Lecture 5

Electrical Measurement and Instrumentation

Ohm Meters

- Used to measure the resistance of a resistor
- Has two types
  - Series Type Ohm meter
  - Shunt Type Ohm meter
- Discussed Later

Series-Type Ohmmeter

- The series-type ohmmeter essentially consists of a d'Arsonval movement connected in series with a resistance and a battery to a pair of terminals to which the unknown resistor is connected.
- The current through the movement then depends on
  - the magnitude of the unknown resistor
  - the indication is proportional to the value of the unknown R
    - provided that calibration problems are taken into account.
- Figure 4-17 shows the elements of a simple single-range series ohmmeter. Here
  - R_1 = current-limiting resistor
  - R_2 = zero adjust resistor
  - E = internal battery
  - R_m = internal resistance of the d'Arsonval movement
  - R_x = unknown resistor

Series-Type Ohmmeter…….

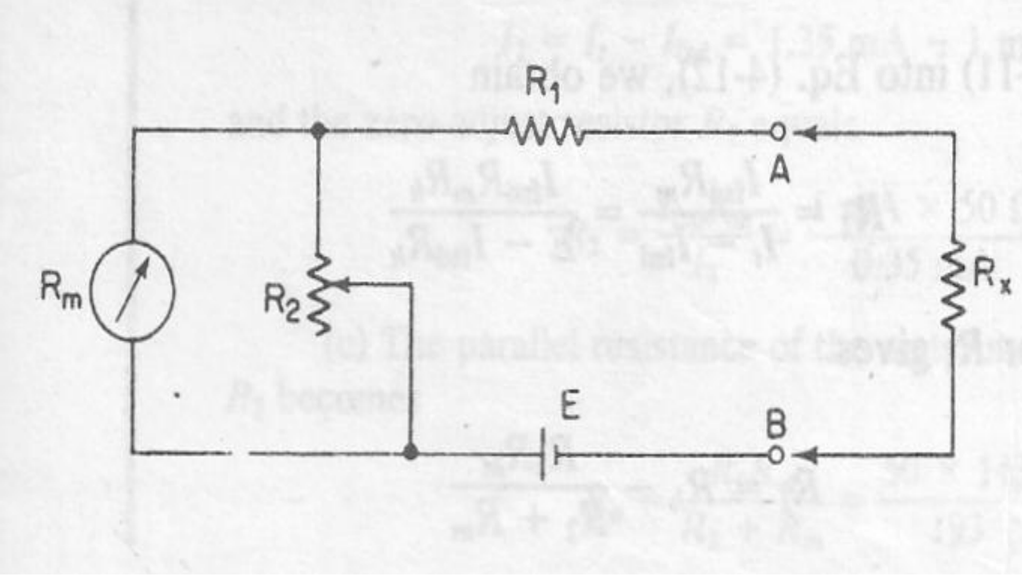

Figure 4-17 Series-type ohmmeter.

- Terminals A and B short circuit gives full scale deflection
  - Scale marked 0 ohm
- Terminals A and B open circuit gives 0 deflection
  - Battery aging is a major issue, so make sure u have new batteries

Series-Type Ohmmeter…….

- **Design Issue**
- Find out the half scale deflection, Rh and determine its value in terms of Rm, R1 and R2 and E
- The design can be approached by recognizing that, if introducing R_h reduces the meter current to ½ I_{fsd}, the unknown resistance must be equal to the total internal resistance of the ohmmeter. Therefore
- $$R_h = R_1 + \frac{R_2 R_m}{R_2 + R_m} \qquad (4\text{-}8)$$
- The total resistance presented to the battery then equals $2R_h$, and the battery current needed to supply the half-scale defection is
- $$I_h = \frac{E}{2R_h} \qquad (4\text{-}9)$$
- To produce full-scale deflection, the battery current must be doubled, and therefore
- $$I_t = 2I_h = \frac{E}{R_h} \qquad (4\text{-}10)$$
- The shunt current through R_2 is
- $$I_2 = I_t - I_{fsd} \qquad (4\text{-}11)$$
- The voltage across the shunt (E_{sh}) is equal to the voltage across the movement and
- $E_{sh} = E_m$ or $I_2R_2 = I_{fsd}R_m$ and $$R_2 = \frac{I_{fsd} R_m}{I_2} \qquad (4\text{-}12)$$

Series-Type Ohmmeter……

- substituting Eq. (4-11) into Eq. (4-12), we obtain
- $$R_2 = \frac{I_{fsd} R_m}{I_t - I_{fsd}} = \frac{I_{fsd} R_m R_h}{E - I_{fsd} R_h} \qquad (4\text{-}13)$$

Solving Eq. (4-8) for R_1

- $$R_1 = R_h - \frac{R_2 R_m}{R_2 + R_m} \qquad (4\text{-}14)$$

Substituting Eq. (4-13) into Eq. (4-14) and solving for R_1 yields

- $$R_1 = R_h - \frac{I_{fsd} R_m R_h}{E} \qquad (4\text{-}15)$$

- For typical calculation see Example 4-7.

Example 4-7

The ohmmeter of Fig. 4-17 uses a 50-Ω basic movement requiring a full-scale current of 1 mA. The internal battery voltage is 3 V. The desired scale marking for half-scale deflection is 2,000 Ω. Calculate (a) the values of R_1 and R_2; (b) the maximum value of R_2 to compensate for a 10% drop in battery voltage; (c) the scale error at the half-scale mark (2,000 Ω) when R_2 is set as in (b).

SOLUTION (a) The total battery current at full-scale deflection is

$$I_t = \frac{E}{R_h} = \frac{3\text{ V}}{2{,}000\ \Omega} = 1.5\text{ mA} \tag{4-16}$$

The current through the zero-adjust resistor R_2 then is

$$I_2 = I_t - I_{\text{fsd}} = 1.5\text{ mA} - 1\text{ mA} = 0.5\text{ mA} \tag{4-17}$$

The value of the zero-adjust resistor R_2 is

$$R_2 = \frac{I_{\text{fsd}}\text{R}_\text{m}}{I_2} = \frac{1\text{ mA} \times 50\ \Omega}{0.5\text{ mA}} = 100\ \Omega \tag{4-18}$$

The parallel resistance of the movement and the shunt (R_p) is

$$R_p = \frac{R_2 R_m}{R_2 + R_m} = \frac{50 \times 100}{150} = 33.3\ \Omega$$

$\frac{1\text{mA} \times 50}{3}$

Example 4-7

The value of the current-limiting resistor R_1 is

$$R_1 = R_h - R_p = 2{,}000 - 33.3 = 1{,}966.7\ \Omega$$

(b) At a 10% drop in battery voltage,

$$E = 3\text{ V} - 0.3\text{ V} = 2.7\text{ V}$$

The total battery current I_t then becomes

$$I_t = \frac{E}{R_h} = \frac{2.7\text{ V}}{2{,}000\ \Omega} = 1.35\text{ mA}$$

The shunt current I_2 is

$$I_2 = I_t - I_{\text{fsd}} = 1.35\text{ mA} - 1\text{ mA} = 0.35\text{ mA}$$

and the zero-adjust resistor R_2 equals

$$R_2 = \frac{I_{\text{fsd}} R_m}{I_2} = \frac{1\text{ mA} \times 50\ \Omega}{0.35\text{ mA}} = 143\ \Omega$$

(c) The parallel resistance of the meter movement and the new value of R_2 becomes

$$R_p = \frac{R_2 R_m}{R_2 + R_m} = \frac{50 \times 143}{193} = 37\ \Omega$$

150/3

Example 4-7

Since the half-scale resistance R_h is equal to the total internal circuit resistance, R_h will increase to

$$R_h = R_1 + R_p = 1{,}966.7\ \Omega + 37\ \Omega = 2{,}003.7\ \Omega$$

Therefore the true value of the half-scale mark on the meter is 2,003.7 Ω whereas the actual scale mark is 2,000 Ω. The percentage error is then

$$\%\ \text{error} = \frac{2{,}000 - 2{,}003.7}{2{,}003.7} \times 100\% = -0.185\%$$

The negative sign indicates that the meter reading is low.

- The ohmmeter of Example 4-7 could be designed for other values of R_h, within limits.
- If $R_h = 3{,}000\ \Omega$, the battery current would be 1 mA, which is required for the full-scale deflection current.
- If the battery voltage would decrease owing to aging, the total battery current would fall below 1 mA and there would then be no provision for adjustment.

Shunt-Type Ohmmeter

- The circuit diagram of a shunt-type ohmmeter is shown in Fig. 4-18.
- It consists of a battery in series with an adjustable resistor R_1 and a d'Arsonval movement.
- The unknown resistance is connected across terminals A and B, in parallel with the meter.
- In this circuit it is necessary to have an off-on switch to disconnect the battery from the circuit when the instrument is not used.
- When the unknown resistor $R_x = 0\ \Omega$ (A and B shorted), the meter current is zero.

Shunt-Type Ohmmeter……

- If the unknown resistor $R_x = 0$ (A and B open), the current finds a path only through the meter, and by appropriate selection of the value of R1, the pointer can be made to read full scale.
- The ohmmeter therefore has the “zero” mark at the left-hand side of the scale (no current) and the “infinite” mark at the right-hand side of the scale (full-scale deflection current).

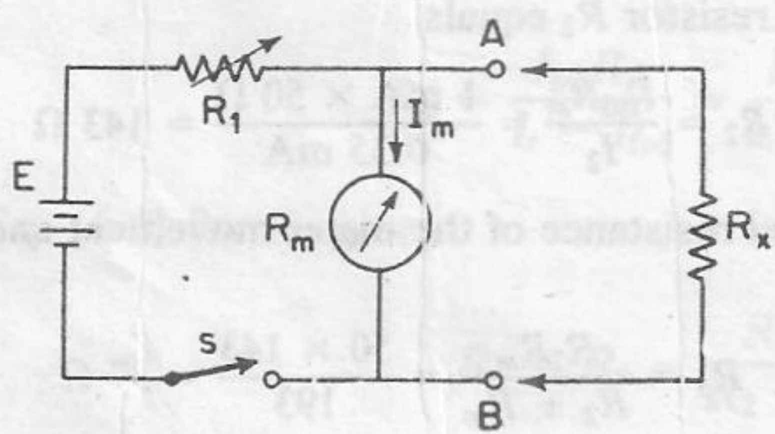

Figure 4-18 Shunt-type ohmmeter.

Shunt-Type Ohmmeter……

- The analysis of the shunt-type ohmmeter is similar to that of the series type ohmmeter.
- In Fig. 4-18, when $R_x = \infty$, the full-scale meter current will be

$$I_{fsd} = \frac{E}{R_1 + R_m} \qquad (4\text{-}19)$$

- **Where** E = internal battery voltage
- R_1 = current-limiting resistor
- R_m = internal resistance of the movement
- Solving for R_1, we find

$$R_1 = \frac{E}{I_{fsd}} - R_m \qquad (4\text{-}20)$$

- For any value of R_x connected across the meter terminals, the meter current decreases and is given by
- $$I_m = \frac{E}{R_1 + [R_m R_x / (R_m + R_x)]} \times \frac{R_x}{R_m + R_x} \qquad (4\text{-}21)$$
- Or

$$I_m = \frac{E R_x}{R_1 R_m + R_x (R_1 + R_m)}$$

Shunt-Type Ohmmeter……

The meter current for any value of R1, expressed as a fraction of the full-scale current, is

$$s = \frac{I_m}{I_{fsd}} = \frac{R_x(R_1 + R_m)}{R_1(R_m + R_x) + R_m R_x}$$

- Or

$$s = \frac{R_x(R_1 + R_m)}{R_x(R_1 + R_m) + R_1 R_m} \qquad (4\text{-}22)$$

- Defining $\frac{R_1 R_m}{R_1 + R_m} = R_p$ (4-23)
- and substituting Eq. (4-23) into Eq. (4-22), we obtain
- $$s = \frac{R_x}{R_x + R_P} \qquad (4\text{-}24)$$
- If Eq. (4-24) is used, the meter can be calibrated by calculating s in terms of R_x and R_p
- At half-scale reading of the meter ($I_m = 0.5\ I_{fsd}$), Eq. (4-21) reduces to

Shunt-Type Ohmmeter……

- If eq. (4-24) is used, the meter can be calibrated by calculating ***s*** in terms of R_x and R_p
- At half-scale reading of the meter ($i_m = 0.5\ i_{fsd}$), eq. (4-21) reduces to
- $$0.51_{fsd} = \frac{ER_h}{R_1 R_m + R_h (R_1 + R_m)} \qquad (4\text{-}25)$$
- Where R_h = external resistance causing half-scale deflection.
- To determine the relative scale values for a given value of R1, the half-scale reading may be found by dividing eq. (4-19) by eq. (4-25) and solving for R_h:
- $$R_h = \frac{R_1 R_m}{R_1 + R_m} \qquad (4\text{-}26)$$
- The analysis shows that the half-scale resistance is determined by limiting resistor R_1 and the internal resistance of the movement, R_m.
- The limiting resistance, R_1, is in turn determined by the meter resistance R_m, and the full-scale deflection current, $I_{fsd.}$

EXAMPLE 4-8

The circuit of Fig. 4-18 uses a 10-mA basic d'Arsonval movement with an internal resistance of 5 Ω. The battery voltage $E = 3$ V. It is desired to modify the circuit by adding an appropriate resistor R_{sh} across the movement, so that the instrument will indicate 0.5 Ω at the midpoint on its scale. Calculate (a) the value of the shunt resistor, R_{sh}; (b) the value of the current-limiting resistor, R_1.

SOLUTION (a) For half-scale deflection of the movement,

$$I_m = 0.5 I_{fsd} = 5 \text{ mA}$$

The voltage across the movement is

$$E_m = 5 \text{ mA} \times 5\ \Omega = 25 \text{ mA}$$

Since this voltage also appears across the unknown resistor, R_x, the current through R_x is

$$I_x = \frac{25 \text{ mV}}{0.5\ \Omega} = 50 \text{ mA}$$

The current through the movement (I_m) plus the current through the shunt (I_{sh}) must be equal to the current through the unknown (I_x). Therefore

$$I_{sh} = I_x - I_m = 50 \text{ mA} - 5 \text{ mA} = 45 \text{ mA}$$

The shunt resistance then is

$$R_{sh} = \frac{E_m}{I_{sh}} = \frac{25 \text{ mV}}{45 \text{ mA}} = \frac{5}{9}\ \Omega$$

(b) The total battery current is

$$I_t = I_m + I_{sh} + I_x = 5 \text{ mA} + 45 \text{ mA} + 50 \text{ mA} = 100 \text{ mA}$$

The voltage drop across limiting resistor R_1 equals 3 V − 25 mV = 2.975 V. Therefore

$$R_1 = \frac{2.975 \text{ V}}{100 \text{ mA}} = 29.75\ \Omega$$

Multimeter Or VOM

- The ammeter, the voltmeter, and the ohmmeter all use the d'Arsonval movement.
- The difference between these instruments is the circuit in which the basic movement is used.
- It is therefore obvious that a single instrument can be designed to perform the three measurement functions.
- This instrument, which contains a function switch to connect the appropriate circuits to the d'Arsonval movement, is often called a multimeter or Volt-Ohm-Milliammeter (VOM).

Multimeter Or VOM……..

- A representative example of a commercial multirneter is shown in Fig. 4-19. See fig 4-20 for ckt diagram
- The meter is a combination of a dc milliammeter, a dc voltmeter, an ac voltmeter, a multirange ohmmeter, and an output meter.
- Figure 4-21 shows the circuit for the dc voltmeter section, where the common input terminals are used for voltage ranges of 0-1.5 to 0-1,000 V.
- An external voltage jack, marked "DC 5,000 V," is used for dc voltage measurements to 5,000 V.
- The operation of this circuit is similar to the circuit of Fig. 4-12, which was discussed earlier

Multimeter Or VOM…….

- The circuit for measuring dc milliamperes and amperes is given in Fig. 4-22 and again the circuit is self-explanatory.
- The positive (+) and “negative” (-) terminals are used for current measurements up to 500 mA and the jacks marked “+10 A” and “-10 A” are used for the 0-10-A range.
- Details of the ohmmeter section of the VOM are shown in Fig. 4-23.
- Before any measurement is made, the instrument is short-circuited and the “zero- adjust” control is varied until the meter reads zero resistance (full-scale current).
- Notice that the circuit takes the form of a variation of the shunt-type ohmmeter.
- Scale multiplications of 100 and 10,000 are shown in Fig. 4-23(b) and (c).
- The ac voltmeter section of the meter is selected by setting the “ac-dc” switch to the “ac” position.

Multimeter Or VOM……..

Figure 4-19 General-purpose multimeter. This instrument has been a familiar sight in electronics laboratories for many years. (Courtesy of Simpson Electric Company.)

Multimeter Or VOM…….

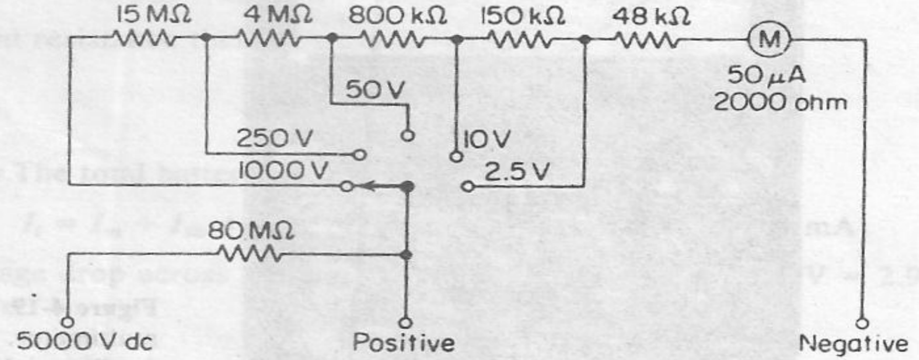

Figure 4-21 Dc voltmeter section of the Simpson Model 260 multimeter. (Courtesy of Simpson Electric Company.)

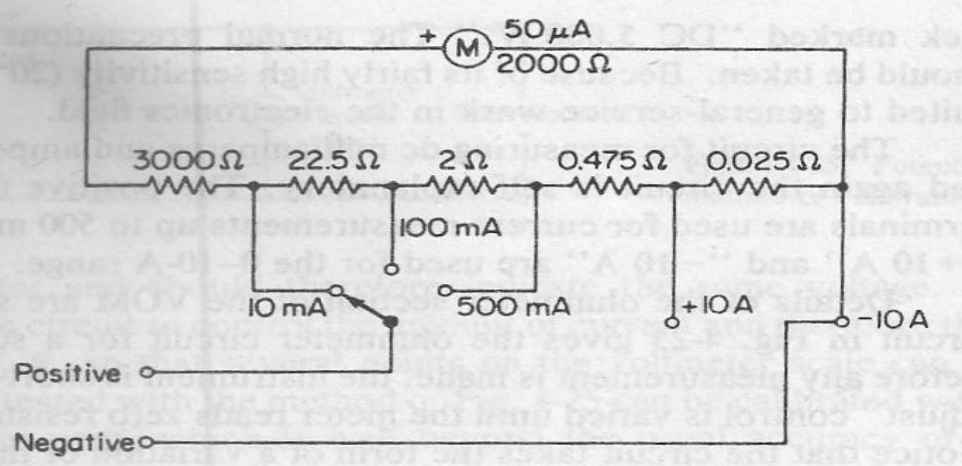

Figure 4-22 Dc ammeter section of the Simpson Model 260 multimeter. (Courtesy of Simpson Electric Company.)

Calibration Of DC Instruments, Ammeter

- Calibration of a dc ammeter can most easily be carried out by the arrangement of Fig. 4-24.
- The value of the current through the ammeter to be calibrated is determined by measuring the potential difference across a standard resistor by the voltmeter method and then calculating the current by Ohm's law.
- The result of this calculation is compared to the actual reading of the ammeter under calibration and inserted in the circuit.
- A good source of constant current is required and is usually provided by storage cells or a precision power supply.
- A rheostat is placed in the circuit to control the current to any desired value, so that different points on the meter scale can be calibrated.

Calibration Of DC Instruments

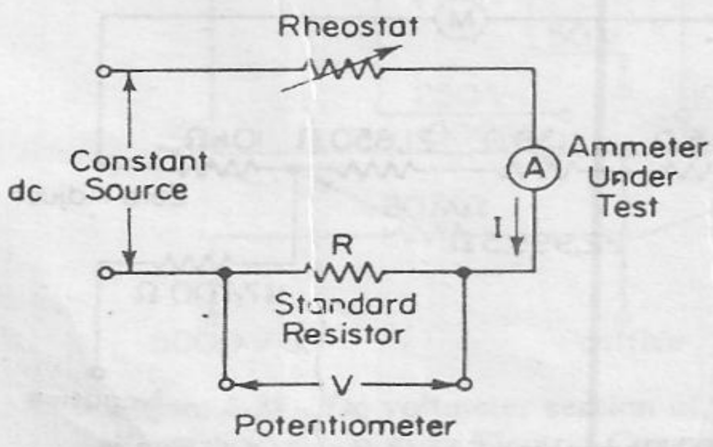

Figure 4-24 Potentiometer method of calibrating a dc ammeter.

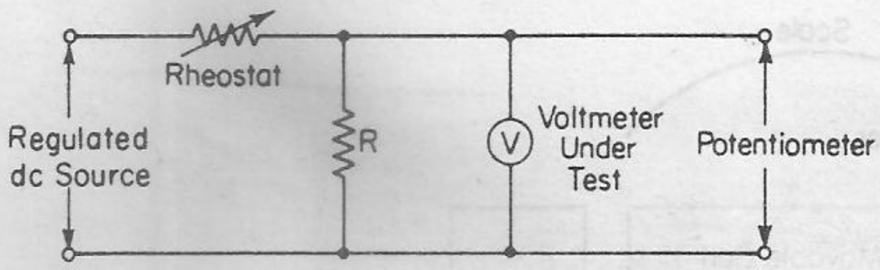

Figure 4-25 Potentiometer method of calibrating a dc voltmeter.

Calibration Of Dc Instruments, Voltmeter

- A simple method of calibrating a dc voltmeter is shown in Fig. 4-25, where the voltage across dropping resistor R is accurately measured with a potentiometer.
- The meter to be calibrated is connected across the same two points as the potentiometer and should therefore indicate the same voltage.
- A rheostat is placed in the circuit to control the amount of current and therefore the drop across the resistor, R, so that several points on the voltmeter scale can be calibrated.
- Voltmeters tested with the method of Fig. 4-25 can be calibrated with an accuracy of ±0.01 percent, which is well beyond the usual accuracy of a d'Arsonval movement.
- The ohmmeter is generally considered to be an instrument of moderate accuracy and low precision.
- A rough calibration may be done by measuring a standard resistance and noting the reading of the ohmmeter.
- Doing this for several points on the ohmmeter scale and on several ranges allows one to obtain an indication of the correct operation of the instrument.

Alternating-Current Indicating Instruments

- The d'Arsonval movement responds to the average or DC value of the current through the moving coil.
- If the movement carries an alternating current with positive and negative half-cycles, the driving torque would be in one direction for the positive alternation and in the other direction for the negative alternation.
- If the frequency of the AC is very low, the pointer would swing back and forth around the zero point on the meter scale.
- At higher frequencies, the inertia of the coil is so great that the pointer cannot follow the rapid reversals of the driving torque and hovers around the zero mark, vibrating slightly.
- To measure AC on a d'Arsonval movement, some means must be devised to obtain a unidirectional torque that does not reverse each half-cycle.
- One method involves rectification of the AC.
- The rectified current deflects the coil.
- Other methods use the heating effect of the alternating current to produce an indication of its magnitude.