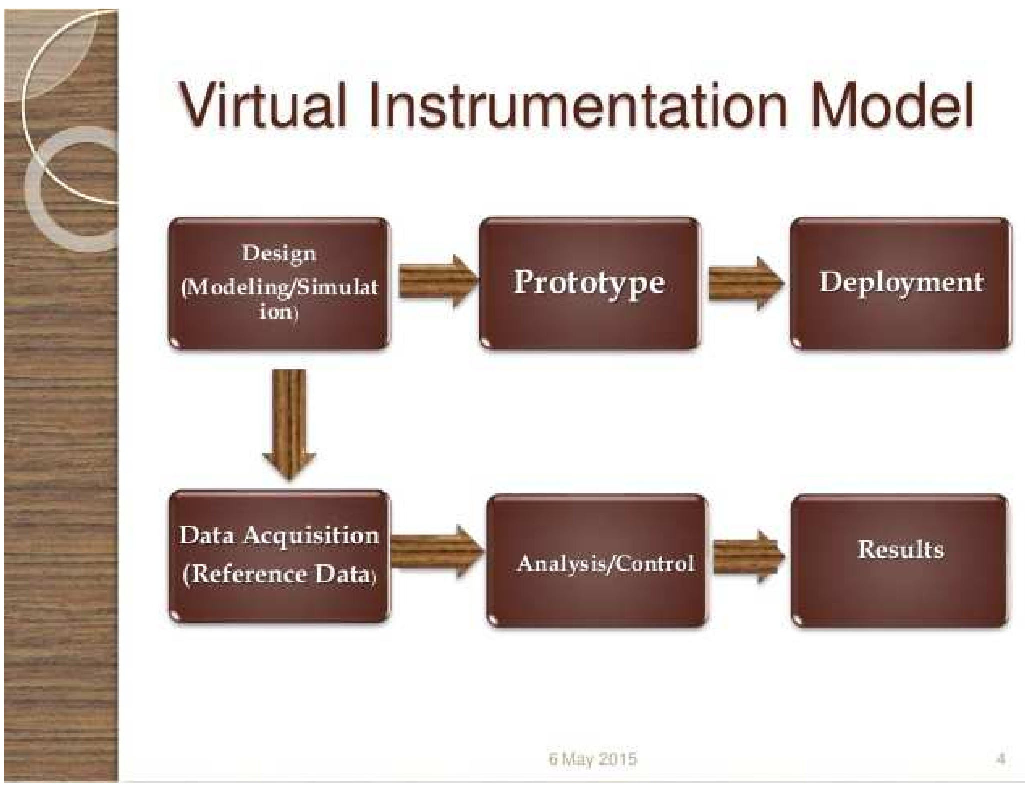
The term instrument may also cover, and for purposes of this description it will be taken to cover, a physical or software device that performs an analysis on data acquired from another instrument and then outputs the processed data to display or recording means. This second category of instruments would, for example, include oscilloscopes, spectrum analyzers and digital multimeters.
The types of source data collected and analyzed by instruments may thus vary widely, including both physical parameters such as temperature, pressure, distance, and light and sound frequencies and amplitudes, and also electrical parameters including voltage, current, and frequency.

History of Instrumentation Systems:-

Historically, instrumentation systems originated in the distant past, with measuring rods, thermometers, and scales. In modern times, instrumentation systems have generally consisted of individual instruments, for example, an electro-mechanical pressure gauge comprising a sensing transducer wired to signal conditioning circuitry, outputting a processed signal to a display panel and perhaps also to a line recorder, in which a trace of changing conditions is inked onto a rotating drum by a mechanical arm, creating a time record of pressure changes.

Even complex systems such as chemical process control applications typically employed, until the 1980s, sets of individual physical instruments wired to a central control panel that comprised an array of physical data display devices such as dials and counters, together with sets of switches, knobs and buttons for controlling the instruments.

The introduction of computers into the field of instrumentation began as a way to couple an individual instrument, such as a pressure sensor, to a computer, and enable the display of measurement data on a virtual instrument panel, displayed in software on the computer monitor and containing buttons or other means for controlling the operation of the sensor. Thus, such instrumentation software enabled the creation of a simulated physical instrument, having the capability to control physical sensing components.



Conventional Instrumentation	Virtual Instrumentation
Pre-defined hardware components	User-defined measurement system
Limited functionality due to hardcoded functions	Versatile functionality using customizable software
Complex and expensive hardware	Complex hardware functionality implemented on software
Re-calibration is required	Re-calibration is not required
Bulky and stimulus specific	Compact and portable

A virtual instrument system comprises of three main components that are:

- Flexible software
- Modular data acquisition hardware (DAQ)
- Computing platform (e.g. PC)

Creation of Virtual Instrumentation

A large variety of data collection instruments designed specifically for computerized control and operation were developed and made available on the commercial market, creating the field now called "virtual instrumentation."
Virtual instrumentation thus refers to the use of general purpose computers and workstations, in combination with data collection hardware devices, and virtual instrumentation software, to construct an integrated instrumentation system; in such a system the data collection hardware devices, which incorporate sensing elements for detecting changes in the conditions of test subjects, are intimately coupled to the computer, whereby the operations of the sensors are controlled by the computer software, and the output of the data collection devices is displayed on the computer screen, in a manner designed in software to be particularly useful to the user, for example by the use of displays simulating in appearance the physical dials, meters and other data visualization devices of traditional instruments.

SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - V

ACQUISITION MEASUREMENT SYSTEMS AND FIBER OPTIC DATA – SEIA1501

Data Acquisition System:

A typical Data Acquisition System consists of individual sensors with the necessary signal conditioning, data conversion, data processing, multiplexing, data handling and associated transmission, storage and display systems.

In order to optimise the characteristics of the system in terms of performance, handling capacity and cost, the relevant sub systems can be combined together. Analog Data Acquisition System is generally acquired and converted into digital form for the purpose of processing, transmission, display and storage.

Processing may consist of a large variety of operations, ranging from simple comparison to complicated mathematical manipulations. It can be for such purposes as collecting information (averages, statistics), converting the data into a useful form (e.g., calculations of efficiency of motor speed, torque and power input developed), using data for controlling a process, performing repeated calculations to separate signals buried in the noise, generating information for display, and various other purposes.

Data may be transmitted over long distances (from one point to another) or short distances (from test centre to a nearby PC).

The data may be displayed on a digital panel or on a CRT. The same be stored temporarily (for immediate use) or permanently for ready reference later.

Data acquisition generally relates to the process of collecting the input data in digital form as rapidly, accurately, and economically as necessary. The basic instrumentation used may be a DPM with digital outputs, a shaft digitiser, or a sophisticated high speed resolution device.

To match the input requirements with the output of the sensor, some form of scaling and offsetting is necessary, and this is achieved by the use of amplifier/ attenuators.

For converting analog information from more than one source, either additional transducers or multiplexers are employed. To increase the speed with which information is accurately converted, sample-hold circuits are used. (In some cases, for analog signals with extra-wide range, logarithmic conversion is used.)

Data Acquisition System Block Diagram:

A schematic block diagram of a General Data Acquisition System (DAS) is shown in Figure.

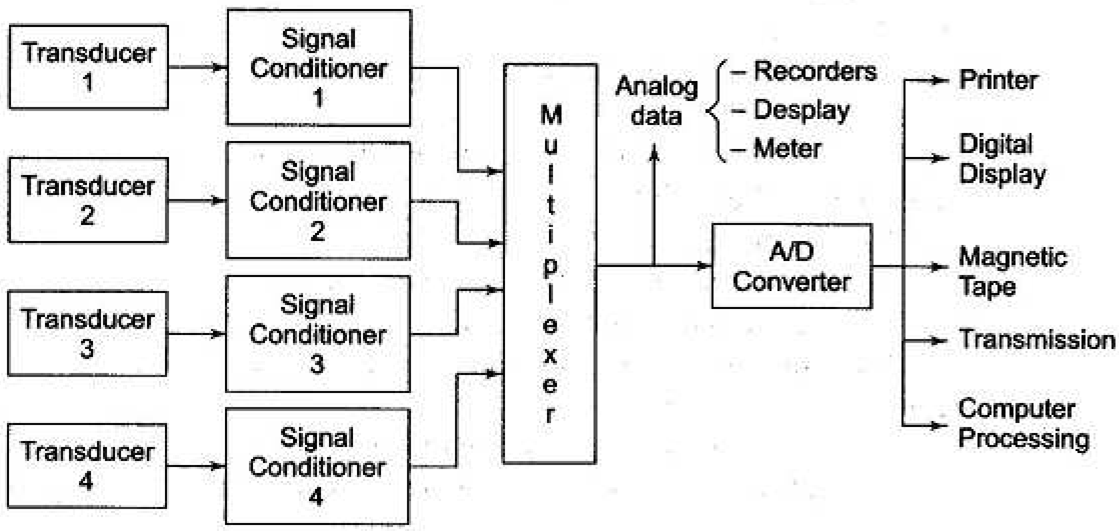


Fig. 17.1 Generalised Data Acquisition System

The characteristics of the data acquisition system, depend on both the properties of the analog data and on the processing carried out.

Based on the environment, a broad Classifications of data acquisition system into two categories.

1. **Those suitable for favourable environments (minimum RF interference and electromagnetic induction)**
2. **Those intended for hostile environments**

The former category may include, among other, laboratory instrument applications, test systems for collecting long term drift information on zeners, high calibration test instruments, and routine measurements in research, as mass spectrometers and lock-in amplifiers. In these, the systems are designed to perform tasks oriented more towards making sensitive measurements than to problems of protecting the integrity of analog data.

The Classifications of data acquisition system specifically includes measure, protecting the integrity of the analog data under hostile conditions. Such measurement conditions arise in aircraft control systems, turbovisous in electrical power systems, and in industrial process control systems.

Most of these hostile measurement conditions require devices capable of a wide range of temperature operations, excellent shielding, redundant paths for critical measurements and considerable processing of the digital data acquisition system.

On the other hand, laboratory measurements are performed over a narrow temperature range with much less electrical noise, employing high sensitivity and precision devices for higher accuracies and resolution.

The important Factors to Consider When Setting Up a Data Acquisition System are as follows.

1. **Accuracy and resolution**
2. **Number of channels to be monitored**
3. **Analog or digital signal**
4. **Single channel or multichannel**
5. **Sampling rate per channel**
6. **Signal conditioning requirements of each channel**
7. **Cost**

The various general Configuration of Data Acquisition System are

1. **Single channel possibilities**

- Direct conversion
- Pre-amplification and direct conversion
- Sample and hold, and conversion
- Pre-amplification, signal conditioning and any of the above

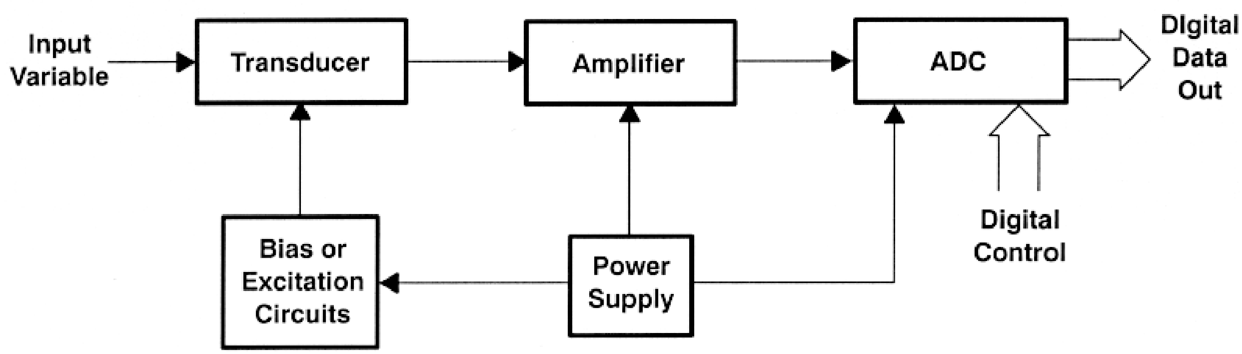
2. **Multi channel possibilities**

- Multiplexing the outputs of single channel converters
- Multiplexing the output of sample-hold circuits
- Multiplexing the inputs of sample-hold circuits
- Multiplexing low level data

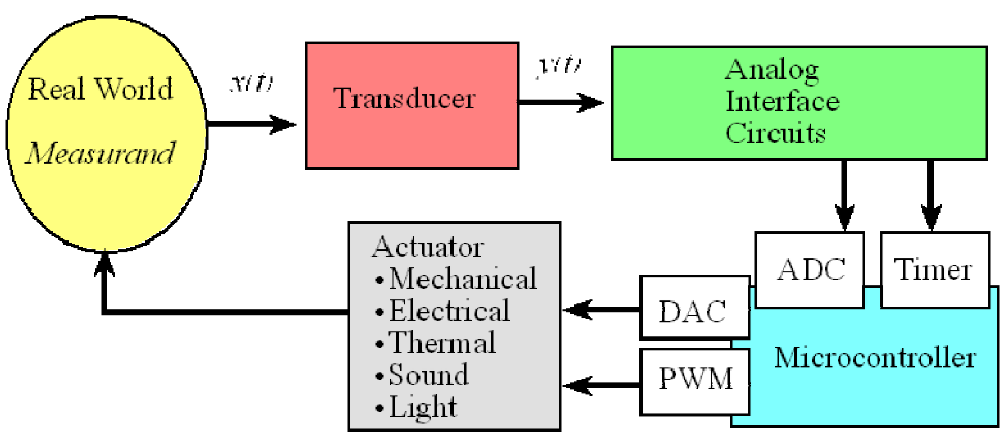
Objectives of Data Acquisition System:

- It must acquire the necessary data, at correct speed and at the correct
- Use of all data efficiently to inform the operator about the state of the
- It must monitor the complete plant operation to maintain on-line optimum and safe operations.
- It must provide an effective human communication system and be able to identify problem areas, thereby minimising unit availability and maximising unit through point at minimum cost.
- It must be able to collect, summarise and store data for diagnosis of operation and record purpose.
- It must be able to compute unit performance indices using on-line, real-time data.
- It must be flexible and capable of being expanded for future require
- It must be reliable, and not have a down time greater than 0.1%.

The typical transducer measurement system block diagram is shown in Figure 1. The transducer is the electronic system's interface with the real world, and it issues data about a variable. The transducer converts the data into an electrical signal adequate for processing by the circuitry that follows the transducer. Bias and excitation circuitry does the care and feeding of the transducer, thus this circuitry provides offset voltages, bias currents, excitation signals, external components, and protection that is required for the transducer to operate properly. The output of the transducer is an electrical signal representing the measured variable.



Block Diagram of a Transducer Measurement System



The variables that must be measured are determined by the customer's application, and the measured variable normally dictates the transducer selection. If the measured variable is temperature, then some sort of temperature sensing transducer must be employed, and the range of temperatures to be measured or the accuracy of the measurement is the primary factor influencing temperature transducer selection. Notice that the electrical output of the transducer is not a major concern at this point in the transducer selection. The transducer's electrical output is always a consideration, although picking the right transducer for the job is the primary goal. The

correct transducer for the job can have an Ohm/C change, AlphaV/C change, or mV/C change. All of these transducers have offset voltages or currents, and they can be referenced to ground, either power supply rail, or some other voltage. The selection of the transducer is out of circuit designer's hands; thus, the circuit designer must accept what the application demands.
The ADC selection is based on several system criteria such as resolution, conversion speed, power requirements, physical size, processor compatibility, and interface structure. The ADC must have enough bits to obtain the resolution required by the accuracy specification.

Multi Channel Data Acquisition System:

The Multi Channel Data Acquisition System can be time shared by two or more input sources. Depending on the desired properties of the multiplexed system, a number of techniques are employed for such time shared measurements.

Multi-Channel Analog Multiplexed System:

The multi-channel DAS has a single A/D converter preceded by a multiplexer, as shown in Fig. 17.5.

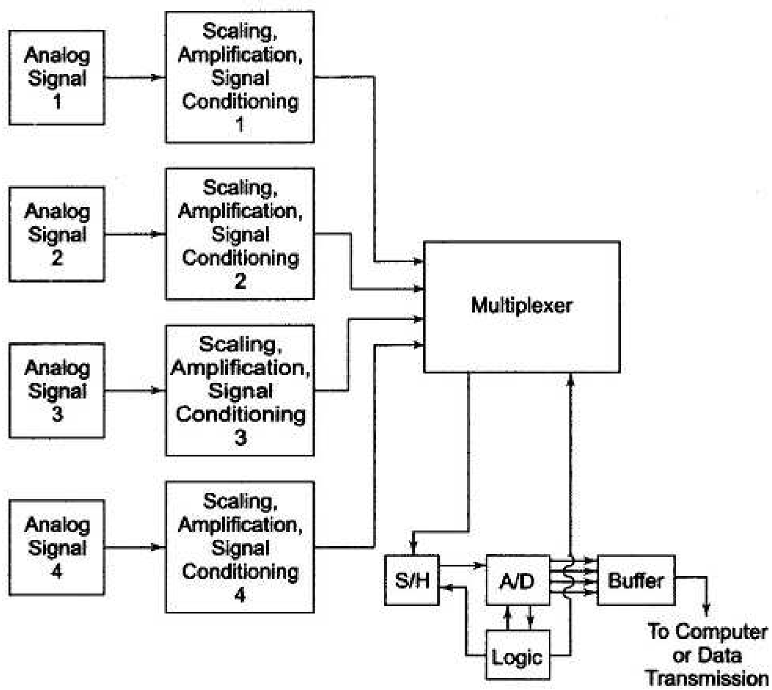


Fig. 17.5 Multi-channel DAS (A/D Preceded by a Multiplexer)

The individual analog signals are applied directly or after amplification and/or signal conditioning, whenever necessary, to the multiplexer. These are further converted to digital signals by the use of A/D converters, sequentially.

For the most efficient utilisation of time, the multiplexer is made to seek the next channel to be converted while the previous data stored in the sample/hold is converted to digital form.

When the conversion is complete, the status line from the converter causes the sample/hold to return to the sample mode and acquires the signal of the next channel. On completion of acquisition, either immediately or upon command, the S/H is switched to the hold mode, a conversion begins again and the multiplexer selects the next channel. This method is relatively slower than systems where S/H outputs or even A/D converter outputs are multiplexed, but it has the obvious advantage of low cost due to sharing of a majority of sub-systems.Sufficient accuracy in measurements can be achieved even without the S/H, in cases where signal variations are extremely slow.

Multiplexing the Outputs of Sample/Hold:

When a large number of channels are to be monitored at the same time (synchronously) but at moderate speeds, the technique of multiplexing the outputs of the S/H is particularly attractive.An individual S/H is assigned to each channel as shown in Fig. 17.6, and they are updated synchronously by a timing circuit.

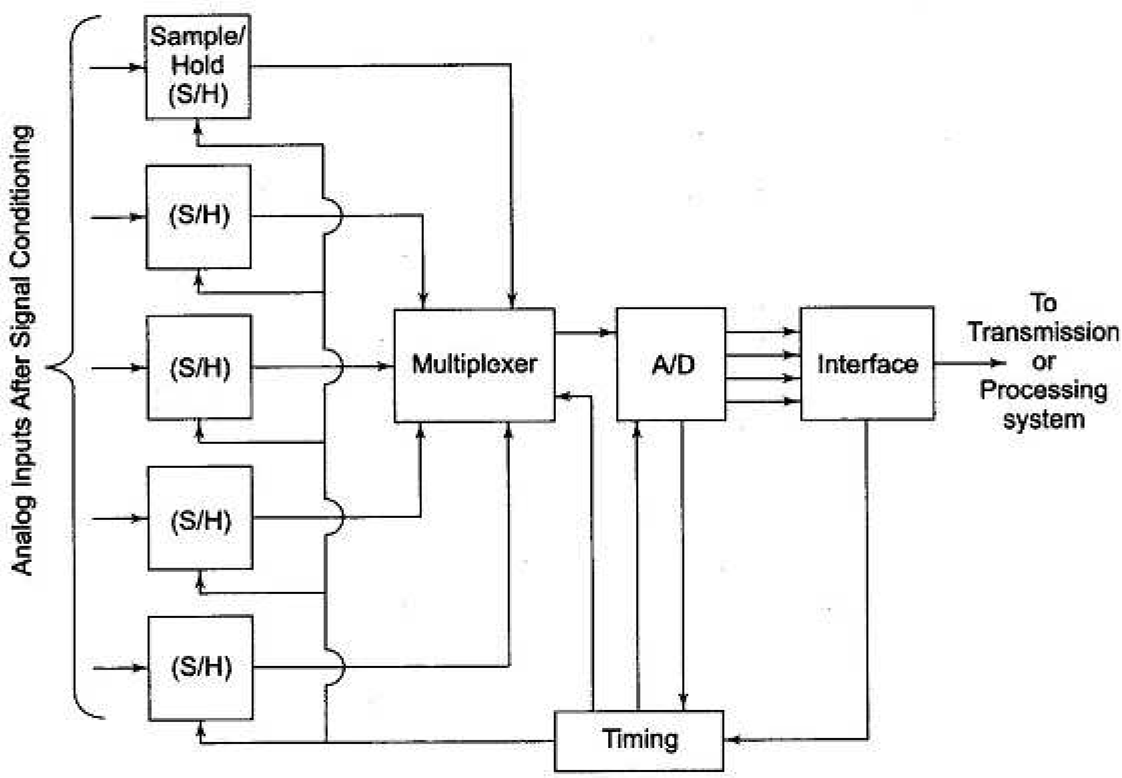


Fig. 17.6 Simultaneous Sampled System Multiplexer

The S/H outputs are connected to an A/D converter through a multiplexer, resulting in a sequential readout of the outputs.

(Applications that might require this approach include wind tunnel measurements, seismographic experimentation, radar and fire control systems. The event to be measured is often a one-shot phenomenon and information is required at a critical point during a one-shot event.)

Data Logger:

Data Logger Operation – For proper understanding of a Data Logger Operation, it is essential to understand the difference between analog and digital signals. For example, measurement of temperature by a milli voltmeter, whose needle shows a reading directly proportional to the emf generated by the thermocouple, is an analog signal.However, digital equipment presents a digital output in terms of pulses and involves an electronic pulse counting equipment which counts the number of pulses. The pulses are generated such that each pulse corresponds to the smallest value of the parameter being measured.These digital signals are precise at all times. Consider the example of temperature. In the case of analog measurements even the accuracy of the potentiometric method is limited by the precision with which the resistance can be subdivided. In the digital method, the electrical signal obtained from the thermocouple is subdivided by an electronic decade circuit and thus the thermocouple voltage can be measured to many places of decimal.

An analog device is capable of measuring with an error of ± 0.5% to ±1%,whereas a digital device can be obtained with an error of any ± 0.01%. An analog instrument responds to a change in input levels in times of the order of 0.25 to 1 s while a digital instrument gives accurate readings in a few hundredth's of a second, and often many times faster.

One advantage of a digital instrument is that its reading can be recorded by suitable printer.The Data Logger Operation senses only digital signals and hence analog signals, if any, have to be converted to digital signals. The digital technique is employed because it measures very small (or large) signals accurately and fast.The recording device may be a printed log or a punched paper tape. The printed output can be either line by line on a paper strip or on a type written page.Time words are printed at the start of each sequence. Time is recorded in hours, minutes and seconds. Data Logger Operation consists of the channel identity number, followed by polarity indication (+ or —), the measured value (4 or 6 digits) and units of measurement. Sometimes the range may also be indicated.

Basic parts of a Data Logger Operation:-

Input scanner

Signal conditioner

A/D converter

Recording equipment

Programmer

The block diagram of a Data Logger Operation involving all these parts is shown in Figure

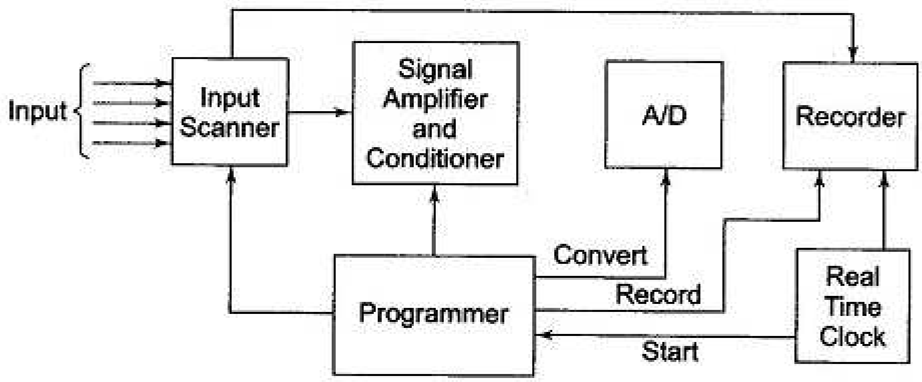


Fig. 17.24 Block Diagram of a Data Logger

The input scanner is an automatic sequence switch which selects each signal in turn. Low level signals, if any, are multiplied to bring them up to a level of 5 V. If the signals are not linearly proportional to the measured parameter, these signals are linearised by the signal conditioner.

The analog signals are then converted to digital signals suitable for driving the recording equipment (printer or punched paper tape).

The programmer (serialiser) is used to control the sequence operation of the various items of the logger. It tells the scanner when to step to a new channel, and receives information from the scanner, converter and recorder. The real time clock is incorporated to automatic the system. The clock commands the programmer to sequence one set of measurements at the intervals selected by the user.

Input Signals

The input signals fed to the input scanner of the Data Logger Operation can be of the following types.

1. **High level signals from pressure transducers**
2. **Low level signals from thermocouples**
3. **ac signals**
4. **Pneumatic signals from pneumatic transducers**
5. **On/off signals from switches, relays, etc.**
6. **Pulse train from tachometer**

7. **Digital quantities**

The last three signals (5, 6 and 7) are of the digital type and are handled by one set of input scanners and the remaining signals are of the analog type and are handled by a different set of input scanner.

Low level dc signals are first amplified and then conditioned by the law network and finally fed to the A/D converter.

High level signals are fed straight to law network and converter.The ac and pneumatic signals are first converted to electrical dc signals, conditioned and then converted.In this manner, all types of signals are converted to a form, suitable for handling by the data logger.The purpose of the conditioner is to provide a linear law for signals from various transducer which do not have linear characteristics.

Filters are used for noise and ripple suppression at the interface of the output of the transducers and the input of the signal conditioner, since these signals carried by the cables are of very low magnitude. Digital signals are then fed to the digital interface, whereas analog signals are first amplified, linearised and then brought to the analog interface. They are then converted into digital form and finally fed to the digital interface.

IEEE 488 BUS:-

The purpose of IEEE 488 BUS is to provide digital interfacing between program-mable instruments. There are many instrumentation systems in which interac-tive instruments, under the command of a central controller, provide superior error-free results when compared with conventional manually operated sys-tems.

Problems such as impedance mismatch, obtaining cables with proper connectors and logic level compatibility are also eliminated by designing the system around a bus-compatible instrument.

The basic structure of an IEEE 488 bus showing interfacing between interactive instruments is given in Figure.

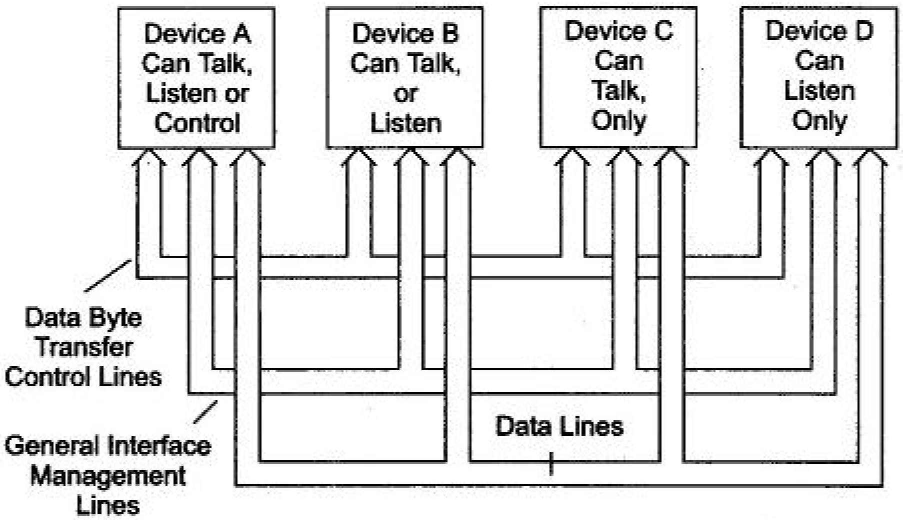
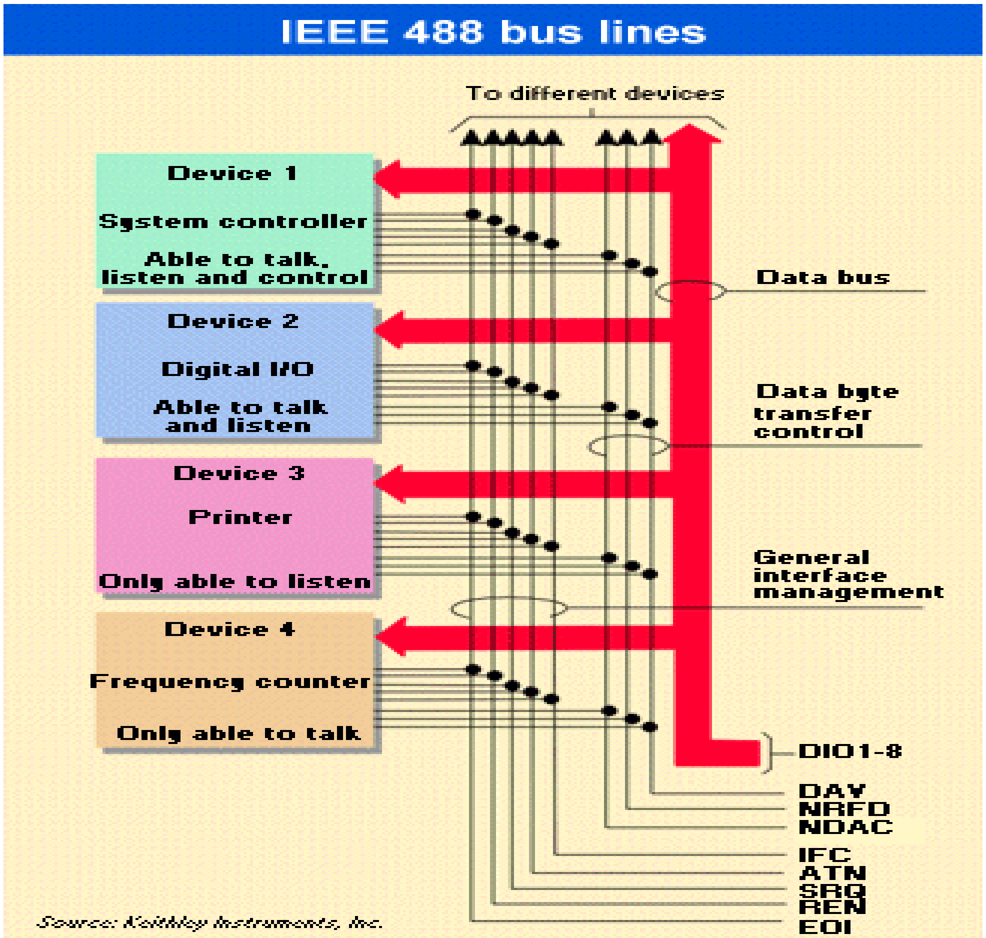


Fig. 6.29 Block Diagram of Devices Interfaced with IEEE 488 Bus

Every device in the system must be able to perform at least one of the roles, namely talker, listener or controller. A talker can send data to other devices via the bus. Some devices, such as programmable instruments, can both listen and talk.

In the listen mode it may receive an instruction to make a particular measure-ment and in the talk mode it may send its measurand. A controller manages the operation of the bus system. It controls data gathering and transfer by designat-ing which devices talk or listen as well as controlling specific actions within other devices.



The IEEE 488 standard permits up to 15 devices to be configured within one system. Each of these devices must have a unique address to avoid confusion. In a similar fashion, every building in town has a unique address to prevent one home from receiving another home's mail. Exactly how each device's address is set is specific to the product's manufacturer. Some are set by DIP switches in hardware, others by software. Consult the manufacturer's instructions to determine how to set the address.

Addresses are sent with universal (multiline) commands from the Active Controller. These commands include My Listen Address (MLA), My Talk Address (MTA), Talk Address Group (TAG), and Listen Address Group (LAG).

Bus Management Lines

Five hardware lines on the GPIB are used for bus management. Signals on these lines are often referred to as uniline (single-line) commands. The signals are active low—that is, a low voltage represents a logic "1" (asserted), and a high voltage represents a logic "0" (unasserted).

ATTENTION (ATN)

ATN is one of the most important lines for bus management. If Attention is asserted, then the information contained on the data lines is to be interpreted as a multiline command. If it isn't, then that information is to be interpreted as data for the Active Listeners. The Active Controller is the only bus device that has control

of this line.
INTERFACE CLEAR (IFC)
The IFC line is used only by the System Controller. It is used to place all bus devices in a known state. Although device configurations vary, the IFC command usually places the devices in the Talk and Listen Idle states (neither Active Talker nor Active Listener).

REMOTE ENABLE (REN)
When the System Controller sends the REN command, bus devices will respond to remote operation. Generally, the REN command should be issued before any bus programming is attempted. Only the System Controller has control of the Remote Enable line.
END OR IDENTIFY (EOI)
The EOI line is used to signal the last byte of a multibyte data transfer. The device that is sending the data asserts EOI during the transfer of the last data byte. The EOI signal is not always necessary, as the end of the data may be indicated by some special character such as carriage return.
The Active Controller also uses EOI to perform a Parallel Poll by simultaneously asserting EOI and ATN.
SERVICE REQUEST (SRQ)
When a device desires the immediate attention of the Active Controller it asserts SRQ. It is then the Controller's responsibility to determine which device requested service. This is accomplished with a Serial Poll or a Parallel Poll.

Handshake Lines
The GPIB uses three handshake lines in an "I'm ready—Here's the data—I've got it" sequence. This handshake protocol assures reliable data transfer, at the rate determined by the slowest Listener. One line is controlled by the Talker, while the other two are shared by all Active Listeners. The handshake lines, like the other IEEE 488 lines, are active low.
DATA VALID (DAV)
The DAV line is controlled by the Talker. The Talker verifies that NDAC is asserted (active low), which indicates that all Listeners have accepted the previous data byte transferred. The Talker then outputs data on the bus and waits until NRFD is unasserted (high), which indicates that all Addressed Listeners are ready to accept the information. When NRFD and NDAC are in the proper state, the Talker asserts DAV (active low) to indicate that the data on the bus is valid.

NOT READY FOR DATA (NRFD)
This line is used by the Listeners to inform the Talker when they are ready to accept new data. The Talker must wait for each Listener to unassert this line (high), which they will do at their own rate when they are ready for more data. This assures that all devices that are to accept the information are ready to receive it.

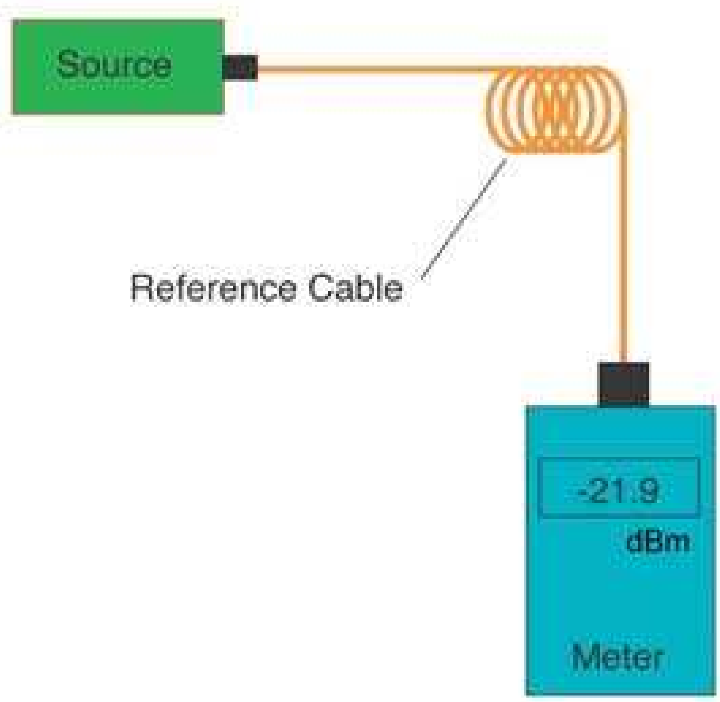
NOT DATA ACCEPTED (NDAC)

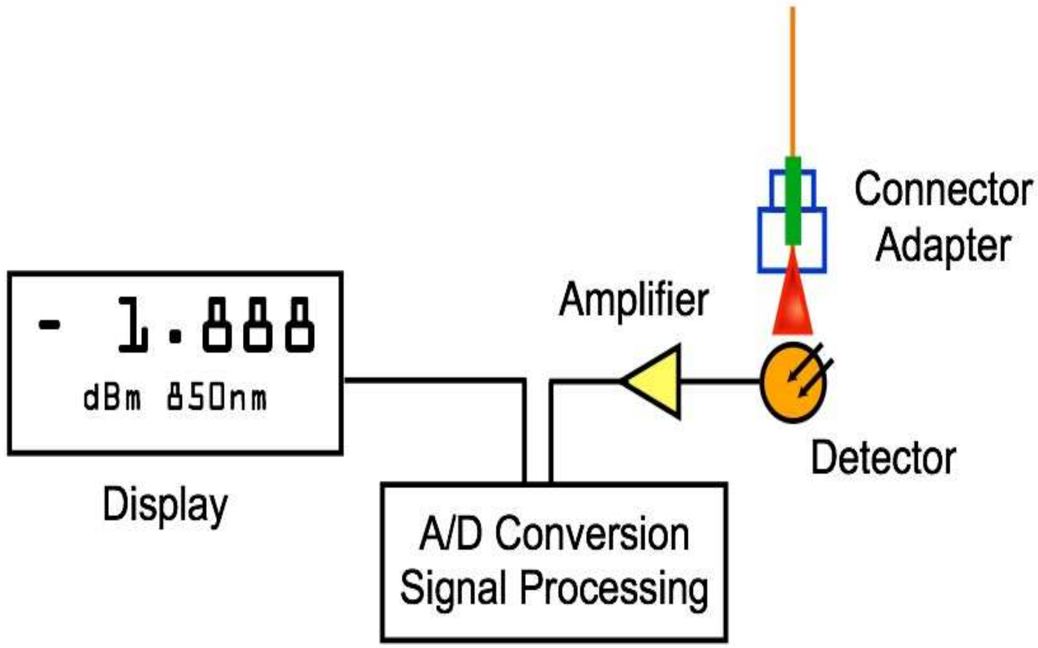
The NDAC line is also controlled by the Listeners. This line indicates to the Talker that each device addressed to listen has accepted the information. Each device releases NDAC (high) at its own rate, but the NDAC will not go high until the slowest Listener has accepted the data byte.

Data Lines
The GPIB provides eight data lines for a bit parallel/byte serial data transfer. These eight data lines use the convention of DIO1 through DIO8 instead of the binary designation of D0 to D7. The data lines are bidirectional and are active low.

OPTIC POWER MEASUREMENTS :-

The most basic fiber optic measurement is optical power from the end of a fiber. This measurement is the basis for loss measurements as well as the power from a source or presented at a receiver. Typically both transmitters and receivers have receptacles for fiber optic connectors, so measuring the power of a transmitter is done by attaching a test cable to the source and measuring the power at the other end. For receivers, one disconnects the cable attached to the receiver receptacle and measures the output with the meter.



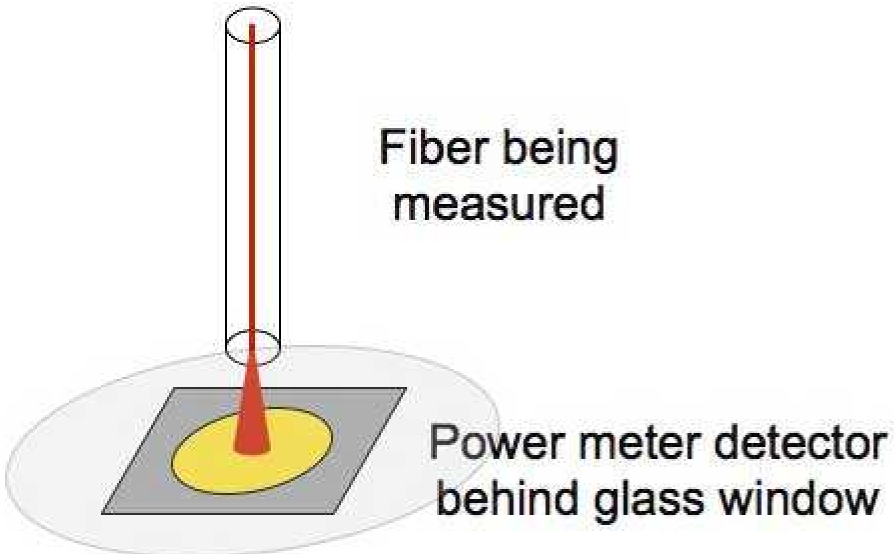


While optical power meters are the primary power measurement instrument, optical loss test sets (OLTSs) and optical time domain reflectometers (OTDRs) also measure power in testing loss. TIA standard test FOTP-95 covers the measurement of optical power.

Optical power is based on the heating power of the light, and some optical lab instruments actually measure the heat when light is absorbed in a detector. While this may work for high power lasers, these detectors are not sensitive enough for the low power levels typical for fiber optic communication systems

Optical power meters typically use semiconductor detectors since they are sensitive to light in the wavelengths and power levels common to fiber optics. Most fiber optic power meters are available with a choice of 3 different detectors, silicon (Si), Germanium (Ge), or Indium-Gallium-Arsenide (InGaAs).

Fiber optic power meters have inputs for attaching fiber optic connectors and detectors designed to capture all the light coming out of the fiber. Power meters generally have modular adapters that allow connecting to various types of connectors. This connection is considered a "no loss" connection. In reality, we do not capture all the light from the fiber because there is a glass window on the detector and that window and the detector are slightly reflective. However the coupling is very consistent and when we calibrated the meter, we calibrate with a fiber optic cable under the same conditions. Thus, what we measure of the light by presenting a connector to the power meter is both consistent and calibrated as long as you choose the proper calibration wavelength.



OPTICAL TIME DOMAIN REFELECTOMETER:-

An OTDR is the optical equivalent of an electronic time domain reflectometer. It injects a series of optical pulses into the fiber under test and extracts, from the same end of the fiber, light that is scattered (Rayleigh backscatter) or reflected back from points along the fiber.

OTDR Working Principles

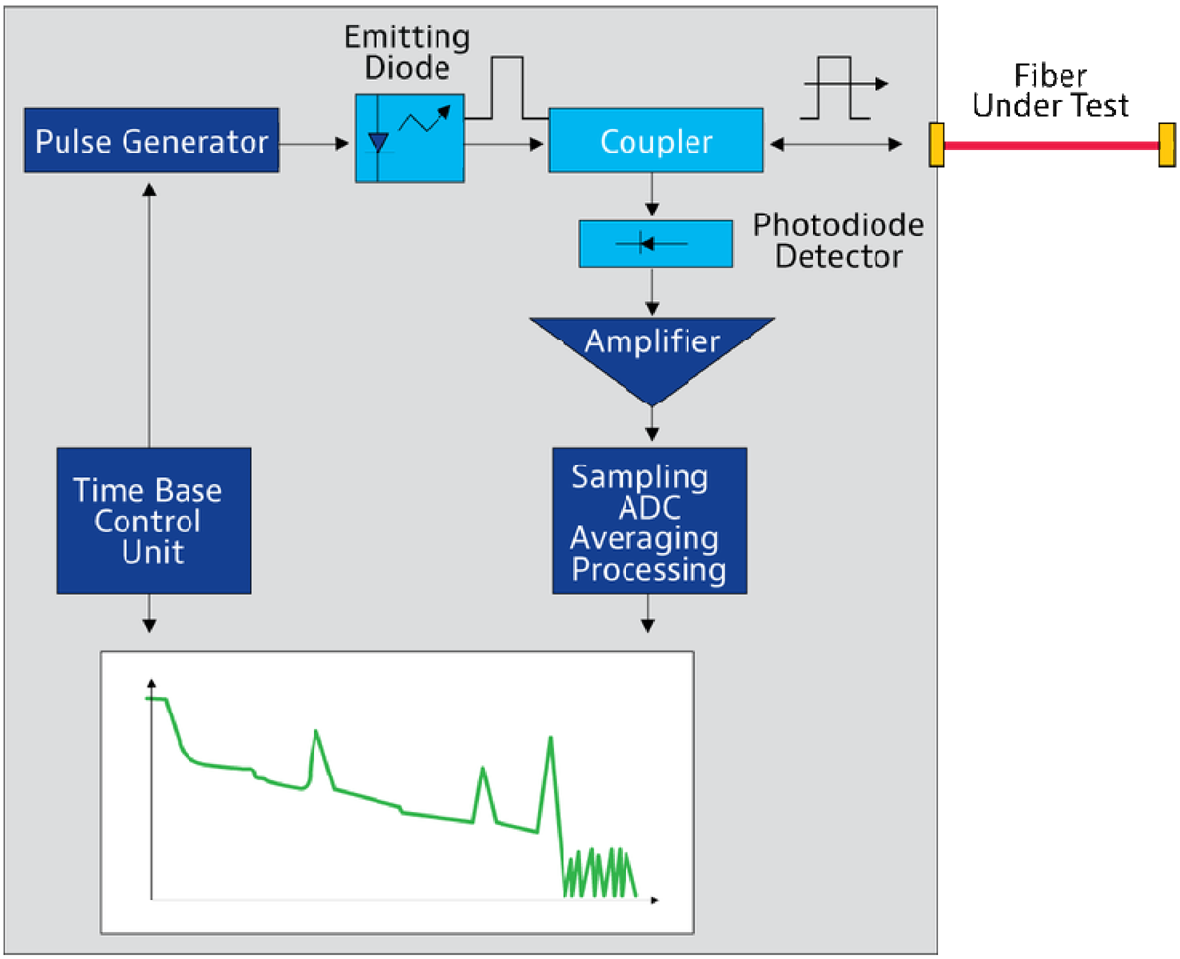
The accuracy and utility of OTDR testing would not be possible without the science that preceded it. Understanding the physics behind the instrument provides invaluable insight into the working principles of OTDR.

When Albert Einstein theorized that electrons could be stimulated to emit a particular waveform, the seed of possibility that would eventually lead to the first operational laser in 1960 was born. While the applications envisioned at that time probably did not include worldwide telecommunications using fiber optics, this technology has now become synonymous with twenty-first century connectivity.

Over the years, many breakthrough discoveries have been leveraged in the development of OTDR testers.

OTDR Symbol Meanings

An OTDR contains a laser diode source, a photodiode detector and a highly accurate timing circuit (or time base). The laser emits a pulse of light at a specific wavelength, this pulse of light travels along the fiber being tested, as the pulse moves down the fiber portions of the transmitted light are reflected/refracted or scattered back down the fiber to the photo detector in the OTDR. The intensity of this returning light and the time taken for it to arrive back at the detector tells us the loss value (insertion and reflection), type and location of an event in the fiber link.



OTDR Basics and Functions

The inherent value of OTDR testing comes from diagnosing the condition of a fiber optic cable that would otherwise be impossible to see. This is essential when the link contains multiple splices and connections that can be subject to failure.

The optical return loss (ORL) and reflectance can be used to diagnose conditions where more loss than expected is occurring at a specific location in the fiber run. The total fiber attenuation can also be assessed, since the amount of backscatter provides an indication of this value.

These same principles are used to calculate distance measurements that are invaluable when repair, troubleshooting or maintenance needs arise. The end of the fiber link or a fiber break will be detectable through Fresnel reflection, since a break or unterminated fiber end is also a change in material media (glass to air). In addition to the overall length of the fiber, the distance to faults, splices and connections can be determined with a graphical presentation of the findings accompanying the analysis.

OTDR Types

As the functional utility of OTDR testing increases along with the demand for enhanced testing speed, accuracy, report generation and storage capabilities, the variation in product offerings continues to diversify. The two predominant categories are bench-top and hand-held. A bench-top OTDR is essentially a feature-rich instrument with a direct AC power source, whereas a hand-held or compact OTDR is typically a lightweight, battery-powered device intended for use in the field.

Beyond this basic division, the features and options available for an OTDR should be carefully considered based on the intended use. One important consideration is the type of fiber you will be testing - multimode, single-mode, or both. Another variable is the length of fiber you will be testing. Products designed for long haul applications typically have higher dynamic range capabilities that would not be required for testing shorter fiber optic links, such as FTTA.

Usability features also vary by product, which is yet another reason the intended application for the OTDR should be the most important factor in product selection (Import factors for choosing an OTDR). For example, a light weight product might not be necessary for a stationary test, but if the testing is going to be performed by technicians climbing cell towers or working in an otherwise active setting, weight, as well as features like battery life and ruggedization of the product enclosure become more important.

OTDR Parameters

With the wide variety of applications for OTDR testing, setting parameters accurately for the task at hand will ensure accurate measurements. Using an auto-test function may be sufficient for some tests, but manual setting of parameters is still advisable given the variation in length, type, and complexity of optical fiber runs. Once the correct parameters for testing a given fiber run have been established, these OTDR testing configurations can be recalled from an instruments memory the next time the same or similar run is evaluated.