4-4 DC AMMETERS

4-4.1 Shunt Resistor

The basic movement of a dc ammeter is a PMMC galvanometer. Since the coil winding of a basic movement is small and light, it can carry only very small currents. When large currents are to be measured, it is necessary to bypass the major part of the current through a resistance, called a *shunt*, as shown in Fig. 4-8.

The resistance of the shunt can be calculated by applying conventional circuit analysis to Fig. 4-8, where

R_m = internal resistance of the movement (the coil)

R_s = resistance of the shunt

I_m = full-scale deflection current of the movement

I_s = shunt current

I = full-scale current of the ammeter including the shunt

Since the shunt resistance is in parallel with the meter movement, the voltage drops across the shunt and movement must be the same and we can write

$$V_{\text{shunt}} = V_{\text{movement}}$$

or

$$I_s R_s = I_m R_m \quad \text{and} \quad R_s = \frac{I_m R_m}{I_s} \tag{4-2}$$

Since $I_s = I - I_m$, we can write

$$R_s = \frac{I_m R_m}{I - I_m} \tag{4-3}$$

For each required value of full-scale meter current we can then solve for the value of the shunt resistance required.

EXAMPLE 4-1

A 1-mA meter movement with an internal resistance of 100 Ω is to be converted into a 0–100-mA ammeter. Calculate the value of the shunt resistance required.

SOLUTION

$$I_s = I - I_m = 100 - 1 = 99 \text{ mA}$$

$$R_s = \frac{I_m R_m}{I_s} = \frac{1 \text{ mA} \times 100\ \Omega}{99 \text{ mA}} = 1.01\ \Omega$$

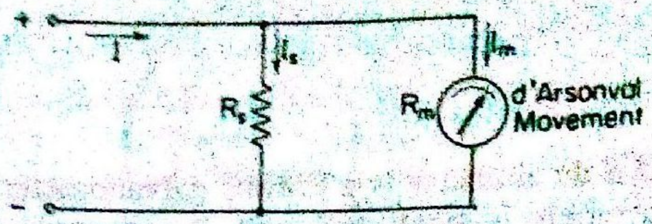

Figure 4-8 Basic dc ammeter circuit.

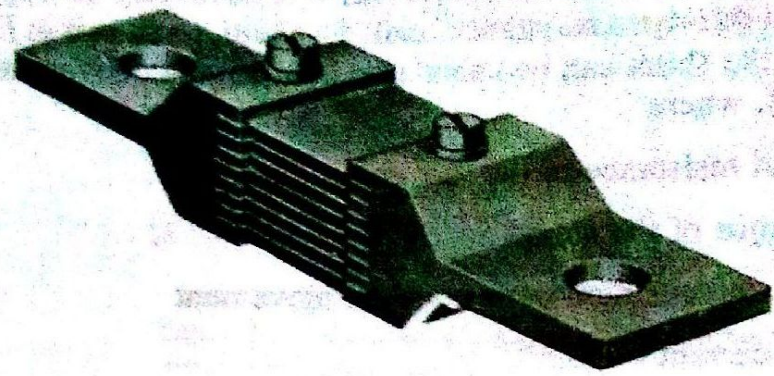

Figure 4-9 High-current shunt for a switchboard instrument. (Courtesy of Weston Instruments, Inc.)

The shunt resistance used with a basic movement may consist of a length of constant-temperature resistance wire within the case of the instrument or it may be an external (manganin or constantan) shunt having a very low resistance. Figure 4-9 shows an external shunt. It consists of evenly spaced sheets of resistive material welded into a large block of heavy copper on each end of the sheets. The resistance material has a very low temperature coefficient, and a low thermoelectric effect exists between the resistance material and the copper. External shunts of this type are normally used for measuring very large currents.

4-4.2 Ayrton Shunt

The current range of the dc ammeter may be further extended by a number of shunts, selected by a *range switch*. Such a meter is called a *multirange* ammeter. Figure 4-10 shows the schematic diagram of a multirange ammeter. The circuit has four shunts, R_a, R_b, R_c, and R_d, which can be placed in parallel with the movement to give four different current ranges. Switch S is a multiposition, *make-before-break* type switch, so that the movement will not be damaged, unprotected in the circuit, without a shunt as the range is changed.

The *universal*, or *Ayrton, shunt* of Fig. 4-11 eliminates the possibility of having the meter in the circuit without a shunt. This advantage is gained at the price of a slightly higher overall meter resistance. The Ayrton shunt provides an excellent opportunity to apply basic network theory to a practical circuit.

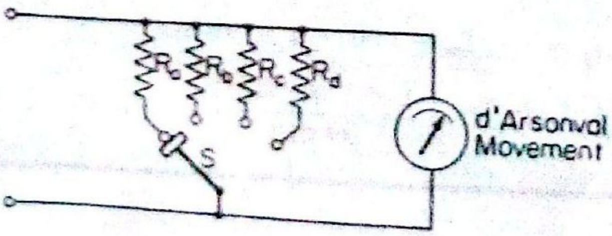

Figure 4-10 Schematic diagram of a simple multirange ammeter.

EXAMPLE 4-2

Design an Ayrton shunt to provide an ammeter with current ranges of 1 A, 5 A, and 10 A. A d'Arsonval movement with an interval resistance $R_m = 50\ \Omega$ and full-scale deflection current of 1 mA is used in the configuration of Fig. 4-11.

SOLUTION *On the 1-A range:* $R_a + R_b + R_c$ are in parallel with the 50-Ω movement. Since the movement requires 1 mA for full-scale deflection, the shunt will be required to pass a current of 1 A − 1 mA = 999 mA. Using Eq. (4-2), we get

$$R_a + R_b + R_c = \frac{1 \times 50}{999} = 0.05005\ \Omega \qquad \text{(I)}$$

On the 5-A range: $R_a + R_b$ are in parallel with $R_c + R_m$ (50 Ω). In this case there will be a 1-mA current through the movement and R_c in series, and 4,999 mA through $R_a + R_b$. Again using Eq. (4-2), we get

$$R_a + R_b = \frac{1 \times (R_c + 50\ \Omega)}{4{,}999} \qquad \text{(II)}$$

On the 10-A range: R_a now serves as the shunt and $R_b + R_c$ are in series with the movement. The current through the movement again is 1 mA, and the shunt passes the remaining 9,999 mA. Using Eq. (4-2) again, we get

$$R_a = \frac{1 \times (R_b + R_c + 50\ \Omega)}{9{,}999} \qquad \text{(III)}$$

Solving the three simultaneous equations (I), (II), and (III), we obtain

$$4{,}999 \times \text{(I)}: 4{,}999R_a + 4{,}999R_b + 4{,}999R_c = 250.2$$

$$\text{(II)}: 4{,}999R_a + 4{,}999R_b - R_c = 50$$

Subtracting (II) from (I), we obtain

$$5{,}000R_c = 200.2$$

$$R_c = 0.04004\ \Omega$$

Similarly,

$$9{,}999 \times \text{(I)}: 9{,}999R_a + 9{,}999R_b + 9{,}999R_c = 500.45$$

$$\text{(III)}: 9{,}999R_a - R_b - R_c = 50$$

Subtracting (III) from (I), we obtain

$$10{,}000R_b + 10{,}000R_c = 450.45$$

Substituting the previously calculated value for R_c into this expression yields

$$10{,}000R_b = 450.45 - 400.4$$

$$R_b = 0.005005\ \Omega$$

$$R_a = 0.005005\ \Omega$$

This calculation indicates that for larger currents the value of the shunt resistor may become very small.

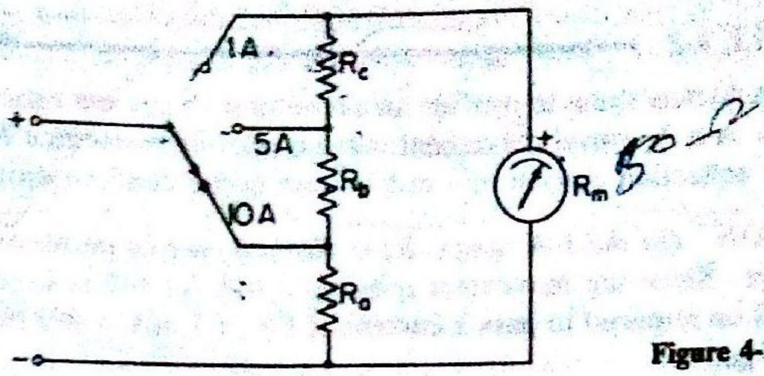

Figure 4-11 Universal or Ayrton shunt.

Direct-current ammeters are commercially available in a large number of ranges, from 20 μA to 50 A full-scale for a self-contained meter and to 500 A for a meter with external shunt. Laboratory-type precision ammeters are provided with a calibration chart, so that the user may correct his readings for any scale errors.

The following precautions should be observed when using an ammeter in measurement work:

(a) *Never* connect an ammeter *across* a source of emf. Because of its low resistance it would draw damaging high currents and destroy the delicate movement. *Always* connect an ammeter in series with a load capable of limiting the current.

(b) Observe the correct *polarity*. Reverse polarity causes the meter to deflect against the mechanical stop and this may damage the pointer.

(c) When using a multirange meter, first use the highest current range; then decrease the current range until substantial deflection is obtained. To increase accuracy of the observation (see Chapter 1), use the range that will give a reading as near to full-scale as possible.

4-5 DC VOLTMETERS

4-5.1 Multiplier Resistor

The addition of a series resistor, or *multiplier*, converts the basic d'Arsonval movement into a *dc voltmeter*, as shown in Fig. 4-12. The multiplier limits the current through the movement so as not to exceed the value of the full-scale deflection current (I_{fsd}). A dc voltmeter measures the potential difference be-

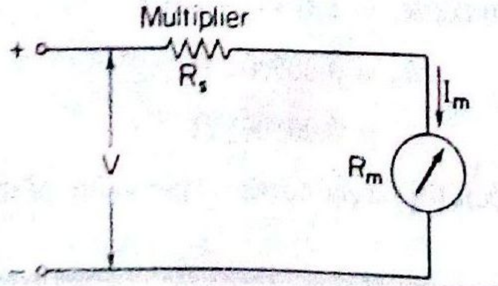

Figure 4-12 Basic dc voltmeter circuit.

tween two points in a dc circuit and is therefore connected *across* a source of emf or a circuit component. The meter terminals are generally marked "pos" and "neg," since polarity must be observed.

The value of a multiplier, required to extend the voltage range, is calculated from Fig. 4-12, where

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

R_m = internal resistance of the movement

R_s = multiplier resistance

V = full-range voltage of the instrument

For the circuit of Fig. 4-12,

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

Solving for R_s gives

$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m \tag{4-4}$$

The multiplier is usually mounted inside the case of the voltmeter for moderate ranges up to 500 V. For higher voltages, the multiplier may be mounted separately outside the case on a pair of binding posts to avoid excessive heating inside the case.

4-5.2 Multirange Voltmeter

The addition of a number of multipliers, together with a *range switch*, provides the instrument with a workable number of voltage ranges. Figure 4-13 shows a *multirange* voltmeter using a four-position switch and four multipliers, R_1, R_2, R_3, and R_4, for the voltage ranges V_1, V_2, V_3, and V_4, respectively. The values of the multipliers can be calculated using the method shown earlier or, alternatively, by the *sensitivity method*. The sensitivity method is illustrated by Example 4-4 in Sec. 4-6, where sensitivity is discussed.

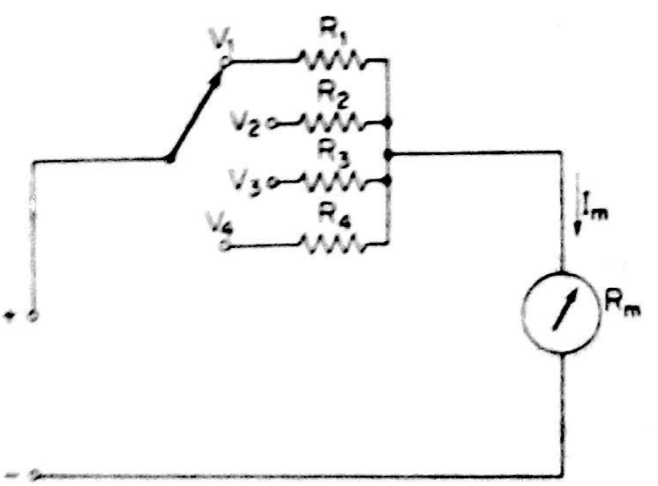

Figure 4-13 Multirange voltmeter.

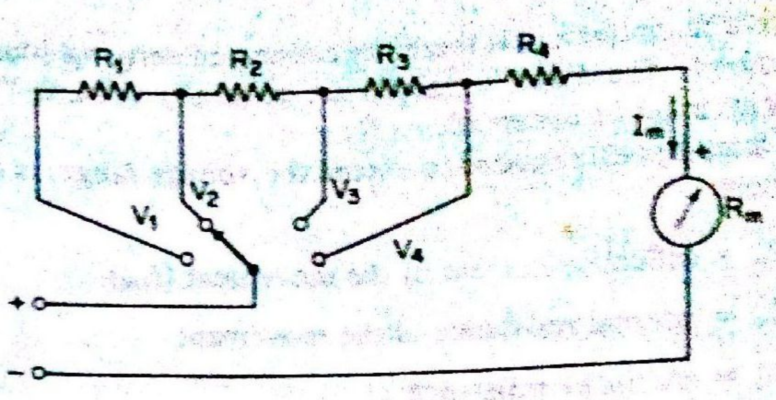

Figure 4-14 More practical arrangement of multiplier resistors in the multirange voltmeter.

A variation of the circuit of Fig. 4-13 is shown in Fig. 4-14, where the multipliers are connected in a series string and the range selector switches the appropriate amount of resistance in series with the movement. This system has the advantage that all multipliers except the first have standard resistance values and can be obtained commercially in precision tolerances. The low-range multiplier, R_4, is the only special resistor that must be manufactured to meet the specific circuit requirements.

EXAMPLE 4-3

A basic d'Arsonval movement with internal resistance, $R_m = 100\ \Omega$, and full-scale current, $I_{fsd} = 1$ mA, is to be converted into a multirange dc voltmeter with voltage ranges of 0–10 V, 0–50 V, 0–250 V, and 0–500 V. The circuit arrangement of Fig. 4-16 is to be used for this voltmeter.

SOLUTION For the 10-V range (V_4 position of range switch), the total circuit resistance is

$$R_T = \frac{10\ \text{V}}{1\ \text{mA}} = 10\ \text{k}\Omega$$

$$R_4 = R_T - R_m = 10\ \text{k}\Omega - 100\ \Omega = 9{,}900\ \Omega$$

For the 50-V range (V_3 position of range switch),

$$R_T = \frac{50\ \text{V}}{1\ \text{mA}} = 50\ \text{k}\Omega$$

$$R_3 = R_T - (R_4 + R_m) = 50\ \text{k}\Omega - 10\ \text{k}\Omega = 40\ \text{k}\Omega$$

For the 250-V range (V_2 position of range switch),

$$R_T = \frac{250\ \text{V}}{1\ \text{mA}} = 250\ \text{k}\Omega$$

$$R_2 = R_T - (R_3 + R_4 + R_m) = 250\ \text{k}\Omega - 50\ \text{k}\Omega = 200\ \text{k}\Omega$$

For the 500-V range (V_1 position of range switch),

$$R_T = \frac{500\ \text{V}}{1\ \text{mA}} = 500\ \text{k}\Omega$$

$$R_1 = R_T - (R_2 + R_3 + R_4 + R_m) = 500\ \text{k}\Omega - 250\ \text{k}\Omega = 250\ \text{k}\Omega$$