SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS

UNIT – I

MEASUREMENT AND INSTRUMENTATION – SEIA3001

UNIT 1
1. BASIC MEASUREMENT

Measurement systems – Static and dynamic characteristics – units and standards of measurements – error :- accuracy and precision, types, statistical analysis – moving coil, moving iron meters – Electrodynamo meter type wattmeter- Energy meter multimeters – Bridge measurements : – Maxwell, Hay, Schering, Anderson and Wien bridge.

1.1 MEASUREMENT SYSTEM

Measurement system, any of the systems used in the process of associating numbers with physical quantities and phenomena. Although the concept of weights and measures today includes such factors as temperature, luminosity, pressure, and electric current, it once consisted of only four basic measurements: **mass** (weight)**, distance or length, area,** and **volume** (liquid or grain measure).Basic to the whole idea of weights and measures are the concepts of uniformity, units, and standards. Uniformity, the essence of any system of weights and measures, requires accurate, reliable standards of mass and length and agreed-on units. A unit is the name of a quantity, such as kilogram or pound. A standard is the physical embodiment of a unit, such as the platinum-iridium cylinder kept by the International Bureau of Weights and Measures at Paris as the standard kilogram. Two types of measurement systems are distinguished historically: an **evolutionary system**, such as the British Imperial, which grew more or less haphazardly out of custom, and a **planned system**, such as the **International System of Units** (SI), in universal use by the world's scientific community and by most nations.

The International System of Units (French: Système international d'unités, SI) is the modern form of the metric system, and is the most widely used system of measurement. It comprises a coherent system of units of measurement built on seven base units. It defines twenty-two named units, and includes many more unnamed coherent derived units. The system also establishes a set of twenty

1.1.1 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 1.

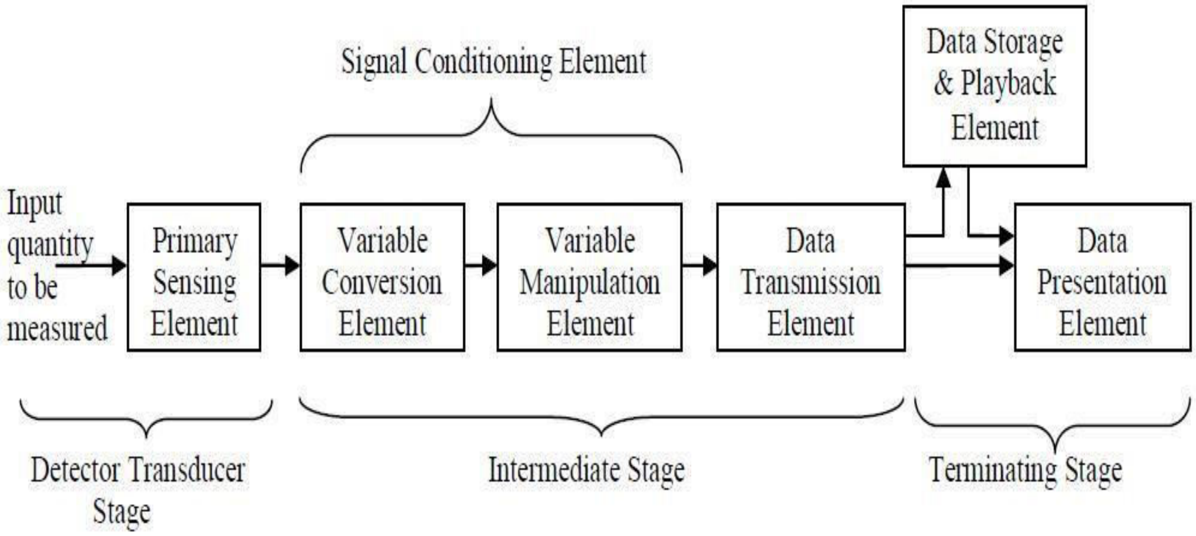


Fig 1.1: Functional elements of generalized measurement system

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 directly converted 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 in the numerical value of signal.

Examples,

1. Voltage amplifier is act as variable manipulation element. Voltage amplifier accepts a small voltage 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 and produces 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 etc.,
   - Nonlinear process manipulation elements: Modulation, detection, sampling, filtering, chopping and clipping etc.,

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 Signal Conditioning 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.

1.1.2 EXAMPLE OF GENERALIZED MEASUREMENT SYSTEM

Bourdon Tube Pressure Gauge:

The simple pressure measurement system using bourdon tube pressure gauge is shown in figure 2.The detail functional elements of this pressure measurement system is given below.

Primary sensing element and : Pressure Sensed

Variable conversion element	: Bourdon Tube
Data Transmission element	: Mechanical
Linkages Variable manipulation Element arrangement	: Gearing
Data presentation Element	: Pointer and Dial

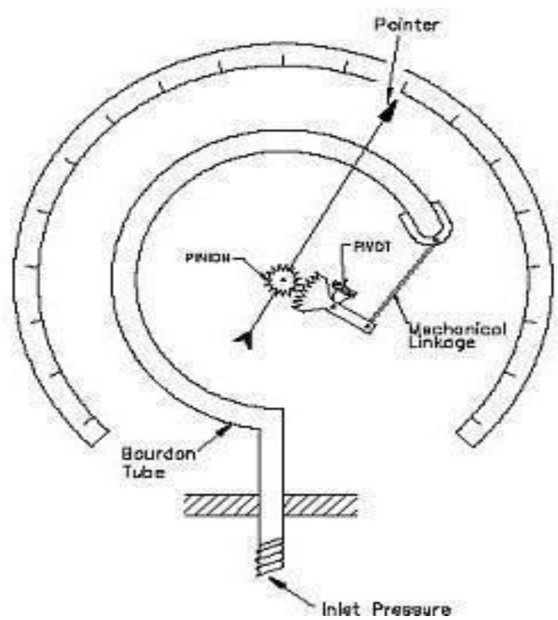


Fig. 1.2 Bourdon tube pressure gauge

In this measurement system, bourdon tube is act as primary sensing and variable conversion element. The input pressure is sensed and converted into small displacement by a bourdon tube. On account of input pressure the closed end of the tube is displaced. Because of this pressure in converted into small displacement. The closed end of bourdon tube is connected through mechanical linkage to a gearing arrangement.

The small displacement signal can be amplified by gearing arrangement and transmitted by mechanical linkages and finally it makes the pointer to rotate on a large angle of scale. If it is calibrated with known input pressure, gives the measurement of the pressure signal applied to the bourdon tube in measurand.

1.2 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 for instruments 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 for instruments which are used to measure a varying process condition. Performance criteria based upon dynamic relations represent the dynamic Characteristics.

1.2.1 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.

Table1: Comparison between accuracy and precision

Accuracy	Precision
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
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 measuring instruments 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.

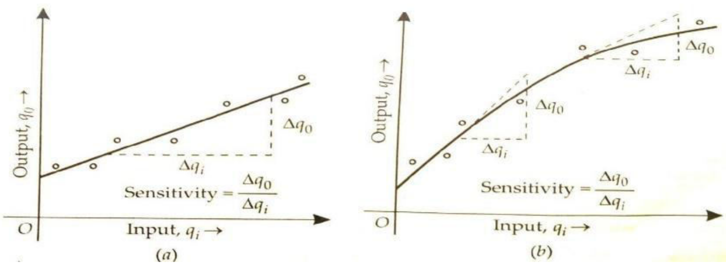


Fig. 3: Definition of sensitivity for (a) Linear and (b) Non linear instrument

When the calibration curve is linear as in figure 3a 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 3b.

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.

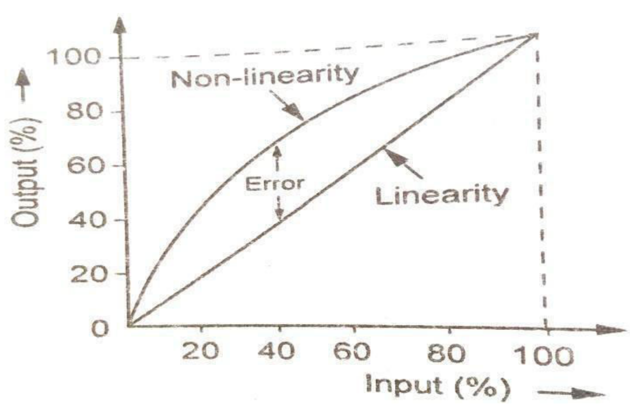


Fig.4: Representation of Linearity and Non-Linearity of an Instrument

Nonlinearity: The maximum difference or deviation of output curve from the

Specified idealized straight line as shown in figure 4. 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 5.(The different outputs from the same value of quantity being measured are reached by a continuously increasing change or a continuously decreasing change)

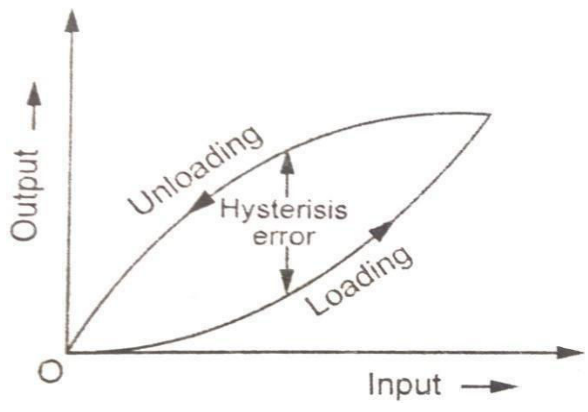


Fig. 1.3: Hysteresis Error of an instrument

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 input quantity.

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)

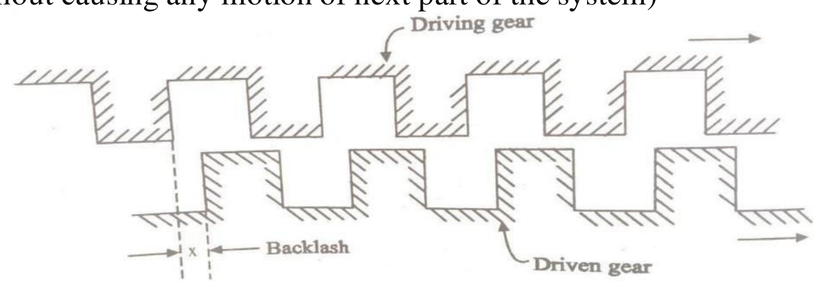


Fig. 1.4: Threshold because of backlash

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 7. (Threshold is the minimum value of the input required to cause the pointer to move from zero position).

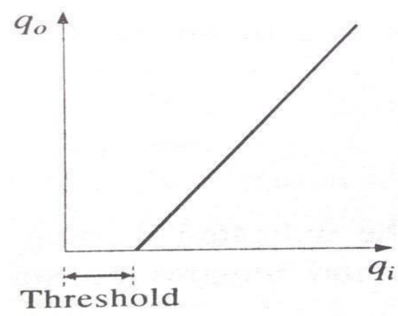


Fig. 1.5 Threshold effect

11) Input Impedance

The magnitude of the impedance of element connected across the signal source is called Input Impedance. Figure 8 shows a voltage signal source and input device connected across it.

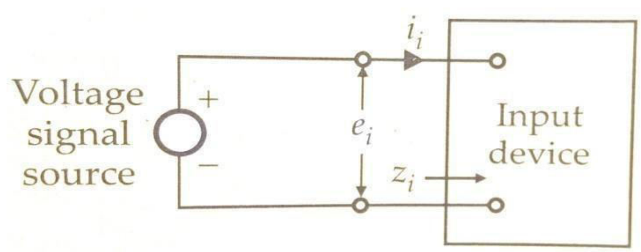


Fig. 1.6 voltage source and input device

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.

15) Static Error

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

Error = Measured value - True

Value $\delta A = A_m - A_t$

δA - error

A_m - Measured value of

quantity A_t - True value of

quantity

16) Static Correction

It is the difference between the true value and the measurement value of the quantity

$\delta C = A_t – A_m = - \delta A$

δC – Static correction

17) Scale Range

It can be defined as the measure of the instrument between the lowest and highest readings it can measure. A thermometer has a scale from −40°C to 100°C. Thus the range varies from −40°C to 100°C.

18) Scale Span

It can be defined as the range of an instrument from the minimum to maximum scale value. In the case of a thermometer, its scale goes from −40°C to 100°C. Thus its span is 140°C. As said before accuracy is defined as a percentage of span. It is actually a deviation from true expressed as a percentage of the span.

1.2.2 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.

1. **Step Input:** Step change in which the primary element is subjected to an instantaneous and finite 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 measured variable, 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

(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 a change in measured variable is occurred.

- **Time delay type:** In this case the response of an instrument begins after a dead time after the application of the input quantity.

(iv) Dynamic Error

Error which is caused by dynamic influences acting on the system such as vibration, roll, pitch or linear acceleration. This error may have an amplitude and usually a frequency related to the environmental influences and the parameters of the system itself.

1.3 UNITS AND STANDARDS OF MEASUREMENTS

1.3.1 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

1.3.2 Voltage

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

1.4CLASSIFICATION 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

i) 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

a) 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.

b) 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.

c) 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.

ii) 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

iii) 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 3.1.

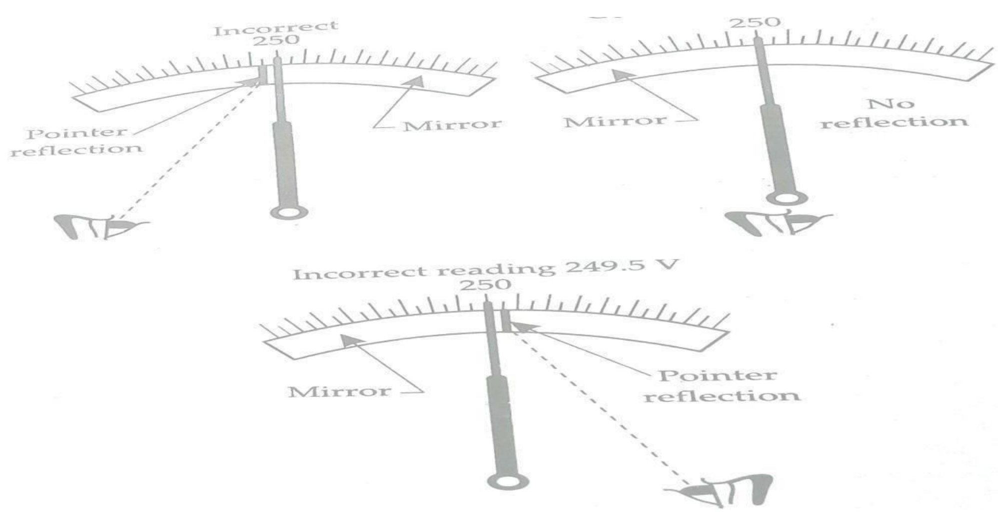


Fig. 1.7: Errors due to parallax

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,

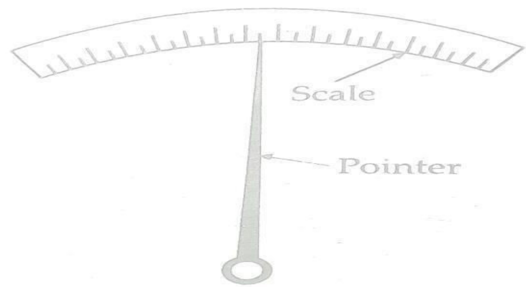


Fig.1.8: Arrangements showing scale and pointer in the same plane

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.

1.4.1 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.

Certain design limitations.

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.

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

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.

$$\varepsilon_0 = \delta A \underline{\hspace{4cm}} (2)$$

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.

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

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

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

$$A_t = A_m - \varepsilon_0$$

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

$$A_t + \varepsilon_r A_t = A_m$$

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

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

$\varepsilon_0 = \delta A$ 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), $A_t = A_m - \varepsilon_r A_t$

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

$$A_t = A_m - \varepsilon_r A_m$$

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

1.5 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 acquired by different instruments, different methods of measurement and different observer.
- **Single Sample Test:** measured data have been acquired by identical conditions (same
  instrument, 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 = Readings or variable or samples and n= number of 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.,

Average Deviation:

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

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).

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

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

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.

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

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

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

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 any measurement.

1.6 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.

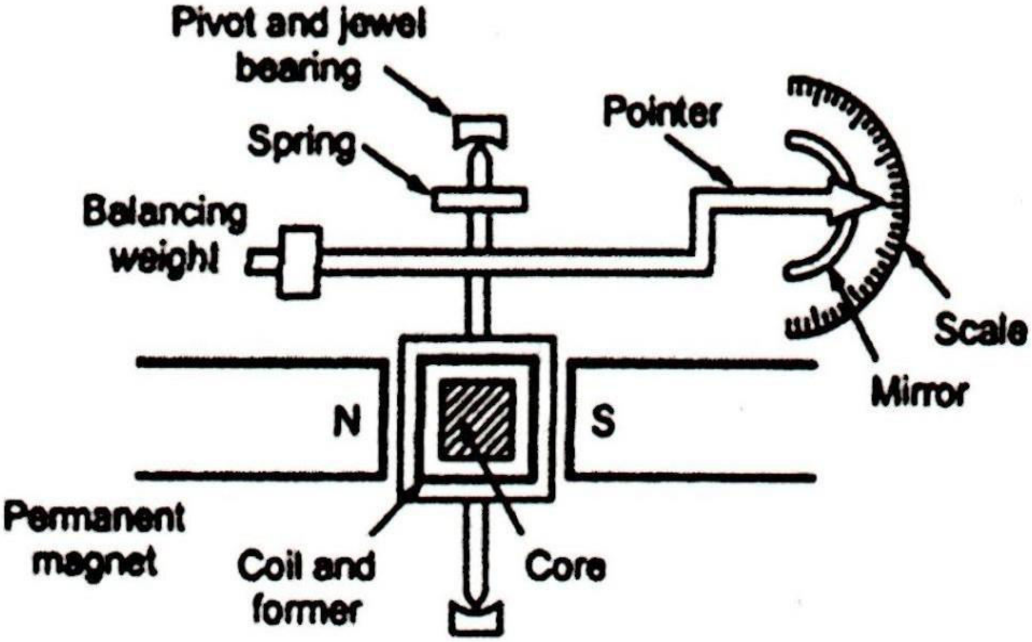


Fig.1.9 Permanent magnet moving coil

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

1. Uniform scale.
2. Very effective eddy current damping
3. Power consumption is low.
4. No hysteresis loss.
5. They are not affected by stray field.
6. Require small operating current.
7. Accurate and reliable.

Disadvantage of PMMC instrument

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

1.7 MOVING IRON INSTRUMENT

There are classified in to two type

1. Attraction type moving iron instrument
2. Repulsion type moving iron instrument

1.7.1 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

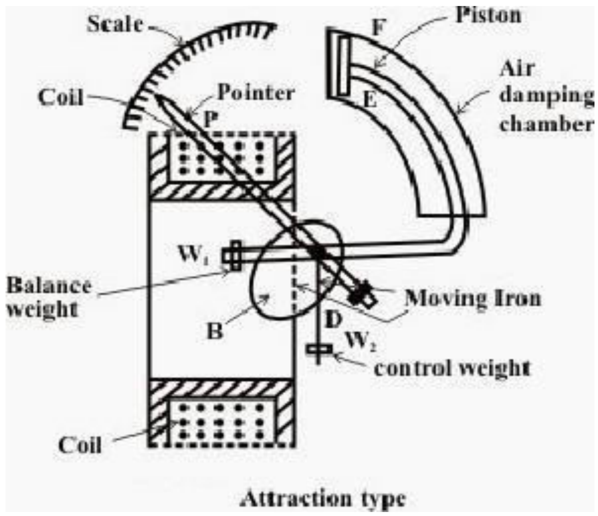


Fig.1.10 Attractive moving iron Instrument

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;

a) Field strength H, produced by the coil.

b)pole strength „m" developed in the iron piece.

F α mH

Since, m α H,

F α H^2

Instantaneous deflecting torque α H^2

Also, the field strength H = μi

If the permeability(μ) of the iron is assumed constant,

Then, H α i

Where, i® instantaneous coil current, Ampere

Instantaneous deflecting torque α i^2

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

Since the instrument is spring controlled,

Tc α θ

In the steady position of deflection, Td = Tc θ

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).

1.7.2 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:

i) Radial vane type and

ii) Co-axial vane type

iii) Radial van repulsion type instrument

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

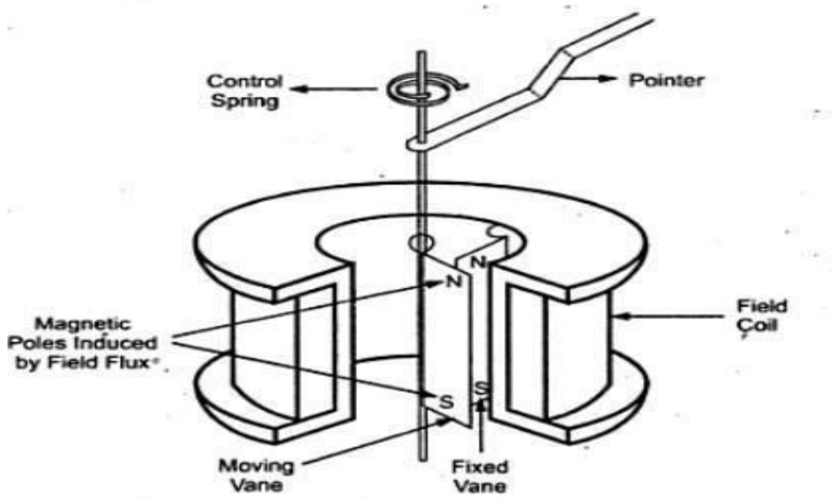


Fig.1.11 Radial vane

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

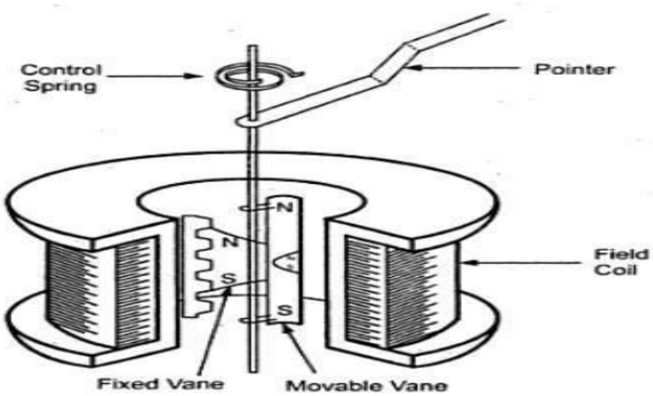


Fig.1.12 Vane repulsion type

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.

Torque 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 $\alpha\ m_1 m_2\ \alpha\ H^2$

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

Instantaneous deflecting torque $\alpha\ i^2$

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

Since the instrument is spring controlled, $T_c\ \alpha\ \theta$

In the steady position of deflection, $Td = T_c\ \theta$

α mean of i^2 over a cycle.

$\alpha\ I^2$

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.
2) As the torque to weight ratio is high, errors due to the friction are very less.
3) A single type of moving element can cover the wide range hence these instruments are cheaper than other types of if instruments.
4) There are no current carrying parts in the moving system hence these meters are extremely rugged and reliable.
5) These are capable of giving good accuracy. Modern moving iron instruments have a d.c. error of 2% or less.
6) These can withstand large loads and are not damaged even under sever overload conditions.
7) The range of instruments can be extended.

Disadvantages

1) 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.
2) There are serious errors due to hysteresis, frequency changes and stray magnetic fields.
3) The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability and hence affect the reading severely.
4) Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.
5) 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.
6) Power consumption is on higher side.

Errors in moving iron instrument

1) **Hysteresis error:** Due to hysteresis effect, the flux density for the same current while 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.

2) **Temperature error:** The temperature error arises due to the effect of temperature on the temperature coefficient of the spring. This error is of the order of 0.02 % 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.

3) **Stray magnetic Field Error:** The operating magnetic field in case of moving iron instruments 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.

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

5) **Eddy Current Error** : When instrument is used for a.c. measurements the eddy currents 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.

1.8 ELECTRODYNAMOMETER WATTMETER

Dynamometer type wattmeter works on very simple principle and this principle can be stated as "when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due this mechanical force deflection of conductor takes place".

Construction and Working Principle

.

It consists of following parts

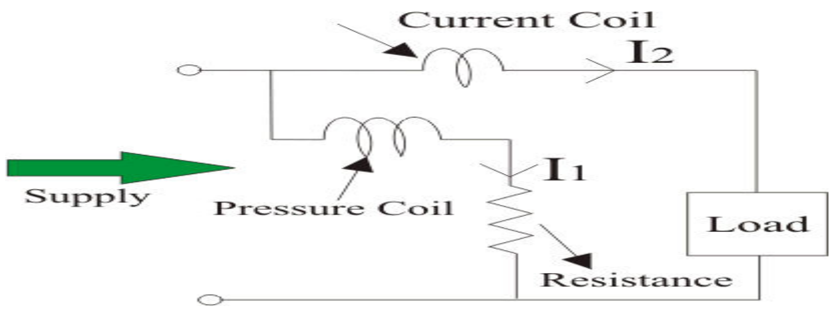


Fig.1.13 Electrodynamometer

There are two types of coils present in the electrodynamometer. They are :

(a) Moving coil : Moving coil moves the pointer with the help of spring control instrument. A limited amount of current flows through the moving coil so as to avoid heating. So in order to limit the current we have connect the high value resistor in series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can moves freely. In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

(b) Fixed coil: The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coils instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

(c) Control system: Out of two controlling systems i.e.

(1) Gravity control

(2) Spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will appreciable amount of errors.

(d) Damping system: Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may leads to error.

(e) Scale: There is uniform scale is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either sides.

Now let us derive the expressions for the controlling torque and deflecting torques. In order to derive these expressions let us consider the circuit diagram given

We know that instantaneous torque in electrodynamic type instruments is directly proportional to product of instantaneous values of currents flowing through both the coils and the rate of change of flux linked with the circuit.

Let I1 and I2 be the instantaneous values of currents in pressure and current coils respectively. So the expression for the torque can be written as:

$$T = {}_1 \times I_2 \times \frac{dM}{dx}$$

where x is the angle.

Now let the applied value of voltage across the pressure coil be

$$= \quad \bar{2}V \sin \omega t$$

Assuming the electrical resistance of the pressure coil be very high hence we can neglect reactance with respect to its resistance. In this the impedance is equal to its electrical resistance therefore it is purely resistive.The expression for instantaneous current can be written as I2 = v / Rp where Rp is the resistance of pressure coil.

$$I_2 = 2 \times \frac{V \sin \omega t}{R_p}$$

If there is phase difference between voltage and electric current, then expression for instantaneous current through current coil can be written as

$$I_1 = I \ t \ = \ \bar{2}I \sin(\omega t - \emptyset)$$

As current through the pressure coil in very very small compare to current through current coil hence current through the current coil can be considered as equal to total load current.

Hence the instantaneous value of torque can be written as

$$2 \times \frac{V \sin \omega t}{R_p} \times 2I \sin \omega t - \emptyset \qquad \frac{dM}{dx}$$

Average value of deflecting torque can be obtained by integrating the instantaneous torque from limit 0 to T, where T is the time period of the cycle.Controlling torque is given by Tc = Kx where K is spring constant and x is final steady state value of deflection.

Advantages of Electrodynamometer Type Wattmeter

Following are the advantages of electrodynamometer type wattmeters and they are written as follows:

(a) Scale is uniform upto certain limit.

(b) They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

Errors in Electrodynamometer Type Wattmeter

Following are the errors in the electrodynamometer type wattmeters:

(a) Errors in the pressure coil inductance

(b) Errors may be due to pressure coil capacitance

(c) Errors may be due to mutual inductance effects

(d) Errors may be due connections (i.e. pressure coil is connected after current coil)

(e) Error due to Eddy currents

(f) Errors caused by vibration of moving system

(g) Temperature error

(h) Errors due to stray magnetic field

1.9 BRIDGE MEASUREMENTS

1.9.1 Maxwell's inductance bridge

The choke for which R1 and L1 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.

L2 is adjusted, until the detector indicates zero current.

Let R1=unknown resistance

L1= unknown

L2 is adjusted, until the detector indicates zero current.

Let R1= unknown resistance

L1= unknown inductance of the choke.

L2= known standard inductance

R1,R2,R4= known resistances

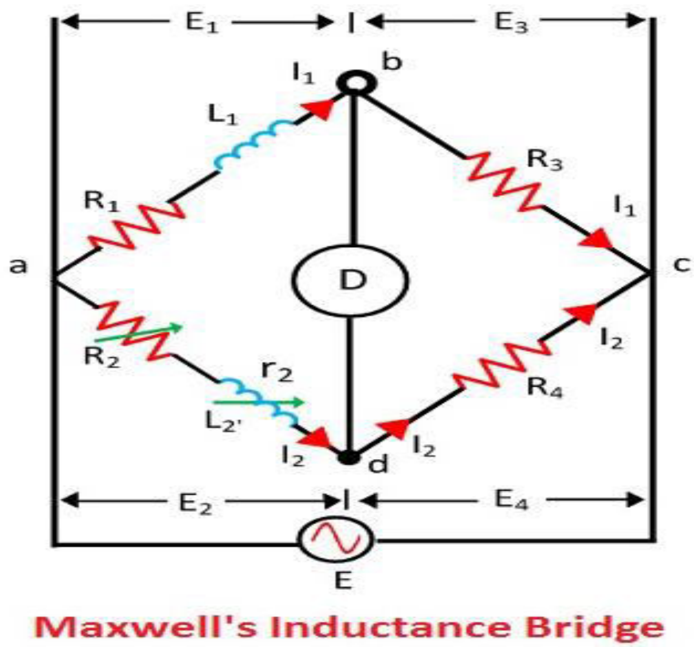


Fig 1.14 Circuit Diagram

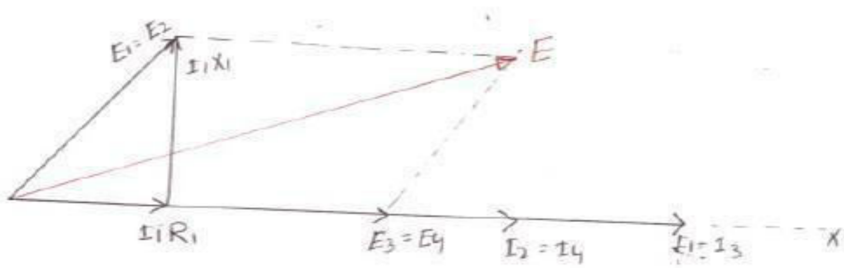


Fig.1.15 Phasor diagram of Maxwell Bridge

Impedance of arm ab, $Z_1 = (R_1+j\omega L_1)$
Impedance of arm ad, $Z_2 = (R_2+r_2+j\omega L_2)$
Impedance of arm bc, $Z_3 = R_3$
Impedance of arm cd, $Z_4 = R_4$
Hence for balanced bridge,

Table1:Maxwell Bridge Parameter

Parameter	IMPEDANCE (Z)	ADMITTANCE (Y) [Y=1/Z]
Resistance(R)	R	1/R
Inductance(L)	jωL	1/jωL
Capacitance(C)	1/jωC	jωC

$$Z_1 Z_4 = Z_2 Z_3$$
$$(R_1+j\omega L_1) R_4=(R_2+r_2+j\omega L_2) R_3$$
$$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3+r_2 R_3 +j\omega L_2 R_3$$
$$R_1 R_4 + j\omega L_1 R_4 = (R_2 +r_2) R_3 +j\omega L_2 R_3$$

- Equating real and imaginary parts
- $R_1 R_4 = (R_2 +r_2) R_3$
- $\boxed{R_1 = (R_2+r_2) (R_3/R_4)}$
- $L_1 R_4 = L_2 R_3$

$\boxed{L_1 = L_2 (R_3 / R_4)}$

- Thus unknown inductance L_1 and its resistance R_1 may be calculated.

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

5.1.2 Maxwell's Inductance Capacitance Bridge

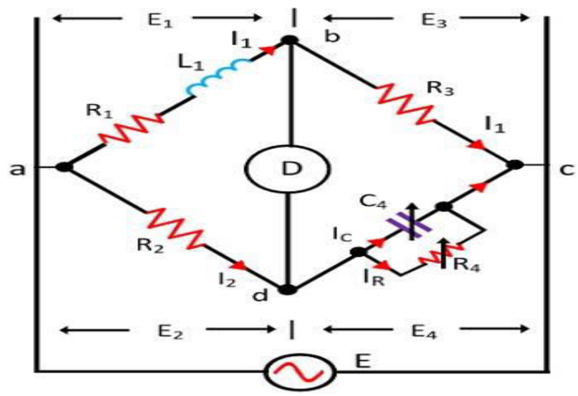


Fig .1.16 Maxwell's Inductance Capacitance Bridge

The unknown inductance is measured with the help of the standard variable capacitance.

L_1 = Unknown inductance with resistance R_1

C_4 =variable standard capacitor

R_2, R_3, R_4 = Known non inductive resistances

Impedance of arm ab, $Z_1 = (R_1+j\omega L_1)$

Impedance of arm ad, $Z_2 = R_2$

Impedance of arm bc, $Z_3 = R_3$

Impedance of arm cd, $Z_4 = 1/\ Y_4$ (R_4 parallel to C_4)

$Y_4 = (1/R_4)+j\omega C_4$

Hence for balanced bridge,

$$Z1Z4 = Z2\ Z3$$

$$Z1(\ 1/\ Y4\ ) = Z2\ Z3$$

$$Z1 = Z2\ Z3\ Y4$$

$$(R1+j\omega L1) = R2\ R3\ ((1/R4)+j\omega\ C4)$$

$$(R1+j\omega L1) = (R2\ R3\ /R4)+j\omega\ C4\ R2\ R3$$

Equating real and imaginary parts

$R_1 = (R_2 R_3 / R_4)$
$L_1 = C_4 R_2 R_3$
Thus unknown inductance L1 and its resistance R1 may be calculated

Table2: Maxwell Capacitance Bridge

Parameter	IMPEDANCE (Z)	ADMITTANCE (Y) [Y=1/Z]
Resistance(R)	**R**	**1/R**
Inductance(L)	**jωL**	**1/jωL**
Capacitance(C)	**1/jωC**	**jωC**

1.9.2 HAY'S BRIDGE

Hay's bridge is modified Maxwell bridge, now question arises here in our mind that where we need to do modification.

- The **Hay's bridge** is used for **determining** the **self-inductance** of the **circuit**.
- The bridge is the **advanced form** of **Maxwell's bridge**.
- The Maxwell's bridge is only appropriate for measuring the medium quality factor.
- Hence, for **measuring** the **high-quality factor** the **Hays bridge** is used in the circuit.
- In **Hay's bridge**, the **capacitor** is **connected** in **series** with the **resistance**, the voltage drop across the capacitance and resistance are varied.
- And in Maxwell bridge, the **capacitance** is **connected** in **parallel** with the **resistance**.
- Thus, the magnitude of a voltage pass through the resistance and capacitor is equal.

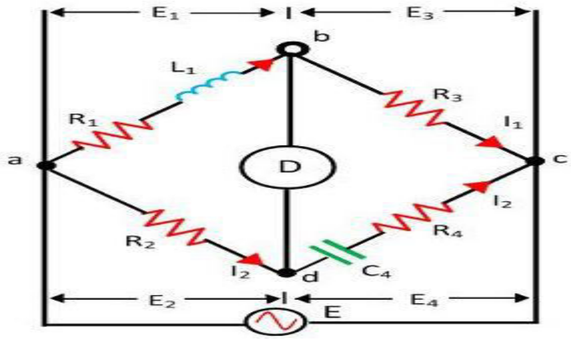


Fig .1.17 Hays Bridge

The unknown inductor L_1 is placed in the arm ab along with the resistance R_1. This unknown inductor is compared with the standard capacitor C_4 connected across the arm cd. The resistance R_4 is connected in series with the capacitor C_4. The other two non-inductive resistor R_2 and R_3 are connected in the arm ad and bc respectively. The **C_4** and **R_4** are adjusted for making the bridge in the balanced condition. When the bridge is in a balanced condition, no current flows through the detector which is connected to point **b** and **c** respectively. The potential drops across the arm **ad** and **cd** are equal and similarly, the potential across the arm **ab** and **bc** are equal.

Let,
L_1 – unknown inductance having a resistance R_1
R_2, R_3, R_4 – known non-inductive resistance.
C_4 – standard capacitor

At balance condition,

$$(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2 R_3$$

$$R_1 R_4 + \frac{L_1}{C_4} + j\omega L_1 R_4 - \frac{jR_1}{\omega C_4} = R_2 R_3$$

Separating the real and imaginary term, we obtain

$$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3 \quad and\ L_1 = \frac{-\ R_1}{\omega^2 R_4 C_4}$$

Solving the above equation, we have

$$L_1 = \frac{R_2 R_3 C_4}{1 + \omega^2 R_4^2 C_4^2}$$

$$R_1 = \frac{\omega^2 C_4^2 R_2 R_3 R_4}{1 + \omega^2 R_4^2 C_4^2}$$

The equation of the unknown inductance and capacitance consists frequency term. Thus for finding the value of unknown inductance the frequency of the supply must be known.

For the high-quality factor, the frequency does not play an important role.

$$Q = \frac{1}{\omega^2 C_4 R_4}$$

Substituting the value of Q in the equation of unknown inductance, we get

$$L_1 = \frac{R_2 R_3 C_4}{1 + (1/Q)^2}$$

For greater value of Q the 1/Q is neglected and hence the equation become

$$L_1 = R_2 R_3 C_4$$

The quality factor of the coil is

$$Q = \frac{\omega L_1}{R_1} = \frac{1}{\omega^2 C_4 R_4}$$

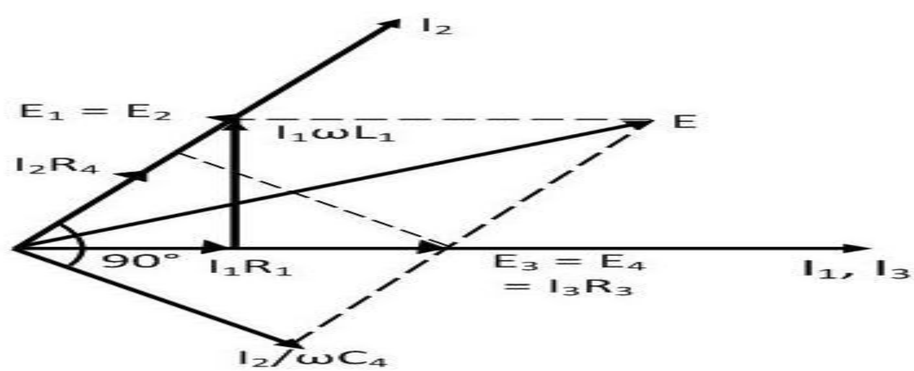


Fig.1.18 Phasor diagram for hays bridge

The phasor diagram of the Hay's bridge is shown in the figure below.The magnitude and the phase of the $\mathbf{E_3}$ and $\mathbf{E_4}$ are equal and hence they are overlapping each other and draw on the horizontal axis. The current $\mathbf{I_1}$ flow through the purely resistive arm **bd.** The current $\mathbf{I_1}$ and the potential $E_3 = I_3R_3$ are in the same phase and represented on the horizontal axis. The current passes through the arm **ab** produces a potential drop $\mathbf{I_1R_1}$ which is also in the same phase of $\mathbf{I_1}$.

The total voltage drop across the arm **ab** is determined by adding the voltage $\mathbf{I_1R_1}$ and $\mathbf{\omega I_1L_1}$.

The voltage drops across the arm **ab** and **ad** are equal. The voltage drop $\mathbf{E_1}$ and $\mathbf{E_2}$ are equal in magnitude and phase and hence overlap each other. The current $\mathbf{I_2}$ and $\mathbf{E_2}$ are in the same phase as shown in the figure above.The current $\mathbf{I_2}$ flows through the arms **cd** and produces the I_2R_4 voltage drops across the resistance and $I_2/\omega C_4$ voltage drops across the capacitor C_4. The capacitance C_4 lags by the currents 90º.

The voltage drops across the esistance C_4 and R_4 gives the total voltage drops across the arm **cd**. The sum of the voltage E_1 and E_3 or E_2 and E_4 gives the voltage drops **E**.

Comparing imaginary part

Advantage

Fixed capacitor is cheaper than variable capacitor.

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

Disadvantage

Equations of L1and R1 are complicated.

Measurement of R1 and L1 require the value of frequency

This bridge cannot be used for measuring low Q - factor

5.3 Measurement of Capacitance Schering Bridge

This bridge is used to measure to the capacitance of the capacitor, dissipation factor and measurement of relative permittivity. Let us consider the circuit of Schering bridge

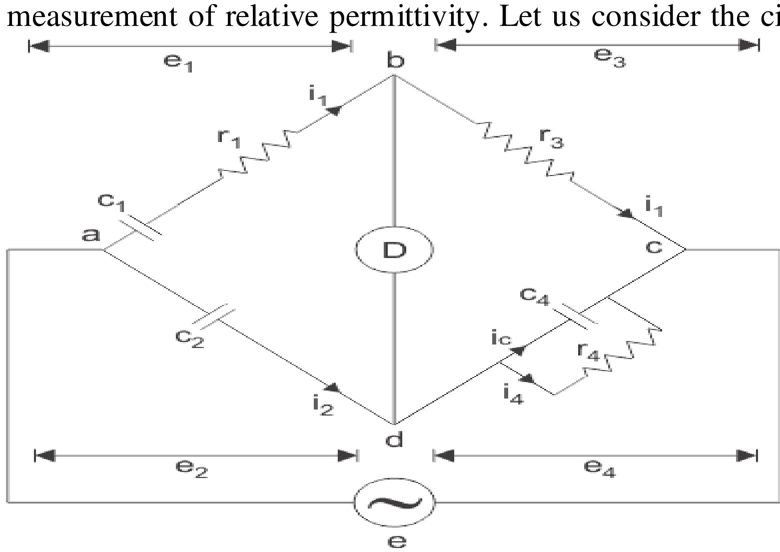


Fig.1.19 Schering Bridge

Here, c_1 is the unknown capacitance whose value is to be determined with series electrical resistance r_1. c_2 is a standard capacitor. c_4 is a variable capacitor. r_3 is a pure resistor (i.e. non inductive in nature). And r_4 is a variable non inductive resistor connected in parallel with variable capacitor c_4. Now the supply is given to the bridge between the points a and c.

The detector is connected between b and d. From the theory of ac bridges we have at balance condition,

Substituting the values of z_1, z_2, z_3 and z_4 in the above equation, we get

$$\left(r_1 + \frac{1}{j\omega c_1}\right)\left(\frac{r_4}{1 + j\omega c_4 r_4}\right) = \frac{r_3}{j\omega c_2}$$

$$(r_1 + \frac{1}{j\omega c_1})r_4 = \frac{r_3}{j\omega c_2}(1 + j\omega c_4 r_4)$$

$$r_1 r_4 - \frac{j r_4}{\omega c_1} = -\frac{j r_3}{\omega c_2} + \frac{r_3 r_4 c_4}{c_2}$$

Equating the real and imaginary parts and the separating we get,

$$r_1 = \frac{r_3 c_4}{c_2}$$

$$c_1 = c_2 \frac{r_4}{r_3}$$

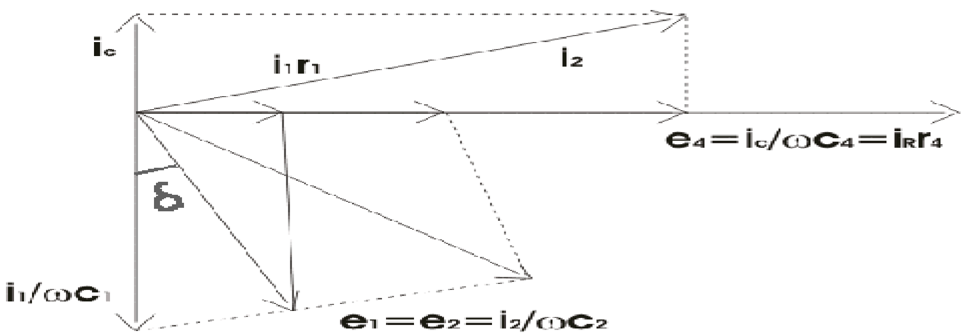


Fig.1.20 Phasor Diagram

consider the phasor diagram of the above Shering bridge circuit and mark the voltage drops across ab,bc,cd and ad as e_1, e_3,e_4 and e_2 respectively. From the above Schering bridge phasor diagram, we can calculate the value of tanδ which is also called the dissipation factor.

$$tan\delta = \omega c_1 r_1 = \omega \frac{c_2 r_4}{r3} \times \frac{r_3 c_4}{c_2} = \omega c_4 r_4$$

1.9.3 ANDERSON'S BRIDGE

- The **Anderson's bridge** gives the **accurate measurement** of **self-inductance** of the circuit.
- The bridge is the **advanced form** of **Maxwell's inductance capacitance bridge.**

- In Anderson bridge, the **unknown inductance** is compared with the **standard fixed capacitance** which is connected between the two arms of the bridge.
- The bridge has fours arms **ab, bc, cd,** and **ad.**
- The arm **ab** consists unknown inductance along with the resistance.
- And the other three arms consist the purely resistive arms connected in series with the circuit.
- The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm.
- The voltage source is applied to the terminal a and c.

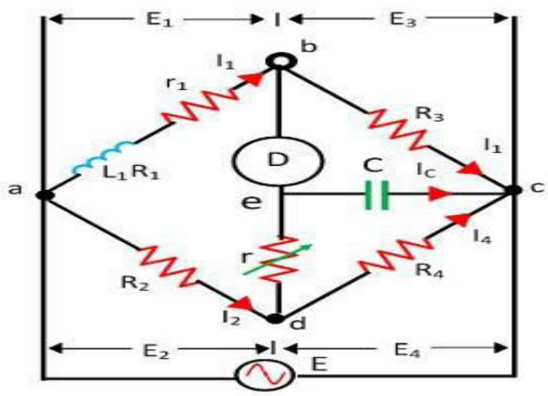


Fig.1.21 Anderson bridge

- The phasor diagram of the Anderson bridge is shown in the figure below.The current I1 and the E3 are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm bc and ec are equal.The current enters into the bridge is divided into the two parts I1 and I2. The I1 is entered into the arm ab and causes the voltage drop I1(R1+R) which is in phase with the I1. As the bridge is in the balanced condition, the same current is passed through the arms bc and ec. The voltage drop E4 is equal to the sum of the IC/ωC and the IC r. The current I4 and the voltage E4 are in the same phase and representing on the same line of the phasor diagram. The sum of the current IC and I4 will give rise to the current I2 in the arm ad.When the bridge is at balance condition the emf across the arm ab and the point a, d and e are equal. The phasor sum of the voltage across the arms ac and de will give rise the voltage drops across the arm ab.The V1 is also obtained by adding the I1(R1+r1) with the voltage drop ωI1L1 in the arm AB. The phasor sum of the E1 and E3 or E2 and E4 will give the supply voltage. Let, L_1: unknown inductance having a resistance .R1,R2,R3,R3-know non inductive resistance

At balance Condition,

$$I_1 = I_3 \; and \; I_2 = I_C + I_4$$

Now,

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

$$I_C = I_1 \omega C R_3$$

The other balance condition equation is expressed as

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_C r$$

$$I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_C) R_4$$

By substituting the value of I_c in the above equation we get,

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

and

$$I_1(R_3 + j\omega R_3 R_4 + j\omega C R_3 r) = I_2 R_4$$

on equating the equation, we get

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1(\frac{R_1 R_2}{R_3} + \frac{j\omega C R_3 r R_2}{R_4} + j\omega C R_3 R_2)$$

Equating the real and the imaginary part, we get

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

$$L_1 = C\frac{R_3}{R_4}[4(R_4 + R_2) + R_2 R_4]$$

The above equation obtained is more complex that we have obtained in Maxwell bridge. On observing the above equations we can easily say that to obtain convergence of balance more easily, one should make alternate adjustments of r1 and r in Anderson's bridge. Now let us look how we can obtain the value of unknown inductor experimentally. At first set the signal generator frequency at audible range. Now adjust r1 and r such that phones gives a minimum sound. Measure the values of r1 and r (obtained after these adjustments) with the help of multimeter. Use the formula that we have derived above in order to find out the value of unknown inductance. The experiment can be repeated with the different value of standard capacitor.

Phasor Diagram of Anderson's Bridge

Let us mark the voltage drops across ab, bc, cd and ad as e1, e2, e3 and e4 as shown

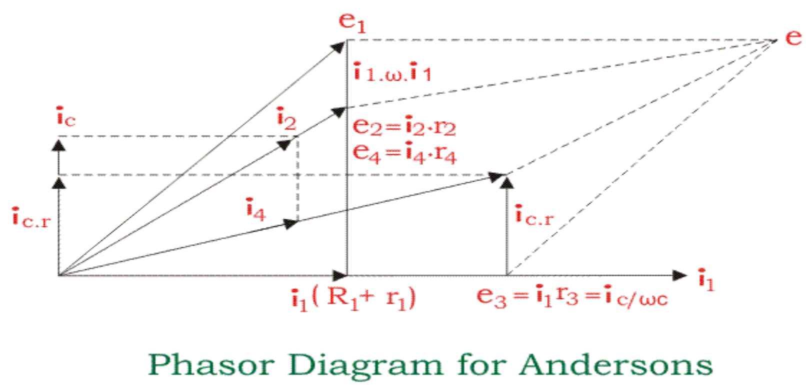


Fig .1.22 Phasor Diagram

Here in the phasor diagram of Anderson's bridge, we have taken i1 as reference axis. Now ic is perpendicular to i1 as capacitive load is connected at ec, i4 and i2 are lead by some angle as shown in figure. Now the sum of all the resultant voltage drops i.e. e1, e2, e3 and e4 is equal to e, which is shown in phasor diagram. As shown in the phasor diagram of Anderson's bridge the resultant of voltages drop i1
(R1 + r1) and i1.ω.l1 (which is shown perpendicular to i1) is e1. e2 is given by i2.r2 which makes angle 'A' with the reference axis. Similarly, e4 can be obtained by voltage drop i4.r4 which is making angle 'B' with reference axis.

Advantages of Anderson's Bridge

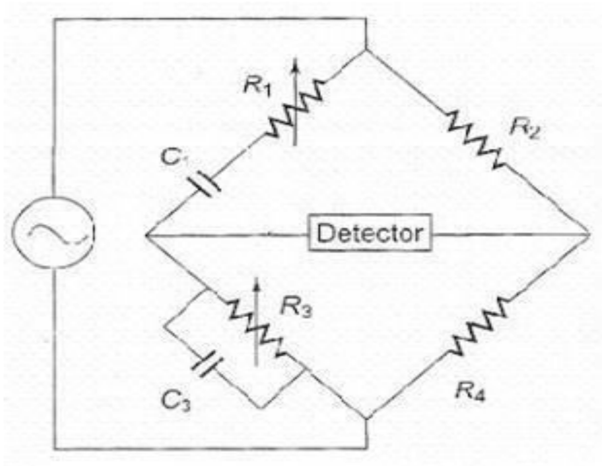
1. It is very easy to obtain the balance point in Anderson's bridge as compared to Maxwell bridge in case of low quality factor coils.
2. There is no need of variable standard capacitor is required instead of thin a fixed value capacitor is used.
3. This bridge also gives accurate result for determination of capacitance in terms of inductance.

Disadvantages of Anderson's Bridge

1. The equations obtained for inductor in this bridge is more complex as complex as compared to Maxwell's bridge.
2. The addition of capacitor junction increases complexity as well as difficulty of shielding the bridge.

1.9.4 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



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

Fig.1.23 Wien's Bridge

The admittance of the parallel arm is

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

Using the bridge balance equation, we have

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

Therefore $\quad Z_1\,Z_4 = Z_2/Y_3$, i.e. $Z_2 = Z_1\,Z_4\,Y_3$

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

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

Equating the real and imaginary terms we have as,

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

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

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

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

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

$$\omega = 2 \pi f$$

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

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.

QUESTION BANK

PART-A (2 MARKS)

1. **What are the basic elements of a generalized measurement system?**
2. List any four Static characteristics of a measuring system.
3. Define the term Accuracy.
4. What is an Error?
5. What is calibration?
6. What is exact difference between accuracy and Precision.?
7. Define the term Precision.
8. Write the two conditions to be satisfied to make an a.c bridge balance.
9. What is transfer instrument?
10. Define sensitivity.

PART - B (16 MARKS)

11. Classify and explain the different types of standards and measurement.
12. Discuss different types of errors in measurement.
13. Discuss the basic characteristics of measuring device.
14. Define and explain the following,

    (i) Instrument errors (ii)Limiting errors (iii)Environmental errors 30. Explain any one bridge circuit for measurement of inductance.

15. Explain the method of measuring the insulating property of a capacitor by relevant bridge circuit.
16. Explain any one bridge circuit for the measurement of inductance.
17. Explain voltage sensitive self balancingbridge,and derive the bridge sensitivity of voltage sensitive bridge with fundamentals.
18. Define dynamic response of a system and explain characteristics of dynamic response
19. Explain the working of moving iron instruments.
20. List the advantages of Rectifier type measuring systems and explain how ac and dc voltages can be measured.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS

UNIT – II

MEASUREMENT AND INSTRUMENTATION – SEIA3001

UNIT 2 BASIC ELECTRONIC MEASUREMENTS

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

2.1 ELECTRONIC MULTIMETERS

A multimeter is basically a PMMC meter. To measure dc current the meter acts as an ammeter with a low series resistance. Range changing is accomplished by shunts in such a way that the current passing through the meter does not exceed the maximum rated value. A multimeter consists of an ammeter, voltmeter and ohmmeter combined with a function switch to connect the appropriate circuit to the D'Arsonval movement.

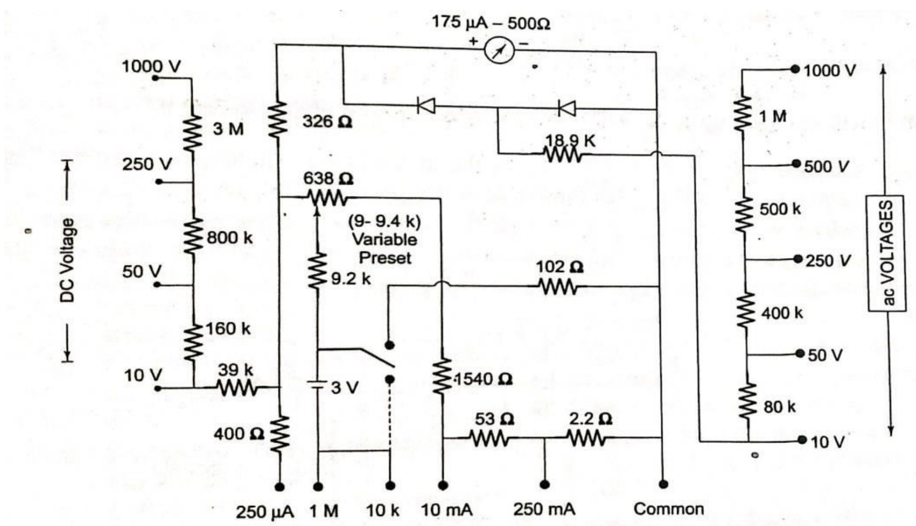


Fig. 2.1 Diagram of a multimeter

The above figure shows the circuit diagram of a multimeter used as a microammeter, ac voltmeter, dc voltmeter, dc milliammeter and an ohmmeter.

2.1.1 Microammeter & DC ammeter

Following figure shows the circuit of a multimeter used as a microammeter as well as its use as a dc ammeter.

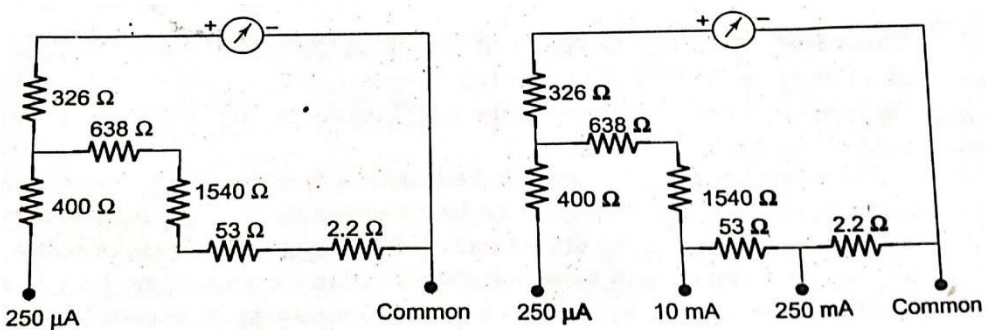


Fig. 2.2 Multimeter as a microammeter and as a dc ammeter.

2.1.2 DC Voltmeter:

Following figure shows the use of multimeter as a dc voltmeter.

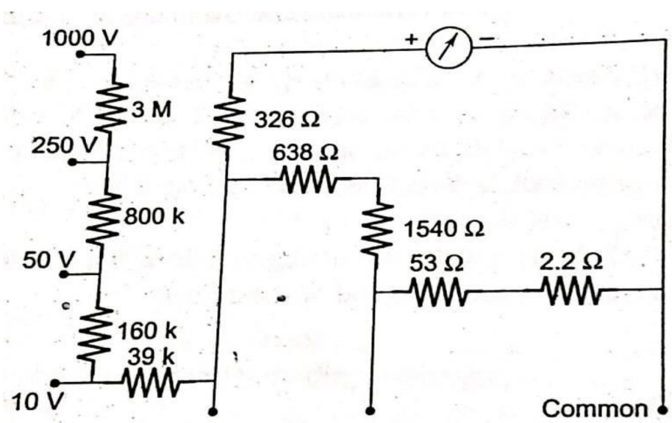


Fig. 2.3 DC voltmeter section of the multimeter.

2.1.3 AC Voltmeter:

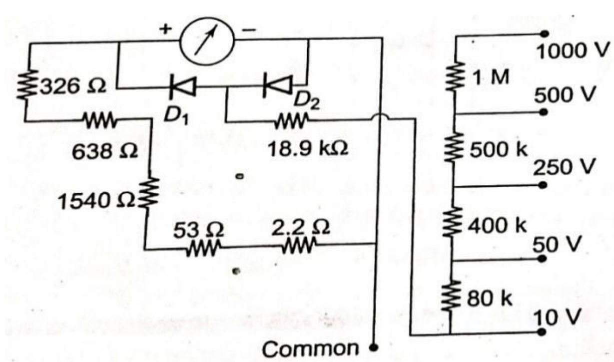


Fig.2.4 AC voltmeter section of a multimeter.

Figure shows the ac voltmeter section of a multimeter. To measure ac voltage, the output voltage is rectified by a half wave rectifier before the current passes through the meter. Across the meter, the other diode serves as protection. The diode conducts when a reverse voltage appears across the diodes, so that current bypasses the meter in the reverse direction.

2.1.4 Ohmmeter:

Referring to the following figure, which shows the ohmmeter section of a multimeter, in the 10k range the 102 Ω resistance is connected in parallel with the total circuit resistance and in the 1M Ω range the 102 Ω resistance is totally disconnected from the circuit.

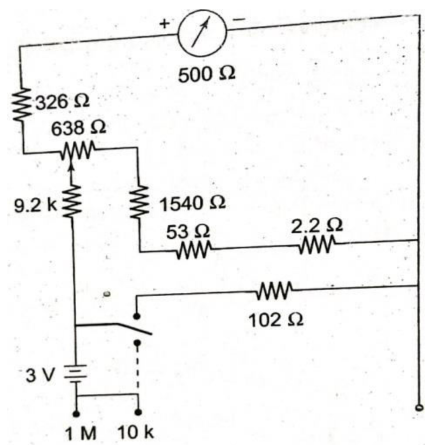


Fig. 2.5 Ohmmeter section of the multimeter.

Therefore on the 1M Ω range, the half scale deflection is 10k. Since on the 10k range, the 102 Ω resistance is joined across the total resistance, therefore in this range the half scale deflection is 100 Ω. The measurement of resistance is done by applying a small voltage installed within the meter. For the 1M Ω range, the internal resistance is 10k Ω. ie., value at the mid scale.

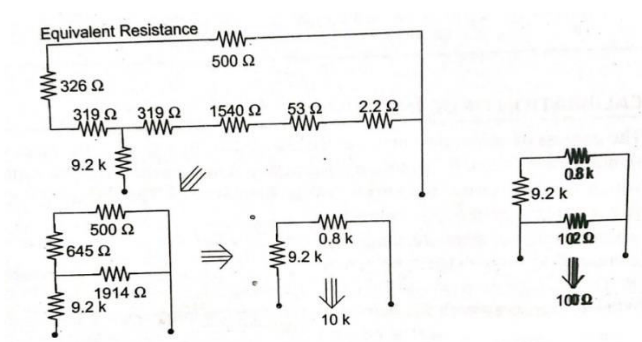


Fig. 2.6 Equivalent resistance on the 1M Ω range and half scale deflection

The range of the ohmmeter can be changed by connecting the switch to a suitable shunt resistance. By using different values of shunt resistance, different ranges can be obtained. By increasing the battery voltage and using a suitable shunt, the maximum values which the ohmmeter reads can be changed.

2.2 INTRODUCTION- CATHODE RAY TUBE (CRT)

In studying the various electronic, electrical networks and systems, signals which are functions of time, are often encountered. Such signals may be periodic or non-periodic in nature. The device which allows, the amplitude of such signals, to be displayed primarily as a function of time, is called cathode ray oscilloscope, commonly known as C.R.O. The C.R.O. gives the visual representation of the time varying signals. The oscilloscope has become an universal instrument and is probably most versatile tool for the development of electronic circuits and systems. It is an integral part of electronic laboratories.

The oscilloscope is, in fact, a voltmeter. Instead of the mechanical deflection of a metallic pointer as used in the normal voltmeters, the oscilloscope uses the movement of an electron beam against a fluorescent screen, which produces the movement of a visible spot. The movement of such spot on the screen is proportional to the varying magnitude of the signal, which is under measurement.

The electron beam can be deflected in two directions: the horizontal or x-direction and the vertical or y-direction. Thus an electron beam producing a spot can be used to produce two dimensional displays. Thus C.R.O. can be regarded as a fast x-y plotter. The X-axis and y-axis can be used to study the variation of one voltage as a function of another. Typically the x-axis of the oscilloscope represents the time while the y-axis represents variation of the input voltage signal. Thus if the input voltage signal applied to the y-axis of C.R.O. is sinusoidal varying and if x-axis represents the time axis, then the spot moves sinusoidal, and the familiar sinusoidal waveform can be seen on the screen of the oscilloscope. The oscilloscope is so fast device that it can display the periodic signals whose time period is as small as microseconds and even nanoseconds. The C.R.O. basically operates on voltages, but it is possible to convert current, pressure, strain, acceleration and other physical quantities into the voltage using transducers and obtain their visual representations on the C.R.O.

2.2.1 The Cathode Ray Tube

The cathode ray tube (CRT) is the heart of the C.R.O. The CRT generates the electron beam, accelerates the beam, deflects the beam and also has a screen where beam becomes visible as a spot. The main parts of the CRT are :

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

A schematic diagram of CRT, showing its structure and main components is shown in the figure below

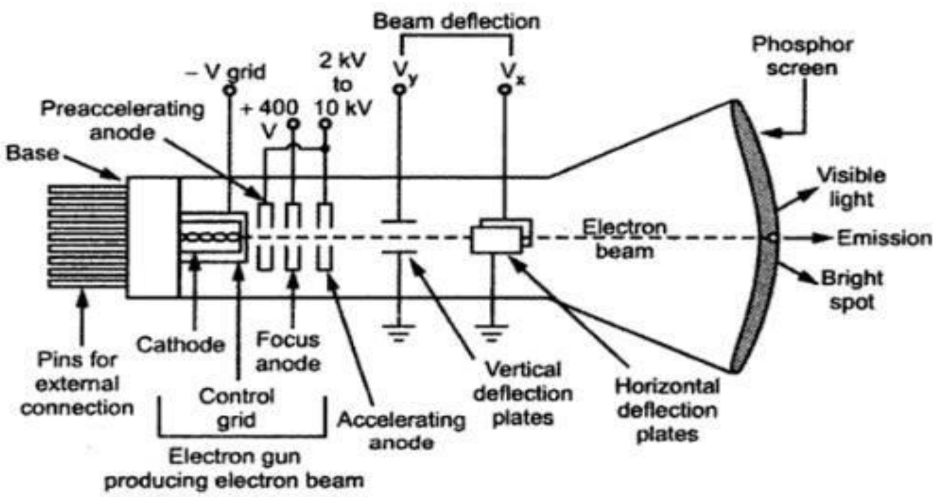


Fig.2.7 Block diagram of cathode ray tube (CRT)

Electron Gun

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

The momentum of the electrons (their number x their speed) determines the intensity, or brightness, of the light emitted from the fluorescent screen due to the electron bombardment. The light emitted is usually of the green colour. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid in CRT, voltages applied to various grids are stated with respect to cathode, which is taken as common point). This negative control voltage can be made variable. Since the electron beam consists of many electrons, the beam tends to diverge. This is because the similar (negative) charges on the electron repel each other. To compensate for such repulsion forces, an adjustable electrostatic field is created between two cylindrical anodes, called the focusing anodes. The high positive potential is also given to the pre-accelerating anodes and accelerating anodes, which results into the required acceleration of the electrons.

Both focusing and accelerating anodes are cylindrical in shape having small openings located in the centre of each electrode, co-axial with the tube axis. The pre-accelerating and accelerating anodes are connected to a common positive high voltage which varies between 2 kV to 10 kV. The focusing anode is connected to a lower positive voltage of about 400 V to 500 V.

Deflection system

When the electron beam is accelerated it passes through the deflection system, with which beam can be positioned anywhere on the screen. The deflection system of the cathode-ray-tube consists of two pairs of parallel plates, referred to as the vertical and horizontal deflection plates. One of the plates in each set is connected to ground 0 V). To the other plate of each set, the external deflection voltage is applied through an internal adjustable gain amplifier stage. To apply the deflection voltage externally, an external terminal, called the Y input or the X input, is available.

As shown in the figure above, the electron beam passes through these plates. A positive voltage applied to the Y input terminal (V_y) causes the beam to deflect vertically upward due to the attraction forces, while a negative voltage applied to the Y input terminal will cause the electron beam to deflect vertically downward, due to the repulsion forces.

Similarly, a positive voltage applied to X-input terminal (V_x) will cause the electron beam to deflect horizontally towards the right; while a negative voltage applied to the X-input terminal will cause the electron beam to deflect. horizontally towards the left of the screen. The amount of vertical or horizontal deflection is directly proportional to the correspondingly applied voltage.

When the voltages are applied simultaneously to vertical and horizontal deflecting plates, the electron beam is deflected due to the resultant of these two voltages. The face of the screen can be considered as an x-y plane. The (x,y) position of the beam spot is thus directly influenced by the horizontal and the vertical voltages applied to the deflection plates V_x, and V_y, respectively.

The horizontal deflection (x) produced will be proportional to the horizontal deflecting voltage, V_x, applied to X-input.

$$x \propto V$$

$$x = K_X V_X$$

where K_x is constant of proportionality. The deflection produced is usually measured in cm or as number of divisions, on the scale, in the horizontal direction.

Then $K_x = x/V_x$ where K_x is expressed as cm/volt or division/volt, is called **horizontal sensitivity** of the oscilloscope.

Similarly, the vertical deflection (y) produced will be proportional to the vertical deflecting voltage, V_y, applied to the y-input.

$$y \propto V$$

$$y = K_y V_y$$

Then $K_y = y/V_y$ and K_y, the **vertical sensitivity**, will be expressed as cm/volt, or division/volt.

The values of vertical and horizontal sensitivities are selectable and adjustable through multipositional switches on the front panel that controls the gain of the corresponding internal amplifier stage. The bright spot of the electron beam can thus trace (or plot) the x-y relationship between the two voltages, V_x and V_y.

The schematic arrangement of the vertical and the horizontal plates, controlling the position of the spot on the screen is shown in the figure below:

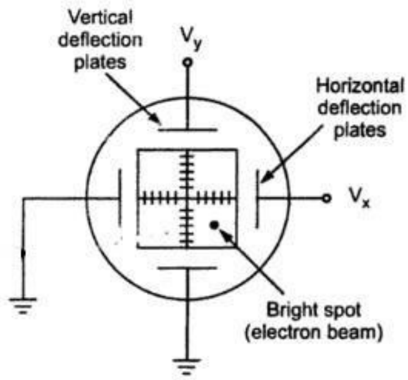


Fig.2.8 Arrangements of Plates in CRT

Fluorescent screen

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

The screen is coated with a fluorescent material called phosphor which emits light when bombarded by electrons. There are various phosphors available which differ in colour, persistence, and efficiency.

One of the common phosphor is Willemite, which is zinc, orthosilicate, ZnO+SiO2, with traces of manganese. This produces the familiar greenish trace. Other useful screen materials include compounds of zinc, cadmium, magnesium and silicon. The kinetic energy of the electron beam is converted into both light and heat energy when it hits the screen. The heat so produced gives rise to "phosphor burn" which is damaging and sometimes destructive. This degrades the light output of phosphor and sometimes may cause complete phosphor destruction. Thus the phosphor must have high burn resistance to avoid accidental damage.

Many phosphor materials having different excitation times and colours as well as different phosphorescence times are available. The type P_1, P_2, P_{11} or P_{31} are the short persistence phosphors and are used for the general purpose oscilloscopes.

Table 1: The Types of Short Persistence of Phosphor

Phosphor	Colour		Persistence	Relative luminance	Relative writing speed	Applications
	Under excitation	After glow				
P1	yellow- green	yellow- green	medium	45	35	General purpose
P2	blue-green	green	medium	60	70	General purpose
P4	white	white	medium to short	50	75	Black and white T.V.
P7	blue-white	yellow- green	medium-short	45	95	Radar
P11	blue-violet	blue	medium-short	25	100	Photographic recording
P15	blue-green	blue-green	visible -short	15	25	Flying spot scanners for T.V.
P19	orange	orange	long	25	3	Radar
P31	green	green	medium-short	100	75	General purpose
P33	orange	orange	very long	20	7	Radar
P39	green	green	medium- long	50	40	Computer graphics

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

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

2.3 CATHODE RAY OSCILLOCOPE

The block diagram of CRO is shown below:

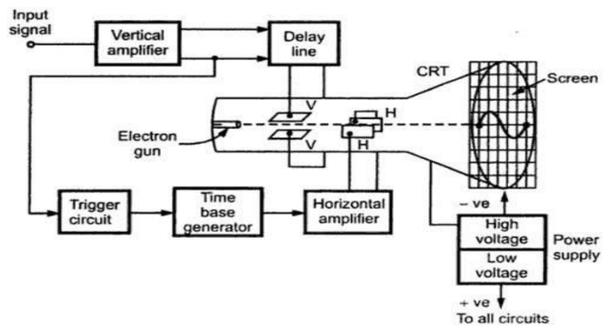


Fig.2.9 Block diagram of Cathode ray Oscilloscope (CRO)

Cathode Ray Tube (CRT): This is the cathode ray tube which is the heart of C.R.O. It is used to emit the electrons required to strike the phosphor screen to produce the spot for the visual display of the signals.

Vertical Amplifier: The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier stage is used to amplify the input signals. The amplifier stages used are generally wide band amplifiers so as to pass faithfully the entire band of frequencies to be measured. Similarly it contains the attenuator stages as well. The attenuators are used when very high voltage signals are to be examined, to bring the signals within the proper range of operation.

The block diagram of a vertical amplifier is shown in the figure below.

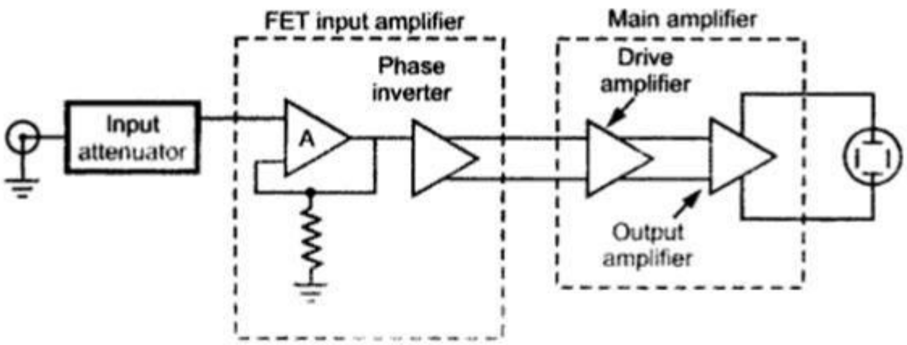


Fig.2.10 Vertical amplifier

It consists of several stages with overall fixed sensitivity. The amplifier can be designed for stability and required bandwidth very easily due to the fixed gain. The input stage consists of an attenuator followed by FET source follower. It has very high input impedance required to isolate the amplifier from the attenuator. It is followed by BJT emitter follower to match the output impedance of FET output with input of phase inverter. The phase inverter provides two anti-phase output signals which are required to operate the push pull output amplifier.

The push pull operation has advantages like better hum voltage cancellation, even harmonic suppression especially large and harmonic, greater power output per tube and reduced number of defocusing and nonlinear effects.

Delay Line: The delay line is used to delay the signal for some time in the vertical sections. When the delay line is not used, the part of the signal gets lost. Thus the input signal is not applied directly to the vertical plates but is delayed by some time using a delay line circuit as shown in the figure below:

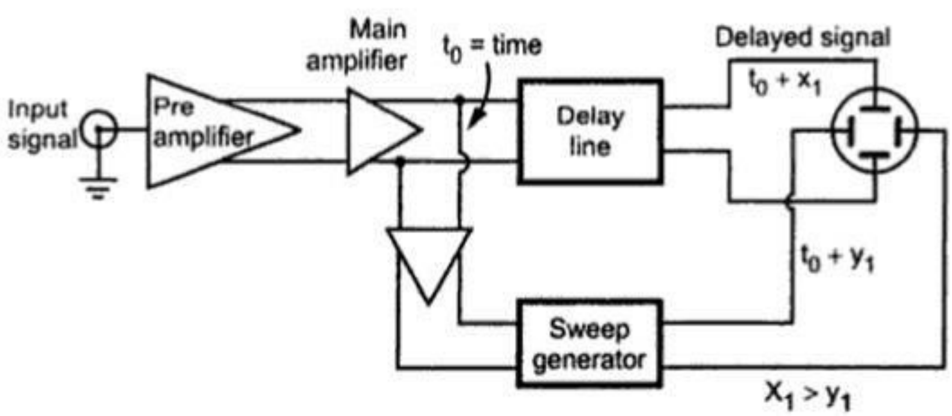


Fig.2.11 Delay line circuit

If the trigger pulse is picked off at a time $t = t_o$ after the signal has passed through the main amplifier then signal is delayed by x_1 nanoseconds while sweep takes y_1 nanoseconds to reach. The design of delay line is such that the delay time x_1 is higher than the time y_1. Generally x_1 is 200 nanoseconds while the y_1 is 80 nanoseconds, thus the sweep starts well in time and no part of the signal is lost.

There are two types of delay lines used in C.R.O. which are :

i) Lumped parameter delay line

ii) Distributed parameter delay line

They are discussed below:

I) Lumped parameter delay line:

Lumped parameter delay line consists of number of cascaded symmetrical LC networks called T sections Each section is capable of delaying the signal by 3 to 6 nano seconds. Such a T filter section is shown in the figure below.

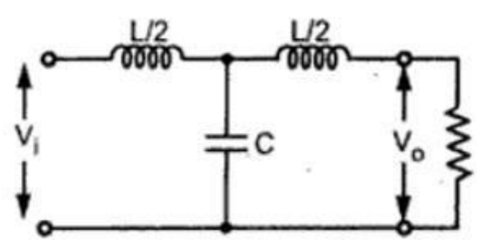


Fig.2.12 T-section filter.

The T-section filter acts as low pass filter having cut-off frequency given as

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

If V_i consists of frequencies much less than the cut-off frequency, output signal V_0. will be a faithful reproduction of V_i but delayed by the time,

$$t_s = \frac{1}{\pi f_c} = \sqrt{LC}$$

where

t_s - Delay for a single T network

where, $t_d = nt_s$

here t_d = Total delay

n = Number of T sections A practical delay line circuit in C.R.O. is driven by push-pull amplifier and is shown in the figure

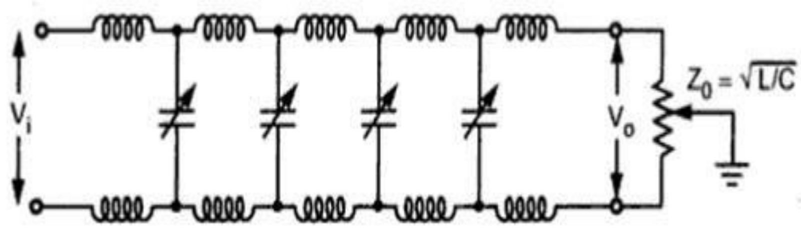


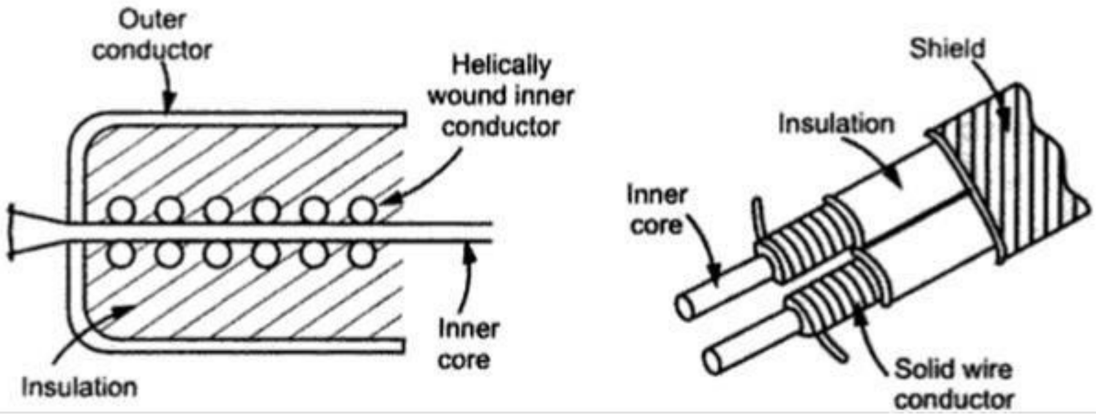
Fig.2.13 Practical delay line

II) Distributed parameter delay line:

It is basically a transmission line constructed with a wound helical coil on a mandrel and extruded insulation between it. It is specially manufactured co-axial cable with high inductance per unit length. The construction of such line is shown in the figure below.

The inductance can be increased by winding the helical inner conductor on ferromagnetic core. This increases the characteristics impedance Z_o and delay time. Typical parameters for helical, distributed parameter delay line are $Z_o = 1000\ \Omega$ and $t_d = 180$ nsec/m. The co-axial delay line is advantageous as:

i) It does not require careful adjustment as lumped parameter. ii) It requires less space.



a) Helical distributed delay line **b)Constructional details**

Fig.2.14 Distributed delay line

Trigger Circuit: It is necessary that horizontal deflection starts at the same point of the input vertical signal, each time it sweeps. Hence to synchronize horizontal deflection with vertical deflection a synchronizing or triggering circuit is used. It converts the incoming signal into the triggering pulses, which are used for the synchronization.

Time Base Generator: The time base generator is used to generate the sawtooth voltage, required to deflect the beam in the horizontal section. This voltage deflects the spot at a constant time dependent rate. Thus the x-axis on the screen can be represented as time, which helps to display and analyse the time varying signals.

Horizontal Amplifier: The sawtooth voltage produced by the time base generator may not be of sufficient strength. Hence before giving it to the horizontal deflection plates, it is amplified using the horizontal amplifier.

Power Supply: The power supply block provides the voltages required by CRT to generate and accelerate an electron beam and voltages required by other circuits of the oscilloscope like horizontal amplifier, vertical amplifier etc.

The negative High Voltage (HV) supply has following advantages:

i) The accelerating anodes and the deflection plates are close to ground potential. This ground potential protects the operator from shocks.

ii) The deflection voltages are measured with respect to ground hence blocking or coupling capacitors are not necessary.

iii) Insulation required between controls and chasis is less.

There are two sections of a power supply block. The High Voltage (HV) section and Low Voltage (LV) section. The high voltages of the order of 1000V to 1500 V are required by CRT. Such high negative voltages are used for CRT. The low voltage is required for the heater of the electron gun, which emits the electrons. This is a positive voltage of the order of few hundred volts. This voltage is also used for other circuits of C.R.O. This is the discussion of basic block diagram of a simple C.R.O.

2.3 CRT Circuits

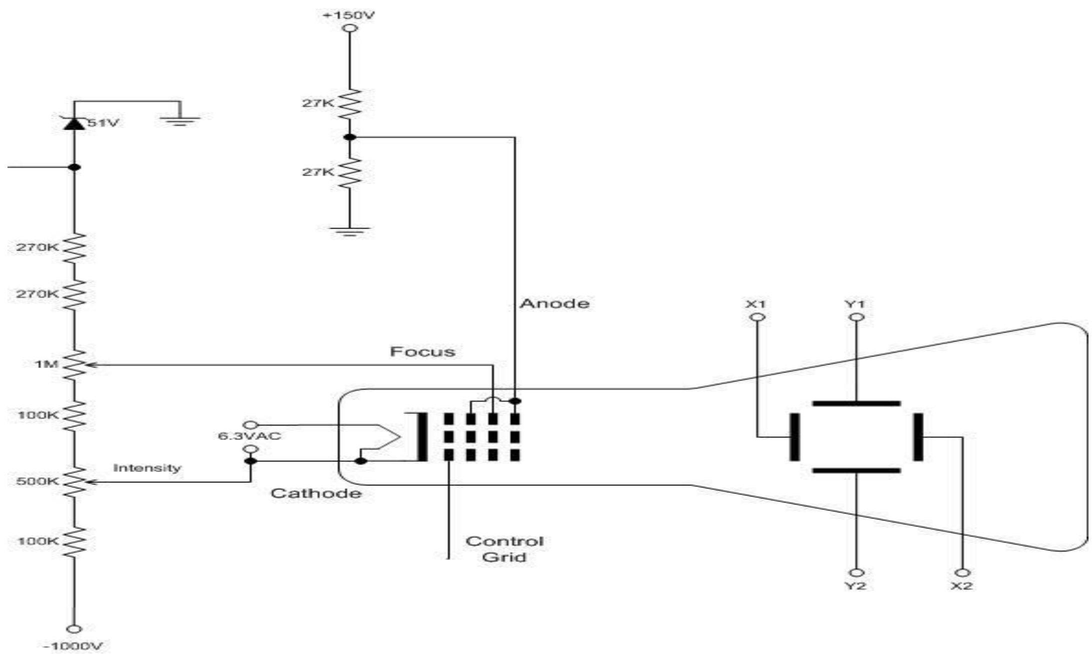


Fig.2.15 CRT Circuits

The CRT needs an anode to cathode supply voltage of 1000V or more to give a bright and sharp display. The deflection plates which move the dot around the screen must be at about the same voltage as the anode. So if the cathode is at or near ground potential as is common in vacuum tube circuits, then the deflection plates are 1KV above ground. If the deflection plates are to be driven by a DC coupled transistor amplifier, and the bases are to be near ground so that they may in turn be driven by low voltage circuits then the output transistors must have a V_{CEO} rating of over 1KV. Transistors with that kind of collector breakdown voltage that are also fast enough to handle megahertz signals are rare indeed.

If, on the contrary, the anode voltage is at ground, then we would need an amplifier with an output stage that could swing 60 or so volts above and below ground. While this is possible, it would be more complex than necessary. A better solution is to put the CRT anode 70 to 80 volts above (more positive than) ground and the cathode about 950 volts below ground. In this way, the drivers for the deflection plates could work from a 150 Volt supply and swing ±60 Volts from a quiescent value of about 75 Volts.

In the circuit above, the two 27KΩ resistors set the anode potential to 75V. The second and fourth grids are internally connected to the anode and along with the third or focus grid form a lens that focuses the electron beam from the cathode to a small sharp dot on the screen. The control grid is held near -1000V by circuitry not shown here. The voltage divider on the left of the drawing provides proper bias voltage for the focus grid and the cathode. The top pot adjusts focus and the lower one sets the brightness of the dot on the screen.

2.3.1 Vertical deflection system

The main function of this amplifier is to amplify the weak signal so that the amplified signal can produce the desired signal. To examine the input signals are penetrated to the vertical deflection plates through the input attenuator and number of amplifier stages.

The schematic arrangement of the vertical plates, controlling the position of the spot on the screen is shown in the figure below:

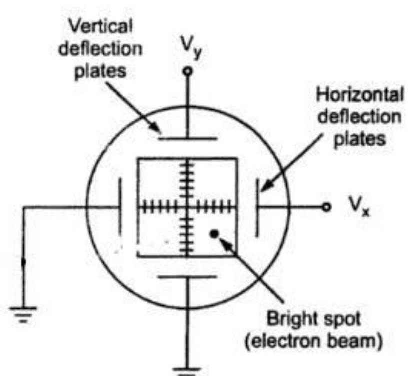


Fig.2.16 Arrangements of Vertical plates in CRT

The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier stage is used to amplify the input signals. The amplifier stages used are generally wide band amplifiers so as to pass faithfully the entire band of frequencies to be measured. Similarly it contains the attenuator stages as well. The attenuators are used when very high voltage signals are to be examined, to bring the signals within the proper range of operation.

The function of vertical deflection system is to provide an amplified signal of the proper level to drive the vertical deflection plates without introducing any appreciable distortion into the system. The input sensitivity of many CROs is of the order of a few milli-volts per division and the voltage required for deflecting the electron beam varies from approximately 100 V (peak to peak) to 500 V depending on the accelerating voltage and the construction of the tube. Thus the vertical amplifier is required to provide this desired gain from milli-volt input to several hundred volt (peak to peak) output. Also the vertical amplifier should not distort the input waveform and should have good response for entire band of frequencies to be measured. The deflection plates of CRO act as plates of a capacitor and when the input signal frequency exceeds over 1 MHz, the current required for charging and discharging of the capacitor formed by the deflection plates increases. So the vertical amplifier should be capable of supplying current enough to charge and discharge the deflection plate capacitor.

As we know that electrical signal is delayed by a certain amount of time when transmitted through an electronic circuitry. In CRO, output signal voltage of the vertical amplifier is fed to the vertical plates of CRT and some of its portion is used for triggering the time base generator circuit, whose output is supplied to the horizontal deflection plates through horizontal amplifier. The whole process, which includes generating and shaping of a trigger pulse and starting of a time-base generator and then its amplification, takes time of the order of 100 ns or so. So the input signal of the vertical deflection plates of a CRT is to be delayed by at least the same or little more amount of time to allow the operator to see the leading edge of the signal waveform under study on the screen.

The block diagram of a vertical amplifier is shown in the figure below.

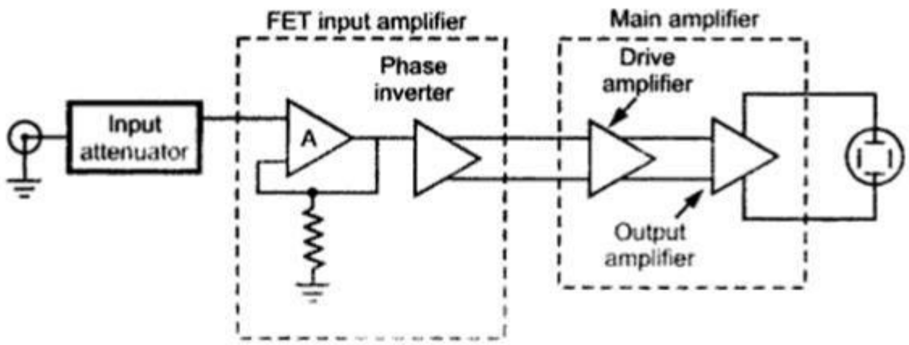


Fig.2.17 Vertical amplifier

It consists of several stages with overall fixed sensitivity. The amplifier can be designed for stability and required bandwidth very easily due to the fixed gain. The input stage consists of an attenuator followed by FET source follower. It has very high input impedance required to isolate the amplifier from the attenuator. It is followed by BJT emitter follower to match the output impedance of FET output with input of phase inverter. The phase inverter provides two anti-phase output signals which are required to operate the push pull output amplifier.

The push pull operation has advantages like better hum voltage cancellation, even harmonic suppression especially large and harmonic, greater power output per tube and reduced number of defocusing and nonlinear effects.

2.3.2 Triggered sweep

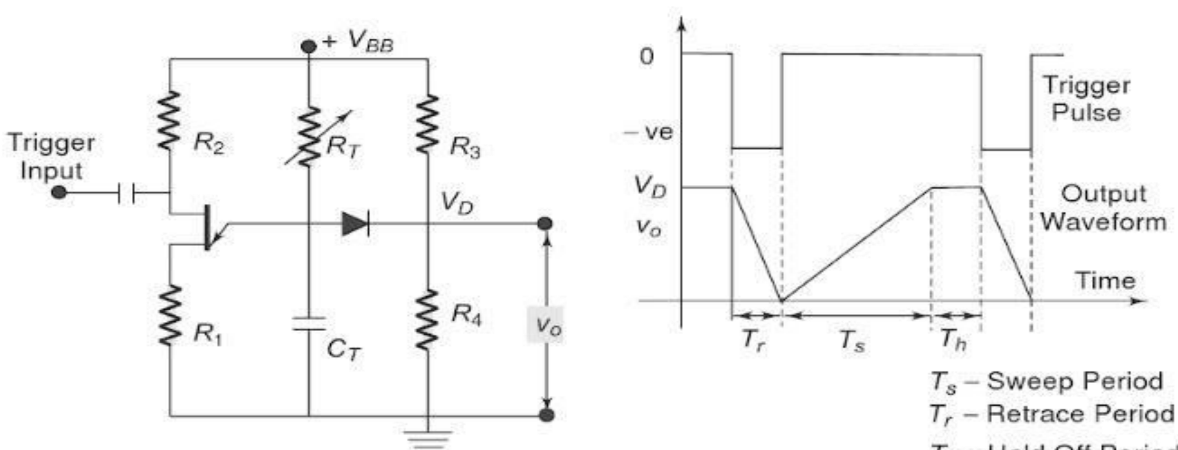


Fig.2.18 Triggered sweep and its output waveform

The continuous sweep is of limited use in displaying periodic signals of constant frequency and amplitude. When attempting to display voice or music signals, the pattern falls in and out of sync as the frequency and amplitude of the music varies resulting in an unstable display.

A triggered sweep can display such signals, and those of short duration, e.g. narrow pulses. In triggered mode, the input signal is used to generate substantial pulses that trigger the sweep. Thus ensuring that the sweep is always in step with the signal that drives it.

As shown in figure above, resistance R_3 and R_4 form a voltage divider such that the voltage V_D at the cathode of the diode is below the peak voltage V_P for UJT conduction. When the circuit is switched on, the UJT is in the non-conducting stage, and C_T charges exponentially through R_T towards V_{BB} until the diode becomes forward biased and conducts, the capacitor voltage never reaches the peak voltage required for UJT conduction but is clamped at V_D. If now a -ve pulse of sufficient amplitude is applied to the base and the peak voltage V_P, is momentarily lowered, the UJT fires. As a result, capacitor C_T, discharges rapidly through the UJT until the maintaining voltage of the UJT is reached; at this point the UJT switches off and capacitor C_T charges towards V_{BB}, until it is clamped again at V_D. Above figure shows the output waveform.

2.4 CRO SPECIFICATIONS

Oscilloscopes are a very common form of test equipment - possibly the most important type of test equipment. As a result it is often necessary to be able to choose one either from the test equipment store or as a rental or when buying an oscilloscope. When selecting an oscilloscope, there are many different specifications and parameters to consider, each one related to the performance. When selecting an oscilloscope, what are the most important specifications and parameters and which ones will affect the performance of the scope in the particular application.

1) Types of oscilloscope: One of the major specifications associated with buying an oscilloscope is the actual type of oscilloscope that is required. Some types of scope will be able to perform other measurements better than others; some use current technology whereas others are older; and there may be cost implications as well. Analogue, analogue storage, digital, digital storage, digital sampling, USB scopes and many more types are available.

2) Oscilloscope bandwidth specification: One important oscilloscope specification is related to the frequency or speed of the waveforms that can be measured. This is determined by the bandwidth of the oscilloscope and it is found that the capability of the oscilloscope to accurately display the waveform falls off with increasing frequency. The oscilloscope specification for bandwidth will typically be quoted in the format: Bandwidth = -3dB at 1500 MHz.

3) Vertical DC gain accuracy: It is important when measuring the amplitude of signals, to know the accuracy of the measurement that is being made. As oscilloscopes are not intended to be used instead of digital multimeters, it is not anticipated that the voltage elements of the oscilloscope specification will be as accurate.

4)Vertical channel Resolution: Digital oscilloscopes need to convert the incoming analogue signal into a digital signal. The vertical channel resolution determines the "granularity" of the signal. Most digital oscilloscopes have 8-bit resolution.

5) Rise Time Specification: Another important oscilloscope specification which needs to be accommodated is the rise time of the oscilloscope. This is a particularly important specification for any digital circuits where the edges on square waves and pulses are often of great importance. The oscilloscope must have a sufficiently fast rise time to capture the rapid transitions accurately, otherwise important information may not be displayed and the results could be misleading. The rise time of the oscilloscope is defined as the time it takes for the image to rise from 10% to 90% of the final value.

6) Oscilloscope sample rate: the sample rate oscilloscope specification is becoming a more widespread and important specification. The sample rate is specified in samples per second (S/s). The faster the oscilloscope samples the waveform, the greater the resolution of the detail on the waveform and with greater sample rates the less the likelihood that any critical information will be lost.

Oscilloscope sample rate = 2.5 x Highest frequency

7) Memory Depth: This is the memory for storing signals. The greater the memory depth the more signal it is possible to capture at the highest sample rate.

2.5 CRO Controls

The various front panel controls of a simple C.R.O. are described in this section. These are divided into four groups,

1. Basic controls

2. Vertical section

3. Horizontal section

4. Z-axis Intensity control

1.Basic Controls :

1. ON-OFF : The on-off switch turns on or off the C.R.O.

2. Intensity : This controls the intensity or brightness of the light produced by beam spot. It actually controls the number of electrons per second that are bombarding the screen which determines the brightness of the spot.

3. Focus : This controls the sharpness of the spot. A sharper spot is always preferred. Focusing or the spot is obtained by varying the voltage applied to the focusing anodes of the cathode ray tube.

4. Astigmatism : This is another focus control. With the help of focus control and astigmatism control, a very sharp spot can be obtained both in the centre and also at the edges of the screen. With the astigmatism control the voltage to accelerating anodes is varied.

5. Scale Illumination : Most C.R.O. s have some sort of plastic screen in front of the cathode ray tube. This screen has a grid engraved on it, giving it an appearance similar to that of graph paper. This is called graticule. This scale facilitates the measurement on the oscilloscope. The scale illumination control, illuminates the scale and hence the lines on the scale can be seen very easily.

2.Vertical Section: Most oscilloscopes have two vertical inputs. These are usually called inputs 1 and 2 or A and B. Two input signals can be applied to these two inputs and thereby both the signals can be observed on the screen simultaneously. This is very useful for comparing two signals. The following controls serve for each vertical input.

a) volts/division:

This control sets the vertical scale; that is, it determines how much the spot will be deflected by an input signals applied to vertical input terminals. The usual units are either volts per centimeter or volts per division, where division refers to the grid marks on the screen. The actual input voltage can be found by measuring the deflection and multiplying it by the scale factor. Thus, if the scale control was set to 5 V/cm and deflection is 1.3 cm, the input would be 6.5 V. The control is shown in the figure below

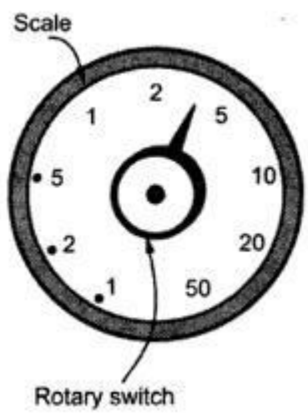


Fig.2.19 Volts/division selection

Suppose the alternating voltage signal of amplitude 10 V is to be displayed. Then if volts/division are selected as 10 then it will be displayed as shown in the figure (a) while if volts/division = 5 is selected, it will be displayed as shown in the figure (b)

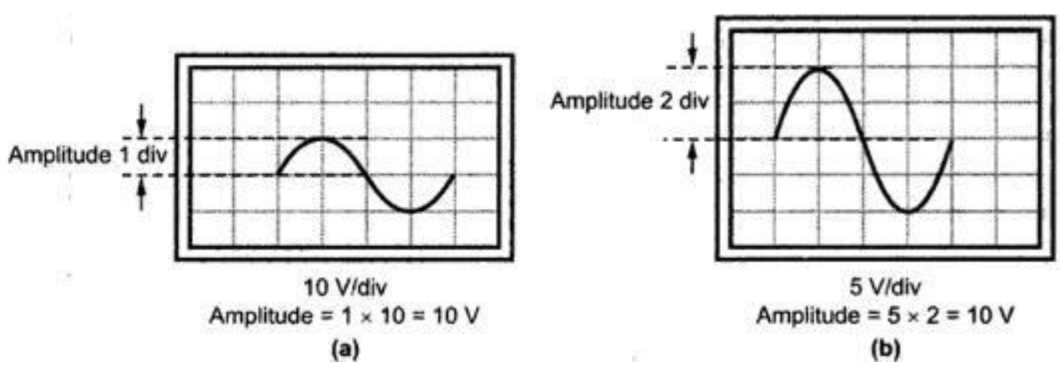


Fig.2.20 Effects of volts/division

b) Invert:

This control inverts the input signal ; that is, it multiplies it by -1. Then positive input voltages become negative and cause downward deflections. The effect of invert is shown in the figure below

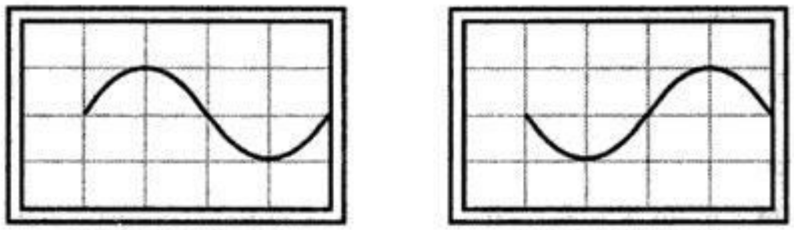


Fig.2.21 The effect of Invert

c) Position :

With the help of this control, the pattern obtained on the screen can be shifted, as a whole, vertically upwards or downwards. This is achieved by adding a d.c. offset voltage to the input signal.

d) X 10 (Multiplied by 10):

This control makes the gain of the vertical amplifier 10 times as great as normal, it changes the scale factor by factor of 10. Thus if the X 10 switch is turned 'ON' and the scope is set on 0.05 V/cm, if the actual scale factor is 0.005 V/cm or 5 mV/cm.

e) Vertical Coupling :

This switch controls the coupling to the vertical amplifier. The usual choices are A.C., D.C., or ground. The meaning of these various positions are as follows:

i. A.C. : The vertical amplifier is a.c. coupled to the input. Thus the d.c. component of the input is blocked, and only the a.c. components of the input signal deflect the beam vertically. This allows to observe small a.c. signals or large d.c. background.

ii. D.C. : The vertical amplifier has d.c. coupling throughout, so that the deflection corresponds to both the a.c. and the d.c. components of the input.

iii. GROUND : The input to the amplifier is grounded. There will be no vertical deflection. If no voltage is applied to horizontal plates, the spot will be at the position corresponding to ground. It is useful for measuring voltage with respect to ground.

f) Vertical Mode Control: The control serves for the vertical section of the scope as a whole. Assume that two input signals are simultaneously applied to the two vertical inputs of the scope. Then this switch determines what is displayed on the screen. Thus usual choices are :

1 only, 2 only, 1+2;1-2, Alternate, and Chop. The meaning of each of these is described briefly below:

<u>i) 1 only :</u> Only the signal at input 1 is displayed.

<u>ii) 2 only :</u> Only the signal at input 2 is displayed.

<u>iii) 1 + 2 :</u> Sum : The sum of the inputs 1 and 2 is displayed.

<u>iv) 1-2 :</u> Sum : Difference : The difference between input 1 and input 2 is displayed.

<u>v) Alternate :</u> Input 1 is displayed first, then input 2 is displayed, then input 1again and so on. By using the vertical position control, the two traces can be separated vertically, and thus, relations between the two signals can be studied.

<u>vi) Chop :</u> In this mode first input 1 is displayed for a fraction of a microsecond, then input 2 for a fraction of microsecond, then input 1 again, and so on. In this way, plots of both inputs can be drawn at the same time. The chop mode is useful with low frequency signals, while the alternate mode is useful for high frequency signals.

3. Horizontal section :

a) Time Base Control: Very often the oscilloscope is used to observe the waveform of time varying signals. Most of the horizontal section of the scope is devoted to generating a time base for such signals. The time base control is calibrated in terms of time per centimeter or time per division. A typical unit might be 0.10 msec/cm, meaning that horizontal deflection of the spot will be 1 cm in 0.1 msec. The usual range on a scope is from about 0.1 sec/cm to 20 to 50 nsec/cm. This is shown in the figure.

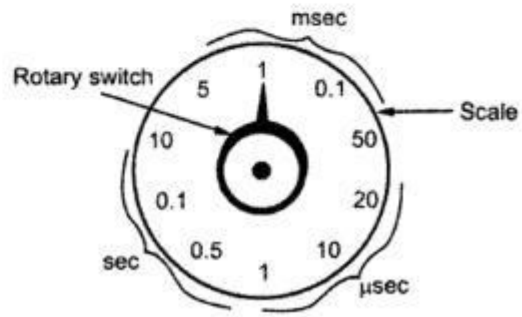


Fig.2.22 Times/division selection

If signal has time period of 20 msec then with two different time base control selections, it can be displayed as shown in the figure below (a) and (b).

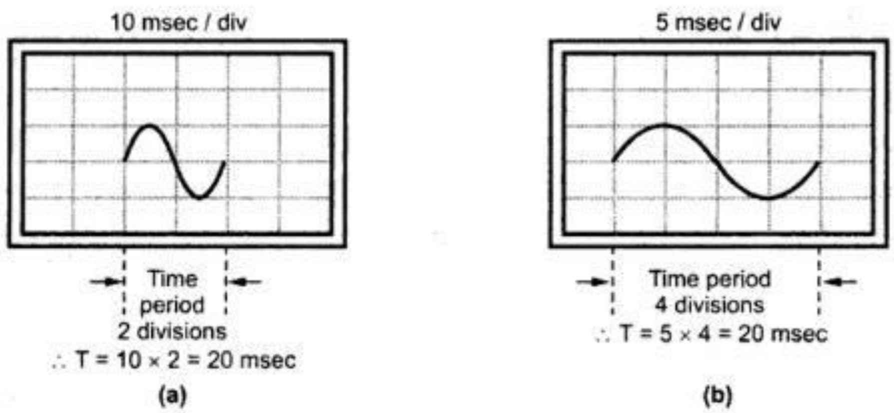


Fig.2.23 Effect of Time base control.

b) Position : This knob can be used to shift the display, as a whole to left or right.

c) Synchronization: It has been mentioned earlier that to obtain the stationary pattern on the screen, the synchronization is must. It is used to operate the time base generator such that the frequency of saw tooth voltage is an integral multiple of input signal frequency. There are various signals which can be applied to the trigger circuit. The signals can be selected using a synchronous selector switch. The types of signals which can be selected are:

i) Internal : The trigger is obtained from signal being measured through the vertical amplifier

ii) Line : The input to the trigger circuit is from a.c mains (say 230 V, 50 Hz) supply. This is useful when observing the signals which are synchronized with power line, such as ripple in a power line.

iii) External : The input to the trigger circuit is from the external trigger circuit.

d) Sweep Selector : When the sweep selector switch S, is in linear position, the horizontal amplifier receives an input from the saw tooth sweep generator which is triggered by the synchronous amplifier. The external signal also can be applied to the horizontal deflecting plates, by putting a selector switch S, to the external position.

4. Z-axis Intensity control:

It is used for brightening the display. Periodic positive pulses are applied to the grid and alternatively negative pulses are applied to cathode, to brighten the beam during its sweep period. This control is obtained by inserting a signal between the ground and the control grid or ground and the cathode.

2.6 CRO PROBES

The CRO probe performs the very important function of connecting the test circuit to the oscilloscope without altering, loading or otherwise disturbing the test circuit.

There are three different probes:

a) Direct reading probe, b)circuit isolation probe, c)detector probe.

They are discussed below:

a) Direct reading probe

This probe is the simplest of all probes and it uses a shielded coaxial cable.

It avoids stray pickups which may lead to problems when low level signals are being measured. It is used usually for low frequency and low impedance circuits. However in using the shielded probe, the shunt capacitance of the probe is added to the input impedance and capacity of the scope and acts to lower the response of the oscilloscope to high impedance and high frequency circuits.

b) Isolation probe

Isolation probe is used in order to avoid the undesirable circuit loading effects of shielded probe. The isolation probe which is used along with the capacitive voltage divider, decreases the input capacitance and increases the input resistance of the oscilloscope. This way the loading effects are drastically reduced.

c) Detector probe

When analyzing the response to modulated signals in communication equipment like AM, FM and TV receivers, the detector probe functions to separate the lower frequency modulation component from the higher frequency carrier. The amplitude of the modulator carrier (which is proportional to the response of the receiver to the much high frequency carrier signal) is displayed on the oscilloscope by rectifying and bypassing action. This permits an oscilloscope capable of audio-frequency response to perform signal tracing tests on communication signals in the range of hundreds of Mhz, a range which is beyond the capabilities of all oscilloscopes except the highly specialized ones.

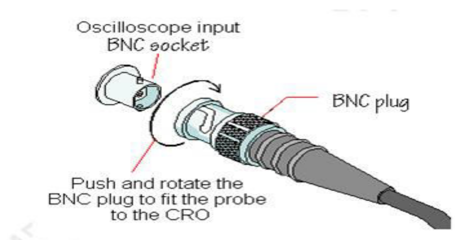


Fig .2.24 A CRO Probe

2.7 MEASUREMENTS ON CRO

The various characteristics of an input signal and the properties of the signal can be measured using C.R.O. The various parameters which can be measured using C.R.O. are voltage, current, period, frequency, phase, amplitude, peak to peak value, duty cycle etc. Let us discuss the amplitude, frequency and phase measurements using C.R.O.

(1) Voltage measurement:

The C.R.O. includes the amplitude measurement facilities such as constant gain amplifiers and the calibrated shift controls. The waveform can be adjusted on the screen by using shift controls so that the measurement of divisions corresponding to the amplitude becomes easy. Generally to reduce the error, peak to peak value of the signal is measured and then its amplitude and r.m.s. value is calculated.

<u>To measure the amplitude use the following steps:</u>

1. Note down the selection in volts/ division from the front panel, selected for measurement

2. Adjust shift control to adjust signal on screen so that it becomes easy to count number of divisions corresponding to peak to peak value of the signal.

3. Note down peak to peak value in terms of the number of divisions on screen.

4. Use the following relation to obtain peak to peak value in volts.

$$V_{p\text{-}p} = (\text{Number of divisions or units noted}) \times \left(\frac{\text{volts}}{\text{divisions}}\right)$$

5.The amplitude can then be calculated as :

$$V_m = \text{Amplitude} = \frac{V_{p\text{-}p}}{2}$$

while the rms value of sinusoidal wave can be given as:

$$V_{RMS} = \frac{V_m}{\sqrt{2}} = \frac{V_{p\text{-}p}}{2\sqrt{2}} \quad \text{only for sinusoidal signals}$$

(2) Current measurement:

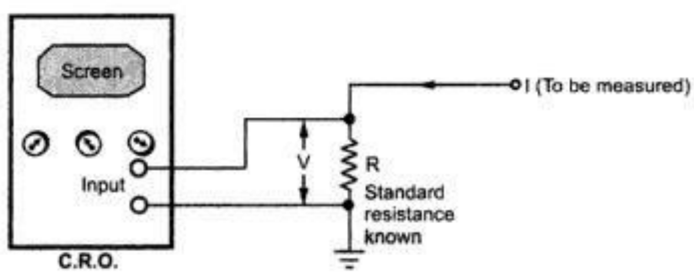


Fig.2.25 Arrangement for current measurement

The CRO is basically voltage indicating device. Hence to measure the current, the current is passed through a known standard resistance. The voltage across resistance is displayed on CRO and is measured. This measured voltage divided by the known resistance gives the value of the unknown current. The arrangement is shown in the figure above. Current is obtained using formula,

$$I = \frac{V_{\text{measured}} \text{ on C.R.O.}}{R}$$

(3) Period & Frequency measurement:

In such measurement, the waveform is displayed on the screen such that one complete cycle is visible on the screen. Thus accuracy increases if a single cycle occupies as much as the horizontal distance on the screen.

Note the time/ division selected on the front panel. Then the period of the waveform can be obtained as,

$$T = (\text{Number of divisions occupied by 1 cycle}) \times \left(\frac{\text{time}}{\text{division}}\right) = \text{time period}$$

The frequency is the reciprocal of the period. That is given by:

$$f = \frac{1}{T}$$

This is the method of frequency measurement without Lissajous pattern.

2.8 MEASUREMENT OF PHASE AND FREQUENCY USING LISSAJOUS PATTERNS:

It is interesting to consider the characteristics of patterns that appear on the screen of a CRT when sinusoidal voltages are simultaneously applied to horizontal and vertical plates. These patterns are called 'Lissajous Patterns'. When two sinusoidal voltages of equal frequency which are in phase with each other are applied to the horizontal and vertical deflection plates, the pattern appearing on the screen is a straight line as its clear from figure below

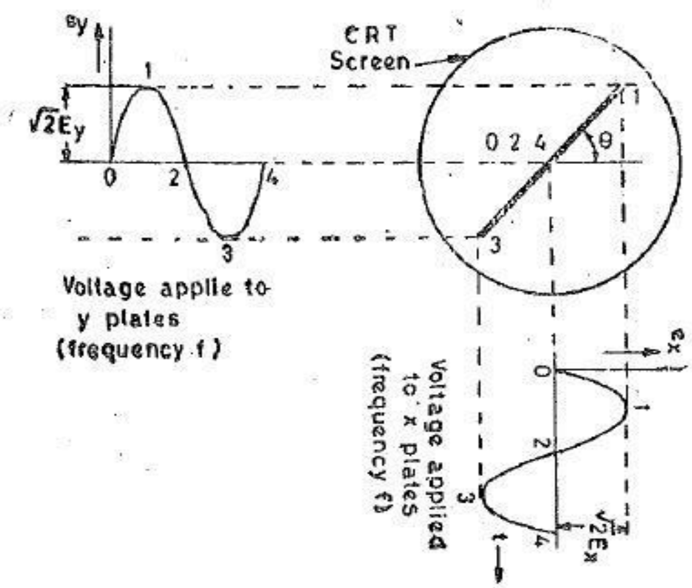


Fig.2.26 Lissajous pattern with equal frequency voltages and zero phase shift

Thus when two equal voltages of equal frequency but with 90^0 phase displacement are applied to a CRO, the trace on the screen is a circle. This is shown in figure below

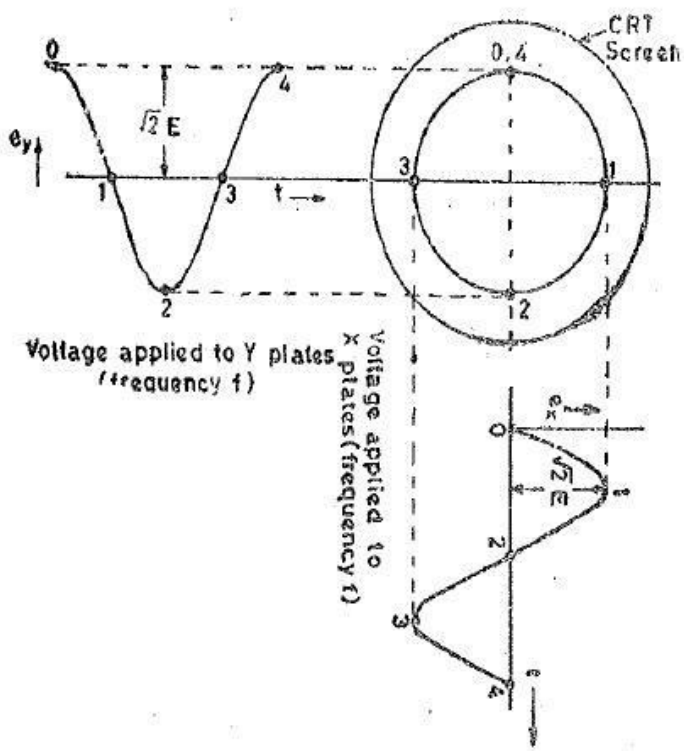


Fig.2.27 Lissajous pattern with equal voltages of equal frequency and phase shift of 90^0

When two equal voltages of equal frequency but with a phase shift ϕ (not equal to 0° or 90°) are applied to a CRO we obtain an ellipse as shown in figure below. An ellipse is also obtained when unequal voltages of same frequency are applied to the CRO.

A number of conclusions can be drawn from the above discussions. When two sinusoidal voltages of same frequency are applied :

(i) A straight line results when the two voltages are equal and are either in phase with each other or 180° out of phase with each other. The angle formed with the horizontal is 45° when the magnitudes of voltages are equal. An increase in the vertical detection voltage causes the line to have an angle greater than 45^0 with the horizontal. On the other hand a greater horizontal voltages makes the angle less than 45° with the horizontal. :

(ii) Two sinusoidal waveforms of the same frequency produce a Lissajous pattern, which may be a straight line, a circle or an ellipse depending upon the phase and magnitude of the voltages.

A circle can be formed only when the magnitude of the two signals are equal and the phase difference between them is either 90° or 270^0. However, if the two voltages are not equal and/or out of phase an ellipse is formed. If the Y voltage is larger, an ellipse with vertical major axis is formed while if the X plate voltage has a greater magnitude, the major axis of the ellipse lies along horizontal axis.

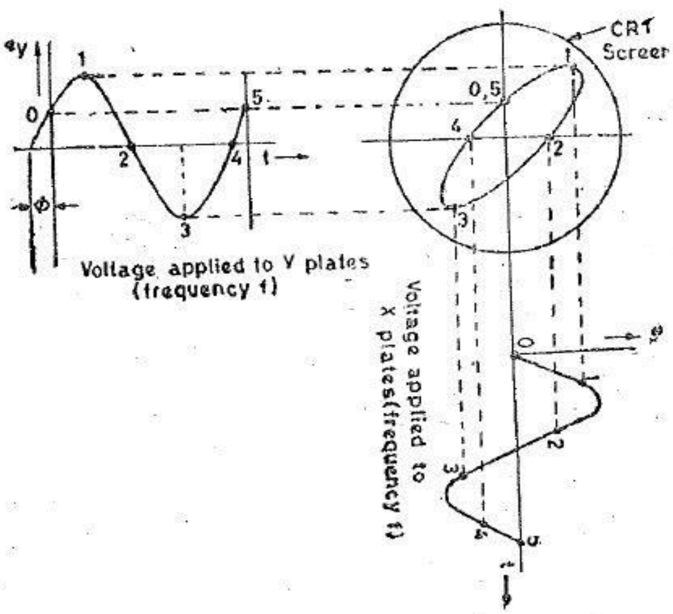


Fig.2.28 Lissajous pattern with two equal voltages of same frequency and phase shift of ϕ

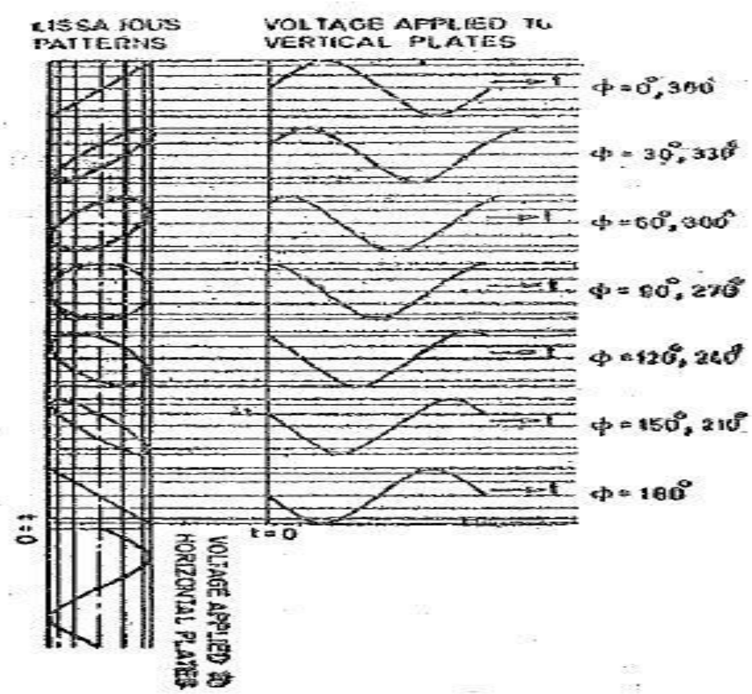


Fig.2.29 Lissajous patterns with different phase shifts

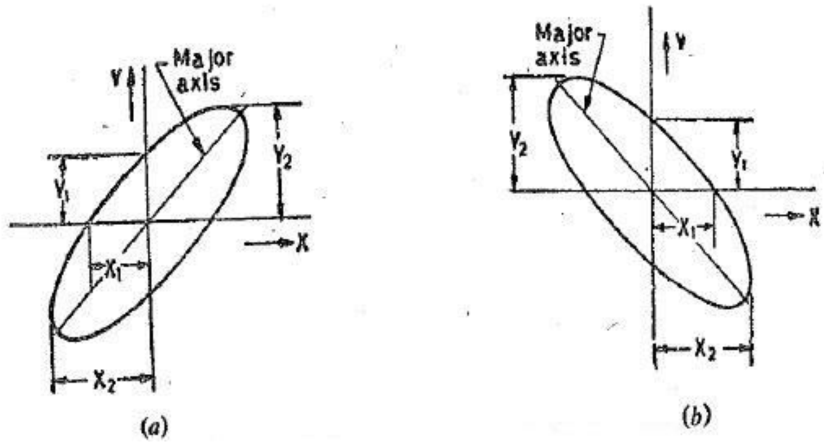


Fig.2.30 Determination of angle of Phase shift

The sine of phase angle between the voltages is given by

$$\sin\phi = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}$$

For convenience, the gains of the vertical and horizontal amplifiers are adjusted so that the ellipse fits exactly into a square marked by the lines on the graticule. If the major axis of the ellipse lies in the first and third quadrants (i.e., its slope is positive) as in figure (a), the phase angle is either between 0° to 90° or between 270° to 360°. When the major axis of ellipse lies in second and fourth quadrants i.e., when its slope is negative as in figure (b), the phase angle is either between 90° and 180° or between 180° and 270°.

Frequency Measurements: Lissajous patterns may be used for accurate measurement of frequency. The signal, whose frequency is to be measured, is applied to the Y plates. An accurately calibrated standard variable frequency source is used to supply voltage to the X plates, with the internal sweep generator switched off. The standard frequency is adjusted until the pattern appears as a circle or an ellipse, indicating that both signals are of the same frequency. Where it is not possible to adjust the standard signal frequency to the exact frequency of the unknown signal, the standard is adjusted to a multiple or a submultiple of the frequency of the unknown source so that the pattern appears stationary.

Let us consider an example Suppose sine waves are applied to X and Y plates as shown in figure below

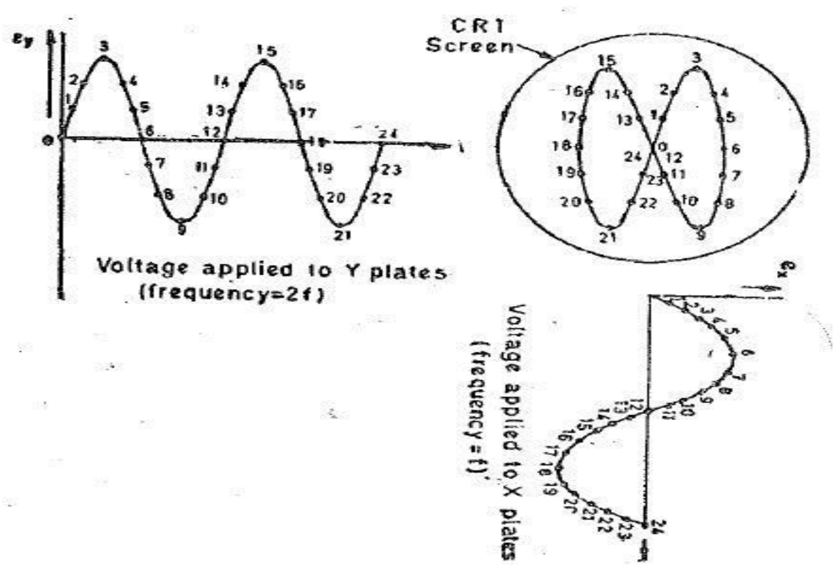


Fig.2.31 Lissajous patterns with frequency ratio 2:1

Let the frequency of wave applied to Y plates is twice that of the voltage applied to X plates. This means that the CRT spot travels two complete cycles in the vertical direction against one in the horizontal direction. The two waves start at the same instant. Lissajous pattern may be constructed in the usual way and a 8 shaped pattern with two loops is obtained. If the two waves do not start at the same instant we get different patterns for the same frequency ratio. The Lissajous patterns for other frequency ratios can be similarly drawn. Some of these patterns are shown in figure below.

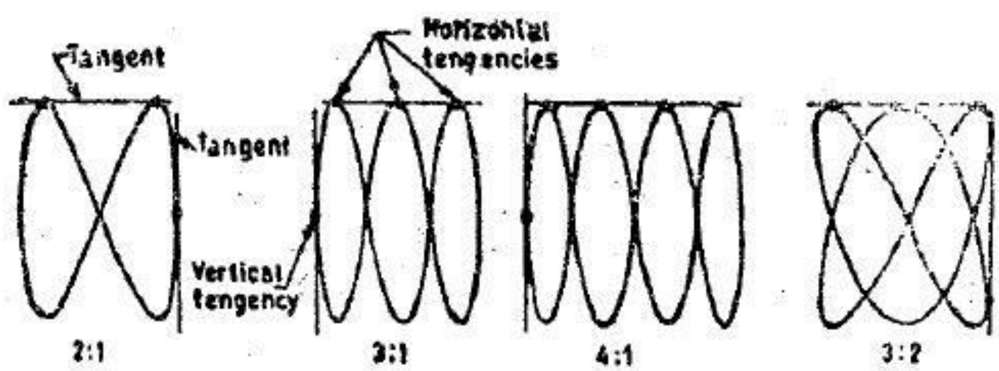


Fig.2.32 Lissajous patterns with different frequency ratios

It can be shown that for all the above cases, the ratios of the two frequencies is :

$$\frac{f_y}{f_x} = \frac{\text{number of times tangent touches top or bottom}}{\text{number of times tangent touches either side}}$$
$$= \frac{\text{number of horizontal tangencies}}{\text{number of vertical tangencies}}$$

where, f_V = frequency of signal applied to Y-plates

f_X = frequency of signal applied to X-plates

2.9 TYPES OF OSCILLOSCOPES

There are a number of oscilloscopes which are used for special applications.

Some of the oscilloscopes are described below:

a) Multiple beam oscilloscopes

In many cases it becomes necessary to compare one signal with that of the other. In such cases Multiple beam oscilloscopes are used. They enclose in a single tube several beam producing systems each with its vertical pair of plates, but mostly with a common time-base. Each Y-channel has its own amplifier. The synchronization or triggering is done from the input of a desired Y-channel or from an external input voltage.
Double beam oscilloscopes use two electron guns within the same cathode ray tube. the electron beam of the two channels are completely independent of each other. The same effect may be produced by a single electron gun, the output from it being split into two.

b) Multiple Trace Oscilloscopes

This oscilloscope uses single electron guns and produces multiple traces by switching the Y-deflection plates from one input signal to another (this means that the Y-channel is time shared by many signals). The eyes interpret this is a continuous simultaneous display of the input signals although it is a sampled display. This method reduces the cost of manufacturing multi-channel oscilloscopes.

c) Sampling oscilloscopes

The oscilloscopes presently can be used for continuous display for frequencies in the 50-300 Mhz range depending upon the design of the oscilloscopes. The display may have upto 1000 dots of luminescence. The vertical deflection for each dot is obtained from progressively later points in each successive cycle of input waveform as shown below:

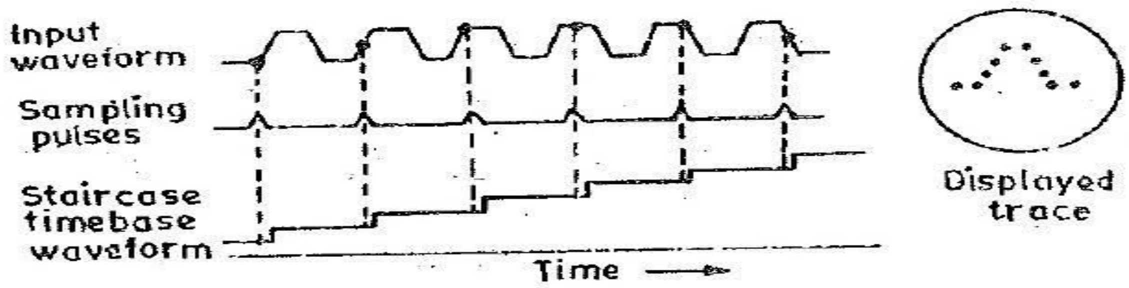


Fig.2.34 Principle of Sampling Oscilloscopes.

The horizontal deflection of the electron beam is obtained by applying staircase waveform to X-deflection plates.The sampling oscilloscope is able to respond and store rapid bits of information and present them in a continuous display. The sampling techniques immediately the input signals into lower frequency domain, where conventional low frequency circuitry is then capable of producing a highly effective display.This type of oscilloscopes can be used beyond 50Mhz into the UHF range around 500Mhz and beyond upto 10Ghz. It should be noted that the sampling techniques cannot be used the display of transient waveforms.

2.10 Sampling Oscilloscope

An ordinary oscilloscope has a Bandwidth of 10 MHz. The high frequency (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 the sampling point is advanced and another sample is taken. The shape of the waveform 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. Figure below shows a block diagram of a sampling oscilloscope.

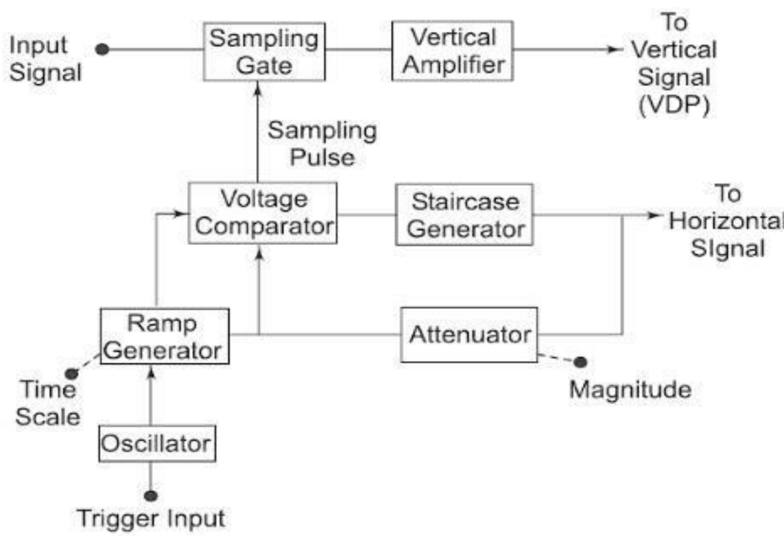


Fig.2.35 Block diagram of Digital Sampling Oscilloscope

The input waveform 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 corresponding waveforms are also shown in below figure

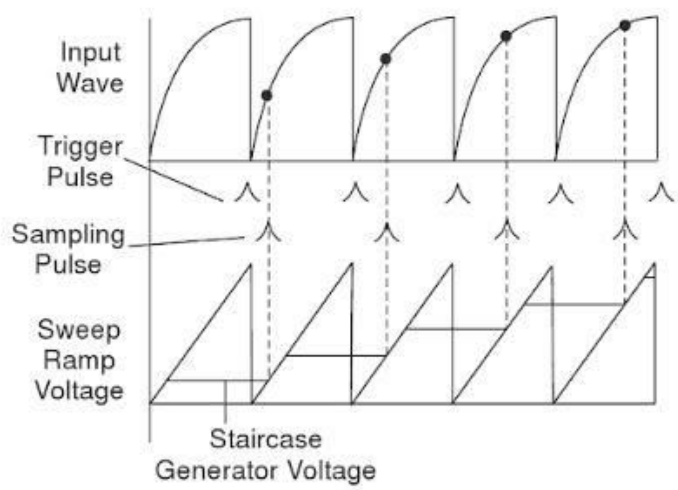


Fig.2.36 Various waveforms at each block of a sampling oscilloscope.

At the beginning of each sampling cycle, the trigger pulse activates an oscillator and a linear ramp voltage is generated. This ramp voltage is applied to a voltage comparator which compares the ramp voltage to a staircase generator, 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 the size of the steps the larger the number of samples and higher the resolution of the image.

d) Scanning Oscilloscopes

These oscilloscopes use television tubes. The data to be measured are applied through intensity modulation on the standard screen. Several phenomena can be observed simultaneously on a single screen by using this technique. As a result of large number of factors influencing the quality of recording, experience with the particular camera CRO combination is usually the best guide.

e) Storage type Oscilloscopes

- They are rapidly becoming one of the most useful tools in the presentation of very slowly swept signals and finds many application in mechanical and biomedical fields.
- Usually in conventional CRTs, the persistence of phosphor ranges from microseconds to seconds. In applications where the persistence of the screen is smaller than the rate at which the signal sweeps across the screen, the start of screen will have disappeared before the end of the display is written.
- In storage oscilloscopes, the persistence times are much greater than a few seconds or even hours are available, making it possible to store events on the CRT screen.
- The special CRT of storage oscilloscope contains electron gun, deflection plates, phosphor bronze screen but also it holds many number of special electrodes. The CRT used here is called as storage tube.
- The schematic diagram of Storage CRT below:

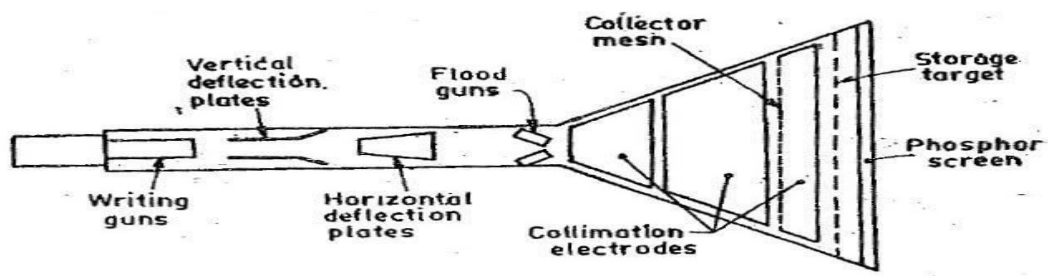


Fig.2.37 Schematic diagram of a storage type CRT

- The storage mesh or the storage target is mounted just behind the phosphor screen is a conductive mesh covered with a highly resistive coating of magnesium fluoride.
- The write gun is a high-energy electron gun, similar to the conventional gun giving a narrow focussed beam which can be deflected and used to write the information to be stored.
- Because of the excellent insulating properties of the magnesium fluoride coating, the positively charged pattern remains exactly in the same position on the storage target which it was first deposited.
- The stored pattern may be made available for viewing at a later time by the use of two special electron guns called flood guns. The flood guns are placed inside the CRT in a position between the deflection plates and the storage target and they emit low-velocity electrons over a large area towards the entire screen.
- When the flood guns are switched for viewing mode low energy electrons are sprayed towards the screen. The electron trajectories are adjusted by the collimating electrodes which constitute a low-voltage electrostatic lens system , so that the flood electrons cover the entire screen area.
- To erase the pattern which is etched on the storage mesh, a negative voltage is applied to the storage target, neutralizing the stored positive charge.
- To get variable persistence, the erase voltage is applied in the form of pulses instead of a steady dc voltage. By varying the width of these pulses, the rate of erase is verified.

f) Impulse waveform oscilloscopes

These oscilloscopes are used for the investigation of transient non-period phenomena which occur at high voltages. These oscilloscopes use special types of CRT wherein the plates are mounted on the sides. The voltage to be measured is applied to these plates either directly or through capacitive potential dividers. Simultaneously, an impulse is suddenly applied to the cathode voltage. A very bright display is obtained on account of the high voltage and the high beam current which exist for a very short duration. Therefore, photographic records of the display can be obtained even at very high speeds of upto $50x10^6$

m/s.

2.11 STORAGE CRO, DIGITAL STORAGE OSCILLOSCOPE

The storage type CRO is rapidly becoming one of the most useful tools in the presentation of very slowly swept signals and finds many applications in the mechanical and biomedical fields. In the conventional CRT the persistence of the phosphor ranges from micro seconds to perhaps seconds. In applications where the persistence of the screen is smaller than the rate at which the signal sweeps across the screen, the start of the display will have disappeared before the end of the display is written.

With the variable-persistence or storage CRO, the slowly swept trace can be kept on display continuously by adjusting the persistence of the CRT screen to match the sweep time. Persistence times much greater than a few seconds or even hours, are available, making it possible to store events on a CRT screen. The storage CRO uses a special CRT, called the storage tube. This special CRT contains all the elements of a conventional CRT, such as the electron gun, the deflection plates, and a phosphor screen, but in addition holds a number of special electrodes A schematic representation of one type storage tube is given in figure below.

The storage mesh or storage target, mounted just behind the phosphor screen, is a conductive mesh covered with a highly resistive coating of magnesium fluoride. The write gun is a high-energy electron gun, similar to the conventional gun, giving a narrow focussed beam which can be deflected and used to write the information to be stored. The write gun etches a positively charged pattern on the storage target by knocking off secondary-emission electrons. Because of the excellent insulating properties of the magnesium fluoride coating, this positively charged pattern remains exactly in the same position on the storage target where it was first deposited. The electron beam, which is deflected in the conventional manner both in the horizontal and the vertical directions, therefore traces out the waveform pattern on the storage target.

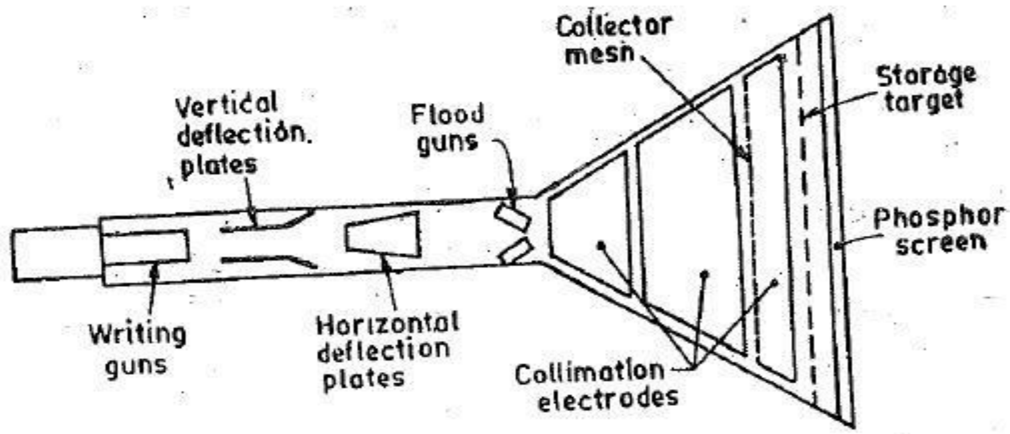


Fig.2.38 Schematic diagram of Storage type CRT

The stored pattern may be made available for viewing at a later time by the use of two special electron guns, called flood guns. The flood guns are placed inside the CRT in a position between the deflection plates and the storage target and they emit low-velocity electrons over a large area towards the entire screen. When the flood guns are switched on (the viewing mode), low energy electrons are sprayed towards the screen. The electron trajectories are adjusted by the collimation electrodes which constitute a low voltage electrostatic lens system, so that the flood-electrons cover the entire screen area. Most of the flood electrons are collected by the collector mesh and therefore never reach the phosphor screen. In the area near the stored positive charge on the storage target, the positive field pulls some of the flood-electrons through the storage mesh and these electrons continue to hit the phosphor. The CRT display therefore will be an exact copy of the pattern which was initially stored on the target and the display will be visible as long as the flood guns continue emission of low-energy electrons. To erase the pattern which is etched on the storage mesh, a negative voltage is applied to the storage target, neutralizing the stored positive charge.

To obtain variable persistence, the erase voltage is applied in the form of pulses instead of a steady d.c. voltage. By varying the width of these pulses the rate of erasing is varied. The variable-persistence control on the front panel of the scope is then the width control of the erase-pulse generator.

2.INDUSTRIAL APPLICATIONS OF CRO

Because the oscilloscope is an extremely flexible and versatile instrument, it can be used to measure a number of parameters associated with DC and AC signals. Using a single channel oscilloscope, it is capable of making measurements of voltage current, time, frequency and rise/fall time. If a dual trace oscilloscope is used the phase shift between two synchronous signals can be measured.

Other major applications of CRO are listed below:

In Radio Work

1. To trace and measure a signal throughout the RF, IF and AF channels of radio and television receivers.
2. It provides the only effective way of adjusting FM receivers, broadband high-frequency RF amplifiers and automatic frequency control circuits;
3. to test AF circuits for different types of distortions and other spurious oscillations;
4. To give visual display of wave-shapes such as sine waves, square waves and their many different combinations;
5. To trace transistor curves
6. To visually show the composite synchronized TV signal
7. To display the response of tuned circuits etc.

Scientific and Engineering applications:

1. Measurement of ac/dc voltages,
2. Finding B/H curves for hysteresis loop,
3. for engine pressure analysis,
4. for study of stress, strain, torque, acceleration etc.
5. Frequency and phase determination by using Lissajous figures,
6. Radiation patterns of antenna,
7. Amplifier gain,
8. Modulation percentage,
9. Complex waveform as a short-cut for Fourier analysis,
10. Standing waves in transmission lines etc.

2.12 Q.Meter

Definition:

- The instrument which measures the storage factor or quality factor of the 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.
- The Q meter works on series resonant.
- The resonance is the condition exists in the circuit when their inductance and capacitance reactance 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, inductance and capacitance of the resonant series circuit.
- The figure below shows a coil of resistance, inductance and capacitance connected in series with the circuit.

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 capacitance reactance 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, inductance and capacitance of the resonant series circuit.

The figure below shows a coil of resistance, inductance and capacitance connected in series with the circuit.

At resonant frequency f_o,

$$X_C = X_L$$

The value of capacitance reactance is

$$X_C = \frac{1}{2}\pi f_o C = \frac{1}{\omega_o C}$$

At inductive reactance,

$$X_L = \frac{1}{2}\pi f_o L = \frac{1}{\omega_o L}$$

At the resonant frequency,

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

and current at resonance becomes

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

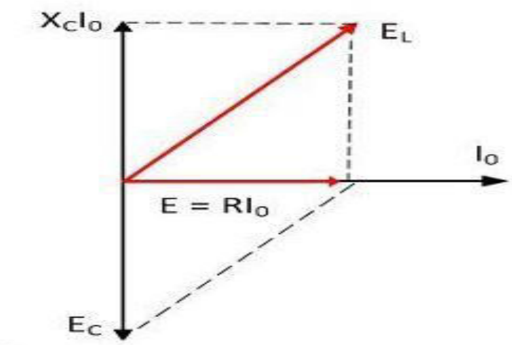


Fig 2.39 Phasor Diagram

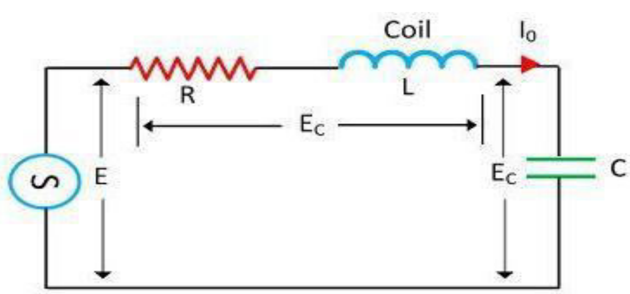


Fig.2.40 Circuit Diagram for Qmeter

Equation

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

$$E = I_0 r$$

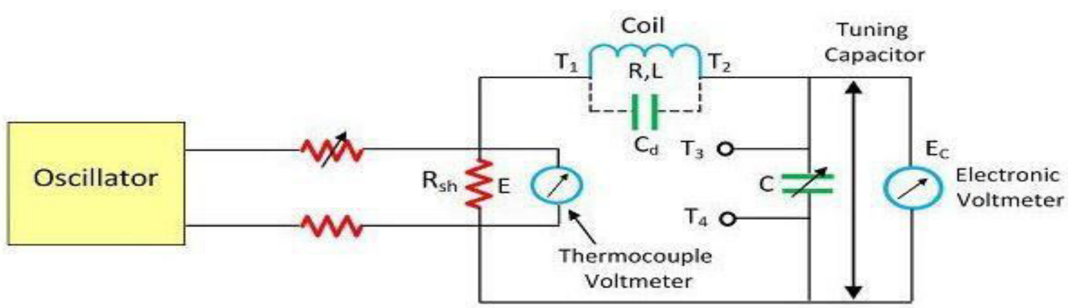
$$\frac{E_C}{E} = \frac{I_0 \omega_0 L}{I_0 R} = \frac{\omega_0 L}{R} = Q$$

$$E_0 = QE$$

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

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



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

Applications of the Q-meter(cont.d)

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

True value is given as

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

$$Q_{true} = Q_{meas}\left(1 + \frac{R_{sh}}{R}\right)$$

Applications of the Q-meter

- 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.

2.13 Vector Impedance Meter

If some knowledge of the reactive and resistive factors is needed, in addition to obtaining a direct reading of the magnitude of the impedance (Z), a test method for determining the Vector Impedance Meter may be employed.

This method determines Z in polar form, that is, it gives the magnitude IZI and the phase angle (θ) of the impedance being tested, rather than the individual resistance and reactance in rectangular form, (R + j X). The test circuit is shown in Fig. 10.5. Two resistors of equal value R is used. The voltage drop across R_{AB} and R_{BC}, that is E_{AB} and E_{BC} will be equal (each value is equal to half the supply voltage, E_{AC}). Since the same current I_1 flows through the variable standard_resistor $R_{st,}$ the unknown impedance in series. The magnitude of Z_x can be determined by the equal deflection method by obtaining equal voltage drops across R_{st} and Z_x, i.e. E_{AD} and E_{PC}, and reading the calibrated standard resistor R_{st}, required to produce this condition.

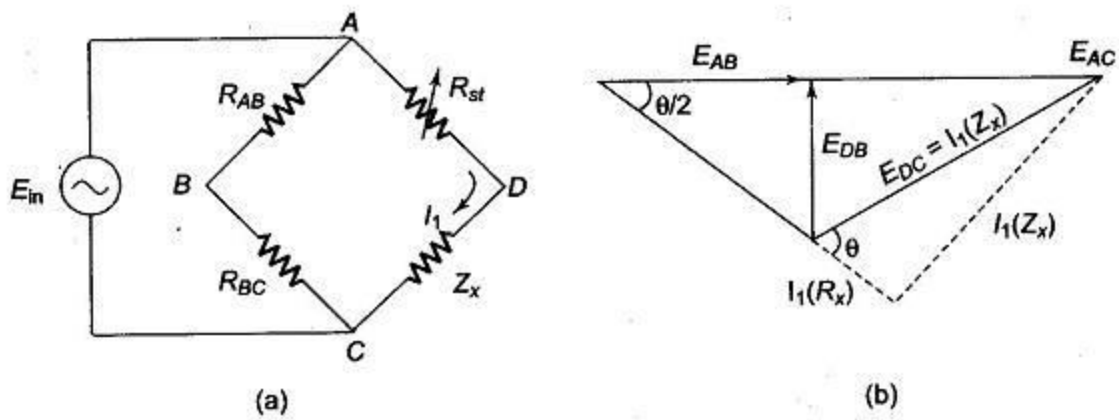


Fig. 10.5 (a) Vector Impedance Method (b) Vector Diagram

The phase angle θ of the impedance Z_x, can be obtained from the reading of the voltage at points B and D, that is, E_{DB}. The deflection of the meter will be found to vary with the Q of the unknown impedance Z_x. The VTVM ac voltage reading will vary from 0 V, when the phase angle of 0° (Q = 0) to the maximum voltage, with an angle of 90° (Q = infinite). The angle between the voltages E_{AB} and E_{AD} is half the phase angle θ, since E_{AD} is made equal to E_{DC}.

$$\frac{\theta}{2} = \tan \frac{E_{DB}}{E_{AB}}$$

Since E_{AB} is known to be half the known input voltage E_{in} the voltmeter reading of E_{DB} can be interpreted in terms of θ/2, and hence the phase angle θ of the unknown Z_x can be determined.

While this method for obtaining both Z and θ is approximate because of the crowding caused by the non-linear relation, it is useful for obtaining a first approximation. A commercial Vector Impedance Meter is used for greater accuracy.

Commercial Vector Impedance Meter

A commercial instrument that measures impedance directly in the polar form, giving the magnitude of Z in ohms, at a phase angle θ, requires only one balancing control for both values.

It measures any combination of R, L and C, and includes not only pure resistive, capacitive or inductive elements but also complex impedances. Since the determination of magnitude and angle requires only one balance control, the awkward condition of sliding balance, frequently encountered when measuring low Q reactors with conventional bridge circuits, which necessitates so much successive adjustments, is avoided.

Measurements of impedances ranging from 0.5 — 100,000 Ω can be made over the frequency range from 30 Hz to 40 kHz, when supplied by an external oscillator. Internally generated frequencies of 60 Hz, 400 Hz or 1 kHz are available. At these internal frequencies and external frequencies up to 20 kHz, the readings have an accuracy of ± 1% for the magnitude of Z and ± 2% for θ.

The fundamental circuit, which is basic for both **Z** and phase angle measurement, is shown in Figs 10.6(a) and (b).

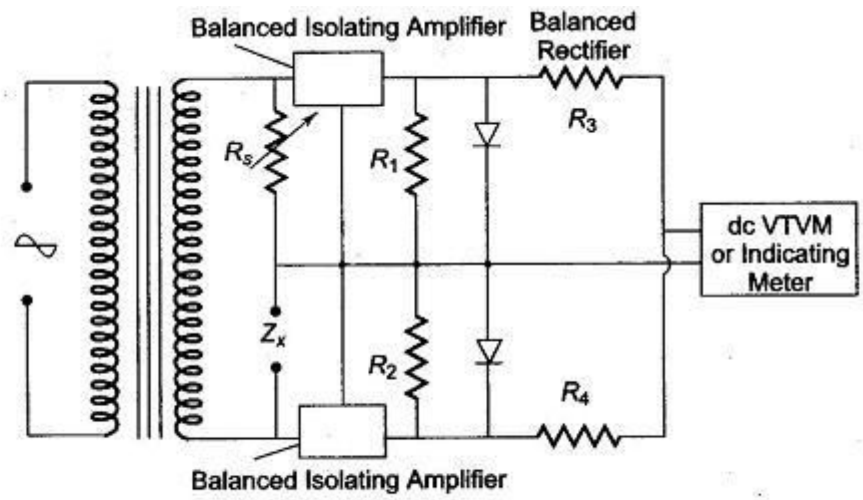


Fig. 10.6 (a) Commercial Vector Impedance Meter (Magnitude of Impedance Measurement)

In both parts, the measurement makes use of the equal deflection method, by comparing the voltage drop across the unknown Z to the drop across a standard resistance, with the same current in both.

In the impedance measuring circuit of Fig. 10.6(a), Z_x, is the unknown impedance and the variable resistance R_s is the standard resistance, which is varied by the calibrating impedance dial. The dial is adjusted until the voltage drops across Z_x and R_s are equal. Each voltage drop is amplified in the two sections of the balanced amplifier and applied to each section of a dual rectifier. The algebraic sum of the rectified outputs will then be zero, as indicated by the null reading of the dc VTVM, regardless of the phase angle of Z_x since rectified voltage depends only on the magnitude IZI of the unknown Z. This unknown Z, in ohms, is read directly on the dial of the variable standard R_s.

The circuit shown in Fig. 10.6(b) is used for the measurement of phase angle, after the Z balance has been obtained.

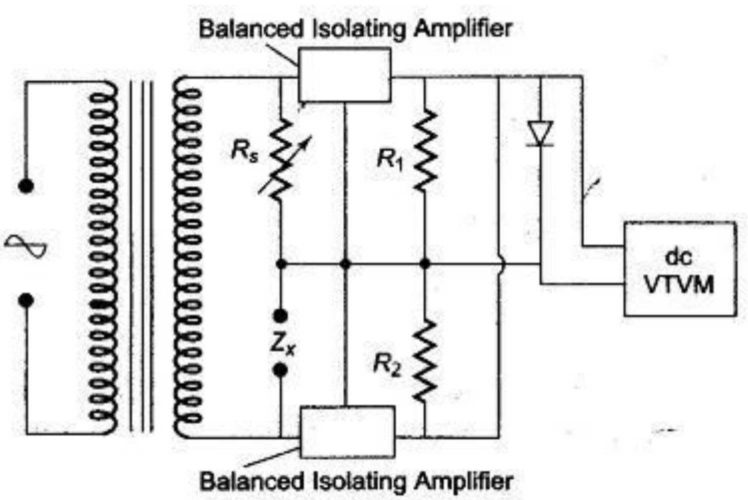


Fig. 10.6 (b) Vector Impedance Meter Circuit for Measurement of Phase Angle

With the switch in the calibration position, the injection voltage is calibrated by adjusting it for full scale deflection on the indicating meter or the VTVM. The function switch is then set to the phase position. In this position, the function switch of the instrument parallels the output of the balanced amplifier, before rectification. The sum of ac output voltages from the amplifiers is now a function of the vector difference between the ac voltages impressed on the amplifiers.

The rectified voltage resulting from this vector difference is shown on the dc VTVM, as a measure of the phase angle between the voltage across Z_x and R_s, which are equal in magnitude but different in phase. Thus the meter is able to indicate direct reading values for the phase angle. If required, this angle can be converted to measure the corresponding values for dissipation factor D and quality factor Q.

Where it is necessary to determine the phase angle to a high degree of accuracy, a phase meter is usually employed, e.g. in servos and precise control applications.

2.14 RF voltage and power measurements

DC and low-frequency **measurements** can be calculated by the formula: P=U2/R. Depending in the match between **RF** or MW source impedance and load impedance, parts of the signal **energy** is reflected. A waveguide setup makes it very difficult to **measure voltage**.

Radio frequency (**RF**) is the oscillation rate of an alternating electric current or **voltage** or of a magnetic, electric or electromagnetic field or mechanical system in the frequency range from around 20 kHz to around 300 GHz. ... Different sources specify different upper and lower bounds for the frequency range.

RF power can be integrated over a frequency band, as is the case for many mobile communication signals. ... Another instrument commonly used to **measure RF power** is a spectrum analyzer. With these more complex **RF** instruments, engineers can **measure** the individual spectral components across frequency.

- output power, whether from a power amplifier feeding an antenna, or from one RF stage to the next;
- power across a wider band of interest, such as the 2.4 GHz Wi-Fi band, which is a rough indication of how much noise and interference from other sources is present;
- narrowband noise, which is overlapping with or adjacent to the frequency of operation;
- received power, which indicates how much of the power from the source – a transmitter/antenna pair or the output of a previous stage – has reached the input of the receiver or the next stage, respectively. Received power at an antenna is usually quite low, such as -100 dBm (roughly in the microvolt range);
- noise power, both in-band and out-of-band, which tells you how much ambient RF noise is in the band of interest; this is used to get a sense of the needed signal-to-noise ratio

2.15 True RMS Meter

There exists a fundamental difference between the readings on a normal ac meter and on a true rms meter. The first uses a D' Arsonval movement with a full or half wave rectifier, and averages the values of the instantaneous rectified current.

The rms meter, however, averages the squares of the instantaneous current values (proportional, for example, to the instantaneous heating effect). The scale of the true rms meter is calibrated in terms of the square roots of the indicated current values. The resulting reading is therefore the square root of the average of the squared instantaneous input values, which is the rms value of the measured alternating current.

A true rms meter is always a combination of a normal mean value indicating meter and a squaring device whose output at any instant is proportional to the instantaneous squared input.

It can be shown that the ac component of the voltage developed across the common collector resistors of two transistors that are connected in parallel, and between the bases of which a small ac voltage is applied, is proportional to the square of the applied input voltage.

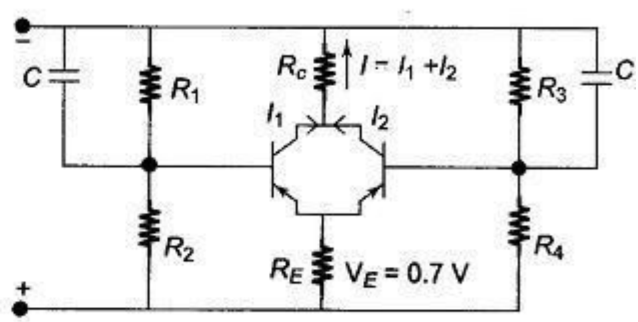


Fig. 4.26 Squaring Device

The basic circuit of Fig. 4.26 employing two transistors is completed by a bridge arrangement in which the dc component is cancelled out. This bridge arrangement is given in Fig. 4.27.

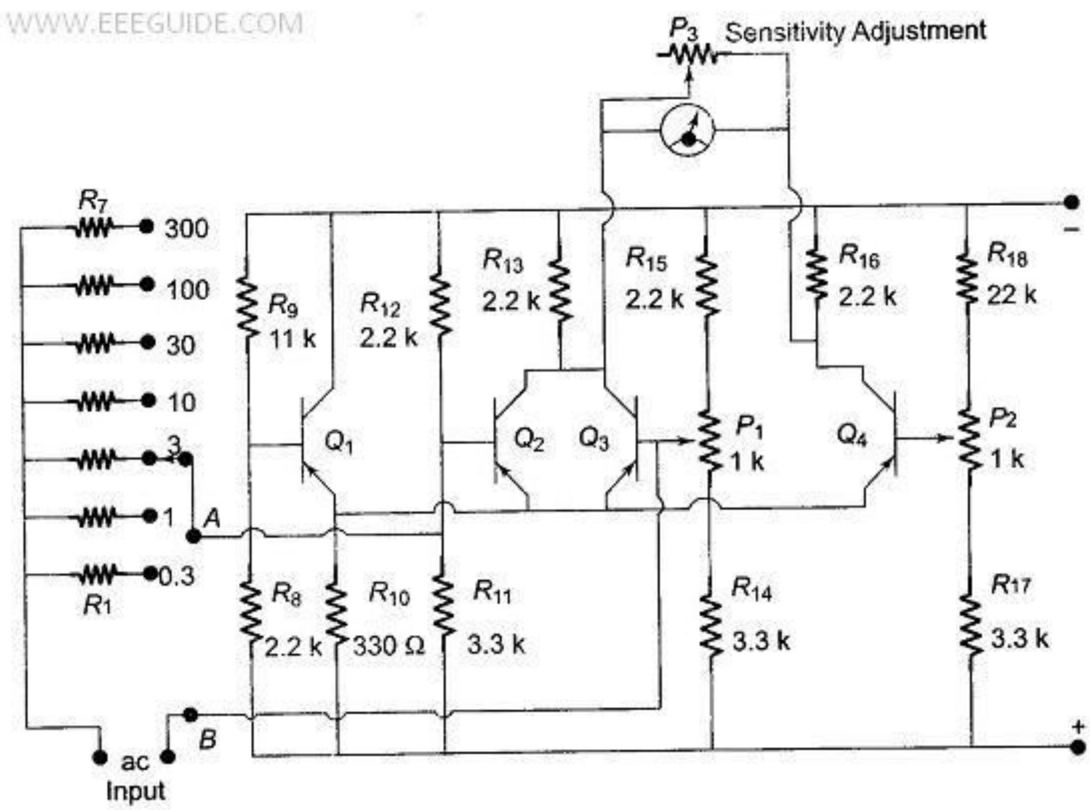


Fig. 4.27 True RMS Meter

One side of the bridge consists of two parallel connected transistors Q_2 and Q_3, and a common collector resistor R_{13}. The side of the bridge, employing P_1 for bias setting, is the basic squaring circuit. The other side of the bridge is made of transistor Q_4 (whose base is biased by means of potentiometer P_2 and collector resistance R_{16}.)

Potentiometer P_1,base bias balance of the squaring circuit, must be adjusted for symmetrical operation of transistors Q_2 and Q_3. To do this, the polarity of a small dc input voltage applied to terminals A and B (bases of Q_2 and Q_3) has to be reversed, and the reading of the output meter must be the same for both input polarities.

Potentiometer P_2 must be set so that for zero input signal (terminals A and B short-circuited), the bridge is balanced and the meter reads zero. The balance condition is reached if the voltage drop across the collector resistance R_{13} of Q_2 — Q_3, and collector resistance R_{16} of Q_4, are equal.

Transistor Q_1 is used to improve the temperature stability of the whole circuit, which is basically obtained by the emitter resistance R_{10}. Optimum temperature compensation is obtained if the voltage drop across the emitter resistance for no signal is 0.7 V for silicon transistor.

The low current through Q_2, Q_3, Q_4 requires a large emitter resistance value to fulfil the condition for compensation. Therefore, another transistor, Q_1 has been added to compensate for the temperature changes of Q_2 and Q_3.

The bias on this transistor has to be adjusted by selecting appropriate values of R_8 and R_9 so that the voltage drop across R_{10} in the balanced condition is 0.7 V for silicon transistor.

The input of the squaring devices (AB) is connected to a voltage divider that is calibrated in seven ranges, namely 0.3, 1, 3, 10, 30, 100, and 300 volts.

QUESTION BANK

PART-A (2 MARKS)

1. Q Factor of coil.
2. What is Vector Voltmeter.
3. What t are the Main Parts of CRT?
4. What is Fluorescence?
5. What t is the Principle of dual beam oscilloscope?
6. What is the principle of sampling oscilloscope?
7. What t deflection system is required for dual beam oscilloscope?.
8. What are the two modes of operation in dual trace oscilloscope.
9. What are Lissajous figures?. On what factor shape of the figures depends?.
10. Lis the Disadvantages of storage cathode ray tube.

PART – B (16 MARKS)

11. With a neat block diagram explain the function of a general purpose oscilloscope.
12. Write Brief notes on:

    a. Storage oscilloscope. B. Sampling oscilloscope

13. Briefly explain the operations of different types of storage oscilloscopes.
14. Sketch the basic block diagram for a digital storage oscilloscope and explain the operation.
15. With a neat block diagram ,explain the working of vector voltmeter.
16. Explain the working of electronic multimeter with necessary diagrams.
17. Explain the working of the following types of CRO (i)Dual trace oscilloscope (ii) Dual beam oscilloscope.
18. Explain the functioning of a strip chart recorder and also the types of marking mechanisms.
19. 72.Explain the working of magnetic recorders and also explain how equalization technique is carried out in a magnetic recorder using direct recording.
20. Explain how the Q-meter can be used for the measurement of Q-factor and effective Resistance and discuss the source of error.

Reference books

1. Sawhney A.K., “A Course in Electrical, Electronic measurement & Instrumentation”, Dhanpat Rai & sons, 18th Edition, Reprint 2010.
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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS

UNIT – III

MEASUREMENT AND INSTRUMENTATION – SEIA3001

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.

IV.SIGNAL GENERATORS

3.1 FUNCTION GENERATORS

Function generators are items of test equipment that are able to generate a variety of simple repetitive waveforms. Straightforward signal generators such as RF signal generators or simple audio oscillators focus on producing a good sine waves, but in many cases other waveforms are needed. In addition to producing sine waves, function generators may typically produce other repetitive waveforms including sawtooth and triangular waveforms, square waves, and pulses. Another feature included on many function generators is the ability to add a DC offset. Often some of the low end function generators may only operate up to frequencies of possibly around 100 kHz as the various shaped waveforms are normally only needed at lower frequencies. However many other more comprehensive function generators are able to operate at much higher frequencies, often up to 10 or 20 MHz.

Function generator controls

In addition to a selection of the basic waveforms that are available, other controls on the function generator may include:

- ***Frequency:*** As would be expected, this control alters the basic frequency at which the waveform repeats. It is independent of the waveform type.
- ***Waveform type :*** This enables the different basic waveform types to be selected:

    1. Sine wave
    2. Square wave
    3. Triangular wave

- ***DC offset:*** This alters the average voltage of a signal relative to 0V or ground.

- ***Duty cycle:*** This control on the function generator changes the ratio of high voltage to low voltage time in a square wave signal, i.e. changing the waveform from a square wave with a 1:1 duty cycle to a pulse waveform, or a triangular waveform with equal rise and fall times to a sawtooth.

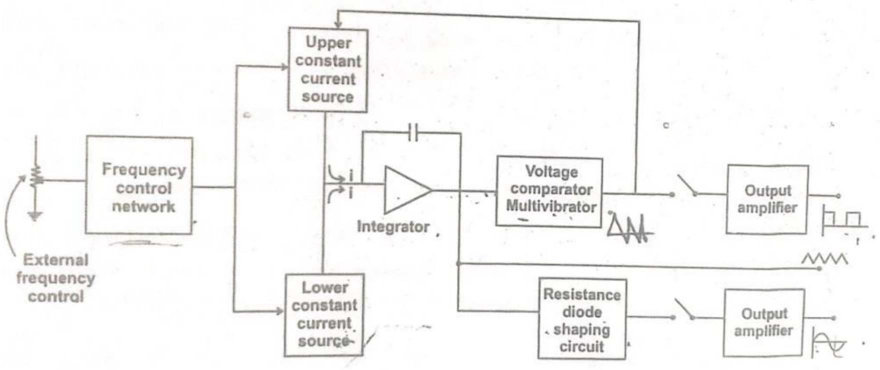


Fig. 3.1 Function generator

In the function generator the frequency is controlled by varying the magnitude of the current which drives the integrator. The frequency control voltage regulates two current sources namely the upper current source and the lower current source. The upper current source supplies constant current to the integrator. The output of the integrator linearly increases with respect to time.. If the current, charging the capacitor increases or decreases, the slope of the output voltage increases or decreases. the voltage comparator multivibrator circuit changes the state of the network when the output voltage of the integrator equals the maximum predetermined upper level. because of this change in state, the upper current source is removed and the lower current source is switched ON. This lower current source supplies opposite current to the integrator circuit. The output of integrator decreases linearly with time.

When the output voltage reaches a predetermined level on the negative slope of the output waveform, the voltage comparator multivibrator again changes the condition of the network by switching OFF the lower current source. The integrator output voltage has a triangular waveform. The frequency of this triangular waveform is determined by the magnitudes of the currents supplied by the upper and lower current sources. The output of the integrator is passed to the comparator and we can get square waveform. The triangular waveform is converted to sine wave by using diode resistance shaping circuit.

Features of the function generator:

1) The frequency range is 0.01Hz to 100Khz

2) Can produce various waveforms like sine, sawtooth, triangular, square wave, etc.,

3) The accuracy is within +1% or -1% in low frequency range.

4) The distortion is less than 1% of the sine wave.

5) Can be phase locked to another external signal source.

6) A continuous adjustable dc offset is available between -5V to +5V.

3.2 Audio generator

The main requirement of sine wave signal generator in instrumentation and measurement system is amplitude stability and frequency stability. The audio frequency signal generator uses RC network for controlled phase shift.

In the wein bridge oscillator circuit shown below, the bridge components are R_1, R_2, R_3, C_1, C_2. The operational amplifier together with R_3 and R_4 forms a non-inverting amplifier and R_1-R_2, C_1-C_2 forms the feedback network.

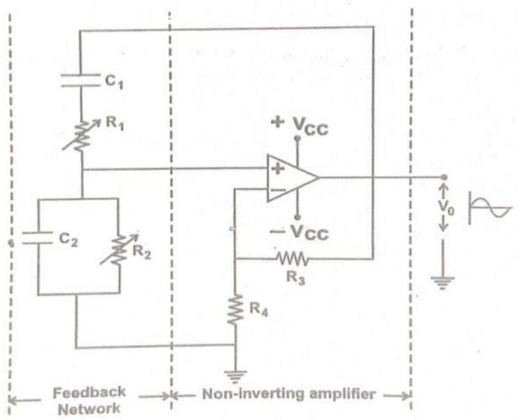


Fig. 3.2 Wein bridge oscillator

Analysis of the bridge shows the balance condition:

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} ; \frac{R_3}{R_4} = 2$$

$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

$$R_1 = R_2 = R ; \; C_1 = C_2 = C$$

$$\boxed{f = \frac{1}{2\pi RC}}$$

The wein bridge oscillator can be tuned by varying either the resistances or capacitances or both. Generally only capacitor tuning is done for variable frequency of signal in one range of frequency. The positive is given by two RC network as shown in above circuit. This creates oscillations.

Advantages:

1) Stable and simple operation
2) Low distortion
3) Good amplitude stability.
4) Relatively easily achievable audio frequency variation.

Audio frequency sine and square wave generator:

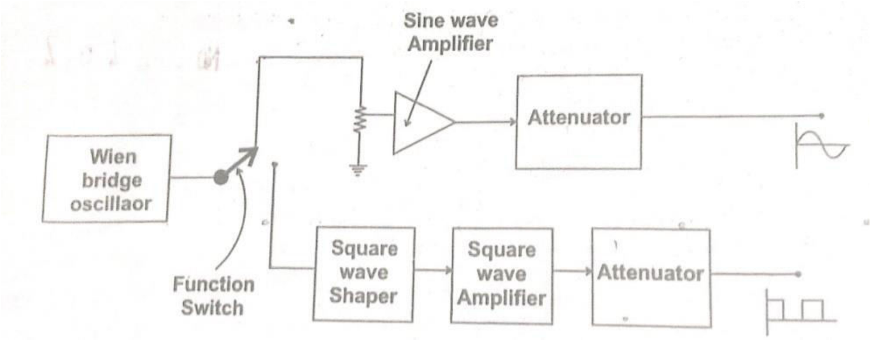


Fig. 3.3 Audio frequency generator.

The wein bridge oscillator is the main part of the sine-square wave generator. The wein bridge oscillator is used to generate a sine wave. The frequency of oscillations can be changed by varying the capacitance in the oscillator. The frequency can be changed insteps by switching in resistors of different values.

The output of the Wein bridge oscillator goes to the function switch. The function switch directs the oscillators output either to the sine wave amplifier or to the square wave shaper. The output is varied by means of an attenuator. The instrument generates a frequency ranging from 10Hz to 1MHz.

3.3 Pulse generators

A pulse generator is either an electronic circuit or a piece of electronic test equipment used to generate rectangular pulses. Pulse generators are used primarily for working with digital circuits, related function generators are used primarily for analog circuits. The fundamental difference between a square wave generator and a pulse generator depends upon the duty cycle. The duty cycle is defined as the ratio of average value of the pulse over one cycle to the peak value. It is also defined as ratio of the pulse width to the period of one cycle.

$$\text{Duty cycle} = \frac{PULSE\ WIDTH}{PULSE\ PERIOD}$$

$$\text{Duty cycle of a square wave} = \frac{\frac{1}{2} peak\ value}{peak\ value} = 0.5$$

Thus square wave produces an output voltage with equal ON and OFF periods, their duty cycle is 0.5 or 50% as the frequency of oscillations is varied. consider a general pulse as shown in figure below:

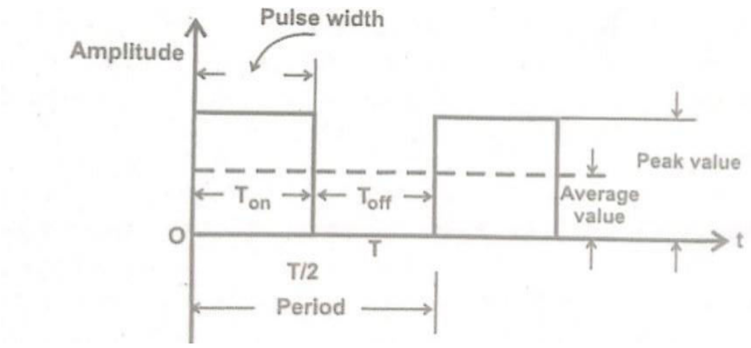


Fig. 3.4 Pulse waveform.

$$\text{Duty cycle} = \frac{Ton}{T} = \frac{Ton}{Ton+Toff}$$

Pulse characteristics and terminology:

The characteristics of pulse is shown below:

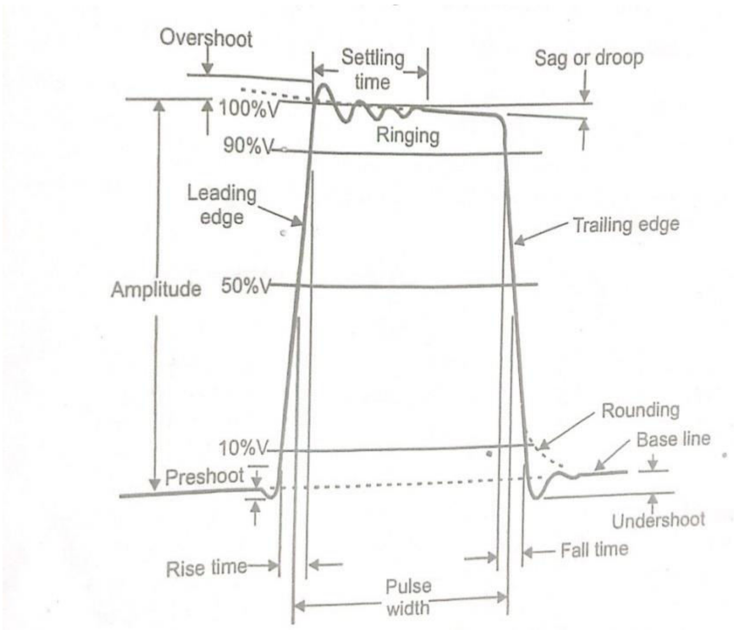


Fig.3.5 Pulse Characteristics.

1) Pulse rise and fall times:

Pulse rise time is the time needed for the pulse to go from 10% to 90% of its amplitude. The fall time is the time needed for the trailing edge to go from 90% to 10% These times are called leading edge and trailing edge transition times.

2) Linearity:

Linearity of a pulse is the deviation of an edge from the straight line drawn through the 10% and 90% amplitude points , expressed as percentage of pulse amplitude.

3) Pulse preshoot:

Its the deviation prior to reaching the base line at the start of the pulse.

4)Overshoot:

Overshoot is the maximum height immediately following the edge.

5) Undershoot:

A distortion of the base value immediately following a falling edge.

6) Ringing:

The positive and negative peak distortion, excluding overshoot or undershoot, on the pulse top or baseline.

7) Droop or Sag:

Occurs when the peak value gradually decreases during the pulse.

8) Pulse repetition rate (PRR):

The rate at which pulses are produced

9) Settling time:

The time required for the signal to decrease to a given percentage typically 1% to 5% of its peak value.

Pulse generator:

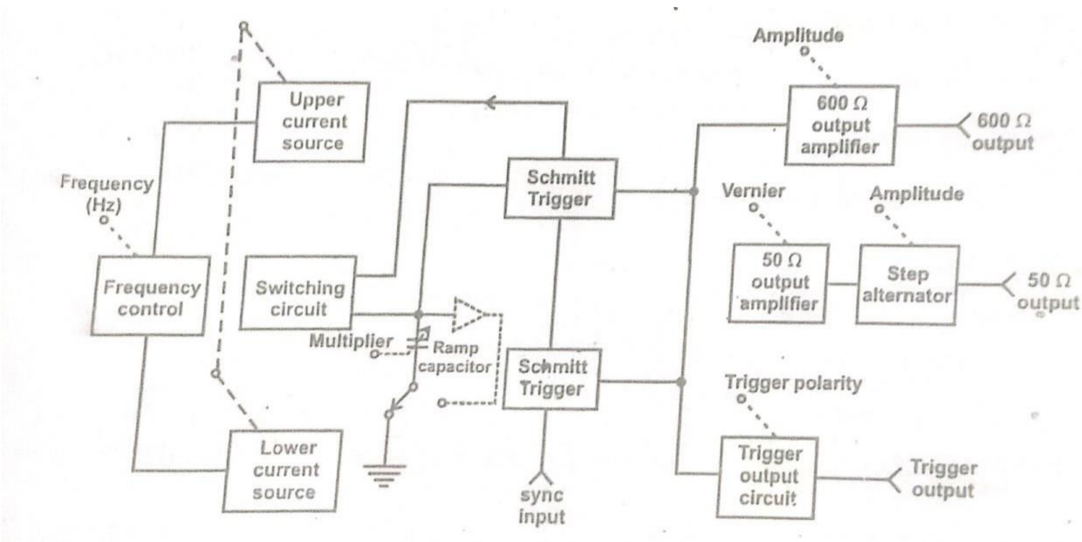


Fig. 3.6 Block diagram of Pulse generator.

The frequency range of the instrument is covered in seven decade steps from 1Hz to 10 MHz, with a linearly calibrated dial for continuous adjustment on all ranges. The duty cycle can be varied from 25 - 75%. Two independent outputs are available, a 50Ω source that supplies pulses with a rise and fall time of 5 ns at 5V peak amplitude and a 600Ω source which supplies pulses with a rise and fall time of 70 ns at 30 V peak amplitude. The instrument can be operated as a free running generator or, it can be synchronized with external signals.

The upper current source supplies a constant current to the capacitor and the capacitor voltage increases linearly. When the positive slope of the ramp voltage reaches the upper limit set by the internal circuit components, the Schmitt trigger changes state. The trigger circuit output becomes negative and reverses the condition of the current switch. The capacitor discharges linearly, controlled by the lower source.

When the negative ramp reaches a predetermined lower level, the Schmitt trigger switches back to its original state. The entire process is then repeated. The ratio i_1/i_2 determines the duty cycle, and is controlled by symmetry control. The sum of i_1 and i_2 determines the frequency. The size of the capacitor is selected by the multiplier switch. The unit is powered by an internal supply that provides regulated voltages for all stages of the instrument.

3.4 RF Signal generator

Radio frequency signal generators (RF signal generators) are a particularly useful item of test equipment widely used in RF microwave design and test applications. These microwave and RF signal generators come in a variety of forms and with a host of facilities and capabilities. In order to gain the most from any RF signal generator or microwave signal generator, it is necessary to have an understanding of its operation and the capabilities it possesses.

Types of RF signal generator:

It is possible to design radio frequency signal generators in a variety of ways. Also with developments that have been made in electronics circuitry over the years, different techniques have evolved. It can be said that there are two forms of signal generator that can be used:

- ***Free running RF signal generators:*** These signal generators are rarely used these days as their frequency tends to drift. However they do have the advantage that the signal produced is very clean and does not have the level of noise (phase noise) either side of the main signal that is present on some other radio frequency signal generators.

Some signal generators used a form of frequency locked loop to provide a means of adding some frequency stability while still retaining the very low levels of phase noise. Again, these are not common these days because the performance of RF signal generators using frequency synthesizer technology has considerably improved.

- ***Synthesized radio frequency signal generators:*** Virtually all radio frequency signal generators used today employ frequency synthesizers. Using this technique enables frequencies to be entered directly from a keypad, or via remote control and it also enables the output signal to be determined very accurately. The accuracy being dependent upon either an internal reference oscillator that can have a very high degree of accuracy, or the signal can be locked to an external frequency reference which can be exceedingly accurate.

  There are two main techniques that are used within synthesized RF signal generators:

  - *Phase locked loop synthesizer:* Phase locked loop synthesizers are used within most RF signal generators as they enable signals to be generated over a wide range of frequencies with a relatively low level of spurious signals. Phase locked loop synthesizer technology is well developed and enables high performance RF signal generators to be produced using them.
  - *Direct Digital Synthesizer, DDS:* Direct digital synthesis techniques may be used in RF signal generators. They enable very fine frequency increments to be achieved relatively easily. However the maximum limit of a DDS is normally much lower than the top frequencies required for the signal generator, so they are used in conjunction with phase locked loops to give the required frequency range.

3.4.1 RF signal generator operation

In order to understand the operation of a generic microwave or RF signal generator it is useful to understand what is included in terms of a basic block diagram.

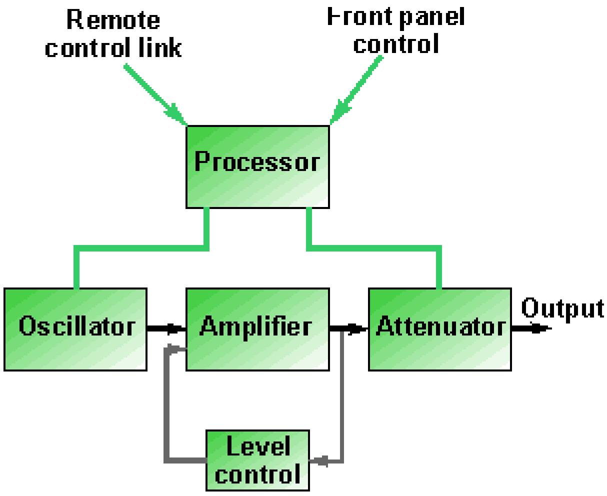


Fig. 3.7 Block diagram of RF signal generator.

The diagram shows a very simplified block diagram for an RF / Microwave signal generator.

From this, it can be seen that the generator has a few major blocks within it:

- ***Oscillator:*** The most important block within the RF signal generator is the oscillator itself. This can be any form of oscillator, but today it would almost certainly be formed from a frequency synthesizer. This oscillator would take commands from the controller and be set to the required frequency.

- ***Amplifier:*** The output from the oscillator will need amplifying. This will be achieved using a special amplifier module. This will amplify the signal, typically to a fixed level. It would have a loop around it to maintain the output level accurately at all frequencies and temperatures.

- ***Attenuator:*** An attenuator is placed on the output of the signal generator. This serves to ensure an accurate source impedance is maintained as well as allowing the generator level to be adjusted very accurately. In particular the relative power levels, i.e. when changing from one level to another are very accurate and represent the accuracy of the attenuator. It is worth noting that the output impedance is less accurately defined for the highest signal levels where the attenuation is less.

- ***Control:*** Advanced processors are used to ensure that the RF and microwave signal generator is easy to control and is also able to take remote control commands. The processor will control all aspects of the operation of the test equipment.

3.5 FREQUENCY SYNTHESIZER

A frequency synthesizer is an electronic circuit that generates a range of frequencies from a single reference frequency. Frequency synthesizers are used in many modern devices such as radio receivers, televisions, mobile telephones, radiotelephones, walkie-talkies, CB radios, cable television converter boxes satellite receivers, and GPS systems. A frequency synthesizer may use the techniques of frequency multiplication, frequency division, direct digital synthesis, frequency mixing, and phase-locked loops to generate its frequencies. The stability and accuracy of the frequency synthesizer's output are related to the stability and accuracy of its reference frequency input. Consequently, synthesizers use stable and accurate reference frequencies, such as those provided by crystal oscillators.

Most frequency synthesizers are based around a phase locked loop or PLL.The PLL uses the idea of phase comparison as the basis of its operation. From the block diagram of a basic loop shown below, it can be seen that there are three basic circuit blocks, a phase comparator, voltage controlled oscillator, and loop filter. A reference oscillator is sometimes included in the block diagram, although this is not strictly part of the loop itself even though a reference signal is required for its operation.

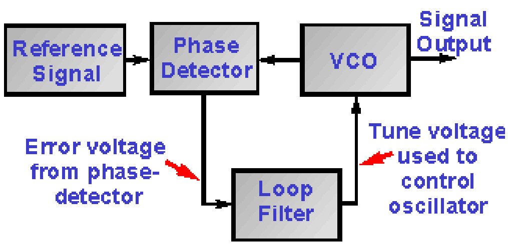


Fig. 3.8 A Phase locked loop

The phase locked loop, PLL, operates by comparing the phase of two signals. The signals from the voltage controlled oscillator and reference enter the phase comparator. Here a third signal equal to the phase difference between the two input signals is produced.

The phase difference signal is then passed through the loop filter. This performs a number of functions including the removal of any unwanted products that are present on this signal. Once this has been accomplished it is applied to the control terminal of the voltage controlled oscillator. This tune voltage or error voltage is such that it tries to reduce the error between the two signals entering the phase comparator. This means that the voltage controlled oscillator will be pulled towards the frequency of the reference, and when in lock there is a steady state error voltage. This is proportional to the phase error between the two signals, and it is constant. Only when the phase between two signals is changing is there a frequency difference. As the phase difference remains constant when the loop is in lock this means that the frequency of the voltage controlled oscillator is exactly the same as the reference.

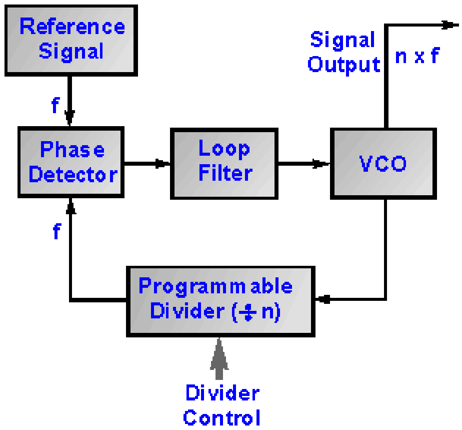


Fig.3.9 Digital Frequency Synthesizer

This is the concept that is at the root of most single loop synthesizers. It involves placing a digital divider in the loop between the voltage controlled oscillator. This means that the voltage controlled oscillator frequency will be divided by the division ratio of the divider, e.g. n, and the VCO will run at n times the phase comparison frequency. By changing the division ratio of the divider, the output frequency of the oscillator can be changed. This makes the frequency synthesizer programmable. These digital frequency synthesizers are ideal for many applications on their own. They perform well where the differences between channels are relatively high. Where virtual continuous tuning using steps of 1 Hz or 10Hz may be needed, this requires very high division ratios and this can degrade the phase noise performance and give rise to other issues.

3.6 WAVE ANALYSER:

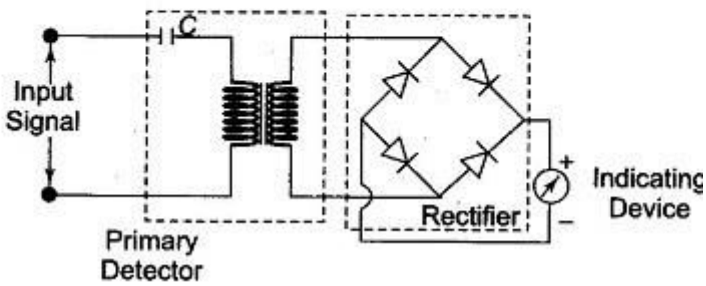


Fig.3.10 Basic Wave Analyzer.

It consists of a primary detector, which is a simple LC circuit. This LC circuit is adjusted for resonance at the frequency of the particular harmonic component to be measured. The intermediate stage is a full wave rectifier to obtain the average value of the input signal. The indicating device is a simple DC voltmeter that is calibrated to read the peak value of the sinusoidal input voltage. Since the LC circuit is tuned to a single frequency it passes only the frequency to which it is tuned and rejects all other frequencies. A number of tuned filters, connected to the indicating device through a selector switch would be required for a useful Wave Analyzer.

1.1 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 audible frequency range (20Hz-20KHz). The block diagram of wave analyzer is shown below:

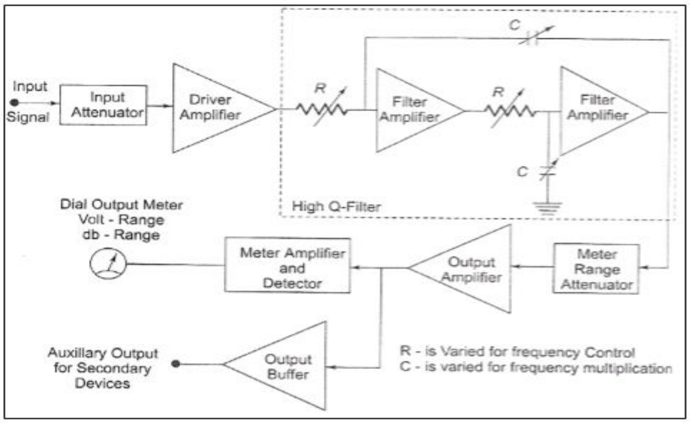


Fig.3.11 Frequency Selective Wave Analyzer.

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 analyser is also called frequency selective voltmeter.

The entire AF range is covered in decade steps by switching capacitors in the RC section. Then selected signal output from the final amplifier stage is applied to the meter circuit and to an untuned amplifier. The main function of the buffer amplifier is to drive output devices such as recorders or electronic counters. The meter has several voltage ranges as well as decibel scales marked on it. It is driven by an average reading rectifier type decoder.

The wave analyser must have extremely low input distortion, undetectable by the analyser itself. The bandwidth of the instrument is very narrow, typically about 1% of selective band given by the following response characteristics.

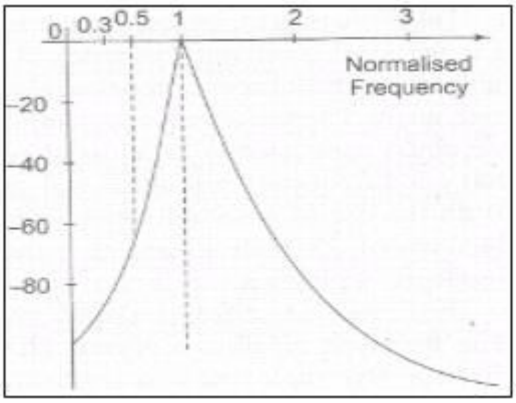


Fig.3.12 Relative response in Decibels (Dbs)

3.7 Heterodyne Wave Analyzer:

Wave analyzers are useful for measurement in the audio frequency range only. For measurements in the RF range and above (MHz range), an ordinary wave analyzer cannot be used. Hence, special types of wave analyzers working on the principle of heterodyning (mixing) are used. These wave analyzers are known as Heterodyne Wave Analyzer. In this wave analyzer, the input signal to be analyzed is heterodyned with the signal from the internal tunable local oscillator in the mixer stage to produce a higher IF frequency. By tuning the local oscillator frequency, various signal frequency components can be shifted within the pass-band of the IF amplifier. The output of the IF amplifier is rectified and applied to the meter circuit.

An instrument that involves the principle of heterodyning is the Heterodyning tuned voltmeter, shown in figure below:

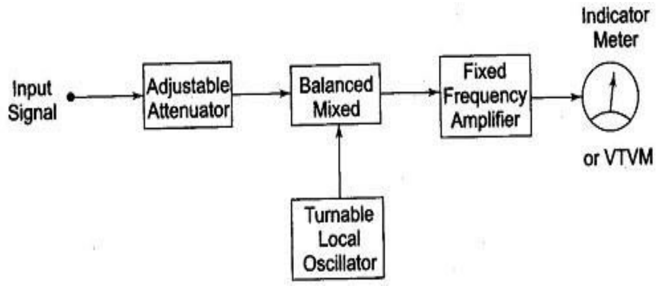


Fig.3.13 Heterodyne Wave Analyzer

The input signal is heterodyned to the known IF by means of a tunable local oscillator. The amplitude of the unknown component is indicated by the VTVM (vacuum tube voltmeter) or output meter. The VTVM is calibrated by means of signals of known amplitude. The frequency of the component is identified by the local oscillator frequency, i.e. the local oscillator frequency is varied so that all the components can be identified. The local oscillator can also be calibrated using input signals of known frequency. The fixed frequency amplifier is a multistage amplifier which can be designed conveniently because of its frequency characteristics. This analyzer has good frequency resolution and can measure the entire AF frequency range. With the use of a suitable attenuator, a wide range of voltage amplitudes can be covered. Their disadvantage is the occurrence of spurious cross-modulation products, setting a lower limit to the amplitude that can be measured.

Two types of selective amplifiers find use in Heterodyne wave analyzers. The first type employs a crystal filter, typically having a centre frequency of 50 kHz. By employing two crystals in a band-pass arrangement, it is possible to obtain a relatively flat pass-band over a 4 cycle range. Another type uses a resonant circuit in which the effective Q has been made high and is controlled by negative feedback. The resultant signal is passed through a highly selective 3-section quartz crystal filter and its amplitude measured on a Q-meter.

When a knowledge of the individual amplitudes of the component frequency is desired, a heterodyne wave analyzer is used.

A modified heterodyne wave analyzer is shown in figure below:

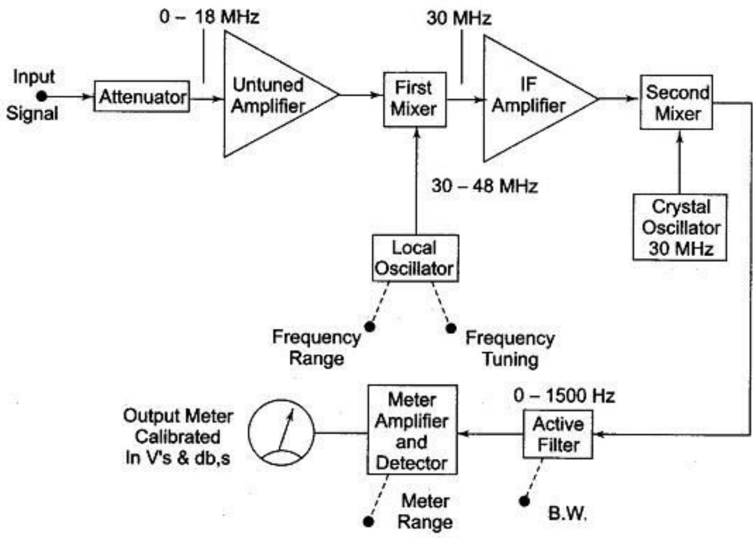


Fig.3.14 RF Heterodyne Wave Analyzer.

In this analyzer, the attenuator provides the required input signal for heterodyning in the first mixer stage, with the signal from a local oscillator having a frequency of 30 —48 MHz.

The first mixer stage produces an output which is the difference of the local oscillator frequency and the input signal, to produce an IF signal of 30 MHz. This IF frequency is uniformly amplified by the IF amplifier. This amplified IF signal is fed to the second mixer stage, where it is again heterodyned to produce a difference frequency or IF of zero frequency.

The selected component is then passed to the meter amplifier and detector circuit through an active filter having a controlled band-width. The meter detector output can then be read off on a db-calibrated scale, or may be applied to a secondary device such as a recorder.

This wave analyzer is operated in the RF range of 10 kHz — 18 MHz, with 18 overlapping bands selected by the frequency range control of the local oscillator. The bandwidth, which is controlled by the active filter, can be selected at 200 Hz, 1 kHz and 3 kHz.

3.8 SPECTRUM ANALYSER

The most common way of observing signals is to display them on an oscilloscope, with time as the X-axis (i.e. amplitude of the signal versus time). This is the time domain.

It is also useful to display signals in the frequency domain. The instrument providing this frequency domain view is the spectrum analyzer.

A Spectrum Analyzer Block Diagram provides a calibrated graphical display on its CRT, with frequency on the horizontal axis and amplitude (voltage) on the vertical axis. Displayed as vertical lines against these coordinates are sinusoidal components of which the input signal is composed. The height represents the absolute magnitude, and the horizontal location represents the frequency. These instruments provide a display of the frequency spectrum over a given frequency band. Spectrum analyzers use either a parallel filter bank or a swept frequency technique. In a parallel filter bank analyzer, the frequency range is covered by a series of filters whose central frequencies and bandwidth are so selected that they overlap each other, as shown in figure below.

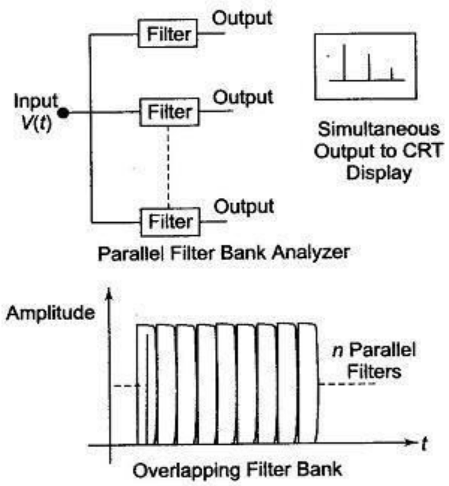


Fig.3.15 Spectrum Analyser (parallel filter bank analyser)

Typically, an audio analyzer will have 32 of these filters, each covering one third of an octave. For wide band narrow resolution analysis, particularly at RF or microwave signals, the swept technique is preferred.

Basic Spectrum Analyser using Swept Receiver Design:

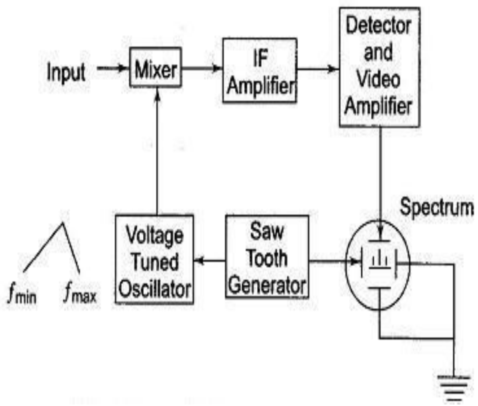


Fig.3.16 Spectrum Analyser

Referring to above block diagram, the sawtooth generator provides the sawtooth voltage which drives the horizontal axis element of the scope and this sawtooth voltage is frequency controlled element of the voltage tuned oscillator. As the oscillator sweeps from f_{min} to f_{max} of its frequency band at a linear recurring rate, it beats with the frequency component of the input signal and produce an IF, whenever a frequency component is met during its sweep. The frequency component and voltage tuned oscillator frequency beats together to produce a difference frequency, i.e. IF. The IF corresponding to the component is amplified and detected if necessary, and then applied to the vertical plates of the CRO, producing a display of amplitude versus frequency.The spectrum produced if the input wave is a single tuned A.M. is given in figure below:

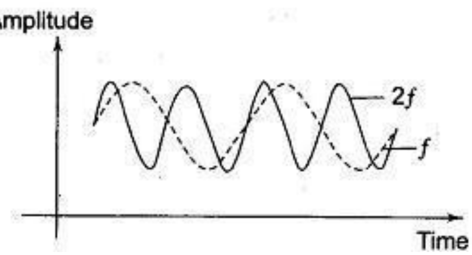


Fig:3.17 Test wave seen on ordinary CRO

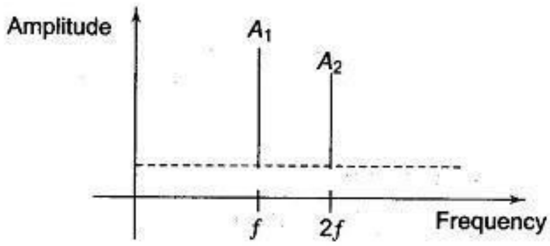


Fig.3.18 Display on the spectrum CRO

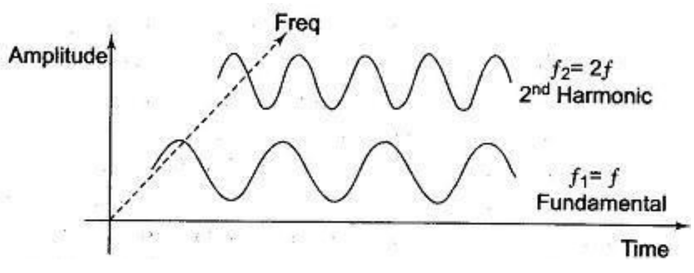


Fig.9 Test waveform as seen on X-axis (time) and Z-axis (frequency)

One of the principal applications of spectrum analyzers has been in the study of the RF spectrum produced in microwave instruments. In a microwave instrument, the horizontal axis can display as a wide a range as 2 — 3 GHz for a broad survey and as narrow as 30 kHz, for a highly magnified view of any small portion of the spectrum. Signals at microwave frequency separated by only a few kHz can be seen individually.

The frequency range covered by this instrument is from 1 MHz to 40 GHz. The basic block diagram is of a spectrum analyzer covering the range 500 kHz to 1 GHz, which is representative of a superheterodyne type

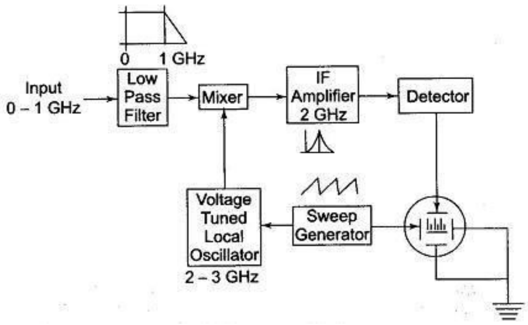


Fig.3.19 RF Spectrum Analyser

The input signal is fed into a mixer which is driven by a local oscillator. This oscillator is linearly tunable electrically over the range 2 — 3 GHz. The mixer provides two signals at its output that are proportional in amplitude to the input signal but of frequencies which are the sum and difference of the input signal and local oscillator frequency.

The IF amplifier is tuned to a narrow band around 2 GHz, since the local oscillator is tuned over the range of 2 — 3 GHz, only inputs that are separated from the local oscillator frequency by 2 GHz will be converted to IF frequency band, pass through the IF frequency amplifier, get rectified and produce a vertical deflection on the CRT.

From this, it is observed that as the saw tooth signal sweeps, the local oscillator also sweeps linearly from 2 — 3 GHz. The tuning of the spectrum analyzer is a swept receiver, which sweeps linearly from 0 to 1 GHz. The saw tooth scanning signal is also applied to the horizontal plates of the CRT to form the frequency axis. (The Spectrum Analyzer Block Diagram is also sensitive to signals from 4 — 5 GHz referred to as the image frequency of the super heterodyne. A low pass filter with a cutoff frequency above 1 GHz at the input suppresses these spurious signals.) Spectrum analyzers are widely used in radars, oceanography, and bio-medical fields.

3.9DISTORTION ANALYSER

3.9.1 Harmonic Distortion Analyser-Fundamental Suppression Type:

A Harmonic 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 Analyzer based on fundamental suppression are as follows.

a)Employing a Resonance Bridge type:

The bridge shown in Figure below. This bridge 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 (vacuum tube voltmeters). This indicates the rms value of all harmonics. When a continuous adjustment of the fundamental frequency is desired, a Wien bridge system is employed.

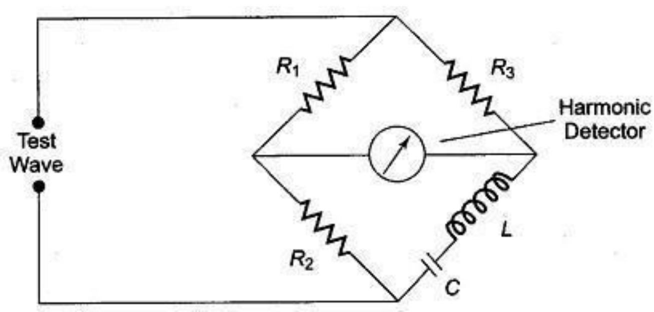


Fig.3.20 Resonance Bridge

b)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, C_1,C_2,C, R_1=R_2=R,R_3=2R_4.

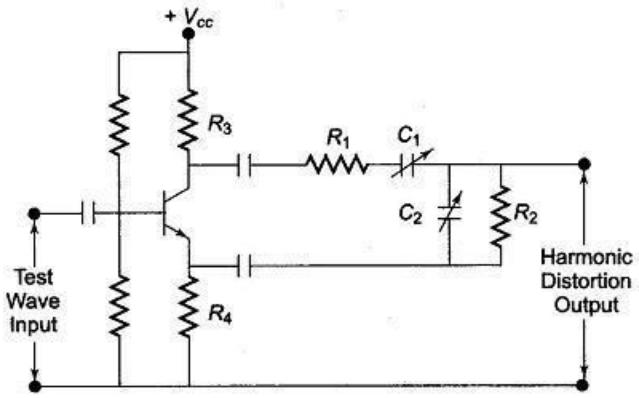


Fig.3.21 Wien's Bridge method.

c)Bridged T-Network:

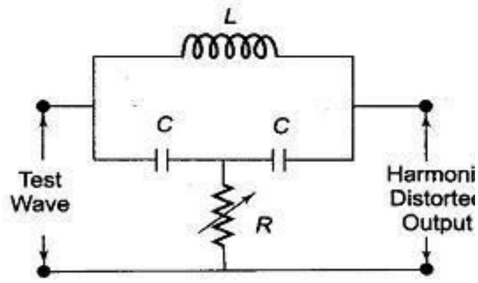


Fig.3.22 Bridge T-Network method.

Referring to figure below, 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 figure below. 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. Minimum output indicates that the bridged T-network is tuned to the fundamental frequency and that the fundamental frequency is fully suppressed.

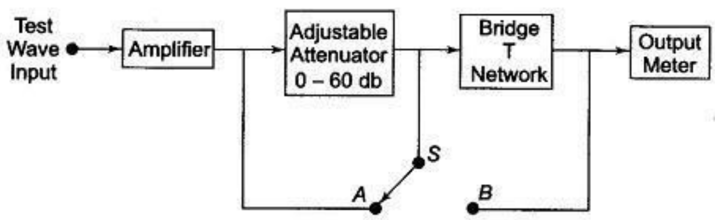


Fig.3.23 Harmonic Distortion Analyser using Bridged-T-Network.

The switch is next connected to terminal B, i.e. the bridged T-network is excluded. Attenuation is adjusted until the same reading is obtained on the meter. The attenuator reading indicates the total rms 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 Analyzer can be calculated. However, distortion meters based on fundamental suppression are simpler to design and less expensive than wave analyzers. The disadvantage is that they give only the total distortion and not the amplitude of individual distortion components.

3.10 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. Two main circuit techniques are used to form the basis of an LCR meter.

- Bridge method
- Current-voltage measurement

Bridge Method

Effect of lead length: At frequencies above 1 MHz or so the lead length can start to have an effect. As a rough guide a good estimate for lead inductance is around 10 nH per cm of lead.

For the best measurements kep the leads as short as possible.

- **Measure at operational frequency**: When making measurements using an LCR meter it helps to use a test frequency as close to the actual operational frequency as possible.

This means that the effects of any stray effects or changes due to frequency are minimised - for example inductor cores may have different properties at different frequencies.

This can make a noticeable difference in some instances.

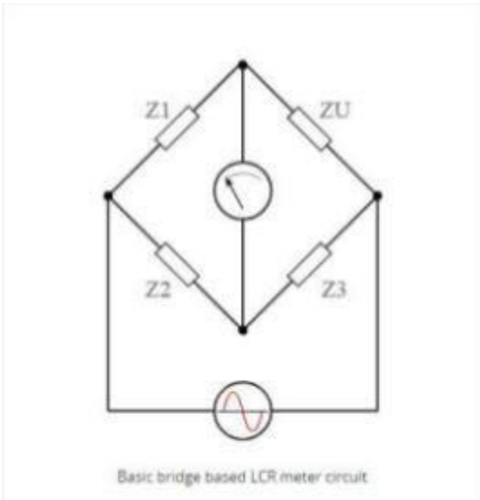


Fig.3.24: LCR circuit

- **Current Voltage Measurement**

Two main circuit techniques are used to form the basis of an LCR meter.

- Bridge method
- Current-voltage measurement

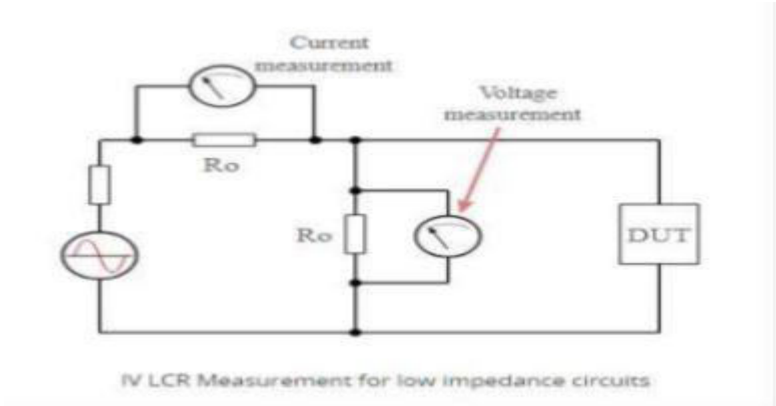


Fig.3.25: LCR Measurement for Low Impedance circuit

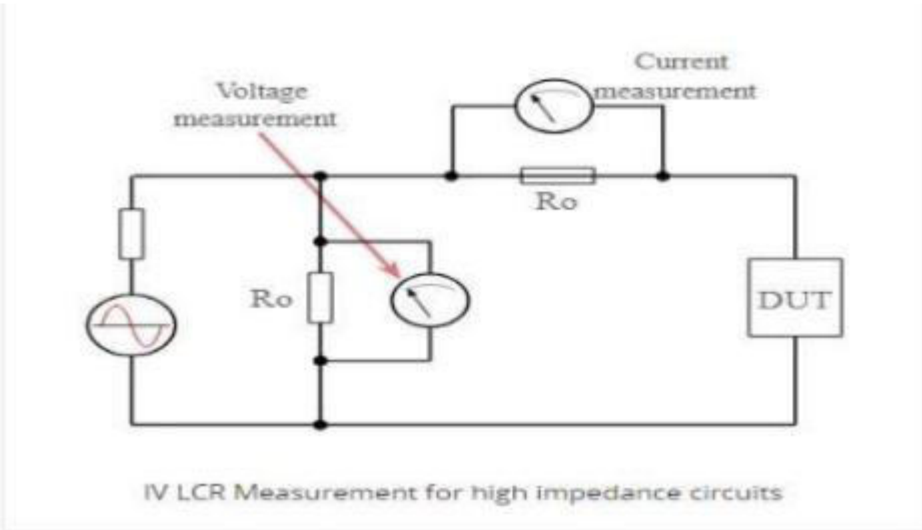


Fig.3.26: Measurement for high Impendence circuits

LCR Meter: Measurement Guidelines

- **Effect of lead length**

At frequencies above 1 MHz or so the lead length can start to have an effect. As a rough guide a good estimate for lead inductance is around 10 nH per cm of lead. For the best measurements kep the leads as short as possible.

- **Measure at operational frequency**

When making measurements using an LCR meter it helps to use a test frequency as close to the actual operational frequency as possible. This means that the effects of any stray effects or changes due to frequency are minimised - for example inductor cores may have different properties at different frequencies. This can make a noticeable difference in some instances.

- **Adjust test amplitude**

    - In the same way that it is good practice to measure at a frequency that is as close to the operational frequency as possible, the same is true for the test amplitude.
    - This is because component values may vary with the signal applied.
    - This is particularly true for inductors that use cores such as ferrite that may introduce losses.
    - These may be amplitude dependent.

- **Discharge capacitors before measurement**

    - Some capacitors may carry a residual charge under some circumstances. It is best to discharge them before any measurements.
    - As charge on some capacitors can linger for some time, it is always best to discharge them before any tests.

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.

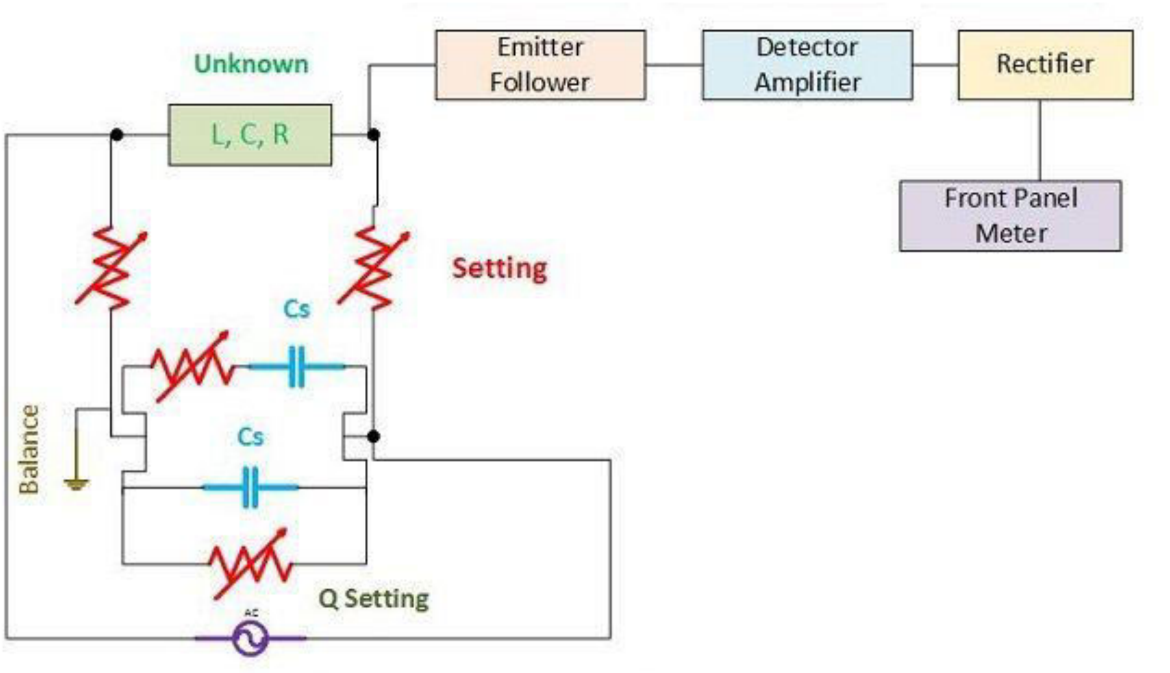
But it is often observed that while dealing with the measurement process, the magnitude of the measuring signal falls down due to attenuation factor. The problem to this solution is to utilize an amplifier.

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.

Definition: LCR meters can be understood as a multimeter, this is because it can measure **resistance, inductance, capacitance** as per the requirement. Thus, it is termed as LCR meter. **L** in its name signifies inductance, **C** stands for capacitance and **R** denotes resistance.

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.**

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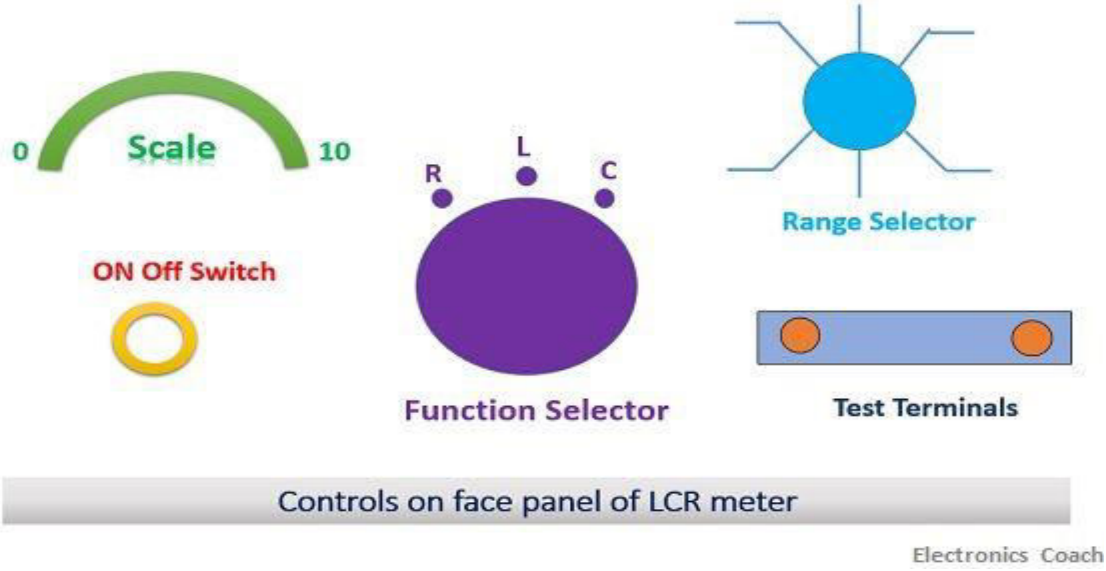
The **rectifier** is used in the circuit to convert the AC signal into DC signal. When the bridge is provided with AC excitation then at the output end of the bridge the AC signal needs transformation into DC signal.

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.



1. **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.
2. **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.
3. **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 mod**e, 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**.
4. **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.

5. **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.

QUESTION BANK

PART-A (2 MARKS)

1. What do you mean by heterodyne principle ?
2. What is Harmonic distortion.
3. What are the drawbacks o tuned circuit analyzers?
4. What is real time spectrum analyzer?
5. Give the functions of an attenuator in a signal generator.
6. Define Rise time and Fall time of a pulse.
7. Write applications of spectrum analyzer.
8. what is the use of distortion netar?
9. what is known as window in FFT spectrum analyzer?
10. write any three applications of wave analyzer?

PART – B (16 MARKS)

1. Describe a signal generator using feedback for amplitude modulation.
2. Describe the working of a spectrum analyzer with it's basic circuit.
3. Explain the functional block diagram of Function generator and mention it's features
4. Explain with the help of block diagram, fundamental suppression distortion analyzer. Discuss it's two modes of operation.
5. With a block diagram explain operation of a heterodyne wave analyzer.
6. Explain various applications of the spectrum analyzer.
7. With the help of neat block explain the operation of a sweep frequency generator.
8. How a spectrum analyzer can be used to operate and measure VHF? Draw the waveforms and Block diagram.
9. What is frequency synthesizer and describe it's types with circuits in detail.
10. Discuss in detail about Function Generator and its applications.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND INSTRUMENTATION

UNIT – IV

MEASUREMENT AND INSTRUMENTATION – SEIA3001

UNIT-4

DIGITAL INSTRUMENTS

Comparison of analog and digital techniques – digital voltmeter – multimeters – frequency counters – measurement of frequency and time interval – extension of frequency range – Automation in digital instruments, Automatic polarity indication, automatic ranging, automatic zeroing, fully automatic digital instruments, Computer controlled test systems, Virtual instruments.

4.1 Comparison of analog and digital techniques

Analog	Digital
An analog signal is a continuous signal that represents physical measurements.	Digital signals are time separated signals which are generated using digital modulation.
It is denoted by sine waves	It is denoted by square waves
It uses a continuous range of values that help you to represent information.	Digital signal uses discrete 0 and 1 to represent information.
Temperature sensors, FM radio signals, Photocells, Light sensor, Resistive touch screen are examples of Analog signals.	Computers, CDs, DVDs are some examples of Digital signal.
The analog signal bandwidth is low	The digital signal bandwidth is high.
Analog signals are deteriorated by noise throughout transmission as well as write/read cycle.	Relatively a noise-immune system without deterioration during the transmission process and write/read cycle.
Analog hardware never offers flexible implementation.	Digital hardware offers flexibility in implementation.
It is suited for audio and video transmission.	It is suited for Computing and digital electronics.
Processing can be done in real-time and consumes lesser bandwidth compared to a digital signal.	It never gives a guarantee that digital signal processing can be performed in real time.
Analog instruments usually have s scale which is cramped at lower end and gives considerable observational errors.	Digital instruments never cause any kind of observational errors.
Analog signal doesn't offer any fixed range.	Digital signal has a finite number, i.e., 0 and 1.

Advantages of Analog Signals

- Easier in processing
- Best suited for audio and video transmission.
- It has a low cost and is portable.
- It has a much higher density so that it can present more refined information.
- Not necessary to buy a new graphics board.
- Uses less bandwidth than digital sounds
- Provide more accurate representation of a sound
- It is the natural form of a sound.

Advantages of Digital Signals

- Digital data can be easily compressed.
- Any information in the digital form can be encrypted.
- Equipment that uses digital signals is more common and less expensive.
- Digital signal makes running instruments free from observation errors like parallax and approximation errors.
- A lot of editing tools are available
- You can edit the sound without altering the original copy
- Easy to transmit the data over networks

Disadvantages of Analog Signals

- Analog tends to have a lower quality signal than digital.
- The cables are sensitive to external influences.
- The cost of the Analog wire is high and not easily portable.
- Low availability of models with digital interfaces.
- Recording analog sound on tape is quite expensive if the tape is damaged
- It offers limitations in editing
- Tape is becoming hard to find
- It is quite difficult to synchronize analog sound
- Quality is easily lost
- Data can become corrupted

- Plenty of recording devices and formats which can become confusing to store a digital signal
- Digital sounds can cut an analog sound wave which means that you can't get a perfect reproduction of a sound
- Offers poor multi-user interfaces

Disadvantage of Digital Signals

- Sampling may cause loss of information.
- A/D and D/A demands mixed-signal hardware
- Processor speed is limited
- Develop quantization and round-off errors
- It requires greater bandwidth
- Systems and processing is more complex.

4.2 Digital voltmeter

Voltmeter is an electrical measuring instrument 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 measure and hence displaying the value of the same. With time analog voltmeters are replaced by **digital voltmeters** due to the same advantages associated with digital systems. Although digital voltmeters do not fully replace analog 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

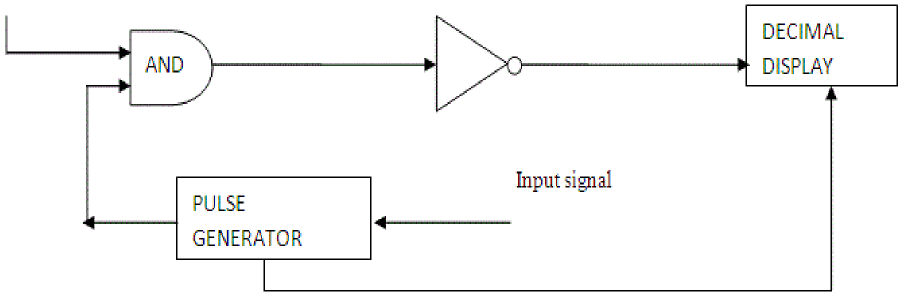


Fig.3 Block Diagram of Digital Voltmeter

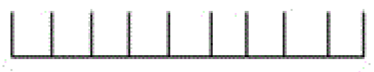
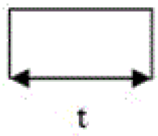
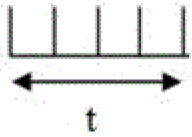
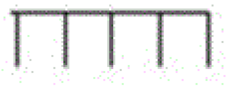
	Train pulse

Table 1:Output of gates

	Rectangular pulse
	Output of AND gate

	Output of NOT gate

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 and 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.

Decimal Display: It counts the numbers of impulses and hence the duration and display the value of voltage on LED or LCD display after calibrating it. Now we are in situation to understand 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.

User can see the working of digital voltmeter that it 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.

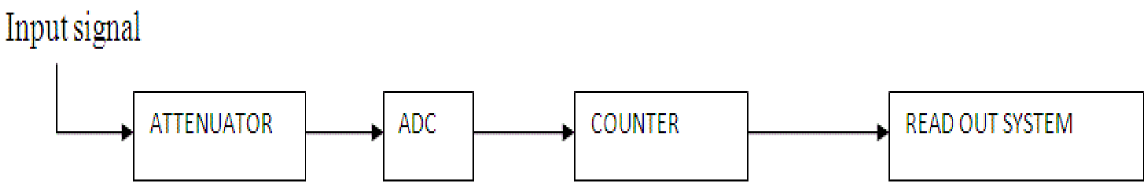


Fig.4 Block diagram of ADC conversion of Digital voltmeter

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.

2.1Ramp type digital voltmeter

- It is also called as single slope DVM or pulse width type DVM.

Principle:

- Voltage is converted into time, and the time period is measured with an electronic counter.
- The reading is displayed as voltage after processing.
- The time taken by a linear ramp voltage to rise from 0V to the level of the input voltage or to decrease from the level of the input voltage to zero is measured with a counter.
- This time interval is proportional to the voltage to be measured.
- The waveforms shown in figure below indicate the method.
- At the start of the measurement cycle, a ramp voltage is initiated. This voltage can be positive going or negative going.

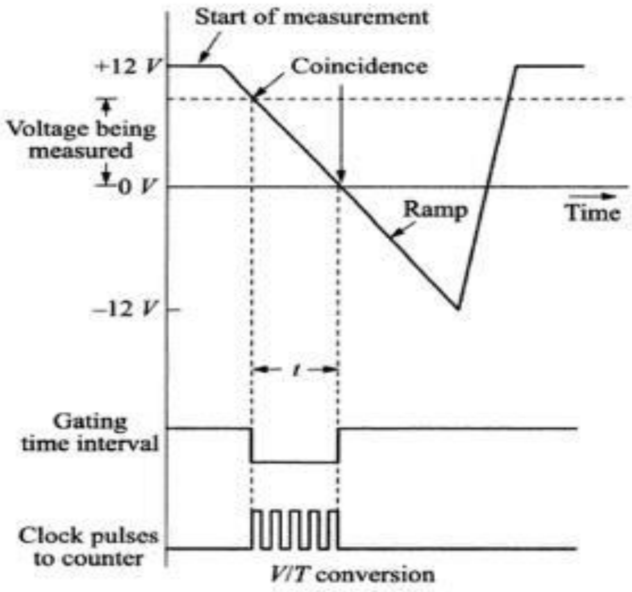


Fig.5 Ramp type voltmeter graph

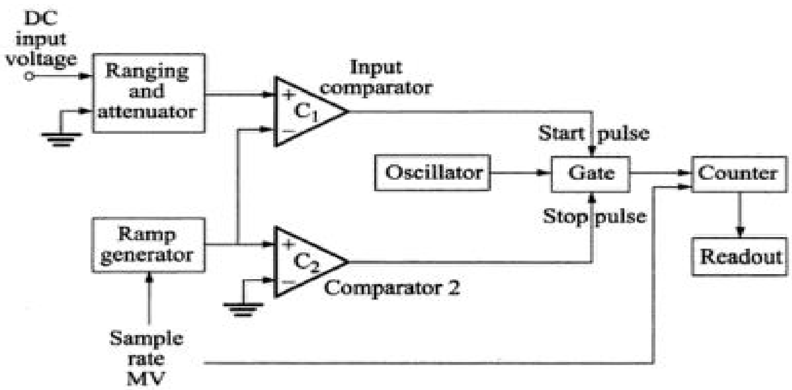


Fig.6 Ramp type Digital voltmeter block diagram

- In the figure, a negative-going ramp is shown.
- It is continuously compared with the unknown input voltage.
- At the instant that the ramp voltage equals the unknown voltage, a comparator or coincidence circuit generates a pulse.
- This pulse opens a gate.
- The ramp voltage continues to decrease with time until it finally reaches 0 V.
- A second comparator generates an output pulse that closes the gate. An oscillator generates clock pulses that are allowed to pass through the gate to a number of decade-counting units (DCUs).
- They totalize the number of pulses passed through the gate.
- The decimal number displayed by the indicator tubes associated with DCUs is a measure of the magnitude of the input voltage.
- A block schematic of the ramp-type DVM is shown below.
- The DC input voltage to be measured is first given to the ranging and attenuator section. If the magnitude of the voltage is large, it is attenuated.
- If it is small, it is amplified. The sample rate multivibrator determines the slope of the ramp. It also determines the period of measurement or the duration of the measurement cycle, which can be in the range from a few cycles/sec to 1000 cycles/ sec.
- The sample rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage. At the same time, a reset pulse is generated, which returns all the DCUs to their zero state.
- The measuring cycle involves:1. Sampling the input and holding it at the same value 2. Measuring the value of the input.3. Display.
- The display remains at the precision value till the next measuring cycle is completed so that there is no flicker in the display and the user finds continuous display.
- The ramp voltage is compared with the input voltage and when the equality is reached, a start pulse is applied to the logic gate. If it is the AND gate, it is enabled.
- The pulses from the clock oscillator are counted in the counter. When the ramp voltage becomes zero, the ground comparator senses the same and the AND gate is disabled. The counting will stop.The number of pulses counted during this time interval is a measure of the input voltage.

2.2 Integrating type digital voltmeter

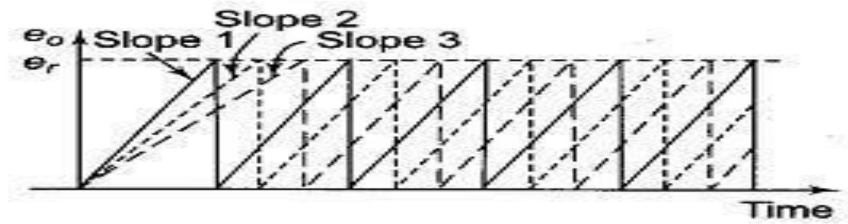


Fig.7 Graph for Integrating Type

Block Diagram of Integrating type DVM

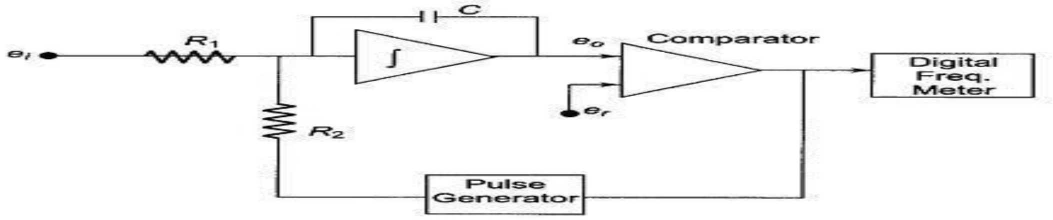


Fig.8 **Block Diagram of Integrating type DVM**

A constant input voltage is integrated and the slope of the output ramp is proportional to the input voltage. When the output reaches a certain value, it is discharged to 0 and another cycle begins. The frequency of the output waveform is proportional to the input voltage.

The input voltage produces a charging current, e_i/R_1 that charges the capacitor 'C' to the reference voltage e_r. When e_r is reached, the comparator changes state, so as to trigger the precision pulse generator. The pulse generator produces a pulse of precision charge content that rapidly discharges the capacitor. The rate of charging and discharging produces a signal frequency that is directly proportional to e_i.

Dual slope method

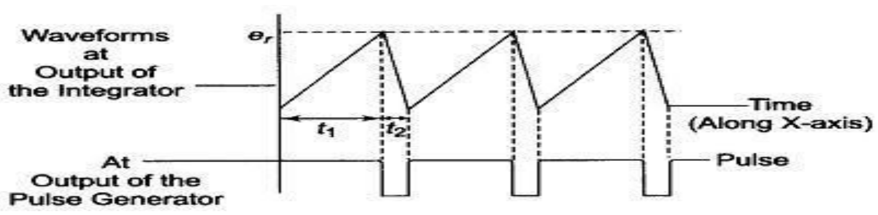


Fig. output Waveform of Integrator

But in this case e_r and t_2 are constants.

$$K_2 = e_r\, t_2$$
$$e_i = K_2 \left(\frac{1}{t_1}\right) = K_2\, (f_0)$$

- The output frequency is proportional to the input voltage e_i.
- This DVM has the disadvantage that it requires excellent characteristics in linearity of the ramp.
- The ac noise and supply noise are averaged out.

2.3 Potentiometric type digital voltmeter

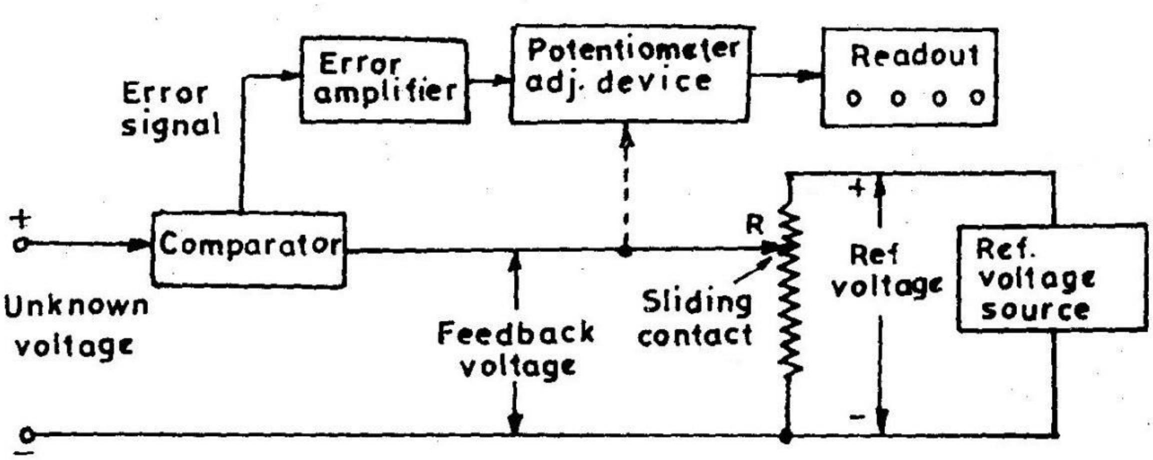


Fig.10 Block Diagram of potentiometric type digital voltmeter

The unknown voltage is filtered and attenuated to a suitable level. This input voltage is applied to a comparator (also known as error detector). This error detector may be chopper (a chopper circuit is used to refer to numerous types of electronic switching devices and circuits used in power control and signal applications. A chopper is a device that converts fixed DC input to a variable DC output voltage directly). The reference voltage is obtained from a fixed voltage source. This voltage is applied to a potentiometric R. The value of the feedback voltage depends upon the position of the sliding contact. The feedback voltage is also applied to the comparator. The unknown voltage and the feedback 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.
- The potentiometer adjustment device i.e., the device which moves the sliding contact is a 2 phase servo motor.
- The reference voltage source must be extremely stable and generally consists of a standard cell or Zener diode sources.

2.4 Successive approximation type digital voltmeter

- The successive approximations principle can be easily understood using a simple example: the determination of the weight of an object.
- By using a balance and placing the object on one side and an approximate weight on the other side, the weight of the object is determined.
- If the weight placed is more than the unknown weight, the weight is removed and another weight of smaller value is placed and again the measurement is performed.
- Now if it is found that the weight placed is less than that of the object, another weight of smaller value is added to the weight already present, and the measurement is performed.
- If it is found to be greater than the unknown weight the added weight is removed and another weight of smaller value is added.

- In this manner by adding and removing the appropriate weight, the weight of the unknown object is determined.

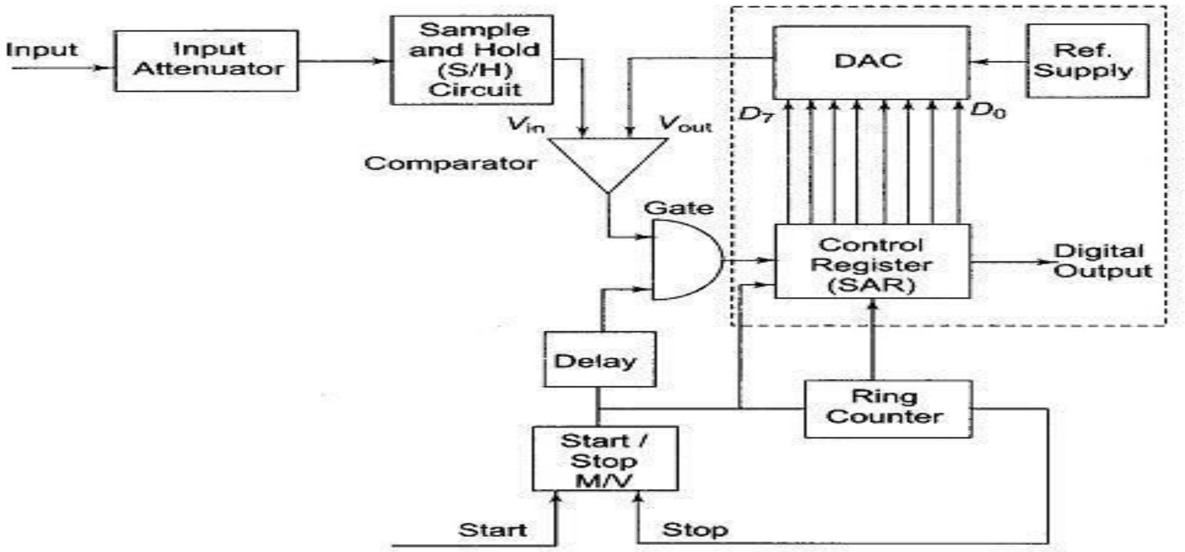


Fig.11 Block Diagram of Successive approximation

- When the start pulse signal activates the control circuit, the successive approximation register (SAR) is cleared.
- The output of the SAR is 00000000. V_{out} of the D/A converter is 0. Now, if $V_{in} > V_{out}$ the comparator output is positive.
- During the first clock pulse, the control circuit sets the D_7 to 1, and V_{out} jumps to the half reference voltage. The SAR output is 10000000.
- If V_{out} is greater than V_{in} the comparator output is negative and the control circuit resets D_7.
- However, if V_{in} is greater than V_{out} the comparator output is positive and the control circuits keep D_7 set.

- Similarly the rest of the bits beginning from D_7 to D_0 are set and tested. Therefore, the measurement is completed in 8 clock pulses.
- At the beginning of the measurement cycle, a start pulse is applied to the start-stop multivibrator.
- This sets a 1 in the MSB of the control register and a 0 in all bits (assuming an 8-bit control) its reading would be 10000000.

- This initial setting of the register causes the output of the D/A converter to be half the reference voltage, i.e. 1/2 V. This converter output is compared to the unknown input by the comparator.
- If the input voltage is greater than the converter reference voltage, the comparator output produces an output that causes the control register to retain the 1 setting in its MSB and the converter continues to supply its reference output voltage of 1/2 $V_{ref.}$
- The ring counter then advances one count, shifting a 1 in the second MSB of the control register and its reading becomes 11000000.
- This causes the D/A converter to increase its reference output by 1 increment to 1/4 V, i.e. 1/2 V + 1/4 V, and again it is compared with the unknown input.
- If in this case the total reference voltage exceeds the unknown voltage, the comparator produces an output that causes the control register to reset its second MSB to 0.
- The converter output then returns to its previous value of 1/2 V and awaits another input from the SAR.
- When the ring counter advances by 1, the third MSB is set to 1 and the converter output rises by the next increment of 1/2 V + 1/8 V.
- The measurement cycle thus proceeds through a series of successive approximations.
- Finally, when the ring counter reaches its final count, the measurement cycle stops and the digital output of the control register represents the final approximation of the unknown input voltage.

Table 5.1

$V_{in} = 1\ V$	Operation	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Compare	Output	Voltage
00110011	D_7 Set	1	0	0	0	0	0	0	0	$V_{in} < V_{out}$	D_7 Reset	2.5
,,	D_6 Set	0	1	0	0	0	0	0	0	$V_{in} < V_{out}$	D_6 Reset	1.25
,,	D_5 Set	0	0	1	0	0	0	0	0	$V_{in} > V_{out}$	D_5 Set	0.625
,,	D_4 Set	0	0	1	1	0	0	0	0	$V_{in} > V_{out}$	D_4 Set	0.9375
,,	D_3 Set	0	0	1	1	1	0	0	0	$V_{in} < V_{out}$	D_3 Reset	0.9375
,,	D_2 Set	0	0	1	1	0	1	0	0	$V_{in} < V_{out}$	D_2 Reset	0.9375
,,	D_1 Set	0	0	1	1	0	0	1	0	$V_{in} > V_{out}$	D_1 Set	0.97725
,,	D_0 Set	0	0	1	1	0	0	1	1	$V_{in} > V_{out}$	D_0 Set	0.99785

Table.2 Current measurement with electronic instruments

The current measurement is often used to diagnose circuits. It reveals a lot about faults in circuits and how these perform. It's also an important component, together with a voltage measurement, of a power measurement.

If the average or effective value has to be measured depends on the goal of the measurement.

2.5 **Continuous Balance DVM:**

The input voltage is applied to one side of a mechanical chopper comparator, the other side being connected to the variable arm of a precision potentiometer. The output of the 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 a mechanical readout, which is an indication of the magnitude of the input voltage.

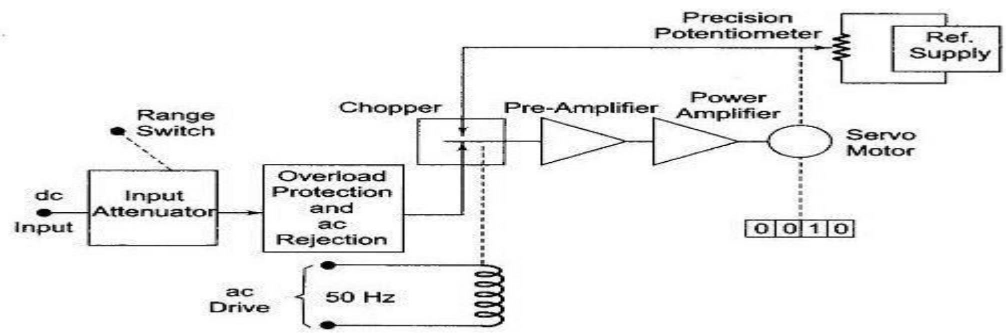


Fig.12 Block Diagram of servo balancing Potentiometer Type DVM

This DVM uses the principle of balancing, instead of sampling, because of mechanical movement. The average reading time is 2 s.

3 1/2 – DIGIT

The number of digit positions used in a digital meter determines the resolution. Hence a 3 digit display on a DVM for a 0 –1 V range will indicate values from 0 – 999 mV with a smallest increment of 1 mV.

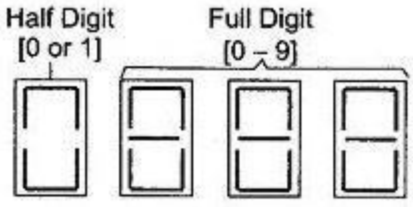


Fig.13 3 ½ Digit display

Normally, a fourth digit capable of indicating 0 or 1 (hence called a Half Digit) is placed to the left. This permits the digital meter to read values above 999 up to 1999, to give overlap between ranges for convenience, a process called over-ranging.

Resolution and Sensitivity of Digital Meters

Resolution

If n= number of full digits, then resolution (R) is 1/10n.

The resolution of a DVM is determined by the number of full or active digits used,

$$\text{If } n = 3, \qquad R = \frac{1}{10^n} = \frac{1}{10^3} = 0.001 \text{ or } 0.1\%$$

Sensitivity is the smallest change in input which a digital meter is able to detect. Hence, it is the full scale value of the lowest voltage range multiplied by the meter's resolution.

3. Current measurement with Electronic Instrument

By definition could a current measurement be one of the most accurate measurements. The electrical current is namely defined as 6,2415077·1018 electrons per second. In principle could the number of electrons be counted who pass a point within a certain time. In this case the accuracy would then only be dependent on the accuracy of the used time standard. Unfortunately we have not yet succeeded to count electrons and therefore we one must rely on indirect phenomena caused by the electron flow. So is the force on a current carrying wire placed within a magnetic field proportional with the current. But the most common way is to measure the voltage across an impedance where the current is flowing through.

Current measurement & impedance

In order to make a current measurement the circuit must be interrupted, whether or not physical. This interruption will be bypassed by the measurement instrument who record the current I. Such a measurement instrument introduces an extra impedance Zm within the circuit and causes a voltage drop . This voltage drop is called the burden voltage.

Take into account that the impedance is more or less frequency dependent and could also cause a phase shift between the current and burden voltage. Thus a current measurement influences always the circuit to measure and the goals is to keep this influence as small as possible.

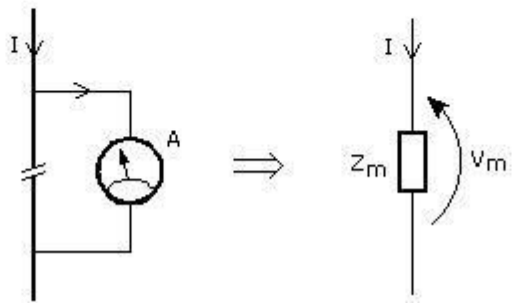


Fig.14 The current circuit must always be interrupted and an extra impedance is introduced.

Measuring accessories

When currents are measured, often instruments are used who aren't able to measure the current directly, such as an oscilloscope. And it can occur that the current is to high to measure this with a standard multimeter. Or it's necessarily to isolate the measurement instrument from the circuit. In these cases measuring accessoiries are used like an external shunt resistor or a current transformer in order to make the measurement possible.

Shunt resistor

A cheap and simple way to measure the current indirectly is by making use of a shunt resistor. The voltage across a shunt resistor is proportional with the current trough it. A shunt resistor is able to measure direct and alternating currents over a wide frequency range.

To reduce the influence of the shunt resistor it must have an as small as possible resistance. Of cause the voltage across it has to be big enough to avoid interference and measurement errors.

Detailed information about calculating and using shunt resistors is to find in the article Shunt resistors.

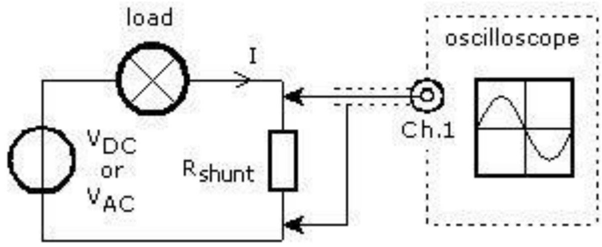


Fig. 3: Measuring set-up where the current indirectly is measured with the use of a shunt.

Current transformer

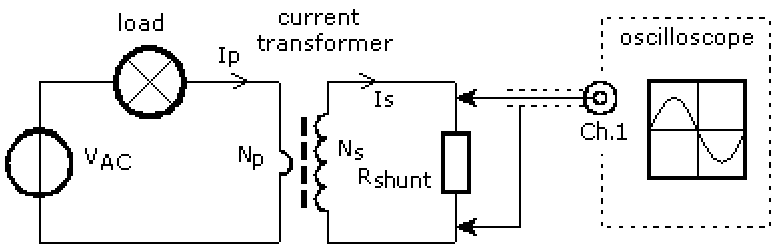


Fig. 4: Measuring set-up where the current is measured with the use of a current transformer and shunt resistor.

Another often used accessory for measuring currents is the current transformer. A great benefit of using current transformers is the galvanic isolation between the measurement instrument and the circuit whereof the current must be measured. A disadvantage of a current transformer is that only alternating currents can be measured, with the exception of special transformer types. Is the measured current includes also a direct current component, than the current transformer could be driven into saturation, that may result in measuring errors. Compared with a shunt resistor, a current transformer has a much smaller frequency range.

Multimeter

Fig. 5: Digital multimeter where the current range is selected.

A commonly used instrument to measure current is the multimeter. The current measurement is based on the measurement of the voltage drop across an internal shunt resistor. The most multimeters use more than one shunt resistors for the different current ranges. Keep in mind that the resistance can be depend on the range that is selected.

Maximum current

A multimeter user's manual will mention a maximum current than may not exceeded. Not every multimeter can handle this prescript maximum current continuously due to possible overheating. In these cases a maximum time that this current may flow is mentioned.

Properties

The measuring of current in the DC-range will normally not cause any problems: This range will always measure the average current regardless the brand and type. The AC-range on the other hand can cause lot of confusions and errors. The reading is subject of the way the multimeter process the current and is therefore depended of brand and type.

Sine shaped currents

As long the measured currents are pure sine shaped it's allowed to add these vectorial. The phase must thus take into account. The practical applications are only basic loads such as ohmic, inductive and capacitive loads.

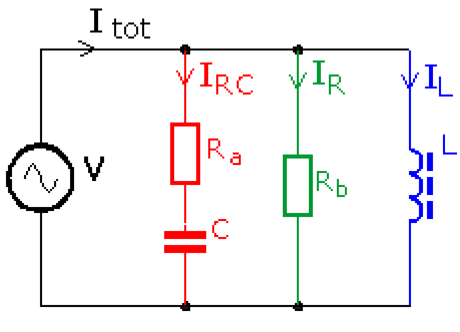


Fig. 6: Circuit with simple loads where the currents are vectorial added.

Figure 6 shows a load example whereof the currents, the phase taken into account, may add together.

A sine shaped alternating voltage V is connected to the following loads: A series circuit of a capacitor and resistor R_a, C, a resistor R_b and an inductor L.

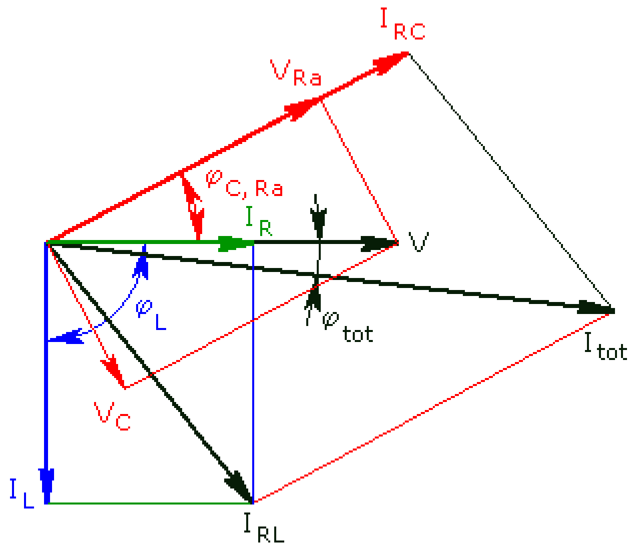


Fig. 7: Vectorial adding of currents

The corresponding vectors of this circuit are shown in figure 7. The colors of the components and vectors match with each other. The vector of the total current I_{tot} is drawn indirectly. First the vector I_{RL} is drawn from I_R and I_L. This intermediate result is used together with the vector I_{RC} to draw the total current.The total current can also be calculated by adding the sine and cosine parts of the three currents. And calculate the total current from these results. The phase is given in degrees, and the light gray calculations are the associated cos-φ.

Non-linear loads

The circuit in figure 9 shows that currents, even if they are measured with a true-RMS multimeter, can't be simply added together. In this example the following loads are connected to an alternating voltage:

- A phase angle control light dimmer (I_d),
- A motor, here represented by a LR-circuit (I_m),
- A rectifier circuit of an electronic device (I_e).

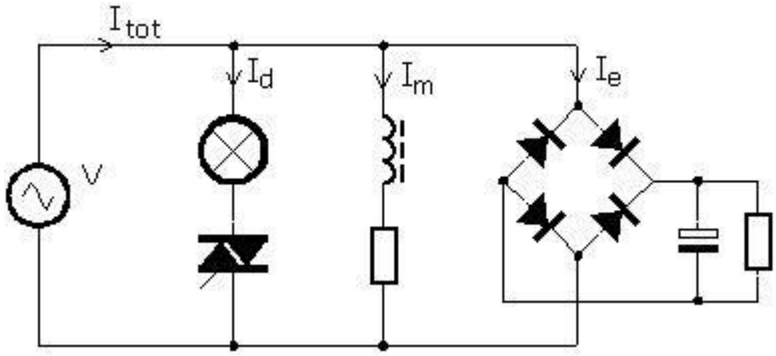


Fig. 9: Circuits with non-linear components who draw irregular currents that can't be easily added.

Each of the loads connected to the alternating current source V_{AC} draw different shaped currents. The total current $I_{tot}(t)$ of the three loads is also shown.The RMS-current of the three loads is calculated: dimmer I_{drms}, motor I_{mrms} and the rectifier circuit I_{erms}. If the three RMS-currents are added together I_{add} than this appears not to agree with the real total RMS-current that flows to the common wire I_{trms}.The conclucion from this is that it's inpossible to calculate the total current if individual currents are measured. The total current must always be measured.

1. Analog Multimeter

Multimeters as the name suggest the meters that we use to measure multiple quantities with the same instrument. The most basic multimeter measures voltage, current, and resistance. Since we use it for measuring current (A), voltage (V) and resistance (Ohm), we call it as AVO meter. We can categorise the multimeters into two groups, namely **analog multimeter** and digital multimeter. We will discuss here in this article about analog multimeter.

Analog multimeter was first of its type, but due to latest technological development after development of digital multimeters, nowadays it is of less use. However, despite such advancements, it is still essential, and we can't neglect it. An analog multimeter is a PMMC meter. It works based on the d'Arsonval galvanometer principle.

It consists a needle to indicate the measured value on the scale. A coil moves in a magnetic field when current passes through it. The indicating needle is fastened to the coil. During the flow of current through the coil, a deflecting torque gets produced due to which the coil rotates at some angle, and the pointer moves over a graduated scale. A pair of hairsprings is attached to the moving spindle to provide the controlling torque. In a multimeter, the galvanometer is a left- zero-type instrument, i.e. needle rests to the extreme left of the scale from where the scale begins with zero.

The meter acts as an ammeter with a low series resistance to measure direct current. For measuring high current, we connect a shunt resistor across the galvanometer so that the current through the galvanometer does not cross its maximum allowed value. Here, a significant portion of the current to be measured bypasses through the shunt. With that shunt resistance, an **analog multimeter** can measure even milli-ammeter or ammeter ranges of current.

For DC voltage measurement, the primary instrument becomes a DC voltage measuring apparatus or DC voltmeter. By adding a multiplier resistance, an analog multimeter can measure the voltage from milli-volts to kilovolts, and this meter works as a millivoltmeter, a voltmeter or even as a kilo voltmeter.

By adding a battery and a resistance network, this instrument can work as an ohmmeter. We can change the range of the ohmmeter by connecting a switch to a suitable shunt resistance. By selecting different values of shunt resistance, we can obtain different scales of resistance measurement. Here below we are showing a basic block diagram of an **analog multimeter**.

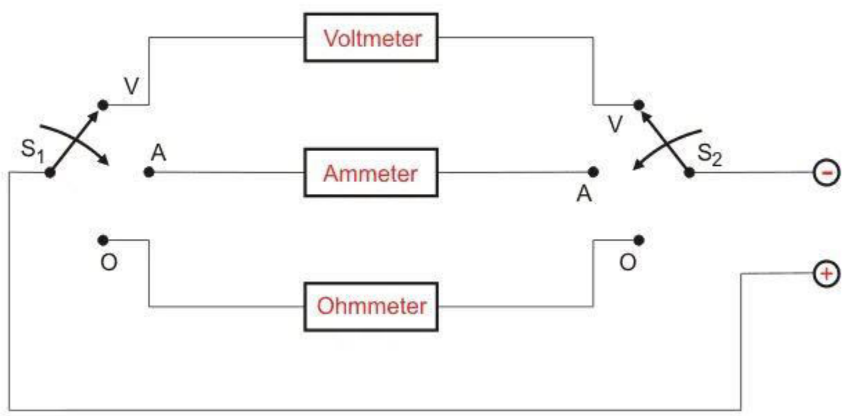


Fig.10: Block Diagram of Multimeter

Here we are using two switches namely S1 and S2 to select the desired meter. We may use additional range-selector switches to choose particular range required in reading amperes, volts, and ohms. We use a rectifier to measure an AC voltage or current with the multimeter.

Advantages of Analog Multimeter

- A sudden change in signal can detect by analog multimeter more swiftly than a digital multimeter.
- All measurements are possible by using one meter only.
- Increase or decrease in signal levels can be observed.

Disadvantage of Analog Multimeter

- Analog meters are bulky in size.
- They are bulky and costly.
- The pointer movement is slow, can't be used to measure voltages with frequencies higher than 50 HZ.
- Inaccurate due to the effect of earth magnetic field.
- They are vulnerable to shock and vibration.

5 .Digital Multimeter

A digital multimeter or DMM is one of the most widely used pieces of test equipment today - they are almost invaluable in any electronics laboratory, for the home, hobbyist and professional electronics engineer.

The cost of digital multimeters varies considerably. Some of these test instruments can be bought very cheaply and provide very good service and they are surprisingly accurate - far more accurate than is needed for most measurements, but top range multimeters are also available with very high specifications for use in the most demanding applications.

Originally analogue multimeters were used, but these are only rarely used these days as digital technology has made digital multimeters cheaper, far more accurate and capable of providing many more capabilities beyond just measuring current, voltage and resistance.

Digital multimeters or DMMs can measure a variety of different parameters within an electrical circuit. The basic DMMs can measure amps, volts and ohms, as the older analogue meters did, but with the ease of incorporating further functionality into an integrated circuit, many digital multimeters are able to make a number of other measurements as well.

Many of them include functions enabling measurement of capacitance, frequency, continuity (with a buzzer to facilitate easy measurements when looking at the circuit board), temperature, transistor functionality, and often a number of other measurements as well.

For many years, analogue multimeters were used. As modern day integrated circuits were not available, these test instruments paved the way for the later digital versions.

Fig.11: Digital Multimeter

The analogue multimeters were able to measure only amps volts and ohms. However the introduction of integrated circuit technology and other technologies enabled analogue to digital converters to be made along with deploys like liquid crystal displays. This enabled test instruments to be made that could measure the basic measurements of amps volts and ohms to be made digitally.

In addition to this, it was possible to add in additional measurements at very little cost, making these test instruments far more versatile than the old analogue counterparts. The basic block diagram of a typical digital multimeter is given in the diagram below. Although different DMMs will use different circuits, the same basic techniques tend to be used from one test instrument to the next.

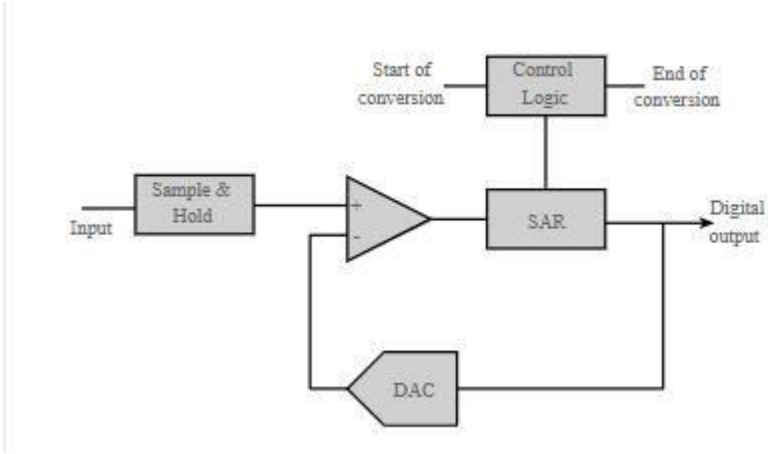


Fig.12: Block diagram of a DMM using successive approximation register ADC

The concept used within the analogue to digital conversion is called a successive approximation register. As the name implies, the successive approximation register ADC operates by successively homing in on the value of the incoming voltage.

Typical DMM controls and connections

The interfaces on the front of a digital multimeter are normally very straightforward. The basic digital multimeter will typically have a switch, display, and the connections for the test probes.

The main connection on a typical digital multimeter are given in the image and description below, but obviously the exact layout and capabilities will be dependent upon the particular test instrument in use.

Fig.13: Digital multimeter showing the controls & connections

1. ***Display*** The display on a DMM is normally easy to see and read. Most have four digits, the first of which can often only be either a 0 or 1, and there will normally be a + / - indication as well. There may also be a few other smaller indicators such as AC / DC etc dependent upon the model of DMM
2. **Main connections** There will be some main connections for the probes to connect to. Although only two are needed at any one time, there may be three or four. Typically these may be:

    - Common - for use with all measurements and this will take the negative or black lead and probe
    - Volts, ohms, frequency - this connection is used for most measurements and will take the positive or red lead and probe.
    - Amps and milliamps - this connection is used for the current measurements and will again take the red lead and probe.
    - High current - there is often a separate connection for high current measurements. Care must be taken to use this rather than the low current connection if high levels of current are anticipated

    These are typical connections for a multimeter and each model of multimeter may have its own requirements and connections.
3. **Main switch** There will usually be a single main rotary switch to select the type of measurement to be made and the range that is needed.
4. **Additional connections** There may be additional connections for other measurements such as temperature where a thermocouple will need its own connections. Some meters are also able to measure the gain of transistors, and these will require separate connections on the meter.
5. **Additional buttons and switches** There will be a few additional buttons and switches. The main one will obviously be the on/off button. Other functions including items such as peak hold may also be available
   The switches and controls are normally set out with the main range switch occupying the central position within the multimeter panel. The display typically occupies a position at the

top of the instrument so that it is easy to see and it is free from being obscured by leads and also it can still be seen if the switch is being operated.

Using the meter it is possible to follow a number of simple steps:

1. Turn the meter on
2. Insert the probes into the correct connections - this is required because there may be a number of different connections that can be used.
3. Set switch to the correct measurement type and range for the measurement to be made. When selecting the range, ensure that the maximum range is above that anticipated. The range on the DMM can then be reduced as necessary. However by selecting a range that is too high, it prevents the meter being overloaded.
4. Optimise the range for the best reading. If possible enable all the leading digits to not read zero, and in this way the greatest number of significant digits can be read.
5. Once the reading is complete, it is a wise precaution to place the probes into the voltage measurement sockets and turn the range to maximum voltage. In this way if the meter is accidentally connected without thought for the range used, there is little chance of damage to the meter. This may not be true if it left set for a current reading, and the meter is accidentally connected across a high voltage point.
6. When making any measurements it is necessary to be careful not to let the test probes slip as it might be possible to short connections on the circuit under test. In extreme circumstances this could cause a power short circuit, or damage the board.
7. Normally, when probing board, connections are sufficiently far apart for this not to be a problem, but care should be taken particularly when dealing with high voltage and high current circuits.
8. DMM overall accuracy
9. There are a number of elements that contribute to what may loosely be termed accuracy. Two of the major constituents are the resolution and the actual accuracy of the measurement system
10. **Resolution** The resolution of a DMM is often specified in the number of digits. DMMs will be specified in terms of the number of digits in the display. Typically this will be a number consisting of an integer and a half, e.g. 3 1/2 digits. By convention a half digit can

display either a zero or 1. This a three and a half digit meter could display up to 1999. Sometimes a three quarters digit may be used. This can display a number higher than one, but less than nine.

11. **Accuracy** The accuracy of the meter is different to the display resolution. This represents the uncertainty of the reading due to inaccuracies in the DMM.
12. Although the accuracy of a digital multimeter will be much greater than that of a analogue multimeter, it helps to understand the difference between the accuracy and resolution.
13. It is also necessary to understand the difference between them to understand the overall accuracy of any measurements that are made

6. Digital Frequency meter

Digital frequency meter is a general purpose instrument that displays the frequency of a periodic electrical signal to an accuracy of three decimal places. It counts the number events occurring within the oscillations during a given interval of time. As the preset period gets completed, the value in the counter display on the screen and the counter reset to zero. Various types of instruments are available which operates at a fixed or variable frequency. But if we operate any frequency meter at different frequencies than the specified range, it could carry out abnormally. For measuring low frequencies, we usually use deflection type meters. The deflection of the pointer on the scale shows the change in frequency. The deflection type instruments are of two types: one is electrically resonant circuits, and other is ratio meter.

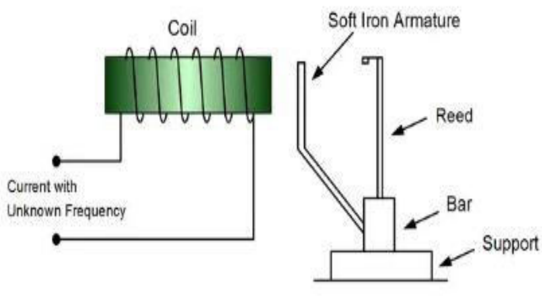


Fig.14: Digital Frequecy Meter

Operating Principle of Digital Frequency Meter

A frequency meter has a small device which converts the sinusoidal voltage of the frequency into a train of unidirectional pulses. The frequency of input signal is the displayed count, averaged over a suitable counting interval out of 0.1, 1.0, or 10 seconds. These three intervals repeat themselves sequentially. As the ring counting units reset, these pulses pass through the time-base-gate and then entered into the main gate, which opens for a certain interval. The time base gate prevents a divider pulse from opening the main gate during the display time interval. The main gate acts as a switch when the gate is open; pulses are allowed to pass. When the gate is closed, pulses are not allowed to pass that means the flow of pulses get obstructed.

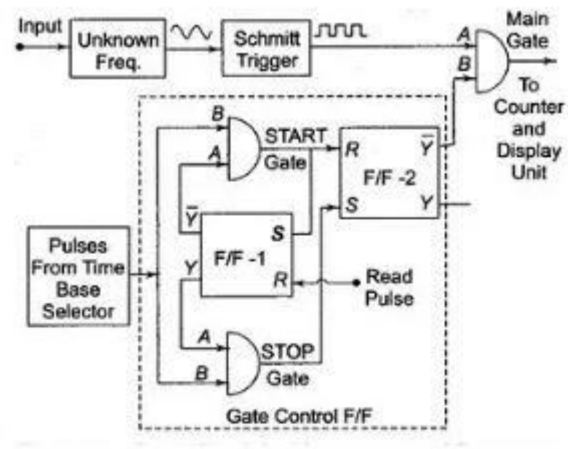


Fig.15 Block diagram Frequency Meter

The functioning of the gate is operated by the main-gate flip-flop. An electronic counter at the gate output that counts the number of pulses passed through the gate while it was open. As the main gate flip-flop receives next divider pulse, the counting interval ends, and divider pulses are locked out. The resultant value displayed on a display screen which has the ring counting units of scale-of-ten circuits and each unit couples to a numeric indicator, which provides the digital display. As the reset pulse generator is triggered, ring counters get reset automatically, and the same procedure starts again.

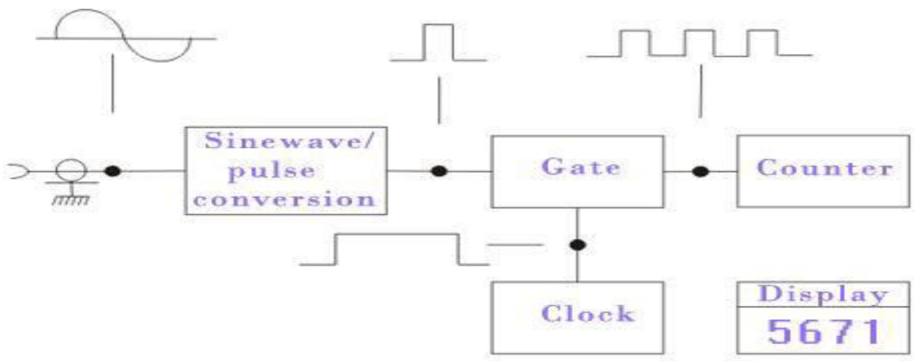


Fig.15 Block diagram digital frequency meter

The range of modern **digital frequency meter** is between the range from104 to 109 hertz. The possibility of relative measurement error ranges between from 10-9 to 10-11 hertz and a sensitivity of 10-2 volt.

Use of Digital Frequency Meter

- For testing radio equipment
- Measuring the temperature, pressure, and other physical values.
- Measuring vibration, strain
- Measuring transducers

7. Time Interval Measurement

Interval timers / time interval counters are used for measuring the intervals between electronic pulses: using very similar circuitry to frequency counters, they are often combined in the same test instrument.

Interval times or time interval counters provide the ability to measure the time interval between edges on waveforms. They can be used for single waveforms, or by providing two separate inputs, they can use one waveform to start the time interval, and another to end the time interval measurement.

Timers use may of the same circuit blocks as those used in frequency counters. By re-arranging the blocks the same circuits can be sued in a slightly different manner to measure the time intervals. Accordingly frequency counters and interval timers are often combined in the same instrument - these test instruments are often referred to as a frequency counter timer.

These test instruments are widely available and often can be purchased relatively cheaply. Some of the major differences are the accuracy of the basic clock oscillator, the display, ease of operation and robustness of the test instrument.

Interval timer basics

The timer interval measurement capabilities of time interval counters can be used in a variety of ways.

Time interval of waveform: The frequency timer counter can be used to simply measure the time interval of the incoming waveform. This is simply the reciprocal of the frequency. It typically measures the positive going edge of the waveform to the next positive going edge.

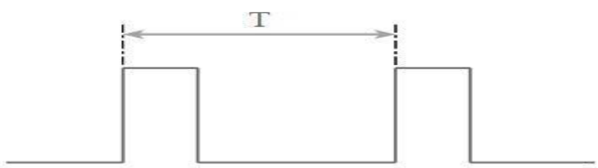


Fig.16: Time interval of waveform

Time interval of pulse*:* Rather than simply measuring one positive going edge to the next, it is also possible to measure a positive going edge to the next negative going one. Or alternatively it could measure a negative going edge to a positive one. In this way it is possible to use the frequency timer counter to measure the time interval of a pulse.

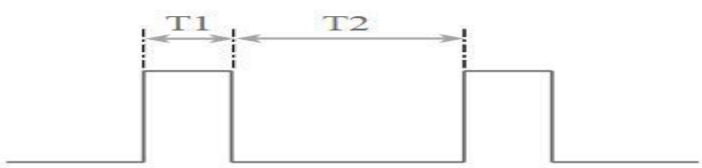


Fig.17: Time interval of pulse

- It can be seen that the two options are represented by the two times T1 and T2: T1 being for the timer interval + to - and T2 for - to + going edges of the waveform.

- In this way the functionality of the instrument has been greatly enhanced by the simple addition of the selection of the waveform edge transition. This can be provided without much additional circuitry, and with the use of integrated circuits comes at virtually no additional cost.

Time interval A to B: Many counter timers have two inputs. In this way it is possible to measure an edge on one signal to an edge on another. Normally it is possible to select either positive or negative going edges on each signal

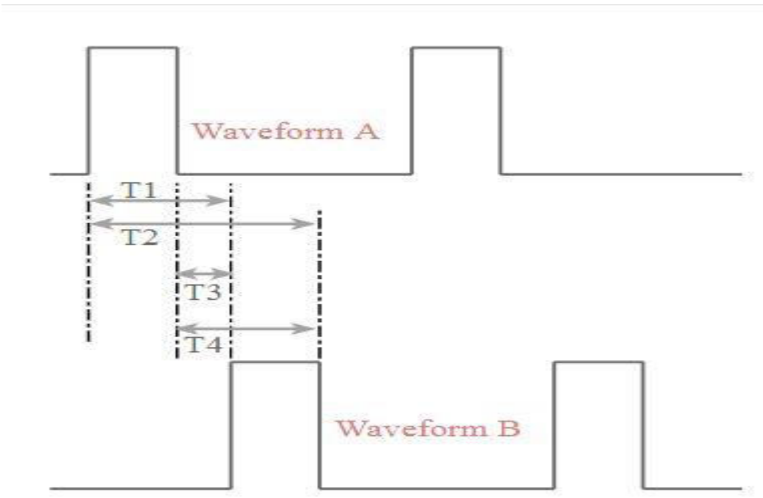


Fig.18: Time interval A to B

- For this measurement there are four combinations that can be selected by using the different edges of the two waveforms. These are represented by T1 (A+ to B+), T2 (A+ to B-), T3 (A- to B+) and T4 (A- to B-), where A- is the negative going edge of waveform A, etc.

The time interval capability of a frequency counter timer, may not be used as often as the straight frequency counter measurement, but it is a key application in some areas. The time interval measurement capability is normally provided in the lower frequency counter timers aimed more for general purpose use. It is not normally included in RF or microwave frequency counters that are aimed specifically at the specific RF applications.

Frequency counter timer operation

Time interval is the reciprocal of frequency. As a result it is possible to make interval timer measurements using a frequency counter timer by simply reconfiguring some of the circuitry from those used for frequency measurements.

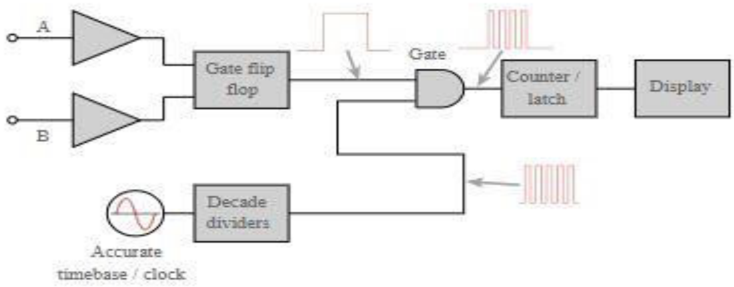


Fig.19: Frequency counter timer operation

Like the frequency counter, the timer counter or interval timer has a number of blocks that make up the test instrument. They are very similar to those used in the counter, and just require reconfiguration to give the interval timing function. The operation of the various stages is summarised below:

- ***Signal input stages:*** In operation the interval timer counter take in the waveforms that require timing. Often timers have both A and B inputs. The input stages condition the input signals and convert them to the logic levels required within the interval timer counter.
- ***Gate Flip-Flop:*** The Gate Flip Flop then generates a pulse equal to the length of the timer interval required. This can easily be achieved using simple logic, although this functionality is normally contained within a special frequency counter timer integrated circuit. Selection of the positive and negative going edges is also selected here.
- ***Clock oscillator:*** The clock oscillator for the frequency counter timer or timer interval counter will typically be a crystal oscillator. In many cases this will be oven controlled, and many test instruments will also have an output to use this oscillator as the clock or reference source for other instruments. They may also be an input so that external clock oscillators can be used. This can enable some test systems to run off a single source thereby giving the advantages of synchronisation across the test system.
- ***Gate:*** The function of the gate within the interval timer is exactly the same as in the frequency counter, except that for the interval timer the inputs are effectively reversed. The circuit will be the same.

The edges to be timed produce a signal that enables the gate for the duration of the timing. During this time, the clock signal passes through. For example, if the signal to be timed is a second long, and the clock entering the gate is 1 MHz, then 1 000 000 pulses will appear at the output of the gate.

- ***Counter/ latch:*** The counter takes the incoming pulses from the gate. It has a set of divide-by-10 stages as a decimal based display is required. The number of stages within the overall counter is equal to the number of display digits minus 1. As the counters are chained the first stage is the input divided by ten, the next is the input divided by 10 x 10 (100) as it has been divided by two stages, 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 transferred and 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. Often the latch may be incorporated into the display circuitry.
- ***Display:*** The display takes the output from the latch and displays it in a normal readable format. LEDs are still widely used although LCDs are more common because of the lower power consumption and the greater flexibility provided for additional characters and indictors. There is a digit for each decade the counter can display. Obviously other relevant information may be displayed on the display as well. The display will be programmed to place the decimal point in the correct position. For example for the 1 second time interval with a 1 MHz clock, 1 000 000 pulses are counted and the decimal point will need to be placed after the figure 1 to indicate 1.000 000 seconds.

Interval timers or timer counters are normally very easy to use. There are simple switches on the front panel or if it is a software instrument, upon the control panel to enable the different inputs and different edges, i.e. positive and negative going edges to trigger the start and stop points.

These test instruments can also measure time intervals very accurately. The measurement accuracy of the interval timer is dependent upon the clock oscillator and this can easily be accurate to one part in 10^6 or a few parts in 10^7 dependent upon the oscillator used. Accordingly these test instruments are capable of being used for high accuracy measurements in many applications.

Automation in Digital Instruments:

Automation in Digital Instruments – One of the advantages of digital multimeters is their ease of operation. The reading is easy to take and does not lend itself to errors of interpretation. Moreover, the number of ranges is limited because the ranges move in steps of 10 (instead of the $\sqrt{10}$ steps used for analog instruments). Demand from users for simple forms of computation signalling and control, and advances in digital circuitry have led to further development, in which more and more automatic functions have been incorporated in digital voltmeters. Nearly all instruments today have automatic polarity display and automatic decimal point positioning, while many have automatic ranging and zeroing too.

This automation includes automatic polarity indication, automatic ranging, and automatic zeroing.

Automatic Polarity Indication

The polarity indication is generally obtained from the information in the ADC. For integrating ADCs, only the polarity of the integrated signal is of importance. The polarity should thus be measured at the very end of the integration period (see Fig. 6.21). As the length of the integration period is determined by counting a number of clock pulses, it is logical to use the last count or some of the last counts to start the polarity measurement. The output of the integrator is then used to set the polarity flip-flop, the output of which is stored in memory until the next measurement is made.

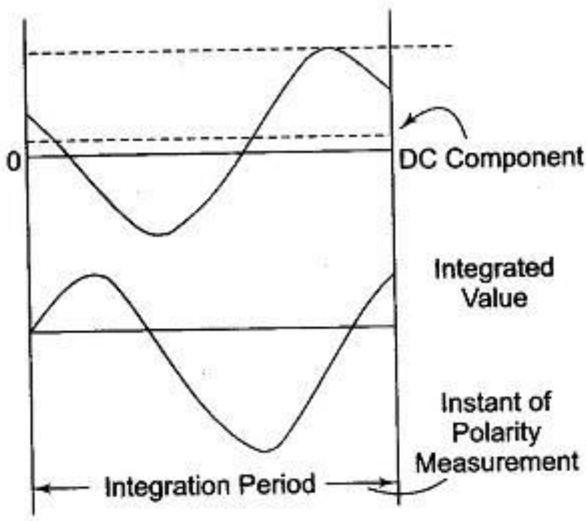


Fig. 6.21 Polarity of Integrated Signal has to be Measured at Very End of Integration Period

Automatic Ranging

The object of automatic ranging is to get a reading with optimum resolution under all circumstances (e.g. 170 mV should be displayed as 170.0 and not as 0.170). Let us take the example of a $3^1/2$ digit display, i.e. one with a maximum reading of 1999. This maximum means that any higher value must be reduced by a factor of 10 before it can be displayed (e.g. 201 mV as 0201). On the other hand, any value below 0200 can be displayed with one decade more resolution (e.g. 195 mV as 195.0). In other words, if the display does not reach a value of 0200, the instrument should automatically be switched to a more sensitive range, and if a value of higher than 1999 is offered, the next less sensitive range must be selected.

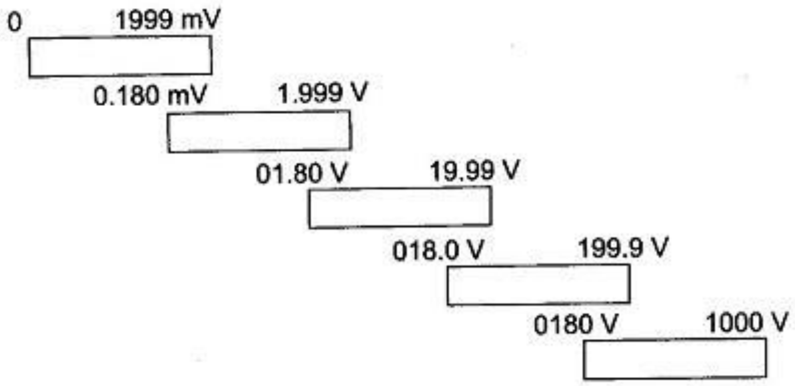


Fig. 6.22 Example of Overlapping Ranges in Automatic Ranging Instruments

Generally the lower limit is taken lower than 0200 (example 0180). Otherwise, a voltage exhibiting slight fluctuations around 2000 would be displayed successively as 1999.9, 0200 and 0201, which would be confusing. By introducing an overlap in the ranges (see Fig. 6.22), we ensure that all values are displayed in the same range (in the above example, as 0199, 0200 or 0201). Values around 0180 also give a stable display e.g. 1798, 1800 and 1807).

The design of an automatic ranging system is indicated in the block diagram in Fig.

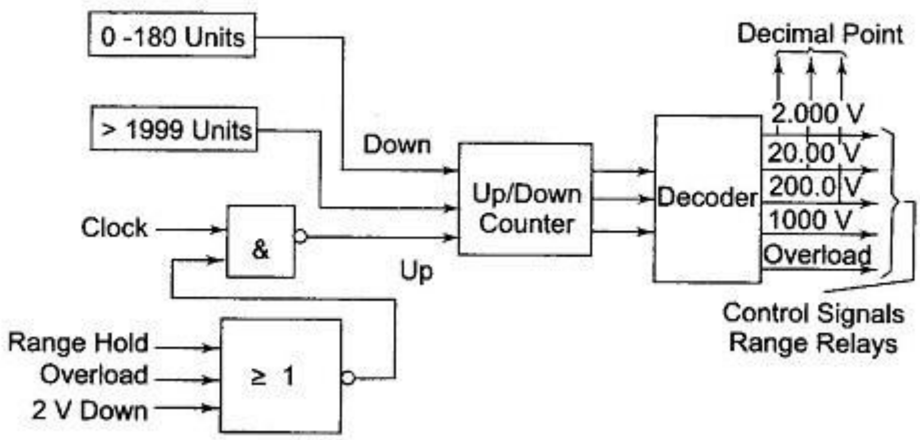


Fig. 6.23 Block Diagram of Automatic Ranging System

The information contained in the counter of the ADC yields a control pulse for down ranging when the count is less than 180 and one for up ranging when the count exceeds 1999 units. The Up/Down counter of the automatic ranging circuit reacts to this information at the moment that a clock pulse (a pulse at the end of the measuring period, also used to transfer new data to memory), is applied, and the new information is used to set the range relays via the decoder. At the same time the decimal point in the display is adapted to the new range, when more than range step has to be made, several measuring periods are needed to reach the final result. Clock pulses, and so automatic ranging, can be inhibited, for example, by a manual range hold command, by a signal that exceeds the maximum range (only for up counts), and course by reaching the most sensitive range, but then only for down counts.

Automatic Zeroing

Each user of a voltmeter expects the instrument to indicate zero when the input is short-circuited. In a digital voltmeter with a maximum reading of 1999, a zero error of 0.05% of full scale deflection is sufficient to give a reading of 0001. For this reason, and in the interests of optimum accuracy with low valued readings, a zero adjustment is necessary. To increase the ease of operation, many instruments now contain an automatic zeroing circuit.

In a system used in several multimeters, the zero error is measured just before the real measurement and stored as an analog signal. A simplified circuit diagram of a circuit that can be used for this purpose is given in Fig. 6.24, for a dual slope ADC.

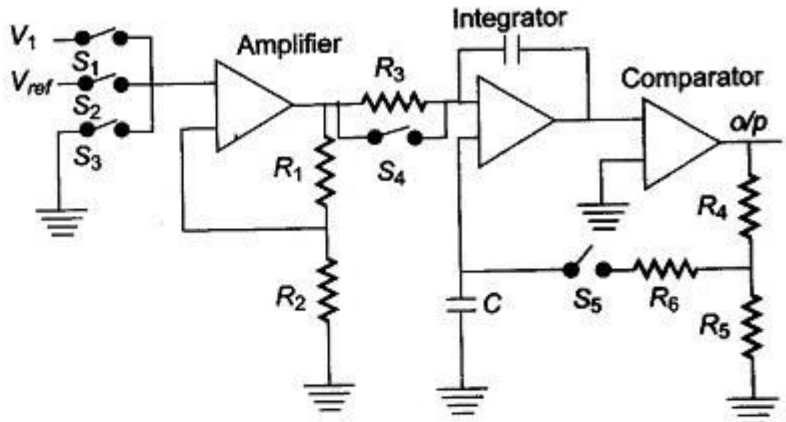


Fig. 6.24 Simplified Circuit Diagram of Automatic Zeroing Circuit that can be Used With Dual Slope ADC

Before the real measurement is made, switches S_3, S_4 and S_5 are closed, say for 50 ms, thus grounding the input, giving the integrator a short RC time, and connecting the output of the comparator to capacitor C. This capacitor is now charged by the offset voltages to the amplifier, the integrator and the comparator. When switches S_3, S_4 and S_5 are opened again to start the real measurement, the total offset voltage of the circuit (equal to zero error) is stored in this capacitor, and the real input voltage is measured correctly.

Fully Automatic Digital Instrument

A multimeter with automatic polarity indication, automatic zero correction and automatic ranging (of course coupled with automatic decimal point indication) only needs a signal applied to its input, and a command as to what quantity (V_{dc}, V_{ac}, **I** or R) to measure; it does all the rest itself.

The digital part of a typical instrument is organised so as to produce a display or a digital output signal, as shown in Fig. 6.25. Before a measurement can

Measurements	Integration Time	Clock Frequency

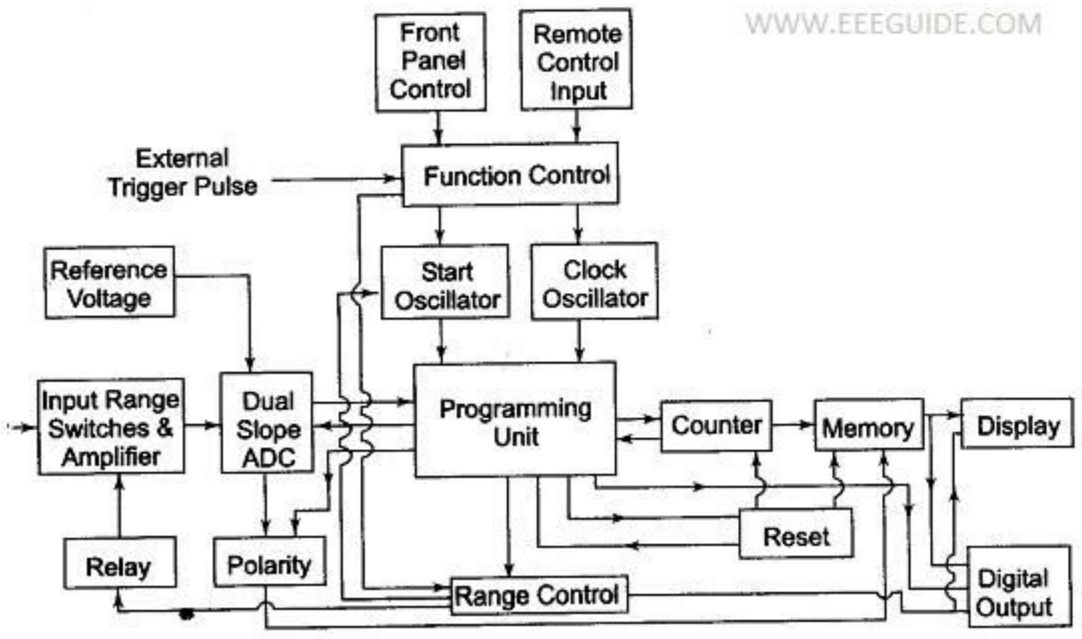


Fig. 6.25 Block Diagram of an Automatic Instrument

begin, the functions of the instrument must be set, that is, we must select the quantity to be measured (e.g. voltage), the ranging mode (automatic or manual), and the start mode (internal or with an external trigger signal). This can be done by the front panel controls, or via a remote control input. In both cases, the signals are fed to the function control unit, while the information on ranging is passed to the range control unit.

Let us assume that in the instrument in question, the ADC is of the dual slope integration type, and that a choice can be made between the combinations given in Table 6.1.

4	100 ms	200 kHz
20	20 ms	1 MHz
200	2 ms	1 MHz

It will be clear that as the number of measurements per second increases, the integration time must be reduced and that it is useful to increase the clock frequency at the same time to maintain good resolution. To select the desired combination, information on the number of measurements per second must be fed to the start oscillator and clock oscillator. The latter constantly supplies clock pulses to the programming unit. The former is free running when the DVM is set for internal start, but it waits for an external trigger signal when the DVM is set for external control. Let us now follow (see Fig. 6.25) the various steps involved in the performance of a measurement, for the case that the instrument is set for automatic ranging and external triggering.

An incoming trigger pulse causes the start oscillator to deliver a pulse to the programming unit, and a measurement is started. The programming unit starts both the counter and the ADC. The ADC is connected to the input. The counter counts the clock pulses to determine the integration time and sends two signals back to the programming unit, one just before the end of the integration period, and the other at the end of this period. The first signal is used by the programming unit to activate the polarity detector, which determines the polarity of the integrated signal, while the second serves to switch the ADC input from the reference signal. At the same time, the counter is reset to zero and starts counting the down integration time of the ADC until it is stopped by the zero-detector signal of the ADC. At that moment, the programming unit compares the counter reading with the automatic ranging limits, and passes an up or down signal to the range control, if necessary. This unit switches the input range switches via a relay and triggers the start oscillator for a new measurement in a more sensitive or less sensitive range. In the meantime, the programming unit will also have reset the counter. This process continues until a measurement which is within the automatic ranging limits has been made. The programming unit then transfers the new data from the counter to the memory, together with the polarity information so as to make them available to the display unit and the digital output. Finally, the programming unit delivers a transfer pulse to the digital output, to warn an instrument connected to this output (e.g. a printer) that new data has been made available.

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 computer screen.

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.

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.

QUESTION BANK

PART-A (2 MARKS)

1. **What are the essential parts of the ramp type DVM?**
2. What are the additional features found on individual digital multimeter?
3. What are the advantages of digital instruments?
4. What is the principles of ramp type DVM?
5. Why is period mode preferred for measurement of very low frequency in a frequency counter?
6. What is the important of gate time in frequency counter?
7. How is trigger time error reduced?

PART – B (16 Marks)

8. Explain the various types of ADC with suitable sketches.
9. Discuss in detail the working of the successive approximation DVM.
10. Explain with neat diagram the working of linear ramp type DVM.
11. Draw and explain the circuit of digital frequency meter.
12. Discuss briefly various types of digital voltmeters.
13. Explain the working of digital multimeter with a schematic block diagram.
14. Explain universal counter with the help of block diagram.
15. Write note on measurement errors in frequency counter.
16. Explain different techniques used for extending frequency measurement range.
17. With a neat schematic ,explain the operation of a dual slope analog to digital conversion.
18. With a block schematic ,explain the frequency mode and the frequency ratio mode operation of a frequency counter.
19. What is meant by gating error in a frequency counter ?How does it arise? can it be eliminated?

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRICAL AND ELECTRONICS

UNIT – V

MEASUREMENT AND INSTRUMENTATION – SEIA3001

UNIT :5 - ACQUISITION MEASUREMENT SYSTEMS AND FIBER OPTIC DATA

Elements of a digital data acquisition system – interfacing of transducers – multiplexing – data loggers –computer controlled instrumentation – IEEE 488 bus – fiber optic measurements for power and system loss – optical time domains reflectometer.I.DATA

5.1 DATA ACQUISITION SYSTEM

In order to optimize the characteristics of the system in terms of performance of the system, data handling capacity and cost, different relevant sub-systems are combined together. The system used for data processing, data conversion, data transmission, data storage is called data acquisition system. The typical data acquisition system consists of sensors with necessary signal conditioning, data conversion, data processing, data handling and transmission, storage and display systems. The modern electronic instrumentation is not becoming more sophisticated because of tremendous development in micro-electronic devices, op-amps, multiplexers, data converters, microprocessors and microcontrollers. The data measurement systems and process controls are very flexible and more programmable now a days, because of development in automation field. The data acquisition system relates to collection of the input data in the digital form rapidly, economically and accurately as necessary.

Objectives of Data Acquisition system:

i) The data acquisition system must acquire the necessary data at correct speed and at the correct time.

ii) It must use all the data efficiently to inform the operator about the state of the plant.

iii) It must monitor the operation of complete plant so that optimum online safe operations are maintained.

iv) It must provide effective human communication system which helps in identifying the problem areas. This minimizes unit availability and maximizes the unit output at lower cost.

v) It must be able to collect, summarise and store data properly for diagnosis and record purpose of any operation.

vi) It must be able to compute unit performance indices using online real time communication.

vii) It must be flexible. Also the expansion facility for the future requirement must be provided by it.

viii) It must be reliable and should not have a down time greater than 0.1%.

The data acquisition systems are basically used to measure and record the signals obtained in two ways. Firstly the signal may be originating from direct measurement of an electrical quantity such as ac or dc voltage, frequency, component value such as resistance, capacitance etc. Such signals are always found in electronic component testing, environmental studies etc. Secondly the signal may originate from the transducers such as pressure transducers, thermocouples.

The data processing involves a variety of operations ranging from simple comparison to complicated arithmetical manipulations. This can be used to collect various data or information, perform some operations if required, convert this information to the suitable form using converters, perform more number of calculations to remove unwanted noise signal, gather results to be displayed and so on. The transmission of data can take place over very long distances or very short distances. The results which are gathered may be displayed directly on the digital panel or may be on CRT. The data stored may be permanent or temporary.

To collect data rapidly, shift digitiser or some high resolution devices may be used. For converting analog signal to digital, additional transducers, amplifiers and multiplexers are used. The use of sample and hold circuit increases the speed with which accurate conversion of information is possible.

The data acquisition system is mainly classified as analog data acquisition system and digital data acquisition system. The analog data acquisition systems mainly deal with the measurement information which is in the analog form. An analog signal is the continuous signal such as voltage versus time or displacement due to the pressure. While the digital data acquisition system may consists of number of discrete and discontinuous pulse representing high and low pulses which is in digital form. The relationship of these pulses with time gives the nature or magnitude of the quantity.

5.2 Analog Data Acquisition System:

The basic components used in the analog data acquisition system are as follows,

1. Transducer: The transducer is used to convert the physical quantity into an electrical signal. The transducers such as strain gauge, thermocouples, piezoelectric devices, photosensitive are most widely used. The transducer generates a voltage proportional to the physical quantity being measured. This voltage is applied as a input to the data acquisition system. Apart from this some special sensors produce frequency which can be counted by an electronic counter. This frequency forms the integral part of the quantity being measured. Otherwise the signal may be modulated then voltage level is reduced with the help of discriminator.

2. Signal Conditioner: This device includes the supporting circuitry for the transducers. It allows the output voltage of transducer to amplify upto desired level. It also converts the output voltage to the desired form so that it is accepted by the next stage. It produces the conditions in transducers so that they work properly. It also provides excitation power and balancing circuits.

3. Multiplexers: It allows a single channel to share it with more than one input quantity. It accepts multiple analog inputs. With the help of multiplexer we can transmit more than one quantity using same channel. The multiplexers are mostly used when many quantities are to be transmitted. Also when the distance between the transmitting end and receiving end is more, the multiplexers are used. Multiplexers reduce the cost of installation, maintenance and periodic replacement of channels if those are used for separate input signals.

4. Calibrating Equipment: Before each test, the calibration is carried out. This is called pre-calibration. Similarly after each test calibration is carried out and it is called post-calibration. It usually consists millivolt calibration of all input circuits and shunt calibration of all bridge type transducers.

5. Integrating Equipment: This block is used for integration or the summation of a quantity. The digital techniques are normally used for integration purposes.

6. Visual Display Devices: These are necessary to monitor the input signal continuously. These devices include panel meters, numerical displays, single or multichannel CROs, storage CRO etc.

7. Analog Recorders: These are required to record the output signal. The analog recorders include strip chart recorder, magnetic tape recorder etc.

8. Analog Computers: These are used as data reduction device. The output voltage of the analog computer may be converted to digital form for further computations. Even though the accuracy of analog computations is comparatively less than the digital one the analog computers are used because of its less cost.

5.3 Digital Data Acquisition system:

The simple digital data acquisition system is shown below:

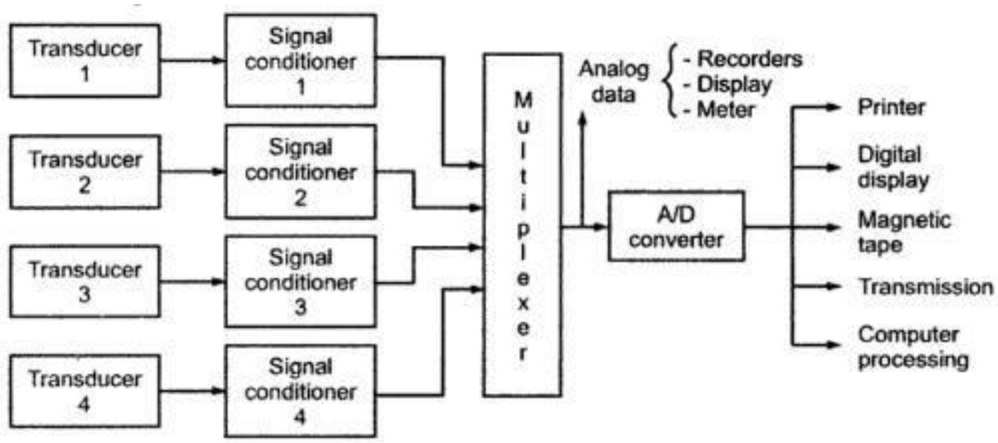


Fig.5.1 Generalized data acquisition system

The digital data acquisition system includes all the blocks shown in the figure. It may use some additional function blocks. The essential functions of a digital data acquisition system are as follows,

i) It handles the analog signals,

ii) It performs measurement,

iii) It converts analog signal into digital data and handles it,

iv) It performs internal programming and control. The various components of the digital data acquisition system are as follows

1. Transducers: They convert the physical quantity into a proportional electrical signal which is given as a input to the digital data acquisition system.

2. Signal Conditioners: They include supporting circuits for amplifying, modifying or selecting certain positions of these signals.

3. Multiplexers: The multiplexer accepts multiple analog inputs and connects them sequentially to one measuring instrument.

4. Signal Converters: The signal converters are used to translate analog signal to a form which is suitable for the next stage that is analog to digital converter. This block is optional one.

5. Analog to Digital Converters (A/D converter) : The analog to digital converter converts the analog voltage to its equivalent digital form. The output of the analog to digital converter may be fed to the digital display devices for display or to the digital recorders for recording. The same signal may be fed to the digital computer for data reduction or further processing.

6. Auxiliary Equipments: The devices which are used for system programming functions and digital data processing are included in the auxiliary equipments. The typical functions of the auxillary equipment includes linearization and limit comparison of the signals. These functions are performed by the individual instruments or the digital computer.

7. Digital Recorders: They record the information in digital form. The digital information is stored on punched cards, magnetic tape recorders, type written pages, floppies or combination of these systems. The digital printer used provides a high quality, hard copy for records minimizing the operator's work.

The data acquisition systems are used, now a days in increasing wide fields. These are becoming very much popular because of simplicity, accuracy and the most important reliability of the systems. These are widely used in industrial areas, scientific areas, including aerospace, biomedical and telemetry industries.

When the lower accuracy is tolerable or when wide frequency bandwidth is needed, the analog data acquisition systems are used. The digital data acquisition systems are used when the physical quantity being measured has very narrow bandwidth. When the high accuracy with low per channel cost is required, the ultimate solution is to use the digital data acquisition system.

5.4 Single channel Data Acquisition system:

The basic single channel data acquisition system consists of a signal conditioner circuit, analog to digital converter, buffer. The analog to digital converter performs the conversions repetitively at a free running internally determined rate. The basic single channel data acquisition system is as shown in the figure below

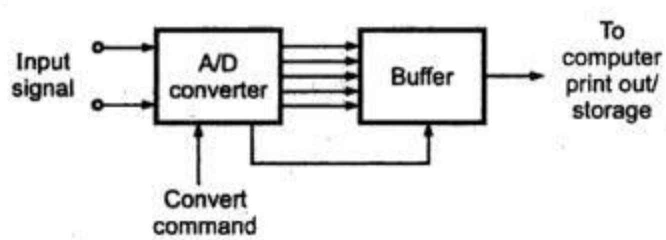


Fig.5.2 Single channel DAS

The digital outputs from the buffer are further fed to either digital computer or storage or print out device. The most popular example of the single channel data acquisition system is the digital panel meter (DPM).

The digital outputs are obtained from the analog to digital converter. The analog to digital converters used for the data acquisition system are designed such that they can accept external commands to convert and hold operations. A/D converters based on dual slope techniques are mostly used for the conversion of low frequency data, generally from thermocouples. The successive approximation technique is most widely used because it gives high resolution and high speed at moderate cost.

Many times it is observed that the signal level is very low compared to the input requirement. In such cases, the amplification of the input signal is done to bring its level to match the input requirement. This is called pre-amplification. If the input signals are to be isolated from the system physically, the conductive paths are broken by using mostly opto-coupled isolation amplifier. The pre-amplifiers may be coupled with active filters before the processing of data. These filters minimise the effect of noise carrier and interfering high frequency components. Sometimes special purpose filter such as tracking filter may be used to preserve the phase dependent data.

5.5 Multi-channel Data Acquisition system:

The different subsystems of DAS can be time shared by two or more input sources. The number of techniques are employed for time shared measurements. Basically there are three types of multiplexed systems. They are as follows,

1) Multichannel analog multiplexed system:

The basic block diagram is shown below

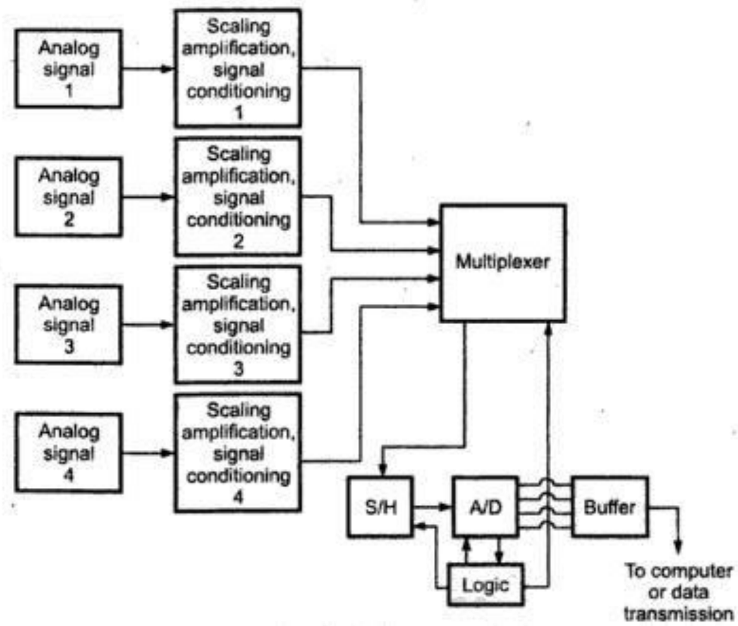


Fig.5.3 Multichannel DAS (A/D preceded by a multiplexer)

In this system, there is a single analog to digital converted preceded by a multiplexer. The individual analog signals are applied directly. They are amplified and signal conditioned and connected to the multiplexer. Then analog to digital converter converts these analog signals to digital signals.

For the utilization of time, the multiplexer gets or selects new channel to be converted while the previous data stored in the sample and hold circuit is converted into digital form. When this conversion completes, the status line from the converter makes the sample and hold circuit to go back to sample mode. Then it again collects the signal of the next channel. When the data is collected, on proper command, the sample and hold circuit mode changes to the hold mode. The conversion starts again while the multiplexer selects next channel.

This process is comparatively slower but has obvious advantage of low cost due to sharing of more than one channel.

2) Multiplexing outputs of sample and hold circuits:

When more number of channels are to be monitored at the same time, the multiplexing of the outputs of sample and hold circuit is done. In this case, each sample and hold circuit is attached to each channel. They are synchronously updated by timing circuit. The sample and hold circuit are first multiplexed and then they are connected to the analog to digital converter. This gives the sequential read out of the signals.

The advantage of this multiplexing technique is that this is moderately faster than earlier.

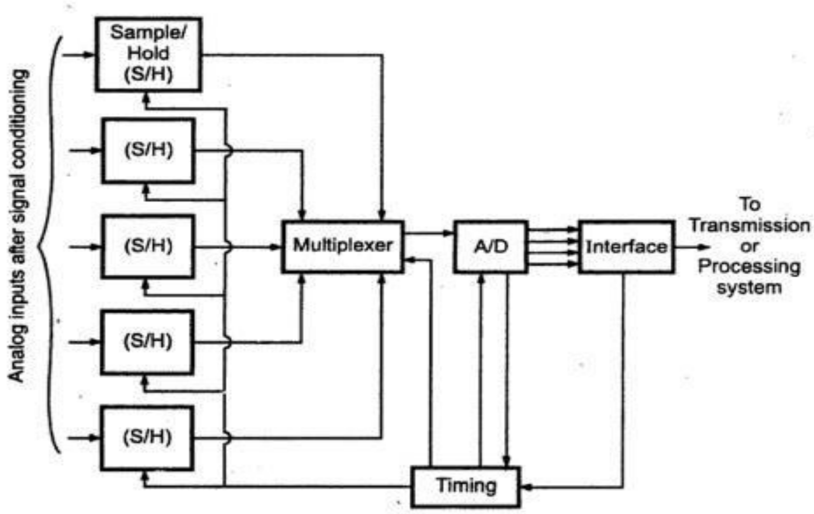


Fig.5.4 Simultaneous sampled system multiplexer.

3) Multiplexing after A/D conversion:

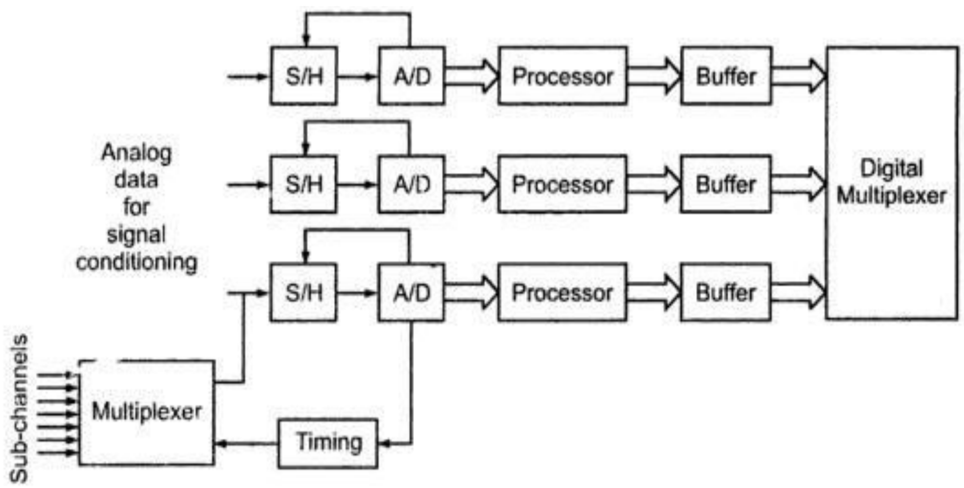


Fig.5.5 Muti-channel DAS using digital multipexing

In this technique, each sample and hold circuit and the analog to digital converter is assigned to the individual channel. The conversion speed is as per the requirement. This technique is exhibiting parallel conversion. In industrial systems, the number of strain gauges, thermocouples, LVDTs are distributed over large area. As the analog signal is digitised at the centre, the data transmission provides great immunity against line frequency and other interferences. The data in digital form performs logical operations. Based on relative speed at which changes occur in the data, the scanning rate can be increased or decreased. These are also called fast data acquisition systems.

4) PC based Data acquisition system:

Nowadays easily available, low cost and wide use of Personal Computer (PC) led the various manufacturers to develop interfaces between PC and the outputs of transducers. The outputs are further processed and analyzed by the PC. The advanced techniques allows user to use a PC ADD-ON card which is available in various configurations. By putting this card in PC, the analog signals can be directly interfaced to PC. This gives very powerful communication and analysis of the multiple measurement data.

The main features of PC based DAS are as follows,

i) The PC based system is used to display the parameters of the system continuously. This helps the operator in monitoring all the parameters instantaneously and conveniently.

ii) The system parameters are displayed with some display attributes such as blinking, underline, inverse video, extra bright so that the attention of the operator is called. Sometimes colour graphic display is used to indicate normal operation, close to the upper limit and out of the limit.

iii) Sometimes some man-machine interfaces called MIMIC displays are used. These are useful in displaying the data measured at any location on the plant near the icon of that location on the screen. This helps operator to take quick corrective action.

iv) Several parameters are plotted individually or simultaneously on the screen to show their characteristics. This helps in pointing out the variations in these parameter measured at two different time. Hence the PC based data acquisition systems gives meaningful and reliable results even though the large number of inputs are measured.

The basic block diagram of PC based data acquisition system is as shown in the figure below.

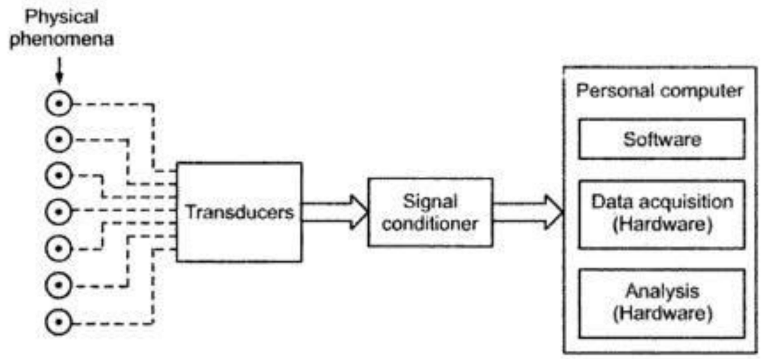


Fig.5.6 PC based data Acquisition system

In the PC based data acquisition system, the personal computer consists of additional hardware such as data acquisition hardware and data analysis hardware. These are associated by the software. The software contains the complete programs written for accessing the data, performing calculations with them and display the result on video display unit (VDU). The data analysis hardware is used to speed up the computations and analysis mainly in case of digital signal processing (DSP) applications. The data acquisition hardware generally acts as a multipurpose, multifunction card. The input signal between the range 10 mV to 10 V is amplified by digitally programmable gain amplifier to a standard level. This amplified input signal is converted to digital signal with the help of high speed analog to digital converters interfaced to the PC bus. This signal is recorded, displayed or may be processed further for analysis by the personal computer.

5.2 DATA LOGGERS

A data logger (also datalogger or data recorder) is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on a digital processor (or computer). They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. Some data loggers interface with a personal computer, and use software to activate the data logger and view and analyze the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device.

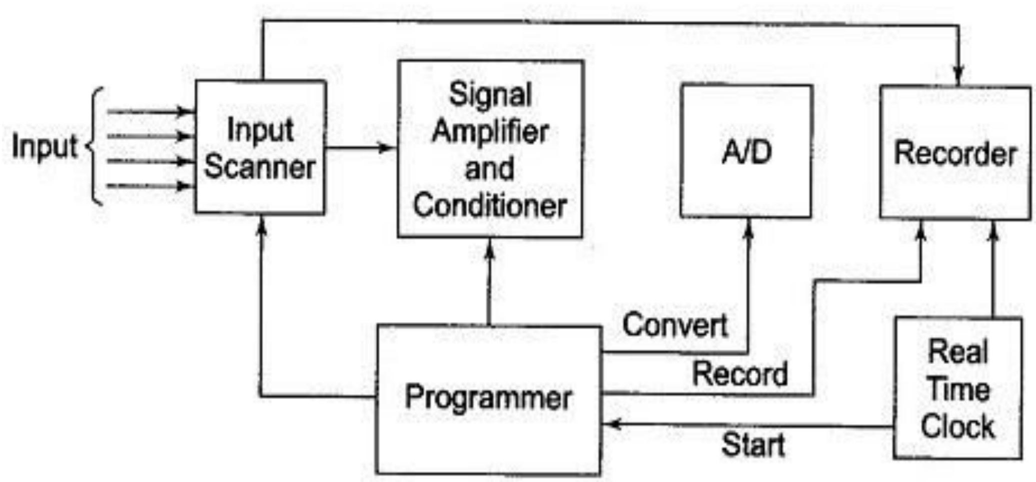


Fig.5.7 Block diagram of Data logger.

The basic blocks of the data logger system are as follows.

1. Input scanner
2. Signal conditioner
3. Analog to digital converter
4. Recording system
5. Programmer.

The data logger can measure any electrical output from almost all the transducers. The input signals those are fed to the input scanner are high level pressure transducer signal, low level thermocouple signal, pneumatic signals from pneumatic transducers, on-off signals from relays or switches, a.c. signals, digital quantities.

The low d.c. level signals are first amplified, then conditioned and then fed to analog to digital converter. The high level signals are directly fed to the analog to digital converter. The pneumatic and a.c. signals are first converted to d.c. voltage level, conditioned and then converted to digital form. In this way all types of input signals are converted to suitable form that can be handled by the data logger. The purpose of conditioner is to provide similarity between the signals from various transducers which might not have linear characteristics. The filter circuits are also used to remove noise signal and ripple voltage suppression.

The input scanner is an automatic switch which can select each signal in turn. The scanner is selecting only one input signal at a time, the data logger needs only one signal amplifier and conditioner also one analog to digital converter and signal digital recorder. The signal amplifier amplifies the low level signals and maintain all the input signals to the 5 V level. The signal if varies non linearly with the parameter measured, the linearization of signal is done by the signal conditioner. The analog signals are then converted to the digital form which are suitable to drive the digital recorders. The programmer controls the sequence operation of the various items of the logger. It commands the scanner when to select new channel. It receives information from the scanner, converter and recorder. The real time clock is used to automate the system. The clock commands the programmer to sequence the measurements at the intervals selected by the user.

5.3 PROBLEMS IN SIGNAL ACQUISITION

Recording strong signals (i.e., those over about 50 mV) is usually a straightforward job, and few problems will be encountered. But as the full-scale value of the signal amplitude drops, then certain acute problems begin to emerge. Signals in the millivolt and high microvolt range will exhibit some of these problems, while signals in the low microvolt and nanovolt range usually exhibit the problems.

Noise signals mixed with the desired signal will be recorded and displayed as a valid signal unless steps are taken to eliminate the noise or at least reduce its value to a point of negligible effect. Noise is any electrical signal or tracing anomaly that is not part of the desired signal. Several different types of noise arc recognized: white noise, impulse noise, and interference noise.

White noise supposedly contains all frequencies, phases, and amplitudes, so it gets its name from the analogy to white light, which contains all visible colors. Such noise is also called gaussian noise, although it is neither truly "white" nor "gaussian" unless there are no bandwidth limits present. True white noise has a bandwidth of de to daylight and beyond. In most instrumentation systems, however, there are bandwidth limitations to consider, so the noise is actually pseudogaussian (also called "pink noise." i.e., bandwidth-limited white noise). The bandwidth limitations are often put in place to limit the effects of noise on the system. Because it integrates to zero given sufficient time, true gaussian noise can be eliminated by low-pass filtering or bandpass filtering. Bandwidth-limited noise, however, does not usually integrate to zero but rather to a very low value.

An example of pseudogaussian bandwidth-limited noise is the "hiss" heard between stations on an FM broadcast band receiver (such noise is present between stations on the AM band as well but is obscured by other forms of noise that are also present). Most such noise in instrumentation systems is due to thermal sources, and it has an rms value of

$$E = \sqrt{4KT\ BR}$$

where E = the rms value of the noise potential in volts (V)

K = Boltzmann's constant (1.38 x 10^{-23} J/K)

T = the temperature in kelvin (K) (use 300 K as standard room temperature)

B = the bandwidth in hertz (Hz)

R = the resistance in ohms (Ω) Note in above equation that a simple resistor, with no power applied, will generate a noise signal due to thermal agitation of the atoms within the resistor.

In above example a signal of 4.1 kV is created by nothing more than thermal agitation of molecules in a circuit resistance. Although this signal may appear to have a low amplitude, keep in mind that many signals recorded on oscilloscopes and graphics recorders are also in the microvolt range. For example, the human electroencephalograph (EEG) is a recording of brain wave potentials and must be able to deal with signals with peak amplitudes in the (1-80)µV range. In that type of application a 4.1µV noise signal represents a sizable artifact.

The answer to this problem is to keep the circuit impedances in the early stages that is those stages that most of the gain stages follow-very low so that the 'R' term in equation above is low. Additionally, the bandwidth of recording amplifiers should be adjusted to that required to faithfully reproduce the input signal waveform. This tactic will reduce the bandwidth term (B) in above equation.

Several other types of noise are peculiar to solid-state amplifiers: shot noise, Johnson noise, and flicker noise. In low-cost amplifiers these noise sources can add up to significant amplitude. Although low-pass filtering offers relief, it is better to specify a low-noise preamplifier when one is dealing with low-level signals. Impulse noise is due to local electrical disturbances such as arcs, lightning bolts, electrical motors, and so forth. Shielding of signal lines will help somewhat, as will low-pass filtering. but the best solution is to eliminate the noise at its source. Filtering, incidentally, is a two-edged sword, and it must be done prudently. Filtering tends to broaden pulse signals, and that can create even more problems than it cures.

Other electrical devices nearby can induce signals into the instrumentation system, the chief among these sources being the 60-Hz ac power lines. It is wise to use only differential amplifier inputs, because of their high common mode rejection ratio (CMRR). Signals from the desired source can be connected across the two inputs, and so become a differential signal, while the 60-Hz interference field affects both inputs equally and thus is common (and is thereby suppressed by the amplifier CMRR).

5.4 COMPUTER CONTROLLED INSTRUMENTATION

TYPICAL SYSTEM CONFIGURATION

It shows the basic block diagram of the system. The Fairchild FST-1 computer is the primary controller. Tester instructions are held in bulk storage (disc or magnetic tape) and are transmitted to the computer memory when required. The test head, power supplies and timing controls receive their instructions from core memory under control of the computer

pins of the unit under test and compares actual outputs to the predicted responses on a "Go/No-Go" basis. The expected output thresholds are programmable as are the input logic levels.

For DC tests, a single pin can be addressed with an instruction that calls for a DC (Absolute) measurement. A switching network then connects the Precision Measurement Unit to the addressed pin and executes the measurement. A pin is always restored to its previous functional test condition prior to being connected to, or released from, the DC Measurement unit.

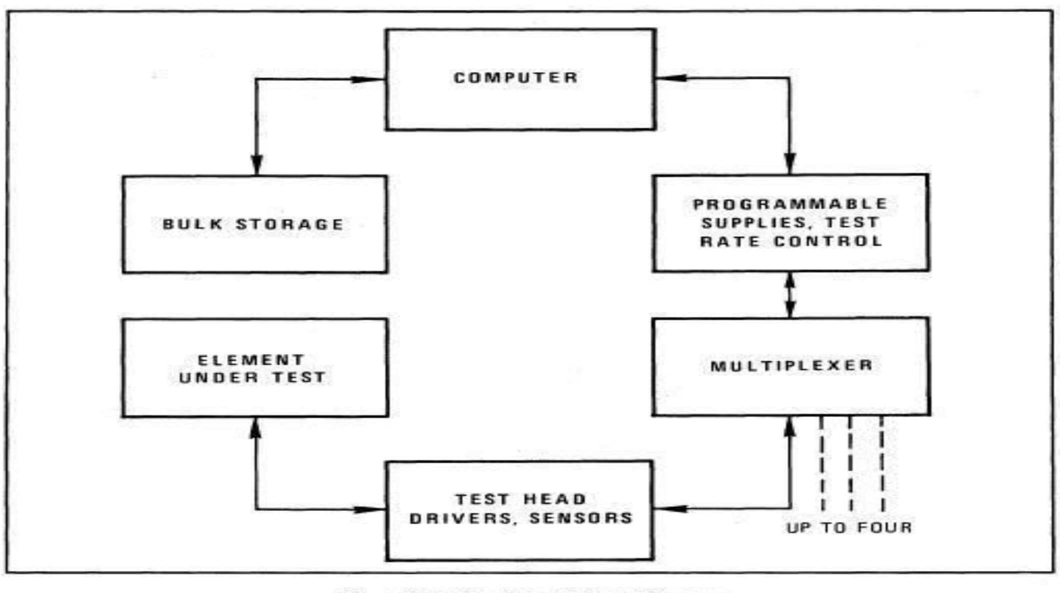


Fig.5.8 Block diagram of functional.

For functional tests, the tester applies logic levels representing forcing functions to the input

The computer can control the unit-under-test device handler such that wafer indexing and "class" sorting is automatic, depending on the result of tests performed. A fifteen-bit storage register is available for this purpose. Figure 1-2 shows a test system with multiple test stations. The configuration allows independent testing of devices of different design, therefore increasing the testing throughput rate. The amount of peripheral equipment required per system varies

according to the environment of operation. For example, test engineering may require the most peripherals since these
groups will be continually generating new-design test programs and new test techniques.

The operations are typical electronic data processing operations and are most efficiently done only if a card reader, magnetic tape, disc, printer, and teletype are available. In the production wafer-test environment, a minimum of peripherals are required. Prepared programs on magnetic tape can easily be transferred to the disc. There can be 350 programs of an average length of 1450 tests stored on the disc for immediate access. Figure 1-3 shows probable peripheral configurations for the engineering, wafer-test, and package test systems.

IEEE-488 INTERFACE BUS (HP-IB/GP-IB)

In the early 1970's, Hewlett-Packard came out with a standard bus (HP-IB) to help support their own laboratory measurement equipment product lines, which later was adopted by the IEEE in 1975. This is known as the IEEE

Std.488-1975. The IEEE-488 Interface Bus (HP-IB) or general purpose interface bus (GP-IB) was developed to provide a means for various instruments and devices to communicate with each other under the direction of one or more master controllers. The HP-IB was originally intended to support a wide range of instruments and devices, from the very fast to
the very slow.

Description:

IEEE-488 devices The IEEE-488 standard provides for the following categories of
device:

1.listeners

2.Talkers

3.controllers.

Listeners They can receive data and control signals from other devices connected to the bus but are not capable of generating data. An obvious example of a listener is a signal generator.

Talkers

Talkers

Talkers are only capable of placing data on the bus and cannot receive data. Typical examples of talkers are magnetic tape, magnetic stripe, and bar code readers. Note that, whilst only one talker can be active

(i.e. presenting data to the bus) at a given time, it is possible for a number of listeners to be simultaneously active (i.e. receiving and/or processing the data).

Talkers and listeners

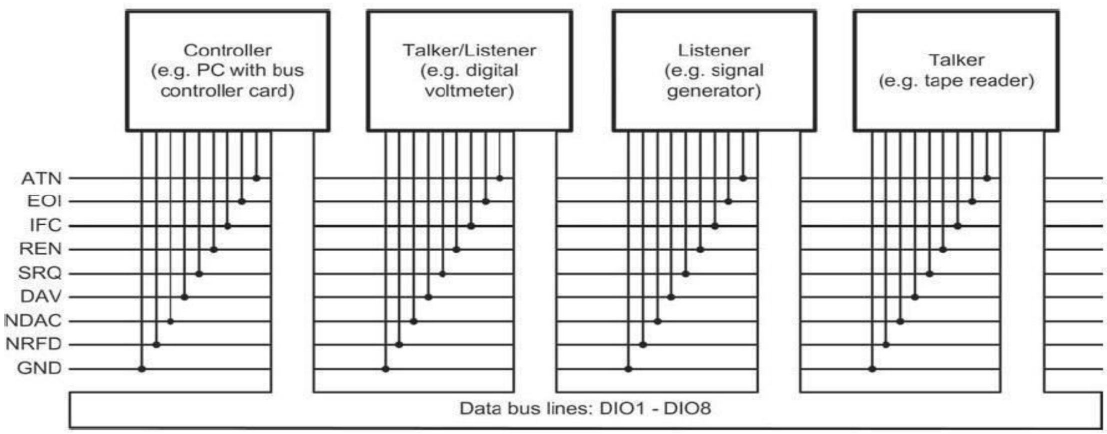
The function of a talker and listener can be combined in a single instrument. Such instruments can both send data to and receive from the bus. A digital multimeter is a typical example of a talker and listener. Data is sent to it in

order to change ranges and returned to the bus in the form of digitized readings of voltage, current, and resistance.

Controllers

Controllers are used to supervise the flow of data on the bus and provide processing facilities. The controller within an IEEE-488 system is invariably a microcomputer and, whilst some manufacturers provide dedicated microprocessor-based IEEE-488 controllers, this function is often provided by smeans of a PC or PC-compatible microcomputer

IEEE-488 bus showing signals and devices



Electrical Interface:

The GP-IB is a bus to which many similar modules can be directly connected, as is shown in Figure 1. A total of 16 wires are shown in the figure - eight data lines and eight control lines. The bus cables actually have 24 wires, providing eight additional for shielding and grounds.

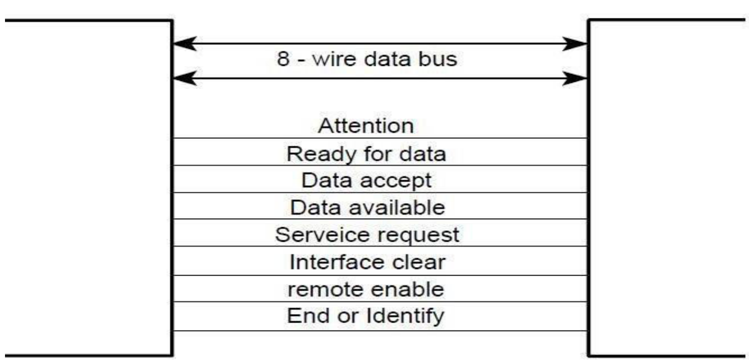


Figure 1. IEEE-488 (HP-IB/GP-IB) Bus Configuration

The GP-IB defines operation of a three-wire handshake that is used for all data transfers on the bus. The bus operation is asynchronous in nature. The data-transfer rate of the GP-IB is 500 kHz for standard applications and can go up 1 MHz if special conventions are followed. Each transaction carries 8 bits, the maximum data bandwidth is on the order of 4 to 8 megabits (1 M byte) per second. The bus is a two way communications channel and data flows in both directions.

IEEE-488 bus signals The IEEE-488 bus uses eight multi-purpose bi-directional parallel data lines (see Figure 8.2). These are used to transfer data, addresses, commands and status bytes. In addition, five bus managements and three handshake lines are provided.

The connector used for the IEEE-488 bus is invariably a 24-pin type (as shown in Figure 8.3) having the following pin assignment

Pin number Abbreviation Function

1 DIO1 Data line 1

2 DIO2 Data line 2

3 DIO3 Data line 3

4 DIO4 Data line 4

5 EOI End or identify.

This signal is generated by a talker to indicate the last byte of data in a multi-byte data transfer. EOI is also issued by the active controller to perform a parallel poll by simultaneously asserting EOI and ATN.
6 DAV Data valid.
Thus signal is asserted by a talker to indicate that valid data has been placed on the bus. 7 NRFD Not ready for data.
This signal is asserted by a listener to indicate that it is not yet ready to accept data
The cabling limitations make it a less-than-ideal choice for large separation between devices. These limitations can be overcome with bus extenders. Those attempting to use bus extenders should be aware that few extenders are as transparent as claimed. This is especially true in handling of continuous data and interrupts. In nonextended environments, it provides an excellent means for high-speed computer control of multiple devices.

The following table shows the various interface functions, the mnemonics and the descriptions.

Since introduction of the IEEE-488, technology produced a generation of medium-speed, low-power,instrumentation which had a need to operate in an automatic test system such as the GP-IB. The HP-IL (Hewlett-Packard Interface Loop), was introduced to meet this need. The HP-IL is a low-cost, low-power alternative to the GP-IB system.The HP-IL and GP-IB provide the same basic functions in interfacing controllers, instruments, and peripherals, but they differ in many other respects. HP-IL is suitable for use in low-power, portable applications (typically used for interface of battery-power systems).

The GP-IB is not practical to operate from battery power. The HP-IL maximum data rate is

20K bytes per second. This is a high rate compared to the RS-232C, but much slower than GP-IB.

The HP-IL can operate over distances of up to 100 meters between any two devices. Since it is a loop environment, there is no maximum system cable restriction. The basic device-addressing scheme allows for up to 30 devices on a loop

Advantages of IEEE-488-based measurement

Systems incorporating PC-based controllers include:

• Elimination of repetitive manual operation (freeing the test engineer for more demanding tasks).

• Equipment settings are highly repeatable thus ensuring consistency of measurement.

• Increased measurement throughput (measurement rates are typically between 10 and 100 times faster than those which can be achieved by conventional manual methods).

• Reduction of errors caused by maladjustment or incorrect readings.

• Consistency of measurement (important in applications where many identical measurements are made).

• Added functionality (stored data may be analyzed and processed in a variety of ways).

• Reduction in skill level of operators (despite the complexity of equipment, user-friendly software can guide operators through the process of connection and adjustment).The original IEEE-488 standard is often referred to as IEEE-488.1 whilst the most recent developments of the standard are known as IEEE-488.2.

5.5 OPTICAL TIME-DOMAIN REFLECTOMETER

An optical time-domain reflectometer (OTDR) is an optoelectronic instrument used to characterize an optical fiber. An OTDR injects a series of optical pulses into the fiber under test. It also extracts, from the same end of the fiber, light that is scattered (Rayleigh backscatter) or reflected back from points along the fiber. (This is equivalent to the way that an electronic time- domain reflectometer measures reflections caused by changes in the impedance of the cable under test.) The strength of the return pulses is measured and integrated as a function of time, and is plotted as a function of fiber length An OTDR may be used for estimating the fiber's length and overall attenuation, including splice and mated- connector losses. It may also be used to locate faults, such as breaks, and to measure optical return loss. To measure the attenuation of multiple fibers, it is advisable to test from each end and then average the results, however this considerable extra work is contrary to the common claim that testing can be performed from only one end of the fiber.

In addition to required specialized optics and electronics, OTDRs have significant computing ability and a graphical display, so they may provide significant test automation. However, proper instrument operation and interpretation of an OTDR trace still requires special technical training and experience.

OTDRs are commonly used to characterize the loss and length of fibers as they go from initial manufacture, through to cabling, warehousing while wound on a drum, installation and then splicing. The last application of installation testing is more challenging, since this can be over extremely long distances, or multiple splices spaced at short distances, or fibers with different optical characteristics joined together. OTDR test results are often carefully stored in case of later fiber failure or warranty claims. Fiber failures can be very expensive, both in terms of the direct cost of repair, and consequential loss of service.

OTDRs are also commonly used for fault finding on installed systems. In this case, reference to the installation OTDR trace is very useful, to determine where changes have occurred. Use of an OTDR for fault finding may require an experienced operator who is able to correctly judge the appropriate instrument settings to locate a problem accurately. This is particularly so in cases involving long distance, closely spaced splices or connectors, or PONs.

OTDRs are available with a variety of fiber types and wavelengths, to match common applications. In general, OTDR testing at longer wavelengths, such as 1550 nm or 1625 nm, can be used to identify fiber attenuation caused by fiber problems, as opposed to the more common splice or connector losses.

The optical dynamic range of an OTDR is limited by a combination of optical pulse output power, optical pulse width, input sensitivity, and signal integration time. Higher optical pulse output power, and better input sensitivity, combine directly to improve measuring range, and are usually fixed features of a particular instrument. However optical pulse width and signal integration time are user adjustable, and require trade-offs which make them application

A longer laser pulse improves dynamic range and attenuation measurement resolution at the expense of distance resolution. For example, using a long pulse length, it may possible to measure attenuation over a distance of more than 100 km, however in this case an optical event may appear to be over

1 km long. This scenario is useful for overall characterisation of a link, but would be of much less use when trying to locate faults. A short pulse length will improve distance resolution of optical events, but will also reduce measuring range and attenuation measurement resolution. The "apparent measurement length" of an optical event is referred to as the "dead zone". The theoretical interaction of pulse width and dead zone can be summarised as follows:

A stand for OTDR calibration (an optical fiber HYPERLINK "http://en.wikipedia.org/wiki/Standardization" standard in the background)

The OTDR "dead zone" is a topic of much interest to users. Dead zone is classified in two ways. Firstly, an "Event Dead Zone" is related to a reflective discrete optical event. In this situation, the measured dead zone will depend on a combination of the pulse length (see table), and the size of the reflection. Secondly, an "Attenuation Dead Zone" is related to a non- reflective event. In this situation, the measured dead zone will depend on a combination of the pulse length (see table).

A long signal integration time effectively increases OTDR sensitivity by averaging the receiver output. The sensitivity increases with the square root of the integration time. So if the integration time is increased by 16 times, the sensitivity increases by a factor of 4. This imposes a sensitivity practical limit, with integration times of seconds to a few minutes.The dynamic range of an OTDR is usually specified as the attenuation level where the measured signal gets lost in the detection noise level, for a particular combination of pulse length and signal integration time. This number is easy to deduce by inspection of the output trace, and is useful for comparison, but is not very useful in practice, since at this point the measured values are random. So the practical measuring range is smaller, depending on required attenuation measurement resolution.

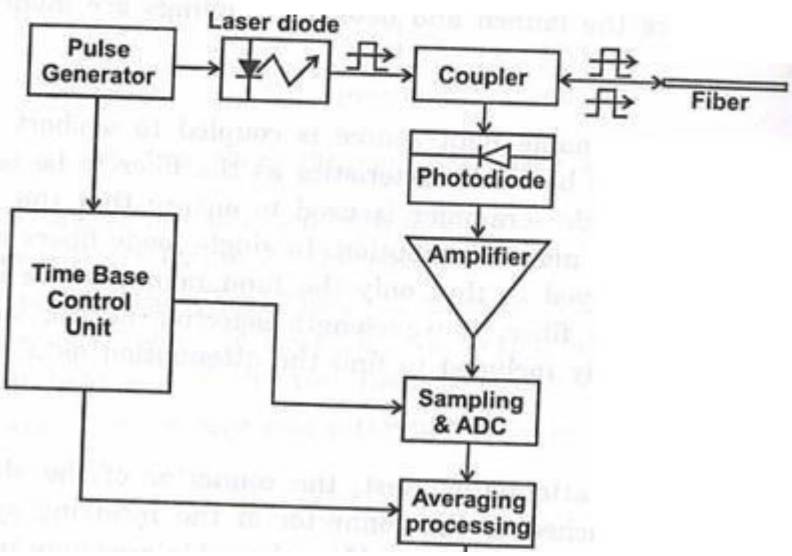
OPTICAL TIME DOMAIN REFLECTOMETER:

An OTDR (Optical Time Domain Reflectometer) is a fiber optic tester characterizing fibers and optical networks. The aim of this instrument is to detect, locate and measure events at any location in the fiber link.

One of the main benefits of the OTDR is that it can fully test a fiber from only one end, as it operates as a one dimensional radar system. The OTDR is similar to an accurate radar as its resolution can be between 6 cm and 40 meters.

The OTDR technique produces geographic information with regard to localized loss and reflective events thereby providing a pictorial and permanent record which may be used as performance baseline.

OTDR block diagram:



When an OTDR is used to measure the attenuation of multiple joined fiber lengths, the output trace can incorrectly show a joint as having gain, instead of loss. The reason for this is that adjacent fibers may have different backscatter coefficients, so the second fiber reflects more light than the first fiber, with the same amount of light travelling through it. If the OTDR is placed at the other end of this same fiber pair, it will measure an abnormally high loss at that joint. However if the two signals are then combined, the correct loss will be obtained. For this reason, it is common OTDR practice to measure and combine the loss from both ends of a link, so that the loss of cable joints, and end to en The theoretical distance measuring accuracy of an OTDR is extremely good, since it is based on software and a crystal clock with an inherent accuracy of better than 0.01%. This aspect does not need subsequent calibration since practical cable length measuring accuracy is typically limited to about 1% due to: The cable length is not the same as the fiber length, the speed of light in the fiber is known with limited accuracy (the refractive index is only specified to 3 significant figures such as e.g. 1.45 etc.), and cable length markers have limited accuracy (0.5% – 1%).

An OTDR excels at identifying the existence of unacceptable point loss or return loss in cables. Its ability to accurately measure absolute end -to-end cable loss or return loss can be quite poor, so cable acceptance usually includes an end-to-end test with a light source and power meter, and optical return loss meter. Its ability to exactly locate a hidden cable fault is also limited, so for fault-finding it may be augmented with other localised tools such as a red laser fault locator, clip-on identifier, or "Cold Clamp" optical cable marker.

Reliability and quality of OTDR equipment

The reliability and quality of an OTDR should be determined on the basis of its accuracy, measurement range, ability to resolve and measure closely spaced events, the speed at which it makes measurements, and its ability to perform satisfactorily under various environmental extremes and after various types of physical abuses. In addition to its cost, the instrument should also be rated on the features provided, its size, its weight, and how simple it is to operate.

Accuracy is defined as the correctness of the measurement (i.e., the difference between the measured value and the true value of the event being measured).

The measurement range of the OTDR is defined as the maximum attenuation that can be placed between the instrument and the event being measured, for which the instrument will still be able to measure the event within acceptable accuracy limits.

Instrument resolution is a measure of how close two events can be spaced and still be recognized as two separate events. The duration of the measurement pulse and the data sampling interval create a resolution limitation for OTDRs: the shorter the pulse duration and the shorter the data sampling interval, the better the instrument resolution, but the shorter the measurement range. Resolution is also often limited when powerful reflections return to the OTDR and temporarily overload the detector circuitry. When this occurs, some time is required before the instrument can resolve a second fiber event. Some OTDR manufacturers use a "masking" procedure to improve resolution. The procedure shields or "masks" the detector from high-power fiber reflections, preventing detector overload and eliminating the need for detector recovery.

The common types of OTDR-like test equipment are:

- Full-feature OTDR
- Hand-held OTDR
- Fiber Break Locator
- RTU in RFTSs

QUESTION BANK

PART-A (2 MARKS)

1. Mention the term used to specify the characteristics of an instrumentation amplifier?
2. List any four important features of instrumentation amplifier?
3. What are the three basic requirements for a computer operated teat system?
4. Give any two applications of micro processor based measurement.
5. What are the requirement of an automatic test system?
6. Write any two instrument used in computer controlled instrumentation.
7. What are the various instrument used in computer controlled instrumentation?
8. What is meant by IEEE 488 system?
9. Mention the single line message for interface function in IEEE488 bus system.

PART – B (16 MARKS)

10. How signal is transmitted in a microprocessor based measurement.
11. 171.Explain in detail the computer controlled measurement system for
    a. testing an radio amplifier.
    b. testing a radio receiver
12. Write a note on
    a. digital control
    b. Microprocessor based instrumentation
13. Explain with block diagram the automatic test system to analyses an audio amplifier and radio receiver.
14. Explain the sequence of operation in case of IEEE 488 bus Withit’s schematic diagram.
15. Mention it’s salient features.
16. What are the objectives of data acquisition system?
17. With the help of block diagram explain the basic components in analog and digital acquisition system.
18. . What are the various techniques of multiplexing? Discuss any one in detail?

19. Explain the generalized block schematic of a Digital Data Acquisition system and list out

20. Explain the optical time domain reflectometer.

21. Howthw frequency counter be modified for operation of IEEE 488 bus

22. Explain the different types of optical encoders.

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