DC and AC Potentiometers

DC potentiometer

- A potentiometer is an instrument used for the measurement of unknown voltage by comparing it with a known voltage. The known voltage is supplied by a standard cell or battery.

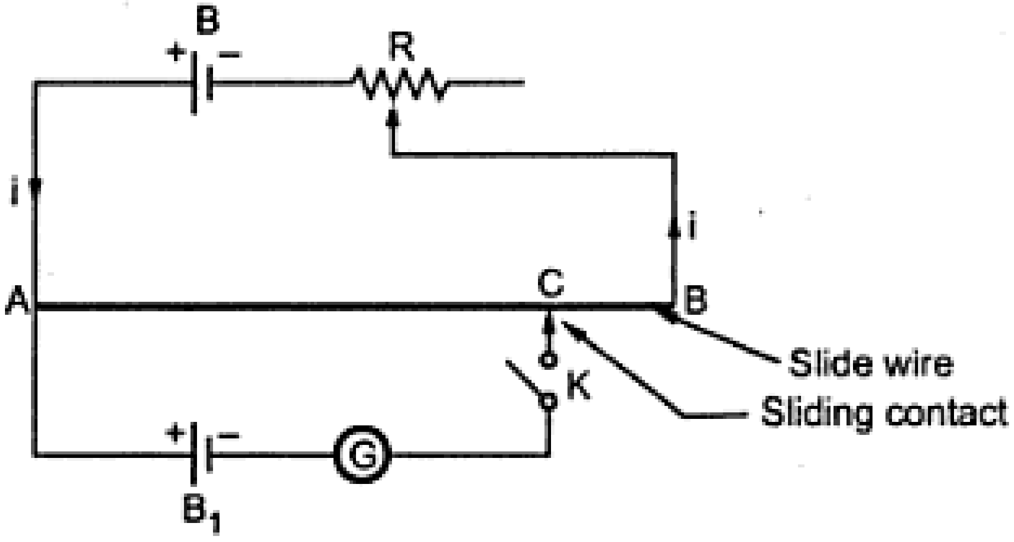
Advantages:

- The accuracy depends on the known reference voltage and not on the deflection of pointer.
- It consumes no power when the circuit is unbalanced.
- It can also be used for the measurement of current.

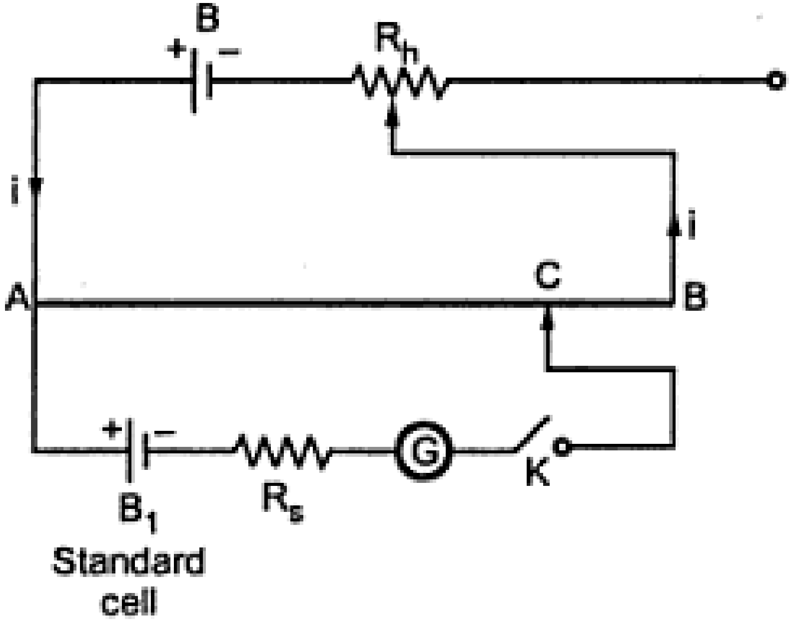
Applications:

- It is mainly used for the calibration of ammeter and voltmeter

Basic slide wire potentiometer & standardization of potentiometer

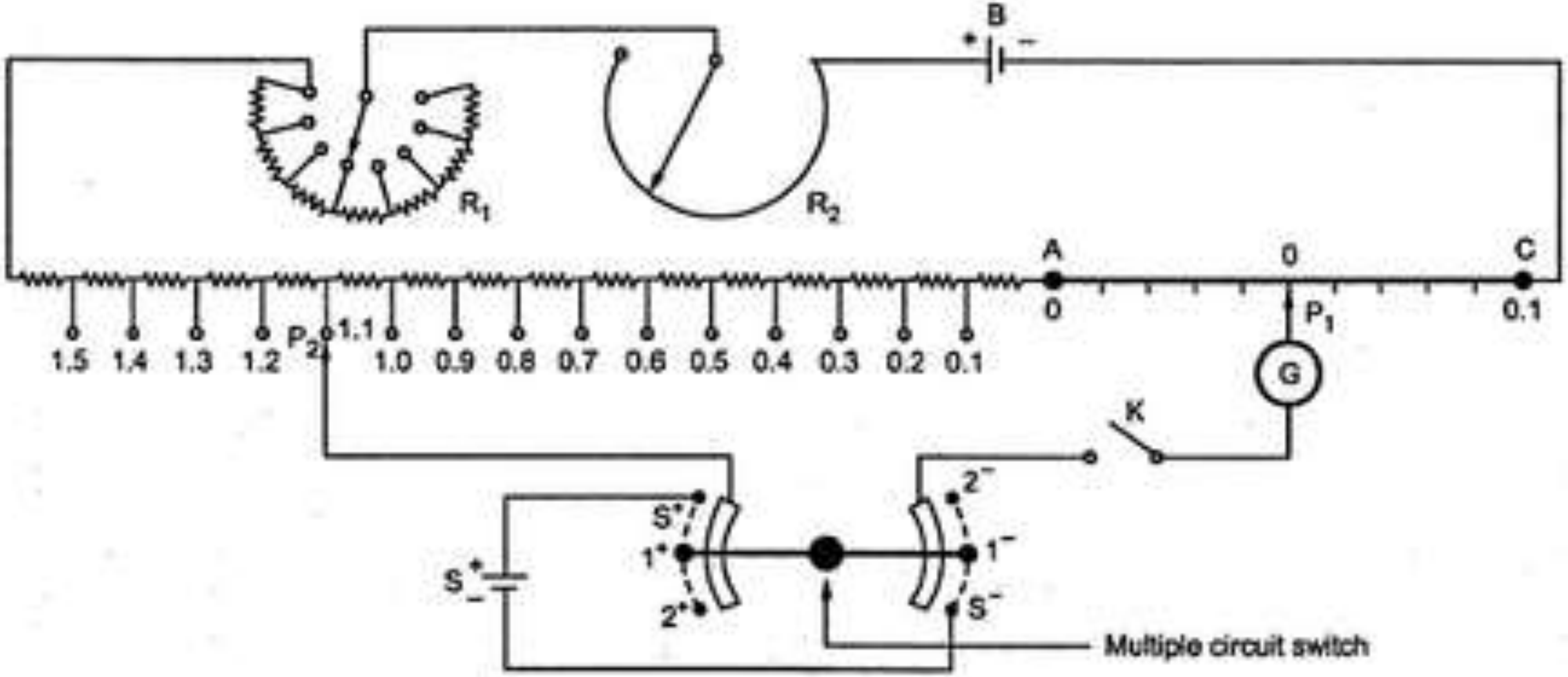


Basic slide wire potentiometer



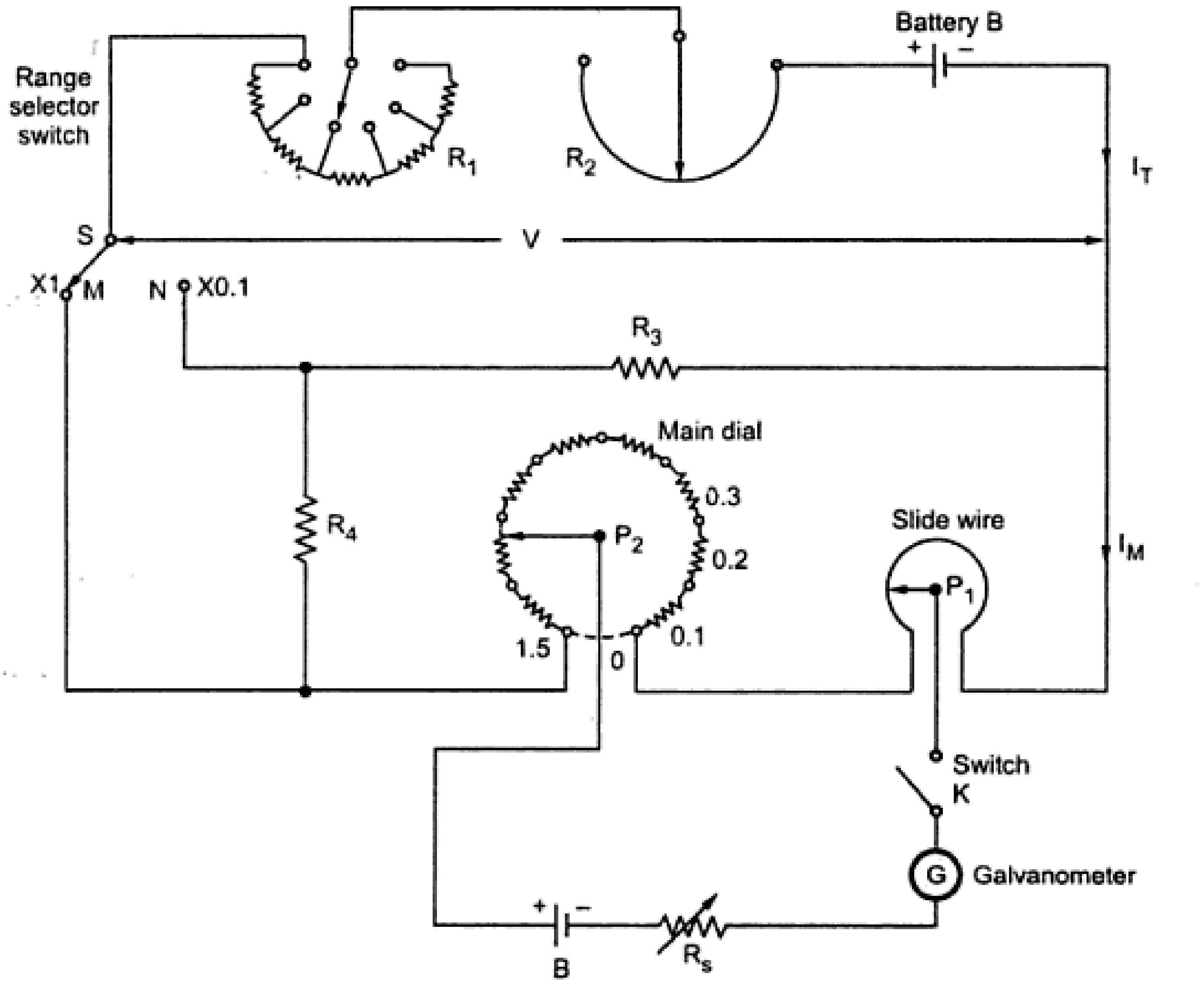
Practical set up for d.c. potentiometer standardisation

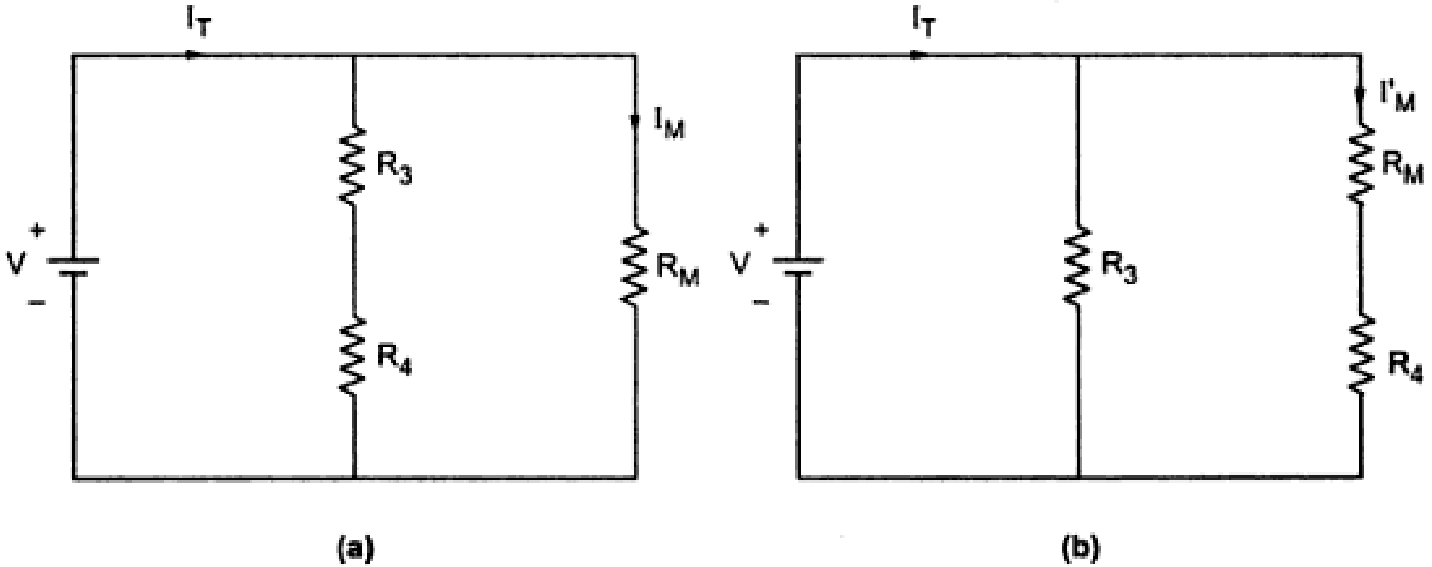
Laboratory type or Crompton potentiometer



Crompton's D.C. potentiometer

Duo range potentiometer





Simplified circuits of duo-range potentiometer for different range selections

In order to have the same current I_T for both ranges, the condition is,

$$(R_3 + R_4) \parallel R_M = R_3 \parallel (R_M + R_4)$$

$$\therefore \quad \frac{(R_3 + R_4) R_M}{R_3 + R_4 + R_M} = \frac{R_3 (R_M + R_4)}{R_3 + R_4 + R_M}$$

$$\therefore \quad R_3 R_M + R_4 R_M = R_3 R_M + R_3 R_4$$

$$R_M = R_3$$

$\therefore$ the second condition states that the current I'_M when switch S is at position N must be equal to $0.1\, I_M$ where I_M is the current through R_M when switch S is at position M.

$$\therefore \qquad I'_M = 0.1\, I_M$$

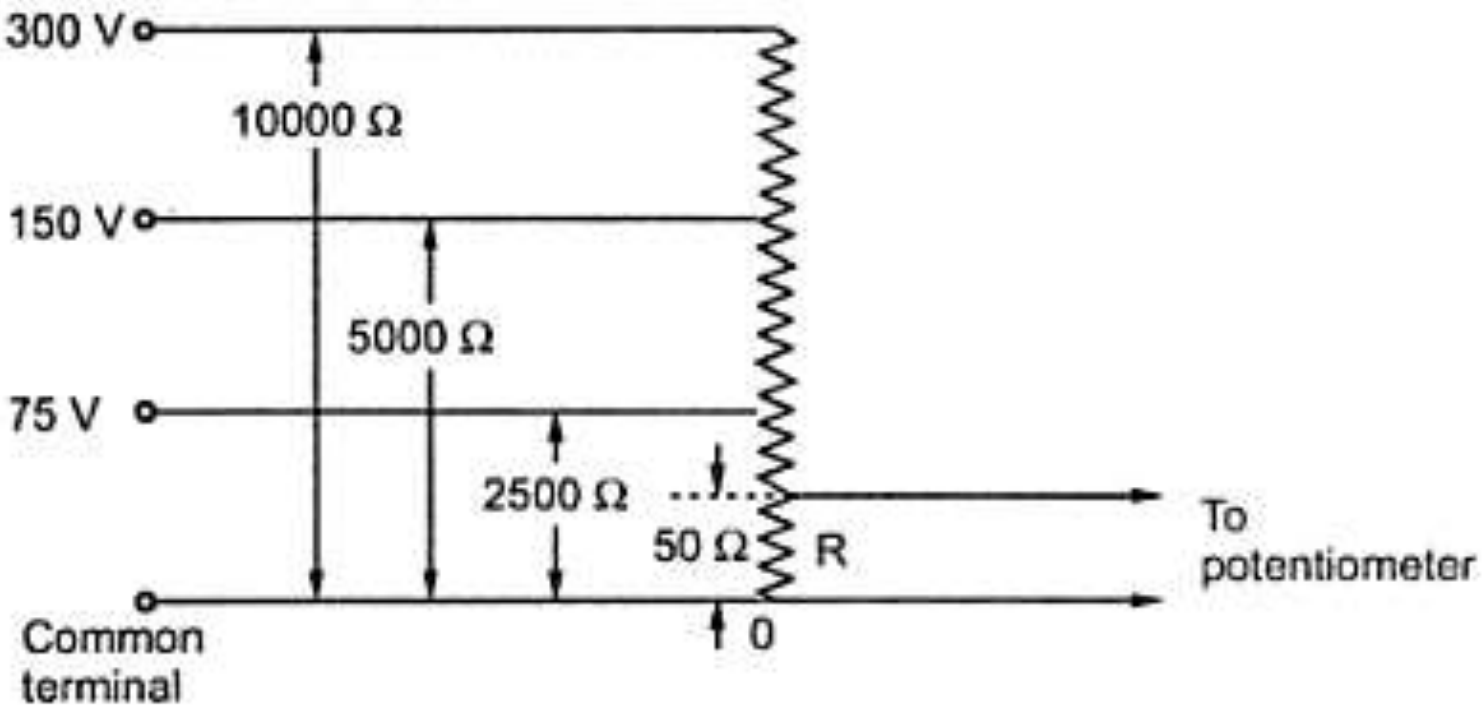
$$\therefore \qquad \frac{V}{R_M + R_4} = 0.1\left[\frac{V}{R_M}\right]$$

$$\therefore \qquad R_M = 0.1\,(R_M + R_4)$$

$$\therefore \qquad R_4 = 9\, R_M = 9\, R_3$$

Thus by properly designing values of R_3 and R_4 we can achieve high resolution in measurement using duo-range potentiometers.

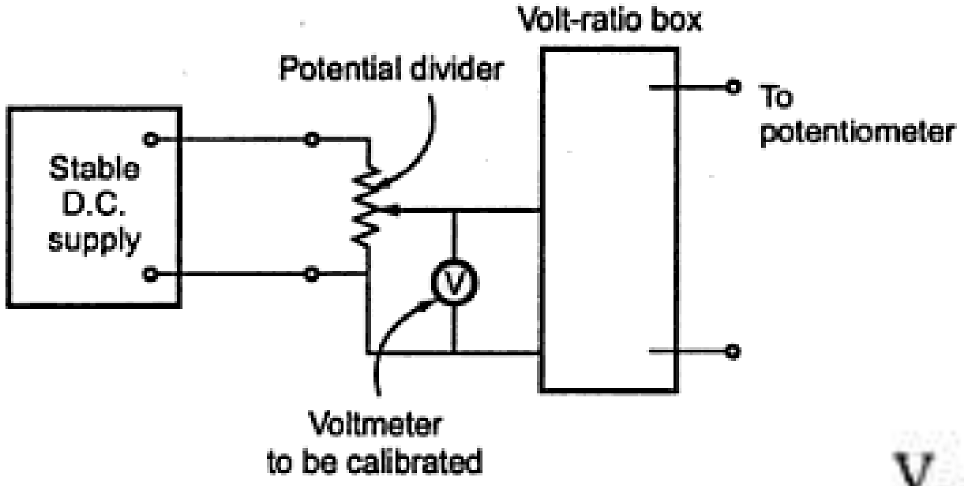
Volt ratio box



Volt-ratio box

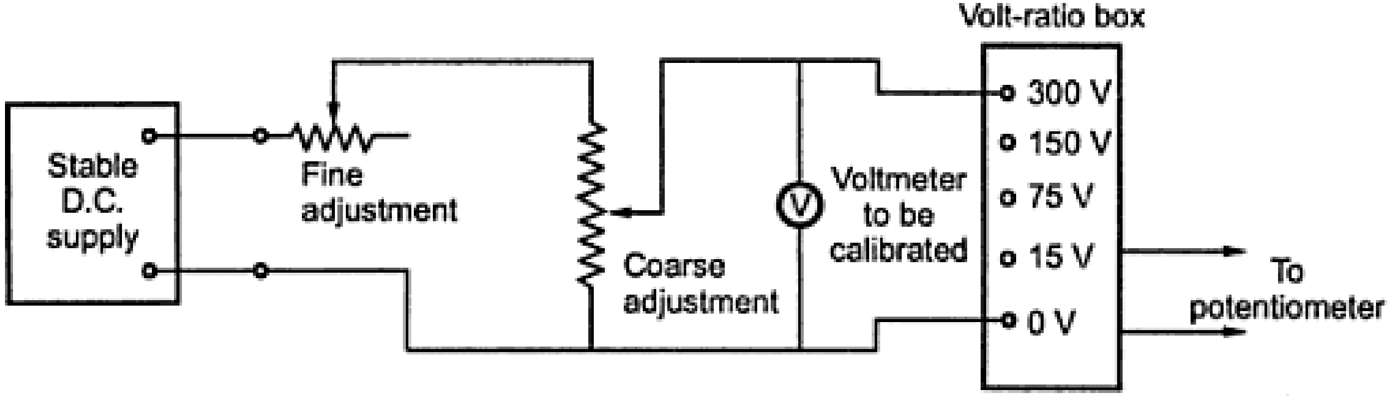
$$V_{unknown} = 1.3\left(\frac{5000}{50}\right) = 130 \text{ V}$$

Applications



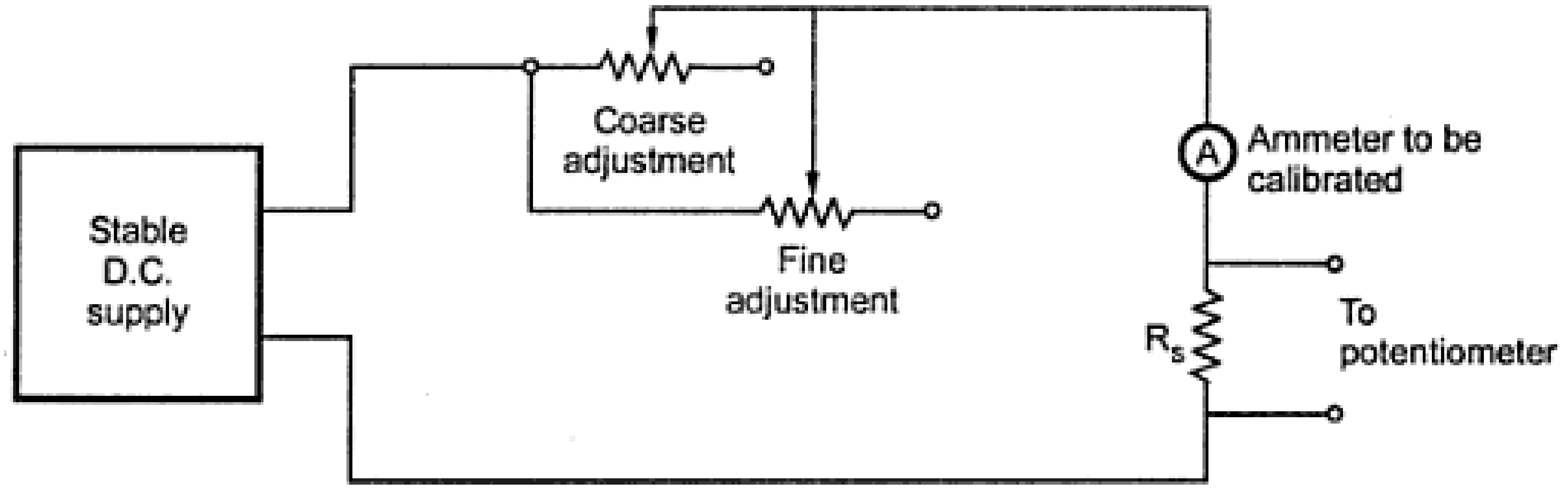
(a)

$$V_{act} = \frac{(\text{Potentiometer reading})}{(\text{V.R. box ratio})}$$



(b)

Calibration of voltmeter

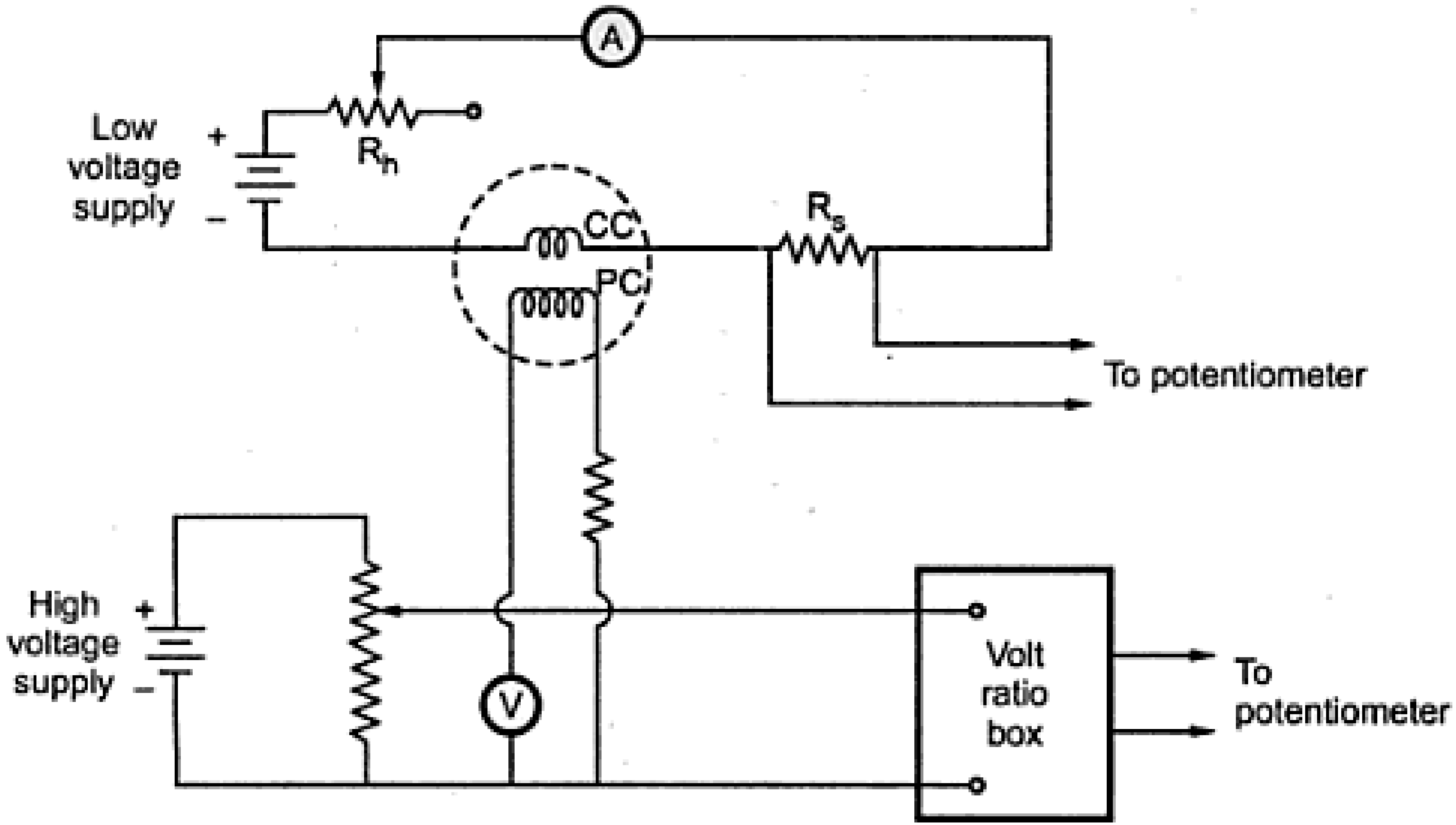


Calibration of ammeter

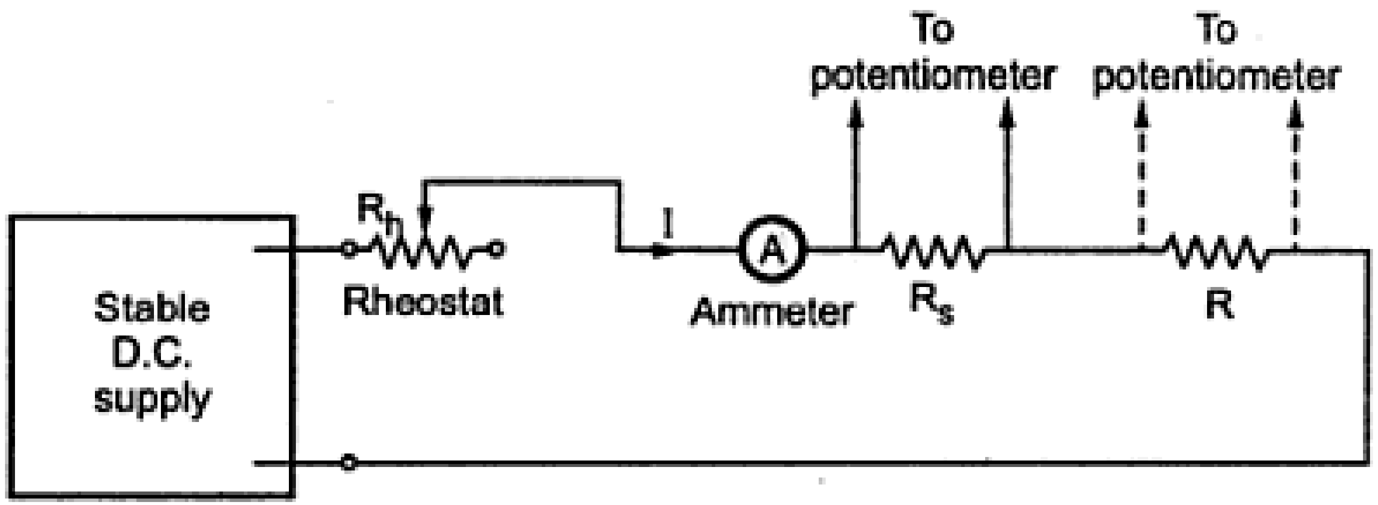
$$I = \frac{V_s}{R_s}$$

where V_s = voltage across R_s measured using potentiometer

R_s = resistance of standard resistor



Calibration of wattmeter



Measurement of unknown resistance

Let the voltage across standard resistance be V_{RS}. Then, we can write,

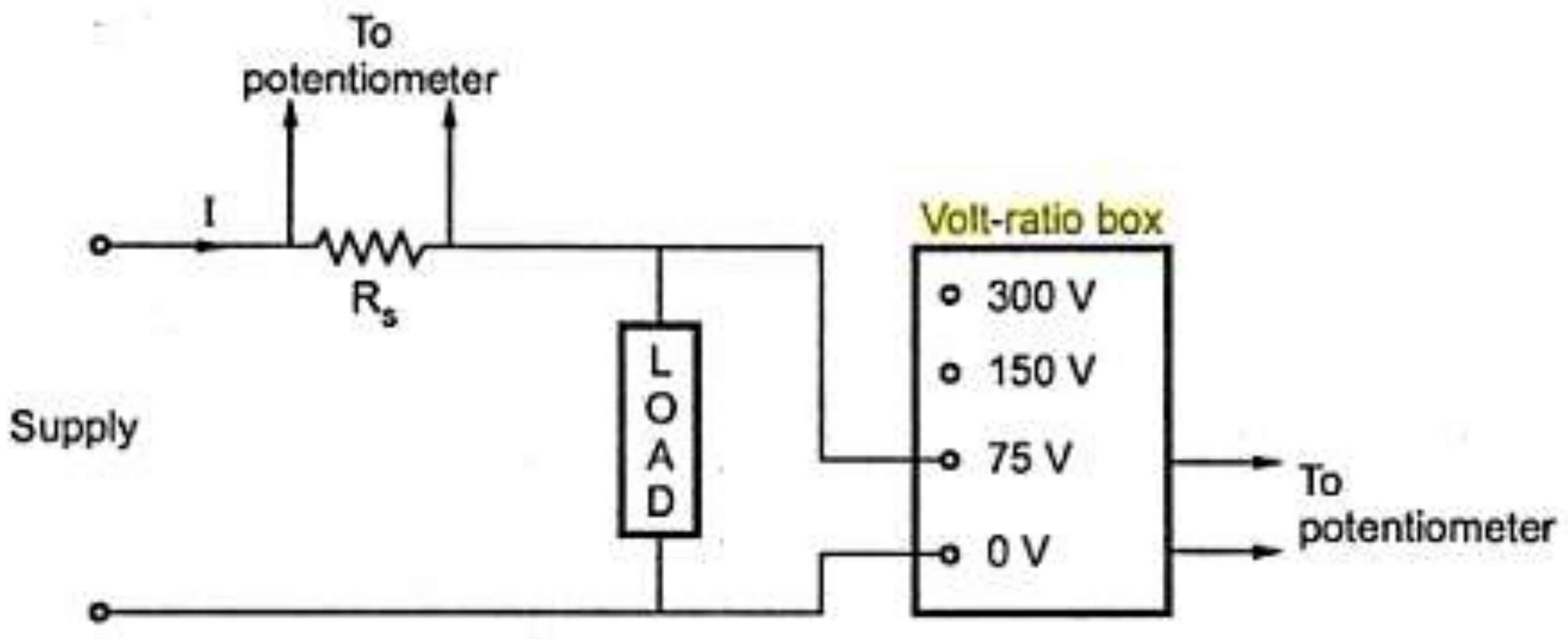
$$V_{RS} = I\, R_s$$

Let the voltage across unknown resistance be V_R. Then, we can write,

$$V_R = I\, R$$

Dividing equation (2) by equation (1),

$$\frac{V_R}{V_{RS}} = \frac{R}{R_s}$$



Measurement of power

AC potentiometer

An ac potentiometer measures the unknown ac voltage or emf similar to dc potentiometers used for measuring dc voltage. The balance condition is obtained when the unknown voltage is equal to the drop across the sliding wire of the potentiometer. It measures the unknown voltage both in terms of magnitude and phase angle by comparing and balancing it with the known reference voltage.

Although the working principle of the ac potentiometer is similar to that of the dc potentiometer (i.e., comparing unknown voltage with a known voltage). But dc potentiometer cannot be used for measuring the ac voltage.

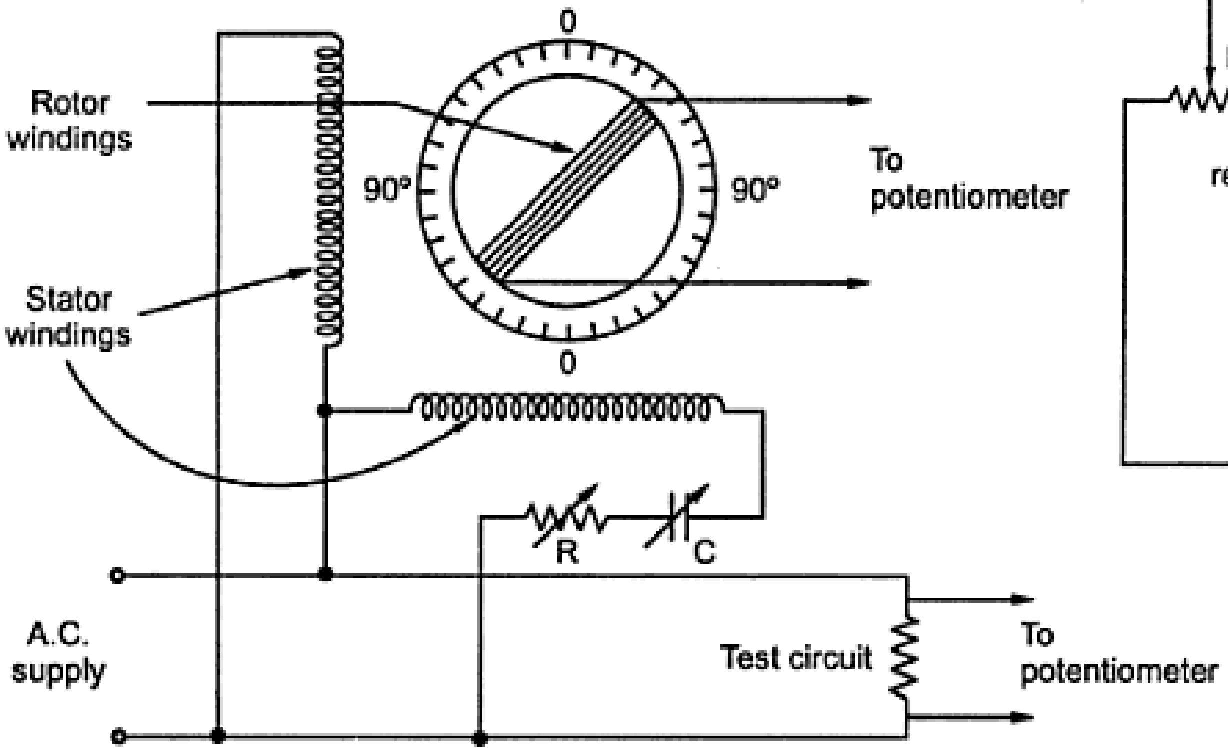
AC potentiometer

- In dc potentiometer, the balance between voltage drop across the slide wire and the magnitude of unknown voltage is obtained.
- In ac potentiometer, the two voltages should be balanced in magnitude as well as in phase.

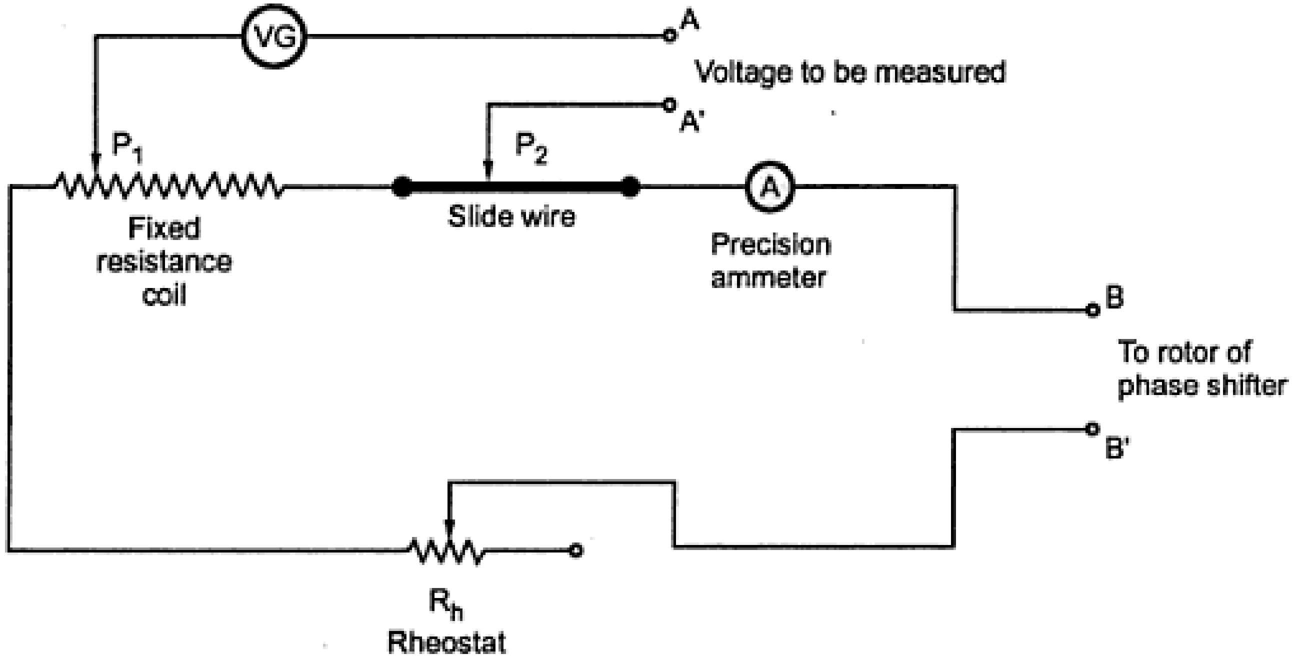
Two types of ac potentiometer,

- Polar type ac potentiometer.
- Co-ordinate type ac potentiometer.

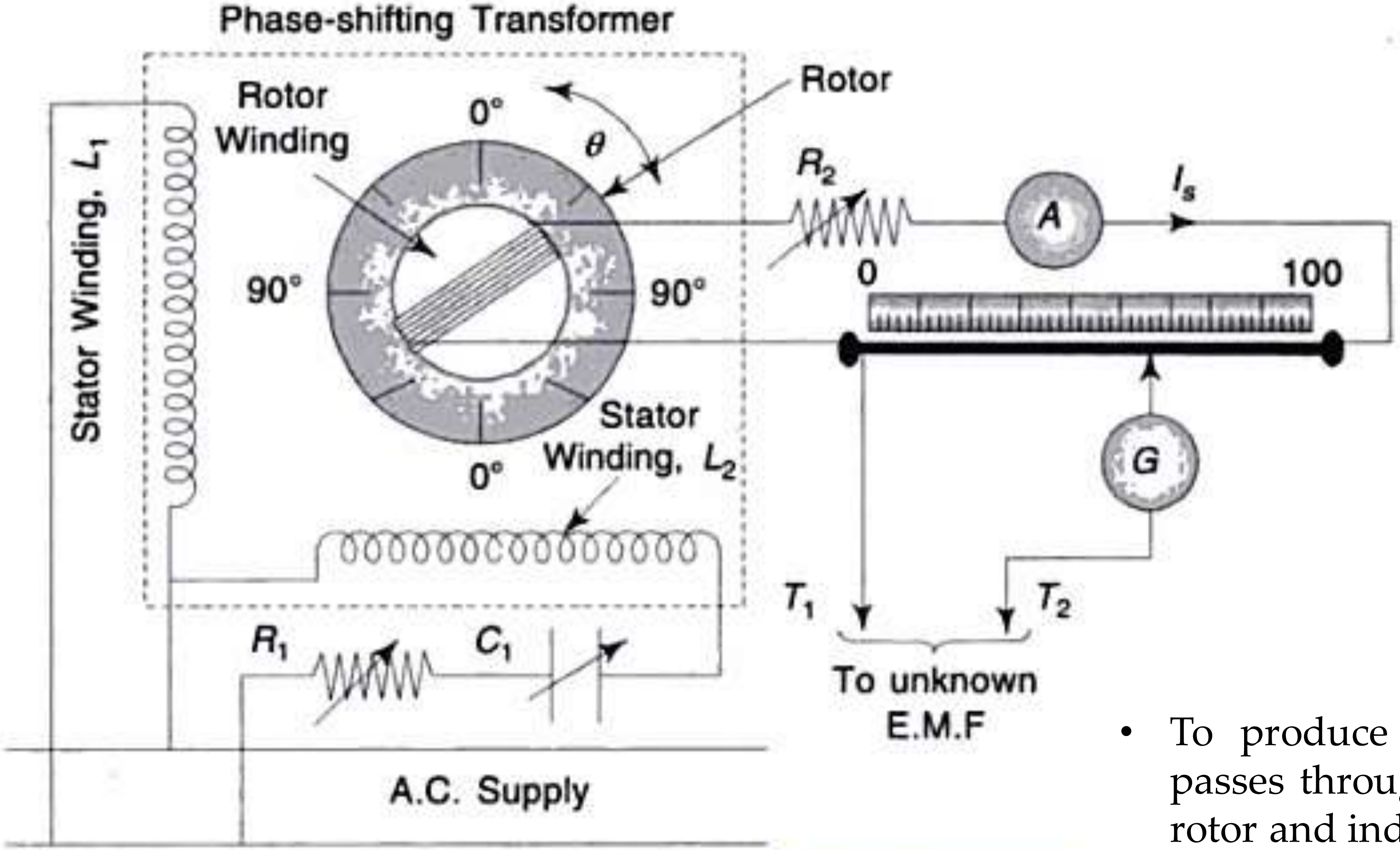
Drysdale-Tinsley polar type ac potentiometer



Drysdale phase shifter connection diagram



Measurement of unknown e.m.f.



Drysdale Polar Potentiometer

- In a phase-shifting transformer, there is a combination of two ring-shaped laminated steel stators connected perpendicularly to each other.
- One is directly connected to power supply and the other one is connected in series with variable resistance and capacitor.
- Between the stators, there is laminated rotor having slots and winding which supplies voltage to the slide-wire circuit of the potentiometer.

- To produce the rotating magnetic field which passes through the air gap between its stator and rotor and induces an emf in the rotor winding.
- To provide the required phase shifting of the rotor induced emf by adjusting the rotor position. The rotor position can be adjusted by adjusting the rotor angle with respect to the null pointer.

Now, the induced emf in the rotor windings due to two stator windings is given by,

$$E_1 = KI\ \sin\omega t\ \cos\theta$$

$$E_2 = KI\ \sin(\omega t + 90)\ \cos(\theta + 90)$$

Therefore, the resultant emf is given by,

$$E = E_1 + E_2$$

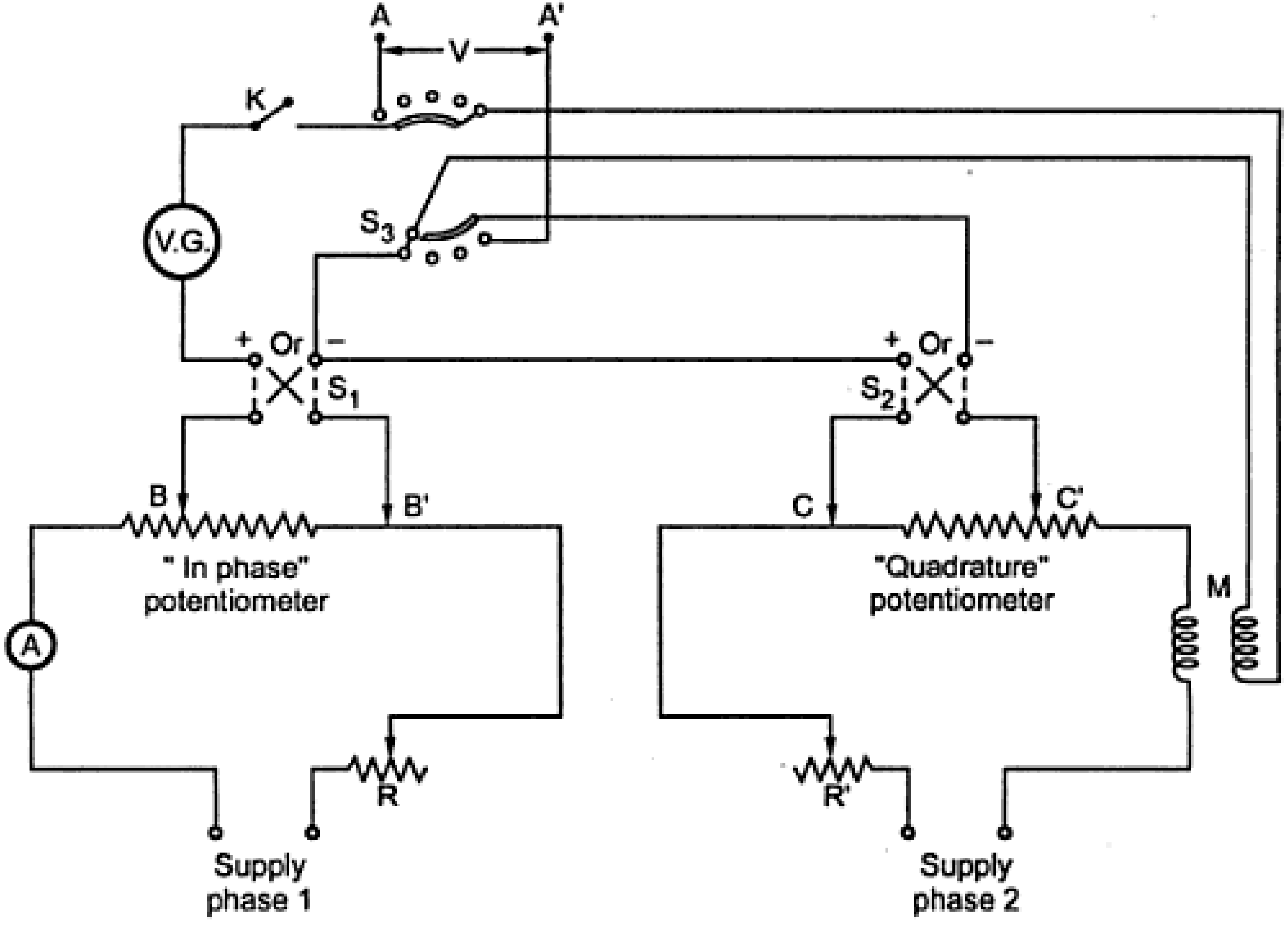
$$E = KI\ [\sin\omega t\ \cos\theta + \sin(\omega t + 90)\ \cos(\theta + 90)]$$

We know that $\sin(\omega t + 90) = \cos\omega t$ and $\cos(\theta + 90) = -\sin\theta$.

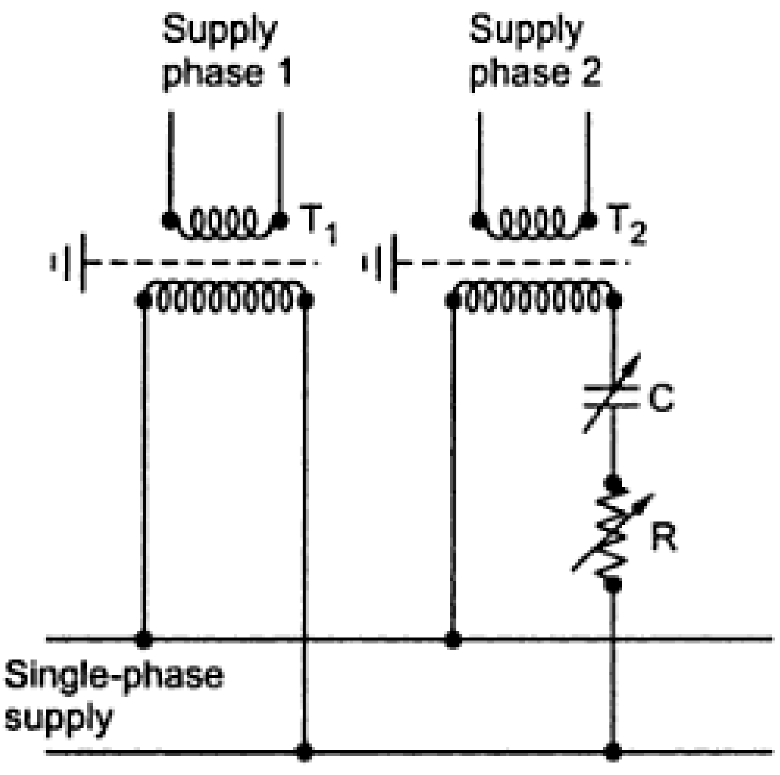
$$\therefore E = KI\ \sin\omega t\ (\omega t - \theta)$$

From the above, it is clear that the rotor emf has constant amplitude and the phase angle is given by the rotor deflection θ.

Gall-Tinsley Co-ordinate type ac potentiometer



Connections of Gall-Tinsley potentiometers



Phase splitting circuit

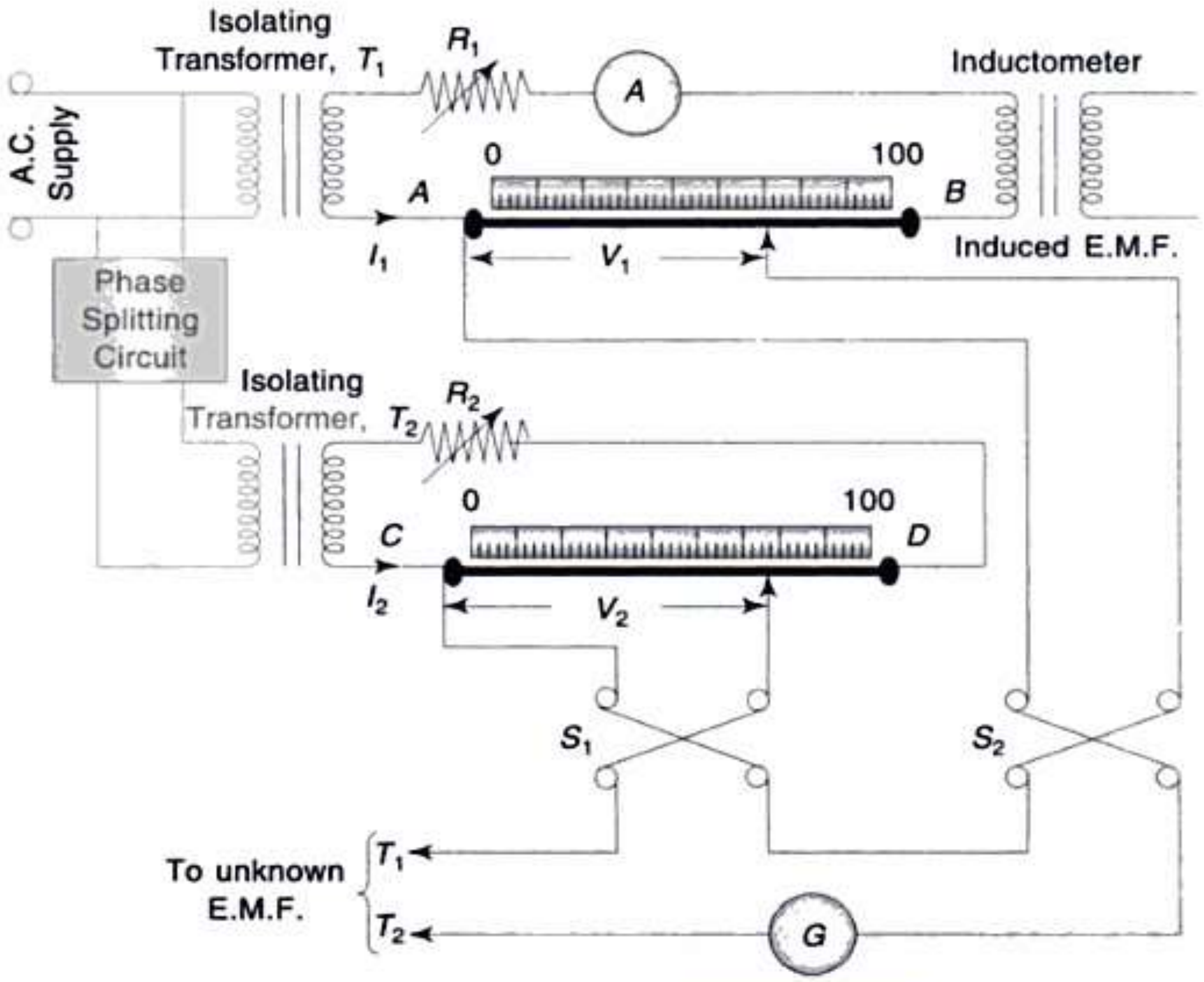


Fig. 2.38 *Gall-Tinsley Potentiometer*

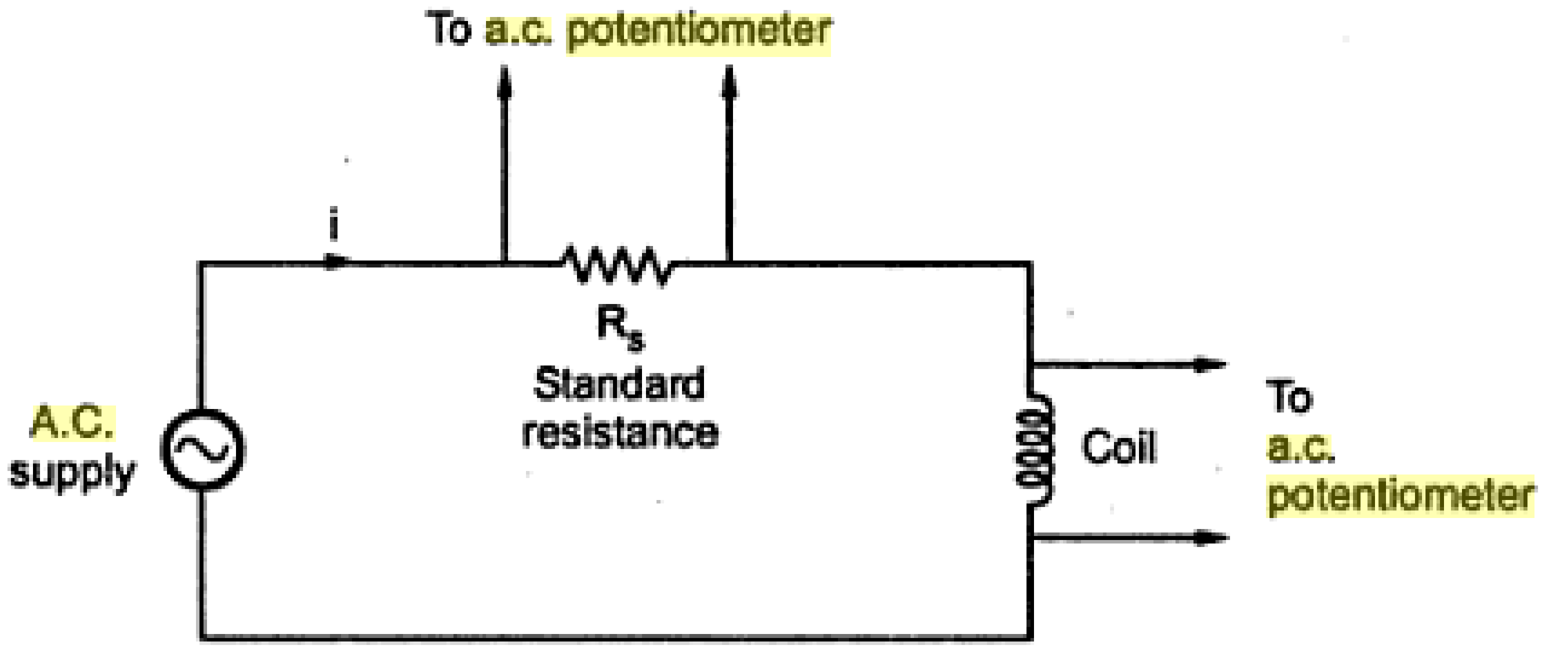
- The first one is named as the in-phase potentiometer which is used to measure the in-phase factor of an unknown e.m.f. and the other one is named as quadrature potentiometer which measures quadrature part of the unknown e.m.f. the sliding contact CD in the in-phase potentiometer and AB in quadrature potentiometer are used for obtaining the desired current in the circuit.

- By adjusting rheostat R1 and R2 and sliding contacts, the current in the quadrature potentiometer becomes equal to the current in the in-phase potentiometer and a variable galvanometer shows the null value. S_1 and S_2 are signs changing switches which are used to change the polarity of the test voltage if it is required for balancing the potentiometer.

Now to measure unknown e.m.f. its terminals are connected across sliding contacts AA′ using selector switch S_3. By doing some adjustments in sliding contacts and rheostat, the whole circuit gets balanced and galvanometer reads zero at the balanced condition. Now the in-phase component V_A of the unknown e.m.f. is obtained from the in-phase potentiometer and quadrature component V_B is obtained from quadrature potentiometer.

Applications of Ac potentiometers

- Calibration of voltmeter
- Calibration of ammeter
- Testing of energymeter and wattmeter
- Measurement of self reactance of coil



Measurement of self reactance of coil

Voltage across coil = $v_c = V_c \angle\theta_c$ in polar form ... (1)

Voltage across R_s = $v_s = V_s \angle\theta_s$ ... (2)

The current through coil can be calculated as,

$$i = \frac{v_s}{R_s} = \frac{V_s \angle\theta_s}{R_s} \qquad \text{... (3)}$$

The impedance of coil can be calculated as,

$$Z = \frac{v_c}{i} = \frac{V_c \angle\theta_c}{\left[\frac{V_s}{R_s}\angle\theta_s\right]} = \frac{R_s V_c}{V_s} \angle\theta_c - \theta_s \qquad \text{... (4)}$$

We can write this impedance Z in rectangular form in real part and imaginary part as resistance and reactance.

The resistive part of impedance is given by,

$$R = Z\cos(\theta_c - \theta_s) = \frac{R_s V_c}{V_s}\cos(\theta_c - \theta_s) \qquad \text{... (5)}$$

The reactive part of impedance is given by,

$$X = Z\sin(\theta_c - \theta_s) = \frac{R_s V_c}{V_s}\sin(\theta_c - \theta_s) \qquad \text{... (6)}$$

Thus equation (6) represents reactance of the coil.

Instrument transformer

Introduction

These are special type of transformers used for the measurement of voltage, current, power and energy. As the name suggests, these transformers are used in conjunction with the relevant instruments such as ammeters, voltmeters, watt meters and energy meters.

Types of Instrument Transformer

Such transformers are of two types :

1. Current Transformer (or Series Transformer)
2. Potential Transformer (or Parallel Transformer)

Current transformers are used when the magnitude of AC currents exceeds the safe value of current of measuring instruments.

Potential transformers are used where the voltage of an AC circuit exceeds 750 V as it is not possible to provide adequate insulation on measuring instruments for voltage more than this.

Uses of Instrument Transformer

It is used for the following two as:

1. To protect the high voltage circuit from the measuring circuit in order to protect the measuring instruments from burning

2. To make it possible to measure the high voltage with low range voltmeter and high current with low range ammeter.

These instrument transformers are also used in controlling and protecting circuits, to operate relays, circuit breakers etc. The working of these transformers are similar as that of ordinary transformers.

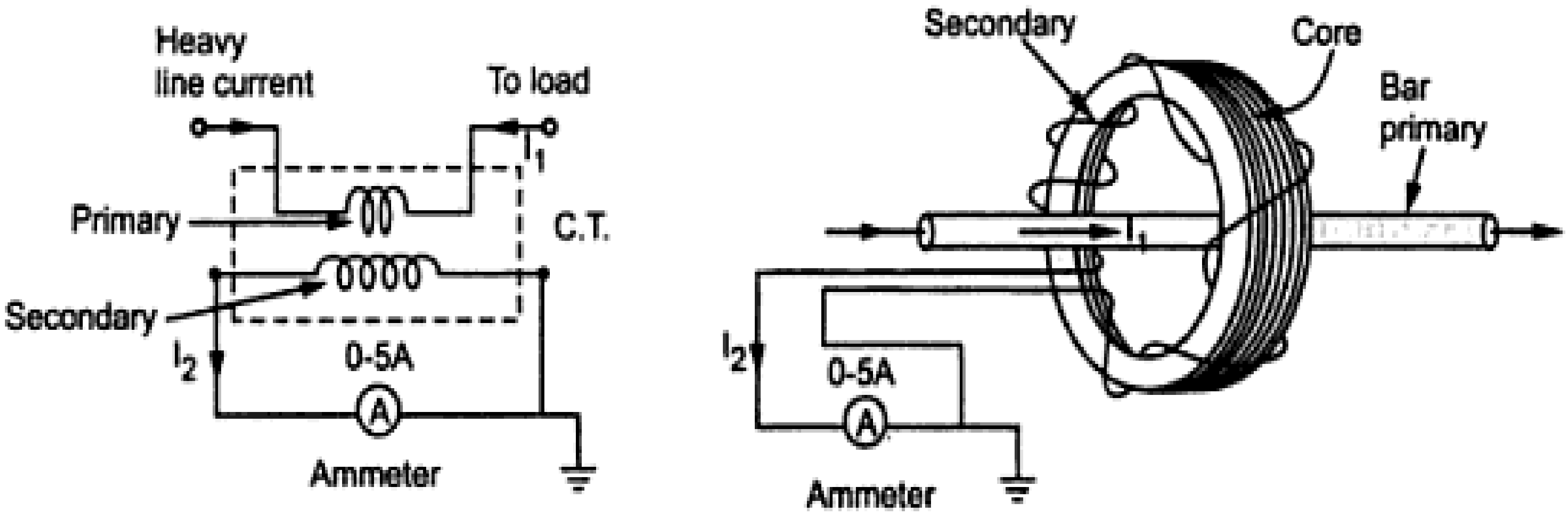
Use of Instrument Transformer

Measurement of current as CT

The primary winding is so connected that the current to be measured passes through it and the secondary is connected to the ammeter .

The function of CT is to step down the current.

Instrument Transformer as CT



(a) Wound primary

(b) Bar primary

Current transformer

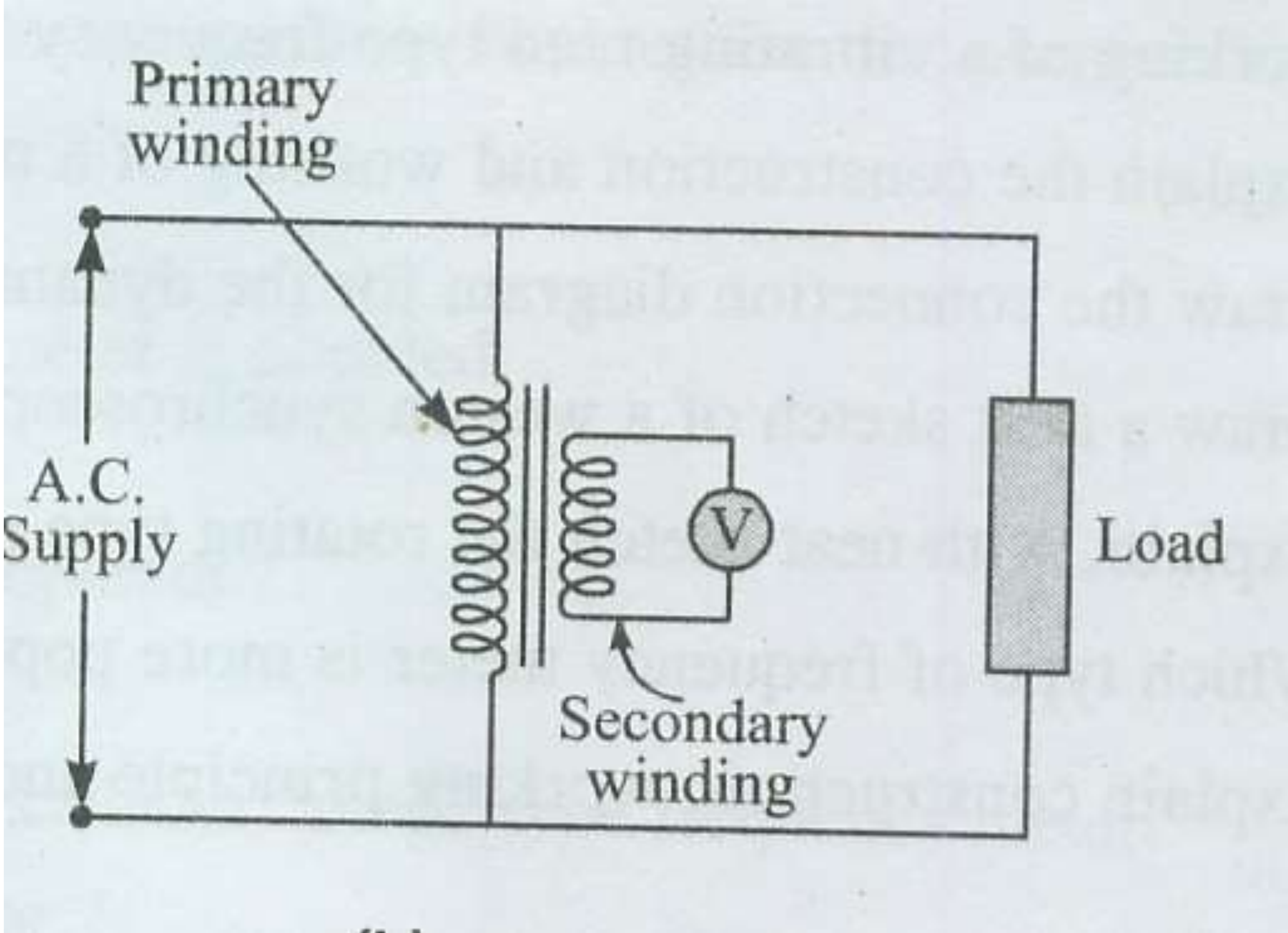
Use of Instrument Transformer

Measurement of voltage by PT

The primary winding is connected to the voltage side to be measured and secondary to the voltmeter.

The function of PT is to steps down the voltage to the level of voltmeter.

Instrument Transformer as PT



Advantages of Instrument Transformer

1. The measuring instruments can be placed for away from the high voltage side by connecting long wires to the instrument transformer. This ensures the safety of instruments as well as the operator.

2. This instrument transformers can be used to extend the range of measuring instruments like ammeters and voltmeters.

3. The power loss in instrument transformers is very small as compared to power loss due to the resistance of shunts and multipliers.

4. By using current transformer with tong tester, the current in a heavy current circuit can be measured.

Disadvantages of Instrument Transformer

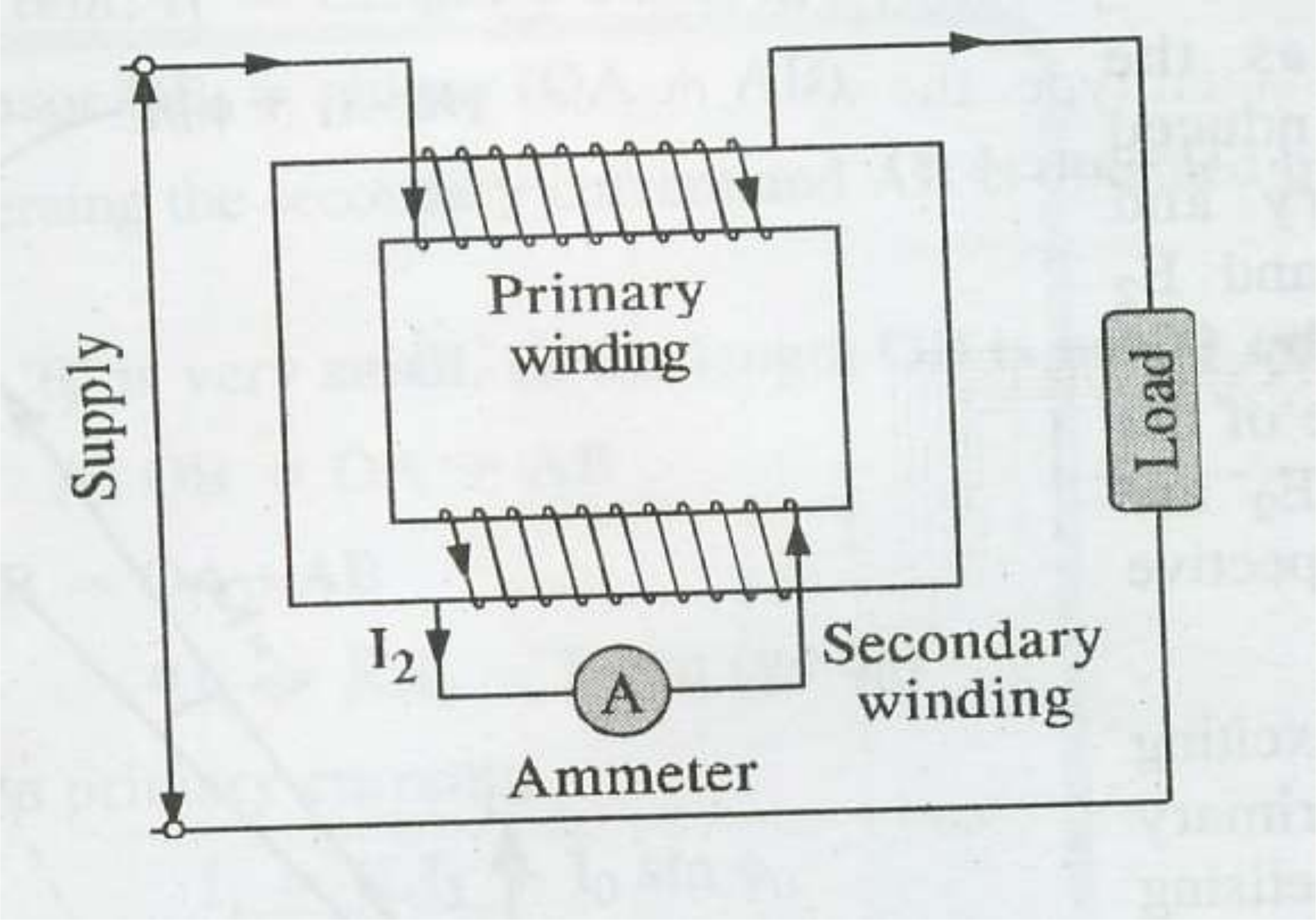
1. The only main draw back is that these instruments can not be used in DC circuits.

Current Transformer (CT)

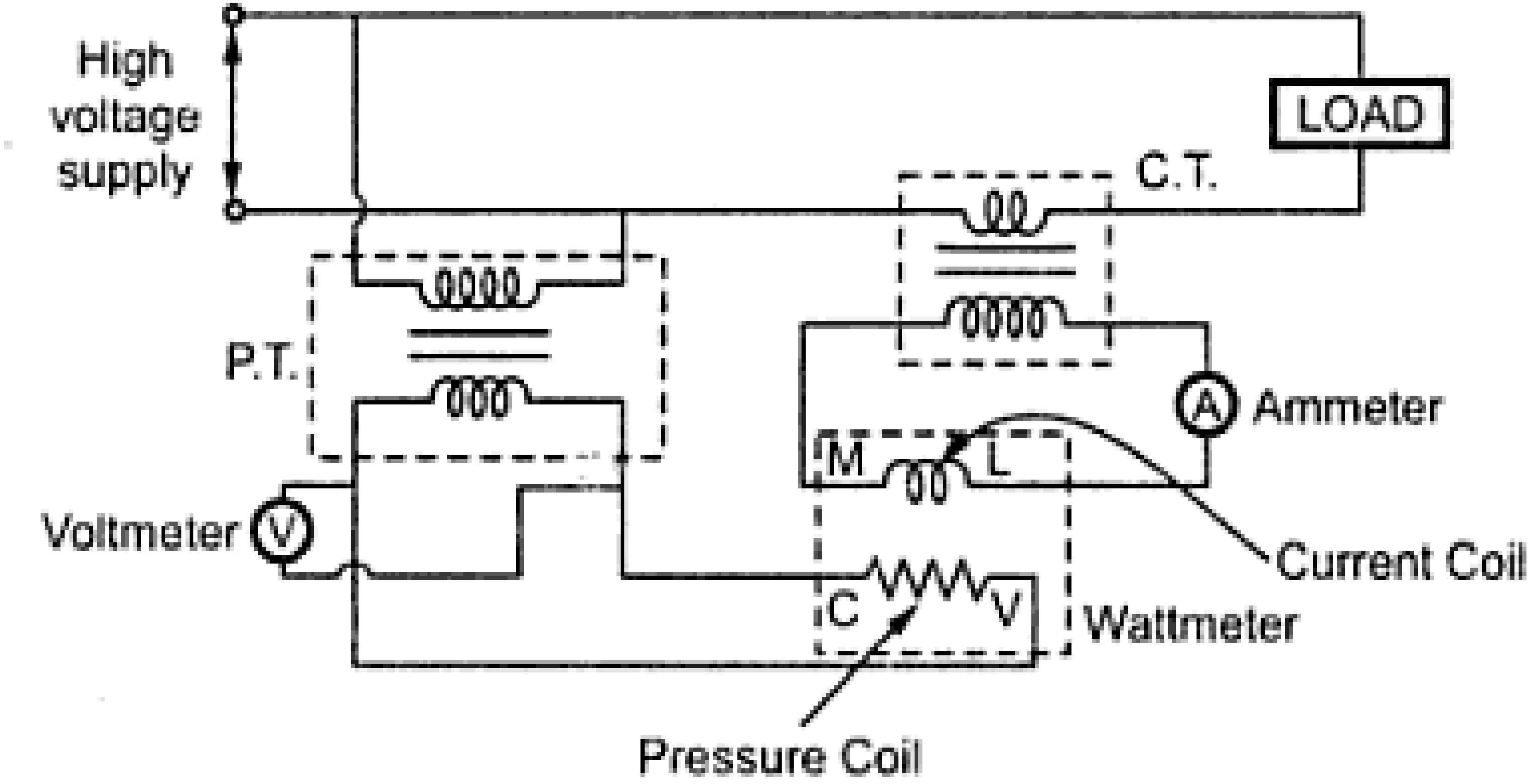
- A current transformer is an instrument transformer which is used to measure alternating current of large magnitude by stepping down by transformer action. The primary winding of CT is connected in series with the line in which current is to be measured and the secondary is connected to the ammeter.

- The secondary winding has very small load impedance which is the current coil of ammeter. The primary side has a few number of turns and the secondary side has large number of turns. The primary winding carries a full load current and this current is stepped down to a suitable value which is within the range of ammeter.

Current Transformer (CT)

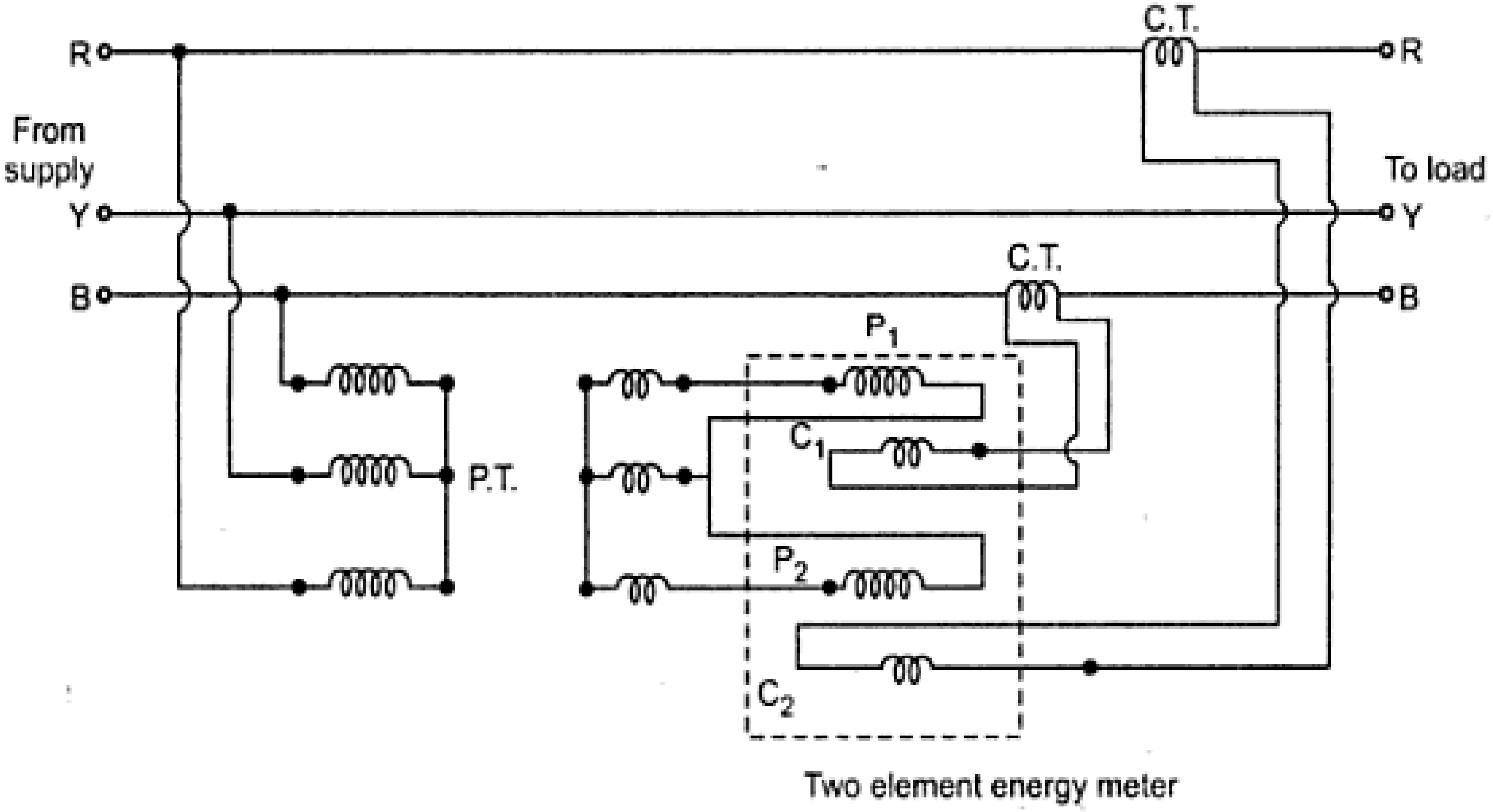


Measurement of power using CT and PT

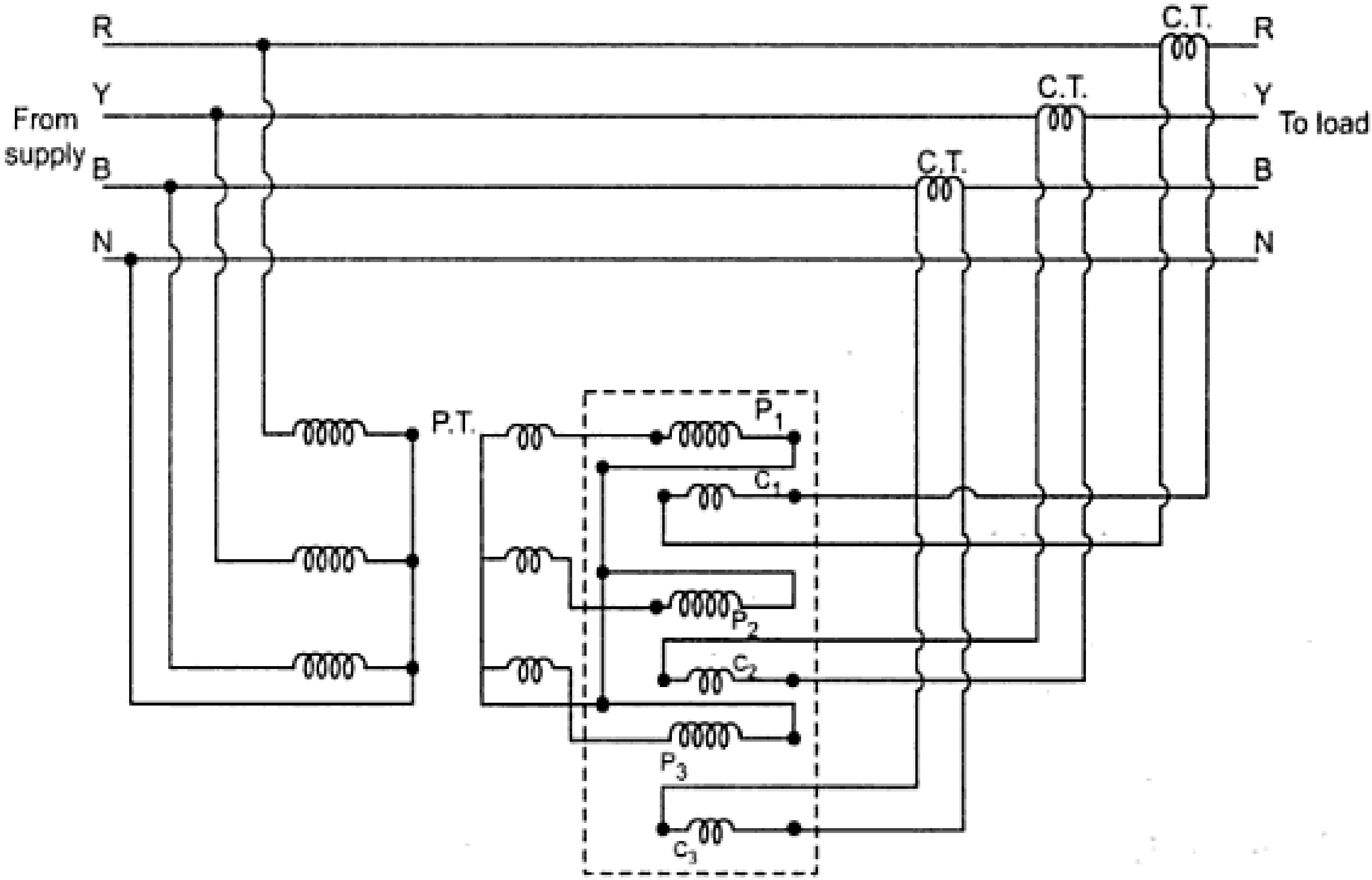


Power measurement using C.T. and P.T.

Measurement of energy using CT and PT



Two element energymeter with C.T. and P.T.



Three element energymeter with C.T. and P.T.

Comparison of C.T. and P.T.

Sr. No.	Current Transformer	Potential Transformer
1.	It can be treated as series transformer under virtual short circuit conditions.	It can be treated as parallel transformer uner open circuit secondary.
2.	Secondary must be always shorted	Secondary is nearly under open circuit conditions.
3.	A small voltage exists across its terminals as connected in series.	Full line voltage appears across its terminals
4.	The winding carries full line current.	The winding is impressed with full line voltge.
5.	The primary current and excitation varies over a wide range.	The line voltage is almost constant hence exciting current and flux density varies over a limited range.
6.	The primary current is independent of the secondary circuit conditions.	The primary current depends on the secondry circuit conditions.
7.	Needs only one bushing as the two ends of primary winding are brought out through the same insulator. Hence there is saving in cost.	Two bushings are required when neither side of the line is at ground potential.

Ratios of Instrument Transformers

The various ratios defined for the instrument transformers are,

1. Actual ratio [R]

The actual transformation ratio is defined as the ratio of the magnitude of actual primary phasor to the corresponding magnitude of actual secondary phasor.

$$\therefore \quad R = \frac{\text{magnitude of actual primary current}}{\text{magnitude of actual secondary current}} \quad \text{... For C.T.}$$

$$= \frac{\text{magnitude of actual primary voltage}}{\text{magnitude of actual secondary voltage}} \quad \text{... For P.T.}$$

The actual ratio is also called **transformation ratio.**

2. Nominal ratio [K_n]

The nominal ratio is defined as the ratio of rated primary quantity to the rated secondary quantity, either current or voltage.

$$\therefore \quad K_n = \frac{\text{rated primary current}}{\text{rated secondary current}} \quad \text{... For C.T.}$$

$$= \frac{\text{rated primary voltage}}{\text{rated secondary voltage}} \quad \text{... For P.T.}$$

3. Turns ratio [n]

$$n = \frac{\text{number of turns of secondary winding}}{\text{number of turns of primary winding}} \quad \text{... For C.T.}$$

$$= \frac{\text{number of turns of primary winding}}{\text{number of turns of secondary winding}} \quad \text{... For P.T.}$$

Theory of Current Transformers

Consider the equivalent circuit of a current transformer along with the load.

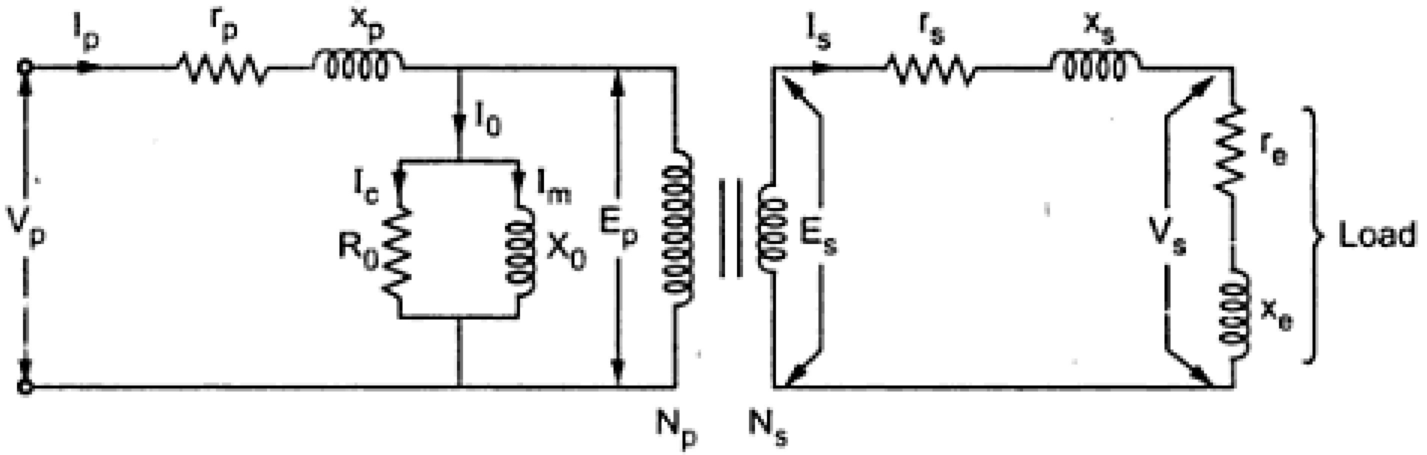


Fig. 2.84 Equivalent circuit of current transformer

The various symbols are,

n = turns ratio = $\dfrac{\text{secondary turns}}{\text{primary turns}} = \dfrac{N_S}{N_P}$

r_p = Resistance of primary winding

x_p = Reactance of primary winding

r_s = Resistance of secondary winding

x_s = Reactance of secondary winding

r_e = Resistance of external burden i.e. load on secondary

x_e = Reactance of external burden i.e. load on secondary

E_p = Primary induced voltage

E_s = Secondary induced voltage

V_s = Secondary terminal voltage

I_p = Primary current

I_s = Secondary current

I_0 = No load current or exciting current

I_c = Core loss component of I_0 i.e. $I_0 \cos\phi_0$

I_m = Magnetising component of I_0 i.e. $I_0 \sin\phi_0$

ϕ = Working flux of transformer

δ = **Angle between E_s and I_s**

= Phase angle of total impedance of secondary including burden

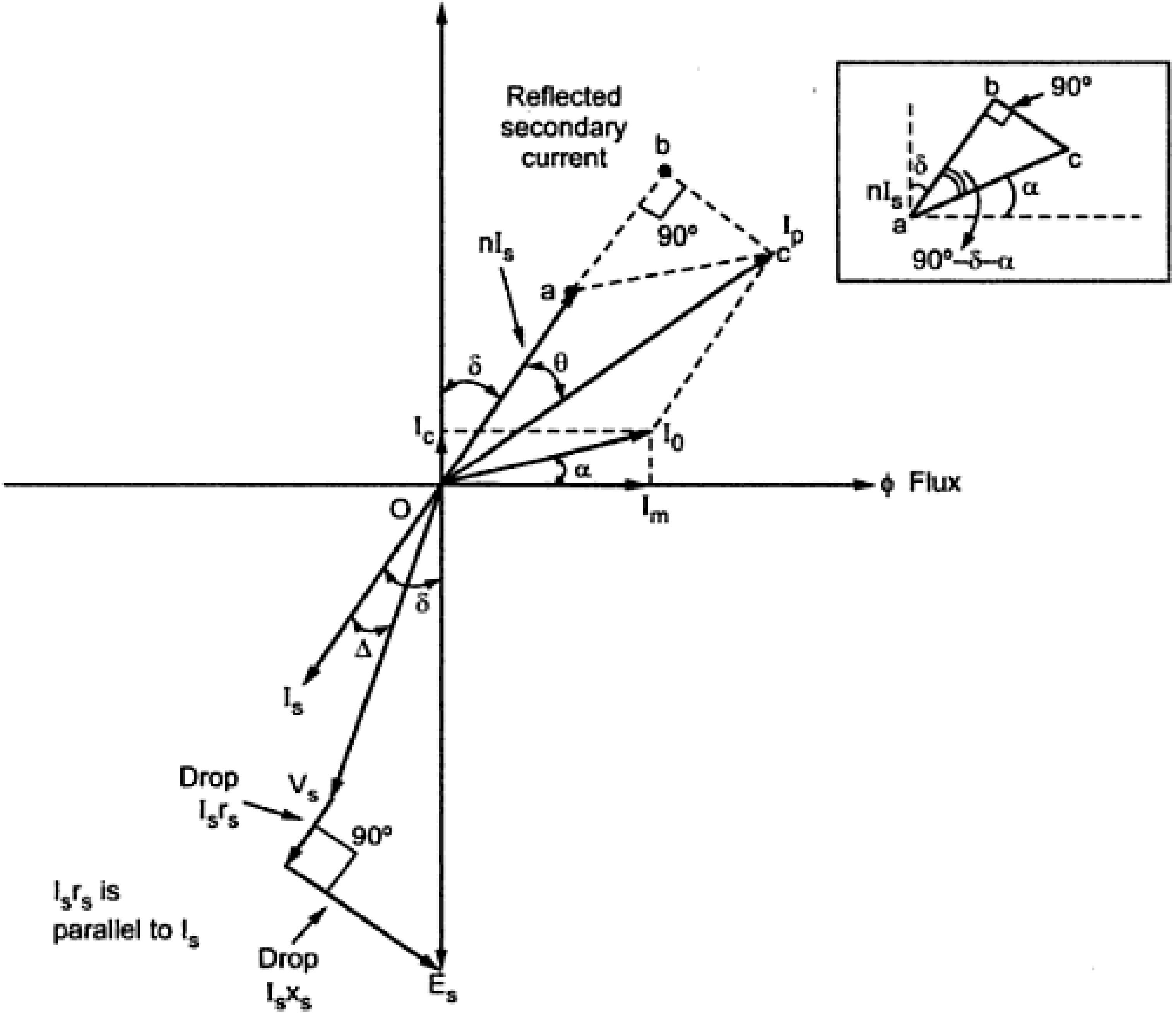
$$= \tan^{-1}\left(\frac{x_s + x_e}{r_s + r_e}\right)$$

θ = Phase angle of transformer

Δ = Phase angle of load or burden i.e. $r_e + j\,x_e$

$$= \tan^{-1}\frac{x_e}{r_e}$$

α = **Angle between I_0 and working flux ϕ.**



Phasor diagram of current transformer

Errors in CT

For an instrument transformer , the transformation ratio must be exactly equal to turns ratio and phase of secondary terms (vtg or Ct) must be displaced by exactly 180^{o} from that of the primary terms.

There are two types of errors in these transformers :

1. Ratio error
2. Phase angle error

- **Ratio error**

For normal operation of these instrument transformers, the current transformation ratio(I_2/I_1) is equal to the turns ration (N_1/N_2)should be constant and within the limits. It has been seen that this ratio are not constant but do vary with the power factor. So this error is known as Ratio Error.

Ratio error is defined as,

$$\%\ Rato\ eror = \frac{nominal\ ratio - actual\ ratio}{actual\ ratio}\ X\ 100$$

$$\%\ \ Rato\ eror = \frac{K_n\ \ - \ R}{R}\ X\ 100$$

Ratio Correction Factor

The ratio between actual ratio of current transformation and the nominal ratio is known as Ratio Correction Factor,

R.C.F. = Actual Ratio/ Nominal Ratio

$= R/ K_N$

Burden of an Instrument transformer

- The nominal ratio of an instrument transformer, does not remain constant in practice as the load on the sec changes. It changes because of the effect of sec current, PF. For the particular class of transformer the specific loading at rated sec winding voltage is specified, such that the errors do not exceed the limits. Such a permissible load is called burden of an instrument transformer

- Phase angle error

The phase of secondary current must be displaced by exactly 180^o from that of the primary current for CT and the phase of secondary voltage must be displaced by exactly 180^o from that of the primary voltage for PT .But actually its is no so. This error is called phase angle error. The phase angle error is due to the no load current or exciting current

Characteristics of CT

- 1. Effect of power factor of secondary circuit

  PF of the sec. circuit depends on the PF of the burden(load) of sec. This affects

a. Ratio error: Inductive load → δ is positive , $\sin(\delta+\alpha)$ is positive and hence $R > n$. For capacitive load → δ is negative , $\sin(\delta+\alpha)$ is positive and hence $R < n$.
b. Phase angle error: Inductive load → δ is positive , then θ is positive. When δ approaches 90^o load becomes highly inductive and θ is negative. For capacitive load → δ is negative , then θ is always positive

- 2. Effect of change is Ip: Ip and Is are directly related. For low Ip, Io is dominating so errors are higher. For higher Ip, Io is less so errors are less.

- 3.Effect of change of burden on secondary: When Sec winding circuit burden increases, sec flux increases, which induces more voltage on sec. Thus I_m and I_c increases to keep flux constant. Due to this errors increases.

- 4. Effect of change in frequency: When frequency increases, flux and flux density increases. So I_m and I_c decreases, hence errors also get reduced.