1 UNIT

Electrical Measurements

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PART-1

Measurement System, Characteristics of Instruments, Methods of Measurement, Errors in Measurement and Measurement Standards, Measurement Error Combination.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. **Discuss measurement system.**

Answer

A measurement system comprises of the following elements :

1. A transducer is one which converts the measurand (quantity) into a usable electrical output.
2. A signal conditioner, which converts the transducer output into an electrical quantity suitable for control, recording and/or display.
3. Display or read out devices to display the required information about the measured, generally in engineering units.
4. An electrical power supply which provides the required excitation to the transducer and the necessary electrical power to the signal conditioners and display devices.
5. The output signal may be an analog or digital quantity. The read out or display device may be in analog or digital form.

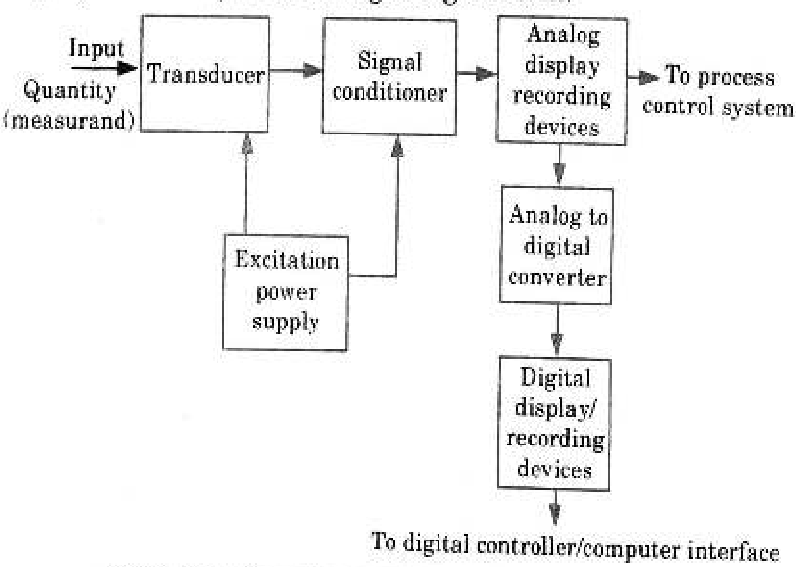


Fig. 1.1.1. A generalised measurement system.

Que 1.2. **What is an instrument ? Classify various types of electrical instruments.**

Answer

A. **Instrument :** It is defined as a device for determining the value or magnitude of a quantity or variable.

B. **Various types of electrical instruments are :**

a. **Absolute instruments :**

1. These instruments give the magnitude of the quantity under measurement in terms of physical constants of the instrument.
2. Examples are Tangent Galvanometer and Rayleigh's Current Balance.

b. **Secondary instruments :**

1. These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument.
2. These instruments are calibrated by comparison with an absolute instrument or another secondary instrument which has already been calibrated against an absolute instrument.
3. Examples are voltmeter, glass thermometer and pressure gauge.

c. **Deflection type :**

1. In instruments of this type, the deflection of the instrument provides a basis for determining the quantity under measurement.
2. The measured quantity produces some physical effect which deflects or produces a mechanical displacement of the moving system of the instrument.
3. An opposing effect is built in the instrument which tries to oppose the deflection or the mechanical displacement of the moving system.
4. The opposing effect is closely related to the deflection or mechanical displacement which can be directly observed.
5. The opposing effect is so designed that its magnitude increases with the increase of deflection or mechanical displacement of the moving system caused by the quantity under measurement.
6. The balance is achieved when opposing effect equals to cause producing the deflection or mechanical movement.
7. The value of the measured quantity can then be inferred from the deflection or mechanical displacement at the point of balance.

d. **Null type :**

1. In a null type of instrument, a zero or null indication leads to determination of the magnitude of measured quantity.

2. The null condition is dependent upon some other known conditions.
3. In contrast to deflection type of instruments, a null type instrument attempts to maintain the deflection at zero by suitable application of an effect opposing that generated by the measured quantity.

e. Analog type :

1. Signals that vary in a continuous fashion and take on infinite number of values in any given range are called analog signals.
2. The devices which produce these signals are called analog devices.

f. Digital type :

1. The signals which vary in discrete steps and thus take up only finite different values in a given range are called digital signals.
2. The devices that produce such signals are called digital devices.

Que 1.3. **Distinguish between the null type and deflecting type of instruments. Give examples to support your answer.**

Answer

S. No.	Null type instrument	Deflection type instrument
1.	It uses null detector, the effect produced by measured quantity and opposite effect to obtain null condition.	In this instrument the quantity of the measured produces some effect which deflects the pointer against controlling torque.
2.	The accuracy is high.	The accuracy is low.
3.	Highly sensitive as null detector has to cover a small range around the null point.	Less sensitive.
4.	Not suitable for the dynamic and rapid measurements.	Preferred for the dynamic measurements.
5.	The example is DC potentiometer.	The example is moving coil ammeter.

Que 1.4. **Discuss with block diagram, generalized instrumentation system.**

Answer

Generalized instrumentation system :

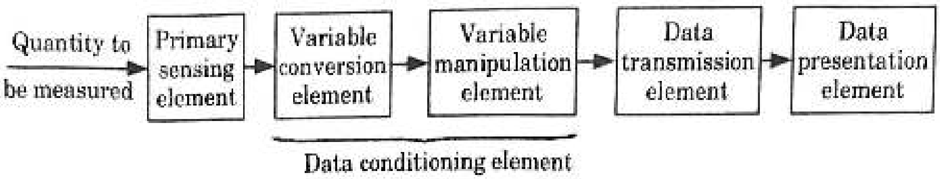


Fig. 1.4.1. Functional elements of an instrumentation system.

A. Primary sensing element :

1. The quantity under measurement makes its first contact with the primary sensing element of a measurement system.
2. This act is then immediately followed by the conversion of measurand into an analogous electrical signal.
3. This is done by transducer. The first stage of measurement system is known as detector transducer stage.

B. Variable conversion element :

1. The output of the primary sensing element may be electrical signal of any form. It may be a voltage, a frequency or some other electrical parameter.
2. Sometimes this output is not suited to the system. For instrument to perform the desired function, it may be necessary to convert this output to some other suitable form while preserving the information content of the original signal.

C. Variable manipulation element :

1. The function of this element is to manipulate the signal presented to it preserving the original nature of the signal.
2. Manipulation here means only a change in numerical value of the signal.
3. It is not necessary that a variable manipulation element should follow the variable conversion element. It may precede the variable conversion element in many cases.

D. Data transmission element :

1. When the elements of an instrument are actually physically separated, it becomes necessary to transmit data from one to another. The element that performs this function is called data transmission element.

E. Data presentation element :

1. The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring control or analysis purposes.
2. The information conveyed must be in a form understandable to the personnel or to the intelligent instrumentation system. This function is done by data presentation element.

3. In case data is to be monitored, visual display devices are needed. These devices may be analog or digital indicating instruments like ammeters, voltmeters, etc.
4. In case the data is to be recorded, recorders like magnetic tapes, high speed camera and T.V. equipment, storage type CRT, printers, analog and digital computers or microprocessors may be used.
5. The final stage in a measurement system is known as terminating stage.

Que 1.5. **What are the different characteristics being used in measurements ?**

Answer

Performance characteristics are of two types :

1. **Static characteristics :** It focuses on the measurement of quantities which are either constantly or very slowly varying with time. There is linear relation with time.
2. **Dynamic characteristics :** It involves the measurement of quantities that vary with time but maintains a second order or third order differential equation with time.

Que 1.6. **What are the desirable static characteristics in a measurement system ?**

Answer

They are of different types as follows :

1. **Accuracy :**

i. Accuracy refers to the closeness of a measured value to a standard or known value.

ii. For example, if you obtain a weight measurement of 3.2 kg for a given substance, but the actual or known weight is 10 kg, then your measurement is not accurate. In this case, your measurement is not close to the known value.

2. **Precision :**

i. Precision refers to the closeness of two or more measurements to each other.

ii. Using the example above, if you weight a given substance five times, and get 3.2 kg each time, then your measurement is very precise.

3. **Sensitivity :** It is the ratio of change in output with respect to change in input.

$$\text{Sensitivity} = \frac{\text{Changes in Output}}{\text{Changes in Input}}$$

4. **Reproducibility :** It indicates that the same output will be shown on the same input conditions.
5. **Resolution :**
   a. Changes in output are achieved only after making a change in pitch value of a specific instrument.
   b. Example : A voltmeter of 100 V with a pitch of 1 V, change in output value from 50 V to next value only when there is smallest of 1 V. Otherwise it will indicate 50 V (previous reading).
6. **Dead zone :** A zone in which instrument never shows change in output with respect to change in input.
7. **Hysteresis :** Hysteresis is defined as the magnitude of error caused in the output for a given value of input.
8. **Static error :** Errors which varies linearly with respect to changes in input.
9. **Drift :** It is undesirable change in output over a period of time. It means that with a given input the measured value vary with time.

Que 1.7. **List some dynamic characteristics of instrument.**

Answer

They are of different types as follows :

1. **Fidelity :** It indicates a degree to which an output changes with respect to change in input without considering dynamic errors.
2. **Lag :** It indicates the delay in output response, whenever there is change in input parameters.
3. **Speed of response :** It refers to rapidity of instrument response towards the changes in input quantities.
4. **Dynamic errors :** It is difference between the value indicated by instrument and the true value changing with time, if there is no static error assumed.

Que 1.8. **Explain the methods of measurement.**

Answer

We classify this generally into two broad categories :

A. Direct measurement :

1. These are made by measuring the unknown quantity to some calibrated standard and comparing the two.
2. It is done by human being, so it is quite possible that an error can be introduced during measurement.
3. Example : Dip a thermometer in hot water container and read the temperature directly.

B. Indirect measurement :

1. These are made by measuring some other quantity that is in relation with the actual unknown quantity.
2. Example : We can measure the temperature of a point on a wall that is filled with melting metal. Thermometer is used to measure the temperature of the wall of furnace at outer side because it may get damaged if it is inside the furnace. Furnace wall temperature is related to the interior temperature by a certain factor.

Que 1.9. **What are the various types of errors occurring in electrical measurements ? Explain them.**

OR

What are different types of systematic error ? Discuss.

Answer

Gross errors :

1. These errors occur due to human mistakes in reading instruments, recording and calculating results of measurement.
2. These errors can be avoided by adopting two means :
   i. Immense care should be taken while taking the reading and recording the data.
   ii. Two, three or even more readings should be taken for the quantity being measured.

Systematic errors :

1. The systematic errors are due to the shortcoming of the instrument and the characteristic of the material used in the instrument.
2. These errors cannot be determined by direct and repetitive observations of the measurand made each time using same technique.
3. These errors can be located only by having repeated measurements under different conditions with different equipment and where possible by an entirely different method.
4. These errors may be instrumental, environmental or observational errors.

a. Instrumental errors :

1. These errors arise due to :
   i. Inherent shortcomings in the instrument.
   ii. Misuse of the instrument.
   iii. Loading effect of instrument.
2. Instrumental errors are inherent due to construction, calibration or operations of the instrument. These errors may cause the instruments reading too low or too high.

3. These errors can be avoided by following methods :
i. Selecting a proper instrument and planning a proper procedure for measurement.
ii. Calibrating the instrument carefully against a standard.
iii. Loading effect can be avoided by using an instrument intelligently and correctly.

b. Environmental errors :

1. The environmental errors are due to external conditions to the measuring device. These errors are much more troublesome than assembly errors.
2. These errors can be reduced by using the instrument in controlled conditions of pressure, temperature, humidity in which it was originally assembled and calibrated.

c. Observational errors :

1. It can be due to wrong scale reading, wrong recording of data, inaccurate estimates of average reading, incorrect conversion of units in between consecutive readings.
2. To eliminate such observational error, one should use the instrument with mirror, knife edged pointers etc. Now-a-days, the instruments with digital display are available which can largely eliminate such observational error.

Que 1.10. Explain limiting errors / guarantee errors in measurement.

Answer

1. Limiting errors/guarantee errors are those errors which are defined by manufacturer.
2. Such errors exist in instruments due to utilization of different part in manufacturing an instrument.
3. Each part has some errors, which combined together will be large.
4. Such errors can be found by comparing the instrument against the standard quantities and accordingly are specified by the manufacturer.
5. The value of limiting error largely dependent upon design constraints of component used in instruments.

Que 1.11. What do you understand by absolute error and relative error ?

Answer

Absolute errors :

1. The difference between the measured value and the true value of quantity is known as absolute error.

2. Absolute error = Measured value – True value

$$\delta A_s = A_m - A_t$$

$\delta A_s \rightarrow$ Static error of measurement/absolute error

$A_m \rightarrow$ Measured value of quantity

$A_t \rightarrow$ True value of quantity

Relative errors :

1. It is defined as the ratio of absolute error to the true value of the quantity under measurement is known as relative error.
2. $$\epsilon_r = \frac{\text{Absolute error}}{\text{True value}} = \frac{\delta A_s}{A_t}$$

$\epsilon_r \rightarrow$ Relative value

The relative error can be positive or negative.

Que 1.12. Differentiate between gross errors and systematic errors. List a few ways of minimizing the effect of errors in measurement. **AKTU 2014-15, Marks 05**

Answer

A. Difference :

Gross errors	Systematic errors
These errors occur due to human mistakes in reading instruments, recording and calculating results of measurement.	The systematic errors are due to the shortcoming of the instrument and the characteristic of the material used in the instrument.

B. Minimization the effect of errors : Refer Q. 1.9, Page 1–8E, Unit-1.

Que 1.13. A thin wire has a length of 21.7 cm and radius 0.46 cm. Calculate the volume of the wire correct to required significant figures. **AKTU 2014-15, Marks 05**

Answer

Given : R = 0.46 cm, H = 21.7 cm

To Find : Volume of wire

$$\text{Volume of wire} = \pi R^2 H$$

$$= \pi (0.46)^2 \times 21.7$$

$$= 14.42 \text{ cm}^3$$

Since, the radius of the wire is given in the significant figure of two. So the result is also rounded off in two digits.

Que 1.14. **Define measurement. Calculate percentage error in determination of time period of a pendulum given by**

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where l and g are measured in ± 2 % and ± 3 % errors.

AKTU 2014-15, Marks 05

Answer

Measurement : It is the process by which one can convert physical parameters to meaningful numbers.

Numerical :

1. Given, $$T = 2\pi\sqrt{\frac{l}{g}}$$
2. $$\text{Percentage error in } \frac{l}{g} = (\text{Percentage error in } l) + (\text{Percentage error in } g)$$ $$= \pm [(2\ \%) + (3\ \%)] = \pm 5\ \%$$
3. $$\text{Percentage error in } \left(\frac{l}{g}\right)^{1/2} = \frac{1}{2}\left[\text{Percentage error in } \frac{l}{g}\right]$$ $$= \pm \frac{1}{2}\ [5\ \%]$$ $$= \pm 2.5\ \%$$

Que 1.15. **A batch of resistors each having a nominal resistance of 330 Ω are to be tested and classified as ± 10 % components at 25 °C. If their temperature coefficient is – 300 ppm/ °C, calculate the maximum and minimum resistance for these components at 100 °C.**

AKTU 2014-15, Marks 05

Answer

Given : R = 330 Ω at 25°C with error = ± 10 %

Temperature coefficient = – 300 ppm/°C

To Find : R_{max} and R_{min} at 100 °C

1. $$\text{Absolute error} = \frac{\text{Tolerance} \times \text{Nominal resistance}}{100}$$

$$= \frac{10 \times 330}{100} = \pm 33\ \Omega$$

2. Largest possible resistance at 25 °C

$$R_{max} = 330 + 33 = 363\ \Omega$$

3. Minimum possible resistance at 25 °C

$$R_{min} = 330 - 33 = 297\ \Omega$$

4. **For R_{max} :**

Resistance change per °C

$$-300 \text{ ppm of } R_{max} = -\frac{363}{1000000} \times 300$$

$$= -0.108\ \Omega/\ ^\circ C$$

Temperature increase = 100 °C – 25 °C = 75 °C

Total resistance increase, $\Delta R = -0.108\ \Omega/\ ^\circ C \times 75\ ^\circ C = -8.1\ \Omega$

Maximum resistance at 100 °C = $R + \Delta R$

$= 363 - 8.1 = 354.9\ \Omega$

5. **For R_{min} :**

Resistance change per °C

$$-300 \text{ ppm of } R_{min} = \frac{-297 \times 300}{1000000} = -0.089\ \Omega/\ ^\circ C$$

Total resistance increase, $\Delta R = -0.089\ \Omega/^\circ C \times 75\ ^\circ C = -6.675\ \Omega$

Minimum resistance at 100 °C = $R + \Delta R$

$= 297 - 6.675 = 290.\ 3\ \Omega$

Que 1.16. **Define systematic errors in details. A batch of resistors each has a nominal resistance of 330 Ω are to be tested and classified as ± 5% and ± 10%, components are specified at 25 °C, and their temperature coefficient is – 300 ppm/°C. Calculate the maximum and minimum resistance for these components at 100 °C and calculate the maximum and minimum absolute resistance for each case.**

AKTU 2015-16, Marks 10

Answer

Systematic error : Refer Q. 1.9, Page 1–8E, Unit-1.

Numerical :

Given : $R = 330\ \Omega$ at 25°C with errors ± 5 % and ± 10 %

Temperature coefficient = – 300 ppm/°C

To Find : R_{max} and R_{min} at 100°C

Case 1 : When, error = ± 5%

1. Absolute error = $\pm 330 \times \frac{5}{100} = \pm 16.5\ \Omega$

2. $R_{max} = 330 + 16.5 = 346.5\ \Omega$ [at 25 °C]

$$R_{min} = 330 - 16.5 = 313.5\ \Omega \quad \text{[at 25 °C]}$$

3. At R_{max}, $\Delta R/°C = 346.5 \times \frac{-300}{10^6} = -0.10395\ \Omega/°C$

At R_{min}, $\Delta R/°C = 313.5 \times \frac{-300}{10^6} = -0.09405\ \Omega/°C$

4. $\Delta T = 100 - 25 = 75\ °C$

5. $\Delta R_{max} = -0.10395 \times 75 = -7.79625\ \Omega$

$\Delta R_{min} = -0.09405 \times 75 = -7.0537\ \Omega$

6. $R_{max} = 346.5 - 7.79625 = 338.70375\ \Omega$ [at 100 °C]

$R_{min} = 313.5 - 7.0537 = 306.4463\ \Omega$ [at 100 °C]

Case 2 : $R = 330\ \Omega$, at $T = 25°$ C, error = 10 %

1. Absolute error = $\pm 330 \times \frac{10}{100} = \pm 33\ \Omega$

2. $R_{max} = 330 + 0.1 \times 330 = 363\ \Omega$ [at 25 °C]

$R_{min} = 330 - 0.1 \times 330 = 297\ \Omega$ [at 25 °C]

Resistance change per °C :

3. At R_{max}, $\Delta R/°C = 363 \times \frac{-300}{10^6} = -0.10891\ \Omega/°C$

At R_{min}, $\Delta R/°\ C = 297 \times \frac{-300}{10^6} = -0.0891\ \Omega/°C$

[where temperature coefficient = – 300 ppm/°C]

4. Temperature increase :

$$\Delta T = 100 - 25 = 75°\ C$$

5. Total resistance increase :

$$\Delta R_{max} = -0.1089 \times 75 = -8.1675\ \Omega$$

$$\Delta R_{min} = -0.0891 \times 75 = -6.6825\ \Omega$$

6. $R_{max} = 363 - 8.1675 = 354.83\ \Omega$ [at 100 °C]

$R_{min} = 297 - 6.6828 = 290.31\ \Omega$ [at 100 °C] [at 100 °C]

Que 1.17. Define systematic errors in details. A batch of resistors that each have a nominal resistance of 330 Ω are to be tested and classified as ± 10 % components at 25 °C. If their temperature coefficient is – 300 ppm/ °C, calculate the maximum and minimum resistance for these components at 75 °C. **AKTU 2017-18, Marks 07**

Answer

A. **Systematic errors :** Refer Q. 1.9, Page 1–8E, Unit-1.

B. **Numerical :** The procedure is same as Q. 1.15, Page 1–11E, Unit-1.

(**Ans.** R_{max} = 357.555 Ω, R_{min} = 292.545 Ω)

Que 1.18. **Explain the term "Standards" in measurement system. Also mention the various types of standards used in industry.**

Answer

Standards of measurement :

1. A standard is a physical representation of unit under measurement.
2. The standards are used for the purpose of obtaining the value of a physical quantity.
3. *e.g.*, the fundamental unit of mass in the international standard (SI) is the kilogram.

The types of standards are classified by their function and application as :

A. **International Standards :**

1. These are defined on the basis of international agreements.
2. These standards are designed to represent certain units of measurement to the closest possible accuracy.
3. These standards are checked and evaluated regularly against absolute measurement in terms of the fundamental units.
4. These are maintained at the international bureau of weights and measures and are not available to ordinary user.

B. **Primary Standards :**

1. These are absolute standards of such a high accuracy that they can be used as the ultimate reference standards.
2. The primary standards are maintained in national standards laboratories.
3. Main function of primary standard is the verification and calibration of the secondary standards.

C. **Secondary Standards :**

1. These are the basic reference standards used in industrial measurement laboratories.
2. These are maintained by the industries working on these standards and checked locally against other reference standards in that area.
3. A particular industry is responsible for the maintenance and calibration of secondary standards.

4. These standards are sent to the national standards laboratories on periodic basis for calibration and comparison against the primary standards.
5. These are always verified in terms of primary standards.

D. Working Standards :

1. These are used to check and calibrate general laboratory instruments for their accuracy and performance.
2. Manufacturer of precision resistance may use a standard resistor in the quality control department of his plant to check the values of resistors that are being manufactured.
3. By this way, manufacturer verifies that his measurement setup performs within the limits of accuracy that are specified.

Que 1.19. **Discuss the measurement error combination.**

Answer

When a quantity is calculated from measurements made on two (or more) instruments, it must be assumed that the errors due to instrument inaccuracy combine in the worst possible way. The resulting error is then larger than the error in any one instrument.

Sum of Quantities : Where a quantity is determined as the sum of two measurements, the total error is the sum of the absolute errors in each measurement. It is shown in Fig. 1.19.1.

$$E = (V_1 \pm \Delta V_1) + (V_2 \pm \Delta V_2)$$
$$E = (V_1 + V_2) \pm (\Delta V_1 \pm \Delta V_2)$$

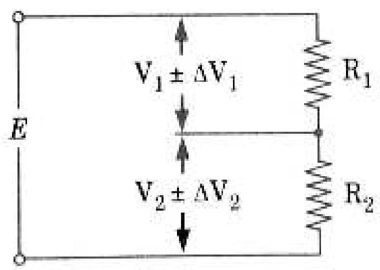


Fig. 1.19.1. Error in sum of quantities equals sum of errors.

Difference of quantities :

1. Fig. 1.19.2 illustrates a situation in which a potential difference is determined as the difference between two measured voltages. Here again, the errors are additive :

$$E = V_1 - V_2$$
$$(V_1 + \Delta V_1) - (V_2 + \Delta V_2)$$
$$E = (V_1 - V_2) \pm (\Delta V_1 - \Delta V_2)$$

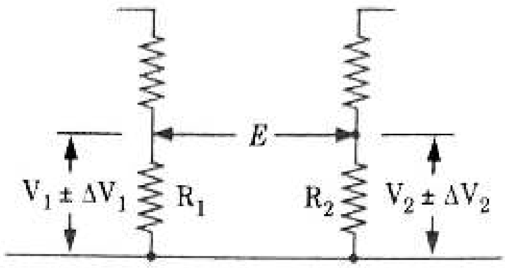


Fig. 1.19.2. Error in difference of quantities equals sum of errors.

Product of quantities :

When a calculated quantity is the product of two or more quantities, the percentage error is the sum of the percentage errors in each quantity Fig. 1.19.3.

$$P = EI$$

$$= (E \pm \Delta E)(I \pm \Delta I) = EI \pm E\,\Delta I \pm I\,\Delta E \pm \Delta E\,DI$$

Since $\Delta E\,\Delta I$ is very small,

$$P = EI + (E\,\Delta I + \Delta E)$$

Percentage error $= \dfrac{E\,\Delta I + I\,\Delta E}{EI} \times 100\,\%$

$$= \left(\frac{E\,\Delta I}{EI} + \frac{I\,\Delta E}{EI}\right) \times 100\,\%$$

$$= \left(\frac{\Delta I}{I} + \frac{\Delta E}{E}\right) \times 100\,\%$$

Percentage error in P = (Percentage error in I) + (Percentage error in E)

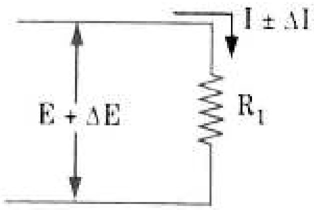


Fig. 1.19.3.

Quotient of quantities : It can be shown that the percentage error is the sum of the percentage errors in each quantity. It is shown in Fig. 1.19.3.

Percentage error in E/I = (Percentage error in E)

+ (Percentage error in I)

Quantity raised to a power : When a quantity A is raised to a power B, the percentage error in A^B can be shown to be

Percentage error in $A^B = B$ (Percentage error in A)

For a current I with an accuracy of ± 3 %, the error in I^2 is 2 (± 3 %) = ± 6 %.

PART-2

Review of Indicating and Integrating Instruments PMMC Instrument, Galvanometer, DC Ammeter, DC Voltmeter, Series Ohmmeter.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.20. **Describe the principle of operation, advantages, disadvantages and applications of PMMC.**

Answer

A. Construction :

1. A PMMC meter mechanism is the basic mechanism for most analog measuring instruments. This movement is also called D'Arsonval movement.
2. Main components of a PMMC instrument are moving coil, permanent magnet, spring control mechanism, damping system, scale and pointer etc.

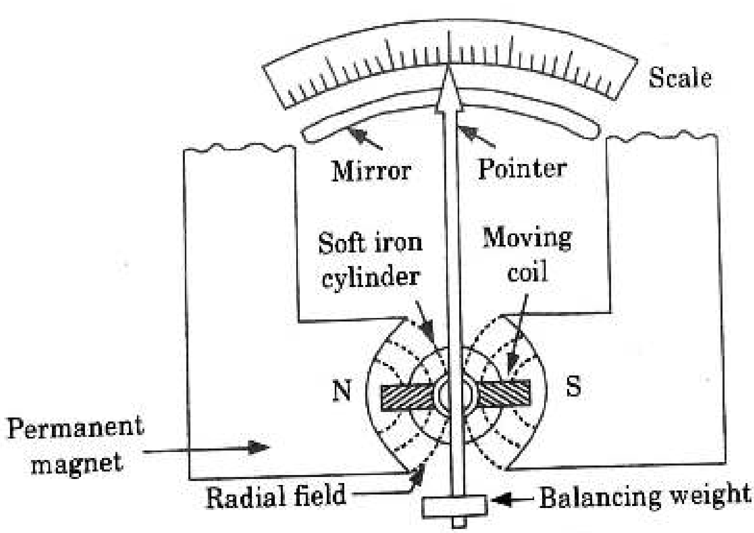


Fig. 1.20.1. PMMC.

3. Moving coil is wound with many turns of enamelled wire on a real angular aluminium former which is pivoted on jewelled bearings.
4. Magnetic system consists of a long U-shaped permanent magnet having soft iron pole pieces. Fig. 1.20.1 shows the basic structure of PMMC.

B. Principle of operation :

1. The permanent magnet applies a strong magnetic field across the space occupied by the moving coil. Therefore magnetic field of moving coil interacts with field of the permanent magnet.
2. When no current flows through the coil, resulting magnetic field does not disturb the magnetic field of the permanent magnet, therefore there is no deflection in the PMMC.
3. When the current flows through the coil, a controlling electromagnetic torque is provided by the interaction of two fields which is responsible for rotating the coil.
4. A pointer is attached to the coil which is extended out to a scale. The scale is calibrated to indicate the amount of current through the coil that is proportional to deflection in the coil.
5. A pair of hair springs is attached (of phosphor bronze material) to each end of the coil. These springs force the coil to return to its initial position when the applied current is zero.
6. The relationship between the electromagnetic torque is

$$T_D = BANI$$

where, $T_D \rightarrow$ Developed or deflecting torque, in N-m
$B \rightarrow$ Flux density in air gap, in Wb/m^2 (Tesla)
$A \rightarrow$ Effective coil area, in m^2
$N \rightarrow$ Number of turns of coil
$I \rightarrow$ Current in the movable coil, in amperes (A)

C. Advantages :

1. Low power consumption.
2. No hysteresis loss.
3. Very effective and reliable eddy current damping.
4. High torque / weight ratio.
5. Small operating current.
6. Very accurate and reliable.
7. Very high sensitivity.
8. Uniform scale.

D. Disadvantages :

1. It cannot be used for AC measurement.
2. Friction and temperature might introduce some errors.

3. Aging of control springs and the permanent magnet may be responsible for wrong readings.
4. Its cost is high.

E. Applications of PMMC :

1. **Ammeter :** When PMMC is used as an ammeter, except for a very small current range, the moving coil is connected across a suitable low resistance shunt, so that only small part of main current flows through the coil.
2. **Voltmeter :** When PMMC is used as a voltmeter, the coil is connected in series with high resistance.
3. **Galvanometer :** It is used to measure small value of current along with its direction and strength. It is mainly used on board to detect and compare different circuits in a system.
4. **Ohmmeter :** It is used to measure resistance of the electric circuit by applying a voltage to a resistance with the help of battery.

Que 1.21. **Explain the construction of a PMMC instrument. Mathematically prove that the scale of such an instrument is linear.**

AKTU 2014-15, Marks 05

AKTU 2015-16, Marks 10

AKTU 2016-17, Marks 10

AKTU 2017-18, Marks 10

Answer

A. Permanent magnet moving coil (PMMC) meters : Refer Q. 1.20, Page 1–17E, Unit-1.

B. Proof :

1. When a current I flows through a one-turn coil situated in a magnetic field, a force F is exerted on each side of the coil,

$$F = BIl \quad \text{newtons}$$

where, B is the magnetic flux density in tesla, I is the current in amperes, and l is the length of the coil in meters.

2. Since the force acts on each side of the coil, the total force for a coil of N turns is

$$F = 2BIlN \quad \text{newtons}$$

3. The force on each side acts at a radius r, producing a deflecting torque,

$$T_D = 2BlINr \text{ (N-m)}$$
$$= BlIN(2r)$$

$$T_D = BIlND \quad ...(1.21.1)$$

where, D is the coil diameter.

4. The controlling torque exerted by the spiral springs is directly proportional to the deformation or "windup" of the springs. Thus, the controlling torque is proportional to the actual angle of deflection of the pointer

$$T_C = K\,\theta$$

where, K is a constant.

5. For a given deflection, the controlling and deflecting torques are equal,

$$K\,\theta = BIlND$$

6. Since all quantities except θ and I are constant for any given instrument, the deflection angle is

$$\theta = CI \quad ...(1.21.2)$$

where, C is a constant.

7. Eq. (1.21.2) shows that the pointer deflection is always proportional to the coil current. Consequently, the scale of the instrument is linear, or uniformly divided *i.e.*, if 1 mA produces a 1 cm movement of the pointer from zero, 2 mA produces a 2 cm movement, and so on.

Que 1.22. **Explain the concept of swamping resistance. What are the materials generally used for manufacturing these resistances ?**

AKTU 2014-15, Marks 05

Answer

1. The moving coil in a PMMC instrument is wound with thin copper wire, and its resistance can change significantly when its temperature changes.
2. The heating effect of the coil current may be enough to produce a resistance change. Any such change in coil resistance will introduce an error in ammeter current measurements.
3. To minimize the effect of coil resistance variation, a swamping resistance made of manganin or constantan is connected in series with the shown in Fig. 1.22.1. Manganin and constantan have resistance temperature coefficients very close to zero.

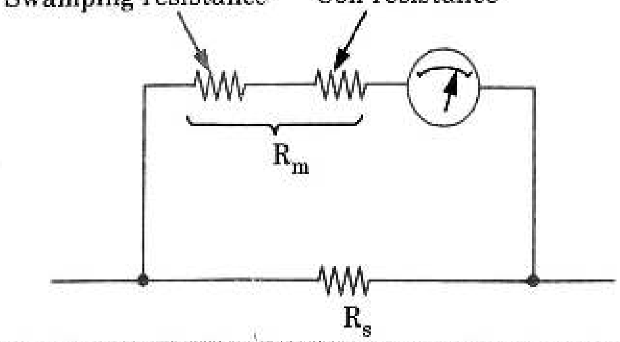


Fig. 1.221. A swamping resistance connected in series with the coil.

4. The ammeter shunt must also be made of manganin or constantan to avoid shunt resistance variations with temperature.
5. In Fig. 1.22.1, the swamping resistance must be considered part of the meter resistance R_m when calculating shunt resistance values.

Que 1.23. **Explain construction and working in galvanometer. A PMMC instrument with FSD of 100 μA and a coil resistance of 2 kΩ is to be converted into a voltmeter. Determine the required multiplier resistance if the voltmeter is to measure 35 V at full scale. Also calculate the applied voltage when the instrument indicates 0.8, 0.5 and 0.2 of FSD with neat circuit diagram.**

AKTU 2015-16, Marks 15

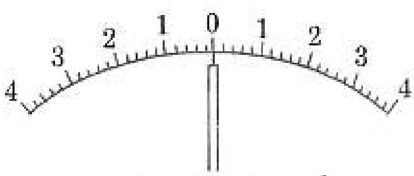
OR

Describe the principle of operation and use of galvanometers.

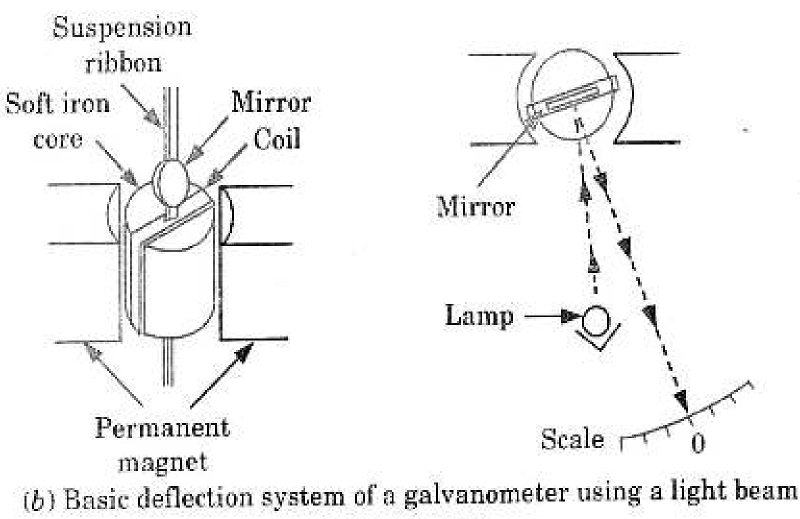
Answer

A. Construction :

1. A galvanometer is essentially a PMMC instrument designed to be sensitive to extremely low current levels.
2. The simplest galvanometer is a very sensitive instrument with the type of center-zero-scale as shown in Fig. 1.23.1(*a*).



(*a*) Center-zero scale



(*b*) Basic deflection system of a galvanometer using a light beam

Fig. 1.23.1.

3. The deflection system is arranged so that the pointer can deflect depending on the direction of current through the moving coil.

B. Working :

1. The deflecting torque is proportional to the number of coil turns, the coil dimensions, and the current flowing in the coil.
2. The most sensitive moving coil galvanometers use taut-ban suspension, and the controlling torque is generated by the twist in the suspension, ribbon. Eddy current damping may be provided by winding the coil on a non-magnetic conducting coil former.
6. Sometimes a non-conducting coil former is employed, and the damping currents are generated solely by the moving coil. In this case, the coil is shunted by a damping resistor which controls the level of eddy currents generated by the coil movements.
7. Frequently, a critical damping resistance value is stated, which gives just sufficient damping to allow the pointer to settle down quickly with only a very small short-lived oscillation.

C. Numerical :

Given : $R_m = 2\text{ k}\Omega$, $V = 35$ V FSD, $I_m = 100\ \mu\text{A}$
To Find : R_s and V at 0.8, 0.5 and 0.2 of FSD.

1.
$$V = I_m (R_s + R_m)$$
$$R_s + R_m = \frac{V}{I_m}$$
$$R_s = \frac{V}{I_m} - R_m = \frac{35\text{ V}}{100\ \mu\text{A}} - 2\text{ k}\Omega = 348\text{ k}\Omega$$

2. At 0.8 FSD :
$$I_m = 0.8 \times 100\ \mu\text{A} = 80\ \mu\text{A}$$
$$V = I_m (R_s + R_m) = 80\ \mu\text{A}\ (348\text{ k}\Omega + 2\text{ k}\Omega) = 28\text{ V}$$

3. At 0.5 FSD :
$$I_m = 0.5 \times 100\ \mu\text{A} = 50\ \mu\text{A}$$
$$V = 50\ \mu\text{A}\ (348\text{ k}\Omega + 2\text{ k}\Omega) = 17.5\text{ V}$$

4. At 0.2 FSD :
$$I_m = 20\ \mu\text{A}$$
$$V = 20\ \mu\text{A}\ (348\text{ k}\Omega + 2\text{ k}\Omega) = 7\text{ V}$$

D. Uses of galvanometers :

1. In measurement of small currents.
2. Sometimes used as a null meter or null detector for detecting zero current or voltage in a circuit rather than to measure the actual level of voltage or current.
3. In measurement of low level voltages.

Que 1.24. **Explain the concept of swamping resistance. What are the materials generally used for manufacturing these resistances ?**

A PMMC instrument with FSD of 0.2 mA and the coil resistance of 10 Ω is to be converted into a voltmeter. Determine the required multiplier resistance if the voltmeter is used to measure 100 V at full scale. Also determine the applied voltage when the instrument indicates 0.75, 0.5, 0.25 and 0.1 of FSD. **AKTU 2017-18, Marks 07**

Answer

A. **Swamping resistance :** Refer Q. 1.22, Page 1–20E, Unit-1.

B. **Materials used :** Refer Q. 1.22, Page 1–20E, Unit-1.

C. **Numerical :** The procedure is same as Q. 1.23, Page 1–21E, Unit-1.

(**Ans.** R_S = 5 MW; At 0.75: V = 500 V; At 0.25: V = 250 V; At 0.1: V = 100 V)

Que 1.25. **Discuss the construction and working of DC ammeter. Also write the advantages and disadvantages.**

Answer

A. **Construction :**

1. A DC ammeter consists of a PMMC instrument and low resistance shunt as shown in Fig. 1.25.1.
2. The shunt or very low resistance is connected in parallel with instrument coil. Here R_m is the meter resistance and R_{sh} is the resistance of shunt.

B. **Working :**

1. Since the coil winding of a basic PMMC movement is small and light therefore it can carry a very small current.

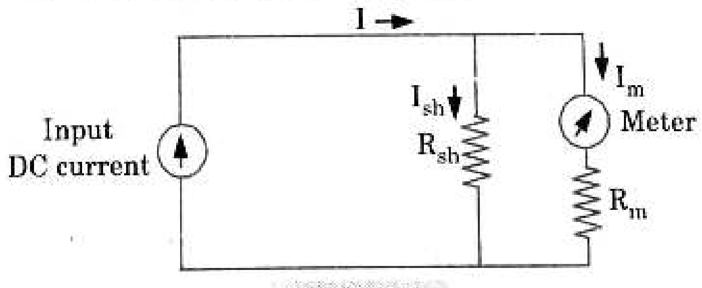


Fig. 1.25.1.

2. When large current is required to be measured then a resistance is connected in parallel with the meter to bypass additional current. This resistance is called a shunt R_{sh}.
3. Out of the total input current, I current equal to meter current I_m passes through the meter and the balance shunt current $I_{sh} = I - I_m$ flows through shunt resistance as per Kirchhoff's current law (KCL).
4. Since the shunt resistance R_{sh} is in parallel with the meter movement, the voltage drop across the shunt and meter movement must be same.

$$V_{shunt} = V_{movement}$$

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

$$R_{sh} = \frac{I_m \cdot R_m}{I_{sh}} = \frac{I_m \cdot R_m}{I - I_m}$$

or

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

5. Therefore ammeter range could be varied by varying the shunt resistance R_{sh}, *i.e.*, $\frac{1}{(I / I_m) - 1}$ times the meter resistance R_m.

C. Advantages :

1. Scale is uniformly divided.
2. Very low power consumption.
3. Torque/weight ratio is high so giving high accuracy.
4. Errors due to stray magnetic field are small.

D. Disadvantages :

1. They can be used for DC only. If connected to AC, readings are zero due to finite inertia of pointer.
2. These instruments are costly.

Que 1.26. **Explain the construction and working of DC voltmeter.**

OR

Explain the working procedure of DC ammeter and voltmeter.

AKTU 2016-17, Marks 05

Answer

A. DC ammeter : Refer Q. 1.25, Page 1–23E, Unit-1.

B. DC voltmeter :

a. Construction :

1. A DC voltmeter is made up of a PMMC instrument and a series multiplier resistor as shown in Fig. 1.26.1.
2. The D'Arsonval movement can be converted into a DC voltmeter when a low current flowing through coil is multiplied with its internal resistance. But the voltage measured is of very low amplitude.

b. Working :

1. To measure high voltages, a resistor should be connected in series with the meter that will drop the excess voltage across it thus the meter movement does not cross its safe ratings.
2. This series resistor is called as multiplier resistor because it multiplies the working ranges of the meter movement.

3. The value of multiplier, required to extend the voltage range can be found out by applying Kirchhoff's voltage law (KVL) across the loop.

$$V_{in} = I_m (R_s + R_m)$$

or $$R_s = \frac{V_{in}}{I_m} - R_m$$

where, R_s = Multiplier resistance

V_{in} = Full range voltage of the instrument

I_m = Deflection current of the movement (I_{FSD})

R_m = Internal resistance of the movement

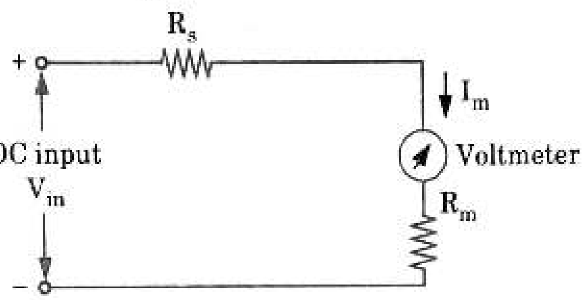


Fig. 1.26.1. Basic DC voltmeter circuit.

Que 1.27. **How would you convert ammeter into voltmeter ?**

AKTU 2016-17, Marks 10

Answer

1. Converting an ammeter to a voltmeter involves increasing the resistance of the ammeter. This is done by adding a high resistance in series with the ammeter.
2. Let the range of the ammeter be $0 - I_0$ ampere and we convert it to a voltmeter of range $0 - V_0$ volt.
3. To calculate the series resistance R_{ss}, we first determine the ammeter resistance using the circuit of Fig. 1.27.1(a).

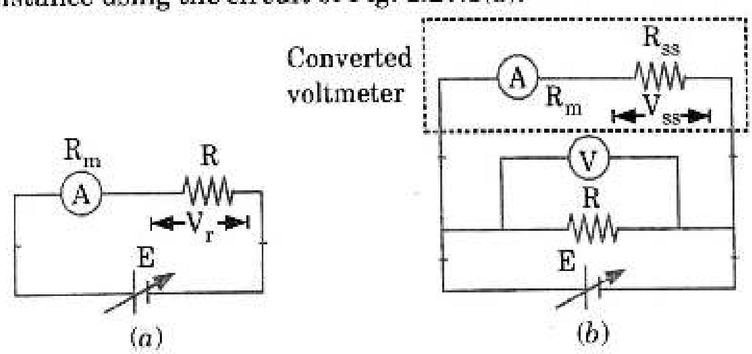


Fig. 1.27.1. (a) Circuit for determination of ammeter resistance, (b) Circuit for using the ammeter as voltmeter.

4. Let R_m be the internal resistance of the ammeter, then the current flowing through the circuit is $i = E/(R + R_m)$, where E is the input voltage.
5. The voltage drop across R is V_r and the current is $i_r = V_r / R$. Since $i = i_r$, the ammeter resistance R_m is obtained as,

$$R_m = \frac{(E - V_r)R}{V_r}$$

6. To calculate R_{ss}, we note that the voltage drop across the ammeter, showing full scale reading I_0, is $V_m = I_0 \times R_m$. To make ammeter full-scale to read full-scale voltage V_0, the remaining voltage $V_{ss} = V_0 - V_m$ should drop across R_{ss} and from this consideration we calculate series resistance as,

$$\frac{V_{ss}}{R_{ss}} = \frac{V_m}{R_m}$$

$$\Rightarrow \qquad R_{ss} = R_m \frac{V_{ss}}{V_m}$$

Que 1.28. **Describe the working of series ohmmeter.**

Answer

Series ohmmeter :

1. The resistance reading is indicated by meter movement. A battery is connected in the circuit to produce required current for meter movement.

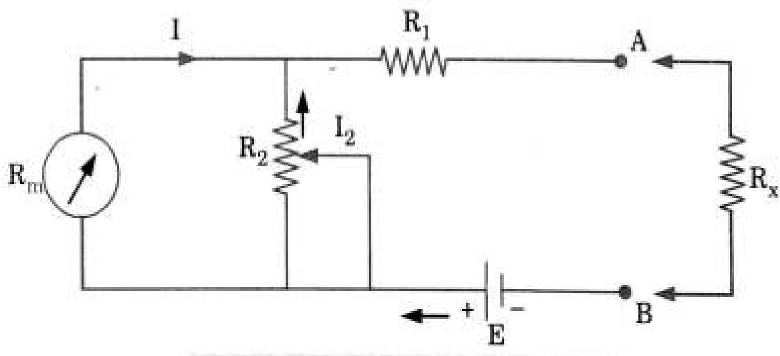


Fig. 1.28.1. Series type ohmmeter.

where, R_m = Internal resistance of D'Arsonval movement

R_2 = Zero adjust resistor

2. Resistance marking on the meter display is inversely proportional to current marking because

$$R \propto 1/I$$

i. When $R_x = 0$ (short circuit), the resistance R_2 is adjusted to get full-scale current through the movement. Thus at $I = I_{FSD}$, the pointer will be deflected to its maximum position. Therefore, at the full scale deflection current (I_{FSD}) is marked for 0 ohms.

ii. When $R_x = \infty$ (open circuit), the pointer will not deflect from its position and will read zero in this condition. Therefore, the zero current reading is marked for ∞ ohms.

3. Resistance is marked at logarithmic pattern on the scale, *i.e.*, expanded at low end and compressed at high end.

4. Let R_h be the desired resistance for the half scale deflection. ($i.e., I = I_{FSD}/2$)

$\therefore$ R_h = Internal resistance of the circuit looking from terminals A and B.

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

5. Battery current is required to produce half scale deflection.

$$I_h = \frac{I_{FSD}}{2} = \frac{E}{2R_h}$$

6. Total current I_t to produce full scale deflection is

$$I_t = I_{FSD} = 2I_h$$

$$I_t = \frac{E}{R_h}$$

7. By applying KCL in the circuit

$$I_t = I_2 + I_{FSD}$$

$$I_2 = I_t - I_{FSD}$$

8. Using Kirchhoff's voltage law

$$I_2 R_2 = I_{FSD} \cdot R_m$$

$$R_2 = \frac{I_{FSD} \cdot R_m}{I_2} = \frac{I_{FSD} \cdot R_m}{I_t - I_{FSD}}$$

$$R_2 = \frac{I_{FSD} \cdot R_m \cdot R_h}{E - I_{FSD} \cdot R_h}$$

$$R_1 = R_h - \frac{R_2 R_m}{R_2 + R_m} = R_h - \frac{I_{FSD} \cdot R_m \cdot R_h}{E}$$

2

UNIT

Electronic Instruments

CONTENTS

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Transistor Voltmeter Circuits,
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PART-1

Electronic Instruments : Transistor Voltmeter Circuits, AC Electronic Voltmeter, Current Measurement with Electronic Instruments, Probes.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. Describe the emitter-follower voltmeter.

Answer

1. Fig. 2.1.1 shows the emitter-follower voltmeter circuit which consists of a PMMC instrument and a multiplier resistance R_s connected in series with the emitter of transistor.

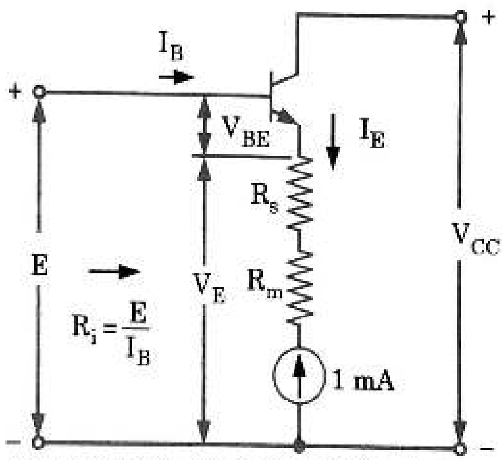

Fig. 2.1.1. Emitter-follower voltmeter.

2. Here, emitter-follower offers a high input resistance to voltages being measured and a low output resistance to drive current through the coil of a deflection meter.
3. The DC supply V_{CC} is connected positive to the transistor collector and negative to the deflection meter.
4. The positive terminal of voltage E (to be measured) is supplied to the base of the transistor and its negative terminal is connected to the same terminal as the power supply is negative.
5. Here, the base current of transistor is lower than the meter current I_m,

$$I_B \approx I_m/\beta$$

where, β is transistor current gain.

6. The circuit input resistance is given by,

$$R_i \approx E/I_B$$

which is much larger than meter circuit resistance $(R_s + R_m)$

i.e., $$R_i >> (R_s + R_m)$$

7. In simple emitter-follower voltmeter, the voltage drop V_{BE} introduces an error in the measurement.
8. This error can be eliminated by using a potential divider and an additional emitter-follower as shown in Fig. 2.1.2.
9. A dual polarity supply (typically, ± 12 V) is used in this practical emitter-follower voltmeter circuit.

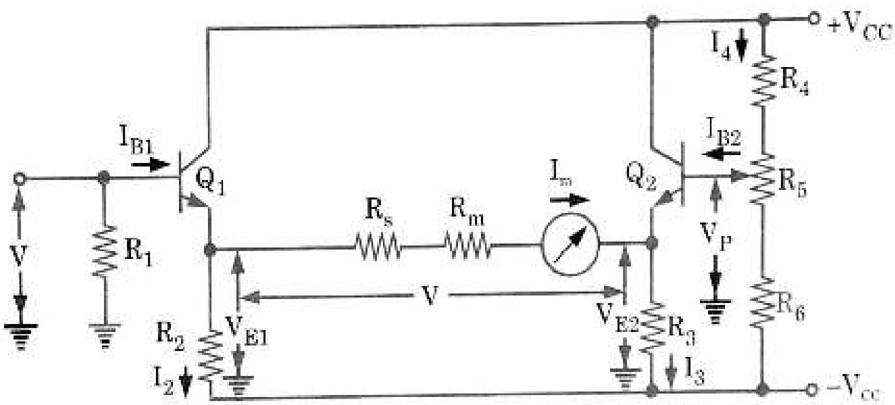

Fig. 2.1.2. Practical emitter-follower voltmeter circuit.

10. In this circuit, potential divider (R_4, R_5 and R_6) provides an adjustable bias voltage V_p to the base of transistor Q_2. Transistor Q_1 has its base biased to ground via R_1. Here, meter circuit is connected between the emitters of the transistor Q_1 and Q_2.
11. When $E = 0$ V, the base voltage of Q_2 is adjusted to give zero meter current. This makes $V_p = 0$ and $V_{E1} = V_{E2} = -0.7$ V

    Hence, meter circuit voltage, $V = V_{E1} - V_{E2} = -0.7 - (-0.7) = 0$ V
12. When input voltage, $E = 5$ V is applied to base of Q_1, then

$$V = V_{E1} - V_{E2} = (E - V_{BE1}) - V_{BE2}$$
$$= (5 - 0.7) - (0.7) = 3.6 \text{ V}$$

Que 2.2. **Explain the working of a source follower electronic voltmeter ? Describe how the range of this voltmeter can be extended ? Explain the use of zero adjustment and calibration resistors.**

AKTU 2016-17, Marks 10

Answer

1. The source follower electronic voltmeter is shown in Fig. 2.2.1. Two FETs form the upper arms of the bridge circuit, and the source resistors form the lower arms.
2. When the input voltage is zero, the bridge is balanced and no current flows through the ammeter. If v_1 is positive input voltage, current flows through the ammeter in the direction indicated.

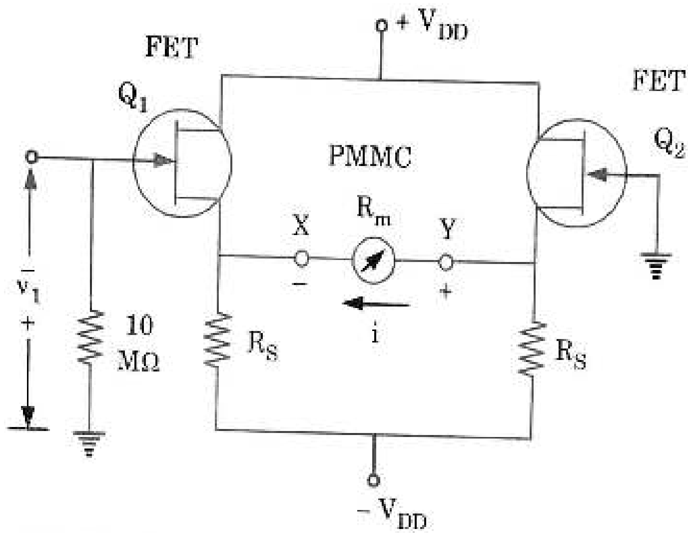

Fig. 2.2.1. The source follower electronic voltmeter.

3. Since the gate of right FET (Q_2) is grounded, no signal is applied to its gate and therefore, no signal appears at terminal Y. The left FET (Q_1), however, is a source follower.
4. This is a negative feedback with a feedback factor $\beta = -1$. Therefore, the closed loop gain can be expressed as :

$$A' = \frac{A}{1 - A\beta} = \frac{A}{1 + A} = \frac{g_m (r_d R_s)/(r_d + R_s)}{1 + g_m (r_d R_s)/(r_d + R_s)}$$

$$= \frac{g_m r_d R_s}{r_d + R_s + g_m r_d R_s} \quad \ldots(2.2.1)$$

5. The output voltage from a source follower is,

$$v_0 = \frac{g_m r_d R_s}{r_d + R_s + g_m r_d R_s} v_1 = \frac{g_m \left(\dfrac{r_d}{g_m r_d + 1}\right) R_s}{\left(\dfrac{r_d}{g_m r_d + 1}\right) + R_s} v_1$$

...(2.2.2)

6. Voltage under open circuit condition is,

$$v_0 = g_m \left(\frac{r_d R_D}{r_d + R_D}\right) v_1 \quad \ldots(2.2.3)$$

7. Comparing eq. (2.2.2) with eq. (2.2.3), for the gain of common source circuit shows that they are of the same form if $r_d/(g_m r_d + 1)$ replaces r_d in common source equation. Thus $r_d / (g_m r_d + 1)$ can be considered to be the output resistance of the FET when used in source follower circuit.
8. The output equation is in the simple form as that of the common source amplifier, except that r_d as specified in the data sheet is replaced by

$$r_d' = r_d / (g_m r_d + 1)$$

or
$$v_0 = g_m \left(\frac{r_d' R_s}{r_d' + R_s} \right) v_1 \qquad ...(2.2.4)$$

9. The Thevenin source generator voltage looking into terminals X and Y is :

$$R_0 = \frac{2 R_s \dfrac{r_d}{g_m r_d + 1}}{R_s + r_d / (g_m r_d + 1)} = \frac{2 R_s r_d'}{R_s + r_d'} \qquad ...(2.2.5)$$

10. The circuit of Fig. 2.2.2 shows the Thevenin equivalent circuit with the ammeter connected between terminals X and Y.
11. In order to obtain an approximate expression, we have $g_m r_d R_s >> r_d$ or R_s for most FETs. Further, $R_s >> r_d / (g_m r_d + 1)$. Under these conditions, eq. (2.2.5), can be simplified as :

$$i \approx \frac{v_1}{2 / (g_m) + R_m} \qquad ...(2.2.6)$$

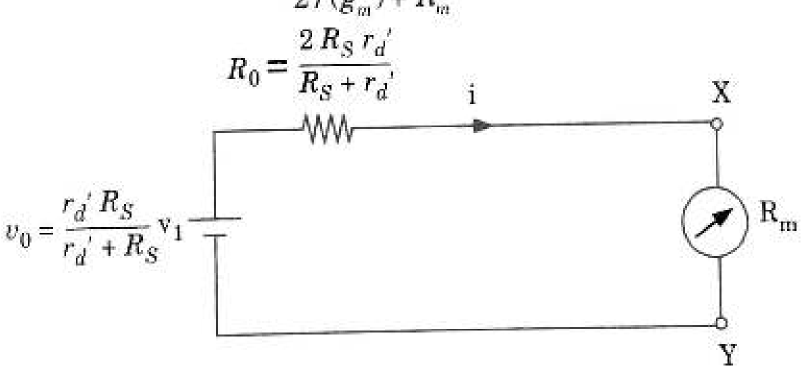

Fig. 2.2.2. Equivalent circuit of a source follower electronic voltmeter.

12. The practical circuit of a source follower type of electronic voltmeter is shown in Fig. 2.2.3. The circuit of Fig. 2.2.3 includes a zero adjustment, a calibration adjustment and a potential divider circuit for extension of voltage range.
13. The input resistance seen from measuring terminals is 9 MΩ at every position of the selector switch.

Now,
$$i = \frac{v_1}{2 / (g_m) + R_m + R_{cal}}$$

$$\because \qquad R_{cal} = \frac{v_i}{i} - \frac{2}{g_m} - R_m$$

where, R_{cal} = Calibrating resistor

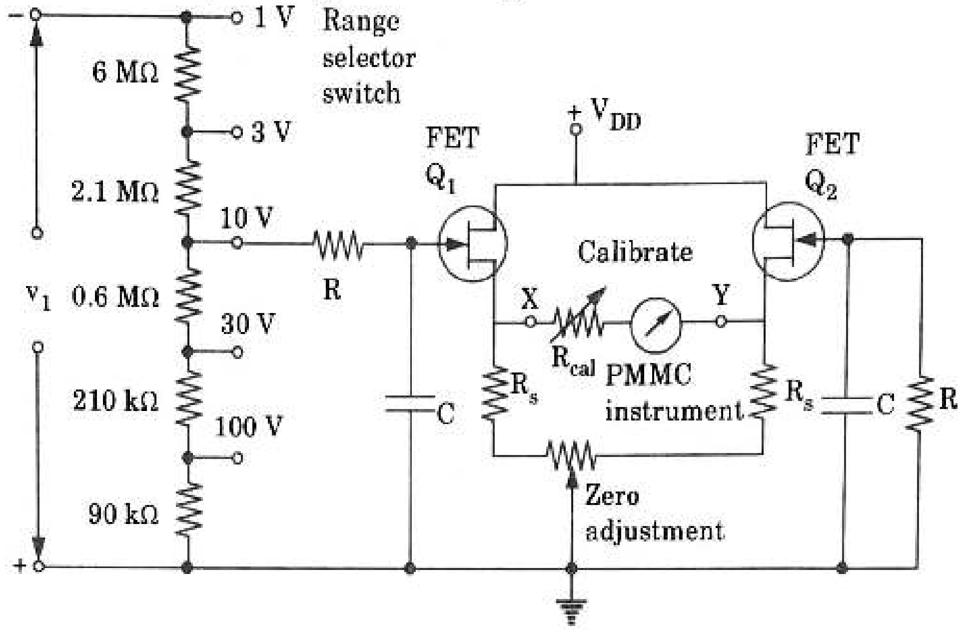

Fig. 2.2.3.

Que 2.3. **Draw and explain the FET input voltmeter circuit with range changing.**

AKTU 2014-15, Marks 05

AKTU 2017-18, Marks 10

OR

Design a multirange FET voltmeter circuit and explain its working with diagram.

AKTU 2015-16, Marks 10

Answer

A. Voltmeter range changing :

1. The potential divider constituted by resistors R_a, R_b, R_c, and R_d in Fig. 2.3.1 allows large input voltages to be measured on an emitter-follower voltmeter.
2. This network, called an input attenuator, accurately divides the voltage to be measured before it is applied to the input transistor. Calculation shows that the Q_3 input voltage (E_G) is always 1 V when the maximum input is applied on any range. For example, on the 5 V range,

$$E_G = 5\text{ V} \times \frac{R_b + R_c + R_d}{R_a + R_b + R_c + R_d}$$

$$= 5\text{ V} \times \frac{100\text{ k}\Omega + 60\text{ k}\Omega + 40\text{ k}\Omega}{800\text{ k}\Omega + 100\text{ k}\Omega + 60\text{ k}\Omega + 40\text{ k}\Omega}$$

$$= 1\text{ V}$$

3. The input resistance offered by this circuit to a voltage being measured is the total resistance of the attenuator, when is 1 MΩ.
4. A 9 MΩ resistor could be included in series when the input terminal to raise the input resistance to 10 MΩ.
5. This would further divide the input voltage by a factor of 10 before it is applied to the gate terminal of Q_3.

B. FET input voltmeter :

1. The circuit diagram for FET input voltmeter is shown in Fig. 2.3.1.
2. In this circuit, an additional emitter-follower is connected at the base of transistor Q_1 to increase the input resistance of simple transistor voltmeter circuit.
3. The FET source follower gives a higher input resistance than that of BJT. A voltmeter input attenuator is used as potential divider that accurately divides the voltage to be measured.
4. Consider the voltage levels in the circuits of Fig. 2.3.1. When $E = 0$ V, the FET gate is at the zero voltage level.
5. The gate of an n-channel FET must always be negative *w.r.t.* its source terminal. This means that the source must be positive *w.r.t.* the gate.
6. If V_{GS} is to be – 5 V, and $E_G = 0$ V, the source terminal voltage must be + 5 V. This means that the base terminal of Q_1 is at + 5 V, and since Q_2 base voltage must be equal to Q_1 base voltage, Q_2 base must also be at + 5 V.

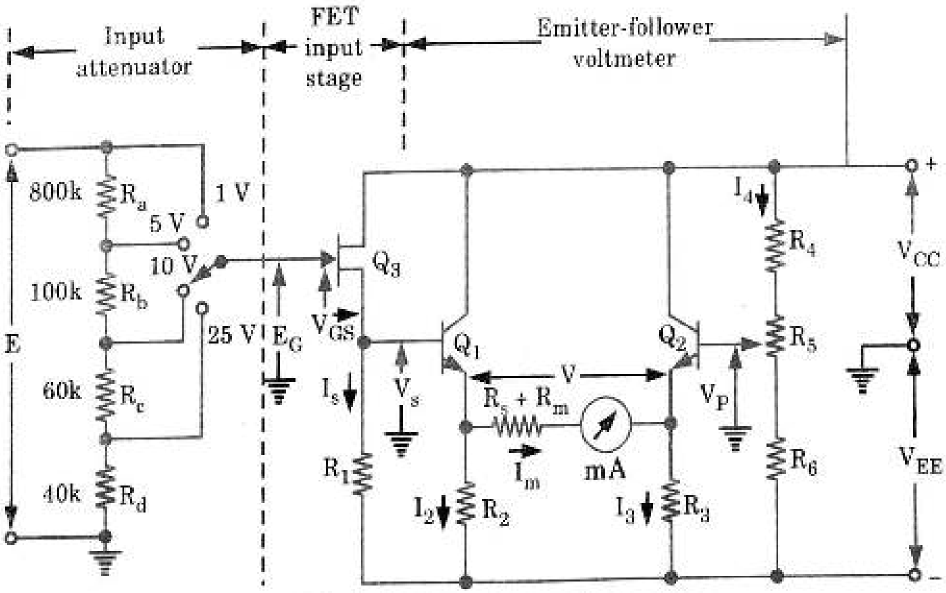

Fig. 2.3.1. FET input voltmeter.

7. When a voltage to be measured, it is applied to the circuit input with the attenuator E_G will be a maximum of 1 V. This causes the FET source terminal to increase until V_{GS} is again – 5 V, *i.e.*, V_S goes from + 5 to + 6 V to maintain V_{GS} equal to – 5 V.
8. The V_S increase of 1 V is also a 1 V increase in the base voltage of Q_1. All of this (1 V) increase appears across the meter circuit.

Que 2.4. **Describe difference amplifier voltmeter using transistor.**

Answer

1. Transistors Q_1 and Q_2 together with R_{L1}, R_{L2} and R_E in Fig. 2.4.1 constitute a differential amplifier or emitter-coupled amplifier. The circuit as a whole is known as a difference amplifier voltmeter.
2. This is because when the voltage at the base of Q_2 is zero, and an input voltage (E) is applied to the Q_1 base, the difference between the two base voltages is amplified and applied to the meter circuit.
3. When a small positive voltage is applied to the base of Q_1 in Fig. 2.4.1, the current through Q_1 is increased, and that through Q_2 is decreased.
4. An increase in I_{C1} causes $I_{C1}R_{L1}$ to increase and thus produces a fall in voltage V_{C1}. Similarly, a decrease in I_{C2} produces a rise in V_{C2}.
5. The consequence of this is that the voltage across the meter circuit increases positively at the right hand side and negatively at the left hand side. This meter voltage (V) is directly proportional to the input voltage (E).
6. Potentiometer R_3 in Fig. 2.4.1 is an alternative method of providing meter zero adjustment.

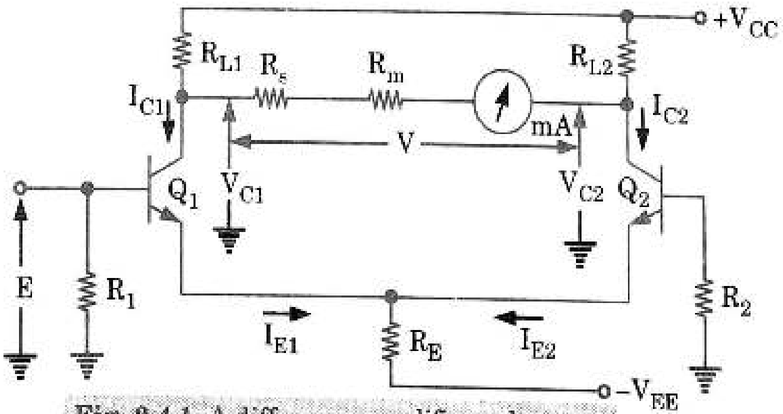

Fig. 2.4.1. A difference amplifier voltmeter.

7. When the movable contact of R_3 is adjusted to the right, the portion of R_3 added to R_{L1} is increased and portion of R_3 added to R_{L2} is reduced. When the contact is moved left, the reverse is true.
8. Thus, V_{C1} and V_{C2} can be adjusted differentially by means of R_3, and the meter voltage can be set to zero.

Que 2.5. **Write a short note on :**

i. Op-amp voltage-follower voltmeter
ii. Op-amp amplifier voltmeter.

Answer

i. Op-amp voltage-follower voltmeter :

The circuit diagram of Op-Amp voltage-follower voltmeter is shown in Fig. 2.5.1.

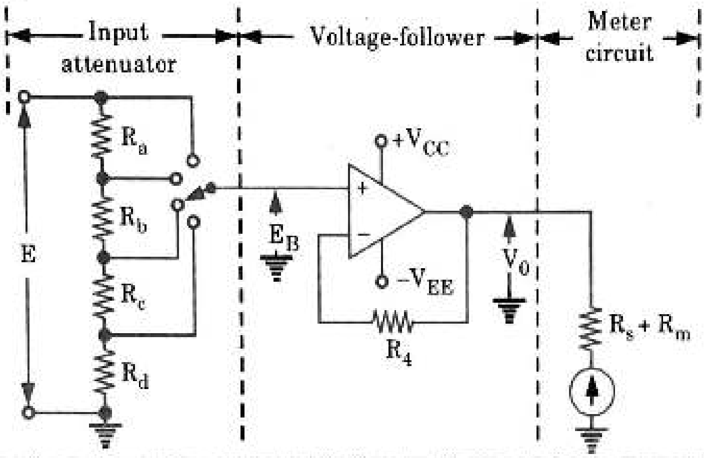

Fig. 2.5.1. An IC operational amplifier voltage-follower voltmeter.

2. The voltage-follower provides much higher input resistance than the emitter-follower. Unlike the emitter follower, there is no base-emitter voltage drop from input to output.
3. In this circuit, the voltage-follower input (E_B) is applied to the non-inverting terminal of the Op-Amp and the feedback from the output goes to the inverting input terminal.
4. The very high voltage gain of Op-Amp, combined with the negative feedback, tends to keep the inverting terminal voltage exactly equal to that at the non-inverting terminal. Thus, output voltage follows the input.
5. The attenuator is used for selecting the range of voltmeter.

ii. Op-Amp amplifier voltmeter :

1. An IC Op-Amp can also be used to amplify low voltages to levels, measurable by a deflection meter. Op-Amp amplifier voltmeter circuit is used for this purpose as shown in Fig. 2.5.2.
2. The input voltage (E) is applied to the non-inverting terminal and voltage V_{R3} is feedback to the inverting terminal of the Op-Amp. The internal voltage gain of Op-Amp causes V_{R3} to be always equal to E. The output voltage is

$$V_0 = E\,\frac{R_3 + R_4}{R_3}$$

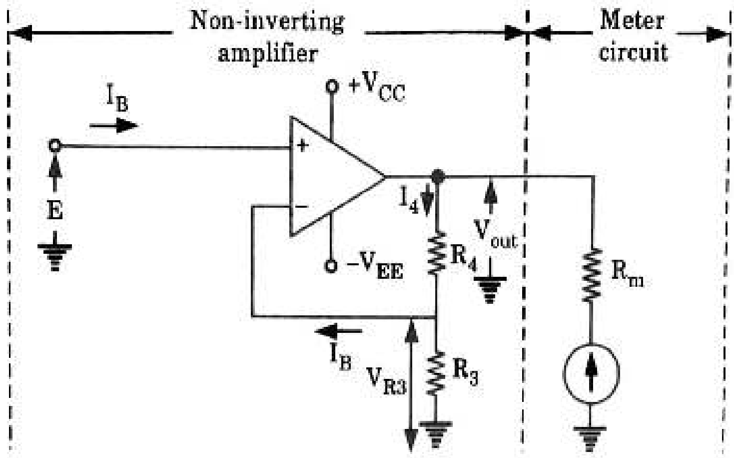

Fig. 2.5.2. An operational amplifier non-inverting amplifier voltmeter.

Que 2.6. **A half wave rectifier op-amp based voltage amplifier circuit has a feedback resistance of 2.4 kΩ and a resistance between the ground and the inverting terminal of 4.9 kΩ. If the rms input voltage to be measured is 89.40 mV at the FSD of the deflection instrument with R_s = 100 Ω and R_{in} = 200 Ω. Find the FSD of the meter.**

AKTU 2014-15, Marks 05

Answer

Given : $R_2 = 2.4\ \text{k}\Omega$, $R_3 = 4.9\ \text{k}\Omega$, $E = 89.40$ mV, $R_s = 100\ \Omega$, $R_{in} = 200\ \Omega$

To Find : I_{avg} at full scale.

1. From the circuit of Fig. 2.6.1,

$$E_P = \frac{E}{0.707} = \frac{89.40 \times 10^{-3}}{0.707} = 126.45\ \text{mV}$$

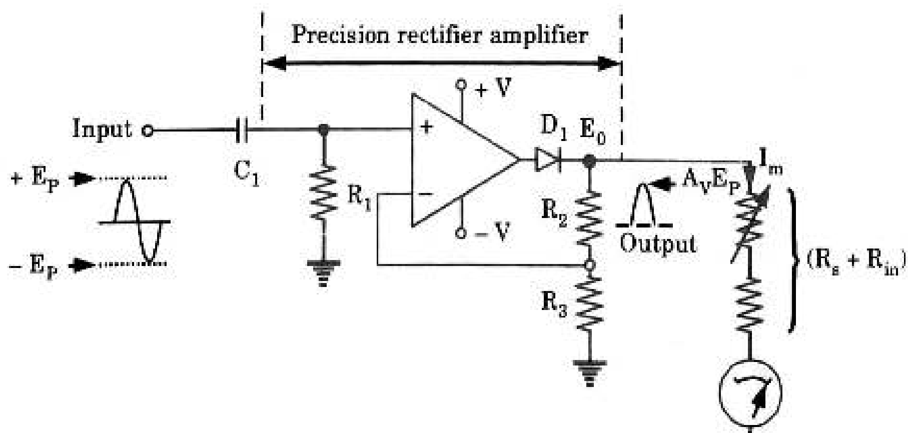

Fig. 2.6.1.

2. Voltage gain, $A_v = 1 + \frac{R_2}{R_3} = 1 + \frac{2.4}{4.9} = 1.49$

$$A_v = \frac{E_0}{E_p}$$

Output voltage,

$$E_0 = 1.49 \times 126.45 = 188.4 \text{ mV}$$

3. $$I_p = \frac{E_0}{R_s + R_m} = \frac{188.4 \times 10^{-3}}{100 + 200} = 0.628 \text{ mA}$$

4. $$I_{avg} = \frac{0.637}{2} \times I_p = \frac{0.637}{2} \times 0.628$$

$$= 0.2 \text{ mA (full scale)}$$

Que 2.7. **Explain the principle of operation of electronic voltmeter.**

OR

Sketch half wave rectifier AC electronic voltmeter using a voltage follower and a precision rectifier. Explain the operation of each circuit.

OR

Explain the working of precision rectifier based voltmeters.

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Answer

A. Working principle of electronic voltmeter :

1. An Op-Amp voltage-follower AC voltmeter can be converted into an AC electronic voltmeter by connecting a rectifier in series with the meter circuit. Such a circuit is shown in Fig. 2.7.1.

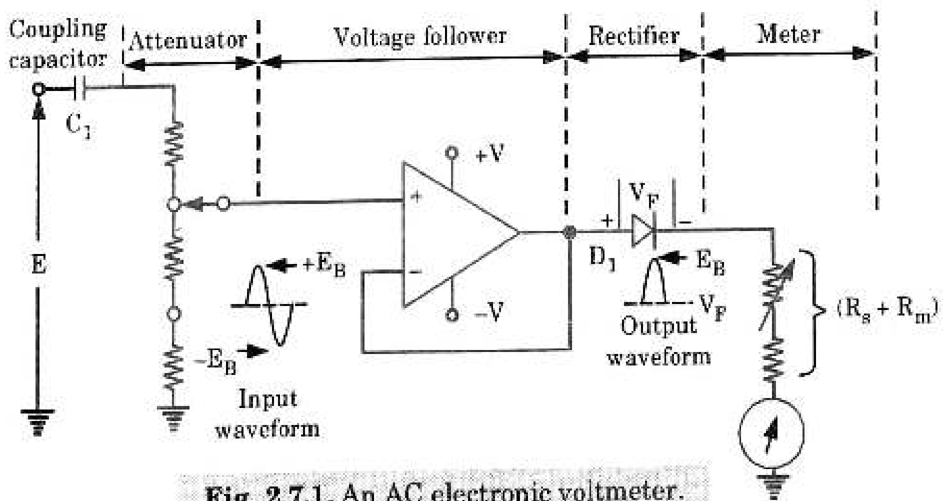

Fig. 2.7.1. An AC electronic voltmeter.

2. An AC input signal (to be measured) is applied to non-inverting terminal input of Op-Amp. The coupling capacitor C_1 in this circuit is used to block unwanted DC voltages.
3. The output from the voltage follower is exactly the same as the AC input signal.
4. This output voltage is fed to the rectifier which gives a half-wave rectified version of the input signal. This rectified voltage is applied to the meter circuit.
5. The limitation of this circuit is that the voltage drop (V_F) across the rectifier acts as an error which must be taken into account in design calculation when the instrument is indicating full scale.
6. This error can be avoided by using a precision rectifier.

B. AC electronic voltmeter using precision rectifier :

1. A precision rectifier is used to improve the accuracy of AC electronic voltmeter.

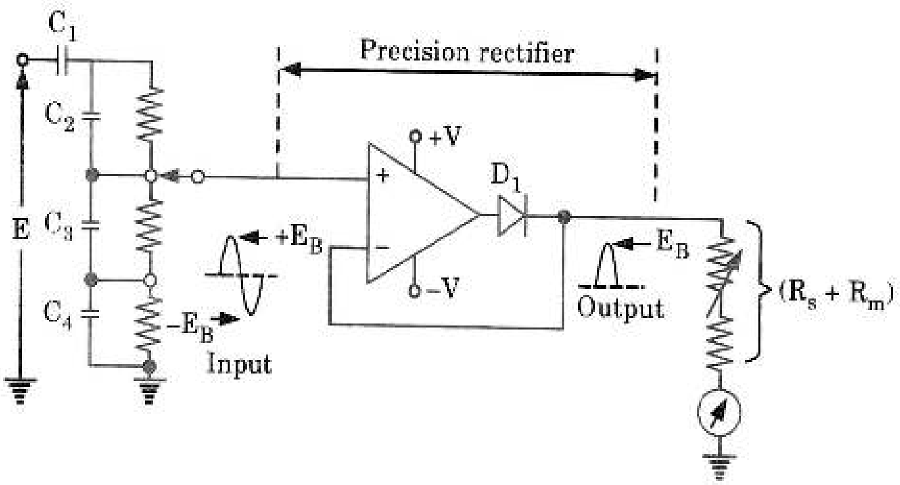

Fig. 2.7.2. AC electronic voltmeter using precision rectifier.

2. Fig. 2.7.2 shows an AC electronic voltmeter using precision rectifier.
3. In this circuit, the voltage-follower feedback connection to the inverting terminal is taken from cathode of rectifier D_1 instead of from the amplifier output.
4. Due to this, half-wave rectified output precisely follows the positive half-cycle of the input voltage and hence there is no rectifier voltage drop occurs from input to output.

Que 2.8. **Explain how an electronic analog voltmeter can be used to measure alternating current ?**

Answer

1. In order to measure AC current on the voltmeter a series resistance is added. The unknown current causes a voltage drop across this resistance.

2. This voltage is measured by the voltmeter. Fig. 2.8.1 shows the basic circuit for measurement of very low current.
3. In this circuit, the small voltage drop across the shunt resistance R_s is amplified before being applied to the deflection instrument.
4. For medium or high current measurements, there is no need to use electronic amplifiers. By measuring the voltage drop across a shunt resistor R_s, current measurement is made.

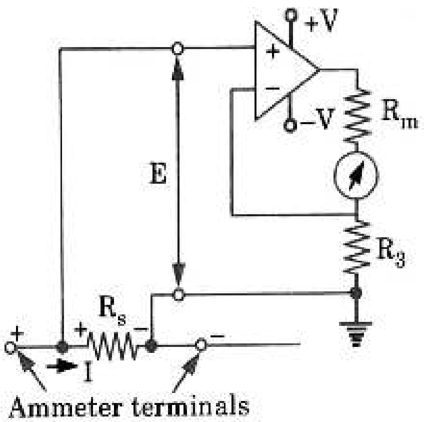

Fig. 2.8.1. An electronic voltmeter.

Que 2.9. **What do you mean by loading effect ? How does electronic voltmeter help in minimizing the loading effect ?**

AKTU 2014-15, Marks 05

Answer

A. Loading effect :

1. A voltmeter is always connected across, or in parallel with the points in a circuit at which the voltage is to be measured.
2. If its resistance is too low, it can alter the circuit voltage. This is known as voltmeter loading effect.
3. Loading effect especially occurs in electronic and communication circuits where low levels are to be measured.

B. Electronic voltmeter :

1. Electronic voltmeters avoid the loading effects by supplying power required for measurement by using external circuits like amplifiers.
2. The amplifiers not only supply power for the operation but make it possible for low level signals also.
3. Electronic voltmeters utilize the amplifying properties of vacuum tubes and transistors and therefore the power required for operating the deflecting element of PMMC instrument can be supplied from an auxiliary source.

4. Thus, while the circuit whose voltage is being measured controls the sensing element of the voltmeter, the power drawn from the circuit under measurement is very small or even negligible.
5. This can be interpreted as that the voltmeter circuit has very high input impedance.
6. This feature of electronic voltmeters is indispensible for voltage measurements in many high impedance circuits such as encountered in communication equipment.

Que 2.10. **Write a short note on multimeter probes.**

AKTU 2014-15, Marks 05

Answer

1. A probe is used to establish a connection between the circuit under test and the measuring instrument.
2. A probe can be any conductor and this conductor could be a piece of bare wires, a multimeter lead or a piece of unterminated coaxial cable.
3. A probe simply extracts minimal energy from the circuit under test and transfers it to a measuring instrument with maximum fidelity.
4. The ideal probe provides the following key attributes :

i. Ease of connection.

ii. Absolute signal fidelity.

iii. Zero signal source loading.

iv. Complete noise immunity.

5. There are many probes for use with multimeters that can extend the range of measurement. Some of these are given as :

i. High voltage probe :

1. A high voltage probe is essentially a potential divider.
2. The voltage to be measured is usually divided by a factor of 1000, so that the instrument scales are effectively multiplied by 1000. Due to this, a 10 V scale becomes a 10 kV scale.

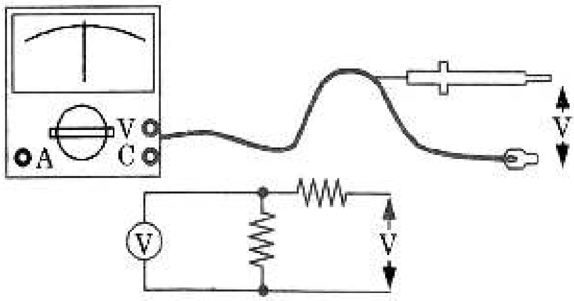

Fig. 2.10.1. A high-voltage probe uses a resistive divider.

ii. High current probe :

1. The AC current probes reduce the high levels of alternating current by the use of current transformer.
2. The core of transformer is open and close to the conductor carrying the current to be measured.
3. The secondary windings of transformer determine the measurable current level. Thus, a 1 mA AC scale on the multimeter is converted into a 1 A scale by the use of the current probe.

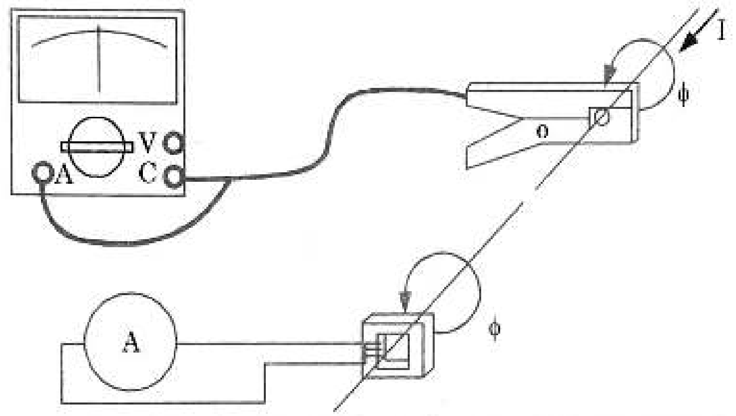

Fig. 2.10.2. A high-current probe uses a current transformer.

Que 2.11. **Explain the following in detail with their diagram :**

i. Attenuator probe.

ii. 1 : 1 probe.

AKTU 2015-16, Marks 15

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Answer

i. Attenuator probe :

1. Attenuator probes attenuate the input signal, usually by a factor of 10. They also normally offer a much larger input impedance than a 1 : 1 probe, thereby minimizing loading effects on the circuit under test.
2. Compensation is included for oscilloscope input capacitance and coaxial cable capacitance.
3. Because of the 10-fold attenuation, these probes are usually referred to as 10 : 1 probes, however, other probes are available with different attenuation factors.

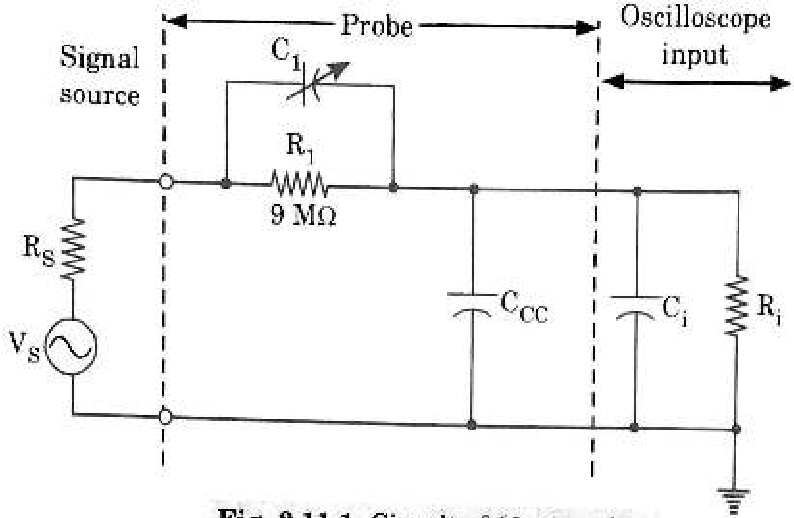


Fig. 2.11.1. Circuit of 10 : 1 probe.

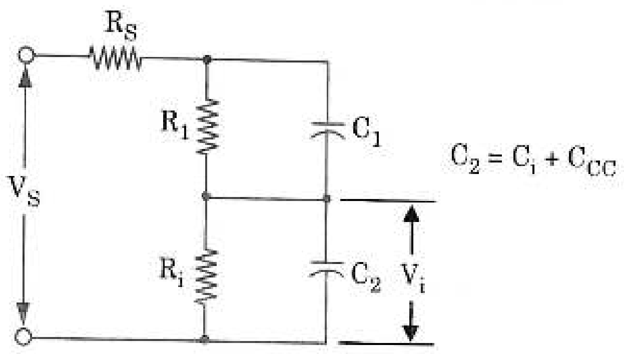


Fig. 2.11.2. Equivalent circuit.

4. At low and medium frequencies, the capacitive impedances are too large to be effective, and the oscilloscope input voltage is

$$V_i = V_s \frac{R_i}{R_1 + R_s + R_i}$$

5. When $R_s << R_1$,

$$V_i = V_s \frac{R_i}{R_1 + R_i}$$

6. With $R_1 = 9\ \text{M}\Omega$ and $R_i = 1\ \text{M}\Omega$

$$V_i = V_s \frac{1\ \text{M}\Omega}{9\ \text{M}\Omega + 1\ \text{M}\Omega}$$

$$= \frac{V_s}{10}$$

7. The attenuation of the signal due to the capacitors acting alone can be calculated from

$$V_i = V_s \frac{X_{C_2}}{X_{C_1} + X_{C_2}}$$

$$= V_s \frac{1/\omega C_2}{1/\omega C_1 + 1/\omega C_2}$$

$$= V_s \frac{1}{(C_2/C_1)+1}$$

$$V_i = V_s \frac{C_1}{C_2 + C_1}$$

8. When the capacitive network attenuates the signal in the same proportion as the resistive network attenuation, C_i across R_i equals V_i across C_2 and

$$\frac{R_i}{R_1 + R_i} = \frac{C_1}{C_2 + C_1}$$

9. The value of C_1 required to compensate for C_2 is determined from following equation as

$$C_1 = C_2 \frac{R_i}{R_1}$$

ii. 1 : 1 probe :

1. The coaxial cable consists of an insulated central conductor surrounded by a braided circular conductor which is covered by an outer layer of insulation.
2. The central conductor carries the input signal, and the circular conductor is grounded so that it acts as a screen to help prevent unwanted signals being picked up by the oscilloscope input.
3. This types of probe is usually referred to as a 1 : 1 (one to one) probe, because it does not contain resistors to attenuate the input signal.
4. The coaxial cable connecting the probe to the oscilloscope has a capacitance (C_{cc}) which can overload a high-frequency signal source.
5. The input impedance of the oscilloscope at the front panel is typically 1 MΩ in parallel with 30 pF. The coaxial cable can add another 100 pF to the total input capacitance.
6. The circuit of a signal source, probe, and oscilloscope input is shown in Fig. 2.11.3.
7. The total impedance offered by the coaxial cable and the oscilloscope input should always be much larger than the signal source impedance.
8. At frequencies where the reactance of (C_{CC} + C_i) is very much larger then R_s and R_i, the capacitances have a negligible effect and the oscilloscope terminal voltage is

$$V_i = V_s \frac{R_i}{R_s + R_i}$$

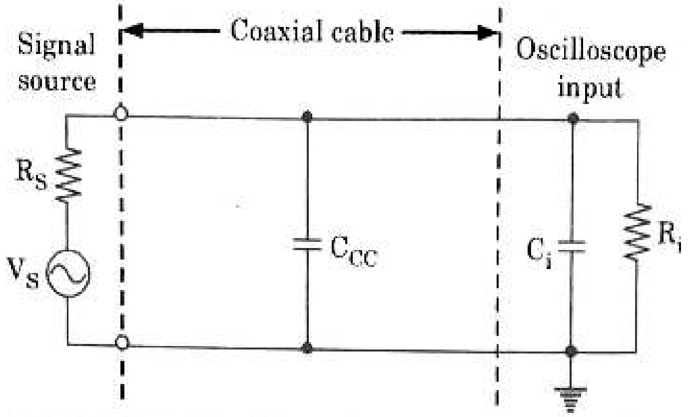


Fig. 2.11.3. Equivalent circuit of signal source, probe, and oscilloscope input.

9. The capacitive reactance becomes progressively smaller as the signal frequency increases, so that the signal may be significantly attenuated at the oscilloscope terminals.
10. An attenuation of 3 dB will occur at the frequency at which the capacitive reactance equal R_s.
11. There is also a 45° phase shift at this frequency. To avoid significant attenuation and phase shift, the signal frequency should not exceed one-tenth of the 3 dB attenuation frequency.

PART-2

Digital Voltmeter Systems : Digital Multimeter, Digital Frequency Meter.

Questions-Answers
Long Answer Type and Medium Answer Type Questions

Que 2.12. **How are digital voltmeters classified ? What are the operating and performance characteristics of a digital voltmeter ?**

Answer

A. Digital voltmeter :

1. Digital voltmeters are essentially analog-to-digital converters with digital display to indicate the measured voltage.
2. A digital voltmeter (DVM) displays measurement of DC or AC voltage as discrete numerals instead of pointer deflections on a continuous scale as in analog instruments.

3. It is a versatile and accurate instrument that is employed in many laboratory measurement applications.

B. Classification of digital voltmeter :

1. Ramp-type DVM.
2. Dual-slope type DVM.
3. Integrating type DVM.
4. Successive approximation DVM.

C. Characteristics features of DVM :

1. **Input range :** From ± 1.000 V to ± 1000 V with automatic selection and overload indication.
2. **Absolute accuracy :** As high as ± 0.005 % of the reading.
3. **Resolution :** 1 part per million.
4. **Stability :** Short term, 0.002 % of the reading (for a 24 hour period), long term, 0.008 % of the reading (for a 6-month period).
5. **Input resistance :** Typically 10 MΩ.

   Input capacitance : 40 pF.
6. **Calibration :** Internally from stabilized reference sources, independent of measuring circuit.
7. **Output signals :** In BCD form, for print output and further digital processing.

Que 2.13. **Define in brief about ramp type DVM and dual slope DVM.**

Answer

a. Ramp type DVM :

1. The principle of operation of ramp type DVM is based on the measurement of the time it takes for a linear ramp voltage to rise from 0 V to the level of the input voltage, or decrease from the level of the input voltage to zero.
2. At the start of measuring cycle, a ramp voltage is initiated; this voltage can be positive going or negative going. The negative going ramp is continuously compared with the unknown input voltage.
3. At the instant when the ramp voltage equals the unknown voltage, a comparator generates a pulse which opens a gate. The ramp voltage continues to decrease with time until it finally reaches 0 V and a second comparator generates an output pulse which closes the gate.
4. An oscillator generates a clock pulses which are allowed to pass through the gate to a number of decade counting units which totalize the number of pulses passed through the gate.

5. The decimal number, displayed by the indicator tube associated with the DCU's is a measure of the magnitude of the input voltage.
6. The sample rate multivibrator determines the rate at which the measurement cycles are initiated.

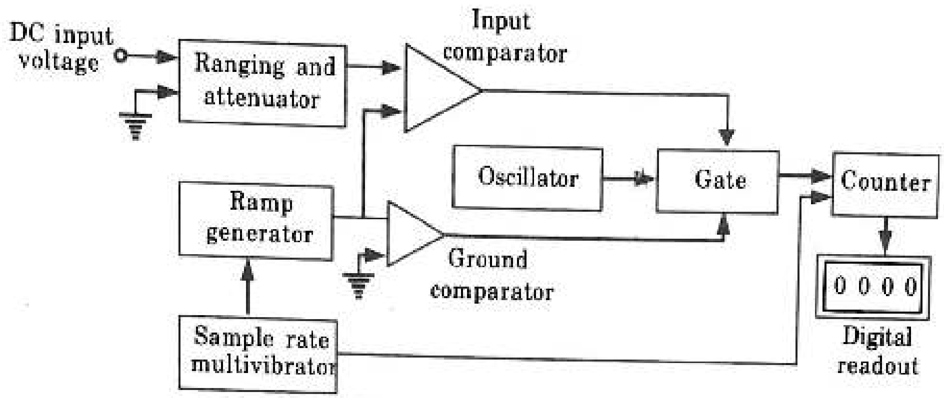


Fig. 2.13.1. Ramp type DVM.

b. Dual slope integrating type (DVM) :

1. Dual-slope integrating type DVM has five basic blocks :
   i. Op-Amp, used as an integrator
   ii. A level comparator
   iii. A basic block, for generating timing pulses
   iv. A set of decimal numbers
   v. A block of logic circuitry.

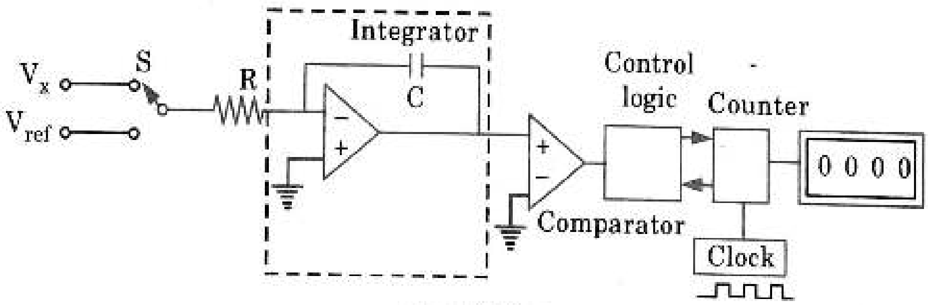


Fig. 2.13.2.

2. The unknown voltage V_x is applied through switch S to integrator for a known period of time T. This period is determined by counting the clock frequency in decimal counters.
3. During time period T, C is charged at the rate proportional to V_x.

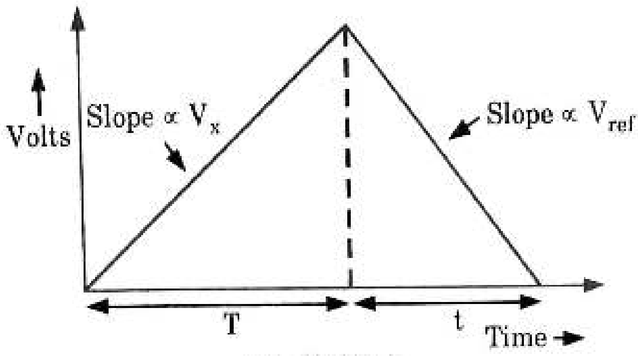


Fig. 2.13.3.

4. At the end of the interval T, S is shifted to the reference voltage $V_{ref.}$ of opposite polarity.
5. The capacitor charge begins to decrease with time and results in downward linear ramp voltage.
6. During the second period a known voltage is observed for an unknown time t. This unknown time t is determined by counting timing pulses from the clock until the voltage across the capacitor reaches its basic reference value.
7. From similar triangle shown in Fig. 2.16.3.

$$\frac{V_x}{T} = \frac{V_{ref}}{t}$$

or,
$$V_x = \frac{V_{ref}}{t} \times T$$

8. The count after t which is inversely proportional to the input voltage V_x is displayed as the measured voltage.
9. This instrument can be used to measure currents, resistances, and AC voltage by using appropriate signal conditions.

Que 2.14. **Define dual-slope integrator and zero crossing detector. Sketch the block diagram and system waveforms for a digital voltmeter that uses a dual slope integrator.**

AKTU 2017-18, Marks 07

Answer

A. Dual-slope integrator : Refer Q. 2.13, Page 2–19E, Unit-2.

B. Zero crossing detection :

1. The basic comparators can be used as zero crossing detector by making $V_{REF} = 0$.
2. Whenever the input voltage crosses the x-axis, V_o changes from $+V_{sat}$ to $-V_{sat}$ or $-V_{sat}$ to $+V_{sat}$ as shown in Fig. 2.14.1.

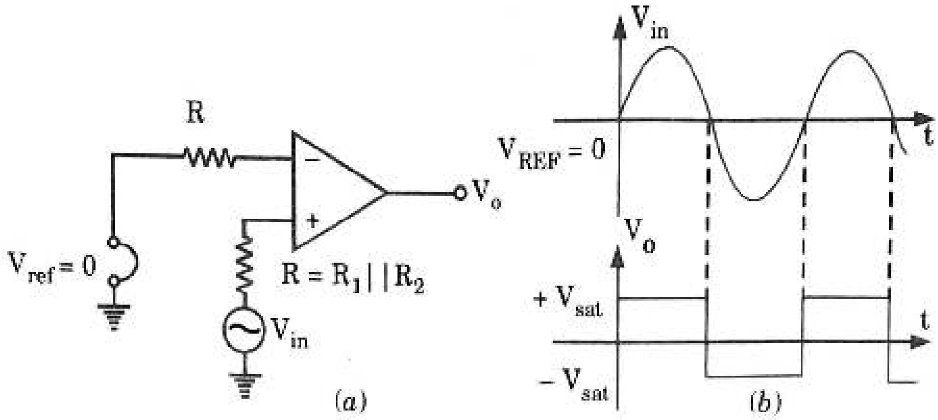


Fig. 2.14.1.

3. Zero crossing detector is also called sine to square wave generator.
4. There are two types of zero crossing detector :

a. **Non-inverting zero crossing detector :**

1. In a non-inverting zero crossing detector, the Op-Amp is used in open loop configuration. Inverting terminal of the Op-Amp is grounded and input is applied to the non-inverting terminal. The circuit is shown in Fig. 2.14.2.

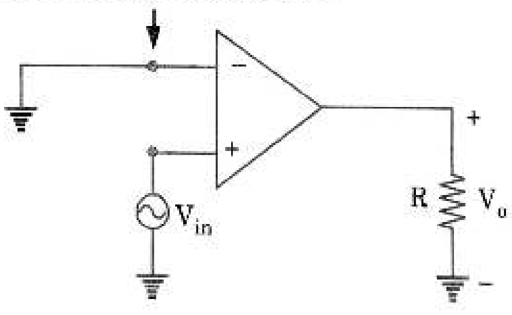


Fig. 2.14.2. Non-inverting zero crossing detector.

2. During the positive half cycle, the input voltage is positive *i.e.*, above the reference voltage (0 V). Hence the output voltage is $+V_{sat}$.
3. During negative half cycle, the input voltage V_{in} is negative, *i.e.*, below the reference voltage. The output voltage is then $-V_{sat}$.
4. Thus the output voltage switches between $+V_{sat}$ and $-V_{sat}$ whenever the input signal crosses the zero level. This is shown in Fig. 2.14.3.

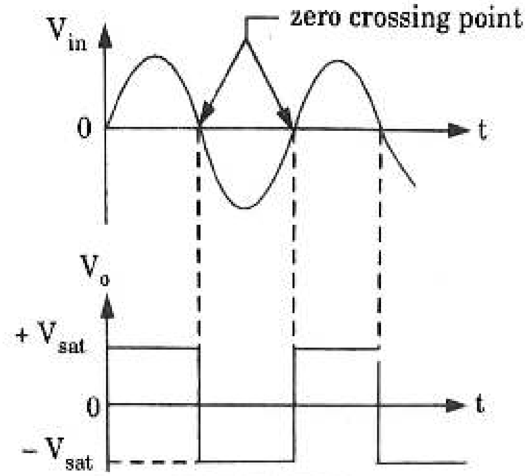


Fig. 2.14.3.

Inverting zero crossing detector :

In the inverting zero crossing detector, input is directly applied to the inverting input terminal while the non-inverting terminal is grounded. The circuit is shown in Fig. 2.14.4.

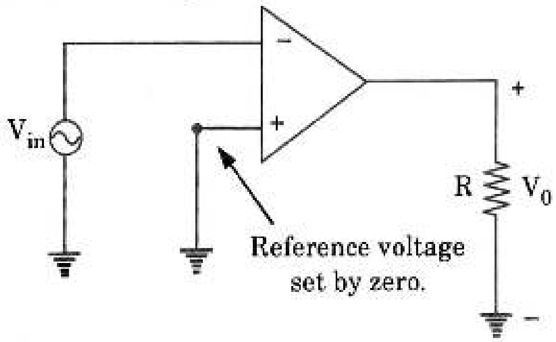


Fig. 2.14.4. Inverting zeor corssing detector.

2. During positive half cycle, inverting terminal is more positive than non-inverting terminal, so output is $-V_{sat}$ while for negative half cycle, the output is $+V_{sat}$. This circuit is called an inverter. The waveforms are shown in Fig. 2.14.5.

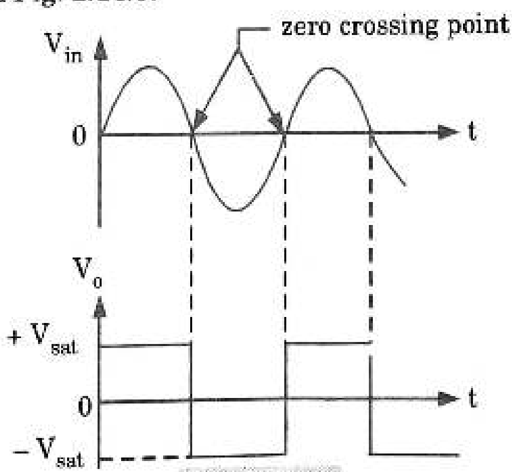


Fig. 2.14.5.

Que 2.15. **Explain the working of integrating type DVM.**

Answer

Integrating type DVM (voltage-to-frequency conversion) :

1. This voltmeter indicates the true average value of the unknown voltage over a fixed measuring period. It employs an "Integration technique" which uses a voltage-to-frequency conversion.
2. The *V/F* converter functions as a feedback control system which governs the rate of pulse generation in proportion to the magnitude of the input voltage.
3. In *V/F* conversion technique, a train of pulses, whose frequency depends upon the voltage being measured, is generated. Then the number of pulses appearing in a definite interval of time is measured.
4. The unknown voltage, V_i is applied to the input of the integrator and the output voltage V_o starts to rise. The slope V_o is determined by the value of input voltage V_i.
5. This voltage is fed to a level detector and when V_o reaches a certain reference level, the detector sends a pulse to pulse generator gate. The level detector is a device similar to a voltage comparator.
6. The output voltage from integrator, V_o is compared with the fixed voltage of an internal reference source and when V_o reaches that level, the level detector produces an output pulse.
7. This output pulse opens the pulse level gate, permitting pulse from a fixed frequency clock oscillator to pass through the pulse generator.

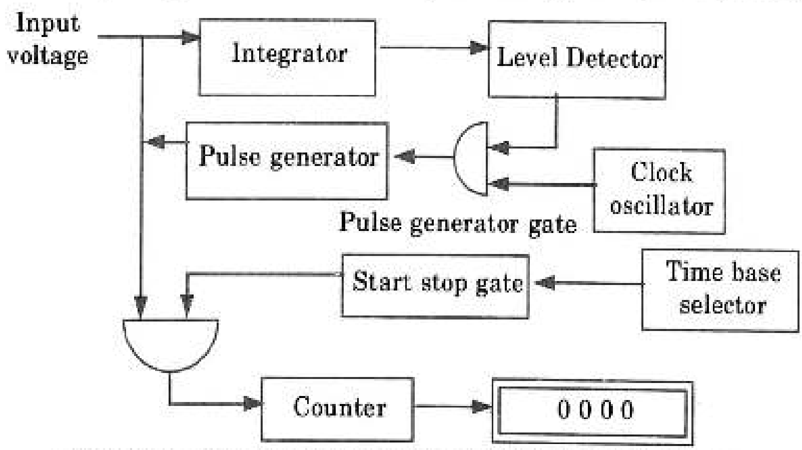


Fig. 2.15.1. Block Diagram of integrating type DVM.

8. The output pulse whose polarity is opposite to that of V_i and has greater amplitude which is fed back to the input of the integrator. The output of the integrator is of reversed polarity. The output V_o drops back to its original level.

9. Since V_o is now below the reference level of the level detector, there is no output from the detector to the pulse generator gate and gate gets closed.
10. When pulse generator passes the pulse generated, V_i is restored to its original value and V_o starts rising again. When it reaches the level of reference voltage again, the pulse generator gate is opened.
11. The entire cycle is repeated again when the pulse generator is triggered by the pulse from the clock generator, thus the waveform of V_o is a sawtooth wave.
12. The frequency of sawtooth V_n is a function of the value V_i, the voltage-being measured. It can be measured by counting the number of pulse in a given interval of time. Pulses from clock oscillator are applied to a time base selector.
13. The drawback of the DVM is that it needs excellent characteristics in the linearity of the ramp. The AC noise and supply noise are averaged out.

Que 2.16. **Explain digital multimeter. A $4\frac{1}{2}$ Digit voltmeter is used to measure voltage. Find (i) Resolution (ii) How would 16.58 be displayed on a 10 V range.** **AKTU 2017-18, Marks 07**

Answer

A. Digital multimeter :

1. Electronic multimeter is a device which is widely used in electrical and electronics measurements.
2. It is used for the measurement of AC as well as DC voltages, currents and resistances. It is called volt-ohm-milliammeter (VOM) meter.
3. The digital multimeter (DMM) uses a digital display device with electronics circuit to display the measured quantity.
4. DMMs are more popular than analog multimeter because of their easy readability, numerical display and improved accuracy.
5. The block diagram of a DMM is shown in Fig. 2.16.1.
6. In a commercial digital multimeter several A/D converters are used. In order to measure unknown current, current to voltage converter is used. This can be done by using an Op-Amp circuit for 1 V conversion.
7. To measure unknown resistance a constant current source is used. The current is allowed to pass through unknown resistance and hence proportional voltage is obtained.
8. To measure AC voltage, a rectifier and filter is used. Rectifier converts AC signal into DC signal, DC signal is applied to A/D converter and to the digital display. The output from the digital multimeter can be used to interface between other equipment.

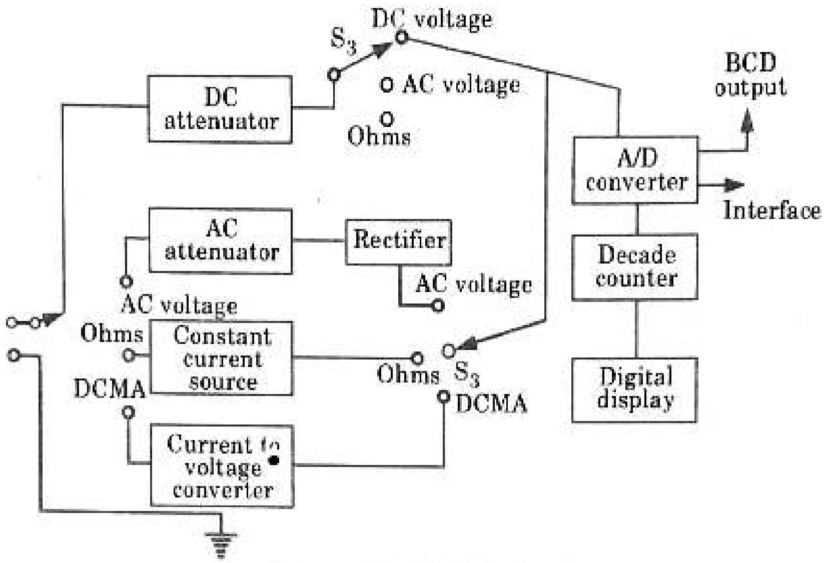


Fig. 2.16.1. Digital multimeter.

B. Numerical :

i. For $4\frac{1}{2}$ digit display the full digits are $n = 4$.

Resolution, $R = \frac{1}{10^4} = 0.0001$

ii. There are 5 digit places in $4\frac{1}{2}$ digits, hence 16.58 would be displayed as 16.580.

Que 2.17. **Explain the working procedure of digital frequency meter system.**

AKTU 2016-17, Marks 05

OR

Draw and explain the block diagram of a digital frequency meter system. **AKTU 2014-15, Marks 05**

Answer

1. The basic block diagram of a digital frequency meter and its associated waveforms are shown in Fig. 2.17.1.

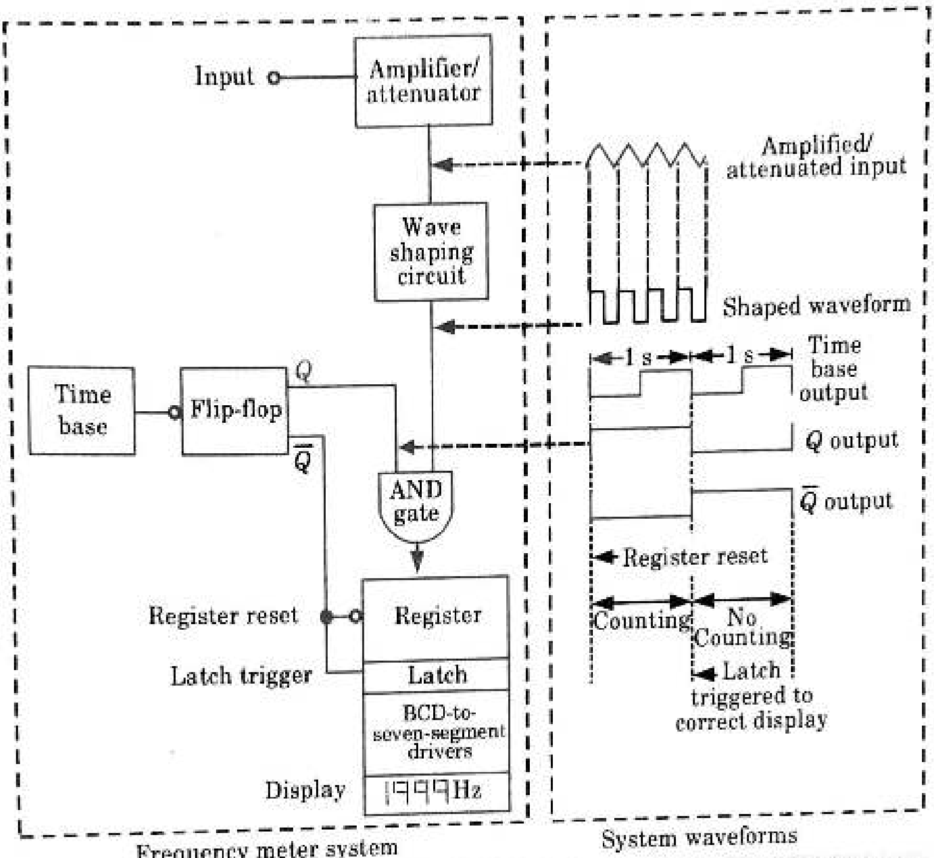


Fig. 2.17.1. Basic block diagram of digital frequency meter and waveforms.

2. In this meter, cycles of the frequency to be measured are counted over a known time period.
3. This meter can measure the frequency of any repetitive type waveform like sinusoidal, square, triangular, etc.
4. The input signal, whose frequency is to be measured, is first amplified or attenuated as necessary and then fed to the wave-shaping circuit which converts it into a square or pulse waveform with the same frequency as the input.
5. The shaped waveform is fed to one input terminal of a two-input AND gate and other AND gate input is controlled by the Q output from a flip-flop.
6. Consequently, the pulses to be counted pass through the AND gate only when the flip-flop Q terminal is high.
7. The flip-flop is controlled by the timing circuit and it changes its state when the timer output waveform goes in negative direction.
8. When output frequency of timing circuit is 1 Hz, the flip-flop Q output terminal is alternatively high for a period of 1 sec, and low for 1 sec. In this case, the counting circuits are toggled for a period of 1 sec, and the total count indicates the frequency directly in hertz.

9. The counting circuit is reset by the negative going edge of the $\bar{Q}$ output from flip-flop. Because of that, the count always starts from zero.

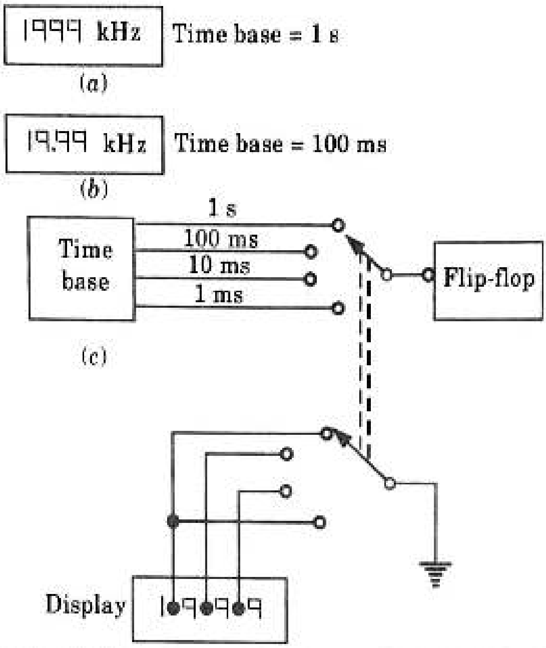


Fig. 2.17.2. Time period and decimal point selection for a digital frequency meter.

10. Latch or digital enable circuits are used to make the digital display readable. The latch circuits are positively edge triggered by $\bar{Q}$ output of flip-flop. Here, time base circuit is used with the digital frequency meter to give several ranges of frequency measurement.
11. If a time base uses 1 sec time period for counting input pulses, then it displays 1999 cycles of input waveform per 1 sec as 1.999 kHz. Similarly, if 100 ms is used as time period, then it displays 1999 cycles of input waveform per 100 ms as 19.99 kHz.

PART-3

Instrument Calibration : Comparison Method, Digital Multimeter as Standard Instrument, Calibration Instrument.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.18. **Write down the purpose of instrument calibration and explain the different methods of calibration.**

Answer

1. The purpose of instrument calibration is to eliminate or reduce any biasing in an instrument reading over a range of values.
2. To get the correct value, reference standard with known values is selected over this range and a relationship is established between the values of the standards and the values measured.

The different methods of calibration are :

1. DC voltmeter calibration.
2. AC instrument calibration.
3. Deflection instrument calibration.
4. DC ammeter calibration.
5. Ohmmeter calibration.
6. Wattmeter calibration.

Que 2.19. **Explain DC voltmeter calibration.**

Answer

1. An instrument can be calibrated by comparing its reading with a more accurate instrument which is used as a standard for comparison.

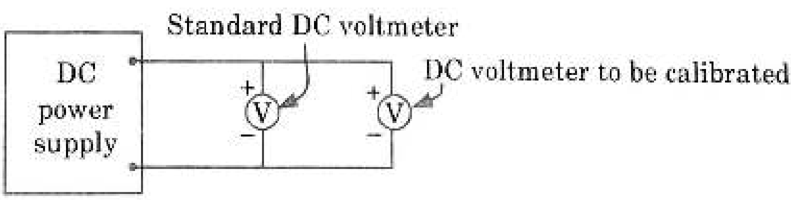


Fig. 2.19.1.

2. For calibration the standard and under calibration voltmeter both are connected in parallel mode to the DC power supply output pins.
3. The reading of both the voltmeters is noted in a tabular form and the error is calculated between the standard and measured value.
4. The instrument used as a standard voltmeter should have accuracy at least four times greater than the instrument to be calibrated.

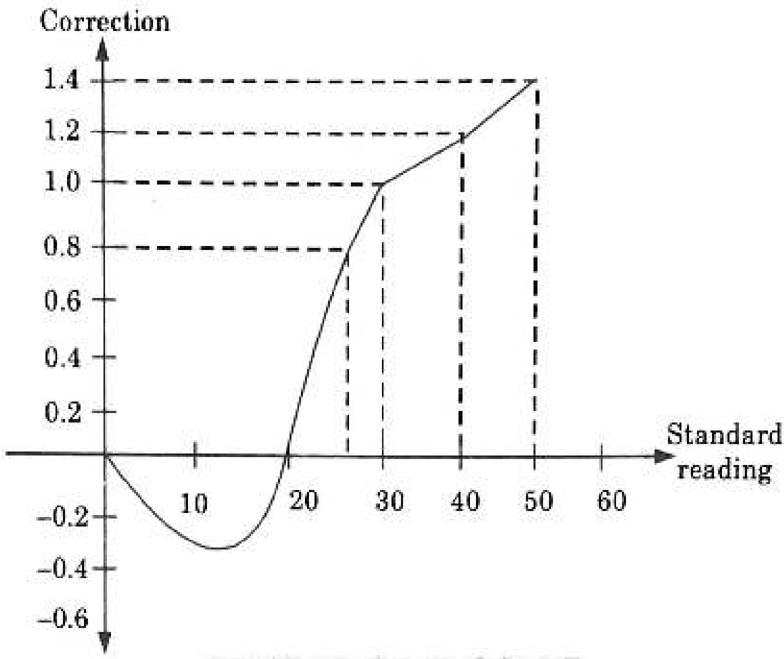


Fig. 2.19.2. Calibration chart.

Que 2.20. **Discuss DC ammeter calibration.**

Answer

DC ammeter calibration :

1. Fig. 2.20.1 shows two DC ammeters connected in series, so that they are both measuring the same current.
2. One ammeter is a standard instrument, known to be accurate, and the other is the ammeter to be calibrated.
3. The current is derived from a DC power supply, and a current-limiting resistor may be included, shown in Fig. 2.20.1.
4. If the power supply has a current level control, the current-limiting resistor is not required.
5. As for voltmeter calibration, the power supply is adjusted to set the measured quantity in convenient steps over the desired range.
6. The two instrument readings are noted, and a calibration chart is prepared.
7. No adjustment to normally make in the case of a digital multimeter employed as an ammeter, because the DMM current measurement function uses the voltage-measuring facility.

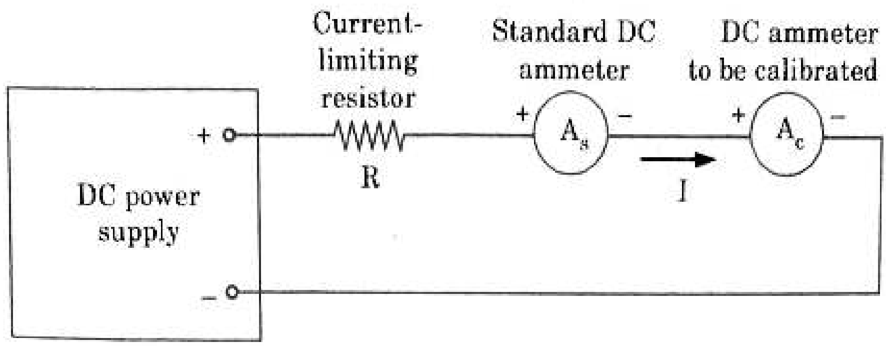
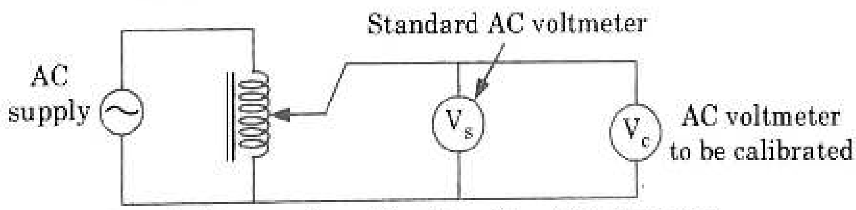


Fig. 2.20.1. DC ammeter calibration.

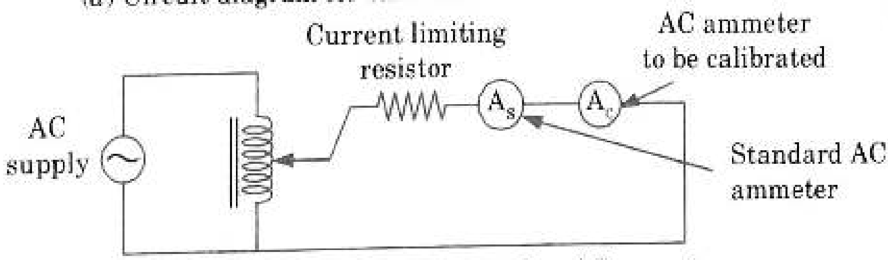
Que 2.21. **Sketch circuit to show how AC voltmeter and ammeter should be calibrated using standard instruments ? Explain.**

Answer

1. The method of calibration of AC instrument is same as the DC instrument. The only difference is that AC supply and an AC standard instrument must be used.
2. AC voltmeter and ammeters may be calibrated by comparing them to more accurate instrument measuring the same quality.
3. The AC supply is generated with auto-transformer.



(*a*) Circuit diagram for calibration of an AC voltmeter



(*b*) Circuit diagram for calibration of an AC ammeter

Fig. 2.21.1.

4. If instrument is to be calibrated at high frequencies, then the oscillator can be used instead of supply.
5. The accuracy of the standard instrument must be at least four times the accuracy of the test instrument.

Que 2.22. **What is the importance of calibration in instrumentation ? Sketch the circuit for calibrating a wattmeter and explain the calibration procedure.** **AKTU 2017-18, Marks 07**

Answer

A. Importance of calibration :

1. Assurance of accurate measurements.
2. Ability to trace measurements to international standards.
3. Correct diagnosis of illness (medical reports).
4. Consumer protection (legal metrology).

B. Circuit of calibration a wattmeter :

1. Wattmeter calibration is a combination of ammeter and voltmeter calibration.
2. Fig. 2.22.1 shows a wattmeter with its current coil connected to one DC power supply and its voltage coil connected to another supply.
3. These ammeter and voltmeter measure current and voltage respectively and eventually the whole device calculate power consumed by load.
4. The wattmeter consists of two coils namely moving coil and fixed coil. These two coils are connected in different circuits for measurement of power.
5. The fixed coil is connected in series with the standard ammeter and to measure the current in the circuit. The fixed coil therefore is called current coil.
6. The moving coil is connected across the standard voltmeter and therefore, measures a current proportional to the voltage.
7. A high non-inductive resistance is connected in series with the moving coil to limit the current to a small value.

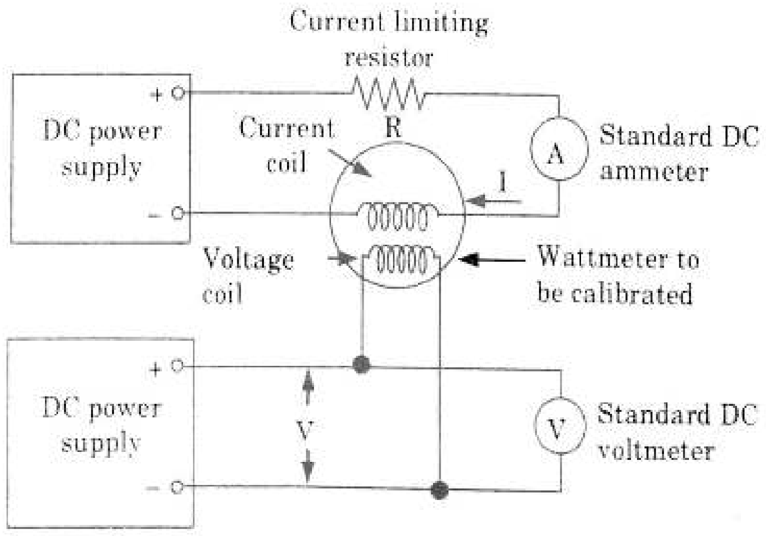


Fig. 2.22.1.

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8. Since moving coil carries a current proportional to voltage, it is also called the pressure coil or voltage coil.
9. Thus, power is calculated by $P = VI$. Once the precise voltage and current are determined for a given reading on the wattmeter, the exact power is determined by $P = VI$.
10. To avoid damaging the instrument, care must be taken to avoid the specified maximum voltage and maximum current.

Que 2.23. **Discuss how DC source and potentiometer may be developed in laboratories for calibration purpose ?**

AKTU 2014-15, Marks 10

Answer

Construction :

1. Modern lab potentiometers use calibrated dial resistors and a small circular wire of one or more turns (instead of previously used long slide wire), thus reducing the size of instrument.
2. In Fig. 2.23.1, there is one dial resistor with 15 steps, each having a precision resistor of 10 Ω total 150 Ω and 1.5 volt.

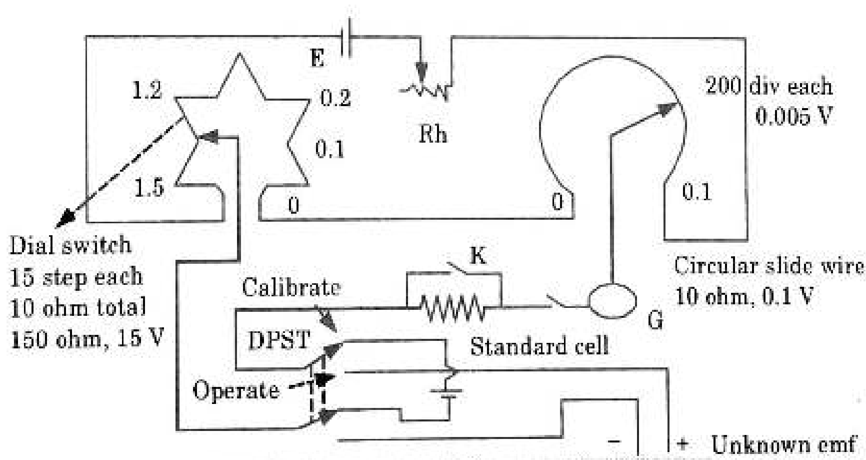


Fig. 2.23.1. Laboratory DC potentiometer.

3. Slide-wire is of single turn having resistance of 10 Ω and 0.1 Volt. The working current is 10 mA. So each step of dial-resistor corresponds to $10 \times 10 \times 10^{-3} = 0.1$ volt.
4. The slide-wire is provided with 200 scale divisions with a total voltage range of 0.1 volt. So each division = 0.1/200 = 0.005 volt.

5. The potentiometer is provided with a double throw switch to make connection to either the standard cell or un-known emf. To operate the Galvanometer at its maximum sensitivity, provision is made to short the protective resistance near balance condition.

Steps to follow to make measurement :

1. The combination of dial-resistor and slide-wire is set to standard cell voltage (1.0186 volt). Dial-resistor set at 1 volt, slide-wire set at 0.0186 V.
2. Galvanometer is calibrated with switch S, connected to standard cell. Rheostat is adjusted foe zero Galvanometer deflection.
3. As the null point is approached, protective resistance is shorted to increase Galvanometer sensitivity. This completes the process of 'Standardization' of Galvanometer.
4. Now switch S is thrown to operate position to find out un-known emf. Now the potentiometer is balanced using dial-switch & slide-wire.
5. At null, the value of emf is read directly from setting of dial adjust and slide-wire.
6. Standardization is checked again.

Que 2.24. **On what factors does the frequency of instrumentation calibration depend ? Explain how AC voltmeter calibration can be done ?**

AKTU 2014-15, Marks 10

Answer

A. Factors :

1. Determination of the frequency at which instruments should be calibrated is dependent upon several factors.
2. If an instrument is required to measure some quantity and an inaccuracy of ± 2% is acceptable, then a certain amount of performance degradation can be allowed if its inaccuracy immediately after recalibration is ± 1 %.
3. It is important that the pattern of performance degradation should be quantified, such that the instrument can be recalibrated before its inaccuracy has reduced to the limit defined by the application.
4. The type of instrument, its frequency of use and the prevailing environmental conditions all strongly influence the calibration frequency.
5. Since, there are so many factors are involved, it is difficult or even impossible to determine the required frequency of instrument recalibration from theoretical considerations.
6. Instead, practical experimentation has to be applied to determine the rate of such changes.

7. Once the maximum permissible measurement error has been defined, knowledge of the rate at which the characteristics of an instrument change allows a time interval to be calculated that represents the moment in time when an instrument will have reached the bounds of its acceptable performance level.
8. Whatever system and frequency of calibration is established, it is important to review this from time to time to ensure that the system remains effective and efficient.

B. AC voltmeter calibration : Refer Q. 2.21, Page 2–31E, Unit-2.

Que 2.25. **Explain how digital multimeters are used as standard instruments.**

Answer

1. Standard instruments are those instruments which are used for calibration of other instruments. The accuracy of standard instrument must be four times greater than the accuracy of instrument to be calibrated.
2. The standard multimeter can be used to calibrate either an analog instrument or low accuracy digital multimeter or a bench type digital instrument.
3. The accuracy of the hand held digital multimeter is $\pm(0.5\ \%$ reading $+ 1\ d)$, *i.e.*, $\pm 0.5\ \%$ of reading $+1$ digit where, the 1 digit refers to the extreme right or least significant number of the display.
4. A hand held digital voltmeter is accurate enough to calibrate an analog instrument.
5. A high performance hand held DVM can be used for calibrating low accuracy DVM.
6. A bench type DVM is usually accurate enough to calibrate a high-performance hand held DVM.

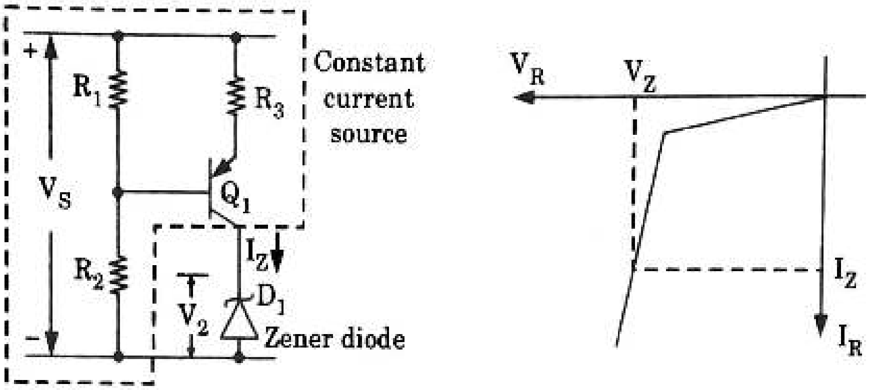
Que 2.26. **Write a short note on calibration instruments.**

Answer

A. Precision DC voltage source :

1. This type of instrument is designed for the purpose of calibrating DC voltmeter is essentially an adjustable precision DC regulator power supply with a high-resolution display of the output voltage.

2. All DC voltage regulators are basically based on the use of Zener diode as a reference voltage.
3. The characteristic of Zener diode is shown in the Fig. 2.26.1(*b*). This characteristic illustrates that the device has very stable anode to cathode voltage (V_Z) when operated in reverse breakdown.



(*a*) Zener diode with constant current source.

(*b*) Zener diode characteristics.

Fig. 2.26.1.

4. The stability of V_Z is improved if the current passing through it is supplied through a constant current source.

B. Voltage calibrator :

1. A voltage calibrator is a precision voltage reference source.
2. The voltage calibrator produces an output of 0 to + 19.999 mV adjustable in 1 mV steps.
3. It provides ± 1.5 mV adjustment. It can be used to calibrate voltmeters with accuracy of ± 0.03 % or worse. It is used for calibrating ADC and DAC.

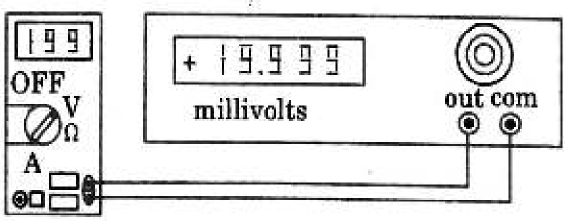


Fig. 2.26.2. Voltage calibrator used for voltmeter calibration.

3 UNIT

Measuring Methods and AC Bridges

CONTENTS

Part-1 : Measuring Methods : Voltmeter and Ammeter Methods, Wheatstone Bridge, Measurement of Low, Medium and High Resistances, Insulation Resistance Measurement .... **3–2E to 3–13E**

Part-2 : AC Bridges for Measurement of Inductance and Capacitance .... **3–14E to 3–27E**

PART-1

Measuring Methods : Voltmeter and Ammeter Methods, Wheatstone Bridge, Measurement of Low, Medium and High Resistance, Insulation Resistance Measurement.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **Classify the methods used for the measurement of resistance.**

Answer

1. Methods for measurement of resistance are classified as :
i. **Low resistance :** All the resistance of the order of 1 Ω and under may be classified as low resistance.
ii. **Medium resistance :** This class includes resistance from 1 Ω upwards to about 0.1 MΩ.
iii. **High resistance :** Resistance of the order of 0.1 MΩ and upwards are classified as high resistance.
2. Following are different methods which are used in measurement of resistance :
i. **For low resistance :**
1. Ammeter-voltmeter method
2. Kelvin's double bridge method
3. Potentiometer method.
ii. **For medium resistance :**
1. Ammeter-voltmeter method
2. Substitution method
3. Wheatstone bridge method
4. Carey-Foster slide wire bridge method
5. Ohmmeter method.
iii. **For high resistance :**
1. Direct deflection method
2. Loss of charge method
3. Meg-ohm bridge
4. Megger.

Que 3.2. **Explain the ammeter-voltmeter method of measurement of resistances.**

OR

Show how an ammeter, a voltmeter, and a DC supply can be used to measure a resistance. Show the two possible connection, write the resistance equation for each and discuss the error.

AKTU 2017-18, Marks 07

Answer

1. The resistance is the ratio of voltage and current.
2. Thus measurement of voltage and current separately is sufficient for resistance measurement.

$$R_m = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}} = \frac{V}{I} \quad ...(3.2.1)$$

3. Two types of connection are used in this method. The connections are shown in Fig. 3.2.1.

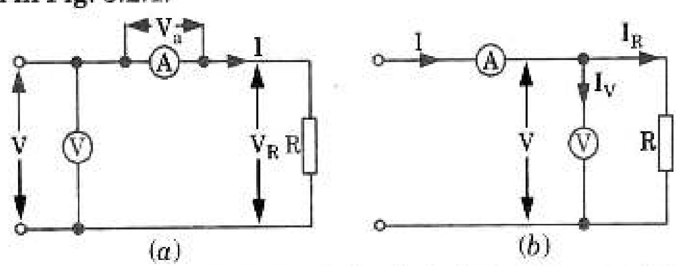


Fig. 3.2.1. Measurement of resistance by ammeter-voltmeter method.

a. Consider circuit of Fig. 3.2.1(*a*).

1. Let R_a be the resistance of the ammeter.
2. $\therefore$ Voltage across the ammeter,

$$V_a = I R_a$$

3. Measured value of resistance,

$$R_{m1} = \frac{V}{I} = \frac{V_R + V_a}{I}$$

$$= \frac{IR + IR_a}{I} = R + R_a \quad ...(3.2.2)$$

4. $\therefore$ True value of resistance,

$$R = R_{m1} - R_a = R_{m1}\left(1 - \frac{R_a}{R_{m1}}\right) \quad ...(3.2.3)$$

5. Thus, measured value is greater than true value.

Relative error, $$\epsilon_r = \frac{R_{m1} - R}{R} = \frac{R_a}{R} \quad ...(3.2.4)$$

6. From eq. (3.2.4) error measurement would be small if value of resistance under measurement is high, therefore, this circuit is used for measuring high resistance value.

b. Consider circuit of Fig. 3.2.1(*b*).

1. Let R_V be the resistance of voltmeter.
2. $\therefore$ Current through the voltmeter,

$$I_V = \frac{V}{R_V}$$

3. Measured value of resistance,

$$R_{m2} = \frac{V}{I} = \frac{V}{I_R + I_V} = \frac{V}{\frac{V}{R} + \frac{V}{R_V}}$$

$$R_{m2} = \frac{R}{1 + \frac{R}{R_V}}$$

4. True value of resistance,

$$R = \frac{R_{m2} R_V}{R_V - R_{m2}} = R_{m2}\left(\frac{1}{1 - \frac{R_{m2}}{R_V}}\right) \quad \text{...(3.2.5)}$$

$$R = R_{m2}\left(1 + \frac{R_{m2}}{R_V}\right) \quad \text{...(3.2.6)}$$

5. Thus, measured value is smaller than true value.
6. Relative error, $\epsilon_r = \dfrac{R_{m2} - R}{R} = \dfrac{R_{m2}^2}{R_V\, R}$ ...(3.2.7)
7. The value of $R_{m2} \cong R$,

$$\therefore \quad \epsilon_r = \frac{R}{R_V} \quad \text{...(3.2.8)}$$

8. From eq. (3.2.8) error in measurement would be small if value of resistance under measurement is very small, therefore, this circuit is used for measuring low resistance value.

Que 3.3. **Draw the circuit of a Kelvin's double bridge used for measurement of low resistances. Derive the condition for balance.**

OR

Draw the circuit of a Kelvin bridge, explain its operation, and derive the equation for the unknown resistance.

AKTU 2017-18, Marks 07

OR

Describe Kelvin double bridge in detail.

AKTU 2016-17, Marks 10

Answer

1. Kelvin's double bridge is used for measuring low resistances (micro ohms to 1 Ω).
2. It is modification of Wheatstone's bridge and provides increased accuracy.
3. It incorporates the idea of second set of ratio arms, hence the name double bridge and the use of four terminal resistances for the low resistance arms.
4. The circuit diagram is shown in Fig. 3.3.1.

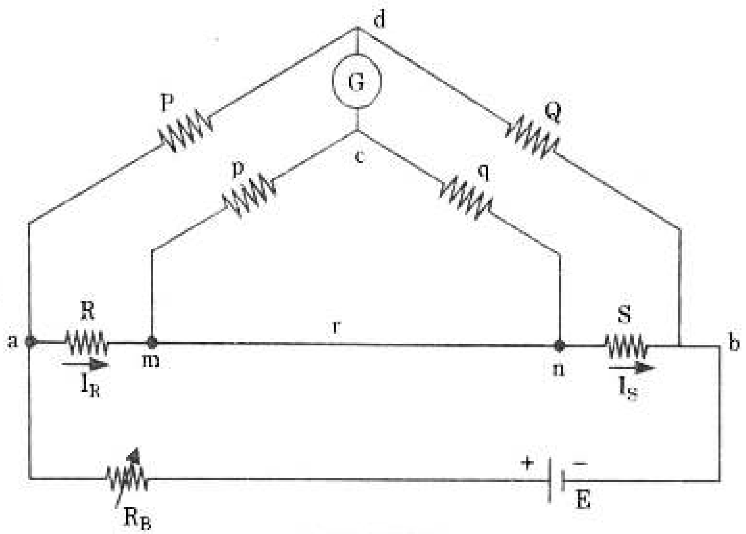


Fig. 3.3.1.

R = Unknown resistance

S = Standard resistance of the order of magnitude as R

r = Connecting link of low resistance

5. P, Q and p, q are two pairs of known non-inductive resistances and one pair P, p or Q, q is variable.
6. The ratio p/q is made equal to P/Q. Under balanced conditions there is no current through galvanometer

i.e., $$E_{ad} = E_{amc} \quad \text{...(3.3.1)}$$

7. Since, $$E_{ad} = \frac{P}{P+Q}E_{ab} \quad \text{(Voltage divider rule)}$$

$$E_{ab} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$$

and $$E_{amc} = \left[R + \frac{p}{p+q}\left(\frac{(p+q)r}{p+q+r}\right)\right]$$

$$= I\left[R + \frac{pr}{p+q+r}\right]$$

8. For balanced condition

$$E_{ad} = E_{amc}$$

$$\frac{P}{P+Q} I \left[\frac{R+S+(p+q)r}{p+q+r}\right] = I\left[R+\frac{pr}{p+q+r}\right]$$

or $$R = \frac{P}{Q}.S + \frac{qr}{p+q+r}\left[\frac{P}{Q}-\frac{p}{q}\right]$$

9. Now if $$\frac{P}{Q} = \frac{p}{q}$$

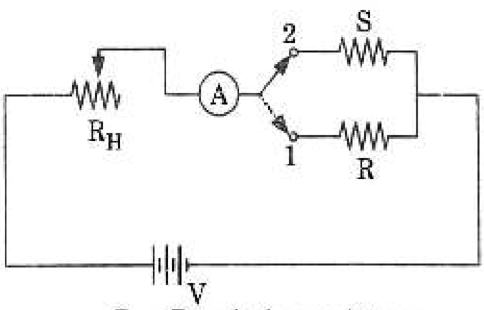
then we have $$R = \frac{P}{Q}S$$

Que 3.4. **Describe the substitution method of measurement of medium resistances.**

Answer

Substitution method :

1. Fig. 3.4.1 shows the circuit diagram for substitution method. The switch connects the resistances R and S alternately.
2. When the switch is at position 1, the resistance R is connected in the circuit. The value of R_H is varied till the ammeter pointer is adjusted on a chosen mark.



R_H : Regulating resistance
S : Standard resistance
R : Unknown resistance

Fig. 3.4.1.

3. When the switch is at position 2, the resistance S is connected in the circuit. The value of S is adjusted till same deflection is obtained as that in the R circuit.
4. The current is unchanged in the substitution method irrespective of change in resistance with switch, provided the battery voltage V and position of R_H are unaltered. The value of unknown resistance R is equal to the dial settings of S.

5. The deflection of the ammeter is directly proportional to the current passing through the circuit. Hence, the deflection is inversely proportional to the total resistance of circuit.
6. Let G be galvanometer / ammeter resistance. Let θ_1 be deflection with standard resistor and θ_2 be deflection with unknown resistor. Then,

$$\frac{\theta_1}{\theta_2} = \frac{R+G}{S+G}$$

$$\therefore \quad R = (S+G)\frac{\theta_1}{\theta_2} - G$$

Que 3.5. **Explain Wheatstone bridge method for calculation of medium resistances.**

Answer

Wheatstone bridge method :

The bridge consists of four resistive arms P, Q, R and S together with a source of emf and a null detector (galvanometer).

Balance condition :

1. When bridge is balanced, the galvanometer carries zero current and does not show any deflection.
2. Thus bridge works on the principle of null deflection. Points B and D must be at same potential.

Thus, $I_1P = I_2R$ ...(3.5.1)

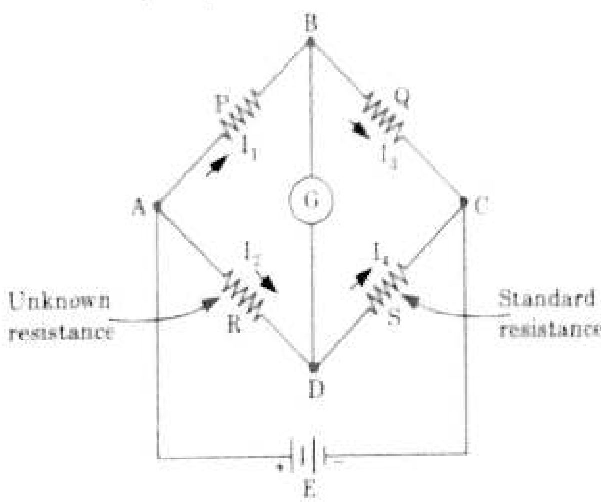


Fig. 3.5.1. Wheatstone bridge.

3. For zero current in galvanometer

$$I_1 = I_3 = \frac{E}{P+Q} \qquad ...(3.5.2)$$

and $$I_2 = I_4 = \frac{E}{R+S} \quad ...(3.5.3)$$

where, E = emf of battery

6. Combining eq. (3.5.1), (3.5.2) and (3.5.3), we obtain :

$$\frac{P}{P+Q} = \frac{R}{R+S}$$

$$R = S\frac{P}{Q}$$

where, R = Unknown resistance.

Que 3.6. **Give numerical example to explain the sensitivity of a Wheatstone bridge. What is the main advantage of using Kelvin's bridge over Wheatstone bridge ?** **AKTU 2014-15, Marks 10**

Answer

Sensitivity of a Wheatstone bridge :

1. The sensitivity is defined as the precision with which the bridge makes resistance measurements. To determine the sensitivity it is necessary to calculate the galvanometer current.
2. The sensitivity of a Wheatstone bridge depends on the current sensitivity of the galvanometer, the galvanometer resistance, and the bridge supply voltage.
3. Galvanometer current depends on the galvanometer resistance and the bridge supply voltage. Fig. 3.6.1 shows the bridge with the galvanometer removed.

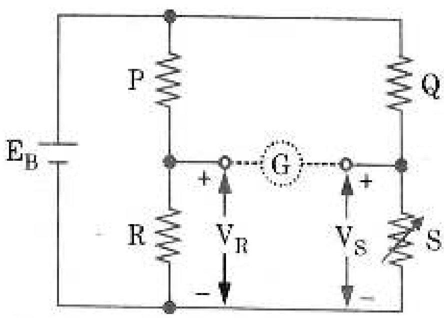


Fig. 3.6.1. Open-circuit voltage at the galvanometer terminals is $(V_R - V_S)$.

4. The open-circuit output voltage across the terminals at which the galvanometer is connected is

$$V_R - V_S = \frac{E_B R}{R+P} - \frac{E_B S}{Q+S}$$

or $$V_R - V_S = E_B\left[\frac{R}{R+P} - \frac{S}{Q+S}\right] \quad ...(3.6.1)$$

5. The internal resistance of the bridge is determined by first assuming that the voltage supply E_B has an internal resistance which is very much smaller than the resistance of the bridge components.

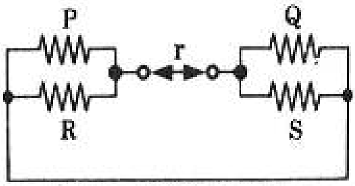


Fig. 3.6.2. Internal resistance is $r = P \,||\, R + Q \,||\, S$.

6. This assumption gives the circuit of Fig. 3.6.2 when E_B is replaced with a short circuit. Thus, the internal resistance of the bridge is

$$r = P \,||\, R + Q \,||\, S \qquad ...(3.6.2)$$

7. The complete equivalent circuit of the bridge and galvanometer is shown in Fig. 3.6.3. The galvanometer current is now

$$I_g = \frac{V_R - V_S}{r + r_g} \qquad ...(3.6.3)$$

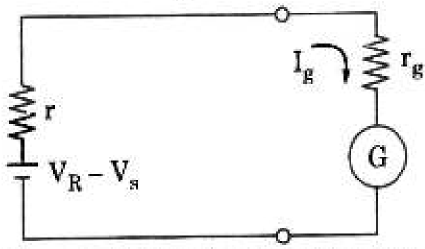


Fig. 3.6.3. Thevenin equivalent circuit.

8. From eq. (3.6.3) it is seen that if $V_R - V_S$ is increased, I_g is increased. $V_R - V_S$ can be increased by using a larger supply voltage E_B. If the lowest detectable change in I_g is made smaller by using a more sensitive galvanometer, $V_R - V_S$ can be reduced Q.
9. Thus, the bridge sensitivity can be improved either by increasing E_B or by using a more sensitive galvanometer.

Numeric example :

1. Let us consider a Wheatstone bridge has $P = 3.5$ kΩ, $Q = 7$ kΩ, and $S = 4$ kΩ when $R = 2$ kΩ. The supply is $E_B = 10$ V, and the galvanometer has a current sensitivity of 1 μA/mm and a resistance $r_g = 2.5$ kΩ. Now we have to calculate the minimum change in R which is detectable by the bridge.
2. From eq. (3.6.2),
$$r = P \,||\, R + Q \,||\, S$$
$$= 3.5 \text{ k}\Omega \,||\, 2 \text{ k}\Omega + 7 \text{ k}\Omega \,||\, 4 \text{ k}\Omega$$
$$= 3.82 \text{ k}\Omega$$
3. From eq. (3.6.3),
$$V_R - V_S = I_g(r + r_g)$$
$$= 1\ \mu\text{A}\ (3.82 \text{ k}\Omega + 2.5 \text{ k}\Omega) = 6.32 \text{ mV}$$
4. When the bridge is balanced,

$$V_R = \frac{E_B \times R}{P + R} = \frac{10\text{ V} \times 2\text{ k}\Omega}{3.5\text{ k}\Omega + 2\text{ k}\Omega}$$

$$= 3.63636\text{ V}$$

5. When the open-circuit galvanometer voltage is 6.32 mV,

$$V_R + \Delta V_R = 3.636\,36\text{ V} + 6.32\text{ mV}$$

and
$$V_P = E - (V_R + \Delta V_R) = 10\text{ V} - 3.642\,68\text{ V}$$

$$= 6.357\,32\text{ V}$$

$$I_P = I_R = \frac{V_P}{P} = \frac{6.357\,32\text{ V}}{3.5\text{ k}\Omega} = 1.816\text{ mA}$$

So,
$$R + \Delta R = \frac{V_R + \Delta V_R}{I_R} = \frac{3.642\,68\text{ V}}{1.816\text{ mA}}$$

$$= 2.0059\text{ kW}$$

$$\Delta R = (R + \Delta R) - R = 2.0059\text{ k}\Omega - 2\text{ k}\Omega$$

$$= 5.9\,\Omega$$

Advantages of using Kelvin's bridge over Wheatstone bridge :

1. Kelvin's double bridge is more accurate than Wheatstone bridge.
2. The effect of load and contact resistance is completely eliminated.

Que 3.7. Explain the loss of charge method for measurement of resistance.

Answer

1. In this method, the insulation resistance R to be measured is connected in parallel with a capacitor C and electrostatic voltmeter.
2. The capacitor is charged to some suitable voltage, by means of a battery having voltage V and is then allowed to discharge through the resistance.
3. The terminal voltage is observed over a considerable period of time during discharge.

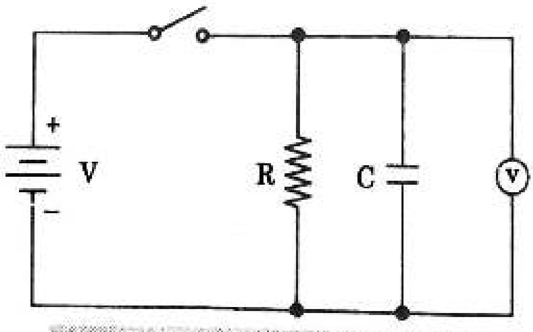


Fig. 3.7.1. Loss of charge method.

4. The voltage across the capacitor at any instant t after the application of voltage is

$$V = v \exp(-t/CR)$$

$$\frac{V}{v} = \exp(-t/CR)$$

Insulation resistance,

$$R = \frac{t}{C \log_e (V/v)} = \frac{0.4343\, t}{C \log_{10} (V/v)} \quad ...(3.7.1)$$

5. The variation of voltage v with time t is shown in Fig. 3.7.2.
6. From eq. (3.7.1) it follows that if V, v, C and t are known, the value of R can be computed.
7. If the resistance R is very large, the time for an appreciable fall in voltage is very large and thus, this process may become time consuming.
8. Also, the voltage-time curve will thus be very flat and unless great care is taken in measuring voltages at the beginning and end of the time A, a serious error may be made in the ratio V/v causing a considerable corresponding error in the measured value of R.
9. More accurate result may be obtained by change in the voltage $V - v$ directly and calling this change as e, the expression for R becomes

$$R = \frac{0.4343t}{C \log_{10}\left(\frac{V}{V-e}\right)}$$

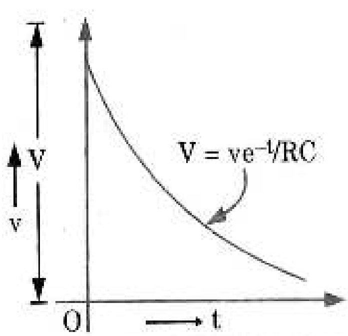


Fig. 3.7.2. Variation of voltage with time.

10. This change in voltage may be measured by a galvanometer.
11. This method is applicable to high resistances but it requires a capacitor of a very high leakage reactance as high as the resistance being measured.

Que 3.8. **Explain direct deflection method of measurement of high resistance.**

Answer

1. In this method, a high resistance (1000 Ω) and very sensitive moving coil galvanometer is connected in series with the resistances to be measured along with supply voltage.
2. By this method, insulation resistance can be obtained with respect to the deflection of galvanometer.
3. The galvanometer measures current I_R between the conductor and metal sheath.
4. The leakage current, I_L over the surface of insulating material are carried by guard wire.
5. The ratio of the voltage applied between conductor and metal sheath to the current flowing between them gives the insulation resistance of the cable.

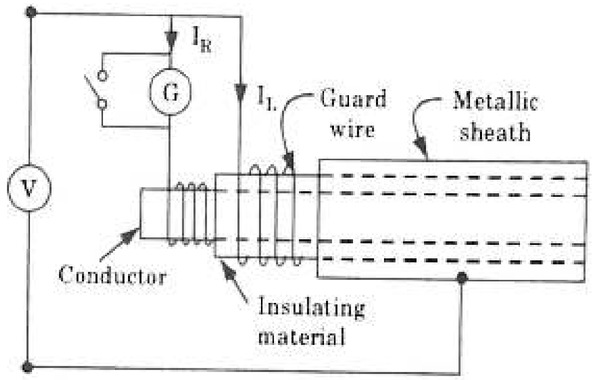


Fig. 3.8.1.

Que 3.9. **Discuss the method of measurement of high resistance by Megger method.**

OR

Discuss insulation resistance measurement.

Answer

1. The value of insulation resistance is usually in order of mega ohms. The instrument used to measure insulation resistance is known as Megger.
2. It consists of a hand driven DC generator and a direct reading ohmmeter.
3. Permanent magnets provide fields for both.
5. The moving element consists of three coils, one current coil, potential or pressure coil and compensating coil.
4. The coils are mounted over a rigid shaft and are free to rotate over a C-shaped stationary iron core.

6. The coils are connected to the circuit by means of flexible leads or ligaments.
7. E and L are the test terminals. The current coil is connected in series with the terminal L.
8. The series resistance R protects the current coil in case the test terminals are short-circuited and controls the range of the instrument.
9. The pressure coil, in series with a compensating coil and protection resistance R is connected across the generator terminals.
10. Compensating coil is provided for better scale proportions and to make the instrument calibrated.
11. When the current from generator flows through pressure coil, the coil tends to align itself at right angle to the permanent magnet field.
12. For infinite resistance, no current flows through the current coil and pressure coil governs the motion of the moving element causing it to move its extreme counter clockwise position, the point under this condition is marked infinite resistance.
13. Current coil produces clockwise torque on moving element, when the terminal L and E are short circuited, the current flowing through current coil is large enough to move the pointer to its extreme clockwise position, marked zero.

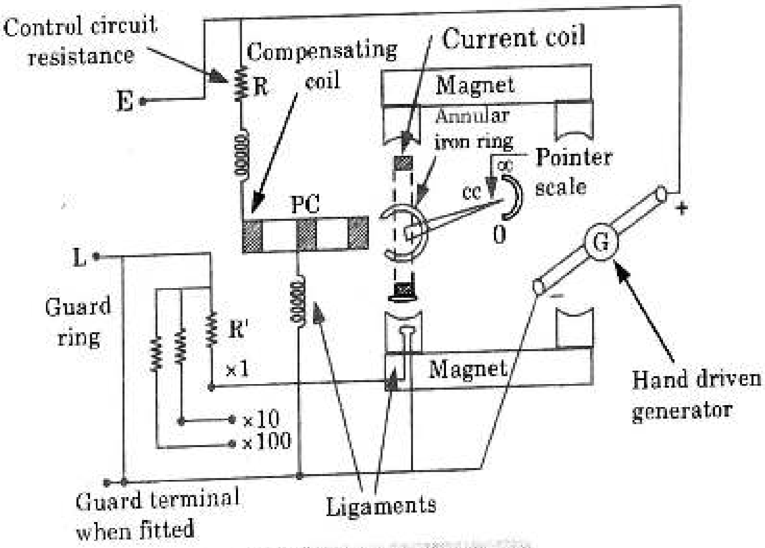


Fig. 3.9.1. Megger.

14. For any resistance connected between L and E, the opposing torque of the coils balances each other so that pointer comes to rest at some intermediate point on the scale.

PART-2

AC Bridges for Measurement of Inductance and Capacitance.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.10. **Explain how AC bridge are balanced with proper phase diagrams ? Derive the expressions of converting series inductor circuits into parallel equivalent circuits.**

AKTU 2014-15, Marks 10

Answer

A. Balance equation :

1. The four bridge arms $\vec{Z}_1, \vec{Z}_2, \vec{Z}_3$, and $\vec{Z}_4$ are (*i.e.*, they are conjugate) indicated as unspecified impedances and detector is represented by headphone.
2. The balanced condition is reached when the detector response is zero or it indicates a null. Balance adjustment to obtain a null response is made by varying one or more of the bridge arms.
3. The condition for bridge balance requires that potential difference from *C* to *D* must be zero. This will be the case when the voltage drop from *A* to *C* equals the voltage drop from *A* to *D* in both magnitude and phase.
4. In complex notation we can write as

$$\vec{E}_{AC} = \vec{E}_{AD} \qquad ...(3.10.1)$$

or

$$\vec{I}_1 \vec{Z}_1 = \vec{I}_2 \vec{Z}_2 \qquad ...(3.10.2)$$

5. Also at balance,

$$\vec{I}_1 = \vec{I}_3 = \frac{\vec{E}}{\vec{Z}_1 + \vec{Z}_3} \qquad ...(3.10.3)$$

$$\vec{I}_2 = \vec{I}_4 = \frac{\vec{E}}{\vec{Z}_2 + \vec{Z}_4} \qquad ...(3.10.4)$$

6. Substituting eq. (3.10.3) and (3.10.4) into eq. (3.10.2)

$$\frac{\vec{E}}{\vec{Z}_1+\vec{Z}_3}\vec{Z}_1 = \frac{\vec{E}}{\vec{Z}_2+\vec{Z}_4}\vec{Z}_2$$

or,
$$\frac{\vec{Z}_2+\vec{Z}_4}{\vec{Z}_2} = \frac{\vec{Z}_1+\vec{Z}_3}{\vec{Z}_1}$$

or
$$1+\frac{\vec{Z}_4}{\vec{Z}_2} = 1+\frac{\vec{Z}_3}{\vec{Z}_1}$$

or
$$\vec{Z}_1\vec{Z}_4 = \vec{Z}_2\vec{Z}_3 \qquad ...(3.10.5)$$

or when using admittances instead of impedance, we have

$$\vec{Y}_1\vec{Y}_4 = \vec{Y}_2\vec{Y}_3$$

Eq. (3.10.5) is the general equation for balance of AC bridge.

7. It states that the product of the impedances of the one pair of opposite arms must be equal to the product of impedances of the other pair of opposite arms with the impedance expressed in complex notation.
8. Eq. (3.10.5) can be written as in polar form :

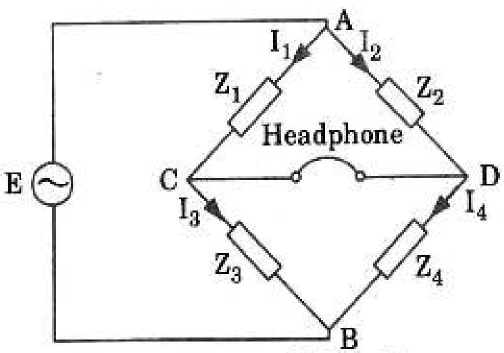
$$(Z_1 \angle\theta_1)(Z_4 \angle\theta_4) = (Z_2 \angle\theta_2)(Z_3 \angle\theta_3) \qquad ...(3.10.6)$$

$$Z_1 Z_4 \angle(\theta_1+\theta_4) = Z_2 Z_3 \angle(\theta_2+\theta_3) \qquad ...(3.10.7)$$

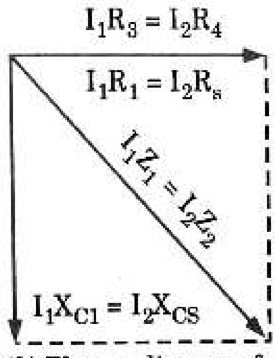
9. Eq. (3.10.6) and (3.10.7) shows that following two conditions must be satisfied simultaneously when balancing an AC bridge :

i. $Z_1Z_4 = Z_2Z_3$

ii. $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$



(a) General form of AC bridge.



(b) Phasor diagram for balanced bridge.

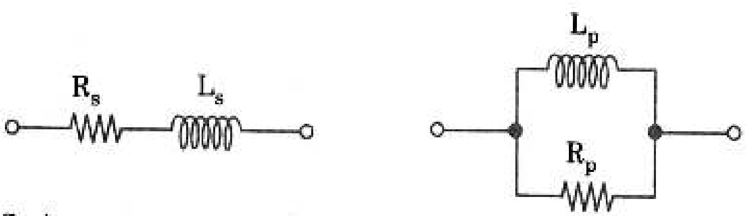
Fig. 3.10.1.

Here,
$$Z_1 = R_1 + X_{C1}$$
$$Z_2 = R_s + X_{Cs}$$
$$Z_3 = R_3$$
$$Z_4 = R_4$$

B. Expressions :

Inductor equivalent circuits :

1. Inductor equivalent circuits are shown in Fig. 3.10.2. The series equivalent circuit in Fig. 3.10.2(*a*) represents an inductor as a pure inductance L_s in series with the resistance R_s of its coil.
2. Ideally, the winding resistance should be as small as possible, but this depends on the thickness and length of the wire used to wind the coil.
3. Physically small high-value inductors tend to have large resistance values, while large low-inductance components are likely to have low resistances.
4. The parallel *RL* equivalent circuit for an inductor as shown in Fig. 3.10.2(*b*) can also be used.
5. As in the case of the capacitor equivalent circuits, it is sometimes more convenient to use a parallel *RL* equivalent circuit rather than a series circuit.



(*a*) Series equivalent circuit (*b*) Parallel equivalent circuit

Fig. 3.10.2.

6. The series circuit impedance is

$$Z_s = R_s + jX_s$$

and the parallel circuit admittance is

$$Y_p = \frac{1}{R_p} - j\frac{1}{X_p}$$

$$Y_p = G_p - jB_p$$

$$Z_s = Z_p$$

$$R_s + jX_s = \frac{1}{G_p - jB_p}$$

$$R_s + jX_s = \frac{1}{(G_p - jB_p)}\left(\frac{G_p + jB_p}{G_p + jB_p}\right)$$

$$R_s + jX_s = \frac{G_p + jB_p}{G_p^2 + B_p^2} \quad \text{...(3.10.8)}$$

7. Equating the real terms in eq. (3.10.8) gives

$$R_s = \frac{G_p}{G_p^2 + B_p^2} = \frac{1/R_p}{1/R_p^2 + 1/X_p^2}\left(\frac{R_p^2 X_p^2}{R_p^2 X_p^2}\right)$$

$$R_s = \frac{R_p X_p^2}{X_p^2 + R_p^2} \quad \text{...(3.10.9)}$$

8. Equating the imaginary terms in eq. (3.10.9) gives

$$X_s = \frac{B_p}{G_p^2 + B_p^2} = \frac{1/X_p}{1/R_p^2 + 1/X_p^2}\left(\frac{R_p^2 X_p^2}{R_p^2 X_p^2}\right)$$

$$X_s = \frac{R_p^2\, X_p}{X_p^2 + R_p^2} \qquad ...(3.10.10)$$

Que 3.11. **Derive an expression for finding unknown resistance and inductance for Maxwell's Bridge.**

AKTU 2017-18, Marks 10

AKTU 2015-16, Marks 10

OR

A Maxwell inductance bridge uses a standard capacitor of $C_3 = 0.1$ μF and operates at a supply frequency of 100 Hz. Balance is achieved when R_1 = 1.26 kΩ, R_3 = 470 Ω, and R_4 = 500 Ω. Calculate the inductance and resistance of the measured inductor, and determine its Q factor.

Answer

A. Maxwell's bridge :

1. Maxwell's bridge is used for measurement of the inductance having low 'Q' values (*i.e.*, $Q < 10$).
2. The general equation for bridge balance is

$$\vec{Z}_1 \vec{Z}_x = \vec{Z}_2 \vec{Z}_3 \qquad ...(3.11.1)$$

$$\vec{Z}_x = \frac{\vec{Z}_2 \vec{Z}_3}{\vec{Z}_1} = \vec{Z}_2 \vec{Z}_3 \vec{Y}_1 \qquad ...(3.11.2)$$

where, $\vec{Z}_1 = R_1$ in parallel with C_1

$$\vec{Y}_1 = \frac{1}{Z_1} = \frac{1}{R_1} + j\omega C_1$$

$$\vec{Z}_2 = R_2,\ \vec{Z}_3 = R_3$$

$\vec{Z}_x = R_x$ in series with $L_x = R_x + j\omega L_x$

Substituting these values in eq. (3.11.2), we get

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

or,
$$R_x + j\omega L_x = \frac{R_2 R_3}{R_1} + j\omega C_1 R_2 R_3 \qquad ...(3.11.3)$$

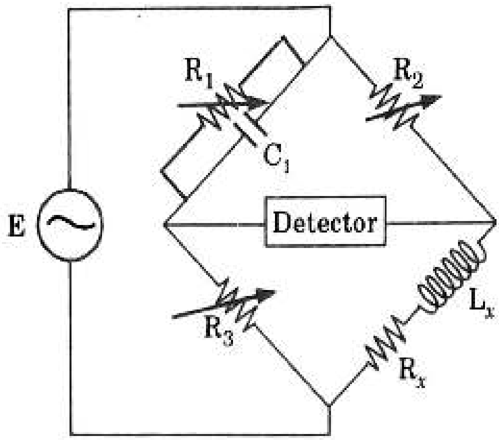


Fig. 3.11.1. Maxwell's bridge diagram.

3. Equating real and imaginary terms in eq. (3.11.3), we have

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

4. To obtain the bridge balance, first R_3 is adjusted for inductive balance and R_1 is adjusted for resistive balance, the quality factor of coil is given by

$$Q = \frac{\omega L_x}{R_x} = \frac{\omega C_1 R_2 R_3}{(R_2 R_3 / R_1)} = \frac{\omega C_1 R_1 R_2 R_3}{R_2 R_3}$$

$$\therefore \quad Q = \omega C_1 R_1 \qquad ...(3.11.4)$$

5. Maxwell's bridge is limited for the measurement of low values of Q $(1 < Q < 10)$.

B. Numerical :

$$L_s = C_3 R_1 R_4 = 0.1\ \mu\text{F} \times 1.26\ \text{k}\Omega \times 500\ \Omega$$
$$= 63\ \text{mH}$$

$$R_s = \frac{R_1 R_4}{R_3} = \frac{1.26\ \text{k}\Omega \times 500\ \Omega}{470\ \Omega} = 1.34\ \text{k}\Omega$$

$$Q = \frac{\omega L_s}{R_s} = \frac{2\pi \times 100\ \text{Hz} \times 63\ \text{mH}}{1.34\ \text{k}\Omega} = 0.03$$

Que 3.12. **Draw the bridge arrangement and describe the Hay's bridge for inductance measurement. Draw the phasor diagram.**

Answer

1. The Hay's bridge is a modification of Maxwell's bridge.
2. This bridge uses a resistance in series with the standard capacitor (unlike the Maxwell's bridge which uses a resistance in parallel with the capacitor).

3. Let L_1 = Unknown inductance having a resistance R_1,
   R_2, R_3, R_4 = Known non-inductive resistance,
   and C_4 = Standard capacitor.
4. At balance,
   $(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2 R_3$
   or $R_1 R_4 + \dfrac{L_1}{C_4} + j\omega L_1 R_4 - \dfrac{jR_1}{\omega C_4} = R_2 R_3$

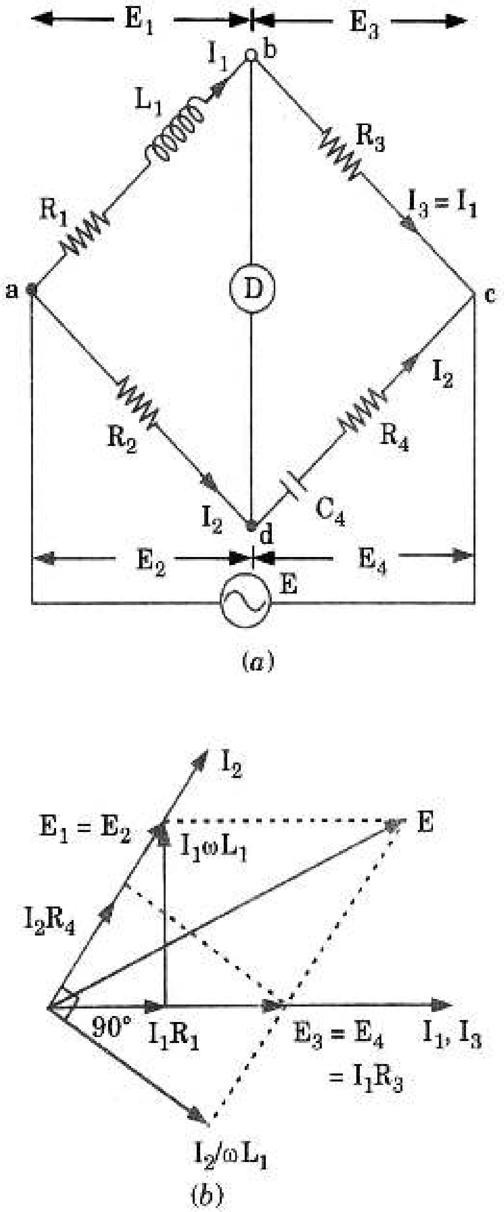


Fig. 3.12.1.

5. Separating the real and imaginary terms, we obtain

$$R_1R_4 + \frac{L_1}{C_4} = R_2R_3 \text{ and } L_1 = -\frac{R_1}{\omega^2 R_4 C_4}$$

6. Solving the two equations, we have

$$L_1 = \frac{R_2R_3C_4}{1+\omega^2C_4^2R_4^2}$$

and $$R_1 = \frac{\omega^2 R_2R_3R_4C_4^2}{1+\omega^2C_4^2R_4^2}$$

7. The Q factor of the coil is,

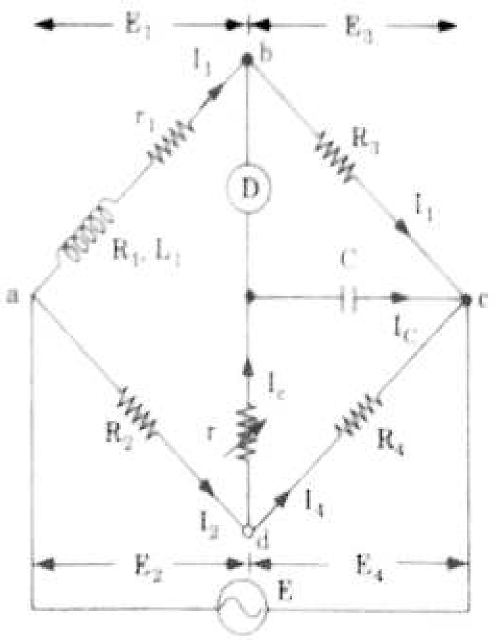
$$Q = \omega L_1/R_1 = 1/\omega C_4R_4$$

8. The expressions for the unknown inductance and resistance contain the frequency term.
9. Therefore it appears that the frequency of the source of supply to the bridge must be accurately known.

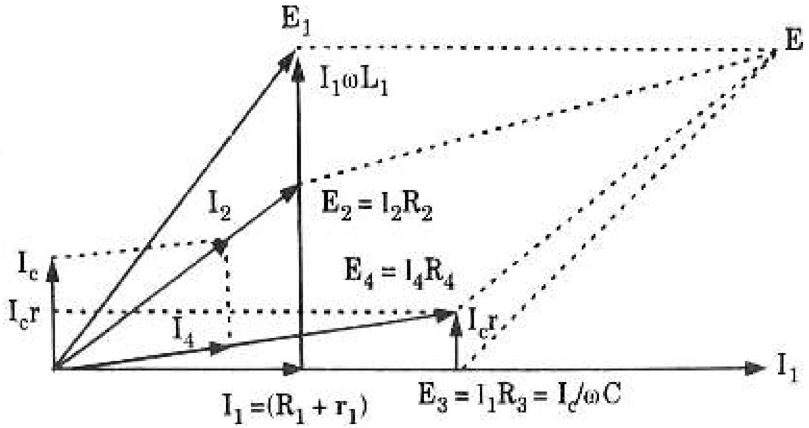
Que 3.13. **Derive balance equation of Anderson's bridge along with its phasor diagram.**

Answer

1. In Anderson's bridge method, inductance is measured in terms of a standard capacitor.



(a)



(b)

Fig. 3.13.1.

2. Let L_1 = Self-inductance to be measured,

   R_1 = Resistance of self-inductor,

   r_1 = Resistance connected in series with self-inductor,

   r, R_2, R_3, R_4 = Known non-inductive resistances,

   and C = Fixed standard capacitor.

3. At balance, $I_1 = I_3$ and $I_2 = I_c + I_4$

4. Now, $$I_1R_3 = I_c \times \frac{1}{j\omega C}$$

   $\therefore$ $$I_c = I_1 j\omega CR_3 \quad ...(3.13.1)$$

5. Writing the other balance equations,

   $$I_1(r_1 + R_1 + j\omega L_1) = I_2R_2 + I_cr \quad ...(3.13.2)$$

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

6. Substituting the value of I_c from eq. (3.13.1) in eq. (3.13.2), we have

   $$I_1(r_1 + R_1 + j\omega L_1) = I_2R_2 + I_1 j\omega CR_3 r$$

   or $$I_1(r + R_1 + j\omega L_1 - j\omega CR_3 r) = I_2R_2 \quad ...(3.13.3)$$

   and $$j\omega CR_3 I_1\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_1 j\omega CR_3)R_4$$

   or $$I_1(j\omega CR_3 r + j\omega CR_3R_4 + R_3) = I_2R_4 \quad ...(3.13.4)$$

7. From eq. (3.13.3) and (3.13.4), we obtain

   $$I_1(r_1 + R_1 + j\omega L_1 - j\omega CR_3 r) = I_1\left(\frac{R_2R_3}{R_4} + \frac{j\omega CR_2R_3 r}{R_4} + j\omega CR_3R_2\right)$$

8. Equating the real and the imaginary parts,

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

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

Que 3.14. **Write the mathematical expression for inductor Q-factor and capacitor D-factor. Explain the working of inductance comparison bridge.** **AKTU 2014-15, Marks 10**

Answer

Q-factor of an inductor :

1. The quality factor, Q-factor, of the inductor is the ratio of the inductive reactance and resistance at the operating frequency.

$$Q = \frac{X_s}{R_s} = \frac{\omega L_s}{R_s}$$

where, L_s and R_s refer to the components of an RL series equivalent circuit.

2. Ideally, ωL_s should be very much larger then R_s, so that a very large Q-factor is obtained.
3. When the parallel equivalent circuit is employed

$$Q = \frac{R_p}{X_p} = \frac{R_p}{\omega L_p}$$

D-factor of a capacitor :

1. The dissipation factor D defines the quality of the capacitor. D is simply the ratio of the component reactance (at a given frequency) to the resistance measurable at its terminals.
2. Using the parallel equivalent circuit,

$$D = \frac{X_p}{R_p} = \frac{1}{\omega C_p R_p}$$

3. Ideally, R_p should be very much large then $1/(\omega C_p)$, giving a very small dissipation factor.
4. When a series equivalent circuit is used, the equation for dissipation factor can be shown to be

$$D = \frac{R_s}{X_s} = \omega C_s R_s$$

Inductance comparison bridge :

1. The circuit of the inductance comparison bridge is shown in Fig. 3.14.1.
2. The unknown inductance, represented by its (series equivalent circuit) L_s and R_s is measured in terms of a precise standard value of inductor.

3. L_1 is the standard inductor, R_1 is a variable standard resistor to balance R_s, R_3 and R_4. Balance of the bridge is achieved by alternately adjusting R_1 and either R_3 or R_4.

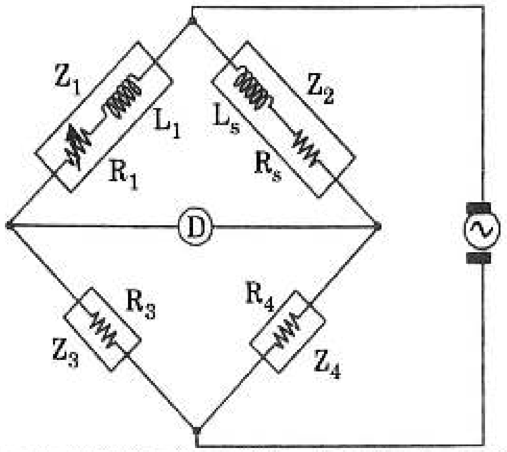


Fig. 3.15.1. Inductance comparison bridge.

4. At balance, we have,

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

$$\frac{R_1 + j\omega L_1}{R_3} = \frac{R_s + j\omega L_s}{R_4}$$

$$\frac{R_1}{R_3} + j\frac{\omega L_1}{R_3} = \frac{R_s}{R_4} + j\frac{\omega L_s}{R_4} \quad \text{...(3.14.1)}$$

5. Equating the real and imaginary components in eq. (3.14.1)

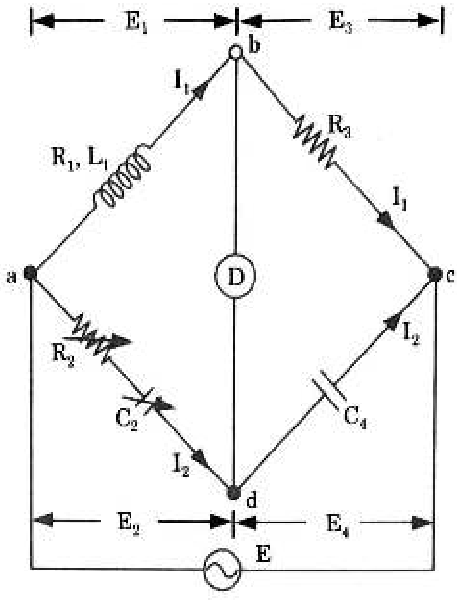
$$\frac{R_1}{R_3} = \frac{R_s}{R_4} \text{ and } \frac{\omega L_1}{R_3} = \frac{\omega L_s}{R_4}$$

$$R_s = \frac{R_1 R_4}{R_3} \text{ and } L_s = \frac{L_1 R_4}{R_3}$$

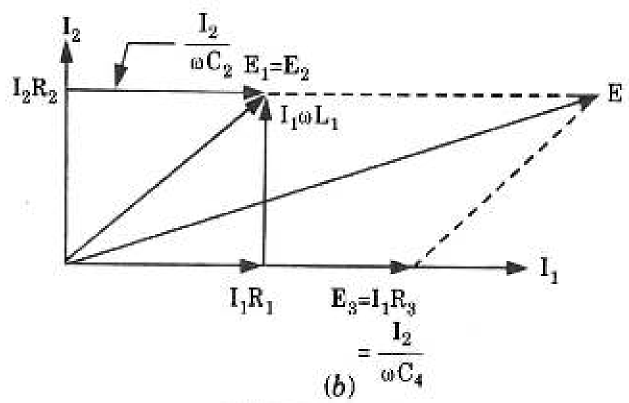
Que 3.15. **Define Owen's Bridge with phasor diagram. Give its advantages and disadvantages also.**

Answer

1. This bridge may be used for measurement of an inductance in terms of capacitance.
2. Let, L_1 = Unknown self-inductance of resistance R_1,
   R_2 = Variable non-inductive resistance,
   R_3 = Fixed non-inductive resistance,
   C_2 = Variable standard capacitor,
   and C_4 = Fixed standard capacitor.



(a)



(b)

Fig. 3.15.1.

3. At balance,

$$(R_1 + j\omega L_1)\left(\frac{1}{j\omega C_4}\right) = \left(R_2 + \frac{1}{j\omega C_2}\right) R_3$$

4. Equating real and imaginary parts, we obtain :

$$L_1 = R_2 R_3 C_4 \quad \text{and} \quad R_1 = R_3 \frac{C_4}{C_2}$$

Advantages :

1. Owen's Bridge can be used over a wide range of measurement of inductance.
2. The balance equation are simple and do not contain any frequency component.

Disadvantages :

Owen's bridge requires a variable capacitor which is expensive.

Que 3.16. **How dielectric loss and unknown capacitance are measured by Schering bridge ?** **AKTU 2015-16, Marks 10**

Answer

A. Measurement of Capacitance :

1. It is one of the most widely used AC bridges for the measurement of unknown capacitors, dielectric loss and power factor.
2. It is also useful for measuring insulating properties, *i.e.*, phase angles very nearly 90°.
3. Fig. 3.16.1 shows basic circuit arrangement.

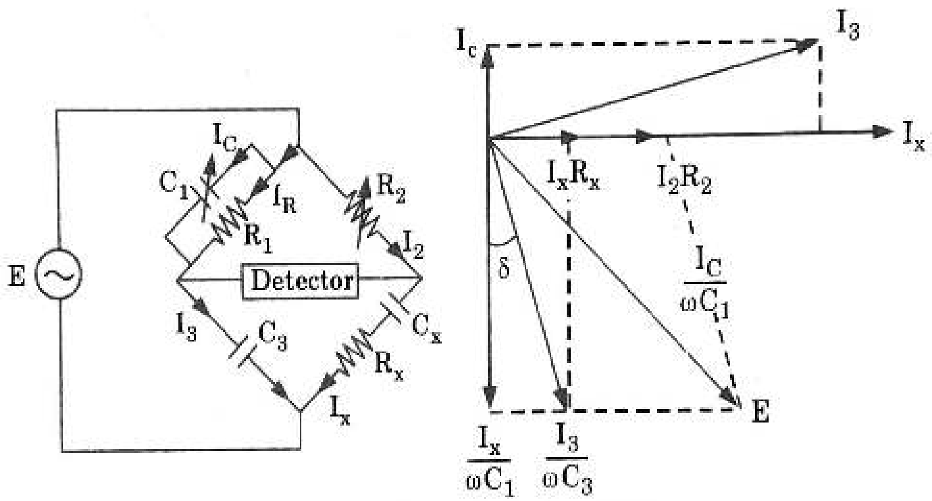


Fig. 3.16.1. Schering bridge.

4. One of the ratio arms consists of a resistance in parallel with a capacitor and standard arm consist only a capacitor.
5. The standard capacitor is a high quality mica capacitor or an air capacitor for insulation measurement.
6. The general bridge balance equation is,

$$Z_1 Z_x = Z_2 Z_3$$

$$Z_x = Z_2 Z_3 Y_1$$

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

$$Z_1 = R_3, Z_2 = R_2, Z_3 = \frac{-j}{\omega C_3}$$

$$Z_x = R_x + \frac{1}{j\omega C_x}$$

Substituting,

$$R_x - \frac{j}{\omega C_x} = R_2 \times \frac{-j}{\omega C_3}\left(\frac{1}{R_1} + j\omega C_1\right)$$

$$R_x - \frac{j}{\omega C_x} = -j\frac{R_2}{\omega R_1 C_3} + \frac{R_2 \omega C_1}{\omega C_3}$$

Separating real and imaginary terms,

$$R_x = \frac{R_2 C_1}{C_3} \qquad ...(3.16.1)$$

$$\frac{1}{\omega C_x} = \frac{R_2}{\omega R_1 C_3}$$

$$C_x = \frac{R_1 C_3}{R_2} \qquad ...(3.16.2)$$

The eq. (3.16.2) gives the value of unknown capacitance C_x in terms of standard capacitor C_3, R_1 and R_2.

B. Measurement of dielectric loss :

For a series combination of R_x and C_x, the angle between the voltage across the series combination and voltage across the capacitor C_x is called loss angle (δ).

Now,
$$\tan\delta = \frac{IR_x}{I\left(\frac{1}{\omega C_x}\right)}$$

$$= \omega R_x C_x$$

$$\tan\delta = \omega\left(\frac{R_1 C_1}{C_3}\right) \times \left(\frac{R_1 C_3}{R_2}\right)$$

$$= \omega R_1 C_1$$

Que 3.17. **Explain capacitance and inductance bridges.**

OR

How the capacitance value is measured with the help of De-Sauty's bridge ? This bridge is used for which type of capacitor.

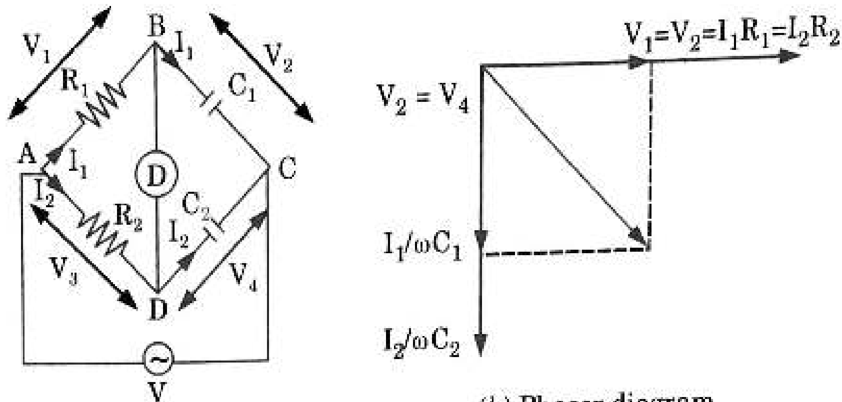
OR

The standard capacitance value in Fig. 3.17.1 is C_1 = 0.1 μF, and R_2/R_1 can be set to any ratio between 100 : 1 and 1 : 100. Calculate the range of measurements of unknown capacitance C_1.

Answer

Capacitance bridge :

1. This bridge is simplest method of comparing two capacitances.



(*a*) Circuit diagram

(*b*) Phasor diagram

Fig. 3.17.1.

2. At balance $I_1R_1 = I_2R_2$ ...(3.17.1)

and $$\frac{-j}{\omega C_1} I_1 = \frac{-j}{\omega C_2} I_2$$ ...(3.17.2)

3. Dividing eq. (3.19.1) by eq. (3.19.2), we have

$$\frac{R_1}{-j/\omega C_1} = \frac{R_2}{-j/\omega C_2}$$

After solving, we get

$$C_1 = C_2 \frac{R_2}{R_1}$$

4. This bridge is used for the capacitor with low dielectric losses such as air capacitor.

Numerical :

$$C_1 = C_2 \frac{R_2}{R_1}$$

For $R_2/R_1 = 100 : 1$:

$$C_1 = 0.1\ \mu\text{F} \times \frac{100}{1} = 10\ \mu\text{F}$$

For $R_2/R_1 = 1 : 100$:

$$C_1 = 0.1\ \mu\text{F} \times \frac{1}{100} = 0.001\ \mu\text{F}$$

Inductance bridge : Refer Q. 3.11, Page 3–17E, Unit-3.

4 UNIT

Electronic Measurements

CONTENTS

Part-1 : Electronic Instruments : .... **4–2E to 4–4E**
Wattmeter and Energy Meter

Part-2 : Time, Frequency and Phase Angle .... **4–4E to 4–21E**
Measurements Using CRO,
Storage Oscilloscope

Part-3 : Spectrum and Wave Analyzer, ... **4–21E to 4–25E**
Digital Counter and
Frequency Meter, Q Meter

PART-1

Electronic Instruments : Wattmeter and Energy Meter.

Questions-Answers
Long Answer Type and Medium Answer Type Questions

Que 4.1. Explain the working of electronic wattmeter.

Answer

1. Electronic wattmeters are used for direct, small power measurements or for power measurements at frequencies beyond the range of electrodynamometer-type instruments.
2. A simplified electronic wattmeter circuit is shown in Fig. 4.1.1.

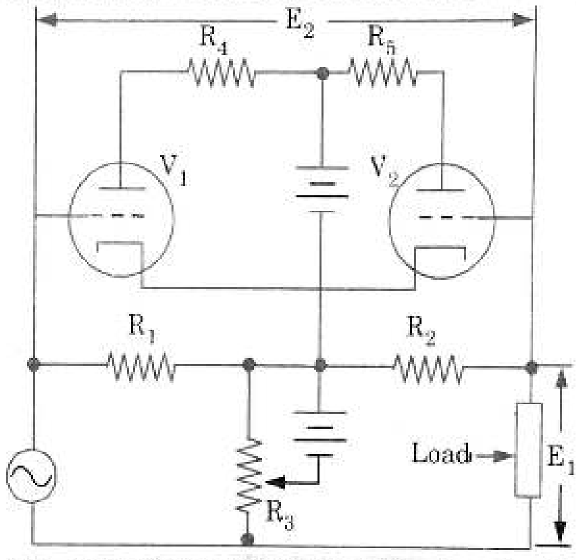


Fig. 4.1.1. Simple electronic wattmeter circuit.

3. The matched triodes are operated in the non-linear portion of their characteristic grid-voltage, plate-current curves.
4. The symmetrical resistive *T* network between the generator and load will provide V_1 and V_2 voltages proportional to, and in phase with, the load current and voltage, respectively.
5. A source of AC power is connected to the load through the series resistors R_1 and R_2.
6. These two resistors are of equal value and are made small to prevent the voltage drop across them from reducing the load voltage appreciably.

7. R_3 is made large enough to have negligible power consumption.
8. Therefore, the R_3 voltage is equal to the load voltage, and the voltage across either series resistor is proportional to the difference in the output currents of the tubes.
9. The average value of the difference could be measured by a DC meter connected to read the voltage potential between the grids of V_1 and V_2.
10. This method is adequate only at low frequencies.
11. As the frequency increases, the stray capacitances and inductances also increase.
12. The frequency range of the electronic wattmeter can be extended up to 20 megahertz by using pentodes instead of triode tubes. The operating conditions in a pentode are adjusted so that plate current is proportional to the product of a linear function of plate voltage and an exponential function of grid voltage.

Que 4.2. **Explain the energy meter.**

Answer

1. The measurement of energy can be done by using an electronic energy meter. Such an electronic energy meter uses integrated circuits. The measurement of energy can be divided into two parts.
2. Basically energy is defined as the total power delivered or consumed over a time period. So the measurement of energy can be done by measuring the power and time over which it is consumed.
3. A functional block diagram of an electronic energy meter is shown in Fig. 4.2.1.
4. Basically the average power is equal to the mean product of the instantaneous voltage across load and instantaneous current through it.
5. By using potential divider, the supply voltage is brought to required level. This voltage is then scaled appropriately in the required range by using voltage scaling device. While the current scaling device scales the load voltage which is proportional to the load current.
6. Both these scaled voltages are connected to voltage and current multiplier unit. This unit outputs the current as a result of the product of AC voltage and current.
7. The current proportional to an instantaneous power is applied to the voltage-controlled oscillator. It works on the principle of constant current charging of the capacitor.
8. As the voltage controlled oscillator is basically voltage to frequency converter, it produces a square wave output.

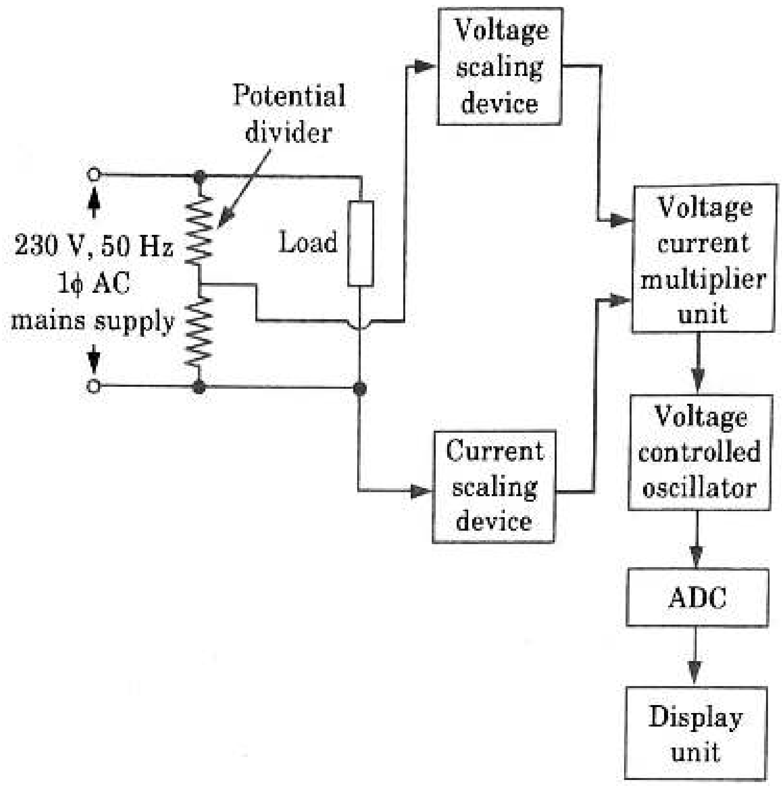


Fig. 4.2.1. Block diagram of electronic energy meter.

9. The frequency of this square wave is proportional to the output current of voltage-current multiplier.
10. Thus the power dependent current and the frequency dependent current decide the value of the consumed energy.
11. The analog signal is converted by using analog to digital converter. The display unit displays energy in watt-hour.

PART-2

Time, Frequency and Phase Angle Measurements using CRO, Storage Oscilloscope.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.3. **Explain the construction and working of a basic Cathode Ray Oscilloscope (CRO) circuit with the help of relevant diagrams.**

OR

How would you measure frequency using CRO ?

AKTU 2016-17, Marks 7.5

Answer

Construction :

1. The Cathode Ray Oscilloscope (CRO) is a very useful and versatile laboratory instrument used for display, measurement and analysis of waveforms and other phenomena in electrical and electronic circuits.

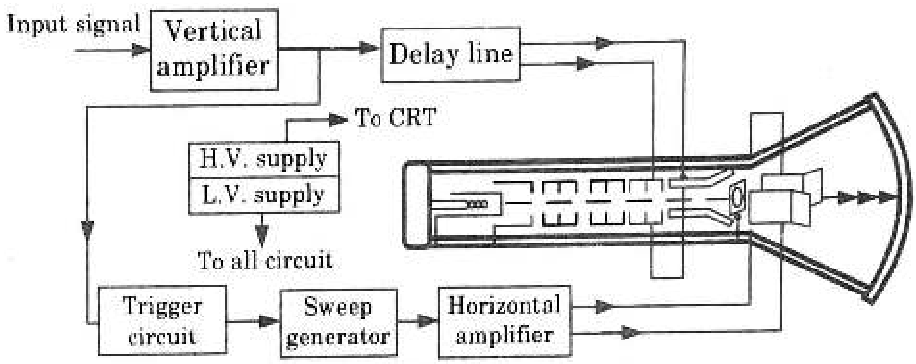


Fig. 4.3.1.

2. CROs are in fact very fast X-Y plotters, displaying an input signal versus another signal or versus time.
3. The normal form of a CRO uses a horizontal input voltage which is an internally generated ramp voltage called "Time Base".
4. However, it is possible to convert current, strain, acceleration, pressure and other physical quantities into voltages with the help of transducers and thus to present visual representations of a wide variety of dynamic phenomena on CROs.

Working of a CRO :

1. When signal is to be displayed or viewed on the screen it is applied across Y-plates of a cathode ray tube (CRT).
2. But to see its waveform or pattern, it is essential to spread it horizontally from left to right. This is achieved by applying a sawtooth voltage wave to X-plates.
3. Under these conditions the electron beam would move uniformly from left to right thereby graphing vertical vibration of the input signal versus time.

4. Due to repetitive tracing of the viewed waveform, we get a continuous display because of persistence of vision. To get a stable stationary display on the screen it is essential to synchronize the horizontal sweeping of the beam with the input signal across the Y-plates.

Time measurement :

1. The waveform is displayed on the screen such that one complete cycle is visible on the screen. Thus accuracy increases if a single cycle occupies as much as the horizontal distance on the screen.
2. The period of the waveform can be obtained as,

$$T = (\text{Number of divisions occupied by 1 cycle}) \times \frac{\text{Time}}{\text{Division}} = \text{Time period}$$

3. The frequency is the reciprocal of the period.

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

Frequency measurement :

1. When two sinusoidal voltages are simultaneously applied to horizontal and vertical deflection plates, a pattern is observed which is called Lissajous pattern.
2. Out of these two inputs, one is known frequency and other one is unknown frequency.
3. The signal whose frequency is to be measured is applied to Y-plates.
4. A known source of variable frequency is applied to X-plates.
5. The standard frequency is adjusted until the pattern appears as a circle or an ellipse indicating that both the signals are of same frequency.
6. It is not possible to adjust the standard signal frequency to the exact frequency of the unknown signal, the standard is adjusted to a multiple or a submultiple of the frequency of unknown source so that pattern appears stationary.
7. As shown is Fig. 4.3.2 sine wave is applied to X and Y plates.

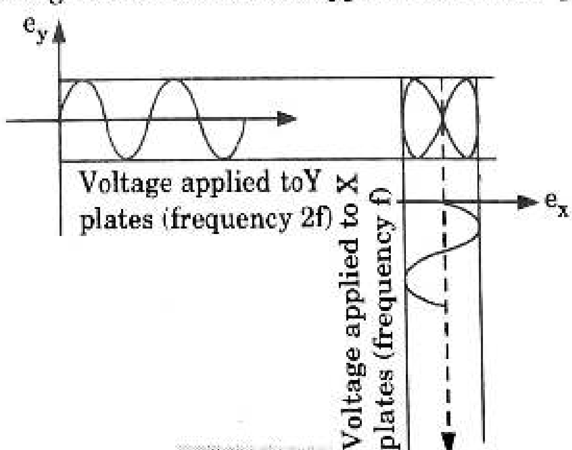


Fig. 4.3.2.

8. It shows that CRT spot travels two complete cycles in the vertical direction against one in horizontal direction.

9. The pattern obtained is in the shape of 8.
10. The ratio of two frequencies is

$$\frac{f_y}{f_x} = \frac{\text{Number of times tangent touches top or bottom}}{\text{Number of times tangent touches either side}}$$

where, f_y = Frequency of signal applied to Y-plates.

f_x = Frequency of signal applied to X-plates.

11. So the time period can also be determined by inverting the frequency.

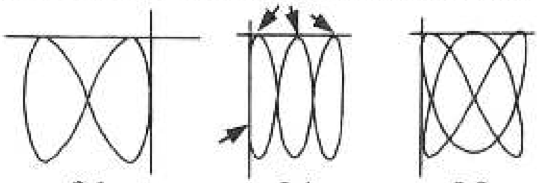
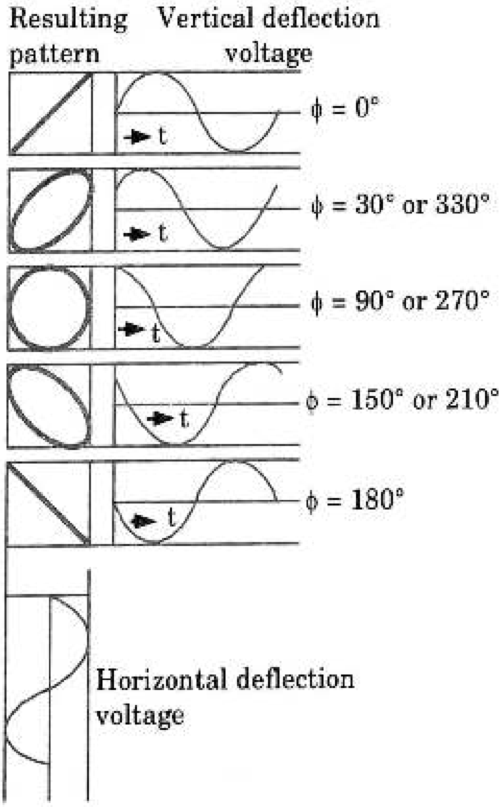


Fig. 4.3.3.

Phase angle measurement :

1. When two sinusoidal voltages of equal frequency which are in phase with each other are applied to the horizontal and vertical deflection plates, the pattern appearing on the screen is a straight line.
2. When two equal voltages of equal frequency but with phase shift 90° are applied to a CRO, the trace on the screen is a circle.
3. Two equal voltages of same frequency but with a phase shift ϕ is applied to a CRO we obtain Fig. 4.3.4.



(*a*) Lissajous pattern with different phase shifts.

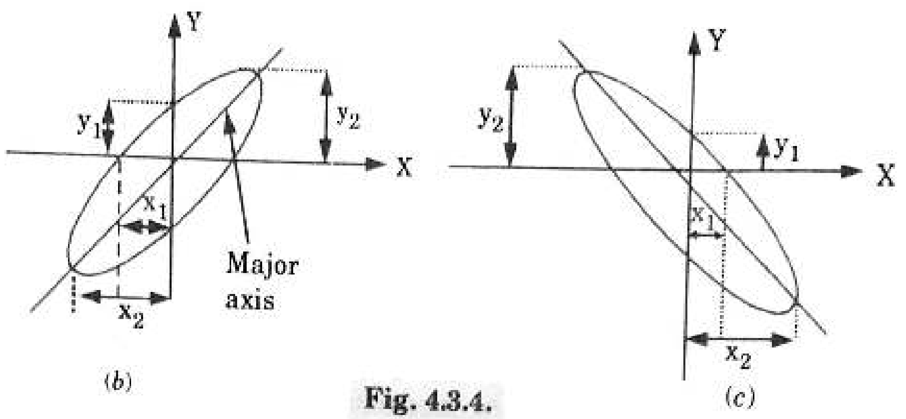


Fig. 4.3.4.

4. Regardless of the two amplitudes of the applied voltage the ellipse provides a simple means of finding phase difference between two voltages.

$$\sin\phi = \frac{y_1}{y_2} = \frac{x_1}{x_2} = \sin^{-1}\frac{y_1}{y_2} = \sin^{-1}\frac{x_1}{x_2}$$

Que 4.4. **Explain storage oscilloscope.**

Answer

Storage oscilloscope : Two storage techniques are used in oscilloscope CRTs : mesh storage and phosphor storage.

1. A mesh-storage CRT uses a dielectric material deposited on a storage mesh as the storage target. This mesh is placed between the deflection plates and the standard phosphor target in the CRT.
2. The writing beam, which is the focused electron beam of the standard CRT, charges the dielectric material positively where hit.
3. The storage target is then bombarded with low velocity electrons from a flood gun and the positively charged areas of the storage target allow these electrons to pass through to the standard phosphor target and thereby reproduce the stored image on the screen.
4. Thus the mesh storage has both a storage target and a phosphor display target. The phosphor storage CRT uses a thin layer of phosphor to serve both as the storage and the display element.

Mesh storage :

1. It is used to display Very Low Frequencies (VLF) signals and finds many applications in mechanical and biomedical fields.
2. A mesh storage CRT is shown in Fig. 4.4.1.

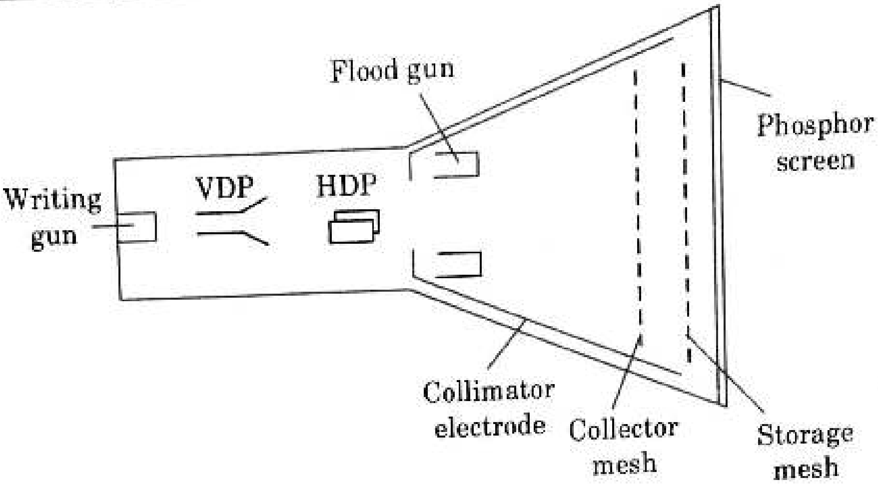


Fig. 4.4.1. Basic elements of storage mesh CRT.

3. It contains a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, in addition to all the elements of a standard CRT.
4. The writing gun etches a positively charged pattern on the storage mesh or target by knocking OFF secondary emission electrons.
5. In order to make a pattern visible a special electron gun, called the flood gun, is switched ON (even after many hours).
6. The electron paths are adjusted by the collimator electrode which continues a low voltage electrostatic lens system as shown in Fig. 4.4.2.

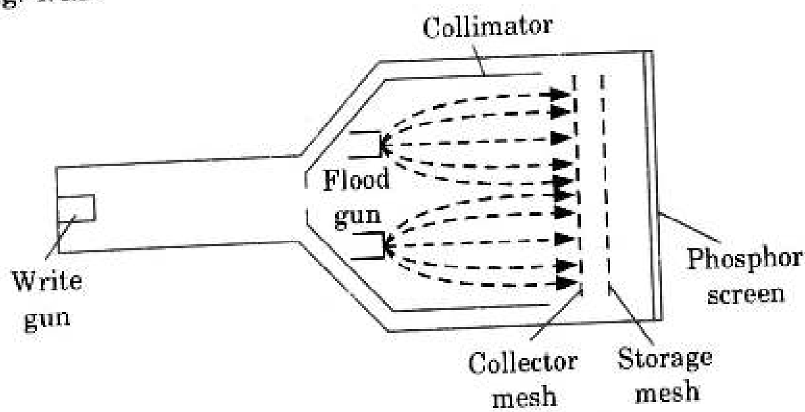


Fig. 4.4.2. Storage mesh CRT.

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

Que 4.5. **Explain dual trace oscilloscope and its application.**

Answer

Dual trace oscilloscope :

1. It has a single electron gun but the beam is split into two separate beams before it passes to the deflection plates.
2. There are two separate vertical input channels, *A* and *B*, and these use separate attenuator and preamplifier stages.
3. Therefore the amplitude of each input, as viewed on the oscilloscope, can be individually controlled.
4. After preamplification the two channels meet at a time into the vertical amplifier, via the delay line.
5. There are two common operating modes for the electronic switch, called alternate and chop, and these are selected from the instrument's front panel.
6. The alternate mode is shown in Fig. 4.5.1.

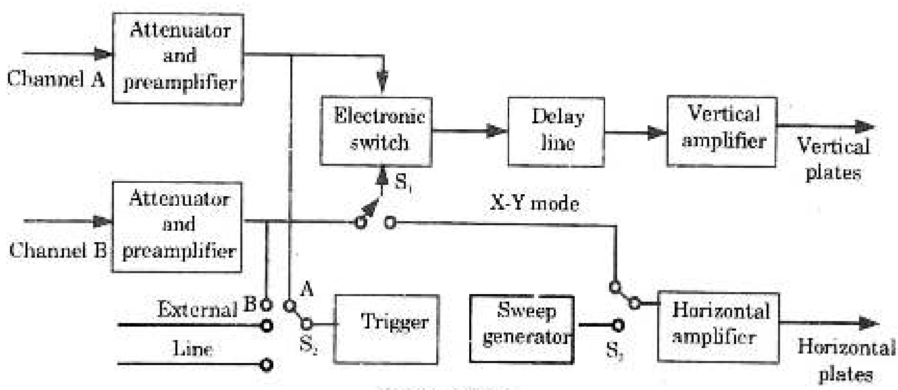


Fig. 4.5.1.

7. In this the electronic switch alternates between channels A and B, letting each through for one cycle of the horizontal sweep.
8. The display is blanked during the flyback and hold-off periods, as in a conventional oscilloscope.
9. Provided the sweep speed is much greater than the delay time of the CRT phosphor, the screen will show a stable display of both the waveform at channels *A* and *B*.
10. The alternate mode cannot be used for displaying very low frequency signals.

Applications :

1. Analyze signals produced by function generators.
2. Check response of a silicon, InGaAs, or avalanche photodiode.
3. Use with analog light meter output to visualize intensity of a source.
4. Troubleshoot electro-optical and electrical systems.
5. Observe a triggered event separately or relative to the trigger itself.

Que 4.6. **Why is delay line used in vertical section of an oscilloscope ? Explain it in detail.** **AKTU 2016-17, Marks 10**

Answer

1. 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.
2. 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 Fig. 4.6.1.

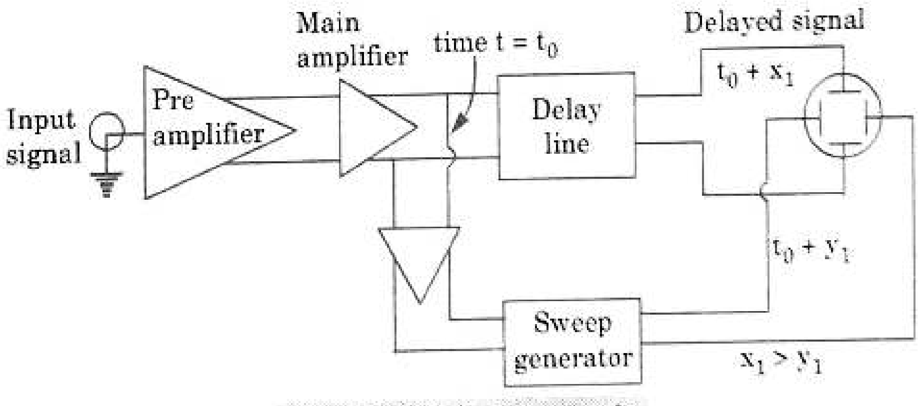


Fig. 4.6.1. Delay line circuit.

3. As the signal is delayed, the sweep generator output gets enough time to reach to the horizontal plates before signal reaches the vertical plates.
4. 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.
5. The design of delay line is such that the delay time x_1 is higher than the time y_1.
6. Generally, x_1 is 200 nanoseconds while the y_1 is 80 nanoseconds, thus the sweep starts well in time and no part of the signal is lost.
7. There are two types of delay lines used in CRO which are

a. Lumped parameter delay line.

b. Distributed parameter delay line.

Que 4.7. **Draw and explain the block diagram of oscilloscope automatic time base with proper waveforms at the output of each block.**

AKTU 2014-15, Marks 10

AKTU 2017-18, Marks 10

Answer

1. For a waveform to be displayed correctly, it is important that the ramp voltage producing the horizontal sweep begin at the instant when the displayed waveform goes positive.
2. The ramp wave must be synchronized with the input waveform.
3. Synchronization is accomplished by means of the sync input to the Schmitt trigger and by the other components of the automatic time base in Fig. 4.7.1.
4. The voltage waveform to be displayed (V_1) is applied to the vertical amplifier and to the time base triggering amplifier. Like the vertical amplifier, the triggering amplifier has differential outputs.
5. These provide two identical but antiphase voltage waveforms (V_{o1} and V_{o2}).
6. In the triggering amplifier, the input is amplified so much that its peaks are cut-off by saturation of the amplifier output stage. So the output waveforms are almost square. One of these waveforms is passed via switch S_2 to the input of an inverting Schmitt trigger circuit.
7. The Schmitt circuit is designed to have upper and lower trigger points. The Schmitt circuit output rapidly goes negative as the input passes the upper trigger point and positive as the input passes the lower trigger point as shown in Fig. 4.7.1.
8. The output from the Schmitt circuit is a square waveform. This square wave is applied to a differentiating circuit.
9. The output produced by the differentiator is proportional to the rate of change of the square wave.
10. Therefore, the differentiated square wave is a series of positive spikes and negative spikes as shown in Fig. 4.7.1.

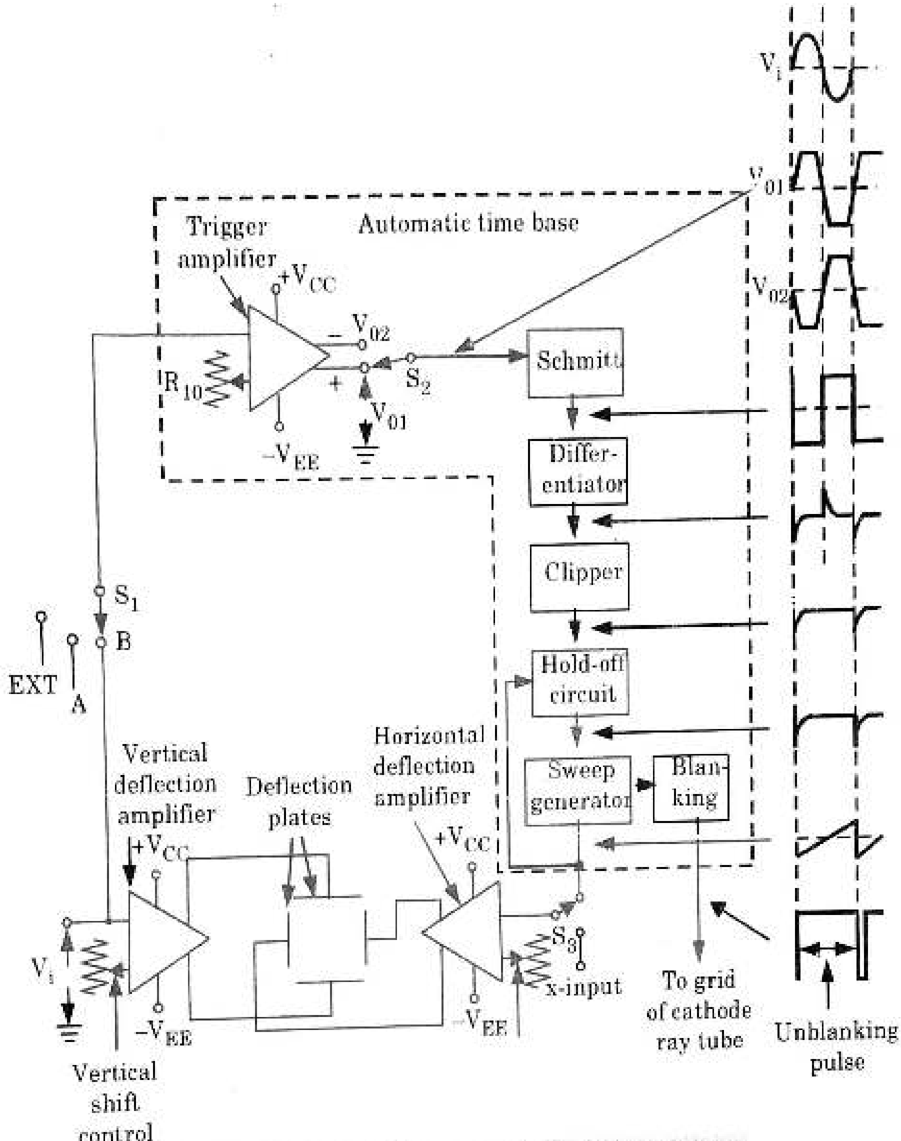


Fig. 4.7.1. Oscilloscope automatic time base.

11. The spike waveform is now fed to a positive clipper circuit. This is essentially a rectifier circuit that passes the negative spikes but blocks the positive spikes.
12. The negative spikes are passed via a hold-off circuit to the sync input of the sweep generator.
13. The train of negative spikes causes the ramp output of the sweep generator to be synchronized with the input waveform that is to be displayed.
14. The ramp commences at the beginning of each positive half-cycle of the input. The ramp output from the sweep generator is fed to the horizontal deflection amplifier.
15. This amplifier provides differential (antiphase) ramp outputs to the horizontal deflecting plates, and causes the electron beam to sweep from left to right on the oscilloscope screen. The input waveform is now displayed exactly as explained.

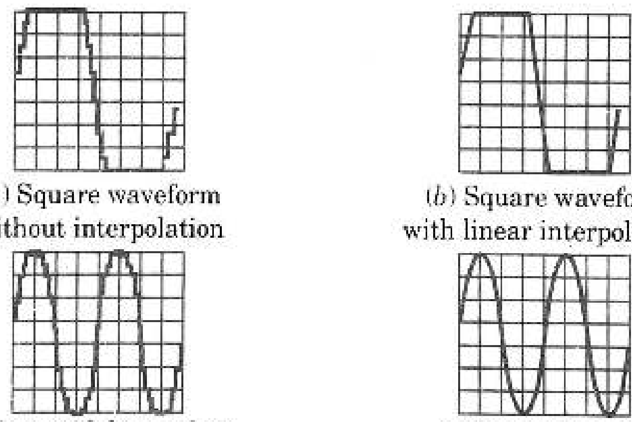
Que 4.8. **What do you mean by interpolation ? Briefly explain the operation of a DSO storage and display system.**

AKTU 2014-15, Marks 10

Answer

A. Interpolation :

1. To obtain a more representative display than the dot or step waveform, digital oscilloscopes normally have a facility for drawing lines between the sampled levels. This is termed as interpolation.
2. Linear interpolation occurs when straight lines are drawn between the levels.
3. This is most suitable for pulse waveform displays. Sine wave interpolation introduces a sinusoidal function between the sample levels, for use with sinusoidal waveforms. In Fig. 4.8.1 shows both types of interpolation.
4. Linear interpolation produces acceptable sine waves when a large number of samples are taken during each cycle. With fewer samples the straight lines between the sample levels give a distorted display.
5. Sine-wave interpolation can give satisfactory results with only 2.5 samples per cycle for sinusoidal waveforms, but when used with a pulse waveform it can introduce distortion such as overshoots.



(*a*) Square waveform without interpolation

(*b*) Square waveform with linear interpolation

(*c*) Sinusoidal waveform without interpolation

(*b*) Sinusoidal with sine-wave interpolation

Fig. 4.8.1.

B. DSO storage and display system :

1. In digital storage oscilloscope, the waveform is sampled at regular intervals and each sample is converted to digital form by means of an analog to digital converter.
2. The block diagram of a basic sampling and storage system for DSO is shown in Fig. 4.8.2

3. Here, the time base generates a pulse waveform at a desired sampling frequency. Each pulse switches the sampling gate and the ADC ON for a brief time period.
4. The sampling gate is used to generate a series of analog samples and the ADC converts each sample into a coded group of pulses.
5. The pulse groups are then passed to semiconductor or other memory, where they are stored for later recovery.

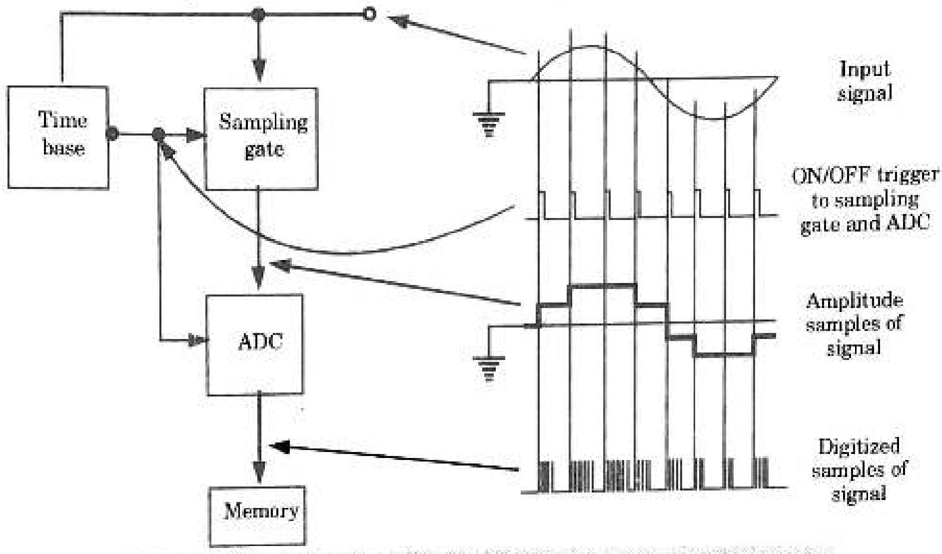


Fig. 4.8.2. Basic sampling and storage system for a DSO.

6. Fig. 4.8.3 shows a system for recovery of the stored information to recreate original waveform. The digital to analog converter (DAC), triggered by pulses from the time base, converts each digital sample back to analog form and passes it to oscilloscope vertical deflection amplifier.
7. The time base also generates a staircase waveform that is fed to the horizontal deflection amplifier. The vertical and horizontal inputs can be used to produce either a dot waveform on the oscilloscope screen.

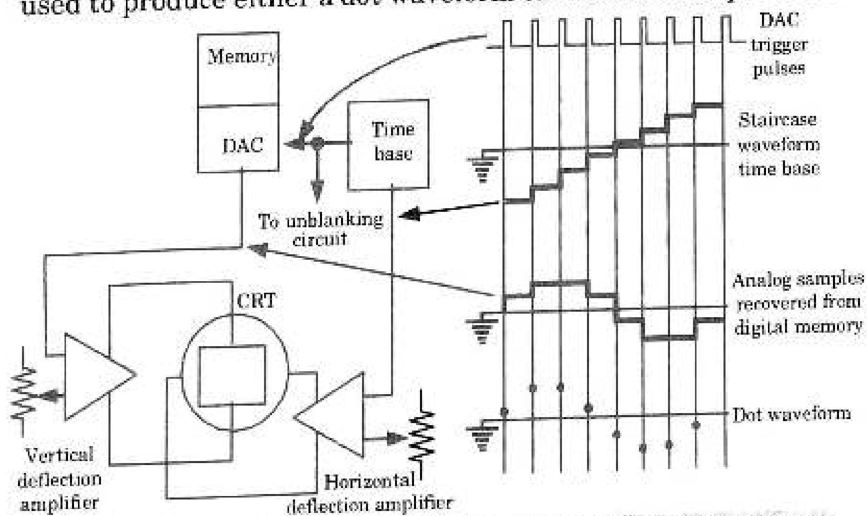


Fig. 4.8.3. Basic DSO system for displaying a stored waveform.

Que 4.9. **Write short note on DSO. Compare it with sampling oscilloscope.**

AKTU 2015-16, Marks 10

AKTU 2017-18, Marks 07

Answer

A. **DSO :** Refer Q. 4.8, Page 4–14E, Unit-4.

B. **Comparison :**

S. No.	Digital storage oscilloscope (DSO)	Digital sampling oscilloscope
1.	It is limited in speed due to digitising capability of the analog to digital converter.	It is fastest oscilloscope among all.
2.	Time base is generated by crystal clock so is more accurate and stable.	Time base is generated by ramp circuit.
3.	Waveform can be stored in digital binary form, which can be analyzed in it or taken to the computer for further analysis.	It can only make measurement of input signal. Data can't be stored for further analysis.
4.	It uses serial processing architecture.	Unlike other oscilloscope, digital sampling oscilloscope uses amplifier after the sampling.
5.	Sampling rate must be at least twice as fast as the highest frequency in input signal.	Sampling rate can be as low as one hundredth of the signal frequency.

Que 4.10. **Write short note with suitable example :**

a. **DSO and its applications.**

b. **Capacitance and inductance bridges.**

c. **Dual trace oscilloscope and its application.**

AKTU 2016-17, Marks 15

Answer

a. **DSO :** Refer Q. 4.8, Page 4–14E, Unit-4.

Applications :

1. **Autoset :** Some digital storage oscilloscopes have vertical (volts/div) and horizontal (time/div) controls, just like an analog oscilloscope.
2. **Multichannel displays :** Digital storage oscilloscopes are normally capable of displaying waveforms applied to two input channels.
3. **Waveform processing :** Digital oscilloscopes normally contain digital voltmeters, digital frequency meters and time measurement circuits, which print the desired measurements on the oscilloscope screen as the waveform is being displayed. Two cursors are employed to define the points on the waveform between which the measurement is to be made.
4. **Pre-triggering and post-triggering :** A DSO can be used to display portions of a waveform that occur before the normal trigger point or after the trigger point. Pre-triggering is possible because the input waveform is continually being digitized and stored in memory.
5. **Zoom and restart :** Zoom and restart are essentially additional methods of time delay selection and each is available with some DSO. The portion of the displayed waveform to be examined is first centered on the screen or marked by cursors.
6. **Glitch and runt catching :** Glitches occurring during the sampling time interval are invisible on oscilloscope, so where such waveform anomalies are important, an oscilloscope with a very high sampling rate should be used. A maximum/minimum level detector circuit is employed in some DSOs to detect the presence of a glitch.
7. **Baby-sitting mode :** A DSO can be set in a baby-sitting mode to deal with particular, *i.e.*, occurrence of waveform only once during a period of hour situation. This waveform is sampled and recorded continuously, so that at any instant several immediately previous cycles are stored. When an anomaly is detected, the stored samples are retained in the memory for later playback.

b. **Capacitance and inductance bridge :** Refer Q. 3.17, Page 3–26E, Unit-3.

c. **Dual trace oscilloscope and application :** Refer Q. 4.5, Page 4–10E, Unit-4.

Que 4.11. **Explain the operation of sampling oscilloscopes.**

Answer

A. **Sampling oscilloscope :**

1. It is specially meant for observing very high frequency signals by sampling the input waveform and reconstructing its shape from the sample.
2. Such high frequency oscillations cannot be viewed by conventional oscilloscope because its frequency range is limited by the gain bandwidth product of its vertical amplifier.

3. The input is applied to the sampling gate. It biases the diode of sampling gate in forward direction momentarily. So it connects the gate input capacitance to the test point.
4. The synchronization of the signal frequency with sampled waveform is done which causes delay in the vertical amplifier allowing horizontal sweep to be initiated by the input signal.
5. At the beginning of each sampling cycle, the trigger pulse activates the oscilloscope and a linear ramp voltage is generated.

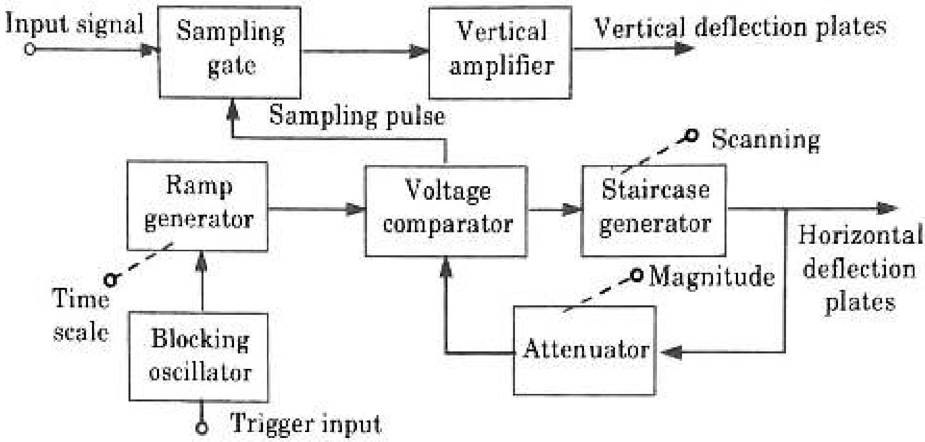


Fig. 4.11.1.

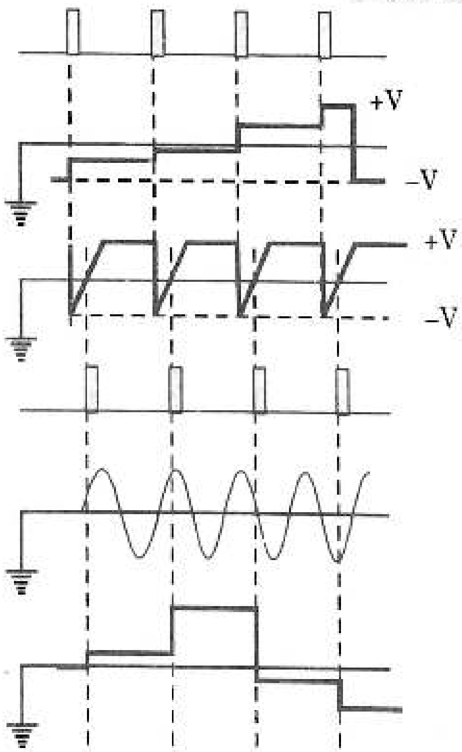


Fig. 4.11.2. Waveforms of sampling oscilloscope.

6. This ramp voltage is applied to a voltage comparator which compares the ramp voltage to a staircase generator which is allowed to advance one step and simultaneously a sampling pulse is applied to the sampling gate.
7. At this moment the sample of input voltage is taken, amplified and applied to the vertical deflection plates. It can be employed beyond 50 MHz – 500 MHz up to 10 GHz.

Que 4.12. **Explain the operation of sampling oscilloscopes. Also explain individual circuits of staircase generator and sampling gate.** **AKTU 2014-15, Marks 10**

Answer

A. **Sampling oscilloscope :** Refer Q. 4.11, Page 4–17E, Unit-4.

B. **Staircase generator :**

1. Fig. 4.12.1 shows the basic circuit of a staircase generator.

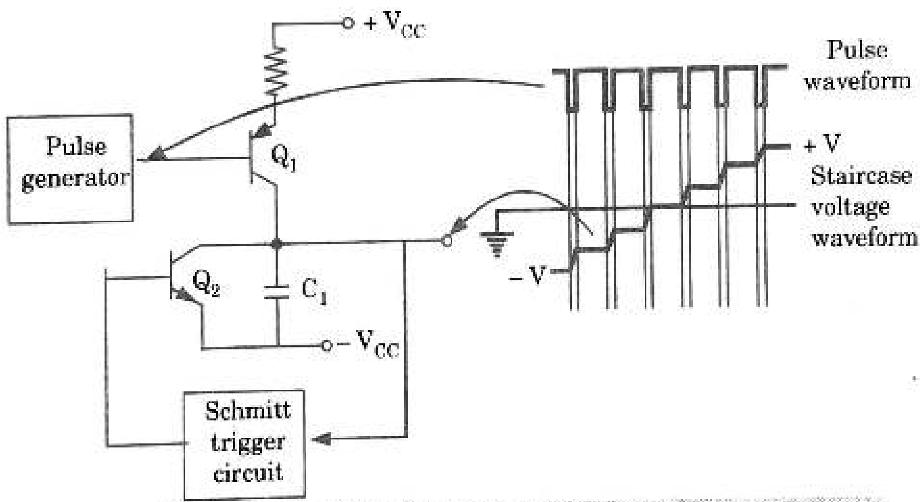


Fig. 4.12.1. Basic circuit and waveforms for a staircase generator.

2. Each negative going pulse from the pulse generator turns Q_1 ON for a brief time period. Each time Q_1 is switched ON, it provides a current pulse to capacitor C_1.
3. Every current pulse charges C_1 to a new voltage level, which remains constant until the next current pulse arrives.
4. When the capacitor voltage exceeds the intended upper level, the Schmitt trigger circuit is activated to turn Q_2 ON to discharge C_1 to its starting level.

C. **Sampling gate :**

1. The sampling gate is shown in Fig. 4.12.2.

2. It consists of FET Q_1 and capacitor C_1. A voltage follower is included to provide low output impedance. With the input to the gate of Q_1 normally biased negatively, Q_1 is OFF.
3. In this condition, it is like an open switch. When a positive pulse occurs at the gate, Q_1 switched ON into saturation.
4. The voltage drop from the drain to source terminals of the FET is extremely small when the device is biased on, so in the ON condition it is like a closed switch.

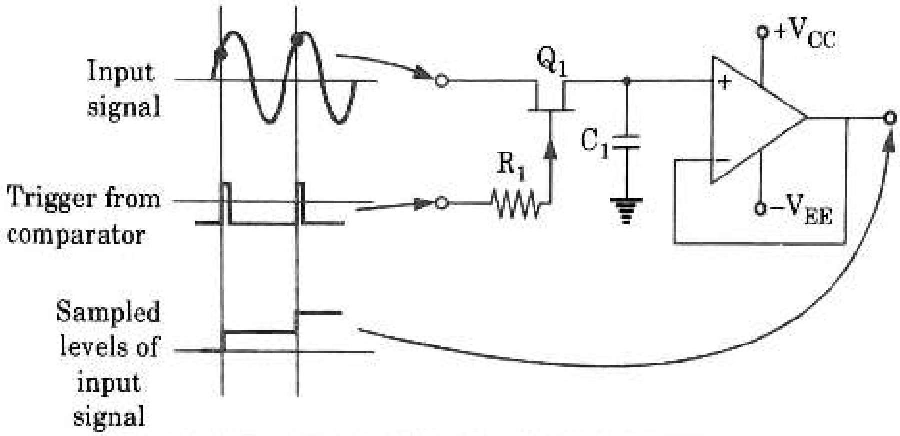


Fig. 4.12.2. Basic sampling gate circuit and waveforms.

5. Capacitor C_1 is charged to the level of the input voltage each time the FET is biased ON. When the FET goes OFF, C_1 retains its voltage constant at the level of the last sample.

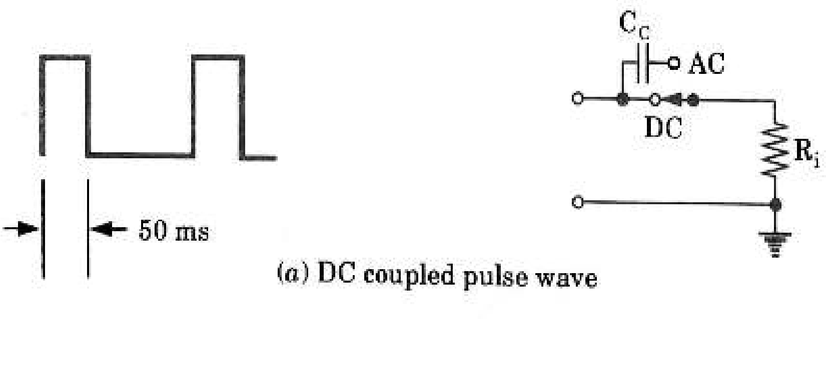
Que 4.13. **Explain pulse distortion and attenuator probe with suitable diagram.**

AKTU 2016-17, Marks 7.5

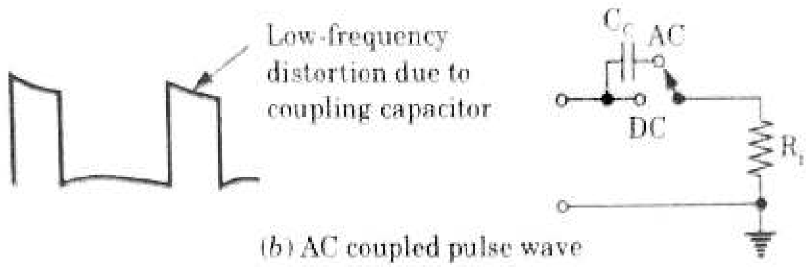
Answer

A. Pulse distortion :

1. The pulse waveform in Fig. 4.13.1(a) is directly coupled to the oscilloscope. Because it is directly coupled, there should be no distortion in the displayed waveform.



(a) DC coupled pulse wave



(b) AC coupled pulse wave

Fig. 4.13.1. A low-frequency pulse waveform will be faithfully reproduced on an oscilloscope if it is DC coupled. When AC coupled, the coupling capacitor may produce low-frequency distortion.

2. If the wave is AC coupled, as shown in Fig. 4.13.1(b), the coupling capacitor (C_C) imposes tilt (also termed slope, or sag) or low-frequency distortion, at the top and bottom of the waveform.
3. This is the result of the input capacitor charging and discharging during the pulse width and space width.
4. In this situation, the time constant of the oscilloscope input is

$$\tau = R_i C_C$$

B. Attenuator probe : Refer Q. 2.11, Page 2–15E, Unit-2.

PART-3

Spectrum and Wave Analyzer, Digital Counter and Frequency Meter, Q Meter.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.14. **Discuss the spectrum analyzer with the help of block diagram.**

Answer

1. Spectrum analysis is defined as the study of energy distribution across the frequency spectrum of a given electrical signal.
2. The study gives valuable information about bandwidth, effects of different types of modulation and spurious signal generation.
3. The spectrum analysis is divided into two major categories on account of instrumentation limitations and capabilities. They are :
   a. Audio frequency (AF) analysis.

b. Radio frequency (RF) spectrum analysis.

4. The spectrum analyzers are sophisticated instruments which are capable of portraying graphically the amplitude as a function of frequency in a portion of RF spectrum.
5. These instruments find wide applications for measurement of attenuation, FM deviation, and frequency in pulse studies.
6. The modern spectrum analyzer basically consists of a narrow band superheterodyne receiver and a CRO.
7. The receiver is electronically tuned by varying the frequency of the local oscillator.
8. The circuit incorporates a sawtooth generator which supplies a ramp voltage to the frequency control element of the voltage tuned local oscillator.
9. The local oscillator then sweeps through its frequency band at a recurring linear rate.

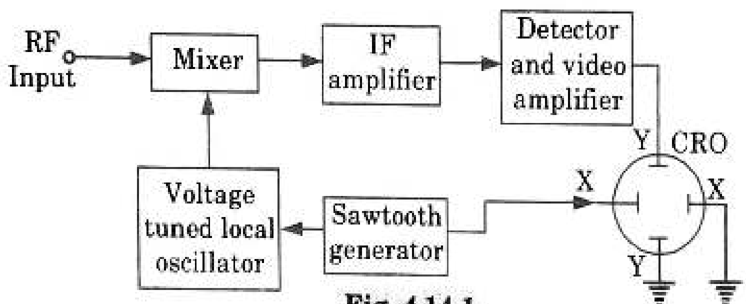


Fig. 4.14.1.

10. The same sawtooth voltage is simultaneously applied to the horizontal plates of the CRO.
11. The RF signal to be tested is applied to the input of the mixer stage.
12. The sawtooth generator makes the local oscillator sweep through its frequency band to beat with the input signal to produce the desired intermediate frequency (IF).
13. An IF component is produced only when the corresponding component is present in the RF input signal.
14. The resulting IF signals are amplified, and then detected.
15. After that they are applied to the vertical deflection plates of the CRO, thereby producing a display of amplitude versus frequency on the screen.

Que 4.15. **Explain the working of wave analyzer with the help of circuit diagram.**

Answer

1. A wave analyzer is an instrument designed to measure relative amplitudes of single frequency components in a complex waveform.

2. There are two types of wave analyzers, depending upon the frequency ranges used :

a. **Frequency selective wave analyzer :**

1. This wave analyzer is used for measurements in the audio frequency range (*i.e.*, from 20 Hz to 20 kHz).
2. The block diagram of this wave analyzer is shown in Fig. 4.15.1.
3. An input attenuator that is set by the meter range switch on the front panel.
4. A driver amplifier feeds the attenuated waveform to a high-Q active filter.
5. The filter consists of a cascaded arrangement of RC resonant sections and filter amplifiers.
6. Close-tolerance polystyrene capacitors are generally used for selecting the frequency ranges. Precision potentiometers are used to tune the filter to any desired frequency within the selection passband.
7. The buffer amplifier can be used to drive a recorder or an electronic counter.

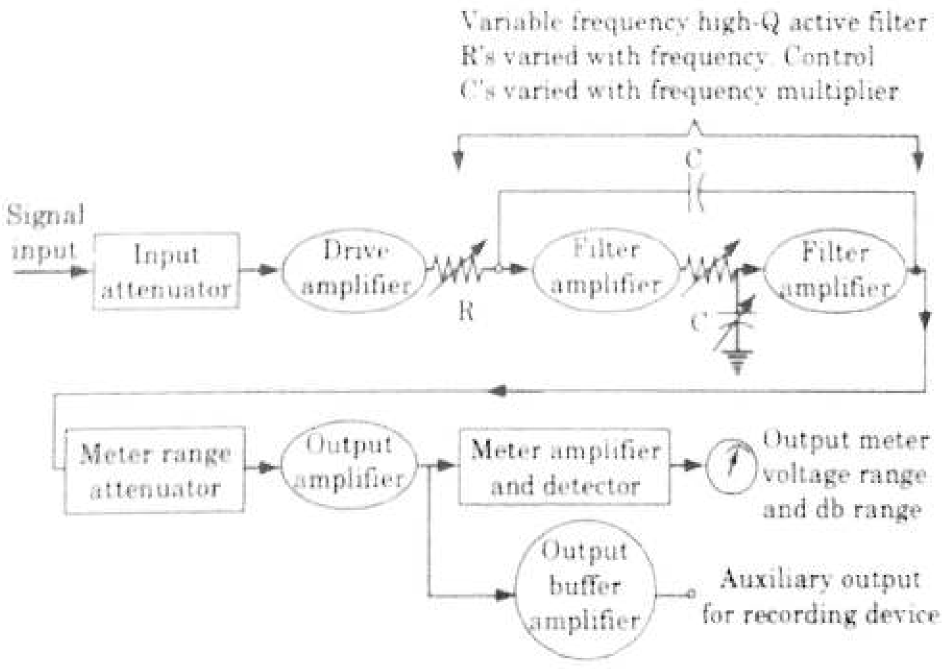


Fig. 4.15.1. Block diagram.

8. The bandwidth of the instrument is very narrow, typically about 1 percent of the selected frequency.

b. **Heterodyne wave analyzer :**

1. For frequency measurements in the megahertz range, a heterodyne wave analyzer construction is used, as shown in Fig. 4.11.2.

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2. The input signal is fed through an attenuator and amplifier before being mixed with a local oscillator.
3. The frequency of this oscillator is adjusted to give a fixed frequency output which is in the passband of the IF amplifier.
4. This signal is then mixed with a second crystal controlled oscillator, whose frequency is such that the output from the mixer is centred on zero frequency.

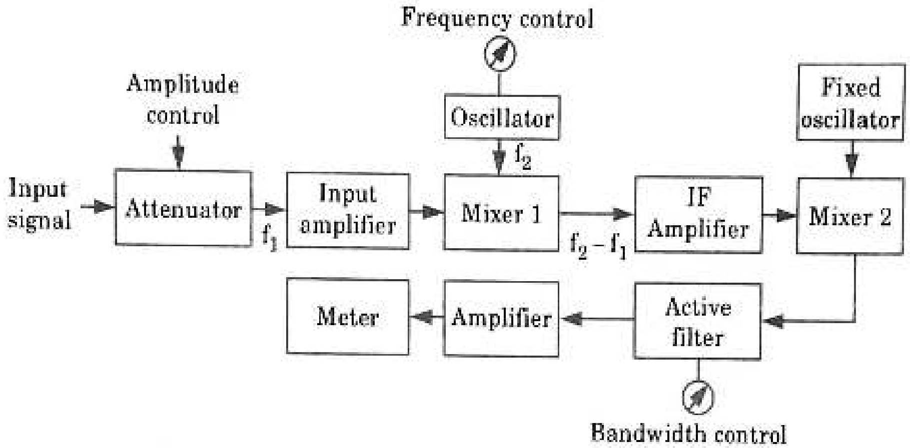


Fig. 4.15.2. Block diagram of a heterodyne wave analyzer.

5. The active filter has a controllable bandwidth and passes the selected component of the frequency to the indicating meter.
6. In automatic frequency control (AFC), the local oscillator locks to the signal, and so eliminates the drift between them.

Que 4.16. **What is a digital counter ? Draw and explain the circuit of digital frequency meter.**

Answer

A. **Digital counter :** Counter is a digital device and the output of the counter includes a predefined state based on the clock pulse applications. The output of the counter can be used to count the number of pulses. Generally, counters consist of a flip-flop arrangement which can be synchronous counter or asynchronous counter.

B. **DFM :** Refer Q. 2.17, Page 2–26E, Unit-2.

Que 4.17. **Explain the working procedure of Q-meter.**

AKTU 2016-17, Marks 05

OR

Explain the construction and working of Q-meter.

AKTU 2015-16, Marks 10

Answer

A. Construction :

1. The basic circuit of a Q meter as shown in Fig. 4.17.1 consists of a variable calibrated capacitor, a variable-frequency AC voltage source, and the coil to be investigated. All are connected in series.
2. The capacitor voltage (V_C) and the source voltage (E) are monitored by voltmeters.
3. The source is set to the desired measuring frequency, and its voltage is adjusted to a convenient level.

B. Working procedure :

1. The voltage across the coil or capacitor is equal to Q times the applied voltage.
2. If a fixed voltage is applied to the circuit, a voltmeter across the capacitor can be calibrated to read Q directly.
3. A wide range oscillator with frequency range from 50 kHz to 50 MHz is used as a power supply to the circuit.
4. Capacitor C is adjusted to obtain resonance, as indicated when the voltage across C is a maximum. If necessary, the source is readjusted to the desired output level when resonance is obtained.

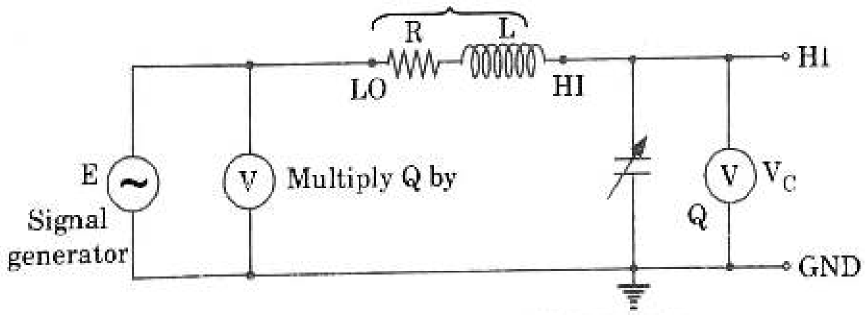


Fig. 4.17.1. Circuit diagram of Q meter.

5. At resonance,

$$V_C = V_L \text{ and } I = \frac{E}{R}$$

also
$$Q = \frac{\omega L}{R} = \frac{1}{\omega CR}$$

and
$$Q = \frac{V_L}{E} = \frac{V_C}{E}$$

5 UNIT

Instrumentation

CONTENTS

Part-1 : Transducers, Classification and Selection of Transducers, Strain Gauges .... **5–2E to 5–8E**

Part-2 : Thermistors, Thermocouples, LVDT, Inductive and Capacitive Transducers, Piezoelectric and Hall-Effect Transducers .... **5–8E to 5–20E**

Part-3 : Measurement of Motion, Force, Pressure, Temperature, Flow and Liquid Control .... **5–20E to 5–28E**

PART-1

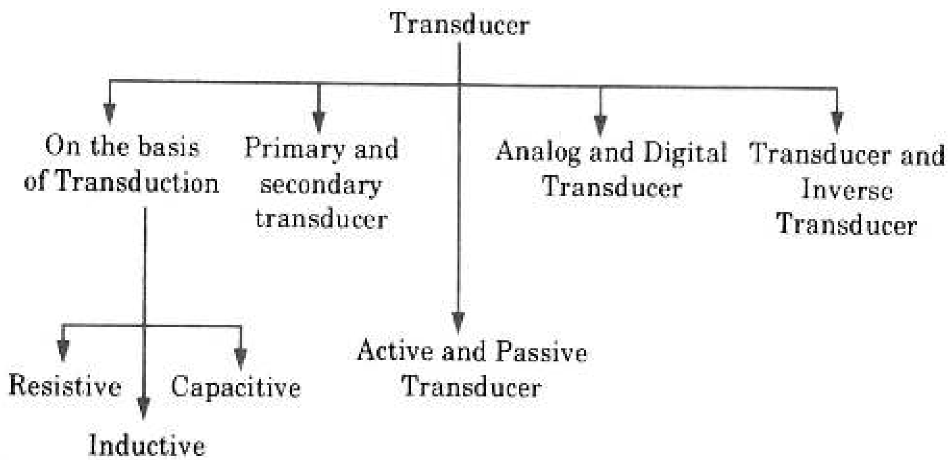
Transducers, Classification and Selection of Transducers, Strain Gauges.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **Classify transducers.**

Answer



A. Classification based on the principle of transduction :

i. The transducer is classified by the transduction medium.

ii. The transduction medium may be resistive, inductive or capacitive depends on the conversion process that how input transducer converts the input signal into resistance, inductance and capacitance respectively.

B. Primary and secondary transducer :

a. Primary transducer :

i. The transducer consists of mechanical as well as the electrical devices.

ii. The mechanical devices of the transducer change the physical input quantities into a mechanical signal. This mechanical device is known as the primary transducers.

b. Secondary transducer :

i. The secondary transducer converts the mechanical signal into an electrical signal.

ii. The magnitude of the output signal depends on the input mechanical signal.

C. Passive and active transducer :

a. Passive transducer :

i. The transducer which requires the power from an external supply source is known as the passive transducer.

ii. They are also known as the external power transducer.

iii. The capacitive, resistive and inductive transducers are the example of the passive transducer.

b. Active transducer :

i. The transducer which does not require the external power source is known as the active transducer.

ii. Such type of transducer develops theirs owns voltage or current, hence known as a self-generating transducer.

iii. The output signal is obtained from the physical input quantity.

D. Analog and digital transducer :

a. Analog transducer :

i. The analog transducer changes the input quantity into a continuous function.

ii. The strain gauge, LVDT, thermocouple and thermistor are the examples of the analog transducer.

b. Digital transducer : These transducers convert an input quantity into a digital signal or in the form of the pulse. The digital signals work on high or low power.

E. Transducer and inverse transducer :

a. Transducer : The device which converts the non-electrical quantity into an electric quantity is known as the transducer.

b. Inverse transducer : The transducer which converts the electric quantity into a physical quantity, such type of transducers is known as the inverse transducer. The transducer has high electrical input and low non-electrical output.

Que 5.2. **What are the factors to be considered while selecting transducer ?**

Answer

1. It should have high input impedance and low output impedance, to avoid loading effect.
2. It should have good resolution over is entire selected range.
3. It must be highly sensitive to desired signal and insensitive to unwanted signal.
4. It should be preferably small in size.

5. It should be able to work in corrosive environment.
6. It should be able to withstand pressure, shocks, vibrations etc.
7. It must have high degree of accuracy and repeatability.
8. Selected transducer must be free from errors.

Que 5.3. **For a transducer describe the following :**

i. Input characteristics;
ii. Output characteristics.

Answer

Input characteristics :

1. **Type of input and operating range :** The choice of transducer depends upon the type of input it is going to measure and its operating range. The upper limit is decided according to the transducer capabilities while the lower limit is decided according to the error. The transducer must possess a good resolution.
2. **Loading effects :** The transducer must have no loading effect on the input.

Output characteristics :

1. **Type of electrical output :** The output of the transducer is in the form of voltage, current, impedance or a time function of these amplitudes, which must be manipulated such that they may be accepted at later stages of instrumentation systems.
2. **Output impedance :**
   i. The output impedance must be made as low as possible to minimize the loading effect. The output impedance determines the amount of power which is to be transferred to next stage of the instrumentation system.
   ii. If the output impedance is low as compared to forward impedance then transducer shows the characteristics of constant voltage source and as constant current source when forward impedance is low as compared to the output impedance.
3. **Useful output range :** The lower output range of the transducer is limited by the noise signals and upper limit is set by maximum useful input level.

Que 5.4. **Enlist the factors affecting the choice of transducers.**

Answer

1. **Operating principle :** The transducers are selected on the basis of operating principle *i.e.*, whether resistive, inductive, capacitive, piezoelectric, optoelectronic etc.
2. **Sensitivity :** The transducers must be sensitive enough to produce detectable output.

3. **Operating range :** It should maintain the range as per the requirement and should have good resolution.
4. **Accuracy :** High degree of accuracy is acquired and gives small values of repeatability.
5. **Cross sensitivity :** This factor is considered when the mechanical quantities are measured. There are conditions where the actual quantity is being measured in one plane and the transducer is subjected to variations in another plane.
6. **Static characteristics :** Transducers must have a low non-linearity, low hysteresis, high resolution and high degree of repeatability. Transducers must be free from load alignment effects and temperature effects.
7. **Stability and reliability :** Transducer should exhibit a high degree of stability. They must be reliable *i.e.*, if transducer fails than also the functioning of instrumentation system should continue uninterruptedly.
8. **Errors :** The transducers should maintain the expected input-output relationship.
9. **Transient and frequency response :** The transducers must have the desired time domain specifications like peak overshoot, rise time, settling time and should ideally have flat frequency response curve.
10. **Loading effects :** The transducers must have high input impedance and low output impedance to avoid loading effects.

Que 5.5. **What are strain gauges ? Explain the construction of wire wound strain gauge and derive the expression for the gauge factor.**

Answer

1. It is used in measurement of strain and associated stress in experimental stress analysis. It works on the principle of piezoresistive effect.
2. If a strip of elastic material is subjected to tension its longitude dimension will increase while there will be a reduction in the lateral dimensions.
3. So when a gauge is subjected to a positive strain, its length increases while its area of cross-section decreases then the resistance of the gauge increases with the strains.

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

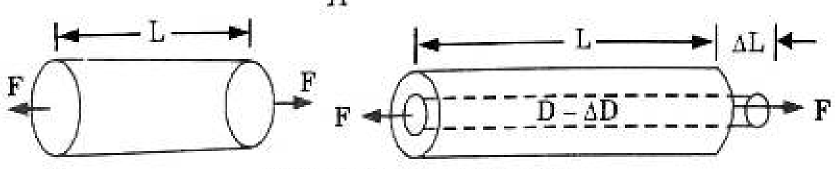


Fig. 5.5.1. Tensile force.

Expression for the gauge factor :

1. The resistance R of a conductor depends on cross-section area A, length L, and resistivity ρ as :

$$R = \frac{\rho L}{A} \quad ...(5.5.1)$$

2. Gauge factor G of the conductor is defined as

$$G = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{\varepsilon_a} \quad ...(5.5.2)$$

3. ΔR being change in resistance R due to axial strain ε_a, which is $\Delta L/L$.

Change $$\Delta R = \left(\frac{\partial R}{\partial L}\right)\Delta L + \left(\frac{\partial R}{\partial A}\right)\Delta A + \left(\frac{\partial R}{\partial \rho}\right)\Delta\rho$$

4. Substituting the expression for derivatives from eq. (5.5.1)

$$\Delta R = \left(\frac{\rho}{A}\right)\Delta L - \left(\frac{\rho L}{A^2}\right)\Delta A + \left(\frac{L}{A}\right)\Delta\rho$$

5. Dividing by expression R from eq. (5.5.1), we get

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A} + \frac{\Delta\rho}{\rho}$$

6. Area $A = CB^2$, where B is geometrical dimension of the strain gauge cross-section and C is a constant whose value depends on the section, equal to $\pi/4$ for circular section of diameter B and 1 for square section of sides B each.

$$\Delta A = 2\, CB\, \Delta B$$

$$\frac{\Delta A}{A} = \frac{2CB\Delta B}{CB^2} = \frac{2\Delta B}{B}$$

7. Thus, $$\frac{\Delta R}{R} = \frac{\Delta L}{L} - 2\frac{\Delta B}{B} + \frac{\Delta\rho}{\rho} = \varepsilon_a - 2\varepsilon_t + \frac{\Delta\rho}{\rho}$$

8. ε_a being axial strain $= \frac{\Delta L}{L}$, ε_t being transverse strain $= -\upsilon\varepsilon_a$, where υ is Poisson's ratio.

9. Finally, $$G = \frac{\Delta R / R}{\varepsilon_a} = 1 + 2\upsilon + \frac{\Delta\rho / \rho}{\varepsilon_a}$$

Que 5.6. **Explain the types of strain gauge.**

Answer

The major types of strain gauges are :

1. **Unbonded metal strain gauges :**

i. They consist of a wire stretched between two points in an insulating medium such as air.

ii. Applying pressure produces a small displacement of about 0.004 mm (full scale). This displacement causes increase or decrease of tension in the wires.

iii. This causes increase or decrease of the resistance causing unbalance in the bridge producing an output voltage proportional to the input displacement and hence to the applied pressure.

2. **Bonded wire strain gauges :**

i. They are used for both stress analysis and for construction of transducers.

ii. A resistive wire strain gauge consists of a grid of fine resistance wire. The spreading of wire permits a uniform distribution of stress over the grid permitting good transfer of strain from carrier to grid of wires.

iii. The wires faithfully follow both the tensile and compressive strains of the specimen.

3. **Bonded metal foil strain gauges :**

i. They are only an extension of the bonded metal wire strain gauges. They have greater heat dissipation capacity.

ii. They are also employed for both stress analysis and for construction of transducers.

4. **Vacuum and sputter deposited thin metal strain gauges :**

i. These gauges are mainly used for the fabrication of transducers. They are of sputter deposited variety.

ii. Both processes begin with a suitable elastic metal element. The elastic metal element converts the physical quantity into a strain.

5. **Semi-conductor strain gauges :**

i. They are used where a very high gauge factor and small envelope are required.

ii. The resistance of the semi-conductor changes with change in applied strain.

6. **Diffused strain gauges :** They are primarily used in transducers.

Que 5.7. **A resistance wire strain gauge with a gauge factor of 2 is bonded to a steel structural member subjected to a stress of 500 kg/cm^2. The modulus of elasticity of steel is 2×10^6 kg/cm^2. Calculate the change in resistance of the strain gauge element due to the applied stress.**

Answer

Given : Gauge factor, $G_f = 2$; Stress, $S = 500$ kg/cm^2

Modulus of elasticity of steel, $E = 2 \times 10^6$ kg/cm^2

To find : $\dfrac{\Delta R}{R}$

1. Strain, $\varepsilon = \frac{S}{E} = \frac{500}{2 \times 10^6} = 250 \times 10^{-6}$
2. $\frac{\Delta R}{R} = G_f \varepsilon = 2 \times 250 \times 10^{-6} = 5 \times 10^{-4}$
   $= 0.0005$
3. $\therefore$ $\frac{\Delta R}{R} = 0.05\ \%$

PART-2

Thermistors, Thermocouples, LVDT, Inductive and Capacitive Transducers, Piezoelectric and Hall Effect.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.8. Explain the construction and working principle of thermistor with suitable diagram and give the applications.

Answer

A. Thermistor :

1. A thermistor (or thermal resistor) is defined as a type of resistor whose electrical resistance varies with changes in temperature.
2. Although all resistors' resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.
3. Thermistors follow the principle of decrease in resistance with increasing temperature.
4. The material used in thermistor is generally a semiconductor material such as a sintered metal oxide (mixtures of metal oxides, chromium, cobalt, iron, manganese and nickel) or doped polycrystalline ceramic containing barium titanate ($BaTiO_3$) and other compounds.
5. As the temperature of semiconductor material increases the number of electrons able to move about increases which results in more current in the material and reduced resistance.
6. Thermistors are rugged and small in dimensions. They exhibit nonlinear response characteristics.
7. Thermistors are available in the form of a bead (pressed disc), probe or chip. Fig. 5.8.1 shows the construction of a bead type thermistor.

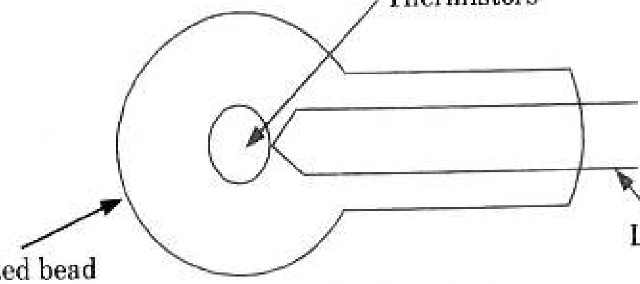


Fig. 5.8.1. Schematic of a thermistor.

8. It has a small bead of dimension from 0.5 mm to 5 mm coated with ceramic or glass material.
9. The bead is connected to an electric circuit through two leads. To protect from the environment, the leads are contained in a stainless steel tube.

B. Thermistor characteristics :

1. The relationship between temperature and resistance is given as :

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} \quad ...(5.8.1)$$

where, R_1 = Resistance of the thermistor at absolute temperature T_1[K].

R_2 = Resistance of the thermistor at temperature T_2[K].

β = Constant depending upon the material of the transducer.

2. As we can see in the eq. (5.8.1) the relationship between temperature and resistance is highly nonlinear.
3. A standard NTC thermistor usually exhibits a negative thermal resistance temperature coefficient of about 0.05/°C.

C. Working principle :

1. The working principle of a thermistor is that its resistance is dependent on its temperature. We can measure the resistance of a thermistor using an ohmmeter.
2. As we have relationship between the temperature and the resistance of the thermistor by measuring the thermistor's resistance we can derive its temperature.

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

3. Change in resistance depends on the type of material used in the thermistor.
4. The relationship between a thermistor's temperature and resistance is non-linear. A typical thermistor graph is shown in Fig. 5.8.2.

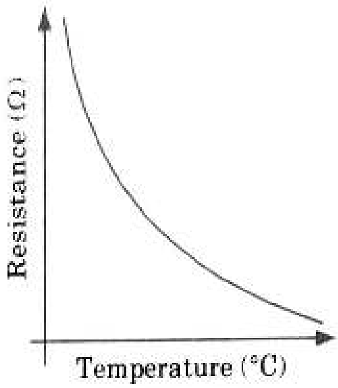


Fig. 5.8.2.

D. Applications of thermistors :

1. To monitor the coolant temperature and/or oil temperature inside the engine.
2. To monitor the temperature of an incubator.
3. Thermistors are used in modern digital thermostats.
4. To monitor the temperature of battery packs while charging.
5. To monitor temperature of hot ends of 3D printers.
6. To maintain correct temperature in the food handling and processing industry equipments.
7. To control the operations of consumer appliances such as toasters, coffeemakers, refrigerators, freezers, hair dryers, etc.

Que 5.9. Explain the working principle of thermocouple instruments.

Answer

1. The working principle of a thermocouple depends on the thermoelectric effect.
2. If two dissimilar metals are joined together so as to form a closed circuit, there will be two junctions where they meet each other.
3. If one of the junction is heated then a current flows in the circuit which can be detected by galvanometer.
4. The amount of the current produced depends on the differences in temperature between the two junctions and on the characteristics of the two metals.
5. This was first observed by Seebeck and known as Seebeck effect.
6. Instrument which record the variations in current flows are calibrated in terms of temperature and are known as thermocouple pyrometer.
7. Thermocouple is made from two different kinds of metals.

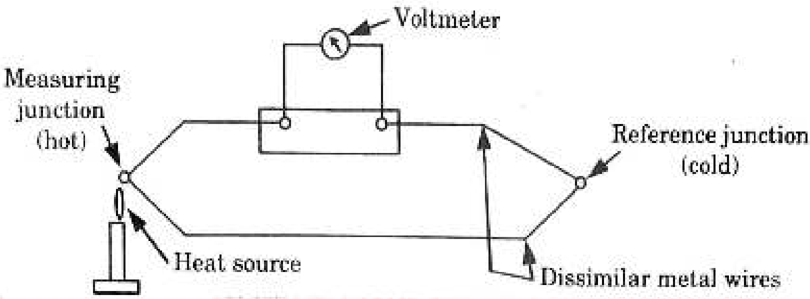


Fig. 5.9.1. Thermocouple.

8. The wires are joined at the end which forms two junctions, a measuring junction and a reference junction.
9. Heating the measuring junction produces a voltage greater than the voltages across the reference junction.
10. The difference between two voltages is measured and voltmeter reading is converted to its corresponding temperatures.
11. It consists of a protective well and head across measuring junction to avoid damages in pressurized systems or when measuring corrosive fluids.
12. The measuring junction of the thermocouple is connected to the voltmeter and reference junction with extension wires. Extension wires are also known as compensating leads.
13. The characteristics of compensating wire must be similar to those of the thermocouples wires it joins otherwise the voltage generated at the connections will be large enough to affect the instruments accuracy.

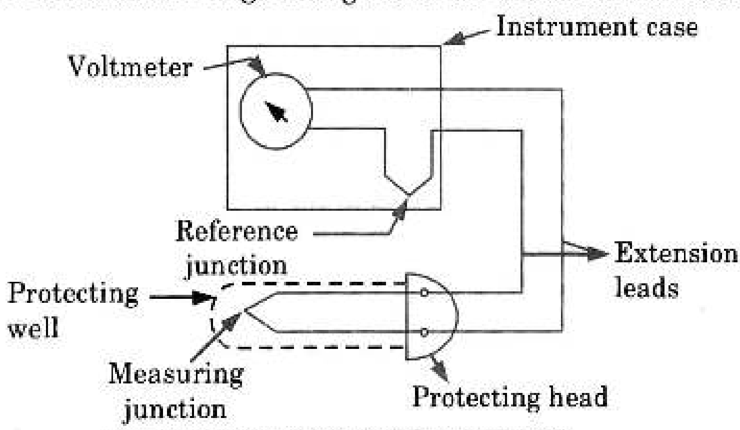


Fig. 5.9.2. Practical thermocouple.

14. The voltmeter reads the difference between the measuring and reference junction voltages which can be calibrated to give temperature reading.

Que 5.10. **Discuss the construction and working of LVDT.**

Answer

LVDT : Linear variable differential transformer is an inductive type of transducer which translates the linear motion into electrical signals.

A. Main features of construction :

1. The transformer consists of a primary winding *P* and two secondary windings S_1 and S_2 wound on a cylindrical former (which is hollow in nature and contains the core).
2. Both the secondary windings have an equal number of turns, and we place them on either side of primary winding.
3. The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
4. A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
5. The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
6. The LVDT is placed inside stainless steel housing because it will provide electrostatic and electromagnetic shielding.
7. The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings as shown in Fig. 5.10.1.

B. Principle of operation and working :

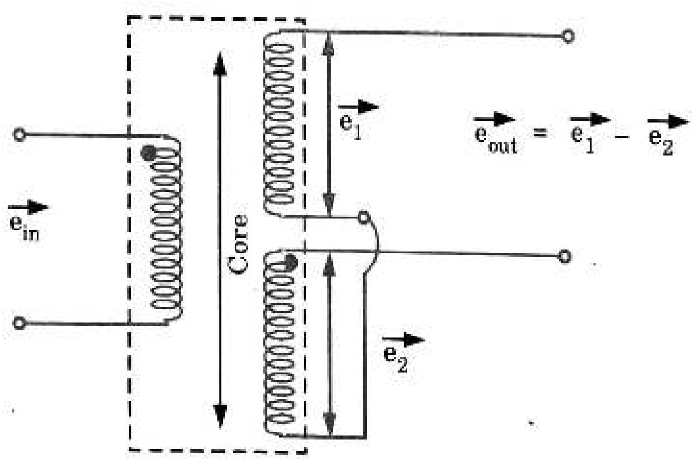


Fig. 5.10.1.

1. As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is e_1 and in the secondary S_2 is e_2. So the differential output is,

$$e_{out} = e_1 - e_2 \qquad ...(5.10.1)$$

2. Eq. (5.10.1) explains the principle of operation of LVDT.

3. Now three cases arise according to the locations of core which explains the working of LVDT :

a. **Case I : When the core is at null position (for no displacement) :**

i. When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings.

ii. So for no displacement the value of output e_{out} is zero as e_1 and e_2 both are equal. So it shows that no displacement took place.

b. **Case II : When the core is moved to upward of null position (For displacement to the upward of reference point) :**

In this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this e_1 will be more as that of e_2. Due to this output voltage e_{out} is positive.

c. **Case III : When the core is moved to downward of null position (for displacement to the downward of the reference point) :**

In this case magnitude of e_2 will be more as that of e_1. Due to this output e_{out} will be negative and shows the output to downward of the reference point.

Que 5.11. **Explain the Inductive transducers.**

Answer

Inductive type transducers : In these types of transducers, the magnetic characteristics of an electric circuit change due to the motion of the object. These may be classified into two types :

i. Self-generating types, in which a voltage signal is generated in the transducer, because of relative motion of a conductor and a magnetic field. Electrodynamic, electromagnetic and eddy circuit types of transducers belong to this category.

ii. Non-self generating or external power source types of transducers, in which an external source is needed to energise a coil the inductance of which would change due to the motion of the object. The following types of transducers belong to this category: attachment type inductance transducer, air gap type, LVDT type and magneto-strictive type of transducer.

Self-generating :

1. Fig. 5.11.1 shows an electrodynamic transducer for measuring rotary motion. The coil moves in the annular space between a magnet and a soft iron core, generating a voltage in the coil.

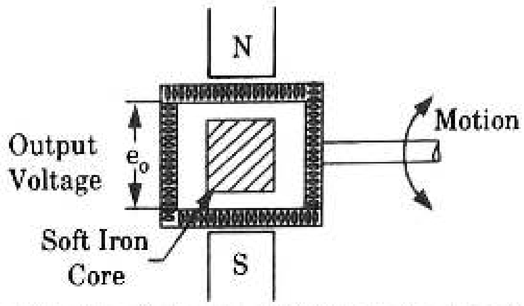


Fig. 5.11.1. Electrodynamic transducer for rotary motion.

2. Fig. 5.11.2 shows an electromagnetic transducer, in which a voltage is induced in the coil when the magnetic flux about it is varied due to the motion of the object, which has to be done for a ferromagnetic material.

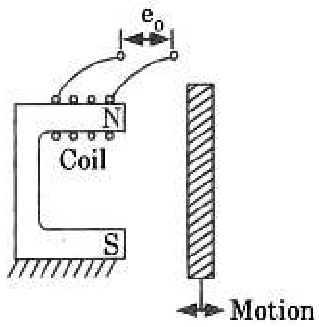


Fig. 5.11.2. Electromagnetic transducer.

3. Fig. 5.11.3 shows an eddy-current-type transducer. A non-ferrous plate moves in a direction perpendicular to the lines of flux of a magnet. Eddy currents are generated in the plate. These are proportional to the velocity of the plate. Since the gap remains constant, the transducer has linear characteristics.

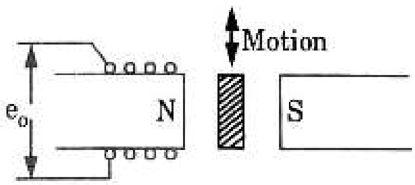


Fig. 5.11.3. Eddy current transducer.

Non-self generating types :

1. An inductance transducer of attachment type is shown in Fig. 5.11.4. The core, made of high permeability steel, is attached to the moving object. The motion changes the length of the core inserted in the coil and thus the inductance of the coil gets changed due to the change of reluctance of the magnetic flux path.

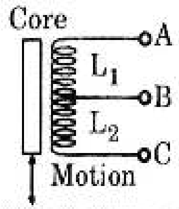


Fig. 5.11.4. Variable inductance transducer.

2. Fig. 5.11.5 shows a variable inductance transducer for measuring angular displacement or torsional motion. One half of the core is made of a magnetic material while the other half of non-magnetic material. In the variable inductance transducer, shown in Fig. 5.11.5 a small air gap in the magnetic flux path of an electromagnet is varied. The inductance of one coil increases while that of the other decreases.

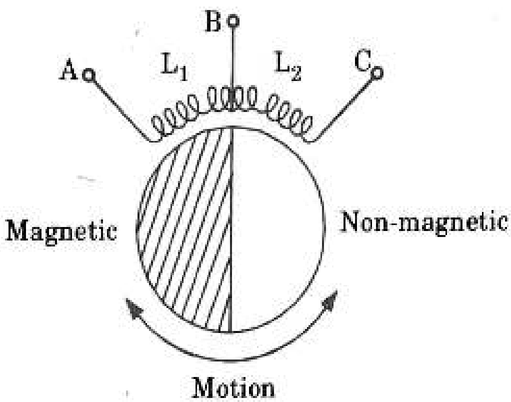


Fig. 5.11.5. Variable inductance transducer for rotary motion.

3. In a linear variable differential transducer (LVDT) type of transducer, shown in Fig. 5.11.6 a soft iron core provides the magnetic coupling between a primary coil and two secondary coils, connected in series opposition. When the core is central and both secondaries are identical, the voltages across them are equal in magnitude.

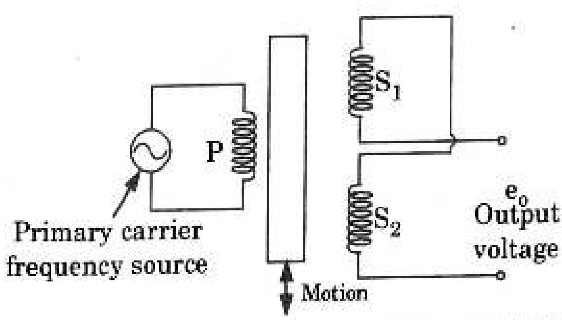


Fig. 5.11.6. LVDT (Linear motion type).

Que 5.12. **Discuss the capacitive transducer. Also write its merits and demerits.**

Answer

1. For a parallel plate capacitor, the capacitance is :

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon x w}{d} \text{ F} \qquad ...(5.12.1)$$

where, x = Length of overlapping part of plates ; m
and w = Width of overlapping part of plates ; m

2. Sensitivity $$S = \frac{\partial C}{\partial x} = \varepsilon \frac{w}{d} \text{ F/m} \qquad ...(5.12.2)$$

The sensitivity is constant and therefore there is linear relationship between capacitance and displacement.

3. Sensitivity for a fractional change in capacitance

$$= S' \frac{\partial C}{C \partial x} = \frac{1}{x} \qquad ...(5.12.3)$$

4. This type of a capacitive transducer is suitable for measurement of linear displacements ranging from 1 mm to 10 mm. The accuracy is as high as 0.005 %.

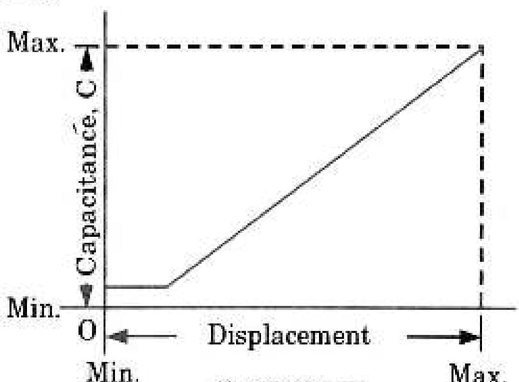


Fig. 5.12.1.

Merits :

1. They require extremely small forces to operate them and hence are very useful for use in small system.
2. They are extremely sensitive.
3. They have high input impedances and therefore the loading effects are minimum.

Demerits :

1. The capacitance of a capacitive transducer may be changed on account of presence of extra means like dust particles and moisture.
2. The capacitive transducers are temperature sensitive and therefore any change in temperature adversely affects their performance.

Que 5.13. **Explain working principle of piezo-electric transducer with diagram.**

Answer

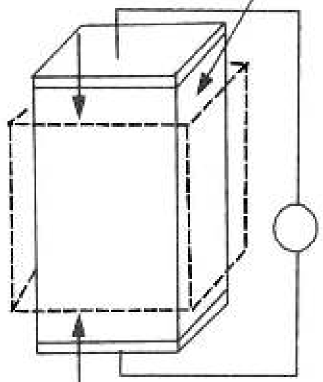


Fig. 5.13.1. Principle of working of piezoelectric sensor.

1. A piezoelectric transducer (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.
2. When pressure is applied to a crystal, it is elastically deformed. This deformation results in a flow of electric charge (which lasts for a period of a few seconds).
3. The resulting electric signal can be measured as an indication of the pressure which was applied to the crystal.
4. These sensors cannot detect static pressures, but are used to measure rapidly changing pressures resulting from blasts, explosions, pressure pulsations (in rocket motors, engines, compressors) or other sources of shock or vibration.
5. Piezoelectric sensor is used for the measurement of pressure, acceleration and dynamic-forces such as oscillation, impact, or high speed compression or tension.
6. It contains piezoelectric ionic crystal materials such as Quartz as shown in Fig. 5.13.1. On application of force or pressure these materials get stretched or compressed.
7. During this process, the charge over the material changes and redistributes. One face of the material becomes positively charged and the other negatively charged.
8. The net charge q on the surface is proportional to the amount x by which the charges have been displaced. The displacement is proportional to force. Therefore we can write,

$$q = kx = SF \quad ...(5.13.1)$$

where k = Constant

S = Constant termed the charge sensitivity.

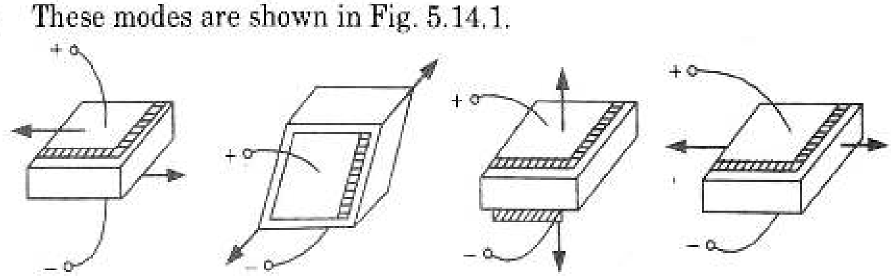
Que 5.14. **Describe the different modes of operation of piezo-electric transducers with suitable diagram.**

AKTU 2016-17, Marks 10

Answer

Modes of operation of piezo-electric transducers :

1. The piezo-electric transducers are used in many modes. These modes are :
   - i. Thickness shear,
   - ii. Face shear,
   - iii. Thickness expansion and
   - iv. Transverse expansion.
2. The mode of motion affected depends on the shape and orientation of the body relative to the crystal axes and the location of the electrodes.
3. Metal electrodes are plated onto selected faces of the piezo-electric material so that, lead wires can be attached for bringing in or leading out the electric charge.
4. Since the piezo-electric materials are insulators, the electrodes also become the plates of a capacitor.
5. A piezo-electric element used for converting mechanical motion to electric signals thus may be thought of as a charge generator and a capacitor.
6. Mechanical deformation generates a charge; this charge then results in a definite voltage appearing between the electrodes according to the usual law for capacitors, $E = Q/C$.
7. The piezoelectric effect is direction-sensitive in that tension produces a definite voltage polarity while compression produces the opposite.
8. These modes are shown in Fig. 5.14.1.



(*a*) Thickness shear (*b*) Face shear (*c*) Thickness expansion (*d*) Transverse expansion

Fig. 5.14.1. Modes of operation of piezo-electric transducers.

Que 5.15. **Explain with diagram of Hall effect transducer.**

Answer

Hall Effect transducer :

1. The principle of working of a Hall Effect transducer is that if a strip of conducting material carries a current in the presence of a transverse magnetic field, a potential difference is produced between the opposite edges of the conductor.
2. The magnitude of the voltage depends upon the current, the strength of magnetic field and property of the conductor called "Hall Effect".
3. The Hall Effect is present in metals and semiconductor in varying amounts, depending upon the densities and mobilities of carriers.
4. Let us consider Fig. 5.15.1 where current is passed through leads 1 and 2 of the strip.
5. The output leads connected to edges 3 and 4 are at the same potential when there is no transverse magnetic field passing through the strip.
6. When a transverse magnetic field passes through the strip, an output voltage appears across the output leads.
7. This voltage is proportional to the current and the field strength.

The output voltage is

$$E_H = K_H IB/t \quad ...(5.15.1)$$

where, K_H = Hall Effect coefficient in $\dfrac{\text{V-m}}{\text{A-Wb/m}^2}$

t = Thickness of strip in 'm'

and I and B are respectively the current in ampere and flux density in Wb/m^2.

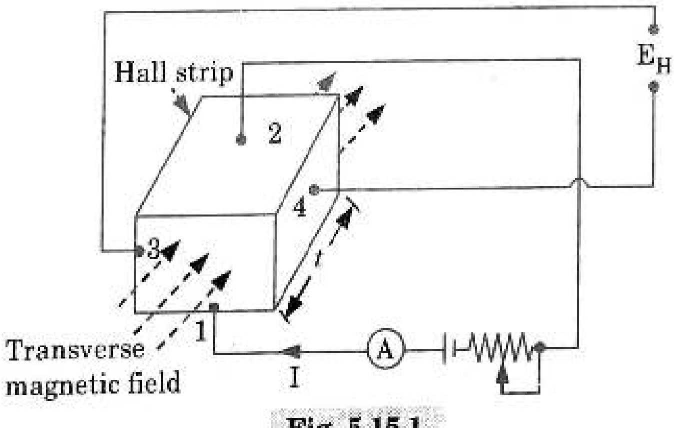


Fig. 5.15.1.

Thus, the voltage produced may be used for measurement of either the current I or the magnetic field strength B.

Que 5.16. **An Hall Effect element used for measuring a magnetic field strength gives an output voltage 10 mV. The element is made of silicon and is 3.0×10^{-3} m thick and carries a current of 2 amp. The Hall co-efficient is 4.1×10^{-6} Vm/A-Wb/m². Find magnetic field strength (β).**

Answer

Given : Output voltage, E_H = 10 mV, Thickness, $t = 3.0 \times 10^{-5}$ m, Current, I = 2 amp, Hall's co-efficient, $K_H = 4.1 \times 10^{-6}$ V-m/A-Wb/m²

To Find : Magnetic field strength (β)

The output voltage is given by :

$$E_H = K_H I\beta/t$$

$$10 \times 10^{-3} = \frac{4.1 \times 10^{-6} \times 2 \times \beta}{3.0 \times 10^{-3}}$$

$$\beta = \frac{3 \times 10 \times 10^{-6}}{8.2 \times 10^{-6}} = 3.66 \text{ Wb/m}^2$$

PART-3

Measurement of Motion, Force, Pressure, Temperature, Flow and Liquid Level.

Questions-Answers
Long Answer Type and Medium Answer Type Questions

Que 5.17. **Describe with diagram the moving magnet type transducer used for measuring linear velocity. Also enlist its merits and demerits.**

Answer

Moving magnet type velocity transducer :

1. This utilizes the output voltage (e_0) produced in coil on account of change in flux linkage, resulting from changes in reluctance.

$$e_0 = \frac{d\phi}{dt} = \frac{N}{R}\frac{di}{dt} = \frac{Ni}{R^2}\frac{dR}{dt}$$

2. If average value of reluctance R is greater than the variations in R, the Ni/R^2 is approximately constant. Thus, rate change of flux is proportional to rate change of reluctance directly.

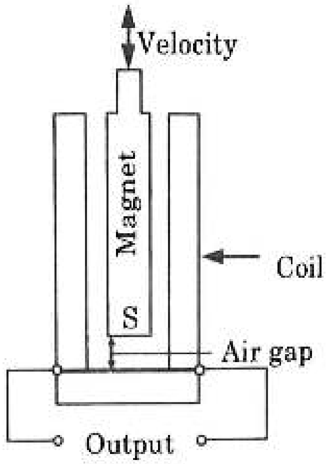


Fig. 5.17.1. Moving magnet type transducers.

3. R varies directly as length of air gap and thus output voltage is directly proportional to rate change of air gap and hence to the velocity.
4. The constant mmf (Ni) is provided by solenoid of N turns as shown.
5. A permanent magnet is used, that provides constant polarizing field, in form of a rod rigidly coupled with device whose speed is to be measured.
6. The polarity of output determines the direction of motion.

Merits :

i. Maintenance is negligible.

ii. Output voltage is linearly proportional to motion.

iii. These are robust and inexpensive to manufacture.

Demerits :

i. Performance is adversely affected by stray magnetic fields.

ii. Frequency response is limited.

Que 5.18. **Explain the measurement of force.**

Answer

Measurement of force is done by

1. **Balance :**

As shown in Fig. 5.18.1(a) is called a balance. To measure the unknown force F at a distance L from the pivot, a mass m at a distance l from the pivot is used. The system is in equilibrium when

$$FL = mgl$$

2. **Hydraulic load cell :**

Hydraulic pressure is used to indicate the force F, applied to a diaphragm or some other type of force transmitting element. Such a device can be used up to very large forces.

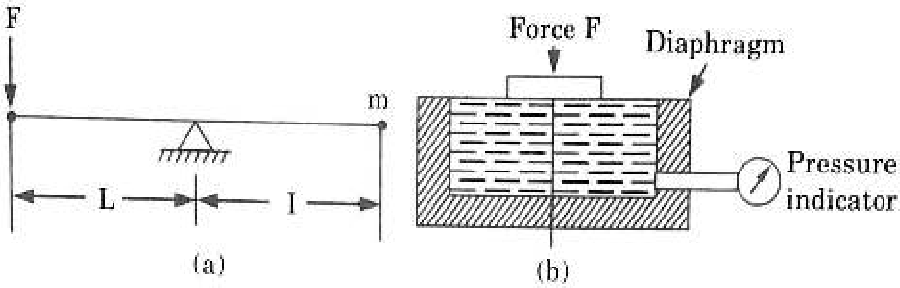


Fig. 5.18.1. (a) Balance principle. (b) Hydraulic load cell.

3. **Pneumatic load cell :**

i. In this type of load cell as shown in Fig. 5.18.2, air is supplied under pressure to a chamber having a diaphragm at one end and a nozzle at the other.

ii. Application of force to the diaphragm deforms it and changes the gap between the extension of the diaphragm and the nozzle, thus changing the pressure in the chamber.

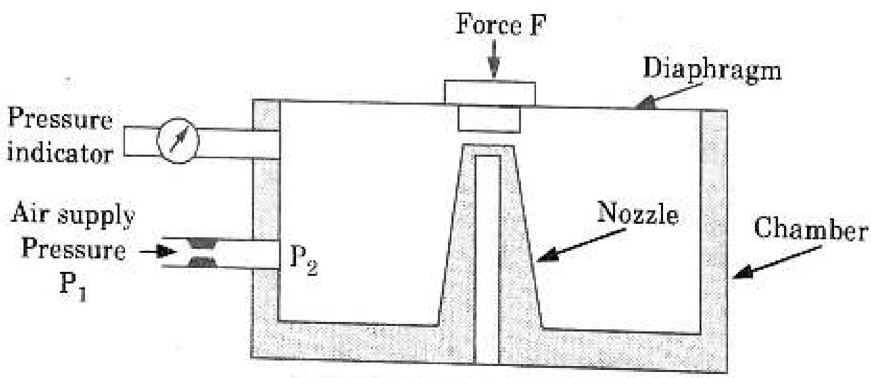


Fig. 5.18.2. Pneumatic load cell.

4. **Elastic force devices :**

i. These are important devices for the measurement of both static and dynamic forces.

ii. In such devices, the force applied to the elastic member result in a displacement or strain in the elastic member, which is sensed by mechanical or electromechanical means.

Que 5.19. **Discuss the measurement of pressure.**

Answer

Measurement of pressure is done by :

A. **Bourdon Tubes :**

1. The bourdon tubes are designed in various forms. These are :

i. C-type

ii. Spiral

iii. Twisted tube

iv. Helical

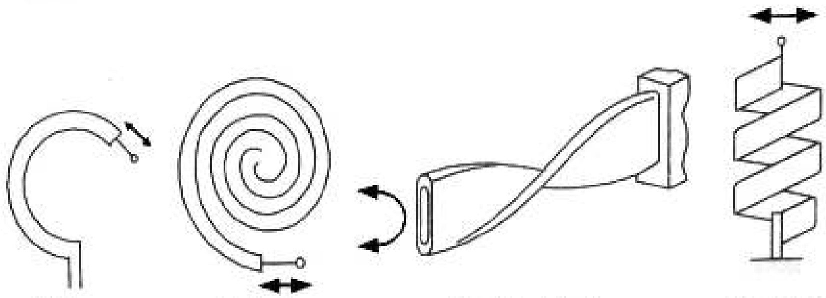


Fig. 5.19.1. Pressure sensitive primary devices.

2. The bourdon tubes are made out of an elliptically flattened tube bent in such a way as to produce the shapes shown in Fig. 5.19.1.
3. One end of the tube is sealed or closed. The other end is open for the fluid to enter.
4. When the fluid whose pressure is to be measured enters the tube, the tube tends to straighten out on account of the pressure applied. This causes a movement of the free end (closed end) and the displacement of this end is amplified through mechanical linkages.
5. The amplified displacement of the free end may be used to move a pointer on a scale calibrated in terms of pressure or may be applied to an electrical displacement transducer whose output may be calibrated in terms of the pressure applied.

B. Bellows :

1. A metallic bellows is a series of circular parts, resembling the folds in an accordion as shown in Fig. 5.19.2.

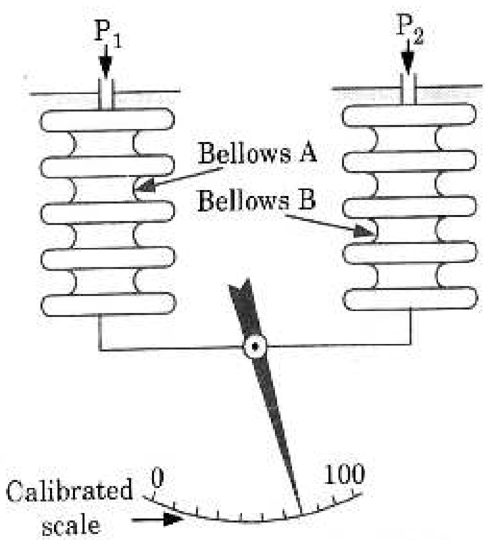


Fig. 5.19.2. Bellows element.

2. These parts are formed or joined in such a manner that they are expanded or contracted axially by change in pressure.
3. The metals used in the construction of bellows, must be thin enough to be flexible, ductile enough for reasonably easy fabrication, and have a high resistance to fatigue failure.
4. Materials commonly used are brass, bronze, beryllium copper, alloys of nickel and copper, steel and monel.
5. There are three main configurations in which bellows elements are used and these are for measurement of absolute, gauge and differential pressures. These configurations may be illustrated with the help of Fig. 5.19.2.
6. There are two bellows, A and B. The pressure applied to bellows A is P_1 and that to bellows B is P_2.
7. In case it is desired to measure the absolute pressure, bellows B is evacuated and the resultant pressure, P_1 is the absolute pressure.
8. When measurement of gauge pressure is desired, bellows B is opened up to atmosphere with pressure P_2 is equal to the atmospheric pressure and therefore the reading of the gauge is the gauge pressure.
9. The measurement of differential pressure $P = P_1 - P_2$ is done when pressure P_1 is applied to bellows A and pressure P_2 is applied to bellows B.

C. Diaphragms :

1. The operating principle of diaphragm elements is similar to that of the follows. The pressure to be measured is applied to the diaphragm, causing it to deflect, the deflection being proportional to the applied pressure.
2. The movement of the diaphragm depends on its thickness and diameter. The movement is small and hence a diaphragm element does not require any springs as is the case in bellows.
3. The movement of a diaphragm is convenient way of sensing a pressure.
4. The unknown pressure is applied to one side of a diaphragm. The edge of the diaphragm is rigidly fixed and causes a deflection on account of the applied pressure.
5. The displacement of the diaphragm may be measured to determine the value of applied pressure, P. A flat diaphragm is shown in Fig. 5.19.3.

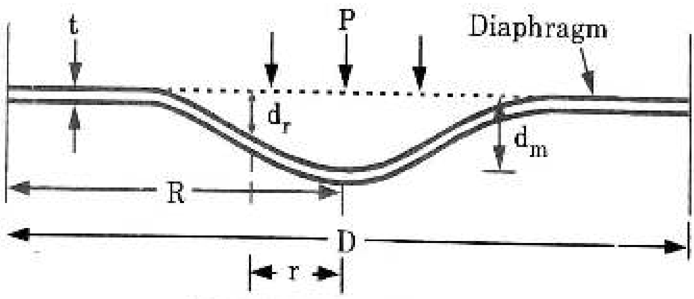


Fig. 5.19.3. Flat diaphragm.

6. Pressure, $$P = \frac{256\, E t^3\, d_m}{3(1-\nu^2)\, D^4}\ \text{N/m}^2 \quad ...(5.19.1)$$

where E = Young's modulus ; N/m^2,

t = Thickness of diaphragm ; m,

D = Diameter of diaphragm ; m,

R = Radius of diaphragm ; m,

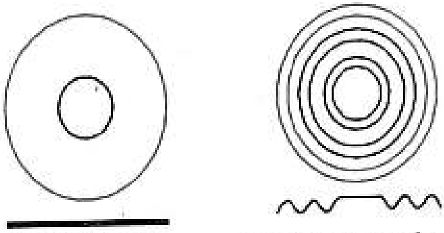
ν = Poisson's ratio,

and d_m = Deflection at the centre of the diaphragm ; m.

7. **The diaphragms are of two types :**

i. Flat type and

ii. Corrugated type.



(*a*) Flat type (*b*) Corrugated type

Fig. 5.19.4.

Que 5.20. **Explain pitot tube with the help of suitable diagram.**

Answer

1. Pitot tube is used mainly for the measurement of fluid velocity.
2. The operating principle of a pitot tube is based on the fact that when a solid body is kept centrally and stationary in a pipe line with a fluid streaming down, the velocity of the fluid starts diminishing due to the presence of the body till it is reduced to zero directly in front of the body. This point is known as the stagnation point.
2. As the kinetic head (pressure) is lost by the liquid, it gains a static head. Thus by measuring the difference between pressure at normal flow line and that at stagnation point, the fluid velocity is determined.
3. A pitot tube consists of a tube with an impact opening of 3.125 to 6.35 mm which is placed directly in the line of flow and a static opening at 90° from the impact opening.
4. The differential pressure across these tubes is proportional to the velocity of the fluid.
5. The measurement of quantity rate is calculated from the ratio of average velocity to the velocity at the point of measurement.

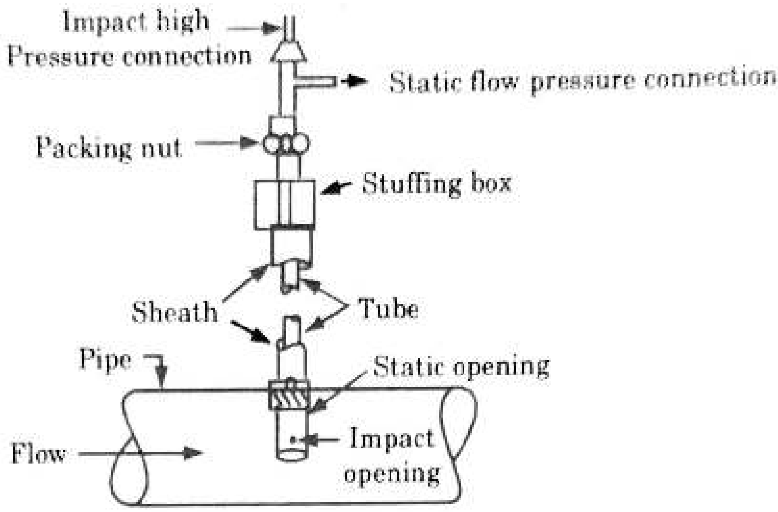


Fig. 5.20.1. Pitot tube.

6. For an accurate measurement, the pitot tube is moved across the entire diameter of the pipe to measure the velocity at several points and then the true average velocity is calculated.
7. The accuracy of a pitot tube may range from ± 1/2 to ± 5 %.

Advantages :

1. These tubes have no process loss.
2. They are economical to install.
3. It can be easily inserted through a small hole into the pipe or duct.

Disadvantages :

1. These tubes have poor accuracy.
2. They are unsuitable for dirty or sticky fluids.
3. They are sensitive to upstream disturbances.
4. Not suitable for measuring low velocities.

Que 5.21. **Describe various electrical methods used for measurement of liquid level. Also enlist their merits and limitations.**

Answer

The various methods of liquid level measurements are :

1. **Float-operated Rheostatic liquid level gauge :**

i. Fig. 5.21.1 shows the schematic diagram of the float-actuated rheostat (resistive) device.

ii. The float displacement actuates the arm which causes the slider to move over the resistive element of a rheostat.

iii. The circuit resistance changes and this resistance change is directly proportional to the liquid level in the tank.

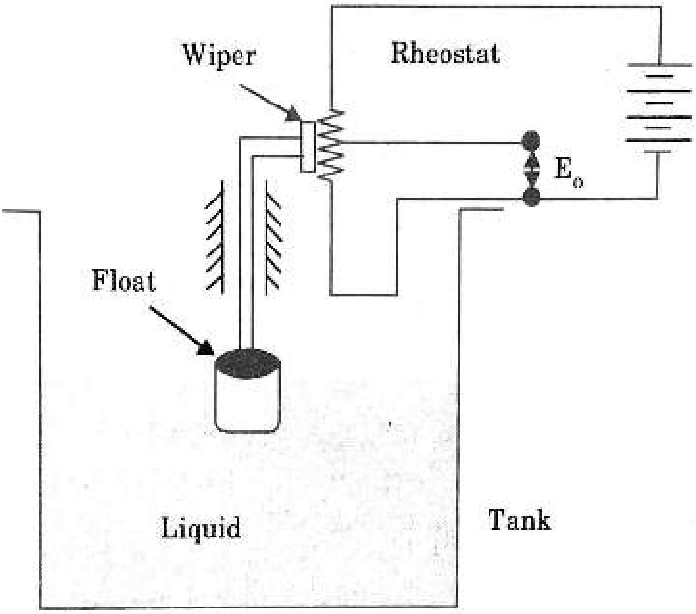


Fig. 5.21.1.

2. Ultrasonic level gauge :

i. In this, sound waves are incident on level by a transmitter and the reflected waves are received by a receiver.

ii. The total time taken by the wave to travel to the liquid surface and then back to receiver depends upon the liquid level in inverse proportion.

iii. Liquid level variations are quite accurately determined by detecting the total time.

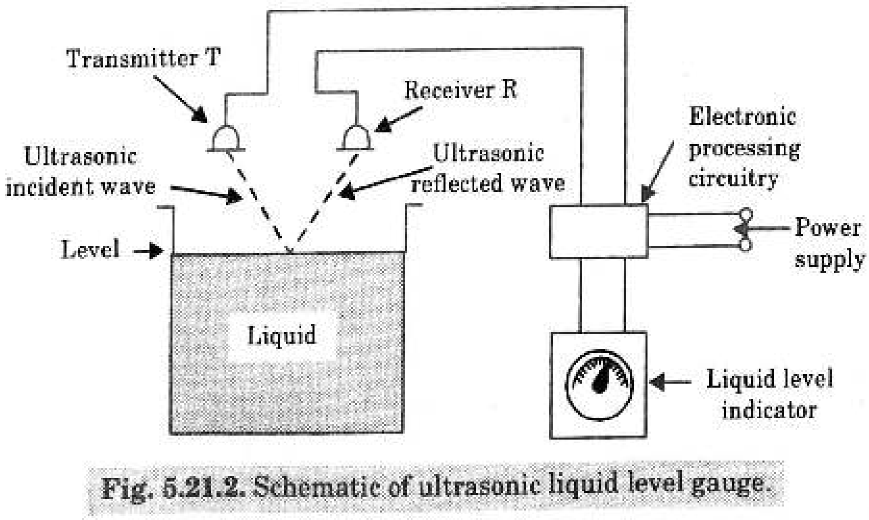


Fig. 5.21.2. Schematic of ultrasonic liquid level gauge.

iv. Though its operating principle is quite simple, but the instrument is expensive and requires high degree of experience and skill in operation.

v. Its main advantage is, however, its wide range of applications in level measurement of different types of liquid and solid substances.