

Electronics Measurements And Instrumentation

(1)

UNIT-1:

*-Introduction :

Instrumentation is a technology of measurement which serves not only science but all branches of engineering, medicine and almost every human endeavour.

Measuring is basically used to monitor a process or operation, or as well as the controlling process.

Ex: Thermometers, barometers, anemometers are used to indicate the environmental conditions.

Similarly water, gas and electric meters are used to keep track of the quantity of the commodity used, and also special monitoring equipment are used in hospitals.

The basic concern of any measurement is that the measuring instrument should not affect the quantity being measured.

* Performance Characteristics :

The performance characteristics of an instrument is essential for selecting the most suitable instrument for specific measuring jobs. It consists of two basic characteristics - Static & dynamic.

*. Static Characteristics :

The static characteristics of an instrument are, in general, considered for instruments which are used to measure an unvarying process condition.

All the static performance characteristics are obtained by one form or another of a process called Calibration.

There are a number of related definitions which are described below. (2)

(1) Accuracy : The degree of exactness (closeness) of a measurement compared to the expected (desired) value.

(2) Resolution : The smallest change in a measured variable to which an instrument will respond.

(3) Precision : A measure of the consistency or repeatability of measurements. i.e., precision is the consistency of the instrument output for a given value of input.

(4) Error : The deviation of the true value from the desired value.

(5) Sensitivity : The ratio of the change in output (response) of the instrument to a change of input or measured value.

* Error in measurement :

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.

$$e = Y_n - X_n$$

where e = absolute error

Y_n = expected value

X_n = measured value

$$\therefore \% \text{ Error} = \frac{\text{Absolute value}}{\text{Expected value}} \times 100 = \frac{e}{Y_n} \times 100$$

$$\therefore \% \text{ Error} = \left[\frac{Y_n - X_n}{Y_n} \right] \times 100$$

It is more frequently expressed as accuracy rather than error. (3)

$$\therefore A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right| ; A = \text{relative accuracy}.$$

Accuracy is expressed as % accuracy

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

$$a = A \times 100\% ; \text{ where } a \text{ is the \% accuracy.}$$

* Types of errors:

Three categories of errors occur in measurements and they are:

- (1) Gross errors
- (2) Systematic errors
- (3) Random errors

(1) Gross errors:

These errors are basically human errors caused by the operator or person using the instrument.

The different types of gross errors are:

- (i) Taking wrong readings
- (ii) Reading with parallax error
- (iii) Incorrect adjustments of zero and full-scale adjustments
- (iv) Improper applications of instruments. (using 0-100V voltmeter to measure 0.1V)
- (v) Wrong computation (i.e, when power is to be determined, 'V' & 'I' are measured, if the computation goes wrong, even though 'V' & 'I' are correct the measurement of power will go wrong, thus wrong computation can result in error)

(2) Systematic error:

- (i) Instrumental error: Due to shortcomings of the instruments.
- (ii) Environmental error: Due to external conditions affecting the instrument

(3) Random errors :

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Good errors and Systematic errors can be avoided by taking proper care, some other errors can also occur in measurements. No specific reason can be assigned and precautions could be taken to avoid these errors.

Such errors are categorized as random errors.

Ex: Noise that is impractical can cause random errors in measurements. To avoid these errors, frequency of measurement is to be increased.

* Dynamic characteristics :

The dynamic characteristics of the instrument are important if the instrument is to be used for varying or dynamic inputs.

The inputs specified are as follows:

(1) Step input (2) Ramp (3) Sinusoidal input

In practice the parameters may vary at different rates and it is not possible to study or design instruments for these specific variations.

* Repeatability :

It is defined as the variation of scale reading when the input is randomly applied (with time gaps).

* Reproducibility :

It is the scale reading over a given period of time when the input is constantly applied.

Ex: If 10V is applied as input, and the input is continuously connected to the instrument, the output reading of the voltmeter must be 10V only. If it fluctuates, and reading changes, reproducibility of the instrument is poor. This parameter indicates the steady-state response of the instrument.

*. Fidelity :

It is ^{the} quality of indication by the instrument with regard to the changes in input. This is indicated as dynamic error.

(5)

*. Lag :

speed of response of the instrument is referred in terms of lag.

If the input is changing rapidly, output must also change exactly at the same rate in an ideal case.

The time delay in the output to change with the input is termed as lag.

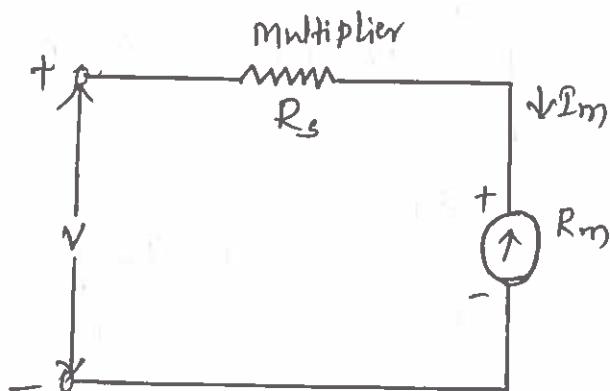
*. Measuring Instruments :

To establish uniformity in measurement and relative comparison and understanding, measurement standards have been established by International Convention.

The fundamental unit of mass in the International System (SI) is the kilogram.

① DC Voltmeter :

By adding a series resistance (multiplier), the D'Arsonval movement can be converted into a dc voltmeter. The series resistance (R_s) or multiplier limits the current through the meter, so as not to exceed the full-scale deflection current I_{FSD} as shown below.



The value of the multiplier resistance required to extend the 6
voltage range is calculated as follows:

I_m = deflection current of the movement

R_m = internal resistance of the movement

R_s = multiplier series resistance

V = full-range voltage of the instrument

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

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

NOTE:

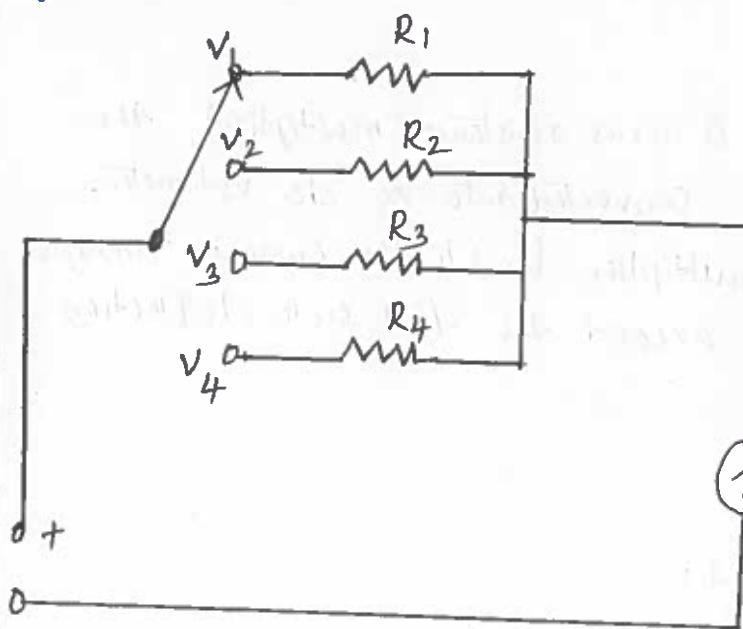
→ DC voltmeters are available upto 500V.

→ The multiplier resistance is built into the meter.

→ For higher voltage ranges, R_m is mounted separately.

* Multirange Voltmeter:

A voltmeter with different ranges can be obtained by connecting a number of multipliers as shown below,



R_1 is the multiplier resistance for the voltage range V_1

R_2 is the multiplier resistance for the voltage range V_2 and so on.

To determine R_1, R_2, R_3, \dots Using KVL we can write.

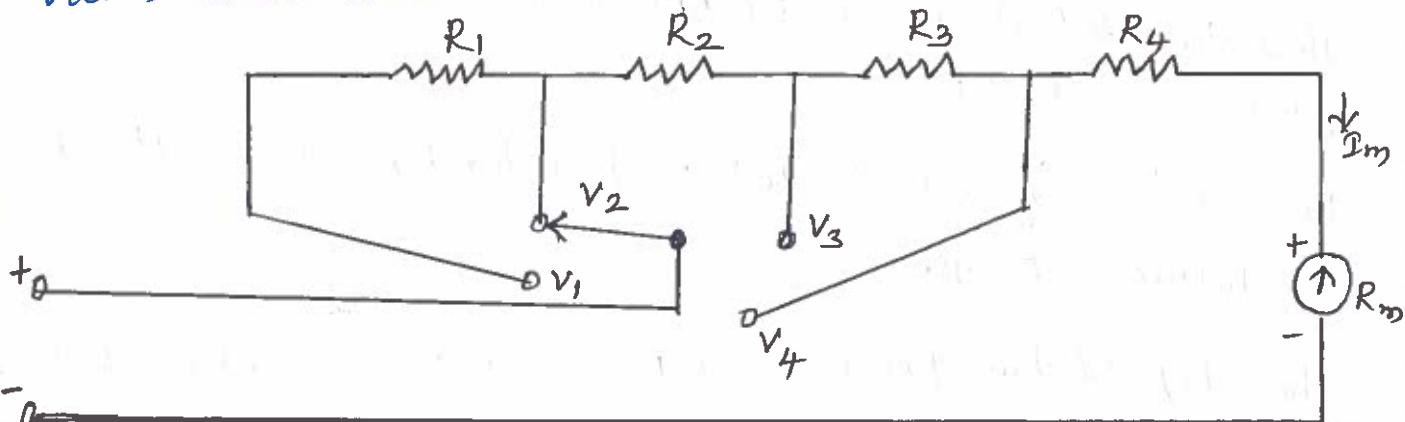
$$V_1 - I_m R_1 - I_m R_m = 0.$$

$$\text{or } V_1 = I_m (R_1 + R_m)$$

$$\text{similarly } V_2 = I_m (R_2 + R_m)$$

$$V_n = I_m (R_n + R_m)$$

The multiplier resistances can also be connected in series (7) as shown below. The advantage with this system is that all multipliers except the first have the standard prevention values and can be obtained commercially.



- NOTE :
- 1.) The resistance offered by the voltmeter for each range is expressed as the sensitivity of the voltmeter.
 - 2.) An ideal voltmeter should have infinite input resistance.
 - 3.) When voltmeter is connected across two points, it ~~shorts~~ shunts the circuit or source as a result the net resistance decreases in turn the voltage measured will be less than the actual voltage, this is known as loading effect.

* D'Arsonval Movement:

The Permanent Magnetic Movement Coil (PMMC) was invented by D'Arsonval, hence it is also called D'Arsonval movement.

This system has a permanent magnet in the horseshoe form with soft pole pieces attached to it.

Between the pole pieces is a cylinder of soft iron. It provides uniform magnetic field in the air gap between the pole pieces and the cylinder.

The coil is wound on a light metal frame and it mounted so

so that it can rotate freely in the air gap. (8)

The pointer attached to the coil moves over a graduated scale which indicates the angular deflection of the coil and therefore the current through the coil.

Thus the deflecting torque (T_d) is produced by the Electro magnetic (EM) effect.

The controlling torque (T_c) is provided by two phosphor-bronze conductive springs.

The top of the pivot may have radius from 0.01 to 0.02 mm.

The deflecting torque T_d is directly proportional to the coil current.

$$T_d \propto I$$

The power requirement of the movement will be in the range 25 - 200 mW. The accuracy of the instrument is of the order of 2 - 5% of full-scale reading (FSR).

~~Demerits~~

Demerit: This instrument is not suitable for AC measurements.

* Construction & principle of operation of PMMC:

(3)

* Construction:

PMCC \Rightarrow Permanent Magnetic Moving Coil.

\rightarrow Below figure shows a permanent horse-shoe magnet with soft iron pole pieces attached to it.

\rightarrow Between the pole pieces is a cylinder of soft iron which serves to provide a uniform magnetic field in the air gap between the pole pieces and the cylindrical core.

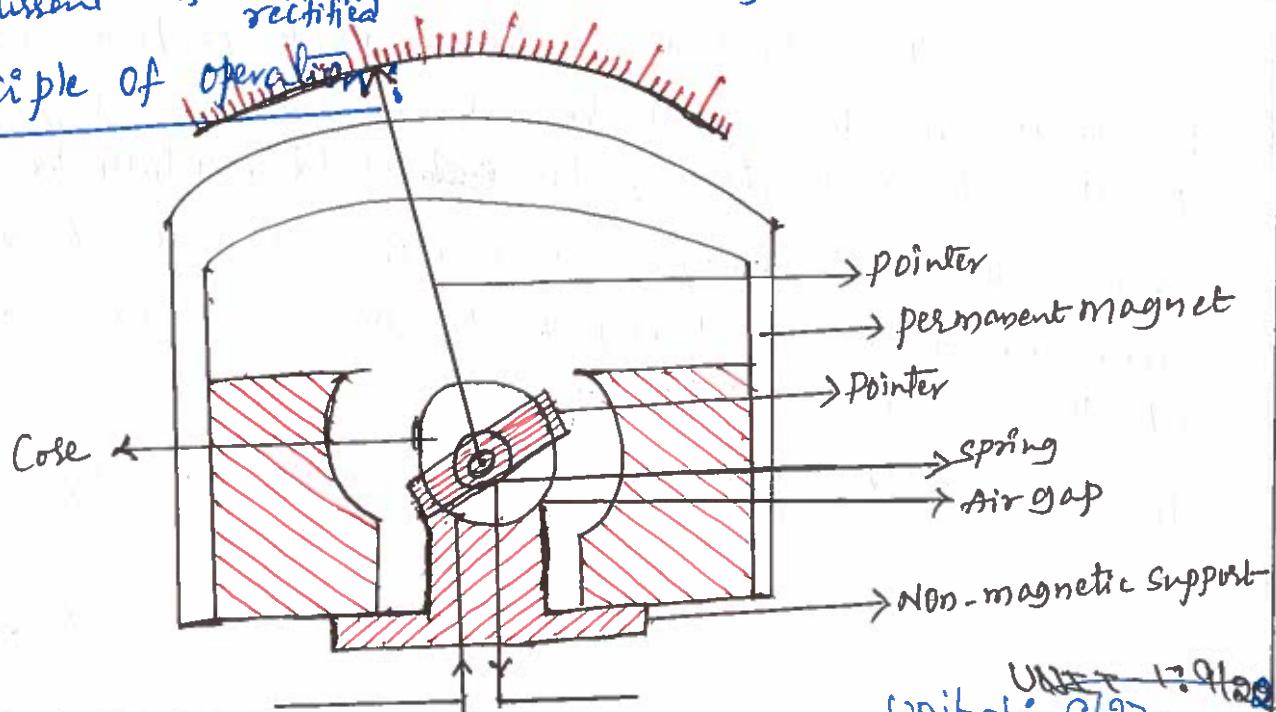
\rightarrow The coil is wound on a light metal frame and is mounted so that it can rotate freely in the air gap.

\rightarrow The pointer attached to the coil moves over a graduated scale and indicates the angular deflection of the coil, which is proportional to the current flowing through it.

\rightarrow If low frequency AC is applied to the movable coil, the deflection of the pointer would be upscale for half the cycle of the input waveform and down scale for the next half.

\rightarrow The PMMC is not suitable for AC measurements, unless the current is ~~rectified~~ rectified before reaching the coil.

* Principle of operation:



- This instrument contains a coil suspended in the magnetic field of a permanent magnet in the shape of a horse-shoe.
- The coil is suspended so that it can rotate freely in the magnetic field.
- When the current flows in the coil, torque gets developed and causes the coil to rotate.
- The Electro magnetic (EM) torque is counter balanced by a mechanical torque of control springs attached to the movable coil.
- The balance of torques and the angular position of the movable coil is indicated by a pointer against a fixed reference called a scale.
- The equation for the developed torque is given by,

$$\tau = B \times A \times I \times N$$

where τ = torque, (Newton-meter)

B = flux density in the air gap (Wb/m^2)

A = effective coil area (m^2)

N = Number of turns of wire of the coil.

I = Current in the movable coil (amperes)

The above eqn shows that the developed torque is proportional to the flux density of the field in which the coil rotates.

Since both flux density and coil constants are fixed for a given instrument, the developed torque is a direct indication of the current in the coil.

The pointer deflection is used to measure current.

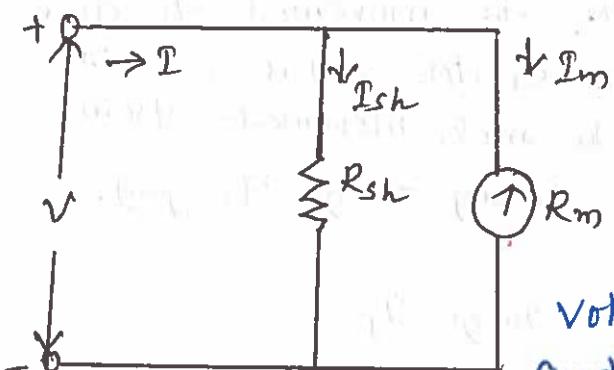
* DC Current Meters :

(10)

The permanent magnetic moving coil (PMMC) constitutes the basic movement of a DC ammeter.

Since the coil winding of a basic movement is small and light, it can carry only 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 as shown below,



The shunt resistance (R_{sh}) can be calculated by using conventional circuit analysis.

R_{sh} is in parallel with R_m , the voltage drop across the shunt (R_{sh}) and movement (R_m) must be same.

$$\therefore V_{sh} = V_m$$

$$I_{sh} R_{sh} = I_m R_m \quad [\because V = IR]$$

$$\therefore R_{sh} = \frac{I_m R_m}{I_{sh}} \rightarrow (1)$$

But according to KCL, $I = I_{sh} + I_m$

$$I_{sh} = I - I_m \rightarrow (2)$$

Substituting the value of I_{sh} from eqn (1) we get,

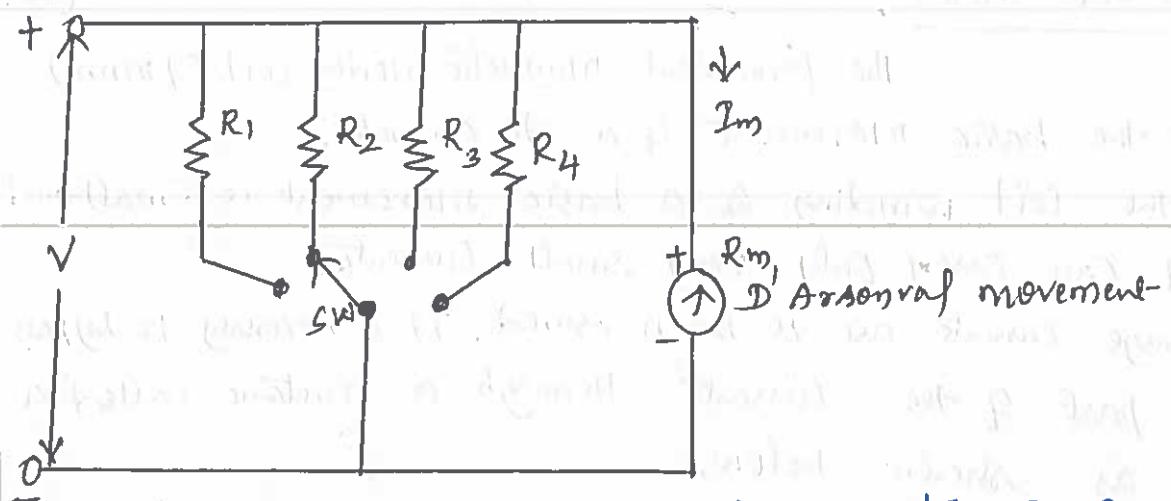
$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

* Multirange ammeters :

The current range of DC ammeter may be further extended by a number of shunts, selected by a range switch. Such a meter is called a multirange ammeter.

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The circuit has 4 shunt resistors R_1, R_2, R_3 and R_4 which are placed in parallel with the movement to give four different ranges of current. Switch SW is a multi optional switch and it protects the meter movement from being damaged without shunt during range changing.

$$\therefore R_1 = \frac{I_m R_m}{I_1 - I_m}; \text{ for current range } I_1$$

$$R_2 = \frac{I_m R_m}{I_2 - I_m}; \text{ for current range } I_2$$

$$\vdots$$

$$R_n = \frac{I_m R_m}{I_n - I_m}; \text{ for current range } I_n$$

Multirange Ammeters are used for ranges upto 50 A.

R_m = internal resistance of the movement

I_{sh} = shunt current

I_m = full scale deflection current of the movement

I = full scale current of the ammeter + shunt (i.e., total current)

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

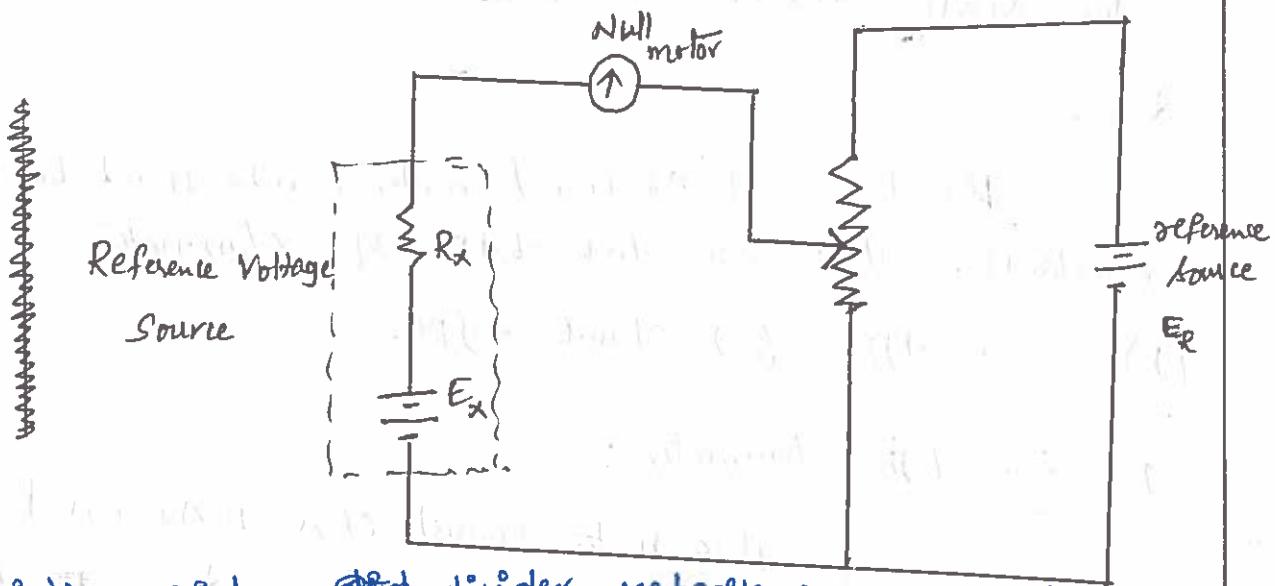
* AC Voltmeters :

(12)

The current to be measured is passed through a series resistor of a suitable value for the current scale. The voltage drop across the resistor can be measured by the voltmeter.

(i) ^{DC} Differential Voltmeter :

It is one of the most accurate means of measuring an unknown voltage. Here the unknown voltage is compared to a known voltage. It is also called potentiometric voltmeter, it is as shown below

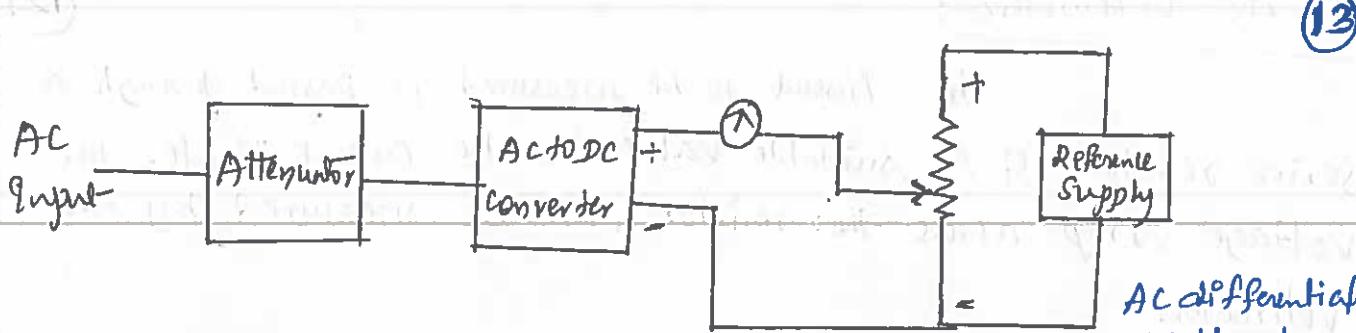


A precision resistance ~~divider~~ network is used to divide down an accurately known reference voltage,

The divider is adjusted until the output voltage equals the unknown voltage. The multimeter indication is proportional to the difference of the potentials between the reference voltage and the unknown voltage source.

To measure high voltages, a high-voltage reference supply can be used.

UNIT-1: Block 2



AC differential voltmeter is a modification of DC differential voltmeter.

The AC-to-DC converter gives an average value of the voltage. Therefore, this voltmeter gives an average value of the AC input. The meter can be calibrated to give the rms value and the scale factor is 1.11.

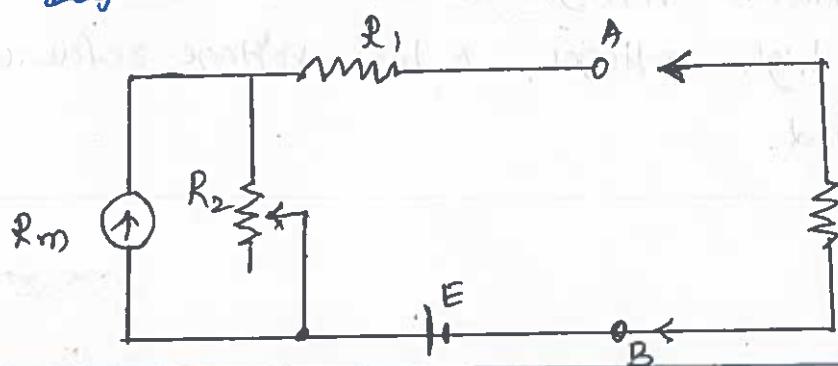
* Ohmmeter :

The basic D'Arsonval meter can be used to measure resistance. There are two types of Ohmmeter.

(1) Series type (2) Shunt type.

(1) Series type ohmmeter :

This meter consists of a D'Arsonval movement connected in series with a resistance and a battery to a pair of terminals where the unknown resistance R_x is connected. The current passing through the meter depends on the value of R_x . Therefore the deflection of the pointer depends is proportional to R_x .

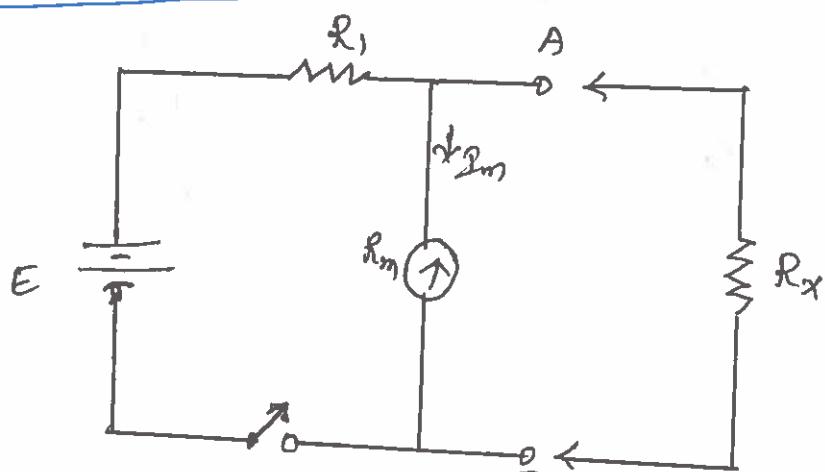


- R_1 = Current-limiting resistor
- R_2 = zero adjust resist.
- E = Internal battery
- R_m = internal resistance of D'Arsonval movement
- R_x = Unknown resistor

The disadvantage with the series type ohmmeter is (14) that it does not compensate for the decrease in battery voltage due to aging (process of becoming older).

As the source voltage decreases, the full scale current decreases. maximum deflection is obtained for zero ohms.

(2) Shunt-type ohmmeter:



The battery (E) is in series with the adjustable resistance (R_s) and the D'Arsonval movement. The unknown resistance is connected across terminals A and B in parallel with the meter.

An On/Off switch is to be provided to disconnect the battery from the circuit when not being used.

If $R_x = 0$, the meter current is zero. If $R_x \neq 0$ the current finds a path only through the meter.

The meter can be read full scale by adjusting R_s , thus the meter deflection is proportional to the value of the unknown resistance R_x .

This meter is more suitable for measuring low values of resistances, up to $100\text{ k}\Omega$.

Application: It is used in laboratories.

* Multimeters :

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.

Below figure shows a meter consisting of a DC milliammeter, a DC voltmeter, an AC voltmeter, a microammeter and an ohmmeter.



MULTIMETER

4.25

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

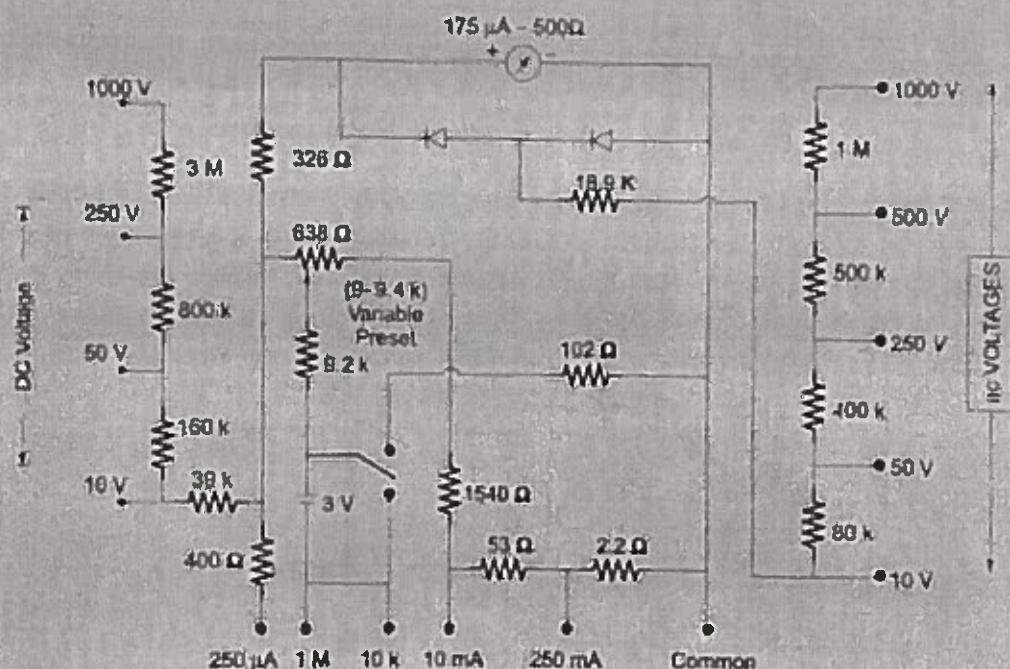


Fig. 4.35 Diagram of a multimeter

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.

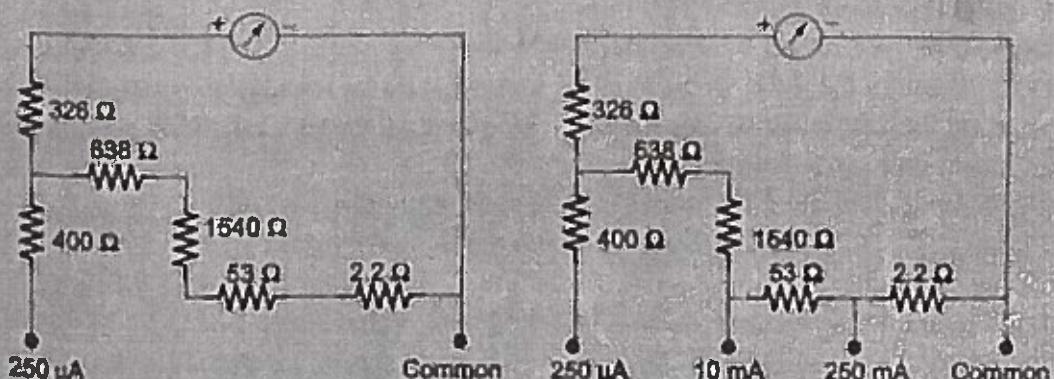


Fig. 4.38 Microammeter section of a multimeter

Fig. 4.37 dc ammeter section of a multimeter

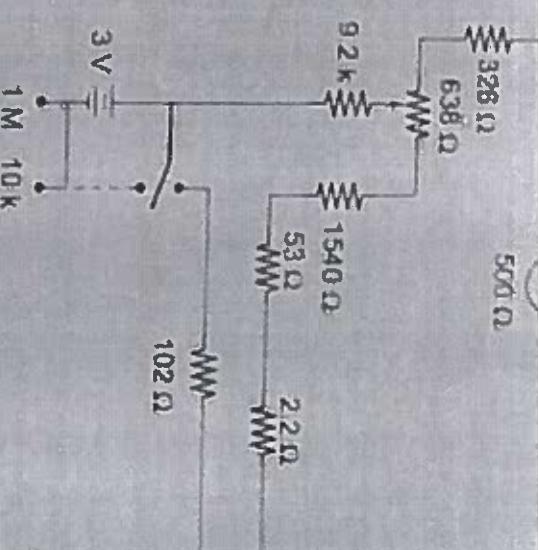


Fig. 4.40 Ohmmeter section of a multimeter

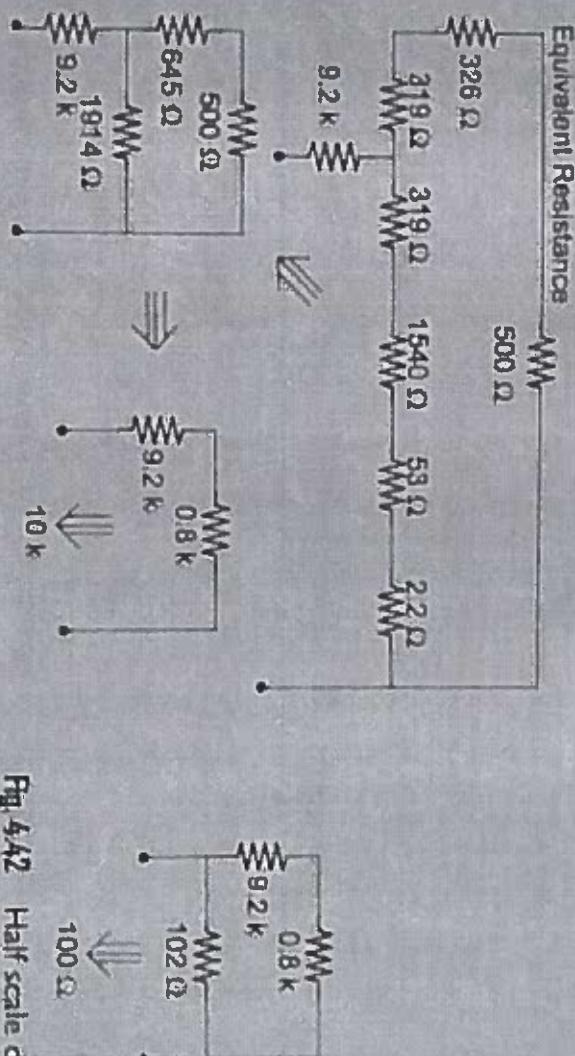


Fig. 4.41 Equivalent resistance on 1 MΩ range

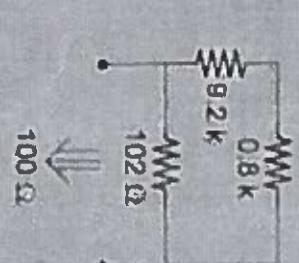


Fig. 4.42 Half scale deflection is 100Ω on 10k range

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

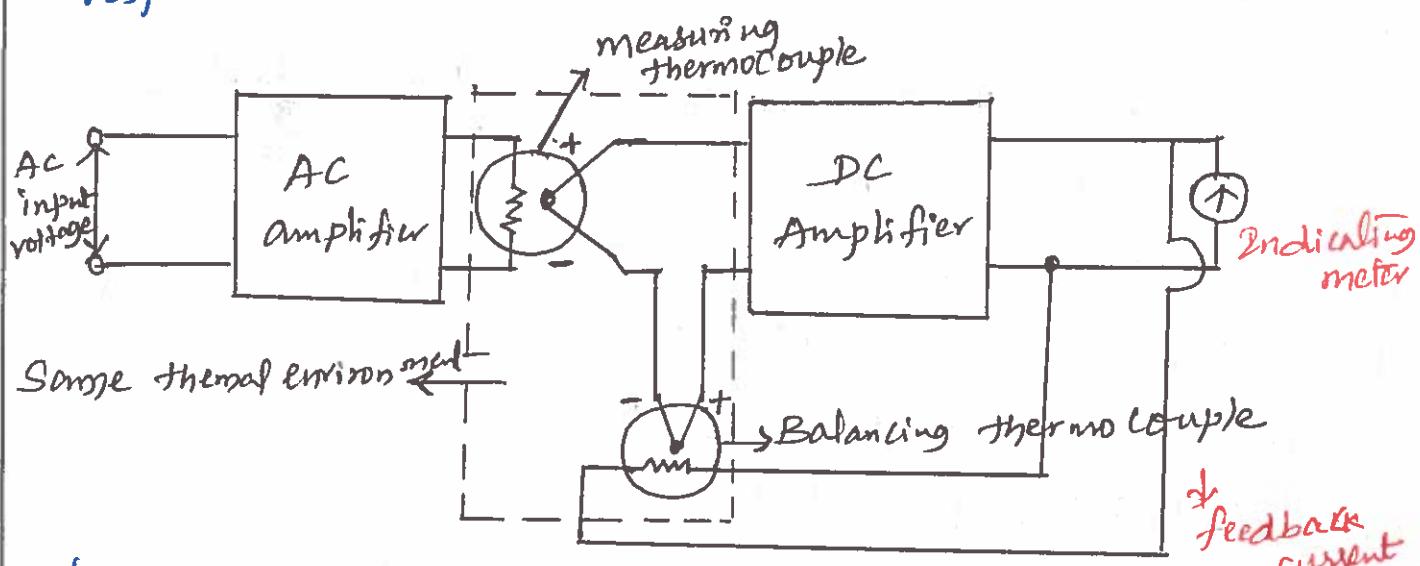
* True RMS Responding Voltmeter:

(16)

RMS voltmeter measures complex waveforms most accurately. This instrument produces a meter indication by sensing waveform heating power, which is proportional to the square of the rms value of the voltage.

This heating power can be measured by amplifying and feeding it to a thermocouple, whose output voltage is then proportional to the E_{rms} .

Below figure shows the block diagram of a true rms responding voltmeter.



Thermocouples are non-linear devices.

The effect of non-linear behaviour of the thermocouple in the input circuit (measuring thermocouple) is cancelled by similar non-linear effects of the thermocouple in the feedback circuit (balancing thermocouple). The two couples form part of a bridge in the input circuit of a dc amplifier.

The unknown ac voltage is amplified and applied to the heating element of the measuring thermocouple. The application of heat produces an output voltage that upsets the balance of the bridge.

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The DC amplifier amplifies the unbalanced voltage, and this voltage is fed back to the heating element of the balancing thermocouple, which heats the thermocouple. So that the bridge is balanced again i.e., outputs of both the thermocouples are same. (17)

At this instant, the AC current in the input thermocouple is equal to the DC current in the heating element of the feedback thermocouple.

This DC current is therefore directly proportional to the effective(rms) value of the input voltage, and is indicated by the meter in the output circuit of the DC amplifier.

* Specifications of Instruments :

Specifications of DC Ammeter (Analog type) / AC Voltmeter (analog)

Type : DC Ammeter / Analog Voltmeter

DC Current range : 0 - 100mA / 0 - 100V

Resolution : 10mA / 1V

Accuracy : $\pm 1\%$ / $\pm 1\%$

Overload protection : available

Operating temperature : 0 to $+50^{\circ}\text{C}$ / 0 to $+50^{\circ}\text{C}$

Humidity : 80% RH / 80% RH

Physical dimensions : Circular 6cm diameter 4cm height / 6 cms X 4 cms X 8 cms

NOTE: For AC Voltmeter (analog)

Input impedance : $10 \text{ M}\Omega$ in parallel with 100 PF

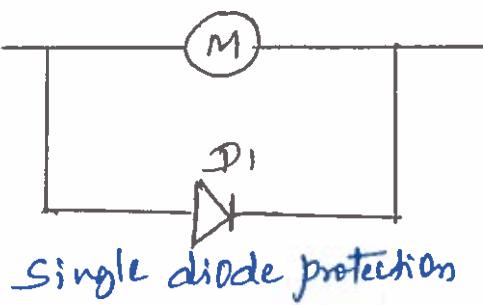
* Meter protection :

(18)

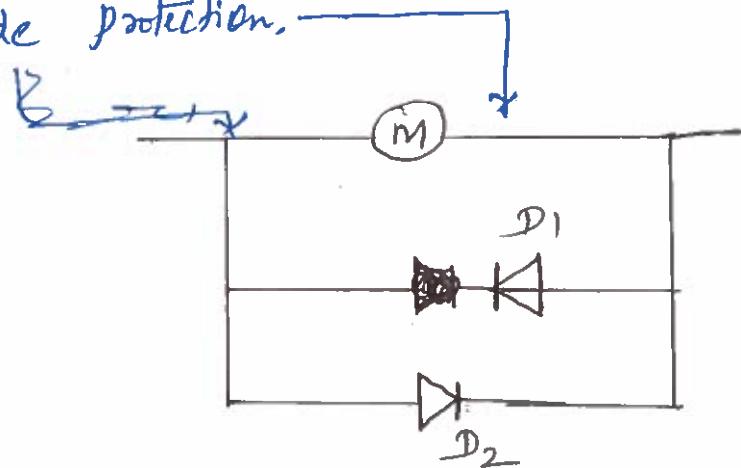
The DC meters are usually protected by connecting a diode across the meter as shown below. If a silicon diode is used the voltage drop across the meter is maintained.

At 0.6V or just before the cut-in voltage (V_S) of the diode when the input exceeds the maximum value, the diode starts conducting as its cut-in voltage value is realised due to the excess input. Therefore the current is diverted through the diode protecting the meter.

If only one diode is used it is called single diode protection. If two diodes are used for both half cycles it is called double diode protection.



Single diode protection



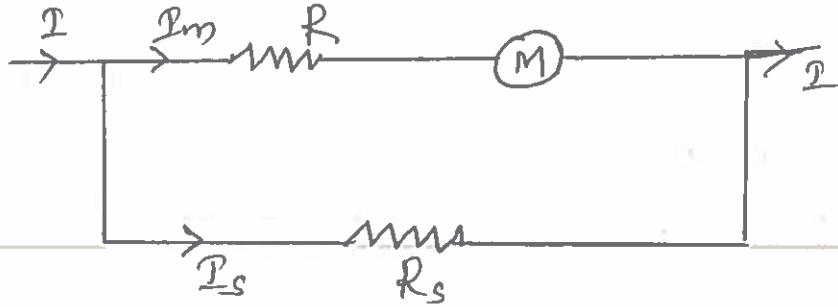
* Extension of range :

The range of measuring instruments can be extended suitably by connecting a resistance in series or shunt as the case may be.

If the range of the ammeter is to be extended, a shunt resistance of a value lower than the meter resistance is connected in parallel with the meter as shown.

The value of the resistance to be connected depends on the current to be measured.

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let,

I = total current to be measured

I_s = Current through the Shunt

I_m = maximum current that can be permitted through the meter

R = resistance of the meter

R_s = shunt resistance

$$I = I_m + I_s$$

$$I_m = I - I_s \quad \text{or} \quad I_s = I - I_m$$

$$I_s R_s = I_m R \quad [V_s = V_m]$$

$$\therefore R_s = \frac{I_m R}{I_s} = \frac{I_m R}{(I - I_m)}$$

$$\therefore R_s = \frac{R}{\left(\frac{I}{I_m} - 1\right)}$$

The ratio of the total current to the instrument current I/I_m is called the multiplying power of the shunt.

This is usually expressed as N .

$$\therefore R_s = \frac{R}{(N-1)} \quad \text{or} \quad N = 1 + \frac{R}{R_i}$$

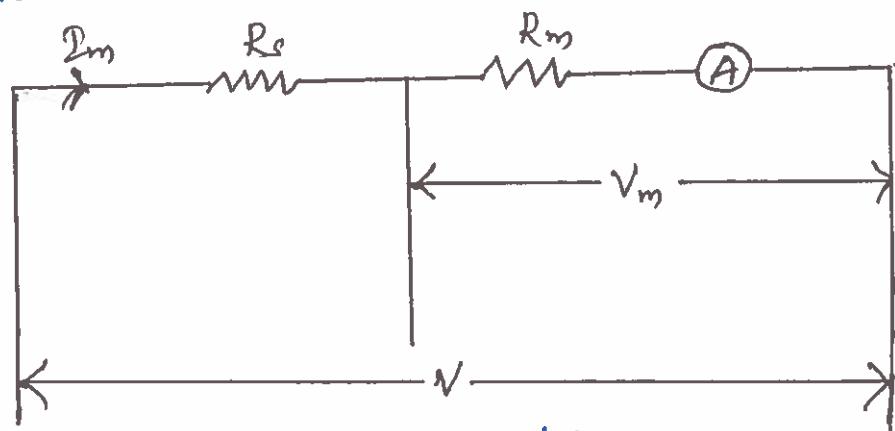
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The shunts are available commercially, they consist of one or more thin strips of manganin, the ends of which are soldered to two heavy copper blocks.

A special pair of leads are usually supplied with ammeters intended to be used.

Manganin has low temperature coefficient, therefore it will not get heated up. The shunts will have good heat radiation ability.

The range of voltmeters can be extended in a similar way by connecting a high resistance in series with the meter, so that only the permissible maximum current passes through the meter as shown below.



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

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

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

$$\therefore R_s = \left(\frac{V}{I_m} + R_m \right)$$

let,

I_m = maximum current that can pass through the meter.

V_m = maximum voltage range of the meter

R_m = meter resistance

R_s = series resistance to be connected to extend the range of meter

V = extended voltage range

Thus, the value of R_s to be connected in series with the meter to extend its voltage range from V_m to V can be calculated.

