UNIT – 1
INTRODUCTION TO E.M.I.

1.1. Introduction to Measurement System

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- *(b) Dynamic characteristics*

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- *Ayrton shunt / Universal shunt*

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- (c) True RMS reading voltmeter
- (d) Differential Voltmeter
- (e) Solid state/ Electronic voltmeter

1.10. Multimeter – *for I , V, & R measurements*

1.1. INTRODUCTION :

Measurement: Measurement of a given quantity is an act (or) result of a quantitative comparison between a pre-defined standard and the quantity to be measured.

Note: (i) The comparison standard must be accurately defined and commonly accepted.
(ii) A standard of measurement is a physical representation of a Unit of measurement.
The unknown quantities are compared with the standard to obtain their values.

Instrument: A device or mechanism used for determining the value/magnitude of the quantity.

Note: (i) The physical quantity/variable/parameter to be measured is called as ***Measurand.***
(ii) physical measurands → velocity, pressure, force, strain, …..etc
electrical measurands → voltage, current, power……etc
electrtonic measurands → frequency, amplitude, phase of the signal.

Instrumentation System:

An instrumentation system is defined as the set of instruments & equipment used to measure one (or) more characteristics/phenomena and to present the obtained information in suitable form.

Applications of EMI :

In all branches of Engineering, Medicine, all human day to day activities.

in Enggineering: mechanical : *measurement of velocity, pressure, force,……etc*
electrical : *measurement of voltage, current, power*
electronic : *measurement of frequency, amplitude, phase of a signal*
in medicine: measurement of BP, body temp., blood flow etc
ECG → heart beats are converted into electrical signals
day to day life: Temp., distance, height, weight, light intensity, humidity….etc

Advantages of electronic instruments:

- High sensitivity
- Greater flexibility
- Highly reliable
- Faster response
- Very compact
- Light weight
- Low power consumption
- Easy to operate

The basic objectives of instrumentation system:

(1) ***Information gathering*** : to measure natural phenomena and other variables

(2) ***Diagnosis*** : to help in detection and correction i.e., trouble shooting

(3) ***Evaluation*** : to determine the ability of the system – proof of performance

(4) ***Monitoring*** : to monitor some process in order to obtain periodic/continuous information about the state of the system being measured.

(5) ***Control*** : to control the operation of a system based on changes in internal parameters or change in the output of the system.

Block diagram of general measurement system & its functional units:

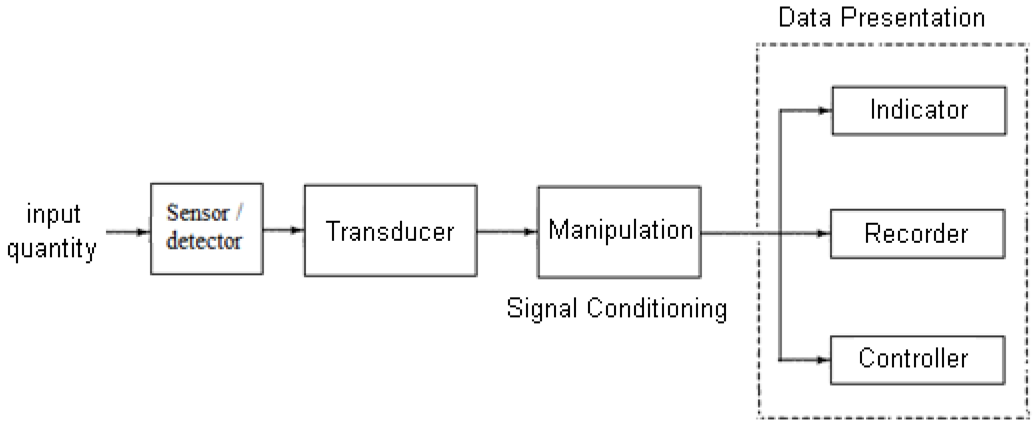


Fig.1.1. Block diagram of general measurement system / Instrumentation system

Primary sensing element:

The physical quantity to be measured is first sensed & detected by an element, which gives the output in different analogues form.

Transducer:

The output from sensor is then converted into an electrical signal by a transducer.
Transducer is a device which converts the physical quantity into an electrical quantity.
In some cases, the physical quantity is directly converted into an electrical signal by the transducer.

Manipulation element / signal conditioning element:

The o/p of transducer is an electrical signal & it may not be suited to the system to perform desired function. The manipulation element operates on the signal according to some mathematical rule without changing the physical nature of the variable.

Ex: linear operations → Amplification, attenuation
Non-linear → modulation, filtering, sampling

Data presentation element:

This element provides a display record (or) indication of output. The information of the *measurand* has to be conveyed for monitoring, control (or) analysis purposes.

Calibration :

- Calibration is the process of making an adjustment (or) marking a scale so that the readings of an instrument will agree with the accepted/ certified standard. It is the procedure for determining the correct values of measurand by comparison with standard one.

- Before using any instrument, we have to calibrate it. Calibration can be done by giving known inputs to the instrument system & taking necessary action to see that the output of measurement system matches with its input.

- If the instrument is not calibrated properly, it will give reading with an error called ***Calibration error***. To reduce this error, re-calibration of instrument should be done at regular intervals

- The calibration characteristics can be determined by applying known values of quantities to be measured and recording the corresponding outputs of instrument. Such a record obtained from calibration is called as ***Calibration record***.

1.2. PERFORMANCE CHARACTERISTICS OF AN INSTRUMENT:

- ✓ The major problem with any measuring instrument is the Error. Hence it is necessary to select the appropriate instrument & measurement procedure which minimizes the error.
- ✓ The measuring instrument should not affect the physical quantity to be measured.
- ✓ To select the most suitable instrument for taking specific measurement, the knowledge of the performance characteristics of the instrument is essential and important.
- ✓ The performance of a measurement system can be described in terms of Static & Dynamic characteristics.

NOTE:

1. Range: The minimum and maximum values of a quantity for which an instrument is designed to measure is called its *range.*

2. Span: It represents the algebraic difference between the upper and lower range values of the instrument.

For example if range is (-25 ^{0}C +25 ^{0}C), the span is 50 ^{0}C.

3. Expected value/True value: It is the designed value, i.e, most probable value that calculations indicate one should expect to measure. *This is the actual magnitude of the signal input to the measuring system*.

(A). STATIC CHARACTERISTICS

The static characteristics are defined for the instruments, used to measure the quantities which do not vary with time (or) quantities which are slowly varying with time.
The various static characteristics are:

1	Error
2	Accuracy
3	Precision
4	Linearity
5	Sensitivity

6	Resolution
7	Threshold
8	Zero drift
9	Hysteresis
10	Dead zone

1. ERROR :

(i) Static / absolute error:

It is defined as the difference between the true value & measured value of the quantity.

Absolute error = True value – Measured value

$$e = Y_n - X_n$$

(ii) Relative error $e_r = \frac{\text{Absolute error}}{True\ value} = \frac{Y_n - X_n}{Y_n}$

(iii) Error expressed as % of True value $= \frac{Y_n - X_n}{Y_n} * 100$

Error expressed as % of full scale reading $= \frac{Y_n - X_n}{fsd} * 100$

2. ACCURACY :

It is defined as the degree of closeness / conformity to the true value of the quantity
It indicates the ability of the instrument to indicate the true value of the quantity.

Relative Accuracy **a =** $1 - e_r \quad = \quad 1 - \left|\frac{Y_n - X_n}{Y_n}\right|$

Accuracy as % of True value = $\left(1 - \left|\frac{Y_n - X_n}{Y_n}\right|\right) * 100$

Accuracy as % of full scale reading = $\left(1 - \left|\frac{Y_n - X_n}{fsd}\right|\right) * 100$

Ex(1): The accuracy of a thermometer having range of 500 ^{0}C can be expressed as ± 0.5% of full scale reading.
when the reading is 500 ^{0}C, the error = ± 2.5 ^{0}C & %error = ± 0.5 %
when the reading is 25^{0}C, the error = ± 2.5 ^{0}C & %error = ± 10 %

Thus as reading decreases, the %error in measurement increases.
Hence, specification of accuracy in this manner is highly misleading.

Ex(2): The accuracy of a thermometer having range of 500 ^{0}C can be expressed as ± 0.5% of true value
when the reading is 500^{0}C, the error = ± 2.5^{0}C & %error = ± 0.5 %
when the reading is 25^{0}C, the error will be ± 0.125^{0}C & %error = ± 0.5 %

Thus as readings get smaller, error also gets reduced. This is the best method of specifying the accuracy.

3. PRECISION

- Precision is the ability of an instrument to reproduce its readings again and again in the same manner for a constant input. Precision is defined as a measure of consistency/repeatability of measurements. i,e, successive readings do not differ.

- Precision is composed of two characteristics (i) Conformity. (ii) No. of significant figures

Precision can be mathematically expressed as

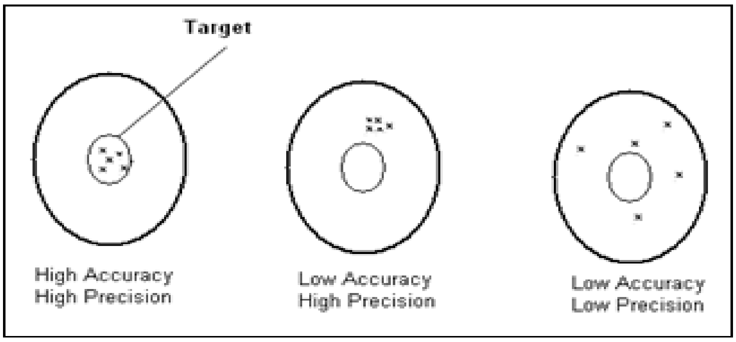
Precision $P_i = \left(1 - \left|\frac{\bar{x}_n - x_i}{\bar{x}_n}\right|\right) * 100$ *where* $\bar{x}_n$ *= avg. of n- readings*

x_i *= value of i* th *reading.*

*** Difference between Accuracy & Precision :***

→ Accuracy indicates the ability of instrument to indicate the true value of the quantity.
→ Precision is the ability of instrument to reproduce it's readings again &again in the same manner for a constant i/p.

Ex(2):



Ex(1): *Let us consider 3 instruments A,B,C measuring a value of 20mm. 5-measurements are taken on same true value.*

Instrument	Measured Values	Comments
A	9.97, 9.98, 9.97, 9.98, 9.97	▪ The measured values are close to true value. → ***high accuracy***. ▪ All measured values are close to each other → ***high precision***
B	9.62, 9.61, 9.60, 9.62, 9.61	▪ The measured values are **Not** close to true value. → ***Low accuracy***. ▪ All measured values are close to each other → ***high precision***
C	9.22, 9.68, 9.30, 9.72, 9.45	▪ The measured values are **Not** close to true value. → ***Low accuracy***. ▪ All measured values are **Not** close to each other → ***Low precision***

Note that, the precision is necessary, but not sufficient condition for accuracy.
i.e., the accurate instrument should be precise but a precise instrument may not be accurate.

Problem 2.1. : *The expected value of the voltage to be measured is 250 V. But the measurement gives a value of 249 V on its (0-200 V) range. Calculate*
(1) Absolute error
(2) Relative error
(3) % Error
(4) Relative accuracy
(5) % Accuracy

Problem 2.2. : *The following table shows a set of 5-measurements recorded in a laboratory. Calculate the precision of the third measurement.* ***Readings : 49, 52, 52, 50, 49***

4. SENSITIVITY

- Sensitivity is defined as the ratio of *change in o/p of an instrument* to *change in i/p quantity*. *Mathematically,*

  $$\text{Sensitivity} \quad \boldsymbol{s} = \frac{change\ in\ o/p\ of\ an\ instrument}{change\ in\ i/p\ quantity} = \frac{q_o}{q_i}$$

- It is represents the slope of the calibration curve as shown in figure.

- The *reciprocal of the sensitivity* is called as *deflection factor* ***(or)*** *scale factor*.

  $$\text{Inverse sensitivity} = \text{deflection factor} = \frac{1}{Sensitivity}$$

5. RESOLUTION

- Resolution defines the smallest change in the input to which an instrument will respond.
- Resolution defines the smallest measurable input change.

$$\text{Resolution} = \frac{full\ scale\ reading}{Total\ no.of\ steps\ (or) divisions\ in\ scale}$$

6. THRESHOLD:

- If the input quantity is slowly varied from zero onwards, the o/p doesn't change until some min.value of the input is exceeded. This Min.value of the input is called as threshold.

- Note that, the resolution is the smallest measurable input change while threshold is the smallest measurable input.

Problem 2.3. : *Determine the resolution of a DVM which has read-out range 0 to 9999 counts & it's f.s.r. is 9.999 V.*

Problem 2.4. : *Determine the % resolution of a moving coil voltmeter having a uniform scale with 50 divisions. The full scale reading is 50V and 2/20 of a scale division can be estimated with a fair degree of certainty.*

Problem 2.5. : *A transducer measures a range of 0-200N force with a resolution of 0.25% of full scale. What is the smallest change which can be measured by this transducer?*

7. LINEARITY

- The ability to reproduce the input characteristics symmetrically is called Linearity.
- Linearity property indicates the straight line nature of the calibration curve.
- Linearity error is defined as the maximum deviation of the actual calibration curve from the idealized straight line.
- It can be expressed as % of f.s.r. (or) % of True value

$$\text{Linearity error} = \frac{\text{max. deviation of the output from idealized straight line}}{full\ scale\ deflection} * 100$$

8. DRIFT

- ***Drift*** is an undesirable graded departure of the instrument output over a period of time that is unrelated to changes in input (or) load.
- If the whole instrument calibration gradually shifts over by the same amount, it is called as ***Zero Drift***
- If the calibration from Zero up words changes proportionally, it is called as ***Span Drift***.
- When the drift occurs only over a portion of span of an instrument it is called as ***Zonal Drift***

9. HYSTERISIS

- Hysteresis is a phenomenon which shows different output effects when loading and unloading as shown in figure.
- If the input to the instrument is increased from a –ve value, the o/p also increases as shown in curve(1).
- But if the input is decreased steadily. The o/p doesn't follow the same curve, but lags by certain value as shown in curve(2).
- The difference between these two curves is called as Hysteresis.

10. DEAD ZONE & DEAD TIME

- ***Dead zone*** is the range with in which variable can vary without being detected.
- ***Dead Time*** *is* the time required by the instrument to begin to respond to a change in the measured.

(B). DYNAMIC CHARACTERISTICS

The dynamic characteristics are considered when the instruments are used to measure rapidly varying quantities. *(When the instrument is subjected to rapidly varying inputs, the relation between output & input becomes totally different than that in the case of static inputs. As input varies from instant to instant, output also varies from instant to instant. The behavior of system under such conditions is called as dynamic response of the system).*

- The dynamic behavior of the measuring system is determined by applying some known & predefined variations of inputs to the instrument.

- The standard/common variations in the input used to obtain dynamic behaviors are

(1) *Step input*: Step input represents sudden/ instantaneous change in the input.
(2) *Ramp input*: Ramp input represents linear change in the input.
(3) *Parabolic input*: This is proportional to the Square of the time.
(4) *Impulse input*: Which has Zero value everywhere except at t = 0 where magnitude is finite.
(5) *Sinusoidal input*: Various sinusoidally as shown in figure.

From the dynamic behavior of measuring system, various dynamic characteristics of the system can be obtained.

(1) ***Speed of Response***:
- It is the rapidity with which an instrument responds to the changes in the i/p quantity
- It gives information about how fast the system reacts to changes in the input.
- It indicates the activeness of the system.
- The measurement system should respond very quickly to the changes in input.

(2) ***Dynamic Error***:
It is the difference between true value of the quantity changing with time and the value indicated by the measurement system, if no static error is assumed.

(3) ***Fidelity***:
It is defined as the degree to which an instrument indicates the changes in the measured quantity without Dynamic Error.

(4) ***Measuring Lag***:
Every system takes some finite amount of time to respond to changes in measured variable. This delay in the response of measurement system is called as Lag (or) measuring Lag.

1.3. TYPES OF ERRORS (Sources of Errors)

Errors may arise from different sources & are usually classified as

1. Gross Errors.
2. Systematic Errors:- *Instrumental, Environmental, Observational*
3. Random Errors.

1. Gross Errors :

These are mainly due to human mistakes.

- Improper reading
- Recording the reading differently
- In the calculation of results
- Due to insufficient knowledge
- Improper use of an instrument

These errors cannot be treated mathematically. It is not possible to eliminate the errors completely, but it can be minimized by following precautions

- by taking care in reading, recording & calculating the results.
- by taking at least three (or) more readings, preferably by different persons.

2. Systematic Errors:

These errors occur due to short comings of instruments, characteristics of materials used in instruments, environment effects, ageing effects…. etc.

A systematic error can be referred to as a constant uniform deviation of the operation of an instrument. Systematic errors are further classified into 3- categories.

(a) Instrumental errors : These errors occur due to following reasons

- Short coming of instruments: *because of faulty components, due to friction, bent (or) distorted pointer, irregular spring tensions, hysteresis of elastic members.*
- Misuse of instruments : *poor initial adjustment, improper zero setting, improper handling, using leads of high resistance.*
- Loading effect : *For ex., a well calibrated voltmeter may give misleading voltage reading when connected across a high resistance, but the same voltmeter may give accurate reading when connected across a low resistance circuit.*

How To Minimize Instrumental errors:

- By selecting a suitable instrument for a particular application.
- Applying correction factor after determining the amount of instrumental error.
- Calibrating the instrument against a standard.

(b) Environment Errors:

These errors are due to conditions external to the measuring instruments Such as:

- Temperature, Pressure changes.
- Effect of external fields (Magnetic / Electrostatic fields).
- Humidity, Dust, Vibrations……e.t.c.

How To Reduce Environmental errors:

- Using air conditioning, temperature control enclosures to keep the surrounding conditions constant.
- Using the magnetic (or) electrostatic shields to reduce the effect of external fields.
- Hermetically sealing certain components in the instruments to eliminate the effects of humidity, dust.
- Using equipment, which is immune to such environmental effects.

(c) Observational Errors :

These errors are introduced by the observer.
The most common error is the parallax error while reading a meter scale.

How To Reduce:-

- Using instruments with mirrors, knife edged pointers.
- Using instruments with digital display.

3. Random Errors :

- After case has been taken to minimize the ***gross*** and ***systematic*** errors, certain errors occur due to unknown causes, even if the instrument is accurately calibrated. These errors are called as ***Random errors.***
- Random errors are accidental, small & independent.
- These errors are generally due to the accumulation of large number of small effects and may be considered only in measurements with high degree of accuracy.
  (ex: *line voltage fluctuations, vibrations of instrument support, outside disturbances…etc)*
- Since random errors are due to unknown causes, these cannot be determined.Ssuch errors are normally small & follows the laws of probability. Thus random errors can be analyzed statistically & treated mathematically.
- The only way to reduce these errors is by increasing number of observations & using statistical analysis to obtain the best approximation of reading.

Statistical Analysis:

The mathematical analysis of various measurements is called statistical analysis of data. For such statistical analysis, the same quantity is measured for number of times, generally by different observers, different instruments & different ways of measurement.

The statistical analysis of various measurements gives the best approximation of reading

1) Arithmetic mean.
2) Average deviation/Mean deviation.
3) Standard deviation.
4) Variance.

1. Arithmetic Mean:

The most probable value of a measured variable is the arithmetic mean of the number of readings taken. The best approximation will be made when the number of readings of same quantity is very large (theoretically infinite). But practically only a finite number of measurements can be made.

Arithmetic mean = $\bar{x} = \frac{x_2 + x_2 + x_3 + \ldots\ldots\ldots\ldots + x_n}{n}$ where x_i = value of i^{th} reading

n = number of readings taken

2. Mean deviation/ Average Deviation:

The deviation of a reading is defined as the difference between the reading & the arithmetic mean of group of readings.

Deviation of i^{th} reading $d_i = (x_i - \bar{x})$

The deviation may be +ve or –ve. The algebraic sum of all deviations must be ZERO.

The average deviation is defined as the ratio of sum of absolute values of deviations to the total number of Readings.

$$D = \frac{|d_1| + |d_2| + |d_3| + \ldots\ldots\ldots + |d_n|}{n}$$

3. Standard Deviation/ Root mean square Deviation:

The standard deviation is the square root of sum of individual deviations divided by no. of readings.

$$\sigma = \sqrt{\frac{d_2^2 + d_2^2 + d_3^2 + \ldots\ldots\ldots\ldots + d_n^2}{n}} = \sqrt{\sum \frac{d_i^2}{n}}$$

4. Variance:

The variance is the mean square deviation. i.e., It is the square of the standard deviation.

$$\text{Variance } V = \sigma^2 = \sum \frac{d_i^2}{n}; \quad \text{where } i = 2,2,3,\ldots..n$$

Limiting Errors:

Most of the manufacturers specify the accuracy of instruments within a certain % of full scale reading. This percentage indicates the deviation from the specified value of particular quantity. These deviations are called as limiting errors (or) guarantee errors.

For ex., the manufacture of the voltmeter may specify the instrument to be accurate within $\pm$ 2% of f.s.d. This specification is called as limiting error.

i.e., If the range is (0-100V) then there will be error of $\pm$ 2V

Similarly, if the resistance of a resistor is given as 500 Ω $\pm$ 10% then,

the manufacturer guarantees that the resistance value falls between **450 Ω** *to* **550 Ω**

Problem 2.14.: *The current through 5 kΩ resistor is measured by an ammeter. The limiting error of the resistance is 5 kΩ ±10%.*

1.4. DC INSTRUMENTS (PMMC METER)
Basic Principle - D'Arsonval Movement

The necessary requirements for any measuring instrument are

(1) The instrument should not affect the quantity to be measured.
(2) The power consumption of their operation should be as small as possible.

The operation of analog instruments such as Ammeter & Voltmeter depends upon the deflection torque produced by an electric current.

In Ammeter → deflection torque is directly proportional to the current to be measured.
In Voltmeter → deflection torque is decided by the current, which is proportional to the voltage to be measured.

Thus, there is no fundamental difference in the operating principle of analog Ammeter & Voltmeter. So these are basically current measuring devices.

PMMC *(Permanent Magnet Moving Coil)* instruments:

The PMMC instruments are used for the measurement of the d.c. current and d.c. voltages. These instruments use the principle of D'Arsonval movement.

D'Arsonval movement : When the current carrying coil is placed in the magnetic field, the coil experiences a force and moves. The amount of force experienced by the coil is proportional to the current passing through the coil.

Constructional features of PMMC meter:

- The moving coil is either rectangular (or) circular in shape and it has number of turns of fine wire. The coil is suspended so that it is free to turn about its vertical axis.
- The coil is placed in uniform, horizontal & radial magnetic field in the air gap between pole pieces of a permanent magnet (*horse shoe type*).
- A light pointer is attached to the moving coil so that as the coil rotates, the pointer moves over a graduated scale.
- A mirror is placed below the pointer to get the accurate reading by removing parallax error.

Operation:

The meter movement works on the principle of *D'Arsonval movement*. When the dc current flows through the coil, the coil experiences a force due to magnetic field produced by permanent magnet. In the operation of basic PMMC instrument, the following torques are present.

Deflection torque:

- It is proportional to the current passing through the coil.
- It moves the pointer from its zero position in the scale.
- Since the scale markings of PMMC instrument are usually linear, the pointer deflections are directly proportional to the deflection torque which depends on the current passing through the coil.

Controlling torque/ Restoring torque:

- It is provide by two phosphor bronze hair springs.
- Controlling torque is equal & opposite to the deflection torque in order to make the deflection of pointer proportional to the magnitude of the quantity to be measured & to prevent coil from continuous rotation.
- It also brings the pointer back to zero position, when the force is removed.

Damping torque:

- It is produced by the eddy currents in the metal former on which the coil is mounted.
- Due to this torque, the pointer quickly comes to the final steady state position without any swing (or) oscillation.

Toruqe equation:

The deflection torque (T_d) can be derived from the basic law of electromagnetic torque.

$T_d = NBAI$ *Where* *N = Number of turns of the coil.*
B = Flux density in air gap (Wb/m^2 (or) Tesla).
A = Effective coil area (m^2).
I = Current in the moving coil.(A)

The controlling torque is given by

$T_c = K\theta$ *Where K = spring constant (N.m/ degree).*
θ = angle deflection.

In steady state condition

$$T_c = T_d$$
$$K\theta = NBAI$$
$$\theta = \left(\frac{NBA}{K}\right) I$$
$$\theta \propto I$$

∴ The deflection is directly proportional to the current passing through the coil.

PMMC Instruments Advantages:

- Low power consumption.
- Uniform scales.
- Range can be extended with shunts (or) multipliers resistors(i.e, multi-range).
- Accuracy of dc measurement is high.
- Since magnetic field of permanent magnet is high, it is not affected by stray magnetic fields.

Disadvantages:

- Suitable for dc measurements only.
- Ageing of permanent magnet & control springs introduces errors.
- Friction & temperature might introduce errors.

Applications:

- DC ammeter by using a shunt resistor.
- DC voltmeter by using a series multiplier resistor.
- Ohm meter by using a battery and series resistor.
- Audio frequency AC ammeter (or) voltmeter by using a rectifier.
- Radio frequency ammeter (or) voltmeter by using a thermocouple.

1.5. DC AMMETER

Basic dc ammeter:

- The basic D'Arsonval movement can be converted into a DC ammeter by connecting a SHUNT resistance in parallel with basic meter as shown in figure.

- Since, the coil windings of a basic movement are very small and light, it can carry very small currents. When large currents are to be measured, it is necessary to bypass a major part of the current through a resistance called a SHUNT.

- The value of shunt resistance R_{sh} can be calculated as follows:

  Let R_m = internal resistance of the coil.
  I_m = full scale deflection current of basic meter.
  I = required range of the ammeter.

  Since R_{sh} & R_m are in parallel,

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

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

∴ For the required ammeter range I, we can determine the value of shunt R_{sh}.

General requirements of shunt:

(1) The temperature co-efficient of shunt & meter should be low.
(2) The resistance of shunt should not vary with time.
(3) The shunt should have low thermal emf.
(4) Materials used to join the shunts should have low thermal dielectric voltage drop. Due to soldering, the values of resistances should not be changed.
(5) The shunt should carry the current without excessive temperature rise.

Multi-range DC ammeter:

- The range of the basic dc ammeter can be extended by using number of SHUNTs and Selector switch as shown in figure. Such a meter is called as Multi-range ammeter.

- Note that for the largest range, Smallest SHUNT is required.

Ranges : $I_2 > I_2 > I_3$

Shunts : $R_2 < R_2 < R_3$

Selector switch: Make before break type

- The selector switch 'S' selects the appropriate SHUNT to change the range of the ammeter.
- When the ordinary switch is used, while changing the range of the meter, the switch remains open and full current passes through the meter. So the meter may get damaged due to high current.
- Hence the switch 'S' is a ***make before break type*** switch, which makes the contact with next terminal before completely breaking the contact with previous terminal.
- The mathematical analysis of basic dc ammeter is equally applicable to multi-range ammeter.
- If the required ranges of ammeter are I_2 , I_2 & I_3 then,
  The values of R_1 , R_2 & R_3 can be calculated as follows:

$$R_1 = \frac{I_m R_m}{I_1 - I_m} \quad , \quad R_2 = \frac{I_m R_m}{I_2 - I_m} \quad \& \quad R_3 = \frac{I_m R_m}{I_3 - I_m}$$

Multi-range DC ammeter
Universal Shunt (or) Ayrton Shunt:

- In multi-range dc ammeter shown in above figure, the make before break type switch is must. The Ayrton shunt eliminates the possibility of having the meter without shunt.
- The selector switch 'S' selects the appropriate shunt required to change the range of the ammeter.

Case (1): For the range $\mathbf{I_1}$

the switch is at position(1) & the SHUNT resistance = R_1

From figure, we have $R_1 = \frac{I_m}{I_1 - I_m}(R_2 + R_3 + R_m)$

Case(2): For the range $\mathbf{I_2}$

the switch is at position(2) & the SHUNT resistance = $R_1 + R_2$

From figure, we have $R_1 + R_2 = \frac{I_m}{I_1 - I_m}(R_3 + R_m)$

Case(3): For the range $\mathbf{I_3}$

the switch is at position(2) & the SHUNT resistance = $R_1 + R_2 + R_3$

From figure, we have $R_1 + R_2 + R_3 = \frac{I_m}{I_1 - I_m}(R_m)$

By solving the above 3-equations, the required Ayrton shunts can be designed for the required ranges of the ammeter. Note that $\mathbf{I_1}$ is the max. range possible (since SHUNT resistance is Low in this case) and $\mathbf{I_3}$ is the min. range.

Precautions to be taken while using an Ammeter:

1. Always connect an ammeter in series with the load.
2. It should not be connected across any source of e.m.f.
3. The polarities must be observed correctly
4. While using multi-range ammeter, first select the highest range and then decrease the range until sufficient deflection is obtained.

Extending of Ammeter Ranges:

The range of the ammeter can be extended to measure high current values by using external SHUNTs as shown in figure. Note that the range of the basic ammeter can be increased but can't be lowered.

Problem 2.6. : *A 2mA d'Arsonval movement with an internal resistance of 100 Ω is to be converted into 0-100 mA ammeter. Show the arrangement with values of resistances used.*

Problem 2.7. : *Design a universal shunt to provide an ammeter with ranges 1A, 5A, & 10A using D'Arsonval movement with an internal resistance of 50 Ω and f.s.d. current of 1 mA.*

1.6. DC VOLTMETER

Basic dc Voltmeter:

- The basic D'Arsonval movement can be converted into a DC voltmeter by connecting a **Multiplier** resistance in series with basic meter as shown in figure.

- The purpose of the Multiplier is to limit the current through the basic meter, so that the meter current does not exceed the f.s.d. value.

- *The value of Multiplier resistance R_s can be calculated as follows*:
  Let R_m = internal resistance of the coil, I_m = full scale deflection current of basic meter.
  V = required range of the voltmeter.

  From figure $V = I_m (R_m + R_s)$

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

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

$\therefore$ By using series Multiplier, we can extend the range of DC voltmeter.

Multi-range Voltmeter:

- The range of the basic voltmeter can be extended by using number of Multipliers and a Selector switch as shown in figure.
- Let R_1 , R_2 & R_3 are multipliers that gives 3- different ranges V_1 , V_2 & V_3.

- The multi-position switch 'S' is used to select the multiplier for the required range.
  For ranges $V_1 > V_2 > V_3$, the multipliers $R_1 > R_2 > R_3$

- The values of multipliers can be calculated as

$$R_1 = \frac{V_1}{I_m} - R_m$$

$$R_2 = \frac{V_2}{I_m} - R_m$$

$$R_3 = \frac{V_3}{I_m} - R_m$$

Problem 2.8. : *A basic D'Arsonval movement with f.s.d. current of 100 µA and internal resistance of 500 Ω is used as a voltmeter. Determine the value of multiplier needed to measure a voltage of 0-20V.*

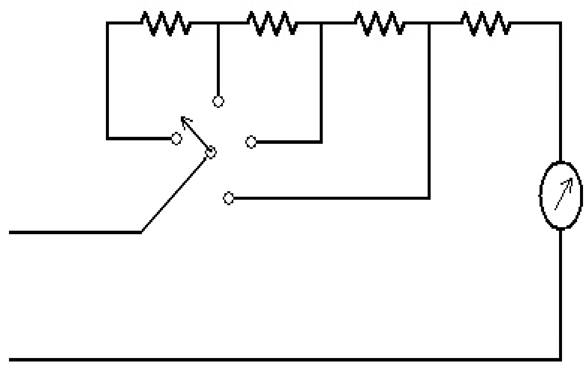
Practical Multi-range Voltmeter

- The multi-range voltmeter shown in above figure requires high precision values of multiplier resistances, which increases the cost.
- The more practical arrangement of multiplier resistances is shown below, in which the multipliers are connected in series string.
- The selector switch selects the appropriate amount of resistance for different voltage ranges

- Note that, when the switch is at ***position(4)***, the multiplier resistance is $\mathbf{R_4}$.
  when the switch is at ***position(1)***, the multiplier resistance is $\mathbf{(R_1+R_2+R_3+R_4)}$.

- Therefore V_4 is the lowest range & V_1 is the highest range. $V_1 > V_2 > V_3 > V_4$

The values of multiplier can be calculated as:



Case(4) : $R_4 = \frac{V_4}{I_m} - R_m$

Case(3) : $R_3 + R_4 = \frac{V_3}{I_m} - R_m$

Case(2) : $R_2 + R_3 + R_4 = \frac{V_2}{I_m} - R_m$

Case(1) : $R_1+R_2+R_3+R_4 = \frac{V_1}{I_m} - R_m$

- Here, the Low range multiplier R_4 is a special resistor, which has to be manufactured specially to meet the circuit requirements. i.e., only R_4 is the high precision resistor, remaining all are standard values.

Precautions to be taken while using a Voltmeter:

1. Always connect across the load (or) component whose voltage is to be measured.
2. The polarities must be observed correctly
3. While using multi-range voltmeter, first select the highest range and then decrease the range until sufficient deflection is obtained.
4. Take care of loading effect.
   (*The loading effect can be minimized by using high sensitivity Voltmeter)*

Extending of Voltmeter Ranges:

The range of the voltmeters can be extended to measure high voltages by using external MULTIPLIERs as shown in figure. Note that the range of the basic voltmeter can be increased but can't be lowered.

Problem 2.9. : *A basic D'Arsonval movement with an internal resistance of 50 Ω and f.s.d. current of 0.5 mA and is to be converted into multi-range voltmeter with ranges 10V, 50V, 250V & 500V. Show the arrangement with values of resistances used.*

1.7. SENSITIVITY OF VOLTMETER

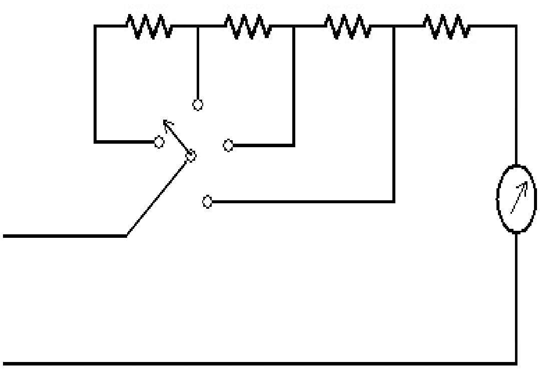
The sensitivity of the Voltmeter is defined as the ratio of total circuit resistance to the Voltage range. It is given by

$$S = \frac{R_{total}}{V} = \frac{R_S}{V} = \frac{1}{I_m} \quad \text{ohm / Volt}$$

Hence, The sensitivity is nothing but the reciprocal of the f.s.d. current of the basic meter.

The sensitivity is useful in calculating the resistance of a multiplier in DC voltmeter. Let us consider the practical multi-range dc voltmeter shown in figure:

Let S = Sensitivity of the voltmeter
R_m = internal resistance of the coil.
I_m = full scale deflection current of basic meter.



Now the multiplier resistances can be calculated as follows:

Case(4) : $R_4 = \frac{V_4}{I_m} - R_m = S.V_4 - R_m$

Case(3) : $R_3 + R_4 = S.V_3 - R_m$

Case(2) : $R_2 + R_3 + R_4 = S.V_2 - R_m$

Case(1) : $R_1+R_2+R_3+R_4 = S.V_1 - R_m$

Where V_1 , V_2 , V_3 & V_4 are required voltage ranges.

LOADING EFFECT

While selecting a voltmeter for a particular measurement, the sensitivity rating is very important.
A low sensitivity voltmeter may give a correct reading in low resistance circuit, but it will produce totally inaccurate reading in high resistance circuit.

When a voltmeter is connected across a Low resistance,

Since the Load resistance is lower the Voltmeter resistance
most of the current passes through low resistance load &
and hence the voltmeter gives True reading

When a voltmeter is connected across a High resistance,

Since the Load resistance & Voltmeter resistance are in parallel
the current will divide through the two paths and hence the
current passes through the load decreases due to loading effect.
→voltmeter will record the voltage drop across load which is much lower than the True value.

Thus, if the Low sensitivity voltmeter is used in high resistance circuit, it gives a lower reading than true reading. This is called ***Loading effect*** of the voltmeter.

Loading effect can be minimized by using a ***High sensitivity voltmeter*** whose resistance is High.

Problem 2.10.: *It is desired to measure the voltage drop across 50kΩ resistor in the circuit shown. Two voltmeters of (0-50V) are available for this purpose. The Voltmeter(A) has Sensitivity 1000 Ω/V and Voltmeter(B) has Sensitivity 20000 Ω/V. Calculate (i) True voltage across 50k resistor*
(ii) Readings of each voltmeter
(iii) Error in each reading expressed as % of True value.

Problem 2.11.: *Find the voltage reading and % error of each reading obtained with a voltmeter on its (a) 10V range and (b) 30V range. The Voltmeter has sensitivity 25000 Ω/V and it is used to measure voltage across 5kΩ resistor in the circuit shown in figure.*

Problem 2.12.: *A voltmeter having sensitivity of 1000 Ω/V reads 100V on its 150V scale when connected across an unknown resistance in series with a milli-ammeter. If the ammeter reads 5 mA then*
Calculate (i) the apparent resistance of unknown resistance
(ii) actual resistance of unknown resistance
(iii) the error due to loading effect of voltmeter.

Problem 2.13.: *A resistor is measured by voltmeter-ammeter method. The voltmeter reading is 125.4V on its 250V and ammeter reading is 288.5mA on 500mA scale. Both meters are guaranteed to accurate within ± 1 % of f.s.r.*
Calculate (i) the apparent resistance/indicate value of resistance
(ii) the limits within which you can guarantee the result.

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1.8. OHM-METER

(A) Series Type Ohm-meter:

The series type ohm meter consists of a D'Arsonval movement connected in series with a multiplier resistance R_1 and a battery E. The unknown resistance is connected in series with basic meter as shown in figure.

R_1 → Current limiting resistor
R_2 → Zero adjust resistor
R_m → internal resistance of basic meter
E → battery voltage
R_x → UNKNOWN RESISTANCE

The current flowing through the meter depends on the magnitude of R_x.

The calibration of Series type Ohm-meter can be done as follows:

(i) When unknown resistance R_x = 0 (A&B are shorted)

max. current flows through the meter.
The resistor R_2 is adjusted so that the current through meter gives f.s.d.current.
This full-scale current position of the pointer is marked as **0 Ω** on the scale.

(ii) When unknown resistance R_x = ∞ (A&B are opened)

the current through the circuit is ZERO.
The PONTER doesn't deflect.
This pointer position is marked as ∞ on the scale.

(iii) Half-scale position resistance (R_h)

It is the value of R_X at which the current through the meter is the ***half*** of the full-scale deflection current.
i.e., when $R_X = R_h$

the meter current = $\frac{1}{2} I_{fsd}$
form figure $R_h = R_1 + R_2 // R_m$

$$\rightarrow \quad R_h = R_1 + \frac{R_2\, R_m}{R_2 + R_m}$$

- The intermediate markings are placed on the scale by connecting different know values of R_x
- As the current is inversely proportional to the resistance, the scale is marked from ∞ *to 0* as shown in figure.
- Due to time & age, there is decrease in the battery voltage. Due to this f.s.d.current drops and meter doesn't show ZERO reading when A & B are shorted. By varying variable shunt resistance R_2, it is possible to bring the pointer back to ZERO ohms on the scale.

(B) Shunt Type Ohm-meter:

- The shunt type ohm meter consists of a D'Arsonval movement connected in series with a multiplier resistance R_1 and a battery E. The unknown resistance is connected across the basic meter as shown in figure.

  R_1 → Current limiting resistor
  R_m → internal resistance of basic meter
  E → battery voltage
  S → switch
  R_x → UNKNOWN RESISTANCE

- The switch S is provided to disconnect the battery when the instrument is not in use.
- The current flowing through the meter depends on the magnitude of R_x.
- *The calibration of Shunt type Ohm-meter can be done as follows*:

(i) When unknown resistance $R_x = 0$ (A&B are shorted)

The current through the meter is ZERO.
This pointer position is marked as $0\ \Omega$ on the scale.

(ii) When unknown resistance $R_x = \infty$ (A&B are opened)

the entire current flows through the meter.
By varying R_1 , the pointer can be made to read f.s.d.current.
This pointer position is marked as ∞ on the scale.

(iii) Half-scale position resistance (R_h)

It is the value of R_X at which the current through the meter is the ***half*** of the full-scale deflection current
.
i.e., when $R_x = R_h$ the meter current $= \frac{1}{2} I_{fsd}$

From figure, $R_h = R_m$

- Thus the Shunt type ohm meter is suitable for the measurement of Low resitances.
- The intermediate markings are placed on the scale by connecting different know values of R_x
- Here the scale is marked from 0 *to* ∞ as shown in figure.
- Due to time & age, there is decrease in the battery voltage. Due to this f.s.d.current drops and meter doesn't show f.s.d. reading when A & B are opened. By varying R_1, it is possible to bring the pointer back to f.s.d reading on the scale.

1.9. AC INSTRUMENTS

(a) AC Voltmeters using Rectifiers
(b) RF ammeters using Thermocouples
(c) True RMS reading Voltmeter
(d) Differential Voltmeter
(e) Solid state/ Electronic voltmeter

Note: (1)The ac voltages are usually expressed in RMS values. So that the meters must be calibrated in terms of RMS value. For such calibration, a pure sinusoidal wave with RMS value of 1 V is applied and then deflection of the meter is adjusted to 1V reading.

(2) For a sinusoidal input $V_{rms} = \frac{V_m}{\sqrt{2}}$

(3) For HWR output $V_{avg} = V_{dc} = \frac{V_m}{\pi}$ & For FWR output $V_{avg} = V_{dc} = \frac{2V_m}{\pi}$

(a) AC Voltmeters using Rectifiers

Rectifier type ac voltmeter uses a PMMC movement along with a rectifier arrangement. Silicon diodes are preferred because their low reverse current and high forward current ratings. The rectifier converts ac to uni-directional dc and this rectified output will be given to D'Arsonval movement.

(i) AC voltmeter using FWR:

- The ac voltmeter using full wave bridge rectifier consists of 4-diodes as shown in fig.
- When dc voltage is applied, the current through meter is $I_m = \frac{V_{dc}}{R_m+R_s}$
- Multiplier resistance $R_s = \frac{V_{dc}}{I_m} - R_m = S_{dc}.V_{dc} - R_m$ *where* $S_{dc} = \frac{1}{I_m}$

- *When a sinusoidal input* $\boldsymbol{V_m}$ ***Sin wt*** *is applied to the rectifier,*

  During +ve half cycles, D_1 & D_3 → Conducts

  During -ve half cycles, D_2 & D_4 → Conducts
- Therefore, the bridge rectifier produces the pulsating unidirectional current as shown in figure.
- This pulsating current is fed to PMMC meter.
- Because of inertia of the coil, the meter will indicate a steady deflection which is proportional to the average value of the input.

For FWR output, $V_{avg} = V_{dc} = \frac{2V_m}{\pi} = \frac{2\sqrt{2}\ V_{rms}}{\pi} = 0.9\ V_{rms}$

- Therefore the meter deflection would be 90% of RMS value of the input voltage.

ac sensitivity $S_{ac} = 0.9\ S_{dc}$ where $S_{dc} = \frac{1}{I_m}$

Now, Multiplier $R_s = S_{ac}.V_{dc} - R_m$

(ii) AC voltmeter using HWR:

For HWR, the diode D_1 conducts only during +ve half-cycles of ac input and unidirectional pulsating voltage is produced at the output as shown in figure.

For HWR output, $V_{avg} = V_{dc} = \frac{V_m}{\pi} = \frac{\sqrt{2}\ V_{rms}}{\pi} = 0.45\ V_{rms}$

Therefore the meter deflection would be 45% of RMS value of the input voltage.

ac sensitivity $S_{ac} = 0.45\ S_{dc}$ where $S_{dc} = \frac{1}{I_m}$

Now, Multiplier $R_s = S_{ac}.V_{dc} - R_m$

The practical rectifiers are non-linear, particularly at low values of forward currents. A general rectifier ac voltmeter arrangement is shown below.

For +ve half cycles of input,

Diode D_1 → Conducts
Meter deflects according to the avg. of input.
The meter movement is shunted by R_{sh} in order to draw more current through D_1
So that the operating point is moved to linear portion of the diode characteristics.

For -ve half cycles of input,

Diode D_2 → Conducts
It bypasses the meter movement.

Hence the meter deflection is directly proportional to the average value of the HWR output.

(iii) Multi range AC voltmeter:

The above circuit is used to measure ac voltages for different ranges. The resistors $\mathbf{R_1}$, $\mathbf{R_2}$, $\mathbf{R_3}$ **&** $\mathbf{R_4}$ form a chain of multipliers for RMS voltages range V_1 , V_2 ,V_3 & V_4.

R_{sh} is the meter shunt to improve the rectifier operation.

Problem 2.15.: *Convert the given D'Arsonval meter to an ac voltmeter whose coil resistance is 250Ω and f.s.d.current of 1mA. The applied ac voltage is 0-250V. Also calculate ohm-per-volt rating of ac voltmeter.*

(b) RF ammeters / Thermocouple Instruments:

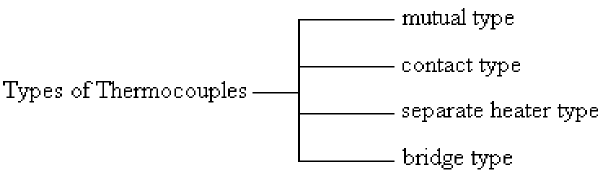
- The combination of thermocouple and PMMC movement can be used to measure ac currents & voltages. These are called as thermocouple instruments.
- A Thermocouple is a junction of **TWO** dissimilar metals, whose contact potential is a function of the temperature of the junction.
- The ac current (or) voltage to be measured is used to heat the junction of the metals.
- The heater raises the temperature of the thermocouple and produces an output voltage which is proportional to the power delivered to the heater. (*Note that the heating effect is the same for both half-cycles of ac input because the heat produced by both half-cycles is same).*

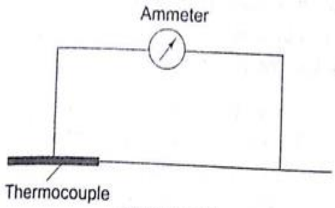
  Output voltage α Power of the input signal

  $$\rightarrow V_0 \;\alpha\; \frac{E_{rms}^2}{R_{heater}}$$

  $$\rightarrow V_0 = K.E_{rms}^2$$

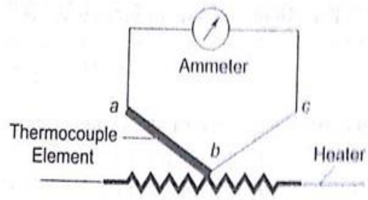
- Materials used to construct thermocouple are Constantan against Copper, Manganin (or) Platinum alloy. Such a junction gives a thermal e.m.f. of 45 µV/ ^{0}C .





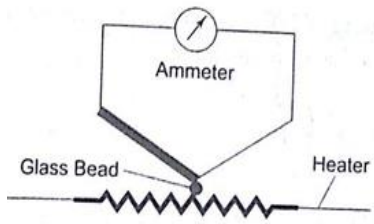
(a) Mutual type

- ***Mutual type*** :
  - In this type, the ac current passes through the
  - thermocouple itself and not through the heater.
  - *Adv:* good sensitivity
  - *Dis-adv*: the meter shunts the thermocouple.



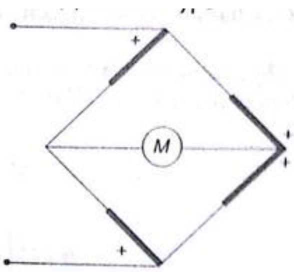
(b) Contact type

- ***Contact type*** :
  - In this type, there are separate thermocouple leads which conduct away the heat from the heater wire.
  - *Adv:* no shunting effect
  - *Dis-adv*: less sensitive than mutual type



(c) Separate heater type

- ***Separate heater type*** :
  - In this type, the thermocouple is held near the heater, but insulated from it by a glass bead.
  - This makes the instrument sluggish and less sensitive.
  - To avoid heat loss from radiation, the thermocouple arrangement is placed in vacuum.



(d) Bridge type thermocouple

- ***Bridge type*** :
  - This is the one of the mutual type of thermocouple.
  - Sensitivity of this device is high.
  - This type get avoids the shunting effect of the ammeter

(c) True RMS reading Voltmeter :

- The true RMS voltmeter is used to measure RMS value of complex waveforms.
- This meter produces a meter deflection by sensing the heating power of a signal, which is proportional to the square of the RMS value of the input signal.
- When heating element is heated by the power of input signal, it's temperature increases.
- A thermocouple is used to measure the temperature of the heater. It produces an output voltage which is proportional to the temperature of the heater which depends on the power delivered to the heater.

Output voltage α *Power of the input signal*

$$\rightarrow V_0 \;\alpha\; \frac{E_{rms}^2}{R_{heater}}$$

$$\rightarrow V_0 = K.E_{rms}^2$$

- The ac voltage to be measured is amplified and applied to the heater to achieve enough heating, so that the thermocouple can generate o/p voltage which is proportional to the E_{rms}^2.
- The non-linear effect of measuring thermocouple is nullified by similar non-linear effect of balancing thermocouple in the feedback circuit as shown in figure.
- Both thermocouples are kept in the same thermal environment and they form a balanced bridge in the input circuit of dc amplifier.

The output of measuring thermocouple $V_1 = K.E_{rms}^2$

The output of balancing thermocouple $V_2 = K.V_0^2$

In balance condition, $V_2 = V_1$

$$K.V_0^2 = K.E_{rms}^2$$

$$V_0 = E_{rms}$$

Therefore, the voltage measured by the meter is the RMS value of the input.

(d) Differential voltmeter:

- The differential voltmeter technique is one of the most common & accurate methods of measuring unknown voltages.
- In this technique, the Null detector is used to indicate voltage difference between Known & Unknown voltages.
- The basic circuit of Differential Voltmeter based on Potentiometer method is shown in figure.
- The potentiometer is varied until the voltage across the potentiometer is equal to the Unknown voltage, which is indicated by Null detector.
- Under null condition, the current through the meter is ZERO.
- Now, The Unknown voltage = The voltage across the POT

$$= \frac{R}{R_{total}} V_{ref}$$

- To detect small differences, the meter movement must be sensitive.
- It is not required to calibrate the meter because, the meter has to indicate only ZERO value.
- The reference source is usually 1 Volt dc standard source (or) a Zener controlled precision supply.
- For measuring high voltages, the voltage dividers (or) attenuators are used to reduce the unknown voltage to specified input range.
- In order to measure ac voltages, the ac voltage must be converted into unidirectional dc by incorporating a precision rectifier circuit as shown in figure.

(e) Solid state / Electronic Voltmeter:

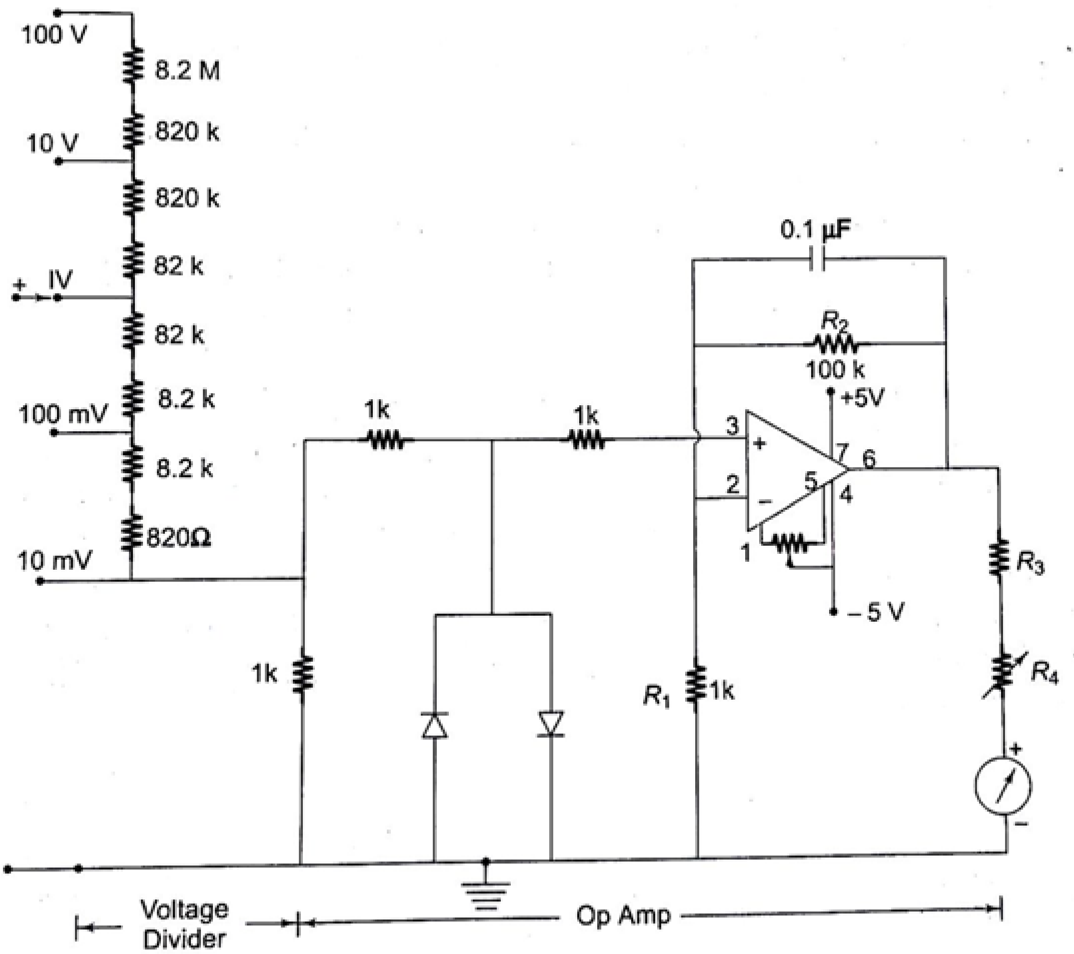


Fig. 4.13 Solid state mV voltmeter using OpAmp

- The above figure shows the circuit of an electronic voltmeter using direct coupled high gain Op-Amp 741C.
- The resistor R_2 between o/p terminal (Pin.6) & Inverting i/p terminal(Pin.2) provides a negative feedback.
- The gain of the Op-Amp can be adjusted to any suitable lower value by adjusting resistors R_1 & R_2.

  The gain of the inverting amplifier (A_F) = $-\left(\frac{R_2}{R_1}\right)$

- The 0.1μF capacitor across R_2 is for stability under stray pick-ups.
- The 10k potentiometer is connected across the Offset null terminals (Pin1. & Pin.5) to make ZERO offset voltage. This potentiometer is adjusted to get ZERO output for ZERO input condition.
- The TWO diodes are used for IC protection. Under normal conditions they are in OFF state as the max. voltage across the diodes is 100 mV. If excessive voltage (more than 100mV) appears across them, one of the diodes conduct and protects the IC.
- The f.s.d. current of PMMC meter may be 50μA – 1000μA.
- The resistor R_4 is adjusted to get maximum full scale deflection.

1.10. MULTI METER

A multimeter is basically a PMMC meter. To measure dc current the meter acts as an ammeter with a low series resistance.

Range changing is accomplished by shunts in such a way that the current passing through the meter does not exceed the maximum rated value.

A multimeter consists of an ammeter, voltmeter and ohmmeter combined, with a function switch to connect the appropriate circuit to the D'Arsonval movement.

Figure 4.35 shows a meter consisting of a dc milliammeter, a dc voltmeter, an ac voltmeter, a microammeter, and an ohmmeter.

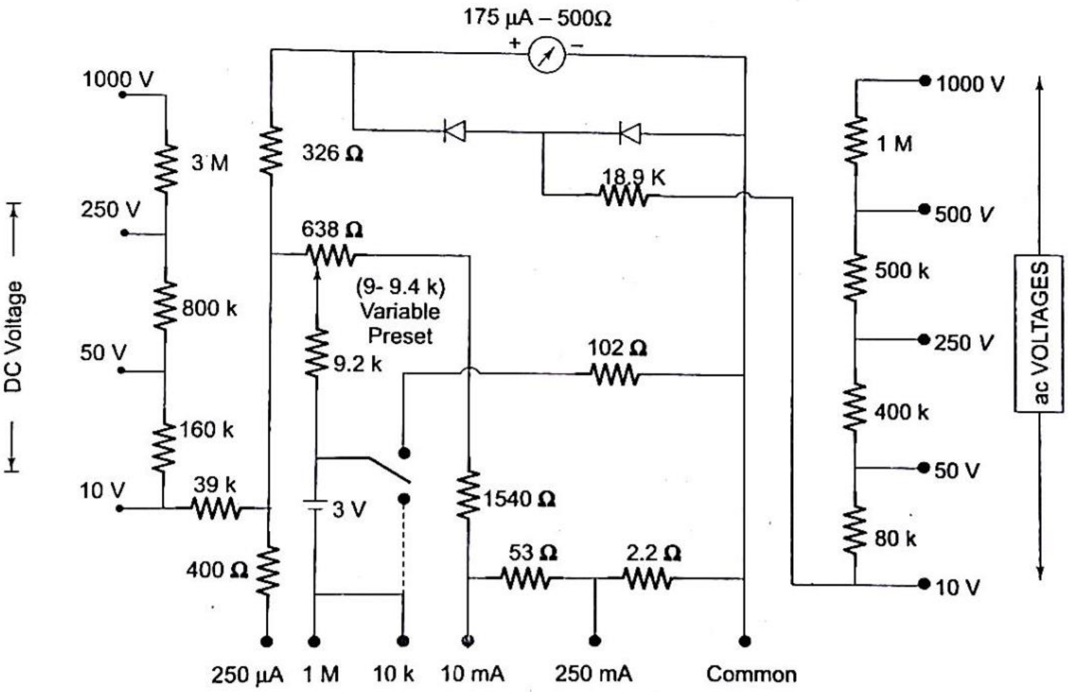


Fig. 4.35 Diagram of a multimeter

Microammeter Figure 4.36 shows a circuit of a multimeter used as a microammeter.

DC Ammeter Figure 4.37 shows a multimeter used as a dc ammeter.

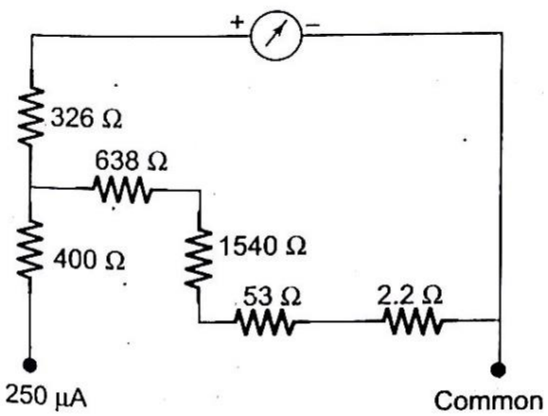


Fig. 4.36 Microammeter section of a multimeter

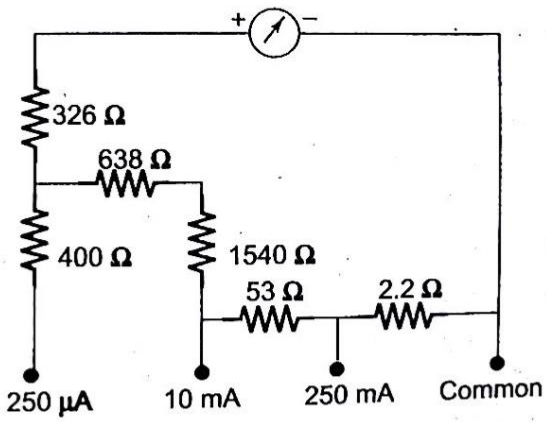


Fig. 4.37 dc ammeter section of a multimeter

DC Voltmeter Figure 4.38 shows the dc voltmeter section of a multimeter.

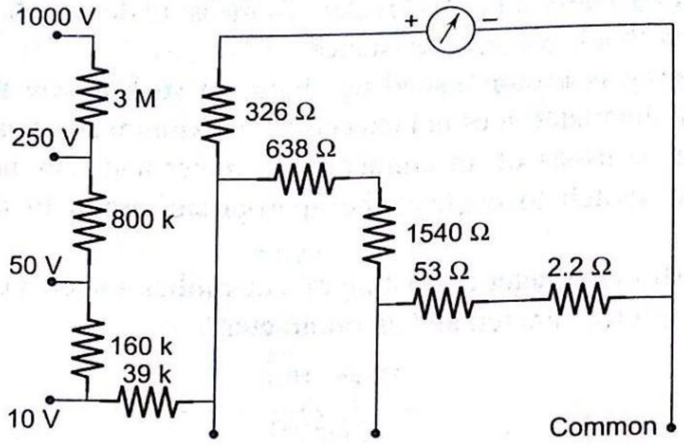


Fig. 4.38 DC voltmeter section of a multimeter

AC Voltmeter Figure 4.39 shows the ac voltmeter section of a multimeter. To measure ac voltage, the output ac voltage is rectified by a half wave rectifier before the current passes through the meter. Across the meter, the other diode serves as protection. The diode conducts when a reverse voltage appears across the diodes, so that current bypasses the meter in the reverse direction.

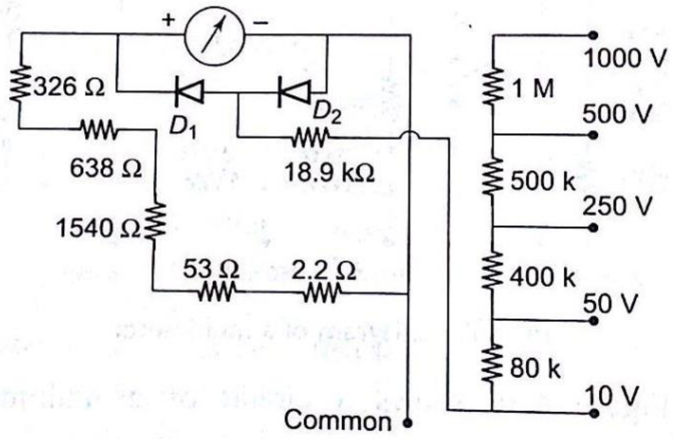


Fig. 4.39 AC voltmeter section of a multimeter

Ohmmeter Referring to Fig. 4.40 which shows the ohmmeter section of a multimeter, in the 10 k range the 102 Ω resistance is connected in parallel with the total circuit resistance and in the 1 MΩ range the 102 Ω resistance is totally disconnected from the circuit.

Therefore, on the 1 M range the half scale deflection is 10 k. Since on the 10 k range, the 102 Ω resistance is connected across the total resistance, therefore, in this range, the half scale deflection is 100 Ω. The measurement of resistance is done by applying a small voltage installed within the meter. For the 1 M range, the internal resistance is 10 kΩ, i.e. value at midscale, as shown in Fig. 4.41. And for the 10 k range, the internal resistance is 100 Ω, i.e. value at mid-scale as shown in Fig. 4.42.

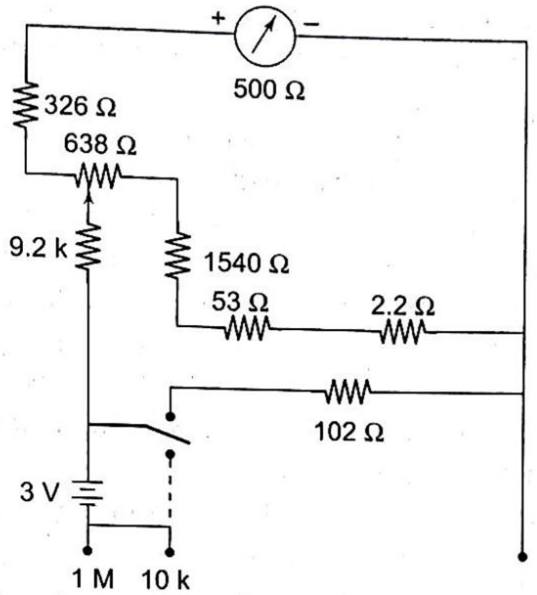


Fig. 4.40 Ohmmeter section of a multimeter

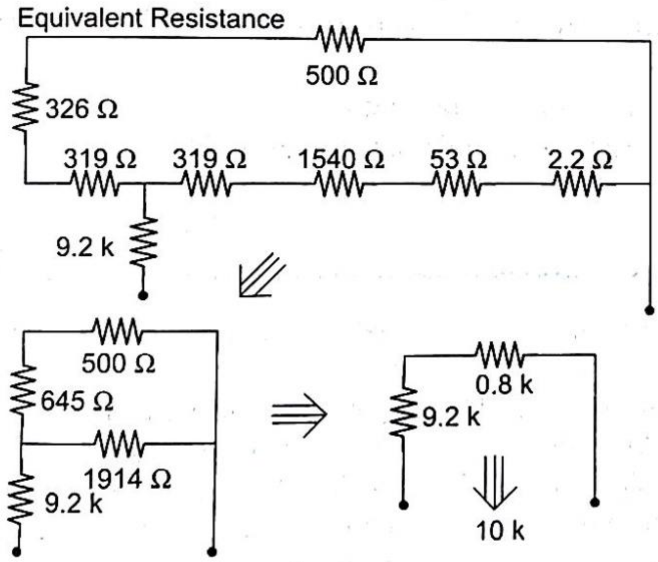


Fig. 4.41 Equivalent resistance on 1 M Ω range

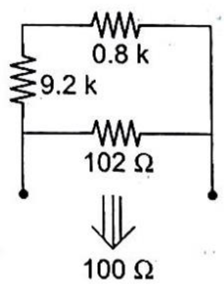


Fig. 4.42 Half scale deflection is 100 Ω on 10k range

The range of an ohmmeter can be changed by connecting the switch to a suitable shunt resistance. By using different values of shunt resistance, different ranges can be obtained.

By increasing the battery voltage and using a suitable shunt, the maximum values which the ohmmeter reads can be changed.

MULTIMETER OPERATING INSTRUCTIONS 4.26

The combination volt-ohm-milliammeter is a basic tool in any electronic laboratory. The proper use of this instrument increases its accuracy and life. The following precautions should be observed.