Benha University
Faculty of Engineering (Shoubra)
Electronics and Communications Engineering

ECE 211
Electrical and Electronic Measurements
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Lecture 4: Electromechanical Instruments Part 2

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Chapter Outline:

1. Permanent Magnet Moving Coil (PMMC).
2. Galvanometer.
3. DC Ammeters
4. DC Voltmeters
5. Ohmmeters
6. AC Ammeters
7. AC Voltmeters
8. Electro-Dynamic Instrument

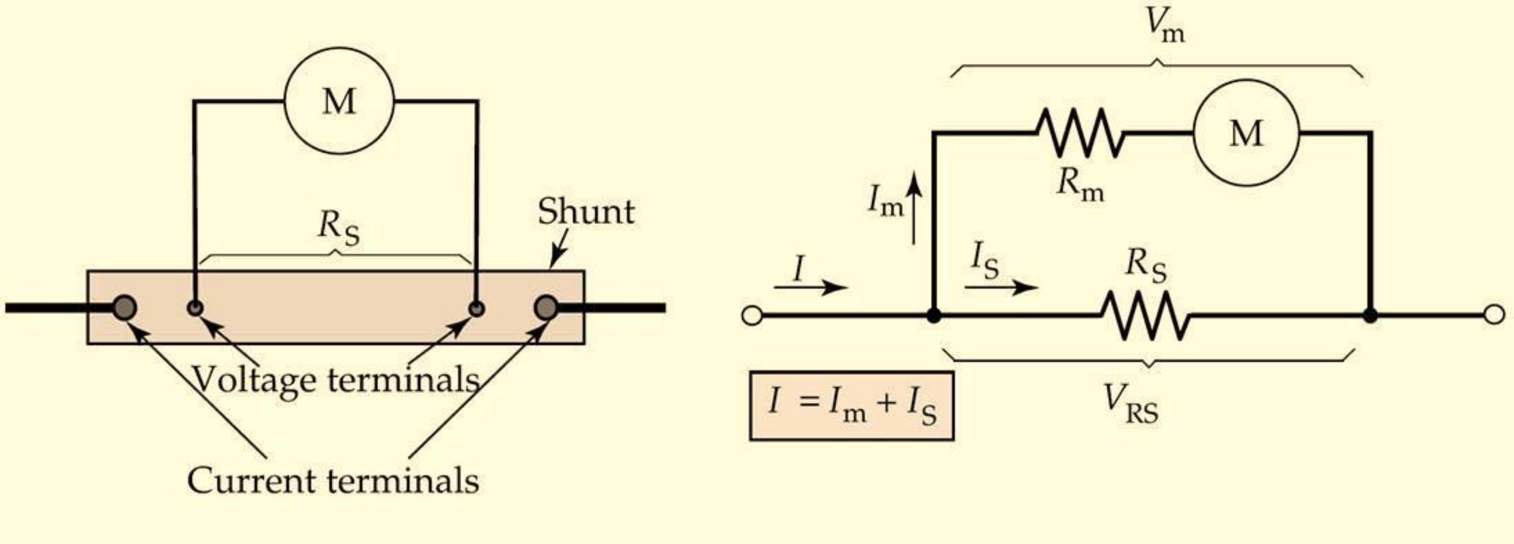
3. DC Ammeters

3.3 DC Ammeters: Ammeter Circuit:

- The PMMC instrument can be used as an ammeter to **measure DC current**. However, the PMMC wire could be quickly **destroyed by large currents.**
- For large currents, a PMMC is modified by adding **a parallel (shunt) resistance** R_s .
- Most of the measured current will pass through R_s and a small portion of it will pass through the moving coil.

Shunt Resistance

It is a small resistance connected in parallel with PMMC to allow measuring large currents. It is a four-terminal resistance to neglect the resistance of the current terminal.



(a) Dc ammeter construction

(b) Ammeter equivalent circuit

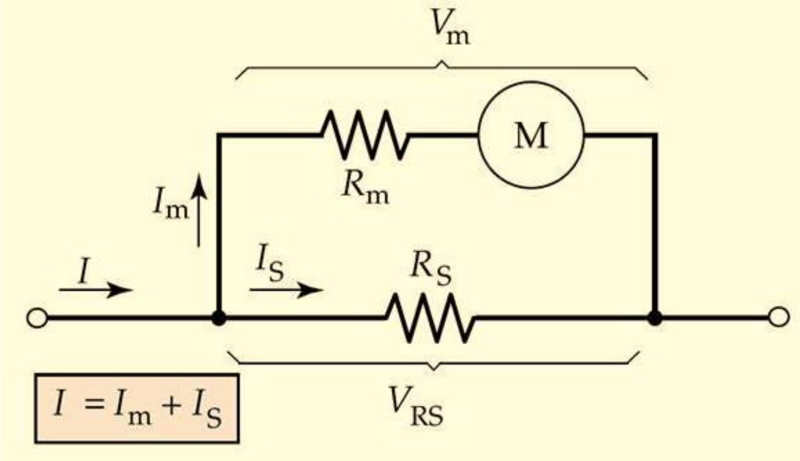
Figure 4-1 A dc ammeter consists of a PMMC instrument and a low-resistance shunt. The meter current is directly proportional to the shunt current, so that the meter scale can be calibrated to indicate the total ammeter current.

3.3 DC Ammeter (Cont.)

Example 3.3:

- An ammeter has a PMMC instrument with a coil resistance of R_m =99 Ω and full-scale deflection (FSD) current of 0.1 mA. Shunt resistance R_s = 1 Ω. **Determine** the total current passing through the ammeter at:

(a) FSD (b) 0.5 FSD (c) 0.25 FSD



Solution

(a) At FSD:

$$\text{meter voltage } V_m = I_m R_m$$

$$= 0.1 \text{ mA} \times 99\ \Omega$$

$$= 9.9 \text{ mV}$$

and $$I_s R_s = V_m$$

$$I_s = \frac{V_m}{R_s} = \frac{9.9 \text{ mV}}{1\ \Omega} = 9.9 \text{ mA}$$

$$\text{total current } I = I_s + I_m = 9.9 \text{ mA} + 0.1 \text{ mA}$$

$$= 10 \text{ mA}$$

(b) At 0.5 FSD:

$$I_m = 0.5 \times 0.1 \text{ mA} = 0.05 \text{ mA}$$

$$V_m = I_m R_m = 0.05 \text{ mA} \times 99\ \Omega = 4.95 \text{ mV}$$

$$I_s = \frac{V_m}{R_s} = \frac{4.95 \text{ mV}}{1\ \Omega} = 4.95 \text{ mA}$$

$$\text{total current } I = I_s + I_m = 4.95 \text{ mA} + 0.5 \text{ mA}$$

$$= 5 \text{ mA}$$

(c) At 0.25 FSD:

$$I_m = 0.25 \times 0.1 \text{ mA} = 0.025 \text{ mA}$$

$$V_m = I_m R_m = 0.025 \text{ mA} \times 99\ \Omega$$

$$= 2.475 \text{ mV}$$

$$I_s = \frac{V_m}{R_s} = \frac{2.475 \text{ mV}}{1\ \Omega} = 2.475 \text{ mA}$$

$$\text{total current } I = I_s + I_m = 2.475 \text{ mA} + 0.025 \text{ mA}$$

$$= 2.5 \text{ mA}$$

3. DC Ammeter (Cont.)

Example 3.4: A PMMC instrument has FSD of 100 μA and a coil resistance of 1 kΩ. Calculate the required shunt resistance value to convert the instrument into an ammeter with (a) FSD = 100 mA and (b) FSD = 1 A.

Solution

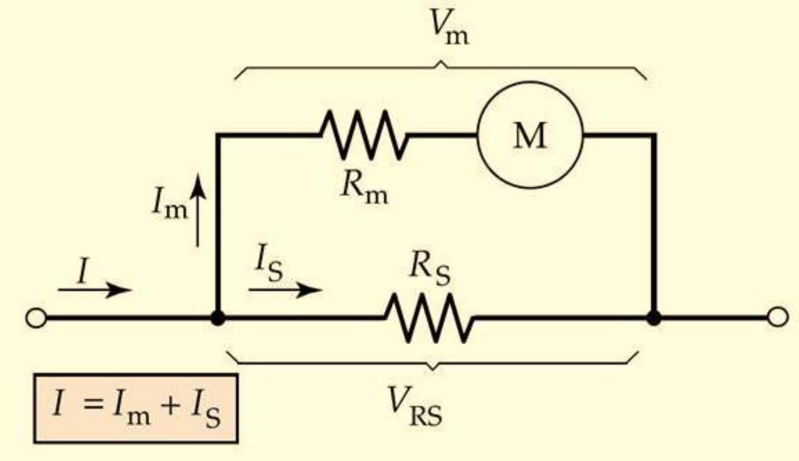
(a) *FSD* = 100 mA:

$$V_m = I_m R_m = 100\ \mu\text{A} \times 1\ \text{k}\Omega = 100\ \text{mV}$$

$$I = I_s + I_m$$

$$I_s = I - I_m = 100\ \text{mA} - 100\ \mu\text{A} = 99.9\ \text{mA}$$

$$R_s = \frac{V_m}{I_s} = \frac{100\ \text{mV}}{99.9\ \text{mA}} = 1.001\ \Omega$$



(b) *FSD* = 1 A:

$$V_m = I_m R_m = 100\ \text{mV}$$

$$I_s = I - I_m = 1\ \text{A} - 100\ \mu\text{A} = 999.9\ \text{mA}$$

$$R_s = \frac{V_m}{I_s} = \frac{100\ \text{mV}}{999.9\ \text{mA}} = 0.10001\ \Omega$$

3.3 DC Ammeters: Swamping Resistance:

- The moving coil in a PMMC instrument is wound with thin copper wire, and its resistance can change with the temperature.
- Any such change in coil resistance will introduce an error in ammeter current measurements.
- To minimize the effect of temperature change on the PMMC resistance, a swamping resistance is connected in series with PMMC.
- The swamping resistance is made from magnain or constantan that have zero temperature coefficients.
- If the swamping resistance is nine times the coil resistance, a 1 % change in coil resistance would result in a total resistance change of 0.1 %.

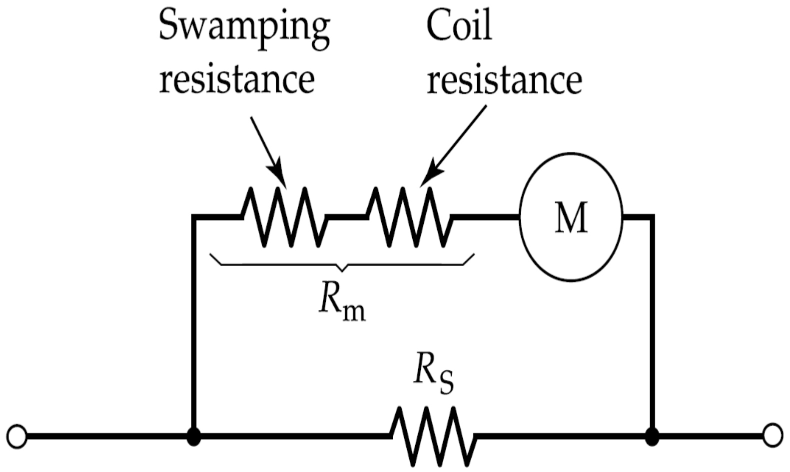
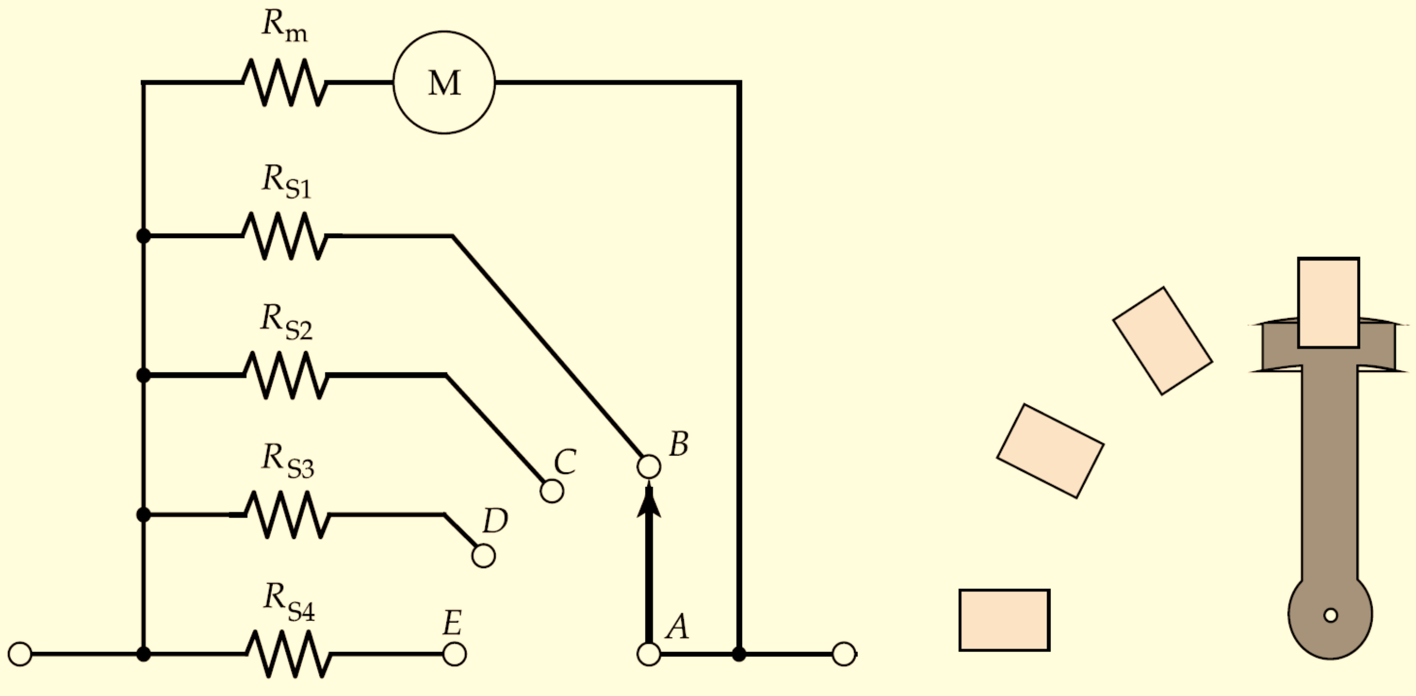


Figure 4-2 A swamping resistance made of a material with a near-zero temperature coefficient can be connected in series with the coil of a PMMC instrument to minimize temperature errors.

3.3 DC Ammeters: Multirange Ammeter:

- A rotary switch is employed to select anyone of several shunt resistances with different values.
- A **make-before-break** switch must be used so that the instrument is not left without a shunt in parallel with it even for a brief instant.
- A make before-break switch makes contact with the next terminal before it breaks contact with the previous terminal.

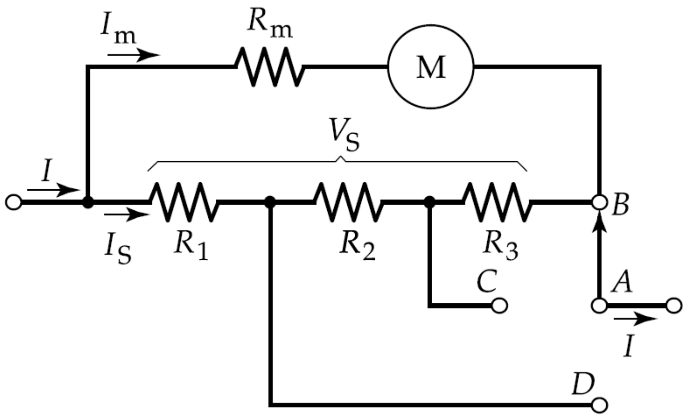


(a) Multirange ammeter circuit

(b) Make-before-break switch

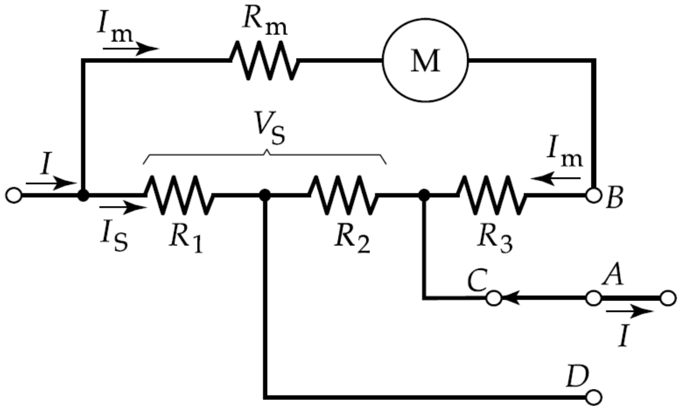
Figure 4-3 A multirange ammeter consists of a PMMC instrument, several shunts, and a switch that makes contact with the next shunt before losing contact with the previous one when range switching.

3.3 DC Ammeters: Multirange Ammeter (Cont.):



(a) Ayrton shunt and meter

$(R_1+R_2+R_3)\|R_m$



(b) Switch at terminal C

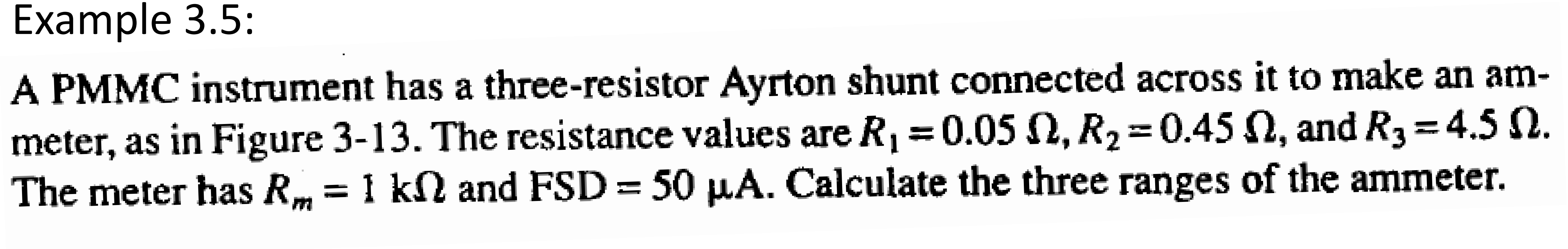
$(R_1+R_2)\|(R_m+R_3)$

Figure 4-4 An Ayrton shunt used with an ammeter consists of several series-connected resistors all connected in parallel with the PMMC instrument. Range change is effected by switching between the resistor junctions.

- Figures show another method of protecting the deflection instrument from excessive current during switching

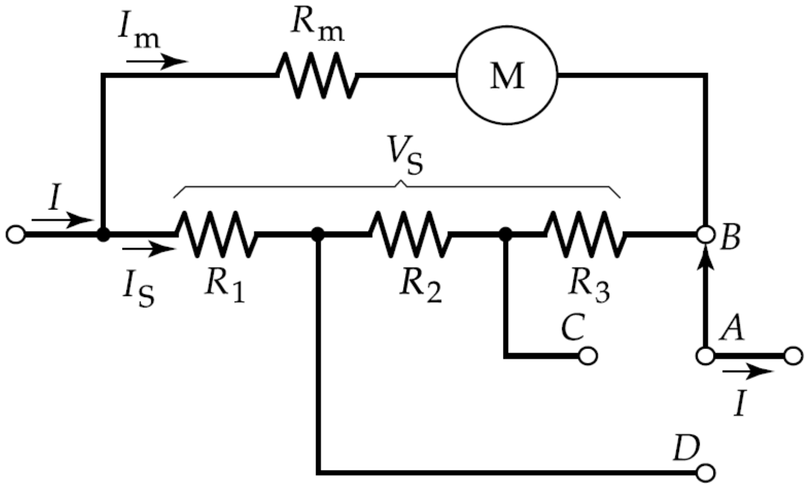
3.3 DC Ammeters: Multirange Ammeter (Cont.):

Example 3.5:



A PMMC instrument has a three-resistor Ayrton shunt connected across it to make an ammeter, as in Figure 3-13. The resistance values are $R_1 = 0.05\ \Omega$, $R_2 = 0.45\ \Omega$, and $R_3 = 4.5\ \Omega$. The meter has $R_m = 1\ \text{k}\Omega$ and FSD = 50 μA. Calculate the three ranges of the ammeter.

Solution



(a) Ayrton shunt and meter

Solution

1. *Switch at contact B:*

$$V_s = I_m R_m = 50\ \mu\text{A} \times 1\ \text{k}\Omega = 50\ \text{mV}$$

$$I_s = \frac{V_s}{R_1 + R_2 + R_3}$$

$$= \frac{50\ \text{mV}}{0.05\ \Omega + 0.45\ \Omega + 4.5\ \Omega} = 10\ \text{mA}$$

$$I = I_m + I_s = 50\ \mu\text{A} + 10\ \text{mA}$$

$$= 10.05\ \text{mA}$$

Ammeter range $\simeq$ 10 mA.

3. *Switch at contact D:*

$$V_s = I_m(R_m + R_3 + R_2)$$

$$= 50\ \mu\text{A}(1\ \text{k}\Omega + 4.5\ \Omega + 0.45\ \Omega)$$

$$\simeq 50\ \text{mV}$$

$$I_s = \frac{V_s}{R_1} = \frac{50\ \text{mV}}{0.05\ \Omega}$$

$$= 1\ \text{A}$$

$$I = 50\ \mu\text{A} + 1\ \text{A}$$

$$= 1.00005\ \text{A}$$

Ammeter range $\simeq$ 1 A.

2. *Switch at contact C:*

$$V_s = I_m(R_m + R_3)$$

$$= 50\ \mu\text{A}(1\ \text{k}\Omega + 4.5\ \Omega)$$

$$\simeq 50\ \text{mV}$$

$$I_s = \frac{V_s}{R_1 + R_2}$$

$$= \frac{50\ \text{mV}}{0.05\ \Omega + 0.45\ \Omega}$$

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

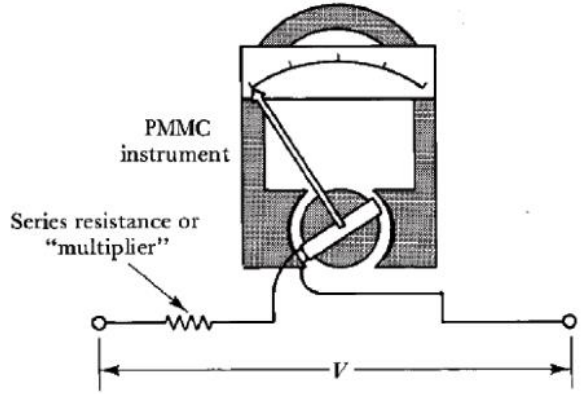
$$I = 50\ \mu\text{A} + 100\ \text{mA}$$

$$= 100.05\ \text{mA}$$

Ammeter range $\simeq$ 100 mA.

3.4 DC Voltmeter: Voltmeter Circuit

- The scale of the PMMC meter can be calibrated to indicate voltage since the **current through the coil is proportional to the voltage**.
- The PMMC is modified by adding a **series resistance** to measure higher voltmeter range.
- Because it increases the range of the voltmeter, the series resistance is termed a multiplier resistance.
- A multiplier resistance that is nine times the coil resistance will increase the voltmeter range by a factor of 10.



Construction of DC Voltmeter

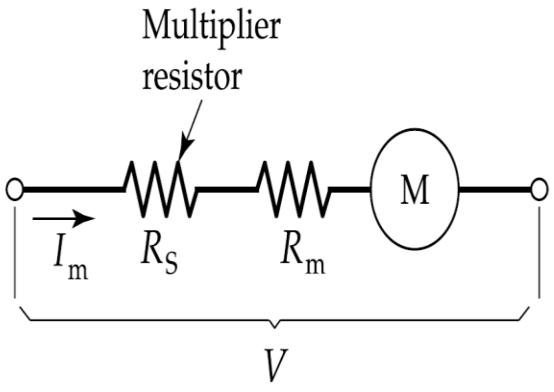


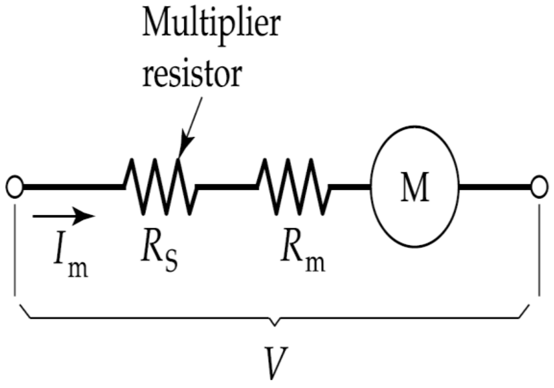
Figure 4-5 A dc voltmeter is made up of a PMMC instrument and a series multiplier resistor. The meter current is directly proportional to the applied voltage, so that the meter scale can be calibrated to indicate the voltage.

3.4 DC Voltmeter (Cont.):

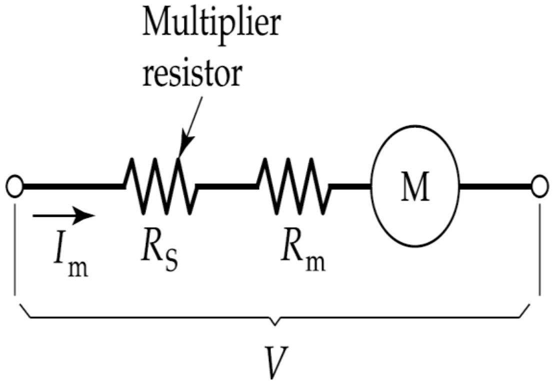
Example 3.6:

- A PMMC instrument with FSD of 100 μA and a coil resistance of 1 kΩ is to be converted into a voltmeter. ***Determine*** the required multiplier resistance if the voltmeter is to measure 50 V at full scale.

  Also ***calculate*** the applied voltage when the instrument indicates 0.8, 0.5, and 0.2 of FSD.



Solution



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

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

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

For $V = 50$ V *FSD,*

$$I_m = 100\ \mu\text{A}$$

$$R_s = \frac{50\ \text{V}}{100\ \mu\text{A}} - 1\ \text{k}\Omega$$

$$= 499\ \text{k}\Omega$$

At 0.8 FSD:

$$I_m = 0.8 \times 100\ \mu\text{A}$$

$$= 80\ \mu\text{A}$$

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

$$= 80\ \mu\text{A}(499\ \text{k}\Omega + 1\ \text{k}\Omega)$$

$$= 40\ \text{V}$$

At 0.5 FSD:

$$I_m = 50\ \mu\text{A}$$

$$V = 50\ \mu\text{A}(499\ \text{k}\Omega + 1\ \text{k}\Omega)$$

$$= 25\ \text{V}$$

At 0.2 FSD:

$$I_m = 20\ \mu\text{A}$$

$$V = 20\ \mu\text{A}(499\ \text{k}\Omega + 1\ \text{k}\Omega)$$

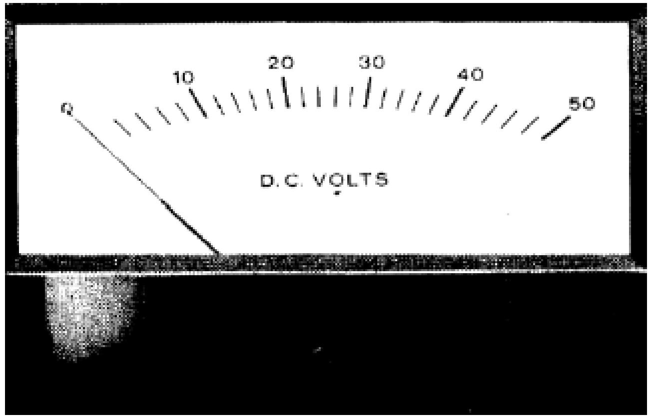
$$= 10\ \text{V}$$

3.4 DC Voltmeter: Voltmeter Sensitivity:

The sensitivity of a voltmeter is equal to the resistance per volt:

$$S_v = \frac{R_m + R_s}{FSD} \qquad \Omega/V$$

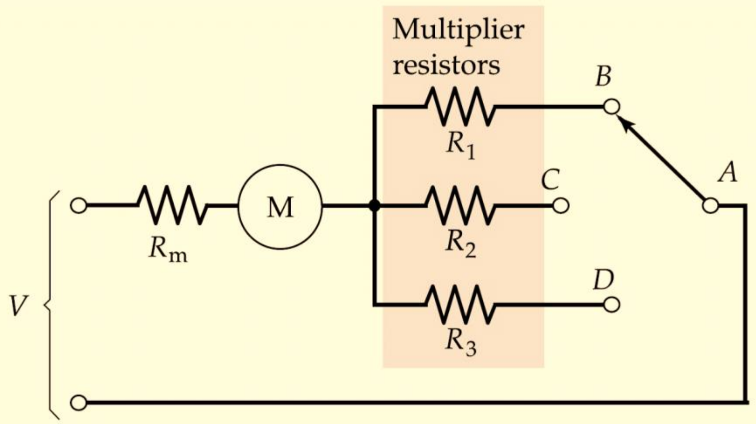
- The voltmeter sensitivity is always specified by the manufacturer.
- If the sensitivity is known, the total voltmeter resistance is easily calculated as (sensitivity x range).
- Ideally, a voltmeter should have an extremely high resistance.
- If the voltmeter resistance is **too low**, it can alter the circuit voltage. This is known as **voltmeter loading effect.**



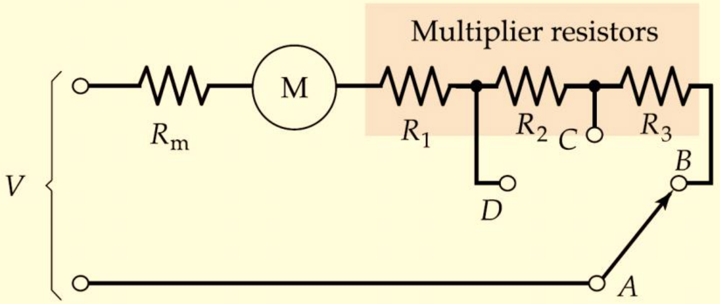
3.4 DC Voltmeter: Multirange Voltmeter

- It consists of a deflection instrument, several multiplier resistors, and a selector switch.
- Two possible circuits are proposed.
- Only one of the three multiplier resistors is connected in series with the meter at any time.
- The range of this voltmeter is

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



(a) Multirange voltmeter circuit using switched multiplier resistors

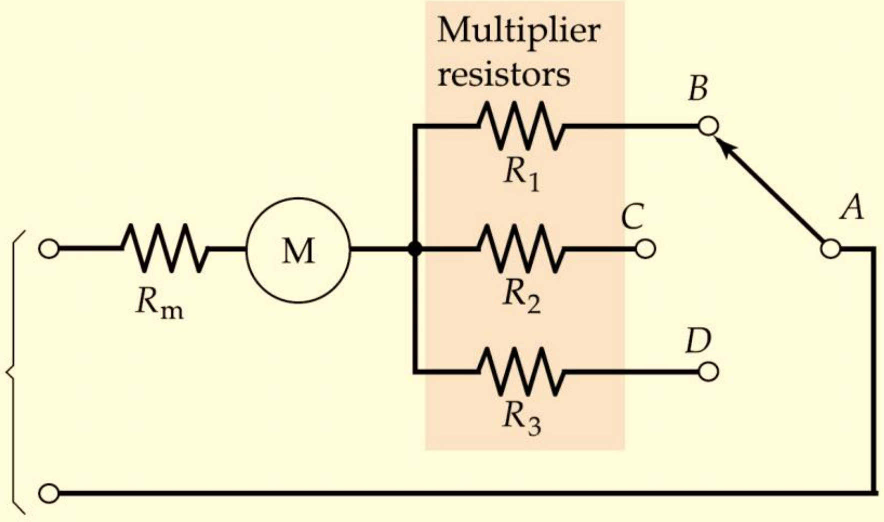


(b) Multirange voltmeter circuit using series connected multiplier resistors

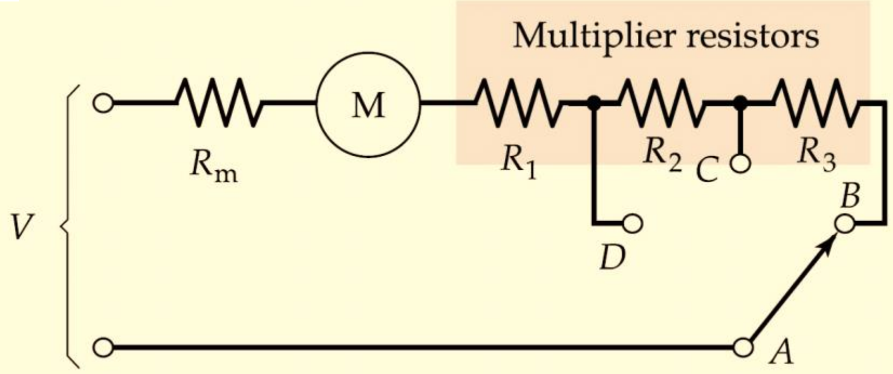
Figure 4-6 A multirange voltmeter consists of a PMMC instrument, several multiplier resistors, and a switch for range selection. Individual or series-connected resistors may be used.

Example 3.7:

A PMMC instrument with FSD = 50 μ A and R_m = 1700 Ω is to be employed as a voltmeter with ranges of 10 V, 50 V, and 100 V. ***Calculate*** the required values of multiplier resistors for the two circuits



(a) Multirange voltmeter circuit using switched multiplier resistors



(b) Multirange voltmeter circuit using series connected multiplier resistors

Solution:

Solution (Cont.)

$$R_m + R_1 = \frac{V}{I_m}$$

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

$$= \frac{10\ \text{V}}{50\ \mu\text{A}} - 1700\ \Omega$$

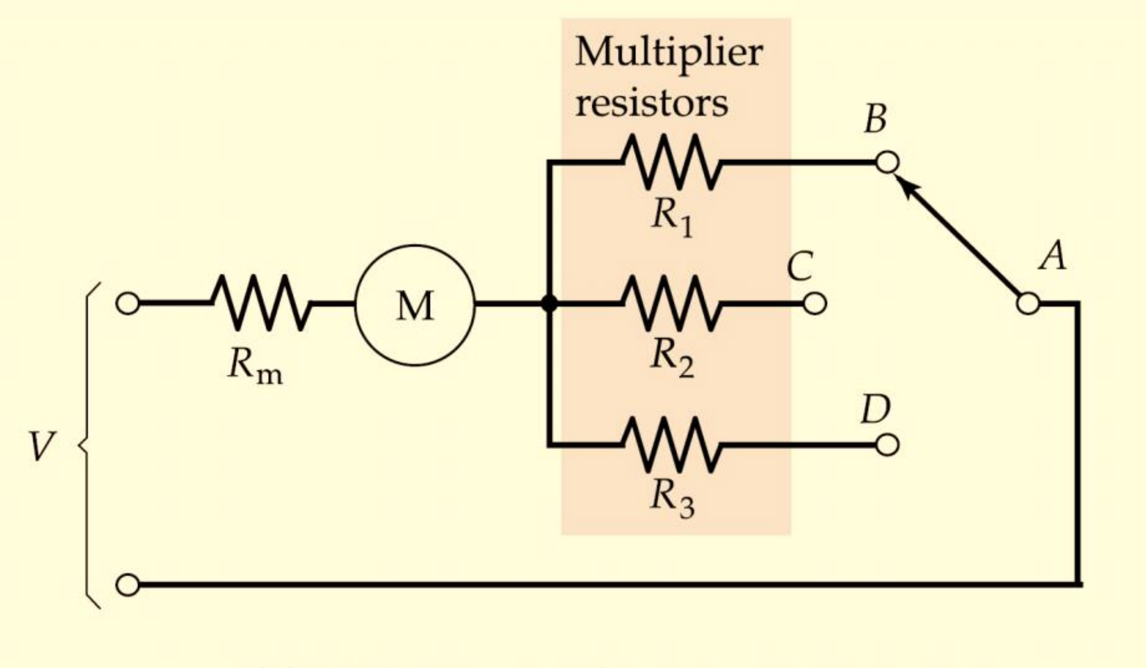
$$= 198.3\ \text{k}\Omega$$

$$R_2 = \frac{50\ \text{V}}{50\ \mu\text{A}} - 1700\ \Omega$$

$$= 998.3\ \text{k}\Omega$$

$$R_3 = \frac{100\ \text{V}}{50\ \mu\text{A}} - 1700\ \Omega$$

$$= 1.9983\ \text{M}\Omega$$



(a) Multirange voltmeter circuit using switched multiplier resistors

Solution (Cont.)

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

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

$$= \frac{10\ \text{V}}{50\ \mu\text{A}} - 1700\ \Omega$$

$$= 198.3\ \text{k}\Omega$$

$$R_m + R_1 + R_2 = \frac{V_2}{I_m}$$

$$R_2 = \frac{V_2}{I_m} - R_1 - R_m$$

$$= \frac{50\ \text{V}}{50\ \mu\text{A}} - 198.3\ \text{k}\Omega - 1700\ \Omega$$

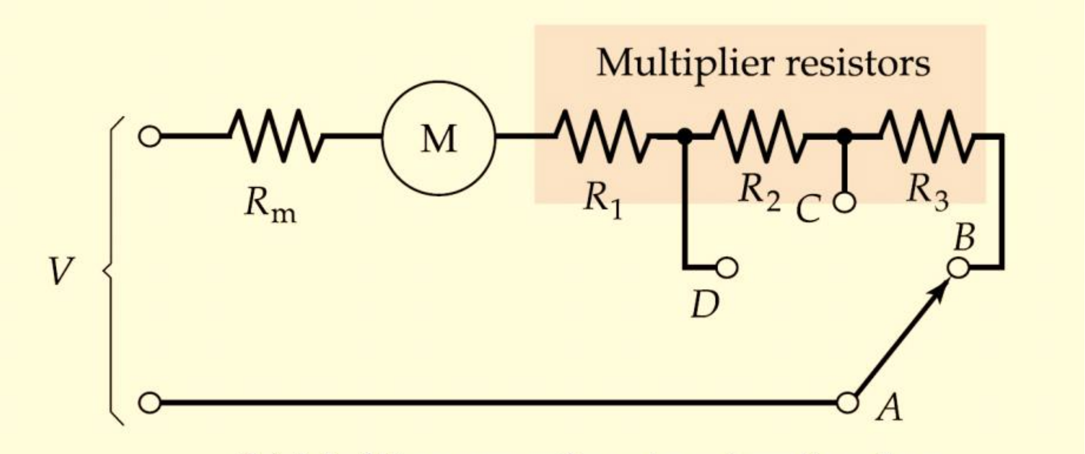
$$= 800\ \text{k}\Omega$$

$$R_m + R_1 + R_2 + R_3 = \frac{V_3}{I_m}$$

$$R_3 = \frac{V_3}{I_m} - R_2 - R_1 - R_m$$

$$= \frac{100\ \text{V}}{50\ \mu\text{A}} - 800\ \text{k}\Omega - 198.3\ \text{k}\Omega - 1700\ \Omega$$

$$= 1\ \text{M}\Omega$$



(b) Multirange voltmeter circuit using series connected multiplier resistors

3.5 Ohmmeter: Basic Circuit: Series Ohmmeter:

- The series ohmmeter consists of a PMMC with a battery voltage Eb connected in series.
- The unknown resistance is connected between terminals, A and B.
- A standard (known) resistance R1 is connected to protect the device from high current when low resistance is connected.

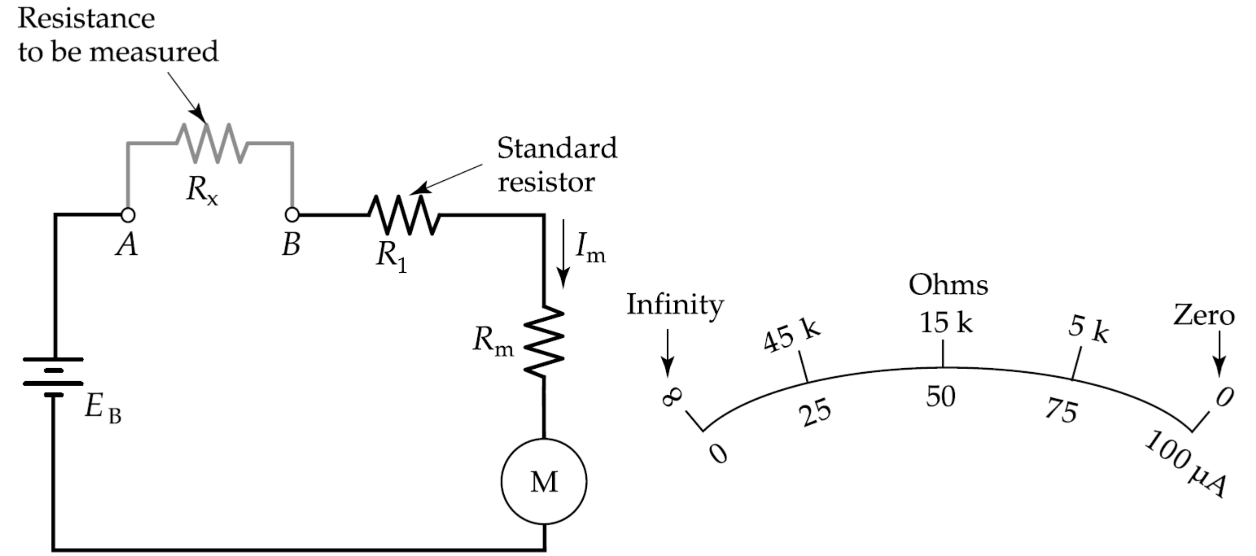


Figure 4-11 Basic series ohmmeter circuit consisting of a PMMC instrument and a series-connected standard resistor (R_1). When the ohmmeter terminals are shorted ($R_x = 0$) meter FSD occurs. At half-scale deflection $R_x = R_1$, and at zero deflection the terminals are open-circuited.

$$I_m = \frac{E_b}{R_1 + R_x + R_m}$$

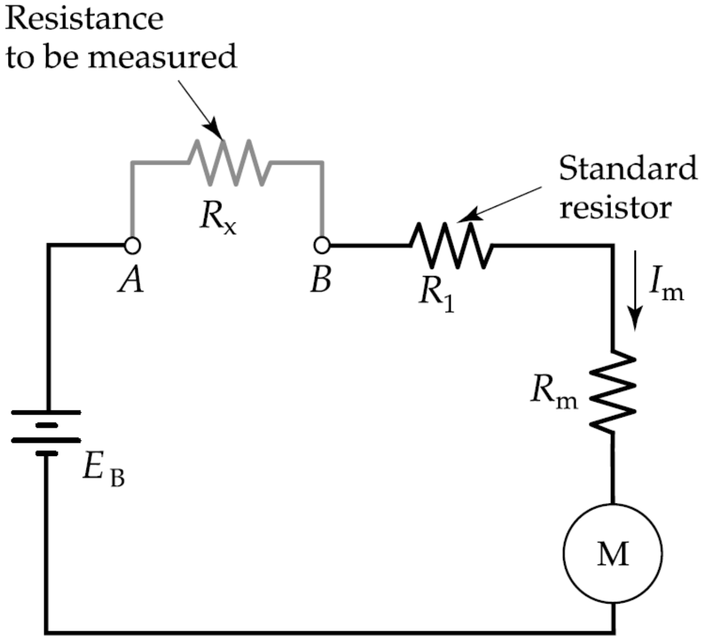
If $R_x = 0,\ I_m = FSD$ and if $R_x = \infty,\ I_m = 0.$

If $0 < R_x < \infty,\ FSD < I_m < 0$

Example 3.8:

Series ohmmeter shown in the figure is made up of a 1.5 V battery and (R_1+ R_m) = 15 kΩ.

- ✓ (a) Determine the instrument indication when R_X =0. .
- ✓ (b) Determine how the resistance scale should be marked at 0.5 FSD, 0.25 FSD, and 0.75 FSD.



Solution

(a) $I_m = \dfrac{E_b}{R_x + R_1 + R_m} = \dfrac{1.5\ \text{V}}{0 + 15\ \text{k}\Omega}$

$= 100\ \mu\text{A}\ (\text{FSD})$

(b) At 0.5 FSD:

$I_m = \dfrac{100\ \mu\text{A}}{2} = 50\ \mu\text{A}$

$R_x + R_1 + R_m = \dfrac{E_b}{I}$

$R_x = \dfrac{E_b}{I_m} - (R_1 + R_m)$

$= \dfrac{1.5\ \text{V}}{50\ \mu\text{A}} - 15\ \text{k}\Omega$

$= 15\ \text{k}\Omega$

(c) At 0.25 FSD: $I_m = \dfrac{100\ \mu\text{A}}{4} = 25\ \mu\text{A}$

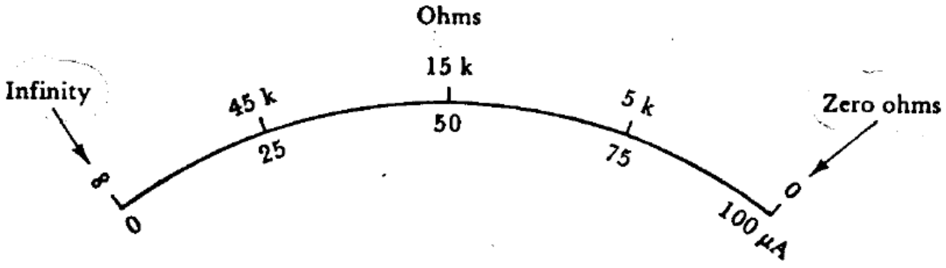
$R_x = \dfrac{1.5\ \text{V}}{25\ \mu\text{A}} - 15\ \text{k}\Omega$

$= 45\ \text{k}\Omega$

(d) At 0.75 FSD: $I_m = 0.75 \times 100\ \mu\text{A} = 75\ \mu\text{A}$

$R_x = \dfrac{1.5\ \text{V}}{75\ \mu\text{A}} - 15\ \text{k}\Omega$

$= 5\ \text{k}\Omega$



3.5 Ohmmeter:
Ohmmeter with Zero Control:

- In the series ohmmeter, if the battery voltage drops, the instrument scale no longer gives correct reading.
- An adjustable resistor R2 is connected in parallel with the meter to adjust the falling battery voltage.
- Ohmmeter is calibrated by making Rx = 0 and adjusting R2 to give FSD (0)

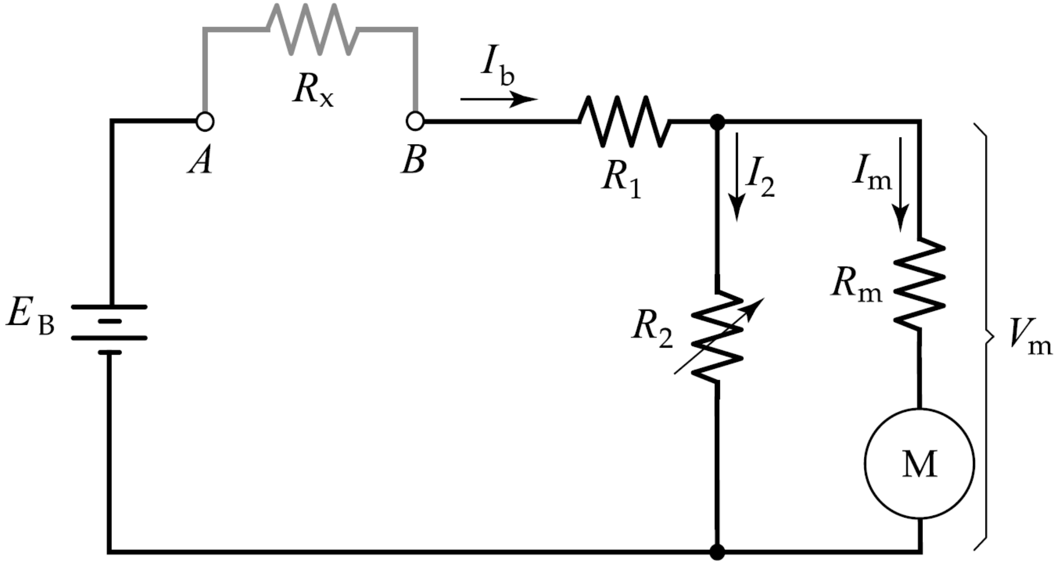


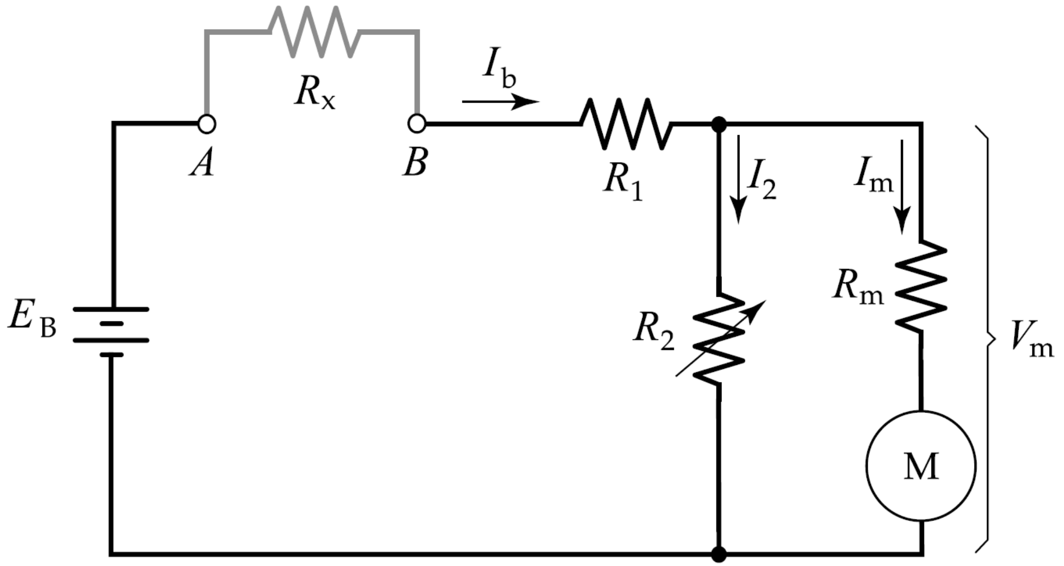
Figure 4-12 An adjustable resistor (R_2) connected in parallel with the meter provides an ohmmeter zero control. The ohmmeter terminals are initially short-circuited and the zero control is adjusted to give a zero-ohm reading. This eliminates errors due to variations in the battery voltage.

$$I_m = V_m/R_m, \quad V_m = I_b.(R_2//R_m)$$

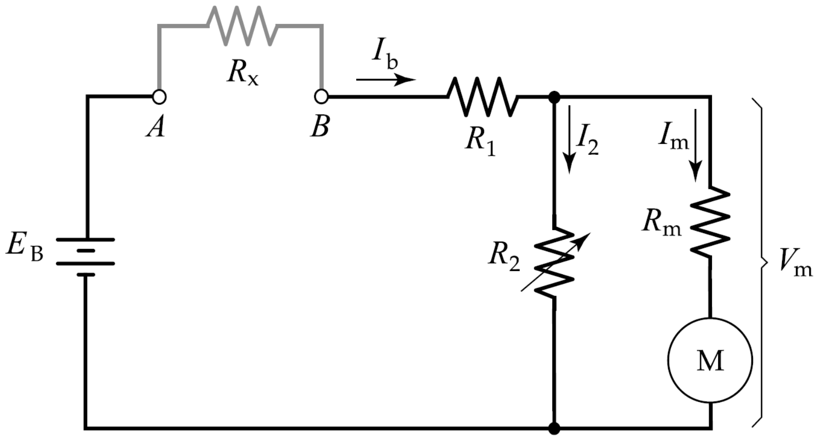
$$I_m = I_b.\frac{R_2//R_m}{Rm}$$

Example 3.8:

The ohmmeter circuit in the figure has E_b = 1.5 V, R_1 = 15 kΩ, R_m=R_2= 50 Ω, and meter FSD = 50 μA. ***Determine*** the ohmmeter scale reading at 0.5 FSD, and ***determine*** the new resistance value that R_2 must be adjusted to when E_b falls to 1.3 V. Also, recalculate the value of R_X at 0.5 FSD when E_b = 1.3 V.



Solution



At 0.5 FSD, with $E_b = 1.5$ V,

$$V_m = I_m \times R_m = 25\ \mu\text{A} \times 50\ \Omega$$

$$= 1.25\ \text{mV}$$

$$I_2 = \frac{V_m}{R_2} = \frac{1.25\ \text{mV}}{50\ \Omega}$$

$$= 25\ \mu\text{A}$$

$$I_b = I_2 + I_m = 25\ \mu\text{A} + 25\ \mu\text{A}$$

$$= 50\ \mu\text{A}$$

$$R_x + R_1 \approx \frac{E_b}{I_b} = \frac{1.5\ \text{V}}{50\ \mu\text{A}}$$

$$= 30\ \text{k}\Omega$$

$$R_x = 30\ \text{k}\Omega - R_1 = 30\ \text{k}\Omega - 15\ \text{k}\Omega$$

$$= 15\ \text{k}\Omega$$

With $R_x = 0$ and $E_b = 1.3$ V,

$$I_b \approx \frac{E_b}{R_x + R_1} = \frac{1.3\ \text{V}}{0 + 15\ \text{k}\Omega}$$

$$= 86.67\ \mu\text{A}$$

$$I_2 = I_b - I_{m(\text{FSD})} = 86.67\ \mu\text{A} - 50\ \mu\text{A}$$

$$= 36.67\ \mu\text{A}$$

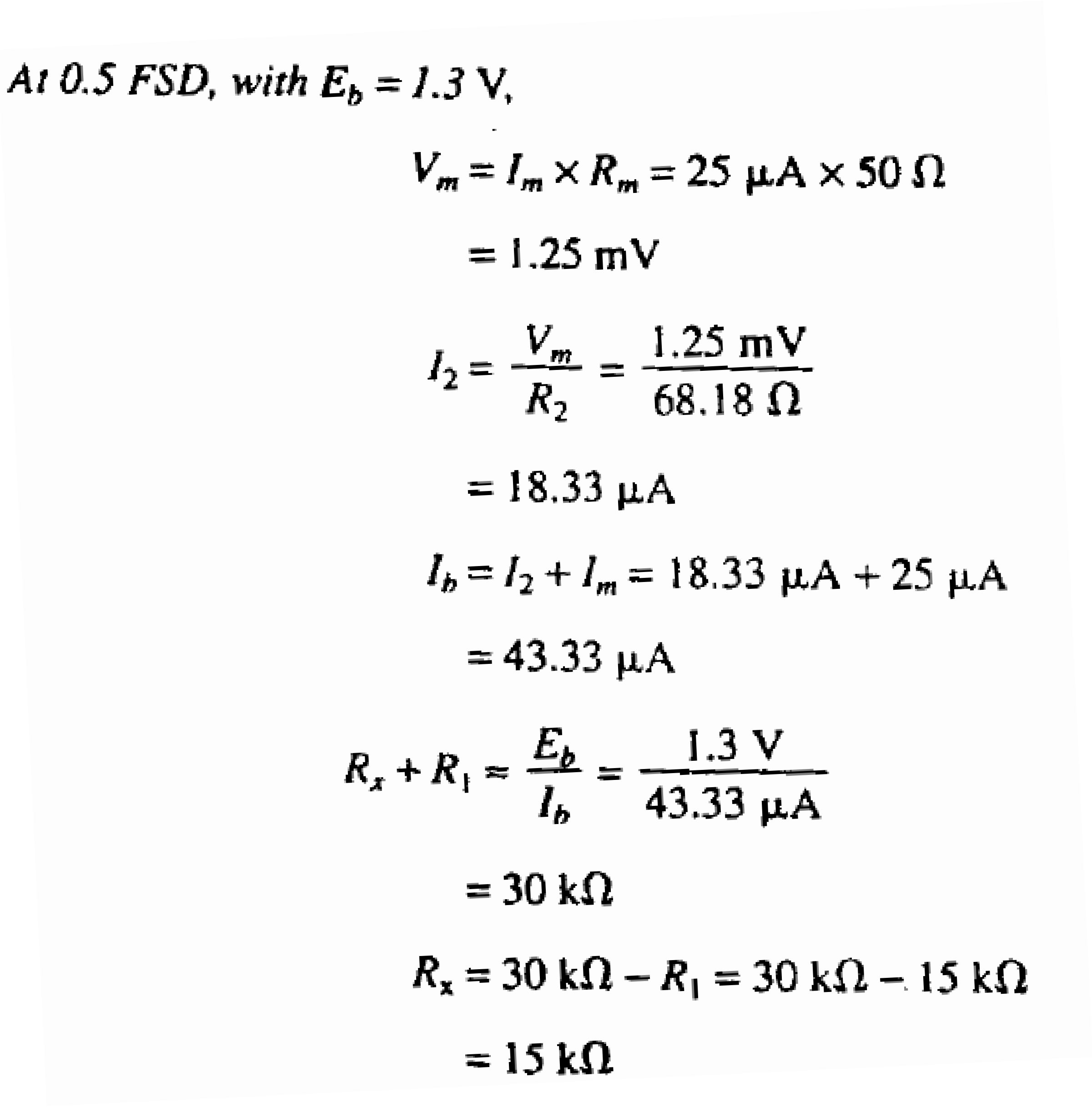
$$V_m = I_m R_m = 50\ \mu\text{A} \times 50\ \Omega$$

$$= 2.5\ \text{mV}$$

$$R_2 = \frac{V_m}{I_2} = \frac{2.5\ \text{mV}}{36.67\ \mu\text{A}}$$

$$= 68.18\ \Omega$$

Solution (Cont.)



At 0.5 FSD, with $E_b = 1.3$ V,

$$V_m = I_m \times R_m = 25\ \mu\text{A} \times 50\ \Omega$$

$$= 1.25\ \text{mV}$$

$$I_2 = \frac{V_m}{R_2} = \frac{1.25\ \text{mV}}{68.18\ \Omega}$$

$$= 18.33\ \mu\text{A}$$

$$I_b = I_2 + I_m = 18.33\ \mu\text{A} + 25\ \mu\text{A}$$

$$= 43.33\ \mu\text{A}$$

$$R_x + R_1 \approx \frac{E_b}{I_b} = \frac{1.3\ \text{V}}{43.33\ \mu\text{A}}$$

$$= 30\ \text{k}\Omega$$

$$R_x = 30\ \text{k}\Omega - R_1 = 30\ \text{k}\Omega - 15\ \text{k}\Omega$$

$$= 15\ \text{k}\Omega$$

End of Lecture

Best Wishes