ⓒ Precision ( Reproducibility ):-
It refers to the measure of the degree to which successive measurements differ from one another.

ⓓ Static Error :-
It is defined as the difference between the measured value and the true value of the quantity.

ⓔ Drift :-
Perfect precision means that the instrument has no drift i.e. with a given input, the measured values don't vary with time.

ⓕ Dead Zone :-
It is defined as the largest change of input quantity for which there is no output of the instrument.

ⓖ Resolution :-
It is the smallest change in measured value to which the instrument will respond.

ⓗ loading effect :-
The incapability of the system to faithfully measure, record or control the input signal in undistorted form is called the loading effect.

ⓘ Linearity :-
Here, output is linearly proportional to the input. Linear behaviour is required for most of the systems as it is desirable.

ⓙ Hysteresis :-
It is a phenomenon which depicts different output effects when loading and unloading whether it is a mechanical or an electrical system. It is non-coincidence of loading and unloading curves.

Dynamic characteristics:-

performance criteria based upon dynamic relations constitute the dynamic characteristics. The dynamic characteristics of a measurement system are:

(a) Speed of response:-

It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.

(b) Measuring lag:-

It is the delay in the response of a measurement system to changes in the measured quantity.

(c) Fidelity:-

It is defined as the degree to which a measurement system indicates changes in the measured quantity without any dynamic error.

(d) Dynamic Error:-

It is the difference between the true value of the quantity under measurement changing with time and the value indicated by the measurement system if no static error is assumed.

Classification of Resistances:-

The classification of resistances from the point of view of measurement is as follows:

(i) low Resistances: $R < 1\Omega$

(ii) Medium Resistances: $1\Omega \leq R < 0.1\,M\Omega$

(iii) High Resistances: $R \geq 0.1\,M\Omega$

## Bridge circuit:-

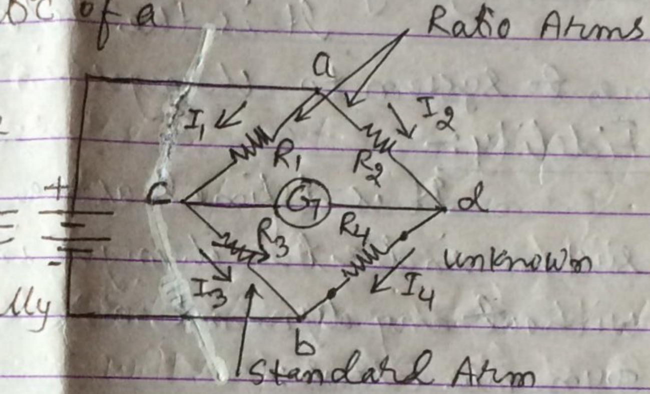
① DC Bridge circuit:-

ⓐ Wheatstone Bridge:-

The Wheatstone Bridge is an instrument for making comparison measurements and operates upon a null indication principle. It is a very important device used in the measurement of medium resistances due to its accuracy and realibility.

Basic Operation:-

Figure shows the schematic of a wheatstone bridge. The bridge has four resistive arms together with a source of emf (a battery) and a null detector, usually a galvanometer or other sensitive current meter.




The bridge is said to be balanced when the potential difference across the galvanometer is 0V so that there is no current through the galvanometer. This condition occurs when the voltage from point c to point a equals the voltage from point d to point a or by referring to the other battery terminal, when the voltage from point c to point b equals the voltage from point d to point b. Hence the bridge is balanced

When $E_{ac} = E_{ad}$

$$\Rightarrow I_1 R_1 = I_2 R_2 \quad \text{— ①}$$

If the galvanometer current is zero, the following conditions also exist:

$$I_1 = I_3 = \frac{E}{R_1 + R_3} \quad \text{— ②} \text{ and}$$

$$I_2 = I_4 = \frac{E}{R_2+R_4} \quad \text{——} \quad (3)$$

Combining eqns (1), (2) and (3), and simplifying, we get

$$\frac{R_1}{R_1+R_3} = \frac{R_2}{R_2+R_4}$$

$$\text{or,} \quad R_1 R_4 = R_2 R_3 \quad \text{——} \quad (4)$$

eqn (4) is the well-known expression for balance of the wheatstone bridge. If three of the resistance have known values, the fourth maybe determined from eqn (4). Hence, if $R_4$ is the unknown resistor, its resistance $R_x$ can be expressed in terms of remaining resistors as

$$R_x = \frac{R_2 R_3}{R_1} \quad \text{——} \quad (5)$$

The measurement of unknown resistance $R_x$ is independent of the characteristics or the calibration of the null-detecting galvanometer provided that the null detector has sufficient sensitivity to indicate the balance position of the bridge with the required degree of precision.

Measurement Errors:-

The main source of measurement error is found in the limiting errors of the three known resistors. Other errors may include the following:

(a) Insufficient sensitivity of the null detector.
(b) Changes in resistance of the bridge arms due to the heating effect of the current through the resistors.
(c) Thermal emfs in the bridge circuit or the galvanometer circuit can also cause problems when low value resistors are being measured.

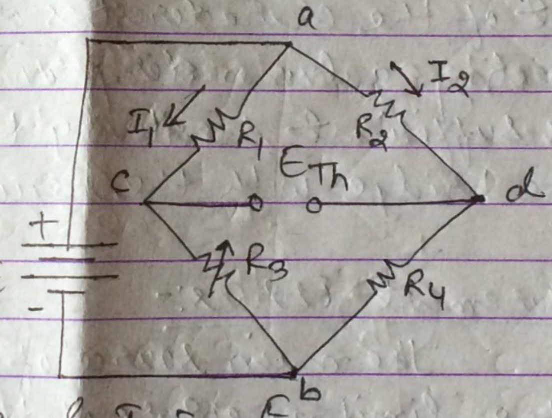
(d) Errors due to the resistance of leads and contacts exterior to the actual bridge circuit play a role in the measurement of very low resistance values. These errors may be reduced by using a Kelvin bridge.

## Thevenin Equivalent Circuit:-

To determine whether or not the galvanometer has the required sensitivity to detect an unbalance condition, it is necessary to calculate the galvanometer current. The Thevenin equivalent circuit is determined by looking into galvanometer terminals c and d. Two steps must be taken to find the Thevenin equivalent circuit:

(a) Finding the equivalent voltage, $E_{Th}$ appearing the terminals c and d when the galvanometer is removed from the circuit.

Now, the Thevenin or open circuit voltage is

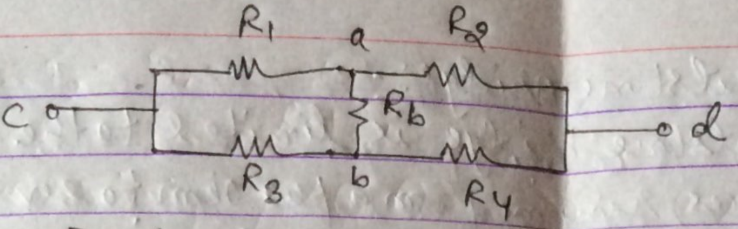



$$E_{Th} = E_{cd} = E_{ac} - E_{ad}$$
$$= I_1 R_1 - I_2 R_2$$

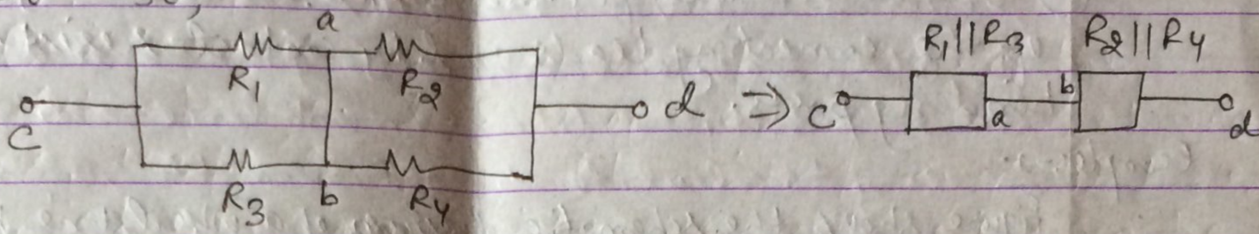
Where, $I_1 = \dfrac{E}{R_1+R_3}$ and $I_2 = \dfrac{E}{R_2+R_4}$

$$\therefore E_{Th} = E\left(\frac{R_1}{R_1+R_3} - \frac{R_2}{R_2+R_4}\right)$$

(b) Finding the equivalent resistance looking into the terminals c and d, with the battery replaced by its internal resistance.



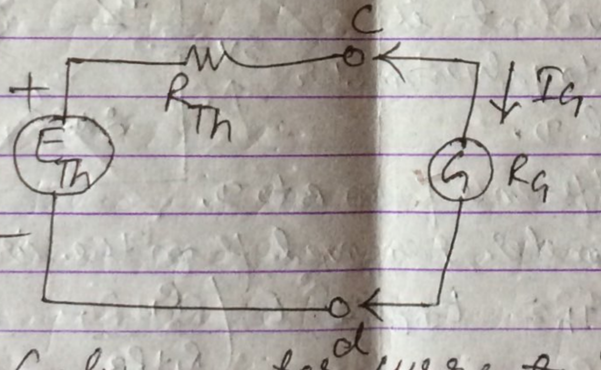

Since, in most cases, the internal resistance, $R_b$ of the battery is extremely low, it can be neglected i.e. $R_b = 0$. So,




$$\therefore R_{Th} = (R_1 || R_3) + (R_2 || R_4)$$

$$= \left(\frac{R_1 R_3}{R_1 + R_3}\right) + \left(\frac{R_2 R_4}{R_2 + R_4}\right)$$

Hence, the complete Thevenin circuit with the galvanometer connected to terminals c and d is




The Galvanometer current, $I_G$ with its resistance, $R_G$ is

$$I_G = \frac{E_{Th}}{R_{Th} + R_G}$$

## Limitations of Wheatstone Bridge:-

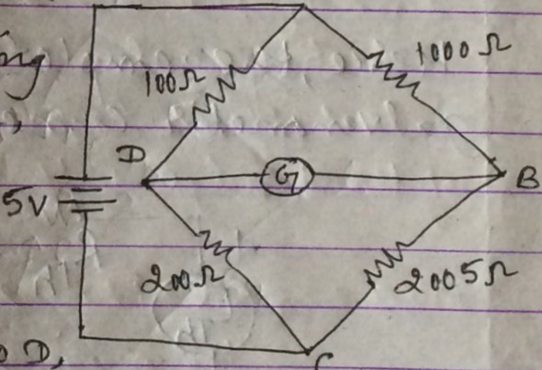
(i) The use of wheatstone bridge is limited to the measurement of resistances ranging from a few ohm to several megaohm

(ii) The upper limit is set by the reduction in sensitivity to unbalance caused by high resistance values.

(iii) The lower limit for measurement is set by the resistance of the connecting leads and by contact resistance at the binding posts.

**Example:- 1.**

Figure shows the schematic diagram of a wheatstone bridge with values of the bridge elements as shown. The battery voltage is 5V and its internal resistance negligible. The galvanometer has a current sensitivity of 10mm/μA and an internal resistance of 100 Ω. Calculate the deflection of the galvanometer caused by the 5 Ω unbalance in the arm BC.



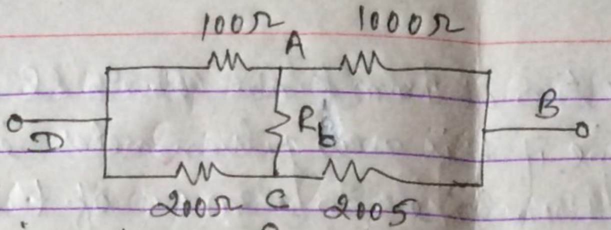

Soln: Since we are interested in finding the current in the galvanometer, the Thevenin equivalent is determined w.r.to galvanometer terminals B and D.

The potential difference from B to D, with the galvanometer removed from the circuit is the Thevenin voltage i.e. $E_{Th} = E_{DB} = E\left(\frac{R_1}{R_1+R_3} - \frac{R_2}{R_2+R_4}\right)$

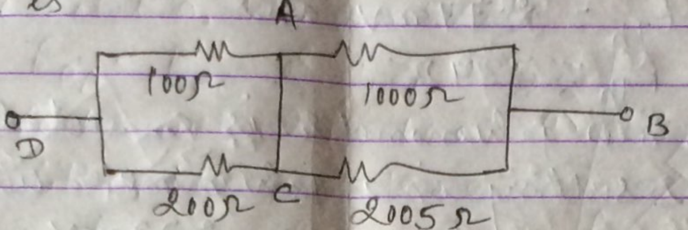
$$= 5\times\left(\frac{100}{100+200} - \frac{1000}{1000+2005}\right) \simeq 2.77\,mV$$

The equivalent Thevenin resistance looking into terminals B and D, and replacing the battery with its internal resistance is

ROLL No.
STREAM
SUBJECT



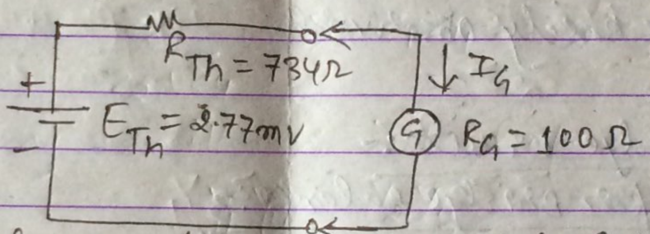

Since internal resistance of battery, $R_b$ is zero Ω, the equivalent ckt is




$$\therefore R_{Th} = (R_1 \| R_3) + (R_2 \| R_4) = \left( \frac{100 \times 200}{100+200} + \frac{1000 \times 2005}{1000+2005} \right)$$

$$= 734\ \Omega$$

The Thevenin equivalent ckt is given as




When the galvanometer is now connected to the output terminals of the equivalent ckt, the current, $I_G$ through the galvanometer is

$$I_G = \frac{E_{Th}}{R_{Th} + R_G} = \frac{2.77\,mV}{734\,\Omega + 100\,\Omega} = 3.32\ \mu A$$

Now, the galvanometer deflection is

$$d = 3.32\ \mu A \times \frac{10\,mm}{\mu A} = 33.2\,mm.$$

Example 1-2

The galvanometer of example 1 is replaced by one with an internal resistance of 500Ω and a current sensitivity of 1mm/μA.

Assuming that a deflection of 1mm canbe observed on the galvanometer scale, determine if this new galvanometer is capable of detecting the 5Ω unbalance in arm BC of the given figure of example 1.

Soln: Here, $E_{Th} = 2.77 mV$ and
$R_{Th} = 734\Omega$

Now, the new galvanometer is connected to the output terminals resulting in a galvanometer current.

$$I_G = \frac{E_{Th}}{R_{Th} + R_G} = \frac{2.77 mV}{734\Omega + 500\Omega} = 2.24 \mu A$$

The galvanometer deflection is

$$d = 2.24 \mu A \times \frac{1 mm}{\mu A} = 2.24 mm$$

which is easily observed.

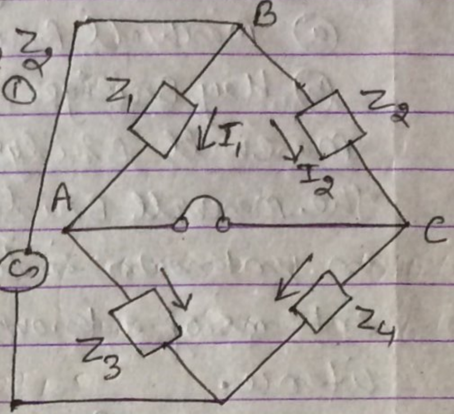
## (2) AC Bridge circuit:-

### Condition for Bridge Balance:-

The ac bridge is a natural outgrowth of the dc bridge and in its basic form consists of four bridge arms, a source of excitation and a null detector. The power source supplies ac voltage to the bridge at the desired frequency. For measurements at low frequencies, the power line may serve as the source of excitation and at higher frequencies, an oscillator generally supplies the excitation voltage. The null detector must respond to ac unbalance currents and in its cheapest but very effective form consists of a pair of headphones or an ac amplifier with an output meter or an electron ray tube indicator.

The general form of an ac bridge is shown in figure. The four bridge arms $Z_1$, $Z_2$, $Z_3$ and $Z_4$ are impedances and the detector is represented by headphones. The balance condition in ac bridge is reached when the detector response is zero or indicate a null. The general equation for bridge balance is obtained by using complex notation for the impedances of the bridge circuit. In complex notation, we can write

$$E_{BA} = E_{BC} \quad \text{or,} \quad I_1 Z_1 = I_2 Z_2 \quad \text{— (1)}$$




For zero detector current i.e. the balance condition, the currents are

$$I_1 = \frac{E}{Z_1 + Z_3} \quad \text{and} \quad \text{— (2)}$$

$$I_2 = \frac{E}{Z_2 + Z_4} \quad \text{— (3)}$$

solving eqns (1), (2) and (3) and simplifying, we get

$$\frac{Z_1}{Z_1 + Z_3} = \frac{Z_2}{Z_2 + Z_4} \Rightarrow Z_1 Z_4 = Z_2 Z_3 \quad \text{— (4)}$$

or when using admittances instead of impedances,

$$Y_1 Y_4 = Y_2 Y_3 \quad \text{— (5)}$$

If the impedance is written in the form $Z = Z \angle \theta$, where Z represents the magnitude and $\theta$ the phase angle of the complex impedance, eqn (4) becomes

$$(Z_1 \angle \theta_1)(Z_4 \angle \theta_4) = (Z_2 \angle \theta_2)(Z_3 \angle \theta_3)$$

$$\text{or,} \quad Z_1 Z_4 \angle (\theta_1 + \theta_4) = Z_2 Z_3 \angle (\theta_2 + \theta_3) \quad \text{— (6)}$$

Equation (6) shows that two conditions must be met simultaneously when balancing an ac bridge i.e.

(i) The magnitudes of the impedances satisfy the relationship

$$Z_1 Z_4 = Z_2 Z_3$$

or the products of the magnitudes of the opposite arms must be equal.

(ii) The sum of the phase angles of the opposite arms must be equal i.e.

$$\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$$

Inductance Bridge:-

(a) Maxwell Bridge

(b) Hay Bridge

Maxwell Bridge:-

The maxwell Bridge measures an unknown inductance interms of a known capacitance.

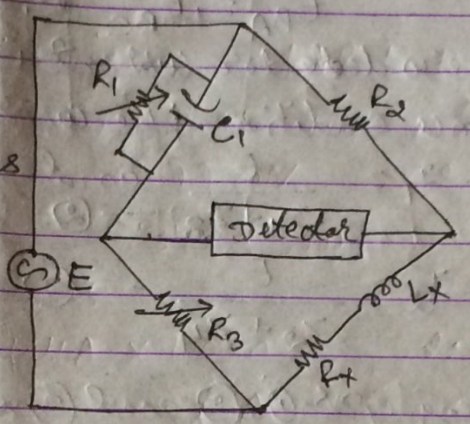



Fig. Maxwell Bridge for inductance measurements.

The general equation for balance of the ac bridge is

$$Z_1 Z_x = Z_2 Z_3$$

$$\Rightarrow Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 Y_1$$

where, $Z_2 = R_2$; $Z_3 = R_3$; $Y_1 = 1/R_1 + j\omega C_1$

so, $Z_x = R_x + j\omega L_x = R_2 R_3 \left(1/R_1 + j\omega C_1\right)$

Separation of the real and imaginary terms yields

$$R_x = \frac{R_2 R_3}{R_1} \text{ and } \quad (1)$$

$$L_x = R_2 R_3 C_1 \quad (2)$$

> Note:-
> The expression for Q-factor is
> $Q = \omega L/R$

Limitations:-

(i) It is limited to the measurement of medium-Q coils ($1 < Q < 10$).

(ii) It is unsuited for the measurement of coils with a very low Q-value ($Q < 1$) because of balance convergence problems.

(iii) This bridge requires a variable standard capacitor which may be very expensive if calibrated to a high degree of accuracy.