

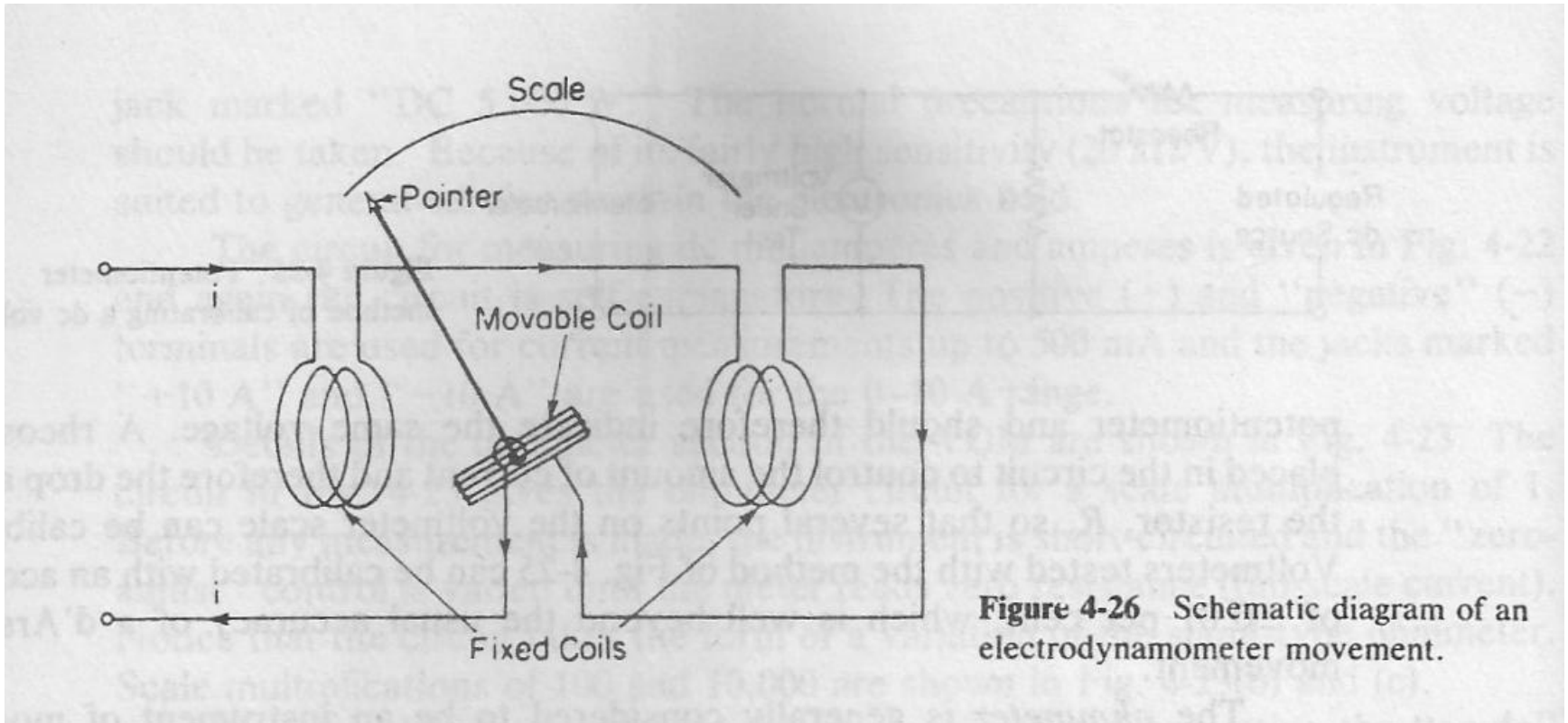
# Lecture 6

Electrical Measurement and  
Instrumentation

# Electrodynamometer

- **Used in making AC**
  - **Voltmeters**
  - **Ammeters**
  - **Wattmeter**
  - **Varmeter**
  - **Power-factor meter**
  - **Frequency meter**
- **Unlike PMMC permanent magnet is replaced by two fixed coils which produces the necessary flux.**
- **Movable coil attached to pointer indicates the intensity of quantity such as voltage current etc as shown in figure**
- **$T = B \times A \times I \times N$**
- **Developed torque becomes a function of the current squared ( $I^2$ ) because flux(B) is dependent on the current supplied.**

# Electrodynamometer

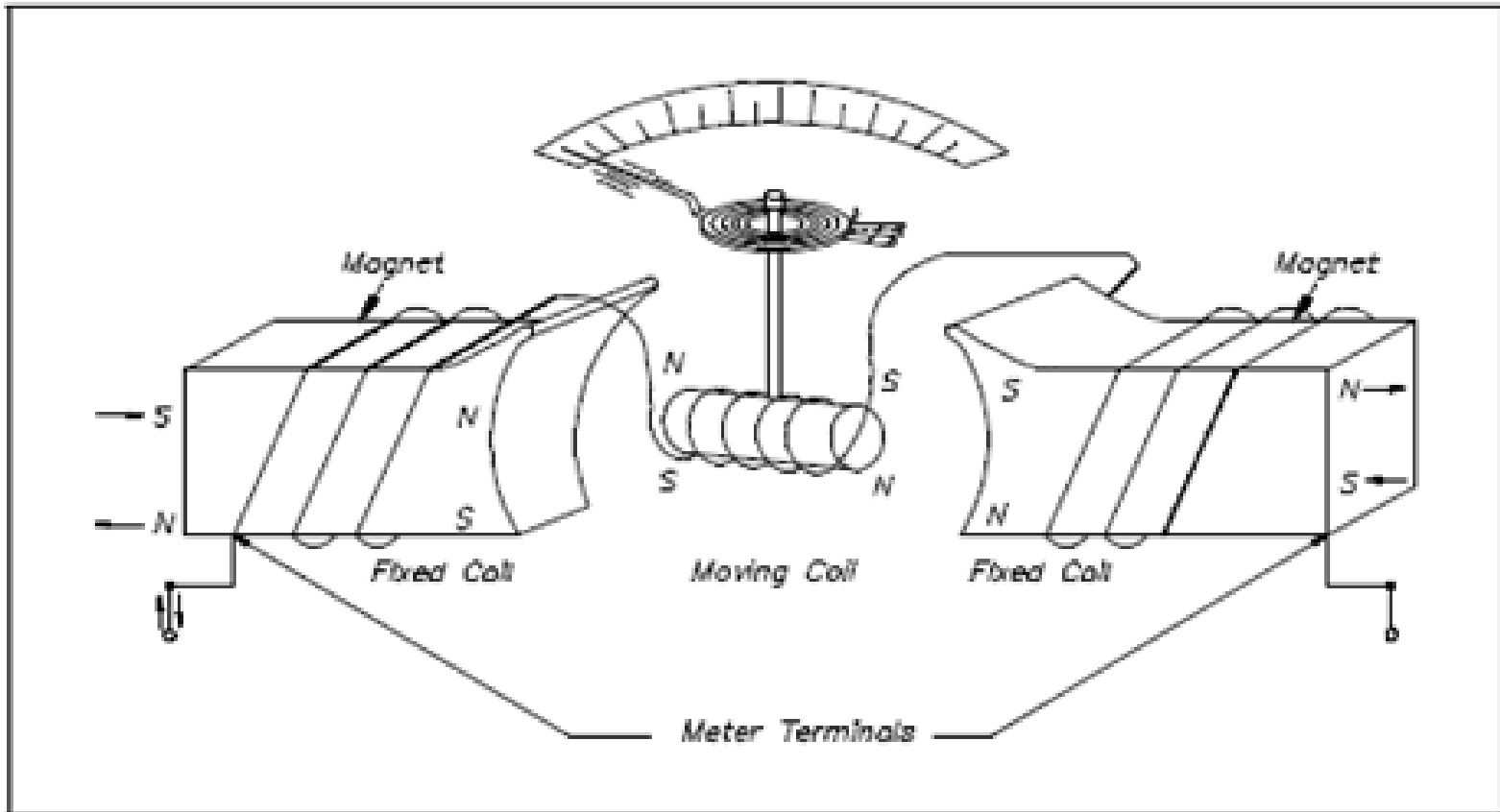


**Figure 4-26** Schematic diagram of an electrodynamic movement.

# Electrodynamometer

- **The electrodymanometer movement may also serve as a transfer instrument, because it can be calibrated on dc and then used directly on ac, establishing a direct means of equating ac and dc measurements of voltage and current.**
- **Where the d'Arsonval movement uses a permanent magnet to provide the magnetic field in which the movable coil rotates, the electrodymanometer uses the current under measurement to produce the necessary field flux.**
- **A fixed coil, split into two equal halves, provides the magnetic field in which the movable coil rotates.**

# Electrodynamometer



# Electrodynamometer

- **The two coil halves are connected in series with the moving coil and are fed by current under measurement.**
- **The fixed coils are spaced far enough apart to allow passage of the shaft of the movable coil.**
- **The movable coil carries a pointer, which is balanced by counterweights.**
- **Its rotation is controlled by springs, similar to the d'Arsonval movement construction.**
- **The complete assembly is surrounded by a laminated shield to protect the instrument from stray magnetic fields which may affect its operation.**
- **Damping is provided by aluminum air vanes, moving in sector-shaped chambers.**

# Electrodynamometer

- **The entire movement is very solid and rigidly constructed in order to keep its mechanical dimensions stable and its calibration intact. A cutaway view of the electro-dynamometer is shown in Fig. 4-27.**
- **The operation of the instrument may be understood by returning to the expression for the torque developed by a coil suspended in a magnetic field.**
- **We previously stated [Eq. (4-1)] that** 
$$T = B \times A \times I \times N$$
- **indicating that the torque, which deflects the movable coil,**
  - **is directly proportional to the coil constants (A and N),**
  - **the strength of the magnetic field in which the coil moves (B), and**
  - **the current through the coil (I).**
- **In the electro-dynamometer the flux density (B) depends on the current through the fixed coil and is therefore directly proportional to the deflection current (I).**
- **Since the coil dimensions and the number of turns on the coil frame are fixed quantities for any given meter, the developed torque becomes a function of the current squared (I<sup>2</sup>).**
- **If the electro-dynamometer is exclusively designed for dc use, its square-law scale is easily noticed, with crowded scale markings at the very low current values, progressively spreading out at the higher current values.**

# Electrodynamometer

- For ac use, the developed torque at any instant is proportional to the instantaneous current squared ( $I^2$ ).
- The instantaneous value of P is always positive and torque pulsation are therefore produced.
- The movement, however, cannot follow the rapid variations of the torque and takes up a position in which the average torque is balanced by the torque or the control springs.
- **The meter deflection is therefore a function of the mean of the squared current.**
- The scale of the electro-dynamometer is usually calibrated in terms of the square root of the average current squared, and the meter therefore reads the rms or effective value of the ac.
- The transfer properties of the electro-dynamometer become apparent when we compare the effective value of alternating current in terms of their heating effect or transfer of power.
- An alternating current that produces heat in a given resistance at the same average rate as a direct current (I) has by definition, a value of I amperes.



# Electrodynamometer

- **Designed specially for use of dc as well as ac current**
- **Scale is calibrated in rms or effective value of ac current**

$$I = \sqrt{\frac{1}{T} \int_0^T i^2 dt} = \sqrt{\text{average } i^2}$$

- **This current,  $I$ , is then called the root-mean-square (rms) or effective value of the alternating current and is often referred to as the equivalent dc value.**
- **And its power can be calculated as**

$$I^2 R = \frac{1}{T} \int_0^T i^2 R dt$$

- **Is also known as “transfer” instrument as is used interchangeably between dc and ac current on equivalent rms scale**
- **One of its disadvantage is its high power consumption**

# Electrodynamometer

- **Disadvantages of Electrodynamometer**
  - One of these is its **high power consumption**, a direct result of its construction.
  - The current under measurement must not only pass through the movable coil, but it must also provide the field flux.
  - To get a sufficiently strong magnetic field, a **high mmf** is required and the source must supply a high current and power.
  - In spite of this high power consumption, **the magnetic field is very much weaker** than that of a comparable d'Arsonval movement because there is no iron in the circuit,
    - i.e., the entire flux path consists of air.
  - Some instruments have been designed using special laminated steel for part of the flux path, but the presence of metal **introduces calibration problems** caused by frequency and waveform effects.

# Electrodynamometer

- The reactance and resistance of the coils also increase with increasing **frequency**, limiting the application of the electro-dynamometer voltmeter to the lower frequency ranges.
- It is, however, very accurate at the power-line frequencies and is therefore often used as a secondary standard.
- The electro-dynamometer movement (even unshunted) may be regarded as an ammeter, but it becomes rather difficult to design a moving coil which can carry more than approximately 100 mA.
- Larger current would have to be carried to the moving coil through heavy lead-in wires, which would lose their flexibility.
- A shunt, when used, is usually placed across the movable coil only.
- The fixed coils are then made of heavy wire which can carry the large total current and it is feasible to build ammeters for currents up to 20 A. Larger values of ac currents are usually measured by using a current transformer and a standard 5-A ac ammeter (Sec. 4-16).

# Rectifier-Type Instruments

- **Rectifier type instruments are used to convert ac into a unidirectional dc and then to use a dc movement to indicate the value of the rectified ac.**
- **dc movement generally has a higher sensitivity than either the electro-dynamometer or the moving-iron instrument.**
- **Rectifier type instruments generally use a PMMC movement in combination with some rectifier arrangement.**
- **The rectifier element usually consist germanium or a silicon diode.**
- **Rectifier instrument work sometimes consist of four diodes in a bridge configuration.**
- **Providing full wave rectification. Figure 4-28 shows an ac voltmeter circuit consisting of a multiplier, a bridge rectifier, and a PMMC movement.**
- **Because of the inertia of the moving coil, the meter will indicate a steady deflection proportional to the average value of the current.**

# Rectifier-Type Instruments

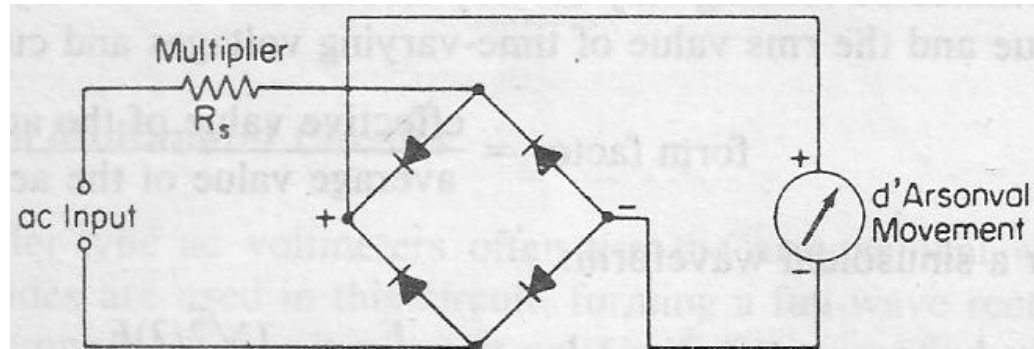
- **The form factor relates the average value and the rms value of time-varying voltages and currents:**

$$\text{form factor} = \frac{\text{effective value of the ac wave}}{\text{average value of the ac wave}}$$

- **For a sinusoidal waveform:**

$$\text{form factor} = \frac{E_{\text{rms}}}{E_{\text{av}}} = \frac{(\sqrt{2}/2)E_m}{(2/\pi)E_m} = 1.11 \quad (4-27)$$

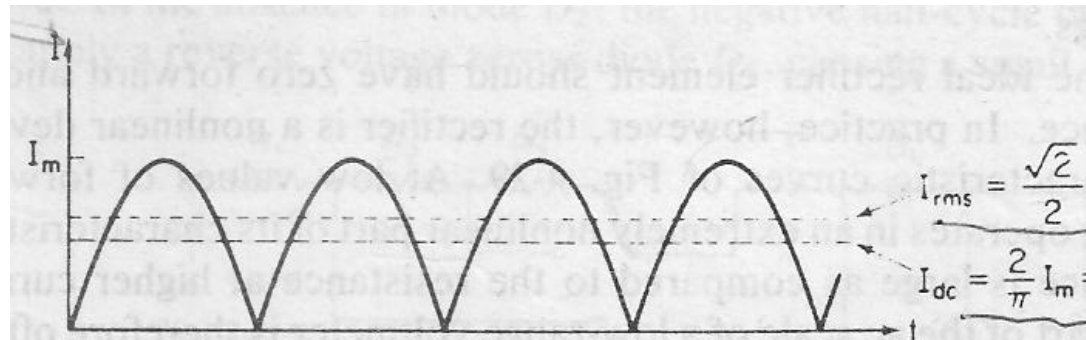
- **The form factor of Eq. (4-27) is therefore also the factor by which the actual (average) dc current is multiplied to obtain the equivalent rms scale markings.**
- **The ideal rectifier element should have zero forward and infinite reverse resistance.**



(a) Circuit

# Rectifier-Type Instruments

- The resistance of the rectifying element changes with varying temperature, one of the major drawbacks of rectifier-type ac instruments.
- At very much higher or lower temperatures, the resistance of the rectifier changes the total resistance of the measuring circuit sufficiently to cause the meter to be gravely in error.
- Frequency also affects the operation of the rectifier elements.



(b) Rectified Current Through Meter Movement

Figure 4-28 Full-wave rectifier ac voltmeter.

# Rectifier-Type Instruments

## EXAMPLE 4-9

An experimental ac voltmeter uses the circuit of Fig. 4-28(a), where the PMMC movement has an internal resistance of  $50\ \Omega$  and requires a dc current of  $1\ \text{mA}$  for full-scale deflection. Assuming ideal diodes (zero forward resistance and infinite reverse resistance), calculate the value of the multiplier  $R_s$  to obtain full-scale meter deflection with  $10\ \text{V}$  ac (rms) applied to the input terminals.

**SOLUTION** For full-wave rectification,

$$E_{\text{dc}} = \frac{2}{\pi} E_m = \frac{2\sqrt{2}}{\pi} E_{\text{rms}} = 0.9E_{\text{rms}}$$

and

$$E_{\text{dc}} = 0.9 \times 10\ \text{V} = 9\ \text{V}$$

The total circuit resistance, neglecting the forward diode resistance, is

$$R_t = R_s + R_m = \frac{9\ \text{V}}{1\ \text{mA}} = 9\ \text{k}\Omega$$

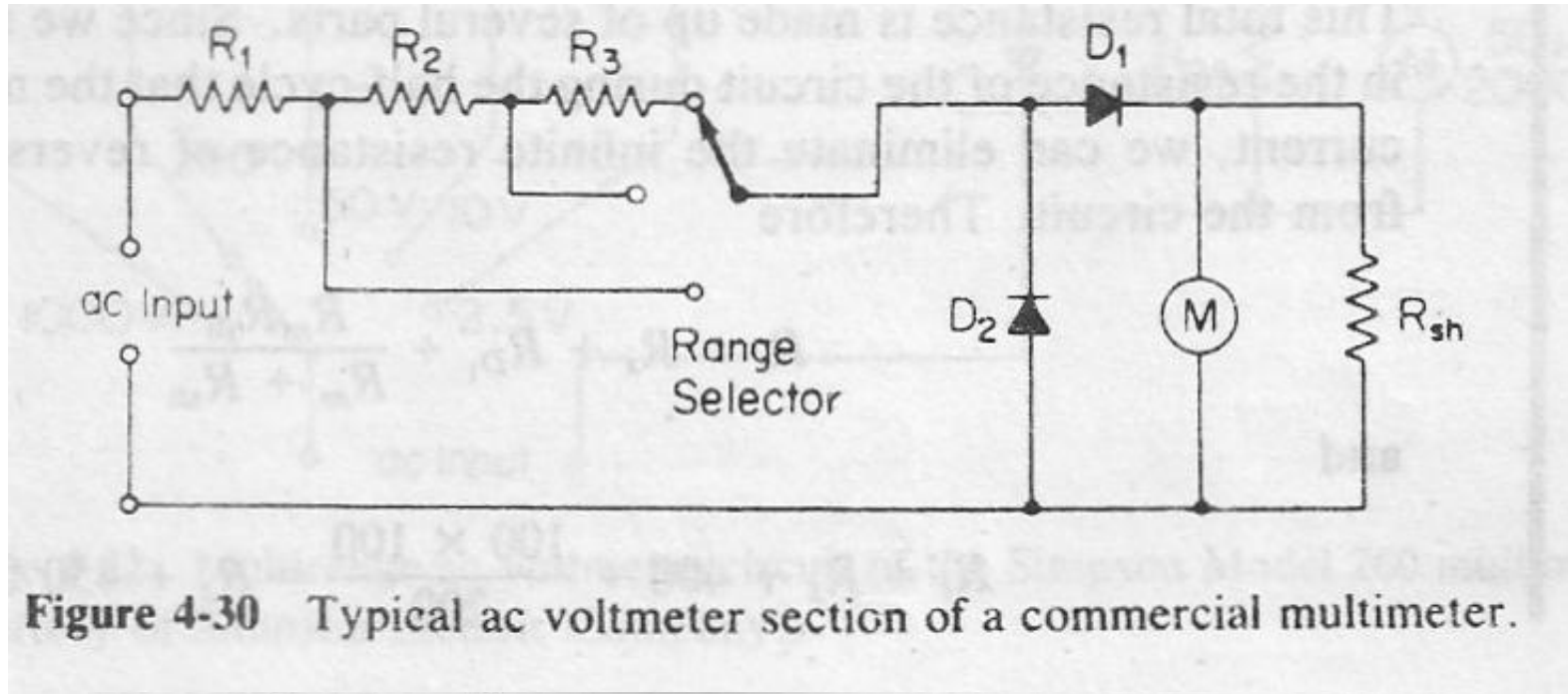
$$R_s = 9,000\ \Omega - 50\ \Omega = 8,950\ \Omega$$

# Typical Multimeter Circuits

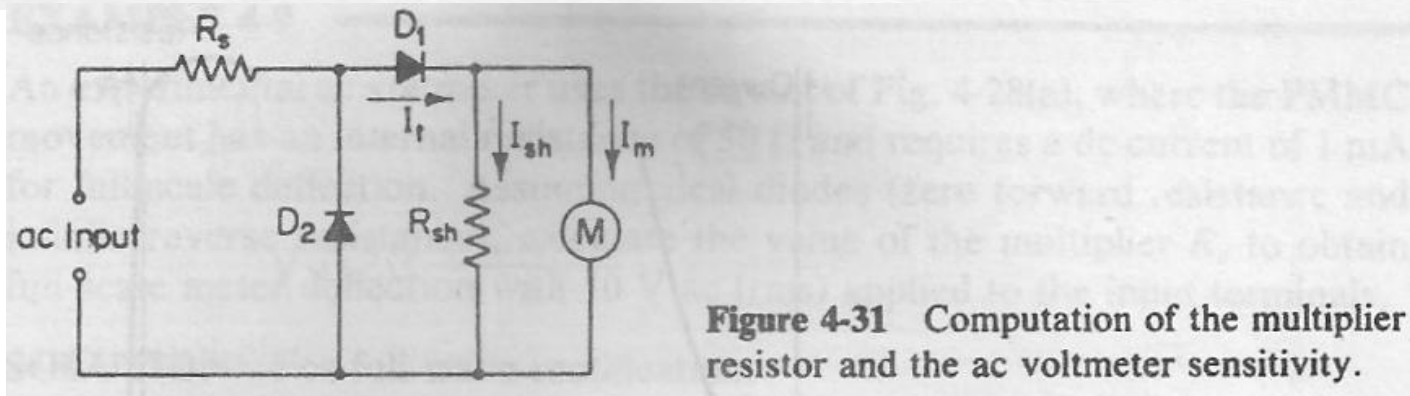
- General rectifier-type ac voltmeters often use the arrangement shown in Fig. 4-30.
- Two diodes are used in this circuit, forming a full-wave rectifier with the movement so connected that it receives only half of the rectified current.
- Diode  $D_1$  conducts during the positive half-cycle of the input waveform and causes the meter to deflect according to the average value of this half-cycle.
- The meter movement is shunted by a resistance  $R_h$ , in order to draw more current through the diode  $D_1$  and move its operating point into the linear portion of the characteristic curve.
- In the absence of diode  $D_2$ , the negative half-cycle of the input voltage would apply a reverse voltage across diode  $D_2$ , causing a small leakage current in the reverse direction.
- The average value of the complete cycle would therefore be lower than it should be for half-wave rectification. Diode  $D_2$  deals with this problem.
- On the negative half-cycle,  $D_2$  conducts heavily, and the current through the measuring circuit, which is now in the opposite direction, bypasses the meter movement.
- The commercial multimeter often uses the same scale markings for both its dc and ac voltage ranges.
- Since the dc component of a sine wave for half-wave rectification equals 0.45 times the rms value, a problem arises immediately.
- In order to obtain the same deflection on corresponding dc and ac voltage ranges, the multiplier for the ac range must be lowered proportionately.



# Typical Multimeter Circuits



**Figure 4-30** Typical ac voltmeter section of a commercial multimeter.



**Figure 4-31** Computation of the multiplier resistor and the ac voltmeter sensitivity.

# Example 4-10

A meter movement has an internal resistance of  $100\ \Omega$  and requires  $1\ \text{mA}$  dc for full-scale deflection. Shunting resistor  $R_{sh}$ , placed across the movement, has a value of  $100\ \Omega$ . Diodes  $D_1$  and  $D_2$  have an average forward resistance of  $400\ \Omega$  each and are assumed to have infinite resistance in the reverse direction. For a  $10\text{-V}$  ac range, calculate (a) the value of multiplier  $R_s$ ; (b) the voltmeter sensitivity on the ac range.

**SOLUTION** (a) Since  $R_m$  and  $R_{sh}$  are both  $100\ \Omega$ , the total current the source must supply for full-scale deflection is  $I_t = 2\ \text{mA}$ . For half-wave rectification the equivalent dc value of the rectified ac voltage will be

$$E_{dc} = 0.45E_{rms} = 0.45 \times 10\ \text{V} = 4.5\ \text{V}$$

The total resistance of the instrument circuit then is

$$R_t = \frac{E_{dc}}{I_t} = \frac{4.5\ \text{V}}{2\ \text{mA}} = 2,250\ \Omega$$

This total resistance is made up of several parts. Since we are interested only in the resistance of the circuit during the half-cycle that the movement receives current, we can eliminate the infinite resistance of reverse-biased diode  $D_2$  from the circuit. Therefore

$$R_t = R_s + R_{D_1} + \frac{R_m R_{sh}}{R_m + R_{sh}}$$

and

$$R_t = R_s + 400 + \frac{100 \times 100}{200} = R_s + 450\ \Omega$$

# Example 4-10

The value of the multiplier therefore is

$$R_s = 2,250 - 450 = 1,800 \Omega$$

(b) The sensitivity of the voltmeter on this 10-V ac range is

$$S = \frac{2,250 \Omega}{10 \text{ V}} = 225 \Omega/\text{V}$$

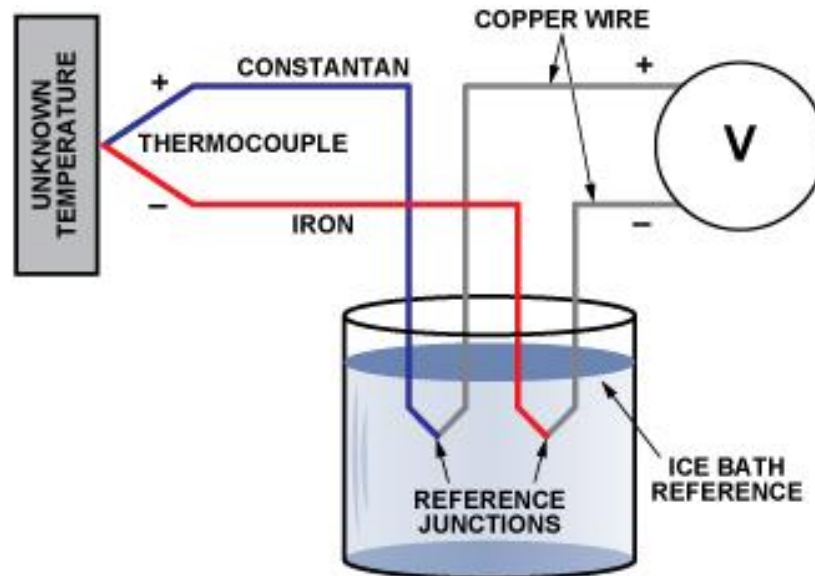
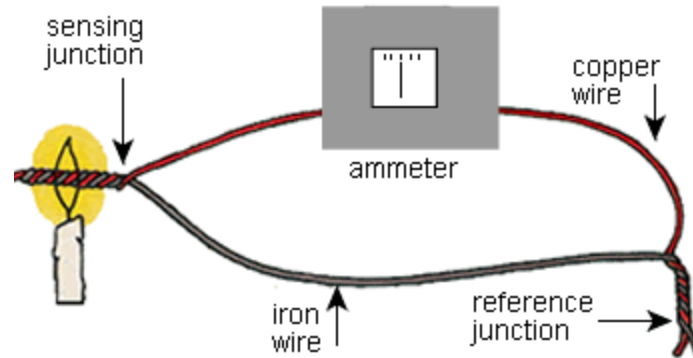
The same movement, used in a dc voltmeter, would have given a sensitivity figure of 1,000  $\Omega/\text{V}$ .

•Section 4-10 dealt with the dc circuitry of a typical multimeter, using the simplified circuit diagram of Fig. 4-20. The circuit for measuring ac volts (subtracted from Fig. 4-20) is reproduced in Fig. 4-32. Resistances  $R_9$ ,  $R_{13}$ ,  $R_7$ , and  $R_6$  form a chain of multipliers for the voltage ranges of 1,000V, 250V, 50V, and 10V, respectively, and their values are indicated in the diagram of Fig. 4-32. On the 2.5-V ac range, resistor  $R_{23}$  acts as the multiplier and corresponds to the multiplier  $R_{24}$  of Example 4-10 shown in Fig. 4-31. Resistor  $R_{24}$  is the meter shunt and again acts to improve the rectifier operation. Both values are unspecified in the diagram and are factory selected. A little thought, however, will convince us that the shunt resistance could be 2,000 (1, equal to the meter resistance. If the average forward resistance of the rectifier elements is 500 $\Omega$  (a reasonable assumption), then resistance  $R_{23}$  must have a value of 1,000 $\Omega$ . This follows because the meter sensitivity on the ac ranges is given as 1,000 $\Omega/\text{V}$ ; on the 2.5-V ac range, the circuit must therefore have a total resistance of 2,500 $\Omega$ . This value is made up of the sum of  $R_{13}$ , the diode forward resistance, and the combination of movement and-shunt resistance, as shown in Example 4-10.

# Thermoinstruments

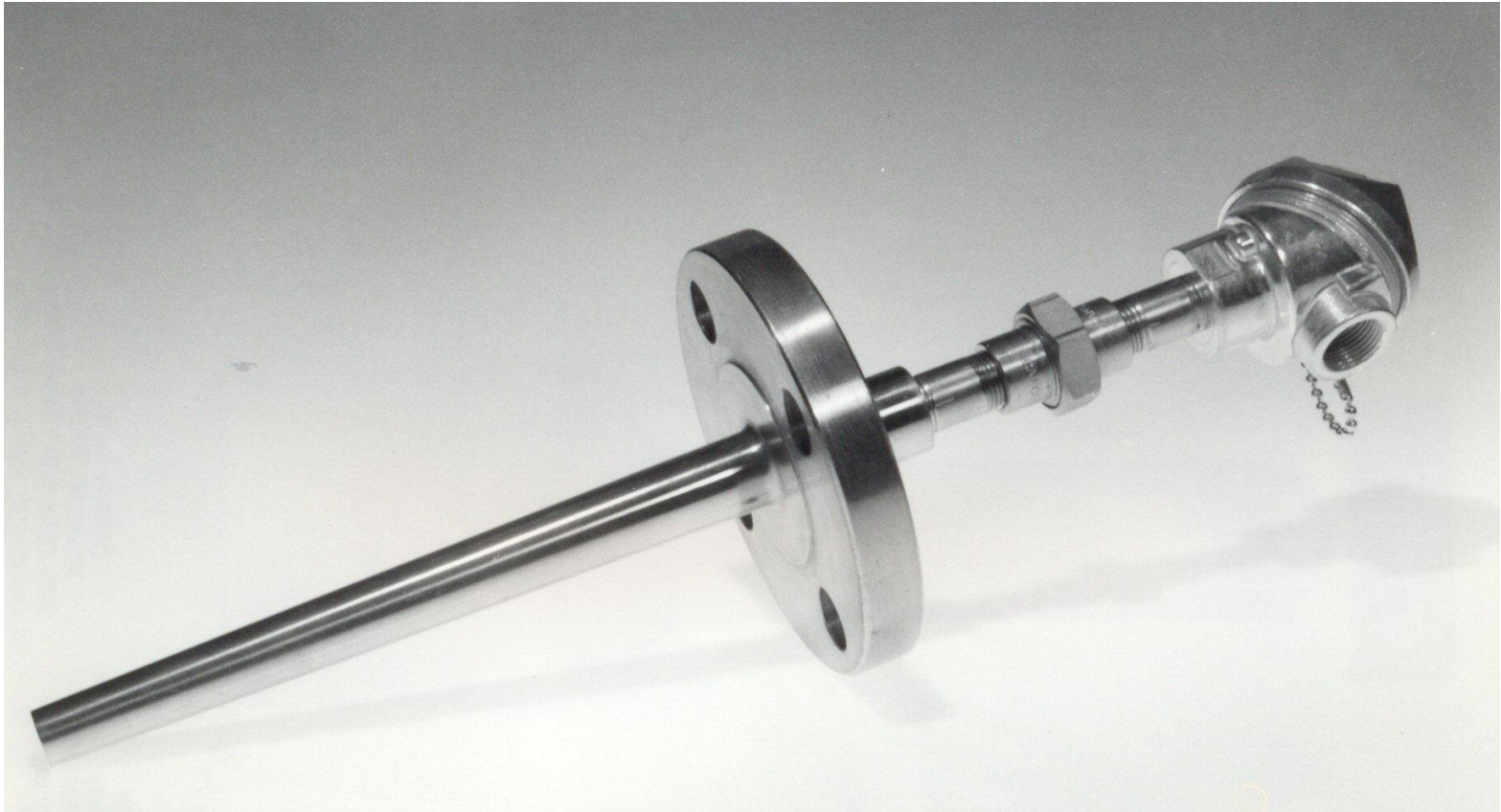
- **Figure 4-33 shows a combination of a thermocouple and a PMMC movement that can be used to measure both ac and dc. This combination is called a thermocouple instrument, since its operation is based on the action of the thermocouple element.**
- **When two dissimilar metals are mutually in contact, a voltage is generated at the junction of the two dissimilar metals. This voltage rises in proportion to the temperature of the junction.**
- **In Fig. 4-33, CE and DE represent the two dissimilar metals, joined at point E. and are drawn as a light and a heavy line, to indicate dissimilarity. The potential difference between C and D depends on the temperature of the so-called cold junction, E. A rise in temperature causes an increase in the voltage and this is used to advantage in the thermocouple. Heating element AB, which is in mechanical contact with the junction of the two metals at point E, forms part of the circuit in which the current is to be measured. AEB is called the hot junction.**
- **Heat energy generated by the current in the heating element raises the temperature of the cold junction and causes an increase in the voltage generated across terminals C and D shown on scale. The heat generated by the current is directly proportional to the current squared ( $I^2R$ ), and the temperature rise (and hence the generated dc voltage) is proportional to the square of the rms current.**

# Thermocouple

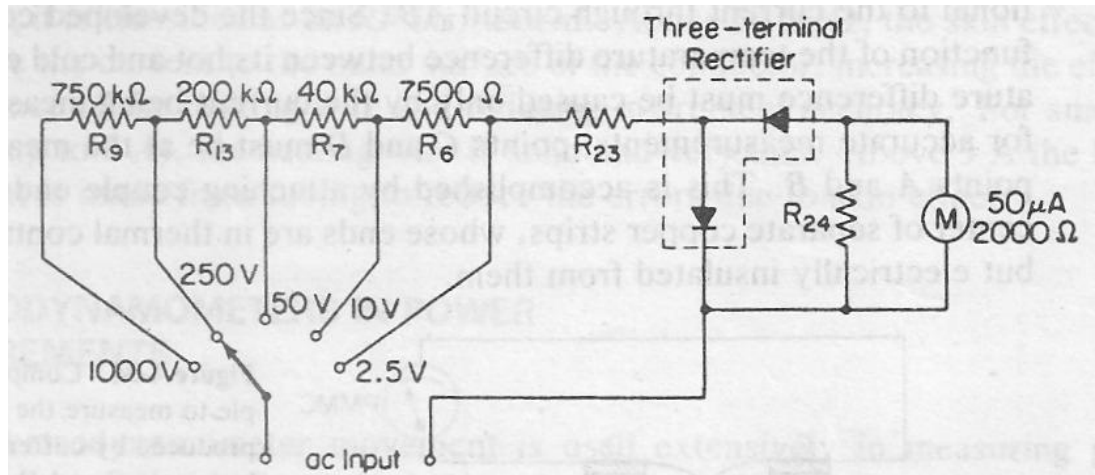


# Thermocouple Devices

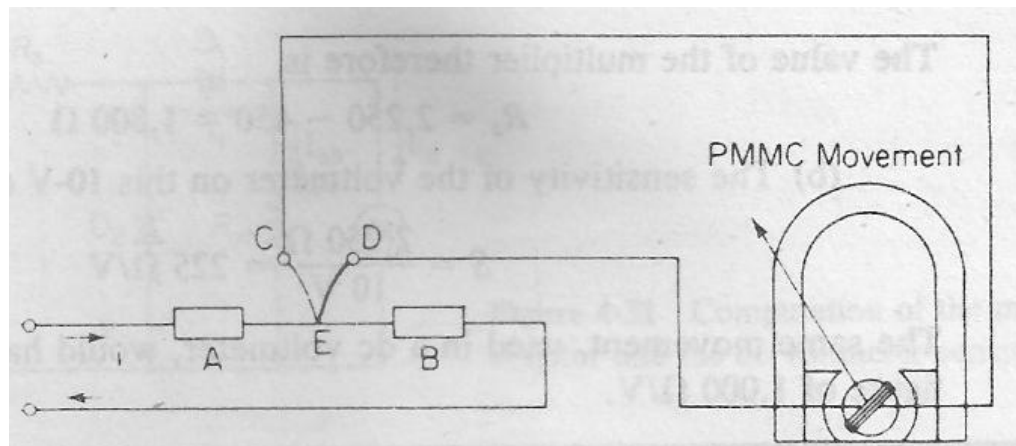
- **Thermocouple based Temperature Sensor**



# Thermoinstruments



**Figure 4-32** Multirange ac voltmeter circuit of the Simpson Model 260 multimeter. (Courtesy of Simpson Electric Company.)



**Figure 4-33** Schematic representation of a basic thermocouple instrument using thermocouple CDE and a PMMC movement.

# Thermoinstruments

- **Self-contained thermoelectric instruments of the compensated type are available in the 0.5-20-A range. Higher current ranges are available, but in this case the heating element is external to the indicator. Thermo-elements used for current ranges over 60 A are generally provided with air cooling fins.**
- **Current measurements in the lower ranges, from approximately 0.1-0.75 A, use a bridge-type thermo-element, shown schematically in Fig. 4-35. This arrangement does not use a separate heater: the current to be measured passes directly through the thermo-elements and raises their temperature in proportion to  $I^2R$ . The cold junctions (marked c) are at the pins which are embedded in the insulating frame, and the hot junctions (marked h) are at splices midway between the pins. The couples are arranged as shown in Fig. 4-35, and the resultant thermal voltage generates a dc potential difference across the indicating instrument. Since the bridge arms have equal resistances, the ac voltage across the meter is 0 V, and no ac passes through the meter. The use of several thermocouples in series provides a greater output voltage and deflection than is possible with a single element, resulting in an instrument with increased sensitivity.**
- **Thermo-instruments may be converted into voltmeters using low-current thermocouples and suitable series resistors. Thermocouple voltmeters are available in ranges of up to 500 V and sensitivities of approximately 100 to 500 $\Omega$ /V.**
- **A major advantage of a thermocouple instrument is that its accuracy can be as high as 1 percent, up to frequencies of approximately 50 MHz. For this reason, it is classified as an RF instrument. Above 50 MHz, the skin effect tends to force the current to the outer surface of the conductor, increasing the effective resistance of the heating wire and reducing instrument accuracy. For small currents (up to 3 A), the heating wire is solid and very thin. Above 3 A the heating element is made from tubing to reduce the errors due to skin effect.**



Thank You