

TOPIC 2

DC METER

2.1 BASIC PRINCIPLE OF ANALOG METER

A meter is any device built to accurately detect and display an electrical quantity in a form readable by a human being. In the analysis and testing of circuits, there are meters designed to accurately measure the basic quantities of voltage, current, and resistance.

The action of all analogue meters (ammeters and voltmeters) depends upon a deflecting torque produced by an electric current. In an ammeter, the torque is produced by the current to be measured or by a definite fraction of it. In a voltmeter, it is produced by a current that is proportional to the voltage to be measured. Ammeters and voltmeters are essentially current measuring devices.

2.1.1 Construction Of Permanent Magnet Moving Coil (PMMC)

The PMMC instrument is the most accurate types and can be used for DC measurement only. The action of most commonly DC meter is based on the fundamental principle of the motor. The motor action is produced by the flow of a small current through a moving coil which is positioned in the field of a permanent magnet.

The basic moving coil system is often called the D'Arsonval galvanometer.

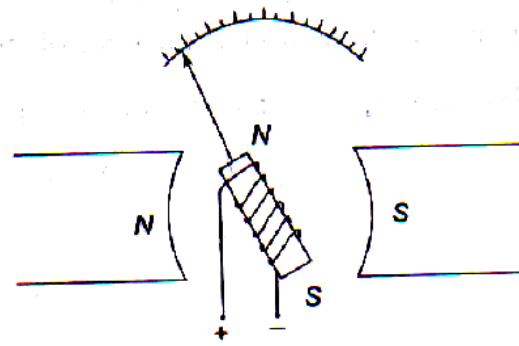


Figure 2.1: D'Arsonval Principle

2.1.2 Principle Operation Of PMMC

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 current flows in the coil, the developed (electromagnetic) torque causes the coil to rotate. The electromagnetic torque is counterbalanced by a mechanical torque of control springs attached to the movable coil. The balance of torques, and therefore the angular position of the movable coil is indicated by a pointer against a fixed reference called a scale.

2.1.3 Deflection Torque

The deflection for developed torque:

Deflection Torque,

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

where τ = torque, Newton-meter (Nm)

N = number of turns of wire of the coil

A = effective coil area, meter square (m^2)

B = flux density in the air gap, Weber per meter square (Wb/m^2)

I = current in the movable coil, amperes (A)

2.1.4 Damping Curve

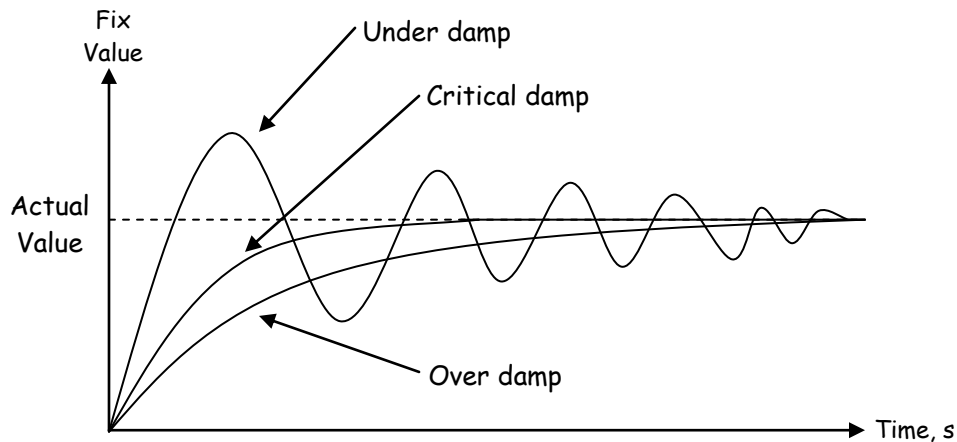


Figure 2.2: Damping Curve

2.1.5 Damping Curve And The Relationship To Moving Coil Needle

- a) Over damp
 - the pointer will move slowly to final value.
 - the measure value will less than expected value.
 - measurement not accurate.
- b) Under damp
 - the pointer will oscillate in long time before it stop.
 - the user difficult to read the measure value accurately.
- c) Critical damp
 - the pointer will stop at absolute value in short time without resonant.
 - accurate and fast.

2.1.6 Compare Common Damping System In Indicating Instrument

The following methods are used to produce torque.

a. Air friction damping

The arrangement consists of a light aluminum piston which is attached to the moving system as shown in the figure below.

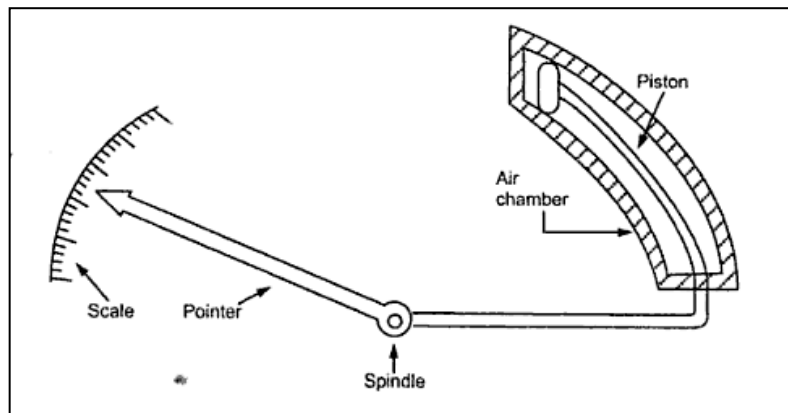


Figure 2.3: Air friction damping

The piston moves in a fixed air chamber. It is closed to one end. The clearance between piston and wall chambers is uniform and small. The piston reciprocates (move backwards and forwards) in the chamber when there are oscillations. When piston moves into the chamber, air inside is compressed and pressure of air developed due to friction opposes the motion of pointer. There is also opposition (resisting) to motion of moving system when piston moves out of the chamber. Thus the oscillations and the overshoot gets reduced due to and fro motion of the piston in the chamber, providing necessary damping torque. This helps in settling down the pointer to its final steady position very quickly.

b. Liquid damping / Fluid Friction Damping

Liquid friction damping may be used in some instruments. The method is similar to air friction damping, only air is replaced by working fluid. The friction between the disc and liquid is used for resisting motion. Damping force due to fluids is greater than that of air due to more viscosity (kelikatan). The disc also called vane.

The arrangement is shown in the figure below. It consists of a vane attached to the spindle which is completely dipped in the oil. The frictional force between oil and the vane is used to produce the damping torque, which resists the oscillating behavior of the pointer.

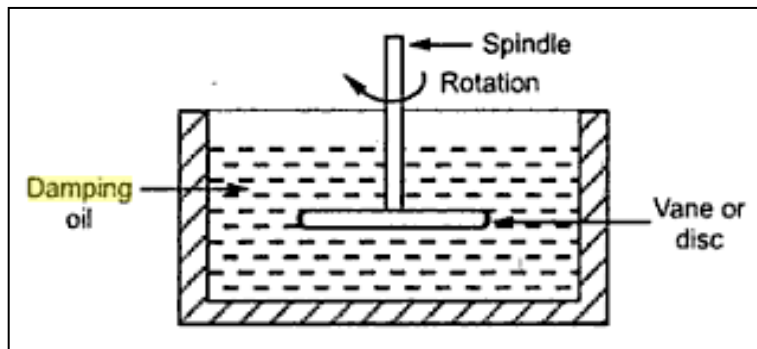


Figure 2.4: Liquid damping

The advantages of this method are :

1. Due to more viscosity of fluid, more damping is provided.
2. The oil can also be used for insulation purposes.
3. Due to up thrust of oil, the load on the bearings is reduced, thus reducing the frictional errors.

The disadvantages of this method are ;

1. This can be only used for the instruments which are in vertical position.
2. Due to oil leakage, the instruments cannot be kept clean.

c. Eddy current damping

In this method, an aluminium disc is connected to the spindle. The arrangement of disc is such that when it rotates, it cuts the magnetic flux lines of a permanent magnet. The arrangement is shown in the figure below.

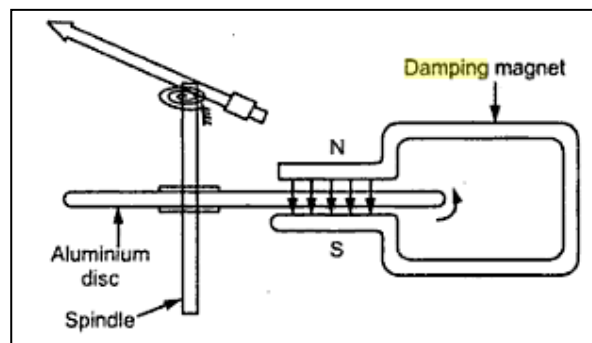


Figure 2.5: Eddy current damping

When the pointer oscillates, aluminium disc rotates under the influence of magnetic field of damping magnet. So disc cuts the flux which causes an induced e.m.f in the disc. The disc is a closed path hence induced e.m.f circulates current through the disc called eddy current. The direction of such eddy current is so as oppose the cause producing it. The cause is relative motion between disc and field. Thus it produces an opposing torque so as to reduce the oscillations of pointer. This brings pointer to rest quickly. This is most effective and efficient method of damping.

2.2 DC VOLTMETER

A dc voltmeter is using for measures the potential difference between two points in a dc circuit or a circuit component. The basic meter movement becomes a dc instrument measuring dc voltage by adding a multiplier resistance forming a millivoltmeter, voltmeter or kilovoltmeter.

2.2.1 DC Voltmeter Circuit

To measure the potential difference between two points in a dc circuit or circuit component, a dc voltmeter is always connected across them with proper polarity.

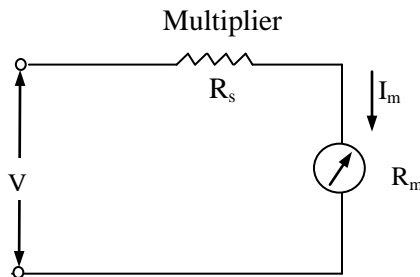


Figure 2.6 : Basic dc meter

2.2.2 Equation For Multiplier Resistor Value In Single Range

The function of the multiplier is to limit the current through the movement so that the current does not exceed the full scale deflection value.

I_m = full scale deflection current of the movement (I_{fsd})

R_m = internal resistance of movement

R_s = multiplier resistance

V = full range voltage of the instrument

From the circuit,

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

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

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

The multiplier limits the current through the movement, so as to not exceed the value of the full scale deflection I_{fsd} .

The above equation is also used to further extend the range in DC voltmeter.

2.2.3 Calculate Multiplier Resistor Value In Single Range

Example 1 :

A basic D'Arsonval movement with a full scale deflection of $50\mu A$ and internal resistance of 500Ω is used as a voltmeter. Determine the value of the multiplier resistance needed to measure a voltage range of 0-10V.

Solution:

$$\begin{aligned} R_s &= \frac{V}{I_m} - R_m = \frac{10}{50\mu} - 500 \\ &= (0.2 \times 10^6) - 500 = 200k - 500 \\ &= 199.5k\Omega \end{aligned}$$

2.2.4 Equation For Multiplier Resistor Value In Two Range Dc Voltmeter

The range of the dc voltmeter can be extended by using number of multipliers and selector switch. Such a meter called **multirange voltmeter** and is shown in the figure below.

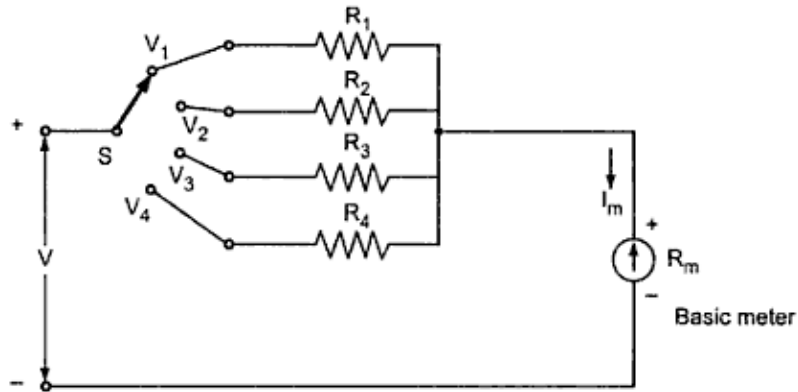


Figure 2.7: Multirange Voltmeter

The R_1, R_2, R_3, R_4 are the four series multipliers. When connected in series with the meter, they can give four different voltage ranges as V_1, V_2, V_3, V_4 . The selector switch S is multiposition switch by which the required multiplier can be selected in the circuit. Thus,

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

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

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

$$R_4 = \frac{V_4}{I_m} - R_m$$

More practical arrangement for multiplier resistance are shown in figure 2.8.

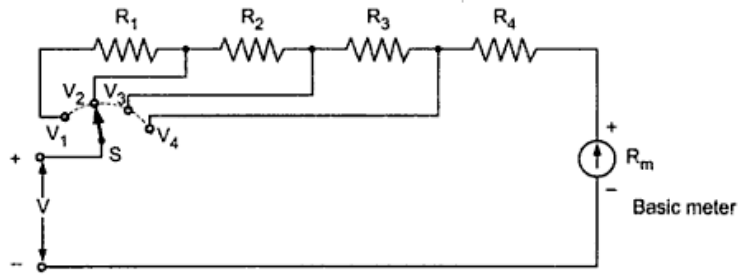


Figure 2.8 : Arrangement for multiplier resistance

In position V_4 , the multiplier is R_4 only. The total resistance of the circuit is R_T .

$$R_T = \frac{V_4}{I_m}$$

$$R_4 = R_T - R_m \quad \dots\dots\dots(1)$$

In the position V_3 , the multiplier is $R_3 + R_4$

$$R_T = \frac{V_3}{I_m}$$

$$R_3 + R_4 = R_T - R_m$$

$$R_3 = R_T - (R_m + R_4) \quad \dots\dots\dots(2)$$

In the position V_2 , the multiplier is $R_2 + R_3 + R_4$

$$R_T = \frac{V_2}{I_m}$$

$$R_2 + R_3 + R_4 = R_T - R_m$$

$$R_2 = R_T - (R_m + R_3 + R_4) \quad \dots\dots\dots(3)$$

In the position V_1 , the multiplier is $R_1 + R_2 + R_3 + R_4$

$$R_T = \frac{V_1}{I_m}$$

$$R_1 + R_2 + R_3 + R_4 = R_T - R_m$$

$$R_1 = R_T - (R_m + R_2 + R_3 + R_4) \dots\dots\dots(4)$$

2.2.5 Calculate Multiplier Resistor Value In Two Range Dc Voltmeter

Example 2 :

A basic D'Arsonal movement with an internal resistance 50Ω and full scale deflection current of 2mA is to be used as a multirange voltmeter. Design the series string of multipliers to obtain the voltage range of $0\text{-}10\text{V}$, $0\text{-}50\text{V}$, $0\text{-}100\text{V}$, $0\text{-}500\text{V}$.

Solution :

The arrangement of voltmeter as below.

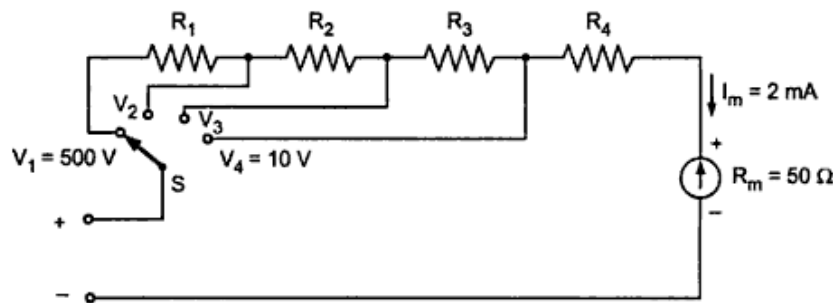


Figure 2.9: Multirange voltmeter

For a meter, $R_m = 50\Omega$ and $I_m = 2\text{mA}$

For position $V_4 = 10V$, series multiplier is R_4

$$R_4 = \frac{V_4}{I_m} - R_m = \frac{10}{2 \times 10^{-3}} - 50$$

$$= 4.95k\Omega$$

In the position $V_3=50V$, series multiplier is $R_3 + R_4$

$$R_3 + R_4 = \frac{V_3}{I_m} - R_m$$

$$R_3 = \frac{50}{2 \times 10^{-3}} - 50 - 4.95k$$

$$= 20k\Omega$$

In the position $V_2 =100V$, series multiplier is $R_2 + R_3 + R_4$

$$R_2 + R_3 + R_4 = \frac{V_2}{I_m} - R_m$$

$$R_2 = \frac{100}{2 \times 10^{-3}} - 50 - 4950 - 20000$$

$$= 25k\Omega$$

In the position $V_1= 500V$, multiplier is $R_1 + R_2 + R_3 + R_4$

$$R_1 + R_2 + R_3 + R_4 = \frac{V_1}{I_m} - R_m$$

$$R_1 = \frac{500}{2 \times 10^{-3}} - 50 - 4950 - 25000 - 20000$$

$$R_1 = 200k\Omega$$

Thus R_1 , R_2 , R_3 , R_4 forms a series string of multipliers.

Sensitivity of Voltmeter

The sensitivity of the voltmeter is defined as,

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

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

Internal resistance of voltmeter = Maximum voltage (range) × Sensitivity in Ω/V

Consider the practical multirange voltmeter circuit below by using sensitivity method of calculating the multiplier resistance.

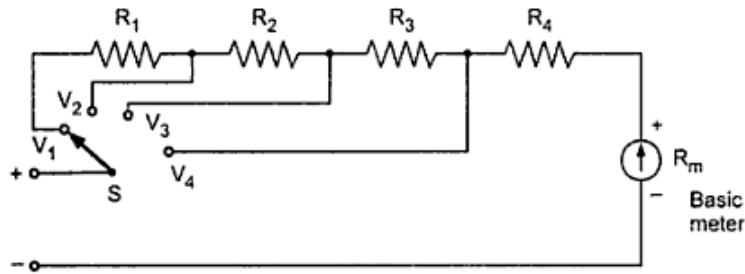


Figure 2.10: Multirange voltmeter

Let S = sensitivity rating in Ω/V

R_m = internal resistance of basic meter or coil

Then the multiplier resistance can be obtained as,

$$R_1 = S V_1 - (R_m + R_2 + R_3 + R_4)$$

$$R_2 = S V_2 - (R_m + R_3 + R_4)$$

$$R_3 = S V_3 - (R_m + R_4)$$

$$R_4 = S V_4 - R_m$$

Where V_1 , V_2 , V_3 and V_4 are the required voltage ranges.

Example 3 :

Solve the Example 2 by using sensitivity method.

Solution :

The basic meter has $R_m = 50\Omega$ and $I_m = 2mA$

$$\text{Now } S = \frac{1}{I_m} = \frac{1}{2 \times 10^{-3}} = 500\Omega/V$$

While $V_1 = 500V$, $V_2 = 100V$, $V_3 = 50V$, $V_4 = 10V$

$$\begin{aligned} R_4 &= S V_4 - R_m \\ &= (500 \times 10) - 50 = 4.95k\Omega \end{aligned}$$

$$\begin{aligned} R_3 &= S V_3 - (R_m + R_4) \\ &= (500 \times 50) - (50 + 4.95k) = 20k\Omega \end{aligned}$$

$$\begin{aligned} R_2 &= S V_2 - (R_m + R_3 + R_4) \\ &= (500 \times 100) - (50 + 20k + 4.95k) = 25k\Omega \end{aligned}$$

$$\begin{aligned} R_1 &= S V_1 - (R_m + R_2 + R_3 + R_4) \\ &= (500 \times 500) - (50 + 25k + 20k + 4.95k) = 200k\Omega \end{aligned}$$

2.2.6 Accomplish Voltage Measurement In A Simple Circuit Using Two Range Dc Voltmeter

1. The range of a voltmeter can be extended to measured high voltages, by using a high voltage probe or by using an external multiplier resistor as shown in figure 2.11.

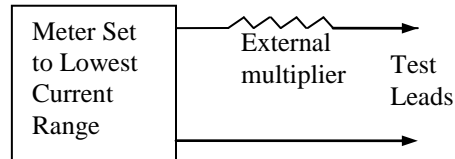


Figure 2.11: Extending voltage range

2. In most meters the basic movement is used on the lowest current range.
3. Values for multipliers can be determined using the procedure above.
4. The basic meter movement can be used to measure very low voltages.

2.2.7 LOADING EFFECT IN DC VOLTMETER

1. When selecting a meter for a certain voltage measurement, it is important to consider the sensitivity of a dc voltmeter.
2. A low sensitivity meter may give an accurate reading when a measure voltage in a low resistance circuit, but will produce inaccurate reading in high resistance circuit.
3. The voltmeter is always connected across two points between which the potential difference is to be measured.
4. If it is connected across a low resistance then as voltmeter resistance is high, most of the current will pass through a low resistance and produce the voltage drop, the accurate reading will obtain.

5. But if the voltmeter is connected across the high resistance then due to two high resistances in parallel, the device will almost divide equally through the two paths. Thus the meter will record the voltage drop across the high resistance which will be much lower than the true reading.
6. Thus the low sensitivity instrument when used in high resistance circuit gives a lower reading than the true reading. This is called **loading effect** of the voltmeters. It is mainly caused due to low sensitivity instruments.

2.2.8 Investigate Loading Effect In Voltage Measurement By Connecting Dc Voltmeter To Difference Load

Example 4 :

The figure 2.12 show a simple series circuit of R_1 and R_2 connected to a 250V dc source. If the voltage across R_2 is to be measured by the voltmeters having

- i. A sensitivity of $500 \Omega/V$
- ii. A sensitivity of $10000 \Omega/V$

Find which voltmeter will read more accurately. Both the meters are used on the 150V range.

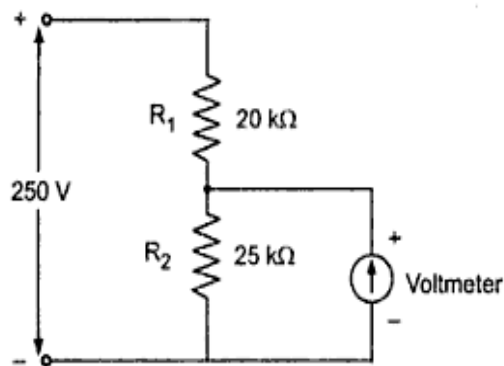


Figure 2.12

Solution :

By the voltage divider rule, the voltage across R_2 is,

$$V = \frac{250}{(20k + 25k)} \times 25k$$

$$= 138.88V$$

This is the true voltage across R_2 .

Case i) $S = 500\Omega/V$

The voltmeter resistance will be,

$$R_v = S \times V$$

$$= 500 \times 150$$

$$= 75k\Omega$$

$$R_{eq} = R_2 \parallel R_v$$

$$= \frac{25k \times 75k}{25k + 75k}$$

$$= 18.75 k\Omega$$

Hence, the voltage across R_{eq} is,

$$V = \frac{R_{eq}}{(R_{eq} + R_1)} \times 250$$

$$= \frac{18.75k}{(18.75k + 20k)} \times 250$$

$$= 120.97 V$$

Thus first voltmeter will read 120.97 V.

Case ii) $S = 10000 \Omega/V$

The voltmeter resistance will be

$$\begin{aligned} R_v &= S V \\ &= 10000 \times 150 \text{ as voltage range } 150V \\ &= 1.5 \text{ M}\Omega \end{aligned}$$

$$\begin{aligned} R_{eq} &= R_2 \parallel R_v \\ &= \frac{25 \times 1.5 \times 10^6 \times 10^3}{(25 \times 10^3 + 1.5 \times 10^6)} \\ &= 24.59 \text{ k}\Omega \end{aligned}$$

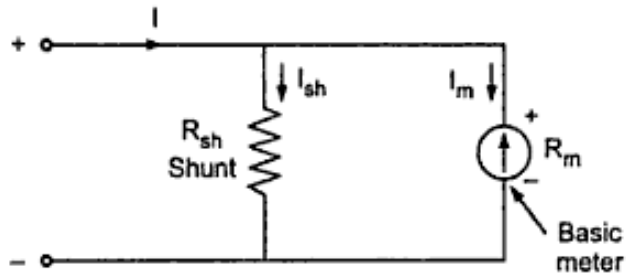
Hence the voltage across R_{eq} is,

$$\begin{aligned} V &= \frac{R_{eq}}{(R_{eq} + R_1)} \times 250 \\ &= \frac{24.59 \text{ k}}{(24.59 \text{ k} + 20 \text{ k})} \times 250 \\ &= 137.87 \text{ V} \end{aligned}$$

Thus the second voltmeter read more accurately. Thus the high sensitivity voltmeter gives more accurate reading, though the voltage range for both the meters is same.

2.3 DC AMMETER

2.3.1 Basic DC ammeter circuit (Single Range)



R_m = internal resistance of coil

R_{sh} = shunt resistance

I_m = full scale deflection current

I_{sh} = shunt current

Figure 2.13

2.3.2 Derive Equation For Shunt Resistor In Single Range DC Ammeter

From the circuit above,

$$I = \text{total current}$$

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

As the two resistances R_m and R_{sh} are in parallel, the voltage drop across them is same.

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

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

But $I_{sh} = I - I_m$

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

$$R_{sh} = \frac{R_m}{m - 1} \quad \text{where } m = \frac{I}{I_m}$$

m is called multiplying power of shunt and defined as the ratio of total current to the current through the coil. It can be expressed as,

$$m = \frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

2.3.3 Calculate Shunt Resistor in Single Range DC Ammeter

Example 1 :

A 2mA meter with an internal resistance of 100Ω is to be converted to 0-150mA ammeter. Calculate the value of shunt resistance required.

Solution:

Given value are,

$$R_m = 100\Omega, I_m = 2 \text{ mA}, I = 150\text{mA}$$

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

$$R_{sh} = \frac{2 \times 10^{-3} \times 100}{150 \times 10^{-3} - 2 \times 10^{-3}}$$

$$= 1.351\Omega$$

2.3.4 Derive Equation For Shunt Resistor In Two Range DC Ammeter

The range of the basic dc ammeter can be extended by using number of shunts and a selector switch. Such a meter is called multirange ammeter and is shown in the figure 2.14.

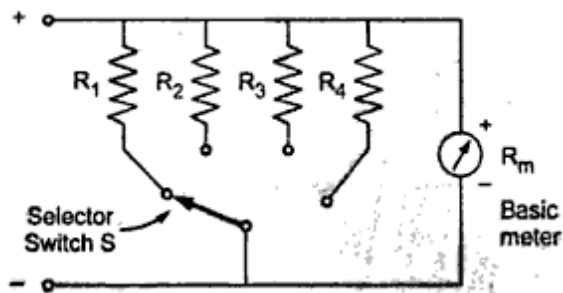


Figure 2.14: Multirange ammeter

R_1 , R_2 , R_3 and R_4 are four shunts and connected in parallel with meter.

They can give four different ranges I_1 , I_2 , I_3 and I_4 .

The mathematical analysis of basic dc ammeter is equally applicable to such multirange ammeter. Thus,

$$R_1 = \frac{I_m R_m}{I_1 - I_m} = \frac{R_m}{m_1 - 1}$$

$$R_2 = \frac{I_m R_m}{I_2 - I_m} = \frac{R_m}{m_2 - 1}$$

$$R_3 = \frac{I_m R_m}{I_3 - I_m} = \frac{R_m}{m_3 - 1}$$

$$R_4 = \frac{I_m R_m}{I_4 - I_m} = \frac{R_m}{m_4 - 1}$$

Where m_1, m_2, m_3 and m_4 are the shunt multiplying powers for the current I_1, I_2, I_3, I_4 .

2.3.5 Calculate Shunt Resistor in Two Range DC Ammeter

Example 2 :

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

Solution :

The first range is 0-10mA,

$$I_1 = 10\text{mA}$$

While $I_m = 2\text{ mA}$ and $R_m = 75\Omega$

$$\begin{aligned} R_1 &= \frac{I_m R_m}{I_1 - I_m} = \frac{2 \times 75}{10 - 2} \\ &= 18.75\Omega \end{aligned}$$

The second range is 0- 50mA,

$$I_2 = 50\text{mA}$$

$$R_1 = \frac{I_m R_m}{I_2 - I_m} = \frac{2 \times 75}{50 - 2}$$

$$= 3.125\Omega$$

The third range is 0- 100mA,

$$I_3 = 100\text{mA}$$

$$R_1 = \frac{I_m R_m}{I_3 - I_m} = \frac{2 \times 75}{100 - 2}$$

$$= 1.53\Omega$$

The designed multirange ammeter with a selector switch is shown in the figure below.

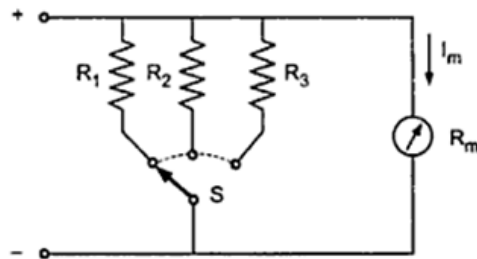


Figure 2.15

2.4 OHMMETER

An ohmmeter is an instrument used to measure resistance and check the continuity of electrical circuit and components. This resistance reading is indicated through a meter movement. The ohmmeter must then have an internal source of voltage to create the necessary current to operate the movement, and also have appropriate ranging resistors to allow desired current to flow through the movement at any given resistance.

Two types of schemes used to design an ohmmeter :

- i. Series type - measuring relatively high values of resistances
- ii. Shunt type - measuring low value of the resistances

2.4.1 Draw basic series type ohmmeter circuit

Figure shows the basic circuit of the series type ohmmeter.

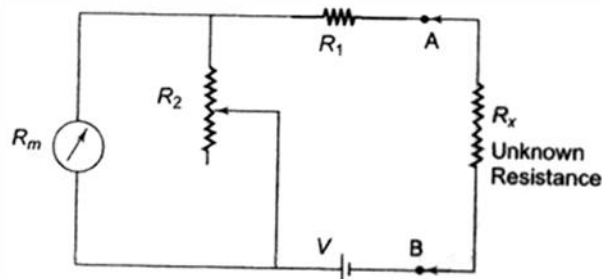


Figure 2.16: Series Type Ohmmeter

2.4.2 Explain function of current limiting resistance (series resistance), zero adjust resistance, meter resistance and unknown resistance in series type ohmmeter.

R_1 = current limiting resistor

R_2 = zero adjust resistor

R_x = unknown resistor

R_m = internal resistor

E = internal battery voltage

A and B = the output terminals of the ohmmeter across an unknown resistor

When terminals A and B are shorted (short circuit), $R_x = 0$ (maximum current flows in the circuit), R_2 is adjusted to get full scale current through the movement. Then $I = I_{fsd}$. The pointer will be deflected to its maximum position on the scale. Therefore the full scale current reading is marked 0 ohms.

When terminals A and B are open (open circuit), $R_x = \infty$ (no current flows in the circuit and there is no deflection of the pointer), $I = 0$. The pointer will read zero. Therefore the zero current reading is marked ∞ ohms.

2.4.3 Derive equation for shunt resistor in series type ohmmeter.

Values of R_1 and R_2 can be determined from the value of R_x which gives half the full scale deflection.

$$R_h = R_1 + R_2 \parallel R_m = R_1 + \frac{R_2 \times R_m}{R_2 + R_m}$$

where R_h = half of full scale deflection resistance

The total resistance presented to the battery equals to $2R_h$ and the battery current required to supply the half-full scale deflection, I_h :

$$I_h = \frac{V}{2R_h}$$

For full scale deflection, the battery current will be doubled:

$$I_{fsd} = 2I_h = \frac{V}{R_h}$$

The current through shunt resistance, R_2 : $I_2 = I_t - I_{fsd}$

The voltage across shunt V_{sh} is equal to the voltage across the meter.

Therefore $V_{sh} = V_m$, $I_2 \times R_2 = I_{fsd} \times R_m$

Therefore

$$R_2 = \frac{I_{fsd} \times R_m}{I_2}$$

But

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

$$R_2 = \frac{I_{fsd} \times R_m}{I_t - I_{fsd}}$$

But

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

Therefore

$$R_2 = \frac{I_{fsd} \times R_m}{\frac{V}{R_h} - I_{fsd}}$$

Therefore

$$R_2 = \frac{I_{fsd} \times R_m \times R_h}{V - (I_{fsd} \times R_h)}$$

2.4.4 Calculation Of Limiting Resistor In Series Type Ohmmeter

Apply equation in 2.4.3 to calculate limiting resistor:

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

Therefore

$$R_1 = R_h - \frac{R_2 \times R_m}{R_2 + R_m}$$

Hence

$$R_1 = R_h - \frac{\left[\frac{I_{fsd} \times R_m \times R_h}{V - (I_{fsd} \times R_h)} \right] \times R_m}{\left[\frac{I_{fsd} \times R_m \times R_h}{V - (I_{fsd} \times R_h)} \right] + R_m}$$

Therefore

$$R_1 = R_h - \left[\frac{I_{fsd} \times R_m \times R_h}{V} \right]$$

Hence, R_1 and R_2 can be determined.

Example 1 :

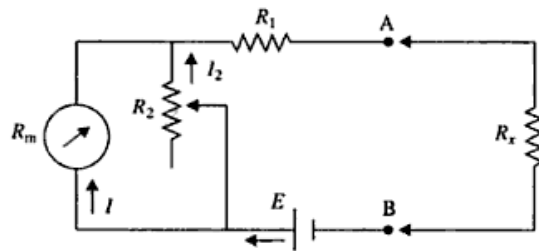


Figure 2.17

In the circuit above, a 1mA meter movement with an internal of 50Ω is to be used. The battery voltage is 3V. Half scale deflection should be for 2500Ω .

- Calculate the values of R_1 and R_2 .
- Find the change in the value of R_2 if the battery voltage reduces by 10%
- What is the half scale deflection if battery voltage reduces by 10%?

Solution:

$$(a) R_2 = \frac{I_{fsd} R_m R_h}{E - I_{fsd} R_h} = \frac{10^{-3} \times 50 \times 2500}{3 - 10^{-3} \times 2500} = 250 \Omega$$

$$R_1 = R_h - \frac{I_{fsd} R_m R_h}{E} = 2500 - \frac{10^{-3} \times 50 \times 2500}{3} = 2458.33 \Omega$$

$$(b) E = 3 - 0.3 = 2.7V$$

$$R_2 = \frac{I_{fsd} R_m R_h}{E - I_{fsd} R_h} = \frac{10^{-3} \times 50 \times 2500}{2.7 - 10^{-3} \times 2500} = 625 \Omega$$

R_2 should be changed from 250Ω to 625Ω to compensate for this reduction in battery voltage.

$$(c) R_h = R_1 + \frac{R_2 R_m}{R_2 + R_m} = 2458.33 + \frac{625 \times 50}{675} = 2504.63 \Omega$$

Half scale deflection now corresponds to 2504.63Ω instead of 2500Ω .

Example 2:

A 100Ω basic movement is to be as an ohmmeter requiring a full deflection of $1mA$ and internal battery voltage of $3V$. A half scale deflection marking of $2k\Omega$ is desired.

Calculate:

- i. value of R_1 and R_2
- ii. the maximum value of R_2 to compensate for a 5% drop in battery voltage.

Solution

(i) Using the equations for R_1 and R_2 :

$$R_1 = R_h - \left[\frac{I_{f_{sd}} \times R_m \times R_h}{V} \right]$$

$$R_1 = 2k\Omega - \left[\frac{1mA \times 100\Omega \times 2k\Omega}{3V} \right]$$

$$R_1 = 1933.3 \Omega$$

And

$$R_2 = \frac{I_{f_{sd}} \times R_m \times R_h}{V - (I_{f_{sd}} \times R_h)}$$

$$R_2 = \frac{1mA \times 100\Omega \times 2k\Omega}{3V - (1mA \times 2k\Omega)}$$

$$R_2 = 200\Omega$$

(ii) The internal battery voltage is 3V, therefore 5% of 3V is 0.15V. The battery voltage with 5% drop is $3V - 0.15V = 2.85V$.

$$R_2 = \frac{I_{f_{sd}} \times R_m \times R_h}{V - (I_{f_{sd}} \times R_h)}$$

$$R_2 = \frac{1mA \times 100\Omega \times 2k\Omega}{2.85V - (1mA \times 2k\Omega)} = 235.29\Omega$$

2.4.5 Draw basic shunt type ohmmeter circuit.

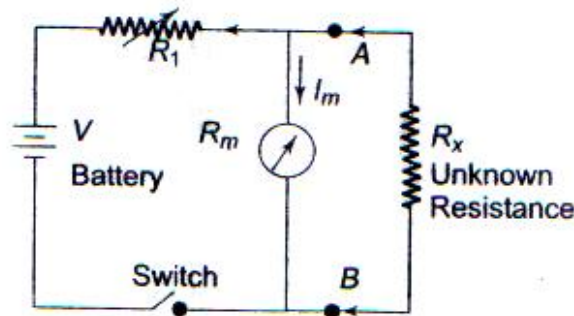


Figure 2.18: Basic Shunt Type Ohmmeter

2.4.6 Explain function of shunt resistance, zero adjust resistance, meter resistance and unknown resistance in shunt type ohmmeter.

Figure 2.18 shows the basic circuit of shunt type ohmmeter where movement mechanism is connected parallel to the unknown resistance. In this circuit it is necessary to use a switch; otherwise current will always flow in the movement mechanism. Resistor R_{sh} is used to bypass excess current.

R_1 = zero adjust resistance

V = battery

R_m = meter resistance (D'Arsonval movement)

R_x = unknown resistance (connected in parallel with the meter):

In this circuit it is necessary to have ON/OFF switch to disconnect the battery from the circuit when the instrument is not used.

Let the switch be closed;

When terminals A and B are shorted (short circuit), $R_x = 0$ (maximum current flows in the circuit), the pointer reads zero because full current flows through R_x and no current flows through the meter and R_{sh} . Therefore zero current reading is marked 0 ohms.

When terminals A and B are open (open circuit), $R_x = \infty$, no current flows through R_x and there is no deflection of the pointer. Resistor R_1 is adjusted so that full scale current flow through the meter. Therefore, maximum current reading is marked ∞ ohms.

2.4.7 Derive equation for limiting resistor in shunt type ohmmeter.

Half scale deflection of the movement, $I_m = R_h \times I_{fsd}$

Voltage across movement, $V_m = I_m \times R_m$

Current through unknown resistance:

$$I_x = \frac{V_m}{R_h}$$

The total battery current, $I_B = I_m + I_x$

Voltage drop across limiting resistor, $V_1 = V - V_m$

Limiting resistor:

$$R_1 = \frac{V_1}{I_B}$$

2.4.8 Apply equation in 2.4.7 to calculate shunt resistor in shunt type ohmmeter.

Example 3:

A shunt type ohmmeter has a D'Arsonval movement of resistance 2Ω . Its full deflection current is 10mA , and the battery voltage is 3 volts. Determine the value of current limiting resistor so that the meter indicates 0.5Ω at the mid point of its scale.

Solution:

Battery voltage, $V = 3\text{V}$

Meter resistance, $R_m = 2\Omega$

Full scale deflection meter current, $I_{fsd} = 10\text{mA}$

Half scale deflection resistance, $R_h = 0.5\Omega$

Half scale deflection of the movement, $I_m = R_h \times I_{fsd} = 0.5\Omega \times 10\text{mA} = 5\text{mA}$

Voltage across movement, $V_m = I_m \times R_m = 5\text{mA} \times 2\Omega = 10\text{mV}$

Current through unknown resistance:

$$I_x = \frac{V_m}{R_h} = \frac{10mV}{0.5\Omega} = 20mA$$

The total battery current, $I_B = I_m + I_x = 5mA + 20mA = 25mA$

Voltage drop across limiting resistor, $V_1 = V - V_m = 3V - 10mV = 2.99V$

Limiting resistor:

$$R_1 = \frac{V_1}{I_B} = \frac{2.99V}{25mA} = 119.6\Omega$$

Example 4 :

In the circuit of figure below, a 1mA meter movement with internal resistance of 50Ω is to be used. The battery voltage is 3V. Half scale deflection should be for 0.5Ω . Calculate the value of R_1 and R_{sh} .

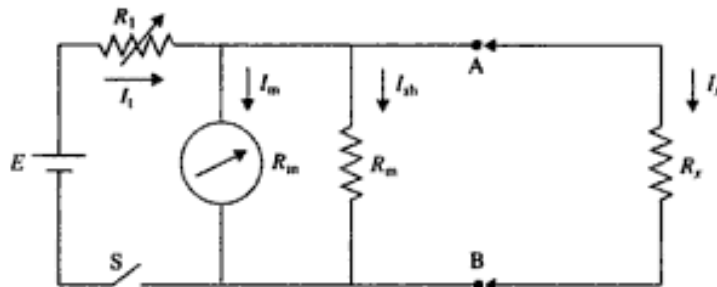


Figure 2.19

Solution :

For half scale deflection, $I_m = I_{fsd} / 2 = 0.5 \text{ mA}$

$$I_{sh} = I_m \left(\frac{R_m - R_h}{R_h} \right) = 0.5 \times 10^{-3} \left[\frac{50 - 0.5}{0.5} \right] = 45mA$$

Therefore,

$$R_{sh} = \frac{I_m R_m}{I_{sh}} = 0.5 \times \frac{50}{45} = \frac{5}{9} \Omega$$

$$I_t = 2I_m \left(\frac{R_m}{R_h} \right) = 2 \times 0.5 \times 10^{-3} \times \frac{50}{0.5} = 100\text{mA}$$

$$R_1 = \frac{E - I_m R_m}{I_t} = \frac{3 - 0.5 \times 10^{-3} \times 50}{100 \times 10^{-3}}$$

$$= 29.75 \Omega$$

We can thus see that shunt type ohmmeter can measure low values of resistance.

2.4.8 Design basic series and shunt type ohmmeter for resistance measurement.

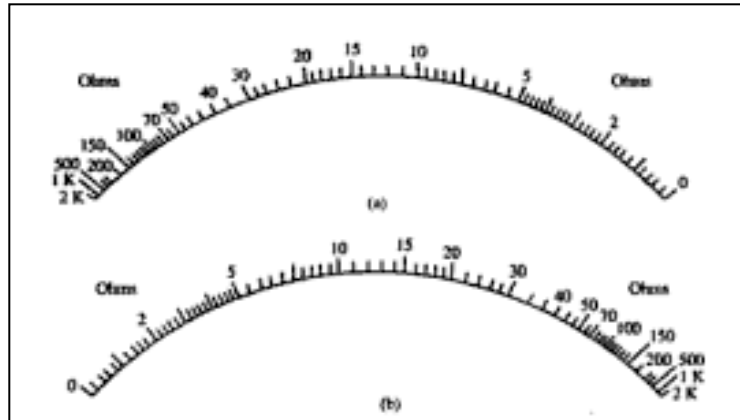


Figure 2.20: Ohmmeter scales (a) series scale (b) shunt scale

2.4.9 Differentiate typical scale in series and shunt type ohmmeter.

	Series Ohmmeter	Shunt Ohmmeter
Scale		
	<p>The Series Type Ohmmeter has a zero mark at the right side of the scale and an ∞ mark at the left side of the scale, corresponding to full scale deflection current.</p>	<p>The Shunt Type Ohmmeter has a zero mark at the left side of the scale and an ∞ mark at the right side of the scale, corresponding to full scale deflection current.</p>

2.5 ANALOGUE MULTIMETER

A multimeter is basically a PMMC meter. A multimeter consists of an ammeter, voltmeter and ohmmeter combined, with a function switch to connect the appropriate circuit to the D'Arsonval movement is often called a volt-ohm-miliammeter (VOM).

2.5.1 Analogue Multimeter Consisting Of Ammeter, Voltmeter And Ohmmeter Combination.

Figure 2.21 shows a meter consisting of a dc miliammeter, a dc voltmeter, an ac voltmeter, a microammeter and an ohmmeter.

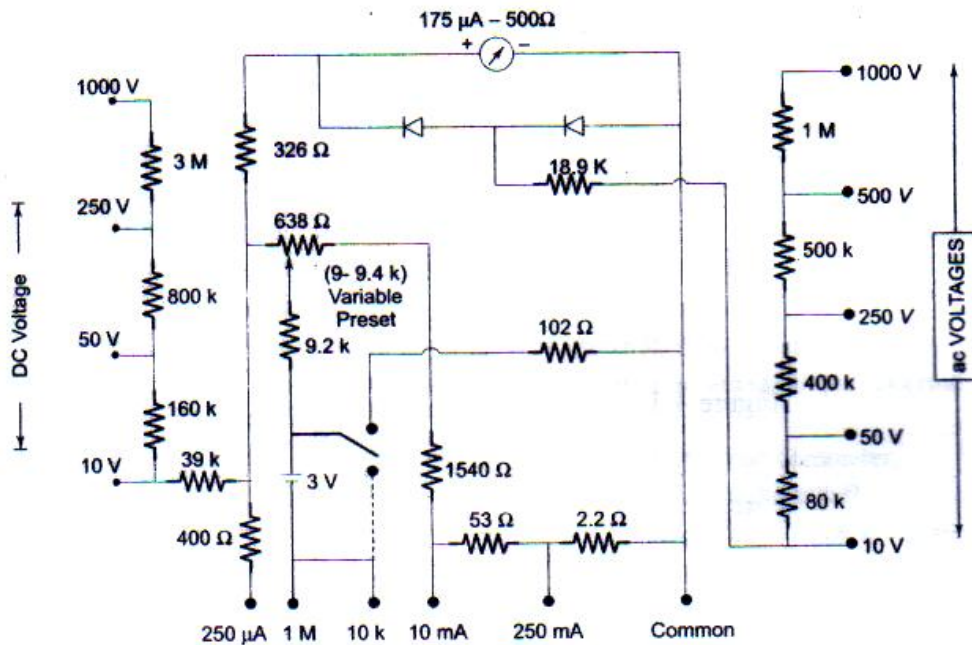


Figure 2.21: Diagram of Analogue Multimeter

2.5.2 Identify Ammeter, Voltmeter And Ohmmeter Section In Analogue Multimeter

i. Microammeter

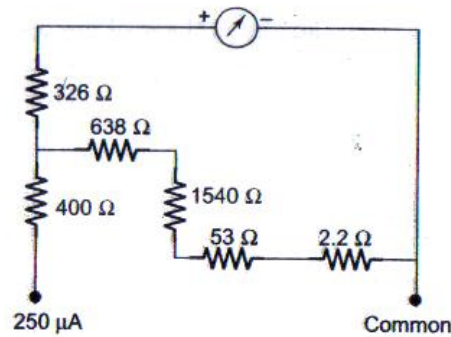


Figure 2.22: Microammeter section of a Multimeter

ii. DC Ammeter

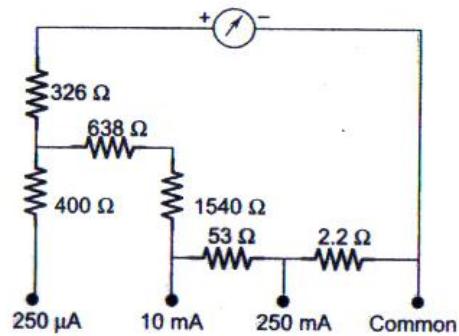


Figure 2.23: DC Ammeter section of a Multimeter

iii. DC Voltmeter

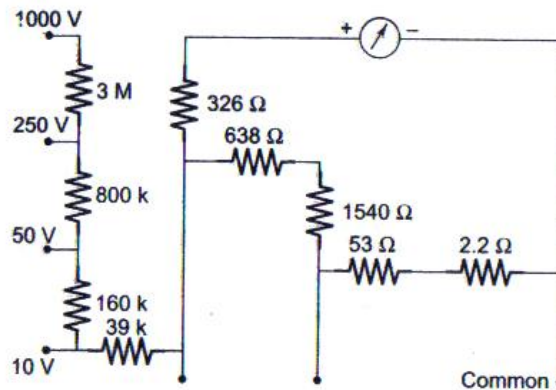


Figure 4: DC Voltmeter section of a Multimeter

iv. AC Voltmeter

Figure 2.25 shows an ac voltmeter section of a multimeter. Two diodes D_1 and D_2 are employed in this circuit, forming a full-wave rectifier with the meter so connected that it receives only half of the rectified current. Diode D_1 conducts during positive half cycle of the input waveform and makes the meter to deflect according to the average value of this half cycle. Across the meter, the other diode D_2 serves as protection. In the absence of diode D_2 , the negative half cycle of the input voltage would apply a reverse voltage across diode D_1 resulting in a small leakage current in the reverse direction. The average value of the complete cycle would thus be lower than it should be for half wave rectification. But when diode D_2 is connected, as shown in the figure, it conducts heavily and current bypasses the meter in reverse direction.

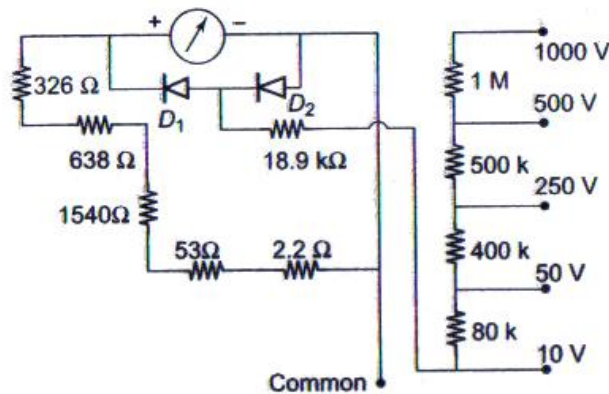


Figure 2.25: AC Voltmeter section of a Multimeter

v. Ohmmeter

Referring to Figure 6 which shows the ohmmeter section of a multimeter, in the $10k\Omega$ range the 102Ω resistance is connected in parallel with the total circuit resistance and in the $1M\Omega$ range the 102Ω resistance is totally disconnected from the circuit.

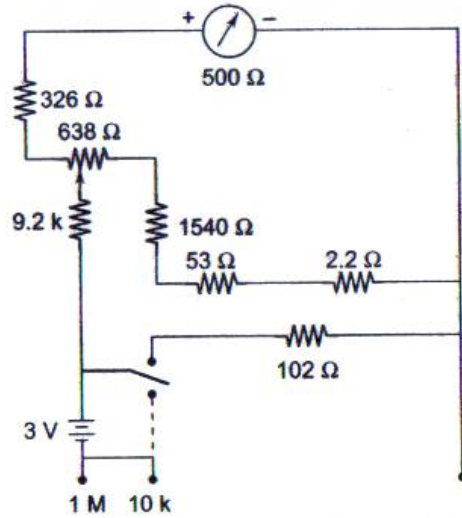


Figure 2.26: Ohmmeter section of a Multimeter

Therefore, on the $1M\Omega$ ranges the half scale deflection is $10k\Omega$. Since on the $10k\Omega$ range, the 102Ω resistance is connected across the total resistance, therefore, in this range, the half scale deflection is 100Ω . The measurement of resistance is done by applying a small voltage installed within the meter. For the $1M\Omega$ range, the internal resistance is $10k\Omega$, i.e. value at midscale, as shown in Figure 7. And for the $10k\Omega$ range, the internal resistance is 100Ω , i.e. value at mid-scale as shown in Figure 8.

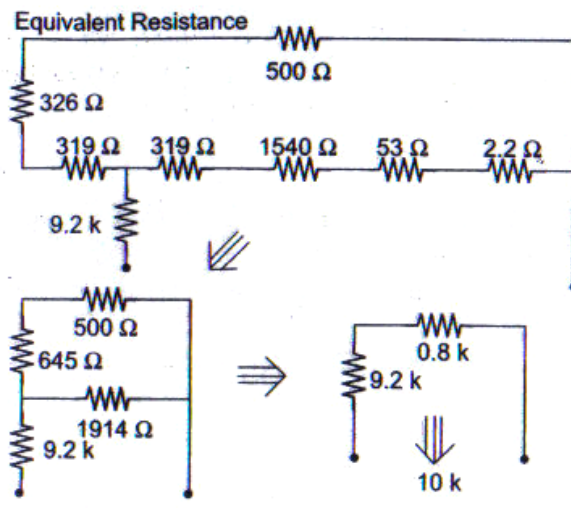


Figure 2.27: Equivalent Resistance on $1M\Omega$ Range

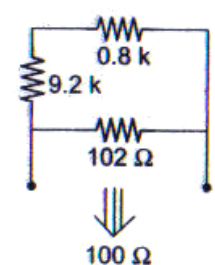


Figure 2.28: half Scale Deflection is 100Ω

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.

2.5.3 Differentiate The Scale Of Ohm, Volt And Ampere In Analogue Multimeter

Typical ranges for analogue multimeters like the one illustrated:

(the voltage and current values given are the maximum reading on each range)

- DC Voltage: 0.5V, 2.5V, 10V, 50V, 250V, 1000V.
- AC Voltage: 10V, 50V, 250V, 1000V.
- DC Current: 50 μ A, 2.5mA, 25mA, 250mA.

A high current range is often missing from this type of meter.

- AC Current: None. (You are unlikely to need to measure this).
- Resistance: 20 Ω , 200 Ω , 2k Ω , 20k Ω , 200k Ω .

These resistance values are in the middle of the scale for each range.

2.5.4 Sensitivity Of Meter

Multimeters must have a high sensitivity of at least 20k Ω /V otherwise their resistance on DC voltage ranges may be too low to avoid upsetting the circuit under test and giving an incorrect reading. To obtain valid readings the meter resistance should be at least 10 times the circuit resistance (take this to be the highest resistor value near where the meter is connected). You can increase the meter resistance by selecting a higher voltage range, but this may give a reading which is too small to read accurately!

2.5.5 State That Analogue Meter Resistance = Sensitivity × Maximum Reading Of Range

On any DC voltage range:

$$\text{Analogue Meter Resistance} = \text{Sensitivity} \times \text{Max. reading of range}$$

e.g. a meter with $20\text{k}\Omega/\text{V}$ sensitivity on its 10V range has a resistance of $20\text{k}\Omega/\text{V} \times 10\text{V} = 200\text{k}\Omega$.

2.5.6 Determine The Step To Do Voltage, Current And Resistance Measurements Using Multimeter

a) Measuring voltage and current with a multimeter

1. Select a range with a maximum greater than you expect the reading to be.
2. Connect the meter, making sure the leads are the correct way round.

Digital meters can be safely connected in reverse, but an analogue meter may be damaged.

3. If the reading goes off the scale: immediately disconnect and select a higher range.

Multimeters are easily damaged by careless use so please take these precautions:

1. Always disconnect the multimeter before adjusting the range switch.
2. Always check the setting of the range switch **before** you connect to a circuit.
3. Never leave a multimeter set to a current range (except when actually taking a reading).

The greatest risk of damage is on the current ranges because the meter has a low resistance.

Measuring voltage at a point

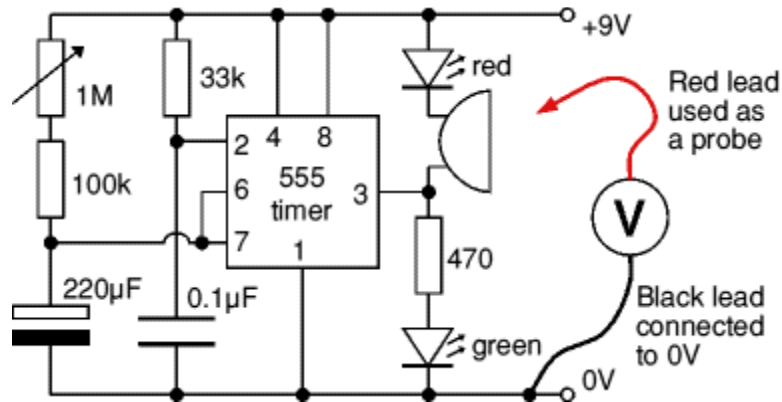


Figure 2.29: Measuring voltage at a point.

1. Connect the **black** (negative -) lead to 0V, normally the negative terminal of the battery or power supply.
2. Connect the **red** (positive +) lead to the point you where you need to measure the voltage.
3. The **black** lead can be left permanently connected to 0V while you use the **red** lead as a probe to measure voltages at various points.
4. You may wish to fit a crocodile clip to the **black** lead of your multimeter to hold it in place while doing testing like this.

Voltage at a point really means the voltage difference between that point and 0V (zero volts) which is normally the negative terminal of the battery or power supply. Usually 0V will be labeled on the circuit diagram as a reminder.

Reading analogue scales

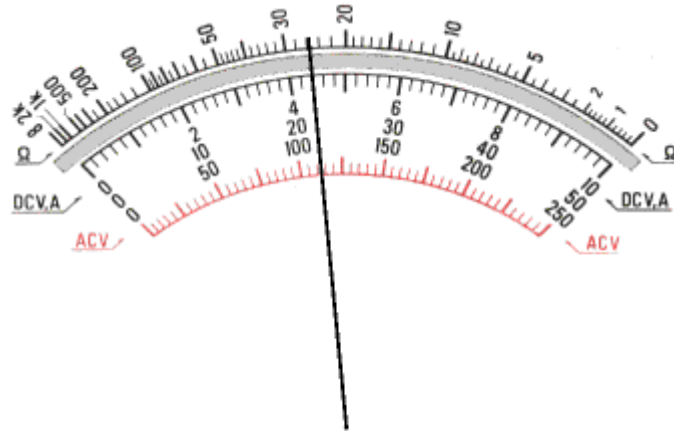


Figure 2.30: Analogue Multimeter Scales

These can appear daunting at first but remember that you only need to read **one** scale at a time!

The top scale is used when measuring resistance.

Check the setting of the range switch and **choose an appropriate scale**. For some ranges you may need to multiply or divide by 10 or 100 as shown in the sample readings below. For AC voltage ranges use the **red** markings because the calibration of the scale is slightly different.

Sample readings on the scales shown:

DC 10V range: 4.4V (read 0-10 scale directly)

DC 50V range: 22V (read 0-50 scale directly)

DC 25mA range: 11mA (read 0-250 and divide by 10)

AC 10V range: 4.45V (use the red scale, reading 0-10)

If you are not familiar with reading analogue scales generally you may wish to see the analogue display section on the general meters page.

b) Measuring resistance with an ANALOGUE multimeter

The resistance scale on an analogue meter is normally at the top, it is an unusual scale because it reads **backwards** and is **not linear** (evenly spaced). This is unfortunate, but it is due to the way the meter works.

1. Set the meter to a suitable resistance range.

Choose a range so that the resistance you expect will be near the middle of the scale. For example: with the scale shown below and an expected resistance of about $50\text{k}\Omega$ choose the $\times 1\text{k}\Omega$ range.

2. Hold the meter probes together and adjust the control on the front of the meter which is usually labelled " 0Ω ADJ" until the pointer reads zero (on the **RIGHT remember!).**

If you can't adjust it to read zero, the battery inside the meter needs replacing.

3. Put the probes across the component.**4. Reading analogue resistance scales**

5. For **resistance** use the **upper scale**, noting that it reads backwards.

6. Check the setting of the range switch so that you know by how much to multiply the reading.

7. Sample readings on the scales shown: $\times 10\Omega$ range: 260Ω

$\times 1\text{k}\Omega$ range: $26\text{k}\Omega$

8. If you are not familiar with reading analogue scales generally you may wish to see the [analogue display](#) section on the general meters page.

2.5.10 Multimeter Safety Precaution

As with other meters, the incorrect use of a multimeter could cause injury or damage.

The following safety precautions for using a multimeter.

1. Reenergize and discharge the circuit completely before connecting or disconnecting a multimeter.
2. Never apply power to the circuit while measuring resistance with a multimeter, the voltage across the resistance may damage the meter.
3. Connect the multimeter in series with the circuit for current measurements, and in parallel for voltage measurements.
4. Verify the circuit polarity before making test, particularly when measuring dc current or voltages.
5. To prevent meter overloading and possible damage when checking voltage or current, start with the highest range of the instrument and move down the range successively.
6. For higher accuracy, the range selected should be such that the deflection falls in the upper half on the meter scale. Select a final range that allows a reading near the middle of the scale.
7. Take extra precaution when checking high voltages and checking current in high voltage circuits.
8. Adjust the "0 ohms" reading after changing resistance ranges and before making a resistance measurement.
9. Be certain the multimeter is switched to ac before attempting to measure ac circuits.
10. Be certain to read ac measurements on the ac scale of a multimeter.

11. When you are finished with a multimeter, switch it to the OFF position, if available. If there is no OFF position, switch the multimeter to the highest ac voltage position.
12. Observe the general safety precautions for electrical and electronic devices.
13. Renew ohmmeter batteries frequently to insure accuracy of the resistance scale.
14. Recalibrate the instrument at frequent intervals.
15. Protect the instrument from dust, moisture, fumes and heat.

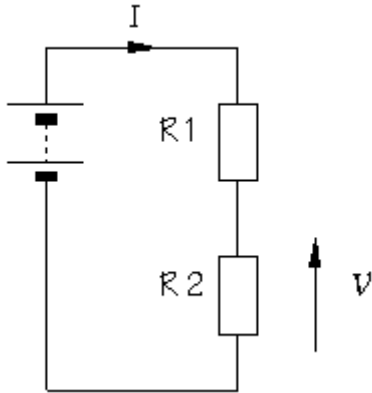
2.5.11 Calibrate The Multimeter

- a) Multimeters come with a red lead and a black lead. There will be slots on the Multimeter. One slot will read volt/ohm, one will read (A) or amps and the other will be the Ground (GND) slot. You will want to take the red lead and insert it into the volt/ohm slot.
- b) Take the black lead and insert it into the ground slot.
- c) Turn on the Multimeter.
- d) Turn or select the Ohms function on the meter.
- e) Touch the leads together. The reading will change from infinite ohms to zero. This is the reading of a properly calibrated multimeter.

2.5.12 Use Multimeter To Measure Voltage, Current And Resistance

i. Measuring voltage

A



B

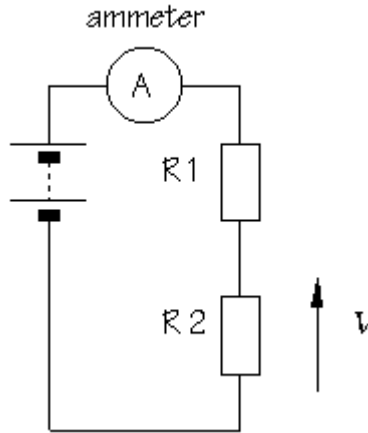
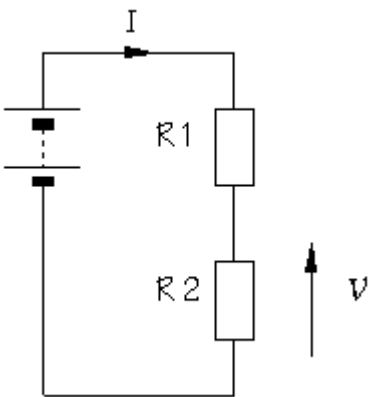


Figure A is basic circuit and Figure B is show an ammeter connection to measure current. The circuit must be broken to allow the ammeter to be connected in series.

Ammeters must have a LOW resistance.

ii. Measuring Current

A



C

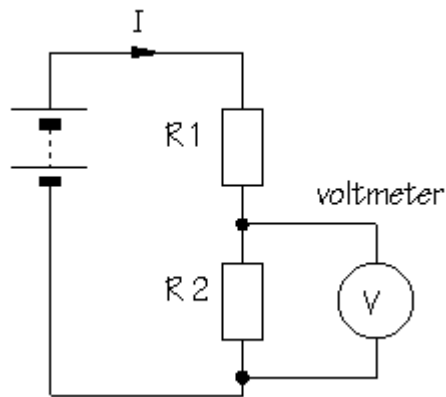


Figure A is basic circuit and Figure C is show a voltmeter connection to measure potential difference (voltage). The circuit is not changed which the voltmeter is connected in parallel.

Voltmeters must have a HIGH resistance.

iii. Measuring Resistance

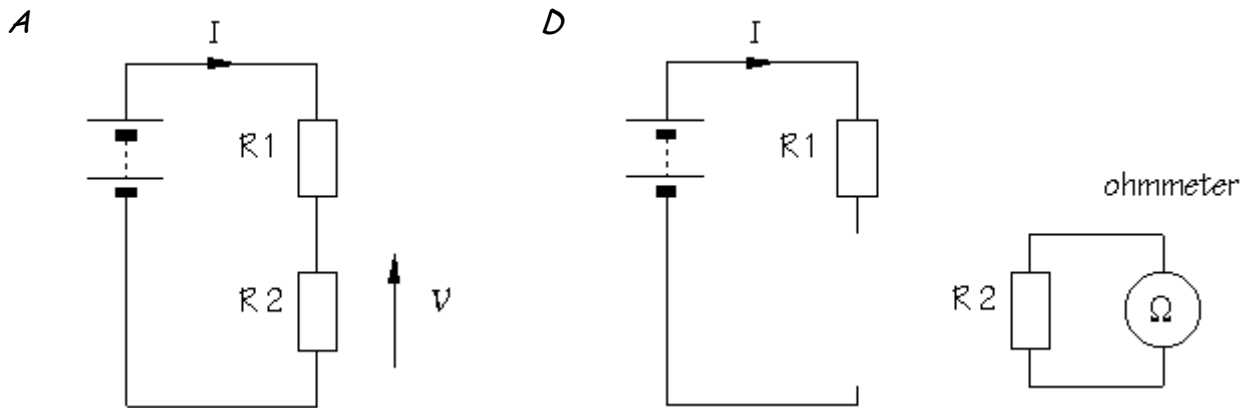


Figure A is basic circuit and Figure D is an ohmmeter connection to measure resistance. The component must be removed from the circuit altogether.

Ohmmeters work by passing a current through the component being tested.