

ELECTRICAL and ELECTRONIC MEASUREMENTS and INSTRUMENTATIONSubject Code : **10EE35**

No. of Lecture Hrs./ Week : 04

Total No. of Lecture Hrs. : 52

IA Marks : 25

Exam Hours : 03

Exam Marks : 100

PART – A**UNIT 1:**

1-(a) Units and Dimensions: Review of fundamental and derived units. S.I. units.

Dimensional equations, problems.

3 Hours

1-(b) Measurement of Resistance: Wheatstone's bridge, sensitivity, limitations. Kelvin's double bridge. Earth resistance, measurement by fall of potential method and by using Megger.

3 Hours

UNIT 2:

Measurement of Inductance and Capacitance: Sources and detectors, Maxwell's inductance bridge, Maxwell's inductance & capacitance bridge, Hay's bridge, Anderson's bridge, Desauty's bridge, Schering bridge. Shielding of bridges. Problems. 07 Hours

UNIT 3:

Extension of Instrument Ranges: Shunts and multipliers. Construction and theory of instrument transformers, Equations for ratio and phase angle errors of C.T. and P.T (derivations excluded). Turns compensation, illustrative examples (excluding problems on turns compensation), Silsbee's method of testing CT. 07 Hours

UNIT 4:

Measurement of Power and Energy: Dynamometer wattmeter. UPF and LPF wattmeters, Measurement of real and reactive power in three-phase circuits. Induction type energy meter — construction, theory, errors, adjustments and calibration. Principle of working of electronic energy meter. 06 Hours

PART – B**UNIT 5:**

(a) Construction and operation of electro-dynamometer single-phase power factor meter. Weston frequency meter and phase sequence indicator. 04 Hours

(b) Electronic Instruments: Introduction. True RMS responding voltmeter. Electronic multimeters. Digital voltmeters. Q meter. 04 Hours

UNIT 6: Dual trace oscilloscope — front panel details of a typical dual trace oscilloscope. Method of measuring voltage, current, phase, frequency and period. Use of

Lissajous patterns. Working of a digital storage oscilloscope. Brief note on current probes. 06 Hours

UNIT 7: Transducers: Classification and selection of transducers. Strain gauges. LVDT. Measurement of temperature and pressure. Photo-conductive and photo-voltaic cells. 06 Hours

UNIT 8: (a) Interfacing resistive transducers to electronic circuits. Introduction to data acquisition systems. 2 Hours

(b) Display Devices and Signal Generators: X-Y recorders. Nixie tubes. LCD and LED display. Signal generators and function generators. 4 Hours

Text Books

1. Electrical and Electronic Measurements and Instrumentation, A. K. Sawhney, Dhanpatrai and Sons, New Delhi.
2. Modern Electronic Instrumentation and Measuring Techniques, Cooper D. and A.D. Heifrick, PHI, 2009 Edition.

References

1. Electronic Instrumentation and Measurement, David A. Bell, oxford Publication ,2nd Edition, 2009.
2. Electrical Measurements and Measuring Instruments, Golding and Widdies, Pitman

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Unit 1

Units & Dimensions

1 Units

To specify and perform calculations with physical quantities, the physical quantities must be defined both in time and magnitude.

The std. measure of each type of physical quantity to be measured is called unit. Mathematically the procedure of measurement can be expressed as

$$\text{Magnitude of measurand} = \text{numerical ratio} * \text{unit}$$

Where numerical ratio = number of times the unit occurs in any given amount of same quantity. Hence it is also called no. of measures. It is also called numerical multiplier.

Hence, process of measurement is to find numerical ratio. The numerical ratio has no physical meaning without the unit.

Ex: If we say the weight of 5kg means well defined weight is one kg and 5 such units are there in the measured weight. Thus, the numerical ratio is 5/1 while the unit is kg.

1.1 Fundamental Units

The units which are independently chosen and not dependent on any other units are called fundamental units. These are also called base units.

The length, mass and time are fundamental to most of the physical quantities. Hence the units which are the measures of length, mass and time are called primary fundamental units.

Ex : m, kg, s

The measures of certain physical quantitative related to numerical, thermal, illumination etc. are called auxiliary fundamental units.

Ex: k, candela, ampere

1.2 Derived Units

All the units which are expressed in terms of the fundamental units using the physical equations are called derived Units.

Ex: Area of rectangle = $l * b$

Each of l & b is measured in m. Thus the product becomes $m * m = m^2$. Hence the new unit which is derived as sq. m. for expressing the area is called derived units

2. Dimensions

Every physical quantity has its own identity. Such an identity is nothing but its quality with which it can be distinguished from all the other quantities. Such a unique quality possessed by a quantity is called its dimension. Symbolically, the dimension is expressed in the characteristic notation which is []

For Ex: the dimension of length is expressed as [L], the dimension of mass is [M]. The dimension of time is [T].

Similar to fundamental unit, each derived unit also has a unique dimension associated with it.

Ex: The volume, $V = l * b * h$ where the dimension of each l, b and h is [L]. Hence the equation in dimensional form becomes,

$$V = [L][L][L]$$

$$V = [L^3]$$

Any constants existing in the equations are always dimensionless. Thus, it can be said the complete algebraic formula to obtain the derived unit from the fundamental units is nothing but the dimension of the derived unit. Thus the equality in terms of dimensions and should not be mixed up with actual numerical values

2.1 Dimensional Equations

The equation obtained by replacing each quantity in the mathematical equation by respective dimensions is called dimensional equations.

2.2 Dimensional equations help

- In conversion from one system of units to another system of units
- In derivation of equations for physical quantities
- In checking the accuracy of an equation

Dimensions of Mechanical Quantities

For deriving the dimensions, let us use the equality sign in the known relations in terms of dimensions

Force Force = m * a = [M] [LT⁻²] = [MLT⁻²]
 a = velocity/time = [LT⁻¹]/[T] = [LT⁻²]
 v = distance/time = [L]/[T] = [LT⁻¹]

Work work = force * distance
 = [MLT⁻²][L]
 = [ML²T⁻²]

Power = work / time = [ML²T⁻²] / [T] = [ML²T⁻³]

Energy = Power * Time = [ML²T⁻³]/[T⁻¹] = [ML²T⁻²]

Momentum = mass * velocity = [M][LT⁻¹] = [MLT⁻¹]

Torque = Force * distance = [MLT⁻²] [L] = [ML²T⁻²]

Stiffness = Torque/ angle = [ML²T⁻²]

Surface tension = force / length = [MLT⁻²]/[L] = [ML⁰T⁻²]

3 C.G.S. System of Units

The CGS system of units was used earlier during the 19th century in the development of the electrical theory. In cgs system of units length, mass and time are the centimeter, gram, the second respectively. In this system of units, in addition to [LMT] an additional fourth quantity is used. Such a fourth fundamental unit is used on based on either electrostatic relations or electromagnetic relations.

Electromagnetic units:

In this system of units the fourth fundamental unit used is μ which is permeability of the medium. All dimensions are derived in terms of these 4 basic dimensions L, M, T, μ . The permeability of free space is assumed to be 1 in such systems. Such a system is called electromagnetic system of units.

Electrostatic units

In this system of units the fourth fundamental unit used is ϵ . which is permittivity of the medium, in addition to 3 basic units L, M and T. All dimensions are derived in terms of these 4 basic dimensions L, M, T and ϵ . The permittivity of free space i.e., vacuum is assumed to be 1 in such system. Such a system is called electrostatic system of units

4. Dimensions in electrostatic system of units

Charge $Q = Q^2 / \epsilon d^2$

$$Q = \sqrt{F \epsilon d^2}$$

$$Q = d \sqrt{F \epsilon}$$

$$[L][MLT^{-2}]^{1/2}[\epsilon^{1/2}]$$

$$[L][M^{1/2}L^{1/2}T^{-1}][\epsilon^{1/2}]$$

$$[M^{1/2}L^{3/2}T^{-1}\epsilon^{1/2}]$$

Current $I = Q/T = [M^{1/2}L^{3/2}T^{-1}\epsilon^{1/2}]/[T] = [T]^{-1} = [M^{1/2}L^{3/2}T^{-2}\epsilon^{1/2}]$

Potential difference $E = \text{workdone} / \text{charge} = W/Q = [M^{1/2}L^{1/2}T^{-1}\epsilon^{-1/2}]$

Capacitance $C = q/v = [M^{1/2}L^{3/2}T^{-1}\epsilon^{1/2}]/[M^{1/2}L^{1/2}T^{-1}\epsilon^{-1/2}] = [L\epsilon]$

Resistance $R = V/I = [M^{1/2}L^{1/2}T^{-1}\epsilon^{-1/2}]/[M^{1/2}L^{3/2}T^{-2}\epsilon^{1/2}] = [L^{-1}T\epsilon^{-1}]$

Inductance $L = E / di/dt = [M^{1/2}L^{1/2}T^{-1}\epsilon^{-1/2}]/[M^{1/2}L^{3/2}T^{-2}\epsilon^{1/2}]/[T] = [L^{-1}T^2\epsilon^{-1}]$

5. SI Units

For the sake of uniformity of units all over the world, an international organization the general conference of weights and measures recommended a unified

systematically constituted system of units. This system of units is called SI system of units.

The SI system of units is divided into 3 categories namely

- Fundamental units
- Supplementary units
- Derived units

5.1 Fundamental units

The units which are not dependent on any other unit is called fundamental unit. Seven such base units form SI units

Meter

Kilogram

Second

Ampere

Kelvin

Mole

Candela

Supplementary units

In addition to the fundamental units, there are two supplementary units added to SI system of units they are

Radians for plane angles

Steradian for solid angles

5.2 Derived units

The units other than fundamental and supplementary are derived from the fundamental and supplementary units. Hence these units are called derived units. They are mainly classified as

Mechanical units such as mass, velocity etc.

Electric and magnetic units such as power, energy, weber, tesla etc

Thermal units such as latent heat, calorific value etc

5.3 Advantages of SI system of units

The advantages of SI system of units are

- The SI system of units use decimals and powers of 10 which simplifies the signification of any quantity.
- The value of any particular quantity in SI system of units can be further simplified by the use of prefixes
- The various SI prefixes such as milli, micro, nano etc simplify the expressions of the units of various quantities
- As the current I is used as fourth fundamental quantity, the derivation of dimensional equations for various quantities are simplified

Questions

1. Discuss briefly on these i) SI Units ii) Dimensional equations – Jan/ Feb 2004
2. Explain the terms ‘ dimensions of a physical quality’ and the significance of the dimensional equations July/Aug 2004
3. Explain the usefulness of dimensional equations July/Aug 2005
4. Derive the dimensions of resistance , inductance, capacitance and permeability in MTI system July/Aug 2006
5. Mention the advantages of SI system of units July/Aug 2007
6. Derive the dimensions of MMF, EMF, magnetizing force and flux density in LMTI system Jan/ Feb 2008
7. Mention the uses and limitations of dimensional analysis Jan/ Feb 2012
July/Aug 2011

B. Measurement of Resistance

1. With a neat sketch explain the working of a megger July/Aug 2004
2. Explain the fall of potential of measurement of earth resistance July/Aug 2005
3. Derive the expression for the measurement of unknown resistance using Kelvin’s double bridge. How the effect of connecting lead resistance is eliminated in this arrangement Jan /Feb 2005, July/Aug 2006
4. Write short notes on Megger July/Aug 2008
5. Explain how a megger is used for the measurement of earth resistance July/Aug 2007
6. Define voltage sensitivity of a galvanometer and hence obtain an expression for whetstone’s bridge sensitivity. When will be S_b maximum? Jan / Feb 2008
7. State and explain sensitivity of whetstone’s bridge? Jan/ Feb 2012, July/Aug 2008

Problems:

1. Deriving equation for resistance is Hay’s bridge, the following expression is obtained. $R = \frac{w^2 R_1 R_2 R_3 e^2}{1 + w^2 R_2^2 C}$ Find whether the equation is dimensionally correct or not. In case there is an error find the error and correct equation accordingly Jan/ Feb 2012

$$\begin{aligned} \text{In MKSA rationalized system, } [R] &= [ML^2T^{-3}I^{-2}] \\ [C] &= [M^{-1}L^{-2}T^4I^2] \\ [w] &= 1/[T] \end{aligned}$$

$$\begin{aligned} \text{R.H.S.} &= \frac{w^2 R_1 R_2 R_3 e^2}{1 + w^2 R_2^2 C} \\ &= [T^{-1}] [ML^2T^{-3}I^{-2}]^3 [M^{-1}L^{-2}T^4I^2]^2 / 1 + [T^{-1}]^2 [ML^2T^{-3}I^{-2}]^2 [M^{-1}L^{-2}T^4I^2] \end{aligned}$$

$$\begin{aligned}
 &= [T^{-1}] [M^3 L^6 T^{-9} I^6] [M^{-2} L^{-4} T^8 I^4] / 1 + [T^{-2}] [M^2 L^4 T^{-6} I^4]^2 [M^{-1} L^{-2} T^4 I^2] \\
 &= [M^1 L^2 T^{-3} I^{-2}] / [M^1 L^2 T^{-4} I^{-2}] \\
 \text{L.H.S.} &= [M^1 L^2 T^{-3} I^{-2}] \\
 &= [M^1 L^2 T^{-3} I^{-2}] / [M^1 L^2 T^{-4} I^{-2}]
 \end{aligned}$$

Multiply $[M^{-1} L^{-2} T^4 I^2]$ to Dr

$$[M^1 L^2 T^{-3} I^{-2}] = [M^1 L^2 T^{-3} I^{-2}]$$

$$[M^{-1} L^{-2} T^4 I^2] = C$$

Therefore multiply the equation by C

$$R = w^2 R_1 R_2 e^2 / 1 + w^2 R_2^2 C^2$$

Thus, dimensionally equation is not correct. It can be seen that numerator dimension of R.H.S. are same as the dimensions of L.H.S.. Hence, to satisfy the equation dimensionally, denominator of R.H.S. must be dimensionless. So, to balance the denominator of R.H.S., it must be multiplied by $[M^{-1} L^{-2} T^4 I^2]$. These are the dimensions of capacitor C. this indicates the term $w^2 R_2^2 C$ must be multiplied by one more C to satisfy the equation dimensionally correct.

The expression for mean torque of an electro-dynamometer type wattmeter may be written as $T \propto M^p E^q Z^t$. Where M = mutual inductance between fixed and moving coils. E = applied voltage, Z = impedance of load circuit. determine the values of p, q, t performing dimensional analysis July/Aug 2007

$$\begin{aligned}
 [T] &= [ML^2 T^{-2}] \\
 [M] &= [M^1 L^2 T^{-2} I^{-2}]
 \end{aligned}$$

$$\begin{aligned}
 [E] &= [M^1 L^2 T^{-3} I^{-1}] \\
 [Z] &= [M^1 L^2 T^{-3} I^{-2}]
 \end{aligned}$$

$$\begin{aligned}
 T &= k M^p E^q Z^t \\
 [ML^2 T^{-2}] &= k [M^1 L^2 T^{-2} I^{-2}]^p [M^1 L^2 T^{-3} I^{-1}]^q [M^1 L^2 T^{-3} I^{-2}]^t \\
 &= [M^{p+q+t} L^{2p+2q+2t} T^{-2p-3q-3t} I^{-2p-q-2t}]
 \end{aligned}$$

By comparing and solving $p=1, q=2, t=-2$

2. Derive the dimensional equation for resistance R, inductance and capacitance C. hence check for dimensionally correctness of the expression below obtained for inductance from ac bridge measurements, point out the error, if any in the expression and suggest the required correction that makes the expression dimensionally valid

$$L = C (R_3/R_4) (R_2 + R_4 + R_2 R_4)$$

$$L = [M^1 L^2 T^{-2} I^{-2}]$$

$$[R] = [M^1 L^2 T^{-3} I^{-2}]$$

$$[C] = [M^{-1} L^{-2} T^4 I^2]$$

$$\text{R.H.S.} = [M^{-1} L^{-2} T^4 I^2] [M^1 L^2 T^{-3} I^{-2}] / [M^1 L^2 T^{-3} I^{-2}] ([M^1 L^2 T^{-3} I^{-2}] + [M^1 L^2 T^{-3} I^{-2}] + [M^1 L^2 T^{-3} I^{-2}])$$

$$[M^1 L^{-2} T^4 I^2] ([M^1 L^2 T^{-3} I^{-2}] + [M^1 L^2 T^{-3} I^{-2}])$$

$$= [T] [T] + [M^1 L^2 T^{-2} I^{-2}]$$

But dimensionally addition is valid only if all the terms to be added are dimensionally same. Thus the given eq is dimensionally incorrect.

To have it correct, multiply R_2 and R_4 by another resistance. Thus the correct equation becomes

$$L = C (R_3/R_4) (R_2 r + R_4 r + R_2 R_4)$$

4. Expression for eddy current loss p/meter length of wire may be written as $p \propto f^a B_m^b d^c \rho^g$

Where f = frequency, B_m = Max. flux density, d = diameter of wire, ρ – resistivity of material. Find the values a, b, c, and g using L, M, T, I system

$$P = k f^a B_m^b d^c \rho^g$$

$$[P] = [I^1 L^{-1}]$$

$$[f] = [T^{-1}]$$

$$[B_m] = [M^1 T^{-2} I^{-1}]$$

$$[d] = [L]$$

$$[\rho] = [M^1 L^3 T^{-3} I^{-2}]$$

$$[I^1 L^{-1}] = k [T^{-1}]^a [M^1 T^{-2} I^{-1}]^b [L]^c [M^1 L^3 T^{-3} I^{-2}]^g$$

$$[I^1 L^{-1}] = k [T^{-a}] [M^b T^{-2b} I^{-b}] [L^c] [M^g L^{3g} T^{-3g} I^{-2g}]$$

By comparing and solving $a = 2$, $b = 2$, $g = 1$, $c = 4$

Unit 2

Measurement of resistance, inductance and capacitance

Introduction:

A bridge circuit in its simplest form consists of a network of four resistance arms forming a closed circuit. A source of current is applied to two opposite junctions. The current detector is connected to other two junctions.

The bridge circuits use the comparison measurement methods and operate on null-indication principle. The bridge circuit compares the value of an unknown component with that of an accurately known standard component. Thus the accuracy depends on the bridge components and not on the null indicator. Hence high degree of accuracy can be obtained.

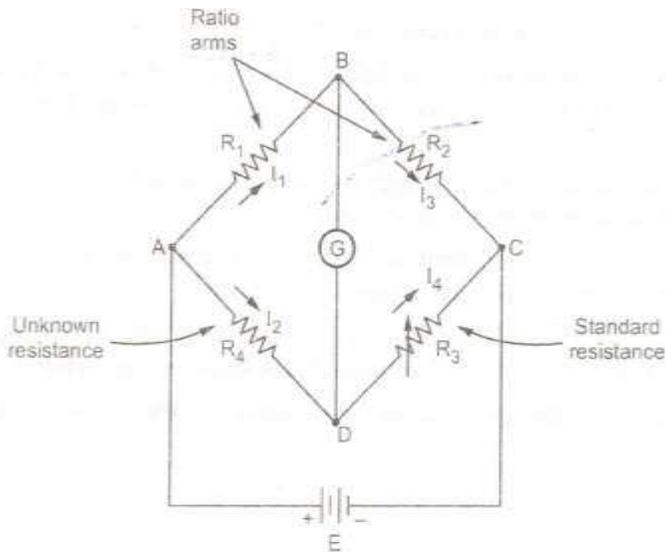
2 Advantages of Bridge Circuit:

The various advantages of the bridge circuit are,

- 1) The balance equation is independent of the magnitude of the input voltage or its source impedance. These quantities do not appear in the balance equation expression.
- 2) The measurement accuracy is high as the measurement is done by comparing the unknown value with the standard value.
- 3) The accuracy is independent of the characteristics of a null detector and is dependent on the component values.
- 4) The balance equation is independent of the sensitivity of the null detector, the impedance of the detector or any impedance shunting the detector.
- 5) The balance condition remains unchanged if the source and detector are interchanged.

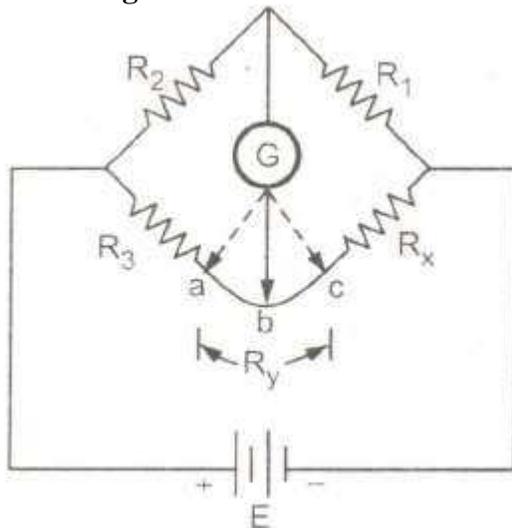
2.1. Wheatstone's bridge:

The bridge consists of four resistive arms together with a source of e.m.f. and a null detector. The galvanometer is used as a null detector.



The arms consisting the resistances R_1 and R_2 are called ratio arms. The arm consisting the standard known resistance R_3 is called standard arm. The resistance R_4 is the unknown resistance to be measured. The battery is connected between A and C while galvanometer is connected between B and D.

2.2. Kelvin bridge:



In the Wheatstone bridge, the bridge contact and lead resistance causes significant error, while measuring low resistances. Thus for measuring the values of resistance below 1Ω , the modified form of Wheatstone bridge is used, known as Kelvin bridge. The consideration of the effect of contact and lead resistances is the basic aim of the Kelvin bridge.

The resistance R_y represents the resistance of the connecting leads from R_1 to R_3 . The resistance R_x is the unknown resistance to be measured.

\ The galvanometer can be connected to either terminal a, b or terminal c. When it is connected to a, the lead resistance R_y gets added to R_x hence the value measured by the bridge, indicates much higher value of R_x .

If the galvanometer is connected to terminal c, then R_y gets added to R_3 . This results in the measurement of R_x much lower than the actual value.

The point b is in between the points a and c, in such a way that the ratio of the resistance from c to b and that from a to b is equal to the ratio of R_1 and R_2 .

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

2.3. A.C. Bridges:

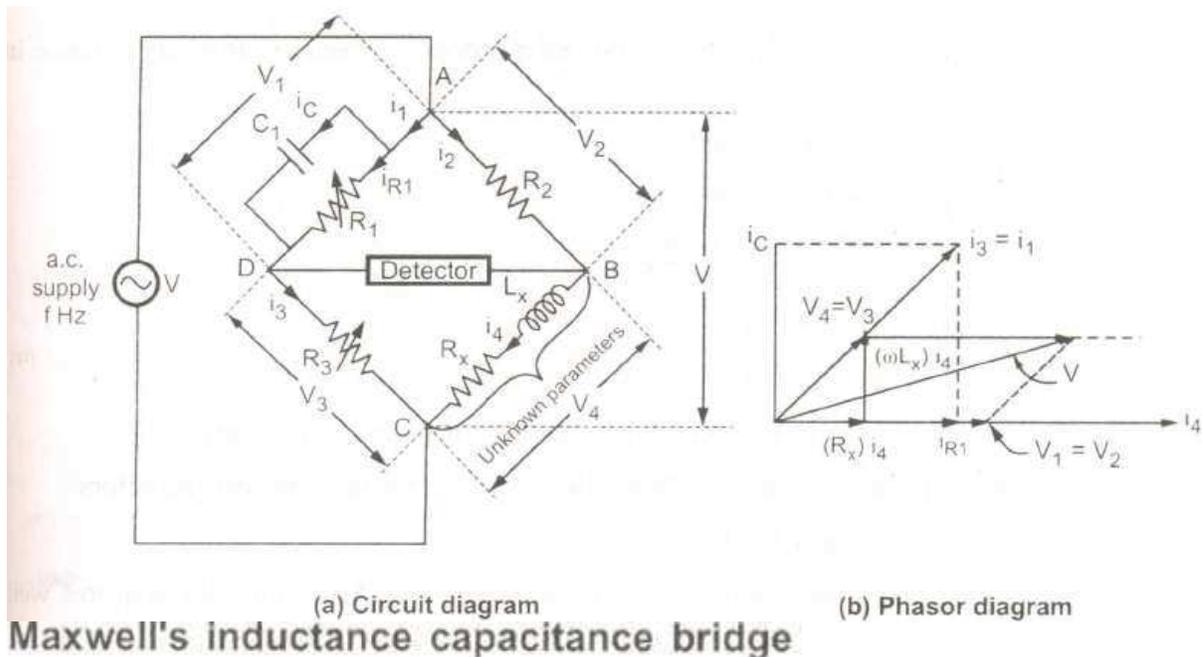
An a.c. bridge in its basic form consists of four arms, a source of excitation and a balance detector. Each arm consists of an impedance. The source is an a.c. supply which supplies a.c. voltage at the required frequency. For high frequencies, the electronic oscillators are used as the source. The balance detectors commonly used for a.c. bridge are head phones, tunable amplifier circuits or vibration galvanometers. The headphones are used as detectors at the frequencies of 250 Hz to 3 to 4 kHz. While working with single frequency a tuned detector is the most sensitive detector. The vibration galvanometers are useful for low audio frequency range from 5 Hz to 1000 Hz but are commonly used below 200 Hz. Tunable amplifier detectors are used for frequency range of 10 Hz to 100 Hz.

2.4. Hay's Bridge:

In the capacitance comparison bridge the ratio arms are resistive in nature. The impedance Z_3 consists of the known standard capacitor C_3 in series with the resistance R_3 . The resistance R_3 is variable, used to balance the bridge. The impedance Z_4 consists of the unknown capacitor C_x and its small leakage resistance R_x .

2.5. Maxwell's Bridge :

Maxwell's bridge can be used to measure inductance by comparison either with a variable standard self inductance or with a standard variable capacitance. These two measurements can be done by using the Maxwell's bridge in two different forms.



2.6. Methods of Measurement of Earth Resistance

2.6.1 Fall of Potential Method

Fig below shows the circuit diagram used for the measurement of earth resistance by fall of potential method. E is the earth electrode. The electrode Q is the auxiliary electrode. The current I is passed through the electrodes E & Q with the help of external battery E. another auxiliary electrode P is introduced in between the electrodes E & Q. the voltage between the electrodes E & P is measured with the help of voltmeter.

Thus if the distance of electrode P is changed from electrode E electrode Q, the electrode P experiences changing potential near the electrodes while a constant potential between the electrodes E & Q but away from the electrodes from Q.

The potential rises near the electrodes E & Q due to higher current density in the proximity of the electrodes. By measuring the potential between the electrodes E & P as V_{EP} , the earth resistance can be obtained as

$$R_E = V_{EP} / I$$

2.6.2 Shielding and grounding of bridges

This is one way of reducing the effect of stray capacitances. But this technique does not eliminate the stray capacitances but makes them constant in value and hence they can be compensated.

One very effective and popular method of eliminating the stray capacitances and the capacitances between the bridge arms is using a ground connection called Wagner Ground connection.

Questions from Question Paper:

1. Explain Maxwell's bridge? June/July 2009
2. Explain Kelvin's bridge? Dec/Jan 2008, Jan/ Feb 2012
3. Explain the importance of Wheatstone bridge? May/June 2010
4. Explain the Capacitance Comparison Bridge? Dec/Jan 2010
5. Explain the Maxwell's bridge? June/July 2009
6. Explain the Wagner's earth connection? Dec/Jan 08, Jan/ Feb 2012
7. Derive the balance equations of the Schering bridge circuit configuration used for measurement of capacitances and hence derive the expression for loss angle of the test capacitor. Draw the phasor diagram at balance.
Jan/Feb-2004, July/Aug 2004, Jan/ Feb- 2008
8. Write a short note on the Wagner earthing device
July/Aug-2004/2010, Jan/Feb-2011
9. Derive the expression for the measurement of capacitance and loss angle of a lossy capacitor using Schering bridge. Draw the phasor diagram at balance condition. What modifications are introduced when the bridge is used at high voltages
Jan/Feb-2005, July/Aug 2004
10. Write briefly on the significance of shields used in ac bridge circuit. Hence discuss on the shielding of resistors and capacitors of the circuit
July/Aug 2005, Jan/ Feb 2005
11. Draw a neat sketch to explain the theory and measurement of unknown inductance and resistance by Anderson bridge. What is type of null detector used in this bridge? What are the sources of errors? Draw phasor diagram at balance
July/Aug 2006, Jan/ Feb 2006, Jan/ Feb 2012
12. Write short notes on source and detectors
July/Aug 2008, Jan/ Feb 2007

Unit 3

Extension of Instrument ranges

Introduction

Moving coil instruments, which are used as ammeters and voltmeters are designed to carry max. current of 50mA and withstand a voltage of 50mV. Hence, to measure larger currents and voltages, the ranges of these meters have to be extended. The following methods are employed to increase the ranges of ammeters and voltmeters

- By using shunts the range of dc ammeters is extended
- By using multipliers, the range of dc voltmeter is extended
- By using current transformers the range of ac ammeter is extended
- By using potential transformer the range of ac voltmeter

3.1 Shunt

When heavy currents are to be measured, the major part of current is bypassed through a low resistance called shunt. It is shown in the below fig

The shunt resistance can be calculated as,

Let R_m = internal resistance of coil
 R_{sh} = shunt resistance
 I_m = full scale deflection current
 I_{sh} = shunt current
 I = Total current

Now, $I = I_{sh} + I_m$

$I_{sh} R_{sh} = I_m R_m$

$R_{sh} = I_m R_m / I_{sh}$

$R_{sh} = R_m / (I / I_m - 1)$

$R_{sh} = R_m / m - 1$ where $m = I / I_m$

And m is called multiplying power of shunt and is defined as the ratio of total current to the current through the coil

3.2 Multirange ammeters

The range of basic dc ammeter can be extended by using no. of shunts and a selector switch, such a meter is called multirange ammeter and is shown in the fig

3.3 Range extension of voltmeter

Multiplier

The resistance is required to be connected in series with 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 meter current does not exceed full scale deflection value.

The multiplier resistance can be calculated as

Let R_m is the internal resistance of the coil.

R_s = series multiplier resistance

I_m = full scale deflection current

V = full range voltage to be measured

$$V = I_m R_m + I_m R_s$$

$$I_m R_s = V - I_m R_m / I_m$$

$$R_s = V/I_m - R_m$$

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

$$M = V/v$$

3.4 Instrument Transformers

They are divided into two types

- Current transformers
- Potential transformers

3.4.1 Current transformer

CT is the one which is to be measure a large current in ckt using low range ammeter.

The primary winding of CT which has few no of turns is connected in series with load. The secondary of transformer is made up of large number of turns. This is connected to the coil of normal range ammeter, which is usually rated for 5A. the representation of CT is as shown fig.

3.4.2 Potential Transformer

P.T. is the one which is used to measure a large voltage using a low range voltmeter. The representation of P.T. is as shown in the fig.

The primary winding consists of large number of turns while secondary has less number of turns. The primary is connected across high voltage line while secondary is connected to low range voltmeter coil.

The high voltage V_p being measured is given by, $V_p = nV_s$

Where, $n = N_p/N_s = \text{turns ratio}$

3.4.3 Why secondary of C.T. should not be open?

It is very important that secondary of C.T. should not be kept open. If it is left open, then current through secondary becomes zero. Hence, the ampere turns produced by secondary which generally oppose primary ampere turns becomes zero. As there is no counter m.m.f., unopposed primary mmf produces high flux in the core. This produces excessive core loss, heating the core beyond limits. Similarly heavy emf's will be induced on the primary and secondary side. This may damage the insulation of winding and this is danger from operator point of view as well

Hence, never open secondary winding ckt of a CT, while its primary winding is energized.

3.5. Ratios of instrument transformers

The various ratios defined for instrument transformers are

Actual ratio[®] :

The actual transformation ratio is defined as the ratio of the magnitude of actual primary phasor to the corresponding magnitude of actual secondary phasor

C.T. $R = \text{magnitude of actual primary current} / \text{magnitude of actual sec. current}$

P.T. $R = \text{magnitude of actual primary voltage} / \text{magnitude of actual sec. voltage}$

Nominal ratio (K_n)

The nominal ratio is defined as the ratio of rated pri quantity to rated sec. quantity, either current or voltage

C.T. $K_n = \text{rated pri. current} / \text{rated sec. current}$

P.T., $K_n = \text{rated pri. voltage} / \text{rated sec. voltage}$

Turns ratio(n)

C.T. , $n = \text{no. of turns of sec. winding} / \text{no. of turns of primary winding}$

P.T., $n = \text{no. of turns of primary winding} / \text{no. of turns of sec. winding}$

3.5.1 Burden of an instrument transformer

The permissible load across sec. winding expressed in volt amperes and the rated sec. winding, voltage or current such that errors do not exceed the limits is called burden of an instrument transformer.

Total sec. winding burden = (sec. winding induced voltage)² / total impedance of sec. ckt including load and winding

Derivation of actual ratio R

Consider triangle BAC as shown in small section where

$$BC / AC = \sin(90 - \delta - \alpha)$$

$$BC = AC \sin(90 - \delta - \alpha)$$

$$BC = AC \cos(\delta + \alpha)$$

$$AB / AC = \cos(90 - \delta - \alpha)$$

$$AB = AC \cos(90 - \delta - \alpha)$$

$$AB = AC \cos(90 - (\delta + \alpha))$$

$$AB = AC \sin(\delta + \alpha)$$

Also,

$$OC^2 = OB^2 + BC^2$$

$$IP^2 = (OA + AB)^2 + BC^2$$

$$\begin{aligned} Ip^2 &= [nIs + I_0 \sin(\delta + \alpha)]^2 + I_0^2 \cos^2(\delta + \alpha) \\ &= nIs^2 + 2nIs I_0 \sin(\delta + \alpha) + I_0^2 \sin^2(\delta + \alpha) + I_0^2 \cos^2(\delta + \alpha) \end{aligned}$$

$$\begin{aligned} Ip^2 &= nIs^2 + 2nIs I_0 \sin(\delta + \alpha) + I_0^2 \\ Ip &= \sqrt{nIs^2 + 2nIs I_0 \sin(\delta + \alpha) + I_0^2} \end{aligned}$$

$$R = Ip / Is = \sqrt{nIs^2 + 2nIs I_0 \sin(\delta + \alpha) + I_0^2 \sin^2(\delta + \alpha)}$$

$$\sqrt{[nIs + I_0 \sin(\delta + \alpha)]^2} / Is$$

$$nIs + I_0 \sin(\delta + \alpha) / Is$$

$$n + I_0 / Is \sin(\delta + \alpha)$$

$$n + I_0 / Is (\sin \delta \cdot \cos \alpha + \cos \delta \sin \alpha)$$

$$R = \frac{n + I_m \sin \delta \cdot I_c \cos \delta}{Is}$$

Errors in C.T.

There are 2 types of errors in instrument transformer. They are

- Ratio error
- Phase angle error

Ratio error

The ratio error is defined as %ratio error = nominal ratio – actual ratio / actual ratio *100

$$\text{Ratio error} = \frac{Kn - R}{R} * 100$$

Phase angle error

The phase angle error is given by $\theta = 180 / \pi [\frac{I_m \cos \delta - I_c \sin \delta}{n I_s}]$

Question paper Problems

1. Design a multirange dc milliammeter with a basic meter having a resistance 75Ω and full scale deflection for the current of 2 mA. The required ranges are 0-10mA, 0-50mA, 0-100mA\

$$R_m = 75 \Omega, \quad I_m = 2\text{mA}$$

$$R_{sh} = \frac{R_m}{I/I_m - 1}$$

$$75 / 10/2 - 1 = 75/5 - 1 = 18.75 \Omega$$

$$R_m = 75 / 50/2 - 1 = 75/25 - 1 = 3.125 \Omega$$

$$75 / 100/2 - 1 = 75/49 = 1.53 \Omega$$

2. A moving coil meter takes 50mA to produce fullscale deflection , the p.d.across its terminals be 75mV. Suggest a suitable scheme for using the instrument as a voltmeter reading 0-100V and as an ammeter reading 0-50A **Jan/ Feb 2012**

As an ammeter

$$V = IR$$

$$R_m = V/I_m = 5 \Omega$$

$$R_{sh} = R_m / I/I_m - 1 = 1.501\text{m} \Omega$$

As an voltmeter

$$R_s = V/I_m - R_m = 6.661 \text{ k}\Omega$$

3. A c.t. has a single turn primary and 400 secondary turns. The magnetizing current is 90A while coreloss current is 40A. secondary ckt phase angle is 28. calculate the actual primary current and ratio error when secondary current carries 5A current

$$I_p = nI_s$$

$$I_p = (N_s / N_p) \cdot I_s$$

$$\% \text{ ratio} = K_n - R / R * 100$$

$$n = N_s / N_p = 400$$

$$R = n + I_m \sin \delta \cdot I_c \cdot \cos \delta / I_s$$

$$= 400 + \frac{90 \sin 28 + 40 \cos 28}{5}$$

$$= 415.513$$

$$\% \text{ ratio error} = 400 - 415.513 / 415.513 * 100 = -3.733\%$$

$$I_p = nI_s$$

$$I_p = N_s / N_p (5) = 400(5) = 2000A$$

$$R = I_p / I_s$$

$$I_p = R I_s = 415.513(5) = 2077.57A$$

4. At its rated load of 25VA, a 10/5 current transformer has an iron loss of 0.2W and magnetizing current of 1.5A. calculate its ratio error and phase angle when supplying rated o/p to a meter having a ratio of resistance to reactance of 5

$$\% \text{ ratio} = K_n - R / R * 100$$

$$R = n + I_m \sin \delta \cdot I_c \cdot \cos \delta / I_s$$

To find I_c

$$E_p I_p = 25VA$$

$$E_p = 25 / 100 = 0.25V$$

$$I_c = P / E_p = 0.2 / 0.25 = 0.8A$$

To find δ

$$\delta = \tan^{-1} X_s / R_s = 11.309$$

$$R = n + I_m \sin \delta \cdot I_c \cdot \cos \delta / I_s$$

$$20 + 1.5(0.1961) + 0.8(0.9805) / 5 = 20.214$$

$$\% \text{ ratio} = K_n - R / R * 100$$

$$20 - 20.215 / 20.215 * 100 = -1.063\%$$

To find θ

$$\theta = 180 / \pi [\frac{I_m \cos \delta}{n I_s} - \frac{I_c \sin \delta}{n I_s}]$$

$$= 180 / \pi [\underline{1.5(0.9805)} - \underline{0.8(0.1961)} / 20(5)]$$

$$= 0.752$$

5. A C.T. of turns ratio 1:199 is rated as 1000/5A, 25VA. The core loss is 0.1W and magnetizing current is 7.2A, under rated conditions. Determine the phase angle and ratio errors for rated burden and rated sec. current 0.8 p.f. lagging. Neglect winding resistance and reactance

$$R = n + I_m \sin \delta + I_c \cos \delta / I_s$$

$$199 + 7.2(0.6) + 4(0.8) / 5 = 200.504$$

$$\% \text{ ratio error} = \frac{Kn - R}{R} * 100$$

$$= \frac{200 - 200.504}{200.504} * 100$$

$$= 0.251\%$$

$$\theta = 180 / \pi [\underline{I_m \cos \delta} - \underline{I_c \sin \delta} / n I_s]$$

$$\theta = 180 / \pi [\underline{7.2(0.8)} - \underline{4(0.6)} / 199 * 5]$$

$$= 0.1934^\circ$$

Descriptive Questions

- Discuss briefly on the shunts and multipliers used for expression of meters in electrical measurements
July/Aug 2005, Jan/ Feb 2004, 2007
- Write a note on the turns compensation used in instrument transformers
July/Aug 2010, Jan/ Feb 2004, Jan/ Feb 2012
- Discuss the various methods generally adopted for range extension of ammeters and voltmeters
July/Aug 2004, July/Aug 2009
- Briefly explain the design features of a CT
July/Aug 2004
- What are the disadvantages of shunts and multipliers used in measurement system
Jan/ Feb 2005
- What are the differences between CT and PT
Jan/ Feb 2005, Jan/ Feb 2004, 2007, 2009, 2010
- What happens if the secondary of a CT is open circuited while the primary is carrying normal load current
Jan/ Feb 2006
- Explain clearly how shunts and multipliers are used to extend the range of instruments
July/Aug 2007

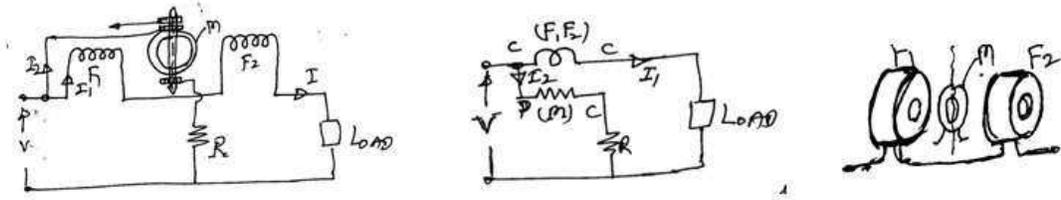
- 9. Explain with circuit diagram Silsbee's method of testing of current transformer
July/Aug 2007, Jan/ Feb 2012
- 10. Explain the principle of range extension of ammeter
Jan/ Feb 2008
- 11. What are the advantages of instrument transformers
July/Aug 2008, Jan/ Feb 2009,2011

Unit 4

Measurement of power and Energy

4.1 DYNAMOMETER TYPE WATTMETER

In this type there will not be any permanent magnets and there will be a pair of fixed coils connected in series when energized gives the same effect as that of the permanent magnets. In the field of these fixed coils there will be a moving coil which when energized acted upon by a torque by which it deflects



$F_1 F_2$: Fixed coils

M: Moving coil

R: High resistance in series with m

I_1 : load current

I_2 : current through

The two fixed coils in series act as the current coil and the moving coil in series with R act as the potential coil. The moving coil is pivoted between the two fixed coils carries a current I_2 proportional to V. This current is fed to m through two springs which also provides the necessary controlling torque. This instrument can be used on both ac and dc circuits as both the coils are energized simultaneously by a common source due to which a unidirectional torque is produced.

4.2 Energy meter

It works on the principle of induction i.e. on the production of eddy currents in the moving system by the alternating fluxes. These eddy currents induced in the moving system interact with each other to produce a driving torque due to which disc rotates to record the energy.

In the energy meter there is no controlling torque and thus due to driving torque only, a continuous rotation of the disc is produced. To have constant speed of rotation braking magnet is provided.

Construction:

There are four main parts of operating mechanism

- 1) Driving system 2) moving room 3) braking system 4) registering system.

1) Driving system: It consists of two electromagnets whose core is made up of silicon steel laminations. The coil of one of the electromagnets, called current coil, is excited by load current which produces flux further. The coil of another electromagnetic is connected across the supply and it carries current proportional to supply voltage. This is called pressure coil. These two electromagnets are called as series and shunt magnets respectively.

The flux produced by shunt magnet is brought in exact quadrature with supply

voltage with the help of copper shading bands whose position is adjustable.

2) Moving system: Light aluminium disc mounted in a light alloy shaft is the main part of moving system. This disc is positioned in between series and shunt magnets. It is supported between jewel bearings. The moving system runs on hardened steel pivot. A pinion engages the shaft with the counting mechanism. There are no springs and no controlling torque.

3) Braking system: a permanent magnet is placed near the aluminium disc for braking mechanism. This magnet reproduces its own field. The disc moves in the field of this magnet and a braking torque is obtained. The position of this magnet is adjustable and hence braking torque is adjusted by shifting this magnet to different radial positions. This magnet is called braking magnet.

4) Registering mechanism: It records continuously a number which is proportional to the revolutions made by the aluminium disc. By a suitable system, a train of reduction gears, the pinion on the shaft drives a series of pointers. These pointers rotate on round dials which are equally marked with equal division.

Working: since the pressure coil is carried by shunt magnet M_2 which is connected across the supply, it carries current proportional to the voltage. Series magnet M_1 carries current coil which carries the load current. Both these coils produce alternating fluxes Φ_1 and Φ_2 respectively. These fluxes are proportional to currents in their coils. Parts of each of these fluxes link the disc and induce e.m.f. in it. Due to these e.m.f.s eddy currents are induced in the disc. The eddy current induced by the electromagnet M_2 reacts with magnetic field produced by M_1 and the eddy current induced by M_1 reacts with magnetic field produced by M_2 . Thus each portion of the disc experiences a mechanical force and due to motor action, disc rotates. The speed of disc is controlled by the C shaped magnet called braking magnet. When disc rotates in the air gap, eddy currents are induced in disc which

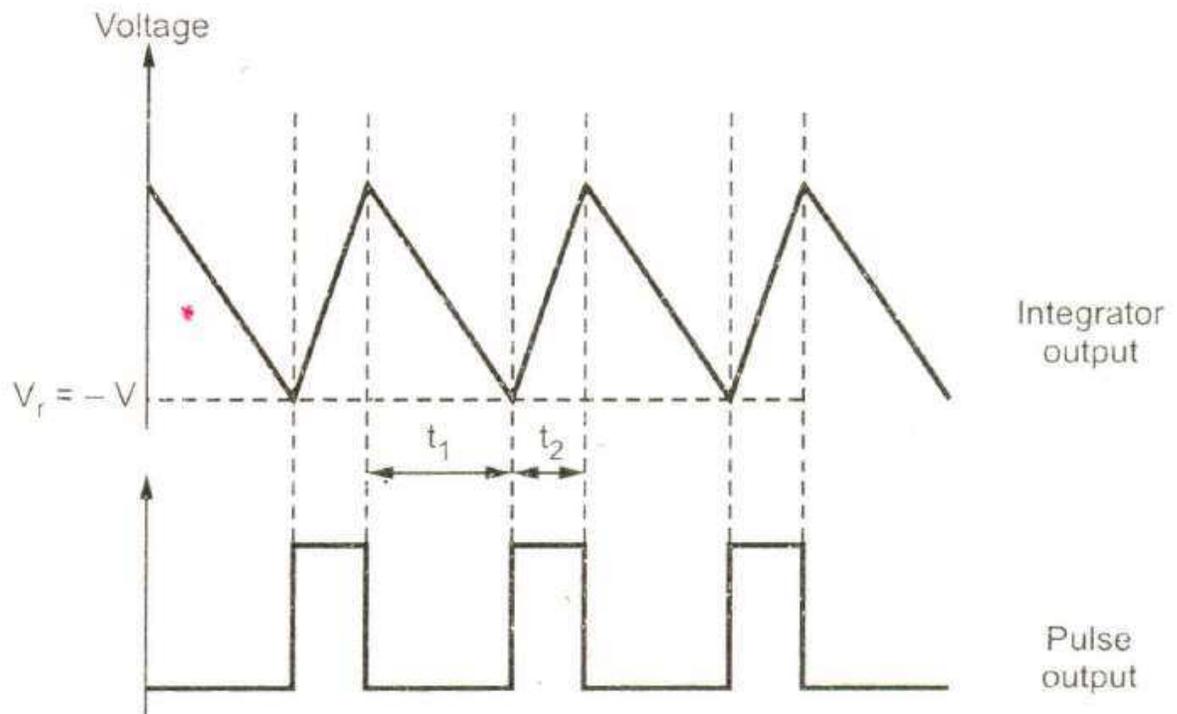
oppose the cause producing them i.e. relative motion of disc with respect to magnet. Hence braking torque T_b is generated. This is proportional to speed N of disc. By adjusting position of this magnet, desired speed of disc is obtained. Spindle is connected for recording mechanism through gears which record the energy supplied.

4.3 Electronic Energy Meter

The function of the Electronic Energy Meter is to produce a pulse of precision charge content. The polarity of this charge is opposite to that of capacitor charge. Thus the pulse generated by the Electronic Energy Meter rapidly discharges the capacitor. Hence the output of the op-amp again becomes zero. This process continues so as to get a sawtooth waveform at the output of op-amp. The frequency of such waveform is directly proportional to the applied input voltage. Thus if the input voltage increases, the number of teeth per unit time in the sawtooth waveform also increases i.e. the frequency increases.

Each teeth produces a pulse at the output of the pulse generator so number of pulses is directly related to the number of teeth i.e. the frequency. These pulses are allowed to pass through the pulse transformer. These are applied at one input of the gate. Gate length control signal is applied at the other input. The gate length' may be 0.1 sec, 1sec, 20 msec etc. The gate remains open for this much time period.

The waveforms of integrator output and output of a pulse generator are shown in the Fig



From the analysis of dual slope technique, we can write,

$$V_{in} = V_r \frac{t_2}{t_1}$$

But in this type, both V_r and t_2 are constants.

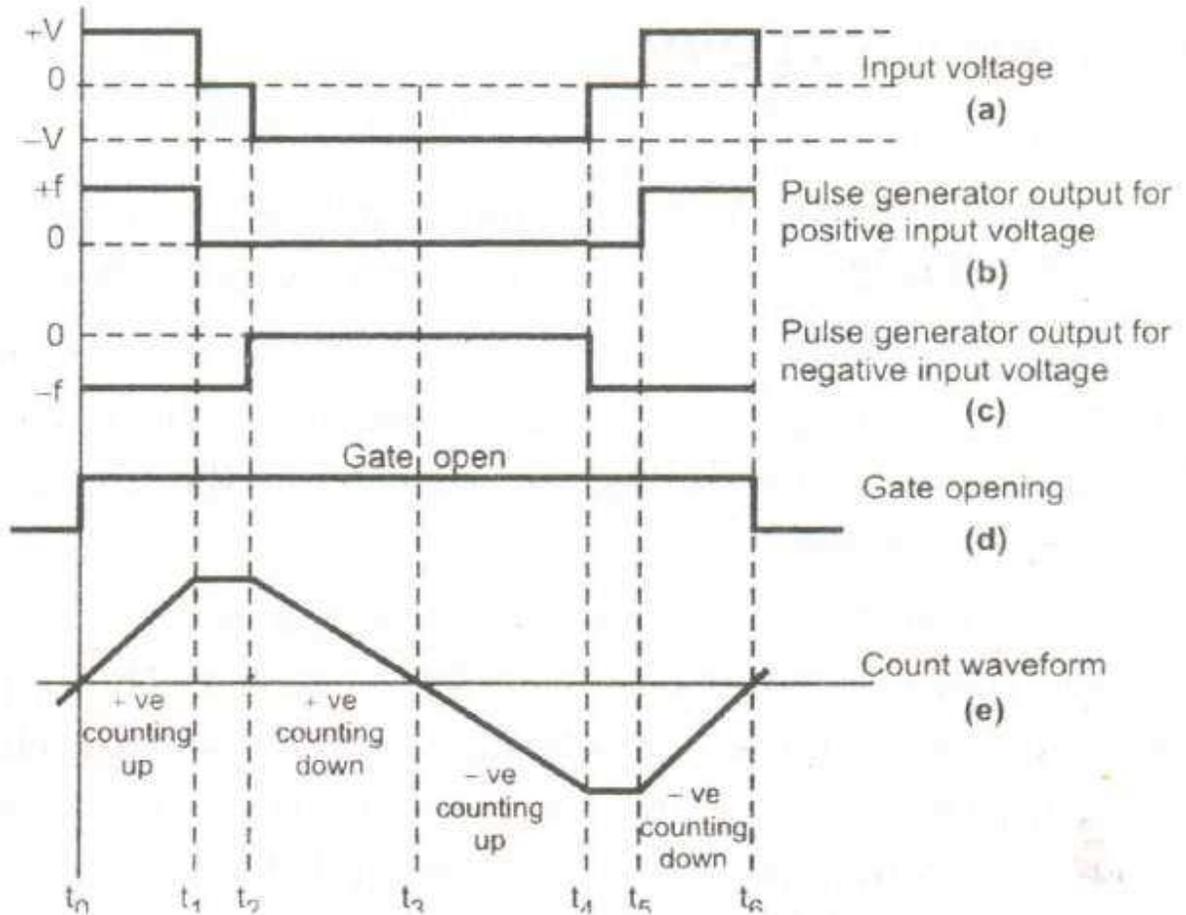
$$K_2 = V_r t_2$$

$$V_{in} = K_2 \left(\frac{1}{t_1} \right) = K_2 (f_o)$$

Accuracy: The accuracy of voltage to frequency conversion technique depends on the magnitude and stability of the charge produced by the pulse generator. Thus the accuracy depends on the precision of the charge feedback in every pulse and also on the linearity, between voltage and frequency.

To obtain the better accuracy the rate of pulses generated by the pulse generator is kept equal to,

- i) the voltage time integration of the input signal
- ii) the total voltage time areas of the feedback pulses.



When input voltage polarity is positive i.e. for the periods t_0 to t_1 and t_5 to t_6 the output of the pulse generator is high. For other time period it is low. This is shown in the Fig. When the input voltage polarity is negative i.e. for the period t_1 to t_4 the output of the pulse generator is high. This is due to other pulse generator used for the bipolar voltages. This is shown in the Fig. For the period t_0 to t_1 , it is positive counting up. For the period t_2 to t_3 it is positive counting down. For t_3 to t_4 negative counting up while for the period t_5 to t_6 , it is negative counting down. To increase the operating speed of this type of Electronic Energy Meter

the upper frequency can be increased i.e. increasing $VI f$ conversion rate. But this results into reduced accuracy and design cost of such circuit is also very high. Hence another method in which 5 digit resolution is available, is used to increase the speed of operation. This is the modified version of $VI f$ integrating type Electronic Energy Meter and is called interpolating integrating Electronic Energy Meter

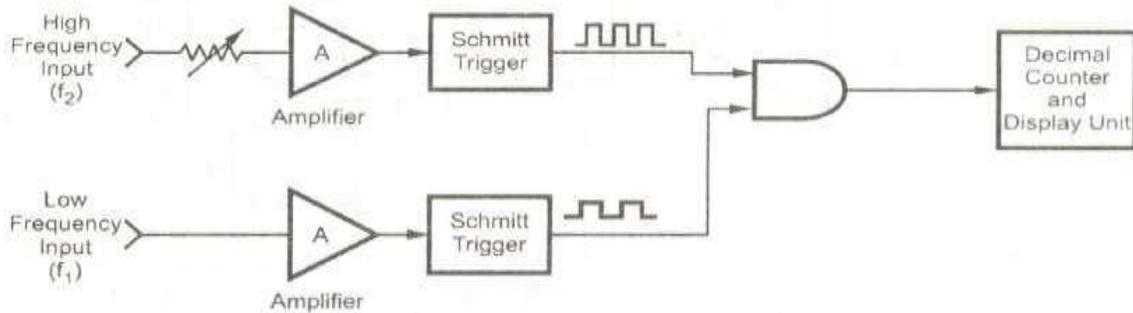
Questions

1. With a neat diagram explain the construction and working principle of a single phase induction type energy meter

- July/Aug 2004, Jan/ Feb 2004, July/Aug 2009, Jan/ Feb 2006, Jan/ Feb 2009
2. Explain the advantages of electronic energy meters over the conventional disc type induction energy meters
Jan/ Feb 2004
 3. With a neat diagram explain the construction and operation of an electro-dynamometer type wattmeter. Derive expression for the same
Jan/ Feb 2004, Jan/ Feb 2009, Jan/ Feb 2011, Jan/ Feb 2009
 4. What is creep in energy meter? How is it prevented?
July/Aug -2004
 5. With a neat circuit arrangements, explain how the calibration of single phase induction type energy meter is carried out in laboratories. Explain the need for adjustments to be followed earlier to calibration analysis
July/Aug -2005, Jan/ Feb -2011
 6. Write a short note on low power factor wattmeter
July/Aug -2005
 7. What are sources of errors in energy meter and how are they eliminated?
May/June-2010, Jan/ Feb -2006
 8. Explain the principle of operation of low power factor meter
July/Aug -2009, Jan/ Feb -2006, Jan/ Feb -2004
 9. Discuss with a block diagram the principle of operation of electronic energy meter
May/June-2010, July/Aug -2006, July/Aug -2008
 10. Explain the working of single phase induction type energy meter and discuss its errors. How can the errors be initialized
July/Aug -2007, July/Aug -2008, Jan/ Feb -2007, Jan/ Feb 2012
 11. Discuss the adjustment required in energy meter for accurate reading
Jan/ Feb -2008
 12. Write a note on measurement of reactive power in 3 phase system
July/Aug -2009, Jan/ Feb 2012

Unit 5

5.1 Weston Frequency Meter



This is a moving iron type instrument and is used to measure frequency.

Construction

It consists of a fixed coil each split into 2 equal parts A & B and these 2 coils are mounted perpendicular to each other.

Force acting on the soft iron needle depends upon variation in current distribution between 2 coils. Values of resistances and inductances are so selected that at normal frequency of supply.

If the frequency increases above the normal value then reactances increase while R remains same. Hence current through coil A is reduced. Therefore current through coil B increases. And this makes magnetic field produced by coil B.

When frequency decreases than normal value the opposite action takes place and pointer deflects to left indicating lower frequency.

5.2 Phase sequence Indicator

This type of indicator works on the principle of induction. It consists of 3 stationary coils which are connected in the form of star connection. The 2 ends of these coils are brought out for connection purpose. And 3 phase supply whose sequence is to be determined is given to these ends star connected. When star connected coils are excited by a 3 phase supply, then each coil produces an alternating flux. Due to the interaction of these 3 fluxes a rotating magnetic field is produced. These rotating fluxes pass over the disc and there is rotation. Hence emf's get induced in this disc which circulates eddy current through disc. These eddy currents produce a flux which interacts with the rotating flux to produce a torque and the disc starts rotating. The direction of the disc indicates the phase sequence of the supply.

If the disc rotates in the same direction as indicated by arrow on the disc, then phase sequence of the supply is same as the that marked on disc i.e. RYB. If the disc rotates in the reverse direction, phase sequence of supply is RBY

5.3 Electro dynamo meter type Power factor Meter

The basic construction of Electro dynamo meter type Power factor Meter is shown in the fig.

The F1-F2 are the two fixed coils which are rigidly connected in series. The A-B are the two moving coils which are connected to each other so that axes are at 90 to each other. The moving coils A-B move together and carry the pointer which indicates the power factor of the circuit.

The moving coils are connected in parallel across the supply voltage and hence called pressure coils. The currents through coils A & B are proportional to the supply voltage. The coil A has non inductive resistance R in series with it while the coil B has an inductance L in series with it. The values of R & L are so adjusted that the coils A & B carry equal currents at normal frequency.

The currents in the coils A & B are equal and produce the magnetic fields of equal strength, which have phase difference of 90 between them. The coils are also mutually perpendicular to each other.

Part B

5.4 Electronic Instruments

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.

5.5 Voltmeters and multimeters

Basic meter:

A basic d.c. meter uses a motoring principle for its operation. It states 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:

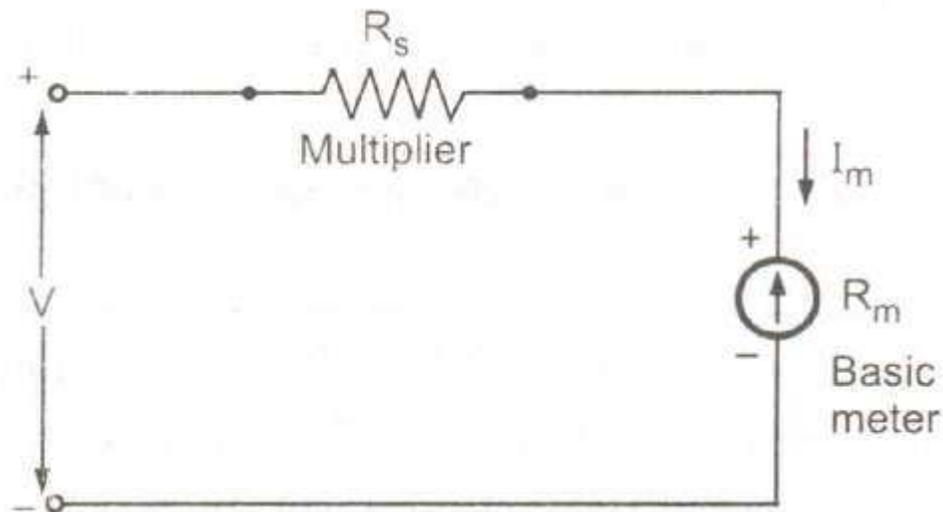
- a) Using shunt resistance, d.c. current can be measured. The instrument is d.c. microammeter, milliammeter or ammeter.
- b) Using series resistance called multiplier, d.c. voltage can be measured. The instrument is d.c. millivoltmeter, voltmeter or kilovoltmeter.
- c) Using a battery and resistive 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 voltmeter:

The basic d.c. voltmeter is nothing but a permanent magnet moving coil (PMMC) or 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 R_m = internal resistance of coil i.e. meter
 R_s = series multiplier resistance
 I_m = full scale deflection current
 V = full range voltage to be measured

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

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

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

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

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

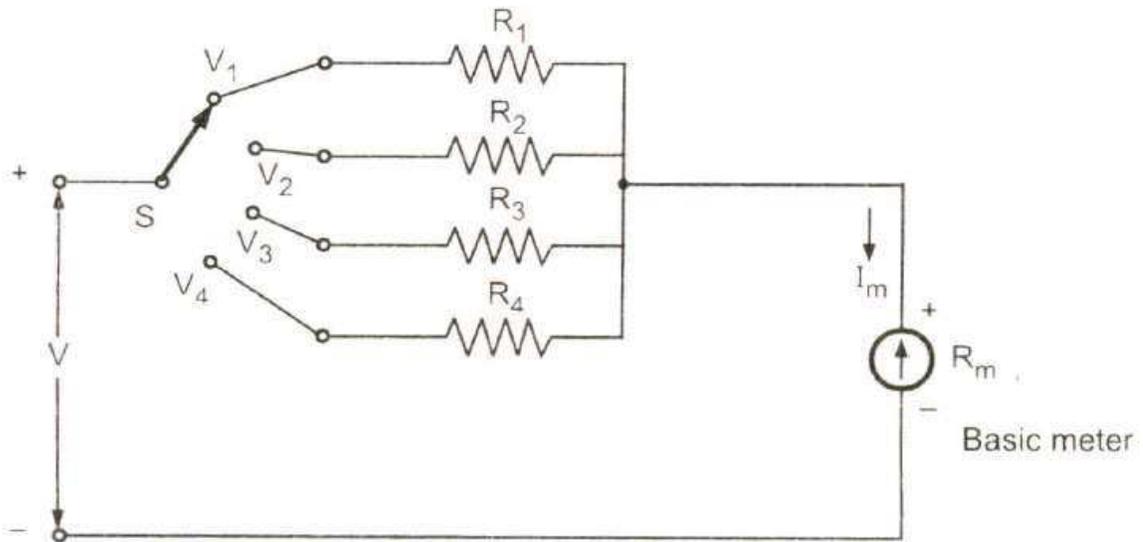
$\therefore m$ = multiplying factor = $\frac{V}{v}$

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

$$m = 1 + \frac{R_s}{R_m}$$

5.6 Multirange voltmeters:

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



The R_1 , R_2 , R_3 and R_4 are the four series multipliers. When connected in series with the meter, they can give four different voltage ranges as V_1 , V_2 , V_3 , and V_4 . The selector switch S is a 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,

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

Sensitivity of voltmeters:

In a multirange voltmeter, the ratio of the total resistance R_t to the voltage range remains same. This ratio is nothing but the reciprocal of the full scale deflection current, of the meter i.e. $1/I_m$. This value is called sensitivity of the voltmeter. Thus the sensitivity of the voltmeter is defined,

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

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

5.6.1 True RMS Responding voltmeter

The 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 movement. The 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 values 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 integration is used. Mathematically the r.m.s. value of the continuous a.c. voltage having time period T is given by,

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

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

For purely sinusoidal quantity,

$$V_{\text{rms}} = 0.707 V_m$$

where $V_m =$ peak value of the sinusoidal quantity

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

$$V_{av} = \frac{2}{T} \int_0^{T/2} V_{in} dt$$

The interval $T/2$ indicates the average over half a cycle.

For purely sinusoidal quantity,

$$V_{av} = \frac{2}{\pi} V_m = 0.636 V_m$$

where V_m = Peak value of the sinusoidal quantity.

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

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

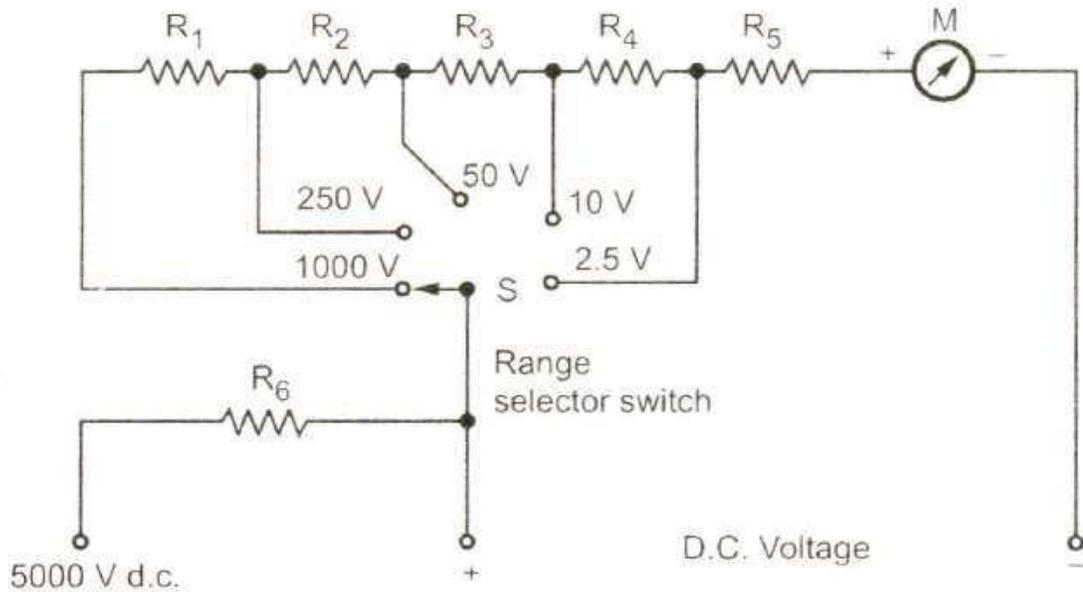
When the a.c. input is applied, for the positive half cycle, the diode O1 conducts and causes the meter deflection proportional to the average value of that half cycle. In the negative cycle, the diode O2 conducts and O1 is reverse biased. The current through the meter is in opposite direction and hence meter movement is bypassed. Thus due to diodes, the rectifying action produces pulsating d.c. and the meter indicates the average value of the input.

5.7 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 VOM are as listed below.

- 1) The basic circuit of VOM 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.

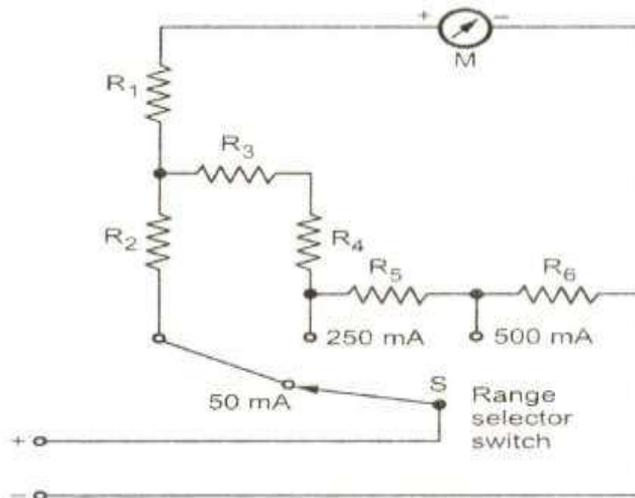
Use of multimeter for D.C measurement:



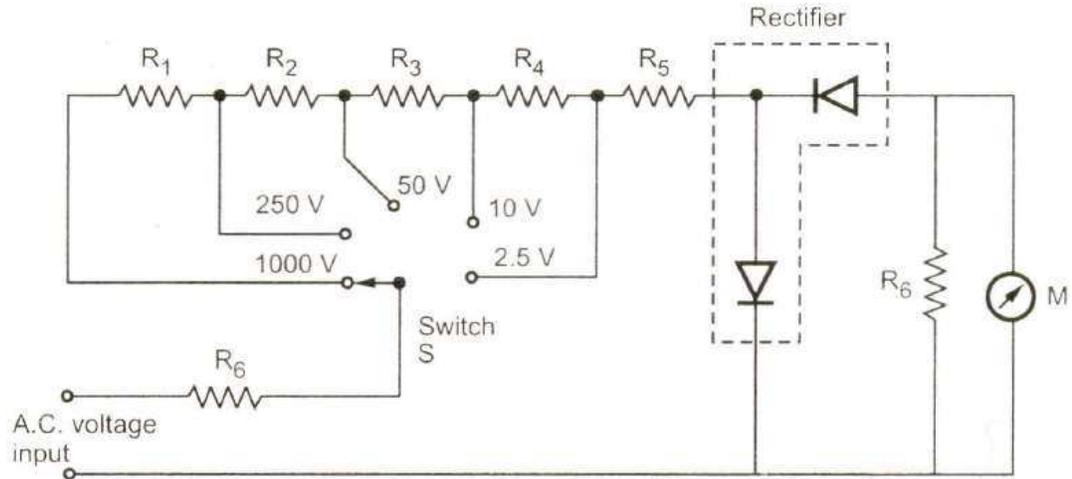
For getting different ranges of voltages, different series resistances are connected in series which can be put in the circuit with the range selector switch. We can get different ranges to measure the d.c. voltages by selecting the proper resistance in series with the basic meter.

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



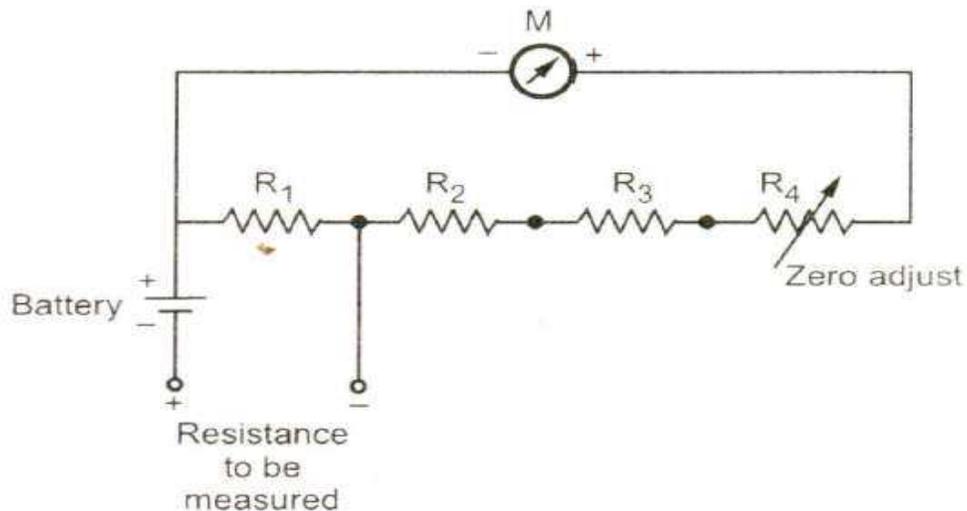
Use of multimeter for measurement of A.C voltage:



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.



5.8 Digital Voltmeters

Performance parameters of digital voltmeters:

1. Number of measurement ranges:

The basic range of any DVM is either 1V or 10 V. With the help of attenuator at the input, the range can be extended from few microvolts to kilovolts.

2. **Number of digits in readout:** The number of digits of DVMs varies from 3 to 6. More the number of digits, more is the resolution.

3. **Accuracy:** The accuracy depends on resolution and resolution on number of digits. Hence more number of digits means more accuracy. The accuracy is as high up to $\pm 0.005\%$ of the reading.

4. **Speed of the reading:** In the digital voltmeters, it is necessary to convert analog signal into digital signal. The various techniques are used to achieve this conversion. The circuits which are used to achieve such conversion are called digitizing circuits and the process is called digitizing. The time required for this conversion is called digitizing period. The maximum speed of reading and the digitizing period are interrelated. The instrument user must wait, till a stable reading is obtained as it is impossible to follow the visual readout at high reading speeds.

5. **Normal mode noise rejection:** This is usually obtained through the input filtering or by use of the integration techniques. The noise present at the input, if passed to the analog to digital converting circuit then it can produce the error, especially when meter is used for low voltage measurement. Hence noise is required to be filtered.

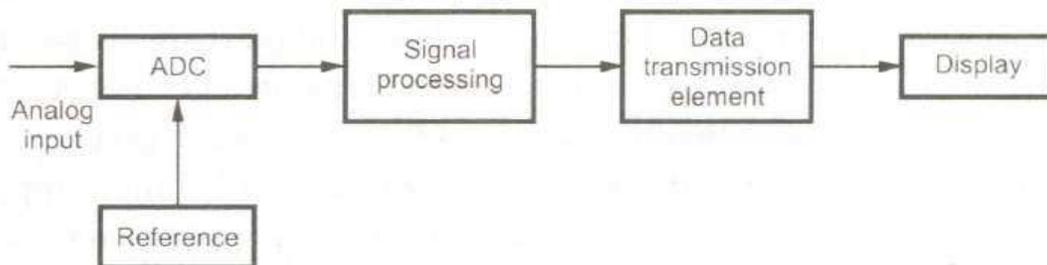
6. **Common mode noise rejection :** This is usually obtained by guarding. A guard is a sheet metal box surrounding the circuitry. A terminal at the front panel makes this 'box' available to the circuit under measurement.

7. **Digital output of several types:** The digital readout of the instrument may be 4 lines BCD, single line serial output etc. Thus the type of digital output also determines the variety of the digital voltmeter.

8. **Input impedance :** The input impedance of DVM must be as high as possible which reduces the loading effects. Typically it is of the order of $10^8 \Omega$.

5.8.1 Block diagram of DVM

Any digital instrument requires analog to digital converter at its input. Hence first block in a general DVM is ADC as shown in the Fig.

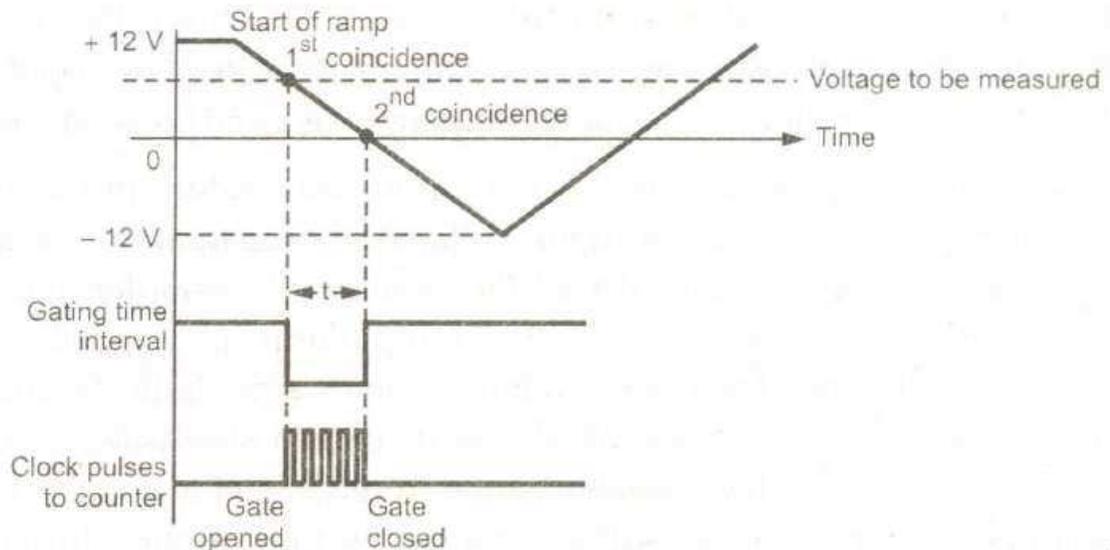


Every ADC requires a reference. The reference is generated internally and reference generator circuitry depends on the type of ADC technique used. The output of ADC is decoded and signal is processed in the decoding stage. Such a decoding is necessary to drive the seven segment display. The data from decoder is then transmitted to the display. The data transmission element may be a latches, counters etc. as per the requirement. A digital display shows the necessary digital result of the measurement.

5.9 Ramp type DVM:

5.9.1 Linear ramp technique:

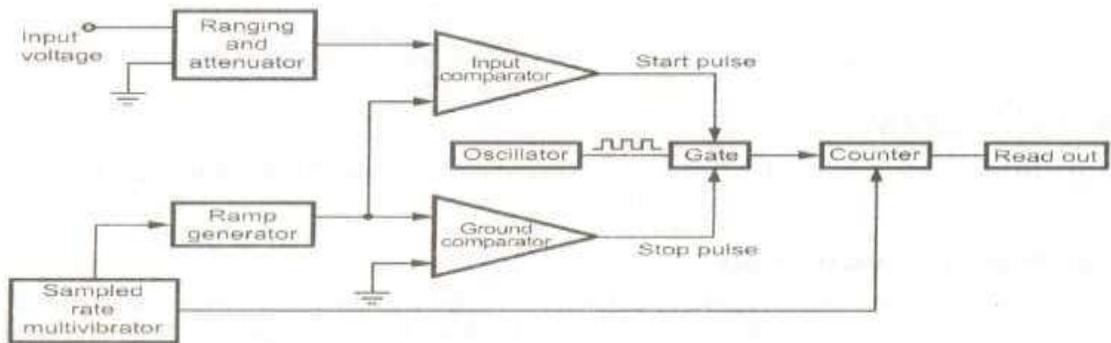
The basic principle of such measurement is based on the measurement of the time taken by a linear ramp to rise from a V to the level of the input voltage or to decrease from the level of the input voltage to zero. This time is measured with the help of electronic time interval counter and the count is displayed in the numeric form with the help of a digital



Basically it consists of a linear ramp which is positive going or negative going. The range of the ramp is ± 12 V while the base range is ± 10 V. The conversion from a voltage to a time interval is shown in the fig

At the start of measurement, a ramp voltage is initiated which is continuously compared with the input voltage. When these two voltages are same, the comparator generates a pulse which opens a gate i.e. the input comparator generates a start pulse. The ramp continues to decrease and finally reaches to 0 V or ground potential. This is sensed by the second comparator or ground comparator. At exactly 0 V, this comparator produces a stop pulse which closes the gate. The number of clock pulses is measured by the counter. Thus the time duration for which the gate is opened, is proportional to the input voltage. For the time interval between starts and stop pulses, the gate remains open and the oscillator circuit drives the counter. The magnitude of the count indicates the magnitude

of the input voltage, which is displayed by the display. The block diagram of linear ramp DVM is shown in the Fig



Properly attenuated input signal is applied as one input to the input comparator. The ramp generator generates the proper linear ramp signal which is applied to both two comparators. Initially the logic circuit sends a reset signal to the counter and the readout. The comparators are designed in such a way that when both the input signals of comparator are equal then only the comparator changes its state. The input comparator is used to send the start pulse while the ground comparator is used to send the stop pulse.

When the input and ramp are applied to the input comparator, and at the point when negative going ramp becomes equal to input voltages the comparator sends start pulse, due to which gate opens. The oscillator drives the counter. The counter starts counting the pulses received from the oscillator. Now the same ramp is applied to the ground comparator and it is decreasing. Thus when ramp becomes zero, both the inputs of ground comparator becomes zero (grounded) i.e. equal and it sends a stop pulse to the gate due to which gate gets closed. Thus the counter stops receiving the pulses from the local oscillator. A definite number of pulses will be counted by the counter, during the start and stop pulses which is measure of the input voltage. This is displayed by the digital readout.'

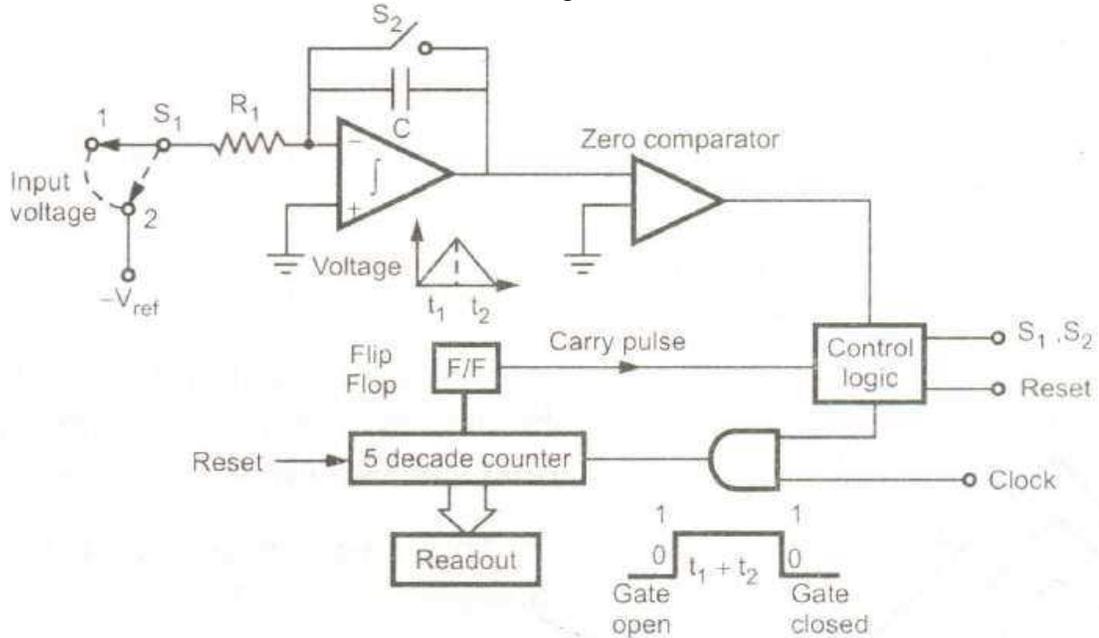
The sample rate multivibrator determines the rate at which the measurement cycles are initiated. The oscillation of this multivibrator is usually adjusted by a front panel control named rate, from few cycles per second to as high as 1000 or more cycles per second. The typical value is 5 measuring cycles/second with an accuracy of $\pm 0.005\%$ of the reading. The sample rate provides an initiating pulse to the ramp generator to start its next ramp voltage. At the same time, a reset pulse is also generated which resets the counter to the zero state.

5.9.2 Dual slope integrating type DVM

This is the most popular method of analog to digital conversion. In the ramp techniques, the noise can cause large errors but in dual slope method the noise is averaged out by the positive and negative ramps using the process of integration. The basic principle of this method is that the input signal is integrated for a fixed interval of time. And then the

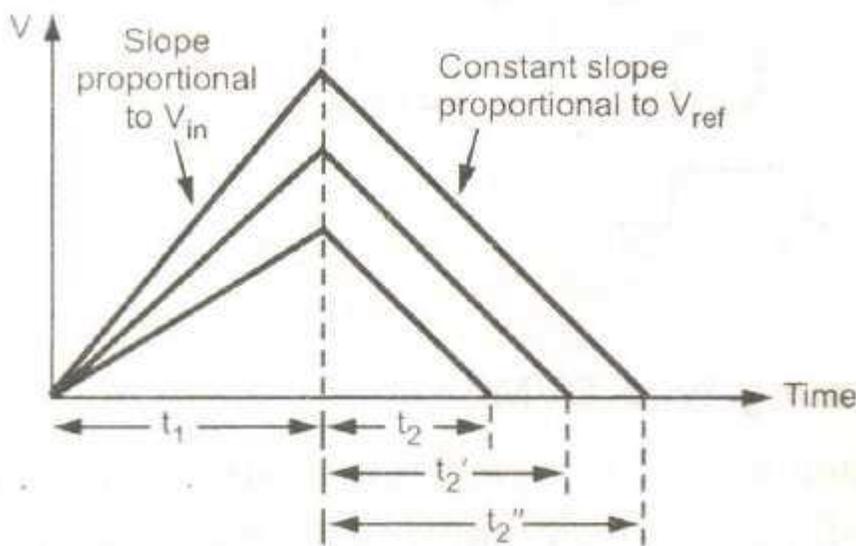
same integrator is used to integrate the reference voltage with reverse slope. Hence the name given to the technique is **dual** slope integration technique.

The block diagram of dual slope integrating type DVM is shown in the Fig. It consists of five blocks, an op-amp used as an integrator, a zero comparator, clock pulse generator, a set of decimal counters and a block of control logic.



When the switch S_1 is in position 1, the capacitor C starts charging from zero level. The rate of charging is proportional to the input voltage level. The output of the op-amp is given by,

After the interval t_1 , the input voltage is disconnected and a negative voltage $-V_{ref}$ is connected by throwing the switch S_1 in position 2. In this position, the output of the op-amp is given by,



Thus the input voltage is dependent on the time periods t_1 and t_2 and not on the values of R and C . This basic principle of this method is shown in the Fig.

At the start of the measurement, the counter is reset to zero. The output of the flip-flop is also zero. This is given to the control logic. This control sends a signal so as to close an electronic switch to position 1 and integration of the input voltage starts. It continues till the time period t_1 .

As the output of the integrator changes from its zero value, the zero comparator output changes its state. This provides a signal to control logic which in turn opens the gate and the counting of the clock pulses starts.

The counter counts the pulses and when it reaches to 9999, it generates a carry pulse and all digits go to zero. The flip flop output gets activated to the logic level T. This activates the control logic. This sends a signal which changes the switch position from 1 to 2. Thus $-V_{ref}$ gets connected to op-amp. As V_{ref} polarity is opposite, the capacitor starts discharging. The integrator output will have constant negative slope as shown in the Fig. 3.5.1. The output decreases linearly and after the interval t_2 , attains zero value, when the capacitor C gets fully discharged.

From equation (3) we can write,

$$V_{in} = V_{ref} \cdot \frac{t_2}{t_1}$$

Let time period of clock oscillator be T and digital counter has counted the counts n_1 and n_2 during the period t_1 and t_2 respectively.

$$V_{in} = V_{ref} \cdot \frac{n_2 T}{n_1 T} = V_{ref} \cdot \frac{n_2}{n_1}$$

Thus the unknown voltage measurement is not dependent on the clock frequency, but dependent on the counts measured by the counter.

The advantages of this technique are:

- i) Excellent noise rejection as noise and superimposed a.c. are averaged out during the process of integration.
- ii) The RC time constant does not affect the input voltage measurement.
- iii) The capacitor is connected via an electronic switch. This capacitor is an auto zero capacitor and avoids the effects of offset voltage.
- iv) The integrator responds to the average value of the input hence sample and hold circuit is not necessary.
- v) The accuracy is high and can be readily varied according to the specific requirements.

Questions:

1. Explain the construction and working of i) Phase sequence indicators
ii) Electrodynamic type power factor meters
July/Aug -2007, Jan/ Feb -2011, July/Aug -2009, Jan/ Feb -2012
- 2) With a neat sketch explain the construction and working of a Weston frequency meter
July/Aug -2004, Jan/ Feb -2005
- 3) What is a rotating type phase sequence indicator and how it is used
July/Aug -2008, Jan/ Feb -2009, Jan/ Feb 2012
4. Explain the principle of operation of a static type of phase sequence indicator
July/Aug -2006, Jan/ Feb -2011
5. Discuss about the working principle of digital voltmeter employing the successive approximation technique
July/Aug-2005, Jan/Feb-2005, July/Aug-2009, Jan/ Feb -2004, Jan/ Feb -2010
6. Discuss the different practical method of connection the unknown components to the test terminals of a Q meter
Jan/ Feb -2004
1. With a block diagram explain the working of a True RMS responding voltmeter
July/Aug-2004, Jan/Feb-2007, July/Aug-2009, Jan/ Feb -2005, Jan/ Feb -2008
July/Aug-2008, Jan/Feb-2009, July/Aug-2010, Jan/ Feb -2011
2. With a block diagram explain the working of a Ramp type DVM
July/Aug-2004, July/Aug-2010
3. List the elements of the basic circuit of an electronic multimeter
July/Aug-2004
4. What is a Q meter? Discuss how the unknown components can be connected to its test terminals
July/Aug-2005
5. Explain with the help of block diagram the function of integrating type digital voltmeter
Jan/ Feb -2006
6. Explain the principle of operation of electronic multimeter
July/Aug-2007, Jan/Feb-2006
7. Explain with block diagram any one type of digital voltmeter
July/Aug-2006
8. What are the advantages of using electronic measuring instruments
July/Aug-2007
9. Explain the operation of a electronic multimeter to measure current, voltage and resistance
Jan/ Feb -2011
10. What is the working principle of Q-Meter? How can the distributed capacitance of the coil be measured using Q-Meter? July/Aug-2006 , Jan/ Feb 2012
11. Mention the salient features of digital voltmeter
July/Aug-2007

Unit 6

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 a function of time, is called **cathode ray** oscilloscope, commonly known as C.R.O. The C.R.O. gives the visual representation of the time varying signals. The oscilloscope has become an universal instrument and is probably most versatile tool for the development of electronic circuits and systems. It is an integral part of electronic laboratories.

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

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 the 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.

6.1 Cathode Ray Tube (CRT)

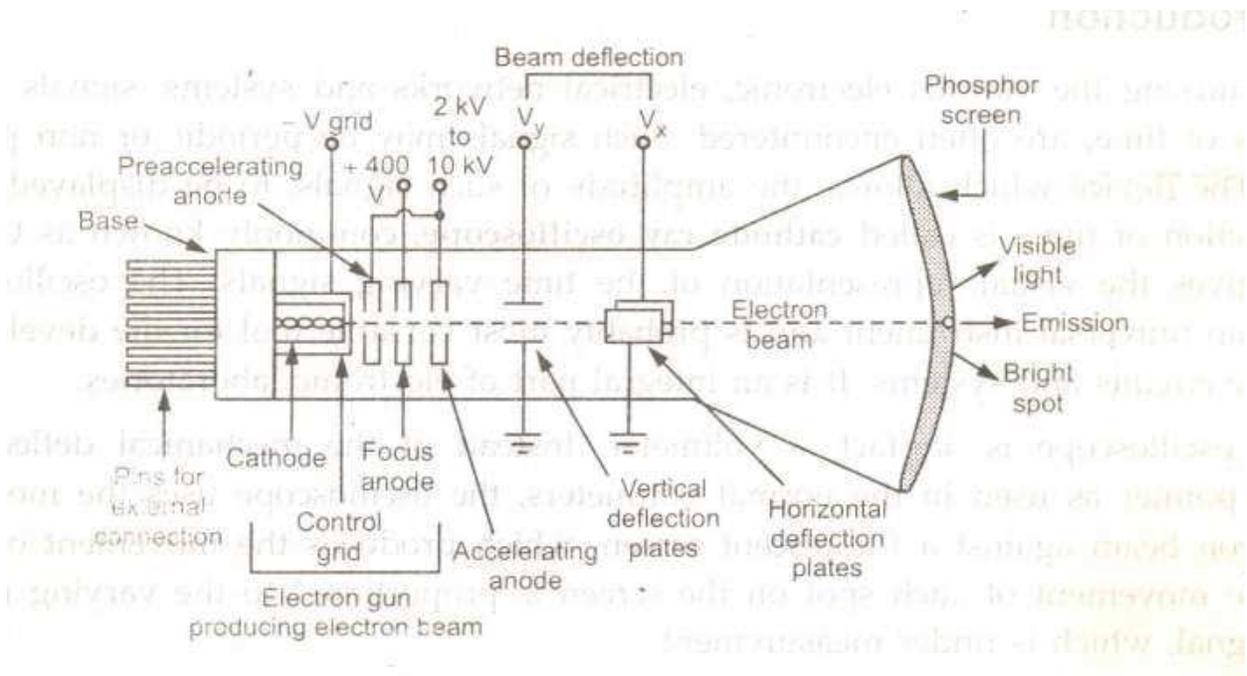
The cathode ray tube (CRT) is the heart of the C.R.O. the CRT generates the electron

beam, accelerates the beam, deflects the beam and also has a screen where beam becomes

visible as a spot. The main parts of the CRT are:

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

A schematic diagram of CRT, showing its structure and main components is shown in the 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 the thermally heated cathode, limiting the electrons. The control grid is given a 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 \times their speed) determines the intensity, or brightness, of the light emitted from the fluorescent screen due to the electron bombardment. The light emitted is usually of the green colour. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid (in CRT, voltages applied to various grids are stated with respect to cathode, which is taken as common point). This negative control voltage can be made variable.

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 (V_y) causes the beam to deflect vertically upward due to the attraction forces, while a negative voltage applied to the Y input terminal will cause the electron beam to deflect vertically downward, due to the repulsion forces.

When the voltages are applied simultaneously to vertical and horizontal deflecting plates, the electron beam is deflected due to the resultant of these two voltages.

Fluorescent Screen

The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero. The time period for which the trace remains on the screen after the signal becomes zero is known as "persistence". The persistence may be as short as a few microseconds, or as long as tens of seconds to minutes.

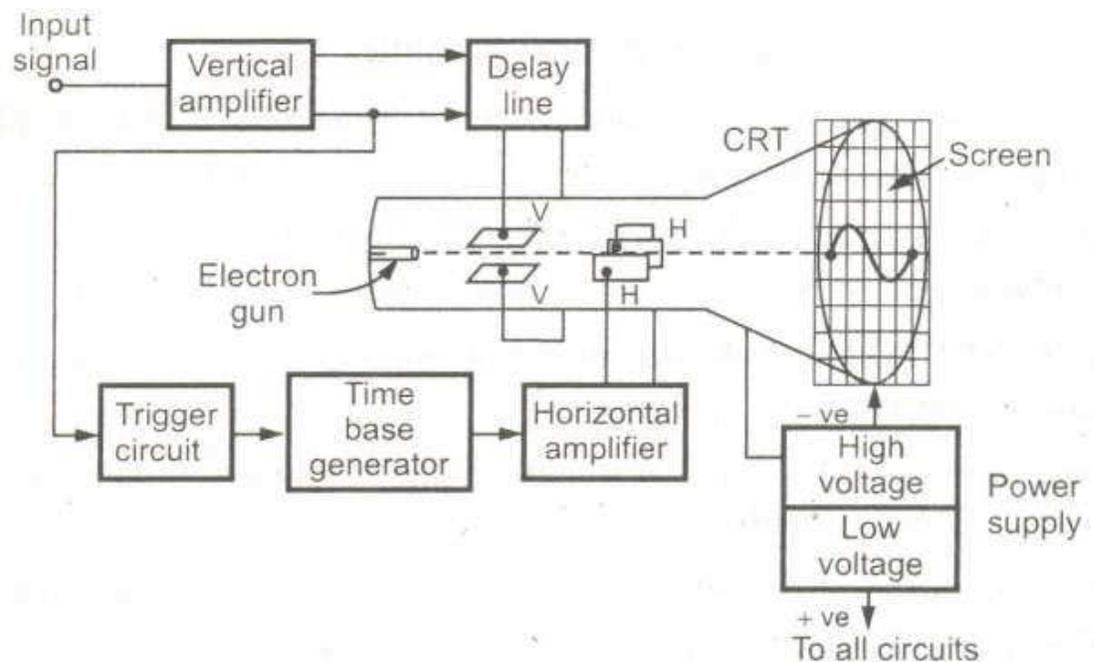
Long persistence traces are used in the study of transients. Long persistence helps in the study of transients since the trace is still seen on the screen after the transient has disappeared.

Phosphor screen characteristics

Many phosphor materials having different excitation times and colours as well as different phosphorescence times are available. The type P1, P2, P11 or P31 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 P1, P2, P4, P7, P11 have medium burn resistance while P1S, P31 have high burn resistance.

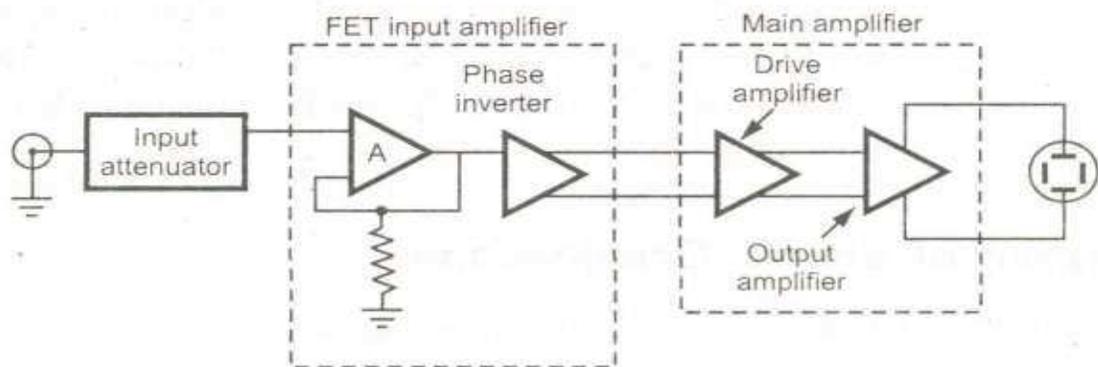


CRT

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

Vertical Amplifier

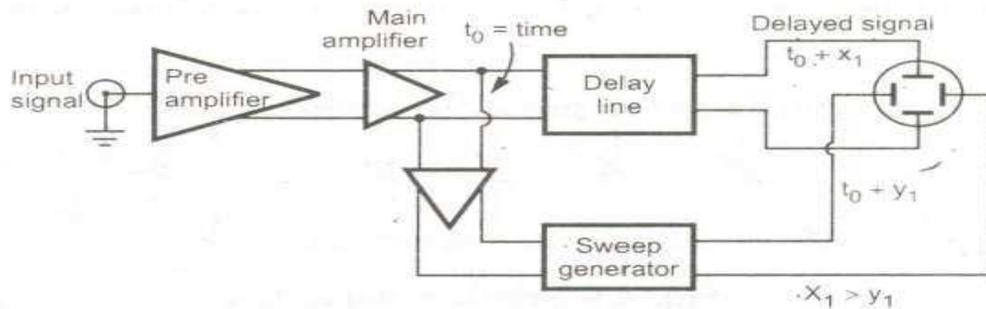
The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier stage is used to amplify the input signals. The amplifier stages used are generally wide band amplifiers so as to pass faithfully the entire band of frequencies to be measured.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



It consists of several stages with overall fixed sensitivity. The amplifier can be designed for stability and required bandwidth very easily due to the fixed gain. The input stage consists of an attenuator followed by FET source follower. It has very high input impedance required to isolate the amplifier from the attenuator. It is followed by BJT emitter follower to match the output impedance of FET output with input of phase inverter. The phase inverter provides two 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 vertical sections. When the delay line is not used, the part of the signal gets lost. Thus the input signal is not applied directly to the vertical plates but is delayed by some time using a delay line circuit as shown in the Fig.



If the trigger pulse is picked off at a time $t = t_0$ after the signal has passed through the main amplifier then signal is delayed by X_1 nanoseconds while sweep takes Y_1 nanoseconds to reach. The design of delay line is such that the delay time X_1 is higher than the time Y_1 . Generally X_1 is 200 nsec while Y_1 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 C.R.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.

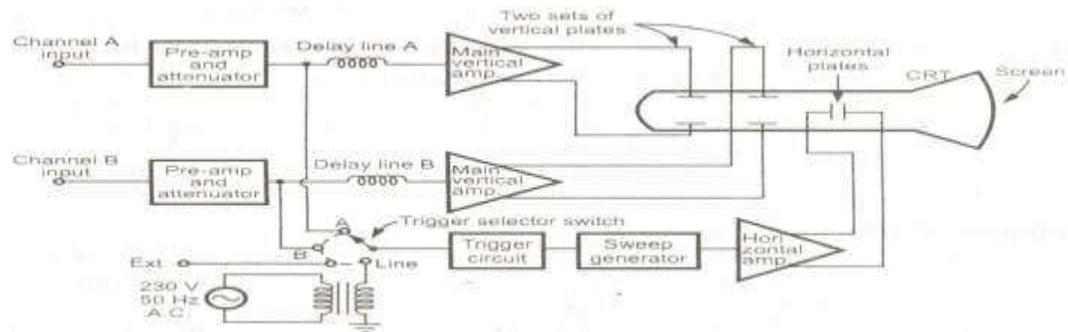
Time base generator

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.

6.2 Dual trace Oscilloscope

Another method of studying two voltages simultaneously on the screen is to use a special cathode ray tube having two separate electron guns generating two separate beams. Each electron beam has its own vertical deflection plates.

But the two beams are deflected horizontally by the common set of horizontal plates. The time base circuit may be same or different. Such an oscilloscope is called **Dual Beam Oscilloscope**.

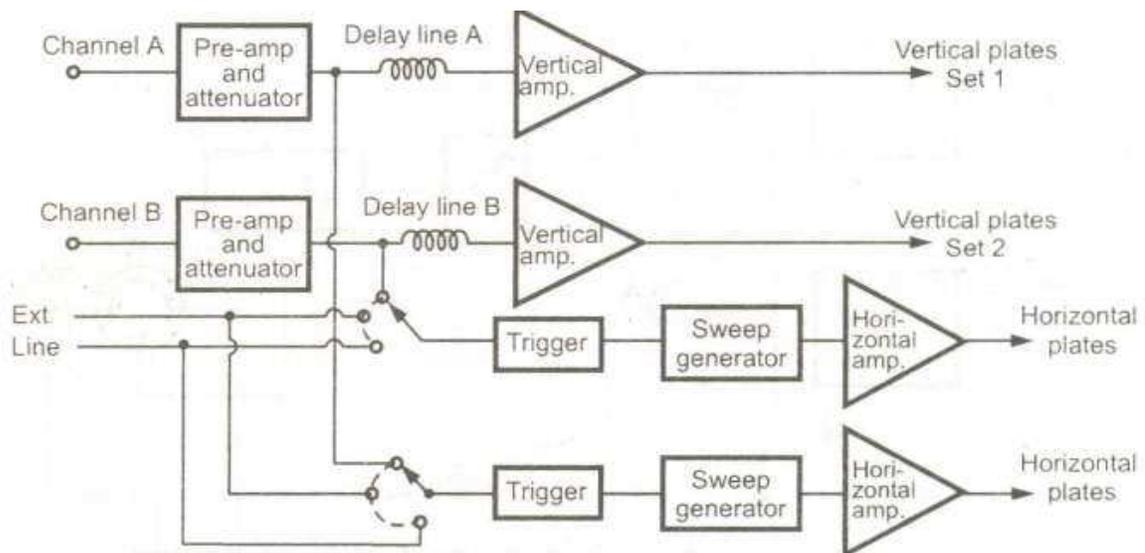
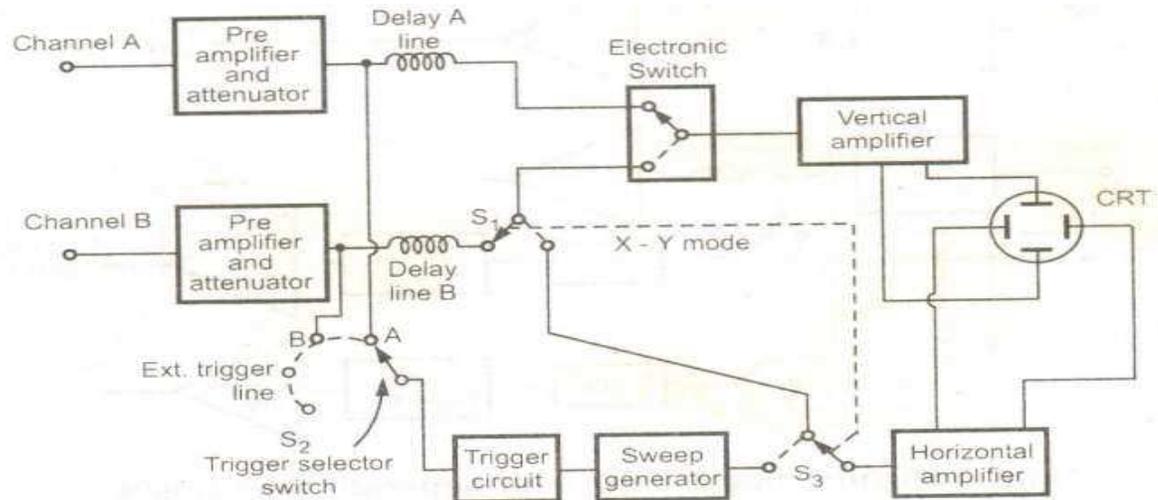


The oscilloscope has two vertical deflection plates and two separate channels A and B for the two separate input signals. Each channel consists of a preamplifier and an attenuator. A delay line, main vertical amplifier and a set of vertical deflection plates together forms a single channel. There is a single set of horizontal plates and single time base circuit. The sweep generator drives the horizontal amplifier which in turn drives the plates. The horizontal plates sweep both the beams across the screen at the same rate. The sweep generator can be triggered internally by the channel A signal or channel B signal. Similarly it can also be triggered from an external signal or line frequency signal. This is possible with the help of trigger selector switch, a front panel control. Such an oscilloscope may have separate timebase circuit for separate channel. This allows different sweep rates for the two channels but increases the size and weight of the oscilloscope.

The comparison of two or more voltages is very much necessary in the analysis and study of many electronic circuits and systems. This is possible by using more than one oscilloscope but in such a case it is difficult to trigger the sweep of each oscilloscope precisely at the same time. A common and less costly method to solve this problem is to use dual trace or multitrace oscilloscopes. In this method, the same electron beam is used to generate two traces which can be deflected from two independent vertical sources. The methods are used to generate two independent traces which the alternate sweep method and other is chop method.

The block diagram of dual trace oscilloscope is shown in the Fig

There are two separate vertical input channels A and B. A separate preamplifier and -attenuator stage exists for each channel. Hence amplitude of each input can be individually controlled. After preamplifier stage, both the signals are fed to an electronic switch. The switch has an ability to pass one channel at a time via delay line to the vertical amplifier. The time base circuit uses a trigger selector switch 52 which allows the circuit to be triggered on either A or B channel, on line frequency or on an external signal. The horizontal amplifier is fed from the sweep generator or the B channel via switch 51 and 51. The X-Y mode means, the oscilloscope operates from channel A as the vertical signal and the channel B as the horizontal signal. Thus in this mode very accurate X-Y measurements can be done.



Dual beam CRO with separate time bases

Method of Measuring

Measuring oscilloscope has a single tube but several beam producing systems inside. Each system has separate vertical deflecting pair of plates and generally (1 common time base system).

The triggering can be done internally using either of the multiple inputs or externally by an external signal or line voltages.

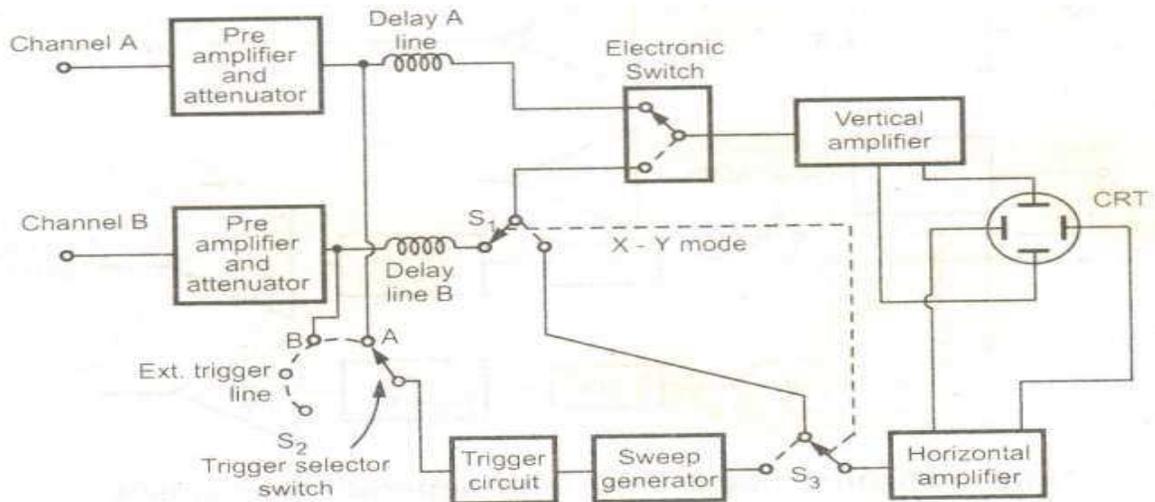
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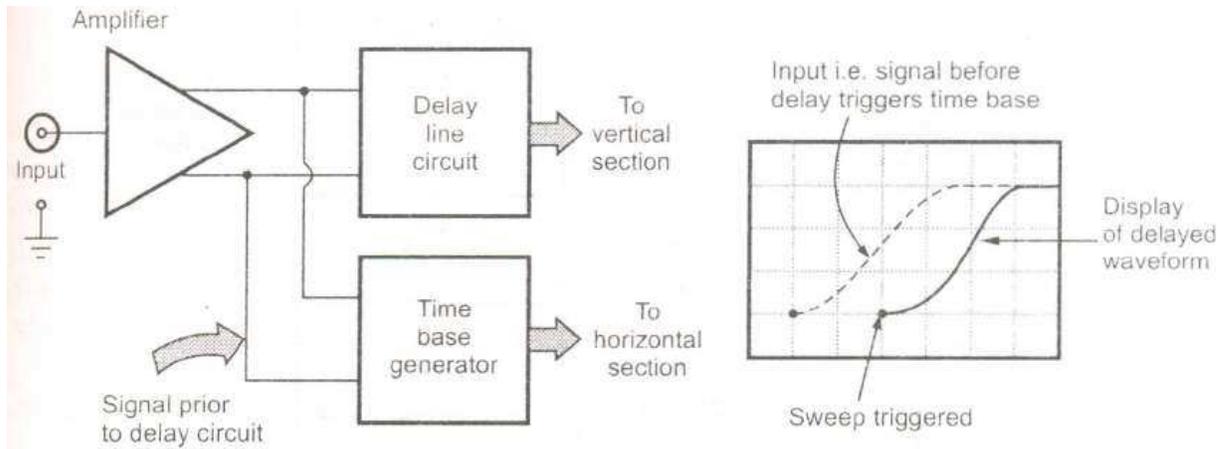
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horizontal amplifier is fed from the sweep generator or the B channel via switch S_1 and S_3 . The X-Y mode means, the oscilloscope operates from channel A as the vertical signal and the channel B as the horizontal signal. Thus in this mode very accurate X-Y measurements can be done.

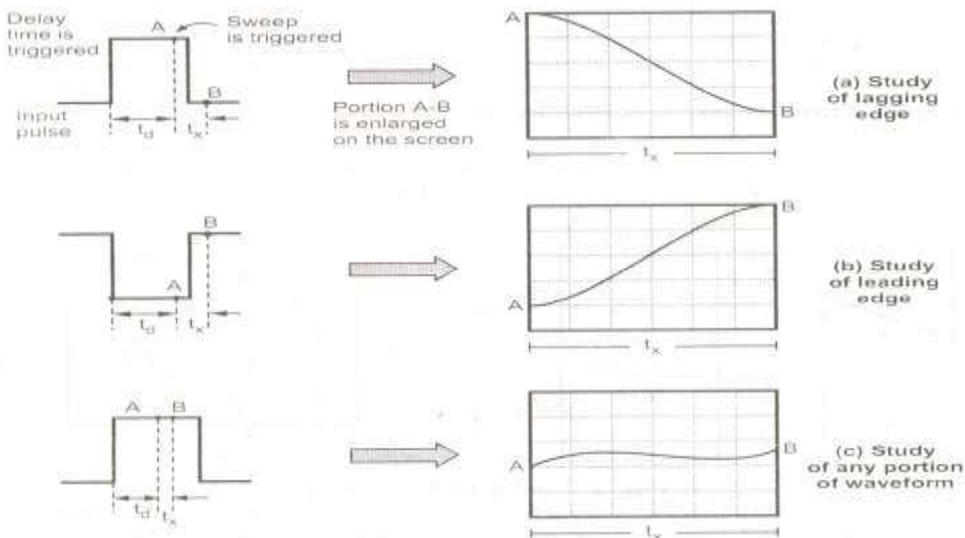




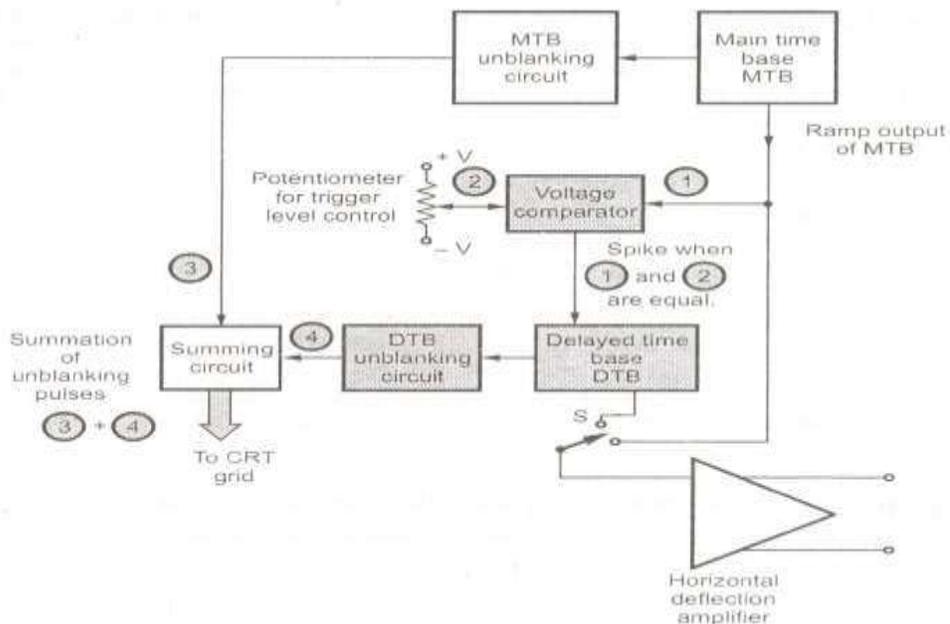
Due to triggering of time base by input signal, sweep starts well in time and when input appears at vertical sections, the sweep is triggered and delayed waveform is displayed. The delay ensures that no part of the waveform gets lost.

In a delayed time base oscilloscope, a variable time delay circuit is used in the basic time base circuit. This allows the triggering of sweep time after the delay time. Thus the delay time is variable. This time is denoted as t_d . After this, the sweep is triggered for the time t_x . Then the portion of the waveform for the time t_x gets expanded on the complete oscilloscope screen, for the detail study.

If input is pulse waveform and leading edge is used to trigger the delay time, then lagging edge can be displayed to fill the entire oscilloscope screen. This is shown in the Fig. (a). Similarly if the lagging edge is used to trigger the delay time then leading edge can be displayed on the entire screen for the time t_x . This is shown in the Fig. (b). If the time delay is perfectly adjusted, then any portion of the waveform can be extended to fill the entire screen. This is shown in the Fig. (c).



Use of additional time delay

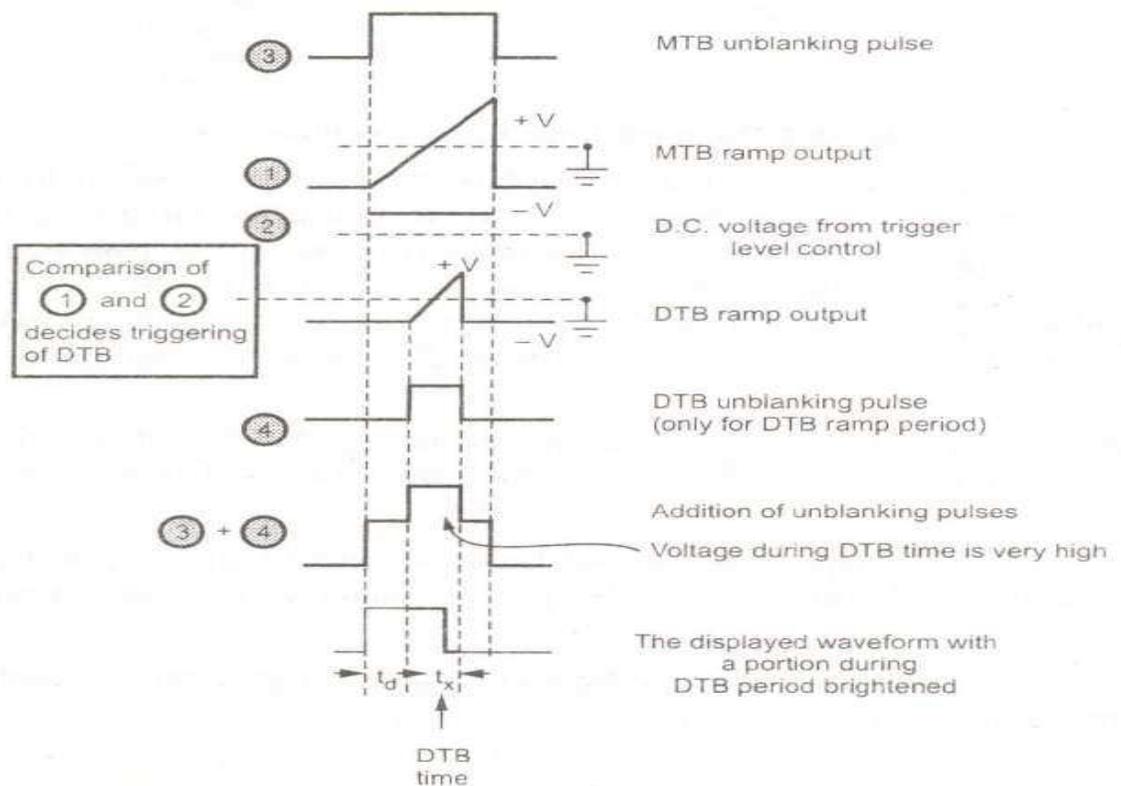


Delayed time base oscilloscope

The normal time base circuit is main time base (MTB) circuit which functions same as conventional oscilloscope. The function of MTB blanking circuit is to produce an unblanking pulse which is applied to CRT grid to turn on an electron beam in the CRT, during the display sweep time. The ramp output of MTB is given to the horizontal deflection amplifier via switch S. It is also given as one input to the voltage comparator. The other input to the voltage comparator is derived from the potentiometer whose level is adjustable.

The unblanking pulses from MTB and DTB are added by **summing circuit** and given to the CRT grid. The unblanking pulse of MTB produces a trace of uniform intensity. But during ramp time of DTB, the addition of two pulses decides the intensity of the trace on the screen. Hence during DTB time, the voltage applied to CRT grid is almost twice than the voltage corresponding to MTB time. This increases the brightness of the displayed waveform for the DTB time.

When the part of the waveform to be brightened is identified, then the DTB ramp output is connected to the input of the horizontal deflection amplifier through switch S. The DTB ramp time is much smaller than MTB period but its amplitude ($-V$ to $+V$) is same as MTB ramp. Hence it causes the oscilloscope electron beam to be deflected from one side of the screen to the other, during short DTB time. By adjusting DTB time/div control, the brightened portion can be extended, so as to fill the entire screen of the oscilloscope. The horizontal deflection starts only after the delay time t_d from the beginning of the MTB sweep. Thus very small part of the waveform can be extended on the entire screen.

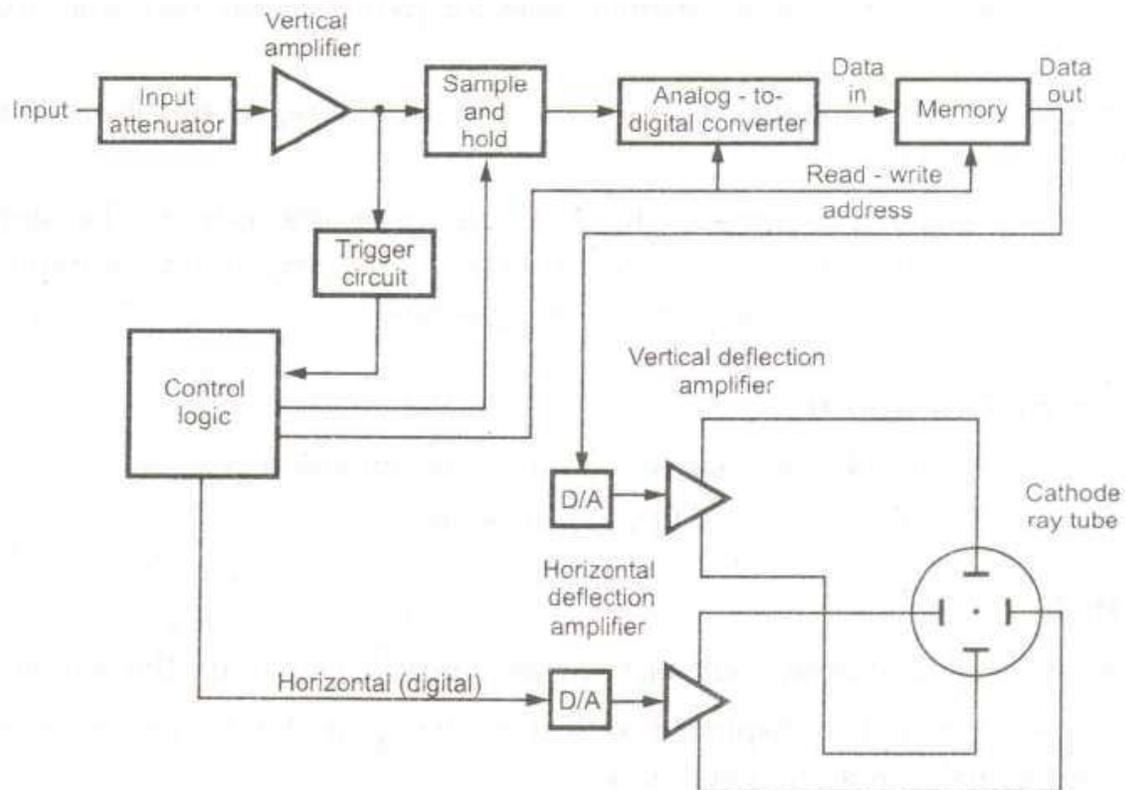


6.3 Digital Storage Oscilloscope

In this digital storage oscilloscope, the waveform to be stored is digitized, and then stored in a digital memory. The conventional cathode ray tube is used in this oscilloscope hence the cost is less. The power to be applied to memory is small and can be supplied by small battery. Due to this the stored image can be displayed indefinitely as long as power is supplied to memory. Once the waveform is digitized then it can be further loaded into the computer and can be analyzed in detail.

Block Diagram:

The block diagram of digital storage oscilloscope is shown in the Fig.



As done in all the oscilloscopes, the input signal is applied to the amplifier and attenuator section. The oscilloscope uses same type of amplifier and attenuator circuitry as used in the conventional oscilloscopes. The attenuated signal is then applied to the vertical amplifier.

The vertical input, after passing through the vertical amplifier, is digitized by an analog to digital converter to create a data set that is stored in the memory. The data set is processed by the microprocessor and then sent to the display.

To digitize the analog signal, analog to digital (A/D) converter is used. The output of the vertical amplifier is applied to the A/D converter section. The main requirement of A/D converter in the digital storage oscilloscope is its speed, while in digital voltmeters accuracy and resolution were the main requirements. The digitized output needed only in the binary form and not in BCD. The successive approximation type of A/D converter is most often used in the digital storage oscilloscopes.

Modes of operation:

The digital storage oscilloscope has three modes of operation:

1. Roll mode
- ii) Store mode
- iii) Hold or save mode.

Roll mode

This mode is used to display very fast varying signals, clearly on the screen. The fast varying signal is displayed as if it is changing slowly, on the screen. In this mode, the input signal is not triggered at all.

Brief note on current probe

It is a primary electrical which is used to measure the change in the t . It is commonly known as resistance thermometer. The resistance thermometers are based on the principle that the resistance of the conductor changes when the temperature changes. Basically the resistance thermometer determines the change in the electrical resistance of the conductor subjected to the temperature

changes. The temperature sensing element used in this thermometer should exhibit a relatively

large change in resistance for a given change in temperature. Also the sensing element should not undergo permanent change with use or age. Another desirable characteristic for

the sensing element is the linear change in resistance with change in temperature. When the sensing element is smaller in size, less heat is required to raise its temperature. This is suitable for measurement of rapid variations in temperature. Platinum, nickel, and copper are the metals most commonly used to measure temperature. The relationship between temperature and resistance of conductor is given by equation:

Almost all metallic conductors have a positive temperature coefficient so that their

resistance increases with an increase in temperature. A high value of α is desirable in a temperature sensing element so that a substantial change in resistance occurs for a relatively small change in temperature. This change in resistance $[L \setminus R]$ can be measured with a Wheatstone bridge, the output of which can be directly calibrated to indicate the temperature which caused the change in resistance.

Most of the metals show an increase in resistivity with temperature, which is first linear and then increases in an accelerated fashion. The metals that exhibit good sensitivity

and reproducibility for temperature measurement purposes are copper, nickel, and platinum. Among these, copper has the highest temperature coefficient with the most linear dependence. However, copper is generally not used due to certain practical problems. Because of its low resistivity, the size of the resistance element increases to get

reasonable sensitivity. In the range below 400 K, a gold silver alloy can be used which has

the same characteristics as platinum.

The wire resistance thermometer usually consists of a coil wound on a mica or ceramic

former, as shown in the Fig. The coil is wound in bifilar form so as to make it non inductive. Such coils are available in different sizes and with different resistance values

ranging from 10 ohms to 25,000 ohms.

To avoid corrosion of resistive element, usually elements are enclosed in a protective

tube of Pyrex glass, porcelain, quartz or nickel, depending on the range of temperature and the nature of the fluid whose temperature is to be measured. The tube is evacuated and sealed or filled with air or any other inert gas and kept around atmospheric pressure or in some cases.

Questions

1. With a neat block diagram explain the working of a digital storage oscilloscope
Jan/ Feb -2008, Jan/ Feb 2012
2. Explain the significance of lissajous pattern
Jan/ Feb -2008, July/Aug-2008,2009
- 4) Explain the panel details of a dual trace oscilloscope
July/Aug-2008, 2010
- 5) Write a note on CRO and its applications
Jan/ Feb -2009
- 6) Explain with the help of block diagram of dual trace oscilloscope
Jan/ Feb -2010, July/Aug-2009
- 7) Explain the working of digital storage oscilloscope
Jan/ Feb -2010,2011, July/Aug-2010, Jan/ Feb 2012

Unit 7

Transducers

Introduction:

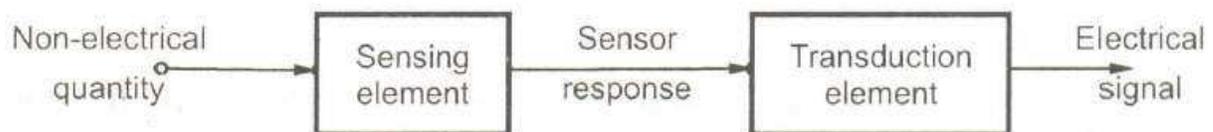
The primary objective of process control is to control the physical parameters such as temperature, pressure, flow rate, force, level etc. The system used to maintain these parameters constant, close to some desired specific value is called **process control system**. These parameters may change because of internal and external disturbances hence a constant corrective action is required to keep these parameters constant or within the specified range.

It consists of four elements,

1. Process
2. Measurement
3. Controller
4. Control element.

A device which converts a physical quantity into the proportional electrical signal is called a transducer.

The electrical signal produced may be a voltage, current or frequency. A transducer uses many effects to produce such conversion. The process of transforming signal from one form to other is called transduction. A transducer is also called pick up. The transduction element transforms the output of the sensor to an electrical output, as shown in the Fig.



The common range of an electrical signal used to represent analog signal in the industrial environment is 0 to 5 V or 4 to 20 mA. In industrial applications, nowadays, 4 to 20 mA range is most commonly used to represent analog signal. A current of 4 mA represents a zero output and current of 20 mA represents a full scale value i.e. 5 V in case of voltage representation. The zero current condition represents open circuit in the signal transmission line. Hence the standard range is offset from zero.

Many a times, the transducer is a part of a circuit and works with other elements of that circuit to produce the required output. Such a circuit is called signal conditioning circuit.

7.1 Passive transducer:

In electrical circuits, there are combinations of three passive elements : resistor, inductor and capacitor. These three passive elements are described with the help of the primary parameters such as resistance, self or mutual inductance and capacitance respectively. Any change in these parameters can be observed only if they are externally powered. We have studied that the passive transducers do not generate any electrical signal by themselves and they require some external power to generate an electrical signal. The transducers based on variation of parameters such as resistance, self or mutual inductance capacitance, due to an external power are known as passive transducers.

Hence resistive transducer, inductive transducer and capacitive transducer are the basic passive transducers.

7.2 Resistive transducer:

In general, the resistance of a metal conductor is given by,

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

where ρ = Resistivity of conductor ($\Omega \text{ m}$)

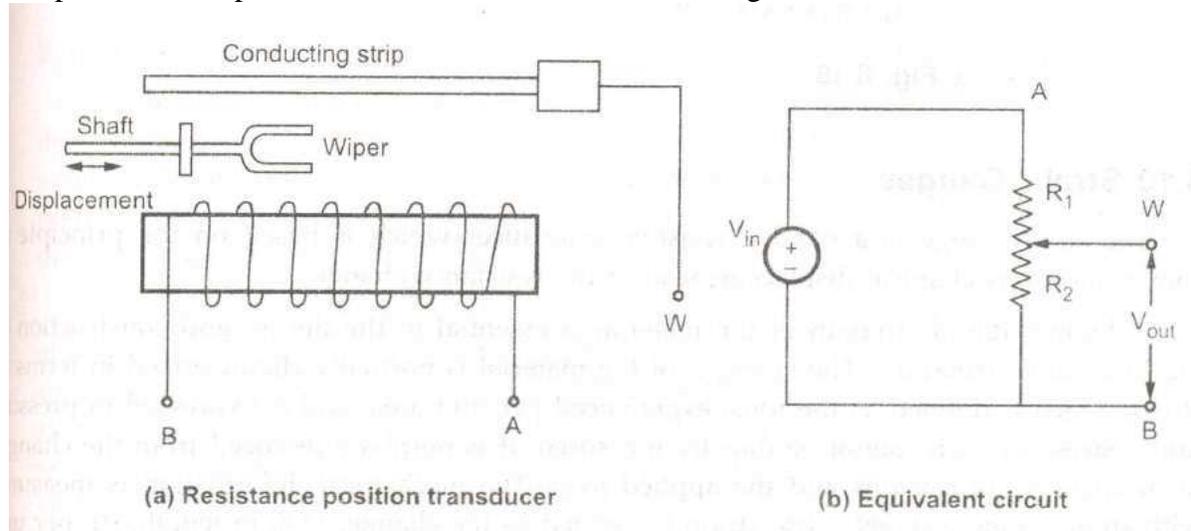
L = Length of conductor (m)

A = Area of cross-section of conductor (m^2)

The electrical resistive transducers are designed on the basis of the methods of variation of any one of the quantities in above equation; such as change in length, change in area of cross-section and change in resistivity. The sensing element which is resistive in nature, may be in different forms depending upon the mechanical arrangement. The change in pressure can be sensed by using sensitive resistive elements. The resistance pressure transducers may use Bellow, Diaphragm or Bourdon tube.

7.3 Resistance Position Transducer:

In many industrial measurements and control applications, it is necessary to sense position of the object or the distance that object travels. For such applications, simple resistance position transducer is very useful. It works on the principle that resistance of the sensing element changes due to the variations in physical quantity being measured. A simple resistance position transducer is as shown in the Fig.



The transducer consists a sliding contact or wiper. A resistive element is mounted with

the sliding contact which is linked with the object whose position is to be monitored. Depending upon the position of the object, the resistance between slider and the one end of resistive element varies. The equivalent circuit is as shown in the Fig. 8.18 (b). The output voltage V_{out} depends on the position of the wiper. Thus depending upon position of the wiper, the output voltage is given by,

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

Thus V_{out} is proportional to R_2 i.e. wiper position. The output voltage is measured using voltmeter which is calibrated in centimeters and allows direct readout of the object position.

7.4 Strain gauges:

The strain gauge is a passive resistive transducer which is based on the principle of conversion of mechanical displacement into the resistance change. A knowledge of strength of the material is essential in the design and construction of machines and structures. The strength of the material is normally characterized in terms of stress, which is defined as the force experienced per unit area, and is expressed in pressure units. **Stress** as such cannot be directly measured. It is normally deduced from the changes in mechanical dimensions and the applied load. The mechanical deformation is measured with strain-gauge elements. The **strain** is defined as the change, (Δl), in length, (l), per unit length and is expressed as ϵ ; ϵ in microstrains. The most common materials used for wire strain gauges are constantan alloys containing 45% Nickel and 55% Copper, as they exhibit high specific resistance, constant gauge factor over a wide strain range, and good stability over a reasonably large temperature range (from 0°C to 300°C). For dynamic strain measurements, Nichrome alloys, containing 80% Nickel and 20% Chromium are used. They can be compensated for temperature with platinum.

Bonding cements are adhesives used to fix the strain gauge onto the test specimen. This cement serves the important function of transmitting the strain from the specimen to the gauge-sensing element. Improper bonding of the gauge can cause many errors.

Basically, the cement can be classified under two categories, viz, solvent-setting cement and chemically-reacting cement. Duco cement is an example of solvent-setting cements which is cured by solvent evaporation. Epoxies and phenolic bakelite cement are chemically-reacting cements which are cured by polymerization. Acrylic cements are contact cements that get cured almost instantaneously. The proper functioning of a strain gauge is wholly dependent on the quality of bonding which holds the gauge to the surface of the structure undergoing the test.

Derivation of Gauge Factor:

The gauge factor is defined as the unit change in resistance per unit change in length. It is denoted as K or S. It is also called sensitivity of the strain gauge.

$$S = \frac{\Delta R/R}{\Delta l/l}$$

S = Gauge factor or sensitivity

R = Gauge wire resistance

ΔR = Change in wire resistance

l = Length of the gauge wire in unstressed condition

Δl = Change in length in stressed condition.

Derivation: Consider that the resistance wire is under tensile stress and it is deformed by $\sim I$ as shown in the Fig.

When uniform stress (J) is applied to this wire along the length, the resistance R

Let ρ = Specific resistance of wire material in $\Omega\text{-m}$

l = Length of the wire in m

A = Cross-section of the wire in m^2

changes to $R + \sim R$ because of change in length and cross-sectional

$$\sigma = \text{Stress} = \frac{\Delta l}{l}$$

$\Delta l/l$ = Per unit change in length

$\Delta A/A$ = Per unit change in area

$\Delta \rho/\rho$ = Per unit change in resistivity
(specific resistance)

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

area.

7.6 Types of Strain Gauges

Depending upon the principle of operation and their constructional features, strain

gauges are classified as mechanical, optical, or electrical. Of these, the electrical strain gauges are most commonly used.

1. **Mechanical Gauges :** In these gauges, the change in length, Δl , is magnified mechanically using levers or gears. These gauges are comparatively larger in size, and as such can be used in applications where sufficient area is available on the specimen for fixing the gauge. These gauges are employed for static strain measurements only.
2. **Optical Gauges:** These gauges are similar to mechanical strain gauges except that the magnification is achieved with multiple reflectors using mirrors or prisms. In one type a plain mirror is rigidly fixed to a movable knife-edge. When stress is applied, the mirror rotates through an angle, and the reflected light beam from the mirror subtends an angle twice that of the incident light. The measurement accuracy is high and independent of temperature variations.
3. **Electrical Strain Gauges :** The electrical strain gauges measure the changes that occur in resistance, capacitance, or inductance due to the strain transferred from the specimen to the basic gauge element. The most commonly used strain gauge is the bonded resistance type of strain gauge. The other two, viz., capacitance and inductance type are used only in special types of applications.

7.7 Basic Forms of Resistance Wire Strain Gauges:

The resistance wire strain gauges of metallic type are available in two basic forms; bonded and unbonded type. Tire banded metallic strain gauges are further classified as flat grid, helical grid and thin foil type strain gauges.

7.7 .1 Resistance temperature detector (RTD)

Resistance temperature detector is a primary electrical transducer which is used to measure the change in the temperature. It is commonly known as resistance thermometer. The resistance thermometers are based on the principle that the resistance of the conductor

changes when the temperature changes. Basically the resistance thermometer determines the change in the electrical resistance of the conductor subjected to the temperature changes. The temperature sensing element used in this thermometer should exhibit a relatively large change in resistance for a given change in temperature. Also the sensing element should not undergo permanent change with use or age. Another desirable characteristic for the sensing element is the linear change in resistance with change in temperature. When the sensing element is smaller in size, less heat is required to raise its temperature. This is suitable for measurement of rapid variations in temperature. Platinum, nickel, and copper are the metals most commonly used to measure temperature. The relationship between temperature and resistance of conductor is given by equation:

$$R_t = R_{ref} [1 + \alpha \Delta t]$$

where

R_t : Resistance of the conductor at temperature $t^\circ\text{C}$,

R_{ref} : Resistance of the conductor at the reference temperature, usually 0°C ,

α : Temperature coefficient of the resistance,

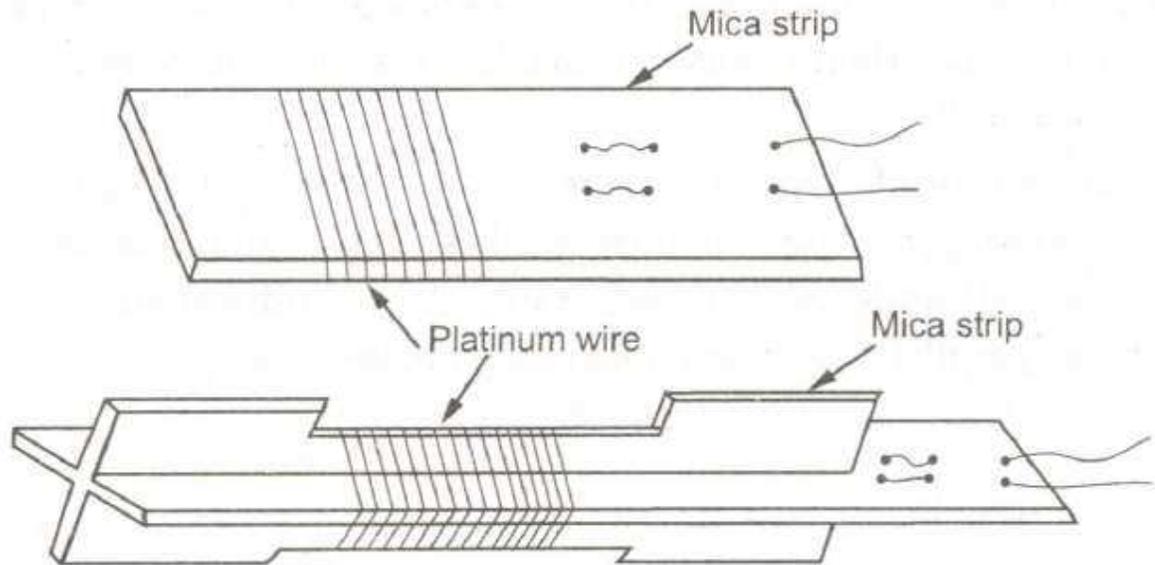
Δt : Difference between the temperature to be measured & reference temperature.

Almost all metallic conductors have a positive temperature coefficient so that their resistance increases with an increase in temperature. A high value of α is desirable in a temperature sensing element so that a substantial change in resistance occurs for a relatively small change in temperature. This change in resistance $[R - R_0]$ can be measured with a Wheatstone bridge, the output of which can be directly calibrated to indicate the temperature which caused the change in resistance.

Most of the metals show an increase in resistivity with temperature, which is first linear and then increases in an accelerated fashion. The metals that exhibit good sensitivity and reproducibility for temperature measurement purposes are copper, nickel, and platinum. Among these, copper has the highest temperature coefficient with the most linear dependence. However, copper is generally not used due to certain practical problems. Because of its low resistivity, the size of the resistance element increases to get reasonable sensitivity. In the range below 400 K, a gold silver alloy can be used which has the same characteristic as platinum.

Construction of RTD

The wire resistance thermometer usually consists of a coil wound on a mica or ceramic former, as shown in the Fig. The coil is wound in bifilar form so as to make it non-inductive. Such coils are available in different sizes and with different resistance values ranging from 10 ohms to 25,000 ohms. To avoid corrosion of resistive element, usually elements are enclosed in a protective tube of pyrex glass, porcelain, quartz or nickel, depending on the range of temperature and the nature of the fluid whose temperature is to be measured. The tube is evacuated and sealed or filled with air or any other inert gas and kept around atmospheric pressure or in some cases at a higher pressure.

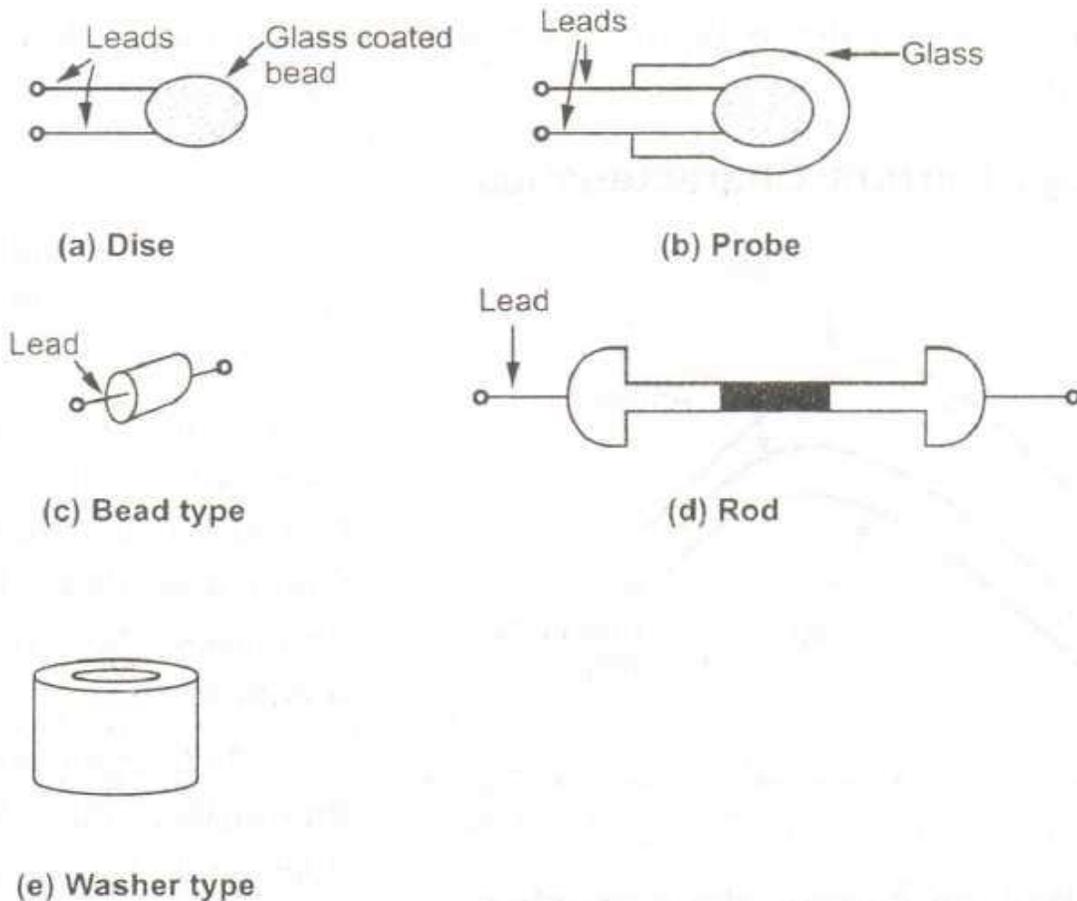


Thermistors:

Basically thermistor is a contraction of a word 'thermal resistors', The resistors depending on temperature are thermal resistors. Thus resistance thermometers are also thermistors having positive -temperature coefficients. But generally the resistors having negative temperature coefficients (NTC) are called thermistors. The resistance of a thermistor decreases as temperature increases. The NTC of thermistors can be as large as few percent per degree Celsius change in temperature. Thus the thermistors are very sensitive and can detect very small changes in temperature too.

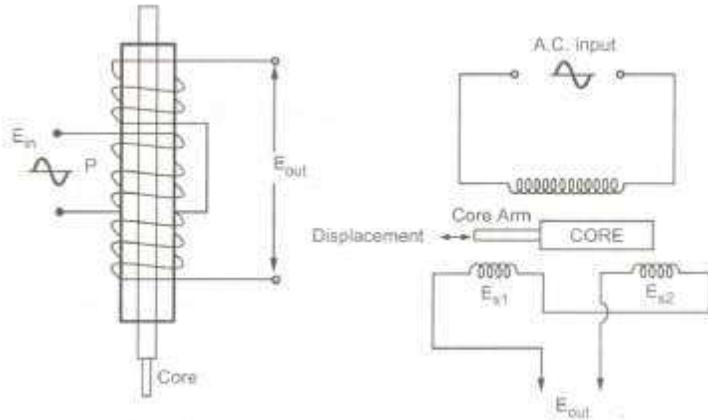
Construction of thermistor

Thermistors are composed of a sintered mixture of metallic oxides, such as manganese, nickel, cobalt, copper, iron, and uranium. Their resistances at ambient temperature may range from 100 Ω to 100 $k\Omega$. Thermistors are available in a wide variety of shapes and sizes as shown in the Fig. Smallest in size are the beads with a diameter of 0.15 mm to 1.25 mm. Beads may be sealed in the tips of solid glass rods to form probes. Disks and washers are made by pressing thermistor material under high pressure into flat cylindrical shapes. Washers can be placed in series or in parallel to increase power dissipation rating.

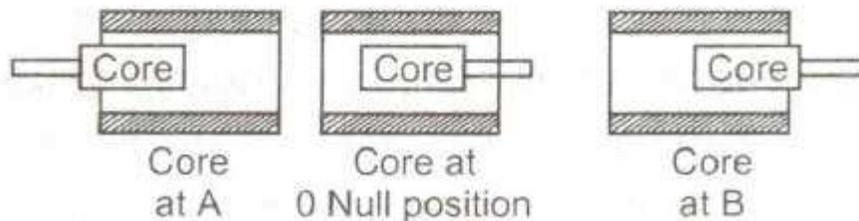
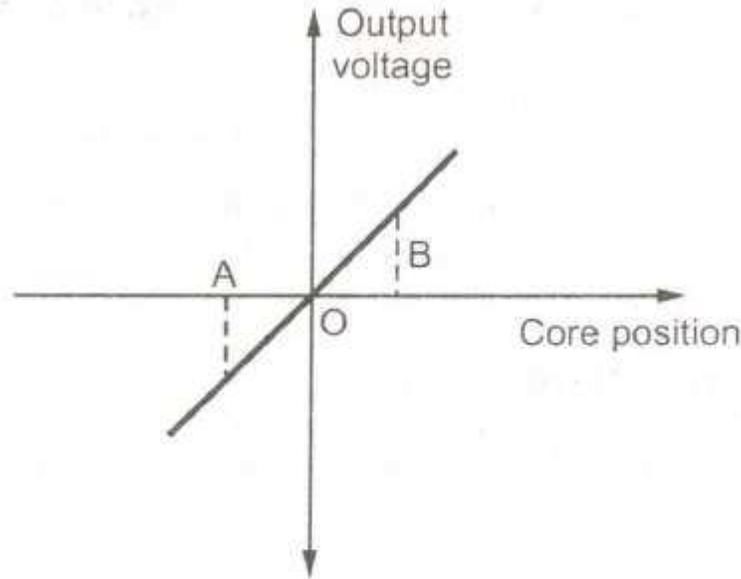


Thermistors are well suited for precision temperature measurement, temperature control, and temperature compensation, because of their very large change in resistance with temperature. They are widely used for measurements in the temperature range -1000 C to $+2000\text{ C}$. The measurement of the change in resistance with temperature is carried out with a Wheatstone bridge.

7.8 Linear variable differential transformer (LVDT)



When an externally applied force moves the core to the left-hand position, more magnetic flux links the left-hand coil than the right-hand coil. The emf induced in the left-hand coil, E_{s1} , is therefore larger than the induced emf of the right-hand coil, E_{s2} . The magnitude of the output voltage is then equal to the difference between the two secondary voltages and it is in phase with the voltage of the left-hand coil.



Previous Question Paper Questions

1. **Explain LVDT? May/June08**
2. **What are the various classification of gauges? Dec/Jan2010**
3. **Explain working of RTD. May/June08**
4. **What are strain gauges? May/June2010**
5. **Explain the Electrical transducers and selecting a transducer? Dec/Jan2008**
6. **Explain the Resistive transducer and Resistive position transducer? June/July2009**
7. **Explain the Thermistor Resistance thermometer? Dec/Jan2008**
8. **Explain the Inductive transducer? May/June2010**
9. **Explain the Differential output transducers and LVDT? Dec/Jan2010**
10. With a neat sketch explain the unbonded strain gauge Jan/ Feb -2004
11. Briefly explain the working of LVDT used in displacement measurements. Why is a phase sensitive detector employed along with the LVDT
Jan/ Feb -2004,2005, 2010, July/Aug-2010
12. What is a transducer? Briefly explain the procedure for selecting a transducer?
Jan/ Feb 2012, Jan/ Feb -2009,2010, July/Aug-2004,2010
13. Briefly explain photoconductive and photovoltaic cells?
Jan/ Feb -2009,2010, July/Aug-2004,2009,2010
14. What is the principle of electric resistance strain gauge? Derive an expression for the gauge factor in terms of the Poisson's ratio
July/Aug-2005, July/Aug-2010
15. Explain the principle of displacement measurements using two differential transformers in a closed loop servo system July/Aug-2005
16. Explain the principle of operation of LVDT in translating a linear motion into an electrical signal Jan/ Feb -2006,2008,2011
17. What are the advantages and disadvantages of LVDT?
Jan/ Feb -2006, Jan/ Feb -2009
18. Explain the classification of electrical transducers
Jan/ Feb -2007, July/Aug-2006, Jan/ Feb 2012
19. What is the principle of electric resistance strain gauge? Explain the unbounded resistance wire strain gauge Jan/ Feb -2007
20. Explain the operation of a LVDT and anyone application of it
July/Aug-2007
21. Explain the advantage of electric transducer. Also describe the classification of transducer Jan/ Feb -2008
22. Differentiate between a sensor and a transducer? What are the factors affecting the choice of transducers? July/Aug-2008
23. Explain the principle and working of LVDT July/Aug-2008

24. Explain the classification of transducers with the help of examples
July/Aug-2009
25. Derive the expression for gauge factor for a strain gauge
July/Aug-2008
26. Explain the classification of transducers with the help of examples
July/Aug-2009
27. What is a transducer? Briefly explain the photoconductive and photovoltaic cells
Jan/ Feb -2011, Jan/ Feb 2012

Unit 8

Display devices and Signal generators

Introduction:

Signal generator provides variety of different signals for testing various electronic circuits at low powers. The signal generator is an instrument which provides several different output waveforms including sine wave, square wave, triangular wave, pulse train and an amplitude modulated waveform.

8.1 Requirements of Laboratory Type Signal Generator

There are different types of signal generator. But the requirements are common to all the types.

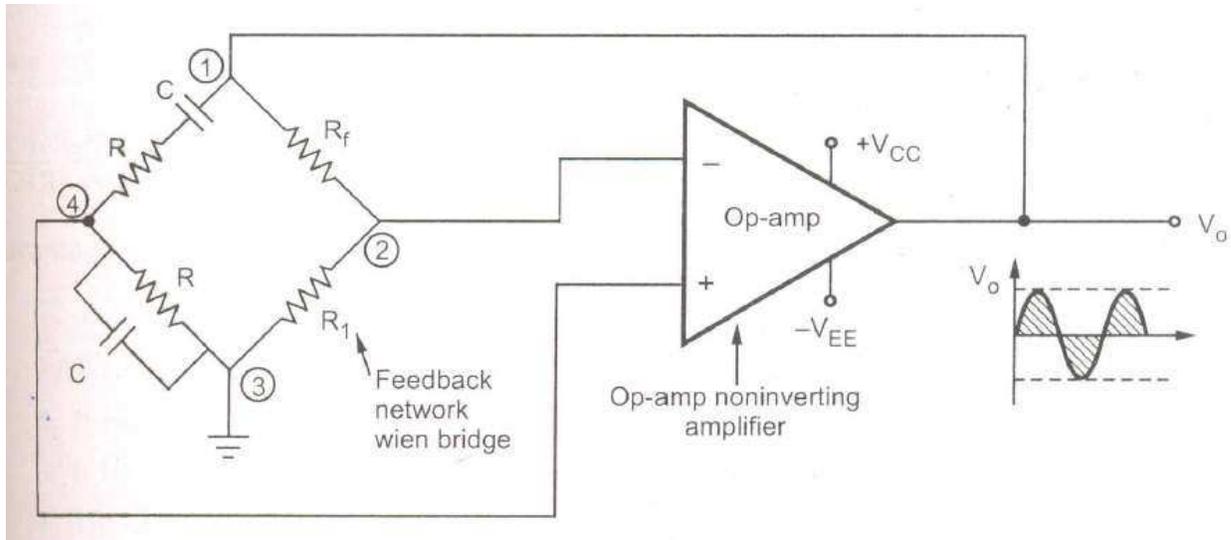
- i) The output frequency of signal generator should be very stable .
- ii) The amplitude of output signal of signal generator should be controllable from low values to relatively large values.
- iii) The amplitude of output signal must be stable. the harmonic contents in the output should be as low as possible. The output signal should be distortion free.
- v) The signal generator should provide very low spurious output; that means effect of hum, noise, jitter and modulation should be negligible.

8.2 A F oscillator

The signal generators which provide sinusoidal waveforms in the frequency range of 20 Hz to 20 kHz are called audio frequency(A.F.) signal generator. Depending upon the load, in modern AF signal generators a provision is made to select output impedance either 50 Ω or 600 Ω . To generate audio frequency signals, in practice RC feedback oscillators are used. The most commonly used RC feedback oscillators are Wien Bridge oscillator and RC phase shift oscillator. Let us discuss both the types of oscillators in detail.

8.3 Wien Bridge Oscillator using Op-amp

The Fig shows the Wien bridge oscillator using an op-amp.



The resistance R and capacitor C are the components of frequency sensitive arms of the bridge. The resistance R_f and R_1 form the part of the feedback path. The gain of noninverting op-amp can be adjusted using the resistance R_f and R_1 . The gain of op-amp

$$A = 1 + \frac{R_f}{R_1}$$

8.4 Standard signal generator

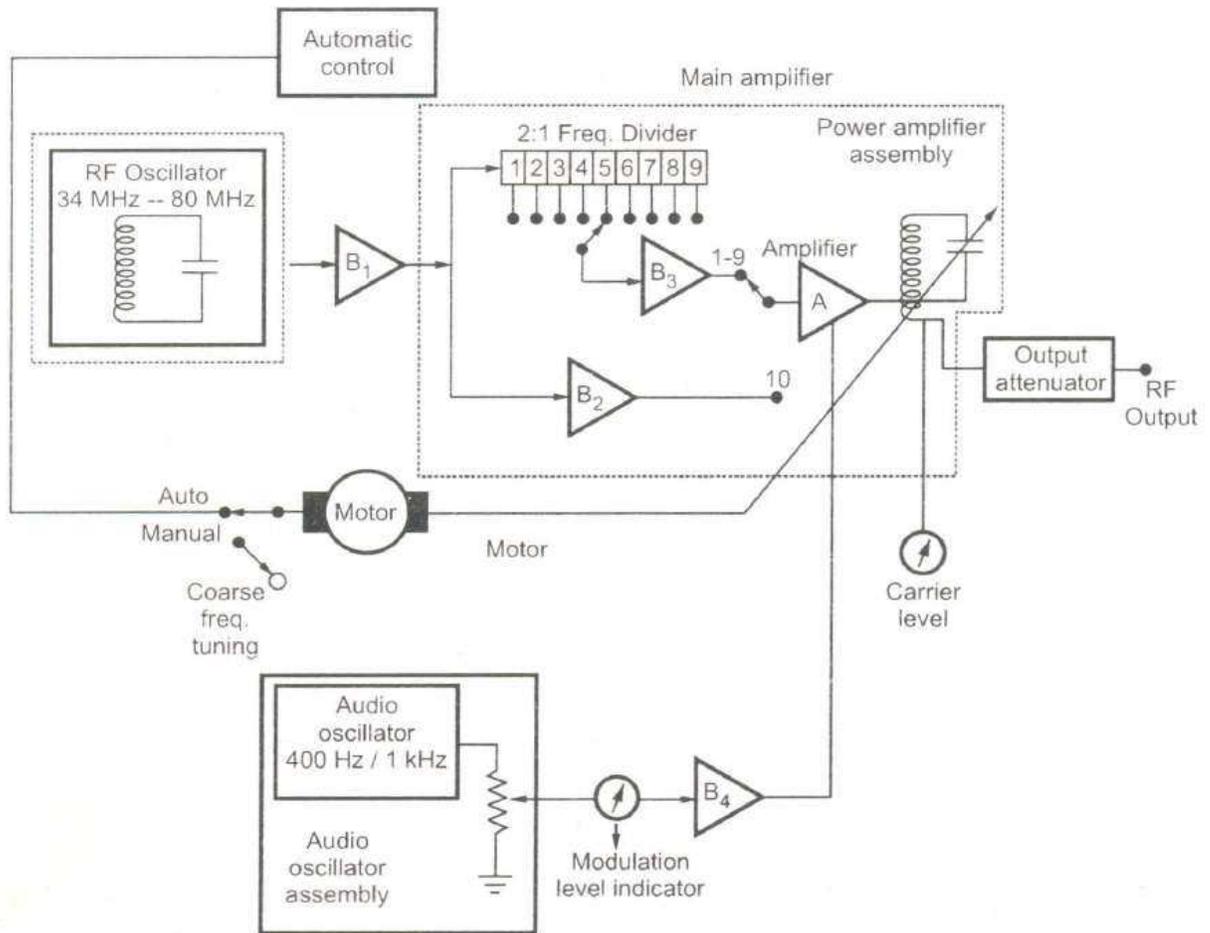
It is extensively used in the testing of radio receivers and transmitters. This is basically a radio frequency (RF) signal generator. The standard signal generator produces known **and controllable voltages**.

Principle of working

The output of the generator is amplitude modulated or frequency modulated. The frequency modulation is possible using a carrier signal from RF oscillator. The amplitude modulation can be done using internal sine wave oscillator. The modulation may be done by a sine wave, square wave, triangular wave or a pulse also. The setting on the front panel indicates the carrier frequency to be used for modulation.

Block Diagram

The block diagram of conventional standard signal generator is shown in the Fig.



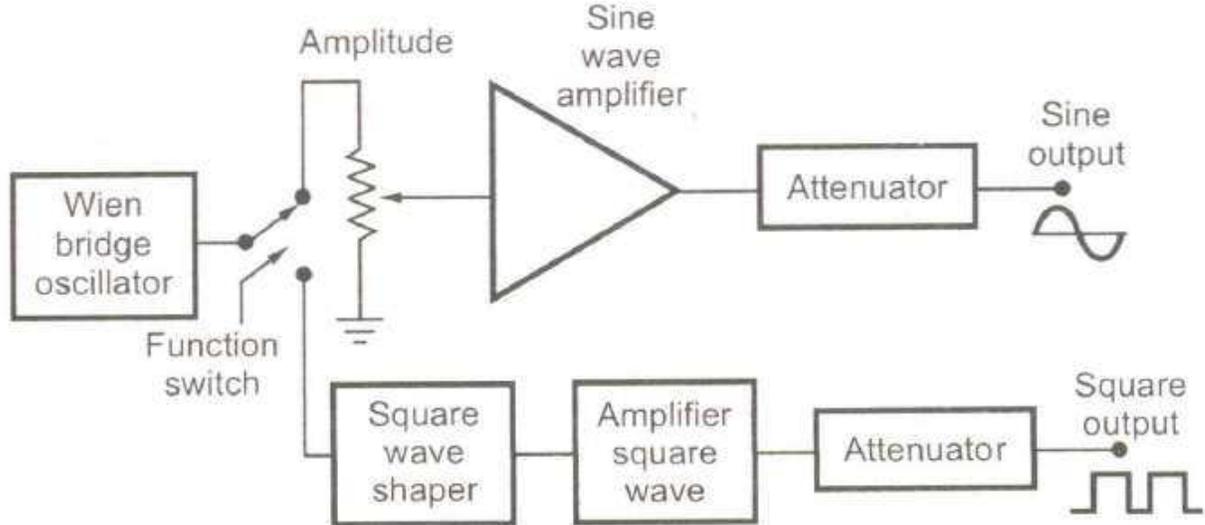
Signal for modulation is provided by an audio oscillator. The frequency given by this oscillator is in the range of 400 Hz to 1 kHz. The modulation takes place in the main amplifier, in the power amplifier stage. The level of modulation can be adjusted up to 95% by using control devices.

The lowest frequency range obtained by using a frequency divider is the highest frequency range divided by 29 or 512. Thus, frequency stability of the highest range is imparted to the lowest frequency range. The effects of frequency range selection are eliminated as the same oscillator is used for all frequency bands. The master oscillator is tuned automatically or manually. In an automatic controller for tuning the master oscillator, a motor-driven variable capacitor is used. This system is extensively used in programmable automatic frequency control devices. The oscillator can be fine-tuned by means of a large rotary switch with each division corresponding to 0.01% of the main dial setting.

The internal calibration is provided by a 1 MHz crystal oscillator. The low power consumption of the instruments makes the output have very low ripple. The supply voltage of the master oscillator is regulated by a temperature-compensated reference circuit. The output of the main amplifier is given to an output attenuator. The attenuator controls the amplitude level and provides the required stable **RF** output.

8.5 AF sine and square wave generator:

The block diagram of an AF sine-square wave generator is as shown in the Fig

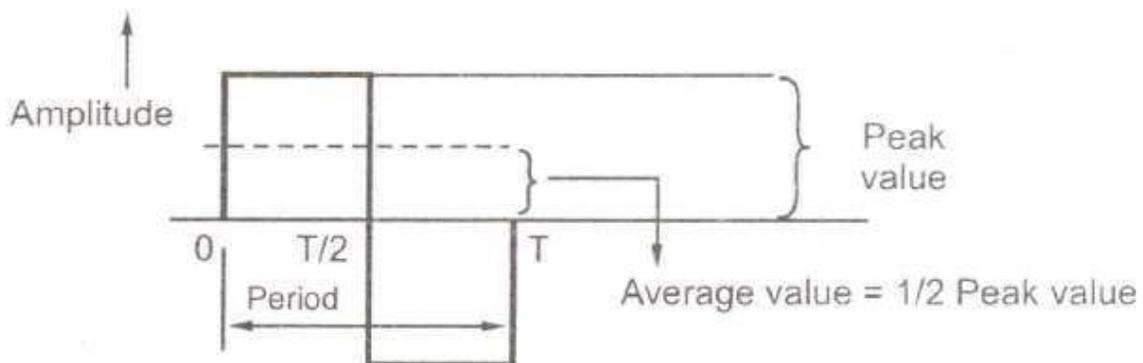


As per our previous discussion, Wien bridge oscillator is the heart of an AF sine-square wave generator. Depending upon the position of switch, we get output as square wave output or sine wave output. The Wien bridge oscillator generates a sine wave. Depending upon the position of switch, it is switched to either circuit. In the square wave generation section, the output of the Wien bridge oscillator is fed to square wave shaper circuit which uses schmitt trigger circuit. The attenuators in both the sections are used to control output signal level. Before attenuation, the signal level is made very high using sine wave amplifier and square wave amplifier.

8.6 Square wave and pulse generator

The square wave generator and pulse generator are generally used as measuring devices in combination with the oscilloscope. The basic difference between square wave generator and pulse generator is in the duty cycle. The duty cycle is defined as the ratio of average value of a pulse over one cycle to the peak value. It is also defined as ratio of the pulse width to the period of one cycle.

$$\text{Duty cycle} = \frac{\text{Pulse width}}{\text{Pulse period}}$$



The average value is half of peak value. Both the average value and peak value are inversely proportional to time duration. The average value of a pulse is given as,

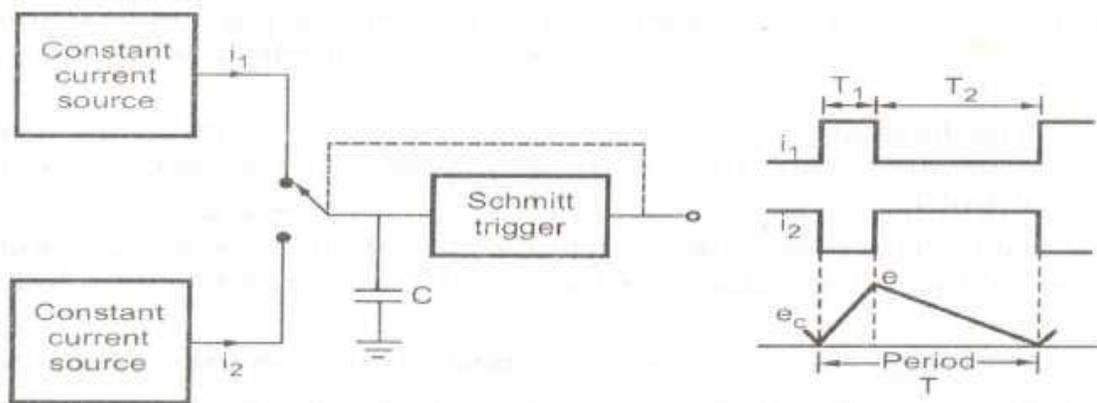
1

Average value = $1/2$ Peak value

Duty cycle of square wave = 0.5

Thus square wave generator produces an output voltage with equal ON and OFF periods as duty cycle is 0.5 or 50% as the frequency of oscillation is varied. Then we can state that irrespective of the frequency of operation, the positive and negative half cycles extend over half of the total period

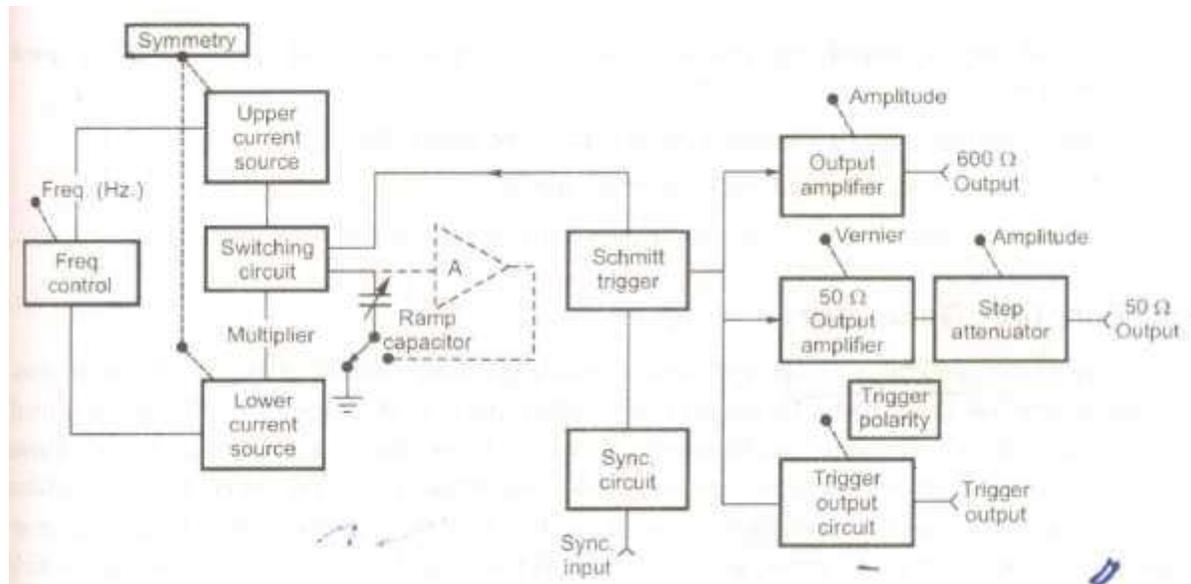
Laboratory type square wave and pulse generator



The circuit consists of two current sources, a ramp capacitor, and Schmitt trigger circuit as well as circuit. The two current sources provide a capacitor for charging and discharging. The ratio of the charging and discharging current is determined by setting of symmetry control. The symmetry control determines duty cycle of output waveform. In the current source, an appropriate control voltage is applied to current control transistors which controls the frequency i.e. sum of two currents.

The multiplier switch provides decade switching control output frequency. While Frequency dials provides continuous control of output frequency.

The block diagram of laboratory type square wave and pulse generator is as shown in fig:

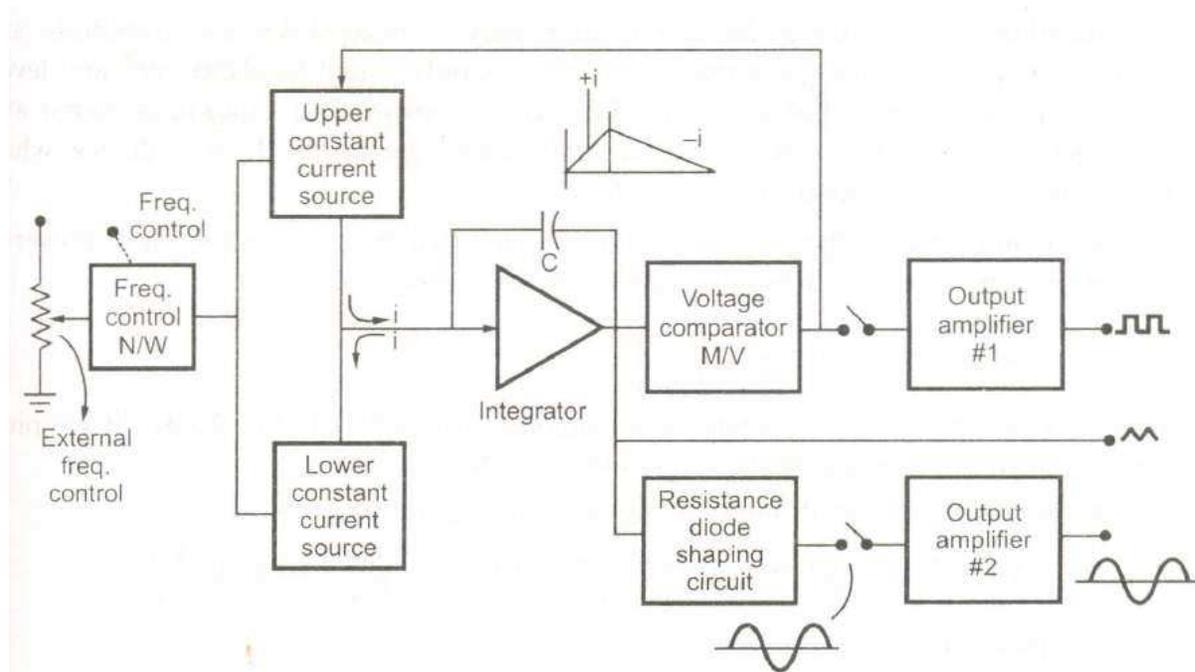


This is an instrument which generates different types of waveforms.

The frequency of these waveforms can vary over a wide range. The most required common waveforms are sine wave, sawtooth wave, triangular wave, square wave. These various outputs of the generator are available simultaneously. We may require a square wave for testing linearity measurements in an audio system. At the same time, we may require a sawtooth output to drive the horizontal deflection amplifier of an oscilloscope which

gives a visual display of the measurements. The purpose of providing simultaneous waves is fulfilled by the function generator.

Block Diagram



The frequency controlled voltage is used to regulate two current sources namely upper current source and lower current source. The upper current source supplies constant current to an integrator. The output voltage of integrator then increases linearly with time. If the current, charging the capacitor increases or decreases, the slope of output voltage increases or decreases respectively. Hence this controls frequency. The voltage comparator multivibrator circuit changes the state of the network when the output voltage of integrator equals the maximum predetermined upper level. Because of this change in state, the upper current source is removed and the lower current source is switched ON. This lower current source supplies opposite current to the integrator circuit. The output of integrator decreases linearly with time. When this output voltage equals maximum predetermined upper level on negative side, the voltage comparator multivibrator again changes the condition of the network by switching OFF the lower current source and switching ON the upper current source.

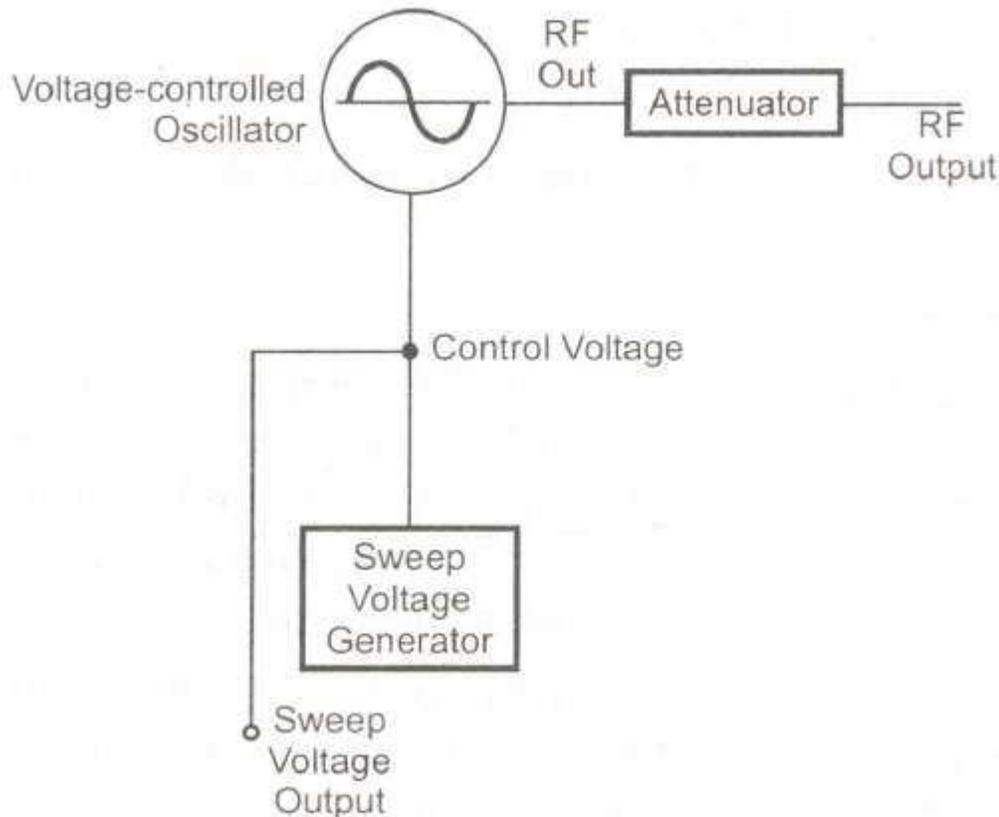
The output voltage of the integrator has triangular waveform. The frequency of this triangular waveform is determined by the magnitudes of the currents supplied by upper current source and lower current source. To get square wave, the output of the integrator is passed through comparator. The voltage comparator delivers square wave output Voltage of same frequency as that of input triangular waveform. The sine wave is derived from triangular wave. The triangular wave is synthesized into sine wave using diode resistance network. In this shaper circuit, the slope of triangular wave is changed as its amplitude changes. This results in a sine wave with less than 1% distortion. The two output amplifiers provide two simultaneous, individually selected outputs of any of the waveform functions.

The function of a signal generators is to supply signals of known amplitude and known frequency. The signal generators are used to supply signal levels at very low levels for the testing of receivers. But it is very difficult to measure and calibrate a signal

at a very low level. Thus attenuators are used in function generators. It is a device which reduces power level of a signal by fixed amount.

8.7 Sweep-Frequency Generators:

The sine wave generator discussed in earlier sections generates output voltage at a known and stable frequency.



The development of solid state variable capacitance diode (vary cap diode) helps in building sweep frequency generators. These are extensively used than any other electronic devices. These varicap diodes provide the method of electronically tuning an oscillator. The block diagram of simple sweep frequency generator is as shown in Fig

The sweep generator is very much similar to the simple signal generator. In the simple signal generator, an oscillator is tuned to fixed single frequency.

In the sweep generator, an oscillator is electronically tuned and by using voltage controlled oscillator variable frequency is obtained. As name indicates, a sweep voltage generator provides voltage, known as control voltage, to the voltage controlled oscillator (VCO). The function of voltage controlled oscillator is to provide various frequency sweeps according to voltage provide by sweep voltage generator.

8.8 Frequency Synthesizers

The frequency generators are of two types.

1. One is free running frequency generators in which the output can be tuned continuously either electronically or mechanically over a wide frequency range. The generators discussed up till now are of this type.
2. The second is frequency generator with frequency synthesis technique. The synthesis means to use a fixed frequency oscillator called reference oscillator or clock and to derive the wide frequency range in steps from the output of the reference oscillator.

The stability and accuracy of free running frequency generator is poor while frequency synthesizers provide output which is arbitrarily selectable, stable and accurate frequency. The reference oscillator used in frequency synthesizers is generally precision crystal oscillator with an output at some cardinal frequency such as 10 MHz. Various signal processing circuits then operate in synchronism to provide a large choice of the output frequencies.

In digital instruments, the output device of the instrument indicates the value of measured quantity using the digital display device. This digital display device may receive the digital information in any form but it converts the information in decimal form. Thus the digital display device indicates the value in decimal digits directly. The basic element in a digital display is the display for a single digit. By grouping such displays for single digits, we can get multiple digit display. In general, digital display is classified as planar and non-planar display. A planar display is a display in which entire characters are displayed in one plane. A non-planar display is a display in which characters are displayed in different planes. In this chapter we will discuss different display devices. In general, LED's are most commonly used in the digital displays. The LED's have advantages such as low voltage, long life, high reliability, low cost, fast switching characteristics.

8.9 Display devices

In the digital electronic field, the most commonly used displays include cathode ray tube (CRT), light emitting diode (LED) and liquid crystal display (LCD), gas discharge plasma displays, electro-luminescent displays, incandescent displays, liquid vapour displays etc.

A) Classification on the basis of conversion of electrical signal into the visible light :

There are two types of such displays.

- a) Active Displays - CRT, gas discharge plasma display, LED
- b) Passive Displays - LCD, electrophoretic image displays

B) Classification on the basis of applications :

- a) Analog Displays - Bar graph display, CRT
- b) Digital Displays - Nixie tubes, alphanumeric display, LED.

C) Classification on the basis of physical dimensions and sizes :

- a) Symbolic Displays - Alphanumeric, Nixie tube, LED
- b) Console Displays - LED, CRT
- c) Large Screen Displays - Enlarged projectors

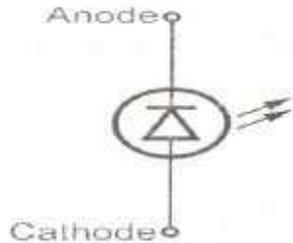
D) Classification on the basis of display format

- a) Direct View Type (Flat Panel) - Segmental display, dot matrix
- b) Stacked Non-planar Type - Nixie tube

E) Classification on the basis of resolution

- a) Simple single element indicator
- b) Multielement displays

8.10 LED

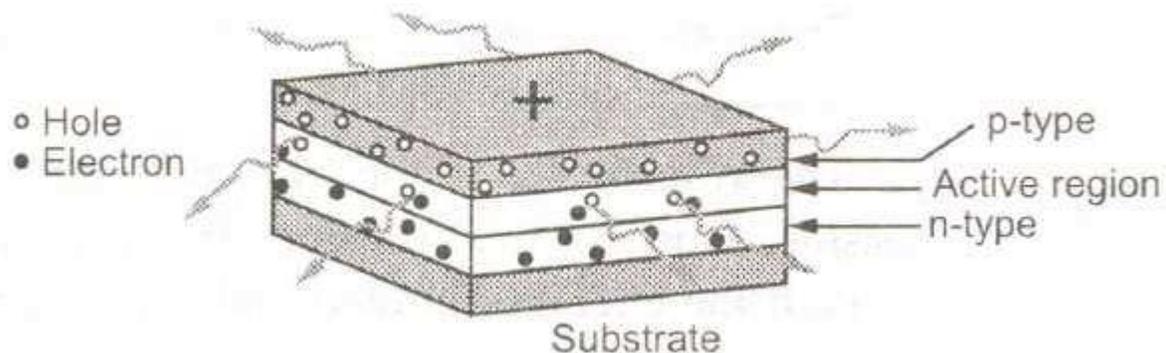


The LED is an optical diode, which emits light when forward biased. The Fig. shows the symbol of LED which is similar to p-n junction diode apart from the two arrows indicating that the device emits the light energy.

Basic Operation:

When a p-n junction is forward biased, the electrons cross the p-n junction from the n-type semiconductor material and recombine with the holes in the p-type semiconductor material. The free electrons are in the conduction band while the holes are present in the valence band. Thus the free electrons are at higher energy level with respect to the holes. When a free electron recombines with a hole, it falls from the conduction band to a valence band. Thus the energy level associated with it changes from higher value to lower value. The energy corresponding to the difference between higher level and lower level is released by an electron while traveling from the conduction band to the valence band. In diodes, this energy released is in the form of heat. But LEDs are made up of some special material which release this energy in the form of photons which emit the light energy. Hence such diodes are called light emitting diodes.

Construction of LEDs:



One of the methods used for the LED construction is to deposit three semiconductor layers on the substrate as shown in the Fig. In between p-type and n-type, there exists an active region.

LED Driver Circuit



The output of a digital circuit is logical i.e. either '0' or '1'. The '0' means low while '1' means high. In the high state the output voltage is nearly 5 V while in low state, it is almost 0 V. If LED is to be driven by such digital circuit, it can be connected as shown in the Fig. 10.10. When output of digital circuit is high, both ends of LED are at 5 V and it can not be forward biased hence will not give light. While when output of digital circuit is low, then high current will flow through LED as it becomes forward biased, and it will give light.

To improve the brightness of display, a dynamic display system is used. In this, the LEDs are not lit continuously but are sequentially lit by scanning in a "vertical strobe" or "horizontal strobe" mode. This is similar to "running lights" used in modern advertisements. In the vertical strobe mode, a single row is selected at a time, the appropriate LEDs are energized in that row, and then the signal is applied to next row. On the contrary, in horizontal strobe mode, a single column is selected at a time.

Alphanumeric displays using LEDs employ a number of square and oblong emitting areas, arranged either as dot matrix or segmented bar matrix. Alphanumeric LEDs are normally laid out on a single slice of semiconductor material, all the chips being enclosed in a package, similar to an IC, except that the packaging compound is transparent, and not opaque.

8.11 Liquid Crystal Displays (LCDs)

The liquid crystals are one of the most fascinating material systems in nature, having properties of liquids as well as of a solid crystal. The term liquid crystal refers to the fact that these compounds have a crystalline arrangement of molecules, yet they flow like a liquid. Liquid crystal displays do not emit or generate light, but rather alter externally generated illumination. Their ability to modulate light when electrical signal is applied has made them very useful in flat panel display technology.

The crystal is made up of organic molecules which are rod-like in shape with a length of $20 \text{ \AA} - 100 \text{ \AA}$. The orientation of the rod like molecule defines the "director" of the liquid crystal. The different arrangements of these rod-like molecules leads to three main categories of liquid crystals.

1. Smectic
2. Nematic
3. Cholesteric

Types of LCDs

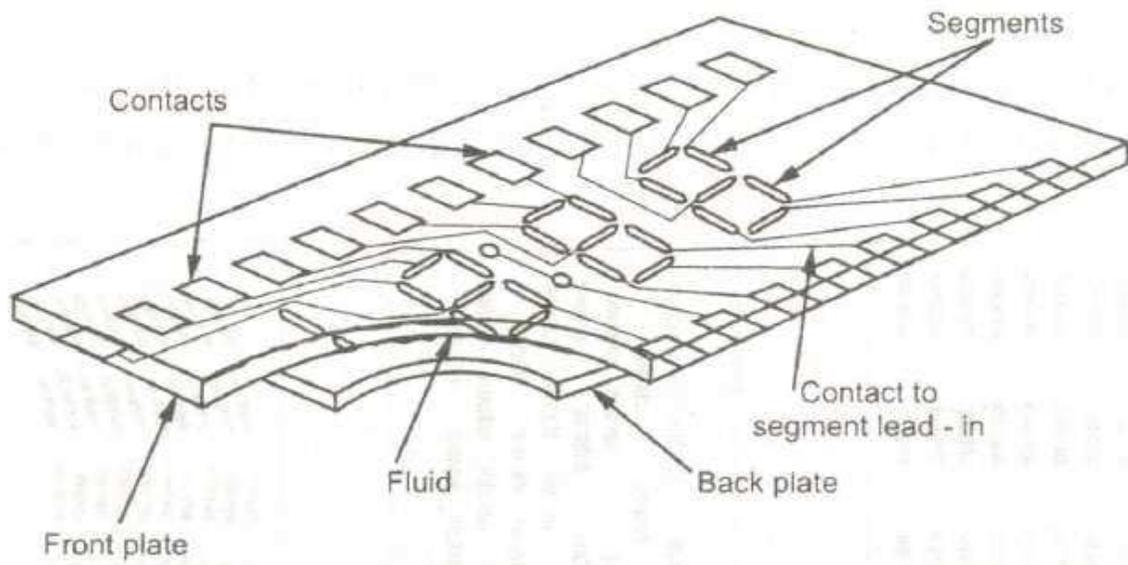
There are two types of liquid crystal displays (LCDs) according to the theory of operation:

1. Dynamic scattering
2. Field effect.

Dynamic Scattering Type LCD

Fig. shows the construction of a typical liquid crystal display. It consists of two glass plates with a liquid crystal fluid in between. The back plate is coated with thin transparent layer of conductive material, whereas front plate has a photoetched

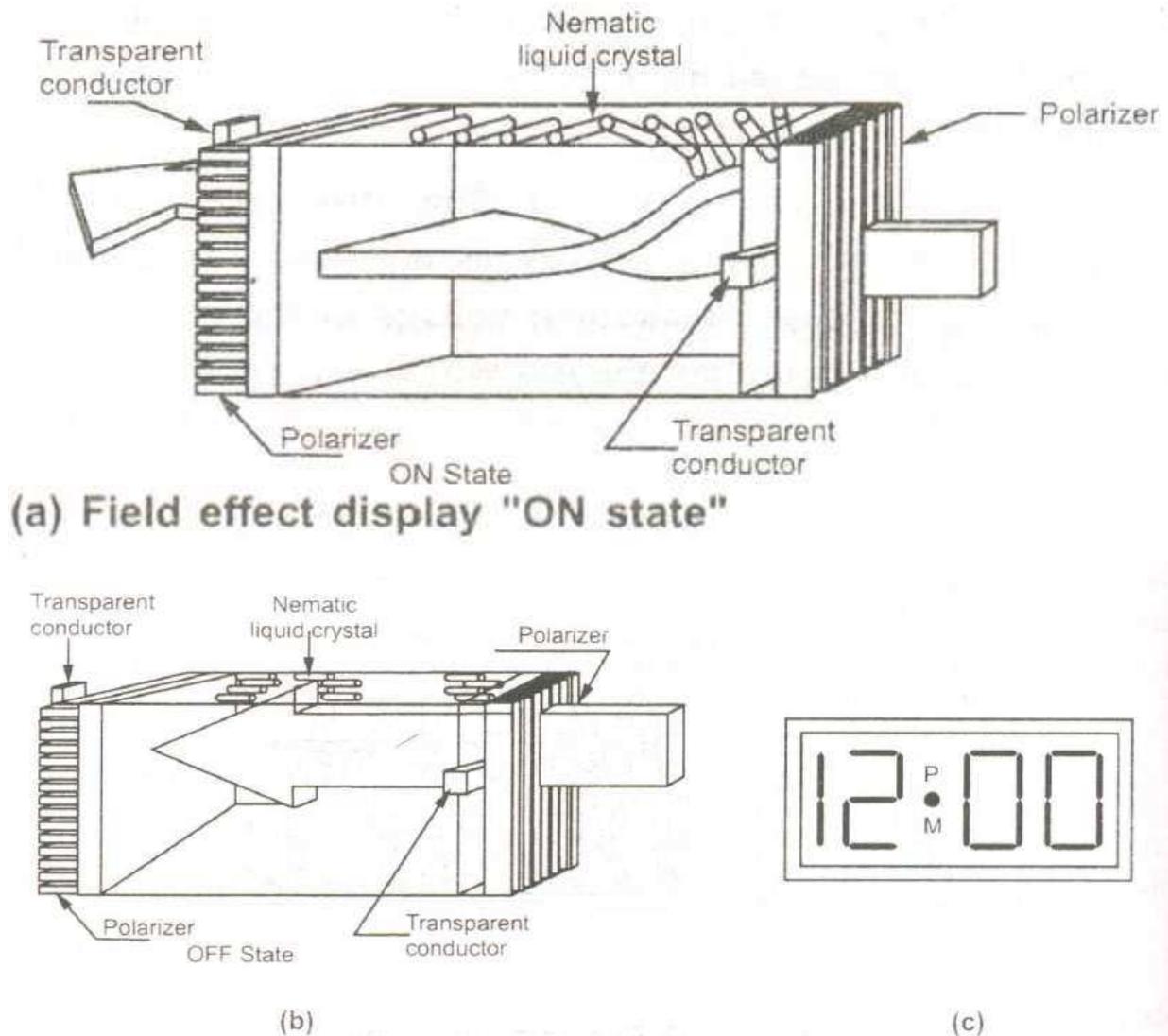
conductive coating with seven segment pattern as shown in Fig



Field Effect Display

In these displays nematic liquid crystals are used. Fig shows operation of field effect liquid crystal display with pneumatic crystals. It consists of two glass plates, a liquid crystal fluid, polarizer and transparent conductors. The liquid crystal fluid is sandwiched between two glass plates. Each glass plate is associated with light polarizer. The light polarizer are placed at right angle to each other. In the absence of electrical excitation, the light coming through the front polarizer is rotated through 90° in the fluid and passed through the rear polarizer. It is then reflected to the viewer by the back mirror as shown in Fig. (a).

On the application of electrostatic field, the liquid crystal fluid molecules get aligned and therefore light through the molecules is not rotated by 90° and it is absorbed by the rear polarizer as shown in Fig. (b). This causes the appearance of dark digit on a light background as shown in Fig. (c).



Advantages of LCDs

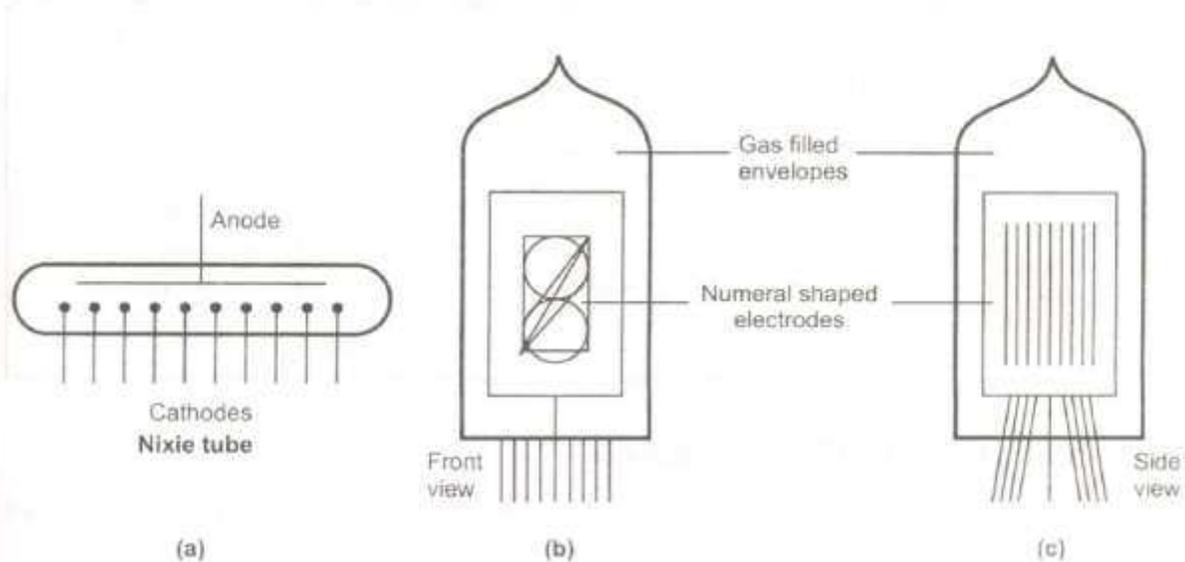
1. Less power consumption
2. Low cost
3. Uniform brightness with good contrast

Nixie tubes

The operation of this display is based on the principle that under breakdown condition, a gas near cold cathode gas filled tube emits light. The cold cathode indicators are called Nixie Tubes. These are based on the principle of glow discharge in a cold cathode gas filled tubes. The construction of the nixie tube is as shown in the Fig. It consists 10 cathode and one anode, all are made of thin wires. But only difference is anode is in the form of thin frame.

When a gas near cathode breaks down, a glow discharge is produced. The gas

electrodes with a positive supply voltage work as an anode. In general this voltage is selected greater than the worst case breakdown voltage of the gas within tube. When the cathode is connected to ground potential, the gas which is close to a cathode glows.



8.13 Data Acquisition system

Introduction

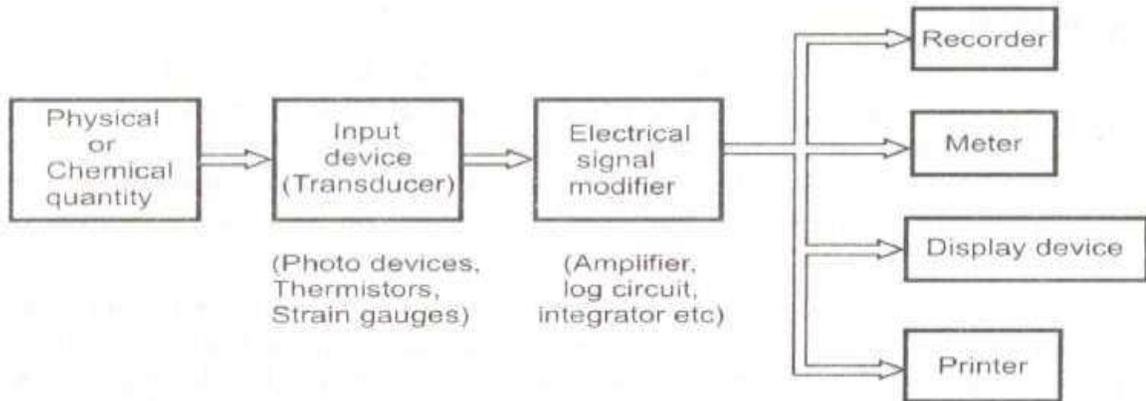
The primary objective of industrial process control is to control physical parameters such as temperature, pressure, flow rate, level, force, light intensity, and so on. The process control system is designed to maintain these parameters near some desired specific value. As these parameters can change either spontaneously or because of external influences, we must constantly provide corrective action to keep these parameters constant or within the specified range.

To control the process parameter, we must know the value of that parameter and hence it is necessary to measure that parameter. **In** general, a measurement refers to the transduction of the process parameter into some corresponding analog of the parameter, such as a pneumatic pressure, an electric voltage, or current. A **transducer** is a device that performs the initial measurement and energy conversion of a process parameter into analogous electrical or pneumatic information. Many times further transformation or signal enhancement may be required to complete the measurement function. Such processing is known as **signal conditioning**.

Data aided measurement:

For any measurement system., the first stage detects the physical quantity to be this is done with the help of suitable transducer. The next stage converts this signal into an electrical form. The second stage is used to amplify the converted signal such that it becomes usable and suitable for the last stage which is signal conditioning stage. The last stage includes various elements used for different purposes such as indicating, recording, displaying, data processing and control elements.

^ typical electronic aided measurement system is as shown in the Fig

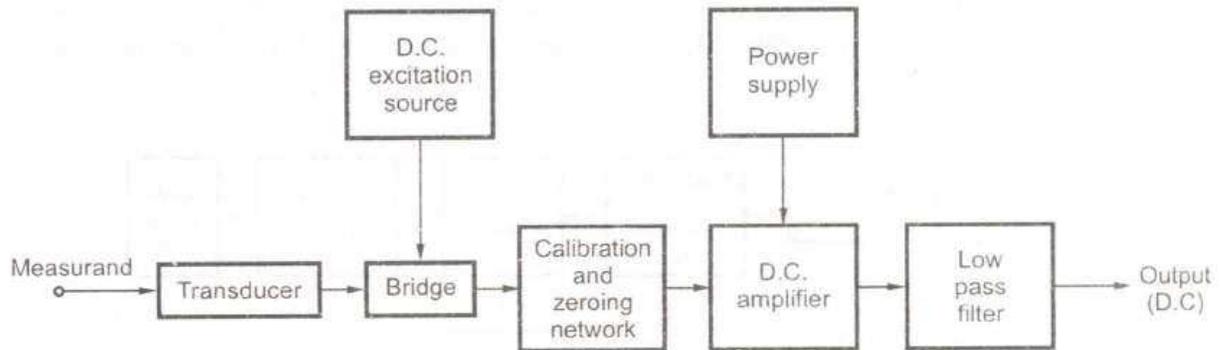


The first stage is the input device which is nothing but a transducer which converts measured into an usable form i.e. electrical signal. In other words, the quantity measured is encoded as an electrical signal. The next stage modifies the electrical signal in the form suitable for the output or read-out devices. Generally the most frequently used electronic circuits are amplifiers, with parameter adjustments and automatic compensation circuits specially used for temperature variation. of the input device and non-linearity's of the input device. The output is obtained from read-out devices such as meter, recorder, printer, display units etc. In general, the quantity which is measured by using transducer can be encoded in different ways. For example, as a physical or chemical quantity or property, as a characteristics of the electrical signal, as a number. The property or different characteristics used to represent a data is called **data** domain.

The electronic aided measurement system represents the measurement of physical quantity faithfully in the analog or digital form of it obtained from the signal conditioning circuits. For passive transducers, the signal conditioning circuit mainly' includes excitation and amplification circuitry, while for active transducers, only amplification circuitry is needed and the excitation is not needed. Depending on the type of the excitation either a.c. or d.c. source, we have a.c. signal conditioning system and d.c. signal conditioning system.

8.14 D.C. Signal Conditioning System

The block diagram of d.c. signal conditioning system is shown in the Fig



The resistance transducers are commonly used for the d.c. systems. The resistance transducers like strain gauge forms one or more arms of a Wheatstone bridge circuit. A separate d.c. supply is required for the bridge. The bridge is balanced using potentiometer and can be calibrated for unbalanced conditions. This is the function of Calibration and zeroing network. Then there is d.c. amplifier which also requires separate d.c. supply.

The d.c. amplifier must have following characteristics:

1. Balanced differential inputs.
2. High common mode rejection ratio. (CMRR)
3. High input impedance.
4. Good thermal and long term stability.

The d.c. system has following advantages:

1. It is easy to calibrate at low frequencies.
2. It is able to recover from an overload condition.

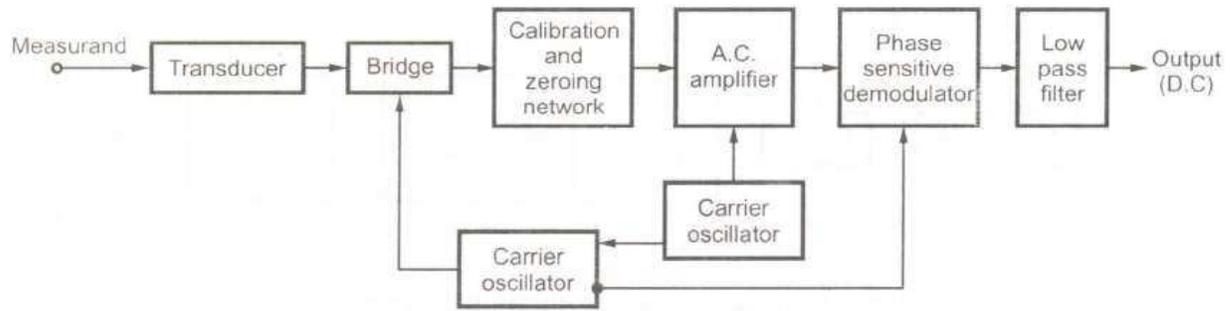
But the main disadvantage of d.c. system is that it suffers from the problems of drift. The low frequency spurious unwanted signals are available along with the required data signal. For overcoming this, low drift d.c. amplifiers are required.

The output of d.c. amplifier is given to a low pass filter. The function of low pass filter is to eliminate unwanted high frequency components or noise from the required data signal. Thus the output of low pass filter is the required data signal. Thus the output of low pass filter is the required d.c. output from the d.c. signal conditioning system.

The applications of such system are in use with common resistance transducers such as potentiometers and resistance strain gauges.

A.C. Signal Conditioning System

The limitation of d.c. signal conditioning system can be overcome upto certain extent, using a.c. signal conditioning system. The block diagram of a.c. signal conditioning system as shown in the Fig



This is carrier type a.c. signal conditioning system. The transducer used is variable resistance or variable inductance transducer. The carrier oscillator generates a carrier signal of the frequency of about 50 Hz to 200 kHz. The carrier frequencies are higher and are atleast 5 to 10 times the signal frequencies.

The bridge output is amplitude modulated carrier frequency signal. The a.c. amplifier is used to amplify this signal. A separate power supply is required for the a.c. amplifier. The amplified signal is demodulated using phase sensitive demodulator. The advantage of using phase sensitive demodulator is that the polarity of d.c. output indicates the direction of the parameter change in the bridge output.

Unless and until spurious and noise signals modulate the carrier, they will not affect the data signal quality and till then are not important. Active filters are used to reject mains frequency pick up. This prevents the overloading of a.c. amplifier. Filtering out of carrier frequency components of the data signal is done by phase sensitive demodulator.

The applications of such system are in use with variable reactance transducers and for the systems where signals are required to be transmitted through long cables, to connect the transducers to the signal conditioning system further processing of signals is required which includes linear and nonlinear operations This type of signal conditioning includes the circuits like sample and hold, multiplexers, analog to digital converters etc.

Questions:

1. Discuss different considerations of power measurement in various frequency ranges. Dec09/June2010
2. Explain briefly the techniques used for power measurement at high frequencies. June/July2009, Jan/ Feb 2012
3. Write a note on power measurement at audio frequency.
4. What are basic requirements of load ? Write different forms of the dummy load satisfying above requirements. Dec09/June2010
5. Explain R.F. power measurement.
6. Write notes on :1) data acquisition systems. May/June2010, Jan/ Feb 2012
7. Explain power measurement using Wheatstone bridge schematic diagram.
8. Explain power measurement using unbalanced bolometer bridge. June/July2009
9. What is meant by signal conditioning? Will it be necessary ? Dec/Jan2009
10. Write a note on data aided measurement system.
11. Explain d.c. signal conditioning system with the help of block diagram. Dec/Jan2009
12. Draw block diagram of signal conditioning system. Explain briefly. May/June2010
13. Explain with block diagram, the essential functional operations of a digital data acquisition system. Compare the digital and analog forms of data acquisition systems Jan/ Feb -2004,2005, July/Aug-2004, Jan/ Feb 2012
14. Explain with block diagram the essential functional operation of a digital data acquisition system Jan/ Feb -2007,2009,2010, July/Aug-2006,2008,2009,2010
15. Explain the interfacing of frequency counter with IEEE – 488 BUS with the help of a block diagram Jan/ Feb -2004,2005,2007, Jan/ Feb 2012
16. Write a note on digital to analog multiplexing July/Aug-2004,2005
17. Explain the timing relationship of signal in an IEEE-488 bus July/Aug-2005, 2006
18. Briefly discuss on the instruments used in computer controlled instrumentation July/Aug-2005
19. Explain the working of IEEE 488 electrical interface towards testing of computer controlled instrumentation system Jan/ Feb -2006
20. What is the function of instrumentation amplifier? What are its characteristic features? Jan/ Feb -2011, July/Aug-2007
21. Briefly explain the instruments used in computer controlled instrumentation July/Aug-2007, Jan/ Feb 2012

22. Write short notes on the following (a) objective of DATA acquisition system
(b) LCD display Jan/ Feb -2008
23. With a neat sketch, explain the working of a X-Y Recorder
Jan/ Feb -2008, 2010, 2011, July/Aug-2008, 2009, 2010
24. Write short note on LCD display Jan/ Feb -2008
25. Write short note on the various display devices viz. LED, LCD, Nixie tube
July/Aug-2008
26. Explain the classification of displays
July/Aug-2009
27. Write a note on LED and LCD display July/Aug-2010
28. Explain the working of signal generator with the help of neat diagram
Jan/ Feb -2010, July/Aug-2009
