ELECTRONIC MEASUREMENTS AND INSTRUMENTATION
B.TECH
(III YEAR – II SEM)
(2018-19)

Prepared by:
Mrs.M.Anusha, Associate Professor
Mrs.P.Anitha, Associate Professor

Department of Electronics and Communication Engineering

MALLA REDDY COLLEGE
OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

Recognized under 2(f) and 12 (B) of UGC ACT 1956

(Affiliated to JNTUH, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2015 Certified)

Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India

MALLA REDDY COLLEGE OF ENGINEERING AND TECHNOLOGY

III Year B.Tech. ECE-II Sem   L   T/P/D   C

                                              4   1/ - /- 3

CORE ELECTIVE – II

(R15A0417) ELECTRONIC MEASUREMENTS AND INSTRUMENTATION

OBJECTIVES:

1. An introduction to measurement techniques and instrumentation design and operation
2. The basic concept of units, measurement error and accuracy, the construction and design of measuring devices and circuits, measuring instruments and their proper applications
3. To use different measuring techniques and the measurement of different physical parameters using different transducers.

UNIT - I:

Block Schematics of Measuring Systems: Performance characteristics, Static characteristics, Accuracy, Precision, Resolution, Types of Errors, Dynamic Characteristics, Repeatability, Reproducibility, Fidelity, Lag; Measuring Instruments: DC Voltmeters, D' Arsonval Movement, DC Current Meters, AC Voltmeters and Current Meters, Ohmmeters, Multimeters, Meter Protection, Extension of Range, True RMS Responding Voltmeters, Specifications of Instruments.

UNIT - II:

Signal Analyzers: AF, HF Wave Analyzers, Harmonic Distortion, Heterodyne wave Analyzers, Spectrum Analyzers, Capacitance-Voltage Meters, Signal Generators: AF, RF Signal Generators, Sweep Frequency Generators, Pulse and Square wave Generators, Function Generators, Arbitrary waveform Generator.

UNIT - III:

Oscilloscopes: CRT, Block Schematic of CRO, Time Base Circuits, Lissajous Figures, CRO Probes, High Frequency CRO Considerations, Delay lines, Applications: Measurement of Time, Period and Frequency.

Special Purpose Oscilloscopes: Dual Trace, Dual Beam CROs, Sampling Oscilloscopes, Storage Oscilloscopes, Digital Storage CROs.

UNIT - IV:

Transducers: Classification, Strain Gauges, Bounded, unbounded; Force and Displacement Transducers, Resistance Thermometers, Hotwire Anemometers, LVDT, Thermocouples, Synchros, Special Resistance Thermometers, Piezoelectric Transducers, MagnetoStrictive Transducers.

UNIT - V:

Bridges: Wheat Stone Bridge, Kelvin Bridge, and Maxwell Bridge.

Measurement of Physical Parameters: Flow Measurement, Displacement Meters, Liquid level Measurement, Measurement of Humidity and Moisture, Velocity, Pressure - High Pressure, Vacuum level, Temperature - Measurements, Data Acquisition Systems.

TEXTBOOKS:

1. Electronic instrumentation: H.S.Kalsi - TMH, 2nd Edition 2004.
2. Modern Electronic Instrumentation and Measurement Techniques: A.D. Helbincs, W.D. Cooper: PHI, 5th Edition, 2003.

REFERENCES:

1. Electronic Instrumentation and Measurements - David A. Bell, Oxford Uiv. Press, 1997.
2. Electronic Measurements and Instrumentation: B. M. Oliver, J. M. Cage TMH Reprint.
3. Measurement Systems - Emest O. Doebelin and Dhanesh N Manik, 6th Ed., TMH.
4. Electronic Measurements and Instrumentations by K. Lal Kishore, Pearson Education - 2010.
5. Industrial Instrumentation: T. R. Padmanabham Spiriger 2009.

OUTCOMES

Upon a successful completion of this course, the student will be able to:

1. Describe the fundamental concepts and principles of instrumentation
2. Explain the operation of various instruments required in measurements
3. Apply the measurement techniques for different types of tests
4. To select specific instruments for specific measurement function.
5. Understand principle of operation and working of different electronic instruments Students will understand functioning, specification and application of signal analyzing instruments

UNIT-1

Block Schematics of Measuring Systems

Introduction:

The measurement of any quantity plays very important role not only in science but in all branches of engineering, medicine and in almost all the human day to day activities.

The technology of measurement is the base of advancement of science. The role of science and engineering is to discover the new phenomena, new relationships, the laws of nature and to apply these discoveries to human as well as other scientific needs. The science and engineering is also responsible for the design of new equipments. The operation, control and the maintenance of such equipments and the processes is also one of the important functions of the science and engineering branches. All these activities are based on the proper measurement and recording of physical, chemical, mechanical, optical and many other types of parameters.

The measurement of a given parameter or quantity is the act or result of a quantitative comparison between a predefined standard and an unknown quantity to be measured. The major problem with any measuring instrument is the error. Hence, it is necessary to select the appropriate measuring instrument and measurement procedure which minimises the error. The measuring instrument should not affect the quantity to be measured.

An electronic instrument is the one which is based on electronic or electrical principles for its measurement function. The measurement of any electronic or electrical quantity or variable is termed as an electronic measurement.

Advantages of Electronic Measurement

The advantages of an electronic measurement are

1. Most of the quantities can be converted by transducers into the electrical or electronic signals.
2. An electrical or electronic signal can be amplified, filtered, multiplexed, sampled and measured.
3. The measurement can easily be obtained in or converted into digital form for automatic analysis and recording.
4 The measured signals can be transmitted over long distances with the help of cables or radio links, without any loss of information.

5. Many measurements can be carried either simultaneously or in rapid succession.

6. Electronic circuits can detect and amplify very weak signals and can measure the events of very short duration as well.

7. Electronic measurement makes possible to build analog and digital signals. The digital signals are very much required in computers. The modern development in science and technology are totally based on computers.

8. Higher sensitivity, low power consumption and a higher degree of reliability are the important features of electronic instruments and measurements. But, for any measurement, a well defined set of standards and calibration units is essential. This chapter provides an introduction to different types of errors in measurement, the characteristics of an instrument and different calibration standards.

Functional elements of an instrument:

Any instrument or a measuring system can be described in general with the help of a block diagram. While describing the general form of a measuring system, it is not necessary to go into the details of the physical aspects of a specific instrument. The block diagram indicates the necessary elements and their functions in a general measuring system.

- **Primary sensing element:** which senses the quantity under measurement

- **Variable conversion element:** which modifies suitably the output of the primary sensing element

- **Variable Manipulation Element:** The signal gets manipulated here preserving the original nature of it

- **Data Transmission Element:** The transmission of data from one another is done by the data transmission element

- **Data presentation element** : The display or readout devices which display the required information about the measurement.
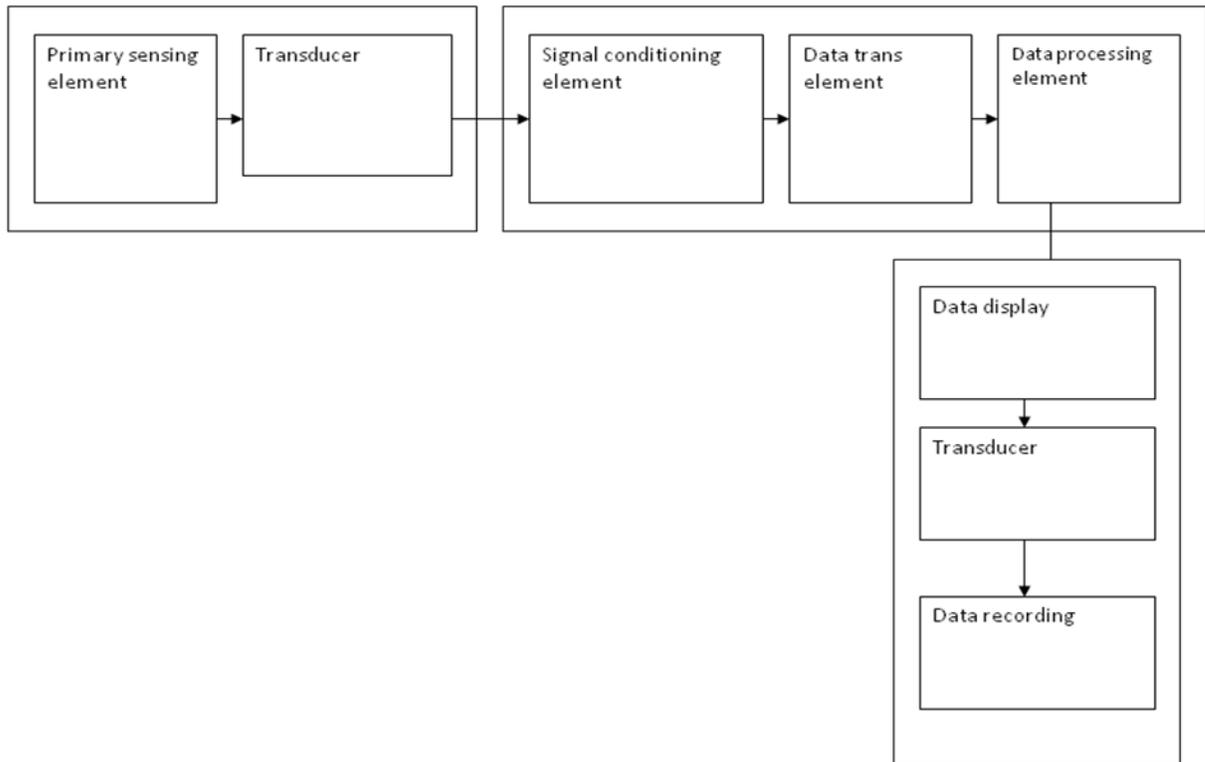
Static characteristics:

As mentioned earlier, the static characteristics are defined for the instruments which measure the quantities which do not vary with time. The various static characteristics are accuracy, precision, resolution, error, sensitivity, threshold, reproducibility, zero drift, stability and linearity.

Accuracy:

It is the degree of closeness with which the instrument reading approaches the true value of the quantity to be measured. It denotes the extent to which we approach the actual value of the quantity. It indicates the ability of instrument to indicate the true value of the quantity. The accuracy can be expressed in the following ways.

1) Accuracy as 'Percentage of Full Scale Reading : In case of instruments having uniform scale, the accuracy can be expressed as percentage of full scale reading.

For example, the accuracy of an instrument having full scale reading of 50 units may be expressed as ± 0.1% of full scale reading. From this accuracy indication, practically accuracy is expressed in terms of limits of error. So for the accuracy limits specified above, there will be ± 0.05 units error

in any measurement. So for a reading of 50 units, there will be error of ± 0.05 units i.e. ± 0.1 % while for a reading of 25 units, there will be error of ± 0.05 units in the reading i.e. ± 0.2%. Thus as reading decreases, error in measurement is ± 0.05 units but net percentage error is more. Hence, specification of accuracy in this manner is highly misleading.

2) Accuracy as 'Percentage of True Value' : This is the best method of specifying the accuracy. It is to be specified in terms of the true value of quantity being measured. For example, it can be specified as ± 0.1% of true value. This indicates that in such cases, as readings get smaller, error also gets reduced. Hence accuracy of the instrument is better than the instrument for which it is specified as percent of full scale reading.

Precision:

It is the measure of consistency or repeatability of measurements.

Let us see the basic difference between accuracy and precision. Consider an instrument on which, readings upto 1/1000th of unit can be measured. But the instrument has large zero adjustment error. Now every time reading is taken, it can be taken down upto '1000th of unit. So as the readings agree with each other, we say that the instrument is highly precise. But, though the readings are precise upto 10100th of unit, the readings are inaccurate due to large zero adjustment error. Every reading will be inaccurate, due to such error. Thus a precise instrument may not be accurate. Thus the precision means sharply or clearly defined and the readings agree among themselves. But there is no guarantee that readings are accurate. An instrument having zero error, if calibrated properly, can give accurate readings but in that case still, the readings can be obtained down upto 1/10th of unit only. Thus accuracy can be improved by calibration but not the precision of the instrument.

The precision is composed of two characteristics:

- Conformity and
- Number of significant figures.

Conformity:

Consider a resistor having true value as 2385692.0Ω, which is being measured by an ohmmeter. Now, the meter is consistently measuring the true value of the resistor. But the reader, can read consistently, a value as 2.4 MΩ due to nonavailability of proper scale. The value 2.4 MΩ is

estimated by the reader from the available scale. There are no deviations from the observed value. The error created due to the limitation of the scale reading is a precision error.

Significant Figures:

The precision of the measurement is obtained from the number of significant figures, in which the reading is expressed. The significant figures convey the actual information about the magnitude and the measurement precision of the quantity.

Resolution:

It is the smallest increment of quantity being measured which can be detected with certainty by an instrument.

So if a nonzero input quantity is slowly increased, output reading will not increase until some minimum change in the input takes place. This minimum change which causes the change in the output is called resolution. The resolution of an instrument is also referred to as discrimination of the instrument. The resolution can affect the accuracy of the measurement.

Errors:

Static error = measured value – true value

The most important static characteristics of an instrument is its accuracy, which is generally expressed in terms of the error called static error.

Mathematically it can be expressed as, e = *At* - Am J

where
$$e = \text{Error}$$
$$A_m = \text{Measured value of the quantity}$$
$$A_t = \text{True value of the quantity}$$

In this expression, the error denoted as e is also called absolute error. The absolute error does not indicate precisely the accuracy of the measurements. For example, absolute error of ± 1 V is negligible when the voltage to be measured is of the order of 1000 V but the same error of ±1 V becomes significant when the voltage under measurement is 5 V or so. Hence, generally instead of specifying absolute error, the relative or percentage error is specified.

Sensitivity:

The sensitivity is always expressed by the manufacturers as the ratio of the magnitude of quantity being measured to the magnitude of the response. Actually, this definition is the reciprocal of the sensitivity is called inverse sensitivity or deflection factor. But manufacturers call this inverse sensitivity as a sensitivity.

$$\text{Inverse sensitivity} = \text{Deflection factor}$$

$$\therefore \quad \text{Deflection factor} = \frac{1}{\text{Sensitivity}} = \frac{\Delta q_i}{\Delta q_o}$$

The units of the sensitivity are millimeter per micro-ampere, millimeter per ohm, counts per volt,

Drift : Gradual shift in the meassured value ,over an extended period, when there is no change in input.

Threshold: The minimum value of input for which the device just starts to respond.

Range/Span: The minimum and maximum value of quantity so that the device is capable of measuring.

Repeatability: A measure of how well the output returns to a given value when the same precise input is applied several times. Or The ability of an instrument to reproduce a certain set of reading within a given accuracy.

Linearity: Input output relationship of a device must be linear.

But practical systems shows small deviations from the linear shape (allowed within the specified limits)

Hysteresis: Input is increased from negative value, output increases as indicated by curve 1

• Then the input is steadily decreased , output does not follow the same path , but lag by a certain value as indicated by curve 2 •

The difference between the two curves is called Hysterisis.
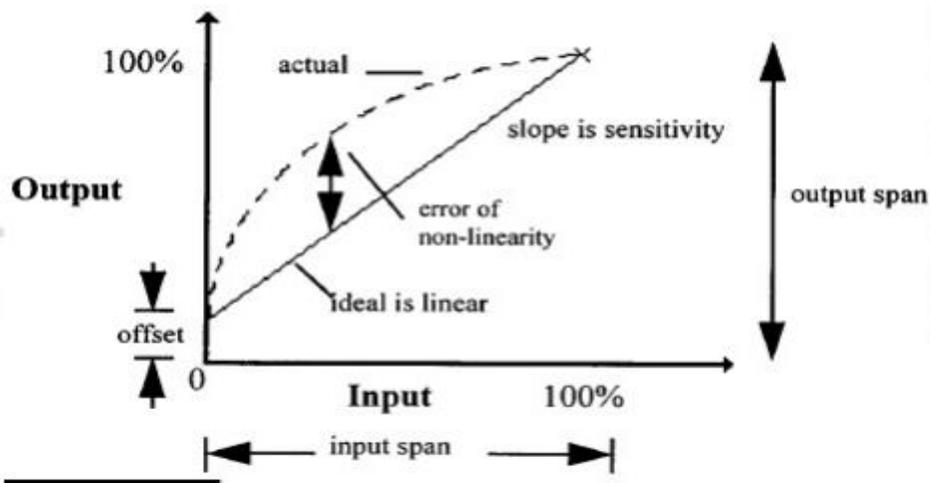
DYNAMIC CHARACTERISTICS:

The response of instruments or systems to dynamic I/P s are also functions of time.

Instruments rarely respond instantaneously to changes in the measured variables.

Instead, they exhibit slowness or sluggishness due to such things as mass, thermal capacitance, fluid capacitance or electric capacitance.

• **Speed of Response**: It is the ability of a system to respond to a sudden changes in the input signal/quantity

• **Fidelity**: It is the degree to which an instrument indicates the changes in the measured variable without dynamic error (Indication of how much faithfully system responds to the changes in input).

Lag: It is the retardation or delay in the response of an instrument to changes in the measured variable. Two types : Process lag(process) and Control lag (Instrument)

Dynamic error:

It is the difference between the true value of the variable to be measured, changing with time and the value indicated by the measurement system, assuming zero static error. The Fig. 1.13 shows the dead time, i.e. time delay and the dynamic error.
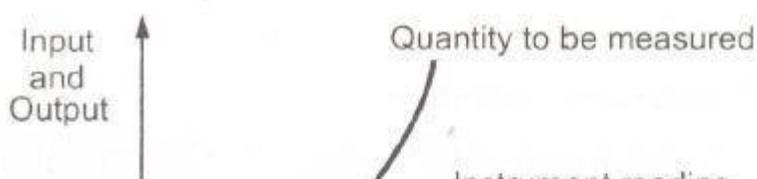
Types of errors:

The static error is defined earlier as the difference between the true value of the variable and the value indicated by the instrument. The static error may arise due to number of reasons. The static errors are classified as:

1) Gross errors

2) Systematic errors

3) Random errors

Gross errors:

The gross errors mainly occur due to carelessness or lack of experience of a human being. These cover human mistakes in readings, recordings and calculating results. These errors also occur due to incorrect adjustments of instruments. These errors cannot be treated mathematically. These errors are also called personal errors. Some gross errors are easily detected while others are very difficult to detect.\

Systematic errors:

The systematic errors are mainly resulting due to the shortcomings of the instrument and the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc.

A constant uniform deviation of the operation of an instrument is known as a systematic error. There are three types of systematic errors as

1) Instrumental errors 2) Environmental errors 3) Observational errors

Instrumental errors :

These errors are mainly due to following three reasons

• Short-comings of instrument

These are because of the mechanical structure of the instruments eg. Friction in the bearings of various moving parts, irregular spring tensions, hysteresis, gear backlash, variation in air gap etc.

Misuse of instrument A good instrument if used in abnormal way gives misleading results. Poor initial adjustments, Improper zero setting, Using leads of high resistance. Elimination: Use the instrument intelligently & Correctly

• Loading effects Loading effects due to Improper way of using the instrument

• **Ellimination.**

– Selecting proper instrument and the transducer for the measurement.

– Recognize the effect of such errors and apply the proper correction factors.

– Calibrate the instrument carefully against standard.

Environmental Errors (due to the External Conditions)

• The various factors : Temperature changes, Pressure, vibratons, Thermal emf., stray capacitance, cross capacitance, effect of External fields, Aging of equipments and Frequency sensitivity of an instrument.

Elimination • Using proper correction factors and using the instrument Catalogue • Using Temperature & Pressure control methods etc. • Reducing the effect of dust, humidity on the components in the instruments. • The effects of external fields can be minimized by using the magnetic or electrostatic shields of screens.

Observational Errors:

Error introduced by the observer

Few souces are:

• Parallax error while reading the meter,

• wrong scale selection,

• habits of individual obsever

• Elimination

Use the

• instrument with mirrors,

• instrument with knife edge pointers,

• Instrument having digital display

Random errors:

Some errors still result, though the systematic and instrumental errors are reduced or atleast accounted for. The causes of such errors are unknown and hence, the errors are called **random** errors. These errors cannot be determined in the ordinary process of taking the measurements.

Absolute and relative errors:

When the error is specified interms of an absolute quantity and not as a percentage, then it is called an absolute error.

Thus the voltage of 10 ± 0.5 V indicated ± 0.5 V as an absolute error. When the error is expressed as a percentage or as a fraction of the total quantity to be measured, then it is called relative error.

Generally the relative error in case of resistances is specified as percentage of tolerances. Another method of expressing error is by specifying it as parts per million (ppm), relative to the total quantity. So it is a relative error specification . Generally change in resistance with temperature is indicated in ppm/ °C shows the variation in resistance with Temperature temperature. Thus if a resistance of 100 kΩ. has a temperature coefficient of 50 *ppm/C* means 50 parts per millionth per degree celcius. Thus one millionth of 100 kohm. is 0.1 ohm and 50 such parts means 5 D.

Limiting errors:

The manufacturers specify the accuracy of the instruments within a certain percentage of full scale reading. The components like the resistor, inductor, capacitor are guaranteed to be within a certain percentage of rated value. This percentage indicates the deviations from the nominal or specified value of the particular quantity. These deviations from the specified value are called **Limiting Errors.** These are also called **Guarantee Errors.**

Thus the actual value with the limiting error can be expressed mathematically as,

$$A_a = A_s \pm \delta A$$

where
A_a = Actual value
A_s = Specified or rated value
δA = Limiting error or tolerance

Relative limiting error:

This is also called fractional error. It is the ratio of the error to the specified magnitude of a quantity.

Thus
$$e = \frac{\delta A}{A_s}$$

where $\qquad e = $ Relative timing error

From the above equation, we can write,

$$\delta A = e . A_s$$

and $\qquad A_a = A_s \pm \delta A$

$$= A_s \pm e A_s$$

$$\therefore \quad A_a = A_s [1 \pm e]$$

The percentage relative limiting error is expressed as

$$\% e = e \times 100$$

The relative limiting error can be also be expressed as,

$$e = \frac{\text{Actual value } (A_a) - \text{Specified value } (A_s)}{\text{Specified value } (A_s)}$$

Voltmeters and multimeters:

Basic meter:

A basic d.c. meter uses a motoring principle for its operation. It stntes that any current carrying coil placed in a magnetic field experiences a force, which is proportional to the magnitude of current passing through the coil. This movement of coil is called D'Arsonval movement and basic meter is called D'Arsonval galvanometer.

D.C instruments:

a) Using shunt resistance, d.c. current can be measured. The instrument is d.c. microammeter, milliammeter or ammeter.

b) Using series resistance called multiplier, d.c. voltage can be measured. The instrument is d.c. millivoltmeter, voltmeter or kilovoltmeter.

c) Using a battery and resistive network, resistance can be measured. The instrument is ohmmeter.

A.C instruments:

a) Using a rectifier, a.c. voltages can be measured, at power and audio frequencies. The instrument is a.c. voltmeter.

b) Using a thermocouple type meter radio frequency (RF) voltage or current can be measured.

c) Using a thermistor in a resistive bridge network, expanded scale for power line voltage can be obtained.

Basic DC voltmeter:

The basic d.c. voltmeter is nothing but a permanent magnet moving coil (PMMC) 0' Arsonval galvanometer. The resistance is required to be connected in series with the basic meter to use it as a voltmeter. This series resistance is called a **multiplier.** The main function of the multiplier is to limit the current through the basic meter so that the meter current does not exceed the full scale deflection value. The voltmeter measures the voltage across the two points of a circuit or a voltage across a circuit component. The basic d.c. voltmeter is shown in the Fig.
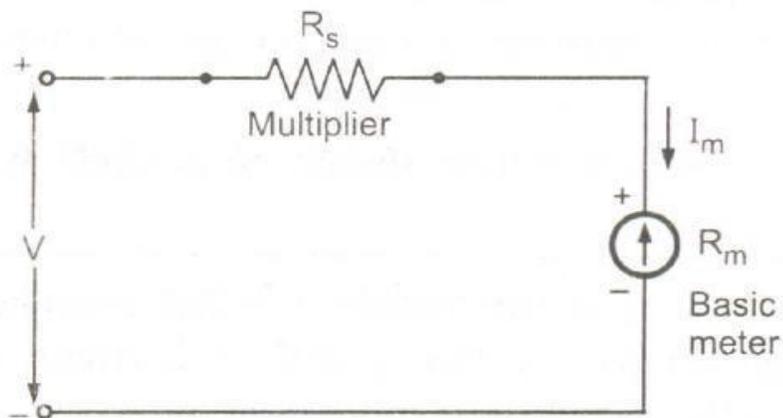
The voltmeter must be connected across the two points or a component, to measure the potential difference, with the proper polarity.

The multiplier resistance can be calculated as:

Let $\qquad$ R_m = internal resistance of coil i.e. meter

$\qquad$ R_s = series multiplier resistance

$\qquad$ I_m = full scale deflection current

$\qquad$ V = full range voltage to be measured

From Fig. 2.1, $\therefore$ $V = I_m(R_m + R_s)$

$\therefore$ $$V = I_m R_m + I_m R_s$$

$\therefore$ $$I_m R_s = V - I_m R_m$$

$\therefore$ $$\boxed{R_s = \frac{V}{I_m} - R_m}$$

The multiplying factor for multiplier is the ratio of full range voltage to be measured and the drop across the basic meter.

Let $\qquad$ v = drop across the basic meter = $I_m R_m$

$\therefore$ $\qquad$ m = multiplying factor = $\dfrac{V}{v}$

$$= \frac{I_m(R_m + R_s)}{I_m R_m}$$

Hence multiplier resistance can also be expressed as,

$$R_s = (m-1) R_m$$

Multirange voltmeters:

The range of the basic d.c. voltmeter can be extended by using number of multipliers clnd a selector switch. Such a meter is called **multirange** voltmeter.

Basic meter
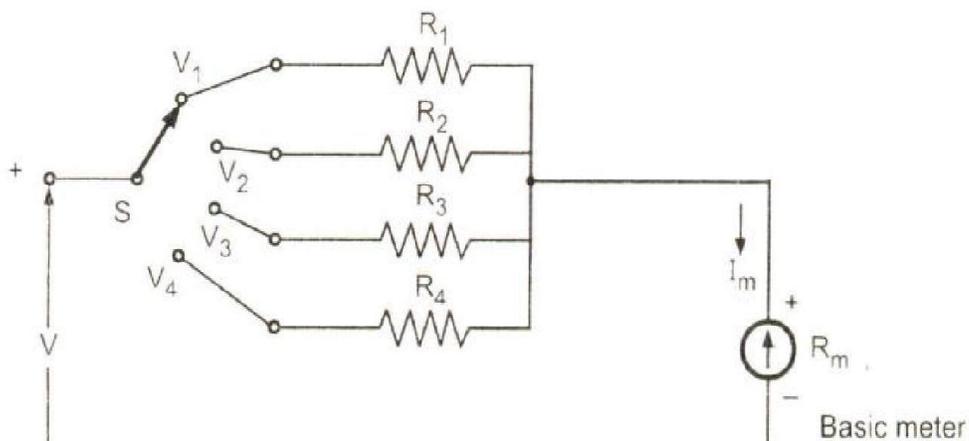
The R1, R2, R3 and R4 are the four series multipliers. When connected in series with the meter, they can give four different voltage ranges as V1, V2, V3, and V4. The selector switch S is multiposition switch by which the required multiplier can be selected in the circuit.

The mathematical analysis of basic d.c.*voltmeter* is equally applicable for such multirange *voltmeter.* Thus,

$$R_1 = \frac{V_1}{I_m} - R_m \qquad R_2 = \frac{V_2}{I_m} - R_m \qquad \text{and so on.}$$

Sensitivity of voltmeters:

In a multirange voltmeter, the ratio of the total resistance Rt to the voltage range remains same.

This ratio is nothing but the reciprocal of the full scale deflection current of the meter i.e. 1/101.

This value is called sensitivity of the voltmeter. Thus the sensitivity of the voltmeter is defined,

$$S = \frac{1}{\text{Full scale deflection current}}$$

$$\boxed{S = \frac{1}{I_m} \ \Omega/V \ \text{or} \ k\Omega/V}$$

Loading effect:

While selecting a meter for a particular measurement, the sensitivity rating IS very important. A low sensitive meter may give the accurate reading in low resistance circuit but will produce totally inaccurate reading in high resistance circuit.

The voltmeter is always connected across the two points between which the potential difference is to be measured. If it is connected across a low resistance then as voltmeter resistance is high, most of the current will pass through a low resistance and will produce the voltage drop which will be nothing but the true reading. But if the voltmeter is connected across the high resistance then due to two high resistances in parallel, the current will divide almost equally through the two paths. Thus the meter will record the voltage drop across the high resistance which will be much lower than the true reading. Thus the low sensitivity instrument when used in high resistance circuit 'gives a lower than the true reading. This is called loading effect of the voltmeters. It is mainly caused due to low sensitivity instruments.

A.C voltmeters using rectifier:

The PMMC movement used in d.c. voltmeters can be effectively used in a.c. voltmeters. The rectifier is used to convert a.c. voltage to be measured, to d.c. This d.c., if required is amplified and then given to the PMMC movement. The PMMC movement gives the deflection proportional to the quantity to be measured.

The r.m.s. value of an alternating quantity is given by that steady current (d.c.) which when flowing through a given circuit for a given time produces the same amount of heat as produced by the alternating current which when flowing through the same circuit for the same time. The r.m.s value is calculated by measuring the quantity at equal intervals for one complete cycle. Then squaring each quantity, the average of squared v,llues is obtained. The square root of this average value is the r.m.s. value. The r.m.s means root-mean square i.e. squaring, finding the mean i.e. average and finally root.

If the waveform is continuous then instead of squaring and calculating mean, the integratioll is used. Mathematically the r.m.s. value of the continuous a.c. voltage having time period T is given by,

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T V_{in}^2 \, dt}$$

The $\frac{1}{T}$ term indicates the mean value or average value.

For **purely sinusoidal quantity,**

If the a.c. quantity is continuous then average value can be expressed mathematically using integration as,

---

The form factor is the ratio of r.m.s. value to the average value of an alternating quantity.

$$K_f = \frac{r.m.s.\ value}{average\ value} = form\ factor$$

Basic rectifier type voltmeter:
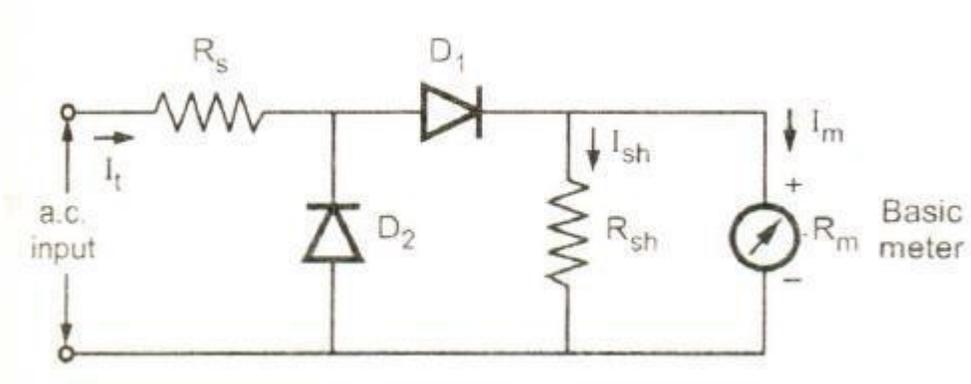
The diodes D1 and D2 are used for the rectifier circuit. The diodes show the nonlinear behaviour for the low currents hence to increase the current through diode D1, the meter is shunted with a resistance Rsh' This ensures high current through diode and its linear behaviour.

When the a.c. input is applied, for the positive half cycle, the diode 01 conducts and causes the meter deflection proportional to the average value of that half cycle. In the negative cycle, the diode D2 conducts and D1 is reverse biased. The current through the meter is in opposite direction and hence meter movement is bypassed. Thus due to diodes, the rectifying action produces pulsating d.c. and lile meter indicates the average value of the input.

A.C voltmeter using fullwave rectifier:

The a.c. voltmeter using full wave rectifier is achieved by using bridge rectifier consisting of four diodes, as shown in the Fig
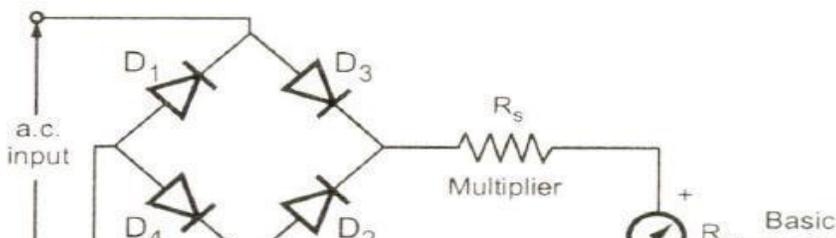
OHMMETER (SERIES TYPE OHMMETER)

A D'Arsonval movement is connected in series with a resistance R_1 and a battery which is connected to a pair of terminals A and B, across which the unknown resistance is connected. This forms the basic type of series ohmmeter, as shown in Fig. 4.30 (a).

The current flowing through the movement then depends on the magnitude of the unknown resistance. Therefore, the meter deflection is directly proportional to the value of the unknown resistance.

Referring to Fig. 4.30 (a)

R_1 = current limiting resistance
R_2 = zero adjust resistance
V = battery
R_m = meter resistance
R_x = unknown resistance
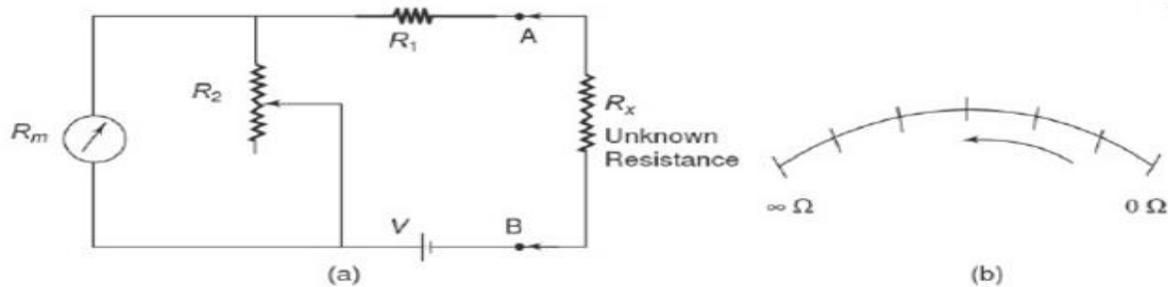
Fig. 4.30 (a) Series type ohmmeter (b) Dial of series ohmmeter

Calibration of the Series Type Ohmmeter

To mark the "0" reading on the scale, the terminals A and B are shorted, i.e. the unknown resistance $R_x = 0$, maximum current flows in the circuit and the shunt resistance R_2 is adjusted until the movement indicates full scale current (I_{fsd}). The position of the pointer on the scale is then marked "0" ohms.

Similarly, to mark the "∞" reading on the scale, terminals A and B are open, i.e. the unknown resistance $R_x = \infty$, no current flow in the circuit and there is no deflection of the pointer. The position of the pointer on the scale, is then marked as "∞" ohms.

By connecting different known values of the unknown resistance to terminals A and B, intermediate markings can be done on the scale. The accuracy of the instrument can be checked by measuring different values of standard resistance, i.e. the tolerance of the calibrated resistance, and noting the readings.

A major drawback in the series ohmmeter is the decrease in voltage of the internal battery with time and age. Due to this, the full scale deflection current drops and the meter does not read "0" when A and B are shorted. The variable shunt resistor R_2 across the movement is adjusted to counteract the drop in battery voltage, thereby bringing the pointer back to "0" ohms on the scale.

It is also possible to adjust the full scale deflection current without the shunt R_2 in the circuit, by varying the value of R_1 to compensate for the voltage drop. Since this affects the calibration of the scale, varying by R_2 is much better solution. The internal resistance of the coil R_m is very low compared to R_1. When R_2 is varied, the current through the movement is increased and the current through R_2 is reduced, thereby bringing the pointer to the full scale deflection position.

The series ohmmeter is a simple and popular design, and is used extensively for general service work.

Therefore, in a series ohmmeter the scale marking on the dial, has "0" on the right side, corresponding to full scale deflection current, and "∞" on the left side corresponding to no current flow, as given in Fig. 4.30 (b).

Values of R_1 and R_2 can be determined from the value of R_x which gives half the full scale deflection.

$$R_h = R_1 + R_2 \| R_m = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

where R_h = half of full scale deflection resistance.

The total resistance presented to the battery then equals $2R_h$ and the battery current needed to supply half scale deflection is $I_h = V/2\ R_h$.

To produce full scale current, the battery current must be doubled.

Therefore, the total current of the ckt, $I_t = V/R_h$

The shunt current through R_2 is given by $I_2 = I_t - I_{fsd}$

The voltage across shunt, V_{sh}, is equal to the voltage across the meter.

Therefore
$$V_{sh} = V_m$$
$$I_2 R_2 = I_{fsd} R_m$$

Therefore
$$R_2 = \frac{I_{fsd} R_m}{I_2}$$

But
$$I_2 = I_t - I_{fsd}$$

∴
$$R_2 = \frac{I_{fsd} R_m}{I_t - I_{fsd}}$$

But
$$I_t = \frac{V}{R_h}$$

Therefore
$$R_2 = \frac{I_{fsd} R_m}{V/R_h - I_{fsd}}$$

Therefore
$$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h}$$

As
$$R_h = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

Therefore
$$R_1 = R_h - \frac{R_2 R_m}{R_2 + R_m}$$

Hence
$$R_1 = R_h - \frac{\dfrac{I_{fsd}\,R_m\,R_h}{V - I_{fsd}\,R_h} \times R_m}{\dfrac{I_{fsd}\,R_m\,R_h}{V - I_{fsd}\,R_h} + R_m}$$

Therefore
$$R_1 = R_h - \frac{I_{fsd}\,R_m\,R_h}{V}$$

Hence, R_1 and R_2 can be determined.

Multirange Ohmmeter   The ohmmeter circuit shown in Fig.   is only for a single range of resistance measurement. To measure resistance over a wide range of values, we need to extend the ohmmeter ranges. This type of ohmmeter is called a multirange ohmmeter, shown in Fig. 4.31.
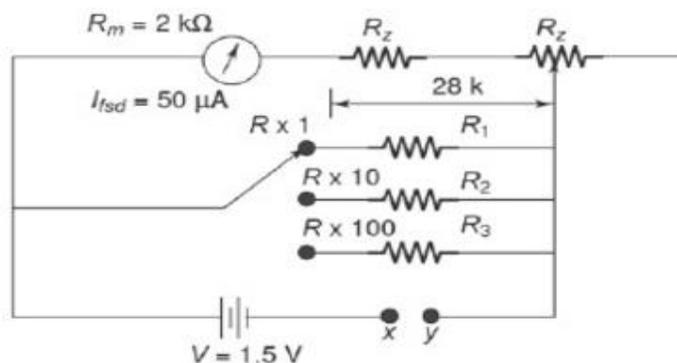
SHUNT TYPE OHMMETER

The shunt type ohmmeter given in Fig   consists of a battery in series with an adjustable resistor R_1, and a D'Arsonval movement

The unknown resistance is connected in parallel with the meter, across the terminals A and B, hence the name shunt type ohmmeter.

In this circuit it is necessary to have an ON/OFF switch to disconnect the battery from the circuit when the instrument is not used.
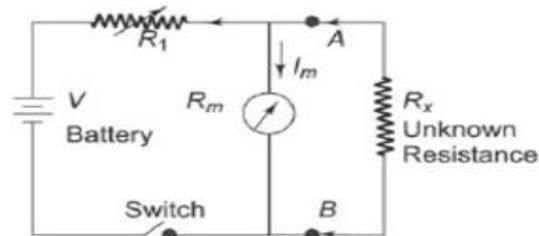

Fig.   Shunt type ohmmeter

Calibration of the Shunt Type Ohmmeter

To mark the "0" ohms reading on the scale, terminals A and B are shorted, i.e. the unknown resistance $R_x = 0$, and the current through the meter movement is

zero, since it is bypassed by the short-circuit. This pointer position is marked as "0" ohms.

Similarly, to mark "∞" on the scale, the terminals A and B are opened, i.e. $R_x = \infty$, and full current flows through the meter movement; by appropriate selection of the value of R_1, the pointer can be made to read full scale deflection current. This position of the pointer is marked "∞" ohms. Intermediate marking can be done by connecting known values of standard resistors to the terminals A and B.

This ohmmeter therefore has a zero mark at the left side of the scale and an ∞ mark at the right side of the scale, corresponding to full scale deflection current as shown in Fig.
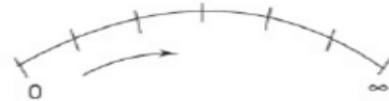
Fig.   Dial of shunt type ohmmeter

The shunt type ohmmeter is particularly suited to the measurement of low values of resistance. Hence it is used as a test instrument in the laboratory for special low resistance applications.

CALIBRATION OF DC INSTRUMENT

The process of calibration involves the comparison of a given instrument with a standard instrument, to determine its accuracy. A dc voltmeter may be calibrated with a standard, or by comparison with a potentiometer. The circuit in Fig. is used to calibrate a dc voltmeter; where a test voltmeter reading V is compared to the voltage drop across R. The voltage drop across R is accurately measured with the help of a standard meter. A rheostat, shown in Fig.   is used to limit the current.

A voltmeter tested with this method can be calibrated with an accuracy of ±0.01%.
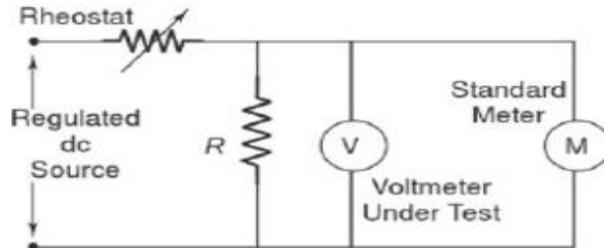
Fig.   Calibration of voltmeter

Electronic multimeter:

For the measurement of d.c. as well as a.c. voltage and current, resistance, an electronic multimeter is commonly used. It is also known as Voltage-Ohm Meter (VOM) or multimeter The important salient features of YOM are as listed below.

1) The basic circuit of YOM includes balanced bridge d.c. amplifier.

2) To limit the magnitude of the input signal, RANGE switch is provided. By properly adjusting input attenuator input signal can be limited.

3) It also includes rectifier section which converts a.c. input signal to the d.c. voltage.

4) It facilitates resistance measurement with the help of internal battery and additional circuitry.

5) The various parameters measurement is possible by selecting required function using FUNCTION switch.

6) The measurement of various parameters is indicated with the help of indicating Meter.

**Use of multimeter for D.C measurement:**

For getting different ranges of voltages, different series resistances are connected in series which can be put in the circuit with the range selector switch. We can get different ranges to measure the d.c. voltages by selecting the proper resistance in series with the basic meter.

Use of multimeter as ammeter:

To get different current ranges, different shunts are connected across the meter with the help of range selector switch. The working is same as that of PMMC ammeter
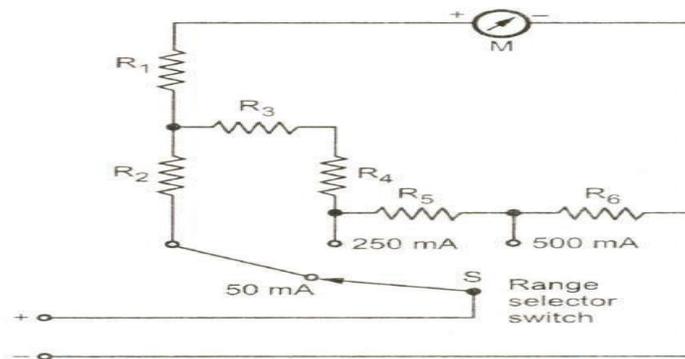
**Use of multimeter for measurement of A.C voltage:**
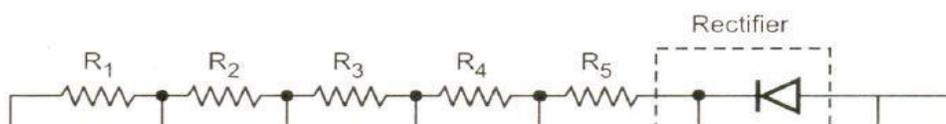
The rectifier used in the circuit rectifies a.c. voltage into d.c. voltage for measurement of a.c.

voltage before current passes through the meter. The other diode is used for the protection purpose.

Use of multimeter for resistance measurement:

The Fig shows ohmmeter section of multimeter for a scale multiplication of 1. Before any measurement is made, the instrument is short circuited and "zero adjust" control is varied until the meter reads zero resistance i.e. it shows full scale current. Now the circuit takes the form of a variation of the shunt type ohmmeter. Scale multiplications of 100 and 10,000 can also be used for measuring high resistances. Voltages are applied the circuit with the help of battery.
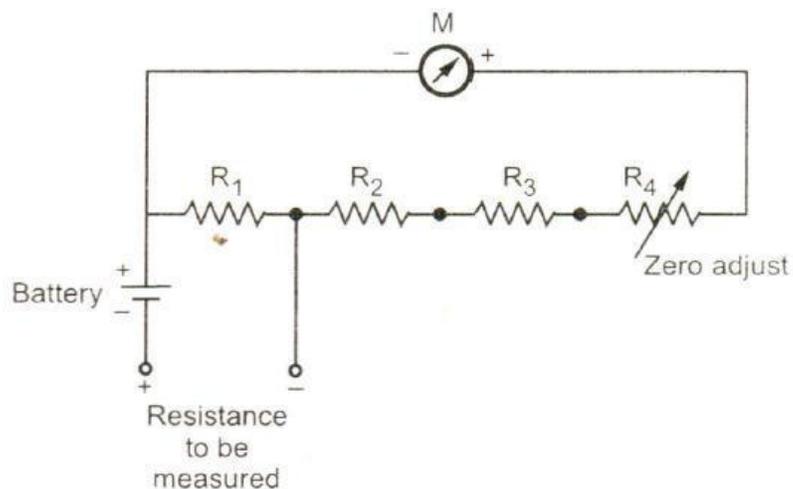
Digital multimeters:

The digital multimeter is an instrument which is capable of measuring a.c. voltages, d.c. voltages, a.c. and d.c. currents and resistances *over* several ranges. The basic circuit of a digital multimeter is always a d.c. voltmeter as shown in the Fig
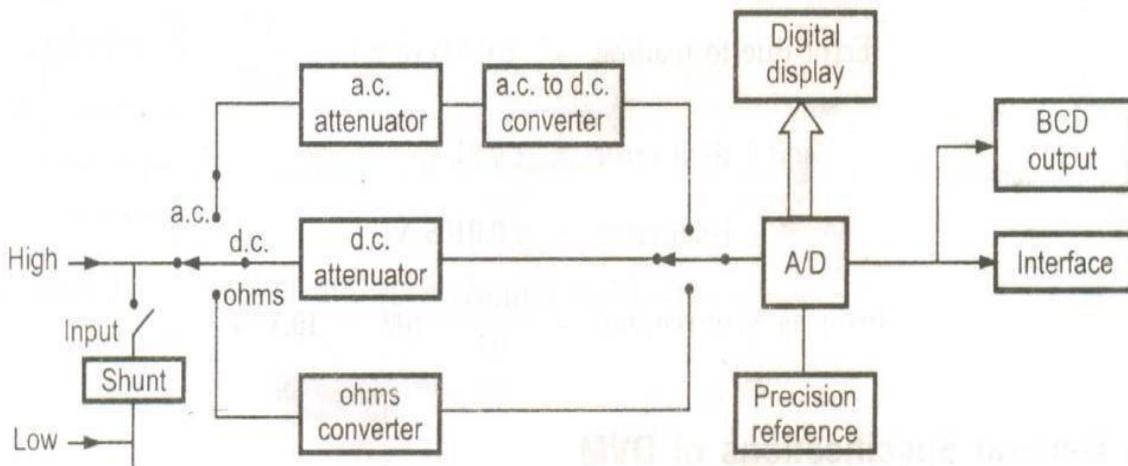
The current is converted to voltage by passing it through low shunt resistance. The a.c. quantities are *converted* to d.c. by employing various rectifier and filtering circuits. While for the resistance measurements the meter consists of a precision low current source that is applied across the unknown resistance while gives d.c. voltage. All the quantities are digitized using analog to digital

converter and displayed in the digital form on the display.The basic building blocks of digital multimeter are several *AID* converters, counting circuitry and an attenuation circuit. Generally dual slope integration type ADC is prefprred in the multimeters. The single attenuator circuit is used for both a.c. and d.c. measurements in many commercial multimeters.

True RMS Reading Voltmeter

Block Diagram of True RMS Reading Voltmeter
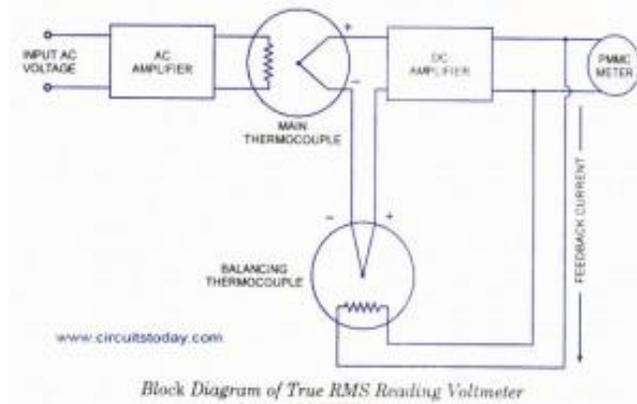
True RMS Responding Voltmeters

RMS value of the sinusoidal waveform is measured by the**average reading voltmeter** of which scale is calibrated in terms of rms value. This method is quite simple and less expensive. But sometimes rms value of the non-sinusoidal waveform is required to be measured. For such a measurement a true rms reading voltmeter is required. True rms reading voltmeter gives a meter indication by sensing heating power of waveform which is proportional to the square of the rms value of the voltage.

Thermo-couple is used to measure the heating power of the input waveform of which heater is supplied by the amplified version of the input waveform. Output voltage of the thermocouple is proportional to the square of the rms value of the input waveform. One more thermo-couple, called the balancing thermo-couple, is used in the same thermal environment in order to overcome the difficulty arising out of non-linear behaviour of the thermo-couple. Non-linearity of the input circuit thermo-couple is cancelled by the similar non-linear effects of the balancing thermo-couple. These thermo-couples form part of a bridge in the input circuit of a dc amplifier, as shown in block diagram.

AC waveform to be measured is applied to the heating element of the main thermocouple through an ac amplifier. Under absence of any input waveform, output of both thermo-couples are equal so error signal, which is input to dc amplifier, is zero and therefore indicating meter connected to the output of dc amplifier reads zero. But on the application of input waveform, output of main thermo-couple upsets the balance and an error signal is produced, which gets amplified by the dc amplifier and fedback to the heating element of the balancing thermo-couple. This feedback current reduces the value of error signal and ultimately makes it zero to obtain the balanced bridge condition. In this balanced condition, feedback current supplied by the dc amplifier to the heating element of the balance thermo-couple is equal to the ac current flowing in the heating element of main thermo-couple. Hence this direct current is directly proportional to the rms value of the input ac voltage and is indicated by the meter connected in the output of the dc amplifier. The PMMC meter may be calibrated to read the rms voltage directly.

By this method, rms value of any voltage waveform can be measured provided that the peak excursions of the waveform do not exceed the dynamic range of the ac amplifier.

UNIT-2

AF Wave analyzer

      The wave analyzer consists of a very narrow pass-band filter section which can Be tuned to a particular frequency within the audible frequency range (20Hz to 20 KHz)). The block diagram of a wave analyzer is as shown in fig 1.
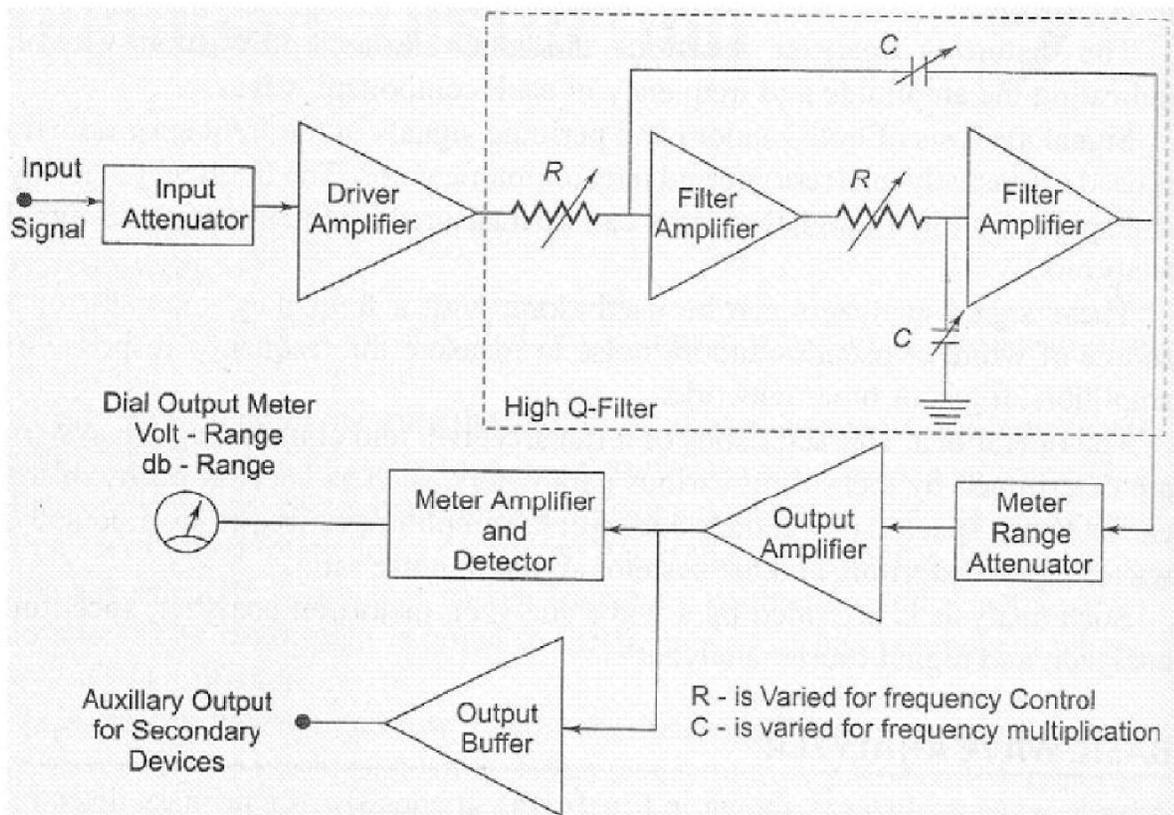

Fig 1: Frequency wave analyzer

      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 requency. The driver amplifier applies the attenuated input signal to a high-Q active filter. This high-Q filter is a low pass filter which allows the frequency which is selected to pass and reject all others. The magnitude of this selected frequency is indicated by the meter and the filter section identifies the frequency of the component. The filter circuit consists of a cascaded RC resonant circuit and amplifiers. For selecting the frequency range, the capacitors generally used are of the closed tolerance polystyrene type and the resistances used are precision potentiometers. The capacitors are used for range changing and the potentiometer is used to change the frequency within the selected pass-band, Hence this wave analyzer is also called a Frequency selective voltmeter. The entire AF range is covered in decade steps by switching capacitors in the RC section.

The selected signal output from the final amplifier stage is applied to the meter circuit and to an unturned buffer amplifier. The main function of the buffer amplifier is to drive output devices, such as recorders or electronics counters.

The meter has several voltage ranges as well as decibel scales marked on it. It is driven by an average reading rectifier type detector. The wave analyzer must have extremely low input distortion, undetectable by the analyzer itself. The band width of the instrument is very narrow typically about 1% of the selective band given by the following response characteristics shows in fig.1.2
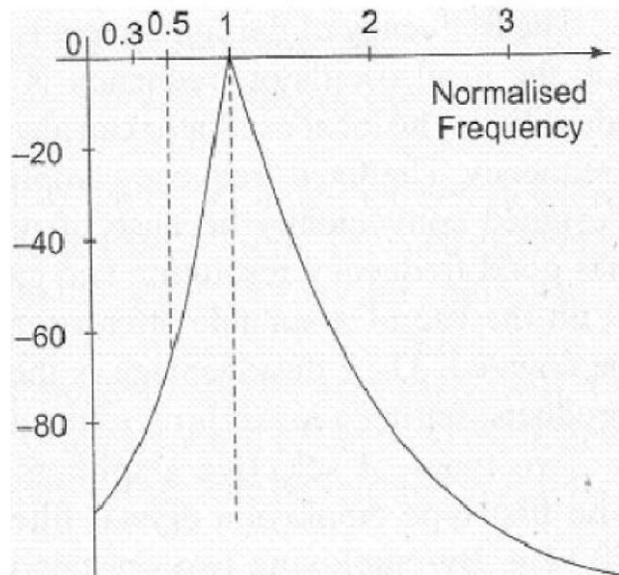
Application of wave analyzer:

1. Electrical measurements

2. Sound measurements

3. Vibration measurements.

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

Heterodyne wave analyzer

A wave analyzer, in fact, is an instrument designed to measure relative amplitudes of single frequency components in a complex waveform. Basically, the instrument acts as a frequency selective voltmeter which is used to the frequency of one signal while rejecting all other signal components. The desired frequency is selected by a frequency calibrated dial to the point of maximum amplitude. The amplitude is indicated either by a suitable voltmeter or CRO.This instrument is used in the MHz range. The input signal to be analysed is heterodyned to a higher IF by an internal local oscillator. Tuning the local oscillator shifts various signal frequency components into the pass band of the IF amplifier. The output of the IF amplifier is rectified and is applied to the metering circuit. The instrument using the heterodyning principle is called a *heterodyning tuned voltmeter.*

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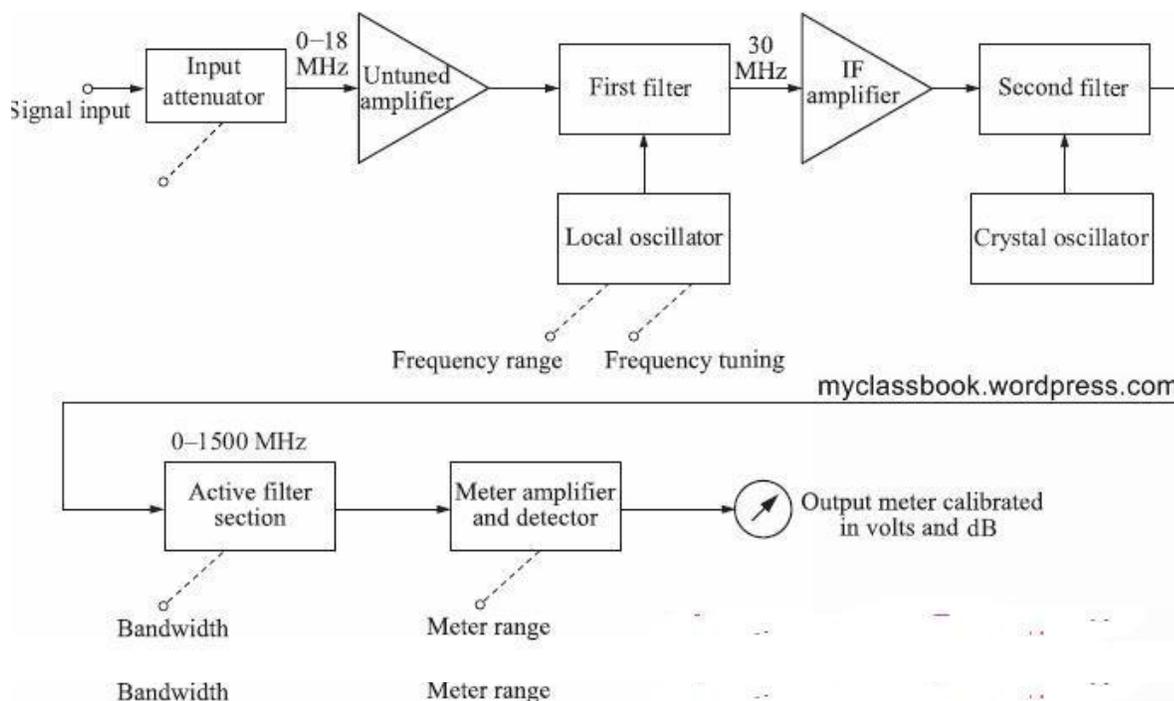
The block schematic of the wave analyser using the heterodyning principle is shown in fig. above. The operating frequency range of this instrument is from 10 kHz to 18 MHz in 18 overlapping bands selected by the frequency range control of the local oscillator. The bandwidth is controlled by an active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

Wave analyzers have very important applications in the following fields:

1) Electrical measurements
2) Sound measurements and
3) Vibration measurements.

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

Harmonic distortion :

The **total harmonic distortion (THD)** is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. **Distortion factor**, a closely related term, is sometimes used as a synonym.

In audio systems, lower distortion means the components in a loudspeaker, amplifier or microphone or other equipment produce a more accurate reproduction of an audio recording.

To understand a system with an input and an output, such as an audio amplifier, we start with an ideal system where the transfer function is linear and time-invariant. When a signal passes through a non-ideal, non-linear device, additional content is added at the harmonics of the original frequencies. THD is a measurement of the extent of that distortion.

When the main performance criterion is the "purity" of the original sine wave (in other words, the contribution of the original frequency with respect to its harmonics), the measurement is most commonly defined as the ratio of the RMS amplitude of a set of higher harmonic frequencies to the RMS amplitude of the first harmonic, or fundamental, frequency

$$\text{THD}_F = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots}}{V_1}$$

where V_n is the RMS voltage of the nth harmonic and $n = 1$ is the fundamental frequency.

Spectrum Analyzer

The modern spectrum analyzers use a narrow band super heterodyne receiver. Supereterodyne is nothing but mixing of frequencies in the super above audio range. The functional block diagram of super heterodyne spectrum analyzer or RF spectrum nalyzer as shown in the Figure

fig.: super hertodyne spectrum analyzer or RF spectrum analyzer

The RF input to be analyzed is applied to the input attenuator. After attenuating, the signal is fed to low pass filter. The low pass filter suppresses high frequency components and allows low frequency components to pass through it. The output of the low pass filter is given to the mixer, where this signal is fixed with the signal coming from voltage controlled or voltage tuned oscillator.

This oscillator is tuned over 2 to 3 GHz range. The output of the mixer includes two signals whose amplitudes are proportional to the input signal but their frequencies are the sum and difference of the input signal and the frequency of the local oscillator.

Since the frequency range of the oscillator is tuned over 2 to 3 GHz, the IF amplifier is tuned to a narrow band of frequencies of about 2 GHz. Therefore only those signals which are separated from the oscillator frequency by 2 GHz are converted to Intermediate Frequency (IF) band. This IF signal is amplified by IF amplifier and then rectified by the detector. After completing amplification and rectification the signal is applied to vertical plates of CRO to produce a vertical deflection on the CRT screen. Thus, when the saw tooth signal sweeps, the oscillator also sweeps linearly from minimum to maximum frequency range i.e., from 2 to 3 GHz.

Here the saw tooth signal is applied not only to the oscillator (to tune the oscillator) but also to the horizontal plates of the CRO to get the frequency axis or horizontal deflection on the CRT screen. On the CRT screen the vertical axis is calibrated in amplitude and the horizontal axis is calibrated in frequency.

FFT spectrum analyzer

A spectrum analyzer, which uses computer algorithm and an analog to digital conversion phenomenon and produces spectrum of a signal applied at its input is known as digital Fourier or digital FFT or digital spectrum analyzer

Principle

When the analog signal to be analyzed is applied, the A/D converter digitizes the analog signal (i.e., converts the analog signal into digital signal). The digitized signal, which is nothing but the set of digital numbers indicating the amplitude of the analog signal as a function of time is stored in the memory of the digital computer. From the stored digitized data, the spectrum of the signal is computed by means of computer algorithm.

Description:

The block arrangement of a digital Fourier analyzer is illustrated in the figure above .The analog signal to be ana1ysed is applied to the low pass filter, which passes only low frequency signals and rejects high pass spurious signals. This filter section is used mainly, to prevent aliasing. The output of low pass filter is given to the attenuator. The attenuator is a voltage dividing

network whose function is to set the input signal to the level of the A/D converter. The use of attenuator prevents the converter from overloading. The function of A/D converter is to convert the samples of analog data into digital i.e. ., to digitize the analog signal. When the output of A/D converter is applied to the digital computer, the computer analyzes the digitized data and adjusts the attenuator setting accordingly in order to obtain the maximum output from the inverter without any overloading. As soon as the entire analog signal is sampled and digitized by the A/D converter) computer performs calculations on the data according to the programmed algorithm and the calculated spectral components are stored in the memory of the computer
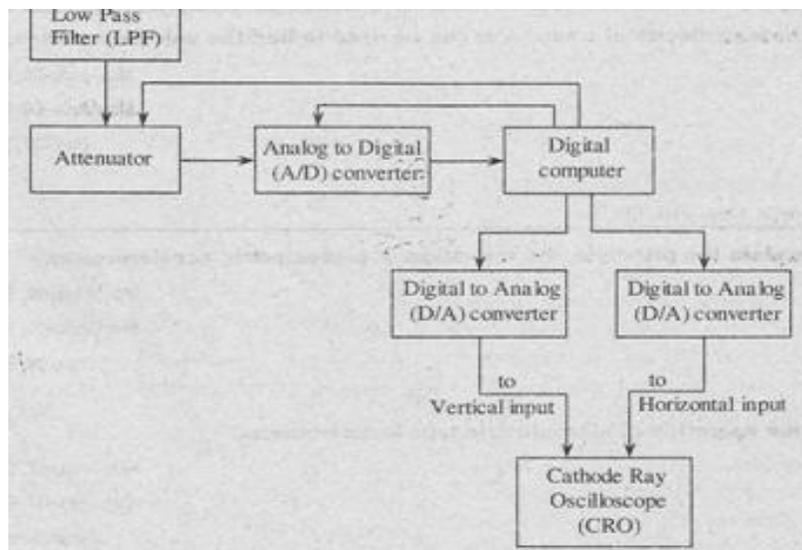
Fig   Digital Fourier Analyzer

If the spectral display is to be viewed on the oscilloscope, the digital values of spectral components stored in the computer memory are converted into analog by using D/A converters and then applied to the CRO. Thus the spectral display of the input waveform is obtained on the CRT screen.

Advantages

1. The use of computer avoids most of the hardware circuitry such as electronic switches, Filters and PLLs. The use of less hardware reduces the cost of the analyzer.

2. More mathematical calculations can be carried-out on the spectral display.

3. The rate of sampling analog signal can be modified in order to obtain better spectral display.

STANDARD SIGNAL GENERATOR:-

A standard signal generator produces known and controllable voltages. It is used as power sourcefor the measurement of gain, signal to noise ratio (SN), bandwidth standing wave ratio and other properties.

It is extensively used in the measuring of radio receivers and transmitter instrument is provided with a means of modulating the carrier frequency, which is indicated by the dial setting on the front panel.

The modulation is indicated by a meter. The output signal can be Amplitude Modulated (AM) or Frequency Modulated (FM). Modulation may be done by a sine wave, Square, rectangular, or a pulse wave.

The elements of a conventional signal generator:

1) RF Osillator

(2) Wide band amplifier.

(3) External Osillator.

4) Modulation Osillator

(5) Out put attenuator.

The carrier frequency is generated by a very stable RF oscillator using an LC tank circuit, having a constant output over any frequency range. The frequency of oscillations is indicated by thefrequency range control and the venire dial setting. AM is provided by an internal sine wavegenerator or from an external source.

The signal generator is called an oscillator. A Wien bridge oscillator is used in this generator.The Wien bridge oscillator is the best of the audio frequency range. The frequency of oscillations can be changed by varying the capacitance in the oscillator.

The frequency can also be changed in steps by switching the resistors of different values. The output of the Wien bridge oscillator goes to the function switch.

The function switch directs the oscillator output either to the sine wave amplifier or to the square wave shaper. At the output, we get either a square or sine wave.The output is varied by means of an attenuator.
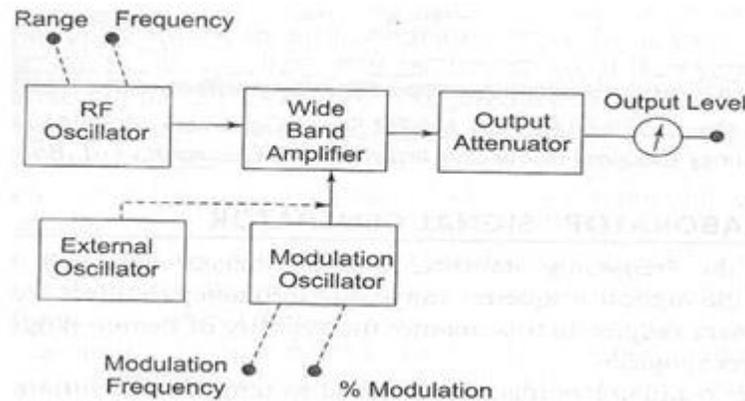
The instrument generates a frequency ranging from 10 Hz to 1 MHz continuously vV (rms).The output is taker through a push-pull amplifier. For low output, the impedance is 6000. The square wave amplitudes can be varied from 0 - 20 v (peak). It is possible to adjust the symmetry of the square wave from 30 -70%. The instrument requires only 7W of power at 220V 50Hz.

The front panel of a signal generator consists of the following.

l. Frequency selector: It selects the frequency in different ranges and varies it continuously in

a ratio of 1: 11. The scale is non-linear.

2. Frequency multiplier: It selects the frequency range over 5 decades from 10 Hz to 7 MHz

3. Amplitude multiplier: It attenuates the sine wave in 3 decades, x l x 0.1 and x 0.01.

4. Variable amplitude: It attenuates the sine wave amplitude continuously

5. Symmetry control: It varies the symmetry of the square wave from 30% to 70%.

6. Amplitude: It attenuates the square wave output continuously.

7. Function switch: It selects either sine wave or square output.

8. Output available: This provides sine wave or square wave output.

9. Sync: This terminal is used to provide synchronization of the internal signal with an external signal.

10. On-Off Switch

Sweep Generator

It provides a sinusoidal output voltage whose frequency varies smoothly and continuously over an entire frequency band, usually at an audio rate. The process of frequency modulation may be accomplished electronically or mechanically. It is done electronically by using the modulating voltage to vary the reactance of the oscillator tank circuit component, and mechanically by means of a motor driven capacitor, as provided for in a modern laboratory type signal generator. Figure shows a basic block diagram of a sweep generator. The frequency sweeper provides a variable modulating voltage which causes the capacitance of the master oscillator to vary. A representative sweep rate could be of the order of 20 sweeps/second. A manual control allows independent adjustment of the oscillator resonant frequency. The frequency sweeper provides a varying sweep voltage synchronization to drive the horizontal deflection plates of the CRO. Thus the amplitude of the response of a test device will be locked and displayed on the screen.

To identify a frequency interval, a marker generator provides half sinusoidal waveforms at any frequency within the sweep range. The marker voltage can be added to the sweep voltage of the CRO during alternate cycles of the sweep voltage, and appears superimposed on the responsecurve.

The automatic level control circuit is a closed loop feedback system which monitors the RF level at some point in the measurement system. This circuit holds the power delivered to the load or test circuit constant and independent o frequency and impedance changes. A constant power level prevents any source mismatch and also provides a constant readout calibration with frequency.

SQUARE AND PULSE GENERATOR:-

These generators are used as measuring devices in combination with a CRO. They provide both quantitative and qualitative information of the system under test. They are made use of in

transient response testing of amplifiers. The fundamental difference between a pulse generator and a square wave generator is in the duty cycle.

Duty cycle = A square wave generator has a 500/o duty cycle.

Requirements of a Pulse

1. The pulse should have minimum distortion, so that any distortion, in the display is solely due to the circuit under test.
2. The basic characteristics of the pulse are rise time, overshoot, ringing, sag, and undershoot.
3. The pulse should have sufficient maximum amplitude, if appreciable output power is required by the test circuit, e.g. for magnetic core memory. At the same time, the attenuation range shouldbe adequate to produce small amplitude pulses to prevent over driving of some test circuit.
4. The range of frequency control of the pulse repetition rate (PRR) should meet the needs of theexperiment. For example, a repetition frequency of 100 MHz is required for testing fast circuits.Other generators have a pulse-burst feature which allows a train of pulses rather than a continuous output.
5. Some pulse generators can be triggered by an externally applied trigger signal; conversely, pulse generators can be used to produce trigger signals, when this output is passed through a differentiator circuit.
6. The output impedance of the pulse generator is another important consideration. In a fast pulsesystem, the generator should be matched to the cable and the cable to the test circuit. A mismatch would cause energy to be reflected back to the generator by the test circuit, and this may be rereflected by the generator, causing distortion of the pulses.
7. DC coupling of the output circuit is needed, when dc bias level is to be maintained.
The basic circuit for pulse generation is the asymmetrical multi-vibrator.

A laboratory type square wave and pulse generator is shown in Fig 6.1
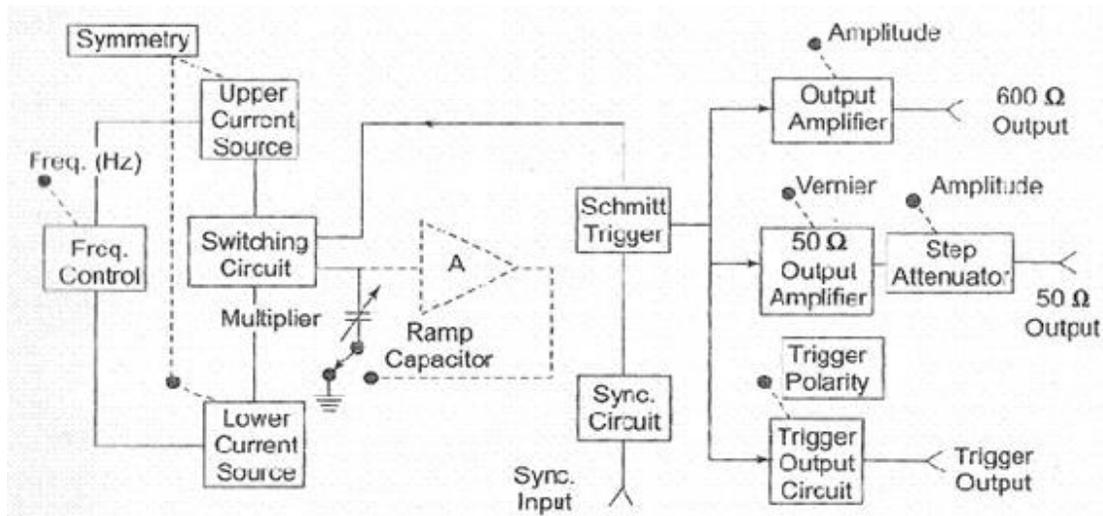
The frequency range of the instrument is covered in seven decade steps from 1Hz to 10 MHz, with a linearly calibrated dial for continuous adjustment on all ranges.

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 tme of 70 ns at 30 V peak amplitude. The instrument can be operated as a freerunning genenrator or, it can be synchronized with externalsignals.

The basic generating loop consists of the current sources, the ramp capacitor, the Schmitt triggerand the current switching circuit as shown in the fig
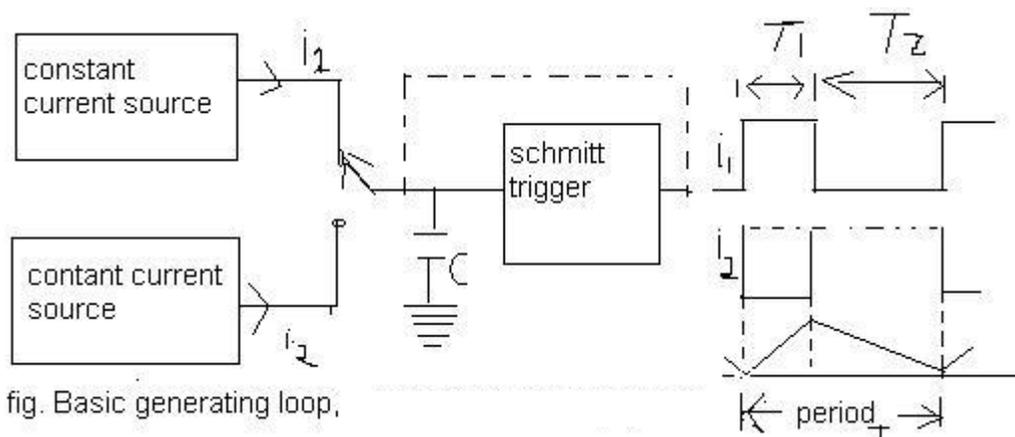
fig. Basic generating loop,

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 theinternal circuit components, the Schmitt trigger changes state. The trigger circuit output becomesnegative and reverses the condition of the current switch. The capacitor discharges linearly, controlled by the lower current 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 i1/i2 determines the duty cycle, and is controlled by symmetry control. The sum of i1 and i2 determines the frequency. The size of the capacitor is selected by the multiplier switch. The unit is powered by an intenal supply that provides regulated voltages for all stages of the instrument.

The precautionary measures to be taken in a signal generator application:-

A signal generator is an instrument, which can produce various types of wave forms such as sine wave, square wave, triangular wave, saw tooth wave, pulse trains etc. As it can generate a variety of waveforms it is widely used in applications like electronic troubleshooting anti development, testing the performance of electronic equipments etc. In such applications a signal generator is used to provide known test conditions (i.e., desired signals of known amplitude and frequency

Hence, the following precautionary measures should be taken while using a signal generator for an application.

1. The amplitude and frequency of the output of the signal generator should be made stable and well known.

2. There should be provision for controlling the amplitude of signal generator output from very small to relatively large values.

3. The output signal of generator should not contain any distortion and thus, it should possess very low harmonic contents.

4. Also, the output of the signal generator should be less spurious.

FUNCTION GENERATOR

A function generator produces different waveforms of adjustable frequency. The common outputwaveforms are the sine, square, triangular and saw tooth waves. The frequency may be adjusted, from a fraction of a Hertz to several hundred kHz lie various outputs of the generator can bemade available at the same time. For example, the generator can provide a square wave to testthe linearity of a rectifier and simultaneously provide a saw tooth to drive the horizontal deflection amplifier of the CRO to provide a visual display.

Capability of Phase Lock the function generator can be phase locked to an external source. One function generator can be used to lock a second function generator, and the two output signals can be displaced in phase by adjustable amount. In addition, the fundamental frequency of one generator can be phase locked to a harmonic of another generator, by adjusting the amplitude and phase of the harmonic; almost any waveform can be generated by addition.

The function generator can also be phase locked to a frequency standard and its output waveforms will then have the same accuracy and stability as the standard source.

The block diagram of a function generator:
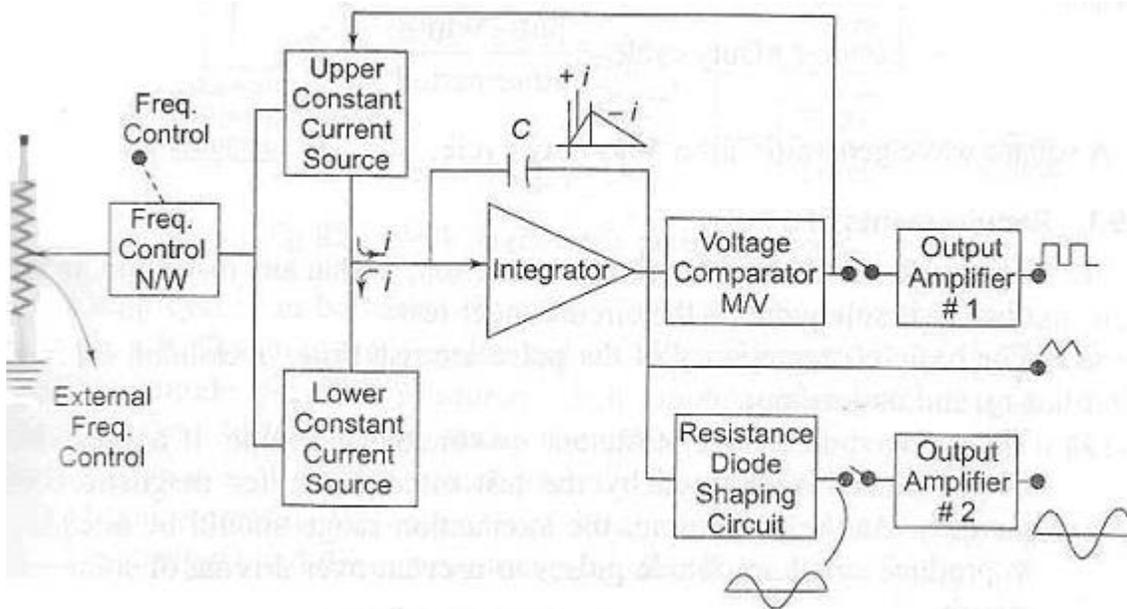
The block diagram of a function generator is illustrated in fig. Usually the frequency is controlled by varying the capacitor in the LC or RC circuit. In the instrument the frequency is

controlled by varying the magnitude of current which drives the integrator. The instrument produces sine, triangular and square waves with a frequency range of 0.01 Hz to 100 kHz.

The frequency controlled voltage regulates two current sources. The upper current source supplies constant current to the integrator whose output voltage increases linearly with time, according to the equation of the output signal voltage. An increase or decrease in the currentincreases or decreases the slope of the output voltage and hence controls the frequency. The voltage comparator multi-vibrator changes states at a pre-determined maximum level of the integrator output voltage. This change cuts off the upper current supply and switches on the lower current supply. The lower current source supplies a reverse current to the integrator, so that its output decreases linearly with time. When the output reaches a pre-determined minimum level, the voltage comparator again changes state and switches on the Lower current source. The output of the integrator is a triangular waveform whose frequency is determined by the magnitude of the current supplied by the constant current sources. The comparator output delivers a square wave voltage of the same frequency.

$e = -1/C \int idt$

The resistance diode network alters the slope of the triangular wave as its amplitude changes and produces a sine wave with less than 1% distortion.

Arbitrary Waveform Generator, AWG

The waveforms produced by arbitrary waveform generators, AWGs can be either repetitive or sometimes just a single-shot. If the AWG waveform is only a single shot, then a triggering mechanism is needed to trigger the AWG and possibly the measuring instrument.

The AWG is able to generate an arbitrary waveform defined by a set of values, i.e. "waypoints" entered to set the value of the waveform at specific times. They can make up a digital or even an analogue waveform.

As a result an arbitrary waveform generator is a form of test equipment that is able to produce virtually any waveshape that is required.

Arbitrary Waveform Generator techniques

There are a number of ways of designing arbitrary waveform generators. They are based around digital techniques, and their design falls into one of two main categories:

- ***Direct Digital Synthesis, DDS:*** This type of arbitrary waveform generator is based around the DDS types of frequency synthesizer, and sometimes it may be referred to as an Arbitrary Function Generator, AFG.

- ***Variable-clock arbitrary waveform generator*** The variable clock arbitrary function generator is the more flexible form of arbitrary waveform generator. These arbitrary waveform generators are generally more flexible, although they do have some limitations not possessed by the DDS versions. Sometimes these generators are referred to as just arbitrary waveform generators, AWGs rather than arbitrary function generators.

- ***Combined arbitrary waveform generator*** This format of AWG combines both of the other forms including the DDS and variable clock techniques. In this way the advantages of both systems can be realised within a single item of test equipment.

Arbitrary waveform generator resolution and speed:

Two of the main specifications for an arbitrary waveform generator are their resolution and also the speed. These two parameters determine the precision with which the waveform can be reproduced. They are governed by different elements within the arbitrary waveform generator circuit.

The amplitude resolution is governed by the resolution of the digital to analogue converter (D/A or D2A). This is described in terms of the number of bits. A 12 bit resolution provides 4096 amplitude steps.

The speed of the arbitrary waveform generator is also very important. The maximum repetition rate for the waveform is governed by two factors: the length of the waveform in terms of the number of samples required to simulate the waveform and the maximum clock frequency. For example if the arbitrary waveform generator had a maximum clock frequency of 25 MHz and the waveform had 1000 points, then the maximum repetition rate would be 25 kHz. If a higher repetition rate was required, then it would be necessary to decrease the number of samples as it would not be possible to increase the clock frequency in the arbitrary waveform generator!

Arbitrary waveform generator applications:

AWGs are used in many applications where specialised waveforms are required. These can be within a whole variety of sectors of the electronics industry.

To give a view of some of the AWG applications, it is possible for DDS-based arbitrary waveform generators is to create signals with precisely controlled phase offsets or ratio-related frequencies. This enables the generation of signals like polyphase sine waves, I-Q constellations, or simulation of signals from geared mechanical systems such as jet engines. Complex channel-channel modulations are also possible.

The arbitrary waveform generator may not be the most widely used of items of test instrumentation, but they can be immensely useful in a variety of applications. Modern arbitrary waveform generators are very flexible and can be used to create very specific waveforms for use in testing a variety of applications.

Direct digital synthesizer, DDS technology lends itself to being used within arbitrary waveform generators, AWGs. Those AWGs that use DDS technology are often referred to as arbitrary function generators, or AFGs.

The reason for being called arbitrary function generators is that they often appear as an extension of the function generator test instruments that are available.

Arbitrary waveform generators using direct digital synthesis technology are able to benefit from the technology, while not adding unwanted additional complexity and cost. DDS technology has developed considerably in recent years and this makes them a very attractive option to form the basis of a waveform generator. As a result arbitrary function generators are relatively widely used.

Arbitrary function generator basics:

As mentioned, this type of arbitrary waveform generator is based around the DDS types of frequency synthesizer, and sometimes it may be referred to as an Arbitrary Function generator, AFG.

The arbitrary function generator uses integrated circuits intended for direct digital frequency synthesizers, but enables an arbitrary waveform generator circuit to be created relatively easily and for an economic price.

To look at how an arbitrary function generator works, it is necessary to look at the operation of a direct digital synthesizer.

This circuit operates by storing the points of a waveform in digital format, and then recalling them to generate the waveform. These points can be on any form of repetitive waveform that is required. The rate at which the DDS completes one waveform governs the frequency. The basic block diagram of the DDS based arbitrary waveform generator is shown below.
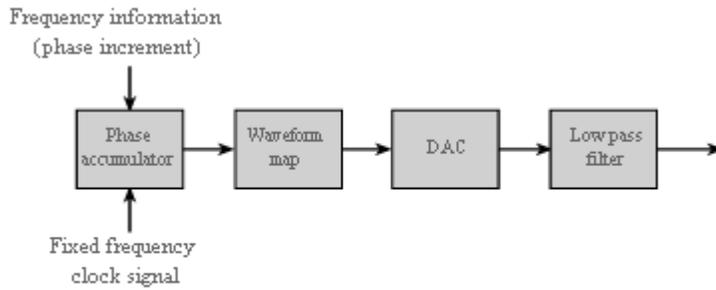
DDS frequency synthesizer as used in an arbitrary function generator, AFG

The operation of the DDS within the arbitrary function generator can be envisaged by looking at the way that phase progresses over the course of one cycle of the waveform.

The phase is often depicted as a line of phasor rotating around a circle. As the phase advances around the circle, this corresponds to advances in the waveform. The faster is progresses, the sooner it completes a cycle and the hence the higher the frequency.
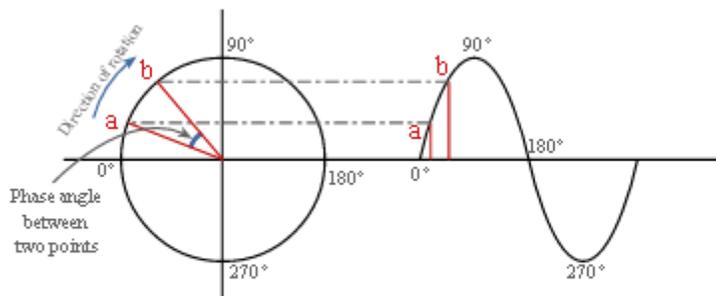
Phase angle of points on a sine wave

The direct digital synthesizer operates by storing various points of the required waveform in digital format in a memory. These can then be recalled to generate the waveform as they are required.

To simulate the phase advances a phase accumulator is used. This takes in phase increment information, and clock pulses from a clock. For each clock pulse, the phase will advance a certain amount. The greater the increment, the larger the phase advance, and hence the higher the frequency generated.

At each clock pulse the phase information is presented to the memory and the relevant location is accessed, proving the waveform information for that particular phase angle.

It can be seen that any waveform can be loaded into the memory; although a sine wave is shown on the diagram, the actual waveform could be anything.

While it is possible to load certain preset waveforms into the memory, it is also possible to load user generated ones in as well. These make the test instrument an arbitrary waveform generator or arbitrary function generator rather than a standard function generator.

Advantages and disadvantages of AFG:

While the arbitrary function generator or DDS based version of the arbitrary waveform generator, has many advantages, there are also some disadvantages that should also be taken into account when choosing what type of signal generator to use.

Arbitrary function generator advantages

- *Sub Hz frequency resolution:* By using a long word length phase accumulator in the phase accumulator of the DDS, it is possible to achieve sub-Hertz frequency resolution levels.
- *Down sampling:* Waveforms are automatically truncated by sampling to allow repetition rates above the clock frequency.
- *Digital modulation:* It is possible to add digital modulation words to the phase accumulator to provide a means of providing digital modulation.

Arbitrary function generator disadvantages

- *Waveform jitter:* Waveform jitter is an issue with arbitrary function generators because frequencies are up-sampled or down-sampled and this results in missing samples and hence jitter. Only frequencies equal to the clock frequency divided by the waveform length and its sub multiples are not sampled and therefore they do not suffer from this problem

- ***Single waveform capability:*** It is only possible to generate a single waveform at a time because memory segmentation and waveform sequencing is not possible using a DDS arbitrary function generator

The arbitrary function generator is the ideal instrument where a variety of programmed waveforms are required without the added flexibility and complexity of the more expensive variable clock arbitrary waveform generator. For most laboratory applications, the arbitrary function generator is an ideal choice.

UNIT -3

Oscilloscopes

Introduction:

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 " function of time, is called **cathode ray** oscilloscope, commonly known as C.R.O. The CR.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.

Basic Principle:

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 CRO. 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 bhe input voltage signal applied to the y-axis of CRO. is sinusoidally varying and if x-axis represents the time axis, then the spot moves sinusoidally, 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 CRO. 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 CRO.

Cathode Ray Tube (CRT):

The cathode ray tube (CRT) is the heart of the CR.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 Fig.
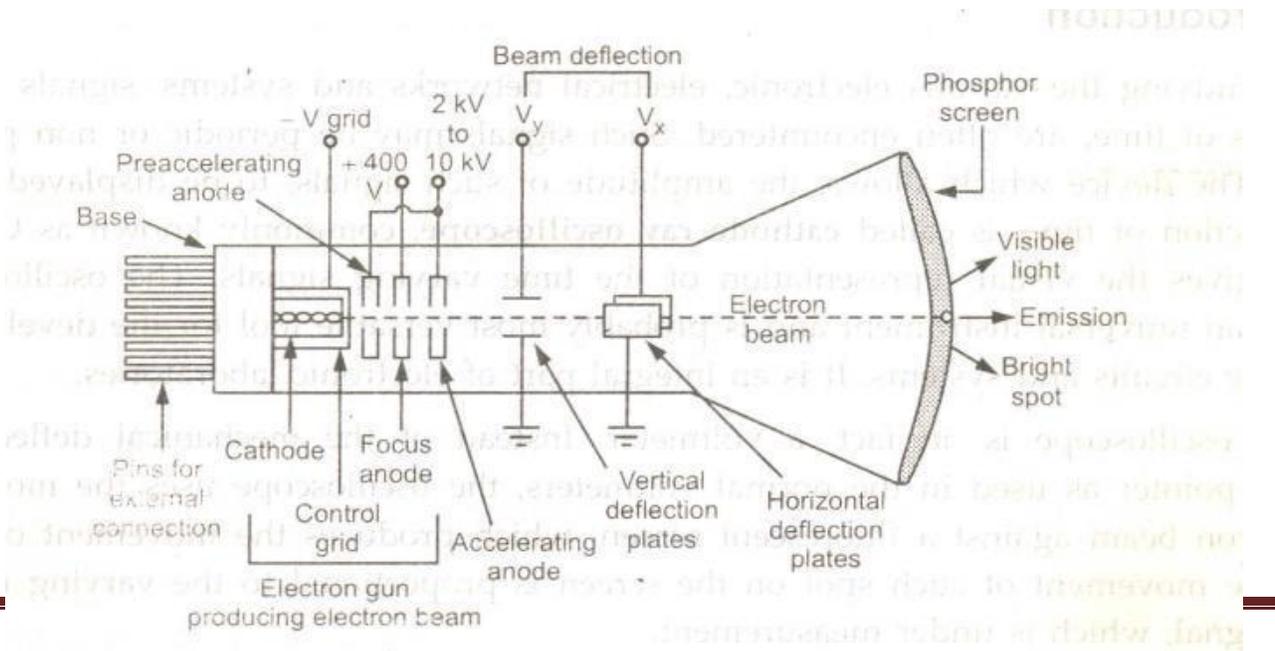
Electron Gun:

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 theql1ally heated cathode, limiting the electrons. The control grid is give!! negative potential with respect to cathode dc. 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 bombclrdl1lent. 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.

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 Fig. , the electron beam passes through these plates. A positive voltage applied to the Y input terminal (Vy) 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. When the voltages are applied simultaneously to vertical and horizontcl1 deflecting plates, the electron beam is deflected due to the resultant-of these two voltages.

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 *jS* short as a few microsecond, or as long as tens of seconds and minutes.

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.

Phosphor screen characteristics:

Many phosphor materials having different excitation times and colours as well as different phosphorescence times are available. The type PI, P2, PI1 or P3I are the short persistence phosphors and are used for the general purpose oscilloscope

Medical oscilloscopes require a longer phosphor decay and hence phosphors like P7 and P39 are preferred for such applications. Very slow displays like radar require long persistence phosphors to maintain sufficient flicker free picture. Such phosphors are P19, P26 and, P33.

The phosphors P19, P26, P33 have low burn resistance. The phosphors PI, P2, P4, P7, Pll have medium burn resistance while PIS, P3I have high burn resistance.

Block diagram of simple oscilloscope:
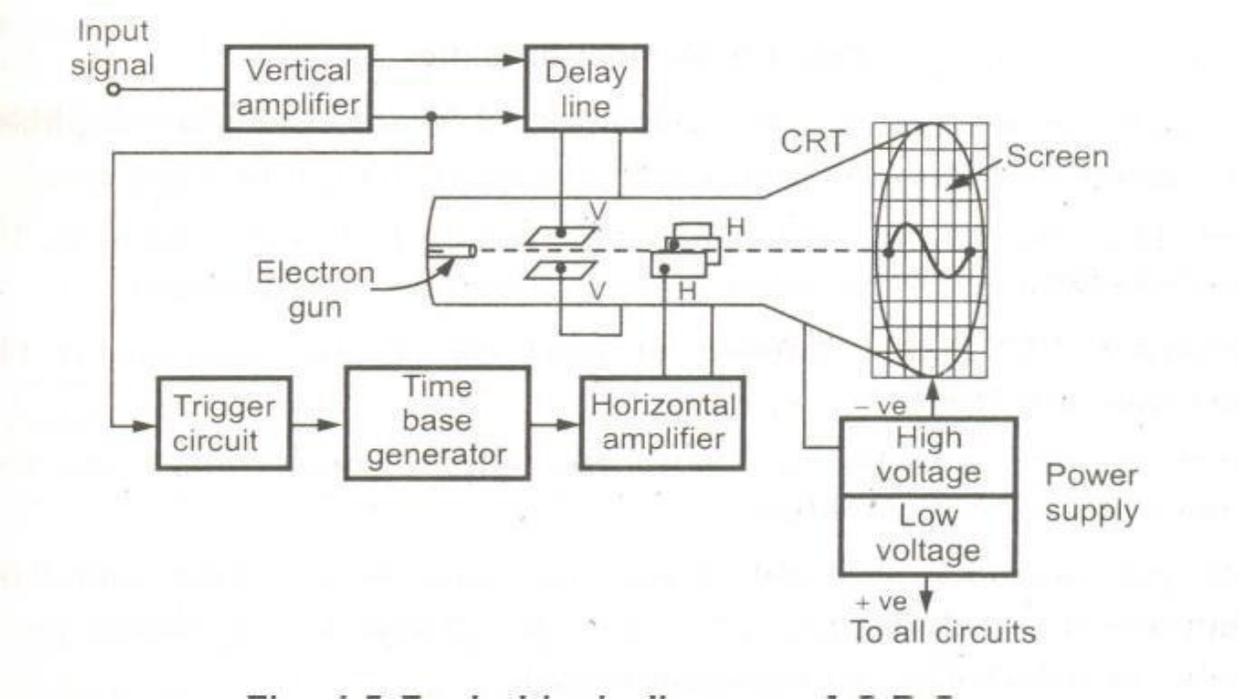
CRT:

This is the cathode ray tube which is the heart of CR.O. It is' used to emit the rlectrons 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 Jo 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.
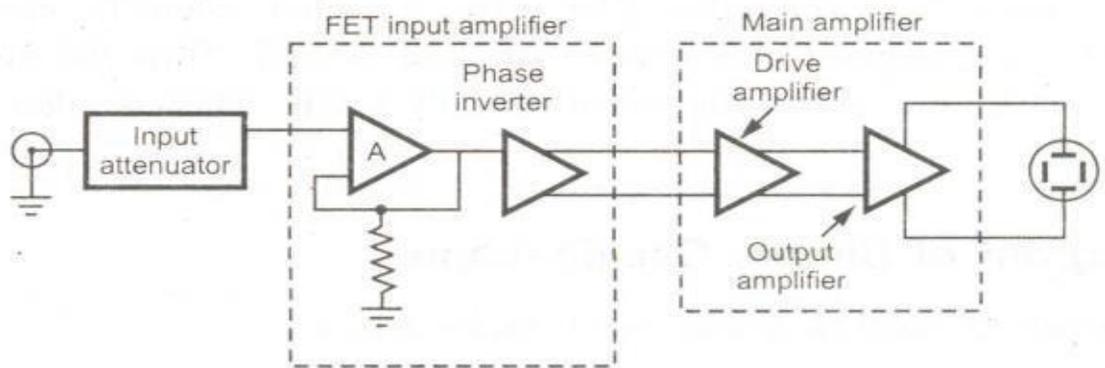
It consists of several stages with overall fixed sensltivity. The amplifier can be designed for stability and required bandwidth very easily due to the fixed gain. The input stage colrtsists of an attenuator followed by FET source follower. It has vel' high input impedance required to isolate the amplifier 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 antiphase 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 2nd 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 verticCll 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 delClyed bv some time using a delay line cu-cuit as shown in the Fig.
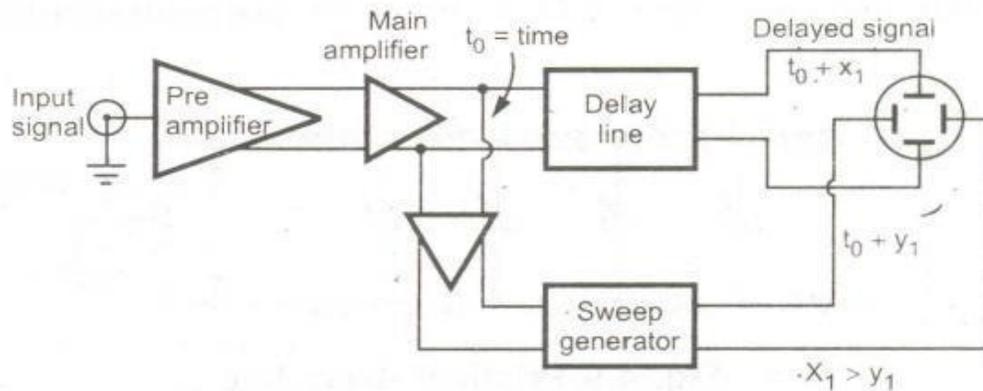
If the trigger pulse is picked off at a time t = to after the signal has passed through the main amplifier then signal is delayed by XI nanoseconds while sweep takes YI nanoseconds to reach. The design of delay line is such that the delay time XI is higher than the time YI' Generally XI is

200. nsec while tl;1.eYI is 80 ns, thus the sweep starts well in time and no part of the signal is lost. There are two types of delay lines used in CR.O. which are:

i) Lumped parameter delay line

ii) Distributed parameter 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.

Oscilloscope probes

Oscilloscopes are widely used for test and repair of electronics equipment of all types. However it is necessary to have a method of connecting the input of the oscilloscope to the point on the equipment under test that needs monitoring.

To connect the scope to the point to be monitored it is necessary to use screened cable to prevent any pick-up of unwanted signals and in addition to this the inputs to most oscilloscopes use coaxial BNC connectors. While it is possible to use an odd length of coax cable with a BNC connector on one end and open wires with crocodile / alligator clips on the other, this is not ideal and purpose made oscilloscope probes provide a far more satisfactory solution.

Oscilloscope probes normally comprise a BNC connector, the coaxial cable (typically around a metre in length) and what may be termed the probe itself. This comprises a mechanical clip arrangement so that the probe can be attached to the appropriate test point, and an earth or ground clip to be attached to the appropriate ground point on the circuit under test.

Care should be taken when using oscilloscope probes as they can break. Although they are robustly manufactured, any electronics laboratory will consider oscilloscope probes almost as "life'd" items that can be disposed of after a while when they are broken. Unfortunately the fact that they are clipped on to leads of equipment puts a tremendous strain on the mechanical clip arrangement. This is ultimately the part which breaks.

X1 and X10 oscilloscope probes

There are two main types of passive voltage scope probes. They are normally designated X1 and X10, although 1X and 10X are sometimes seen. The designation refers to the factor by which the impedance of the scope itelf is multiplied by the probe.

The X1 probes are suitable for many low frequency applications. They offer the same input impedance of the oscilloscope which is normally 1 MΩ. However for applications where better accuracy is needed and as frequencies start to rise, other test probes are needed.

To enable better accuracy to be achieved higher levels of impedance are required. To achieve this attenuators are built into the end of the probe that connects with the circuit under test. The most common type of probe with a built in attenuator gives an attenuation of ten, and it is known as a X10 oscilloscope probe. The attenuation enables the impedance presented to the circuit under test to be increased by a factor of ten, and this enables more accurate measurements to be made.

As the X10 probe attenuates the signal by a factor of ten, the signal entering the scope itself will be reduced. This has to be taken into account. Some oscilloscopes automatically adjust the scales according to the probe present, although not all are able to do this. It is worth checking before making a reading.

The 10X scope probe uses a series resistor (9 M Ohms) to provide a 10 : 1 attenuation when it is used with the 1 M Ohm input impedance of the scope itself. A 1 M Ohm impedance is the standard impedance used for oscilloscope inputs and therefore this enables scope probes to be interchanged between oscilloscopes of different manufacturers.
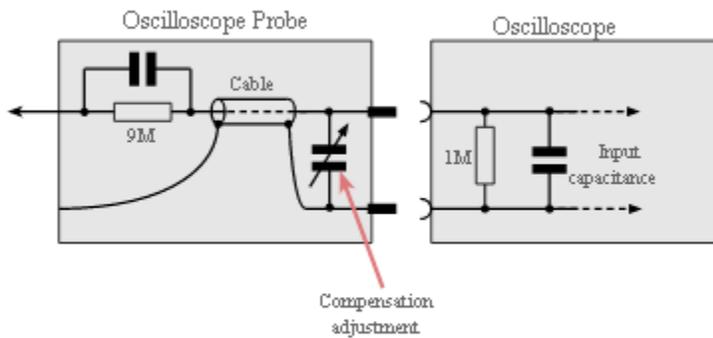
Oscilloscope probe circuit

The scope probe circuit shown is a typical one that might be seen - other variants with the variable compensation capacitor at the tip are just as common.

In addition to the X1 and X10 scope probes, X100 probes are also available. These oscilloscope probes tend to be used where very low levels of circuit loading are required, and where the high frequencies are present. The difficulty using the is the fact that the signal is attenuated by a factor of 100.

X10 oscilloscope probe compensation

The X10 scope probe is effectively an attenuator and this enables it to load the circuit under test far less. It does this by decreasing he resistive and capacitive loading on the circuit. It also has a much higher bandwidth than a traditional X1 scope probe.

The x10 scope probe achieve a better high frequency response than a normal X1 probe for a variety of reasons. It does this by decreasing the resistive and capacitive loading on the The X10 probe can often be adjusted, or compensated, to improve the frequency response.

Typical oscilloscope probe

For many scope probes there is a single adjustment to provide the probe compensation, although there can be two on some probes, one for the LF compensation and the other for the HF compensation.

Probes that have only one adjustment, it is the LF compensation that is adjusted, sometimes the HF compensation may be adjusted in the factory.

To achieve the correct compensation the probe is connected to a square wave generator in the scope and the compensation trimmer is adjusted for the required response - a square wave.

Compensation adjustment waveforms for X10 oscilloscope probe.

As can be seen, the adjustment is quite obvious and it is quick and easy to undertake. It should be done each time the probe is moved from one input to another, or one scope to another. It does not hurt to check it from time to time, even if it remains on the same input. As in most laboratories, things get borrowed and a different probe may be returned, etc . .

A note of caution: many oscilloscope probes include a X1/X10 switch. This is convenient, but it must be understood that the resistive and capacitive load on the circuit increase significantly in the X1 position. It should also be remembered that the compensation capacitor has no effect when used in this position.

As an example of the type of loading levels presented, a typical scope probe may present a load resistance of 10MΩ along with a load capacitance of 15pF to the circuit in the X10 position. For the X1 position the probe may have a capacitance of possibly 50pF plus the scope input capacitance. This may end up being of the order of 70 to 80pF.

Other types of probe

Apart from the standard 1X and 10X voltage probes a number of other types of scope probe are available.

- *Current probes:* It is sometimes necessary to measure current waveforms on an oscilloscope. This can be achieved using a current probe. This has a probe that clips around the wire and enables the current to be sensed. Sometimes using the maths functions on a scope along with a voltage measurement on another channel it is possible to measure power,

- **Active probes:** As frequencies rise, the standard passive probes become less effective. The effect of the capacitance rises and the bandwidth is limited. To overcome these difficulties active probes can be used. They have an amplifier right at the tip of the probe enabling measurements with very low levels of capacitance to be made. Frequencies of several GHz are achievable using active scope probes.

- **Differential scope probes:** In some instances it may be necessary to measure differential signals. Low level audio, disk drive signals and many more instances use differential signals and these need to be measured as such. One way of achieving this is to probe both lines of the differential signal using one probe each line as if there were two single ended signals, and then using the oscilloscope to add then differentially (i.e. subtract one from the other) to providethedifference.

  Using two scope probes in this way can give rise to a number of problems. The main one is that single ended measurements of this nature do not give the required rejection of any common mode signals (i.e. Common Mode Rejection Ratio, CMMR) and additional noise is likely to be present. There may be a different cable length on each probe that may lead to a time differences and a slight skewing between the signals.

  To overcome this a differential probe may be used. This uses a differential amplifier at the probing point to provide the required differential signal that is then passed along the scope probe lead to the oscilloscope itself. This approach provides a far higher level of performance.

- **High voltage probes:** Most standard oscilloscope voltage probes like the X1 or X10 are only specified for operation up to voltages of a few hundred volts at most. For operation higher than this a proper high voltage probe with specially insulated probe is required. It also will step down the voltage for the input to the scope so that the test instrument is not damaged by the high voltage. Often voltage probes may be X50 or X100.

# Special Purpose Oscilloscopes

Dual Beam CRO

The dual trace oscilloscope has one cathode ray gun, and an electronic switch which switches two signals to a single vertical amplifier. The dual beam CRO uses two completely separate electron beams, two sets of VDPs and a single set of HDPs. Only one beam can be synchronised at one time, since the sweep is the same for both signals, i.e. a common time base is used for both beams. Block diagram of a Dual Beam CRO.

Therefore, the signals must have the same frequency or must be relatedharmonically, in order to obtain both beams locked on the CRT screen, e.g. the input signal of an amplifier can be used as signal A and its output signal as signal
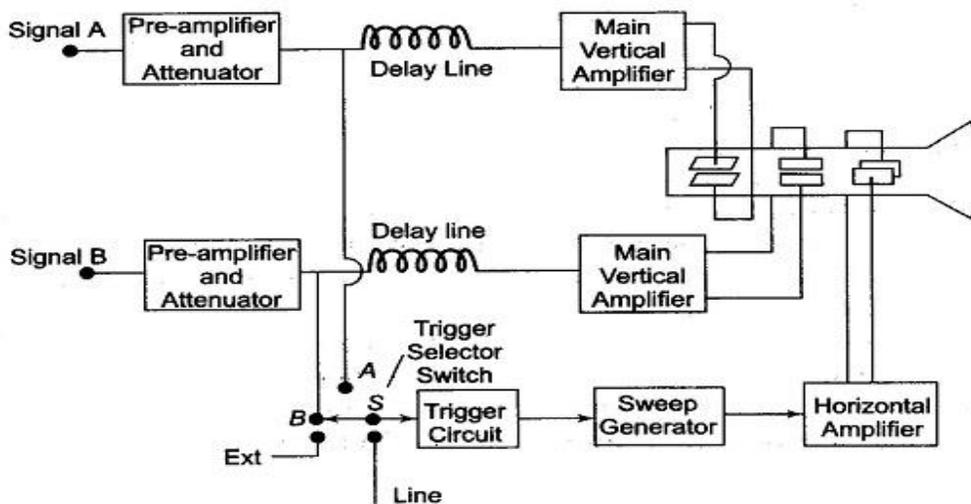
Fig. 7.18   Dual Beam CRO

B.

DUAL TRACE OSCILLOSCOPE

This CRO has a single electron gun whose electron beam is split into two by an electronic switch. There is one control for focus and another for intensity. Two signals are displayed simultaneously. The signals pass through identical vertical channels or vertical amplifiers. Each

channel has its own calibrated input attenuator and i positioning control, so that the amplitude of each signal can be ndependpntly adjusted.
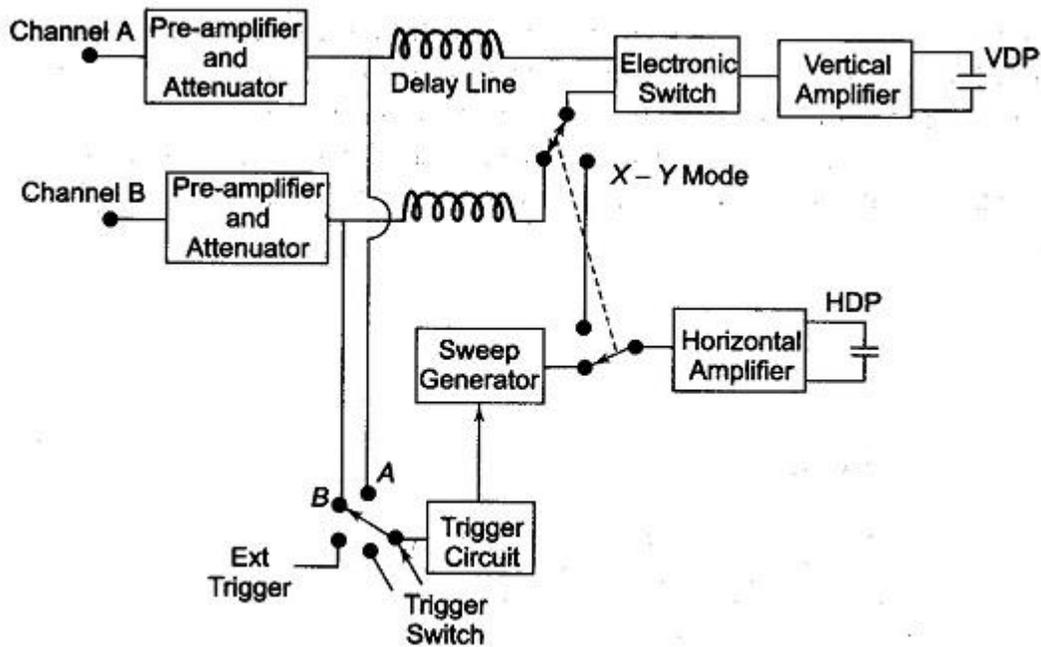
Fig. 7.19   (a) Dual Trace Oscilloscope

A mode control switch enables the electronic switch to operate in two modes. Wheri the switch is in ALTERNATE position, the electronic switch feeds each signal alternately to the vertical amplifier. The electronic switch alternately connects the main vertical amplifier to channels A and **B** and adds a different dc component to each signal; this dc component directs the beam alternately to the upper or lower half of the screen. The switching takes place at the start of each new sweep of the sweep generator. The switching rate of theelectronic switch is synchronised to the sweep rate, so that the CRT spot traces the channel A signal on one sweep and the channel B signal on the succeeding sweep [Fig. 7.19 (b)]
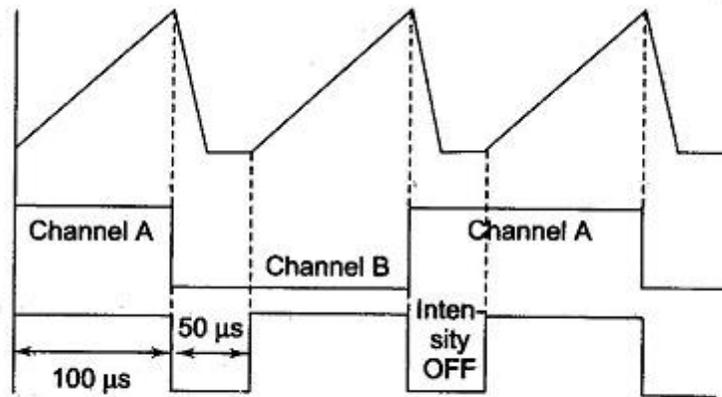
Fig. 7.19 (b) Time Relation of a Dual-Channel Vertical Amplifier in Alternate Mode

The sweep trigger signal is available from channels A or B and the trigger pick-off takes place before the electronic switch. This arrangement maintains the correct phase relationship between signals A and B.

When the switch is in the CHOP mode position, the electronic switch is free running at the rate of 100-500 kHz, entirely independent of the frequency of the sweep generator. The switch successively connects small segments of A and B waveforms to the main vertical amplifier at a relatively fast chopping rate of 500 kHz e.g. 1 i.ts segments of each waveform are fed to the CRT display (Fig. 7.19 (c)).

If the chopping rate is slow, the continuity of the display is lost and it is better to use the alternate mode of operation. In the added mode of operation a single image can be displayed by the addition of signal from channels A and B, i.e. (A + B), etc. In the X — Y mode of operation, the sweep generator is disconnected and channel B is connected to the horizontal amplifier. Since both preamplifiers are identical and have the same delay time, accurate X — Y measurements can be made.

Dual trace Oscilloscope(0-15MHz)

Block Description Y-Channels

A and B vertical channels are identical for producing the dual trace facility. Each comprises an input coupling switch, an input step attenuator, a source follower input stage with protection

circuit, a pre-amplifier from which a trigger signal is derived and a combined final amplifier. The input stage protection circuit consists of a diode, which prevents damage to the FET transistors that could occur with excessive negative input potentials, and a resistor network which protects the input stage from large positive voltage swings.

As the transistors are the balanced pre-amplifier stage, they share the same IC block. The resulting stabilisation provides a measure of correction to reduce the drift inherent in high gain amplifiers. The trigger pick-off signal is taken from one side of the balanced pre-amplifier to the trigger mode switch, where either channel A or channel **B** triggering can be selected. The supply for the output of the pre-amplifier stage is derived from a constant current source controlled by the channel switching logic. Under the control of channel switching, signals from A and **B** channels are switched to the final amplifier. The combined balanced final amplifier is a direct coupled one to the Y-plates of the CRT (refer to Fig. 7.20).

Channel Switching

The front panel A and B channel selection (push button or switch), controls an oscillator in the CHOP mode. For channel switching electronic switching logic and a F/F is used. When either A or B channels are selected, the F/F is switched to allow the appropriate channel.

In the ALTERNATE mode, a pulse from the sweep-gating multivibrator via the electronic switching logic, switches the F/F, thus allowing A and B channels for alternate sweeps.

In the CHOP mode, the oscillator is switched via the logic stage to provide rapid switching of the channels via the F/F.

Triggering

A triggering signal can be obtained from the vertical amplifier of Channels A and **B** from an external source or internally from the mains supply (LINE triggering). The triggering signal is selected and normally fed via the amplifier stage to the pulse shaper, which supplies well defined trigger pulses to the sweep-gating multivibrator for starting the sawtooth generator.

Triggering from the TV line and frame signals can be obtained from the sync separator and peak detector stages. The latter stage is switched into circuit in the TOP position.

Time Base

The time base generator circuit operates on the constant current integrator principle.

The sweep-gating multivibrator, triggered by pulses from the differentiator and auto circuits, starts the sawtooth generator. Sweep signals are fed to the final X-amplifier.

A gate pulse is supplied by the sweep-gating multivibrator for unblanking the CRT during the forward sweep. In addition this pulse is supplied to an external socket for probe adjustment via a diode network.

X–Channel

Under the control of diode switching from the TIME/DIV switch, the X- amplifier receives its input signal from either the time base sawtooth generator or from an external source (X-EXT input socket via the **X** and trigger pre-amplifier). The X-MAGN (x 5) circuit is incorporated in the X-final amplifier. The output of this amplifier is direct coupled to the horizontal deflection plates of the CRT.

Cathode–Ray Tube Circuit and Power Supply

The high voltages required for the CRT, which has an acceleration potential of 1.5 kV, are generated by a voltage multiplier circuit controlled by a stabilised power supply. The CRT beam current is controlled by:

The intensity potentials network across the Extra High Tension (EHT) supply. During flyback (movement of electron beam from right to left) by the blanking pulses coming from the sawtooth generator via the beam blanking stages to blank the trace during right to left movement of the electron.

Regulation of the mains input voltage is achieved by a diode clipper network controlled by a signal fed back from an LED in the + 14 V rectifier supply.

SAMPLING OSCILLOSCOPE (VHF)

An ordinary Sampling Oscilloscope has a B.W. of 10 MHz. The HF performance can be improved by means of sampling the input waveform and reconstructing its shape from the sample, i.e. the signal to be observed is sampled and after a few cycles 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.
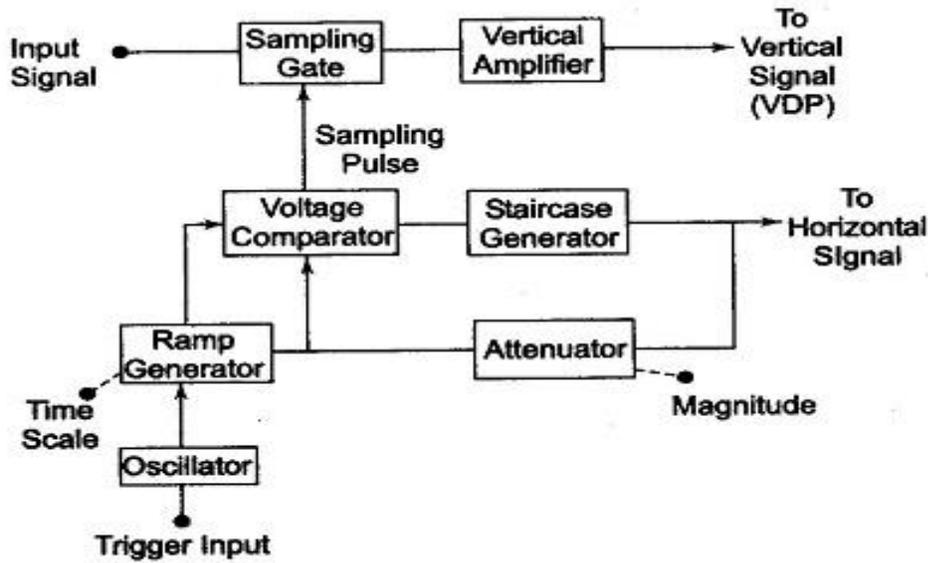

Fig. 7.24   Sampling Oscilloscope

Figure 7.24 shows a block diagram of a 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 synchronised with the input signal frequency. The signal is delayed in thevertical amplifier, allowing the horizontal sweep to be initiated by the input signal. The waveforms are shown in Fig. 7.25.
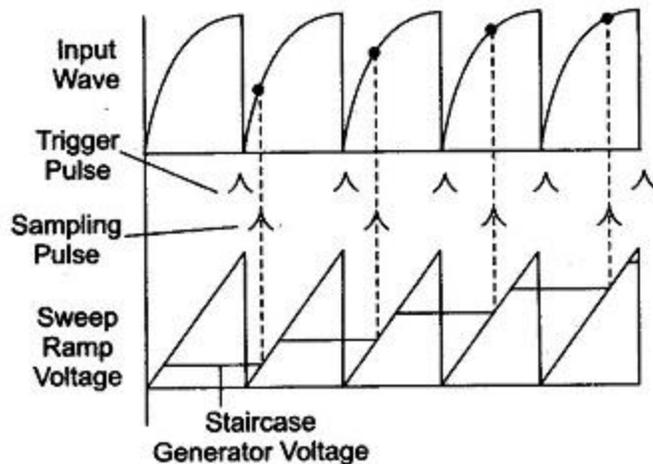
Fig. 7.25 Various Waveforms at Each Block of a Sampling Oscilloscope

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.

STORAGE OSCILLOSCOPE

Storage targets can be distinguished from standardphosphor targets by their ability to retain a waveform pattern for a long time, independent of phosphor peristence. Two storage techniques are used in oscilloscope CRTs, mesh storage and phosphor storage.

A mesh-Storage Oscilloscope uses a dielectric material deposited on a storage mesh as the storage target. This mesh is placed between the deflection plates and the standard phosphor target in the CRT. The writing beam, which is the focussed electron beam of the standard CRT, charges the dieletric material positively where hit. The storage target is then bombarded with low velocity electrons from a flood gun and the positively charged areas of the storage target allow these electrons to pass through to the standardphosphor target and thereby reproduce

the stored image on the screen. Thus the mesh storage has both a storage target and a phosphor display target. The phosphor Storage Oscilloscope uses a thin layer of phosphor to serve both as the storage and the display element.

Mesh Storage

It is used to display Very Low Frequencies (VLF) signals and finds many applications in mechanical and biomedical fields. The conventional scope has a display with a phosphor peristence ranging from a few micro seconds to a few seconds. The persistence can be increased to a few hours from a few seconds.
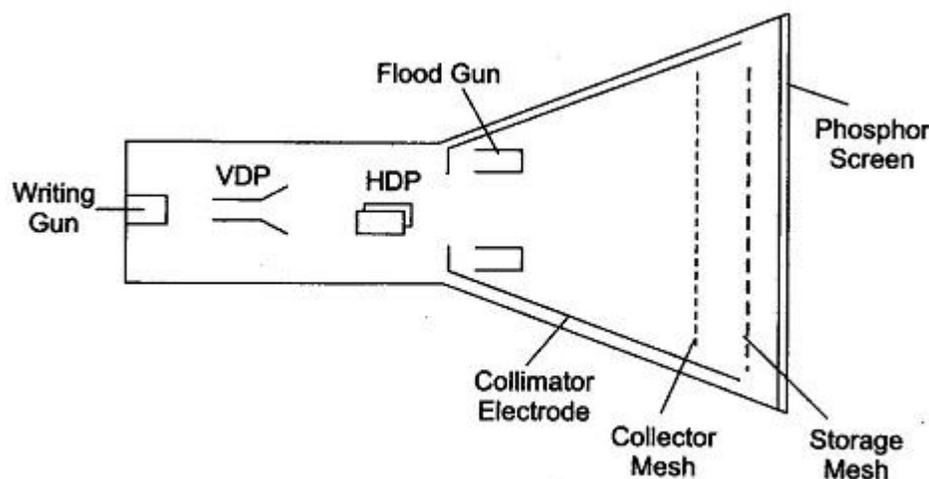
Fig. 7.26   Basic Elements of Storage Mesh CRT

A mesh Storage Oscilloscope, shown in Fig. 7.26, contains a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, in addition to all the elements of a standard CRT. The storage target, a thin deposition of a dielectric material such as Magnesium Fluoride on the storage mesh, makes use of a property known as secondary emission. The writing gun etches a positively charged pattern on the storage mesh or target by knocking off secondary emission electrons. Because of the excellent insulating property of the Magnesium Fluoride coating, this positively charged pattern remains exactly in the position where it is deposited. In order to make a pattern visible, a special electron gun, called the flood gun, is switched on (even after many hours).

The electron paths are adjusted by the collimator electrode, which constitutes a low voltage electrostatic lens system (to focus the electron beam), as shown in Fig. 7.27. Most of the

electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen. The CRT will now display the signal and it will remain visible as long as the flood guns operate. To erase the pattern on the storage mesh, a negative voltage is applied to neutralise the stored positive charge.
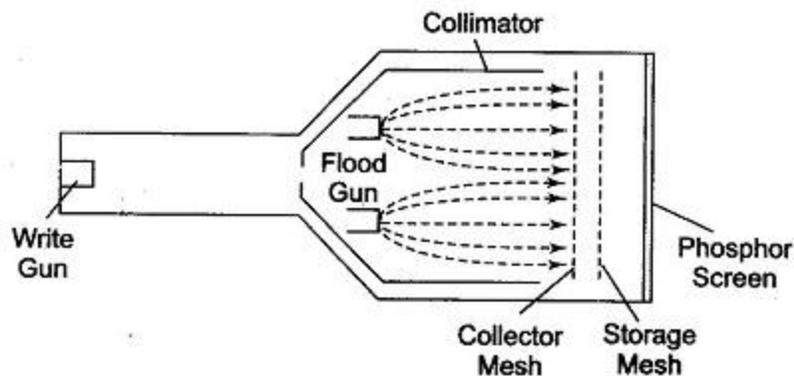
Fig. 7.27   Storage Mesh CRT

Since the storage mesh makes use of secondary emission, between the first and second crossover more electrons are emitted than are absorbed by the material, and hence a net positive charge results.

Below the first crossover a net negative charge results, since the impinging electrons do not have sufficient energy to force an equal number to be emitted. In order to store a trace, assume that the storage surface is uniformly charged and write gun (beam emission gun) will hit the storage target. Those areas of the storage surface hit by the deflecting beam lose electrons, which are collected by the collector mesh. Hence, the write beam deflection pattern is traced on the storage surface as a positive charge pattern. Since the insulation of the dielectric material is high enough to prevent any loss of charge for a considerable length of time, the pattern is stored. To view, the stored trace, a flood gun is used when the write gun is turned off.

The flood gun, biased very near the storage mesh potential, emits a flood of electrons which move towards the collector mesh, since it is biased slightly more positive than the deflection region. The collimator, a conductive coating on the CRT envelope with an applied potential, helps to align the flood electrons so that they approach the storage target perpendicularly.

When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region on the storage surface or a negatively charged region where no trace has been stored.

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

Figure 7.28 shows a display of the stored charge pattern on mesh storage.
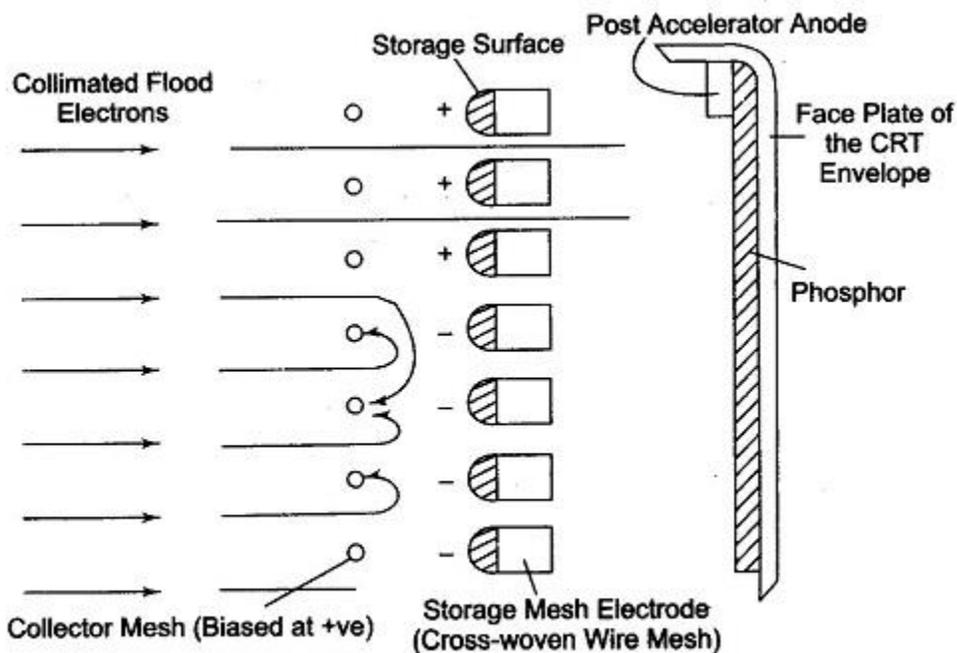
Fig. 7.28   Display of Stored Charged Pattern on a Mesh-storage

Digital Storage Oscilliscope

Digital Storage Oscilliscopes are available in processing and non-processing types. Processing types include built in computing power, which takes advantage of the fact that all data is already in digital form.

The inclusion of interfacing and a microprocessor provides a complete system for information acquisition, analysis and output. Processing capability ranges from simple functions (such as average, area, rms, etc.) to complete Fast Fourier Transform (FFT) spectrum analysis capability.

Non–processing digital scopes are designed as replacements for analog instruments for both storage and non-storage types. Their many desirable features may lead to replace analog scopes entirely (within the Bandwidth range where digitization in feasible).

The basic principle of a digital scope is given in Fig. 7.51. The scope operating controls are designed such that all confusing details are placed on the back side and one appears to be using a conventional scope. However, some digital scope panels are simpler also; most digital scopes provide the facility of switching selectable to analog operation as one of the operating modes.

The basic advantage of digital operation is the storage capability, the stored waveform can be repetitively read out, thus making transients appear repetitively and allowing their convenient display on the scope screen. (The CRT used in Digital Storage Oscilliscope is an ordinary CRT, not a storage type CRT.)

Furthermore, the voltage and time scales of display are easily changed after the waveform has been recorded, which allows expansion (typically to 64 times) of selected portions, to observe greater details.

A cross-hair cursor can be positioned at any desired point on the waveform and the voltage/time values displayed digitally on the screen, and/or readout electrically.

Some scopes use 12 bit converters, giving 0.025% resolution and 0.1% accuracy on voltage and time readings, which are better than the 2-5% of analog scopes.

Split screen capabilities (simultaneously displaying live analog traces and replayed stored ones) enable easy comparison of the two signals.

Pretrigger capability is also a significant advantage. The display of stored data is possible in both amplitude versus time and X- Y modes. In addition to the fast memory readout used for CRT display, a slow readout is possible for producing hard copy with external plotters.

When more memory than the basic amount (typically 4096 points/words) is needed, a magnetic disk accessory allows expansion to 32,000 points.

All Digital Storage Oscilliscope scopes are limited in bandwidth by the speed of their A/D converters. However, 20 MHz digitizing rates available on some scopes yield a 5 MHz bandwidth, which is adequate for most applications.

Consider a single channnel of Fig. 7.51. The analog voltage input signal is digitised in a 10 bit A/D converter with a resolution of 0.1% (1 part in 1024) and frequency response of 25 kHz. The total digital memory storage capacity is 4096 for a single channel, 2048 for two channels each and 1024 for four channels each.
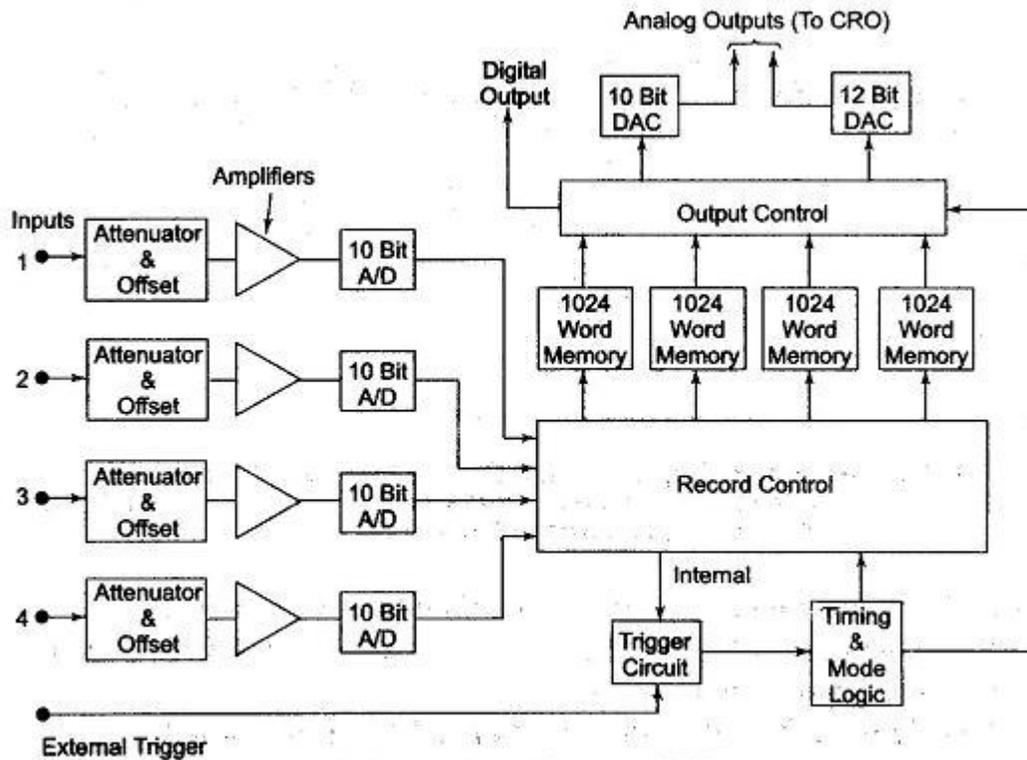
Fig. 7.51   Digital Storage CRO

The analog input voltage is sampled at adjustable rates (up to 100,000 samples per second) and data points are read onto the memory. A maximum of 4096 points are storable in this particular instrument. (Sampling rate and memory size is selected to suit the duration and waveform of the physical event being recorded.)

Once the sampled record of the event is captured in memory, many useful manipulations are possible, since memory can be read out without being erased.

If the memory is read out rapidly and repetitively, an input event which was a single shot transient becomes a repetitive or continuous waveform that can be observed easily on an ordinary scope (not a storage scope). The digital memory also may be read directly (without going through DAC) to, say, a computer where a stored program can manipulate the data in almost any way desired.

Pre-triggering recording allows the input signal preceding the trigger points to be recorded. In ordinary triggering the recording process is started by the rise of the input (or some external triggering) above some preset threshold value.

As in digital recorder, DSO can be set to record continuously (new data coming into the memory pushes out old data, once memory is full), until the trigger signal is received; then the recording is stopped, thus freezing data received prior to the trigger signal in the memory.

An adjustable trigger delay allows operator control of the stop point, so that the trigger may occur near the beginning, middle or end of the stored information.

Digital Storage Oscilliscope Features

1. Sampling rate 20 Mega-samples per second per channel. Max. (simultaneous) capture of both channels.

2. Pre-trigger: 25%, 50%, 75%, for Single Shot, Roll normal.

3. Roll mode: (Continuous and Single Shot with Pre-trigger of 25%, 50%, 75%)

4. Single shot (0.5 p.s Single shot @ 10 pts. /div resolution with pre-trigger 25%, 50%, 75%)

5. Digital Sweep rate: 0.5. μs/cm to 50 sec/cm, (event as long as 8.33 minutes can be captured)

6. Computer built in Interface: (RS 232 Serial port and Centronics Parallel interface).

UNIT-4

Transducers

Transducer is a device that converts energy in one form of energy to another form of energy. This converts non-electrical quantity into electrical quantity.

A transducer is defined as a device that receives energy from one system and transmits it to another, often in a different form.

Broadly defined, the transducer is a device capable of being actuated by an energising input from one or more transmission media and in turn generating a related signal to one or more transmission systems. It provides a usable output in response to a specified input measurand, which may be a physical or mechanical quantity, property, or conditions. The energy transmitted by these systems may be <u>electrical</u>, mechanical or acoustical.

The nature of electrical output from the transducer depends on the basic principle involved in the design. The output may be analog, digital or frequency modulated.

Basically, there are two types of transducers, electrical, and mechanical. Transducer is a device that converts energy in one form of energy to another form of energy. This converts non-electrical quantity into electrical quantity.

A transducer is defined as a device that receives energy from one system and transmits it to another, often in a different form.

Broadly defined, the transducer is a device capable of being actuated by an energising input from one or more transmission media and in turn generating a related signal to one or more transmission systems. It provides a usable output in response to a specified input measurand, which may be a physical or mechanical quantity, property, or conditions. The energy transmitted by these systems may be <u>electrical</u>, mechanical or acoustical.

The nature of electrical output from the transducer depends on the basic principle involved in the design. The output may be analog, digital or frequency modulated.

Basically, there are two types of transducers, electrical, and mechanical.

Electrical Transducer Definition

An electrical transducer is a sensing device by which the physical, mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an <u>electrical voltage</u>/current proportional to the input measurand.

An electrical transducer must have the following parameters:

Electrical Transducer Definition

An electrical transducer is a sensing device by which the physical, mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an electrical voltage/current proportional to the input measurand.

An electrical transducer must have the following parameters:

1. **Linearity:** The relationship between a physical parameter and the resulting electrical signal must be linear.

2. **Sensitivity:** This is defined as the electrical output per unit change in the physical parameter (for example V/°C for a temperature sensor). High sensitivity is generally desirable for a transducer.

3. **Dynamic Range:** The operating range of the transducer should be wide, to permit its use under a wide range of measurement conditions.

   4. **Repeatability:** The input/output relationship for a transducer should be predictable over a long period of time. This ensures reliability of

   5. **Physical Size:** The Electrical Transducer Definition must have minimal weight and volume, so that its presence in the measurement system does not disturb the existing conditions.

Advantages of Electrical Transducer

The main advantages of electrical transducer (conversion of physical quantity into electrical quantities) are as follows:

1. Electrical amplification and attenuation can be easily done.

2. Mass-inertia effects are minimised.

3. Effects of friction are minimised.

4. The output can be indicated and recorded remotely at a distance from the sensing medium.

5. The output can be modified to meet the requirements of the indicating or controlling units. The signal magnitude can be related in terms of the voltage current. (The analog signal information can be converted in to pulse or frequency information. Since output can be modified, modulated or amplified at will, the output signal can be easily used for recording on any suitable multichannel recording device.)

6. The signal can be conditioned or mixed to obtain any combination with outputs of similar transducers or control signals.

7. The electrical or electronic system can be controlled with a very small power level.

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

Electrical transducer can be broadly classified into two major categories,

Classification of transducers

- *Primary and Secondary Transducers*

- *Analog and Digital Transducers*

- *Active and Passive Transducers*

- *Transducers and Inverse Transducers*

- *Primary and Secondary Transducers*

  When the input signal is directly sensed by the transducer and physical phenomenon is converted into the electrical form directly then such a transducer is called the primary transducer.

  Example: The thermistor senses the temperature directly and causes the change in resistance with the change in temperature.

  When the input signal is sensed first by some detector or sensor and then its output being of some form other than input signals is given as input to a transducer for conversion into electrical form, then such a transducer falls in the category of secondary transducers.

  For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT.

- *Analog and Digital Transducers*

Analog transducer converts input signal into output signal, which is a continuous function of time such as thermistor, strain gauge, LVDT, thermo-couple etc.

Digital transducer converts input signal into the output signal of the form of pulse e.g. it gives discrete output.

- *Transducers and Inverse Transducers*

Transducer, as already defined, is a device that converts a non-electrical quantity into an electrical quantity.

Normally a transducer and associated circuit has a non-electrical input and an electrical output, for example a thermo-couple, photoconductive cell, pressure gauge, strain gauge etc.

An inverse transducer is a device that converts an electrical quantity into a non-electrical quantity.

Example: piezoelectric oscillator

- *Active and Passive Transducers*

An **active transducer** generates an electrical signal directly in response to the physical parameter and does not require an external power source for its operation. Active transducers are self generating devices, which operate under energy conversion principle and generate an equivalent output signal (for example from pressure to charge or temperature to electrical potential).

Typical example of active transducers are piezo electric sensors (for generation of charge corresponding to pressure) and photo voltaic cells (for generation of voltage in response to illumination).

Passive transducer operate under energy controlling principles, which makes it necessary to use an external electrical source with them. They depend upon the change in an electrical parameter (R, L and C).

Typical example are strain gauges (for <u>resistance</u> change in response to pressure), and thermistors (for <u>resistance</u> change corresponding to temperature variations).

Electrical transducer is used mostly to measure non-electrical quantities. For this purpose a detector or sensing element is used, which converts the physical quantity into a displacement. This displacement actuates an electric transducer, which acts as a secondary transducer and gives an output that is electrical in nature. This electrical quantity is measured by the <u>standard</u>method used for electrical measurement. The electrical signals may be current, voltage, or frequency; their production is based on R, L and C effects.

A transducer which converts a non-electrical quantity into an analog electrical signal may be considered as consisting of two parts, the sensing element, and the transduction element.

The sensing or detector element is that part of a transducer which responds to a physical phenomenon or to a change in a physical phenomenon. The response of the sensing element must be closely related to the physical phenomenon.

The transduction element transforms the output of a sensing element to an **electrical output**. This, in a way, acts as a secondary transducer.

Transducers may be further classified into different categories depending upon the principle employed by their transduction elements to convert physical phenomena into output **electrical** signals.

Selecting a Transducer

The transducer or sensor has to be physically compatible with its intended application. The following should be considered while selecting a transducer.

1. **Operating range:** Chosen to maintain range requirements and good

2. **Sensitivity:** Chosen to allow sufficient output.

3. **Frequency response and resonant frequency:** Flat over the entire desired range.

4. **Environmental compatibility:** Temperature range, corrosive fluids, pressure, shocks, interaction, size and mounting restrictions.

5. **Minimum sensitivity:** To expected stimulus, other than the measurand.

6. **Accuracy:** Repeatability and calibration errors as well as errors expected due to sensitivity to other stimuli.

7. **Usage and ruggedness:** Ruggedness, both of mechanical and electrical intensities versus size and weight.

8. **Electrical parameters:** Length and type of cable required, signal to noise ratio when combined with amplifiers, and frequency response limitations.

Resistive Transducer

Resistive Transducers are those in which the resistance changes due to a change in some physical phenomenon. The change in the value of the resistance with a change in the length of the conductor can be used to measure displacement.

Strain gauges work on the principle that the resistance of a conductor or semiconductor changes when strained. This can be used for the measurement of displacement, force and pressure.

The resistivity of materials changes with changes in temperature. This property can be used for the measurement of temperature.

$$R = \frac{\rho L}{A}$$

Potentiometer(Displacement Transducer)

A resistive potentiometer (pot) consists of a resistance element provided with a sliding contact, called a wiper. The motion of the sliding contact may be translatory or rotational. Some have a combination of both, with resistive elements in the form of a helix, as shown in Fig. 13.1(c). They are known as helipots.

Translatory resistive elements, as shown in Fig. 13.1(a), are linear (straight) devices. Rotational resistive devices are circular and are used for the measurement of angular displacement, as shown in Fig. 13.1(b).

Helical resistive elements are multi turn rotational devices which can be used for the measurement of either translatory or rotational motion. A potentiometer is a passive transducer since it requires an <u>external power</u> source for its operation.

Advantage of Potentiometers

1. They are inexpensive.

2. Simple to operate and are very useful for applications where the requirements are not particularly severe.

3. They are useful for the measurement of large amplitudes of displacement.

4. Electrical efficiency is very high, and they provide sufficient output to allow control operations.

Disadvantages of Potentiometers

1. When using a linear potentiometer, a large force is required to move the sliding contacts.

2. The sliding contacts can wear out, become misaligned and <u>generate noise.</u>
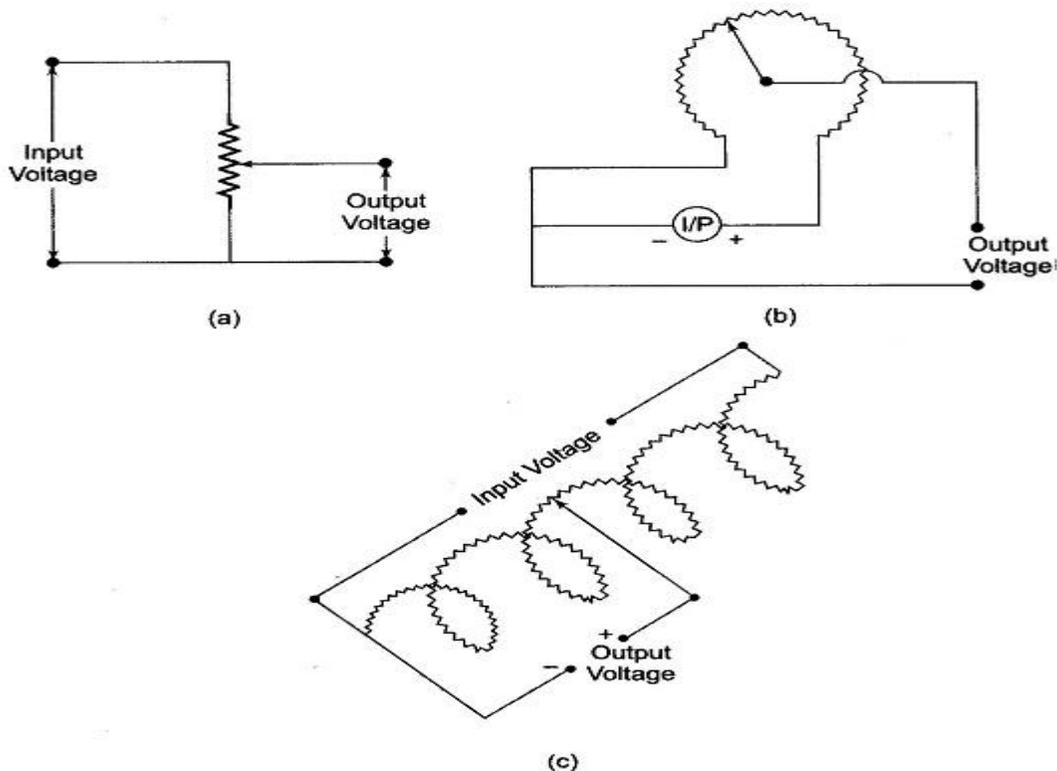
Fig. 13.1   (a) Translatory Type (b) Rotational Type (c) Helipot (Rotational)

Strain gauges

The strain gauge is an example of a passive transducer that uses electric resistance variation in wires to sense the strain produced by a force on wires. It is a very versatile detector and transducer for measuring weight, pressure, mechanical force, or displacement.

The construction of a bonded strain gauge (see figure) shows a fine wire element looped back and forth on a mounting plate, which is usually cemented to the member undergoing stress. A tensile stress tends to elongate the wire and thereby increase its length and decrease its cross-sectional area.

Bonded type strain gauges are three types, namely

1. **Wire Strain Gauges**

2. **Foil Strain Gauge**

3. **Semiconductor Strain Gauge**

1. Wire Strain Gauges:

Wire Strain Gauges has three types namely,

1. Grid type
2. Rossette type
3. Torque type
4. Helical type
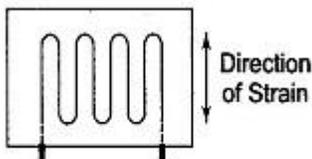
Fig. 13.6   Grid Type Strain Gauge

The grid arrangement of the wire element in a bonded strain gauge creates a problem not encountered in the use of unbonded strain gauges. To be useful as a strain gauge, the wire element must measure strain along one axis. Therefore complete and accurate analysis of strain in a rigid member is impossible, unless the direction and magnitude of stress are known. The measuring axis of a strain gauge is its longitudinal axis, which is parallel to the wire element, as shown in Fig. 13.6.

When a strain occurs in the member being measured, along the transverse axis of the gauge, it also affects the strain being measured parallel to the longitudinal axis. This introduces an error in the response of the gauge.

In most applications, some degree of strain is present along the transverse axis and the transverse sensitivity must be considered in the final gauge output. Transverse sensitivity cannot be completely eliminated, and in highly accurate measurements the resultant gauge error must be compensated for.

If the axis of the strain in a component is unknown, Strain Gauge Transducer Types may be used to determine the exact direction. The standard procedure is to place several gauges at a point on the member's surface, with known angles between them. The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member.

Contd...
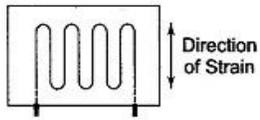
Fig. 13.6   Grid Type Strain Gauge
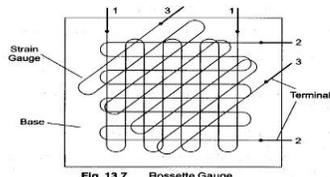
Fig. 13.7   Rossette Gauge
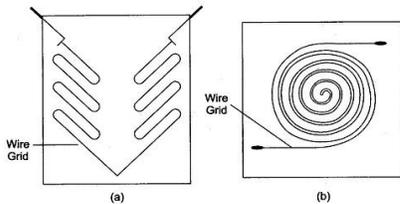
Fig. 13.8   (a) and (c) Torque Type Gauge (b) Helical Gauge
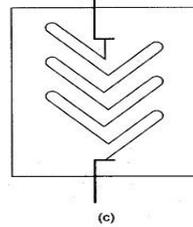
Characteristics of a resistance wire strain gauge

- The Strain Gauge Transducer Types should have a high value of gauge factor (a high value of gauge factor indicates a large change in resistance for particular strain, implying high sensitivity).

- The resistance of the strain gauge should be as high as possible, since this minimizes the effects of undesirable variations of resistance in the measurement circuit. A high resistance value results in lower sensitivity.

- The strain gauge should have a low resistance temperature coefficient.

- The strain gauge should not have hysteresis effects in its response

- The variation in resistance should be a linear function of the strain.

- Strain gauges are frequently used for dynamic measurements and hence their frequency response should be good.

- Leads used must be of materials which have low and stable resistivity and lowresistance temperature coefficient.

Foil Strain Gauge

This class of strain gauges is an extension of the <u>resistance</u> wire strain gauge. The strain is sensed with the help of a metal foil. The metals and alloys used for the foil and wire are nichrome, constantan (Ni + Cu), isoelastic (Ni + Cr + Mo), nickel and platinum.

Foil gauges have a much greater dissipation capacity than wire wound gauges, on account of their larger surface area for the same volume. For this reason, they can be used for a higher operating temperature range. Also, the large surface area of foil gauges leads to better bonding.

Foil type <u>Strain Gauge Transducer Types</u> have similar characteristics to wire strain gauges. Their gauge factors are typically the same.

The advantage of foil type <u>Strain Gauge Transducer Types</u> is that they can be fabricated on a large scale, and in any shape. The foil can also be etched on a carrier.

Etched foil gauge construction consists of first bonding a layer of strain sensitive material to a thin sheet of paper or bakelite. The portion of the metal to be used as the wire element is covered with appropriate masking material, and an etching solution is applied to the unit. The solution removes that portion of the metal which is not masked, leaving the desired grid structure intact.

This method of construction enables etched foil strain gauges to be made thinner than comparable wire units, as shown in Fig. 13.9. This characteristic, together with a greater degree of flexibility, allows the etched foil to be mounted in more remote and restricted places and on a wide range of curved surfaces. The <u>resistance</u> value of commercially available foil gauges is between 50 and 1000 Ω
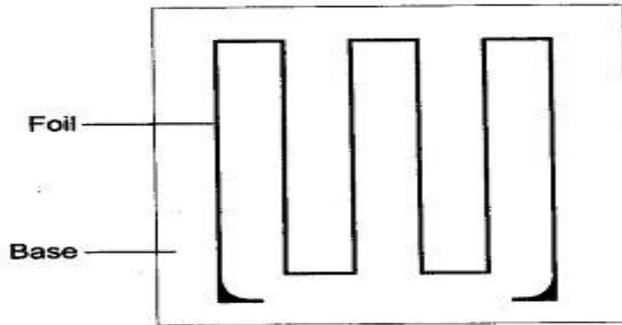
Fig. 13.9   Foil Type Strain Gauge

Semiconductor Strain Gauge

To have a high sensitivity, a high value of gauge factor is desirable. A high gauge factor means relatively higher change in resistance, which can be easily measured with a good degree of accuracy.

Semiconductor strain gauges are used when a very high gauge factor is required. They have a gauge factor 50 times as high as wire strain gauges. The resistance of the semiconductor changes with change in applied strain.

Semiconductor strain gauges depend for their action upon the piezo resistive effect, i.e. change in value of the resistance due to change in resistivity, unlike metallic gauges where change in resistance is mainly due to the change in dimension when strained. Semiconductor materials such as germanium and silicon are used as resistive materials.

A typical strain gauge consists of a strain material and leads that are placed in a protective box, as shown in Fig. 13.10. Semiconductor wafer or filaments which have a thickness of 0.05 mm are used. They are bonded on suitable insulating substrates, such as Teflon.
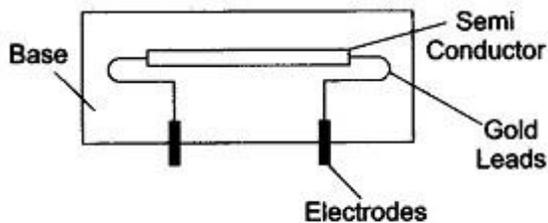
Fig. 13.10   Semiconductor Strain Gauge

Gold leads are generally used for making contacts. These strain gauges can be fabricated along with an IC Op Amp which can act as a pressure sensitive transducer. The large gauge factor is accompanied by a thermal rate of change of <u>resistance</u> approximately 50 times higher than that for resistive gauges. Hence, a semiconductor strain gauge is as stable as the metallic type, but has a much higher output.

Simple temperature compensation methods can be applied to semiconductor strain gauges, so that small values of strain, that is micro strains, can also be measured.

Advantages of Semiconductor Strain Gauge

1. Semiconductor strain gauges have a high gauge factor of about + 130. This allows measurement of very small strains, of the order of 0.01 micro

2. Hysteresis characteristics of semiconductor strain gauges are excellent, e. less than 0.05%.

3. Life in excess of 10 x 10^6 operations and a frequency response of 10^{12} HZ.

4. Semiconductor strain gauges can be very small in size, ranging in length from 0.7 to 7.0 mm.

Disadvantages of Semiconductor Strain Gauge

1. They are very sensitive to changes in temperature.

2. Linearity of semiconductor strain gauges is poor.

3. They are more expensive.

Temperature Transducers

- Resistance Temperature Detectors (RTD)
- Thermocouples
- Thermistor

Resistance Temperature Detector (RTD)

Detectors of wire resistance temperature common employ platinum, nickel or resistance wire elements, whose resistance variation with temperature has high intrinsic accuracy. They are

available in many configurations and size and as shielded or open units for both immersion and surface applications.

The relationship between temperature and resistance of conductors can be calculated from the equation:

$$R = R_{\mathrm{o}}\left(1 + \alpha \Delta T\right)$$

where

R   = the resistance of the conductor at temperature t (^{0}C)

R_0 = the resistance at the reference temperature, usually 20^{0}C

α   = the temperature coefficient of resistance

ΔT   = the difference between the operating and the reference temperature

Thermistor

A thermistor is a semiconductor made by sintering mixtures of metallic oxide, such as oxides of manganese, nickel, cobalt, copper and uranium.

Termistors have negative temperature coefficient (NTC). That is, their resistance decreases as their temperature rises.

Types of thermistor   Resistance

    Disc   1 to 1MΩ

    Washer   1 to 50kΩ

    Rod   high resistance
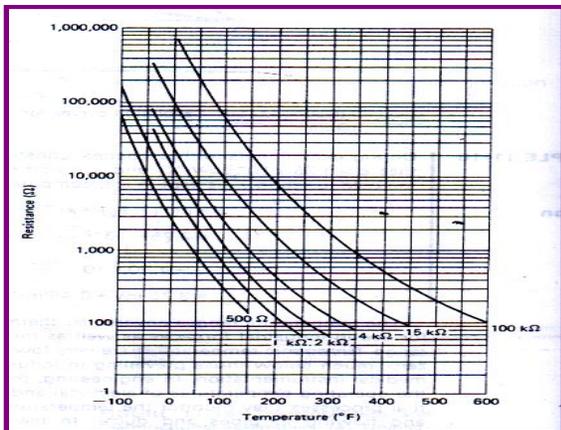
This figure shows resistance versus temperature for a family thermistor. The resistance value marked at the bottom end of each curve is a value at 25^0C

The resistance decreases as their temperature rises-NTC

Advantages of thermistor

• Small size and low cost

• Fast response over narrow temperature range

• Good sensitivity in Negative Temperature Coefficient

(NTC) region

• Cold junction compensation not required due to dependence

of resistance on absolute temperature.

• Contact and lead resistance problems not encountered due

to large resistance

Limitations of thermistor

• Non linearity in resistance vs temperature characteristics

• Unsuitable for wide temperature range

• Very low excitation current to avoids self heating

• Need of shielded power lines, filters, etc due to high resistance

Thermocouples

It consists of two wires of different metals are joined together at one end, a temperature difference between this end and the other end of wires produces a voltage between the wires. The magnitude of this voltage depends on the materials used for the wires and the amount of temperature difference between the joined ends and the other ends.
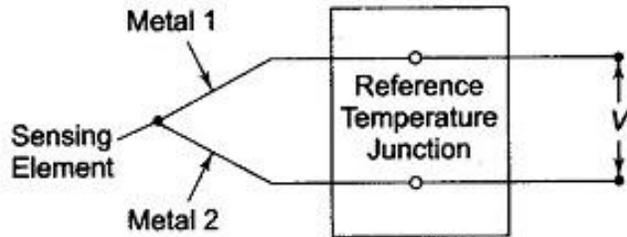
| Fig. 13.41 | Basic Thermocouple Connection |
| Fig. 13.42 | Current through Two dissimilar Metals |
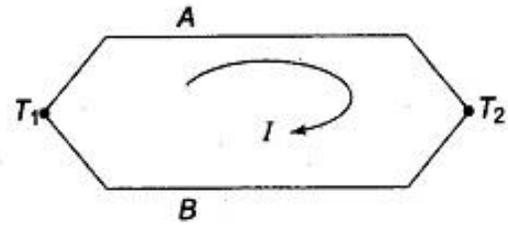
A current will circulate around a loop made up of two dissimilar metal when the two junctions are at different temperatures. When this circuit is opened, a voltage appears that is proportional to the observed seeback current. The Thomson and Peltier emfs originate from the fact that, within conductors, the density of free charge carriers (electrons and holes) increases with temperature.

- If the temperature of one end of a conductor is raised above that of the other end, excess electrons from the hot end will diffuse to the cold end. This results in an induced voltage, the **Thomson effect**, that makes the hot end positive with respect to the cold end.

Conductors made up of different materials have different free-carriers densities even when at the same temperature. When two dissimilar conductors are joined, electrons will diffuse across the junction from the conductor with higher electron density. When this happens the conductor losing electrons acquire a positive voltage with respect to the other conductor. This voltage is called the **Peltier emf.**

- When the junction is heated a voltage is generated, this is known as seeback effect. The seeback voltage is linearly proportional for small changes in temperature.
- The magnitude of this voltage depends on the material used for the wires and the amount of temperature difference between the joined ends and the other ends. The junction of the wires of the Thermocouple Circuit is called the **sensing junction.**
- The temperature at this end of the Thermocouple Circuit wire is a reference temperature, this function is known as the reference, also called as the cold junction.
- When the reference end is terminated by a meter or a recording device, the meter indication will be proportional to the temperature difference between the hot junction and the reference junction.
- The magnitude of the thermal emf depends on the wire materials used and in the temperature difference between the junctions.
- Thermal emfs for some common thermocouple materials.

The thermocouple (TC) is a <u>temperature transducer</u> that develops an emf that is a function of the temperature difference between its hot and cold junctions.

- **Type 'E'** Thermocouple units use Chromel alloy as the <u>positive electrode</u> and constantan alloy as the negative electrode.
- **Type 'S'** Thermocouple produces the least output voltage but can be used over greatest temperature range.
- **Type 'T'** uses copper and constantan.
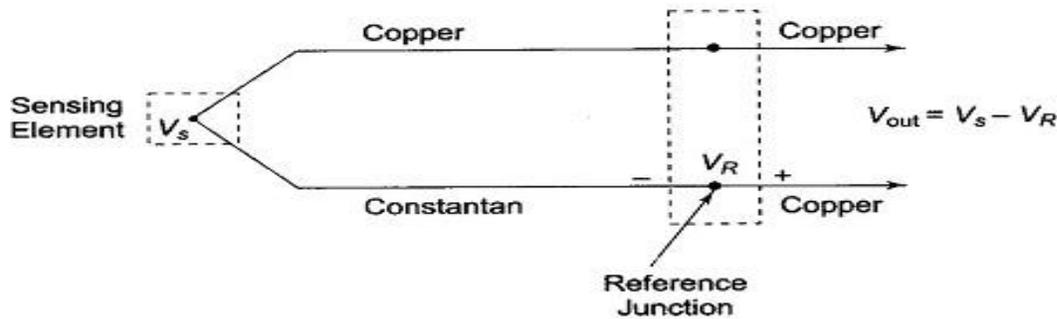
Fig. 13.44   A Type T Thermocouple with Reference Junction

The emf of the thermocouple:

$$E = c(T_1 - T_2) + k(T_1^2 - T_2^2)$$

Where

        c and k   = constant of the thermocouple materials

        T_1 = The temperature of the "hot" junction

        T_2 = The temperature of the "cold" or "reference" junction

Advantages of Thermocouple

- It has rugged construction.
- It has a temperature range from —270 °C-2700 °C.
- Using extension leads and compensating cables, long distances transmission for temperature measurement is possible.
- Bridge <u>circuits</u> are not required for temperature measurement.
- Comparatively cheaper in cost.
- Calibration checks can be easily performed.
- Thermocouples offer good reproducibility.
- Speed of response is high compared to the filled system <u>thermometer</u>.
- Measurement accuracy is quite good.

Disadvantages of Thermocouple

- Cold junction and other compensation is essential for accurate
- They exhibit non-linearity in the emf versus temperature characteristics.

- To avoid stray electrical signal pickup, proper separation of extension leads from thermocouple wire is essential.
- Stray voltage pick-ups are possible.
- In many applications, the signals need to be amplified.

Capacitive Transducer

The capacitance of a parallel plate capacitor is given by

$$C = \frac{kA\varepsilon_0}{d}(Farads)$$

where

k   = dielectric constant

A   = the area of the plate, in m^2

ε_0 = 8.854 x 10^{-12} F/m

d   = the plate placing in m

The capacitance of this unit proportional to the amount of the fixed plate that is covered, that shaded by moving plate. This type of transducer will give sign proportional to curvilinear displacement or angular velocity.
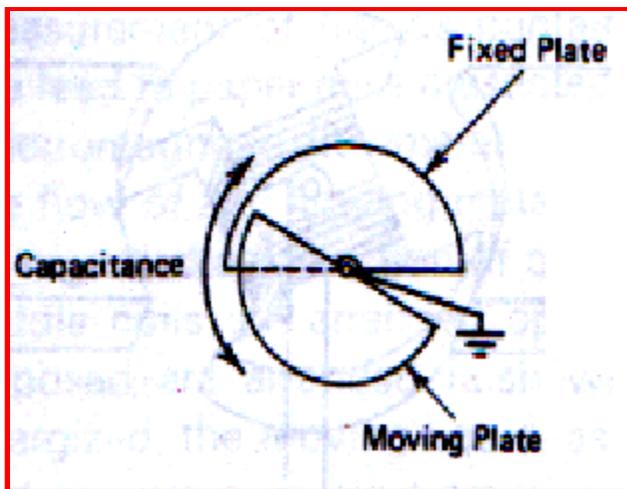
It consists of a fixed cylinder and a moving cylinder. These pieces are configured so the moving piece fits inside the fixed piece but insulated from it.
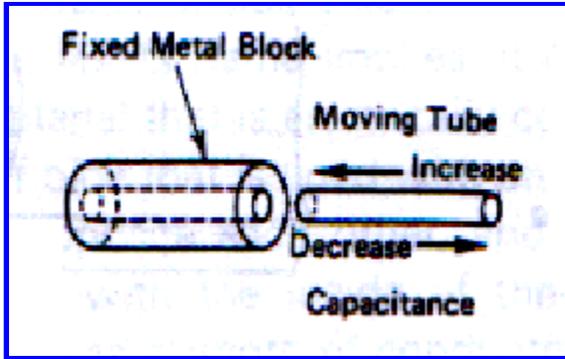
Capacitive Pressure Transducer

A transducer that varies the spacing between surfaces. The dielectric is either air or vacuum.

Often used as Capacitance microphones.
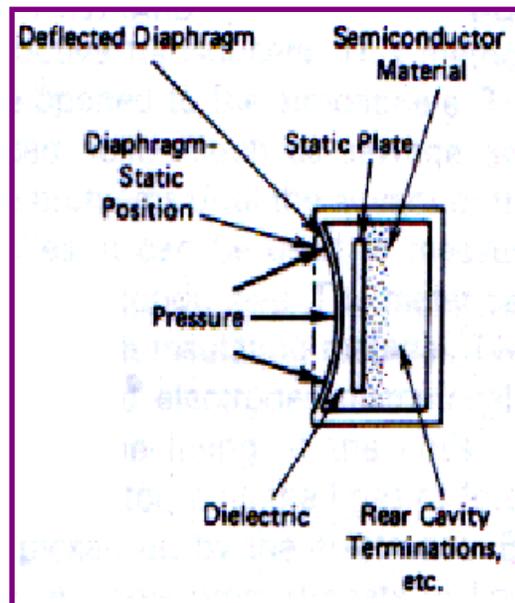
Inductive Transducer

Inductive transducers may be either of the self generating or passive type. The self generating type utilises the basic electrical generator principle, i.e, a motion between a conductor and magnetic field induces a voltage in the conductor (generator action). This relative motion between the field and the conductor is supplied by changes in the measurand.

An inductive electromechanical transducer is a device that converts physical motion (position change) into a change in inductance. Transducers of variable inductance type work upon one of the following principles:

1. Variation of self inductance and Variation of mutual inductance

Inductive transducers are mainly used for the measurement of displacement. The displacement to be measured is arranged to cause variation in any of three variables

- **Number of turns**

- **Geometric configuration**

- **Permeability of the magnetic material**

$$L = \frac{e}{di/dt} = \frac{N^2}{R} \qquad\qquad (13.10)$$

Change in Self Inductance with Numbers of Turns

The output may be caused by a change in the number of turns. Figures 13.14(a) and (b) are transducers used for, the measurement of displacement of linear and angular movement respectively.
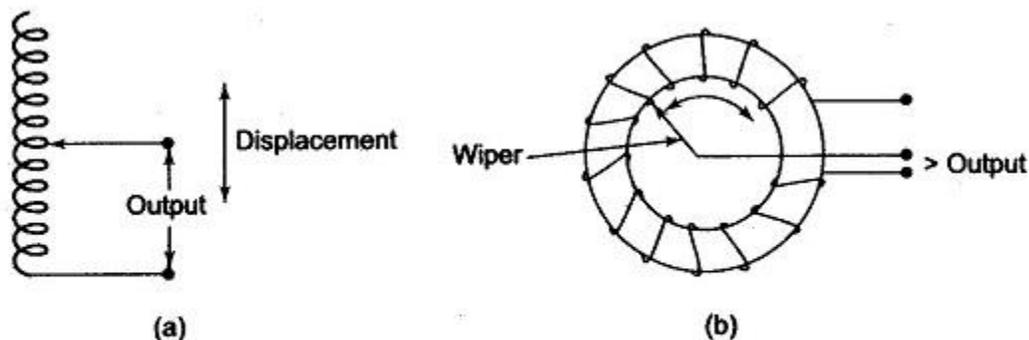
Fig. 13.14 (a) Linear Inductive Transducer (Using Air Core) (b) Angular Inductive Transducer (Using Ferrite Core)

Transducer Working on the Principle of Change in Self Inductance with Change in Permeability

Figure 13.15 shows an <u>Inductive Transducer Definition</u> which works on the principle of the variation of permeability causing a change in self inductance. The iron core is surrounded by a winding. If the iron core is inside the winding, its permeability is increased, and so is the inductance. When the iron core is moved out of the winding, the permeability decreases, resulting in a reduction of the self inductance of the coil. This transducer can be used for measuring displacement.
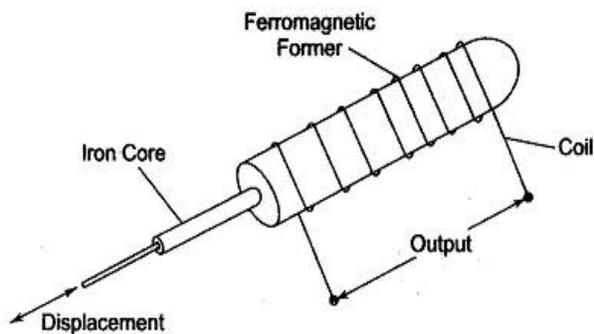
Fig. 13.15 Inductive Transducer Working on the Principle of Variation of Permeability

Variable Reluctance Type Transducer

A transducer of the variable type consists of a coil wound on a ferromagnetic core. The displacement which is to be measured is applied to a ferromagnetic target. The target does not have any physical contact with the core on which it is mounted. The core and the target are separated by an air gap, as shown in Fig. 13.16(a)

The reluctance of the magnetic path is determined by the size of the air gap. The inductance of the coil depends upon the reluctance of the magnetic <u>circuits</u>. The self inductance of the coil is given   by
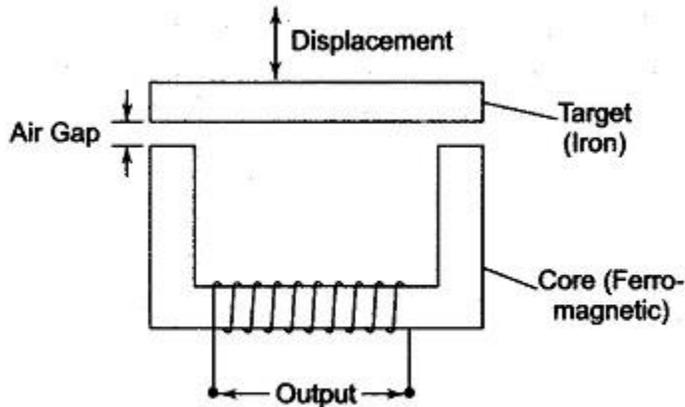
Fig. 13.16(a)   Variable Reluctance Transducer

$$L = \frac{N^2}{R_i + R_g} \qquad\qquad (13.11)$$

where N = number of turns

         R_i = reluctance of iron parts

         R_g = reluctance of air gap

But reluctance of the air gap is given by

$$R_g = \frac{l_g}{\mu_o \times A_g} \qquad\qquad (13.13)$$

                                             Where

l_g = length of the air gap

A_g = area of the flux path through air

μ_o = permeability

R_g is proportional to l_g, as μ_o and A_g are constants.

Hence L is proportional to l/l_g, i.e. the self inductance of the coil is inversely proportional to the length of the air gap.

- The inductance of one part increases from L to L + ΔL, while that of the other part decreases from L to L — ΔL. The change is measured as the difference of the two, resulting in an output of 2 ΔL instead of ΔL, when one winding is used. This increases the sensitivity and also eliminates error.

(a)   (b)
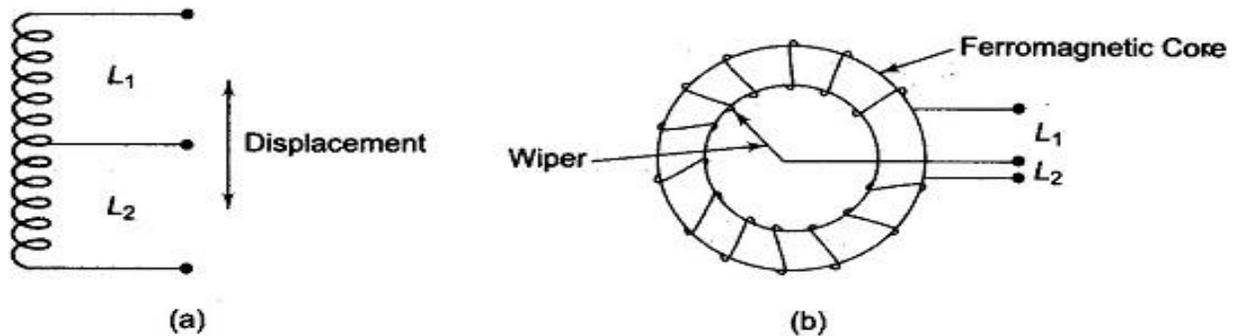
Fig. 13.17   (a)   Linear Differential Output Transducer
                    (b)   Angular Differential Output Transducer

Linear Variable Differential Transducer (LVDT)

- The differential transformer is a passive inductive transformer. It is also known as a Linear Variable Differential Transducer (LVDT).
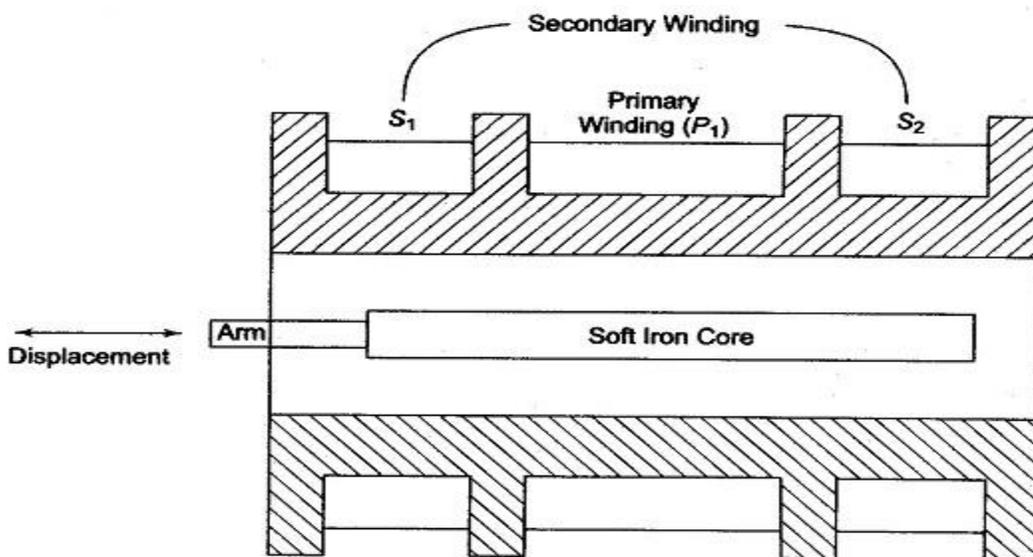
Fig. 13.19   Construction of a Linear Variable Differential Transducer (LVDT)

- The transformer consists of a single primary winding P_1 and two secondary windings S_1 and S_2 wound on a hollow cylindrical former. The secondary windings have an equal

number of turns and are identically placed on either side of the primary windings. The primary winding is connected to an ac source.

- An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries. The displacement to be measured is applied to an arm attached to the soft iron core.

- When the core is in its normal (null) position, equal voltages are induced in the two secondary windings. The frequency of the ac applied to the primary winding ranges from 50 Hz to 20 kHz.

- The output voltage of the secondary windings S_1 is E_{s1} and that of secondary winding S_2 is E_{s2}.

- In order to convert the output from S_1 to S_2 into a single voltage signal, the two secondaries S_1 and S_2 are connected in series opposition,

(a) Construction   (b) Basic Circuit
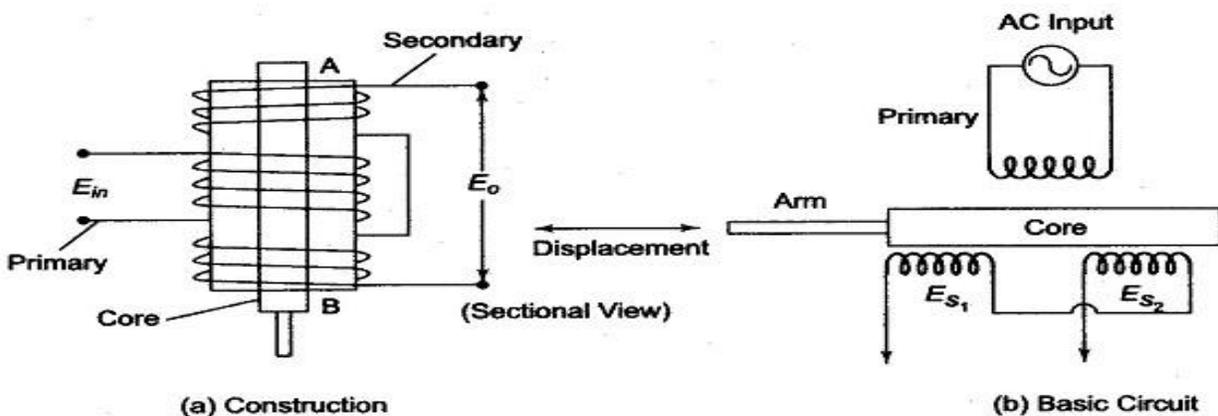
Fig. 13.20   Secondary Winding Connected for Differential Output

- Hence the output voltage of the transducer is the difference of the two voltages. Therefore the differential output voltage $E_o = E_{s1} \sim E_{s2}$.

- When the core is at its normal position, the flux linking with both secondary windings is equal, and hence equal emfs are induced in them. Hence, at null position $E_{s1} = E_{s2}$. Since the output voltage of the transducer is the difference of the two voltages, the output voltage E_o is zero at null position.

- Now, if the core is moved to the left of the null position, more flux links with winding S_1 and less with winding S_2. Hence, output voltage E_{s1} of the secondary winding S_1 is greater than E_{s2}. The magnitude of the output voltage of the secondary is then $E_{s1} - E_{s2}$, in phase with E_{s1} (the output voltage of secondary winding S_1).

- Similarly, if the core is moved to the right of the null position, the flux linking with winding S_2 becomes greater than that linked with winding S_1. This results in E_{s2} becoming larger than E_{s1}. The output voltage in this case is $E_o = E_{s2} - E_{s1}$ and is in phase with E_{s2}.
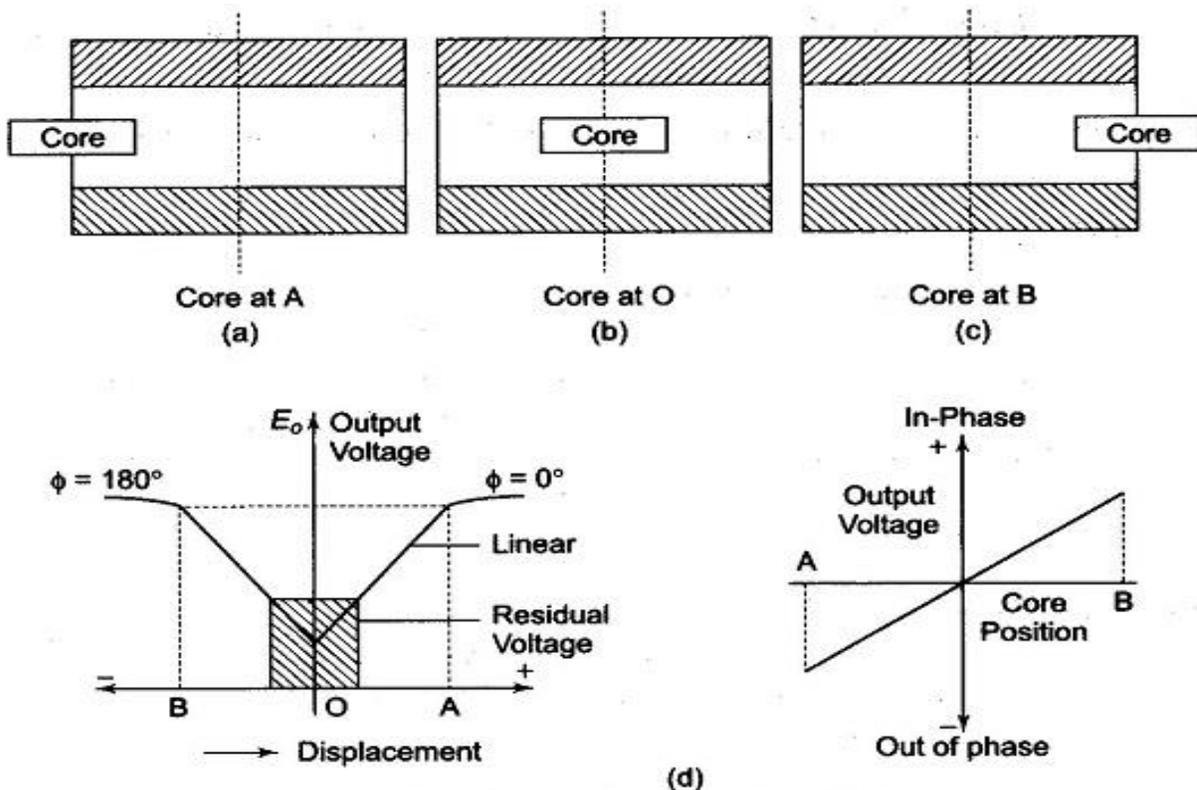
Fig. 13.21   (a), (b), (c) Various Core Position of LVDT
(d) Variation of Output Voltage vs Displacement

Advantages

- **Linearity:** The output voltage of this transducer is practically linear for displacements upto 5 mm (a linearity of 0.05% is available in commercial LVDTs).

- **Infinite resolution:** The change in output voltage is stepless. The effective resolution depends more on the test equipment than on the

- **High output:** It gives a high output (therefore there is frequently no need for intermediate amplification devices).

- **High sensitivity:** The transducer possesses a sensitivity as high as 40 V/mm.

- **Ruggedness:** These transducers can usually tolerate a high degree of vibration and shock.

- **Less friction:** There are no sliding contacts.

- **Low hysteresis:** This transducer has a low hysteresis, hence repeatability is excellent under all conditions.

- **Low power:** consumption Most LVDTs consume less than 1 W

Disadvantages

- Large displacements are required for appreciable differential output.

- They are sensitive to stray magnetic fields (but shielding is possible).

- The receiving instrument must be selected to operate on ac signals, or ademodulator network must be used if a dc output is required.

- The dynamic response is limited mechanically by the mass of the core and electrically by the applied voltage.

- Temperature also affects the transducer.

Piezoelectric Transducer

- A Symmetrical crystalline materials such as Quartz, Rochelle salt and Barium titanate produce an emfwhen they are placed under stress. This property is used in Piezoelectric Transducer Working Principle, where a crystal is placed between a solid base and the force-summing member.
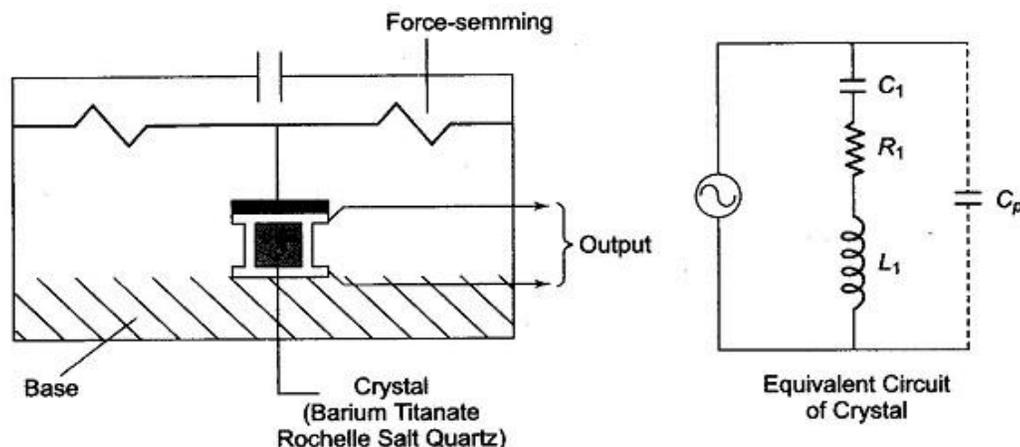
Fig. 13.31   Piezo Electric Transducer

- For a Piezoelectrical Transducer element under pressure, part of the energy is, converted to an electric potential that appears on opposite faces of the element, analogous to a charge on the plates of a capacitor. The rest of the applied energy is

converted to mechanical energy, analogous to a compressed spring. When the pressure is removed, it returns to its original shape and loses its <u>electric charge</u>.

From these relationships, the following formulas have been derived for the coupling coefficient K

$$K = \frac{\text{Mechanical energy converted to electrical energy}}{\text{Applied mechanical energy}}$$

or

$$K = \frac{\text{Electrical energy converted to mechanical energy}}{\text{Applied electrical energy}}$$

- An <u>alternating voltage</u> applied to a crystal causes it to vibrate at its natural resonance frequency. Since the frequency is a very stable quantity, Piezoelectrical Transducer crystals are principally used in HF accelerometers.

- The principal disadvantage is that voltage will be generated as long as the pressure applied to the piezo electric element changes.

Synchros

wherein a change in the inductance of a sensing element is produced by a pressure change <u>Pressure Inductive Transducer</u>.A Synchro can be an angular position transducer working on <u>Pressure Inductive Transducer</u> principle, wherein a variable coupling between primary and secondary winding is obtained by changing the relative orientation of the windings.A Synchro appears like an <u>AC motor</u> consisting of a rotor and a stator.They have a rotor with one or three windings capable of revolving inside a fixed stator. There are two common types of rotors, the <u>salientpole</u> and the wound rotor.

- The stator has a 3-phase winding with the windings of the 3-phase displaced by 120°. The synchro may be viewed as a variable coupling transformer.
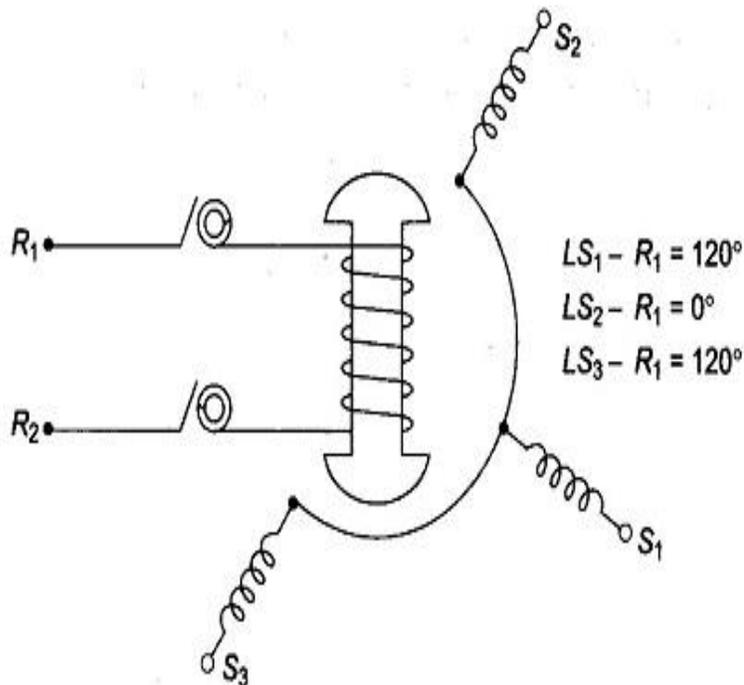
Fig. 13.23   Basic Synchro

- The rotor is energized by an ac voltage and coupling between rotor and stator windings varies as a trigonometric or <u>linear function</u> of the rotor position.

A Synchro system formed by interconnection of the devices called the Synchro transmitter and Synchro control transmitter is perhaps the most widely used error detector in feedback control system. It measures and compares two angular displacements and its output voltage is approximately linear with angular displacement.

When an ac excitation voltage is applied to the rotor, the resultant current produces a <u>magnetic field</u> and by transformer action induces voltages in the stator coils.

The effective voltage induced in any <u>stator coil</u> depends upon the angular position of the coil axis with respect to the rotor axis.

Suppose the voltage is V, the coupling between S_1 and S_2 of the stator and primary (rotor) winding is a cosine function. In general if the rotor is excited by 50 Hz ac, also called reference voltage, the voltage induced in any stator winding will be proportional to the cosine of the angle between the rotor axis and the stator axis.

For example, if a reference voltage V sin ωt excites the rotor of a synchro (R_1— R_2), the stator terminals will have a voltage of the following form:

These voltages are known as Synchro format voltages.

$$V(S_1 - S_2) = V \sin \omega t \sin \theta$$
$$V(S_1 - S_2) = V \sin \omega t (\sin \theta + 120°)$$
$$V(S_2 - S_3) = V \sin \omega t (\sin \theta + 240°)$$

- These voltages are known as Synchro format voltages.

(a)
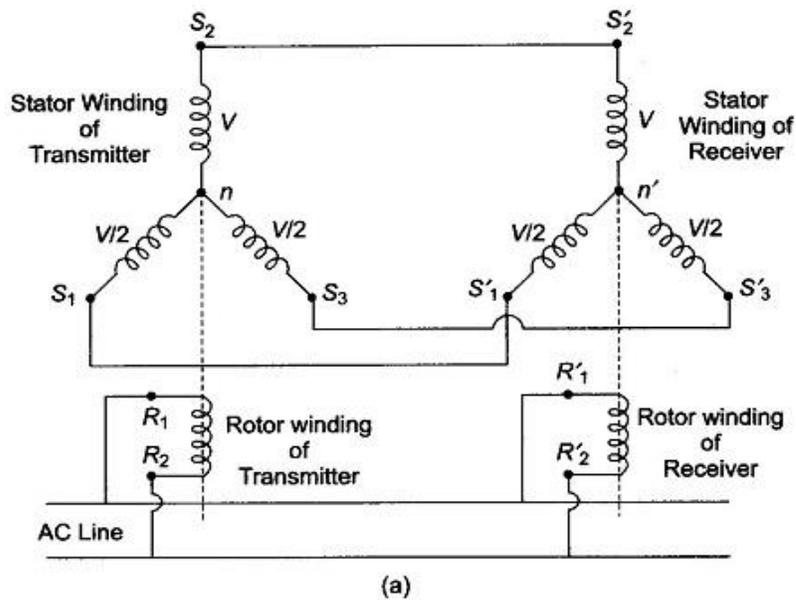
(a) Torque Transmission Using Synchro Trans
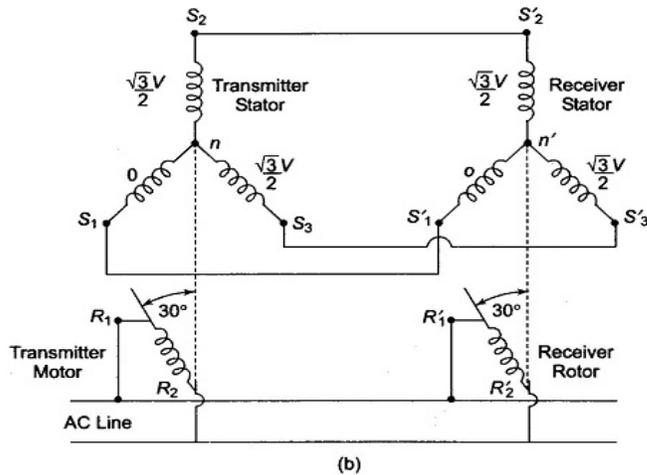
Fig. 13.24

(b) Follow Up Conditions of Transmitter-Receiver System

A Synchro system formed by interconnection of the devices called the Synchro transmitter and Synchro control transmitter is perhaps the most widely used error detector in feedback control system. It measures and compares two angular displacements and its output voltage is approximately linear with angular displacement.

The conventional Synchro transmitter (TX) uses a salient pole rotor with sleeved slot. When an ac excitation voltage is applied to the rotor, the resultant current produces a magnetic field and by transformer action induces voltages in the stator coils. The effective voltage induced in any stator coil depends upon the angular position of the coil axis with respect to the rotor axis (when the coil voltage is known, the induced voltage at any angular displacement can be determined).

Initially winding S_2 of the stator of transmitter is positioned for maximum coupling with the rotor winding as shown in Fig. 13.24(a). Suppose the voltage is V, the coupling between S_1 and S_2 of the stator and primary (rotor) winding is a cosine function. In general if the rotor is excited by 50 Hz ac, also called reference voltage, the voltage induced in any stator winding will be proportional to the cosine of the angle between the rotor axis and the stator axis. The voltages induced across any pair of stator terminals (S_1— S_2, S_I — S_3, or S_2 —S_3) will be sum or difference, depending on the phase of the voltage measured across the coils.

For example, if a reference voltage V sin ωt excites the rotor of a synchro (R₁— R₂), the stator terminals will have a voltage of the following form:

$$V(S_1 - S_2) = V \sin \omega t \sin \theta$$
$$V(S_1 - S_2) = V \sin \omega t (\sin \theta + 120°)$$
$$V(S_2 - S_3) = V \sin \omega t (\sin \theta + 240°)$$

where θ is the shaft angle.

These voltages are known as Synchro format voltages.

Therefore, the effective voltages in these windings are proportional to cos 60° or they are V/2 each. So long as the rotors of the transmitter and receiver remains in this position, no current will flow between the stator windings because of the voltage balance.

When the rotor of the transmitter is moved to a new position, the voltage balance is disturbed or changed. Assuming that the rotor of the transmitter is moved through 30° as shown in Fig. 13.24(b), the stator winding voltages of the transmitter will be changed to 0,√3/2 V and √3/2 V respectively.

Hence, a voltage imbalance occurs between the stator windings of the transmitter and receiver. This voltage imbalance between the windings causes current to flow between the windings producing a torque that tends to rotate the rotor of the receiver to a new position where the voltage balance is again restored. This balance is restored only if the receiver turns through the same angle as the transmitter and also the direction of rotation is the same as that of the transmitter. Hence a Synchro can be used to determine the magnitude and direction of angular displacement.

Magnetostrictive Transducer

- Magnetostrictive materials transducer converts magnetic energy to mechanical energy and vice versa. As a magnetostrictive material is magnetized, it strains; that is it exhibits a change in length per unit length.

- Conversely, if an external force produces a strain in a magnetostrictive material, the material's magnetic state will change. This bi-directional coupling between the magnetic and mechanical states of a magnetostrictive material provides a transduction capability that is used for both actuation and sensing devices.

Magnetostriction is an inherent material property that will not degrade with time.

Hot Wire Anemometer

Basic Principle:

- When an electrically heated wire is placed in a flowing gas stream, heat is transferred from the wire to the gas and hence the temperature of the wire reduces, and due to this, the resistance of the wire also changes. This change in resistance of the wire becomes a measure of flow rate.

- There are two methods of measuring flow rate using a anemometer bridge combination namely:

  Constant current method

- Constant temperature method

Constant current method

- The bridge arrangement along with the anemometer has been shown in diagram. The anemometer is kept in the flowing gas stream to measure flow rate.

Constant Current Method
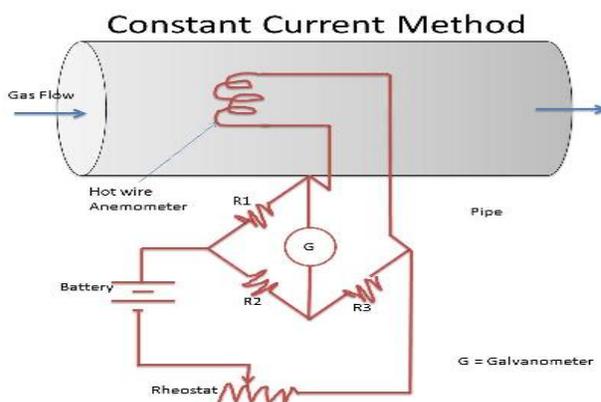
- A constant current is passed through the sensing wire. That is, the voltage across the bridge circuit is kept constant, that is, not varied.

- Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and hence the temperature of the sensing wire reduces causing a change in the resistance of the sensing wire. (this change in resistance becomes a measure of flow rate).

- Due to this, the galvanometer which was initially at zero position deflects and this deflection of the galvanometer becomes a measure of flow rate of the gas when calibrated.

Constant temperature method

- The bridge arrangement along with the anemometer has been shown in diagram. The anemometer is kept in the flowing gas stream to measure flow rate.

- A current is initially passed through the wire.

Constant Temperature Method
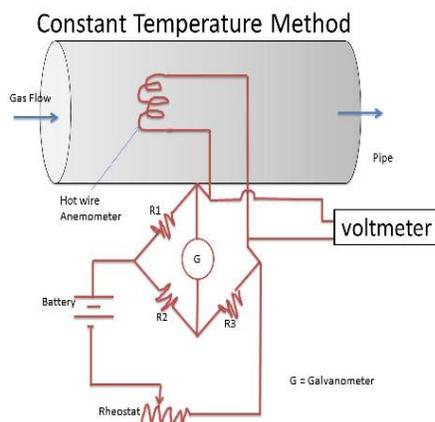
- Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and this tends to change the temperature and hence the resistance of the wire.

- The principle in this method is to maintain the temperature and resistance of the sensing wire at a constant level. Therefore, the current through the sensing wire is increased to bring the sensing wire to have its initial resistance and temperature.

- The electrical current required in bringing back the resistance and hence the temperature of the wire to its initial condition becomes a measure of flow rate of the gas when calibrated.

UNIT-5

BRIDGES

Two types of bridge circuits are used in measurement:

1) DC bridge:

a) wheatstone bridge

b) kelvin bridge

2) AC bridge: Maxwell Bridge

wheatstone bridge: The Wheatstone bridge is an electrical bridge circuit used to measure resistance.It consists of a voltage source and a galvanometer that connects two parallel branches, containing four resistors. One parallel branch contains one known resistance and one unknown; the other parallel branch contains resistors of known resistances.

In the circuit at right, $R4$ is the unknown resistance; $R1$, $R2$ and $R3$ are resistors of known resistance where the resistance of $R3$ is adjustable. How to determine the resistance

of the unknown resistor, R4? "The resistances of the other three are adjusted and balanced until the current passing through the galvanometer decreases to zero".
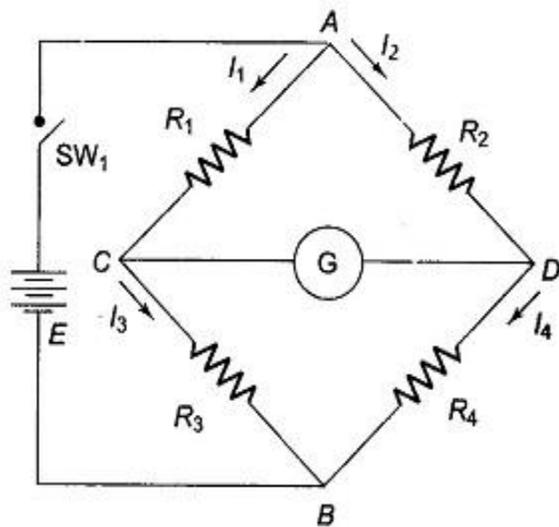
Fig. 11.1   Wheatstone's Bridge

R3 is varied until voltage between the two midpoints (**B** and **D**) will be **zero** and no current will flow through the galvanometer.

When the bridge is in balance condition (no current flows through galvanometer G), we obtain; voltage drop across R1 and R2 is equal,

I1R1 = I2R2

voltage drop across R3 and R4 is equal,

I3R3 = I4R4

For the galvanometer current to be zero, the following conditions should be satisfied

$$I_1 = I_3 = \frac{E}{R_1 + R_3} \qquad\qquad (11.2)$$

$$I_2 = I_4 = \frac{E}{R_2 + R_4} \qquad\qquad (11.3)$$

Substituting in Eq.

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$

$$R_1 \times (R_2 + R_4) = (R_1 + R_3) \times R_2$$

$$R_1 R_2 + R_1 R_4 = R_1 R_2 + R_3 R_2$$

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

Unbalanced Wheatstone's Bridge

- To determine the amount of deflection that would result for a particular degree of unbalance, general circuit analysis can be applied, but we shall use Thevenin's theorem.
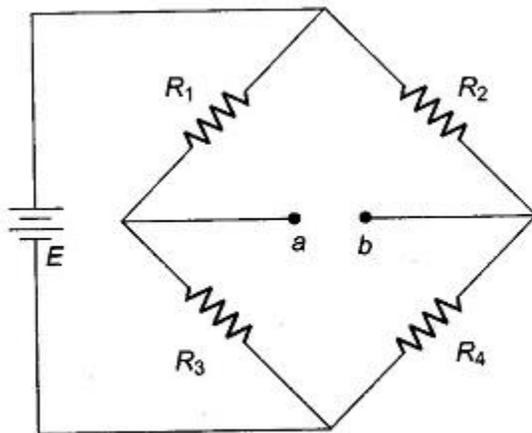

Fig. 11.2   Unbalanced Wheatstone's Bridge

Applying the voltage divider equation, the voltage at point a can be determined as follows

$$E_a = \frac{E \times R_3}{R_1 + R_3} \quad \text{and at point } b, \quad E_b = \frac{E \times R_4}{R_2 + R_4}$$

Therefore, the voltage between a and b is the difference between E_a and E_b, which represents Thevenin's equivalent voltage.

$$E_{th} = E_{ab} = E_a - E_b = \frac{E \times R_3}{R_1 + R_3} - \frac{E \times R_4}{R_2 + R_4}$$

Therefore

$$E_{ab} = E \left(\frac{R_3}{R_1 + R_3} - \frac{R_4}{R_2 + R_4} \right)$$
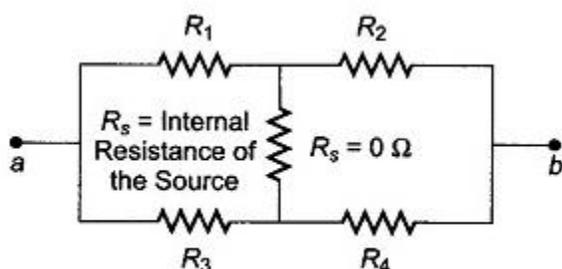
Fig. 11.3 Thévenin's Resistance

The equivalent resistance of the circuit is $R_1//R_3$ in series with $R_2//R_4$ i.e. $R_1//R_3 + R_2//R_4$.

$$R_{th} = \frac{R_1 R_3}{R_1 + R_3} + \frac{R_2 R_4}{R_2 + R_4}$$

Therefore, Thevenin's equivalent circuit is given in Fig. 11.4. Thevenin's equivalent circuit for the bridge, as seen looking back at terminals a and b in Fig. 11.2, is shown in Fig. 11.4.
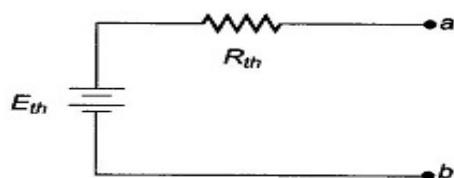
Fig. 11.4 Thévenin's Equivalent

$$I_g = \frac{E_{th}}{R_{th} + R_g} \quad\quad\quad\quad (11.5)$$

Kelvin's bridge

Kelvin's bridge is a modification of Wheatstone's bridge and is used to measure values of resistance below 1 Ω. In low resistance measurement, theresistance of the leads connecting the unknown resistance to the terminal of the bridge circuit may affect the measurement.
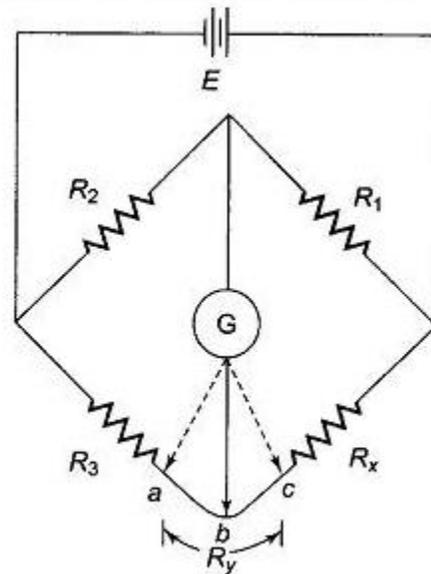
Fig. 11.10   Kelvin's Bridge

$$\frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2} \qquad\qquad\qquad (11.6)$$

and the usual balance equations for the bridge give the relationship

$$(R_x + R_{cb}) = \frac{R_1}{R_2}(R_3 + R_{ab}) \qquad\qquad (11.7)$$

$$R_{ab} + R_{cb} = R_y \text{ and } \frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2}$$

$$\frac{R_{cb}}{R_{ab}} + 1 = \frac{R_1}{R_2} + 1$$

$$\frac{R_{cb} + R_{ab}}{R_{ab}} = \frac{R_1 + R_2}{R_2}$$

i.e.
$$\frac{R_y}{R_{ab}} = \frac{R_1 + R_2}{R_2}$$

$$R_{ab} = \frac{R_2 \, R_y}{R_1 + R_2} \quad \text{and as} \quad R_{ab} + R_{cb} = R_y$$

$$R_{cb} = R_y - R_{ab} = R_y - \frac{R_2 \, R_y}{R_1 + R_2}$$

$$R_{cb} = \frac{R_1 \, R_y + R_2 \, R_y - R_2 \, R_y}{R_1 + R_2} = \frac{R_1 \, R_y}{R_1 + R_2}$$

Substituting for R_{ab} and R_{cb} in Eq. (11.7), we have

$$R_x + \frac{R_1 \, R_y}{R_1 + R_2} = \frac{R_1}{R_2}\left(R_3 + \frac{R_2 \, R_y}{R_1 + R_2} \right)$$

$$R_x + \frac{R_1 \, R_y}{R_1 + R_2} = \frac{R_1 \, R_3}{R_2} + \frac{R_1 \, R_2 \, R_y}{R_2 \, (R_1 + R_2)}$$

$$R_x = \frac{R_1 \, R_3}{R_2} \qquad\qquad (11.8)$$

Maxwell Bridge:
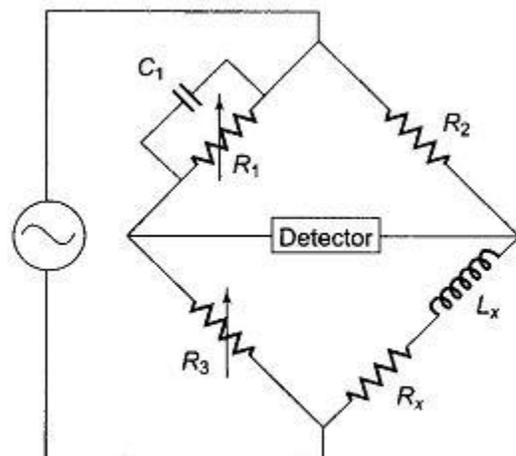
Fig. 11.21   Maxwell's Bridge

The general equation for bridge balance is

$$Z1Z3 = Z2Z4$$

Maxwell's bridge is limited to the measurement of low Q values (1 — 10). The measurement is independent of the excitation frequency. The scale of the resistance can be calibrated to read inductance directly.

The Maxwell bridge using a fixed capacitor has the disadvantage that there is an interaction between the resistance and reactance balances. This can be avoided by varying the capacitances, instead of R_2 and R_3, to obtain a reactance balance.

$$Z_1 Z_x = Z_2 Z_3$$

i.e.
$$Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 Y_1$$

Where
$$Z_1 = R_1 \text{ in parallel with } C_1 \text{ i.e. } Y_1 = \frac{1}{Z_1}$$

$$Y_1 = \frac{1}{R_1} + j\omega C_1$$

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_x = R_x \text{ in series with } L_x = R_x + j\omega L_x$$

$$R_x + j\omega L_x = R_2 R_3 \left(\frac{1}{R_1} + j\omega C_1 \right)$$

$$R_x + j\omega L_x = \frac{R_2 R_3}{R_1} + j\omega C_1 R_2 R_3$$

Equating real terms and imaginary terms we have

$$R_x = \frac{R_2 R_3}{R_1} \text{ and } L_x = C_1 R_2 R_3$$

$$Q = \frac{\omega L_x}{R_x} = \frac{\omega C_1 R_2 R_3 \times R_1}{R_2 R_3} = \omega C_1 R_1$$

Measurement of Physical parameters

Flow Measurement

- Turbine flow meter
- electromagnetic flow meter
- Ultrasonic Flow Meter

Turbine flow meter:
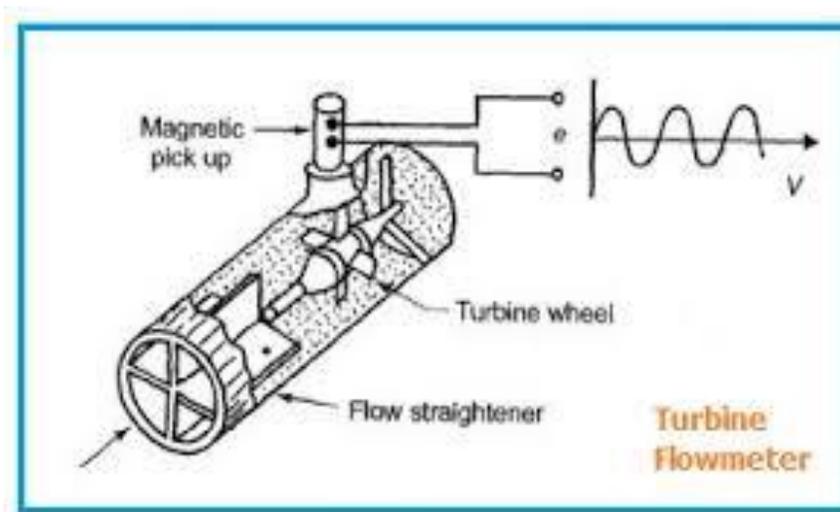
The turbine flow meter translates the mechanical action of the turbine rotating in the liquid flow around an axis into a user-readable rate of flow (gpm, lpm, etc.). The turbine tends to have all the flow traveling around it.The turbine wheel is set in the path of a fluid stream. The flowing fluid impinges on the turbine blades, imparting a force to the blade surface and setting the rotor in motion. When a steady rotation speed has been reached, the speed is proportional to fluid velocity. Turbine flow meters are used for the measurement of natural gas and liquid flow. These are less accurate.

Electromagnetic flow meter:
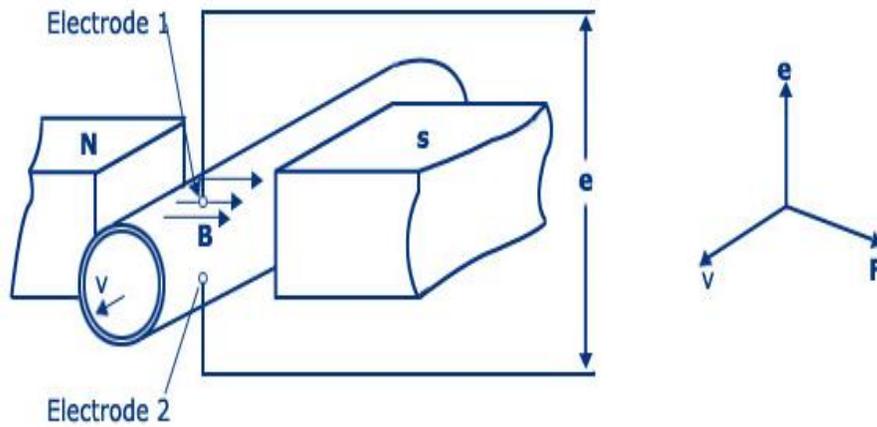
An electromagnetic flow meter can be used to measure the flow of fluids. According to Faraday's law, a voltage 'e' is induced in a conductor of length 'l' meters which is dependent on the flux density and liquid flowing velocity 'v'm/s The parameter used for the measurement of flow is the speed of flow, and is measured in terms of the potential difference induced when the moves in a tubing/pipe with a transverse magnetic field impressed.

$$E = B.l.v$$

Ultrasonic Flow Meter:

P_1 , P_2 – piezocrystals
sw – switch
d – distance between crystals
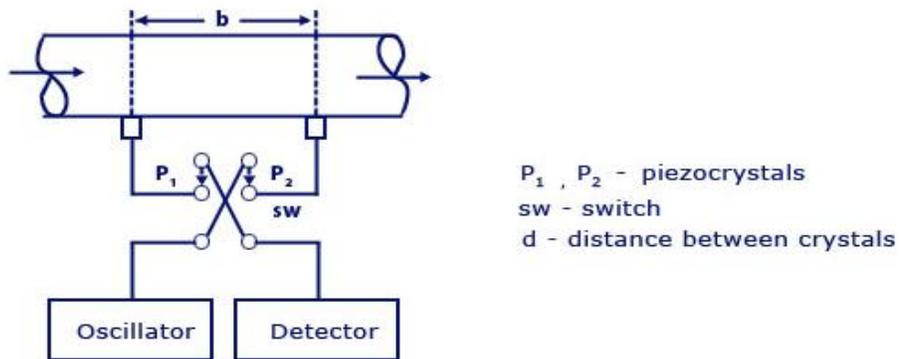
When pressure waves are released into the flowing fluid, their velocity and amplitude are affected by the fluid velocity. Ultrasonic flow meters help in measuring these

pressure wave changes, especially in the ones having frequencies greater than 20KiloHertz using specialized techniques. There are two types of ultrasonic flow meters. One of them is based on the measurement of phase shift between the waves directed downstream and upstream alternately.

The other one is based on the measurement of separation of frequency of oscillation directed downstream and upstream simultaneously.

Liquid level measurement

- Resistive method
- Float method
- Capacitance method
- Ultrasonic method

Humidity

The presence of moisture (water vapor, an invisible gas) in the atmosphere is measured by the humidity of the air.

Humidity and condensation are closely related as condensation inevitably occurs when the air is saturated with moisture (100% humidity).

Absolute humidity measures the amount of water vapor in air. Grams H_2O/m^3 of air. This water is a gas, water vapor.

Relative humidity measures the amount of water vapor in air relative to the maximum amount of water vapor the air could hold at that temperature.

Relative humidity increases with increasing water vapor or decreasing temperature. Cold air can't "carry" as much water vapor as warm air.

The **dew point** is the temperature to which a given parcel of humid air must be cooled, at constant barometric pressure, for water vapor to condense into liquid water.

A hygrometer is a sensor that senses the amount of evaporated water in air by a mechanical or electronic method. A hygrometer is an instrument used for measuring the moisture content in the atmosphere.

The more humidity that is the air the longer the hair is. The less the humidity the tighter and shorter the hair gets. This transducers the amount of humidity into a force which can then

be converted into an electronic or other mechanical signal. where salt water conducts electricity to turn a light on is utilized in a electronic resistive sensor. As humidity decreases, the salt concentration increases causing the resistivity of the circuit to decrease.

Thus, resistance is directly proportional to humidity. Since voltage changes are much smaller when dealing with small humidity differences, precise measurement equipment must be used making these sensors less practical. Temperature variation also produces varied results during constant humidity and must be taken into account when measuring from this sensor.

Electrolytic Hygrometer:

It utilizes a cell coated with a thin film of phosphorous pentoxide. Which absorbs water from the sample gas. The cell has a bifilar winding of inert electrodes on a fluorinated hydrocarbon capillary. Direct voltage applied to the electrodes dissociates the water which is absorbed by the P2O5 into hydrogen and oxygen.

Two electrons are required for electrolyzing each water molecule and so the current in the cell represents the no.of molecules dissociated. Based on the fliow rate tempeqature and current yields the humidity in ppm

Aluminium oxide hygrometer:

It is formed by depositing a layer of aluminum oxide on a conductive substrate and then coating the oxide with a thin film of gold. The conductive base and gold layer become the capacitor electrodes and aluminium oxide coating becomes capacitors dielectric.

Water vapour penetrates into the gold layer and is absorbed by the oxidation layer. The no. of water molecules absorbed determines the impedance of the capacity which is measure of Relative humidity.

Resistive Hygrometer:

These are electrical transducers to measure Relative humidity. Insulative substrate coated with a lithium chloride solution of a controlled concentration. where salt water conducts electricity to turn a light on is utilized in a electronic resistive sensor. As humidity decreases, the salt concentration increases causing the resistivity of the circuit to decrease.

The hygroscopic nature of salt makes it to take up water vapour from the surrounding atmosphere.

Moisture

It is defined as the amount of water absorbed by a solid or liquid. The standard method is Gravimetric method. Moisture measurement involve electrical measurement. Electrical quantities like conductivity or capacitance of material change with the moisture content. The materials like coffee,grain,flour ,wood,coal,oil etc are used to measure moisture. conductivity and capacitance vary from material to material.

Moisture Content (MC): a measure of the amount of water in wood

$$MC = \frac{\text{Weight of Wood plus Water} - \text{Oven Dry Weight of Wood}}{\text{Oven Dry Weight of Wood}} \times 100$$

$$= \frac{\text{Weight of Water}}{\text{OD Weight}} \times 100$$

Since MC calculation is based on OD weight, it can have values greater than 100%

VELOCITY MEASUREMENTS

MEASUREMENT OF LINEAR VELOCITY

- Velocity is the first derivative of displacement.
- Linear velocity is defined as the rate of change of the position vector with time at an instant in time.
- The methods used for measurement of linear velocity
- ❑ Electro-magnetic transducers.

This transducer utilizes the voltage produced in a coil on account of change in flux linkages resulting from change in reluctance

- ➤ Moving magnet type
- ➤ Moving Coil Type

MOVING MAGNET TYPE TRANSDUCER:

The sensing element is a rod type permanent magnet that is rigidly coupled to the device whose velocity is being measured .There is a coil surrounding the permanent magnet.The motion of the magnet induces   a voltage in the coil and the amplitude   of the voltage is directly proportional to the velocity.The polarity of the output voltage determines the direction of motion.
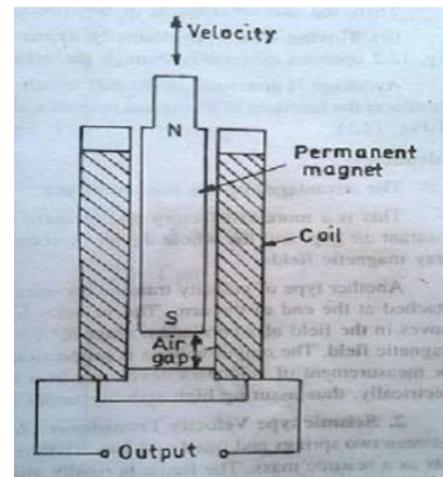
- • For a coil placed in magnetic field the voltage generated is:

$$e_0 = B.A.N.v$$

B=flux density ; Wb/m2 ,

A= area of coil;

 N= Number of turns of coil,

v=relative velocity of magnet with respect to coil

$$e_0 = Kv$$

K=BAN= a constant

- • **ADVANTAGES**
1. The maintenance requirements of these transducers are negligible, because there are no mechanical surfaces or contacts.

2. The output voltage is linearly proportional to velocity.

- **DISADVANTAGES**

1. The performance of these transducers is adversely affected by stray magnetic fields. These fields can cause noise.

2. The frequency response is usually limited and is stated.

3. These transducers are not very useful for measurement of vibrations because their calibration deteriorates as contact with steel tools etc. leads to progressive demagnetization.

MOVING COIL TYPE VELOCITY TRANSDUCER:

It operates essentially through the action of a coil moving in a magnetic field. A voltage is generated in the coil which is proportional to the velocity of the coil. The velocity to be measured is applied to the arm and therefore the coil moves in the field of permanent magnet. A voltage is generated on account of motion of the coil in the magnetic field.

The output voltage is proportional to the velocity.

ADVANTAGES

1. This is a more satisfactory arrangement as the system now forms a closed magnetic circuit with a constant air gap, and the whole device is contained in an antimagnetic case which reduces the effects of stray magnetic fields.

2. The instrument has permanent pole pieces which generate the magnetic field.

3. There is a pivoted arm on which a coil is mounted. There is a mass attached to the end of the coil.The whole device is contained in an antimagnetic case.
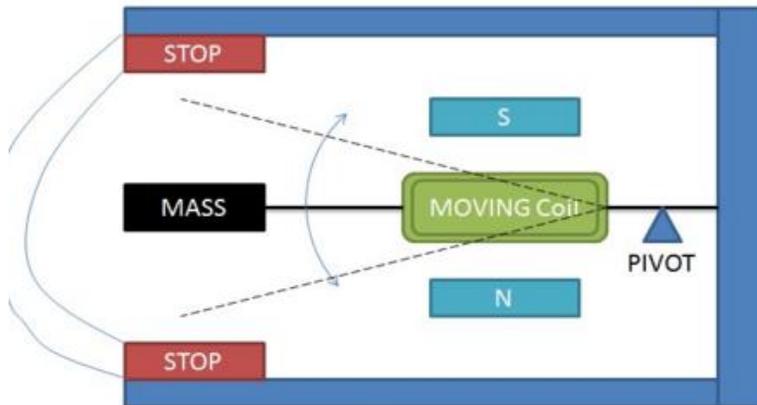
MEASUREMENT OF ANGULAR VELOCITY

- The measurement of angular velocity may be made with a tachometer.

- The tachometer(Mechanical Transducer) may be defined as:

i. An instrument used for measure of angular velocity , as of shaft , either by registering the total number of revolutions during the period of contact, or by indicating directly the number of revolutions per minute.

ii. An instrument which either continuously indicates the value of rotary speed or continuously displays a reading of average speed over rapidly operated short intervals of time.

ELECTRICAL TACHOMETERS:

- **D.C. Tachometer Generators**

They consist of a small armature which is coupled to the machine whose speed is to be measured. This armature revolves in a field of permanent magnet. The emf generated is proportional to the product of flux and speed. Since the flux of the permanent magnet is constant, the voltage generated is proportional to speed. The polarity of output voltage indicates the direction of rotation. This emf is measured with the help of a moving coil voltmeter having a uniform scale and calibrated directly in terms of speed.

A series resistance is used in the circuit for the purpose of limiting the current from the generator in the event of a short circuit on the output side.

Speed to be measured — N — Brushes — Resistance — PMCC Voltmeter — Commutator — S — Permanent magnet
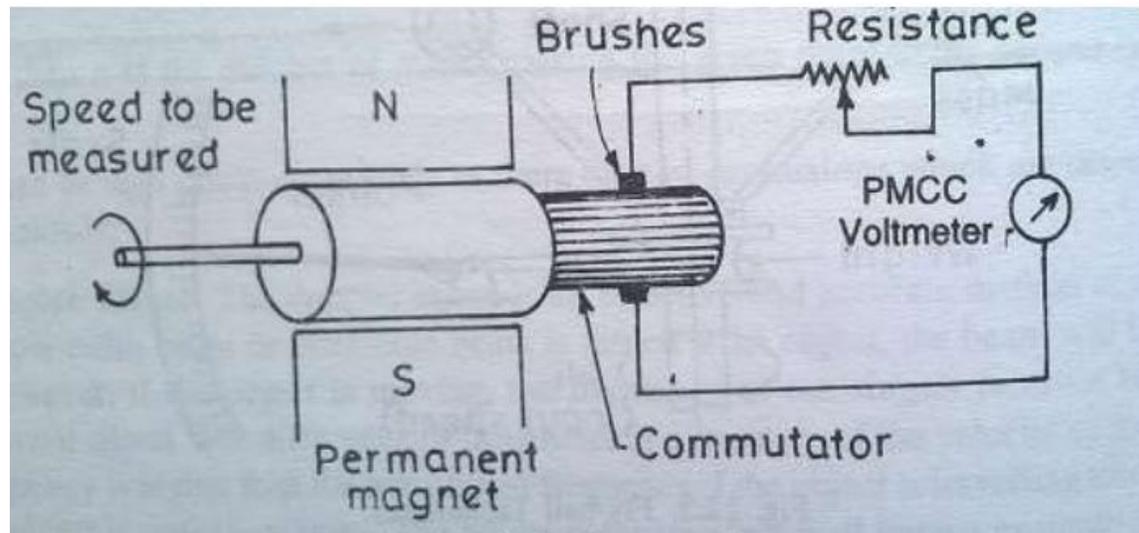
- **Advantages**

i. The direction of rotation is directly indicated by the polarity of the output voltage.

ii. The output voltage is typically 10mv/rpm

- **Disadvantages**

i. Brushes of small tachometer generators often produce maintenance problems, as their contact resistance may vary and produce appreciable error. Thus the commutator and the brushes require periodic maintenance.

ii. The input resistance of meter should be very high as compared with output resistance of generator. This is required to limit the armature current to small value. If the armature current is large, the field of the permanent magnet is distorted giving rise to non-linearity.

A.C. Tachometer Generator
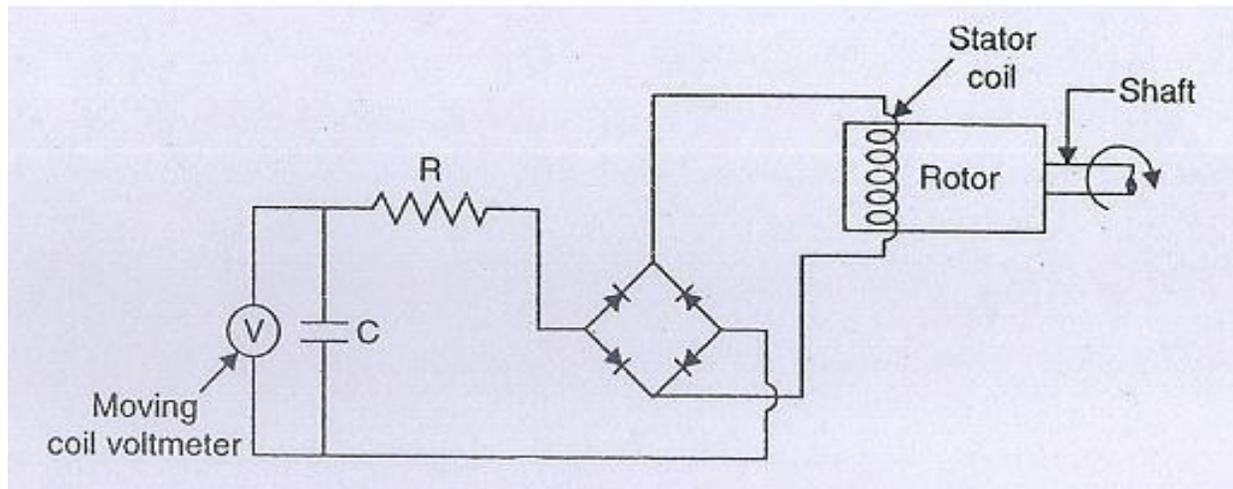
It consists of, like an alternator, a stationary armature (stator) and a rotating field system (rotor). Owing to the generation of e.m.f in a stationary coil on a stator, commutation problems no longer exist.The alternating e.m.f. induced in the stationary coil is rectified, and the output D.C. voltage is measured with the help of a moving coil voltmeter (V).

The ripple content of the rectified voltage is smoothened by the capacitor filter (C).As the speed depends on both the amplitude of the voltage and frequency, anyone of themcan be used as a measure of the speed. In an A.C. tachometer, it is the induced voltage that is considered as the required parameter.

Various types of pressure gauges

Bourdon tubes

Diaphragms

Differential or absolute
Bellows
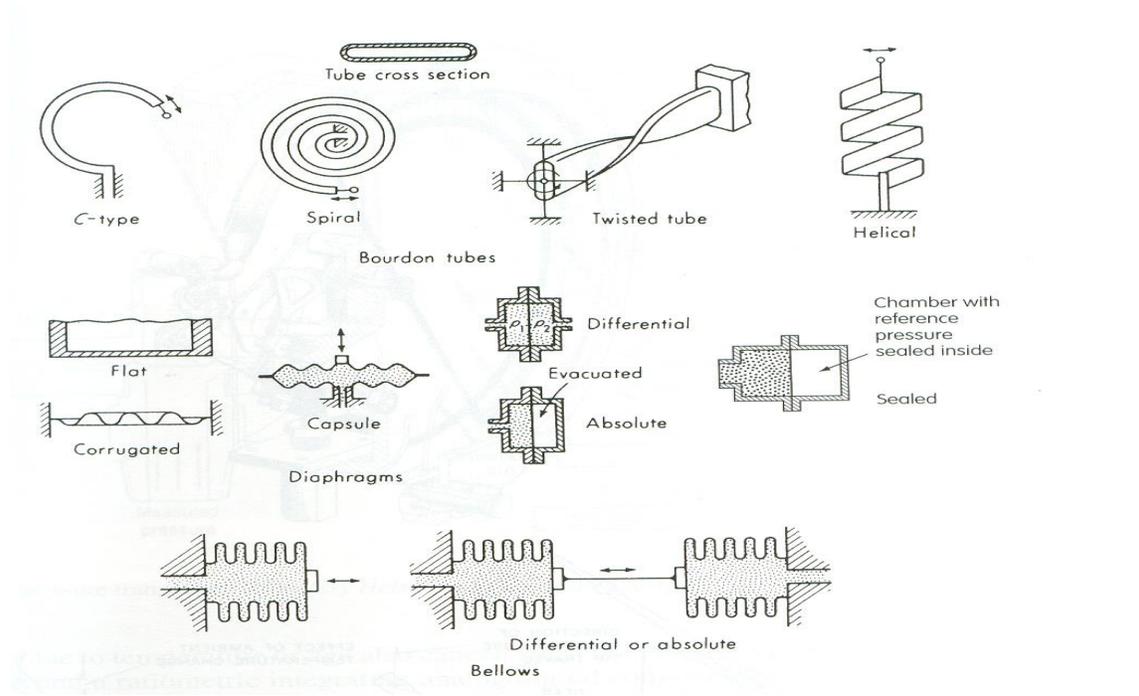
## Bourdon Type:

Flexible element used as sensor. Pressure changes cause change in element position. Element connected to pointer to reference pressure.
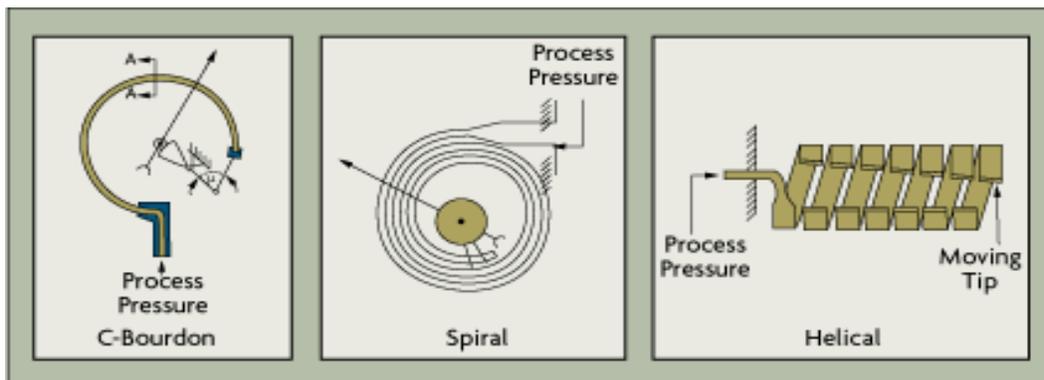

Diaphragm and Bellows Element:

- Similar concept to Bourdon type. Widely used because they require less space and can be made from materials that resist corrosion.

Convex Diaphragm Capsule   Nested Diaphragm Capsule   Corrugated Single Diagram   Multiple Capsule Element
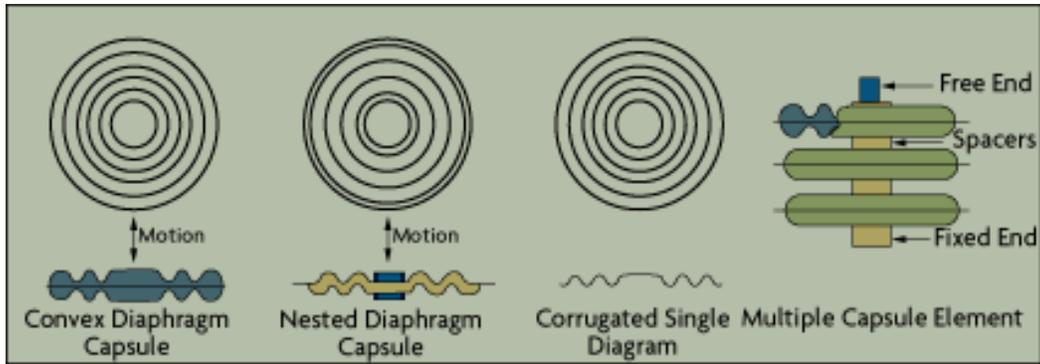
THERMOCOUPLE GAUGE

A Thermocouple is kept in contact with the heated wire and the temperature of the wire is directly measured as a measure of pressure. For different pressures, the temperature is measured by the fine-wire thermocouple, the hating current being initially fixed by the resistance as shown in the figure. This device is usually used for comparison purposes. The sensitivity of such an instrument depends on the pressure and the wire current.

Two sets of thermocouples are used to measure temperatures of heater wires in the two chambers and oppose each other. When there is a difference in pressures, there occurs an unbalance which is measured by a potentiometer circuit. Instead of a single thermocouple per wire, a thermopile is often chosen to increase sensitivity. The thermocouple gauge is also composition dependent and needs empirical calibration for the high vacuum range.
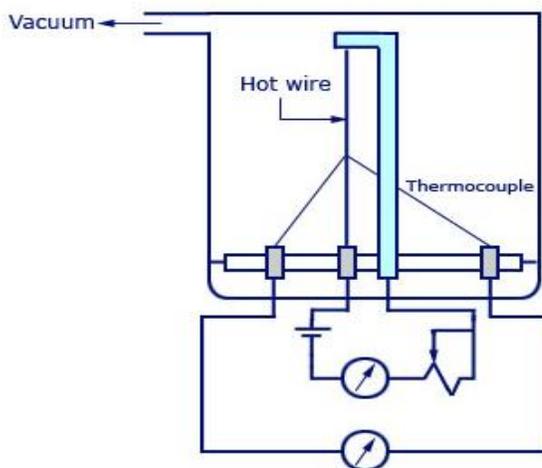
Pirani gauge:

A basic pirani gauge consists of a fine wire of tungsten or platinum of about 0.002 cm in diameter. This wire is mounted in a Tube and then connected to the system whose vacuum is to be measured. The temperature range is around (7-400) degree Celsius and the heating current is between (10-100) mA. A bridge circuit is also used for greater accuracy.
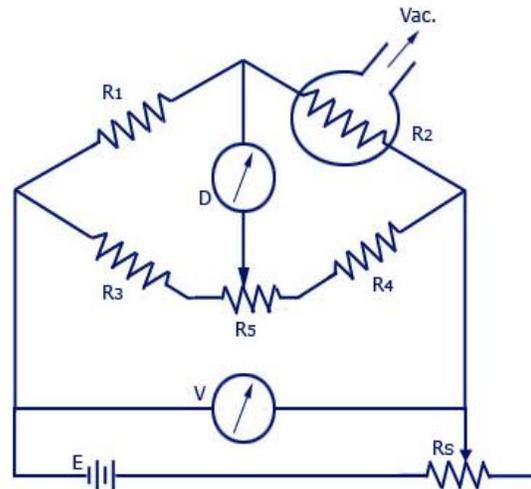
When the pressure changes, there will be a change in current. For this, the voltage V has to be kept constant. The resistance R2 of the gauge is measured, by keeping the gauge current constant. The null balance of the bridge circuit is maintained by adjusting the voltage or current. This change is made with the help of a potentiometer and the change brought will be a measure of the pressure produced.

Ionization Gauge

The construction of a hot cathode type ionization gauge consists of a basic vacuum triode.
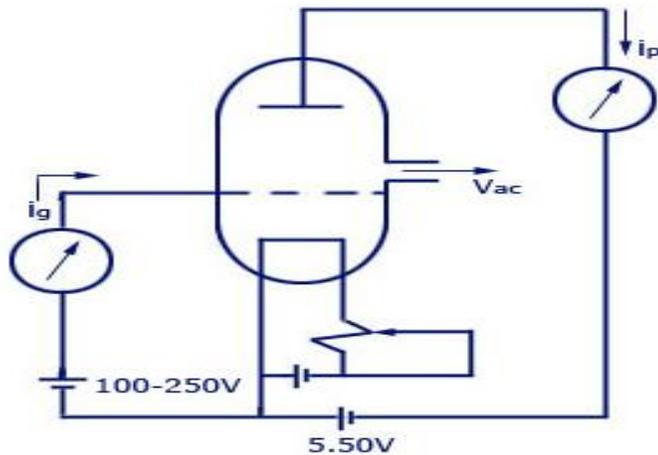
The grid is maintained at a large positive potential with respect to the cathode and the plate. The plate is at a negative potential with respect to the cathode. This method is also known as the external control type ionization gauge as the positive ion collector is external to the electron collector grid with reference to the cathode. The positive ions available between the grid and the cathode will be drawn by the cathode, and those between the grid and the plate will be collected by the plate.

Data acquisition system

A schematic block diagram of a General Data Acquisition System (DAS).
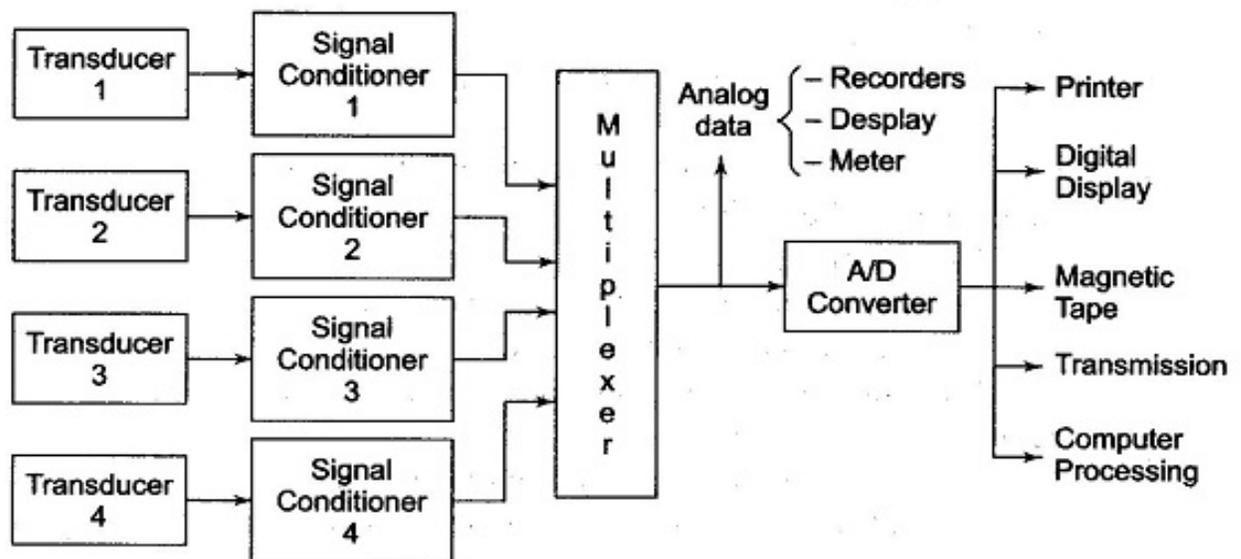
- A typical Data Acquisition System consists of individual sensors with the necessary signal conditioning, data conversion, data processing, multiplexing, data handling and associated transmission, storage and display systems.

Objectives of Data Acquisition System:

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

The important factors that decide the configuration and sub systems of thedata acquisition system are as follows.

- Accuracy and resolution
- Number of channels to be monitored
- Analog or digital signal
- Single channel or multichannel
- Sampling rate per channel
- Signal conditioning requirements of each channel
- Cost

The various general configurations include the following.

- **Single channel possibilities**
- Direct conversion
- Pre-amplification and direct conversion

- Sample and hold, and conversion

- Pre-amplification, signal conditioning and any of the above

- **Multi channel possibilities**

- Multiplexing the outputs of single channel converters

- Multiplexing the output of sample-hold circuits

- Multiplexing the inputs of sample-hold circuits

- Multiplexing low level data
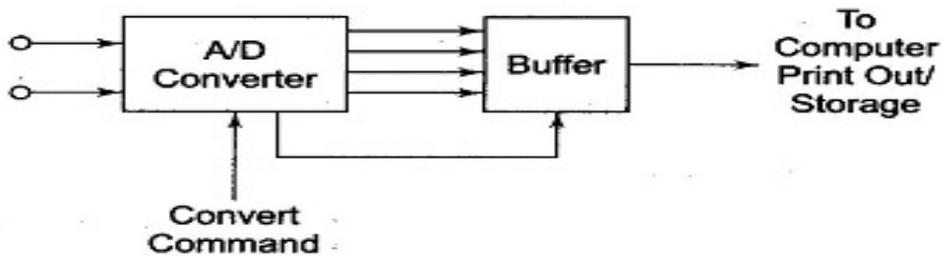
Fig. Single Channel DAS
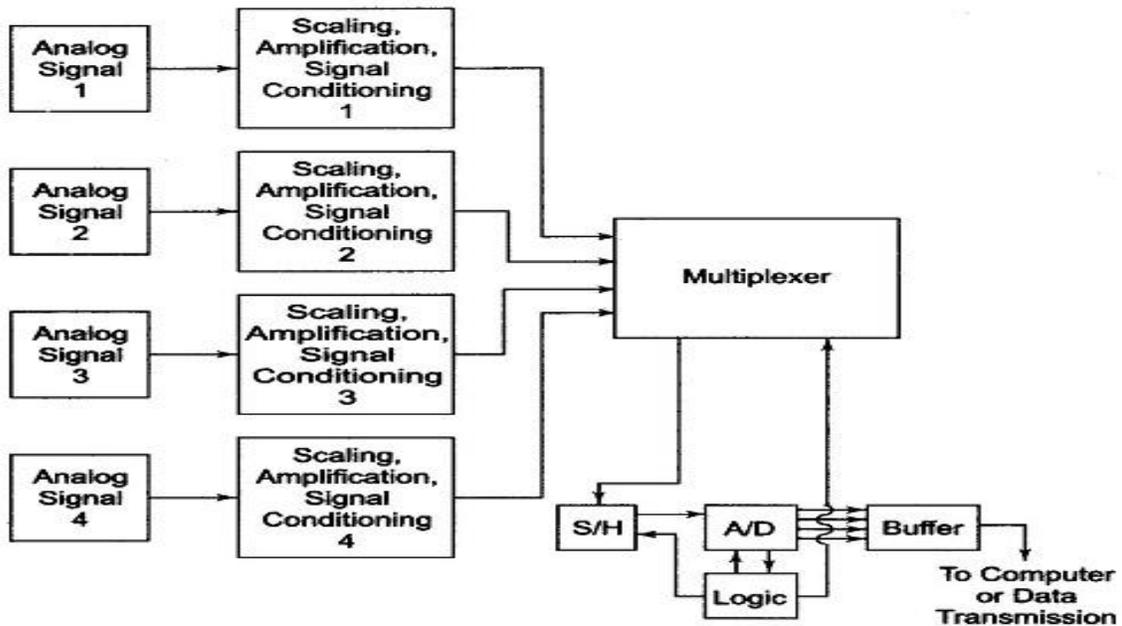
Fig. 17.5   Multi-channel DAS (A/D Preceded by a Multiplexer)