
CHAPTER 2

DC AND AC METER

OBJECTIVES

- At the end of this chapter, students should be able to:
 1. Explain the basic construction and working principle of D'Arsonval meter movement.
 2. Perform basic electronic circuit analysis for D'Arsonval meter family.
 3. Identify the difference electronic circuit design for measurement meters using D'Arsonval meter principle.

CHAPTER OUTLINE

1. D'Arsonval Meter Movement
2. DC Ammeter
3. DC Voltmeter
4. Multi-range Voltmeter
5. Voltmeter Loading Effects
6. Ammeter Insertion Effects
7. Ohmmeter
8. Multi-range Ohmmeter
9. Multimeter
10. AC Voltmeter using half-wave rectifier
11. AC Voltmeter Loading Effects
12. Wheatstone Bridge
13. Kelvin Bridge
14. Bridge-controlled Circuit

2.1: D'ARSONVAL METER MOVEMENT

- ❑ Also called Permanent-Magnet Moving Coil (PMMC).
- ❑ Based on the moving-coil galvanometer constructed by Jacques d' Arsonval in 1881.
- ❑ Can be used to indicate the value of DC and AC quantity.
- ❑ Basic construction of modern PMMC can be seen in Figure 2.1.

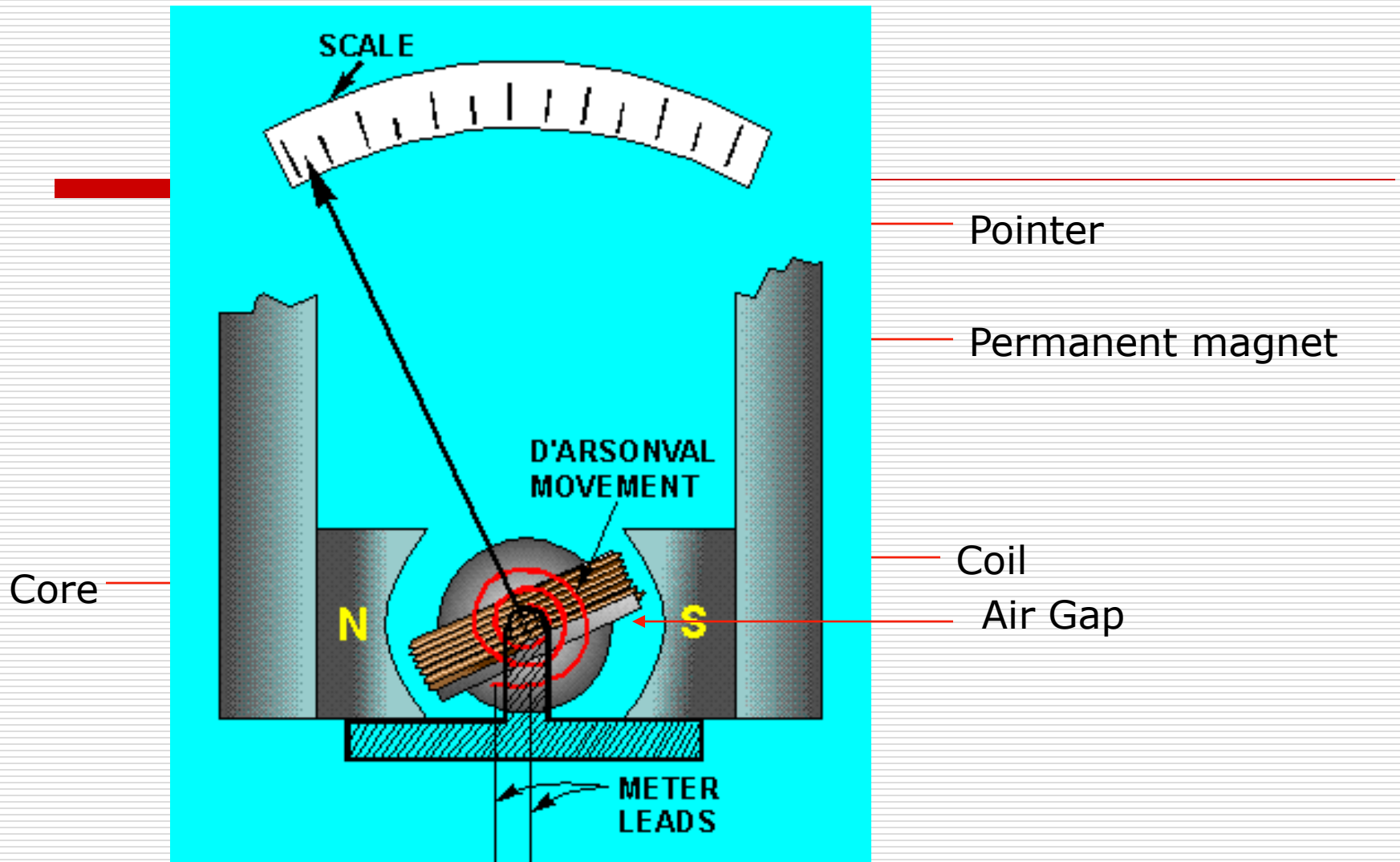


Figure 2.1: Modern D'Arsonval Movement

2.1.1: Operation of D'Arsonval Meter

- ❑ When current flows through the coil, the core will rotate.
- ❑ Amount of rotation is proportional to the amount of current flows through the coil.
- ❑ The meter requires low current ($\sim 50\mu\text{A}$) for a full scale deflection, thus consumes very low power (25-200 μW).
- ❑ Its accuracy is about 2% -5% of full scale deflection

2.2: DC AMMETER

- ❑ The PMMC galvanometer constitutes the basic movement of a dc ammeter.
- ❑ The coil winding of a basic movement is small and light, so it can carry only very small currents.
- ❑ A low value resistor (shunt resistor) is used in DC ammeter to measure large current.
- ❑ Basic DC ammeter:

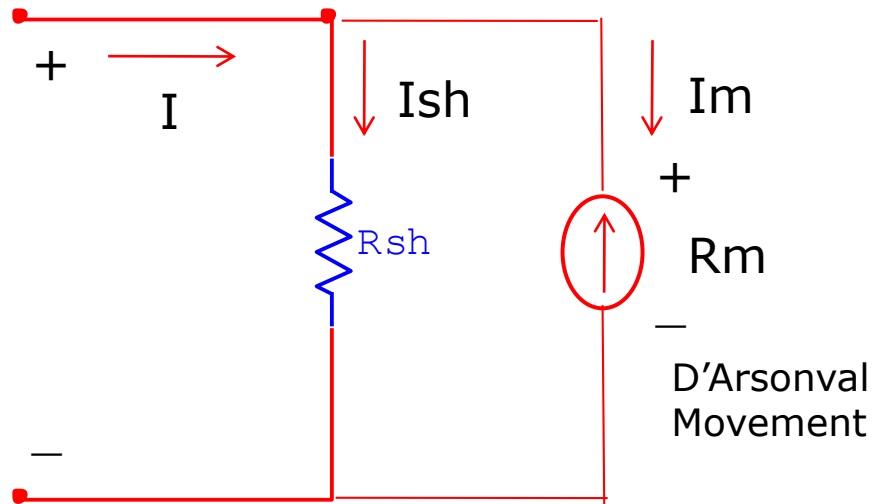


Figure 2.2: Basic DC Ammeter

□ Referring to Fig. 2.2:

R_m = internal resistance of the
movement

R_{sh} = shunt resistance

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)

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

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

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

EXAMPLE 3.1

A 1mA meter movement with an internal resistance of 100Ω is to be converted into a 0-100 mA. Calculate the value of shunt resistance required. (ans: 1.01Ω)

2.2.1: MULTIRANGE AMMETER

- ❖ The range of the dc ammeter is extended by a number of shunts, selected by a range switch.
- ❖ The resistors is placed in parallel to give different current ranges.
- ❖ Switch S (multiposition switch) protects the meter movement from being damage during range changing.
- ❖ Increase cost of the meter.

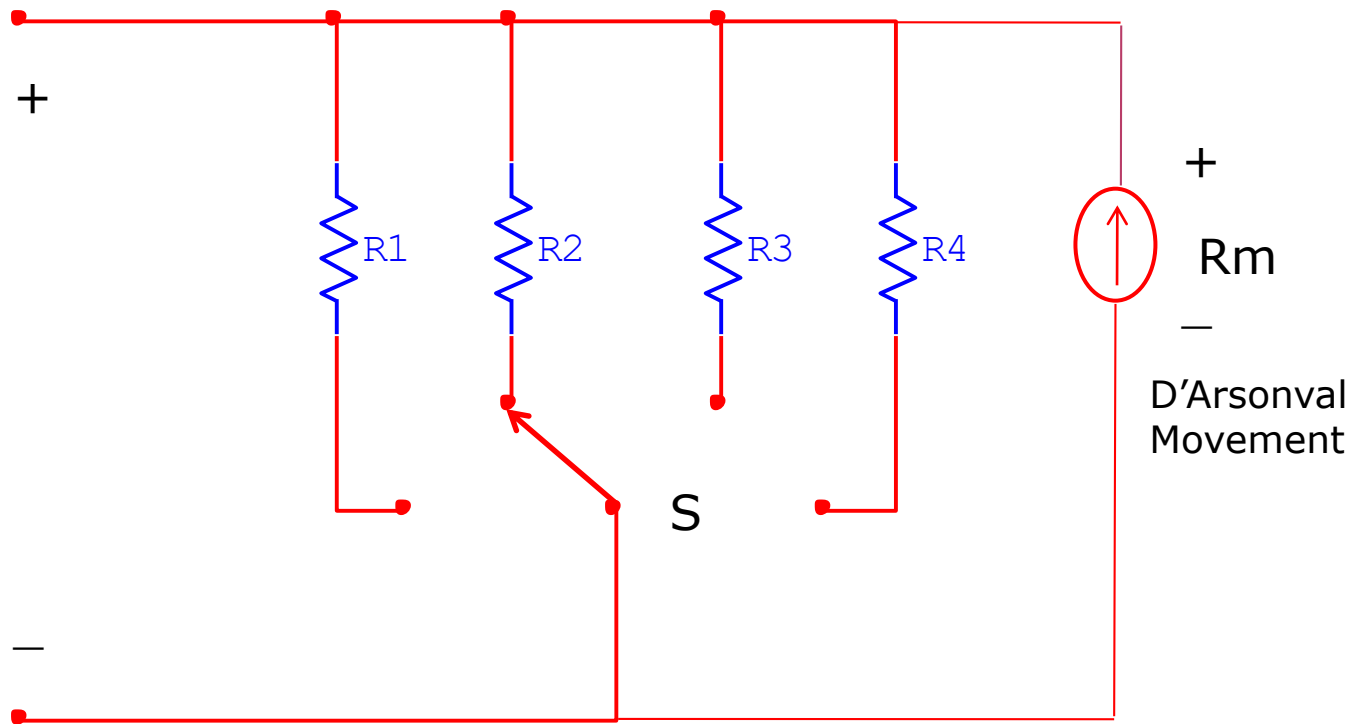


Figure 2.3: Multirange Ammeter

2.2.2: ARYTON SHUNT OR UNIVERSAL SHUNT

- ❖ Aryton shunt eliminates the possibility of having the meter in the circuit without a shunt.
- ❖ Reduce cost
- ❖ Position of the switch:
 - a) '1': R_a parallel with series combination of R_b , R_c and the meter movement. Current through the shunt is more than the current through the meter movement, thereby protecting the meter movement and reducing its sensitivity.
 - b) '2': R_a and R_b in parallel with the series combination of R_c and the meter movement. The current through the meter is more than the current through the shunt resistance.
 - c) '3': R_a , R_b and R_c in parallel with the meter. Maximum current flows through the meter movement and very little through the shunt. This will increase the sensitivity.

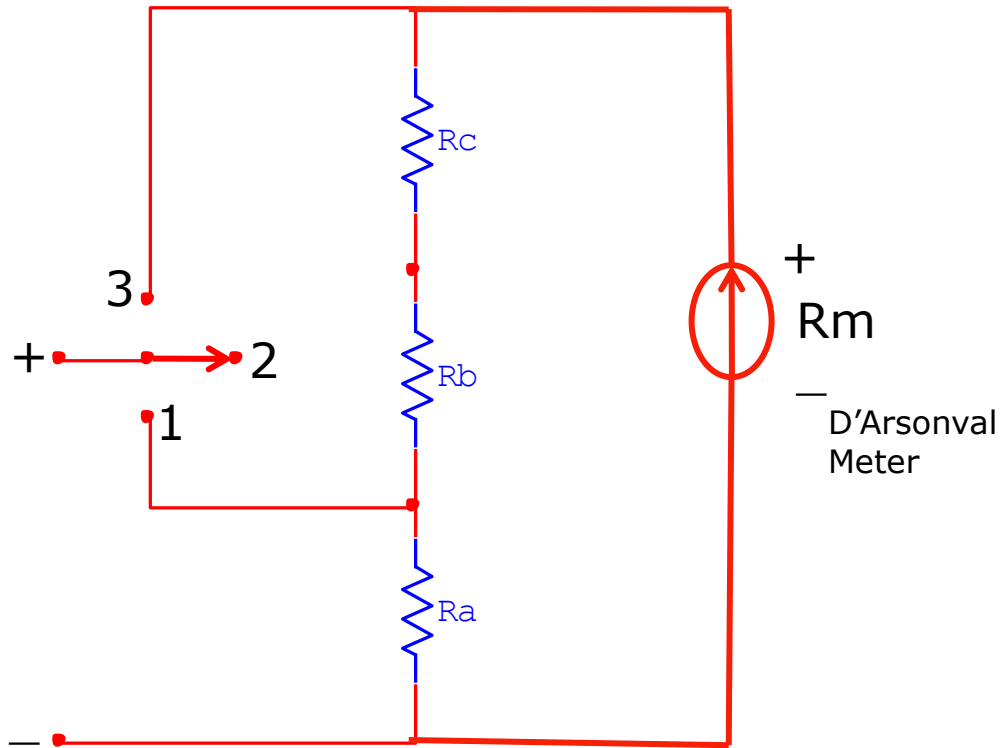
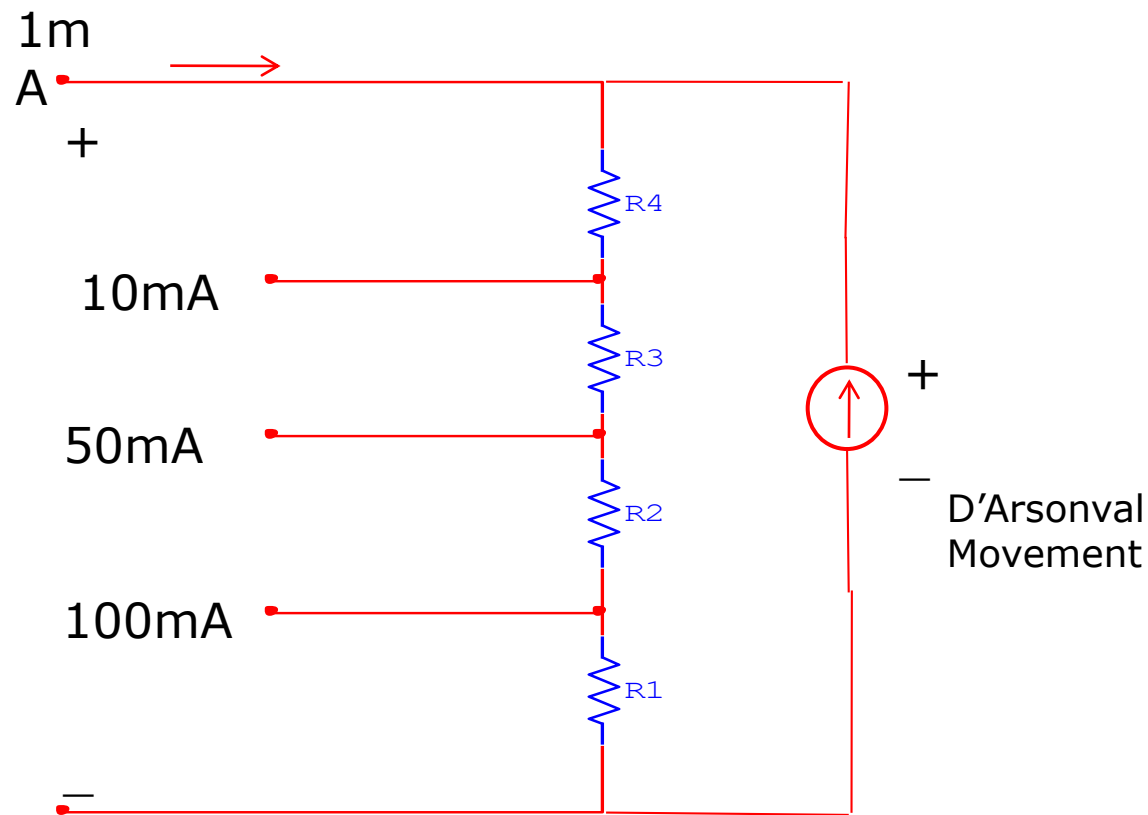


Figure 2.4: Ayrton Shunt

EXAMPLE 2.2

- Design an Ayrton shunt to provide an ammeter with a current range of 0-1 mA, 10 mA, 50 mA and 100 mA. A D'Arsonval movement with an internal resistance of 100Ω and full scale current of $50\mu\text{A}$ is used.



REQUIREMENT OF A SHUNT

1) Minimum Thermo Dielectric Voltage Drop

Soldering of joint should not cause a voltage drop.

2) Solderability

- never connect an ammeter across a source of e.m.f
- observe the correct polarity
- when using the multirange meter, first use the highest current range.

2.3: BASIC METER AS A DC VOLTMETER

- ❑ To use the basic meter as a dc voltmeter, must know the amount of current (I_{fsd}) required to deflect the basic meter to full scale.
- ❑ The sensitivity is based on the fact that the full scale current should result whenever a certain amount of resistance is present in the meter circuit for each voltage applied.

$$S = \frac{1}{I_{fsd}}$$

EXAMPLE 2.3

Calculate the sensitivity of a 200 μA meter movement which is to be used as a dc voltmeter.

Solution:

$$S = \frac{1}{I_{fsd}} = \frac{1}{200\mu\text{A}} = 5\text{k}\Omega/\text{V}$$

2.4: A DC VOLTMETER

□ A basic D'Arsonval movement can be converted into a DC voltmeter by adding a series resistor (multiplier) as shown in Figure 2.3.

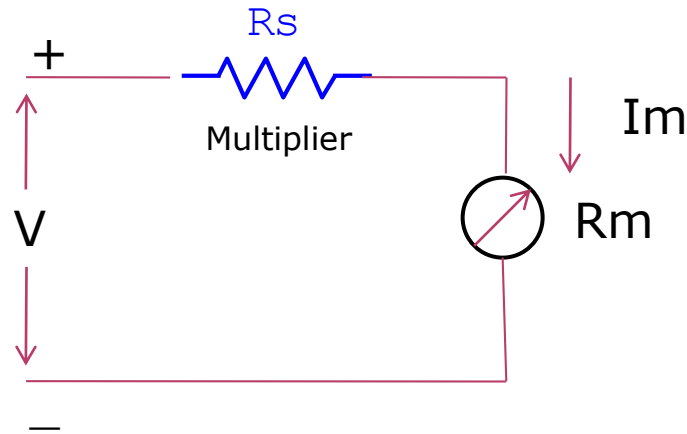


Figure 2.5: Basic DC Voltmeter

I_m =full scale deflection current of the movement (Ifsd)

R_m =internal resistance of the movement

R_s =multiplier resistance

V =full range voltage of the instrument

- From the circuit of Figure 2.5:

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

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

Therefore,

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

EXAMPLE 2.4

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

Solution:

$$R_s = \frac{V}{I_m} - R_m = \frac{10V}{50\mu A} - 500\Omega = 199.5k\Omega$$

- Sensitivity and voltmeter range can be used to calculate the multiplier resistance, R_s of a DC voltmeter.

$$R_s = (S \times \text{Range}) - R_m$$

- From example 2.4:

$$I_m = 50\mu\text{A}, R_m = 500\Omega, \text{Range} = 10\text{V}$$

Sensitivity,

$$S = \frac{1}{I_m} = \frac{1}{50\mu\text{A}} = 20\text{k}\Omega/\text{V}$$

$$\begin{aligned} \text{So, } R_s &= (20\text{k}\Omega/\text{V} \times 10\text{V}) - 500\Omega \\ &= 199.5\text{ k}\Omega \end{aligned}$$

2.5: MULTI-RANGE VOLTMETER

- A DC voltmeter can be converted into a multirange voltmeter by connecting a number of resistors (multipliers) in series with the meter movement.
- A practical multi-range DC voltmeter is shown in Figure 2.6.

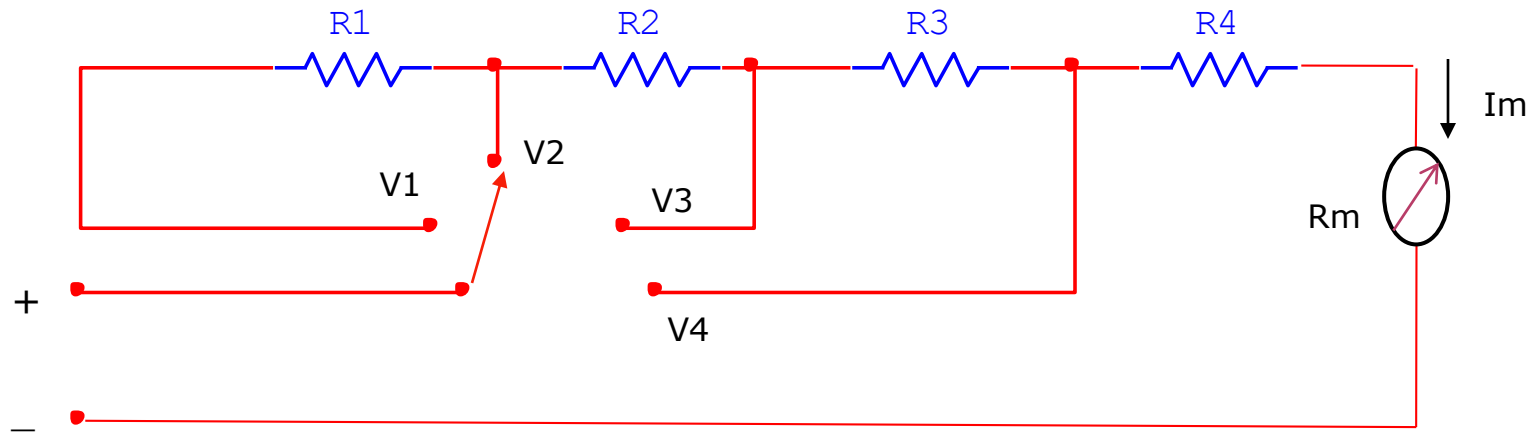


Figure 2.6: Multirange voltmeter

EXAMPLE 2.5

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

2.6: VOLTMETER LOADING EFFECTS

- When a voltmeter is used to measure the voltage across a circuit component, the voltmeter circuit itself is in parallel with the circuit component.
- Total resistance will decrease, so the voltage across component will also decrease. This is called voltmeter loading.
- The resulting error is called a loading error.
- The voltmeter loading can be reduced by using a high sensitivity voltmeter.
- How about ammeter??

2.7 AMMETER INSERTION EFFECTS

- Inserting Ammeter in a circuit always increases the resistance of the circuit and, thus always reduces the current in the circuit. The expected current:

$$I_e = \frac{E}{R_1} \quad (2-4)$$

- Placing the meter in series with R1 causes the current to reduce to a value equal to:

$$I_m = \frac{E}{R_1 + R_m} \quad (2-5)$$

2.7 AMMETER INSERTION EFFECTS

- Dividing equation (2-5) by (2-4) yields:

$$\frac{I_m}{I_e} = \frac{R_1}{R_1 + R_m} \quad (2-6)$$

- The Ammeter insertion error is given by :

$$\text{Insertion Error} = \left(1 - \frac{I_m}{I_e} \right) \times 100 \quad (2-7)$$

2.8 OHMMETER (Series Type)

- Current flowing through meter movements depends on the magnitude of the unknown resistance.(Fig 4.28 in text book)
- The meter deflection is non-linearly related to the value of the unknown Resistance, R_x .
- A major drawback – as the internal voltage decreases, reduces the current and meter will not get zero Ohm.
- R_2 counteracts the voltage drop to achieve zero ohm. How do you get zero Ohm?
- R_1 and R_2 are determined by the value of $R_x = R_h$ where R_h = half of full scale deflection resistance.

$$R_h = R_1 + (R_2 // R_m) = R_1 + \frac{R_2 R_m}{R_2 + R_m} \quad (2-8)$$

- The total current of the circuit, $I_t = V/R_h$
- The shunt current through R_2 is $I_2 = I_t - I_{fsd}$

2.8 OHMMETER (Series Type)

- The voltage across the shunt, $V_{sh} = V_m$

So, $I_2 R_2 = I_{fsd} R_m$

Since $I_2 = I_t - I_{fsd}$

Then,

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

Since $I_t = V/R_h$

So,

$$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h} \quad (2-9)$$

2.8 OHMMETER (Series Type)

From equation (2-8) and (2-9):

$$R_1 = R_h - \frac{I_{fsd} R_m R_h}{V} \quad (2-10)$$

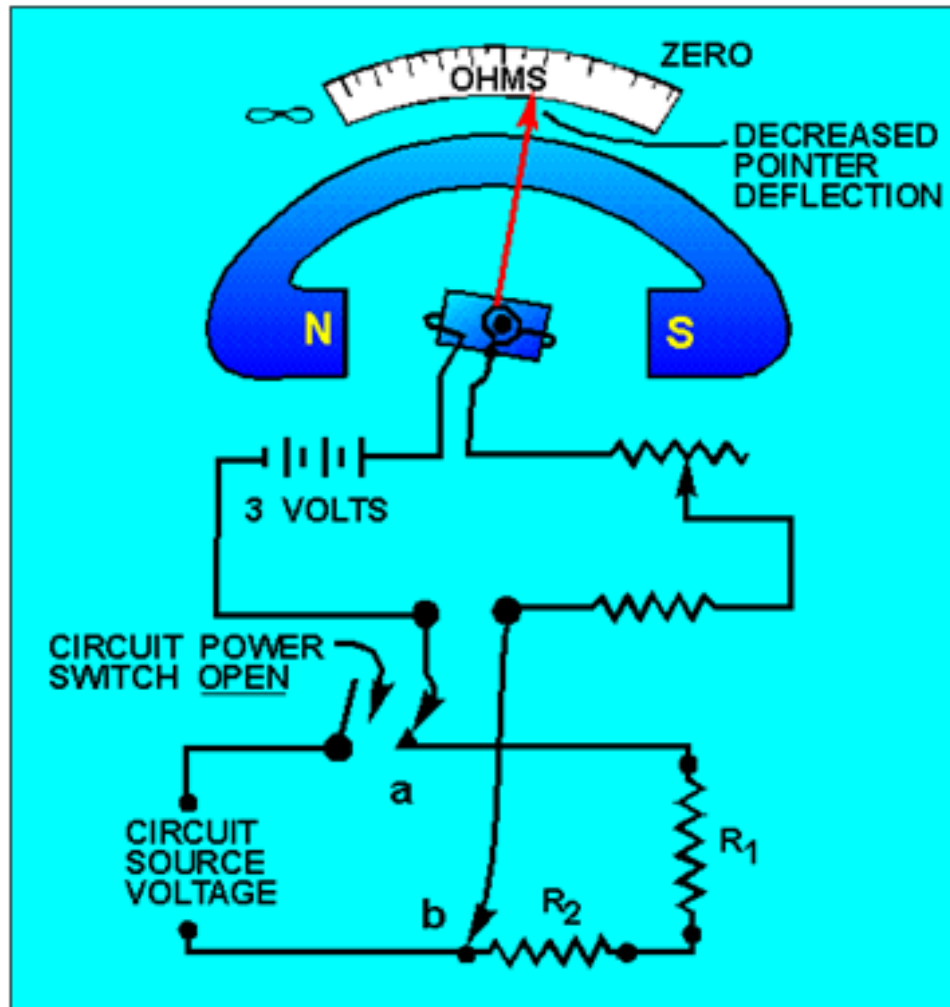


Figure 2.7: Measuring circuit resistance with an ohmmeter

Example:

- 1) A $50\mu\text{A}$ full scale deflection current meter movement is to be used in an Ohmmeter. The meter movement has an internal resistance $R_m = 2\text{k}\Omega$ and a 1.5V battery is used in the circuit. Determine R_z at full scale deflection.
- 2) A 100Ω basic movement is to be used as an ohmmeter requiring a full scale deflection of 1mA and internal battery voltage of 3V . A half scale deflection marking of 2k 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

2.9 MULTI-RANGE OHMMETER

- Another method of achieving flexibility of a measuring instrument is by designing it to be in multi-range.
- Let us analyse the following examples. (figure 4.29 of your textbook)

2.10 MULTIMETER

- Multimeter consists of an ammeter, voltmeter and ohmmeter in one unit.
- It has a function switch to connect the appropriate circuit to the D'Arsonval movement.
- Fig.4.33 (in text book) shows DC miliammeter, DC voltmeter, AC voltmeter, microammeter and ohmmeter.

2.11 AC VOLTMETER USING HALF-WAVE RECTIFIER

- The D'Arsonval meter movement can be used to measure alternating current by the use of a diode rectifier to produce unidirectional current flow.
- In case of a half wave rectifier, if given input voltage, $E_{in} = 10$ V_{rms}, then:

Peak voltage, $E_p = 10V_{rms} \times 1.414 = 14.14V$

Average voltage, $E_{ave} = E_{dc} = 0.636 \times E_p = 8.99V$

- Since the diode conducts only during the positive half cycle as shown in Fig 4.18(in text book), the average voltage is given by:

$$E_{ave} / 2 = 4.5V$$

2.11 AC VOLTMETER USING HALF-WAVE RECTIFIER

- Therefore, the pointer will deflect for a full scale if 10 Vdc is applied and only 4.5 V when a 10 Vrms sinusoidal signal is applied.

- The DC voltmeter sensitivity is given by:

$$S_{dc} = \frac{1}{I_m} = \frac{1}{1mA} = 1k\Omega/V$$

- For the circuit in Figure 4.18, the AC voltmeter sensitivity is given by:

$$S_{ac} = 0.45S_{dc} = 0.45k\Omega/V$$

- This means that an AC voltmeter is not as sensitive as a DC voltmeter.

2.11 AC VOLTMETER USING HALF-WAVE RECTIFIER

- To get the multiplier resistor, R_s value:

$$E_{dc} = 0.45 \times E_{rms}$$
$$R_s = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.45 \times E_{rms}}{I_{dc}} - R_m \quad (2-11)$$

- The AC meter scale is usually calibrated to give the RMS value of an alternating sine wave input.
- A more general AC voltmeter circuit is shown in Fig. 4.17 (in text book)
- A shunt resistor, R_{sh} is used to draw more current from the diode D1 to move its operating point to a linear region.
- Diode D2 is used to conduct the current during the negative half cycle.
- The sensitivity of AC voltmeter can be doubled by using a full wave rectifier.

EXAMPLE

- Calculate the value of the multiplier resistor for a 10 V_{rms} range on the voltmeter shown in Fig 4.19 (in text book)

2.11 AC VOLTMETER USING FULL-WAVE RECTIFIER

- Consider the circuit in Fig 4.20 (in text book)

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

- **Example:**

Calculate the value of the multiplier resistor for a 10 Vrms ac range on the voltmeter in Fig. 4.21

2.12 WHEATSTONE BRIDGE

- Accurate method for measuring resistance between $1\Omega \sim 1M\Omega$.
- Figure 11.1 shows the schematic diagram of a Wheatstone Bridge.
- When the bridge is set to null condition, voltages at point C & D are equal.
- Thus

$$I_1 R_1 = I_2 R_2 \quad (2-12)$$

$$I_3 R_3 = I_4 R_4 \quad (2-13)$$

2.12 WHEATSTONE BRIDGE

- Since $I_1 = I_3$ and $I_2 = I_4$, divide equation 2-12 by equation 2-13:

$$\frac{R_1}{R_3} = \frac{R_2}{R_4} \quad \text{So,} \quad R_X = R_4 \frac{R_2 R_3}{R_1} \quad (2-14)$$

Usually, the resistor R_3 is a variable resistor to balance the bridge.

- R_X is the unknown resistor to be measured.
- When bridge is balance, the value of the unknown resistor R_X is equal to resistance value of R_3

2.12 WHEATSTONE BRIDGE

- **Example:**

1. Given the Wheatstone bridge with $R_1 = 15 \text{ k}\Omega$, $R_2 = 10 \text{ k}\Omega$, and $R_3 = 4.5 \text{ k}\Omega$. Find R_X .
2. Calculate the current through the Galvanometer in the circuit. Given $R_1 = 1 \text{ k}\Omega$, $R_2 = 1.6 \text{ k}\Omega$, $R_3 = 3.5 \text{ k}\Omega$, $R_4 = 7.5 \text{ k}\Omega$, $R_G = 200\Omega$ and $V = 6V$.

2.13 KELVIN BRIDGE

- Kelvin Bridge is used to measure resistance below 1Ω .
- In low resistance measurement, the leads connecting the unknown resistor to the bridge may effect the measurement.
- Kelvin's Double Bridge known as Kelvin Bridge is constructed to overcome this problem.
- Figure 11.10 (in text book) shows the Kelvin's Bridge and Figure 11.11 shows the Kelvin's Double Bridge.

2.13 KELVIN BRIDGE

- The resistor R_Y represents the lead and contact resistance present in the Wheatstone Bridge.
- The resistors R_a and R_b are used to compensate this low lead-contact resistance.
- From circuit analysis, the unknown Resistor R_X in a balanced Kelvin Bridge is given by:

$$\frac{R_X}{R_2} = \frac{R_3}{R_1} = \frac{R_b}{R_a} \quad (2-15)$$

See example 11.4 (textbook)

2.14 BRIDGE CONTROLLED CIRCUIT

- When a bridge is imbalance, a potential difference exists at its output terminal.
- If it is used as an error detector in a control circuit, the potential difference at the output of the bridge is called an error signal.
- The error signal is given by:

$$E_s = E \times \left(\frac{R_3}{R_1 + R_3} - \frac{R_V}{R_2 + R_V} \right) \quad (2-16)$$

- The unknown resistor R_V can be any passive circuit elements such as strain gauge, thermistor and photo resistor.
- Since R_V varies by only a small amount, an amplifier often needed before being used for control purposes.
- Fig. 11.14 shows the Wheatstone Bridge error detector.