Electrical Engineering

Electrical & Electronic Measurements

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

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Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 011-45124660, 8860378007
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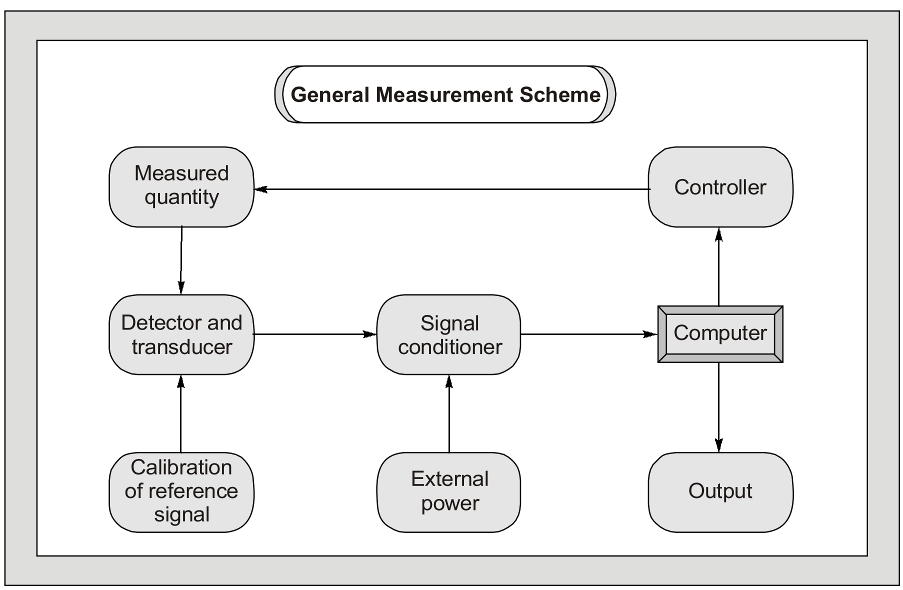
Introduction to Electrical and Electronic Measurements

Measurement and instrumentation systems have wide applications such as measurement of electrical and physical quantities like current, voltage, power, temperature, pressure, displacement etc.

The reason for measurement arises when one wants to generate data for design or when one wants to propose a theory based on a set of measurement and instrumentation for commerce.

The measurement and instrumentation systems can also be used to locate things or events. Like employees present in a building, the epicenter of an earthquake. Sometimes, measurement systems are made a part of control system. One can observe the change in the field of measurement and instrumentation due to the introduction of new standards, and sensors.



This course on instrumentation and measurement is intended to make the engineers familiar about the art of modern instrumentation and measurement systems. It is well suited for classroom courses of engineering as well as for various competitive examinations.

Equal importance has been provided to both theory as well as problems with illustrative examples after every topic. It has been tried to cover every topic so that even a beginner understands it easily to excel in the subject of measurement and instrumentation.

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CHAPTER 2

Measurement and Resistance

2.1 Resistors

Resistors and resistive networks are extensively used instrumentation and measurement. Resistors are the passive elements which opposes the flow of current in a conductor.

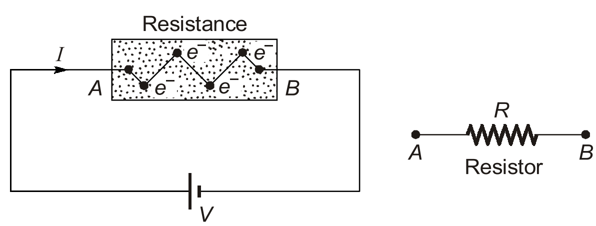

***Figure*-2.1 :** *Random motion of electrons in a resistor*

- When electric voltage is applied across a resistor, electrons starts moving in random motion (in a zig-zag fashion). Due to this reason resistors have symbol close to zig-zag shape.
- Unit: ohm (Ω)

Properties of Resistance

- Resistance should be stable and should not change with time.
- The temperature coefficient of resistance should be low. (i.e. $\propto$ should be low) so that R doesn't changes much with temperature.
- The resistance material should have low value of thermoelectric emf.
- The resistivity (ρ) should be high.
- Frequency error should be low (when used at high frequency).

Frequency Errors in Resistors

Resistor may be represented at different frequencies as shown below.

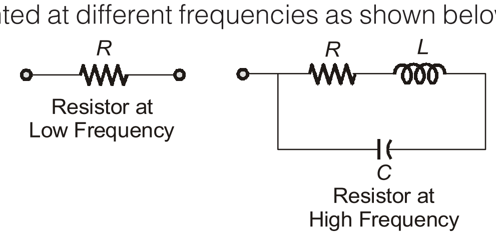

***Figure*-2.2 :** *Resistors at lower and higher frequencies*

At high frequency, the circuit shows an inductance (L) in series with the dc resistance (R) and the combination of R and L in series is shunted by a capacitance (C).

2.2 Methods of Reducing Residual Inductance and Capacitance in Resistors

Method of reducing residual inductance – Bifilar winding

Method of reducing residual capacitance – Aryton perry Winding

Bifilar Winding

Here, the wire is doubled on itself as shown in figure. Thus, the wires carries current in opposite direction and produces two equal and opposite magnetic fields and since the two wires are very close to each other, the net magnetic field is zero. Therefore, the net inductance of the coil is almost negligible.

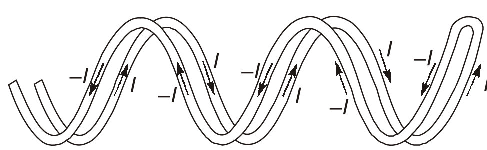

***Figure*-2.3 :** *Bifilar Winding*

Aryton Perry Winding

It uses two winding connected in parallel and wound in opposite direction around a card with one winding spaced between adjacent turns of the other. There is capacitance between each adjacent turns; but if there are several turns the capacitances acts in series and hence their resultant is small. This winding is expensive to construct.

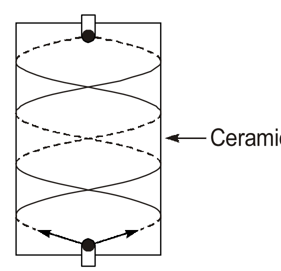

***Figure*-2.4**

Materials used for Resistors

The most widely used materials for precision resistors are:

(*i*) **Manganin:** An alloy of Cu, Mn and Ni (α = 0.00004/°c)

(*ii*) **Constantan:** Alloy of Ni and Cu (Ni – 40 to 60%) (α = 0.00045/°c)

(*iii*) Gold Chromium

(*iv*) Nickel Chromium alloys

Example - 2.1 In order to reduce skin effect in resistance standards when they are used on high frequency ac:

(a) The diameter of the resistance wire should be small

(b) Adjacent turns of the resistance coil should carry currents in the opposite direction.

(c) They should be provided with four terminals

(d) All of the above

Solution: (a)

One of the error which occur in resistance standard is due to skin effect when they are used at high frequency. These errors are minimized by using wires of small diameter so that resistance value is increased.

Example - 2.2 A standard resistance is made 'Bifilar Winding' type to eliminate

(a) Stray capacitance (b) Temperature effect

(c) Inductive effect (d) Skin effect

Solution: (c)

Bifilar Winding – to reduce inductance effect.

Aryton Perry Winding: to reduce capacitance effect.

Example - 2.3 The residue of a resistor at high frequencies are

(a) inter-turn capacitance (b) inductance

(c) ground capacitance (d) all of these

Solution: (d)

At high frequency, the residues of a resistor constitute both capacitance (inter-turn or ground or both) and inductance. Refer to Figure 2.2 of previous article.

Example - 2.4 Materials used for precision resistor should have

(a) low resistivity (b) high resistance temperature coefficient

(c) high thermo-electric emf against copper (d) none of these

Solution: (d)

Refer to various properties of resistance.

Classification of Resistance

Resistance are classified into 3 categories as follows:

Classification	Value of R	Application
Low Resistance	$R \leq 1\ \Omega$	Winding coils of Generator, motor, transformer etc.
Medium Resistance	$1\ \Omega < R < 100\ \text{k}\Omega$	Used in electronic accessories
High Resistance	$R > 100\ \text{k}\Omega$	Insulation of cables, motor, generator, transformers etc.

Representation of Resistances

<table>
<tr><th>Low Resistance Standard</th><th>Medium Resistance Standard</th><th>High Resistance Standard</th></tr>
<tr>
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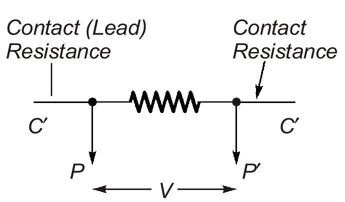
⇒ *Low Resistance Standard are "Four terminal type"*

⇒ 

⇒ *With four terminal resistors, the errors on account of contact (Lead) resistance are avoided*

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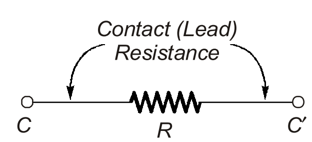
⇒ *Medium Resistance standard are "two terminal type".*

⇒ 

⇒ *It measures resistance of R + Lead resistance*

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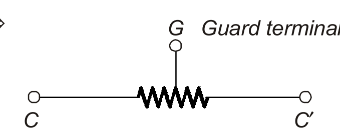
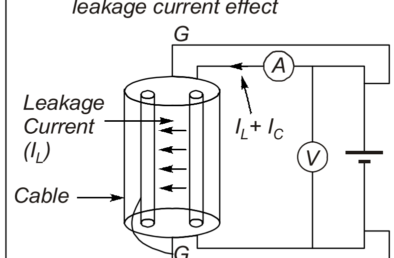
⇒ *High resistance standard are "three terminal type*

⇒ 

⇒ *Guard terminal is used to avoid leakage current effect*



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2.3 Measurement of Low Resistance

The methods for measurement of low resistance are:

1. Ammeter voltmeter method (or V-I method)
2. Kelvin double bridge method
3. Potentiometer method

Ammeter Voltmeter Method

- The instruments required for this test are usually available in the laboratory. Therefore, it is very popular method.
- Basic Principle: Measured value of resistance, $\boxed{R_m = \dfrac{V}{I}}$

  Voltage, V across the resistor is measured by a voltmeter.
  Current, I flowing through the resistor is measured using an Ammeter.

The ratio of V and I gives the measured resistance.

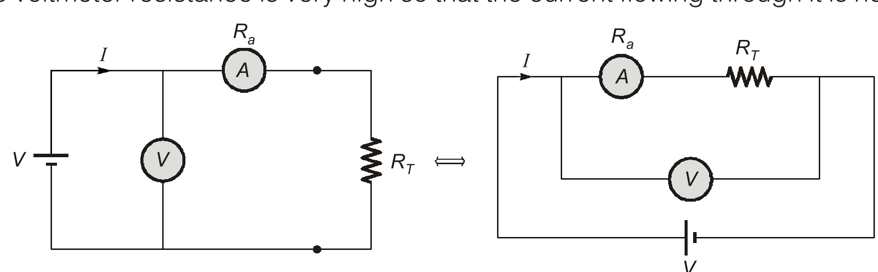
This is reason why this method is called V-I method (or voltmeter-Ammeter) method.

Case-I: Ammeter is near to the unknown (Test) resistance

Assumption:

(*i*) Ammeter is having an internal resistance of R_a

(*ii*) The voltmeter resistance is very high so that the current flowing through it is negligible.



{ R_a = Ammeter internal resistance, R_T = Test resistance }

***Figure-2.5 :** Measurement of resistance by V–I method (Case-I)*

Circuit Analysis:

Applying KVL to the circuit shown above:

$$V = I(R_a + R_T) \quad \text{or} \quad \frac{V}{I} = R_a + R_T$$

or, $$R_m = R_a + R_T \qquad \text{(Where, } R_m = \text{measured value of resistance)}$$

Error in measurement of R_T:

$$\%\ \text{Error} = \%\ \varepsilon_r = \left(\frac{R_m - R_T}{R_T}\right)\times 100 \quad \text{or} \quad \varepsilon_r = \left(\frac{(R_a - R_T) - R_T}{R_T}\right)\times 100 = \frac{R_a}{R_T}\times 100$$

$$\therefore \qquad \boxed{\%\ \text{Error} = \frac{R_a}{R_T}\times 100}$$

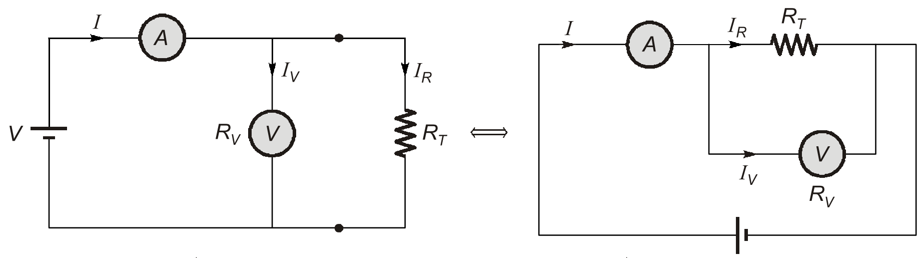
NOTE: Error, ε_r is low if $R_T >> R_a$

Case-II: Voltmeter is near to the unknown (Test) resistance

Assumptions:

(*i*) Ammeter internal resistance is negligible

(*ii*) Voltmeter is having an internal resistance of R_V and current flowing through voltmeter is I_V.



{ R_T = Test resistance
R_V = Voltmeter internal resistance
I_V = Current flowing through Voltmeter
I_R = Current flowing through test resistance }

Figure-2.6 Measurement of resistance by V–I method (Case-II)

Circuit Analysis:

(a) Exact Analysis:

$$I_V = \frac{V}{R_V},\quad I_R = \frac{V}{R_T}$$

∴ Total current, $I = I_R + I_V$

$$I_R = I - I_V = \text{Current through test resistance}$$

$$R_T = \frac{V}{I_R} = \text{True value of resistance}$$

$$R_m = \frac{V}{I} = \text{Measured value of resistance}$$

∴ Error, $$\varepsilon_r = \left(\frac{R_m - R_T}{R_T}\right)$$

and $$\boxed{\%\ \text{error} = \left(\frac{R_m - R_T}{R_T}\right) \times 100}$$

(b) Approximate Analysis:

Net current, $$I = I_V + I_R = \frac{V}{R_V} + \frac{V}{R_T} \quad \text{or} \quad \frac{I}{V} = \frac{1}{R_V} + \frac{1}{R_T} = \frac{1}{R_m}$$

So, $$\frac{1}{R_V} = \frac{1}{R_m} - \frac{1}{R_T}$$

or, $$\frac{1}{R_V} = \frac{R_T - R_m}{R_m R_T} \quad \text{or} \quad R_m - R_T = \frac{-R_m R_T}{R_V}$$

Assume $R_m \simeq R_T$ then,

$$(R_m - R_T) = \frac{-R_T^2}{R_V}$$

Error, $\varepsilon_r = \frac{R_m - R_T}{R_T} = \frac{R_T^2}{R_V \cdot R_T} = \frac{-R_T}{R_V}$

$\therefore$ Error, $\varepsilon_r = \frac{-R_T}{R_V}$ and $\boxed{\% \text{ error} = \frac{-R_T}{R_V} \times 100}$

NOTE: Error, ε_r is low if $R_T << R_V$

Example - 2.5 Two arrangements are available as shown in figure below (i) and (ii) for measurement of unknown resistance R_T.

Which of the following statements are correct?

(i) Figure (i) and (ii) are suitable for measurement of medium resistance or low resistance.

(ii) Figure (i) is suitable for high range

(iii) Figure (ii) is suitable for low range

(iv) Figure (i) and (ii) are suitable for any range of resistance

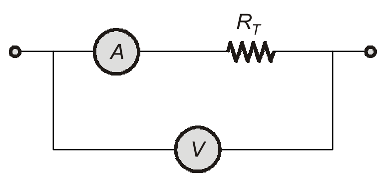


Figure (*i*)

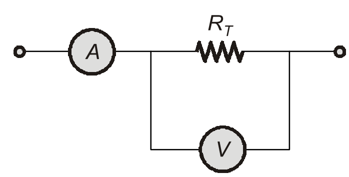


Figure (*ii*)

(a) i, ii, iii, iv
(b) i, iii
(c) i, ii
(d) i, ii, iii

Solution: (d)

For Figure (i):

Ammeter is near to the test resistance. So, error = R_a/R_T

$\therefore$ Error is low if R_T is high. So, option (ii) is correct.

For Figure (ii):

Voltmeter is near to the test resistance. So, error = $-R_T/R_V$

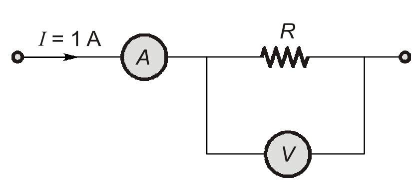
$\therefore$ Error is low if R_T is low. So, option (iii) is correct.

Figure (i) and (ii) are called $V - I$ (or Voltmeter-Ammeter) method which are used to measure low and medium resistance.

So, option (i) is correct.

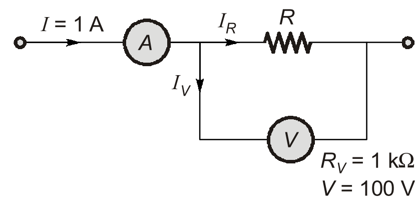
Hence (d) i, ii, iii is the right answer.

Example - 2.6 For the arrangement shown in figure, the value of unknown resistance is



(a) 100 Ω
(b) 111 Ω
(c) 99 Ω
(d) 10 Ω

Solution: (b)



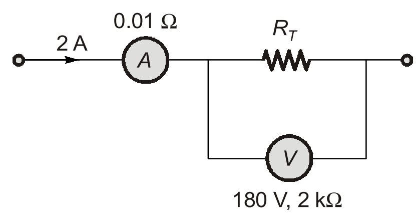
$$I_V = \frac{100}{1\times10^3}A = 0.1\text{ A}$$

$$I_R = I - I_V = 1 - 0.1 = 0.9\text{ A}$$

$$R = \frac{V}{I_R} = \frac{100}{0.9} = 111\ \Omega$$

∴ Unknown resistance = 111 Ω

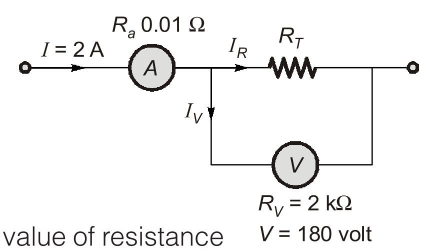
Example - 2.7 For the arrangement shown in figure ammeter is having internal resistance of 0.01 Ω and reads current of 2 A and the voltmeter has a voltage of 180 V and 2 kΩ of internal resistance. The measured value of resistance is 90 Ω. Find the error in the measurement of the unknown resistance R_T



(a) 2.3% (b) 2.7%
(c) 4.5% (d) 4.7%

Solution: (c)

Using exact analysis:



$$I_V = \frac{180}{2k} = 0.09\,A$$

$$I_R = 2 - 0.09 = 1.91A\ (I - I_V)$$

$$R_T = \frac{V}{I_R} = \frac{180}{1.91} = 94.24\,\Omega = \text{True value of resistance}$$

$$R_m = \frac{V}{I} = \frac{180}{2} = 90\,\Omega = \text{Measured value of resistance}$$

∴ $$\text{Error, } \varepsilon_r = \frac{R_m - R_T}{R_T} = \frac{90 - 94.24}{94.24} = -0.045$$

∴ $$\%\ \varepsilon_r = -4.5\%$$

Remember

Optimum value of resistance in *V-I* method when errors are same in case-I and II

For Case-I: $$\varepsilon_r = \frac{R_a}{R_T}$$

For Case-II: $$\varepsilon'_r = -\frac{R_T}{R_V}$$

When errors in both cases are same:

i.e. $$|\varepsilon_r| = |\varepsilon'_r|$$

or, $$\frac{R_a}{R_T} = \frac{R_T}{R_V} \Rightarrow \boxed{R_T = \sqrt{R_a R_V}}$$

Which of the above statement (s) is/are true ?

(a) 1 only (b) 1, 2 & 4 only

(c) 2 and 3 only (d) 1, 3 and 4

Q.13 In a laboratory, a voltmeter of 200 Ω resistance and an ammeter of 0.02 Ω resistance are available. The value of resistance that can be measured by the ammeter-voltmeter method for which the two different circuit measurements give equal errors is

(a) 20 Ω (b) 0.2 Ω

(c) 200 Ω (d) 2 Ω

Q.14 Potentiometer method is used for the measurement of

(a) low L (b) high R

(c) low R (d) medium R

Answer Key:

1. (c)	**2.** (c)	**3.** (d)	**4.** (c)
5. (a)	**6.** (b)	**7.** (d)	**8.** (c)
9. (b)	**10.** (c)	**11.** (c)	**12.** (d)
13. (d)	**14.** (c)		

Student's Assignments 2 Explanations

1. (c)

For measurement of low resistance ($R \leq 1\ \Omega$), four terminals are used to avoid lead resistance effect.

2. (c)

For option (a),

$$\text{error} = \frac{R_a}{R_T} \times 100\%$$

$$= \frac{0.02}{10} \times 100 = 0.2\%$$

$$\therefore \quad |\varepsilon_r| = 0.2\%$$

For option (b),

$$\text{error} = \frac{R_T}{R_V} \times 100\%$$

(approximate analysis)

$$= -\frac{10}{5000} \times 100\% = -0.2\%$$

$$\therefore \quad |\varepsilon_r| = 0.2\%$$

Since magnitude of error in both cases are same, therefore any of the two connections can be used.

5. (a)

The value of earthing electrodes should be low to allow an easy flow of fault current for the protection of equipment and personal handling the equipment.

6. (b)

Substitution method is used for the measurement of medium resistance

9. (b)

At $t = 0$,

a capacitor acts as short circuit ($X \to 0$)

At $t = \infty$,

a capacitor acts as open circuit ($X \to \infty$)

13. (d)

For the errors to be same in two different connection of ammeter - voltmeter method, we have:

$$\left|\frac{R_a}{R_T}\right| = \left|\frac{R_T}{R_V}\right|$$

or, $$R_T = \sqrt{R_a R_V} = \sqrt{0.02 \times 200}$$

$$= 2\ \Omega$$

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