MODULE 1

Measurement and Error

Introduction:

The measurement of any quantity plays very important role not only in science but in all branches of engineering, medicine and in almost all the human day to day activities. The technology of measurement is the base of advancement of science. The role of science and engineering is to discover the new phenomena, new relationships, the laws of nature and to apply these discoveries to human as well as other scientific needs. The science and engineering is also responsible for the design of new equipment. The operation, control and the maintenance of such equipment and the processes is also one of the important functions of the science and engineering branches. All these activities are based on the proper measurement and recording of physical, chemical, mechanical, optical and many other types of parameters.

Measurement: The measurement of a given parameter or quantity is the act or result of a quantitative comparison between a predefined standard and an unknown quantity to be measured.

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

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

Accuracy: It is the degree of closeness with which the instrument reading approaches the true value of the quantity. It denotes the extent to which we approach the actual value of the quantity. It indicates the ability of instrument to indicate the true value of the quantity.

Ex: if voltmeter reads 100V with ±1% error, then true or actual value lies between 99V and 100V.

Precision: It is the measure of consistency or repeatability of measurements.

Resolution: It is the smallest increment of quantity being measured which can be detected with certainty by an instrument. OR The smallest change in a measured value to which device responds.

Ex: If a digital voltmeter indicates 8.135V and if the measured quantity increases or decreases by 0.001 or 1mV, then reading becomes either 8.136V or 8.134V respectively. Thus the resolution of the instrument is 1mV.

Significant Figures: The significant figures convey the actual information about the magnitude and also contributes to the resolution.

Ex: If 8.134V indicates a voltage measured, then it has significant figures of 4.

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

$e = A_m - A_a$ where

e – Error
A_m – Measured value
A_a – Actual value

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

1) Gross errors: The gross errors mainly occur due to carelessness or lack of experience of a human being. These cover human mistakes in readings, recordings and calculating results. These errors also occur due to incorrect adjustments of instruments. These errors cannot be treated mathematically. These errors are also called personal errors.

2) Systematic errors: The systematic errors are mainly resulting due to the shortcomings of the instrument and the characteristics of the material used in the instrument, such as defective or worn parts, ageing effects, environmental effects, etc. A constant uniform deviation of the operation of an instrument is known as a systematic error.

There are three types of systematic errors as

1) Instrumental errors: these errors are inherent because of their mechanical structure and moving component. Ex: stretching of springs, irregular tension to spring, overloading and others. These errors can be avoided by
    - Selecting suitable instrument for measurement
    - Correction factors can be applied after determining instrumental errors
    - Calibrating the device against standard
2) Environmental errors: Due to external condition of a measuring device i.e the surrounding area of the instrument like temperature, humidity, magnetic or electrostatic fields. These errors can be avoided by
    - Air conditioning
    - Using magnetic shields
    - Hermetically scaling components
    - Using heat sinks
3) Observational errors: are the errors introduced by the observer. The most common error is the parallax error introduced in reading a meter scale

3) Random errors: these are the errors that remain after gross and systematic errors. These errors are due to unknown causes. These errors are small and can be treated mathematically.

When the error is specified in terms of an absolute quantity and not as a percentage, then it is called an **absolute error**. Thus the voltage of 10 ± 0.5 V indicated ± 0.5 V as an absolute error. When the error is expressed as a percentage or as a fraction of the total quantity to be measured, then it is called **relative error.**

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Error may be expressed either as absolute or as percentage of error.

Absolute error may be defined as the difference between the expected value of the variable and the measured value of the variable, or

$$e = Y_n - X_n$$

where e = absolute error

Y_n = expected value

X_n = measured value

$$\text{Therefore } \% \text{ Error} = \frac{\text{Absolute value}}{\text{Expected value}} \times 100$$

$$= \frac{e}{Y_n} \times 100$$

$$\text{Therefore } \% \text{ Error} = \left(\frac{Y_n - X_n}{Y_n}\right) \times 100$$

It is more frequently expressed as a accuracy rather than error.

$$\text{Therefore} \qquad A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right|$$

where A is the relative accuracy.

Accuracy is expressed as % accuracy

$$a = 100\% - \%\text{ error}$$

$$a = A \times 100\ \%$$

where a is the % accuracy.

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Statistical Analysis:

Statistical analysis of measurement helps in analytical determination of the uncertainty of the final test result. To make statistical analysis meaningful, large number of measurement is usually required. This method is used when deviation of measurement from its true value is to be determined and the reason for the error is unpredictable.

Arithmetic Mean: When quantity is measured many times and all the measurement are not same then this method is used. Using mean the best approximation to the actual value is found. The arithmetic mean of n measurements at a specific count of the variable x is given by the expression

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\sum_{n=1}^{n} x_n}{n}$$

where $\bar{x}$ = Arithmetic mean

x_n = nth reading taken

n = total number of readings

Deviation from Mean: This is the deviation of a given reading from the arithmetic mean of the group of readings. If the deviation of the first x_1, is called d_1 and for 2nd reading it is called d_2 and so on. The deviation may be positive or negative and the algebraic sum of all deviations must be zero. The deviations from the mean can be expressed as

$$d_1 = x_1 - \bar{x}\ ,\ d_2 = x_2 - \bar{x}\ \ \ldots.\ \text{similarly}\ d_n = x_n - \bar{x}$$

Average Deviation: is an indication of the precision of the instrument used in measurement. Average Deviation is defined as the sum of absolute values of the deviation divided by the number of readings. Average deviation may be expressed as

$$D_{av} = \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n}$$

$$\text{or} \qquad D_{av} = \frac{\sum |d_n|}{n}$$

where D_{av} = average deviation

$|d_1|, |d_2|, \ldots, |d_n|$ = Absolute value of deviations

and n = total number of readings

Standard Deviation: The standard deviation is the square root of the sum of all individual deviations squared, divided by the number of readings. It may be expressed as

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n}}$$

$$\sigma = \sqrt{\frac{d_n^2}{n}}$$

where σ = standard deviation

Standard deviation is also known as root mean square deviation and is an important factor in the statistical analysis of measurement. Reducing this quantity helps in improving the measurement.

The square of standard deviation is known as variance and it is expressed as

$$\sigma^2 = \frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n}$$

Probable Error: It is denoted by PE and is given by

PE = ±0.6745 σ

Dynamic Characteristics of Instruments:

The set of criteria defined for the instruments, which are changes rapidly with time, is called **'dynamic characteristics'.** The dynamic characteristics are

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Speed of response: The speed of response of measuring instrument is defined as the quickness with which an instrument responds to a change in the output signal.

Lag: It is the retardation or delay in the response of a measurement system to changes in the measured quantity.

Fidelity: It is the ability of a measurement system to reproduce the output in the same form as the input.

Dynamic error: It is the difference between the true value of the quantity changing with time and the value indicated by the measurement system if no static error is assumed. It is also called measurement error.

Measurement error combinations:

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

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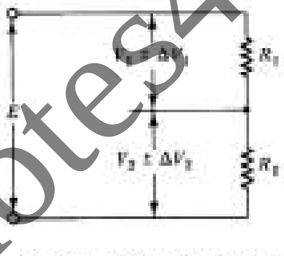
Sum of quantities:

Where a quantity is determined as the sum of two measurements, the total error is the sum of the absolute errors in each measurement. As illustrated in Figure

$$E = (V1 \pm \Delta V1) + (V2 \pm \Delta V2)$$

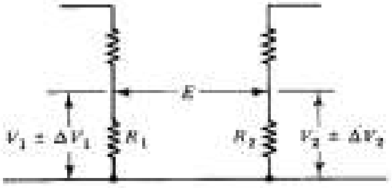


Error in sum of quantities equal sum of errors

Thus, % error in $E = (V1 + V2) \pm (\Delta V1 + \Delta V2)$

Difference of quantities:

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



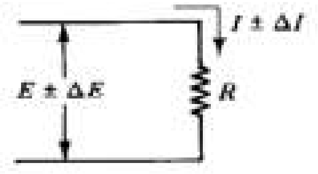
Error in difference of quantities equal sum of errors

$E = (V1 \pm \Delta V1) - (V2 \pm \Delta V2)$

Giving $E = (V1 - V2) \pm (\Delta V1 + \Delta V2)$

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 [consider Figure]



Percentage error in product or quotient of quantities equals sum of percentage errors.

P = EI

P = (E ± ΔE) × (I ± ΔI)

% error in P = (E * I) ± [(% error in E) + (% error in I]

Quotients of quantities:

Here again it can be shown that the percentage error is the sum of the percentage errors in each quantity.

R = (E ± ΔE)/ (I ± ΔI)

% error in R= (E/I) ± [(% error in E) + (% error in I)]

Raised to a power of quantity:

When a quantity A is raised to a power B. the percentage error in A B can be shown to be

% error A^B = B (% error in A)

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AMMETERS

Introduction:

Ammeter is measuring instrument to measure current in circuit. It uses PMMC galvanometer as a basic meter. As the name suggests it has permanent magnets which are employed in this kind of measuring instruments. It is particularly suited for DC measurement because here deflection is proportional to the current. This type of instrument is called D' Arnsonval type instrument. It has major advantage of having linear scale, low power consumption, high accuracy.

An ammeter can measure a wide range of current values because at high values only a small portion of the current is directed through the meter mechanism, a shunt in parallel with the basic meter carries the major portion as shown in Fig 1. The value of shunt can be determined as follows:

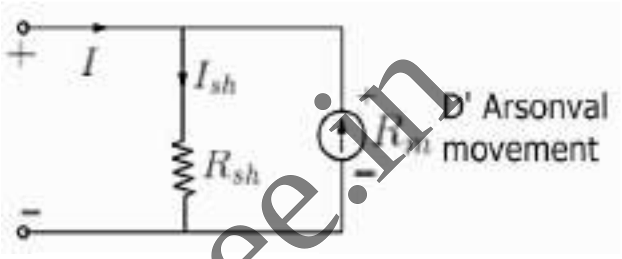

Fig. 1 Basic Ammeter

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Rsh = resistance of the shunt
Rm = internal resistance of the meter movements (movable coil)
Ish = shunt current
Im = full scale deflection current of the meter movement
I = full-scale deflection current for the ammeter

As shunt is parallel with the basic meter, the drop across shunt and basic meter will be same and it is given by,

Vm = Im*Rm and Vsh = Ish*Rsh
Vsh = Vm
IshRsh = ImRm

$$Rsh = \frac{ImRm}{Ish} \quad (\Omega)$$

But I = Ish + Im
Thus Ish = I – Im

Therefore,

$$Rsh = \frac{ImRm}{(I - Im)} \quad (\Omega)$$

This determines the value of shunt resistance for full scale meter current.

Multirange Ammeter:

- The range of the basic d.c. ammeter can be extended by using number of shunts and a selector switch. Such ammeter is called multirange ammeter as shown in the Fig 2
- R1, R2, R3 and R4 are four shunts. When connected in parallel with the meter, they can give four different ranges I1 ,I2 , I3 and I4.

- The selector switch S is multiposition switch, having low contact resistance and high current carrying capacity.
- This uses a make before break type switch for the range changing.
- If the ordinary switch is used, while range changing the switch remains open and full current passes through the meter damaging the meter due to high current. So make before break switch is used.
- While using the multirange ammeter, highest range should be used first and the current range should be decreased till good upscale reading is obtained.
- All the shunts are very precise resistance and hence cost of such multirange ammeter is high.

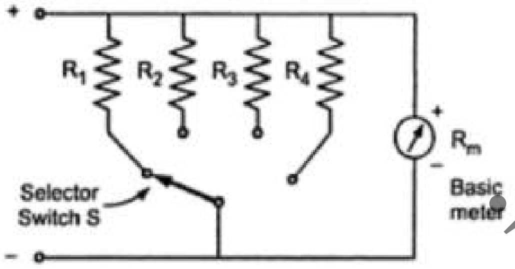

Fig 2. Multirange Ammeter

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The Ayrton Shunt or Universal Shunt:
The Ayrton shunt or universal shunt is another configuration of ammeter which eliminates the possibility of having a meter without a shunt. The meter with Ayrton shunt is shown in the Fig. 3.

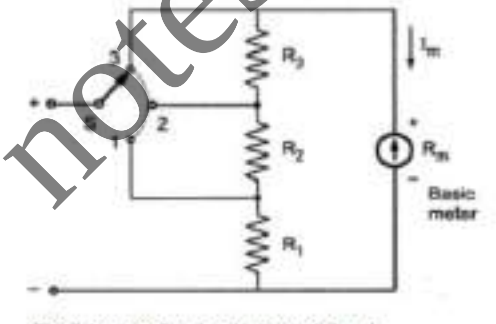

Fig. 3 Ayrton shunt or Universal shunt

- The selector switch S, selects the appropriate shunt required to change the range of the meter.
- When the position of the switch is '1' then the resistance R1 is in parallel with the series combination of R2, R3 and Rm. Hence current through the shunt is more than the current through the meter, thus protecting the basic meter.
- The voltage drop across the two parallel branches is always equal.
  Thus, Ish Rsh = Im Rm ,
  In position 1, R1 is in parallel with R2 + R3 + Rm
  Thus I1[R1] = Im[R2+R3+Rm]
- When the switch is in the position '2', then the series resistance of R1 and R2 is in parallel with the series combination of R3 and Rm.
  In position 2, R1+R2 is in parallel with R3+Rm

Thus I2[R1+R2] = Im[R3+Rm]

- In the position '3', the resistances R1, R2 and R3 are in series and acts as the shunt. In this position, the maximum current flows through the meter. This increases the sensitivity of the meter.

  In position 3, R1 + R2 + R3 is in parallel with Rm
  I3[R1+R2+R3] = ImRm

Requirements of Shunts:

- The electrical resistance of these shunts should not differ at higher temperature,
- They should have very low value of temperature coefficient.
- The resistance should not vary with time.
- They should be able to carry high value of current without much rise in temperature.
- The material used to join the shunts should have low thermo dielectric voltage drop i.e soldering of joins should not cause voltage drop.
- Solderability: The shunt resistances can be of different values and size and while soldering the change in value should be minimum

Usually ‘manganin’ is used as shunt for DC instruments as it gives low thermal emf and ‘constantan’ is useful material for AC instruments.

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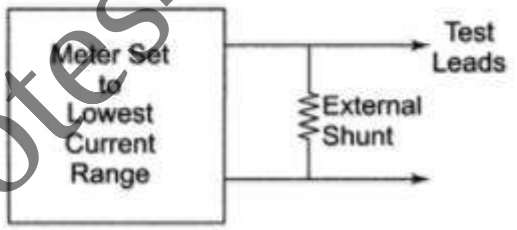
Extending of Ammeters:

The range of ammeter can be extended by using external shunts connected to the basic meter movement as shown in the figure below.



Extending of ammeters

RF Ammeter (Thermocouple)

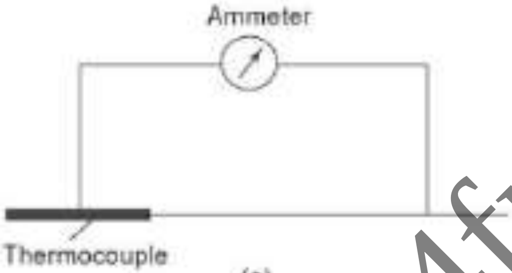
- Basically thermocouple consists of two different metals which are placed in contact with each other.
- First part is called the heater element because when the current will flow through this, a heat is produced and the temperature is increased at the junction.
- At this junction an emf is produced, the emf produced is a DC voltage which is directly proportional to root mean square value of electric current or voltage proportional to heating effect. This DC voltage generation by heating effect is called as thermoelectric effect.
- A permanent magnet moving coil instrument is connected with the second part to read the current passing through the heater.

- Usually a permanent magnet coil instrument is used because it has greater accuracy and sensitivity towards the measurement of value.
- The thermocouple type instruments employ thermocouple in their construction and have greater accuracy in measuring the current and voltages at very high frequency accurately. Thermocouple type instruments can be used for both ac and dc applications.

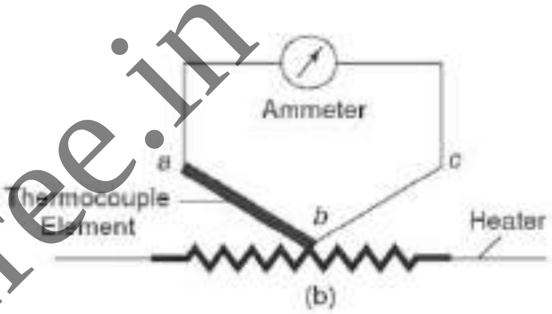
Types of Thermocouples:

Mutual Type: In this type, the current is passed directly to the thermocouple itself and through any heater wire as shown in fig (a). But the problem seen is the meter shunts the thermocouple and may not be very accurate. The sensitivity of this is very high.

Contact Type: In this it has a separate heater which is shown in fig (b). The current to be measured is passed to the heater and not to the thermocouple. Thus it is less sensitive compared to mutual type.



(a)



(b)

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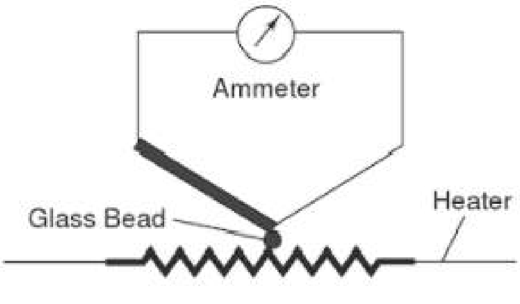
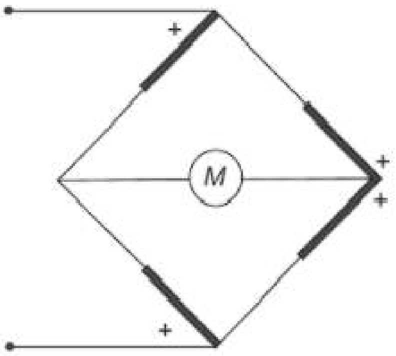
Separate Heater Type: It is also called as a non-contact type. There is insulation between the heating element and the thermocouple i.e. there no direct contact between two. The thermocouple is held near heater but insulated using a glass bead. This is shown in fig (c). Due to this the instruments are not much sensitive as compared contact type and also sluggish. The separate type is useful for certain applications.

Bridge type: This has high sensitivity as that of mutual type and also eliminates the shunting effect. This is seen in bridge configuration as shown in fig (d).



(c)



(d)

In the bridge configuration all 4 arms have similar thermocouple and to increase the sensitivity the instrument is placed in vacuum.

- Materials (metal combinations) used commonly for thermocouple are copper-constantan, iron-constantan, chromel-constantan, chromel-alumel and platinum-rhodium
- The heating element usually for open air heaters is a platinum alloy, which is non-corroding and in vacuum type heaters carbon filament is used.

Limitations of Thermocouple:

- Thermocouple heaters can withstand only small overloads.
- With rise in temperature there is change in resistance of the heater.
- There are harmonics present which changes the meter readings due to heating effect.

Advantages of Thermocouple:

- Accurate r.m.s value of current or voltage can be measured.
- Have very high sensitivity.
- Not affected by stay magnetic fields.
- In comparison with other instruments have high accuracy and frequency range

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VOLTMETERS AND MULTIMETERS

Voltmeter is used measure potential difference between two points of an electric circuit. The analog voltmeters gives indication by moving pointer across the scale proportional to the voltage in the circuit.

With basic meter and by adding various elements different instruments can be formed.

I. Basic meter movement can be made D.C instrument to measure

(i) DC current: adding a shunt resistance it results in forming a microammeter, miliammeter or an ammeter.

(ii) DC voltage: adding series resistance called multiplier it results in forming a milivoltmeter, voltmeter or kilovoltmeter.

(iii) Resistance: with a battery and resistive network, resistance can be measured. The instrument is ohmmeter.

II. Basic meter movement can be made A.C instruments to measure

(i) AC voltage or current: with a rectifier circuit it forms a rectifier meter which measures power and audio frequencies.

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

(iii)Expanded scale for power line voltage: Using a thermistor in a resistive bridge network, expanded scale for power line voltage can be obtained. This can be used for power line monitoring.

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Basic meter as dc voltmeter:

The basic d.c voltmeter is nothing but a PMMC D' Arsonval movement meter. To this a resistance is required to be connected in series to use it as a voltmeter. This series resistance is called a multiplier. The multiplier resistance limits the current through the basic meter so that the meter current does not exceed the full scale deflection value. The voltmeter measures the voltage across the two points of a circuit or a voltage across circuit component. The basic d.c. voltmeter is shown in the Fig.3.1

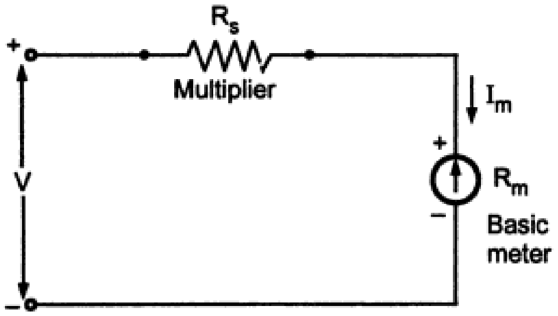

Fig. 3.1. Basic d.c voltmeter

The voltmeter must be connected across the two points or a component/load, to measure the potential difference, with the proper polarity.

The multiplier resistance can be calculated as:

Let Rm = Internal resistance of coil i.e. meter

Rs = series multiplier resistance

Im = full scale deflection current (can also be represented as I_{fsd})

V = full range voltage to be measured

From the Fig. 3.1 using KVL,

$$V = Im\ (Rm + Rs)$$

$$V = ImRm + Im\ Rs$$

$$ImRs = V - Im\ Rm$$

$$\text{Thus } Rs = \frac{V - ImRm}{Im}$$

or $$Rs = \frac{V}{Im} - Rm$$

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Multirange Voltmeter:

As we have seen in multirange ammeter, the range of the basic d.c. voltmeter can also be extended by using number of multipliers and a selector switch. Such type of meter is called multirange voltmeter. Fig. 3.2 shows multirange voltmeters with 3 multipliers R1, R2 and R3

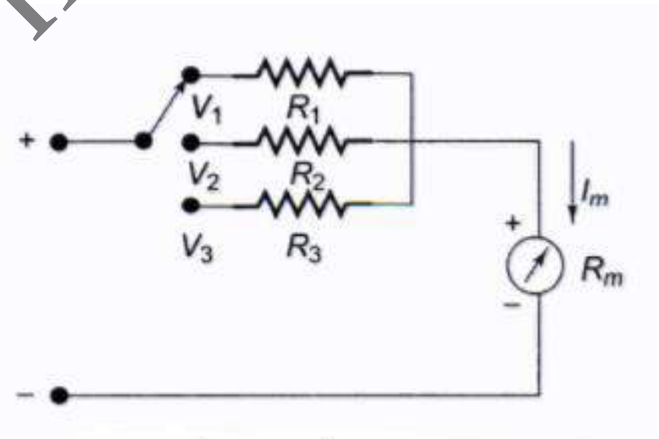

Fig. 3.2 Multirange voltmeter

This can further be modified which gives a more practical multiplier arrangement in multirange voltmeter. The arrangement is shown in Fig 3.3. The multipliers R1, R2, R3 and R4 are connected in series along with the selector switch.

This configuration is advantageous as all resistors expect R4 are all standard resistor values.

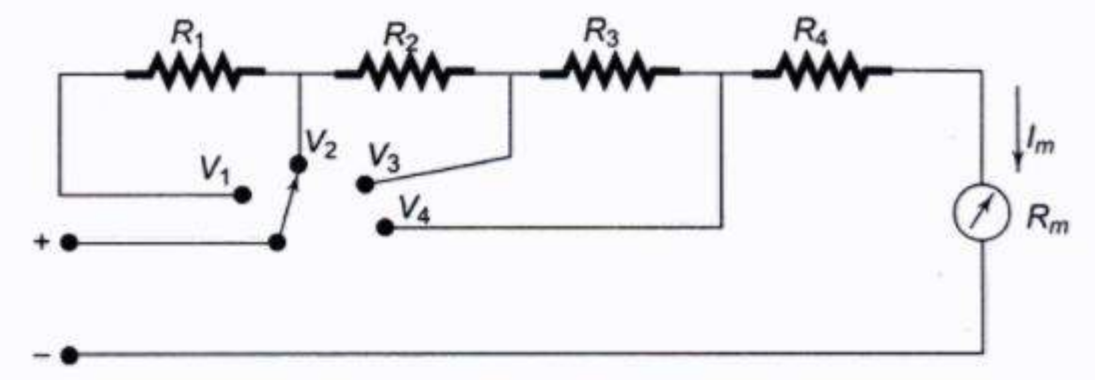

Fig. 3.3 Multipliers connected in series string

Extending voltmeter ranges:

The range of voltmeters can be extended to measure high voltages using an external multiplier resistor as shown in Fig 3.4. The basic meter can be used to measure low voltages and care must be taken to see that the voltage does not exceed the full scale deflection.

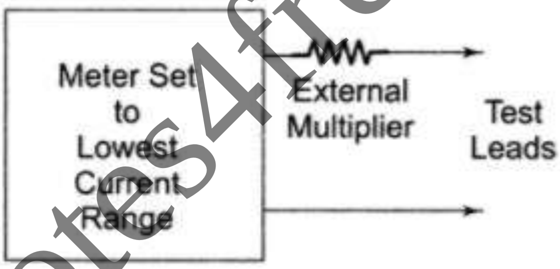

Fig.3.4 Extending voltage range

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Sensitivity:

The sensitivity of a voltmeter is given in ohms per volt. It is determined by dividing the sum of the resistance of the meter (Rm), plus the series resistance (Rs), by the full-scale reading in volts. In other words sensitivity can be defined as the ratio of total resistance to voltage to be measured (i.e voltage range). In equation form, sensitivity is expressed as follows:

Sensitivity = (Rm+Rs)/E = R/V

This is the same as saying the sensitivity is equal to the reciprocal of the full-scale deflection current.

$$\text{Sensitivity} = \frac{1}{I_{fsd}}$$

Loading effect:

- While selecting the voltmeter, the voltmeter consideration of sensitivity is very important.
- A low resistance voltmeter may give correct reading when measuring voltage in low resistance circuit but the Voltmeter produces unreliable and erroneous reading when connected in high resistance circuit.
- This is because the resistant of the meter acts as shunt and the equivalent resistance at that portion reduces.
- This results in showing lower reading indication than the actual value that existed before connecting of the meter. This is calling as loading effect.
- Thus ideally the resistance of a Voltmeter should be infinite so that voltmeter does not alter circuit current and gives correct readings.

Transistor voltmeter (TVM):

- Figure 3.5 gives a simplified schematic diagram of a dc coupled amplifier with an indicating meter.

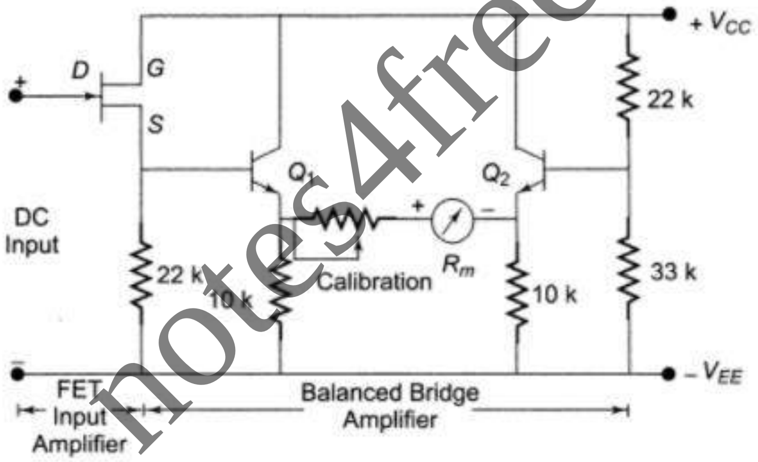

Fig. 3.5 Transistor voltmeter

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- The input stage consists of a FET which provides high input impedance to effectively isolate the meter circuit from the circuit under measurement. This forms the input amplifier. The input impedance of a FET is greater than 10 MΩ.
- It has two transistors, Q1 and Q2 forms a dc coupled amplifier driving the meter movement, along with resistors forms the bridge. The bridge is balanced, so that for zero input the dial indicates zero. If not, balance can be obtained through calibration resistance.
- Within the dynamic range of the amplifier, the meter deflection is proportional to the magnitude of the applied input voltage.
- The input exceeds then it does not burn the meter because the amplifier saturates, limiting the maximum current through the meter.
- The gain of the dc amplifier allows the instrument to be used for measurement of voltages in the mV range.

- Instruments in the μV range of measurement require a high gain dc amplifier to supply sufficient current for driving the meter movement.

Differential Voltmeters:

- The differential voltmeter provides extremely accurate voltage measurements and it is highly reliable piece of precision test equipment. The function is to compare an unknown voltage with a known internal reference voltage and to indicate the difference in their values.
- Figure 3.6 shows a basic circuit of a basic differential voltmeter which is based on the potentiometric method. Hence it is also called a potentiometric voltmeter.

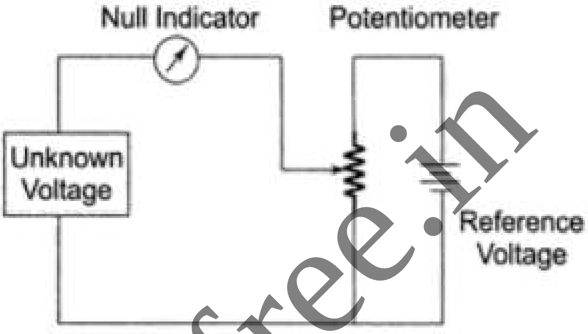

Fig. 3.6 Basic Differential Voltmeter

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- In this, upon the application of unknown voltage the potentiometer is varied until the voltage across it equals the unknown voltage.
- At this point the null indicator reads zero. Under null conditions, potential across either side of potentiometer is same and the meter draws current from neither the reference source nor the unknown known voltage source
- This shows that unknown voltage equals to the reference voltage.
- Thus the differential voltmeter presents an infinite impedance to the unknown source.
- The null meter serves as an indicator and does not measure any voltages.
- To detect small differences the meter movement must be sensitive, but it need not be calibrated, since only zero has to be indicated.
- The reference source used is usually a 1 V dc standard source or a Zener controlled precision supply. For measuring high voltages a high voltage reference supply can be used but this increases the cost and also loading effect is seen.
- Alternate to this voltage dividers or attenuators across an unknown source can be used to reduce the voltage. But even this has low input impedance and loading effect respectively.

In order to measure ac voltages, the ac voltage must be converted into dc by incorporating a precision rectifier circuit. A block diagram of an ac differential voltmeter is shown in Fig. 3.7.

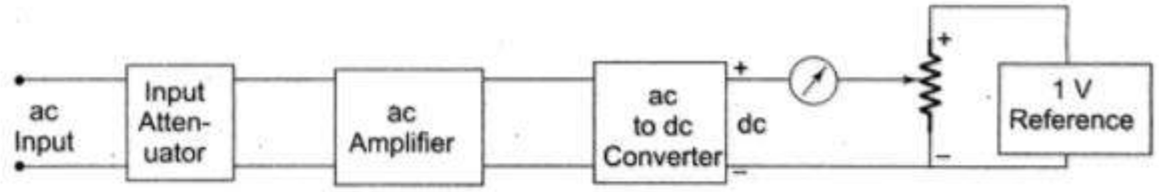

Fig. 3.7 Block diagram of an ac differential voltmeter

AC Voltmeters using Rectifiers:

- The PMMC movement along with rectifier arrangement is used in rectifier type ac instruments. The rectifier is used to convert a.c voltage to be measured, to d.c.
- This d.c if required is amplified and then given to the PMMC movement.
- The PMMC movement gives the deflection proportional to the quantity to be measured. For this silicon diodes are preferred as they exhibit low reverse current and high forward current ratting.
- Fig 3.8 (a) shows ac voltmeter having a multiplier, a bridge rectifier and basic meter movement.

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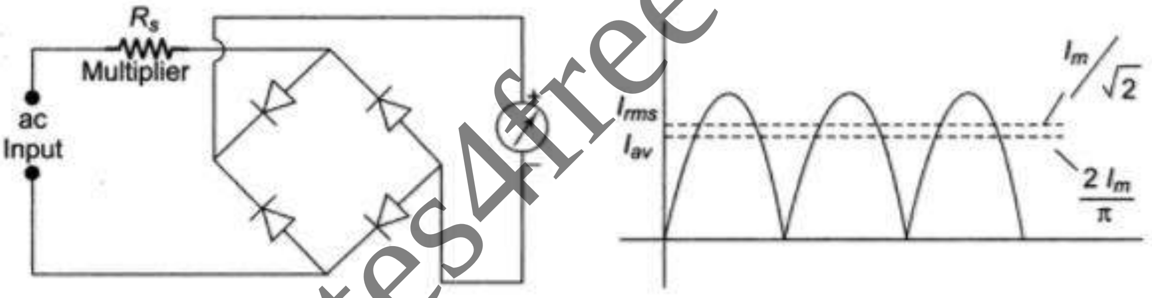

Fig. 3.8 (a) ac voltmeter (b) Average and RMS value of current

- Bridge rectifier gives a full wave pulsating dc and meter indicates steady deflection proportional to the average value of the current as shown in Fig 3.8 (b). However the meter can be calibrated to give rms value of the input signal.

rms value and average value: The rms. value of an alternating quantity is given by that steady current (d.c.) which when flowing through a given circuit for a given time produces the same amount of heat as produced by the a.c current which when flowing through the same circuit for the same time.

The rms value is calculated by measuring the quantity at equal intervals for one complete cycle. Then squaring each quantity, the average of squared values is obtained. The square root of this average value is the rms. value. The rms means root-mean square i.e. squaring, finding the mean i.e. average and taking the root.

For continuous signal the rms value is obtained by integrating the signal over the period of time T. It is given by,

$$\text{Vrms} = \sqrt{\frac{1}{T}\int_0^T Vin^2\,dt}$$ and 1/T represents the average value.

For pure sinusoidal signal it is given by

$$\text{Vrms} = 0.707 \text{ Vm},$$

where Vm = peak value of the sine wave.

Similarly the average value of a continuous a.c signal can be calculated by taking the average value over half period of the signal. It is given by

$$\text{Vav} = \frac{2}{T}\int_0^{T/2} Vin\, dt$$

T/2 represents the average value over half cycle.

For pure sinusoidal signal it is given by

$$\text{Vav} = \frac{2}{\pi} Vm = 0.636 \text{ Vm}$$

Where Vm = peak value of the sine wave.

General rectifier type ac voltmeter:

Practical rectifiers are non-linear devices particularly at low forward current and hence the meter scale is non-linear at lower values. This can be observed in the diode characteristics shown in Fig 3.9

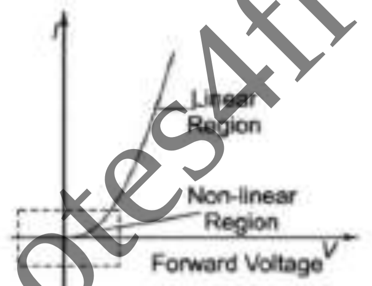

Fig. 3.9 Diode characteristics (Forward)

A general rectifier type voltmeter is shown in Fig. 3.10

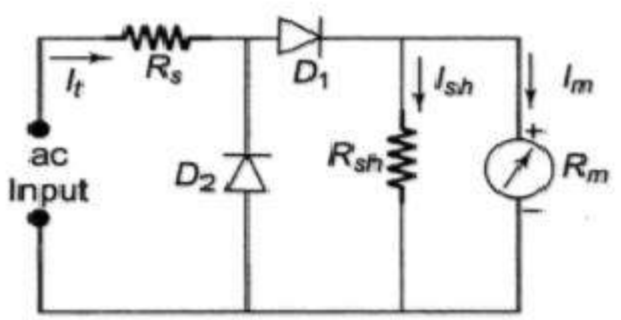

Fig. 3.10 General rectifier type ac voltmeter

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- Two diodes D1 and D2 are used in the rectifier circuit. When the a.c. input is applied, for the positive half cycle, the diode D1 conducts and causes the meter deflection proportional to the average value of that half cycle.
- As the diodes exhibit nonlinear behavior for the low currents and to increase the current through diode D1, the meter is shunted with a resistance Rsh. This helps in moving the diode operation into linear region of the characteristic curve.
- In the negative cycle, the diode D2 conducts and D1 is reverse biased. The current through the meter is in opposite direction and hence meter movement is bypassed.
- Thus due to diodes, the rectifying action produces pulsating d.c. and the meter indicates the average value of the input.

AC voltmeter using half wave rectifier:

To the ac voltmeter if a diode D1 is added as shown in Fig. 3.11, we get an half wave rectifier circuit capable of measuring ac voltages.

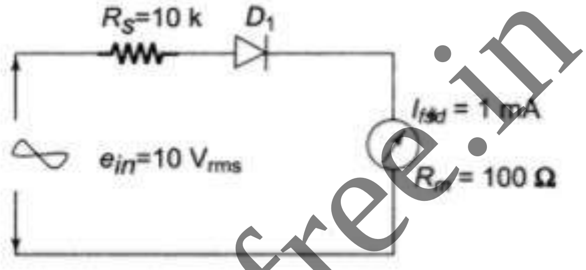

Fig. 3.11 ac voltmeter using half wave rectifier

Considering an example of the basic meter having full scale deflection current of 1mA and assuming D1 to be an ideal diode with negligible forward bias resistance, if the sensitivity of the dc voltmeter is given by

Sdc = $1/I_{fsd}$ = 1/1mA = 1KΩ/V

For this if dc input is replaced by a 10 V rms sine wave input. The voltages appearing at the output is due to the +ve half cycle due to rectifying action. The peak value of 10 V rms sine wave is given by,

Ep = 0.707 × $\sqrt{2}$ × Vrms = 0.707 × $\sqrt{2}$ × 10 = 14.41V

The dc will respond to the average value of the ac input, therefore

Eav = 0.636 Ep = 0.636 ×14.41 = 8.99V = 9 V

Since the diode conducts only during the positive half cycle, the average value over the entire cycle is one half the average value of 8.99 V, i.e. about 4.5 V.

Thus, the pointer will deflect for a full scale if 10 V dc is applied and 4.5 V when a 10 Vrms sinusoidal signal is applied. This indicates that an a.c voltmeter is not as sensitive as a dc voltmeter.

Thus we can say that **Edc = 0.45 Eac**

With rectifier in the voltmeter, the multiplier resistance can be calculated as

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$$\text{Rs } = \frac{Edc}{Idc} - Rm \text{ or Rs } = = \frac{0.45Eac}{Idc} - Rm$$

AC voltmeter using Full Wave Rectifier:

The full wave rectifier circuit uses a bridge to convert a.c to d.c as shown in the Fig. 3.12. During both half cycles the diodes will be conducting.

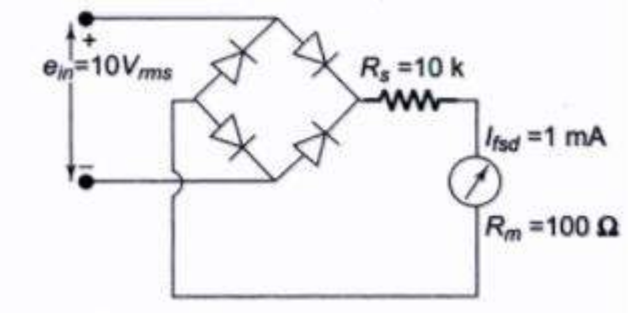

Fig. 3.12 ac voltmeter using full wave rectifier

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To this now 10 V rms signal is applied then the peak value is given by,

Ep = 0.707 × $\sqrt{2}$ × Vrms = 0.707 × $\sqrt{2}$ × 10 = 14.41V

The average value is given by,

Eav = 0.636 Ep = 0.636 ×14.41 = 8.99V = 9 V

As the diode conducts for both the half cycle the average value over one entire cycle is 9 V only.

Therefore, we can see that a 10 V rms voltage is equal to a 9 V dc for full scale deflection, i.e. the pointer will deflect to 90% of full scale. Thus we can say that,

Edc = 0.9 Eac

With full wave rectifier in the voltmeter, the multiplier resistance can be calculated as

$$\text{Rs } = \frac{Edc}{Idc} - Rm \text{ or Rs } = = \frac{0.9\,Eac}{Idc} - Rm$$

- With sensitivity we can have for both half wave and full wave as

Sensitivity (ac) = 0.45 Sensitivity (dc) -----Half wave rectifier

Sensitivity (ac) = 0.9 Sensitivity (dc) -----Full wave rectifier

True RMS Voltmeter:

- RMS value of the sinusoidal waveform can be measured by the average reading voltmeter and if can be calibrated to read the rms value.
- This method is quite simple and less expensive. But sometimes rms value of the non-sinusoidal or complex waveform may be required to be measured. For such a measurement a true rms reading voltmeter is required.
- True rms reading voltmeter gives meter reading based on heating power of waveform which is proportional to the square of the rms value of the voltage.

- Thermocouple is used to measure the heating power of the input waveform and it is given to the heater by the amplified version of the input waveform.
- Output voltage of the thermocouple is proportional to the square of the rms value of the input waveform.
- One more thermocouple, called the balancing thermo-couple, is used in the same thermal environment in order to eliminate the difficulty arising due to non-linear behavior of the thermo-couple.
- Thus the non-linearity of the input circuit thermo-couple is cancelled by the similar non-linear effects of the balancing thermocouple.
- These thermocouples form part of a bridge in the circuit of a dc amplifier, as shown in block diagram in Fig.3.13.

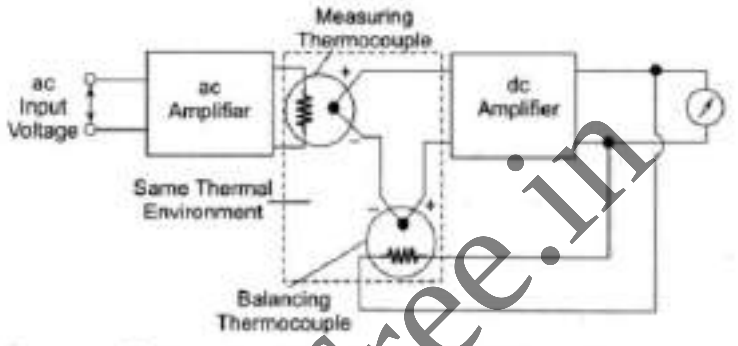

Fig.3.13 True RMS voltmeter (Block diagram)

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

Considerations while choosing an analog voltmeter:

Input Impedance: The input impedance or resistance of the voltmeter should be as high as possible so as to avoid the loading effect. Input impedance should always be higher than the impedance of the circuit under measurement.

Voltage Ranges: The voltage ranges on the meter scale should have same dB separation (may be in a 1-3-10 sequence with 10 dB or a 1.5-5-15 sequence) or in a single scale calibrated in decibels. In any case, the scale division should be compatible with the accuracy of the instrument.

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Decibels: For measurements covering a wide range of voltages, the use of the decibel scale can be very effective, e.g., in the frequency response curve of an amplifier, where the output voltage is measured as a function of the frequency of the applied input voltage.

Sensitivity v/s Bandwidth: Noise consists of unwanted frequencies. Since noise is a function of the bandwidth, a voltmeter with a narrow bandwidth picks up less noise than a large bandwidth voltmeter. Lesser the noise higher is the sensitivity of the meter.

Battery Operation: A voltmeter (VTVM) powered by an internal battery is essential for field work.

To summarize, the general guidelines are as follows:

- For dc measurement, select the meter with the widest capability meeting the requirements of the circuit.
- For ac measurements involving sine waves with less than 10% distortion, the average responding voltmeter is most sensitive and provides the best
- For high frequency measurement (> 10 MHz), the peak responding voltmeter with a diode probe input is best. Peak responding circuits are acceptable if inaccuracies caused by distortion in the input waveform are allowed (tolerated).
- For measurements where it is important to find the effective power of waveforms that depart from the true sinusoidal form, the rms responding voltmeter is the appropriate choice.

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Multimeter:

A multimeter has ammeter, voltmeter and ohmmeter together with a function switch to connect appropriate circuit to Basic meter or D'Arsonval movement. It is also known as Voltage-Ohm Meter (VOM) or multimeter.

Multimeter as a voltmeter:

To get different ranges of voltages, different multiplier resistances are connected in series (as this configuration is more practical than the parallel configuration of multiplier resistance) which can be put in the circuit with the range selector switch. We can get different ranges to measure the d.c. voltages by selecting the proper resistance in series with the basic meter. This is shown in the fig 3.14. To measure a.c voltages rectifiers are included in the circuit.

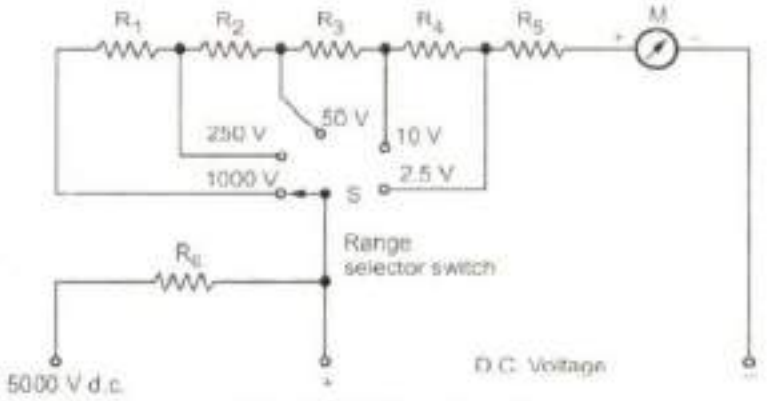

Fig. 3.14. Multirange voltmeter within multimeter

Multimeter as an ammeter:

To get different current ranges for ammeter, different shunts are connected across the meter with the help of range selector switch. This is shown in fig 3.15.

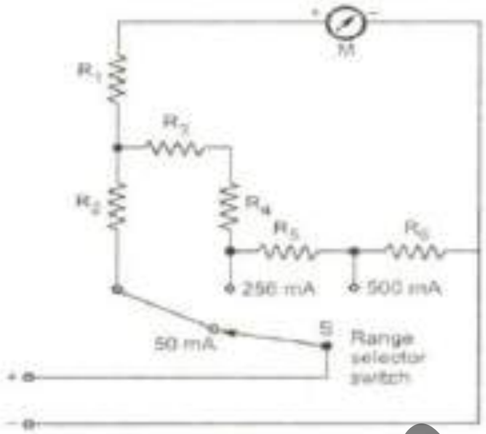

Fig. 3.15 Multirange ammeter within Multimeter

Multimeter as ohmmeter: As mentioned earlier with a battery and resistive network, resistance can be measured.

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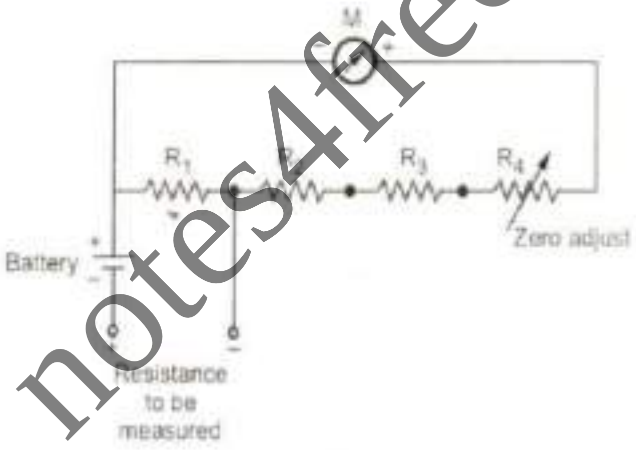
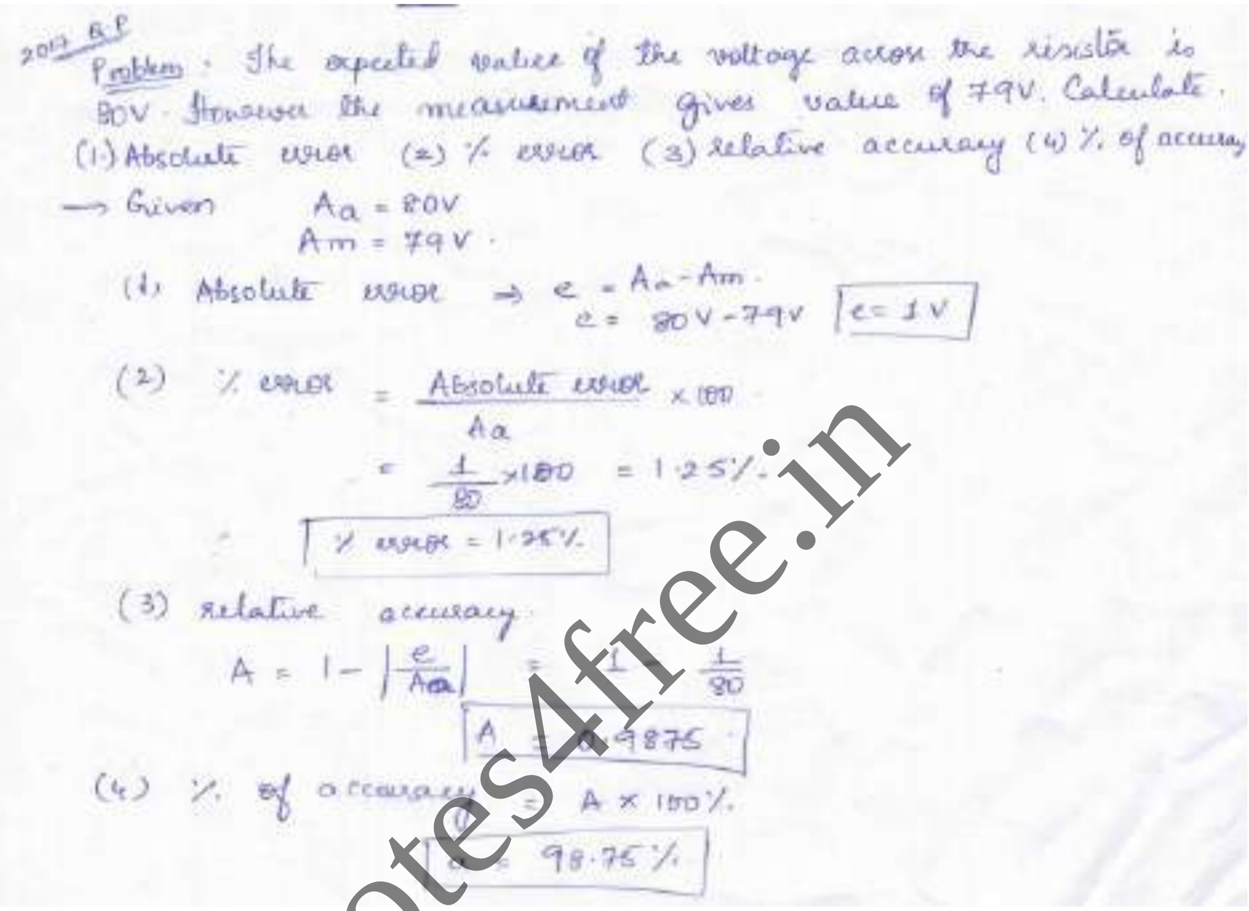


Fig. 3.16. ohmmeter within multimeter

The Fig.3.16 shows ohmmeter section of multimeter. Before any measurement is made, the instrument is to be calibrated for zero adjustments. This is done by short circuiting the instrument and "zero adjust" control is varied until the meter reads zero resistance i.e. it shows full scale current. With resistor network the circuit takes the form of a variation of the shunt type ohmmeter. Scale multiplications of 100 and 10,000 can also be used for measuring high resistances. Voltage is supplied to the circuit with the help of battery.

Measurement and Errors.

Problem related to absolute and relative error.



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Problem: The expected value of the voltage across the resistor is 80V. However the measurement gives value of 79V. Calculate. (1) Absolute error (2) % error (3) relative accuracy (4) % of accuracy

→ Given $A_a = 80V$

$A_m = 79V$.

(1) Absolute error ⇒ $e = A_a - A_m$.

$e = 80V - 79V$ $\boxed{e = 1V}$

(2) % error $= \frac{\text{Absolute error}}{A_a} \times 100$

$= \frac{1}{80} \times 100 = 1.25\%$.

$\boxed{\%\ \text{error} = 1.25\%}$

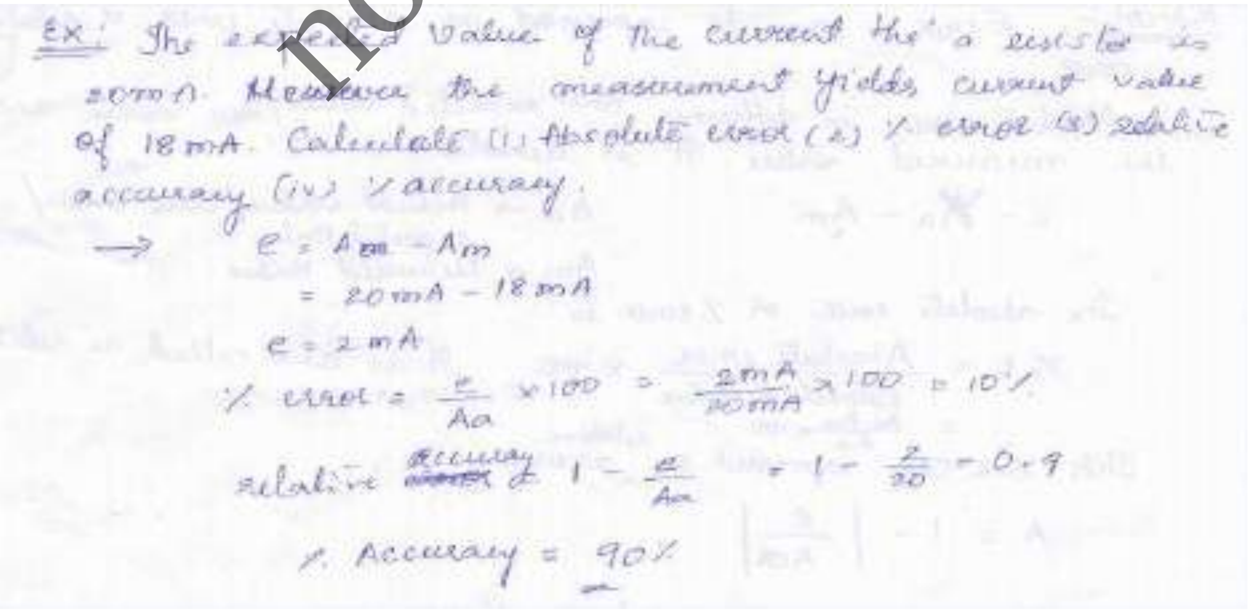
(3) relative accuracy

$A = 1 - \left|\frac{e}{A_a}\right| = 1 - \frac{1}{80}$

$\boxed{A = 0.9875}$

(4) % of accuracy $a = A \times 100\%$.

$\boxed{a = 98.75\%}$



Ex: The expected value of the current the a resistor is 20mA. However the measurement yields current value of 18mA. Calculate (1) Absolute error (2) % error (3) relative accuracy (iv) % accuracy.

→ $e = A_a - A_m$

$= 20mA - 18mA$

$e = 2mA$

$\%\ \text{error} = \frac{e}{A_a} \times 100 = \frac{2mA}{20mA} \times 100 = 10\%$

relative ~~error~~ accuracy $= 1 - \frac{e}{A_a} = 1 - \frac{2}{20} = 0.9$

% Accuracy = 90%

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given & the chang will be 1°c

Ex:- Manufacturer constructs resistance b/w 1.14kΩ & 1.26kΩ & classifies them to be 1.2kΩ. what tolerance should be stated? If the resistance values are specified at 25°C & resistor have temp coefficient of +500ppm/°c. Calculate max resistance that one of these components might have at 75°C.

Given : True value of resistor = 1.2kΩ

→ Absolute error = 1.26kΩ − 1.2kΩ
= 1.14kΩ − 1.2kΩ
= ±0.06kΩ.

$$\text{Tolerance} = \frac{0.06k\Omega}{1.2k\Omega} \times 100 = \pm 5\%$$

The largest possible resistance at 25°c
R = 1.2kΩ + 0.06kΩ
= 1.26kΩ.

least possible resistance at 25°c is
R = 1.2kΩ − 0.06kΩ
R = 1.14kΩ.

Resistance change/°c

R = 1.2kΩ
x ppm = 500ppm

$$500\ ppm\ of\ R = \frac{R}{1000000} \times x\,ppm$$

$$= \frac{1.2k\Omega \times 500}{1000000}$$

$$= 0.63\ \Omega/°c$$

Temperature increase = ΔT = 75°c − 25°c
= 50°c.

Total resistance increase = ΔR = Resistance change/°c × °c
= Resistance change
= 0.63Ω/°c × 50°c

$$\boxed{\Delta R = 31.5\ \Omega}$$

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Ex:- An ammeter reads 6.7A & the true value of current is 6.54A. Find the absolute error & the correction for this instrument.

→ Measured value = 6.7A

True value = 6.54V

Absolute error = 6.7 − 6.54 = 0.16A.

Correction for the instrument is <u>−0.16A</u> since the measu value is 0.16 A excess of the true value.

Ex:- Current thr' resistor is 2.5A, but measurement yields value of 2.45A, Find the % error of measurement

→ True value = 2.5A

Measured value = 2.45A

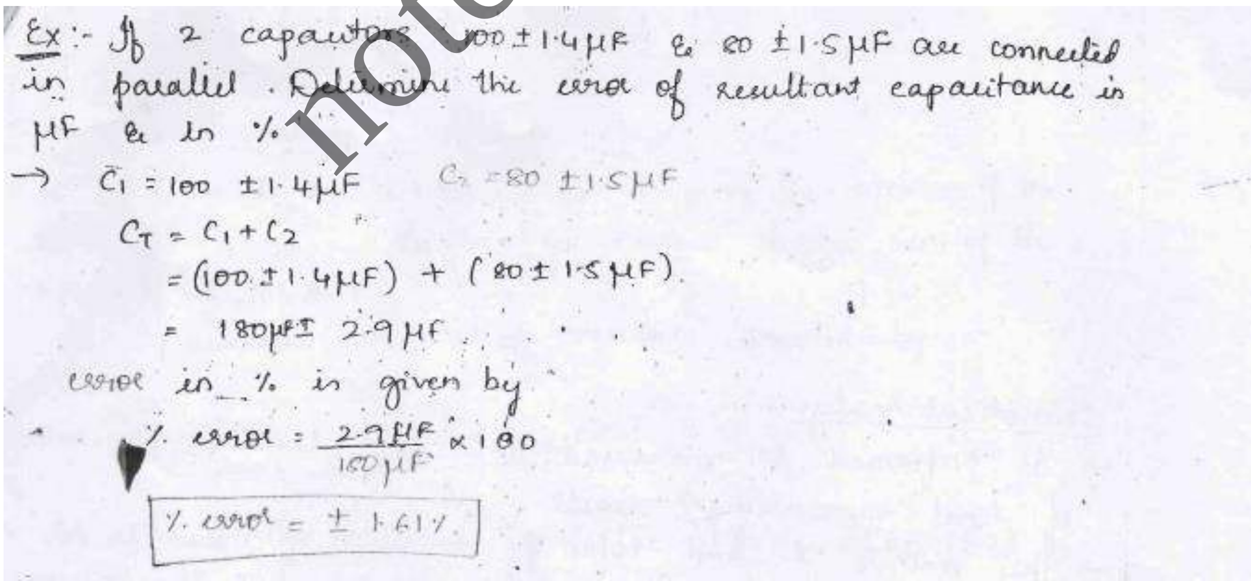
Absolute error = 2.45 − 2.5

= 0.05A.

% error = Relative error = $\pm \frac{0.05}{2.5} \times 100$

= ±2%

Problem related to combination of errors.



Ex:- If 2 capacitors 100 ± 1.4μF & 80 ± 1.5μF are connected in parallel. Determine the error of resultant capacitance in μF & in %

→ $C_1 = 100 \pm 1.4\mu F$ $C_2 = 80 \pm 1.5\mu F$

$C_T = C_1 + C_2$

$= (100 \pm 1.4\mu F) + (80 \pm 1.5\mu F)$.

$= 180\mu F \pm 2.9\mu F$

error in % is given by

$\% \text{ error} = \frac{2.9\mu F}{180\mu F} \times 100$

$\boxed{\% \text{ error} = \pm 1.61\%}$

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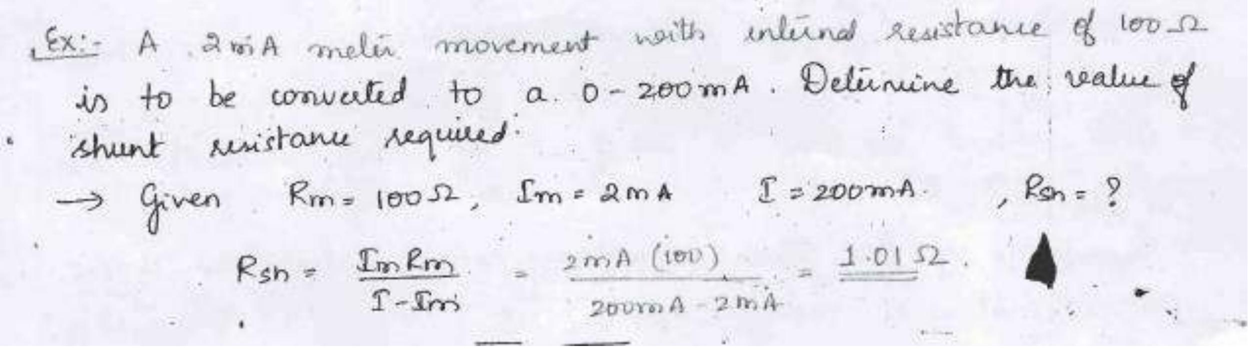
Ammeter

Problem related to DC Ammeter.



Ex:- A 2mA meter movement with internal resistance of 100Ω is to be converted to a 0-200mA. Determine the value of shunt resistance required.

→ Given $R_m = 100\Omega$, $I_m = 2mA$ $I = 200mA$, $R_{sh} = ?$

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{2mA\ (100)}{200mA - 2mA} = \underline{1.01\Omega}.$$

Problem related to Multi Range DC Ammeter.

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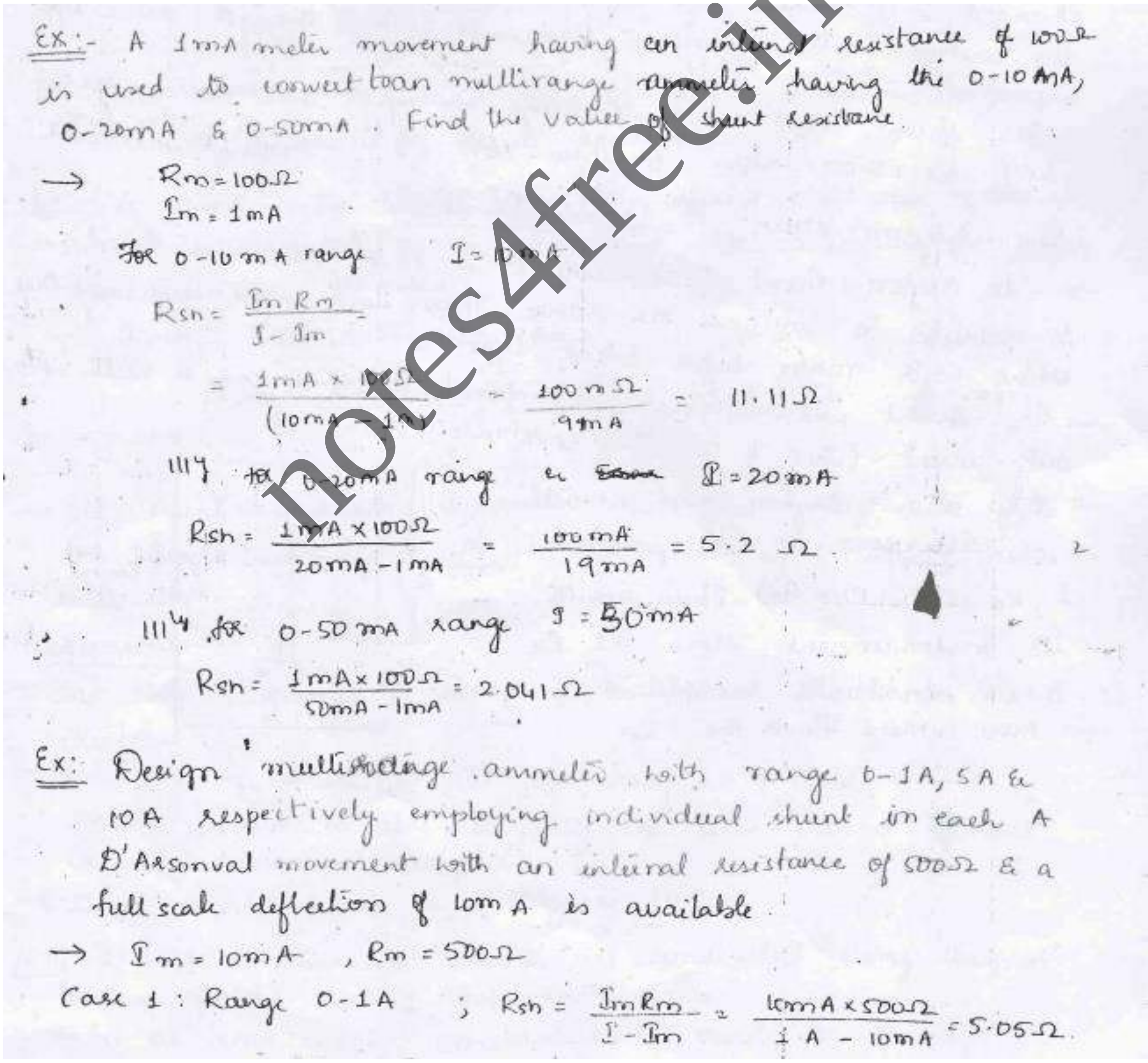

Ex:- A 1mA meter movement having an internal resistance of 100Ω is used to convert to an multirange ammeter having the 0-10mA, 0-20mA & 0-50mA. Find the value of shunt resistance

→ $R_m = 100\Omega$

$I_m = 1mA$

For 0-10mA range $I = 10mA$

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

$$= \frac{1mA \times 100\Omega}{(10mA - 1mA)} = \frac{100 m\Omega}{9mA} = 11.11\Omega$$

lll^y for 0-20mA range i.e. ~~[illegible]~~ $I = 20mA$

$$R_{sh} = \frac{1mA \times 100\Omega}{20mA - 1mA} = \frac{100mA}{19mA} = 5.2\ \Omega.$$

lll^y for 0-50mA range $I = 50mA$

$$R_{sh} = \frac{1mA \times 100\Omega}{50mA - 1mA} = 2.041\Omega$$

Ex: Design multirange ammeter with range 0-1A, 5A & 10A respectively employing individual shunt in each. A D'Arsonval movement with an internal resistance of 500Ω & a full scale deflection of 10mA is available.

→ $I_m = 10mA$, $R_m = 500\Omega$

Case 1: Range 0-1A ; $R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{10mA \times 500\Omega}{1A - 10mA} = 5.05\Omega.$

se 2 : Range 0-5A $R_{sh} = 1.002\,\Omega$

ase 3 : Range 0-10A $R_{sh} =$ ~~0.050Ω~~ $0.50\,\Omega$.

Hence the values of shunt resistances are $5.05\,\Omega$, $1.002\,\Omega$ & $0.50\,\Omega$

Ex:- A 100µA meter movement with an internal resistance of 500Ω is to be used in a 0-100mA Ammeter. Find the values of the shunt required.

→ ※ The shunt can also be determined by considering current I to be 'n' times larger than Im. This is called a multiplying factor & relates total current & meter current.

$$I = n I_m$$

Thus the equation for shunt $R_s = \frac{I_m R_m}{I - I_m} = \frac{I_m R_m}{n I_m - I_m} = \frac{I_m R_m}{I_m (n-1)}$

$$R_{sh} = \frac{R_m}{n-1}$$

Given parameters $I_m = 100\,\mu A$, $R_m = 500\,\Omega$, $I = 100\,mA$

$$\text{now } n = \frac{I}{I_m} = \frac{100\,mA}{100\,\mu A} = 1000$$

$$R_{sh} = \frac{500}{1000-1} = 0.5\,\Omega \qquad \boxed{R_{sh} = 0.5\,\Omega}$$

$$\boxed{OR}$$

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{100\,\mu A \times 500\,\Omega}{100\,mA - 100\,\mu A} = 0.50\,\Omega \qquad \boxed{R_{sh} = 0.5\,\Omega}$$

Thus both gives same value.

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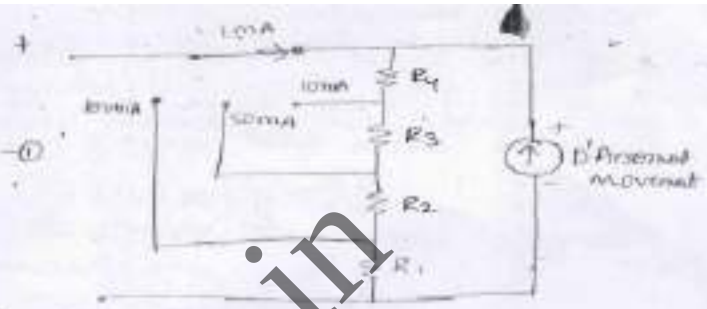
Ex:- Design an Asyton shunt to provide an ammeter with current range of 0-1mA, 10mA, 50mA & 100mA. A D'Arsonval movement with an internal resistance of 100Ω & full scale current of 50μA is used

→ Given $I_m = 50\mu A$, $R_m = 100\Omega$.



Case 1:
For 0-1mA range

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

$$R_{sh} = \frac{I_m R_m}{I_{sh}} = \frac{I_m R_m}{I - I_m} \quad —①$$

$R_{sh} = R_4 + R_3 + R_2 + R_1$

$I = 1mA$

Now ① becomes

$$R_4 + R_3 + R_2 + R_1 = \frac{50\mu A \times 100}{1mA - 50\mu A}$$

$$R_1 + R_2 + R_3 + R_4 = 5.26\,\Omega \quad — Ⓐ$$

case 2:
For 0-10mA range

$$R_3 + R_2 + R_1 = \frac{50\mu A \times (100 + R_4)}{10mA - 50\mu A}$$

∵ R_4 is in series with R_m

$$9950\mu A\,(R_1 + R_2 + R_3) = 50\mu A\,(100 + R_4) \quad — Ⓑ$$

case 3 : For 0-50mA range

$$I_{sh} R_{sh} = I_m R_m \Rightarrow (I - I_m) R_{sh} = I_m R_m$$

$$49.95mA\,(R_1 + R_2) = 50\mu A\,(R_4 + R_3 + 100) \quad — Ⓒ$$

Case 4 : For 0-100mA range

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

$$99.95mA\,(R_1) = 50\mu A\,(R_4 + R_3 + R_2 + 100) \quad — Ⓓ$$

Rearranging Ⓐ $R_1 + R_2 + R_3 = 5.26\,\Omega - R_4$

Using the above eqⁿ in Ⓑ

$$9950\mu A\,(5.26\,\Omega - R_4) = 50\mu A\,(100 + R_4)$$

solving for R_4

$$9950\mu A \times 5.26 - 9950\mu A\, R_4 = 50\mu A \times 100 + 50\mu A \times R_4$$

$$\boxed{R_4 = 4.733\,\Omega}$$

Using R_4 in Ⓐ, we get

$$R_1 + R_2 + R_3 = 5.26 - 4.73 = 0.53$$

$$R_1 + R_2 + R_3 = 0.53$$

$$R_1 + R_2 = 0.53 - R_3$$

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sing this in ©

$49.95mA\,(R_1+R_2) = 50\mu A\,(R_4+R_3+100)$

$49.95mA\,(0.53-R_3) = 50\mu A\,(4.73+100+R_3)$

solving for R_3.

$\boxed{R_3 = 0.424\,\Omega} = \boxed{R_3 = 0.42\,\Omega}$

we have $R_1+R_2 = 0.53-R_3$

$R_1+R_2 = 0.53-0.42$

$R_1+R_2 = 0.11$

$R_2 = 0.11-R_1$

We have eqⁿ Ⓓ as

$99.95mA(R_1) = 50\mu A\,(\underbrace{R_4+R_3+R_2}+100)$

But $R_2+R_3+R_4 = 5.26-R_1$ (using Ⓐ)

$\therefore 99.95mA(R_1) = 50\mu A((5.26-R_1)+100)$

$99.95mA\,R_1 = 50\mu A\times5.26 - 50\mu A\,R_1 + 50\mu A\times100$

$\therefore R_1 = 0.05263$

$\boxed{R_1 = 0.053\,\Omega}$

we have

$R_2 = 0.11-R_1$

$= 0.11-0.053$

$\boxed{R_2 = 0.057\,\Omega}$

Thus, the value of shunts for universal ammeter are

$R_1 = 0.053\,\Omega$

$R_2 = 0.057\,\Omega$

$R_3 = 0.42\,\Omega$

$R_4 = 4.73\,\Omega$

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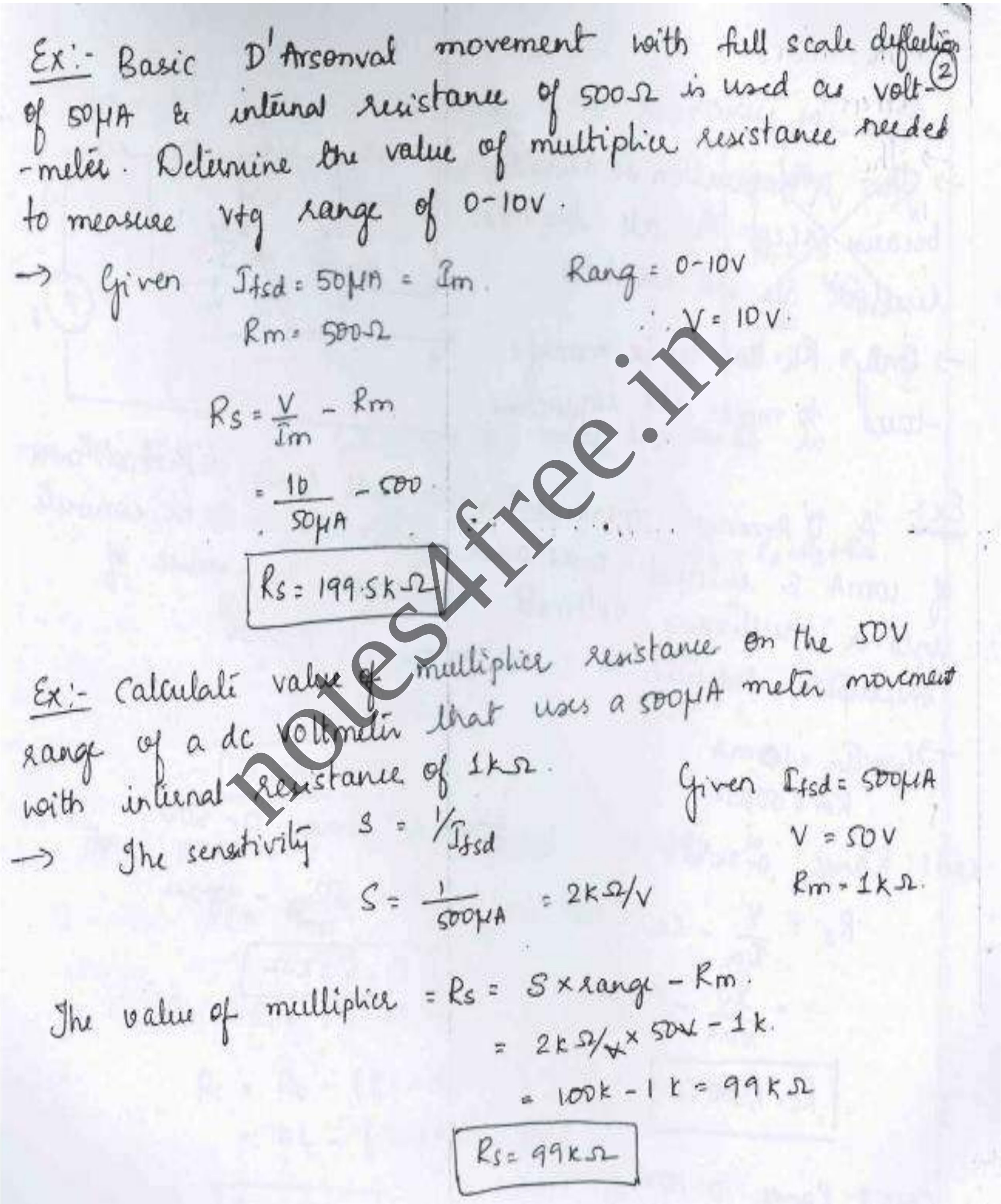
Voltmeter and Multimeter

Problems related to DC Voltmeter



Ex:- Basic D'Arsonval movement with full scale deflection of 50μA & internal resistance of 500Ω is used as volt-meter. Determine the value of multiplier resistance needed to measure vtg range of 0-10V.

→ Given $I_{fsd} = 50\mu A = I_m$. Rang = 0-10V

$R_m = 500\Omega$ ∴ $V = 10V$.

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

$$= \frac{10}{50\mu A} - 500$$

$$\boxed{R_s = 199.5k\Omega}$$

Ex:- Calculate value of multiplier resistance on the 50V range of a dc voltmeter that uses a 500μA meter movement with internal resistance of 1kΩ.

Given $I_{fsd} = 500\mu A$

$V = 50V$

$R_m = 1k\Omega$.

→ The sensitivity $S = 1/I_{fsd}$

$$S = \frac{1}{500\mu A} = 2k\Omega/V$$

The value of multiplier $= R_s = S \times \text{range} - R_m$.

$$= 2k\Omega/V \times 50V - 1k.$$

$$= 100k - 1k = 99k\Omega$$

$$\boxed{R_s = 99k\Omega}$$

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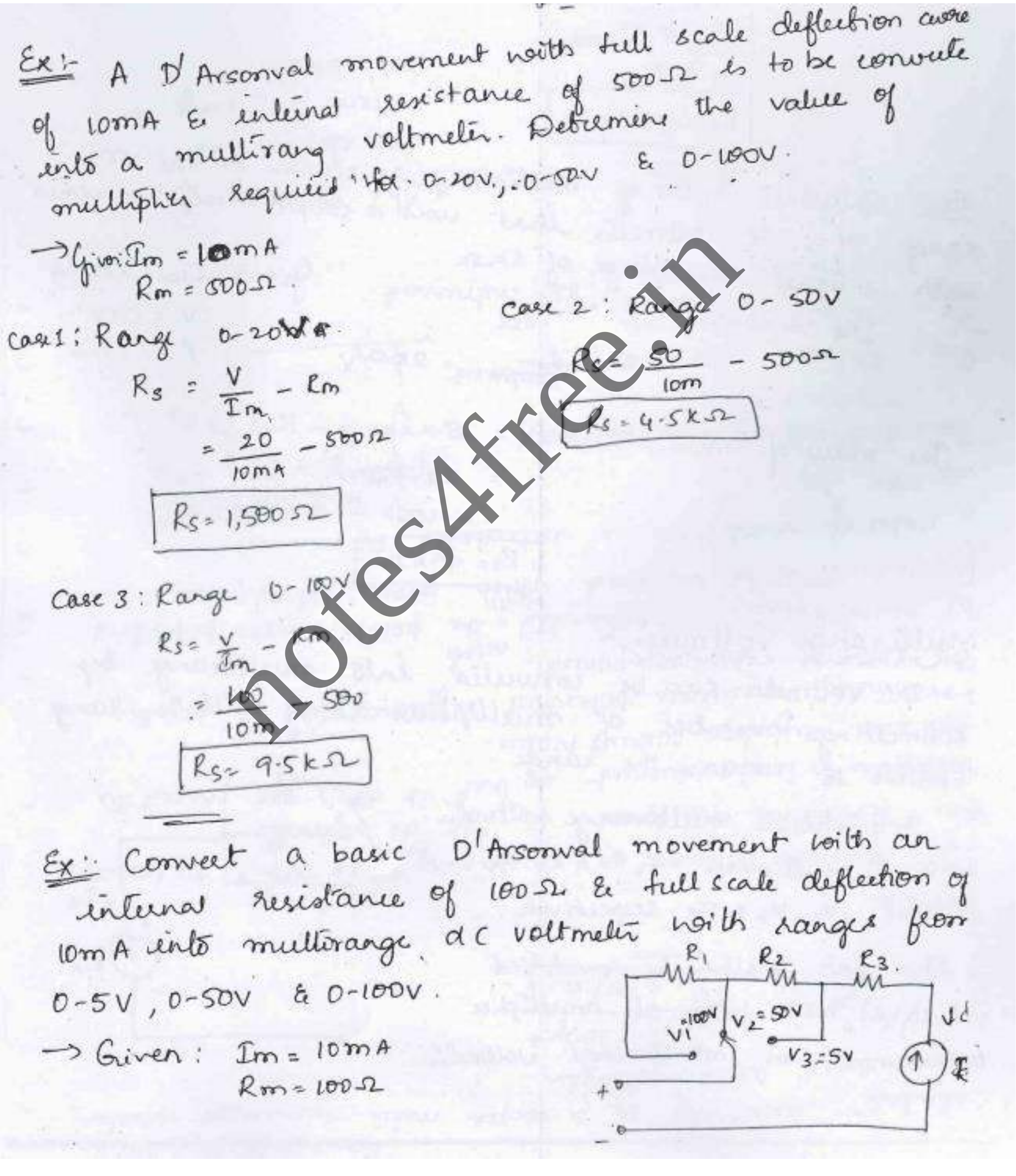
Problems related to Multirange Voltmeter.



Ex:- A D'Arsonval movement with full scale deflection curre of 10mA & internal resistance of 500Ω is to be converte into a multirang voltmeter. Determine the value of multiplier required for 0-20V, 0-50V & 0-100V.

→ Given: $I_m = 10\,mA$

$R_m = 500\Omega$

Case 1: Range 0-20V

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

$$= \frac{20}{10mA} - 500\Omega$$

$$\boxed{R_s = 1,500\,\Omega}$$

Case 2: Range 0-50V

$$R_s = \frac{50}{10m} - 500\Omega$$

$$\boxed{R_s = 4.5\,k\Omega}$$

Case 3: Range 0-100V

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

$$= \frac{100}{10m} - 500$$

$$\boxed{R_s = 9.5\,k\Omega}$$

Ex: Convert a basic D'Arsonval movement with an internal resistance of 100Ω & full scale deflection of 10mA into multirange dc voltmeter with ranges from 0-5V, 0-50V & 0-100V.

→ Given: $I_m = 10\,mA$

$R_m = 100\Omega$

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For 5V ie V_3 position, the total resistance is. ③

$$R_t = \frac{V3}{I_{fsd}} = \frac{5}{10mA} = 500\Omega$$

$\therefore R3 = R_t - R_m$

$= 500 - 100$

$$\boxed{R_3 = 400\Omega}$$

~~$S = \Omega/V = R_t/V$~~

~~$R_t = S \cdot V$~~

~~$= V/I_{fsd}$~~

~~or~~

$V = IR$ or $R = \frac{V}{I}$

For 50V ie V_2 position, the total resistance is

$$R_t = \frac{V_2}{I_{fsd}} = \frac{50}{10mA} = 5k\Omega$$

$R_t = R_2+R_3+R_m.$

$\therefore R_2 = R_t - (R_3+R_m)$

$= 5k - (400 + 100)$

$= 5k - 500\Omega$

$$\boxed{R_2 = 4 \cdot 5k\Omega}$$

For 100V ie V_1 position, total resistance is -

$$R_t = \cancel{10}\frac{V_1}{I_{fsd}} = \frac{100}{10mA} = 10k\Omega.$$

$\therefore R_t = R_1 + R_2 + R_3 + R_m.$

$R_1 = R_t - (R_2+R_3+R_m)$

$= 10k - (4.5k + 400 + 100).$

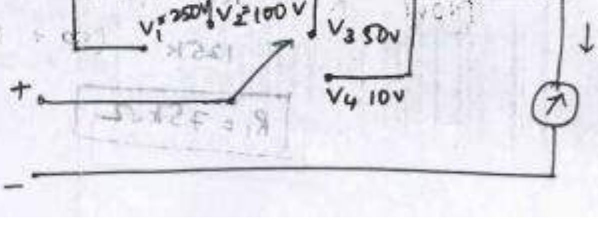
$$\boxed{R_1 = 5k\Omega}$$

Only R_3 is nonstandard value

ii Convert a basic D'Arsonval movement with an internal resistance of 50Ω & a full scale deflection current of 2mA into multirange dc voltmeter with voltage range of 0-10V, 0-50V, 0-100V, & 0-250V.

Given: $R_m = 50\Omega$

$I_m = 2mA.$



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i) for 10V range i.e :- V_4 position of Switch, the total resistance of the circuit is

$$R_t = \frac{V}{I_{fsd}} = \frac{10V}{2mA} = 5k\Omega.$$

$$\therefore R_4 = R_t - R_m = 5k\Omega - 50\Omega = 4.95k$$

$$\boxed{R_4 = 4.95k\Omega}$$

(ii) For 50V range ie V_3 position of switch, the total resistance of the circuit is.

$$R_t = \frac{V}{I_{fsd}} = \frac{50V}{2mA} = 25k\Omega.$$

$$\text{Now, } R_3 = R_t - (R_m + R_4) = 25k\Omega - (50\Omega + 4.95k\Omega)$$

$$\therefore \boxed{R_3 = 20k\Omega}$$

(iii) For 100V range, ie V_2 position of switch, the total resistance of the circuit is

$$R_t = \frac{V}{I_{fsd}} = \frac{100}{2mA} = 50k\Omega.$$

$$\& \quad R_2 = R_t - (R_m + R_3 + R_4) = 50k - (50\Omega + 4.95\Omega + 20$$

$$\boxed{R_2 = 25k\Omega}$$

(iv) For 250V range ie V_1 position of switch, the tota circuit resistance is

$$R_t = \frac{V}{I_{fsd}} = \frac{250}{2mA} = 125k\Omega.$$

$$\text{Now } R_1 = R_t - (R_m + R_2 + R_3 + R_4)$$

$$= 125k - (50 + 25k + 20k + 4.95k).$$

$$\boxed{R_1 = 75k\Omega}$$

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Ex:- Calculate the value of multiplier resistance on 50V range of a dc voltmeter, that uses a 200μA meter movement with an internal resistance of 100Ω.

→ $R_s = ?$, $I_m = 200\mu A$, $R_m = 100\Omega$, $V = 50V$ (Range).

$\therefore R_s = S \times V - R_m$

$S = 1/I_{fsd} = \frac{1}{200\mu A} = 5000$

$\therefore R_s = 5000 \times 50 - 100$

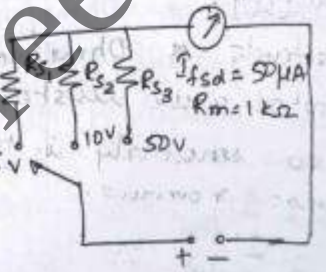
$\boxed{R_s = 249.9k\Omega}$

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

$= \frac{50}{200 \times 10^{-6}} - 10\Omega$

$= 249.9k\Omega$

Ex:- Calculate the value of multiplier resistance for the multiple range dc voltmeter circuit shown in fig.



→ The sensitivity of the meter movement is given by.

$S = 1/I_{fsd} = 1/50\mu A$

$S = 20,000$

{Given $I_{fsd} = 50\mu A$, $R_m = 1k\Omega$.}

Now the value of multiplier resistances are

(i) for range 5V.

$R_{s_1} = S \times V - R_m$

$= 20,000 \times 5 - 1k$

$\boxed{R_{s_1} = 99k\Omega}$

(ii) for range 10V

$R_{s2} = S \times V - R_m$

$= 20,000 \times 10 - 1k$

$\boxed{R_{s2} = 199k\Omega}$

(iii) For range 50V

$R_{s_3} = S \times V - R_m$

$= 20,000 \times 50 - 1k$

$\boxed{R_{s_3} = 999k\Omega}$

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Ex:- A moving coil instrument gives a full scale deflection of 20 mA when the potential difference across its terminals ⑤ is 100 mV. Calculate

(i) shunt resistance for full scale deflection corresponding of 50A

(ii) The series resistance for a full scale reading with 500 V. Also calculate the power dissipation in each case.

→ Given $I_m = 20mA$ & voltage = 100mV

To find $R_m = \frac{\text{voltage}}{I_m} = \frac{100mV}{20mA} = 5$

$$\boxed{R_m = 5\Omega}$$

(i) To find shunt,

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{20m \times 5}{50 - 20m}$$

$R_{sh} = 2.0m\Omega$ or $R_{sh} = 0.002\Omega$

$$\boxed{R_{sh} = 0.002\Omega}$$

(ii) To find series resistance or voltage multiplier.

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

$$= \frac{500}{20mA} - 5$$

$$\boxed{R_s = 24.999\,k\Omega}$$

Power $= V_m \times I_m$
$= 500 \times 20 \times 10^{-3}$

$$\boxed{P = 10\,W}$$

Power $= I_m^2 R_m$
$= (20mA)^2 \times 5$

$$\boxed{\text{Power} = 2mW}$$

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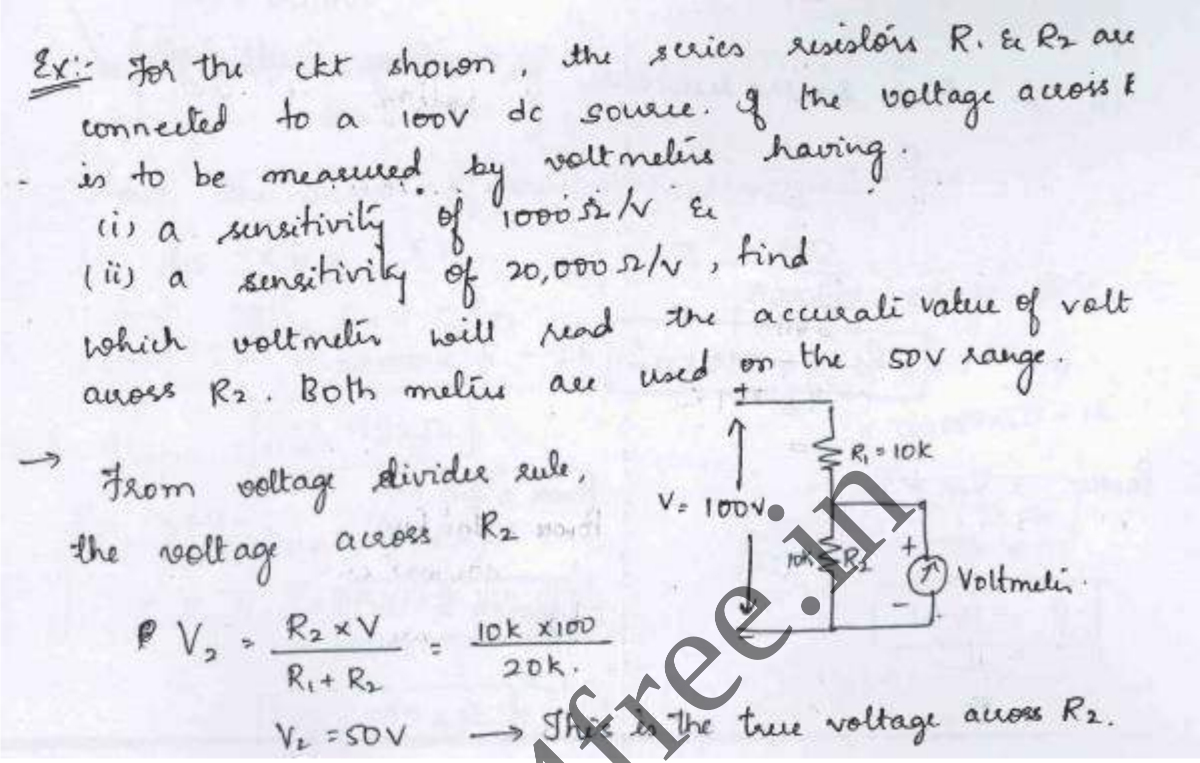
Problems related to Loading effect.



Ex:- For the ckt shown, the series resistors R_1 & R_2 are connected to a 100V dc source. If the voltage across is to be measured by voltmeters having.

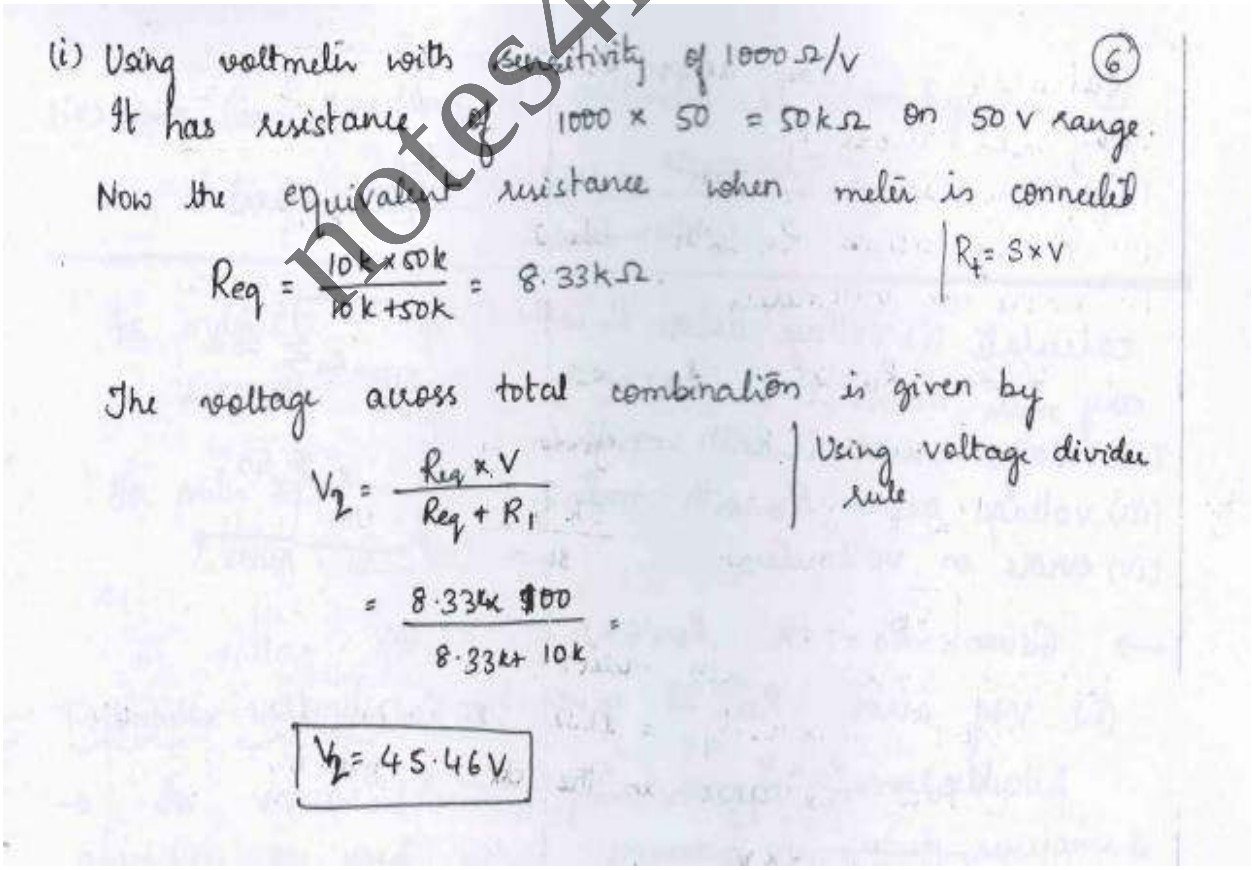
(i) a sensitivity of 1000Ω/V &

(ii) a sensitivity of 20,000 Ω/V, find which voltmeter will read the accurate value of volt across R_2. Both meters are used on the 50V range.

→ From voltage divider rule, the voltage across R_2

$$V_2 = \frac{R_2 \times V}{R_1 + R_2} = \frac{10k \times 100}{20k}$$

$V_2 = 50V$ → This is the true voltage across R_2.



(i) Using voltmeter with sensitivity of 1000Ω/V ⑥

It has resistance of 1000 × 50 = 50kΩ on 50V range.

Now the equivalent resistance when meter is connected

$$R_{eq} = \frac{10k \times 50k}{10k + 50k} = 8.33k\Omega$$

| $R_t = S \times V$

The voltage across total combination is given by

$$V_2 = \frac{R_{eq} \times V}{R_{eq} + R_1}$$

| Using voltage divider rule

$$= \frac{8.33k \times 100}{8.33k + 10k}$$

$$\boxed{V_2 = 45.46V}$$

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(ii) Using voltmeter with sensitivity of 20,000 Ω/V.

It has resistance of 20,000 × 50 = 1 MΩ on 50V range.

Now the equivalent resistance, when meter is connected

$$R_{eq} = \frac{10k \times 1M\Omega}{10k + 1M\Omega} = 9.9k\Omega$$

The voltage across total combination is given by.

$$V_2 = \frac{R_{eq} \times V}{R_{eq} + R_1} = \frac{9.9k \times 100}{9.9k + 10k}$$

$$\boxed{V_2 = 49.74V}$$

Observing both o/ps, the meter with high sensitivity gives accurate readings.

x:- Two different voltmeters are used to measure the voltage across R_b in the ckt shown. The meters are as follows

Meter 1: $S = 1k\Omega/V$ $R_m = 0.2K$, range = 10V.

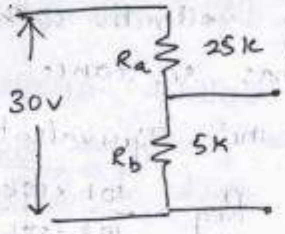
Meter 2: $S = 20k\Omega/V$ $R_m = 1.5K$, range = 10V

calculate (i) voltage across R_b without any meter across it.

(ii) voltage across R_b with meter 1

(iii) voltage across R_b with meter 2

(iv) errors in voltmeters.



→ Given: $R_a = 25K$, $R_b = 5k\Omega$ $V = 30V$.

(i) Vtg across R_b is given by:

$$V_{Rb} = \frac{R_b \times V}{R_b + R_a} = \frac{5k \times 30}{30K} = 5V$$

$$\boxed{V_{Rb} = 5V}$$

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(ii) vtg across R_b with meter 1 :

Meter 1's sensitivity = 1kΩ , $R_m = 0.2K$ & range = 10V.

∴ Total resistance in the ckt is given by.

$$R_{m_1} = S \times V$$

$$R_{m_1} = 1k\Omega\cancel{/V} \times 10\cancel{V} = 10k\Omega.$$

with meter1 across R_b , the equivalent resistance

$$R_{eq} = \frac{R_b \times R_{m1}}{R_b + R_{m1}} = \frac{5k \times 10k}{15k} = 3.33k\Omega.$$

Now the voltage across R_b with meter1 gives.

$$V_{Rb} = \frac{3.33k \times 30}{3.33k + 25k} = 3.53V$$

$$\boxed{V_{Rb} = 3.53V}$$

(iii) vtg across R_b with meter2 : $R_m = 1.5K$ & range = 10V.

Meter2's sensitivity = 20kΩ/V

Total resistance in the ckt is given by.

$$R_{m_2} = S \times V = 20k\Omega/\cancel{V} \times 10\cancel{V} = 200k\Omega.$$

with meter 2 across R_b, the equivalent resistance will be.

$$R_{eq} = \frac{R_b \times R_{m2}}{R_b + R_{m2}} = \frac{5k \times 200k}{205k} = 4.88k\Omega.$$

Now voltage across R_b with meter 2 gives

$$V_{Rb} = \frac{4.88k \times 30}{4.88k + 25k} = 4.89V$$

$$\boxed{V_{Rb} = 4.9V}$$

(iv) Error in reading of voltmeter is given by.

$$\% \text{ Error} = \frac{\text{Actual voltage} - \text{Measured vtg}}{\text{Actual voltage}}$$

For meter 1 :

$$\% \text{ error} = \frac{5 - 3.53}{5} = 29.4\%.$$

For meter 2 :

$$\% \text{ error} = \frac{5 - 4.9}{5} = 2\%$$

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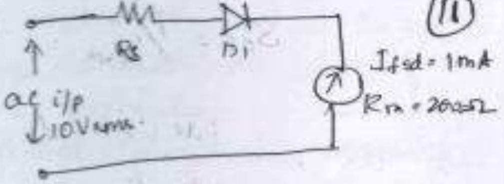
Problems related to AC Voltmeter using Rectifiers.

Ex:- Calculate value of multiplier resistor for 10V range on the voltmeter shown.

⑪



→ Given : $I_{fsd} = 1mA$

$R_m = 200\Omega$

$R_s = ?$

Sensitivity of ~~meter~~ meter is given by

$$S_{dc} = \frac{1}{I_{fsd}} = \frac{1}{1mA} = 1k\Omega$$

$$\boxed{S_{dc} = 1K\Omega/V}$$

we have expression for Rs

$$R_s = S_{dc} \times V - R_m$$

$$= ~~1K\Omega \times 10V - 200\Omega =~~$$

$R_T = S \times V$

$R_s + R_m = S \times V$

$\therefore R_s = S \times V - R_m$.

Suppose Here V → voltage range is the average dc value.

$$\therefore R_s = S \times 0.45 \times E_{rms} - R_m$$

$$= 1k \times 0.45 \times 10 - 200$$

$V_{dc} = 0.45 V_{rms}$.

$\Downarrow \qquad \Downarrow$

$E_{dc} = 0.45\ E_{rms}$

$$\boxed{R_s = 4.3k\Omega}$$

OR

Another method.

$$R_s = \frac{0.45 E_{rms}}{I_m} - R_m.$$

$$= \frac{0.45 \times 10}{1mA} - 200$$

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

$V = 0.45 E_{rms}$.

$= 0.45 \times 10$

$$\boxed{R_s = 4.3k\Omega}$$

Ex:- Calculate value of multiplier resistor for a 10 V rms range on the voltmeter using a full wave bridge rectifier and basic meter with scale deflection current of 1 mA & meter resistance is of 2500Ω.

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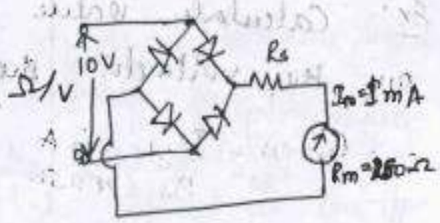
→ dc sensitivity is given by



$$S_{dc} = 1/I_{fsd} = 1/1mA = 1k\Omega/V$$

$$S_{dc} = 1\,k\Omega/V$$

ac sensitivity is given by

$$S_{ac} = 0.9 \times S_{dc}$$

$$= 0.9 \times 1k\Omega/V$$

$$S_{ac} = 0.9\,k\Omega/V$$

Now multiplier resistor is given by

$$R_s = S_{ao} \times range - R_m$$

$$= 0.9k\Omega/V \times 10V - 250$$

$$= 9k - 250$$

$$\boxed{R_s = 8.75\,k\Omega}$$

$\boxed{OR}$

→ Full wave rectifier,

$$E_{dc} = 0.9\,E_{rms}$$

Now $R_s = \frac{E_{dc}}{I_{dc}} - R_m$

$$= \frac{0.9\,E_{rms}}{1 \times 10^{-3}} - 250.$$

$$= \frac{9}{1 \times 10^{-3}} - 250$$

$$\boxed{R_s = 8.75\,k\Omega}$$

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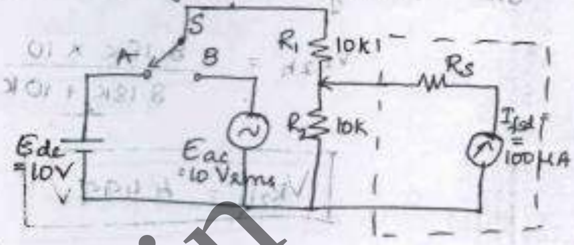
⑫

Ex:- Determine the reading obtained with a dc voltmeter in the ckt, when the switch is set to position A, then set the switch to position B & determine the reading obtained with a half wave rectifier and a full wave rectifier ac voltmeter.
All meters uses a 100μA full scale deflection meter movement and are set ~~to~~ on 10Vdc or rms ranges.



→ The sensitivity of dc voltmeter is

$S_{dc} = 1/I_{fsd} = 1/100\mu A$

$\boxed{S_{dc} = 10k\Omega/V}$

The Rs resistance value is given by

$R_S = S_{dc} \times \text{range} = 10k\Omega/V \times 10V$

$\boxed{R_S = 100\,k\Omega}$

Now Rs acts as shunt across $\overset{R_2}{10k\Omega}$ resistance thus the equivalent resistance is given by

$$R_2 = \frac{R_2 * R_S}{R_2 + R_S} = \frac{10k \times 100k}{10k + 100k} = 9.09k\Omega$$

The voltage a/c R₂ now is (Edc = 10V = Range)

$$V_{R2} = \frac{R_2 \times \text{Range}}{R_1 + R_2} = \frac{9.09k \times 10}{10k + 9.09k}$$

$\boxed{V_{R2} = 4.76V}$

$V_{R2} = 4.76V$ is the voltage read by $\overset{dc}{\wedge}$ voltmeter.

Using half wave rectifier, the voltage read by the ac voltmeter is determined as follows:

we have $S_{hw} = 0.45 \times S_{dc}$ | Sensitivity of ac meter = 0.45 × Sensitivity of dc

$= 0.45 \times 10\,k\Omega/V$

$S_{hw} = 4.5\,k\Omega/V$

Now $R_{S_H} = S_{hw} \times \text{Range} = 4.5k\Omega/V \times 10V = 45k\Omega$ | R_{SH} ⇒ series resistance with half wave rectifier

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$$R_{2h} = \frac{R_{sn} \times R_2}{R_{sn} + R_2} = \frac{45k \times 10k}{45k + 10k} = 8.18\ k\Omega$$

$$\boxed{R_{2h} = 8.18K}$$

The voltage across R_{2h} now is

$$V_{R_{2h}} = \frac{8.18K \times 10}{8.18K + 10K}$$

$$\boxed{V_{R_{2h}} = 4.499V}$$

The voltage read by ac voltmeter using full wave rectifier is determined as follows.

$$S_{fw} = 0.9\ S_{dc}$$
$$= 0.9 \times 10 k\Omega/V$$

$$\boxed{S_{fw} = 9 k\Omega/V.}$$ Sensitivity of ac meter with full wave rectifier.

$$R_{sf} = S_{fw} \times \text{Range}$$
$$= 9k\Omega/V \times 10\ V$$

$$\boxed{R_{sf} = 90k\Omega}$$ R_{sf} Series resistance of ac meter with full wave rectifier.

Now with R_{sf}, it acts as shunt across R_2, these effect resistance is given by.

$$R_{2f} = \frac{R_{sf} \times R_2}{R_{sf} + R_2} = \frac{90k \times 10k}{100k} = 9\ k\Omega$$

Now the voltage read across R_{2f} is given by

$$V_{R_{2f}} = \frac{R_{2f} \times \text{Voltage range}}{R_{2f} \times R_1} = \frac{9k \times 10V}{9k + 10k}$$

$$\boxed{V_{R_{2f}} = 4.736V}$$

Thus ac voltmeter using half & full wave rectifier has more loading effect than dc voltmeter.

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Ex:- A 25mA full scale current meter with an internal resistance of 100Ω is available for constructing an ac voltmeter with a voltage range of 200Vrms. The meter uses the bridge configuration for the rectifier of the instrument. If each diode has forward resistance of 500Ω & infinite reverse resistance, calculate the value of series resistance, to limit the current to the rated value at the rated voltage.

→ Given $I_{fsd} = 25mA$.

$R_m = 100\Omega$.

Voltage range = $V_{rms} = E_{rms} = 200V$, $R_s = ?$

We have $E_{dc} = 0.9\ E_{rms}$ | Full wave rectifier.

$$\& \quad R_s = \frac{E_{dc}}{I_{dc}} - R_m$$

$$R_s \Rightarrow \frac{0.9 E_{rms}}{I_{dc}} - R_m.$$

But in the rectifier ckt, the diode forward resistance = 500Ω. Since bridge configuration is used, 2 diodes will be conducting & will be series. ~~at~~ + Thus the diode resistance will be

$500\Omega + 500\Omega = 1k\Omega$.

Thus the total meter resistance will be

$R_m = 100\Omega + 1k\Omega = 1100\Omega$.

Now $$R_s = \frac{0.9 \times 200}{25mA} - 1100$$

$$\boxed{R_s = 6.1k\Omega}$$

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MODULE 2

DIGITAL VOLTMETERS

The digital voltmeters referred as DVM, converts the analog signals into digital and display the voltages to be measured as discrete numerals rather than pointer deflection, on the digital displays.

DVMs can be used to measure a.c. and d.c. voltages and with proper transducer and signal conditioning circuit it can also measure parameters like pressure, temperature, stress etc.

The output voltage is displayed on the digital display on the front panel.

These DVMs reduces the human reading and interpretation errors and parallax errors. The DVMs have various features and the advantages, over the conventional analog voltmeters having pointer deflection on the continuous scale.

There are different types of DVM which differ in number of digits, accuracy, speed of reading, size, power requirements and cost.

The important performance characteristics of DVM are as follows:

1. The input ranges from 1v to 1000v with provision for range selection and also indicates the overload condition.
2. Accuracy is high as ±0.005% of reading
3. Resolution is 1ppm i.e the meter can read 1μv on a 1V range
4. Input impedance is around 10MΩ which helps in reducing loading effect.
5. Output is in BCD form and for other forms of output digital processing modules can be included.

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Ramp Technique:

The basic principle is based on measuring the time taken by linear ramp change input level to ground level or vice-versa. This time is measured with the help of electronic time interval counter and the count is displayed in the numeric form with the help of a digital display. This measured value is proportional to the input. Block diagram and operation principle is shown in the below figures.

- At the start of measurement, a ramp voltage is initiated along with resetting the counter by a multivibrator.
- The ramp voltage generated is continuously compared with the input voltage by the input comparator and when both these voltages equals, the comparator generates a 'start' pulse which opens/enables the gate.
- The ramp continues to decrease and finally reaches to 0 V or ground potential and this is sensed by the second comparator or ground comparator.
- As soon as the gate is enabled the oscillator circuit drives the counter and the counter starts counting.
- When the ramp voltage is exactly 0V, the ground comparator produces a ‘stop’ pulse which closes/disables the gate.
- From the time the gate is enabled to disabled, the number of clock pulses are measured by the counter and this time duration for which the gate is enabled, is proportional to the input voltage.
- The magnitude of the count indicates the magnitude of the input voltage, which is displayed by the display. The block diagram of linear ramp DVM is shown in the Fig

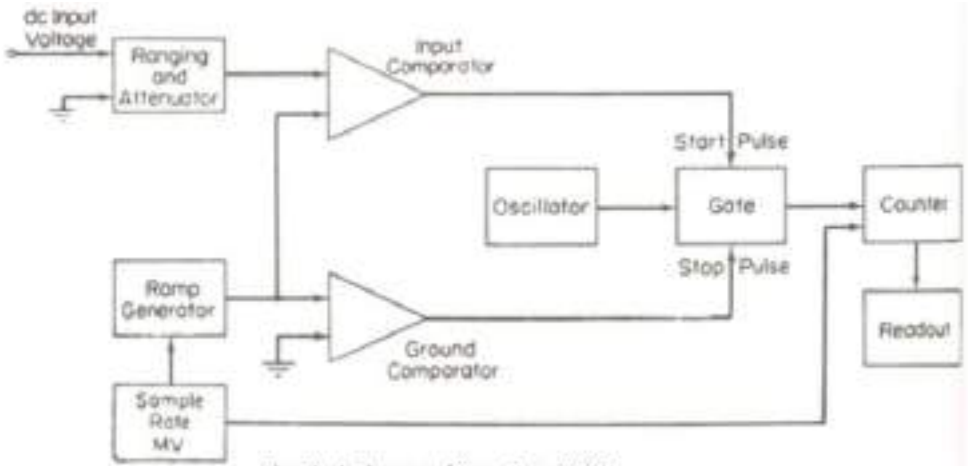

Fig. Block Diagram of Ramp Type DVM

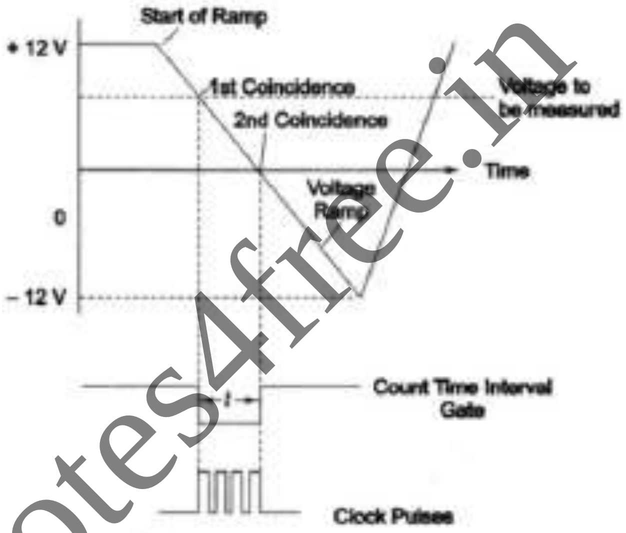

Fig. Voltage to time conversion

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Advantages:

- Easy to design
- Low cost
- Output pulses can be transmitted over longer feeder lines

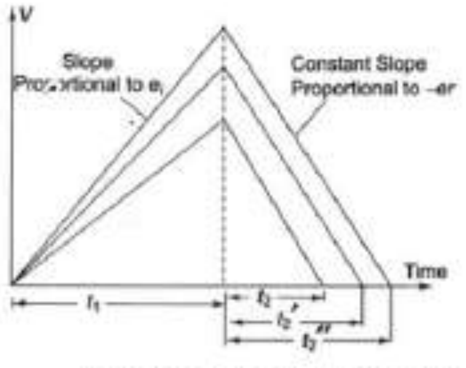
Disadvantages:

- Ramp generator requires excellent characteristics related to linearity
- Large errors are possible when noise is super imposed on the input signal.

Dual Slope DVM: (Voltage to Time conversion)

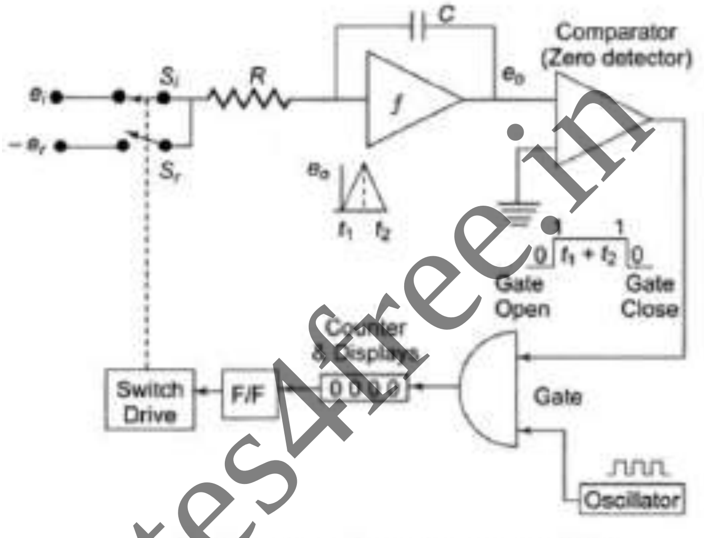
Operating Principle:

The basic principle of this method is that the input signal is integrated for a fixed interval of time. And then the same integrator is used to integrate the reference voltage with reverse slope. Hence which is constant and proportional to the magnitude of the input. Thus the name given to the technique is **dual slope** integration technique. This is shown in the figure below.



Basic principle of dual slope type DVM

The block diagram of dual slope integrating type DVM is shown in the Fig.



Block diagram of a dual slope type DVM

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- At the start, a pulse resets the counter and the flip-flop and this makes the switch Si to close and switch Sr to open.
- The input ei appears at the integrator and the capacitor C begins to charge. As the output of the integrator exceeds 0, the comparator output is changed to 1 and this enables the gate. This causes the clock pulses to feed the counter.
- The counter starts counting until it reaches it maximum count i.e 9999. The time taken for this is denoted as t1. During this time the capacitor is charged to the input ei.
- Upon max count value at the counter and for the next clock pulse the counter value will be 0000 with a carry which is fed to the flip-flop. This drives the switch Sr to close and Si is now open.
- With this now –er (-ve reference) is given to the integrator. Now the capacitor begins to discharge causing output of integrator to decrease. At some time instant t2, the integrator output reaches 0 and this cause the comparator to change its state to 0. This disables the gate.
- During time t2, the capacitor discharges with a constant slope and this is proportional to the input voltage.
- When the counter stops counting the pulses, the value has a direct relation with the input voltage and it is given by,
  During charging of capacitor, i.e during time t1, the output of integrator is given by,

$$e_0 = \frac{-1}{RC}\int_0^{t1} ei\ dt\ = \frac{-ei*t1}{RC} \text{ --------------(1)}$$

During Discharging of capacitor, i.e during time t2, the output is given by

$$e_0 = \frac{1}{RC}\int_0^{t2} -er\ dt\ = \frac{-er*t2}{RC} \text{ -------------(2)}$$

Subtracting (2) from (1)

$$e_0 - e_0 = \frac{-ei*t1}{RC} + \frac{er*t2}{RC}$$

$$\frac{ei*t1}{RC} = \frac{er*t2}{RC}$$

$$ei = er * \frac{t2}{t1} \text{ ---------------------(1)}$$

Suppose if the oscillator period is T and the counter indicates n1 and n2 counts, then

$$ei = er * \frac{n2 * T}{n1 * T}$$

$$ei = er * \frac{n2}{n1}$$

Now n1 and n2 are constants and considering variable K1 = er/n1 then we can write ei as

$$ei = K1 * n2 \text{ --------------------------(2)}$$

From eqn (1) and (2), it is clear that accuracy of measured value does not depend on the integrator time constant.
From eqn (2) it indicates that the accuracy is independent of the oscillatory frequency.

Advantages:

- It has excellent noise rejection and the noise is averaged out by the positive and negative ramps using the process of integration.
- Accuracy is ±0.005%

Disadvantage:

- The only disadvantage seen in this type DVM is that the process is slow

Integrating type DVM (Voltage to Frequency Converter):

Operating principle: In this a constant input voltage is integrated and the slope of the output ramp is proportional to the input voltage. When the output voltage reaches certain value, it discharges to 0 and the next cycle begins and this continues. Frequency of this output is proportional to the input voltage. The principle of conversion from voltage to frequency is shown in the fig.
The number of pulses appearing in a definite interval of time is counted and as the frequency of these pulses is a function of the unknown voltage, the number of pulses counted in that period of time is the indication of the unknown input voltage.

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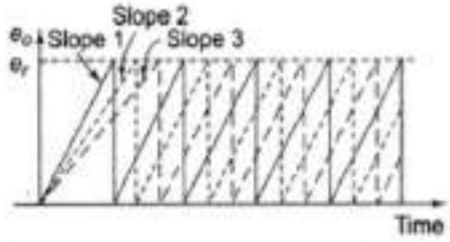

Fig. Voltage to frequency conversion

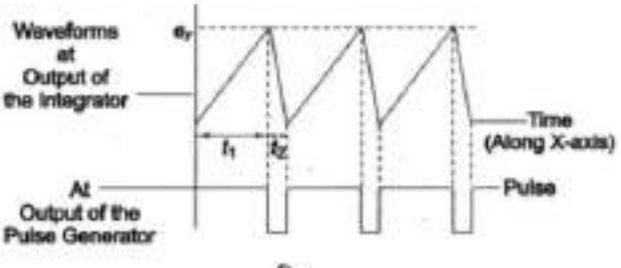

Fig.

- The heart of integrating type of DVM is the operational amplifier which used as an integrator. The block diagram of integrating ramp DVM is shown in fig. below.
- The input voltage ei, when applied generates a charging current ei/R which charges the capacitor to the reference voltage er.
- When the integrator output reaches er (i.e charging of capacitor to er) the comparator changes its state and this triggers the precision pulse generator.
- The precision pulse genertates a pulse of precison charge of negative polarity of the er and this rapidy discharge the capacitor. The output of integrator and pulse generated output waveform is showin in the above fig.
- As the capacitor discharges the output of integrator changes and causes the comparator to change its state bake to initial state and this cycle repeates.
- The rate of charging and discharging produces signal frequency that is directly proportional to input ei.

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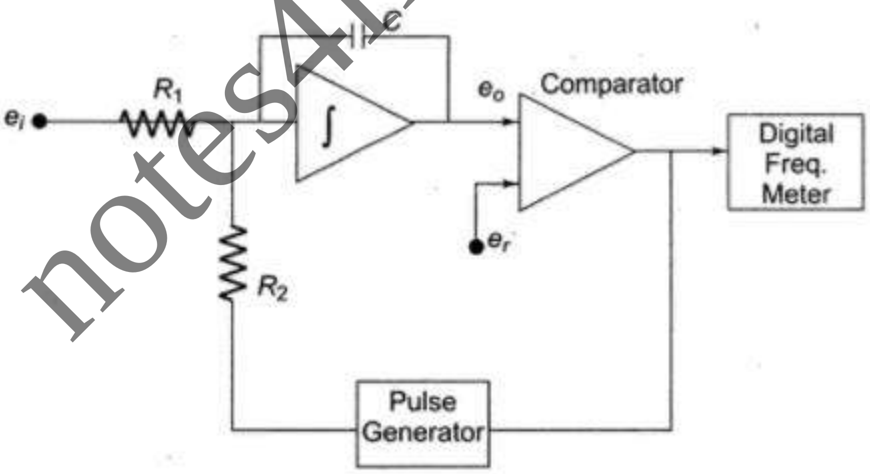

Fig. Block diagram of an integrating type DVM

- The output expression for integrating type DVM is same as that of Dual Slope integrating, using the same we have,

$$ei = er * \frac{t2}{t1}$$

Here er and t2 are constants. Considering another variable K2 as
Let K2 = er *t2

$$ei = K2 * \frac{1}{t1}$$

Therefore we can say, $ei = k2 * f0$
Thus measured input is function of the frequency.

Advantages:

- This type of DVM is capable of giving accurate results even in the presence of noise.

Staircase Ramp Technique:

In this method the input signal is compared with an internally generated voltage which increases in steps from 0. The number of steps required to match both the inputs is counted.

Operation Principle: The input signal Vi is compared with internally generated staircase voltage Vc. As the inputs are not same at the begining a counter is initiated to count. The counter will count until Vi = Vc and then the counter is disabled. The counted valued is displayed which is proportional to the input Vi.

- The block diagram of staircase ramp type DVM is shown in Fig b
- At the initial step of measurement, the counter is reset to 0 and this counter output drives the Digital to Analog Converter (DAC). The output of DAC, which is an analog voltage is given as input to the comparator, denoted as Vc (this is the staircase voltage which is internally generated)
- Upon the application of Vc, the comparator changes its state to 1 and this enables the gate, which allows the clock pulses to the counter and the counter starts counting. This time is t1 (i.e gate is enabled at time t1)
- For each count at the counter, the DAC will generate corresponding analog voltages which increases in small amount. Thus the output of DAC is a staircase voltage as shown in Fig a.
- The process is repeated until the input voltage Vi equals the DAC voltage Vc(until this the gate is enabled and the counter will be counting) at the moment Vi = Vc the comparator changes its state to 0 and this disables the gate, thus blocking the clock pulses. The counter stops counting and the displayed value is proportional to the input value.

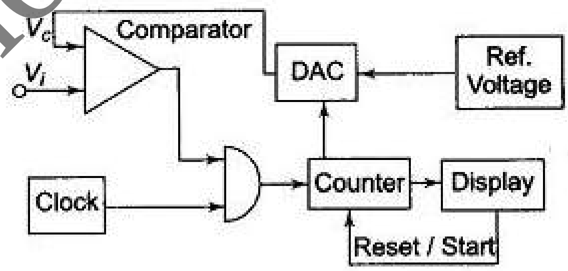

Fig. b Block Diagram of a Staircase Ramp Type

Advantages:

- Input impedance of the DAC is high when the compensation (Vi=Vc) is reached.
- The accuracy depends only on the stability and accuracy of the voltage and DAC. The clock has no effect on the accuracy.

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Disadvantages:

- The system measures the instantaneous value of the input signal at the moment compensation is reached. This means the reading is rather unstable, i.e. the input signal is not a pure dc voltage.
- Until the full compensation is reached, the input impedance is low, which can influence the accuracy.

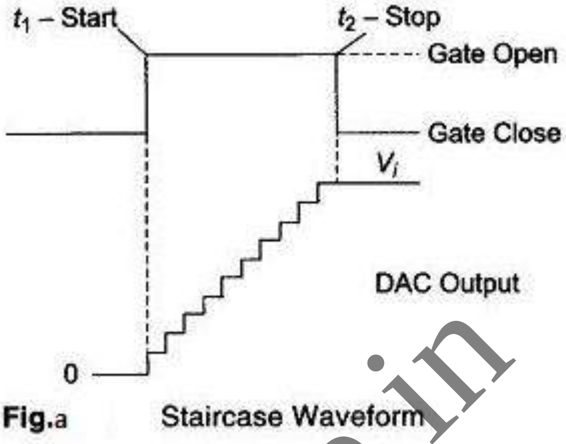

Fig.a Staircase Waveform

Successive Approximation Technique

The principle of successive approximations can be understood using a simple example of measuring the weight of an object using a balance. In the process an approximate weight is placed and then adding or removal of smaller weights is done for balancing. Or it uses the same principle used in binary search algorithm.

- The basic block diagram is shown in Fig.2.1.
- When the start pulse signal is given through multivibrator, the successive approximation register (SAR) is cleared.
- The output of the SAR is 00000000 which the input to DAC and thus Vout of the D/A converter is 0.
- When the input Vin is applied and during the first clock pulse, the control circuit sets the (MSB) D7 to 1. The SAR output is 10000000 and this causes the output of DAC, Vout to Vref/2.
- If Vin > Vout the comparator produces an output which retains the set state of D7.
- In the next pulse the ring counter in the block advances the count value and impends 1 in the next MSB position i.e D6. Now the SAR output is 11000000.
- The DAC now produces Vout as Vref/2+Vref/4 and this voltage is again compared with Vin.
- In the next pulse if Vin > Vout the D6 will be retained as set state and D5 will be set and SAR is now 11100000 and DAC produces output as Vref/2+Vref/4+Vref/8.

- Suppose if Vin is less than Vout the comparator produces an output which resets the D7 and the ring counter impends 1 to D6. The SAR is now 01000000. The DAC output is now Vref/4.

- This is compared with Vin. If still Vin < Vout D6 will be reset and D5 will be set by ring counter. SAR has now 00100000 and DAC output for this is Vref/8.

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- The measurement cycle repeats and continues until ring counter reaches its max count.

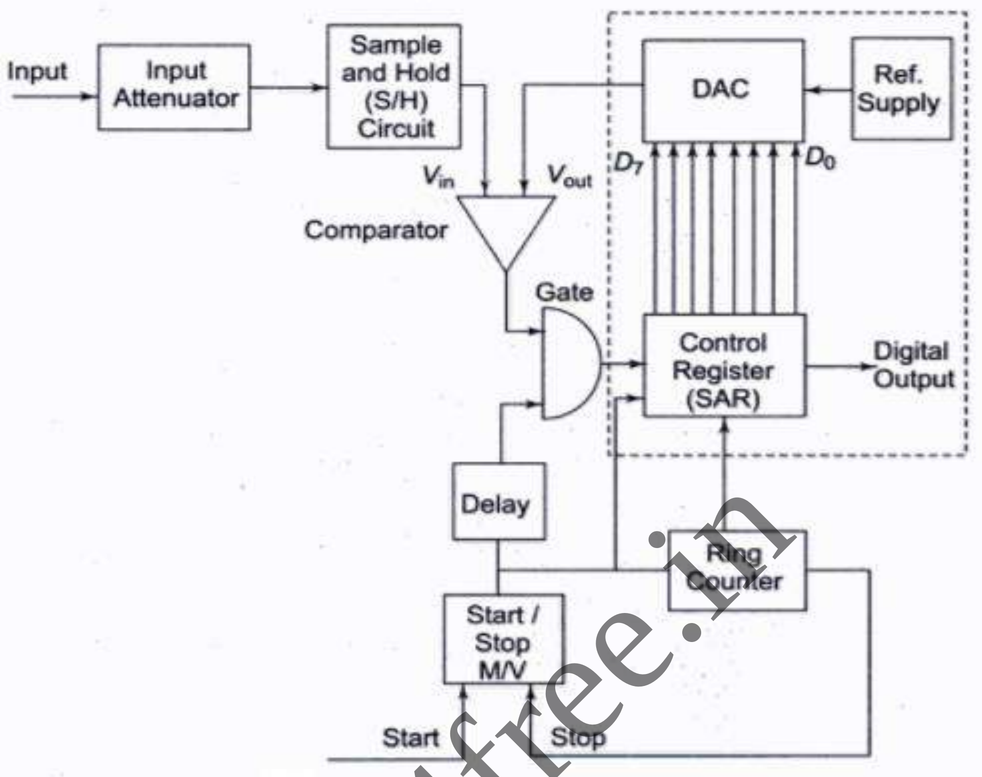

Fig. 2.1 Successive approximation DVM

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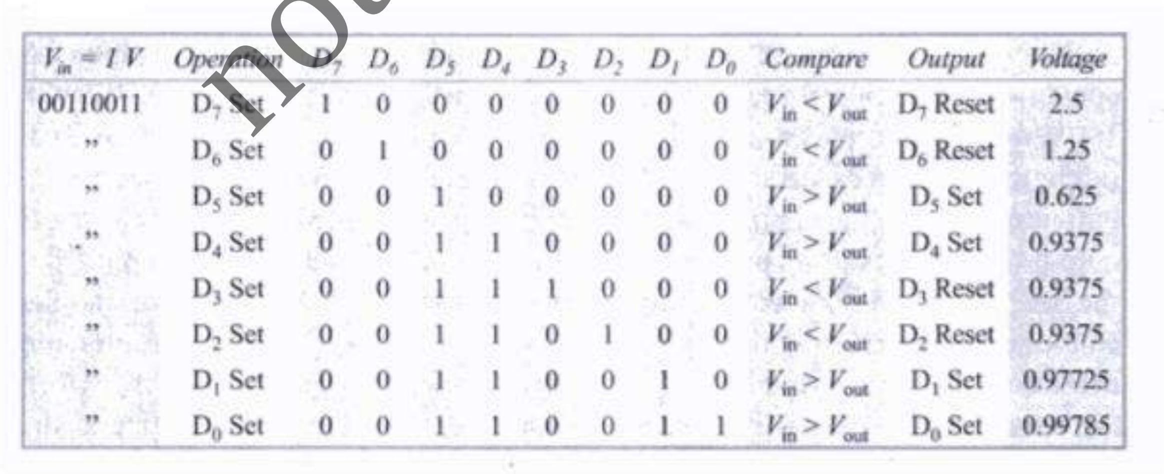
Suppose if the converter measures a max of 5V and if this corresponds to max count of 11111111. If the test voltage Vin = 1V, the following steps will take place in the measurement.



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

Sample and Hold Circuit:

- A sample and hold circuit is shown in Fig 2.3 and it consists of a switch and a capacitor.
- In sample mode, the switch is closed and the capacitor gets charged to the instantaneous value of the input voltage
- In hold mode, the switch is opened and the capacitor holds the voltage that it had at the instant the switch was opened.

- The sample and input and output waveform is shown in Fig. 2.4

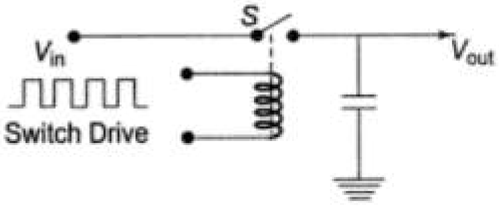


Fig. 2.3 Simple sample hold circuit

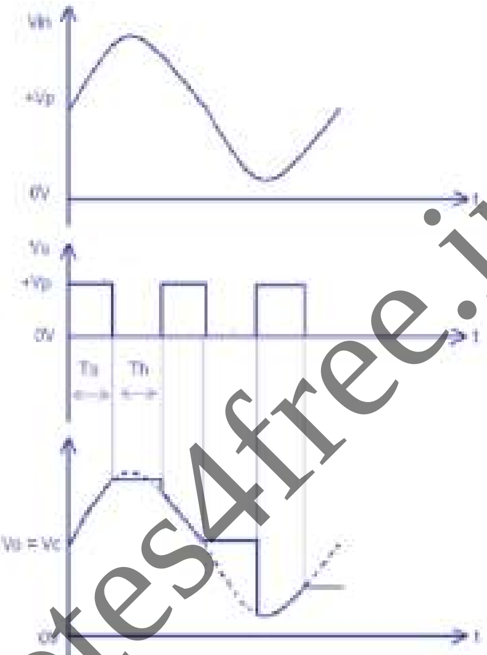


Fig. 2.4. Sample and Hold input and output waveform

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Continuous Balance DVM or Servo Balancing Potentiometer Type DVM:

- The block diagram of Continuous Balance Voltmeter is shown in Fig. 2.5.
- It works on the same principle as that of the differential voltmeter or Potentiometric voltmeter.
- The input is a dc signal which is attenuated, overloaded protected and all the ac component is removed and is applied to one input of chopper comparator.
- Chopper is a power switch which converts fixed dc to variable dc and it acts as comparator.The other input to chopper is connected to the variable arm of a precision potentiometer.
- The output of the chopper comparator is driven by the line voltage at the line frequency rate and it is a square wave signal whose amplitude is a function of the difference in voltages connected to the opposite side of the chopper. This is also the error signal
- The square wave signal is amplified and fed to a power amplifier, and the amplified square wave is given to a servomotor which moves the sliding contact of the potentiometer

- The servomotor moves the sliding contact of potentiometer proportional to the error signal.
- When the error signal becomes zero, the servomotor stops moving the sliding contact. Also the servomotor drives a readout.
- When the error signal is zero the readout is proportional to the input.

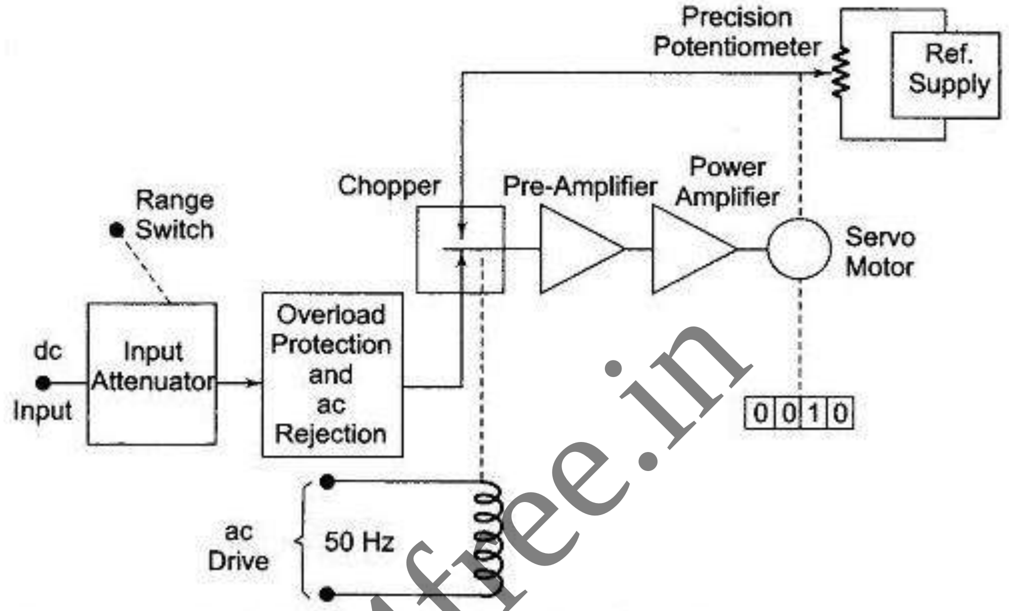

Fig. 2.5 Block Diagram of a Servo Balancing Potentiometer Type DVM

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$3\frac{1}{2}$ Digit:

- This is related to the display in the DVM.
- The number of digit positions used in a digital meter determines the resolution. Hence a 3 digit display on a DVM for a 0 –1 V range will indicate values from 000 – 999 mV with a smallest increment of 1 mV. Similarly for 0-10 V range will indicate values from 000 – 9.99V with a smallest increment of 10 mV.
- The fourth digit capable of indicating 0 or 1 (hence called a Half Digit) is placed to the left. This permits the digital meter to read values above 999 up to 1999.
- The 3 ½ digit display is shown in Fig. 2.6

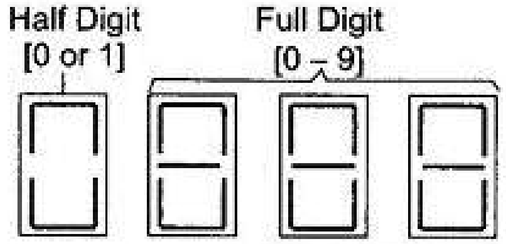

Fig. 2.6 3½–Digit Display

Resolution and Sensitivity of digital meter:

Resolution: Resolution of a DVM is determined by the number of full or active digits used

If n= number of full digits,

then the Resolution (R) $= \frac{1}{10^{n}}$

If n=3, then the resolution R = $\frac{1}{10^{3}} = 0.001$

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

Sensitivity $S = (fs)_{min} \times R$

Where $(fs)_{min}$ = lowest full scale of the meter

R = Resolution expressed as decimal.

Microprocessor based Ramp type DVM:

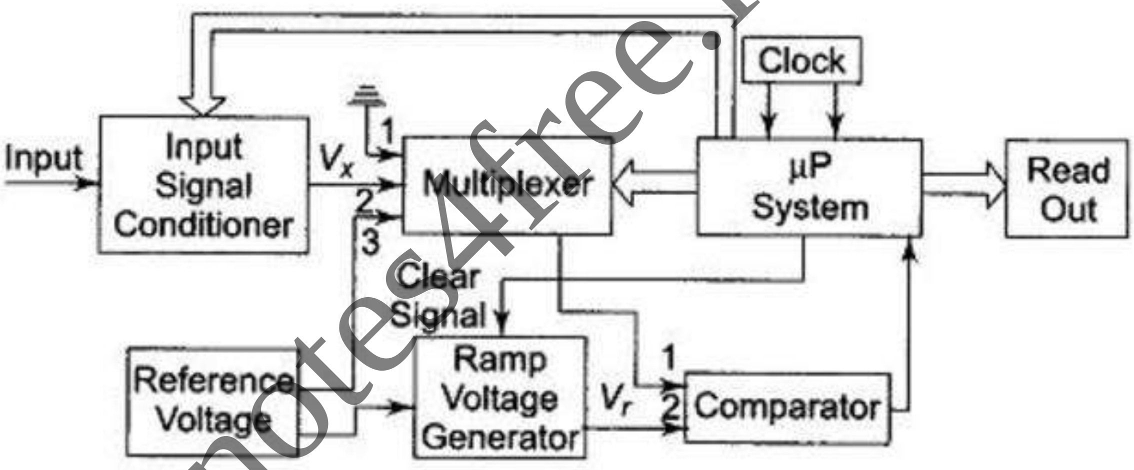

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Fig. 2.7 (a) Basic Block Diagram of a Microprocessor-based Ramp Type DVM

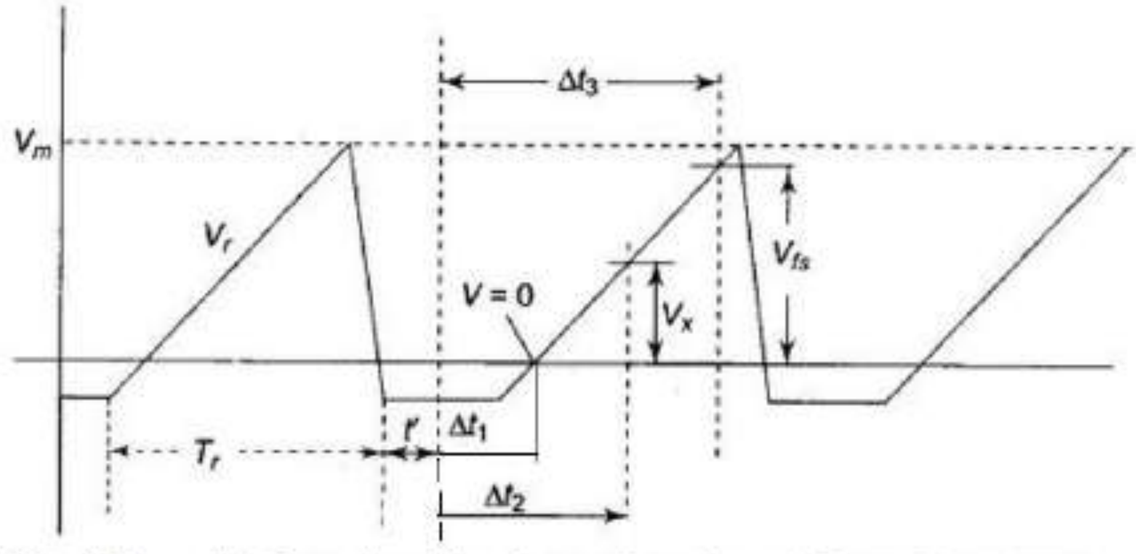

Fig. 2.8 (b) Operating Waveform of a µp-based Ramp Type DVM

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- Depending on command fed to control input of multiplexer by microprocessor comparator connects to multiplexer input 1,2,3.
- Input 1 connects to ground, Input 2 connects to unknown input, Input 3 connects to reference voltage input.
- Comparator has two inputs, input 1 accepts output signal from multiplexer and input 2 accepts ramp voltage from ramp generator.
- Microprocessor remain suspended in resting state until it gets start command to start conversion. In this state it regularly send reset signal to ramp generator resets its capacitor discharge producing ramp signal having constant Tr and Vm with with enough time for capacitor discharge.
- When conversion command arrives at time t^1 to microprocessor, multiplexer connects input 1 to comparator input and brings to ground potential i.e zero voltage. Microprocessor pauses until another sawtooth pulse begins.
- Input 2 voltage arrived from ramp generator becomes equal to input 1 and voltage will become zero at time Δt1 and the count during this interval be N1 and it is stored in microprocessor.
- When 2nd command from microprocessor causes comparator input connected to input 2 of multiplexer, i.e: unknown input voltage Vx. In this instant ramp generator voltage will be compared with unknown voltage and Δt2 is the time taken to equal both inputs and number of count during this interval is N2 and it is stored in microprocessor.
- For next command microprocessor causes comparator input connected to input 3 of multiplexer, i.e: reference voltage Vref. In this instant ramp generator voltage will be compared with reference voltage and Δt3 is the time taken to equal both inputs and number of count during this interval is N3 and it is stored in microprocessor.
- Then microprocessor computes unknown voltage Vx by

$$V_x = C.\frac{(N2-N1)}{(N3-N1)}$$

Where C is coefficient dependent characteristic of the instrument.

N1,N2,N3 are the counts represents zero drift, unknown voltage and full scale voltage.

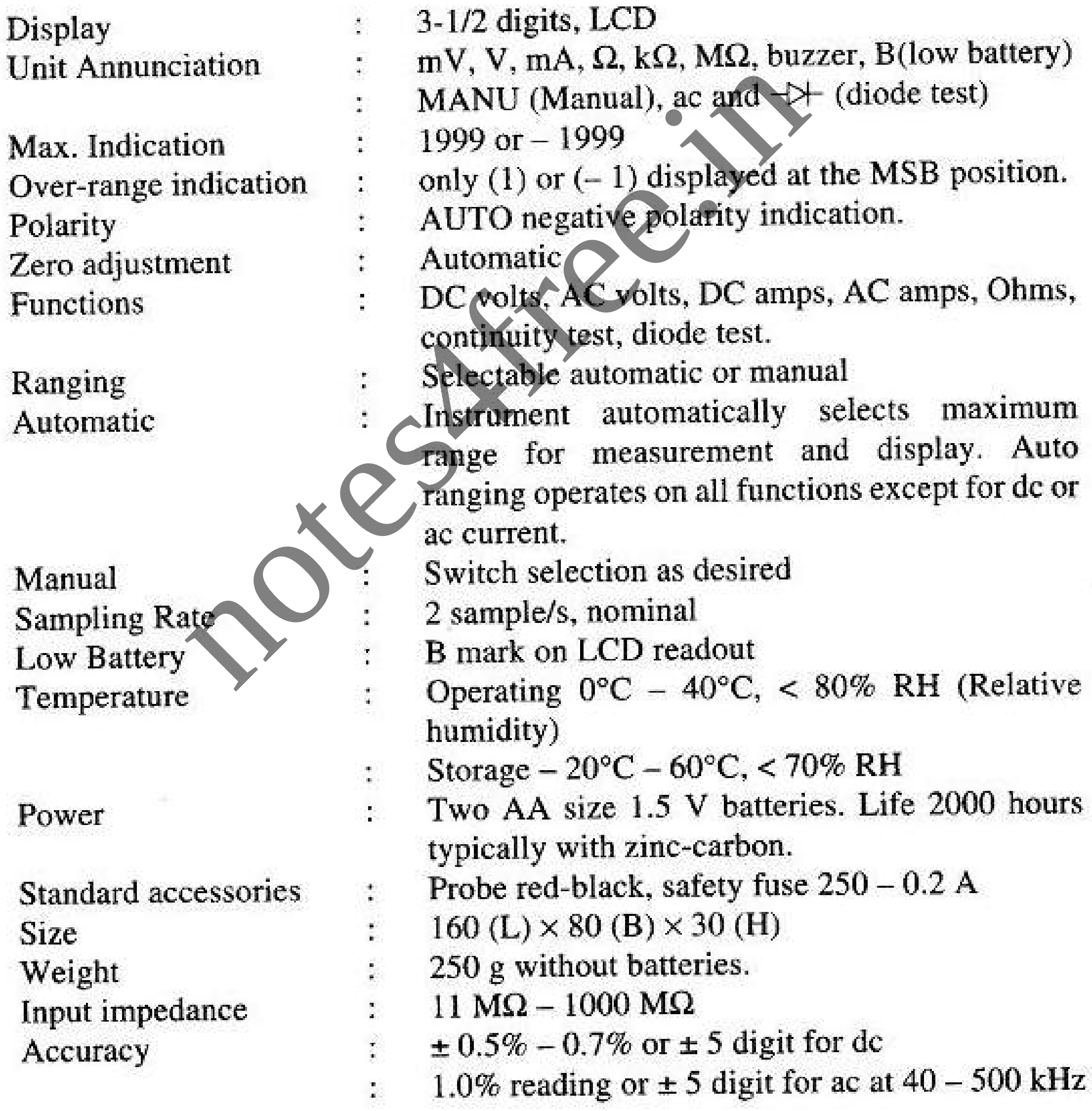
Advantages:

- Its scale size remains constant due to zero drift correction and maximum
- The accuracy of the instrument is not affected by the time and temperature instabilities of the circuit element values.
- There is a good repeatability in switching instants in the presence of noise and interference. This is because the ramp approaches the point at which the comparator operates always the same side and always the same rate.

Disadvantages

- Noise and interference cannot be suppressed.

General Specifications of DVM:



Display	:	3-1/2 digits, LCD
Unit Annunciation	:	mV, V, mA, Ω, kΩ, MΩ, buzzer, B(low battery)
	:	MANU (Manual), ac and ▷| (diode test)
Max. Indication	:	1999 or – 1999
Over-range indication	:	only (1) or (– 1) displayed at the MSB position.
Polarity	:	AUTO negative polarity indication.
Zero adjustment	:	Automatic
Functions	:	DC volts, AC volts, DC amps, AC amps, Ohms, continuity test, diode test.
Ranging	:	Selectable automatic or manual
Automatic	:	Instrument automatically selects maximum range for measurement and display. Auto ranging operates on all functions except for dc or ac current.
Manual	:	Switch selection as desired
Sampling Rate	:	2 sample/s, nominal
Low Battery	:	B mark on LCD readout
Temperature	:	Operating 0°C – 40°C, < 80% RH (Relative humidity)
	:	Storage – 20°C – 60°C, < 70% RH
Power	:	Two AA size 1.5 V batteries. Life 2000 hours typically with zinc-carbon.
Standard accessories	:	Probe red-black, safety fuse 250 – 0.2 A
Size	:	160 (L) × 80 (B) × 30 (H)
Weight	:	250 g without batteries.
Input impedance	:	11 MΩ – 1000 MΩ
Accuracy	:	± 0.5% – 0.7% or ± 5 digit for dc
	:	1.0% reading or ± 5 digit for ac at 40 – 500 kHz

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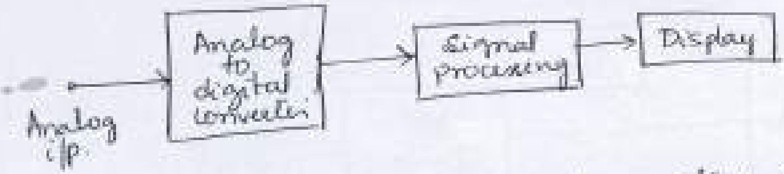
①

Digital Instruments

* The analog measuring instruments are being replaced b the digital instruments
* A digital measuring instrument can measure volta current, power, frequency and logic
* The block diagram of digital instrument is



* Thus in a digital instrument system it has a conver at the i/p stage
* The display can be analog or digital in nature
    - → If analog readout — It needs a Digital to ana converter and deflection arra
    - → If digital readout — with some signal processing data can be readout direct
* In general a digital system may include Resistors, Capacitors, Transistors, Linear IC's, Digital Display devices, ADC & DAC (converter).

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Digital Multimeter:-

Digital meters have the following advantages

- → High accuracy
- → High input impedance
- → smaller in size
- → ~~gives~~ Unambigious reading
- → O/P is available such that it can be interfaced with devices also can be readout.

Analog meters have the following advantages

- → They do not need power supply
- → Better visual indication of sudden changes in the parameter.

DIGITAL MULTIMETER

- A digital multimeter is used to measure voltage, current and resistance.
- A DMM is made up of several A/D converters, circuitry for counting and attenuation circuit.
- To measure resistance-the unknown resistor is connected across the input probes. Some current flows through the resistor, from constant current source.
- Now according to ohm's law voltage is produced across it which is directly proportional to its resistance, then fed to A/D converter, to get the digital display.
- To measure AC voltage-connect an unknown AC voltage across input probes. The voltage is attenuated, if it is above the selected range and then rectified to convert it into proportional DC voltage. It then fed to A/D converter, to get the digital display.
- To measure DC voltage-connect an unknown DC voltage across input probes. The voltage is attenuated, if it is above the selected range and then directly fed to A/D converter, to get the digital display.
- To measure AC current-connect an unknown AC current across input probes. The current is converted proportionally into voltage with help of current to voltage converter and then rectified. Now the voltage in terms of AC current is fed to A/D converter, to get the digital display.
- To measure DC current--connect an unknown DC current across input probes. The current is converted proportionally into voltage with help of current to voltage converter and then rectified. Now the voltage in terms of DC current is fed to A/D converter, to get the digital display.

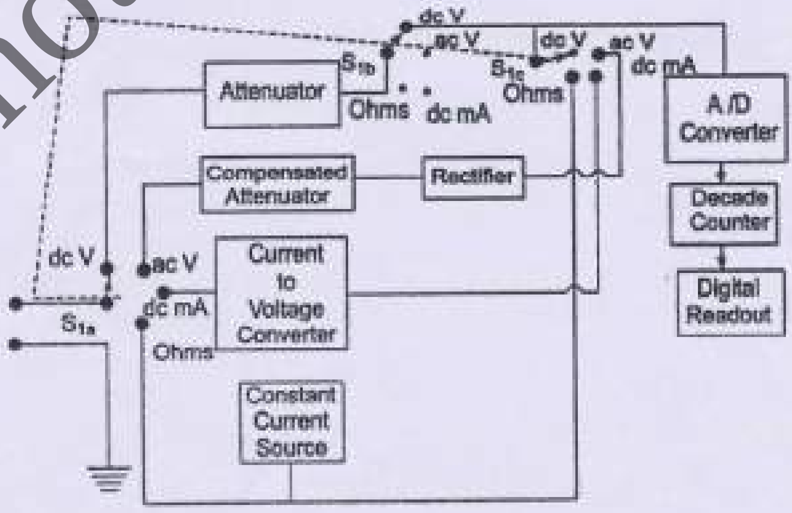

Fig: Block diagram of Basic Digital Multi-meter

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- Current to voltage converter- The current to be measured is applied to the summing junction (∑i) at the input of the opamp.
  Since the opamp has very high input impedance, the current I_R is very nearly equal to I_i. The current I_R causes a voltage drop which is proportional to current, to be developed across the resistor.
  This voltage drop is the input to A/D converter, thereby providing a reading that is proportional to the unknown current.

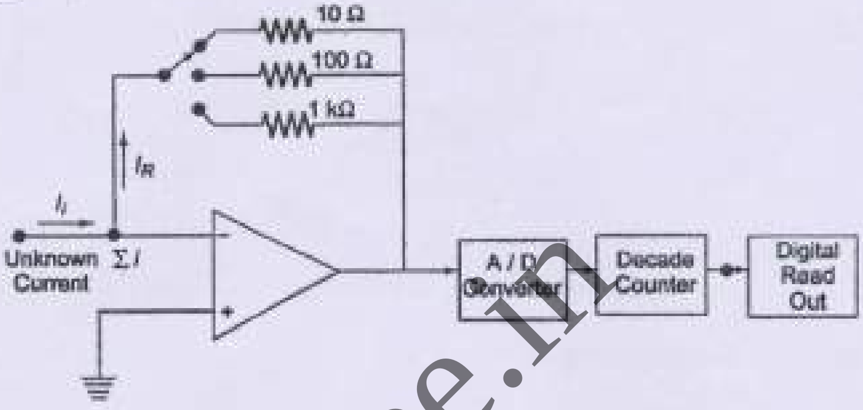

Fig: current to voltage converter

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The basic circuit shown below is always a dc voltmeter

- Current is converted to voltage by passing it through a precision low shunt resistance, while ac current is converted into dc by employing rectifiers and filter circuits.
- For resistance measurement, the meter includes a precision low current source that is applied across the unknown resistance, which gives a dc voltage which is digitized and readout as ohms.

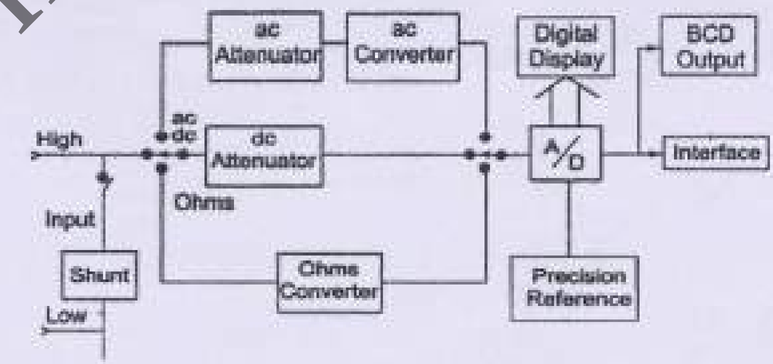

Fig: Digital multi-meter

DIGITAL FREQUENCY METER

Principle of operation

- The signal whose frequency is to be measured is converted into a train of pulses, one pulse for each cycle of the signal.
- The number of pulses occurring in a definite interval of time is counted by electronic counter.
- The number of counts is direct indication of the frequency of the signal (unknown).

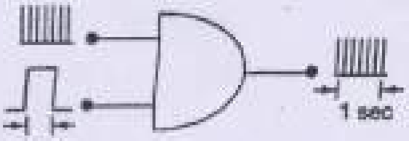

Fig: Principle of Digital Frequency measurement

Basic circuit of a digital frequency meter

- The signal is amplified before applying it to Schmitt trigger.
- The Schmitt trigger converts the input signal into square wave which then differentiated and clipped to obtain train of pulses, one pulse per each cycle of signal.
- The outputs from Schmitt trigger are fed to START/STOP gate.
- When this gate is enabled the input pulses pass through this gate and are fed directly to electronic counter, which counts the number of pulses.
- When this gate is disabled, the counter stops counting the incoming pulses.

Fig: Basic circuit of Digital Frequency meter

Basic circuit for frequency measurement

- The output of the unknown frequency is applied to a Schmitt trigger, producing positive pulses at its output.
- These pulses are called the **counter signals** and present at point A of main gate.
- Positive pulses from the time base selector are present at point B of START gate and point B of the STOP gate.
- Initially the flip flop (F/F-1) is at logic 1 state. The resulting voltage from output Y is applied to point A of the STOP gate and enables this gate. The logic 0 stage

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at the output $\overline{Y}$ of the F/F-1 is applied to the input A of the START gate and disables the gate.

- As the STOP gate is enabled, the positive pulses from the time base pass through the STOP gate to the Set(S) input of the F/F-2 thereby setting F/F-2 to state 1.
- The resulting 0 output level from $\overline{Y}$ of F/F-2 is applied to terminal B of the main gate.
- In order to start the operation, a positive pulse is applied to reset input of F/F-1, thereby causing its state to change.
- Hence Y=1, Y=0, and as a result the STOP gate is disabled and the START gate enabled.
- This read pulse is simultaneously applied to reset the counters, so that counting can start.
- When the next pulse from the time base arrives, it is able to pass through the START gate to reset F/F-2, therefore the F/F-2 output changes state from 0 to 1, hence $\overline{Y}$ changes from 0 to 1.
- This resulting positive voltage from $\overline{Y}$ called the **gating signal** is applied to input B of the main gate thereby enabling the gate.
- Now the pulses from the unknown frequency source pass through the main gate to the counter and the counter start counting. This same pulse from the START gate is applied to set input of F/F-1,changing its state from 0 to 1
- This disables the START gate enables the STOP gate.

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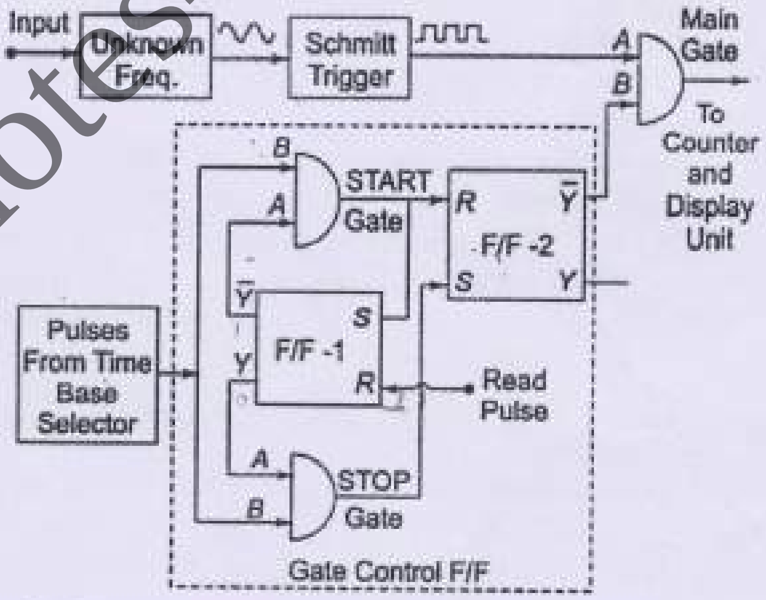

Fig: Basic circuit for measurement of frequency showing gate control F/F

Block diagram of a digital frequency meter

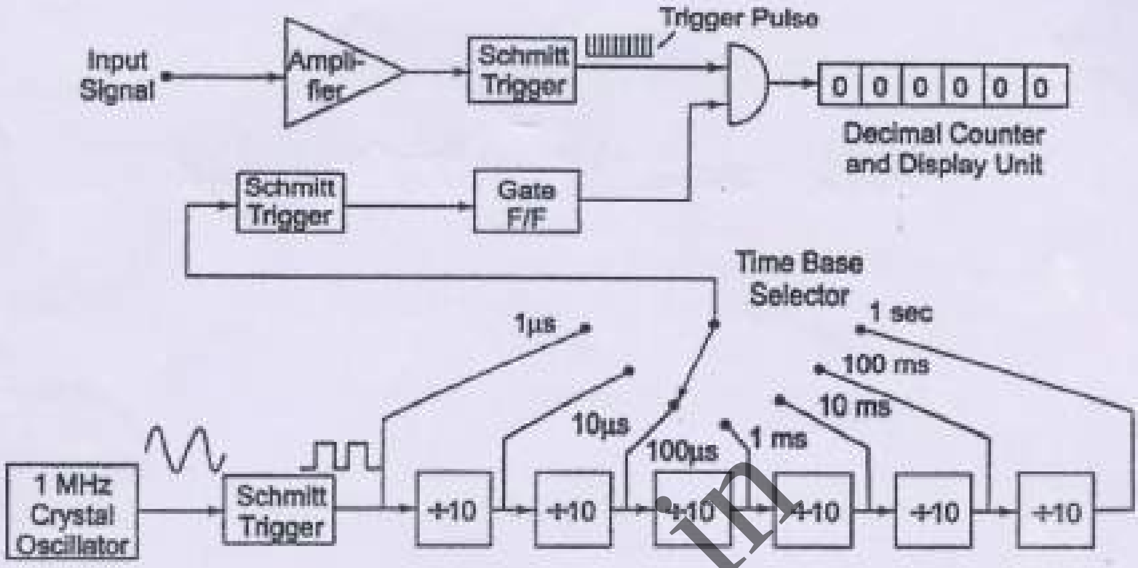

Fig: Block diagram of a digital frequency meter

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- The input signal is amplified and converted to a square wave by a Schmitt trigger circuit, which is then differentiated and clipped to produce a train of pulses, each separated by the period of the input signal.
- The time base selector output is obtained from the oscillator and is converted into positive pulses.
- The first pulse activates the gate control F/F. this gate control F/F provides the enable signal t he and gate.
- The trigger pulses of the input signal are allowed to pass through the gate for selected time period and counted.
- The second pulse from decade frequency divider changes the state of the control F/F and removes the enable signal from the AND gate, thereby closing it.
- The decimal counter and display unit output corresponds to the number of input pulses received during a precise time interval.

High Frequency Measurement (extending frequency range)

- Techniques other than direct counting have been used to extend the range of digital frequency meters to above 40GHz .the input frequency is reduced before it is applied to digital counter. This is done by special techniques. Some are follows
    1. **Prescaling**: The high frequency signal by the use if high speed is divided by the integral numbers such as 2,4,6,8 etc. divider circuits, to get it within the frequency range of DFM.

2. **Heterodyne converter**: The high frequency signal is reduced in frequency to range within that of the meter, by using heterodyne techniques.
3. **Transfer oscillator**: A harmonic or tunable LF continuous wave oscillator is zero beat with the unknown high frequency signal. The LF oscillator frequency is measured and multiplied by an integer which is equal to the ratio of two frequencies, in order to determine the value of unknown HF.
4. **Automatic Divider**: The high frequency signal is reduced by some factor, such as 100:1, using automatically tuned circuits which generated an output frequency equal to 1/100th or 1/1000th of the input frequency.

DIGITAL MEASUREMENT OF TIME

Time Base Selector

- The time base selector consists of a fixed frequency crystal oscillator, called the clock oscillator.
- The output of clock oscillator is fed to Schmitt trigger, which converts the input sine wave to output consisting of train pulses at the rate equal to the frequency of clock oscillator.
- The train of pulses is then passed through a series frequency divider decade assemblies connected in cascade.
- Each decade divider consists of a decade counter and divides the frequency by ten.
- Outputs are taken from decade frequency divider by means of selector switch.

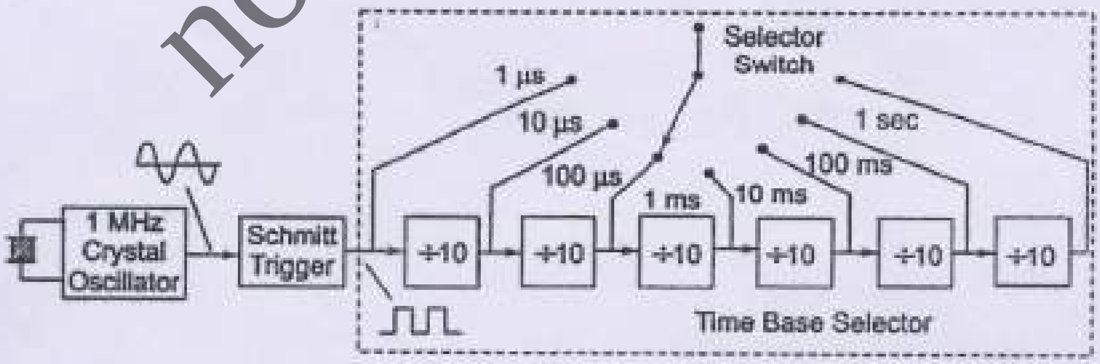

Fig: Time Base Selector

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Measurement of time (period measurement)

Principle of operation

- The beginning of time period is start pulse originating from input 1 and end of time period is stop pulse coming from input 2.
- The oscillator runs continuously, but oscillator pulses reach the output only during the period when the control F/F is in 1 state.
- The number of pulses counted is a measure of time period.

Block diagram explanation:

- The gating signal is derived from the unknown input signal, which controls the enabling and disabling of the main gate.
- The number of pulses which occur during one period of the unknown signal are counted and displayed by the decade counting assemblies.
- The only disadvantage is that the operator has to calculate the frequency from time by using the equation f=1/T.

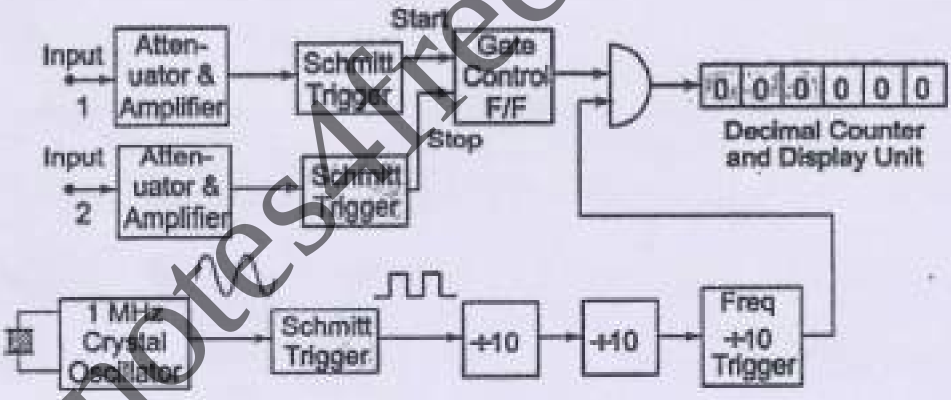

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Fig: Basic block diagram of Time measurement

- The accuracy of period measurement and hence of frequency can be greatly increased by using the **multiple period average mode** of operation.
- In this mode, the gate is enabled for more than one period of unknown signal.
- This is obtained by passing the unknown signal through one or more decade divider assemblies (DDAs), so that the period is extended by a factor of 10000 or more.
- The decimal point location and the measurement units are changed when each time an additional decade divider is added, so that the display is always in terms of the period of one cycle of input signal.

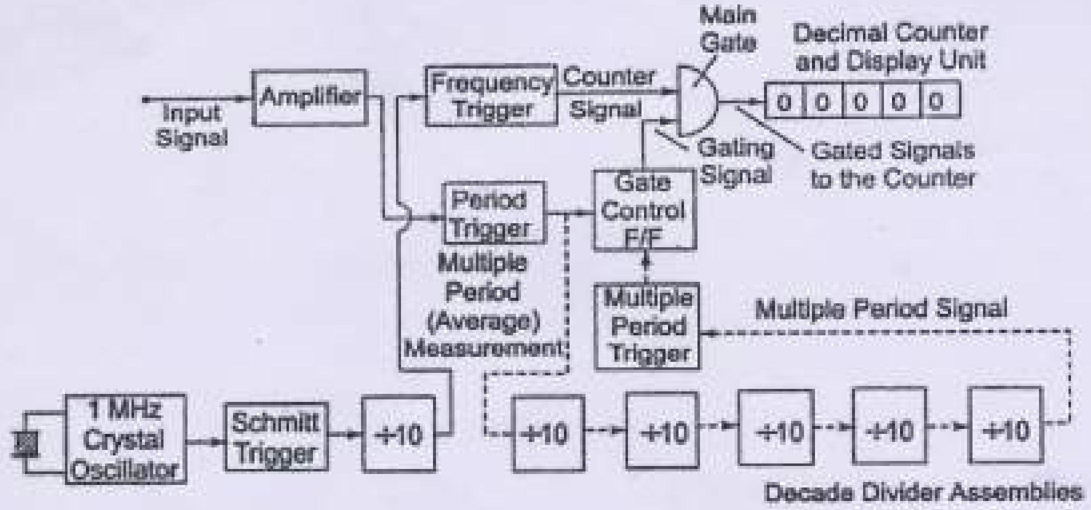

Fig: Block diagram of a single and multiple periods (average) measurement

Ratio and multiple ratio measurement

- The ratio measurement involves the measurement of the ratio of two frequencies.
- A low frequency is used as gating signal while high frequency is the counted signal.
- The number of cycles of high frequency signal which occurs during the period of lower frequency signal are counted and displayed by the decimal counter and display unit.
- In multiple ratio measurements the period of low frequency signal is extended by a factor of 10, 100 etc by using DDAs.

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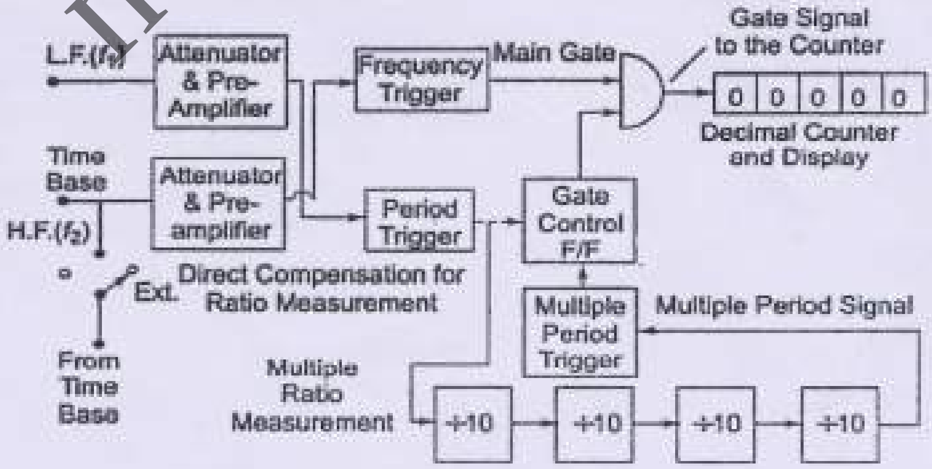


Fig: Block diagram for Ratio and multiple ratio measurement

Universal Counter :-

→ Universal counter can be considered as a block to which can ~~measure~~ do all measurements of time ~~ratio~~ period & freq in the same ckt

→ It is the combinations of various circuits (like time freq, ratio measurements etc) which is assembled together to form one complete block known as 'Universal Counter Timer'

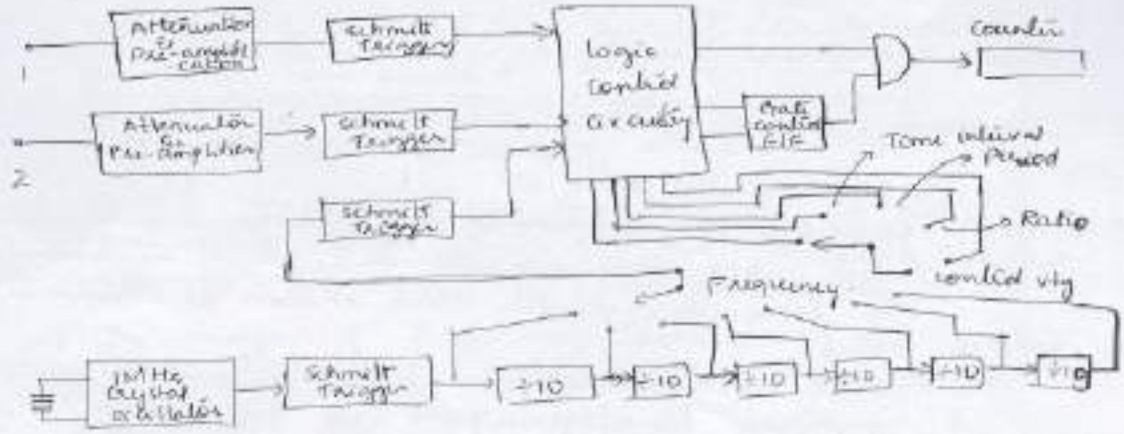
→ The universal counter has a 'function switch' which is driven by logic gates & this switch controls and selects the function of universal counter

→ when the function switch is in the frequency mode, the signal whose freq is to be measured is connected to counter signal of the main gate simultaneously from the time base selector proper time is selected & proceed through gate control F/F which enables & disables the main gate. Both the paths are connected / latched so that they operate in proper sequence. All the controlling is done by the logic circuitry.

→ when the function switch is connected to period measurement mode, the logic circuitry connects the unknown signal for enabling & disabling the main gate simultaneously connects the signal from time base selector to the counter signal of the main gate

→ Similarly when the functions switch is in other position it performs different functions like ratio, multiple ratio measurement ~~set~~ etc.

→ The main part is the logic ckty in universal counter



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Digital Tachometer:

- A digital Tachometer is digital device which measure the speed of a rotating object. A rotating object can be a ceiling fan, motor shaft, car tire etc. The block diagram is shown in Fig. a
- The technique employed for measurement is similar to the technique used in a conventional frequency counter, except that the selection of the gate period is in accordance with the rpm calibration.
- If we consider R as the rpm of a rotating shaft.
- Let P be the number of pulses produced by the pick-up for one revolution of the shaft, now if this is divided by 60 it gives number of no. of pulses per minute as P/60.
- Therefore, in one minute the number of pulses from the pick-up will be R × P/60.
- Now if G is the gating period, and the pulses counted within the gating period will be given by
  - (R × P × G)/60
- This can be calibrated to get direct reading by selecting G as 60/P

Then this will result in

$$\frac{R \times P \times 60}{60 \times P} = R$$

Thus the relation between gate period and no. of pulses is G = 60/P and if G is fixed for 1s (G=1s) then revolution pick up must be capable of producing 60 pulses per revolution.

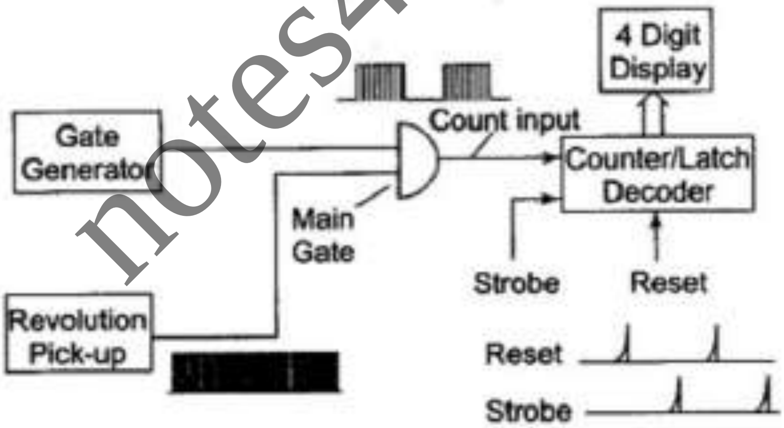

Fig. a Basic Block Diagram of a Digital Tachometer

Digital pH meter:

- A pH meter is an instrument whuch measures the hydrogen-ion activity in water-based solutions, indicating its acidity or alkalinity expressed as pH. The output of pH meter is the difference in electrical potential between a pH electrode and a reference electrode.
- pH is a quantative measure of acidity. If the pH is less than 7, the solution is acidic (the lower the pH, the greater the acidity). A neutral solution has a pH of 7 and alkaline (basic) solutions have a pH greater than 7.

The pH unit is defined as

$$pH = -\log(\text{concentration of } H^+)$$

Where H^+ is the hydrogen or hydronium ion.

- The basic block diagram of a digital pH meter is shown in Fig. b
- A digital pH meter differs from an ordinary pH meter, where the meter has an analog to digital converter (ADC) and a digital display. The ADC used for this application is the dual slope converter.
- The dual slope ADC generates a pulse which has a duration proportional to the input signal voltage (T pulse width signal). This pulse width is converted to a digital signal using the signal from oscillator (which generates a count digital signal). The count signal is counted and displayed.

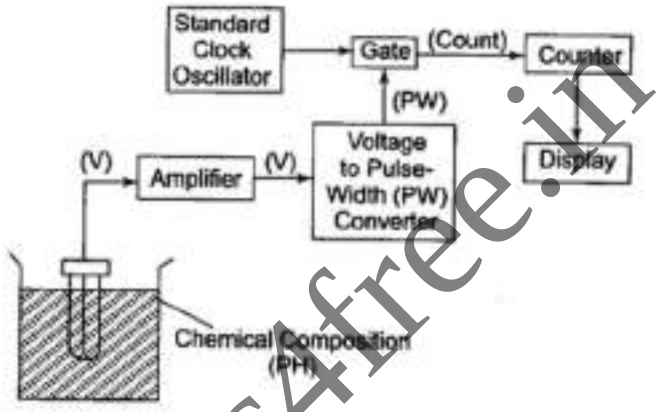

Fig. b Digital pH Meter

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Digital Phase meter:

- A phase meter measures the phase difference between 2 signals of same frequencies.
- The block diagram consists of two pairs of preamplifier's for conditioning the input signal, zero crossing detectors to shape the input signal to a square waveform without any change in their phase, J-K F/Fs, and a single control gate.
- The process of measuring the phase difference is illustrated by the schematic diagram shown in Fig. c.
- Two signals having phases Po and Px respectively are applied as inputs to the preamplifier and attenuation circuit. The frequency of the two inputs should be same and their phases are different.
- As input Po signal increases in the positive half cycle, the ZCD detects the change in state when the input crosses zero (0) giving a high (1) level at the output. This causes the J-K F/F-1's output (Q) to go high.
- This high output from the F/F-1 enables the AND gate, and pulses from the clock are fed directly to the counter. The counter starts counting these pulses.
- Also this high output level of F/F-1 is applied to the clear input of J-K F/F-2 which clears the output of the F/F-2 (i.e Q of F/F-2 is 0).

- Now as the other input Px which has a phase difference with respect to Po, crosses zero in positive half cycle, the ZCD detects and causes its output to go high (1). This high input is given to J-K F/F-2, causing its output go high.

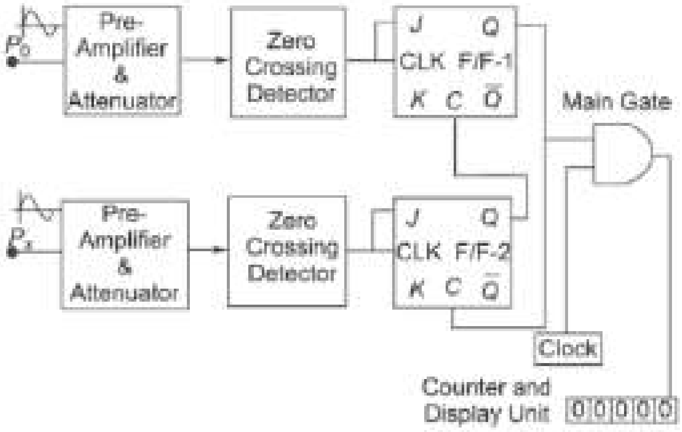

Fig. c Digital phase meter

- This high output (Q) of F/F-2 is connected to the clear input of F/F-1 forcing the F/F-1 to clear/reset and its output goes to 0.
- The AND gate is thus disabled, and the counter stops counting.
- The number of pulses counted while enabling and disabling the AND gate is in direct proportion to the phase difference, hence the display unit gives a direct readout of the phase difference between the two inputs having the same frequency.

Digital Capacitance Meter:

The principle of operation involves counting the no. of pulses derived from constant frequency oscillator during a fixed interval produced by another lower frequency oscillator. This oscillator uses the capacitor being measured as the timing. The capacitance measurement is proportional to the counting during fixed time interval.

- Since the capacitance is linearly proportional to the time constant i.e,
    - $\tau = RC$
- Thus the capacitor is charged by a constant current source and discharged through a fixed resistance. The 555 timer along with some digital test equipment is used to measure capacitances. This method is illustrated in Fig. d.
- By choosing the right size of charging resistance, can get a reading directly in microfarads or nanofarads. This measurement method easily measures electrolytic type up to the tens of thousands of microfarads.
- A better way is to measure only the capacitor discharge time.
- In the circuit, the 555 timer is used as an astable multivibrator. When the capacitor charges to its max i.e at the peak of the charging curve, a digital counter is reset, the **gate** is enabled and a clock of 100 kHz pulses is turned on.
- As the gate is enabled the counter starts counting till the discharge portion of the cycle is completed.
- As the capacitor discharges completely, the input to the **gate** is disabled and counter stops counting and the display is updated and the value of the capacitor is readout.

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- By selecting the proper reference frequency and charging currents, one can obtain a direct digital display of the value of the capacitance.
- But precaution should be taken to make sure to properly shield the leads and keep them short for low capacity measurements, since the 50 Hz hum can cause some slight instability.

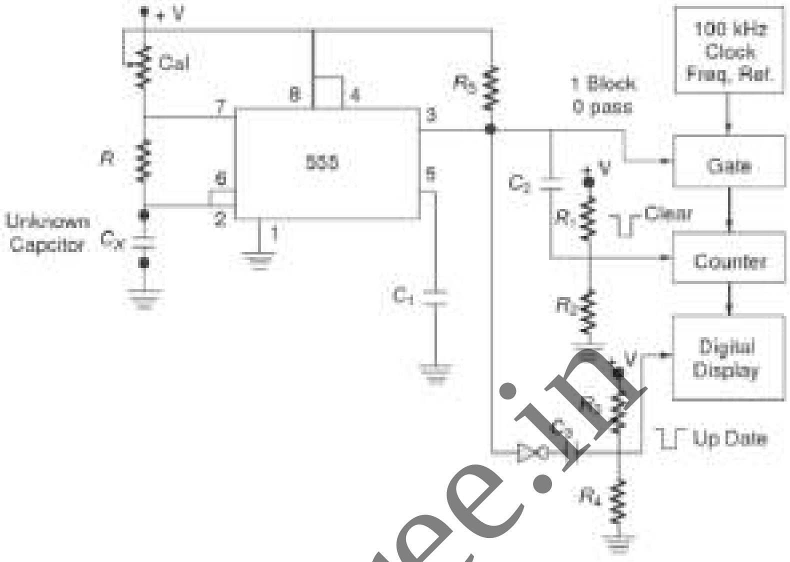

Fig. d Block diagram of a basic digital capacitance meter

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Microprocessor based instrument:

The digital instruments are designed and constructed with logic circuits without memory but with the use of microprocessor in measuring instrument, it is considered as a new class of instruments called intelligent instruments.

Fig. e shows the block diagram of microprocessor based

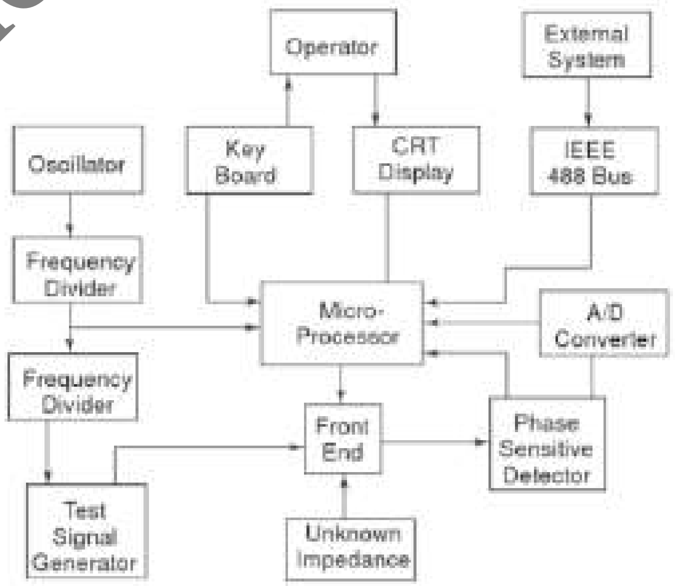

Fig. e Block diagram of a μp (microprocessor) based instrument

- The front end provides the test signal for unknown impedance under measurement and a standard impedance.
- This produces a voltage drop with phase shift proportional to the voltage across it.
- The phase sensitive detector detects this and converts the ac input of impedance in vector form to a dc output.
- This dc input is provided to ADC which gives the digital data which is used by the microprocessor to compute the unknown value of the impedance.
- This value is displayed on the CRT or can be sent as output to the IEEE 488 bus (used to provide interface between instruments)

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MODULE 3

OSCILLOSCOPES

Introduction:

An oscilloscope is a test instrument which allows you to look at the 'shape' of electrical signals like current,voltage or power to be displayed against time on the screen. Oscilloscope also called as Cathode Ray Oscilloscope (CRO) is the most versatile tool for development of electronic circuits and systems. CRO uses electron beam which is bombarded on screen which is coated with fluorescent material to produce visible spot. When beam is deflected along X and Y axis a 2 – D display is generated.

Oscilloscope is basically an electron beam voltmeter and reproduces rapid variations, pulsations or transients and the user can observer waveform and measure amplitude at any instant of time.

It is completely electronic in nature and can reproduce high frequency waves which mechanical devices cannot follow. Thus oscilloscopes has simplified many tests and measurements.

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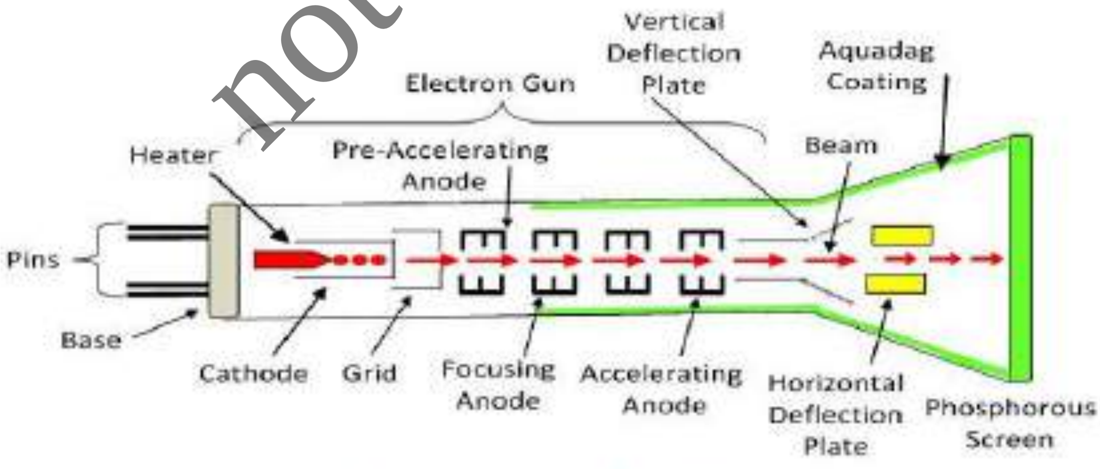
Basic Principle:

- The heart of the oscilloscope is CRT – Cathode Ray Tube
- It has electron gun which gives a narrow electron beam when focused on flat end of glass tube (screen), it glows at the point of collision generating a bright spot. The electron beam when deflected by means of electric or magnetic field, the spot moves accordingly and traces the pattern.
- The Fig. below shows the diagram of CRT



Cathode Ray Tube

- The electron gun is the source of the electron beams. The electron gun assembly has a heater, cathode, grid, pre-accelerating anode, focusing anode and accelerating anode.

- The control grid is cylindrical in shape and has small aperture which is in line with the cathode. The cathode emits electrons which emerges from this aperture as a divergent beam.
- A negative bias is applied to control grid which controls the beam current and this beam current in turn controls the intensity of spot.
- The diverging electron beam from cathode is made converged and focused onto the screen by anodes. These anodes acts as electronic lens.
- Ahead of control grid there are focusing anodes whose aperture is in line with cathode. The first anode is maintained at positive voltage with respect to cathode. (i.e., focusing anode are connected to the lower voltage of about 500V). The second anode which is pre-accelerating and accelerating anode are connected to the positive high voltage of about 1500V (at a higher positive potential). These anodes acts as accelerators and converges the beam of electron. The combination of anodes focuses the electron beam on the screen.
- After exiting the focusing anode, the beams passes through the vertical and horizontal deflecting plates which deflects the electron beam and helps in positioning the beam anywhere on the screen.
- In most oscilloscope electrostatic deflection is used rather than electromagnetic deflection as it is helpful in high frequency application and also consumes less power.
- The front of the CRT is called the face plate and it is made up of fiber optics. The internal surface of the faceplate is coated with the phosphor. The phosphorous converts the electrical energy into light energy. This produces the spots on the screen.
- The Aquadag is the aqueous solution of graphite which is connected to the secondary of the anode.The Aquadag collects the secondary emitted electrons which are necessary for keeping the CRT screen in the state of electrical equilibrium.

CRT Features:

Electrostatic CRTs are available in a number of types and sizes to suit individual requirements. The important features of these tubes are as follows.

1. **Size**
   - It refers to the diameter of the screen. The CRTs for oscilloscopes are available in sizes of 1, 2, 3, 5, and 7 inches. 3 inches is most common for portable instruments.
   - If the number of CRT is - 5GP1, the first number 5 indicates that it is a 5 inch tube.Both round and rectangular CRTs are found in scopes today.

2. **Phosphor**
   - The fluorescent material used for coating the screen is phosphor. This material determines the colour and persistence of the trace.The trace colours in electrostatic CRTs for oscilloscopes are blue, green and blue green.
   - The time period for which the traces remains on the screen even after the signal becomes zero is called '**persistence**'. This persistence can be expressed as short, medium and long.
   - Medium persistence traces are mostly used for general purpose applications.
   - Long persistence traces are used for transients, since they keep the fast transient on the screen for observation after the transient has disappeared.

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- Short persistence is needed for extremely high speed phenomena, to prevent smearing and interference caused when one image persists and overlaps with other.

The phosphor of the oscilloscope is designated as follows.
P1 – Green medium
P2 – Blue green medium
P5 – Blue very short
P11 – Blue short

- These designations are combined in the tube type number. Hence 5GP1 is a 5 inch tube with a medium persistence green trace.

3. Operating Voltages

The CRT requires a heater voltage of 6.3 volts ac or dc at 600 mA.The voltages vary with the type of tube used.
Negative grid (control) voltage – 14 V to – 200 V.
Positive anode no. 1 (focusing anode) – 100 V to – 1100 V
Positive anode no. 2 (accelerating anode) 600 V to 6000 V
Positive anode no. 3 (accelerating anode) 200 V to 20000 V in some cases

4. Deflection Voltages

To deflect the beam ac or dc voltage is required. The movement of spot on screen is proportional to the dc, or peak ac amplitude. The deflection sensitivity of the tube is usually stated as the dc voltage (or peak ac voltage) required for each cm of deflection of the spot on the screen.

5. Viewing Screen

The viewing screen is the glass plate, the inside wall of which is coated with phosphor. This screen is a rectangular screen having graticules marked on it and standard size used is 8 cm x 10 cm (8 cm on the vertical and 10 cm on horizontal). Each centimeter on the graticule corresponds to one division (div). The standard phosphor colour used is blue.

Basic principle of Signal Display/ Function of Sweep Generator:

Principle of Sweep Generator:

- For dc voltage measurement gives a straight line trace representing the amplitude of the voltage.
- But for ac voltage, pulsating or transient, straight line trace does not give any information. Thus it is required to obtain a graph of amplitude versus time, where the voltage is traced on the screen by the spot.
- To obtain such a display the signal voltage is applied to the vertical plates (directly or through the vertical amplifier) and it moves the spot vertically corresponding to the instantaneous values of the signal.
- Simultaneously, to move the spot horizontally a sweep voltage applied to the horizontal plates. The combined action of these two voltages causes the spot to produce a trace on the screen.
- Thus sweep voltage produces the time base by moving the spot horizontally with time, while the signal moves the spot vertically in proportional to the voltage at a particular instant of time.

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There are two important sweep generator requirements.

1. The sweep must be linear (the sweep voltage must rise linearly to the maximum value required for full screen horizontal deflection of the spot).
2. The sweep voltage must drop suddenly after reaching its maximum value so that the spot moves only in one direction i.e., from left to right.

These requirements call for a sweep voltage having a linear saw tooth waveform is shown in Fig below.

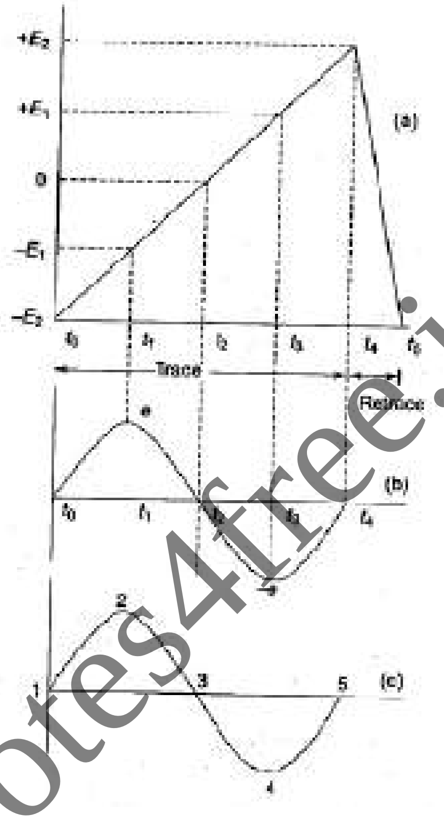

Fig. Waveform of sweep voltage

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- Now at time t0, the sweep voltage is - E2, and this negative horizontal voltage moves the spot to point 1 on the screen. At this instant, the signal voltage is 0, so the spot rests at zero line on the screen.
- At time t1, the linearly increasing sweep voltage reaches - E1, this voltage moves the spot to point 2. At this instant, the signal voltage is e, the +ve peak value, so the point represents its maximum upward deflection of the spot.
- At time t2, the sweep voltage is 0, there is no horizontal deflection and the spot is at the centre, point 3. At this instant, the signal voltage is 0, so there is no vertical deflection either.
- At time t3, the sweep voltage is +E1 and this moves the spot to point 4. At this instant, the signal is -e, the -ve peak value, so point 4 is the maximum downward deflection of the spot.
- At time t4, the sweep voltage is +E2 and this moves the spot to point 5. Now the signal voltage is 0, so the spot is not vertically deflected.

- Between t4 and t5, the saw-tooth / sweep voltage falls quickly through 0 to its initial value of -E2, causing the spot back to point 1.
- This repeats for the next cycle of signal voltage. Thus due to effect of both voltages sinusoidal waveform appear on the screen.
- When sweep and signal frequencies are equal, a single cycle appears on the screen. When the sweep is lower than the signal, several cycles appear and when sweep is higher than signal, less than one cycle appears.
- The signal trace appears stationary only when the sweep and signal frequencies are either same or integral multiples of each other. For other frequencies the trace keeps on drifting horizontally.

The sweep voltage also known as sawtooth sweep voltage is generated by a multivibrator, relaxation oscillator or pulse generator. The different types of sweep voltage generated are as follows.

1. **Recurrent Sweep:** In this ac voltage alternates rapidly so that the display occurs repetitively and the image is seen by the eye. This is repeated operation is recurrent sweep.
2. **Single Sweep:** The signal under study produces a trigger signal, which in turn produces a single sweep.
3. **Driven Sweep:** There may be a chance that the sweep cycle may start after the signal cycle and this may result in missing a part of the signal. In driven sweep this problem is eliminated since the sweep and signal cycles start at the same time.
4. **Triggered Sweep:**In a recurrent mode, the voltage rises to a maximum and then suddenly falls to a minimum and it is repeated. This causes the electron beam to movefrom left to right, retraces rapidly to the left and the pattern is repeated. In this the horizontal sweep action takes place whether the input signal is applied to the oscilloscope or not, and a horizontal line is displayed on the screen continuously.

In case of triggered sweep, the sweep signal does not start unless initiated by a trigger voltage. This trigger is usually the incoming signal. If there is no signal then the sweep will be in hold mode and the screen will be blank.

The recurrent sweep uses a free running multivibrator. Butin triggered sweep it uses a monostable multivibrator which is in its off state until a trigger pulse arrives.

Thus in triggered sweep, when input signal is applied, a trigger pulse is generated and is applied to the multivibrator. This turns on sweep generator and produces a sweep signal and trace appears on the screen. For a specific period of time depending on voltage, the multivibratorwill be on after that it switches back to its off state. The process is repeated for next incoming signal.

5. **Intensity Modulation:**The ac signal is applied to the control electrode of the CRT and this causes the intensity of the beam itself to vary in step with signal alternations. This may result, the trace to be brightened during the +ve half cycles and diminished or darkened during -ve half cycles. This process, is called intensity modulation or Z-axis modulation.

Block diagram of Oscilloscope:

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The block diagram of general purpose CRO is shown below.The function of the various blocks are as follows.

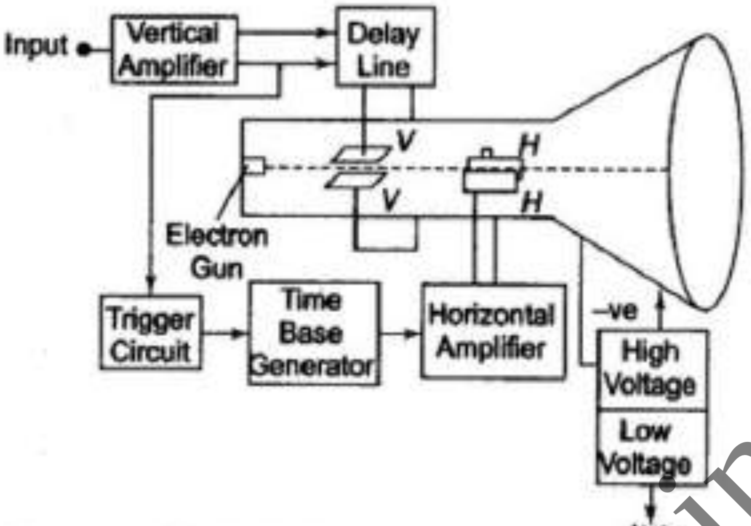

Fig. Basic CRO Block Diagram

1. **CRT:** This is the cathode ray tube which is used to emit electrons that strikes the phosphor screen to provide a visual display of signal.
2. **Vertical Amplifier:** The input signals to be measured are not strong to provide deflections, hence they are amplified using the vertical amplifier. The amplifier uses wide band so that it passes the entire band of frequencies.
3. **Delay Line:**It is used to delay the signal for some time in the vertical sections else part of the signal gets loss.
4. **Time Base:**It is used to generate the sawtooth voltage, required to deflect the beam in the horizontal section. This voltage deflects spots at a constant time dependent rate
5. **Horizontal Amplifier:**The sawtooth voltage generated by the time base generator may not be of sufficient strength. Thus before it is applied to horizontal deflection plates it is amplified using horizontal amplifier.
6. **Trigger Circuit:** trigger circuit converts the incoming signal into trigger pulses which can be used for synchronization. It is required that horizontal deflection starts at the same time as that of input vertical signal. Thus to synchronize the triggering circuit is used.
7. **Power Supply:**There are two power supplies, a -ve High Voltage (HV) supply and a +ve Low Voltage (LV) supply. Two voltages are generated in the CRO. The +ve volt supply is from + 300 to 400 V. The -ve high voltage supply is from -1000 to -1500 V. These voltages are required for controlling intensity, focus and positioning or accelerating the electrons.

Advantages of using -ve HV Supply:

- The accelerating anodes and the deflection plates are close to ground. This ground potential protects the operator from HV shocks.
- The deflection voltages are measured with respect to ground, therefore HV blocking or coupling capacitor are not needed.

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- Less insulation is needed between positioning controls and chasis.

8. Graticules: this is the plastic/glass/fiber glass sheet screen in front of the CRO. This screen has grids similar to graph paper/sheet. This helps in measuring parameters on the oscilloscope. It is practically designed as 8×10 pattern i.e., 8 divisions vertical and 10 divisions horizontal.

Simple CRO:

- The Basic block diagram of a simple CRO is shown in Fig.
- The 'ac heater supply' supplies power to the CRT heaters.
- CRT dc voltage is obtained from the 'HV dc supply' through voltage dividers R1-R5. It also includes potentiometer (R3) which varies the potential at the focusing electrode, known as focus control, and one which varies the control grid voltage, called the intensity control (R5).
- Capacitor C1 is used to ground the deflection plates and the second anode for the signal voltage, but dc voltage isolates these electrodes from the ground.
- S2 connects the sweep generator output to the horizontal input. The sweep voltage is amplified before being applied to the horizontal deflecting plates.
- When an externally generated sweep is used then, S2 is connected to its external position and the external generator is connected to the input. The sweep synchronizing voltage is applied to the internal sweep generator through switch S1, which selects the type of synchronization.

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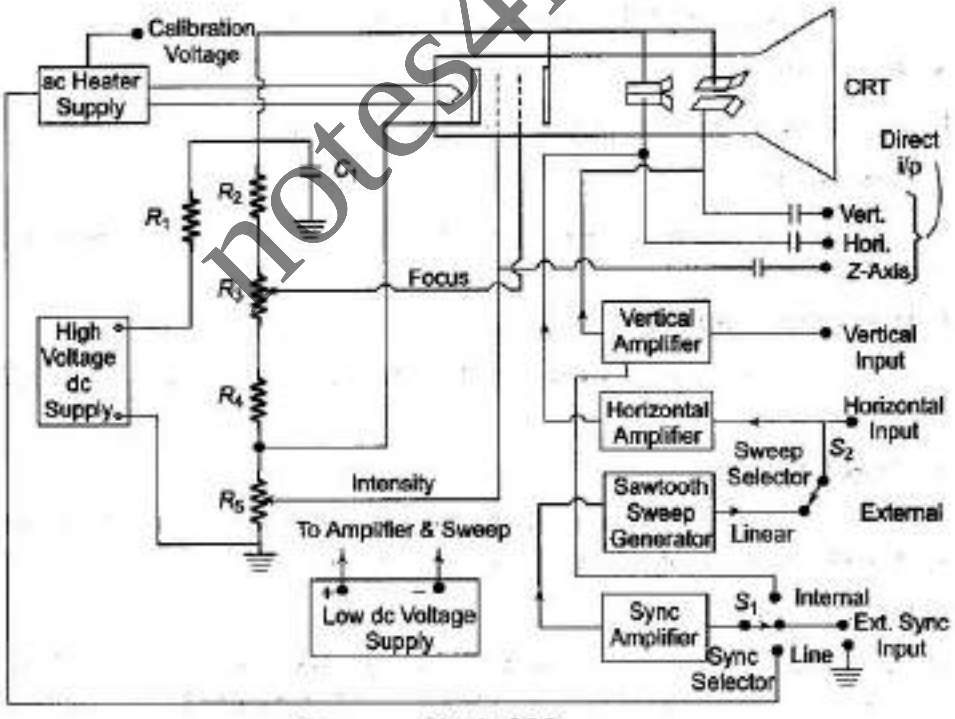

Fig. Simple CRO

Vertical Amplifier:

The vertical amplifier in oscilloscope determines the sensitivity (gain) and frequency bandwidth (BW). The gain and B.W. product is constant. Thus to obtain a greater sensitivity the BW is narrowed or to get better/greater frequency sensitivity is reduced.

Some oscilloscopes provides two alternatives

- Switching to a wide bandwidth position
- Switching to a high sensitivity position.

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

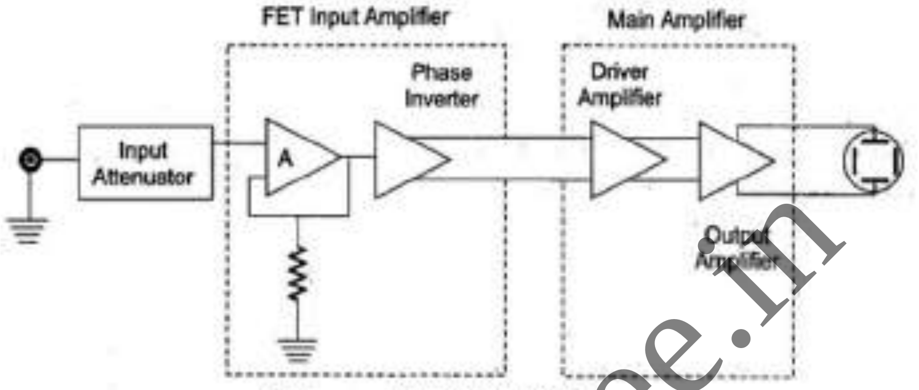

Fig. Vertical Amplifier

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- The vertical amplifier stage is used to amplify the input signal as these signals are not strong enough to provide measurable deflection. Usually wide band amplifiers are used so that entire band of frequencies is passed faithfully.
- Similarly it also has a attenuator which brings down the signals within the measurable range. The attenuators are used when very high voltage signals are to be measured.
- The vertical amplifier consists of several stages, with sensitivity or gain fixed and expressed in V/divs. The advantage of fixed gain is that the amplifier can be more easily designed to meet the requirements of stability and B.W.
- The input stage has a FET source follower whose high input impedance isolates the amplifier from the attenuator.
- This FET input stage is followed by a BJT emitter follower. The output of FET stage has medium impedance and it has to be connected to the phase inverter which has low impedance. Thus impedance matching is obtained with BJT emitter follower.
- This phase inverter provides two antiphase output signals which are required to operate the push-pull output amplifier. The push-pull output stage delivers equal signal voltages of opposite polarity to the vertical plates of the CRT.
- The advantages of push-pull operation in CRO are better hum voltage cancellation, even harmonic suppression and greater power output per tube. In addition, a number of defocusing and non-linear effects are reduced.

Horizontal Deflecting System

- The Horizontal Deflecting System consist of a Time Base Generator and an output amplifier

Continuous or Time Base Generator:A continuous sweep CRO using a UJT as a time base generator is shown in Fig. a.

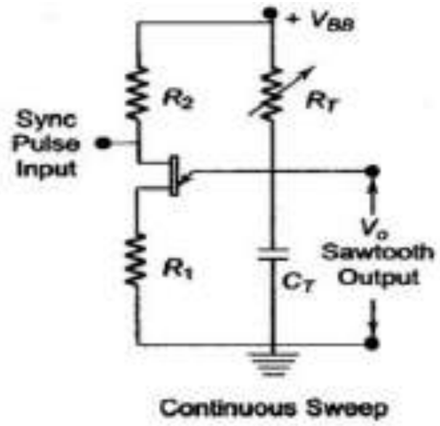

Fig. a Continuous Sweep

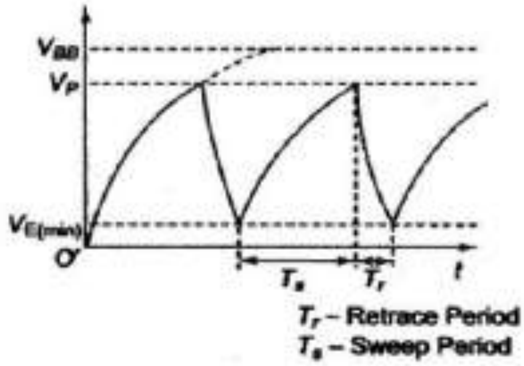

Fig. b Sawtooth Output Waveform

- The UJT is used to produce the sweep. When the power is first applied, the UJT is off and the C_T changes exponentially through $R_T$towards V_{BB}.
- At the same time the emitter voltage $V_E$of UJT rises towards V_{BB}. When capacitor charges to it max i.e., V_P, the emitter to base diode becomes forward biased and the UJT triggers ON.
- When UJT is ON it provides a low resistance path and the capacitor discharges rapidly.
- When the emitter voltage V_E reaches the minimum value, the UJT goes OFF and the capacitor begins to recharges and the cycle repeats. This is shown in Fig. b
- From the output waveform we can see that sweep output is not linear. Thus to improve sweep linearity, two separate voltage supplies are used
    - A low voltage supply for UJT and
    - A high voltage supply for the R_TC_T circuit.
- To control frequency, R_T is varied and CT is varied or changed in steps for range changing.
- The sync pulse in Fig. a, provides the sweep frequency to be exactly equal to the input signal frequency, so that the signal is locked on the screen and does not drift.

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Storage Oscilloscope

- Conventional CRT has persistence ranging from few milliseconds to several seconds and sometimes it becomes necessary to retain the pattern for a longer period. In this case it becomes necessary to store the waveform for certain duration, which is independent of phosphor persistence.
- Two storage techniques are used in oscilloscope CRTs, mesh storage and phosphor storage.

Mesh Storage:

- Mesh storage CRT is used in displaying very low frequency (VLF) signals. It finds application in biomedical and mechanical fields.
- A mesh Storage Oscilloscope, shown in Fig. a. it has a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, along with the elements of a standard CRT.
- In the storage mesh, the dielectric material deposited area is known as ‘storage target’. It is deposited with material such as Magnesium Fluoride. It makes use of a property known as secondary emission.

- The writing gun or electron gun emits electrons, which etches a positively charged pattern on the storage mesh when focused on storage target. Because of the excellent insulating property of the Magnesium Fluoride coating, the positively charged pattern remains where it is deposited.

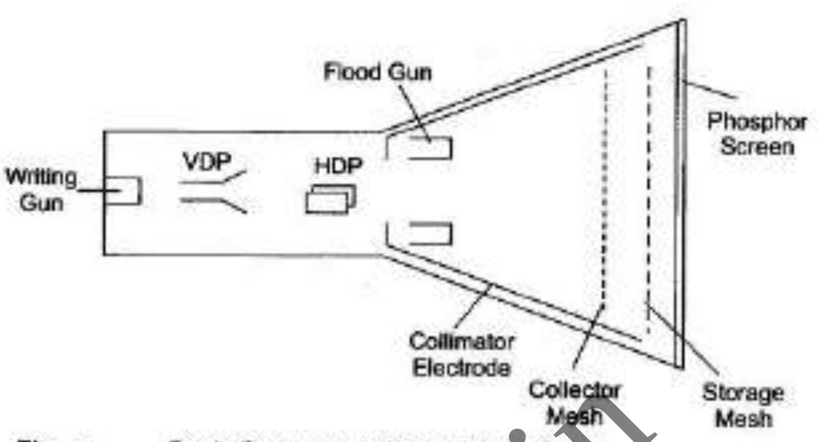

Fig. a Basic Elements of Storage Mesh CRT

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- In order to make a pattern visible, a special electron gun, called the **flood gun**, is switched on.
- The flood gun emits low velocity electrons and these are bombarded on the storage mesh/target.
- The electrons from flood gun is adjusted by the collimator electrode, which forms a low voltage electrostatic lens system (to focus the electron beam), as shown in Fig. b.

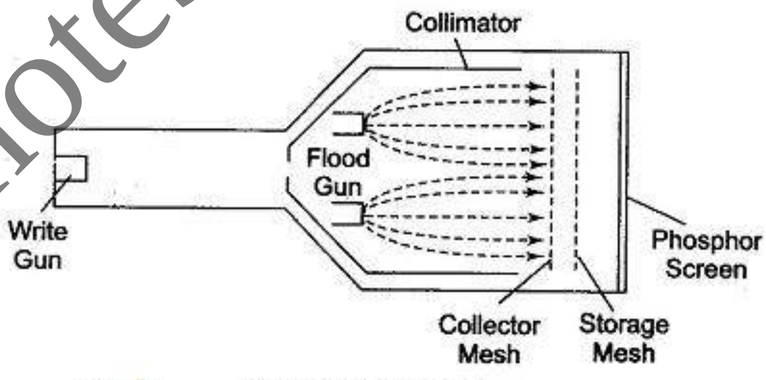

Fig. b Storage Mesh CRT

- Most of the electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen.
- The CRT will now display the signal and it will remain visible as long as the flood guns operate.
- To erase the pattern on the storage mesh, a negative voltage is applied to neutralize the stored positive charge.
- To make the pattern visible flood guns and collimator electrodes are used, where the guns emits electrons and collimator electrodes focuses the electron path.

- Most of the electrons are stopped and collected by collector mesh. When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region or negative charge region.
- The positive charge region has trace pattern while negatively charged region does not have any trace.
- The positivecharged areas allow the electrons to pass through to the post accelerator region and the display target phosphor. The negatively charged region repels the flood electrons back to the collector mesh.
- Thus the charge pattern on the storage surface appears and is reproduced on the CRT as though being traced with deflected beam.
- Figure c shows a display of the stored charge pattern on a mesh storage.

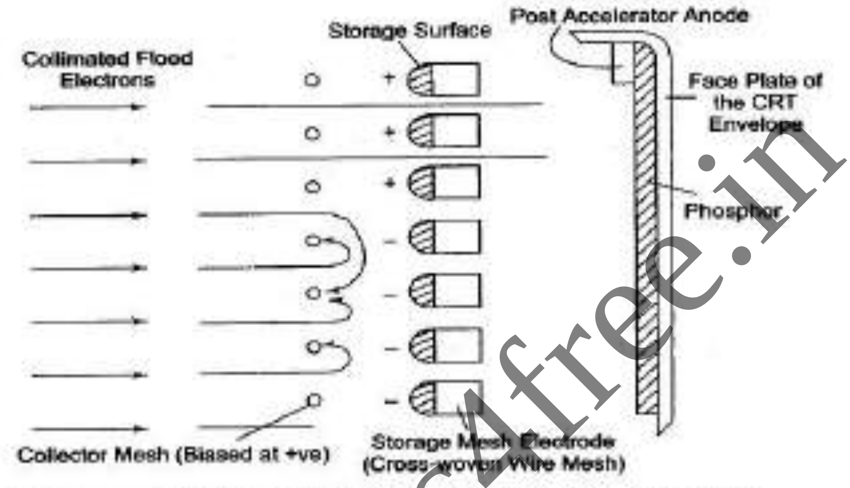

Fig. C Display of Stored Charged Pattern on a Mesh-storage

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Phosphor Storage:
In this type of CRT, it uses a thin layer of phosphor to serve both storage and display element.

Note:
Secondary emission: the writing gun produces beam of electrons, which has the information of the signal. This beam hits the surface of the storage surface and this seperates other electrons from the surface of the target. This is known as secondary emission.

Digital Readout Oscilloscope:

- The Digital Readout Oscilloscope instrument has a CRT display and a counter display. The Fig. d shows the block diagram of digital read out oscilloscope when measuring voltage.
- The input signal is sampled by a sampling circuit at regular interval of time and this process is called as '**strobing**'.
- The sweep time and input signal decides the equivalent time between 2 samples. Ex: if sweep time of 1 nano-sec/cm and a sampling rate/time of 100 samples/cm then it gives a time of 10 pico-sec/sample.

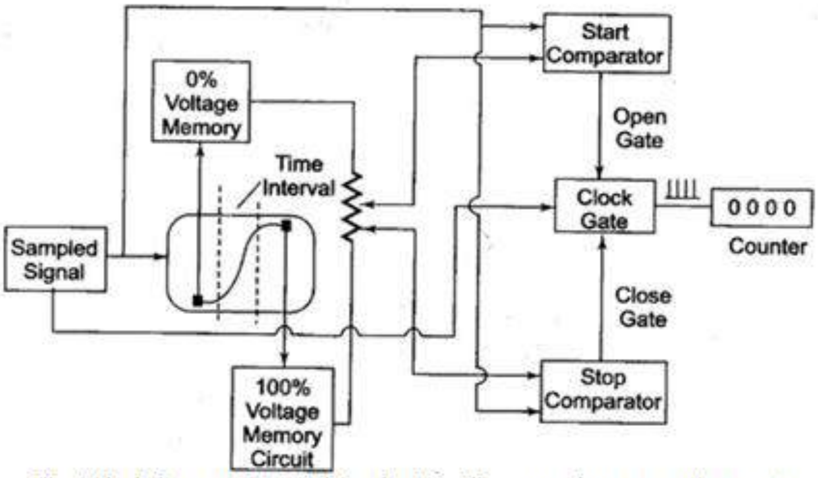

Fig. d Block diagram of Digital Readout Oscilloscope when measuring Voltage

- CRT trace is used to identify 0% and 100% zones position. This portion can be shifted to any part of the display.
- The potential/voltage divider taps voltage between the 0% and 100% level and these will be one of the signals for input to start and stop comparators respectively.
- Comparators are used for comparing the input waveform with selected % point.
- When the sampled signal is at 0% level is used to produce a pulse for opening gate. The output of comparator enables the clock gate andcounter starts counting the pulses.
- Similarly when 100% level is sensed, it gives a stop pulse and the clock gate is disabled and counter stops counting.
- The number of pulses counted by the counter is proportional to the actual sample taken and read out digitally in ns, µs, ms or seconds.
- Fig e (below) shows the block diagram of digital read out oscilloscope used for measuring time.
- In this a linear ramp generator is used which produces a voltage and this is one of the input to start and stop comparator respectively.

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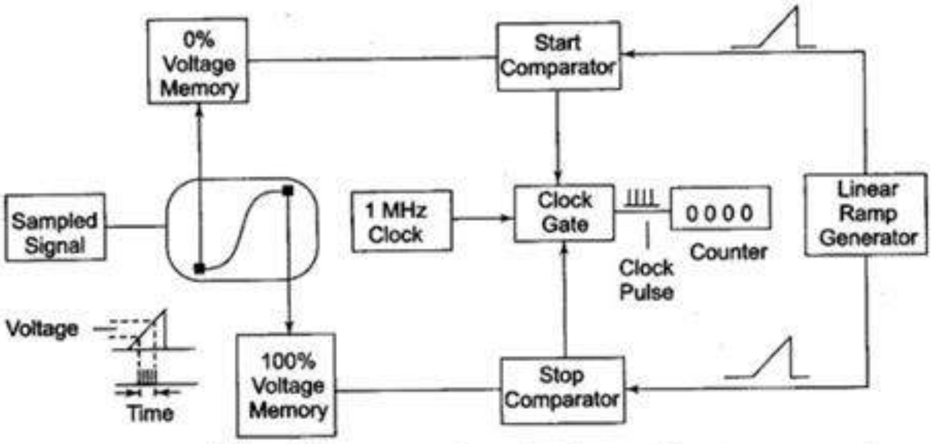

Fig. e Block Doagram of Digital Readout Oscilloscope to measure the voltage to time conversion

- When the linear ramp voltage equals the 0% reference the clock gate gets enabled/opens. When the ramp equals 100% reference the clock gate disables/closes.

- The number of clock pulses that activate the counter is directly proportional to the voltage between the selected references and is read out in mV or volts by the Nixie tube display.

Lissajous Method for frequency measurement:

- The phase and frequency measurement can be done using the oscilloscope.
- One of the fastest method to determine frequency is by using Lissajous patterns.
- These patterns results when sine waves aresimultaneously applied to both the deflection plates pairs. If one frequency is an integral multiple (harmonic) of the other, the pattern will be stationary, and is called a Lissajous figure.
- The measurement method involves applying known frequency (standard frequency) to the horizontal plates and unknown frequency (of approximately the same amplitude) is simultaneously applied to the vertical deflection plates.
- TheLissajous figures depends on (i)Amplitude of two waves, (ii)Phase difference between 2 waves and (iii)Ratio of frequencies of two waves
- The horizontal signal is designated as fh and the vertical signal as fv.
- Now if 2 signals of having same amplitude, frequency and phase difference of ϕ between them and if this is applied to the deflecting beams. Then difference in phase produces various patterns which varies from straight diagonal line to ellipse of different tilts
- Figure below shows the basic circuit for frequency measurement.

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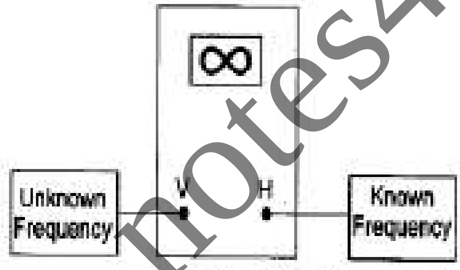
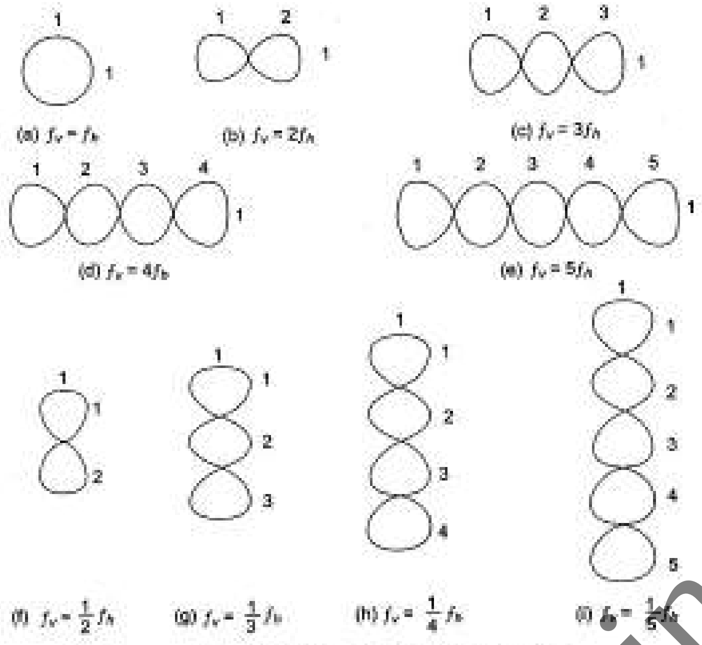


Fig. Basic Circuit for Frequency Measurements with Lissajous Figures

Measurement of frequency:

- The oscilloscope is set up and the internal sweep is switched off (or change to Ext). The signal source are connected as in above Fig.
- Keep frequency fv (unknown frequency) constant and vary frequency fh (known frequency), when observed the pattern spins in alternate directions and shape is changed.
- The pattern becomes stationary when fv and fh are in an integral ratio (either even or odd). The fv = fh pattern is still and is a single circle or ellipse. When fv = 2 fh, a two loop horizontal pattern is obtained as shown in below Fig.



(a) $f_v = f_h$ (b) $f_v = 2f_h$ (c) $f_v = 3f_h$

(d) $f_v = 4f_h$ (e) $f_v = 5f_h$

(f) $f_v = \frac{1}{2} f_h$ (g) $f_v = \frac{1}{3} f_h$ (h) $f_v = \frac{1}{4} f_h$ (i) $f_v = \frac{1}{5} f_h$

Fig. Lissajous Patterns for Integral Frequencies

- The frequency from Lissajous figure can be determined by, counting the number of horizontal loops in the pattern and divide it by the number of vertical loops and multiply this quantity by fh (known or standard frequency).
- In fig (h), the number of horizontal loop is 1 and vertical loop is 4. This gives a fraction of ¼. Thus the unknown frequency fv is equal to ¼ of fh.
- When the two frequencies are equal and in phase, the pattern appears as a straight line at an angle of 45° with the horizontal. If the phase between the two alternating signals changes, the pattern changes cyclically.
    - An ellipse pattern (at 45° with the horizontal) is seen when the phase difference is π/4
    - A circle pattern is seen when the phase difference is π/2
    - An ellipse (at 135° with horizontal) when the phase difference is 3π/4
    - A straight line pattern (at 135° with the horizontal) when the phase difference is π radians.
    - Thus as the phase angle between the two signals (fh and fv) changes from π to 2π radians, the pattern changes correspondingly through the ellipse-circle-ellipse cycle to a straight line.
- Now if the two frequencies being compared are not equal and if they are fractionally related, then a more complex stationary pattern appears. In this the patterns depends on the frequency ratio and the relative phase between the two signals.
- This is shown below in fig.

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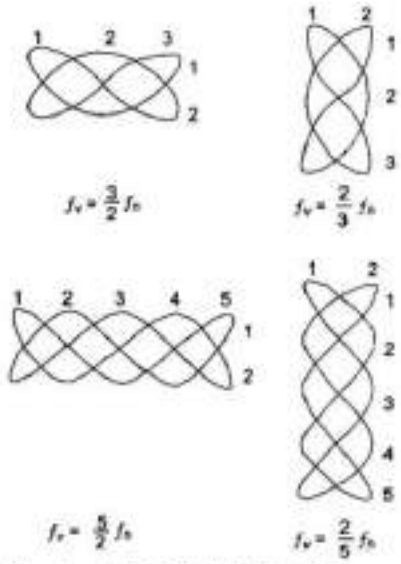

Fig. 1 Lissajous Patterns for Non-Integral Frequencies

- The fractional relationship between the two frequencies is determined by counting the number of cycles in the vertical and horizontal and is given below.

$$f_v = (\text{fraction}) \times f_h$$

$$\text{or } \frac{f_v}{f_h} = \frac{\text{number of horizontal tangencies}}{\text{number of vertical tangencies}}$$

Digital Storage Oscilloscope (DSO):

DSO are available in processing and non-processing types. In Processingequipment it includes interfacing and a microprocessor which provides a complete system for information acquisition, analysis and output. Processing capability ranges from simple functions (such as average, area, rms, etc.) to complex Fast Fourier Transform (FFT) spectrum analysis capability.

Non–processing digital scopes are designed such that they can be replacements for analog instruments for both storage and non-storage types. They include many desirable features which may lead to replace the analog scopes entirely.

The block diagram of DSO is shown below in the figure.

- These oscilloscope uses same type of amplifier and attenuator circuitry as used in the conventional oscilloscopes.
- The attenuated signal is applied to the vertical amplifier.
- From the amplifier the input signal is sampled through sample and hold circuit and to digitize the analog signal, it is fed to analog to digital (A/D) converter.
- The successive approximation type of A/D converter is most often used in the digital storage oscilloscopes.
- The sampling rate and memory size are selected based on the duration & the waveform to be recorded.
- Once the input signal is sampled, the A/D converter digitizes it.The signal is then captured/stored in the memory.

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- Once it is stored in the memory, many manipulations are possible as memory can be readout without being erased.
- The input signal is also used for trigger circuit (sweep generator) to generate the signal for horizontal deflecting plates.
- To the deflecting plates the digital data is again converted to analog and is amplified and fed.

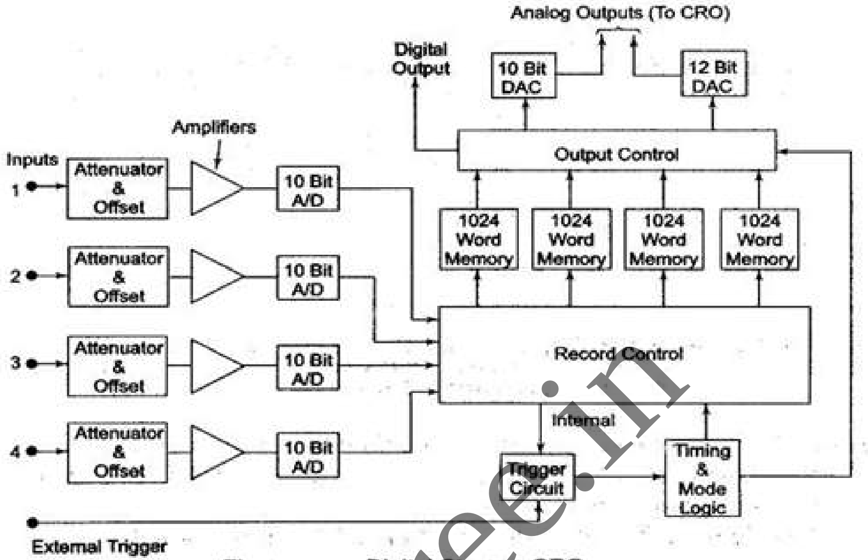

Fig. Digital Storage CRO

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Advantages of digital storage oscilloscope:

1. It is easier to operate and has more capability.
2. The storage time is infinite.
3. The voltage and time scales of display can be changed after the waveform has been recorded, which allows expansion (typically to 64 times) of selected portions, to observe greater details.
4. A cross-hair cursor (◎)can be positioned at any desired point on the waveform and the voltage/time values displayed digitally on the screen, and/or readout electrically.
5. Some scopes use 12 bit converters, giving 0.025% resolution and 0.1% accuracy on voltage and time readings.
6. Split screen capabilities (simultaneously displaying live analog traces and replayed stored ones) enable easy comparison of the two signals.
7. The display flexibility is available. The number of traces that can be stored and recalled depends on the size of the memory.
8. The characters can be displayed on screen along with the waveform which can indicate waveform information such as minimum, maximum, frequency, amplitude etc.
9. The X-Y plots, B-H curve, P-V diagrams can be displayed.
10. The pre-trigger viewing feature allows to display the waveform before trigger pulse.
11. Keeping the records is possible by transmitting the data to computer system where the further processing is possible
12. Signal processing is possible which includes translating the raw data into finished information e.g. computing parameters of a captured signal like r.m.s. value, energy stored etc.

SIGNAL GENERATORS

Signal generator is a vital component in test set up. It provides variety of waveforms for testing electronic circuits at low power.

Oscillator → provides sine wave
Generator → provides several output waveforms

Energy is not created in generators: it is simply converted from dc source to ac energy at some specified frequency.

Requirements of signal generators are

*The amplitude should be controllable from very small to relatively large values
*The signal should be distortion free

In some cases a particular signal required by the instrument is internally generated by a self-contained oscillator.

Classes of generators that are available as separate instruments to provide signals for general test purpose are called signal generators.

AF → Audio frequency- 20 Hz to 20 KHz
RF → Radio frequency- above 30 KHz

5.1: Fixed frequency AF oscillator

Some Instruments has self contained oscillator is an integral part of the instrument circuitry and is used to generate a signal at some specified audio frequency. Such a fixed frequency might be a 400 Hz signal used for audio testing or a 1000 Hz signal for exiting a bridge circuit.

Oscillations at specified audio frequency are generated by the use of an iron core transformer to obtain positive feedback through inductive coupling between the primary and secondary windings.

5.2: Variable AF oscillator

A variable AF oscillator for general purpose use in a laboratory should cover at least the full range of audibility (20 Hz to 20 KHz) and should have a pure sinusoidal wave output over the entire frequency range. These oscillators are of RC feedback oscillator type or beat frequency oscillator type

5.3: Basic standard signal generator (sine wave)

In most of the measurement and instrumentation systems, the input signal required is sinusoidal signal. Such a periodic, sinusoidal signal is generated using an oscillator. An oscillator is a circuit which generates a sinusoidal signal with constant amplitude and constant desired frequency using positive feedback. It generates an output waveform at a desired frequency in a range from few hertz to several giga hertz

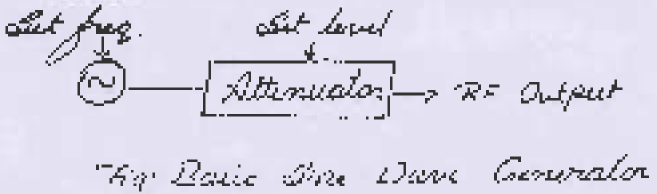

Fig: Basic Sine Wave Generator

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A simple sine wave generator consists of two basic blocks,

- (i) Oscillator
- (ii) Attenuator

The oscillator uses an active device such as an op-amp. The output of an op-amp is fed back in phase with input. This positive feedback causes regenerative action resulting in oscillation.

The attenuator provides amplitude control. Basically the attenuator is a device which reduces or attenuates the power level of the signal by fixed amount. The proper functioning of a signal generator depends on the performance of an oscillator and attenuator.

July-2017

5.4: Conventional standard signal generators

Standard signal generator is basically a radio frequency (RF) signal generator. It produces known and controllable voltages.

This instrument is provided with a means of modulating the carrier frequency. The modulation is indicated by a meter. The output signal can be amplitude modulated (AM) or frequency modulated (FM). Modulation may be done by a sine wave, square wave, triangular wave or a pulse.

The block diagram of conventional standard signal generator is shown below

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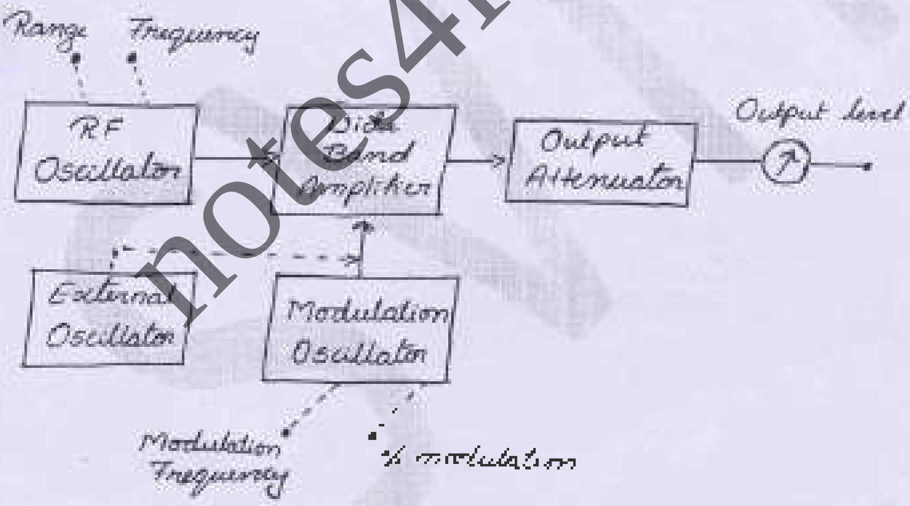

Fig: Conventional Standard Signal Generator

The carrier frequency is generated by a very stable RF oscillator which has constant output over any frequency range. Modulation is done in the output amplifier circuit. The output of amplifier is modulated carrier and is given to an attenuator. This attenuator helps in selecting proper range of attenuation and thus the output signal level is controlled

In LC tank circuit design of master oscillator, frequency stability is limited. The switching of frequency in various ranges is achieved by selecting appropriate capacitor. This upsets circuit design and requires some time to stabilize at new resonant frequency.

In high frequency oscillators, it is essential to isolate the master oscillater from output circuit. Because of this isolation, changes in output circuit do not reflect on the oscillator frequency, amplitude characteristics. For isolation buffer amplifiers are used.

ADVANTAGES

*The output is stable

*The output voltage can be controlled according to the requirement

DISADVANTAGES

*Due to LC tank circuit, the frequency stability is limited.

*It takes some time to stabilize at new freq when the range is changed

*In high frequency oscillators, isolation of master oscillator from output is necessary

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5.5: Modern laboratory type signal generator

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In modern laboratory type signal generator, the frequency stability is increased by using single master oscillator. With this single master oscillator we can get the highest frequency range with good stability as compared to conventional signal generator.

The master oscillator is made insensitive to temperature variations. Temperature compensation devices are used which can work properly for any temperature changes. The influence of the succeeding stages is also overcome by using buffer amplifiers

The block diagram of modern laboratory type signal generator is shown below

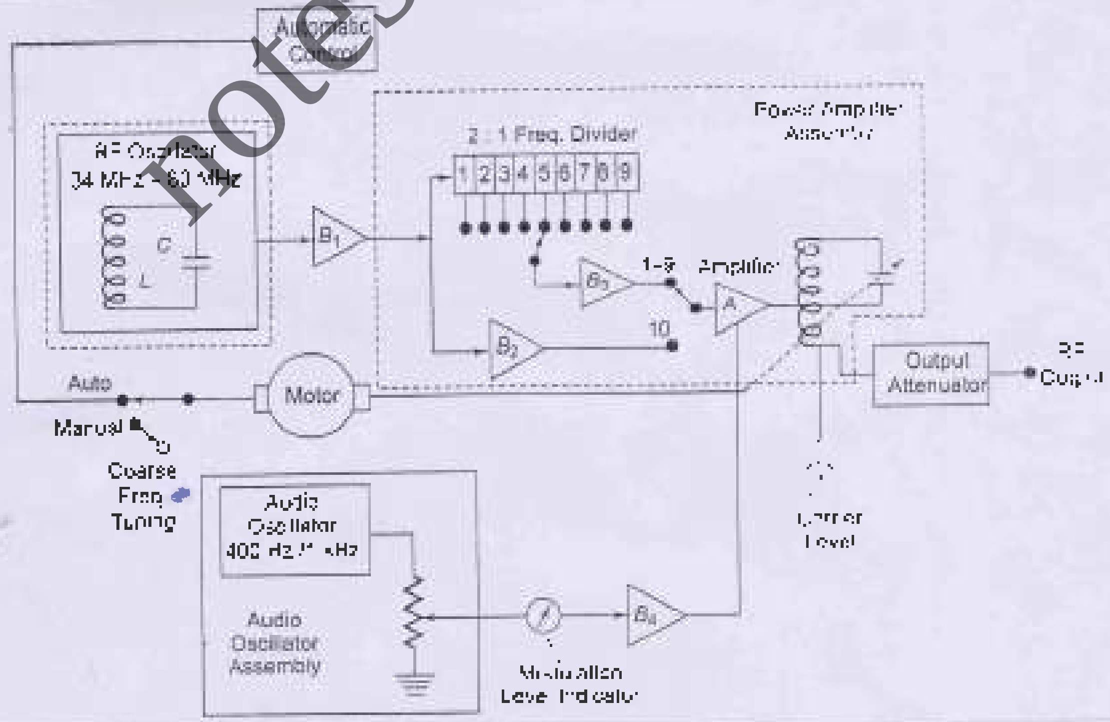

Fig: Modern Signal Generator

The RF oscillator consists of LC tank circuit. It gives frequency range from 34 MHz to 80 MHz. This signal is connected to untuned buffer amplifier B_1. The output of this amplifier is given to frequency divider circuit. The circuit shown above consists of 9 frequency dividers. The frequency division can be done by using flip-flops to get ratio of 2:1.

The lowest frequency range obtained by using frequency divider is the highest frequency range divided 2^9 or 512. The master oscillator has both automatic and manual controllers. Availability of motor driven frequency control is employed for programmable automatic frequency control devices.

The LC tank circuit and frequency divider provides a carrier signal. The buffer amplifiers B2 and B3 are used for isolation. The use of buffer amplifiers provides very high degree of isolation between master oscillation stage and power amplifier stage. This eliminates all frequency distortions caused by loading between input and output circuits.

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

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ADVANTAGES

*As same master oscillator is used to get various frequency ranges, the stability is improved even at the highest frequency range.

*The use of buffer amplifiers provides good isolation between the master oscillator and main power amplifier eliminating loading effect completely

*The change in the output due to temperature variations is compensated by compensation devices for all frequency ranges.

*The power consumption of the instrument is very low.

*Good regulation and crystal stability, with low ripple, is obtained.

*Range switching effects are eliminated as the same oscillator is used on all the bands.

*Excellent Q stability with very low ripple.

*Due to high degree of isolation, distortion get eliminated between the input and output circuits.

DISADVANTAGES

*The circuit is complex, so cost is increased as compared to conventional signal generator

DIFFERENCE BETWEEN STANDARD AND MODERN SIGNAL GENERATOR

	Standard signal generator	Modern signal generator
1	It has limited frequency stability.	Frequency stability over entire frequency range is maintained
2	Temperature compensation is not provided	Temperature compensation is provided
3	The frequency range is small	Wide frequency range is possible
4	Loading and distortion effects are more	Loading and distortion effects are less
5	It takes time to stabilize at new frequency	It gets stabilized to new frequency very quickly
6	Regulation is poor	Regulation is excellent
7	Less Q stability with high ripple	Good Q stability with low ripple
8	Automatic tuning with motor is not available	Motorized automatic tuning is possible
9	Construction is simple	Construction is complicated
10	Cost is low	Cost is high

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5.6: AF sine and square wave generator

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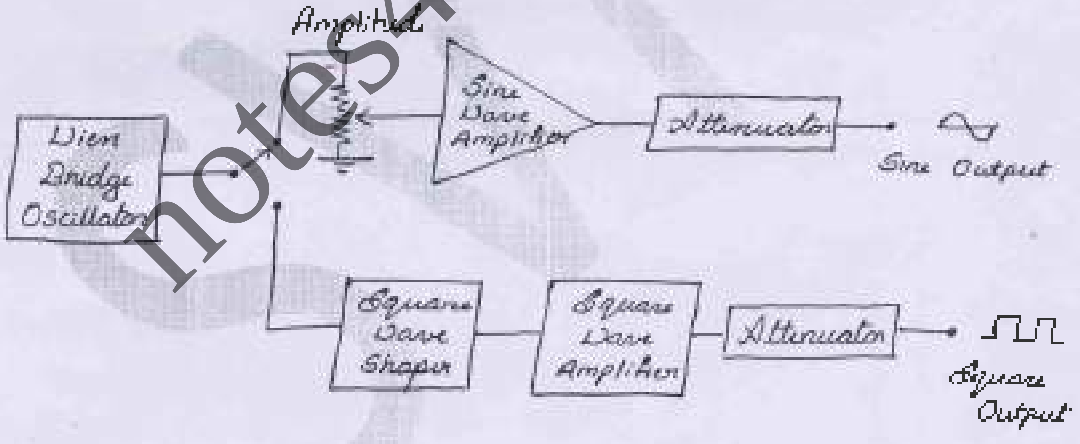

Fig: Sine and Square Wave Generator

The block diagram of AF sine and square wave generator is shown above. A Wien bridge oscillator is used in this generator. The Wien bridge oscillator is the best for audio frequency range. The frequency of oscillations can be changed by varying the capacitance in the oscillator. The frequency can also be changed in steps by switching in resistors of different values.

The output of the Wien bridge oscillator goes to the function switch. The function switch directs the oscillator output either to the sine wave amplifier or to the square wave shaper. At the output, we get either a square wave or sine wave. The output is varied by means of an attenuator.

The front panel of a signal generator consists of the following

1. *Frequency selector*: It selects the frequency in different ranges and varies it continuously in a ratio of 1:11. The scale is non-linear.
2. *Frequency multiplier*: It selects the frequency range over 5 decades, from 10 Hz to 1 MHz
3. *Amplitude multiplier*: It attenuates the sine wave in 3 decades, ×1, ×0.1 and × 0.01.
4. *Variable amplitude*: It attenuates the sine wave amplitude continuously
5. *Symmetry control*: It varies the symmetry of the square wave from 30% to 70%
6. *Amplitude*: It attenuates the square wave output continuously
7. *Function switch*: It selects either sine wave or square wave output.
8. *Output available*: This provides sine wave or square wave output
9. *Sync*: This terminal is used to provide synchronization of the internal signal with an external signal.
10. ON-OFF Switch

June 2012
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5.7: Function generator

A function generator produces different waveforms of adjustable frequency. The output waveforms are sine, square and triangular. Frequency can be adjusted from 0.01 Hz to 100 kHz. Various outputs can be used at the same time. The function generator can be phase locked to an external source. One function generator can be used to lock a second function generator, and thus the two output signals can be displayed in phase.

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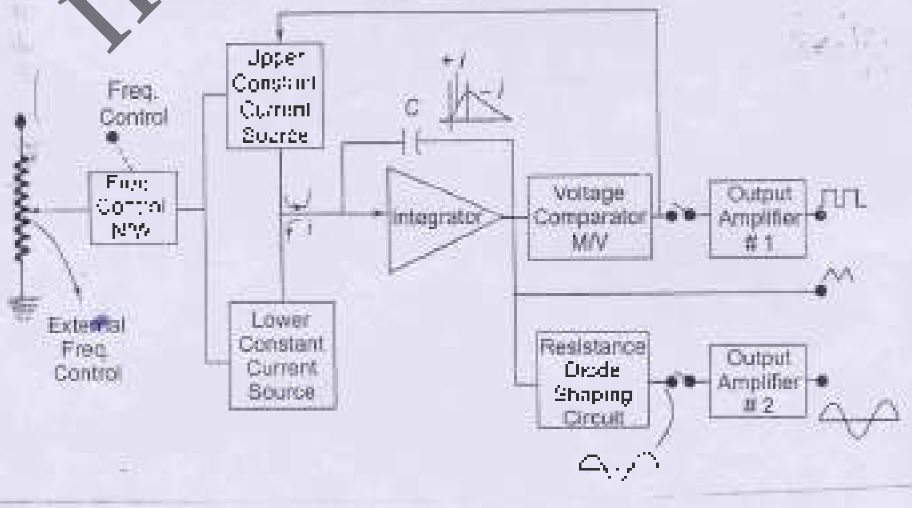

Fig: Block diagram of Function Generator

The block diagram of the function generator is shown above. The frequency is controlled by varying the magnitude of current which drives the integrator.

The frequency controlled voltage regulates two current sources. The upper current source supplies constant current to the integrator whose output voltage increases linearly with time, according to the equation of the output signal voltage.

$$e_{out} = -\frac{1}{C}\int_0^t i\,dt$$

An increase or decrease in the current increases or decreases the slope of the output voltage and hence control the frequency. The voltage comparator multi-vibrator changes states at a pre-determined maximum level of the integrator output voltage. This change cuts off the upper current supply and switches on the lower current supply. The lower current source supplies a reverse current to the integrator, so that its output decreases linearly with time. When the output reaches pre-determined maximum level, the voltage comparator again changes state and switches on the upper current source.

The output of the integrator is a triangular waveform whose frequency is determined by the magnitude of the current supplied by the constant current sources.

The comparator output delivers a square wave voltage of the same frequency. The resistance diode network alters the slope of the triangular wave as its amplitude changes and produces a sine wave with less than 1% distortion.

5.8: Square and pulse generator (laboratory type)

The fundamental difference between a pulse generator and a square wave generator is in the duty cycle. A pulse with 50% duty cycle is called a square wave.

$$Duty\ cycle = \frac{pulse\ width}{pulse\ period}$$

Requirements of a pulse:

1. Pulse should have minimum distortion
2. Basic characteristics of the pulse are rise time, overshoot, ringing, sag and undershoot.
3. Pulse should have sufficient maximum amplitude and also the attenuation range should be adequate to produce small amplitude pulses.
4. The range of frequency control of the pulse repetition rate (PRR) should meet the needs of the experiment.
5. Pulse generators can be triggered by an external trigger signal and also pulse generators can be used to produce trigger signals
6. Output impedance of pulse generator is important consideration. Generator should be matched to cable and cable to test circuit.
7. DC coupling of the output circuit is needed when dc bias level is to be maintained.

Overshoot: The maximum height immediately following the leading edge

Ringing: It is the positive and negative peak distortion, excluding overshoot

Sag (pulse drop): It is the fall in pulse amplitude with time

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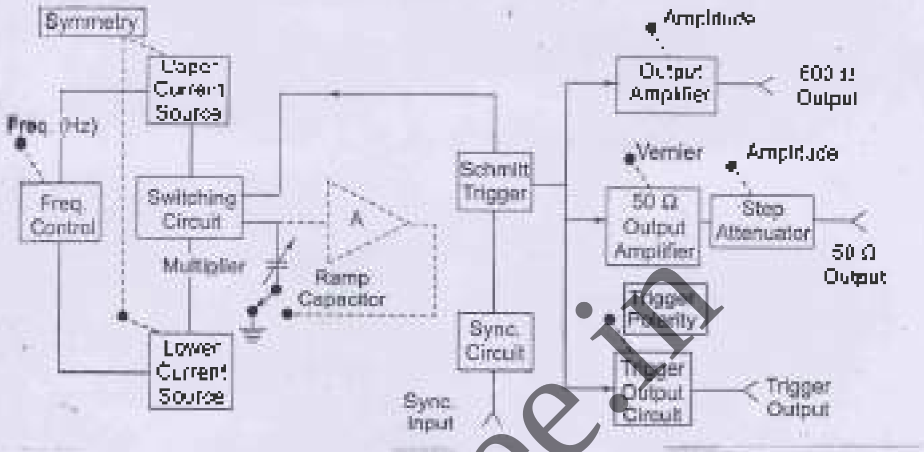

Fig: Block diagram of Pulse Generator

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A laboratory type square wave and pulse generator is shown above. The frequency range of the instrument is from1 Hz to 10 MHz. The duty cycle can be varied from 25-75%. Two independent outputs are available, a 50Ω source that supplies pulses with rise and fall time of 5 ns at 5V peak amplitude and 600 Ω source which supplies pulses with a rise and fall time of 70 ns at 30 V peak amplitude. This instrument can be operated as a free running generator or it can be synchronized with external signals.

The basic generating loop consists of the current sources, the ramp capacitor, the Schmitt trigger and the current switching circuit as shown below.

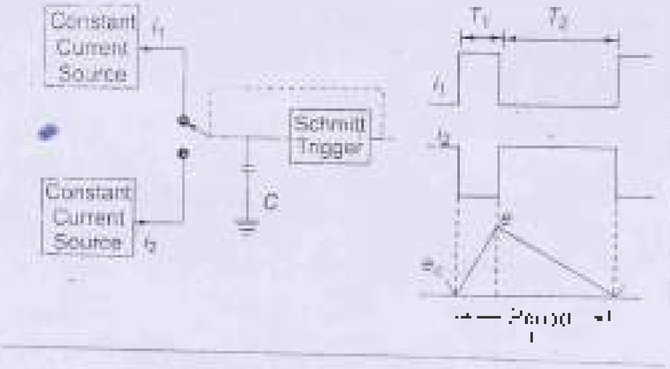
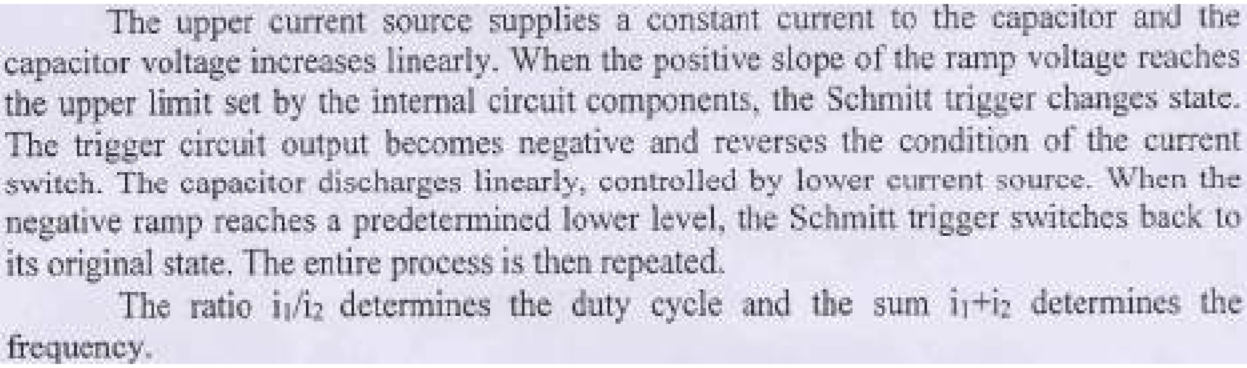


Fig: Basic Generating Loop



The upper current source supplies a constant current to the capacitor and the capacitor voltage increases linearly. When the positive slope of the ramp voltage reaches the upper limit set by the internal circuit components, the Schmitt trigger changes state. The trigger circuit output becomes negative and reverses the condition of the current switch. The capacitor discharges linearly, controlled by lower current source. When the negative ramp reaches a predetermined lower level, the Schmitt trigger switches back to its original state. The entire process is then repeated.

The ratio i_1/i_2 determines the duty cycle and the sum i_1+i_2 determines the frequency.

SWEEP FREQUENCY GENERATOR:

The process of testing frequency response of amplifiers and filters can be simplified and speed up using signal generator that automatically varies its frequency over a pre-determined range. Such an instrument is called as sweep generator.

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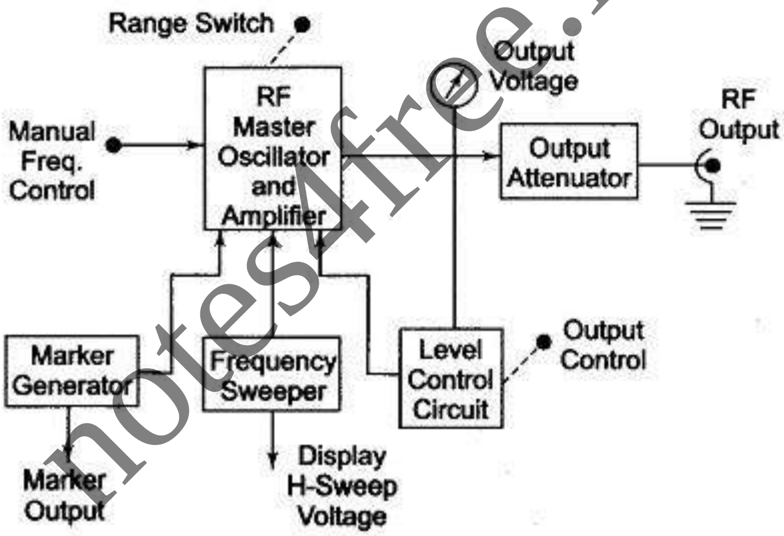

Fig. 8.10 Sweep Generator

- Sweep generator provides a sinusoidal output voltage whose frequency varies smoothly and continuously over an entire frequency band.
- The process of frequency modulation may be accomplished electronically or mechanically.
- It is done electronically by varying reactance of the oscillator tank circuit component and mechanically by means of a motor driven capacitor.
- **Frequency sweeper**: provides a variable modulating voltage which causes the capacitance of the master oscillator to vary and used for synchronization to drive the horizontal deflection plates of the CRO. The amplitude of the response of a test device will be locked and displayed on the screen.
- **Manual control:** allows independent adjustment of the oscillator resonant frequency.

- In **automatic level control circuit** has closed loop feedback system which provide constant power delivery to test circuit which monitors the RF level at some point in the measurement system. Thus constant power level prevents any source mismatch and also provides a constant readout calibration with frequency.
- **Marker generator** provides half sinusoidal waveforms at any frequency within the sweep range. The marker voltage is added to the sweep voltage of the CRO during alternate cycles of the sweep voltage, and appears superimposed on the response curve.

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MODULE 4

BRIDGES

Introduction:

- Bridges is a circuit which is used for measuring various components like R, C and L
- Bridge as a simple circuit consists of having 4 resistance arms in a closed loop, with dc current source applied to 2 opposite junction and current detector connected to other 2 junction as shown in Fig. 4.1.
- In this the unknown component is measured in comparison with known component called as standard.
- This method of measurement is very accurate and the accuracy of measurement is directly proportional to the bridge component.

There are 2 types of bridges

- ac bridge – impedances consisting of C and L
- dc bridges – measure resistance

The dc bridge used for measuring resistance is called **Wheatstone's bridge**.

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Wheatstone's Bridge:

- It is the most accurate method for measuring resistance and a common method used in laboratory.
- The circuit is shown in Fig 4.1.

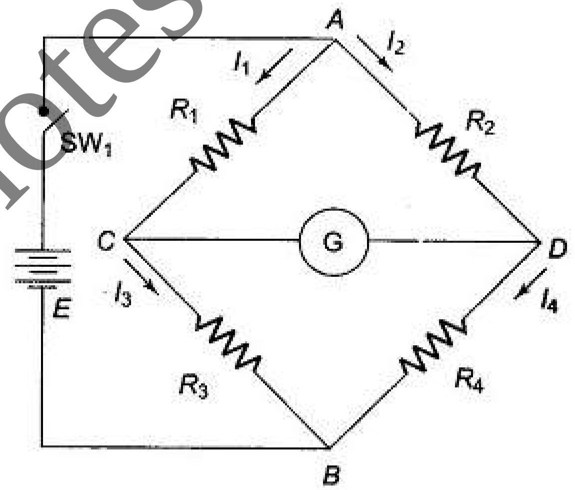

Fig. 4.1 Wheatstone's Bridge

- It has an emf source E and switch Sw connected between points A and B.
- A sensitive current indicating meter is connected to point C and D. Meter used is a zero center scale, when at rest it is mid scale at 0 current. Current in one direction causes pointer to deflect in one direction and for current in the opposite direction causes the pointer to deflect in opposite direction. When no current flowing in the circuit, the pointer rests at '0'.
- When Sw is closed current flows and divides into 2 arms at point A as I1 and I2.

- Bridge is balanced when current through G is '0' i.e potential difference at C and D should be equal.

i.e $I1R1 = I2R2$ ------------ (1)

For galvanometer current to be zero, I1=I3 and I2=I4

Thus under balanced condition,

$$I1 = I3 = \frac{E}{R1 + R3} \qquad (a)$$

And

$$I2 = I4 = \frac{E}{R2 + R4} \qquad (b)$$

Using (a) and (b) in equation (1), we get

$$\frac{E * R1}{R1 + R3} = \frac{E * R2}{R2 + R4}$$

Simplifying the above equation we get,

$$R1(R2 + R4) = R2(R1 + R3)$$

$$R1R2 + R1R4 = R1R2 + R2R3$$

$$R1R4 = R2R3$$

Now $R4 = \frac{R2\ R3}{R1}$

This is the equation for bridge to be balance.

For balancing one of the resistance will be made adjustable and if R4 is the unknown resistance then

$$Rx = \frac{R2\ R3}{R1}$$

Sensitivity of Wheatstone's bridge:

- When there is unbalance in the bridge, there is deflection in the pointer of galvanometer (G) which depends on the sensitivity of the galvanometer.
- If the G is more sensitive then, the deflection is more for the same amount of current. Thus sensitivity is considered as **deflection/unit current. i.e S = D/I** , D = deflection and I = current in µA
- Sensitivity can be expressed in linear or angular with the units as S = mm/µA (Linear) and S = degree/µA or S = radian/µA (Angular)
- Thus total deflection D = S * I

Unbalanced Wheatstone's bridge:

This is the analysis of Wheatstone's bridge under unbalanced condition and this determines the amount of current flowing in the G.

The circuit analysis can be done using any general circuit analysis, considering "Thevenin's Theorem" will determine the current through G.

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Since the interest is to find the current through G under unbalanced condition we need to find the Thevenin's equivalent circuit as seen by G

The first step is to remove G and find open circuit voltage between terminals a and b as shown in fig 4.2

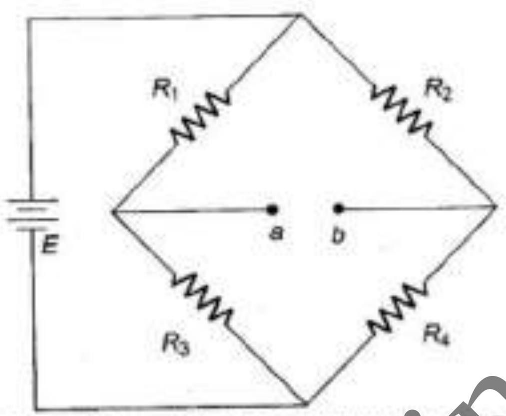

Fig. 4.2 Unbalanced Wheatstone's Bridge

Applying voltage divider at point 'a' and 'b', we get

$$Ea = \frac{R3\,E}{R1 + R3}$$

$$Eb = \frac{R4\,E}{R2 + R4}$$

Voltage between a and b is the difference between Ea and Eb and this represents the Thevenin's equivalent voltage,

$$Eth = Ea - Eb = \frac{R3\,E}{R1 + R3} - \frac{R4\,E}{R2 + R4}$$

Thus $$Eth = E\left(\frac{R3\,E}{R1+R3} - \frac{R4\,E}{R2+R4}\right)$$

Thevenin's equivalent resistance can be determined by replacing voltage source by its internal impedance or with a short and looking into a and b as shown in fig 4.3.,

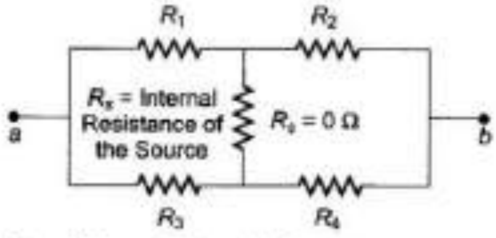

Fig. 4.3 Thévenin's Resistance

$$Rth = (R1 \parallel R3) + (R2 \parallel R4)$$

Thus $$Rth = \frac{R1\,R3}{R1+R3} + \frac{R2\,R4}{R2+R4}$$

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Thevenin's equivalent circuit is shown in fig 4.4

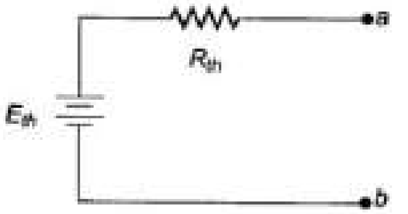

Fig. 4 .4 Thévenin's Equivalent

If G is connected between a and b in the above circuit and its original circuit then both experencies same deflection.

The magnitude of current is limited by Rth and the resistance seen with G i.e Rg (internal resistance of G)

Thus the deflection of current in galvanometer is given by

$$Ig = \frac{Eth}{Rth + Rg}$$

Slightly unbalanced Wheatstone's bridge:

If three of the four resistor in a bridge are equal to R and the fourth differs by 5% or less, we can develop an approximate but accurate expression for Thevenin's equivalent voltage and resistance as follows. The circuit is shown in Fig 4.5

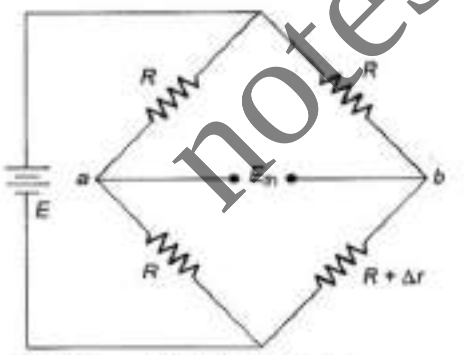

Fig. 4.5 Slightly Unbalanced Wheatstone's Bridge

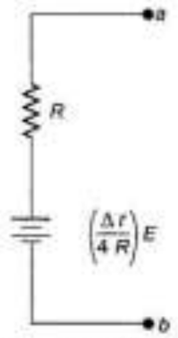

Fig. 4.6 Thévenin's Equivalent of a Slightly Unbalanced Wheatstone's Bridge

Voltage at point 'a' is given by

$$Ea = \frac{E\,R}{R + R} = \frac{E\,R}{2\,R} = \frac{E}{2}$$

Voltage at point 'b' is given by

$$Eb = \frac{E\,(R + \,\Delta r)}{R + (R + \,\Delta r)} = \frac{E\,(R + \,\Delta r)}{2R + \,\Delta r}$$

Thevenin's equivalent voltage is given by,

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$$Eth = Ea - Eb = Eb - Ea$$

$$Eth = \frac{E\ (R + \Delta r)}{2R + \Delta r} - \frac{E}{2}$$

Simplifying this,

$$Eth = E\left(\frac{2R + 2\Delta r - 2R - \Delta r}{2(2R + \Delta r)}\right)$$

$$Eth = E\left(\frac{\Delta r}{4R + 2\Delta r}\right)$$

Now if Δr is 5% of R or less, then Δr can be neglected at the denominator without appreciable error. Thus Eth now is

$$Eth = \frac{\Delta r}{4R}$$

The equivalent resistance can be calculated by replacing the voltage source with its internal impedance,

$$Rth = \frac{R\,R}{R + R} + \frac{R\ (R + \Delta r)}{R + \ (R + \Delta r)}$$

Simplifying the above equation,

$$Rth = \frac{R}{2} + \frac{R\ (R + \Delta r)}{2R + \Delta r}$$

If Δr is small compared to R, then it can be neglected

$$Rth = \frac{R}{2} + \frac{R\ R)}{2R}$$

$$Rth = \frac{R}{2} + \frac{R}{2} = \frac{2R}{2} = R$$

Thus the Thevenin’s equivalent circuit is shown in Fig 4.6

The current through the G is given by,

$$Ig = \frac{Eth}{Rth + Rg}$$

Applications of Wheatstone’s bridge:

- Wheatstone bridge is used to measure resistance in the range of 1Ω to low MΩ.
- Used to measure the dc resistance of various types of wire, either for the purpose of quality control of the wire itself, or of some assembly in which it is used.
- To find the resistance of motor windings, transformers, solenoids, and relay coils.
- Wheatstone Bridge Circuit is also used extensively by telephone companies and others to locate cable faults.

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Advantages of Wheatstone's bridge:

- It operates on null deflection i.e., indication is independent on indicating instrument's characteristics and this is reason it has high degrees of accuracy.
- The variation in the source does not alter the balance of bridge, hence the corresponding errors are completely avoided.
- In Wheatstone bridge potential errors are canceled out including the bridge excitation, and temperature errors.

Limitations of Wheatstone's bridge:

- For low resistance measurement, the resistance of the leads and contacts becomes significant and this may introduce error.
- While measuring high resistance, the resistance presented by the bridge becomes so large that the galvanometer will be insensitive to imbalance. Thus for high resistance measurements in mega ohms, the Wheatstones bridge cannot be used.
- Another problem in Wheatstone Bridge Circuit is the change in resistance of the bridge arms due to the heating effect of current through the resistance. The rise in temperature causes a change in the value of the resistance, and sometimes high current may cause a permanent change in value.

Kelvin's bridge

- When the resistance to be measured is of the order of magnitude of bridge contact and lead resistance, a modified form of Wheatstone's bridge, the Kelvin's bridge is used.
- Kelvin's bridge is used to measure values of resistance below 1 Ω. In low resistance measurement, the resistance of the leads connecting the unknown resistance to the terminal of the bridge circuit may affect the measurement.
- Thus in Kelvin's bridge, the effect of contact and lead resistance is important.
- Consider the circuit in Fig.4.7, where Ry represents the resistance of the connecting leads from R3 to Rx (unknown resistance). The galvanometer can be connected either to point c or to point a.
- When it is connected to point a, the resistance Ry, of the connecting lead is added to the unknown resistance Rx, resulting in too high indication for Rx.
- When the connection is made to point c, R3, is added to the bridge arm R3 and resulting measurement of Rx is lower than the actual value.
- If the galvanometer is connected to point b, in between points c and a, in such a way that the ratio of the resistance from c to b and that from a to b equals the ratio of resistances R1 and R2, then

$$\frac{Rcb}{Rab} = \frac{R1}{R2}$$

The bridge balance equation is given by,

$$R1 * R3 = R2 * Rx$$

But R3 is now R3 +Rab and Rx is now Rx + Rcb

Therefore $$R1 * (R3 + Rab) = R2 * (Rx + Rcb) \text{ -------------- } (1)$$

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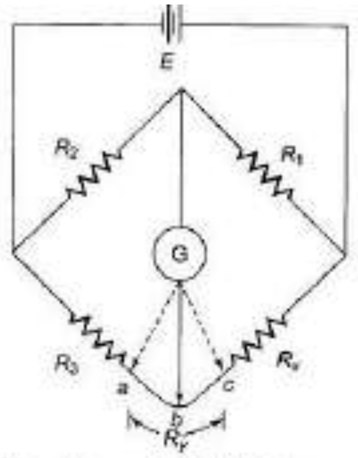

Fig. 4.7 Kelvin's Bridge

From the Fig 4.7,

Rab + Rcb = Ry ----------------- (A)

and

$$\frac{Rcb}{Rab} = \frac{R1}{R2} \quad ------(B)$$

Adding 1 to both sides of equation (B), we get

$$\frac{Rcb}{Rab} + 1 = \frac{R1}{R2} + 1$$

$$\frac{Rcb + Rab}{Rab} = \frac{R1 + R2}{R2}$$

using equation (A) in the above equation, we get

$$\frac{Rcb + Rab}{Rab} = \frac{Ry}{Rab} = \frac{R1 + R2}{R2}$$

and Rab is now

$$Rab = \frac{R2 * Ry}{R1 + R2}$$

Rearranging equation (A) and using equation for Rab,

$$\text{Rcb} = \text{Ry} - \text{Rab}$$

$$\text{Rcb} = \text{Ry} - \frac{R2 * Ry}{R1 + R2}$$

$$Rcb = \frac{R1Ry + R2Ry - R2Ry}{R1 + R2}$$

$$Rcb = \frac{R1\ Ry}{R1 + R2}$$

Substituting Rab and Rcb in equation (1)

$$\text{R1} * (\text{R3} + \frac{R2\ Ry}{R1+R2}) = \text{R2} * (\text{Rx} + \frac{R1\ Ry}{R1+R2})$$

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$$Rx + \frac{R1\ Ry}{R1+R2} = \frac{R1}{R2}\left(\text{R3 } + \frac{R2\ Ry}{R1+R2}\right)$$

$$Rx + \frac{R1\ Ry}{R1+R2} = \frac{R1\ R3}{R2} + \frac{R2\ Ry}{R1+R2} * \frac{R1}{R2}$$

$$Rx + \frac{R1\ Ry}{R1+R2} = \frac{R1\ R3}{R2} + \frac{R1\ Ry}{R1+R2}$$

Upon simplification, we get

$$Rx = \frac{R1\ R3}{R2}$$

- The above equation is the normal Wheatstone's bridge under balanced condition.
- Also the effect of lead resistance connecting from a to c is eliminated by connecting galvanometer to intermediate position 'b'.
- This is the principle of constructing Kelvin's double bridge also known as Kelvin's bridge. It is called double bridge as it incorporates 2nd set of resistance ratio arms.
- The schematic of Kelvin's double bridge is shown in Fig 4.8
- In this 2nd set of arms a and b connect galvanometer to point c
- The galvanometer gives null indication when potential at k and c are equal i.e $Elk = Elmc$

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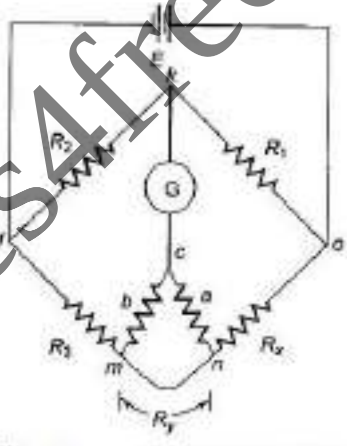

Fig. 4.8 Kelvin's Double Bridge

Now Elk is given by

$$Elk = \frac{R2\ E}{R1+R2}$$

and E is given by

$$\text{E} = \text{I} * \text{R}$$

$$Elk = \frac{R2}{R1+R2} * I * R$$

R is to determined considering path l-m-n-o-l, in this path at point m – n, the resistance is Ry ∥ (a+b). Thus total resistance now becomes as

$$R = R3 + Rx + \frac{Ry\ (a+b)}{a+b+Ry}$$

Now Elk is given by

$$Elk = \frac{R2}{R1+R2} * I * \left[R3 + Rx + \frac{Ry\ (a+b)}{a+b+Ry}\right]$$

Similarly Elmc is given by, Elmc = Elm +Emc

Elm = I R3

$Emc = \frac{b\ Emn}{a+b}$ using voltage divider rule

$Emn = (a+b) \| Ry * I = \frac{Ry\ (a+b)}{a+b+Ry} * \mathrm{I}$

Thus now

$$Emc = \frac{b}{a+b} * \ I * \frac{Ry\ (a+b)}{a+b+Ry}$$

Therefor

$$Elmc = I\ R3 + \frac{b}{a+b} * \ I * \frac{Ry\ (a+b)}{a+b+Ry}$$

$$Elmc = I\ \left[R3 + \frac{b}{a+b} * \frac{Ry\ (a+b)}{a+b+Ry}\right]$$

But under balanced condition,

$$Elk = Elmc$$

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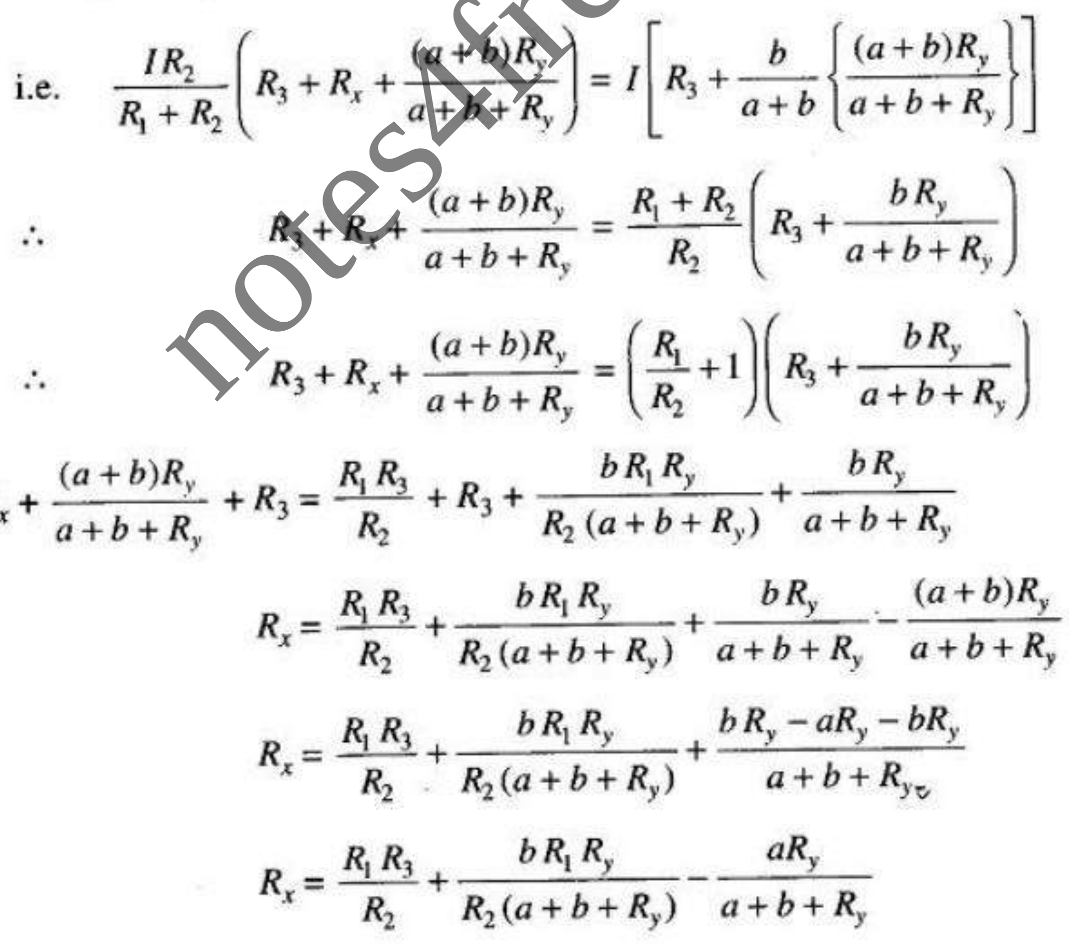

i.e. $$\frac{IR_2}{R_1+R_2}\left(R_3+R_x+\frac{(a+b)R_y}{a+b+R_y}\right) = I\left[R_3+\frac{b}{a+b}\left\{\frac{(a+b)R_y}{a+b+R_y}\right\}\right]$$

$$\therefore \quad R_3+R_x+\frac{(a+b)R_y}{a+b+R_y} = \frac{R_1+R_2}{R_2}\left(R_3+\frac{bR_y}{a+b+R_y}\right)$$

$$\therefore \quad R_3+R_x+\frac{(a+b)R_y}{a+b+R_y} = \left(\frac{R_1}{R_2}+1\right)\left(R_3+\frac{bR_y}{a+b+R_y}\right)$$

$$R_x+\frac{(a+b)R_y}{a+b+R_y}+R_3 = \frac{R_1 R_3}{R_2}+R_3+\frac{bR_1 R_y}{R_2\ (a+b+R_y)}+\frac{bR_y}{a+b+R_y}$$

$$R_x = \frac{R_1 R_3}{R_2}+\frac{bR_1 R_y}{R_2(a+b+R_y)}+\frac{bR_y}{a+b+R_y}-\frac{(a+b)R_y}{a+b+R_y}$$

$$R_x = \frac{R_1 R_3}{R_2}+\frac{bR_1 R_y}{R_2(a+b+R_y)}+\frac{bR_y-aR_y-bR_y}{a+b+R_y}$$

$$R_x = \frac{R_1 R_3}{R_2}+\frac{bR_1 R_y}{R_2(a+b+R_y)}-\frac{aR_y}{a+b+R_y}$$

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

But $$\frac{R_1}{R_2} = \frac{a}{b}$$

Therefore, $$R_x = \frac{R_1 R_3}{R_2}$$

- The above is the equation for Kelvin's bridge.
- From the above equation, Ry i.e., resistance of the connecting lead has no effect on the measurement provided the resistance ratio of arms are equal.
- This bridge can measure resistance in the range of 1Ω - 10μΩ with accuracy of ±0.05% to ±0.02%.

AC Bridges:

- The ac bridges are similar to dc bridge except that the bridge arms have impedances and the bridge is excited by ac source rather than dc source.
- Impedances at audio frequency and radio frequency can be determined by means of ac bridges.

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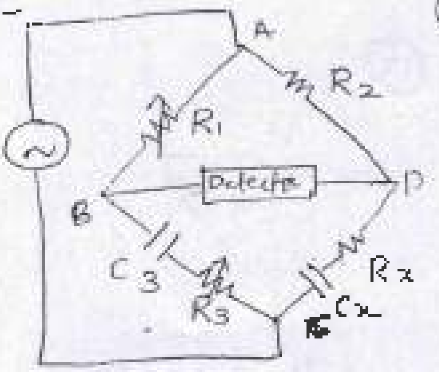
Capacitance comparison bridge:-



- The resistance ratio arms R_1 & R_2 are resistive
- ~~The~~ std. known capacitance C_3 is in series with R_3 which is variable in order to balance the bridge.
- C_x is the unknown capacitor and R_x is leakage resistance of the capacitor.
- The unknown capacitor is determined by comparing it with std capacitance along with δ and also R_x value is found.

$Z_1 = R_1$

$Z_2 = R_2$

$Z_3 = R_3 - jX_3 = R_3 - j(1/\omega C_3)$

$Z_4 = R_x - jX_4 = R_x - j(1/\omega C_x)$

- The condition of bridge balance is

$$Z_1 Z_4 = Z_2 Z_3$$

$$R_1\left(R_x - \frac{j}{\omega C_x}\right) = R_2\left(R_3 - j/\omega C_3\right)$$

$$R_1 R_x - \frac{R_1 j}{\omega C_x} = R_2 R_3 - \frac{R_2 j}{\omega C_3}$$

- Two complex quantities are said to be equal when their real & imaginary terms are equal.
- Thus $R_1 R_x = R_2 . R_3 \Rightarrow \boxed{R_x = \frac{R_2 R_3}{R_1}}$

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

$$\Rightarrow \boxed{C_x = \frac{R_1 C_3}{R_2}}$$

$$C_x = \frac{R_1 C_3}{R_2} = \boxed{C_x = \frac{R_1 C_3}{R_2}}$$

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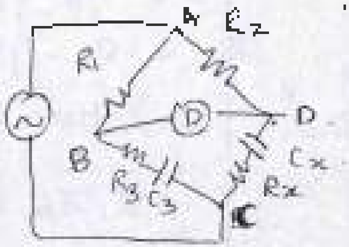
Using both equations the unknown capacitance & its leakage resistance can be measured.

Ex:- A capacitance comparision bridge is used to measure capacitive impedance at freq. of 2kHz. The bridge constants at balance are $C_3 = 100\mu F$, $R_1 = 10k\Omega$ $R_2 = 50k\Omega$, $R_3 = 100k\Omega$. Find the equivalent series ckt of unknown impedance.

→ $R_1 = 10k\Omega$, $R_2 = 50k\Omega$, $R_3 = 100k\Omega$, $C_3 = 100\mu F$.



$R_x = \frac{R_2 R_3}{R_1} = \frac{50k \times 100k}{10k} = 500k\Omega$

$\boxed{R_x = 500k\Omega}$

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

$= \frac{\cancel{100}^{10}\mu F \times \cancel{10k}}{\cancel{50k}}$

$\boxed{~~C_x = 500\mu F~~}$ $\boxed{C_x = 20\mu F}$

Ex:- An ac bridge is balanced at 2kHz with the following components in each arm ; AB: 10kΩ , Arm BC = 100μF with series 100kΩ , Arm AD = 50kΩ Find the unknown impedance in arm CD , if the detector is b/w BD

→ $Z_1 = 10k\Omega$

$Z_2 = 50k\Omega$

$Z_3 = 100k - j\left(\frac{1}{\omega C_3}\right)$

$= 100k - j\left(\frac{1}{2\pi\, 2k \times 100\mu F}\right)$

$Z_3 = 100k - j\,0.795$

$Z_4 = Z_x$

$Z_1 Z_4 = Z_2 Z_3$

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

$$Z_x = \frac{50k \times [100k - j\,0.795]}{10k}$$

$$Z_x = 500k - j\,0.795 \times 5$$

$$Z_x = R_x + j X_c$$

$$X_c = 3.975$$

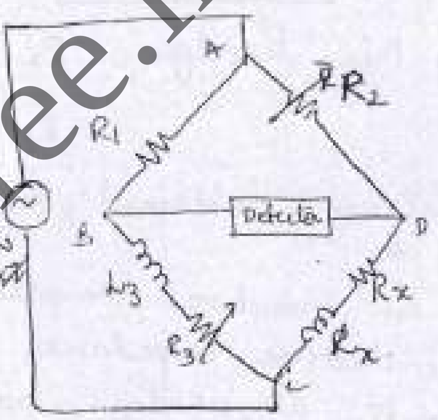
$$\boxed{\therefore R_x = 500k}$$

$$X_c = \frac{1}{2\pi f C_x} \Rightarrow C_x = \frac{1}{2\pi \times 2000 \times 3.975}$$

$$\boxed{C_x = 20\mu F}$$

Inductance Comparision bridge:-

- In this the unknown inductance & its internal resistance Rx is obtained by comparing with std inductor & resistance ie l_3 & R_3
- the ckt is shown.
- the bridge balance is obtained as



$$Z_1 Z_4 = Z_2 Z_3$$

$$\Rightarrow Z_1 Z_x = Z_2 Z_3$$

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

$Z_1 = R_1$

$Z_2 = R_2$

$Z_3 = R_3 + j X_3$

$Z_3 = R_3 + j\omega L_3$

$Z_4 = R_x + j X_x$

$Z_4 = R_x + j\omega L_x$

$$Z_1 Z_2 = Z_2 Z_3$$

$$\downarrow$$

$$[R_x + j X_{L}]$$

~~$Z_x = \frac{R_2 (R_3 + j\omega L_3)}{R_1}$~~

~~$Z_x = \frac{R_2 R_3}{R_1} + \frac{R_2 j\omega L_3}{R_1}$~~

~~$Z_x = R_x + j\omega L_x.$~~

~~$\boxed{R_x = \frac{R_2 R_3}{R_1}}$~~

$$\boxed{Z_1 Z_x = Z_2 Z_3} \rightarrow \text{Balanced Bridge.}$$

$$R_1 (R_x + j\omega L_x) = R_2 (R_3 + j\omega L_3)$$

$$R_1 R_x + j\omega L_x R_1 = R_2 R_3 + j\omega L_3 R_2$$

Equating real & imaginary parts

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$$\boxed{R_1 R_x = R_2 R_3}$$

~~$R_1 R_x + j\omega L_x R_1 = R_2 R_3 + j\omega L_3 R_2$.~~

~~$R_1 R_x + j\omega \frac{R_2}{R_1} L_3 R_1 = R_2 R_3 + j\omega L_3 R_2$.~~

~~$R_1 R_x + j\omega R_2 L_3 = R_2 R_3 + j\omega L_3 R_2$~~

$$\therefore \boxed{R_x = \frac{R_2 R_3}{R_1}}$$

~~$\boxed{R_1 R_x = R_2 R_3}$~~ → I Balance

~~$R_x = \frac{R_2 R_3}{R_1}$~~

$$j\omega L_x R_1 = j\omega L_3 R_2$$

~~R_x~~ = ~~$R_2 R_3$~~

$$\boxed{L_x = \frac{R_2 L_3}{R_1}}$$

* In this bridge R_2 → ~~is~~ used for inductive balance control.

R_3 → is used for resistance balance

Balance is obtained by varying L_3 or R_3 alternatively.

Ex:- An inductive comparision bridge is used to measure the inductive impedance at a freq of 1.5KHz. The bridge constants at bridge balance are $L_3 = 8mH$, $R_1 = 1k\Omega$, $R_2 = 25k\Omega$, $R_3 = 50k\Omega$. Find the equivalent series ckt of unknown impedance.

→ $R_1 = 1K\Omega$, $R_2 = 25K\Omega$, $R_3 = 50K\Omega$, $L_3 = 8mH$

$$R_x = \frac{R_2 R_3}{R_1} = \frac{25K \times 50K}{1K} = 1250K = 1.25 M\Omega$$

$$\boxed{L_x = \frac{R_2 L_3}{R_1}} = \frac{25K}{1K} \times 8mH = 200mH$$

Maxwell's bridge:-

* Maxwell's bridge is used to measure unknown inductance in comparision with known capacitor (std) or using variable std self inductance.

- → Maxwell's inductance bridge
- → Maxwell inductance capacitance bridge.

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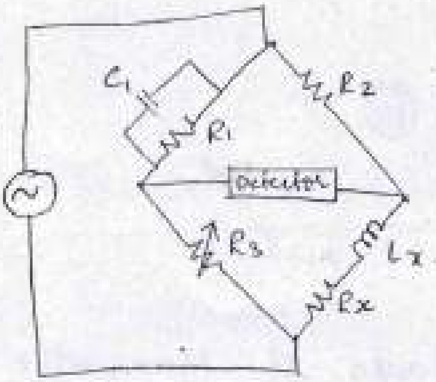

→ The ckt shown Maxwells inductance capacitance bridge, where L is found in comparision with C (~~known~~ std C).

→ One of the ratio arm consists of R in ||le with C. & thus it is easier to write the bridge balance equation using in admittance form

Admittance = $\frac{1}{\text{Impedance}}$

$Y = \frac{1}{Z}$

→ The bridge balance Eqn is

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_1 Z_x = Z_2 Z_3$$

$$Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 \cdot \frac{1}{Z_1}$$

$$\Rightarrow Z_x = Z_2 Z_3 Y_1$$

$\therefore Y_1 = \frac{1}{Z_1}$

$Z_1 = R_1 \parallel C_1$

~~$\frac{R_1 \pm}{R_1} j\omega 2C_1$~~

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

$Y_1 = 1/R_1 + j\omega C_1$

C is || with R

$\therefore \frac{R}{R + j/\omega C}$

$Z_2 = R_2, \quad Z_3 = R_3,$

$Z_x = R_x + j\omega L_x.$

$$Z_x = Z_2 Z_3 Y_1$$

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

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

Equating real & imaginary parts.

$$\boxed{R_x = \frac{R_2 R_3}{R_1}}$$

$$\boxed{L_x = R_2 R_3 C_1}$$

Q or Quality factor of L is given by

$$Q = \frac{\omega L_x}{R_x}$$

$$Q = \frac{\omega R_2 R_3 C_1 \cdot R_1}{R_2 R_3}$$

$$\boxed{Q = \omega C_1 R_1}$$

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Advantages of Maxwell's bridge:-

1) Balance eq^n is independent of losses associated with inductance.

2) Balance eq^n is independent of freq of measurement.

3) Scale of resistance can be calibrated to read the inductance directly.

4) R_1 can be calibiated to read Q value of coil directly.

Disadvantages of Maxwell's bridge:-

- * It is limited to measure values of Q b/w 1 - 10 ~~cannot~~ Not suitable for Q value < 1 Q > 10
- * Balance adjustment is little difficult due to interaction b/w resistance & reactance balances.
- * Bridge balance eq^n are independent of freq, but practically the coil under test vary with freq which may cause error

Anson's bridge:-

Ex - The arms of a.c maxwell's bridge are adjusted as

Arm AB: Nonreactive resistance of 700Ω

Arm CD: Non reactive resistance of 300Ω

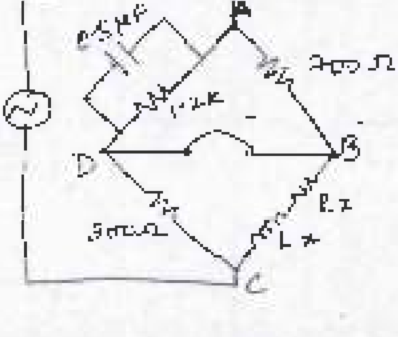
Arm AD Nonreactive resistance of 1200Ω in ||^{el} with C of 0.5μF. If the bridge is balanced under this condition, find the components of the branch BC ?

→ Given $C_1 = 0.5\mu F$

$R_1 = 1.2K\Omega$

$R_2 = 700\Omega$

$R_3 = 300\Omega$



From Eq^n 3 $R_x = \frac{R_2 R_3}{R_1} = \frac{\overset{175}{\cancel{700}} \times 300}{\underset{4}{\cancel{1200}}} = 175\Omega$

$L_x = R_2 R_3 C_1$

$= 700 \times 300 \times 0.5 \mu F$

$L_x =$

$\boxed{R_x = 175\Omega}$

$\boxed{L_x = 0.105 H}$

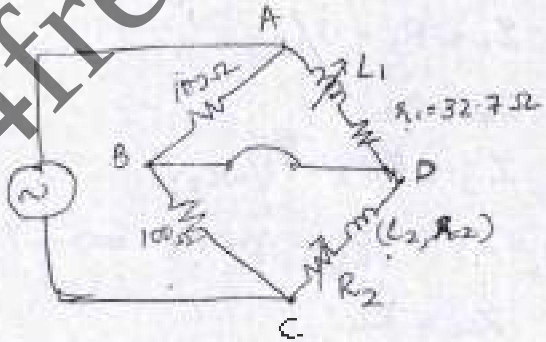
Ex: The arms of an a.c Maxwell's bridge are arranged as follows. AB & BC are non-reactive resistor of 100Ω each. DA is standard variable inductor L_1 of resistance 32.7 Ω & CD comprises a std variable resistance R in series with a coil of unknown impedance. Balance was obtained with L = 47.8 mH & R = 1.36Ω. Find the resistance & inductance of coil.

→ Given : $L_1 = 47.8 mH$

$R = 1.36\Omega$

Balance will be obtained when $L_2 = 47.8 mH$

$R_2 = 1.36\Omega$



At balance

$100 (r_1 + j\omega L_1) = 100 [(R_2 + r_2) + j\omega L_2]$

$100 r_1 + 100 j\omega L_1 = 100 (R_2 + r_2) + 100 j\omega L_2$

Equating real & imaginary parts.

$r_1 = R_2 + r_2$

$\boxed{L_2 = L_1 = 47.8 mH}$

$r_2 = r_1 - R_2$

$= 32.7 - 1.36$

$\boxed{r_2 = 31.34\Omega}$

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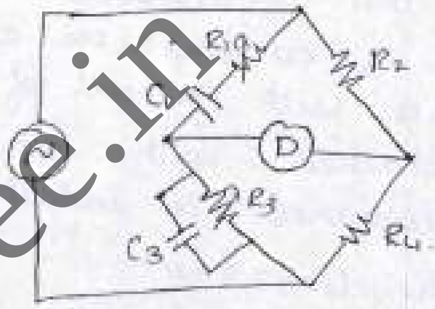
Wein bridge:-

- Wein bridge in its basic form is used to measure frequency
- But it can be used to measure unknown capacitor with great accuracy.
- The Wein bridge is shown in fig.

→ It has series RC & parallel RC combination in the adjoining arm



- The impedances of arms are

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

$$Z_2 = R_2$$

$$Z_3 = R_3 + 1/\omega C_3$$

$$1/Y_3 = Z_3 = 1/R_3 + j\omega C_3 \implies Y_3 = 1/R_3 + j\omega C_3 \Rightarrow \text{Admittance}$$

$$Z_4 = R_4$$

- The balance eq^n is

$$R_4 \quad Z_1 Z_4 = Z_2 Z_3$$

ie ~~$Z_1 Z_4 = Z_2 Y_3$~~.

$$Z_1 Z_4 = Z_2 / Y_3$$

$$Z_2 = Z_1 Z_4 Y_3.$$

$$R_2 = (R_1 - j/\omega C_1) R_4 \; (1/R_3 + j\omega C_3).$$

$$= R_4 \; (R_1 - j/\omega C_1)(1/R_3 + j\omega C_3).$$

$$= R_4 \left[\frac{R_1}{R_3} + j\omega C_3 R_1 - j/\omega C_1 R_3 + \frac{C_3}{C_1} \right].$$

$$R_2 = \frac{R_1 R_4}{R_3} + j\omega C_3 R_1 R_4 - \frac{jR_4}{\omega C_1 R_3} + \frac{R_4 C_3}{C_1}$$

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$$R_2 = \left[\frac{R_1 R_4}{R_3} + \frac{R_4 C_3}{C_1}\right] - j\left[\frac{R_4}{\omega C_1 R_3} - \omega C_3 R_1 R_4\right]. \quad (14)$$

Equating real & imaginary parts

$$\frac{R_1 R_4}{R_3} + \frac{R_4 C_3}{C_1} = R_2 \quad \Rightarrow \text{Real part}$$

$$\frac{R_4}{\omega C_1 R_3} = \omega C_3 R_1 R_4 \quad \Rightarrow \text{imaginary part.}$$

Considering real parts:

$$R_4\left[\frac{R_1}{R_3} + \frac{C_3}{C_1}\right] = R_2$$

$$\boxed{\frac{R_2}{R_4} = \left[\frac{R_1}{R_3} + \frac{C_3}{C_1}\right]} \longrightarrow Ⓐ$$

Considering imaginary parts

$$\cancel{R_3 = \omega^2 C_1 C_3 R_1^2 R_4}$$

$$\frac{\cancel{R_4}}{\omega C_1 R_3} = \omega C_3 R_1 \cancel{R_4}$$

$$1 = \omega^2 C_1 C_3 R_1 R_3.$$

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

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

$$2\pi f = \omega.$$

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

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Eqⁿ Ⓐ --- & Ⓑ --- result.

Eqⁿ Ⓐ & Ⓑ helps in determining resistance ratio R_2/R_4 & freq.

- Then if we satisfy $\frac{R_2}{R_4}$ ratio ie Eqⁿ Ⓐ & excite the bridge with freq f (Eqⁿ Ⓑ) then the bridge will be balanced.

- In most of the wein bridge ckt, the components are chosen such that $R_1 = R_3 = R$
$C_1 = C_3 = C$.

$$\therefore \frac{R_2}{R_4} = 1+1 = 2$$

$$f = \frac{1}{2\pi RC}$$ → General form of equation for the freq of the bridge ckt.

Applications:-

→ Bridge is used to measure freq in audio range 90 Hz – 20 kHz. Resistance → used for range changing
Capacitors → used for freq control

→ Bridge can be used to measure capacitor if operating freq is known.

→ Bridge can be used in harmonic distortion analyzer, as a notch filter & in AF & RF oscillators as freq determining element.

→ Accuracy of 0.5% – 1% can be obtained using this bridge.

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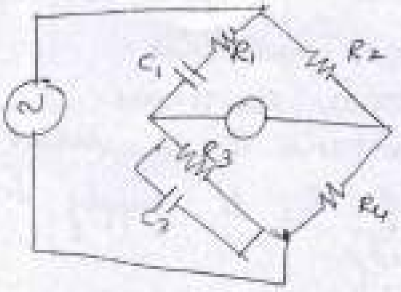
Ex:- Find the equivalent parallel resistance & capacitance ⑮ that causes a Wein bridge to null with the following component values. $R_1 = 3.1 k\Omega$, $C_1 = 5.2 \mu F$, $R_2 = 25 k\Omega$, $f = 2.5 kHz$ ㉛ & $R_4 = 100 k\Omega$.

→ From given data Wein bridge can be drawn as.

∴ From the bridge balance eqn we have

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

$$\frac{R_2}{R_4} = \left[\frac{R_1}{R_3} + \frac{C_3}{C_1}\right] \quad -②$$



Given R_1, C_1, R_2, R_4
C_3 & R_3 have to be found.

Rearranging ①.

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

Using C_3 in ②

$$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{1}{C_1^2 \omega^2 R_1 R_3}$$

$$\frac{25K}{100k} = \frac{3.1K}{R_3} + \frac{1}{(5.2\mu F)^2 \times (2\times\pi\times 2.5K)^2 \times 3.1K \times R_3}$$

$$0.25 = \frac{3.1K}{R_3} + \frac{0.0483}{R_3} = \frac{3.1K + 0.0483}{R_3}$$

$$\boxed{R_3 = 12.4 k\Omega}$$

Using R_3

$$C_3 = \frac{1}{C_1 \omega^2 R_1 R_3} = \frac{1}{5.2\mu \times (2\times\pi\times 2.5K)^2 \; 3.1K \times 12.4K}$$

$$\boxed{C_3 = 20.28 pF}$$

Ex:- The 4 arm bridge ABCD, supplied with a sinusoidal voltage, have the following values:

AB = 730Ω in parallel with 0.2 μF capacitor.

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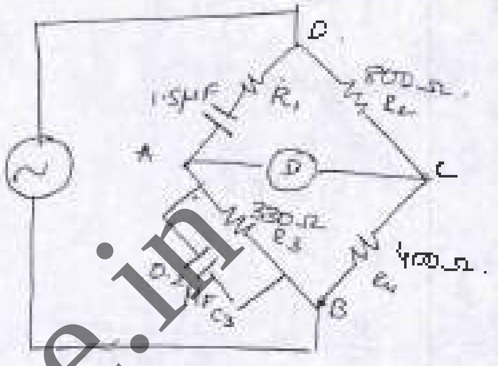
BC = 400Ω resistance.

CD = 800Ω resistance.

DA resistance R in series with a 1.5μF capacitor. Determine value of R & supply freq at which bridge will be balanced



→ $Z_1 = R_1 - j/\omega C_1 = R_1 - j/2\pi f C_1$

$Z_2 = R_2 = 800\Omega$

~~R_3~~ = [illegible]

$Z_4 = R_4 = 400\Omega$.

$Y_3 = \frac{1}{Z_3} = \frac{1}{R_3} + j\omega C_3$.

~~Th~~ The balance eqⁿ is

$$Z_1 Z_4 = Z_2 Z_3$$

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

$$Z_2 = Z_1 Z_4 Y_3$$

$$800 = \left(R_1 - \frac{j}{\omega C_1}\right)(400)\left(\frac{1}{R_3} + j\omega C_3\right)$$

$$2\cancel{800} = \left(R_1 - j\frac{666.667\times10^{3}}{\omega}\right)(\cancel{400})\left(3.030\times10^{-3} + j\omega\, 0.2\mu F\right)$$

~~2 800 = R₁ × 3.030×10⁻³~~

$$2 = \left(R_1 - j\frac{666.667\times10^{3}}{\omega}\right)\left(3.0303\times10^{-3} + j\omega\, 0.2\mu\right).$$

$$= 3.0303\times10^{-3}R_1 + j\omega\, 0.2\mu R_1 - j\frac{666.667\times10^{3}}{\omega}\cdot 3.0303\times10^{-3}$$

$$+ \frac{666.667\times10^{3}\times \cancel{\omega}\, 0.2\mu}{\cancel{\omega}}$$

$$2 = \left[3.0303\times10^{-3}R_1 + 0.1333\right] + j\left[\omega\, 0.2\mu R_1 - \frac{2020.20}{\omega}\right].$$

Equating real & imaginary part.

$$2 = 3.0303\times10^{-3}R_1 + 0.13334$$

$$R_1 = \frac{2 - 0.1333}{3.0303 \times 10^3}$$

$$R_1 = 615.9\ \Omega.$$

$$\boxed{R_1 = 616\ \Omega = R}$$ unknown resistance

Imaginary part

$$\omega\, 0.2\mu R_1 - \frac{2020.20}{\omega} = 0.$$

$$\omega^2 0.2\mu R_1 - 2020.20 = 0.$$

$$(2\pi f)^2 0.2 \times 10^{-6} \times 616 - 2020.20 = 0$$

$$(2\pi f)^2 = \frac{2020.20}{0.2 \times 10^{-6} \times 616} = 16.397 \times 10^6$$

$$2\pi f = \sqrt{16.397 \times 10^6} = 4.049 \times 10^3$$

$$f = \frac{4.049 \times 10^3}{2\pi}$$

$$\boxed{f = 644.48\ Hz}$$

Ex:- Find the parallel 'R' & 'C' that causes a Wein bridge to null with the following component values. $R_1 = 2.7k\Omega$, $R_2 = 22k\Omega$, $C_1 = 5\mu F$, $R_4 = 100\ k\Omega$ & the operating freq is 2.2 kHz

→ we have eq^ns R_3 & C_3 ?

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

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

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

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Using C_3 in R_2/R_4 Eqⁿ.

$$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{1}{\omega^2 R_1 C_1^2 R_3}$$

$$\boxed{R_3 = 12.273\,k\Omega}$$

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

$$\boxed{C_3 = 31.58\,pF}$$

Wagner's Earth Connection :-

Note: In electrical ckt, parasitic or stray capacitance is an unavoidable & unwanted capacitance that exists b/w parts of electronic compoment or ckt due to proximity to each other.

& All actual elements such as diode, transistor & inductors have internal capacitance which can cause their behaviour to vary from that of ideal ckt element

→ While performing high freq measurement, stray capacitance b/w bridge elements & ground & b/w the bridge arms exists & they become significant.

→ This introduces error in the measurement when we are measuring small capacitance & large inductance values

→ This can be avoided or controlled by providing shielding & grounding the shield. However this does not eliminate the capacitance but makes its value constant

→ Another effective & popular method for eliminating stray capacitance is by using "Wagner's ground connection"

→ ckt is shown. The ckt is a capacitance measuring bridge

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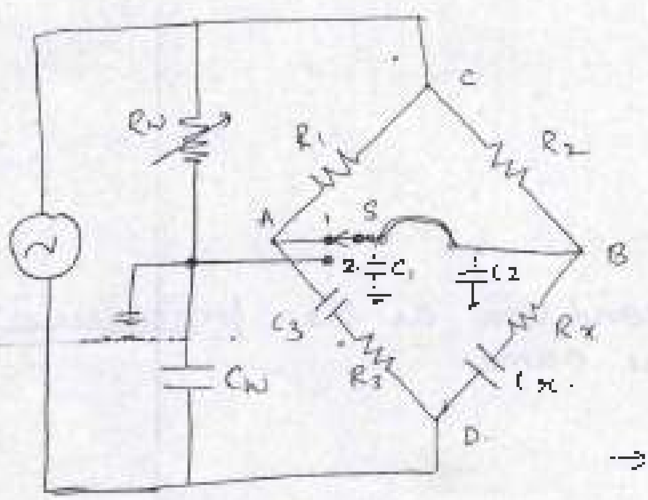

→ In the ckt C1 & C2 represent the stray capacitance

→ In Wagner's Earth/Gnd connection ~~also~~ one more arm having Rw & Cw which acts/forms a potential divider is used.

→ The Rw & Cw jn is gnded and is called Wagner's Gnd connection.

-> The adjustment procedure is as follows

→ The switch S is connected to point 1 & adjusted for null or min sound in headphone by varying R1

-> Then S is connected to point 2 ~~&~~ i.e Wagner's gnd point & Rw is adjusted to get min or null sound in headphone.

-> When S is connected again to point 1 there will be some imbalance so R1 & R3 are varied to get min sound

-> S is again connected to point 2 & vary Rw to get min sound. This procedure is repeated until null is obtained at both point 1 & 2 This gives the "ground potential"

-> At ~~the~~ this condition, C1 & C2 ie stray capacitance are effectively short ckted & have no effect on the normal bridge. (⊣⊢ ⏚)

-> From point C to D the capacitance that exists are also eleminated by the Wagner's ground connection. As the current thr' capacitance will enter the Wagner's ground connection & their effect will also be nullified.

→ ~~The~~ addition of Wagner's ground connection will

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not effect the balance condition as the procedure for measurement remains same.

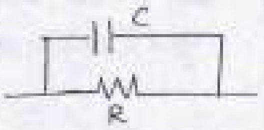
Note

→ series impedance.

$R + X_C \qquad X_C = 1/j\omega C.$

$R + \frac{1}{j\omega C}$

$\boxed{R - j/\omega C = Z}$



→ Parallel impedance

$$\frac{R \times X_C}{R + X_C} = \frac{R \times 1/j\omega C}{R + 1/j\omega C}$$

$$= \frac{R/j\omega C}{\frac{jR\omega C + 1}{j\omega C}}$$

$$Z = \frac{R}{jR\omega C + 1}$$

$$= \cancel{\frac{R}{jR\omega C} + R}$$

$$= \cancel{R + \frac{1}{j\omega C}}$$

$$Y = 1/Z$$

$$Y = \frac{1}{\frac{R}{jR\omega C + 1}}$$

$$= \frac{1 + jR\omega C}{R}$$

$$= 1/R + j\frac{\omega CR}{R}$$

$$\boxed{Y = 1/R + j\omega C}$$

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MEASURING INSTRUMENTS

①

:- Are the devices for measuring physical quantaties.

→ They play an important role in all phases of electronics & helps in determining how an electronic ckt is performing.

→ ~~The~~ fundamental electrical measurements are voltage, current & resistance/impedance.

The insts which are used for measuring these quantaties form the building blocks for more complex equipments/devices used for measuring other parameters like power, freq & other special measurements

→ A measuring device converts primary indication into some other form of energy that can be easily displayed on a scale.

Q meter :-

→ Q factor also called quality factor or storage factor.

→ The overall efficiency of coils & capacitors which are used in RF applications can be evaluted using Q value

→ It is an instrument designed to measure electrical properties of coils & capacitors

→ The principle is based on series resonance

→ It is also defined as ratio of reactance to resistance of a reactive element.

Working principle

→ It works on series resonance. — A freq point at which inductive reactance of inductor becomes equal to capacitive reactance of capacitor. ie $X_L = X_C$

→ In other words: The voltage drop across the coil or capacitor is Q times applied voltage.

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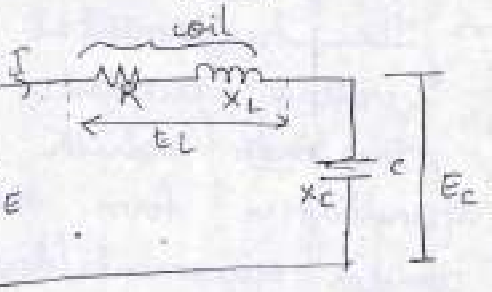
→ Series resonant ckt is shown in which



E = Applied Voltage

E_C = Capacitor voltage

E_L = inductive voltage

X_L = inductive reactance

X_L = capacitive reactance.

R = coil resistance

I = current

At resonance $X_L = X_C$

$$E_C = I X_C$$

$$E_L = I X_L$$

$$E = IR$$

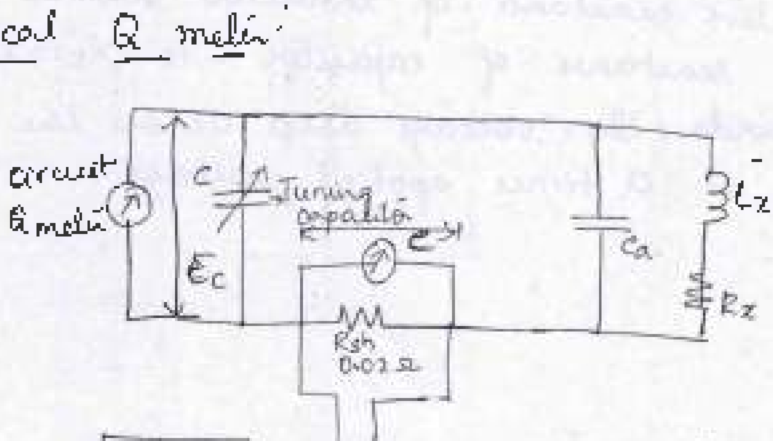
$$\therefore Q = \frac{\text{Reactance}}{\text{Resistance}}$$

$$Q = \frac{X_C}{R} = \frac{X_L}{R} = \frac{E_C}{E}$$

From the above eq^n if E is kept constant, then voltage across capacitor is Q times E.

Thus a voltmeter when calibrated across capacitor ~~gives the~~ can read Q value

Practical Q meter



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→ Wide range oscillator with freq range 50kHz to 50MHz is used as source to provide current to resistance R_{sh} whose value is 0.02 Ω.

→ current through R_{sh} represents voltage source of magnitude 'e' with small internal resistance

→ The voltage across shunt is measured using a thermocouple meter and voltage across capacitor is measured using electronic voltmeter corresponding to E_c ~~then~~ is adjusted directly to read Q.

$$Q = \frac{E_c}{e}$$

$$\text{or } E_c = Q e$$

→ If inductance of coil has to be determined then it has to be connected to the test terminals of the instrument

→ The circuit is tuned to resonance by varying either capacitance or oscillator freq.

→ If C is varied, then oscillator freq. is adjusted to given freq to obtain resonance.

→ If oscillator freq is varied, then C is pre-setted to desired value to get resonance.

→ To get the actual Q value, the output obtained should be multiplied by index setting or "Multiply Q by" notch

→ The inductance of the coil can be found from the known values of oscillator freq & resonating capacitor C.

$$X_L = X_C \Rightarrow 2\pi f L = \frac{1}{2\pi f C}$$

$$f^2 = \frac{1}{4\pi^2 LC} \qquad f = \frac{1}{2\pi\sqrt{LC}}$$

$$\text{or } L = \frac{1}{4\pi^2 f^2 C}$$

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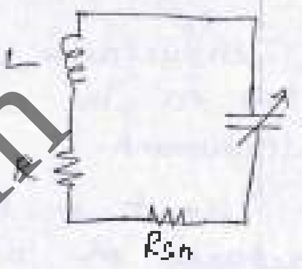
Factors that may cause error:-

1. Due to Rsh :-

* At high freq. the electronic voltmeter will suffer from losses ~~(~~due to transit time effect) & this effect ~~to~~ results in introducing Rsh into the tank ckt as shown below.



$$Q_{act} = \frac{X_L}{R} = \frac{\omega L}{R} = \frac{2\pi f L}{R}$$

$$Q_{obs} = \frac{\omega L}{R + R_{sh}}$$

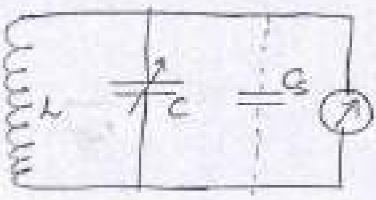
$$\therefore \frac{Q_{act}}{Q_{obs}} = \frac{\omega L / R}{\frac{\omega L}{R + R_{sh}}} = \frac{\omega L}{R} \times \frac{R + R_{sh}}{\omega L} = 1 + \frac{R_{sh}}{R}$$

$$\cancel{\frac{Q_{act}}{Q_{obs}}} = \quad \therefore Q_{act} = Q_{obs}\left[1 + \frac{R_{sh}}{R}\right].$$

Thus in order to make Qact close to Qobs, Rsh should be made as small as possible.

2. Due to stray capacitance:-

* The presence of stray capacitance modifies the actual Q & inductance of coil.
* At resonant freq, $X_L = X_C$ & the ckt impedance purely resistive & this chae can be used to measure stray / distributed / self capacitance.
* One method of measuring stray or distributed capacitance C_s of coil is by making 2 ~~measurements~~ at different freq
* The ~~Capacitor~~ C ~~of Q meter is calibrated to indicate capacitance value.~~
* The coil under test is connected to Q meter terminal as shown in fig.



- The C is kept to high value i.e. max & ckt is resonated by varying oscillator freq.
- At resonance, the oscillatory freq & capacitor be denoted by

  f_1 Hz & C_1

- The oscillator freq is now ↑ to twice the original freq i.e. $f_2 = 2f_1$ & the C is varied to obtain Resonance at C_2. Thus ~~the~~ at resonance the freq & capacitor values are

  $f_2 = 2f_1$ Hz

  C_2

- The resonant freq of LC ckt is given

$$X_C = X_L \qquad 2\pi f L = \frac{1}{2\pi f C}$$

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

- At the initial or 1st resonance condition, the total capacitance in the ckt is

  $C_1 + C_s$ & the resonant freq is now

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

- At the 2nd resonance condition, the total capacitance in the ckt is

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

- But we have $f_2 = 2f_1$

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

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$$\frac{1}{\sqrt{L(C_2+C_s)}} = \frac{2}{\sqrt{(C_1+C_s)L}}$$ squaring both sides

~~$C_1 + C_s =$~~

$$\frac{1}{\cancel{L}(C_2+C_s)} = \frac{4}{\cancel{L}(C_1+C_s)}$$

$$C_1 + C_s = 4\ (C_2 + C_s)$$

$$C_1 + C_s = 4C_2 + 4C_s$$

$$C_1 = 4C_2 + 4C_s - C_s$$

$$C_1 = 4C_2 + 3C_s$$

$$\boxed{C_s = \frac{C_1 - 4C_2}{3}}$$

Thus the stray capacitance can be calculated using above Eq^n.

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<u>Ex:-</u> The self capacitance ~~of~~ coil is ~~done~~ measured by making 2 measurements at diff frequencies. The first measurement is at $f_1 = 1MHz$ & $C_1 = 500pF$. The 2nd measurement is at $f_2 = 2MHz$ & $C_2 = 110pF$. Determine distributed capacitance. Also calculate value of L.

$$\rightarrow \quad C_s = \frac{C_1 - 4C_2}{3}$$

$$C_s = \frac{500\times10^{-12} - 4\times110\times10^{-12}}{3} = \frac{(500-440)pF}{3} = \overset{20}{\cancel{\frac{60}{3}}}pF$$

$$\boxed{C_s = 20pF}$$

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

$$1MHz = \frac{1}{2\pi\sqrt{L(500pF + 20pF)}}$$

Squaring both sides.

$$(1MHz)^2 = \frac{1}{4\pi^2 L(500pF + 20pF)}$$

$$L = \frac{1}{4\pi (1MHz)^2 \times 520pF}$$

$$L = \underline{\underline{48.712 \mu H}}$$

Ex:- Determine the value of self capacitance when the follwg measurements are performed.

$f_1 = 2MHz \quad C_1 = 500pF$

$f_2 = 6MHz \quad C_2 = 50pF$

→ Given $f_2 = 3f_1$

At resona

$$\frac{1}{\cancel{2\pi}\sqrt{L(C_2+C_S)}} = \frac{3}{\cancel{2\pi}\sqrt{L(C_1+C_S)}}$$

squaring both sides.

$$\frac{1}{C_2 + C_S} = \frac{9}{C_1 + C_S}$$

$$C_1 + C_S = 9C_2 + 9C_S.$$

$$C_1 - 9C_2 = 8C_S.$$

$$\therefore C_S = \frac{C_1 - 9C_2}{8}$$

$$C_S = \frac{500p - 9(50p)}{8} = \frac{500p - 450p}{8} = \frac{50pF}{8}$$

$$\boxed{C_S = 6.25pF}$$

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Megger

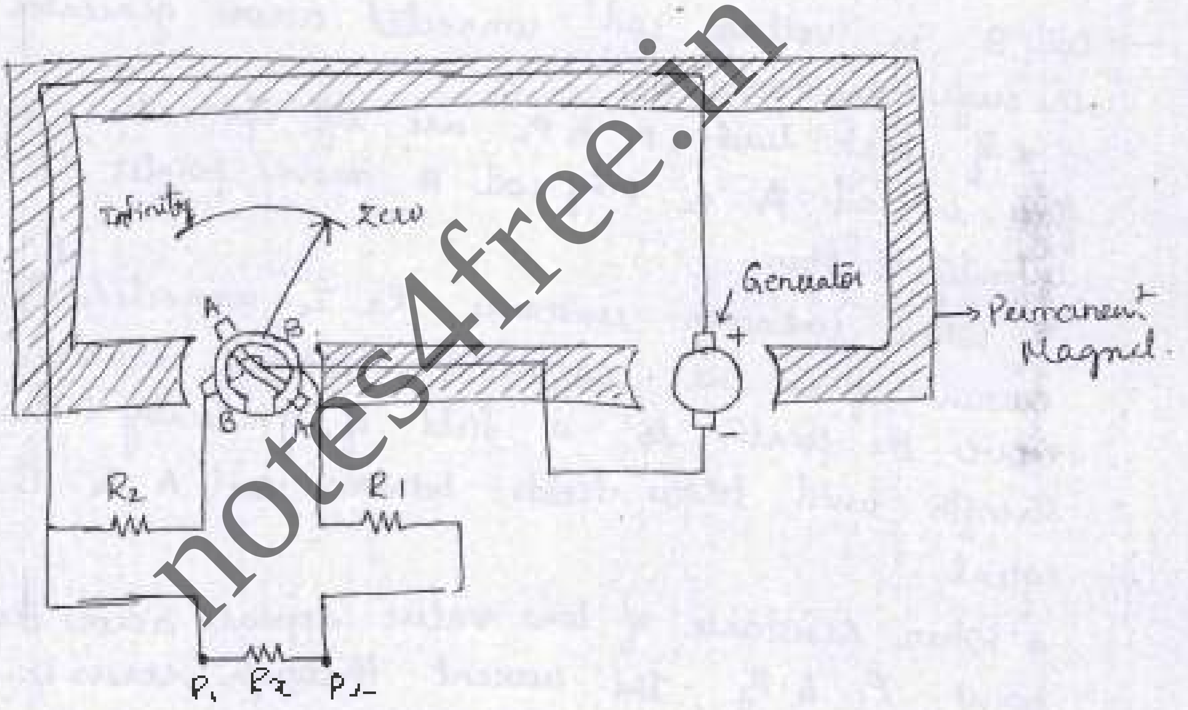
→ Resistances of order 0.1MΩ and upwards are classified as high resistances and these can be measured using portable instrument called as "Megger".

→ It is used to measure high resistances seen in cable insulation, transformer windings, between motor windings etc.

→ It works on the principle of electromagnetic induction

→ Megger is an portable ohmmeter which has an inbuilt high voltage source.

→ The Megger is shown in fig below.



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→ It has 2 main elements

1. Magnet type dc generator → To supply current for measurement
2. Ohmmeter → Measure resistance value.

→ The dc generator is the high voltage source, which produces high voltages such as 500V, 1000V, 2500V or 5000V depending on model.

→ The meter has 2 windings.

* One winding B is in series with R2 and is connected to output of generator (ie +ve). This windings moves pointer towards high resistance end on the scale

when generator is operating.

- Other winding A which is in series with R_1 is connected between -ve terminal of generator & the test line. This winding moves the pointer towards zero end when current flows.
- Both windings are mounted on same shaft and they are at right angle to each other.

→ The test leads are P_1 & P_2 to which unknown resistance to be measured is connected.

→ Coil A is 'current coil' connected to -ve o/p of generator & is in series with R_1 to the test lead P_2.

→ Test lead P_1 is connected to the +ve o/p of generator.

→ Coil B is 'voltage coil' connected across generator o/p thro' the high resistance R_2.

- If test leads P_1 & P_2 are left open then no current flows in coil A & only coil B moves pointer to indicate infinity or open
- When unknown resistance R_x is connected at P_1 & P_2 current flows thro' coil A. The torque developed moves the pointer to a field of gradually increasing strength until torque fields between coil A & B are equal.
- When resistance of low value appears across test point P_1 & P_2, the current through series winding causes pointer to move towards zero.

Applications:-

→ Megger is used to determine high resistance between conducting part of ckt and ground (called as insulation)

→ Used to test continuity between any 2 points.

- when pointer points to full scale deflection there is electrical continuity between them.

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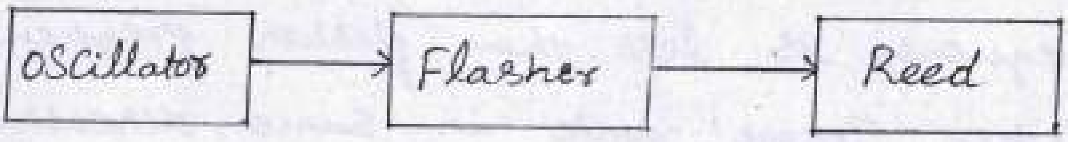
Stroboscope

- Stroboscope Consists of an Oscillator, a reed and a flasher.



- Working principle of Stroboscope
  A high intensity light is flashed at precise intervals directed upon rotating or Vibrating object.

- **Oscillator** :- It is externally triggered multivibrat-or which provide trigger pulses to flasher mechanism to Control flash rate.

- **Flasher** :- It is tube fired by Capacitor discharge, which is Controlled by trigger pulses. Tube is filled with inert gas which produces light when it is ionised.

- **Reed** :- is Driven from ac line & Vibrates at 7200 times per minute.

- When frequency of moving object exactly matches Stroboscope frequency, moving object appear as single stationary image.

- When Image appears to rotate in opposite direction to that of actual rotation. Rotation.

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frequency is less than flasher frequency.

- when Image rotate in same direction as actual rotation, rotation frequency is higher than the flasher frequency.

- Stroboscope is used to check motor (or) generator speeds ranging from 60 - 1,000,000 rpm.

- It has an accuracy of measurement as close as 0.1 %.

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Phase meter.

- Also Called as phase Sensitive Detector used for Comparing AC Signal with reference signal.
- Detector produces a rectified o/p which is given to DC meter to clearly read o/p of phase detector swings zero Center pointer in one Direction for in phase error & in opposite direction for out-phase Condition.
- Detector Distinguishes only b/w in phase & 180° out of phase, without regard for other phase angles.

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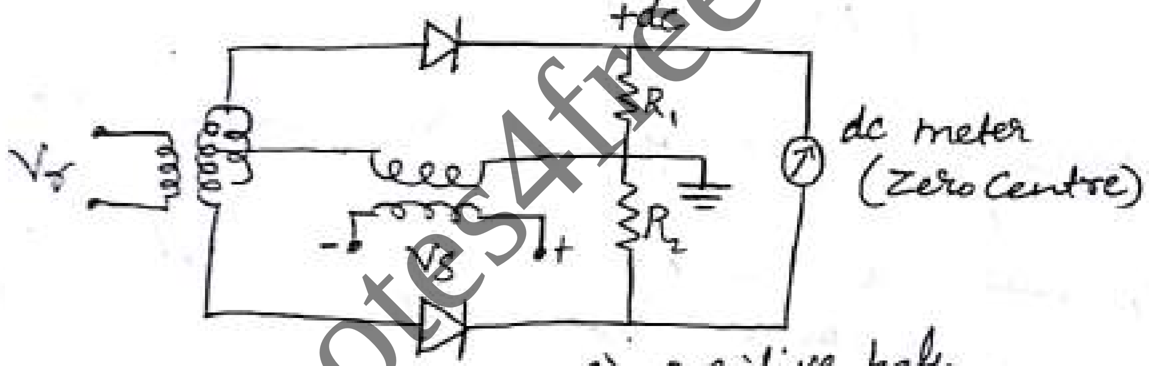

a) positive half.

- when $V_S = 0$, During +ve half cycle of reference V/g V_r Causes rectified Current to flow through D_1, producing +ve V/g to ground across R_1. which Deflects meter to right.
- During -ve half cycle V_r Causes an equal rectified Current to flow through Diode D_2, producing equal tendency for meter to Deflect to the left.
- So equal & opposite tendencies, the galvanometer reads zero over full cycle,

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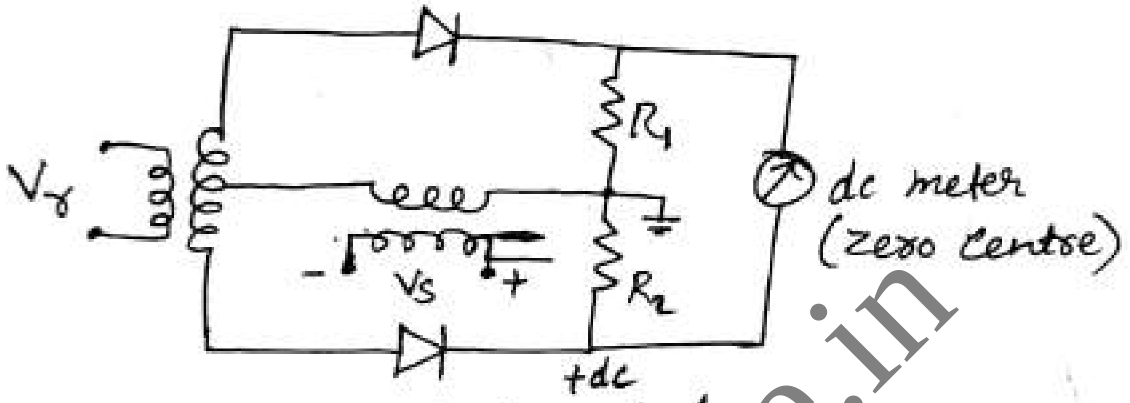
* when I/p V_s is Applied, and V_s is inphase with V_r, produces larger Current through D_1 & larger DC o/p V/g on first half.
* D_2 Does not Conduct; so V/g across R_2 is $V_s - V_r$.
* And V/g across R_1 is $V_s + V_R$



b) Negative half

* During -ve half cycle of V_s, signal V/g is in opposite Direction.
* D_1 will not Conduct & Signal oppose instantan ac V/g produces smaller dc V/g across R_2.
* Galvanometer deflects to right proportional to magnitude of inphase I/p Signal V_s.
* $|||^{ly}$, if V_s is 180° out of phase with V_r, V/g add on lower half on transformer secondary, so galvanometer deflects to left proportional to magnitude of I/p signal.

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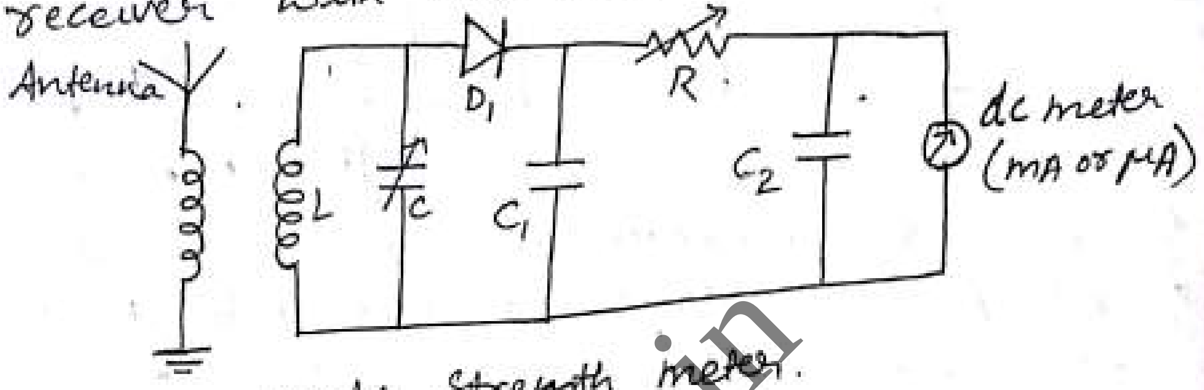
Field Strength meter.

- It is used to measure radiation intensity of a transmitting antenna.
- It has its own small whip antenna for essential receiver with an indicator.



Field Strength meter.

- wave meter ckt with rectified-meter indicator is often equipped with small whip Antenna, & its is called as field strength meter.
- Although we can get indications by this setup fairly positioning close to transmitting antenna but sensitivity is not high enough for use with ordinary low powered transmitters.
- Also field strength measurement to be made at Distance of several wavelengths from transmitting antenna to avoid misleading reading. obtained Due to radiation field with combination of induction field close to transmitter.
- To enable wavemeter to measure field strength greater sensitivity is obtained with addition

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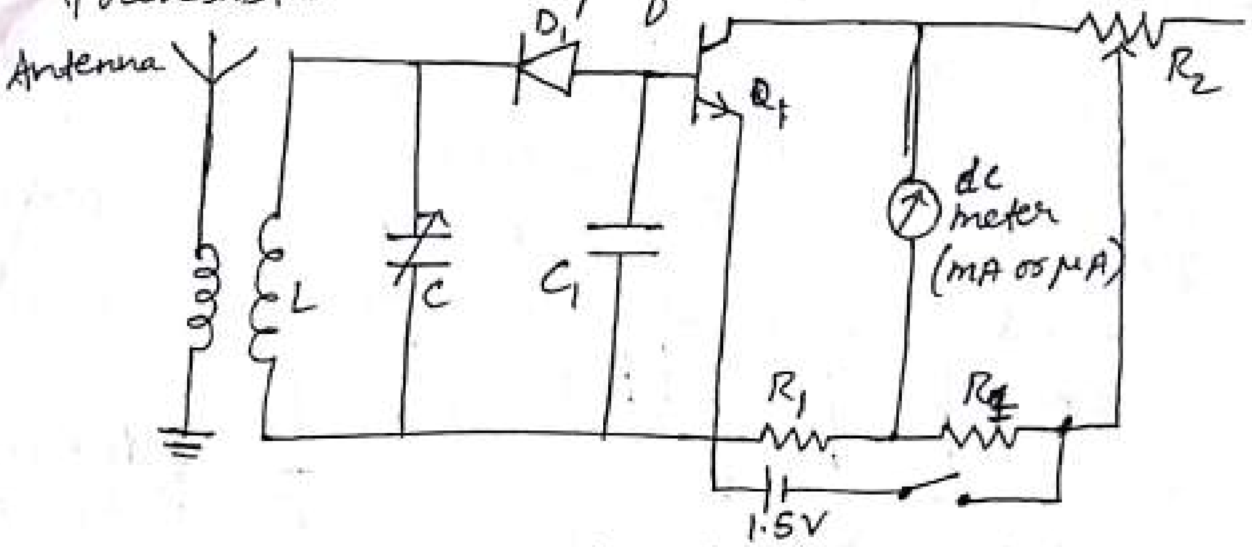
of transistor DC amplifier. as shown below.



* Transistor Connected in CE Configuration.

* It provides ample current gain, with Satisfact -ory Sensitivity.

* Quiescent Current is balanced by back up current through variable Resistor R_2.

* Quiescent current is checked at intervals. since it vary with temp changes.

* Collector Current through meter provides indicati -on of strength of RF wave obtained.

* Current is not Strickly proportional to field strength because of non-linearities of Semi Conductor Diode & transistors.

* the response is Satisfactory for relative Comparison of field Strength.

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MODULE 5

TRANSDUCERS

→ In any measurement, sensor or primary sensing element is required for measurement & automatic control.

Sensor:- Is element which senses the condition or value of the variable & generates an signals which represents the state or value

or Sensor is a device that produces a measurable response to the change in physical condition.

Transducer:- Is a device for which converts one form of energy to another form when actuated. The process of converting one physical quantity to another physical quantity is called as transduction.

→ Transducer is a conversion element and sensor is a sensing element (which detects only physical parameter)

Ex: of sensor → springs, diaphragm, bellow, Bourdon tube, flow nozzle, Orifice etc

Ex: of transducer → potentiometer, strain gauge, LVDT, piezoelectric transducer, ~~&~~ photoelectric transducer etc

→ common range of electrical signal used in industries are 0 - 5V or 4 to 20mA.

Types of transducer:-

1> Mechanical Transducer 2> Electrical transducer.

Mechanical transducer :- converts physical or mechanical quantity into other physical or mechanical form.

→ The o/p signal generated is mechanical in nature, this helps in differentiating with electrical transducer.

Advantages:-

1> They ~~are~~ ~~have~~ shows high accuracy & they are rugged.

2> low cost & can operate without any external power supply

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Disadvantages :-

1) freq response is very poor.

2) For remote indication or control requires large forces

Electrical transducer :-

→ converts physical, mechanical or optical quantity into electrical voltage / current proportional to the input signal directly by a suitable mechanism.

An electrical transducer must have the following parameters

1) Linearity :- The resulting electrical signal must be a linear function of the input physical parameter which is being measured.

2) Sensitivity :- Electrical output / unit change in the physical parameter. Ex :- V/°c → for temp sensor. High sensitivity is desirable or smallest change in the physical quantity for which the electrical transducer responds.

3) Repeatability :- The closeness in the number of measurements done under same conditions. This ensures reliability of operation

4) Dynamic range :- The operating range of the transducer shall be wide & this helps user to select proper range for measurement

5) Physical size :- The volume & size of transducer should be minimum such that no much disturbance is created when it is used in measurement system.

Advantages of Electrical transducers :-

1) The electrical attenuation & amplification can be done easily to the o/p signals of transducers.

2) Power requirement of transducer is very small.

3) The electrical o/p of transducer can be easily used, transmitted and processed for the purpose of measurement

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4) The effects of friction are minimised.

5) Mass inertia effects are minimised.

6) The o/p can be modified to meet the requirements of the indicating & controlling unit.

7) The signal can be conditioned or mixed to obtain any combination with o/p of similar transducer or control signals

8) The o/p can be indicated & recorded remotely at a distance from the sensing medium

* Electrical transducers can be classified into 2 categories

I Active transducer

→ generates electrical signals in response to physical parameter

→ Do not require external power source for operation

→ self generating devices - operate under energy conversion principle.

Ex:. temp → electrical potential.

Typical examples → piezo electric sensor, photo voltaic cell

II Passive transducer

→ They need external power source for operation & then generates electrical signals.

→ They are not self generating devices. operate under energy controlling principles.

→ They depend on the change in electrical parameter R, L & C

Ex:- strain gauge (ΔR → Pres

thermistor (ΔR → Temp)

* A transducer consists of 2 parts

1. Sensing element
2. Transduction element

1. Sensing element is that part of the transducer which responds to physical phenomenon change. This is also the primary transducer

2 Transduction element is that part which transforms the output of sensing element to electrical output. This is

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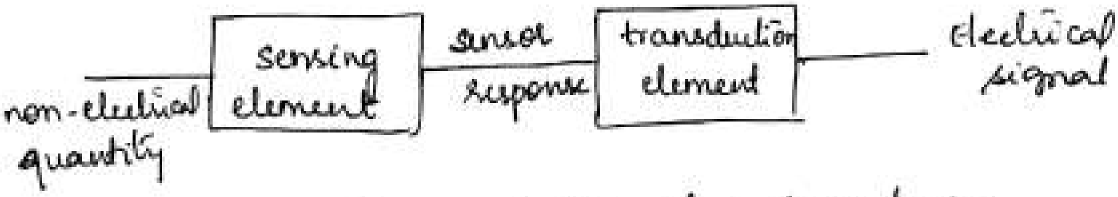
also the secondary transducer.



Block Representation of a transducer

* Depending on the principle employed by transduction element to convert physical phenomena into electrical signals are as follows.

1. Resistive
2. Inductive
3. Capacitive
4. Electromagnetic
5. Piezo electric
6. Photo-emissive
7. Photo-resistive
8. Potentiometric
9. Thermo-electric
10. Frequency generating

* Selecting a transducer :-

The following should be considered while selecting a transducer

1. Operating range : wide enough to maintain range requirements and good resolution.
2. Sensitivity :- Should be high to allow sufficient o/p.
3. Environmental compatability :- Conditions under which the transducer gives satisfactory output. It also includes installation, size, shape, resistance to corrosion, accessibility of the transducer for repairs etc.
4. Accuracy :- should be high. Also repeatability & calibration errors.
5. Usage & ruggedness :- It should be rugged to withstand overloads & Also have overload protection.
6. Electrical parameters :- length & type of cable required, signal to noise ratio when combined with amplifier and freq response limitations.
7. Loading effect :- should be min
8. Cost & availability.
9. Measuring system compatability.
10. High reliability & stability.

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Resistive transducer :-

* Resistive transducers are those in which the resistance changes due to change in physical phenomenon.
* The resistance of metal conductor is given by.

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

ρ → Resistivity of conductor (Ω m)
L → Length of conductor (m)
A → Area of cross-section of conductor (m^2)

* In resistive transducer there is change in resistance when any one of the quantities in the above equation changes such as change in length, change in area of cross-section & change in resistivity.
* Resistive transducers can be used as either primary transducer or secondary transducer.
* change in length of conductor ~~can be~~ which results in change in resistance can ~~be~~ used to measure linear and rotational displacement. This principle is used in ~~translation~~ translational or rotational potentiometers.

Potentiometer (Potentiometric Resistive transducer) :-

→ Resistive potentiometer (Pot) has resistance element along with a sliding contact called as wiper.

→ The resistive element is made up of moulded carbon or carbon film, which is wire wounded. The wire is made up of platinum or —— nickel alloy.

→ The motion of the sliding contact may be translatory or rotational. Some have combination of both. They are known as helipots.

→ In this the mechanical displacement is converted into electrical output.

→ The linear (translatory) or angular (rotational) displacement is applied to sliding contact & then the corresponding change in resistance is converted to voltage or current.

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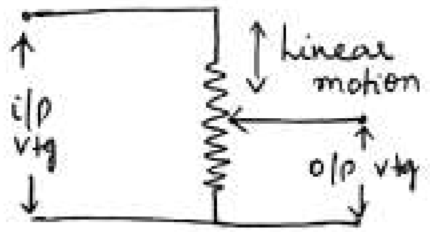
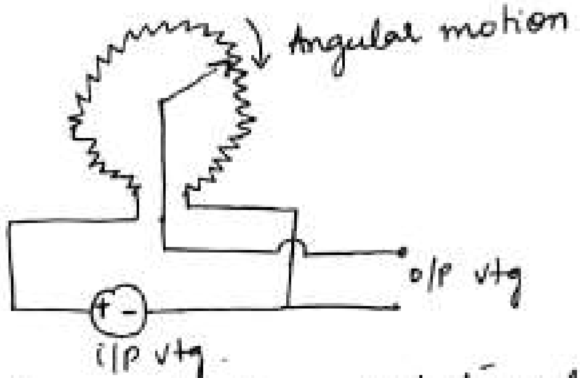
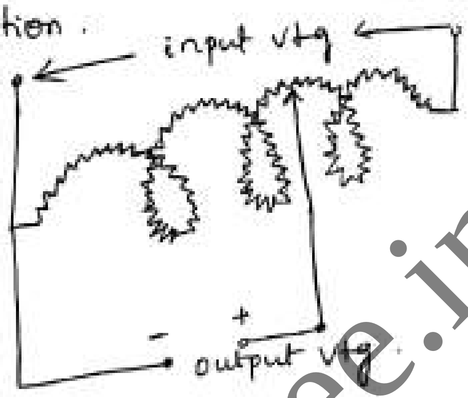
→ The translatory & rotational potentiometers are shown below





→ Helical resistive elements are multi turn rotational devices which can be used to measure either translatory or rotational motion.



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→ It is a passive transducer as it requires external power for its operation. Either ac or dc voltage is required for exciting the pot.

Advantages:-

1) They are low cost.
2) simple to operate & best suitable for with less requirements.
3) Simple in construction
4) Useful for measurement of large amplitudes of displacement.
5) Electrical efficiency is very high & provide sufficient o/p to allow control operations.

Disadvantages:-

1) Large force is required while using linear pot to move the sliding contacts.
2) Sliding contacts can wear out & become misaligned & generate noise.

Resistance Pressure Transducer:-

→ Measurement here is based on change in pressure results in change in resistance in the sensing element.

3(b)

→ Resistance pressure transducers are of 2 types

(1) Electromechanical resistance transducer:

In this input like pressure, stress, position, displacement or mechanical variations are applied to variable resistor

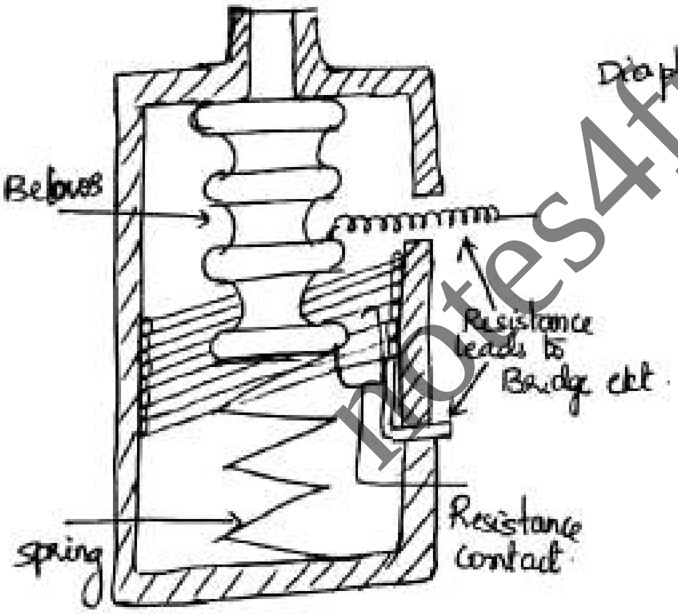
(2) Strain gauge:

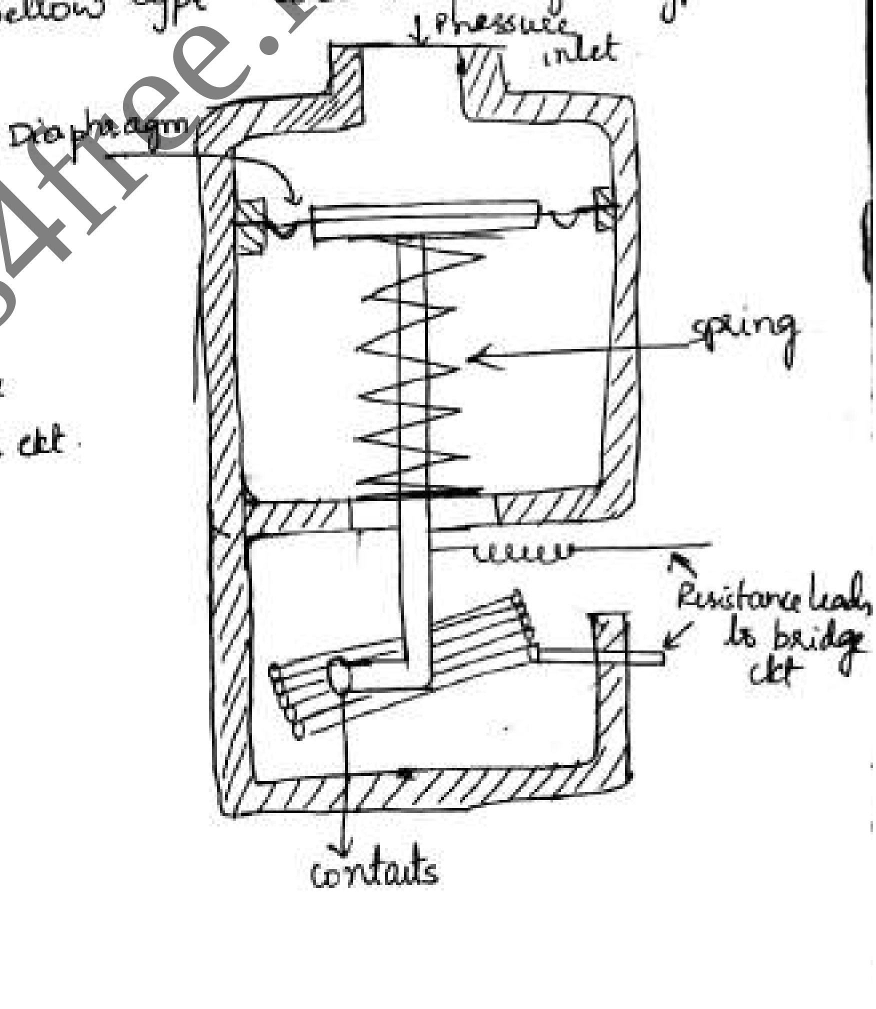
Here stress is directly applied on the resistance.

Fig below shows 2 ways by which pressure acts on sensitive resistance element

Here applied pressure varies resistance & the change in resistance can be measured using bridge configuration.

There are 2 types bellow type and diaphragm type





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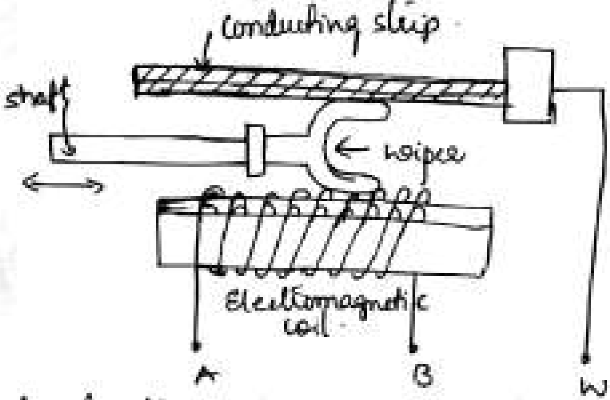
Resistive Position transducer :-

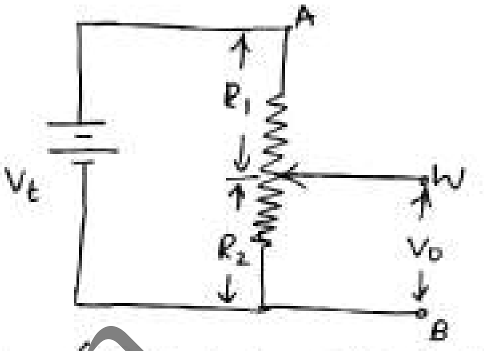
→ The principle is the physical variable under measurement causes change in the resistance in the sensing element.

→ This is useful in industry where the position of the object or the distance of the object moved is to be known.

→ Resistive position transducer is shown below.



(construction of resistive position transducer)



(Method of use) fig (b).

→ The transducer consists of sliding contact or wiper linked with a resistive element. This is linked to the object which is being measured or monitored.

→ Thus the resistance between the slider and one of end of resistance element depends on position of the object.

→ The equivalent ckt is shown in fig (b)

→ The output voltage Vo is a fraction of Vt, depending on the position of the wiper.

i.e
$$V_o = \frac{V_t \cdot R_2}{R_1+R_2}$$

&
$$\frac{V_o}{V_t} = \frac{R_2}{R_1+R_2}.$$

→ Thus Vo is proportional to R₂ ie wiper position.

~~Note~~

Ex:- A displacement transducer with a shaft stroke of 3.0 in. is applied to the ckt shown. The total resistance of pot is 5kΩ. The applied vtg Vt is 5V when the wiper is 0.9 in. from B, what is the value of the output vtg?

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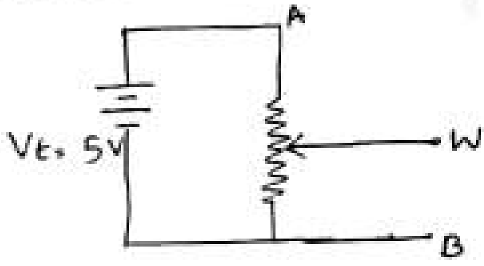
→ We have



$$\frac{V_0}{V_t} = \frac{R_2}{R_1+R_2}$$

$$R_2 = \frac{V_0}{V_t} R_1+R_2$$

$$R_2 = \frac{\overset{0.3}{\cancel{0.9}}\text{ in}}{\cancel{3}\text{ in}} 5k = 1500\Omega \qquad \boxed{R_2 = 1500\Omega}$$

Now

$$V_0 = \frac{R_2}{R_1+R_2} \times V_t$$

$$= \frac{1500}{5k} \times 5$$

$$\boxed{V_0 = 1.5V}$$

<u>Ex:-</u> A resistive position transducer with a resistance of 5kΩ & a shaft stroke of 8 cm is applied with voltage of 5V. when wiper is 3 cm from the reference, what is the value of the o/p vtg?

→ $$R_2 = \frac{V_0}{V_t} R_1+R_2$$

$$R_2 = \frac{3}{8} \times 5k = 1875\Omega \qquad \boxed{R_2 = 1875\Omega}$$

$$V_{o\cancel{ut}} = \frac{R_2}{R_1+R_2} \times V_t = \frac{1875 \times \cancel{5}}{\cancel{5}k} = 1.875V$$

$$\boxed{V_0 = 1.875V}$$

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Strain gauges:-

* Is a passive transducer, which causes change in resistance due to strain produced by a force on the wires.

stress → force/unit area

strain → elongation ~~or~~ compression /unit length.

→ stress & strain can be easily measured by using variable resistance transducer. These transducers are called as strain gauges.

→ If a metal conductor is stretched or compressed,

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the length & diameter of the conductor chang
also the resistivity of conductor changes.
This effect is called as piezo resistive effect.

→ Thus strain gauges are also known as piezo resistive gauges.

→ Many detectors uses strain gauge as secondary transducer.
Ex:- load cells, torque meter, pressure gauges etc

The types of strain gauges are.
1. Wire strain gauges.
2. Foil strain gauges.
3 semiconductor strain gauges.

Resistance Wire gauge:-
Are used in 2 basic forms
1. Unbonded type & 2. Bonded type.

Unbonded Resistance Wire strain gauge:-

→ Unbonded strain gauge consists of wire stretched between 2 points in an insulating medium such as air.

→ Wires are copper nickel, chrome nickle or a nickle iron alloys.

→ Wires are kept under tension so that there is no sag & no free vibration.

→ The flexture element is connected thr' a rod to ~~diaphragm~~ diaphragm which is used for sensing of pressure.

→ The resistance wires are connected in a wheatstone's bridge.

→ Without application of any load, the resistance & strains of all arms are nominally equal & causes the bridge o/p as '0'.

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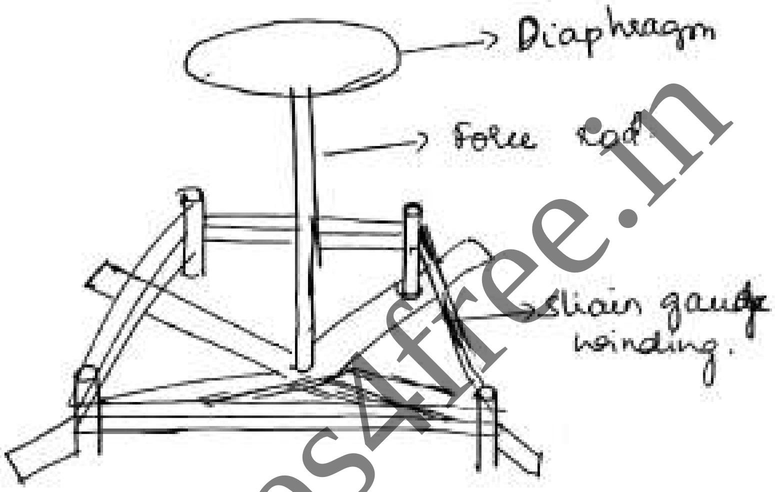
→ with application of pressure, produces change, small displacement.

→ The displacement increases tension in 2 wires, & decreases tension in other ~~to~~ 2. This causes change in the resistance resulting in unbalancing the bridge.

→ The unbalance ~~causes~~ produces the output voltage which is proportional to the input displacement and hence to the applied pressure.

→ Displacement of the order 50μm can be detected with these strain gauges.



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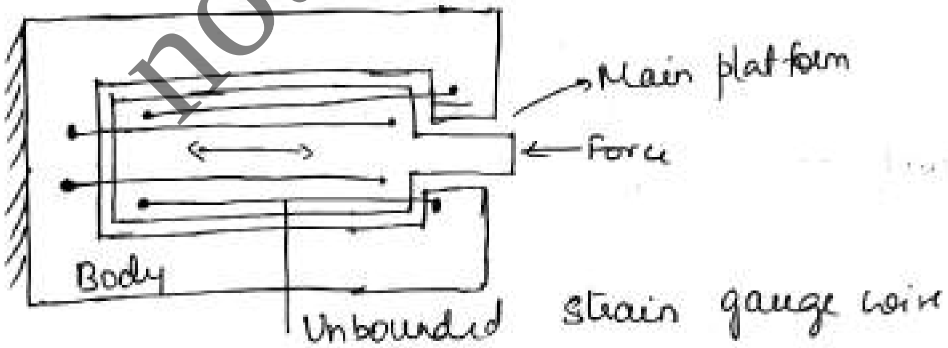

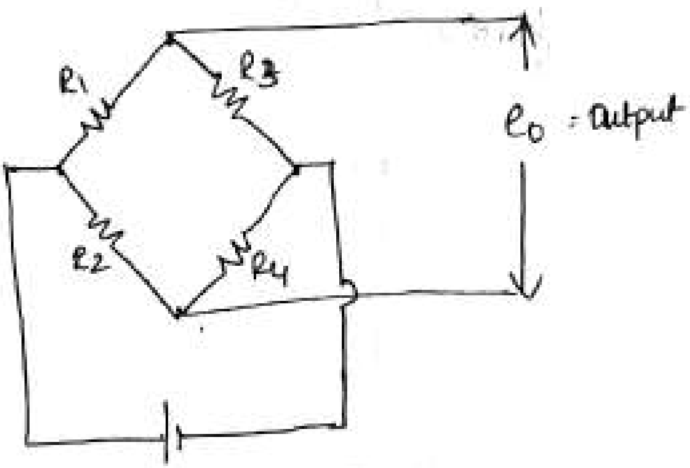

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Bonded Resistance wire strain gauge:-

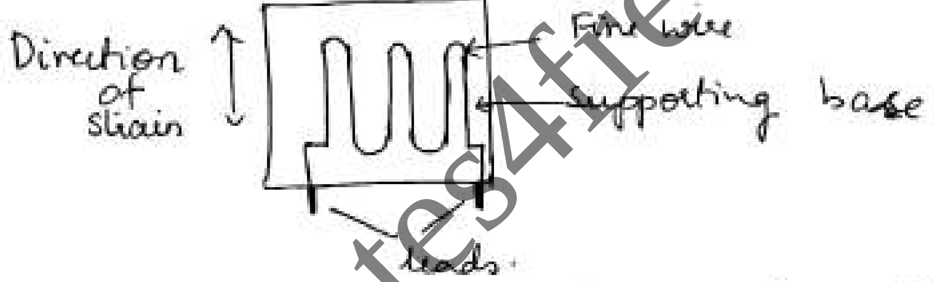
→ In this the gauges are directly bonded or pasted on the surface of structure under study. Thus they are called as bonded strain gauges.

→ A fine wire resistance of 25 μm in diameter is looped back & forth & is placed between two carrier bases which undergoes stress.

→ The resistance wire is bent again & again to increase the length the wire to permit uniform distribution of stress

→ The carrier base may be thin sheet of paper, bakelite or teflon.

→ The wire is covered with thin material on top to protect from damages.



→ Leads are provided for connecting the strain gauge to measuring instrument.

→ When the structure is subjected to tensile stress or force. The structure will change the dimension. As the strain gauge is bonded to the structure it will also undergo change in length & cross sectional area.
ie length ↑ & cross sectional area ↓.
The combined effect is that there is an ↑ in the resistance.

→ Thus here 2 physical parameters are important one is change in gauge resistance & other is change in length.

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→ With this we can define one more parameter called the "gauge factor"

→ ie measurement of strain sensitivity of material to strain is called as gauge factor. It is also the ratio of chang in resistance to change in the length.

→ Gauge factor is denoted as → 'K'

or $K = \frac{\Delta R/R}{\Delta l/l}$

ΔR → change in initial resistance in Ω's.
Δl → change in length in m.
R → Initial resistance in Ω
l → initial length in m.

* Also strain is defined as change in length divided by original length.

∴ $Strain = \sigma = \Delta l/l$

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* Now gauge factor can be written as

$$K = \frac{\Delta R/R}{\Delta l/l} = \frac{\Delta R/R}{\sigma} \quad \Big| \ \Delta l/l = \sigma$$

σ → strain in lateral direction.

* The resistance of a conductor of uniform cross section is given by

$$R = \rho \frac{length}{Area}$$

length = l
Area = πr^2 (O^{cle})

$$\therefore \ R = \rho \frac{l}{\pi r^2}$$

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But $r = d/2$

$$\therefore \quad R = \frac{\rho l}{\pi d^2/4} = \frac{\rho l}{\pi/4 \, d^2}$$

$$R = \rho \frac{l}{\pi/4 d^2}$$

$\rho \rightarrow$ specific resistance of conductor.

$l \rightarrow$ length of conductor

$d \rightarrow$ diameter of conductor.

→ When conductor is stressed → length ↑ by Δl &

↓ by Δd in diameter.

∴ Now the resistance of conductor is written as.

$$R_s = \rho \frac{l + \Delta l}{\pi/4 \, (d - \Delta d)^2}$$

$$R_s = \rho \frac{l + \Delta l}{\pi/4 \; d^2 + \Delta d^2 - 2 d \Delta d}$$

Since Δd is small and Δd^2 can be neglected

$$\therefore R_s = \frac{\rho(l + \Delta l)}{\pi/4 \, (d^2 - 2d\Delta d)}$$

$$= \frac{\rho\,(l + \Delta l)}{\pi/4 \; d^2 \left(1 - \frac{2\Delta d}{d}\right)}$$

$$R_s = \frac{\rho l \,(1 + \Delta l/l)}{\pi/4 \; d^2 \left(1 - \frac{2\Delta d}{d}\right)} \quad \text{— ①}$$

We have Poisson's ratio 'μ' defined as the ratio of strain in lateral direction to strain in the axial direction.

$$\mu = \frac{\Delta d / d}{\Delta l / l}$$

$$\therefore \Delta d/d = \mu \frac{\Delta l}{l}$$

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substituting $\Delta d/d$ in eqⁿ ① we get

$$R_s = \frac{\rho l\,(1+\Delta l/l)}{\pi/4\, d^2\,(1 - 2\mu\,\frac{\Delta l}{l})} \quad - ②$$

÷ & × ly by $\left(1+2\mu\frac{\Delta l}{l}\right)$ in eqⁿ ②.

$$R_s = \frac{\rho l(1+\Delta l/l)}{\pi/4\, d^2(1-2\mu\frac{\Delta l}{l})}\,\frac{(1+2\mu\,\Delta l/l)}{(1+2\mu\,\Delta l/l)}$$

$$= \frac{\rho l}{\pi/4 d^2}\;\frac{1+2\mu\,\Delta l/l + \Delta l/l + 2\mu(\Delta l/l)^2}{1-4\mu^2(\Delta l/l)^2}$$

since Δl is small, & neglecting higher powers of Δl

$$R_s = \frac{\rho l}{\pi/4 d^2}\left(1+2\mu\,\Delta l/l + \Delta l/l\right)$$

$$= \frac{\rho l}{\pi/4 d^2}\left[1+(2\mu+1)\Delta l/l\right].$$

$$R_s = \frac{\rho l}{\pi/4\, d^2} + (1+2\mu)\frac{\Delta l}{l}\;\frac{\rho l}{\pi/4 d^2}$$

we have expression $R = \frac{\rho l}{\pi/4 d^2}$

∴ R_s can be written as:

$$R_s = R + \Delta R$$

where $R = \frac{\rho l}{\pi/4 d^2}$ & $\Delta R = \frac{\rho l}{\pi/4 d^2}(1+2\mu)\frac{\Delta l}{l}$

Gauge factor k is given by.

$$k = \frac{\Delta R/R}{\Delta l/l} = \frac{\left[\frac{\cancel{\rho l}(1+2\mu)\Delta l/l}{\cancel{\pi/4 d^2}}\right]\Big/\cancel{\rho l/\pi/4 d^2}}{\Delta l/l}$$

$$k = \frac{(1+2\mu)\cancel{\Delta l/l}}{\cancel{\Delta l/l}} \qquad \therefore \boxed{k = 1+2\mu}$$

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Ex:- Resistance strain gauge with gauge factor of 2 is cemented to a steel member, which is subjected to a strain of 1×10^{-6}. If the original resistance value of gauge is 130 Ω, calculate the change in resistance

→ $K = 2$

$\sigma = \text{strain} = \Delta l / l = 1 \times 10^{-6}$.

$R = 130\ \Omega$

$\Delta R = ?$

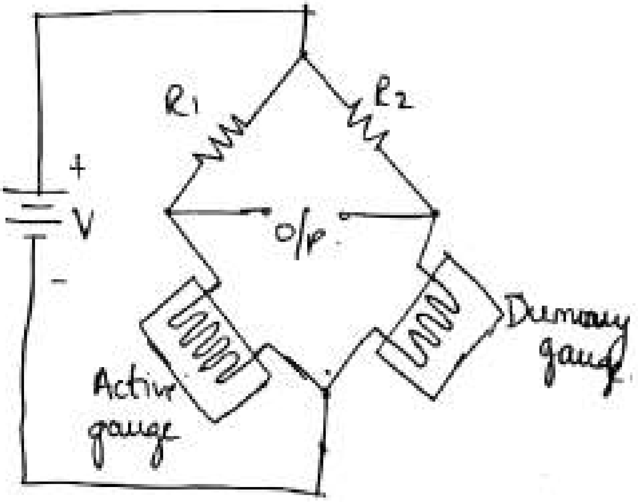
~~$K = 1+2\mu$~~ $K = \dfrac{\Delta R / R}{\Delta l / l}$.

$$2 = \frac{\Delta R / 130}{1 \times 10^{-6}}$$

$\Delta R = 2 \times 1 \times 10^{-6} \times 130$.

$$\boxed{\Delta R = 260 \times 10^{-6}\ \Omega}$$

* Strain gauge is normally used in bridge configuration



- → gauge is in one arm
- → bridge is ac / dc excited
- → One active gauge which undergoes strain, dummy gauge does not undergoes strain but it is used to balance the brige.
- → Gauges are sensitive to change in temp & stress. Under both condition it will change the bridge to unbalanced condition
- → The active gaug will produce an o/p proportional to the strain.

⇒ Dummy gauge → Used for compensating as both the gauges are placed in the same environmental conditions.

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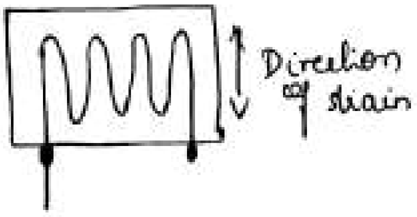
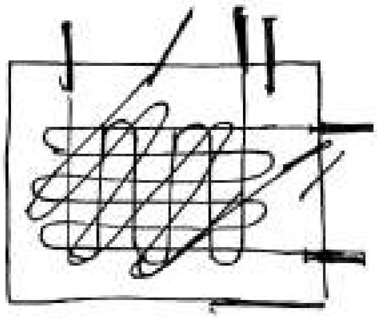
Types of Wire strain gauges:-

1. Grid type
2. Rossette type
3. Torque type
4. Helical type.

1)

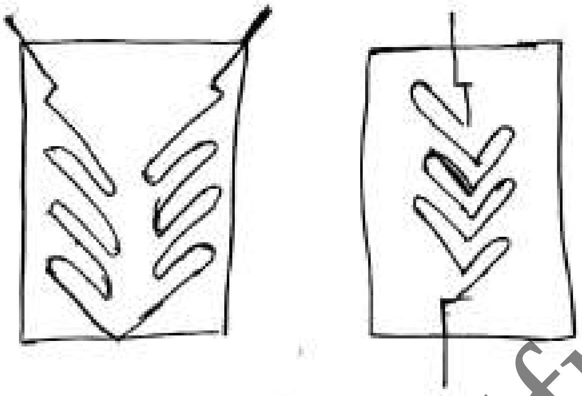


2)



→ 3 element gauge
→ angle b/w any 2 longitudinal gauge axes is 45°

3)



Torque type gauge.

4) Helical gauge

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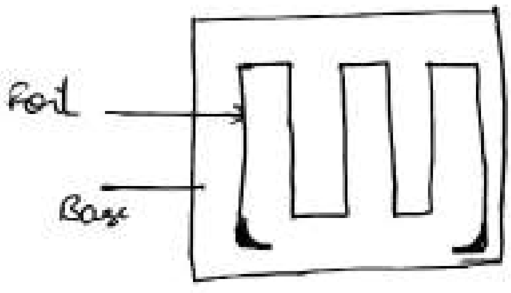
To obtain good results the desirable char of wire strain gauge.

- → high gauge factor. (↑ k → large change in R for strain).
- → Resistance of strain gauge should be high (reduces variation)
- → Gauges should have low ~~temp~~ resistive temp coeff.
- → Good freq response → used in dynamic range.
- → Linear char
- → Leads must be made of materials that have low resistance temp coeff & stable resistivity.
- → Do not have hysteresis

Foil strain gauge:-

- → It is an extension of wire strain gauge & the strain is sensed with the help of metal foil.
- → Metals used are nichrome, constantan, isoelastic, Ni & Platanium.
- → Foil have greater dissipation capacity than wire wound because of larger surface area for same volume. Hence can be used for higher operating temp range.
- → They have similar char & also gauge factor is same.
- → Advantage → The foil type gauge transducer can be fabricated on large scale & in any shape.
- → The etched foil strain gauge can be made thinner when compared to coil wire strain gauge. This helps in mounting etched foil in more remote & restricted places.



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Semiconductor strain gauge :-

→ They are
→ When a strain gauge of high gauge factor is needed then semiconductor strain gauges can be used as their gauge factor are 50 times larger than wire strain gauges.

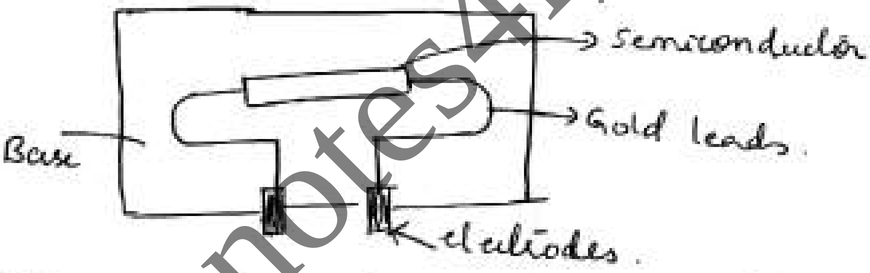
→ The semiconductor strain gauges are based on principle of piezo-resistive effect. ie R is change due to change in resistivity. (In other types it is change in dimension).

→ Resistive material used are Ge & Si

→ The semiconductor filament of 0.05mm thickness is bonded on suitable insulating substrates like teflon

→ Gold leads are used for contacts

→ The semiconductor strain gauge is shown in fig



→ With simple temp compensation method, the semiconductor strain gauge can be used to measure small values of strain ie µstrains.

→ The semiconductor strain gauges have low hysteresis

→ The semiconductor strain gauges is a stable & practical device for operating & measuring small strains ~~from~~ of range 0.1 – 500 microstrains.

Advantages :-

→ Have high gauge factor

→ low hysteresis / Hysteresis char are excellent.

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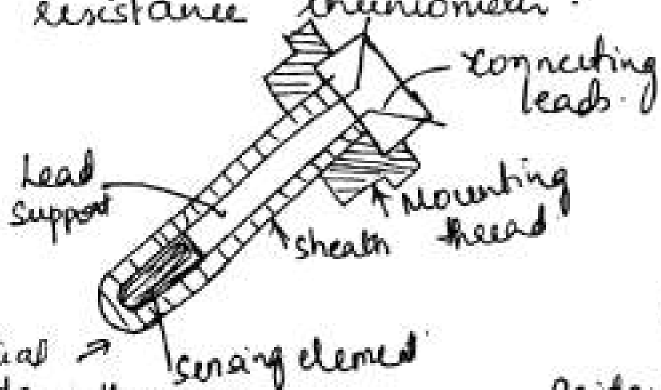
→ Freq response is good
→ They can be of very small size → ranging from 0.7 to 7 mm

Disadvantages:-

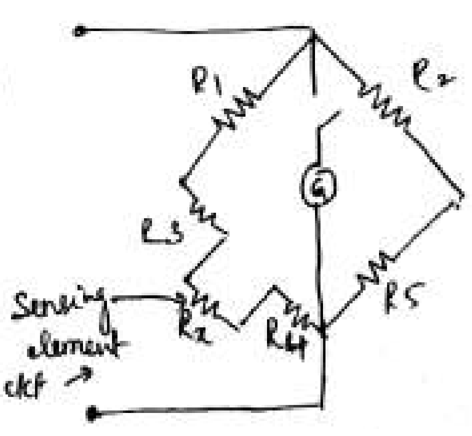
→ Sensitive to temp
→ Linearity is poor
→ More expensive.

Resistance thermometer:-

→ When a conductor is considered, its change in resistance due to change in temp is used for measuring ~~temp~~ ie electrical resistance is used to measure temp.
→ The sensing element in resistance thermometer is main part & its char determines sensitivity & operating temp range of transducer.
→ The sensing element is chosen such that it is very sensitive to temp ie large change in R to change in temp.
→ Also the resistance & its temp coeffs should not undergo permanent change with use or age.
→ The stability of it should be considered.
→ There should be linearity
→ Pt, Ni & Cu are the common materials used for temp measurement.
→ The response to change in temp is very much necessary for measurement.
→ In Pt, the resistivity ↑ less rapidly at high temp & hence it is the most common used material for resistance thermometer.
→



Industrial → Pt resistance thermometer



Bridge ckt →

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→ Resistance change due to change in temp is detected by bridge configuration.

→ Rs is the resistance of sensing element having high temp coefficient. R1, R2 & R5 are constant resistances under normal temp changes.

→ The balance condition of bridge is

$$R_1 R_5 = R_2 R_s.$$

$$\frac{R_1}{R_2} = \frac{R_s}{R_5}$$

→ when Rs senses temp, there is current flow in indicator & R3 & R4 is the lead resistance of the resistance thermometer

$$\therefore \quad \frac{R_1}{R_2} = \frac{R_3 + R_s + R_4}{R_5}$$

→ The galvanometer can be calibrated to give suitable temp scale.

Advantages of Resistance thermometer:-

→ Accurate measurement.

→ With o/p the indicators, recorders or controllers can be operated.

→ Temp sensitive element can be easily installed & replaced.

→ flexibility with regard to choice of measuring equipment.

→ Best suited for remote indication.

→ They have wide working range without loss of accuracy

→ Response time is of the order of 2 - 10s.

→ No temp compensation ckty required.

→ stability of performance over long periods of time.

Limitations of Resistance thermometer:-

→ High cost.

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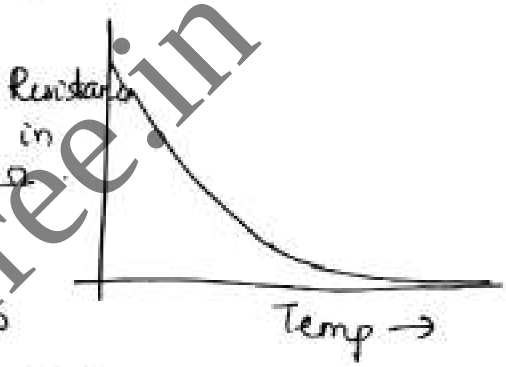
- → Possibility of self-healing.
- → large size
- → Need bridge ckt & power source.

Thermistor:-

- → Thermally sensitive resistor are non-metallic resistors
- → They have -ve temp co-efficients. ie as temp ↑ the R ↓. (At room temp ~~with~~ + the resistance ranges from 100Ω to 10MΩ)
- → They are suitable for use up to 800°C.
- → They are highly temp sensitive which make them useful for precision temp measurement, control & compensation.
- → The thermistors are in the form of beads & composed of sintered mixture of metallic oxides like manganese, Ni, Co, Fe & Ur.



- → The various configuration of thermistor are.

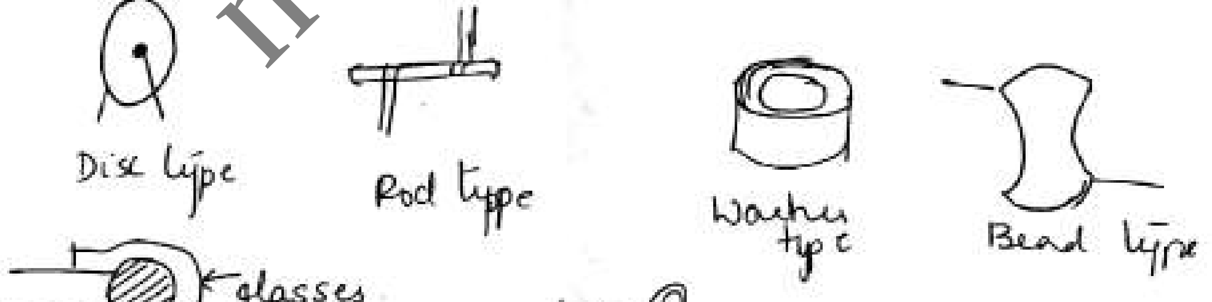


fig ⓐ.

- → with greater power requirements, thermistors are available diff other forms As shown above in fig ⓐ
- → Also thermistors can be connected in series/parallel in application ~~which uses~~ with increased power handling capability.
- → They are chemically stable & can be used in

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nuclear environments.

→ They are non-linear devices.

Advantages:-

→ Small size & low cost.

→ fast response over narrow temp range.

→ high sensitivity in negative temp coefficient region.

→ Signal conditioning ckt required is simple.

Limitation:

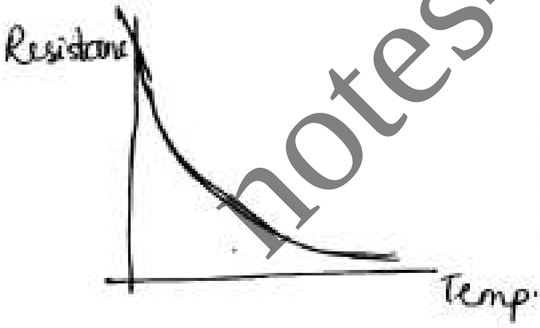
→ The resistance vs temp char is highly non linear

→ Unsuitable for wide temp range.

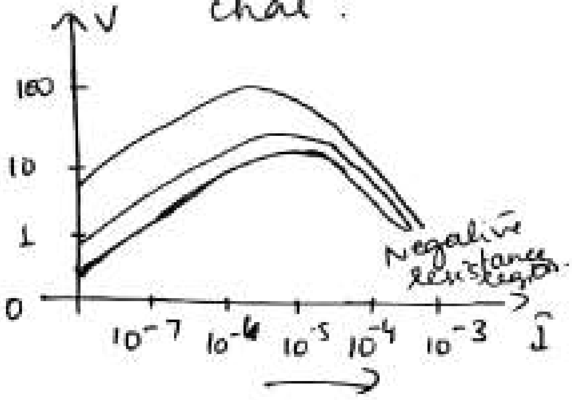
→ Because of high resistance of thermistor, shielded cables have to be used to min interference.

Char of thermistor:

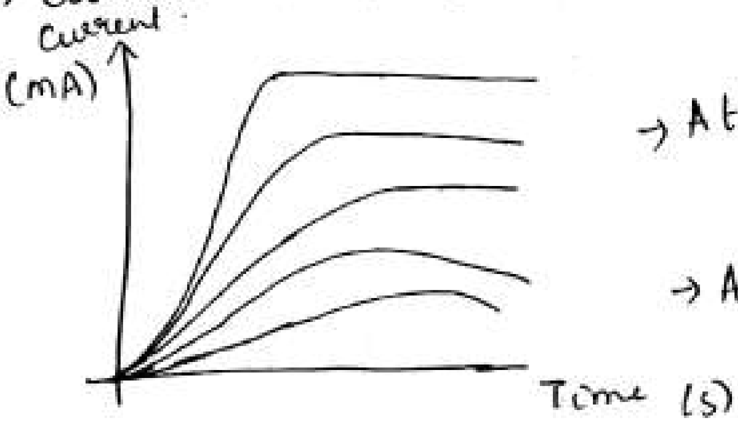
1. Resistance temp char:



2) Voltage current char:



3) Current time char.



→ At low vtgs, thermistor takes long time to reach peak current.

→ As vtg level ↑, the time taken to reach peak current ↓.

→ This is current time char.

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Inductive transducer-

→ It is an electromechanical transducer that converts physical motion into change in inductance

→ It works on either the variation of self inductance or mutual inductance.

→ The inductive transducer utilizes the electrical generator principle of → when a conductor is moved with in magnetic field it induces voltage and in the generator. This change in emf is used in the measurement.

→ These inductive transducers are mainly used for displacement measurement. When there is variation in displacement, it causes variations in either of the 3 following parameters

1. No of turns
2. Geometric configuration
3. permeability of magnetic material.

→ When an general inductive transducer is considered, it has N turns & Reluctance R. When current i passes thr' it, the flux ϕ is given by

$$\phi = \frac{Ni}{R}$$

differentiating w.r.t 't'

$$\frac{d\phi}{dt} = \frac{N}{R}\frac{di}{dt} - \frac{Ni}{R^2}\frac{dR}{dt}$$

If current varies very rapidly, then

$$\frac{d\phi}{dt} = \frac{N}{R}\frac{di}{dt}$$

The emf induced in the coil is given by

$$e = N \times \frac{d\phi}{dt}.$$

$$e = N \cdot \frac{N}{R}\frac{di}{dt} \Longrightarrow e = \frac{N^2}{R}\frac{di}{dt}.$$

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And the self inductance is given by

$$L = \frac{e}{di/dt} = \frac{N^2/R \, \cancel{di/dt}}{\cancel{di/dt}}$$

$$L = \frac{N^2}{R}$$

→ Thus the o/p of inductive transducer can either be in the form of change in voltage or change in inductance.

<u>Transducer based on self Inductance (L)</u>:-

Change in self inductance with no of Turns:-

→ The self inductance of an inductor is given by

$$L = \frac{N^2}{R}$$

where R → Reluctance of coil (A/Wb)
N → No of turns

But Reluctance is given by

$$R = \frac{l}{\mu a}$$

$$L = \frac{N^2 \mu a}{l} \quad \text{—} ①$$

μ → permeability of core (H/m)
l → length of magnetic ckt
a → Area of magnetic ckt thr' flux (m^2).

Thus the self inductance can be varied due to N, μ & a (geometry)

~~change in self inductance of an inductor is given by~~

Change in self inductance with number of turns

→ with Eqn ① as $L \propto N^2$ This property is used to measure linear as well as angular displacement

→ as N → no of turns changes, the value of L changes & ~~thds~~ thus changes the o/p voltages.

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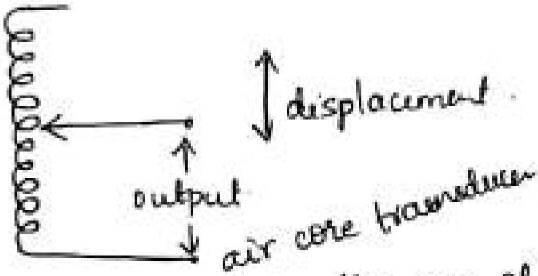
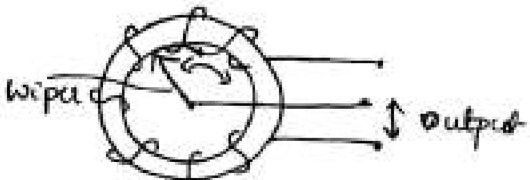
→ Fig shows air cored & iron cored coil transducer for the measurement of linear and angular displacement respectively.



air core transducer



iron cored coil transducer

→ In both cases, as the no of turns are changed, this changes self inductance & this changes O/P also.

change in self inductance due to change in permeability :-

→ Fig shows inductive transducer which works on change in self inductance due to variation in permeability.

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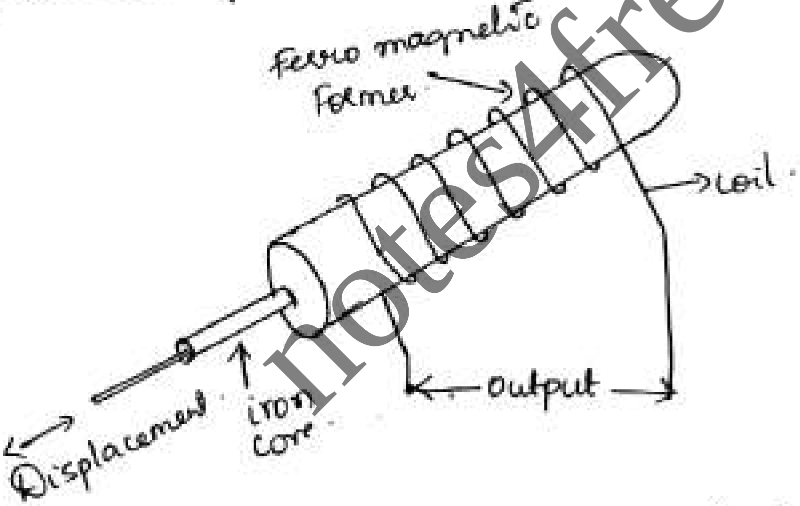


→ This transducer is used to measure displacement

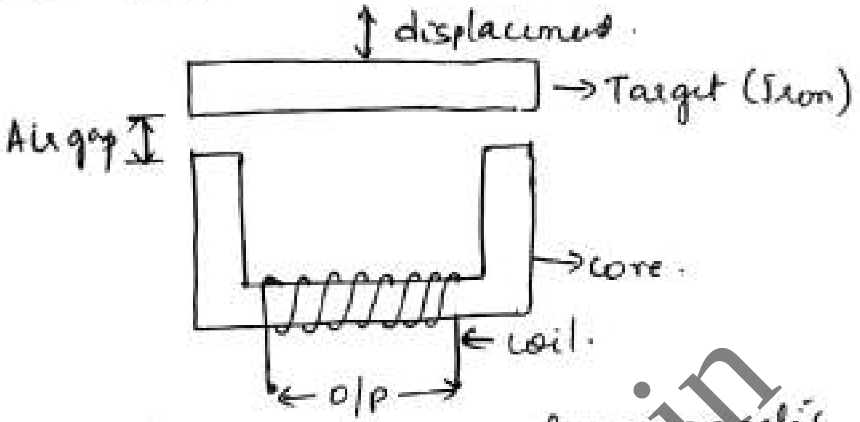
→ The displacement to be measured is applied to the rod. As the rod moves in and out, the effective permeability ↑ and ↓ respectively. This changes the output voltage.

→ These transducers are used in current sensitive ckts.

Change in self inductance ~~due~~ with variation in Reluctance of magnetic ckt :-

→ With $L = \frac{N^2}{R}$, the self inductance is inversely proportional to reluctance 'R'

→ Variable reluctance transducer is shown in fig.



→ It has coil wound on ferromagnetic core.

→ The displacement to be measured is applied to target.

→ The target & core have no physical contact & they are seperated by an airgap [as shown in fig].

→ The reluctance of magnetic path is determined by the size of air gap. The inductance of coils depends on reluctance

→ Thus the self inductance is

$$L = \frac{N^2}{R_g + R_i}$$

N → No of turns.
R_g → Reluctance of air gap.
R_i → Reluctance of iron path.

But R_i is negligible than R_g ;

$$\therefore L = \frac{N^2}{R_g}$$

→ The Reluctance of air gap is given by

$$R_g = \frac{l_g}{\mu_0 A_g}$$

l_g → length of air gap
μ_0 → permeability
A_g → area of the flux path through air.

$$\therefore L = \frac{N^2 \mu_0 A_g}{l_g}$$

→ L → self inductance is inversely proportional to

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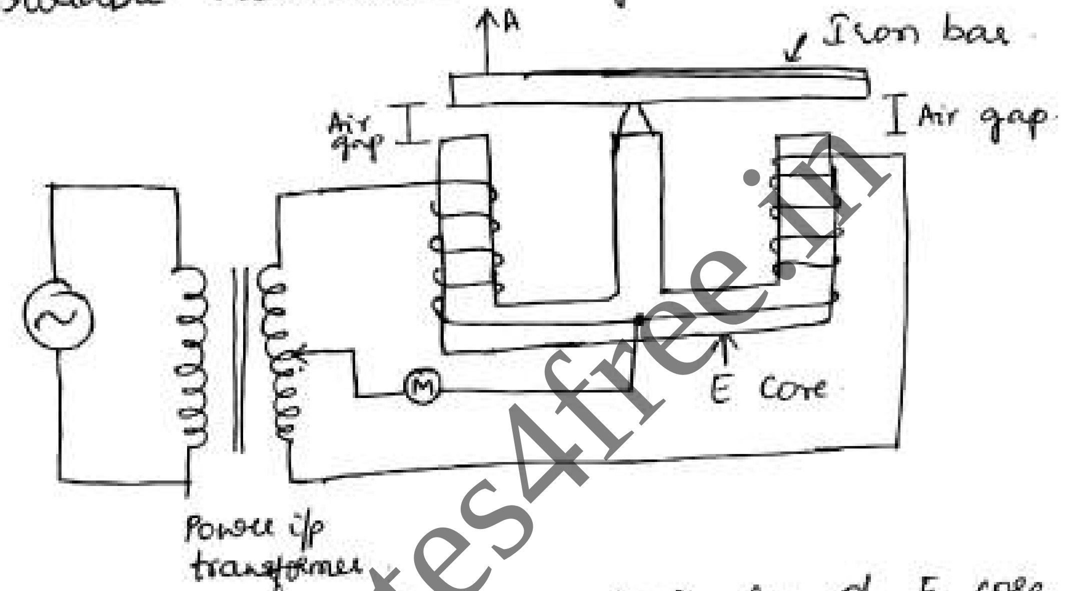
length of air gap.

→ when the target is near the core, the length of air gap is small & the self inductance is large.
And when target is away, the length of air gap is large & the self inductance is small.

→ Since displacement is the parameter, which changes the length of air gap, the self inductance is a function of displacement.

Variable reluctance bridge ckt is shown



→ Coil is wound on outside leg of E core & iron bar is pivoted on the centre leg.

→ Moving membrane is attached to one end of iron bar and causes iron bar to wobble, which varies air gap.

→ Bridge has 2 transducer coil & it is balanced only when inductance of them are equal ie when iron bar is in exact horizontal position & air gap are equal.

→ when iron bar at point A moves, this alters the air gap & bridge is unbalanced. The unbalanced is proportional to change in inductance which in turn is proportional to displacement.

→ The variation in inductance with varying air gap are non-linear & so is the o/p.

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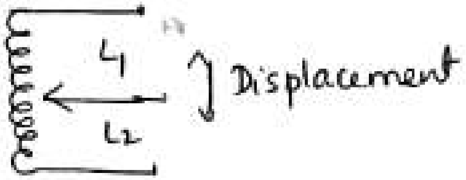
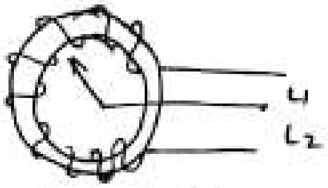
Differential output transducer :-

same as that of change in self inductance principle.





* These transducers can provide 2 O/PS.
  - → One is the inductance
  - → Other is decrease in inductance.
* The succedding n/w or ckt can be used to measure the difference b/w these O/Ps. this is called as differential O/P.

Advantages:

→ sensitivity and accuracy is increased.
→ O/P is less effected by external magnetic signal.
→ Variation due to temperature variation is reduced

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LVDT :-

→ Linear Variable Differential Transformer/Transducer

→ It is a passive transducer

→ It is a transducer which is used to measure displacement, which can be linear or angular.

- With the help of displacement transducer, other quantities such as force, stress, pressure can be found.
- With displacement transducer, magnitude of measurement ranges from μm to few cms.
- LVDT is a type of displacement transducer, which uses variable inductance for measurement. i.e the inductance displacement causes variation in the inductance due to either by varying self inductance or by mutual inductance
- LVDT is most suitable position measuring device

construction :-

→ The transformer consists of single primary winding P1 & 2 secondary winding S1 & S2 wound on a hollow cylinder.

→ The primary winding is connected to an a c source. (ranges from 50Hz to 20kHz) The secondary winding have equal no of turn and are identically placed on either side of primary winding in series opposition so that emf's induced in the coil oppose each other.

→ A moveable soft iron core slides within the hollow former. Due to the movement of core it affects the magnetic coupling between the primary and the 2 secondaries.

→ Fig shows the construction.

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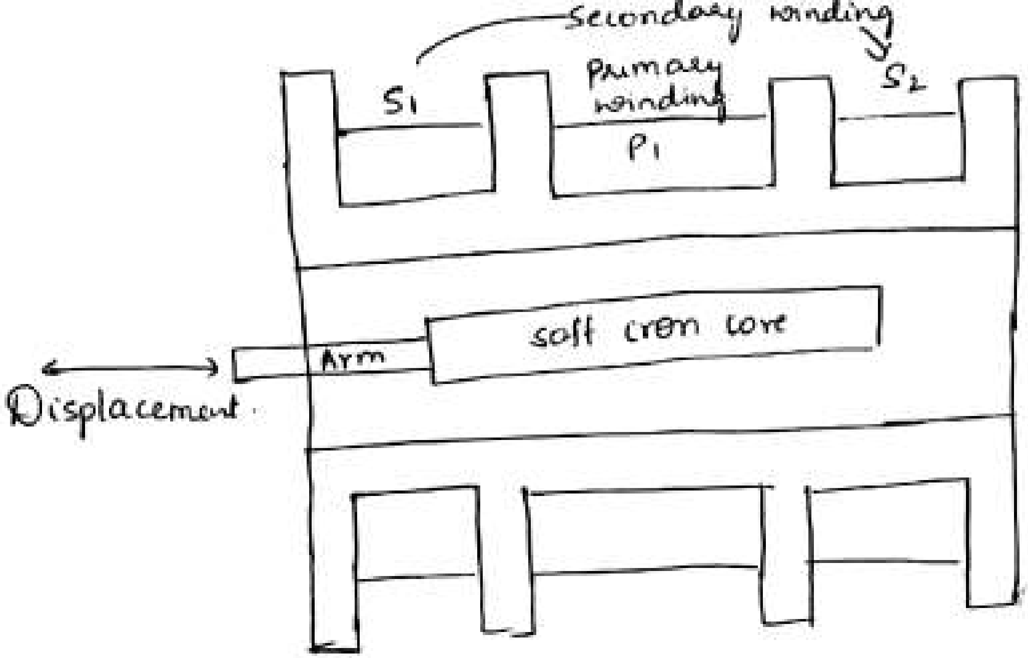
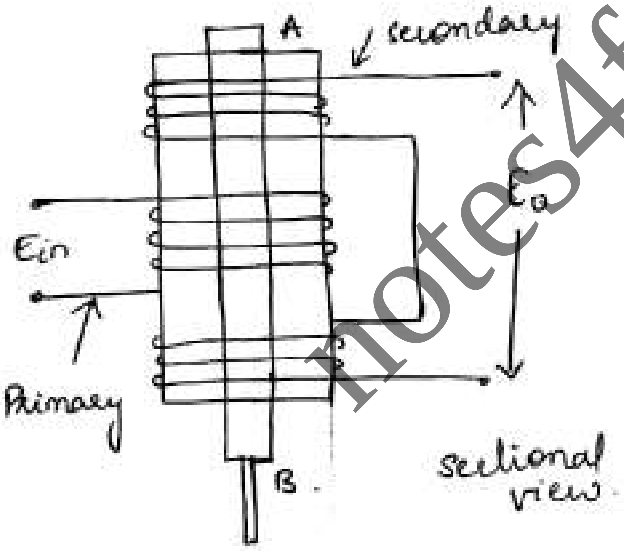
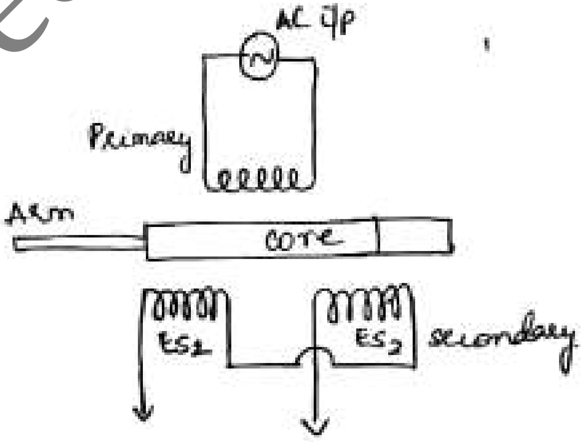


→ The displacement to be measured is applied to the arm attached to the core.

→ The below fig shows the secondary windings connections for differential o/p





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→ when the core is in its null position, equal vtg are induced at the 2 secondary windings.

→ Let E_{S1} represents the o/p vtg of secondary winding S_1 & E_{S2} o/p vtg of secondary winding S_2.

→ Since there are 2 o/ps in order to convert it into single o/p, it is connected in series opposition. Thus the o/p vtg is the difference of the two voltages ie $E_0 = E_{S1} - E_{S2}$

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→ when core is in null position, flux induced due to both windings of secondary are same as hence the O/P is same. ie $Es_1 = Es_2$

$$\therefore\ E_0 = Es_1 \sim Es_2 = \underline{0} \qquad E_0 = 0 \text{ at null position}$$

→ When core is moved to left of null position, more flux is induced with S_1 & less with S_2. Thus Es_1 is greater than Es_2. The magnitude of E_0 is

$$E_0 = Es_1 - Es_2$$

This movement represents a positive value & hence phase angle $\phi = 0$.

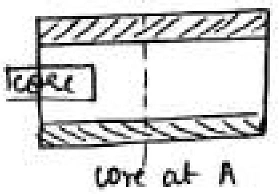
* When there is core movement from null position. there will be difference in voltag ~~but~~ and 180° out of phase with the voltage from the source

→ When core is move to the right of null position, more flux is induced with S_2 & less with S_1. Thus Es_2 is greater than Es_1. The magnitude of output voltage E_0 will be

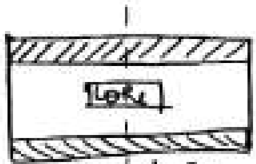
$$E_0 = Es_2 - Es_1$$

This movement represents a negative value & S_2 is 180° out of phase with voltage which is obtained when core is moved to the left.

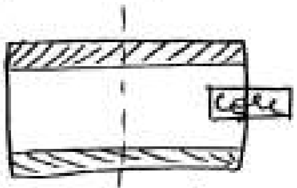
→ Fig below shows core at different position



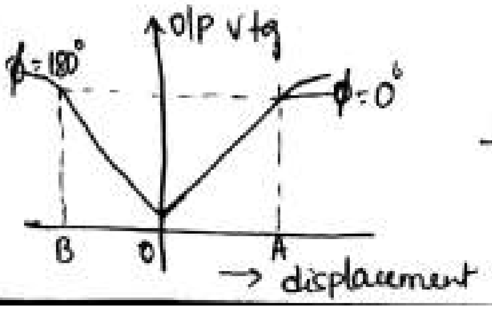
core at A

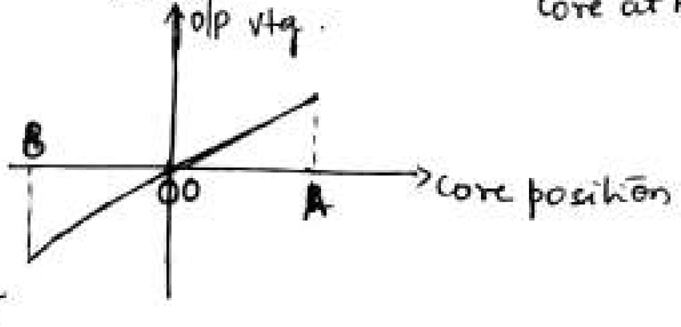


core at O



core at B





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Advantages:-

1. Linearity :- O/P vtg is pratically linear for displacement up to 5mm.
2. Infinite resolution :- The change in O/P vtg is continuous. The resolution depends on test equipment than on transducer.
3. High O/P :- It gives high output.
4. High sensitivity :- It has high sensitivity as high as 40V/mm
5. Ruggedness: They can withstand high degree of vibration & shock
6. Less friction :- Since there are no slidings contacts friction is less.
7. Low hysteresis :- Has low hysteresis & repeatability is excellent.
8. Low power consumption :- Consumes less than 1W of power.

Disadvantages:-

1. Large displacements are required for appreciable differential O/P.
2. Sensitive to stray magnetic field. (can be avoided with protections ckts).
3. They are temp sensitive
4. Dynamic response is limited by mass of core.

Ex:- An LVDT has following data.

i/p = 6.3V, O/P = 5.2V, range = ±0.5 in.

(i) Calculate the O/P vtg vs core position for a core movement going from +0.45 in. to -0.30 in.

(ii) O/P vtg when core is at -0.25 in. from the centre.

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→ Given

0.5 in displacement gives 5.2V

∴ 0.45 in displacement gives.

$$\frac{0.45\text{ in} \times 5.2\text{V}}{0.5\text{in}} = \underline{\underline{4.68\text{ V}}}.$$

111ly −0.3 in displacement gives.

$$\frac{-0.3 \times -5.2}{-0.5} = \underline{\underline{-3.12\text{V}}}$$

(ii) For −0.25in movement it gives

$$\frac{-0.25 \times -5.2}{-0.5} = \underline{\underline{-2.6\text{V}}}$$

Ex:- An LVDT with secondary voltage of 5V has a range of ±100mm, Find

(1) O/P voltage when core is −7.5mm from centre.

(2) Core displacement from centre when output is 3V &e −1V.

→ The LVDT is operated in linear range. As core displacement is from centre and is either side of centre, the linear operating range is twice the full scale displacement. Such a range is called nominal linear range of LVDT.

∴ The nominal linear range = 2×100mm = 200mm.

In linear range, Vout = m Xin

Vout → O/P vtg of LVDT

m → slope of straight line

Xin → core displacement from centre.

Given Vout = 5V , xin = 200mm

$$\therefore m = \frac{V_{out}}{x_{in}} = \frac{5}{200\text{mm}} = 0.025\text{ V/mm}.$$

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∴ $V_{out} = 0.025 \, X_{in}$

(i) $V_{out} = ?$ when $X_{in} = -7.5mm$

$$V_{out} = 0.025 \times -7.5mm = \underline{\underline{-1.875}}$$

(ii) $X_{in} = ?$ when $V_{out} = 3V$

$$X_{in} = \frac{V_{out}}{0.025mm} = \frac{3\,V}{0.025\ V/mm} = \underline{\underline{120\ mm}}$$

$X_{in} = ?$ when $V_{out} = -1V$

$$X_{in} = \frac{V_{out}}{0.025mm} = \frac{-1\ V}{0.025 V/mm} = \underline{\underline{-40\ mm}}$$

Piezoelectric Transducer:-

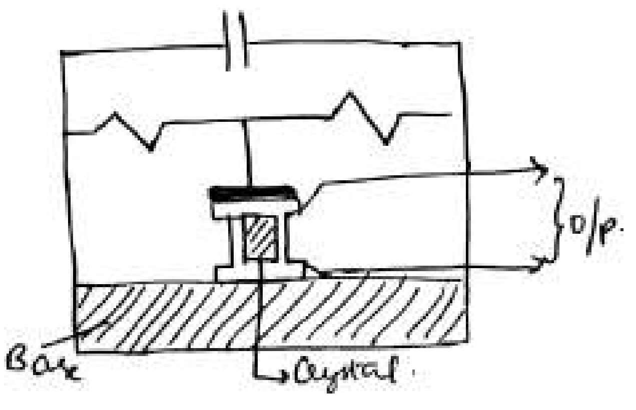
* When a crystal is subjected to mechanical force, opposite charges are developed on the surfaces. The magnitude of electrical potential between the 2 faces is proportional to the deformation produced.
ie when symmetrical crystal is placed under stress it produces an emf.

* Also the converse holds good. If electric potential to is applied along axis of crystal, the dimensions are changed & the crystal deforms.

→ This phenomenon is called "piezoelectric effect."

→ The piezoelectric materials → Quartz, Rochelle Salt & Barium titanate.

→ Piezoelectric transducer construction is shown below



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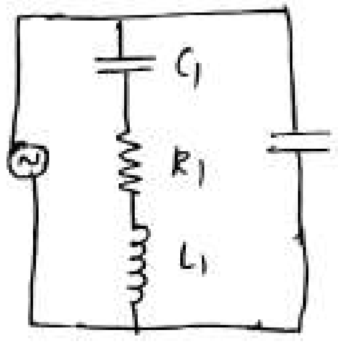

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→ When external force is applied on the top of the crystal, it produces an emf across the crystal proportional to the magnitude of applied pressure.

→ The o/p vtg E is given by

$$E = \frac{Q}{C_p}$$

Q → generated charge.
C_p → shunt capacitances.

Features:-

→ The device needs no external power supply. ie it is an active transducer.

→ The transducer is dynamic responding sensor & does not measure static conditions.

→ It has good freq response & it used in the accelerometers.

→ O/p vtg is affected by temp variations of the crystals.

→ When stress is applied, part of it is converted ~~by temp variations~~ to an electric potential and ~~composition~~ the rest is converted to mechanical energy.

→ When pressure is removed, it returns to its original state & electric charge is lost.

→ The coupling coefficient, k is given by.

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

$$\text{Or } K = \frac{\text{Electrical energy converted Mechanical energy}}{\text{Applied electrical energy}}$$

→ Since freq used is stable, piezo electric crystals are used in HF accelerometers.

→ Disadvantage is → voltage is generated as long as ~~pressure applied~~ pressure applied to piezo electric

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element charges

Advantages:-

- → Rugged construction
- → High o/p with negligible phase shift.
- → Excellent freq response.

Disadvantages:-

- → Piezo electric transducer are water soluble.
- → Temp sensitive
- → Used only for dynamic measurement.

Ex:-

A crystal has coupling coefficient of 0.32. How much electrical energy must be applied to produce o/p of 1 oz.in. of mechanical energy?

→ $k = 0.32.$

we have $k = \frac{\text{Electrical energy converted to mech energy}}{\text{Applied Electrical energy}}.$

given $1\,\text{oz in} = 1\,\text{oz}\cdot\text{in} \times \frac{1\,\text{ft}}{12\,\text{in}} \times \frac{1\,\text{lb}}{16\,\text{oz}} \times \frac{1.3561}{1\,\text{ft}\,1\,\text{lb}} =$

$\therefore 1\,\text{oz in} = 7.06 \times 10^{-3}$

$$\text{Applied electrical energy} = \frac{7.06 \times 10^{-3}\,\text{J}}{0.32}$$

$$= \underline{\underline{22.19\,\text{mJ}}}.$$

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Photoelectric Transducer:-

→ classified as
- → Photo emissive
- → Photo conductive
- → photo voltaic.

→ Converts visible radiations (light) into electrical signals.

* **Photoemissive** devices → when light / radiations falls on cathode, it causes electrons to be ejected from the surface of cathode.

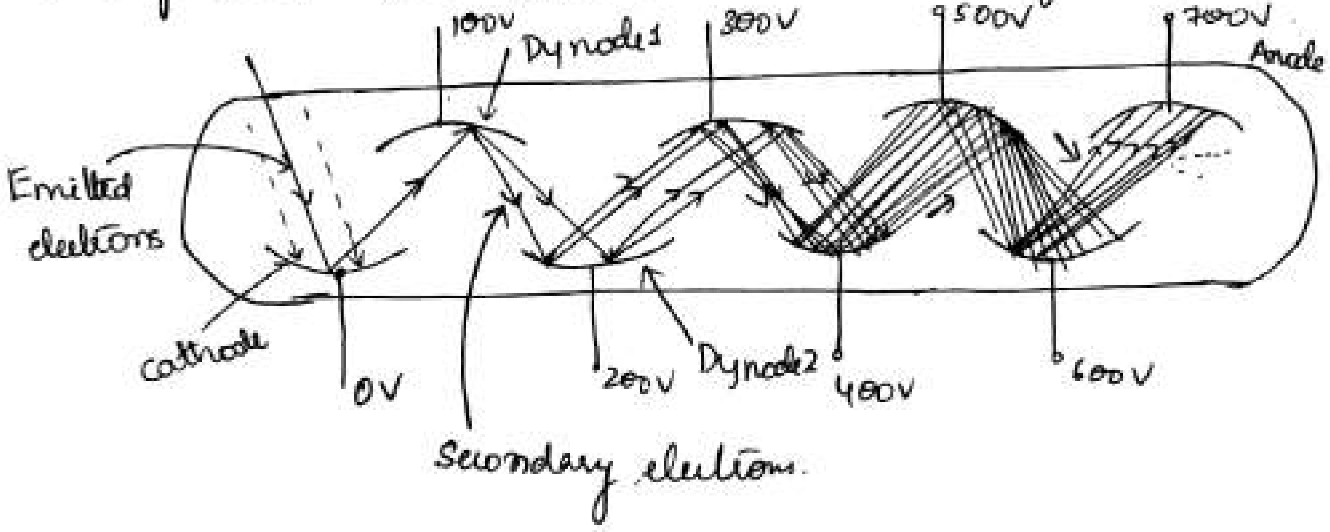
* **Photo conductive** → Due to illumination of radiations the resistance of a material changes.

* **Photo voltaic**:→ generates an output voltage proportional to the intensity of radiation. Radiations may be IR, UV, γ rays, x-rays & visible light.

1. Photo Multiplier tube (PMT)

→ It has an evacuated glass envelop ~~or~~ including a photo cathode, anode and additional electrodes called as Dynodes, where each of dynode is maintain-ed at high voltages than the previous one.

→ Fig shows the cross sectional view of PMT and



principle of its operation.

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Principle is - when a high ~~veloci~~ velocity electron strike an appropriate ~~target~~ material there is emission of electron. This electron is further made to strike the dynodes which are maintained at higher voltages. This increases the no of electron emission which causes ~~to~~ multiplication of electrons.

→ Between anode and cathode, high voltage is maintained which provides high velocity in the device.

→ The electrons emitted by first dynode are attracted to second dynode & this continues.

→ Each of the dynodes are maintained at higher ~~Amp~~ voltage to achieve higher ~~voltage~~ electron velocity in each stage.

→ This results in multiplication & increase in electron flow.

→ There is amplification of current by an amount of $10^5 - 10^9$ & current radings are 100μA - 1 mA.

→ Problem seen in the PMT is that, the magnetic field affect the Photomultiplier & this causes some electrons to deflect from normal path. These electrons never reach the dynodes. This reduces the gain.

→ To minimize this effect μ-metal magnetic shields are placed around the photo multiplier tube.

Photoconductive cells or photo cells:-

→ It uses photo conductive effect [Another form of photoelectric effect]. ie when light is incident on the device, the electrical resistance of the material used in the device changes.

The variation in resistance is proportional to the amount of incident light.

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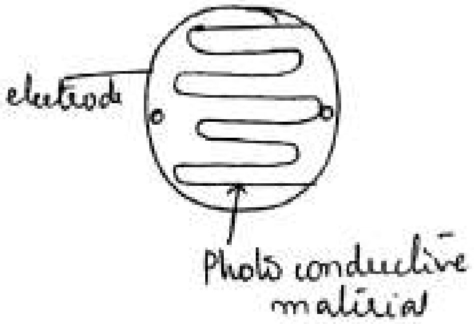
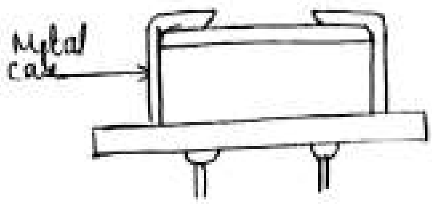
→ Construction is shown below



Top view



side view

→ The photo conductive material is Cadium sulphide, Cadium celenide or Cadium sulpho selenide.

→ This material is deposited on an insulating base material such as ceramic.

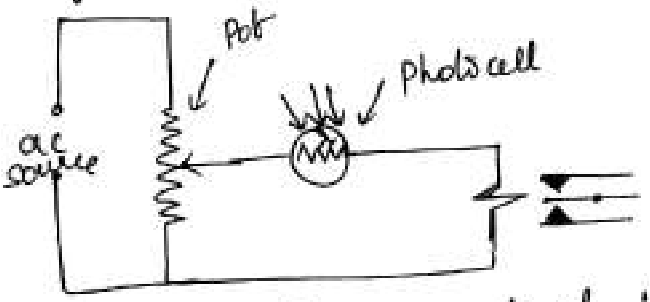
→ The material is deposited in a zig zag ~~fashion~~ fashion to obtain desired resistance value & power rating

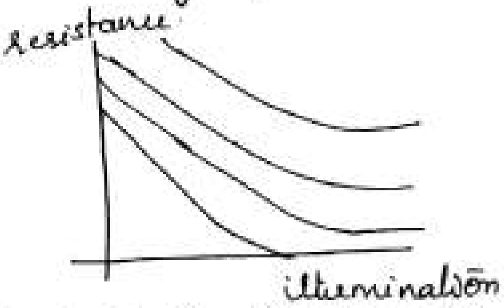
→ It has 2 seperated metal coated areas which acts as electrodes for contact

→ This assembly is enclosed in a metal case with a glass window on the photoconductive material.

→ The diameter size of photo cell varies b/w 1/8 in to 1 in. Small size is used in application where size is the limitation. But with ↓ in size power dissipation also decreases.

→ Fig shows controlling unit/ckt using photo cell





when appropriate amount of light is incidented on photo cell its resistance ↓ & current ↑. This current is sufficient to turn on/operate relay. when light is disturbed, the resistance ↑ & current ↓ and this de-energise the relay. Graph shows the relation.

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Photovoltaic cell :-

→ It is also the solar cells.

→ These devices produces an electrical current when connected to load.

→ Photovoltaic cell works on the phenomenon known as "photovoltaic effect"

* When an open ~~ckted~~ circuited pn junction is illuminated, large no of electron, hole pairs will be near the junction ~~reag~~ region. A small voltage appears across its terminals which acts as a voltage source. This phenomenon converts light energy into electrical energy is called photovoltaic effect.

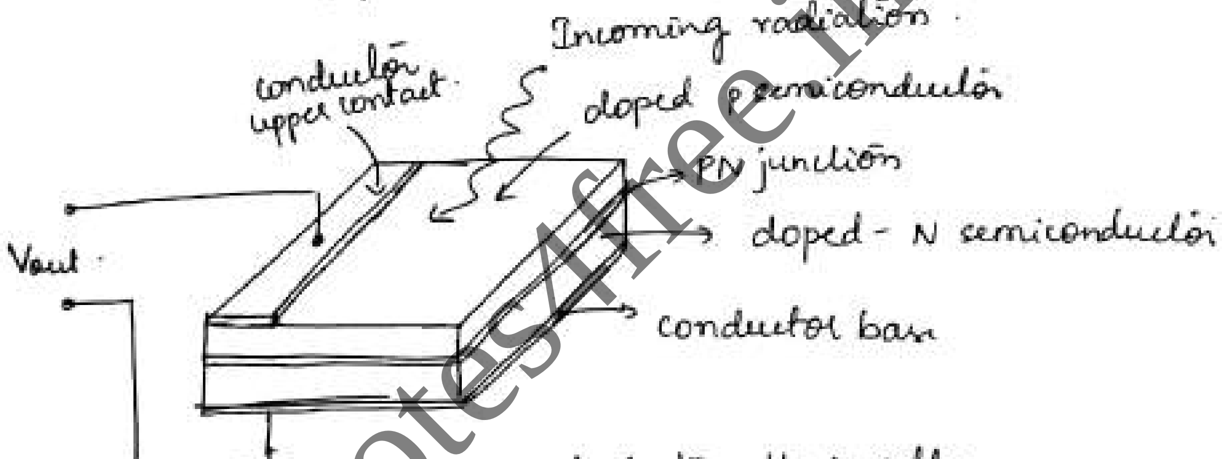

fig. Structure of photovoltaic cell.

→ When photon strike on the thin-p doped semiconductor material layer, they are absorbed by electrons in n layer. They result in the formation of ~~electron hole pair~~ conduction electron & holes. They are separated by the depletion region potential. When a load is connected across the cell, the depletion region potential causes photocurrent to flow thro' the load.

→ Photo-voltaic devices are used ~~for~~ sensing light in reading punched cards in data processing industry.

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Photo diode :- (Semiconductor photo diode).

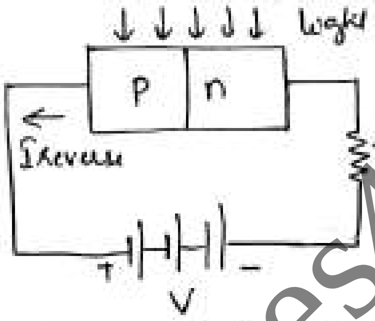
→ When a pn junction is exposed to light & if it is connected in reverse biased condition, a very small leakage current flows.

In this condition as the light intensity is increased the current also increases in the same proportion.

Thus photodiode is a device which responds to intensity of light in the reverse biased condition. And it is limited to only to the reverse biased mode.

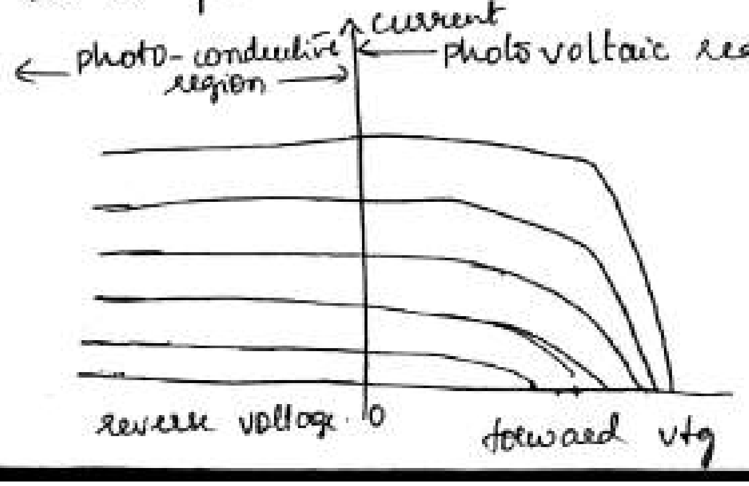
→ The funtion of photodiode in the reverse biased state is same as the photo-conductive cell.

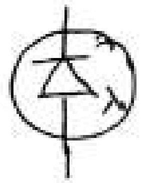
→ The ckt arrangement is shown below



[In reverse biased condition, when light falls on photodiode, the energy in the form of photons is transfered to the atomic structure. It results in ↑ no of minority carriers & this in turn increases reverse current level.]

→ The photodiode without reverse biased voltage operates as a photo voltic cell.





Illumination chae & symbol is shown in figure.

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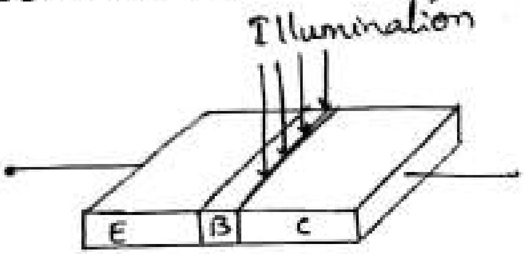
→ When there is no light illumination on photo diode, there is still flow of current due to leakage charges. This current is called as the '<u>dark current</u>'.

Photo transistor :-

→ When to photodiode a junction is added it results in the formation of NPN device

→ This also increases the sensitivity of the photodiode, by about 100 times.

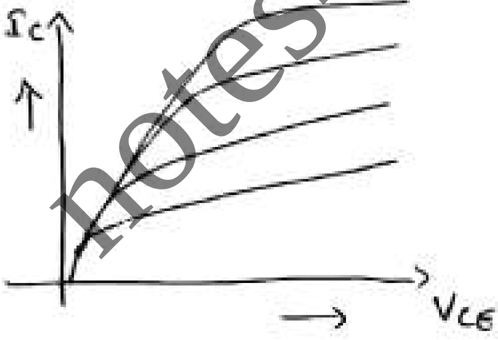
→ Construction is shown below



construction

symbol

o/p char



→ When light is incidented to the central region it releases electron-hole pair. This reduces the barrier potential across junction & causes an increase in the flow of electrons from left region to centre and to the right region.

→ In phototransistor only a small area is illuminated & this provides sufficient output current that that of photo diode. Thus photo-transistor is more sensitive device.

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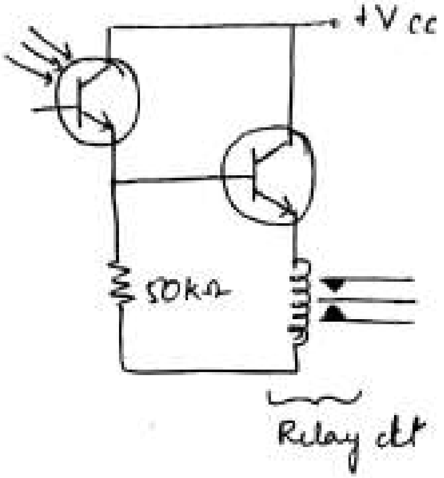
→ Fig shows an application of using photo transistor for relay control operation.



When light is incident on phototransistor, it ↑ current. This increases voltage drop across 50kΩ & input vtg of transistor. This drives / controls the relay ckt for its operation.

Temperature transducer:-

→ Temperature is one of the most common measured & control variable in industry.

→ For this, there is wide variety of temperature transducer & temp measurement ckt.

→ The common temp transducers are

* Resistance Temp Detectors (RTD)
* Thermistors
* Thermocouple

→ RTD & Thermistor are passive device

→ Thermocouple is an active device

* The above transducer requires contact with temp for measurement. For non-contact temp measurement transducer available is called as "Radiation Pyrometer".

Resistance Temperature Detector (RTD):-

→ When these devices are subjected to heat it results in varying the resistance with temp.

→ They use ~~pt~~ platinum, nickle & any resistance wire whose resistance varies with temp and also have high accuracy.

→ The relationship between temp & resistance of conductor is given by

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$R_t = R_{ref}(1+\alpha \Delta t)$ — Ⓐ

R_t = Resistance of conductor at temp t°c.
R_{ref} = Resistance of ref temperature, at 0C.
α = temp coefficient of resistance.
Δt = Difference between operating & reference temp.

→ The RTD is available in diff configuration & size and are used for both immersion & surface application.

→ All metals will have a positive temp coefficient (PTC) of resistance. so their resistance ↑ with ↑ in temp. But some materials have -ve temp coefficient like carbon & Germanium. RTD uses PTC

→ If Eqⁿ Ⓐ is considered, value of 'α' should be high so that change in resistance occurs for ~~smaller~~ small change in temp. This change in resistance can be measured using wheatstone's bridge.

→ The sensing element of RTD is selected according to intended applications.

→ Platinum is the most widely used resistance wire because of its high stability & large operating range.

The advantages are.

1. Linearity.
2. Wide operating range.
3. Higher temp operation.
4. Better stability at high temp.

The disadvantages are.

1. Low sensitivity.
2. High cost.
3. Requires more wires for its operation & instrumentation to eliminate errors due to lead resistance.

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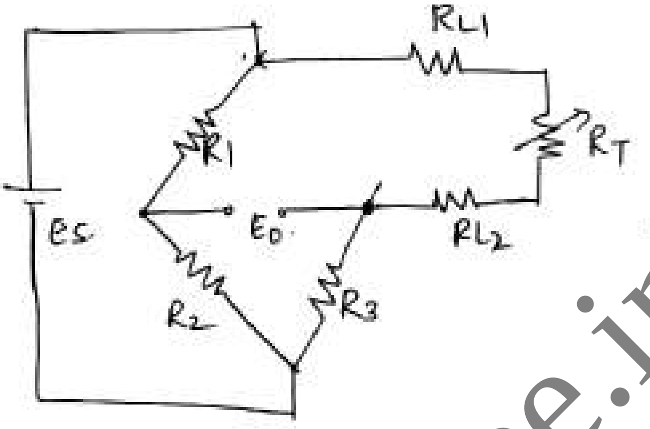
RTD instruments are used along with wheatstone's bridge, where RTD leads are connected to arm of bridge.

→ Bridge is measuring device which converts resistance into electrical signal ~~and~~ that can be used for controlling and monitoring temperature.

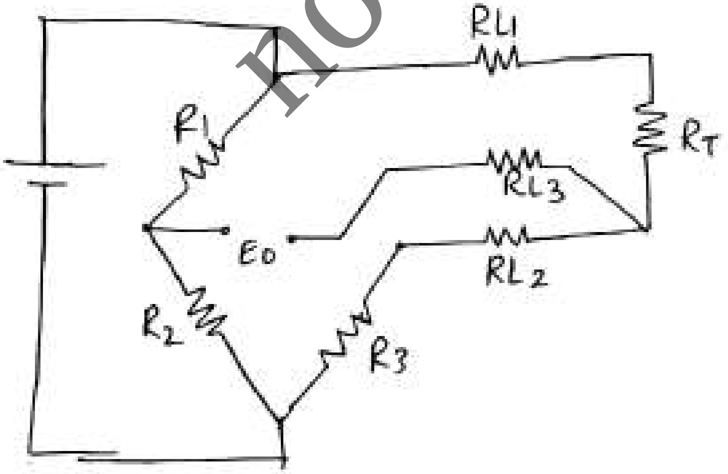
→ Two wire RTD connection is shown below



RL1 = RL2 → leads of RTD.

→ If lead resistance are small, then errors introduced by them is not significant.

→ If the lead resistance is large, then method employed to obtain high accuracy is to use lead compensation technique or 3 wire and four wire RTD.



Under balanced condition same current flows thr' all the arms of bridge. Also current is same in lead L1 & L2. The voltage drop developed across them is same & also they get cancelled out.

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