UNIT 2

Difference Between AC & DC Bridge

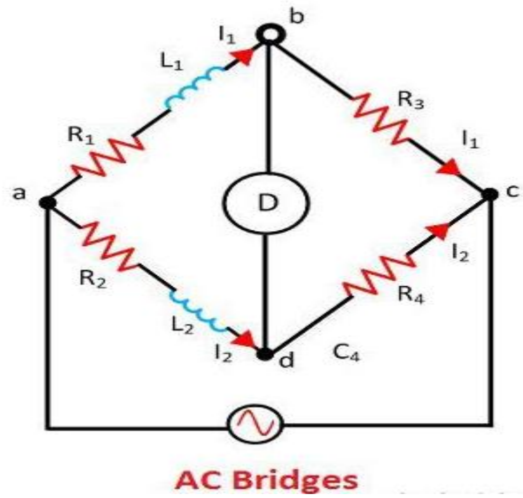
One of the significant difference between the AC and DC bridge is that the AC bridge is used for measuring the unknown impedance of the circuit whereas the DC bridge is used for measuring the unknown resistance of the circuit. The other differences between the AC and DC bridge are shown below in the comparison chart.

Comparison Chart

Basis for Comparison	**AC Bridge**	**DC Bridge**
Definition	The bridge which is used for measuring the value of unknown impedance is known as the AC bridge.	The DC bridge measures the unknown resistance of the circuit.
Supply	AC supply is used	DC supply is used
Current Detector	AC Detector	DC Detector
Components	Resistive and Reactive	Resistive
Wagner's Earthing Device	Required	Not required
Types	Two	Seven
Balancing Time	Relatively Less	High

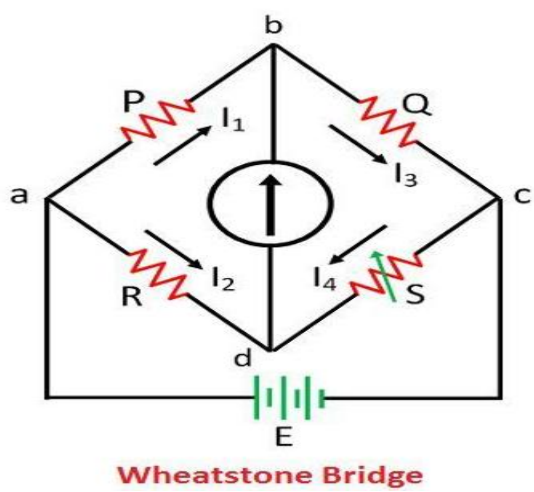
Definition of AC Bridge

The ac bridge consists source, balanced detector, and the four arms. The arms of the bridge consist the impedance. The AC bridge is constructed by replacing the battery with the ac source. The bridges are formed by replacing the DC battery with the AC source and galvanometer with the Wheatstone bridge. The bridge is used for detecting the inductance, capacitance, storage factor, dissipation factor etc.



Definition of DC Bridge

The DC Bridge is used for measuring the unknown electrical resistance. This can be done by balancing the two legs of the bridge circuit. The value of one of the arm is known while the other of them is unknown.



Key Differences Between AC and DC Bridge

1. The bridge which is used for measuring the unknown impedance of the circuit is known as the Wheatstone bridge. The DC bridge is used for measuring the unknown resistance of the circuit.

2. The AC bridge uses the AC supply. The DC bridge uses the DC supply for measuring the resistance.

3. In AC bridge the current is detected by using the AC detector. While in DC bridge the current is detected by using the DC detector.

4. The resistive and reactive components are used in the AC bridge circuit while in the DC circuit only resistive components are used.

5. The AC bridge circuit uses the Wagner earth device for removing the earth capacitance from the circuit. It also reduces the harmonics and the error which occurs because of the stray magnetic field. The Wagner earthing device is not used in the DC bridge circuit.

6. The AC bridges take less time to comes in balance condition while the DC bridge uses comparatively more time to comes in the balanced condition.

7. Wheatstone Bridge and the Kelvin bridge are the types of the DC bridge. The AC bridges are classified into seven types. These are capacitance comparison bridge, inductance comparison bridge, Maxwell's bridge, Hay's bridge, Anderson Bridge, Schering bridge, Wein bridge.

Conclusion

The AC and DC bridge both are used for measuring the unknown parameter of the circuit. The AC bridge measures the unknown impedance of the circuit. The DC bridge measures the unknown resistance of the circuit.

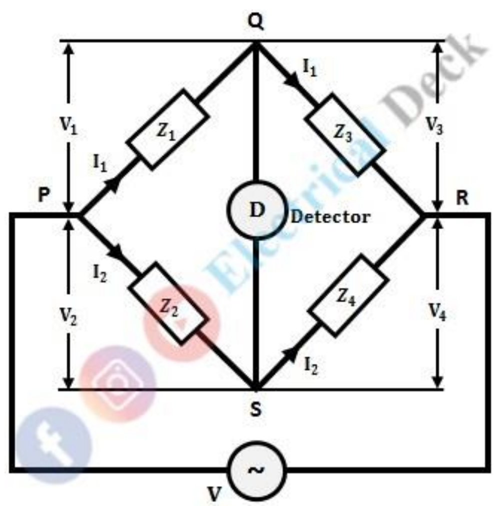
AC Bridges - Definition, Construction, Balance Equation & Errors

The AC Bridges are the alternating current electrical circuits used to find or measure the unknown resistance, inductance, and capacitance. These are basically measuring instruments similar to DC Bridges (e.g. Wheatstone bridge, Kelvin's bridge, etc) and only works with ac supply.

The principle of operation is based on the comparison measurement method i.e., comparing the unknown value to be determined with the known value when the bridge circuit is balanced.

Construction of AC Bridge :

The ac bridge mainly consists of four arms with four impedances (each arm consists of an impedance) and a balance detector. The four arms are connected in such a way that, it forms a closed circuit with four junctions. In the four impedances of the bridge, one of them is unknown (which is to be determined) and the remaining are known impedances. The below shows the general ac bridge circuit.



An ac voltage source at the required frequency is connected across two opposite junctions and a balance detector across the other two opposite junctions. The balance detector used is headphones or vibration galvanometers depending upon the frequency of the supply.

Mostly vibrational galvanometers are used for balance detectors in ac bridges. Because vibrational galvanometers are tuned detectors i.e., they respond only to the fundamental frequency for which they are tuned.

In the case of ac bridges, frequency and supply waveform plays a very important role. If the input waveform is perfect and does not contain any harmonics then the balancing condition for bridges can be obtained easily. But, if the supply waveform contains any harmonics, it will be very difficult to obtain the balance condition.

Thus the variation in the frequency will once again create problems for obtaining balance condition (since the balance equation in ac bridges is a function of frequency). The above problems can be eliminated by using a vibrational galvanometer as a detector in the case of ac bridges. The vibrational galvanometer will give deflection for resonant frequency and hence will not respond to other frequencies and harmonics.

Conditions for Balancing of AC Bridge :

In order to measure unknown resistance, inductance, or capacitance connected to one arm. At first, the bridge is to be balanced. For balancing of the bridge, no current should pass through the detector. This condition is obtained when the potential difference across the detector is zero (i.e., across points Q and S). If ac source potential be V and the potential drops across Z_1, Z_2, Z_3, and Z_4 be V_1, V_2, V_3, and V_4 respectively.

Thus, at when the bridge is balanced,

$V_1 = V_2$ ...(1)

$V_3 = V_4$ ...(2)

Consider equation 2, i.e., $V_3 = V_4$,

$$V_3 = I_1 Z_3 \;\; and \;\; V_4 = I_2 Z_4$$

$$I_1 Z_3 = I_2 Z_4 \dots (3)$$

$$But \; I_1 = \frac{V}{Z_1 + Z_3} \;\; and \;\; I_2 = \frac{V}{Z_2 + Z_4}$$

Substituting the values of I_1 and I_2 in equation 3, we get,

$$\frac{V}{Z_1 + Z_3} \times Z_3 = \frac{V}{Z_2 + Z_4} \times Z_4$$

$$Z_3(Z_2 + Z_4) = Z_4(Z_1 + Z_3)$$

$$Z_2 Z_3 + Z_3 Z_4 = Z_1 Z_4 + Z_3 Z_4$$

$$Z_1 Z_4 = Z_2 Z_3 \ldots (4)$$

We know that, Z = 1/Y. Therefore, for the balance of the bridge, equation 4 can also be written in admittance form as,

$$\frac{1}{Y_1} \times \frac{1}{Y_4} = \frac{1}{Y_2} \times \frac{1}{Y_3}$$

$$Y_1 Y_4 = Y_2 Y_3 \ldots (5)$$

The equation 4 can be written in polar form as,

$$Z_1 \llcorner \theta_1 . Z_4 \llcorner \theta_4 = Z_2 \llcorner \theta_2 . Z_3 \llcorner \theta_3$$

$$Z_1 Z_4 \llcorner \theta_1 + \theta_4 = Z_2 Z_3 \llcorner \theta_2 + \theta_3$$

Similarly, equation 5 can be written in polar form as,

$$Y_1 Y_4 \llcorner - \theta_1 - \theta_4 = Y_2 Y_3 \llcorner - \theta_2 - \theta_3$$

Therefore, from the above equation, the conditions for balancing ac bridges are,

- The magnitude of impedance or admittances should satisfy the relation.

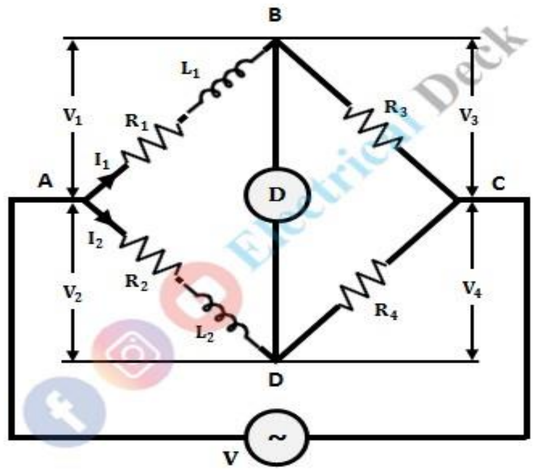
$Z_1\ Z_4 = Z_2\ Z_3$

- The phase angles of impedances or admittances should satisfy the relation.

$\vartheta_1\ \vartheta_4 = \vartheta_2\ \vartheta_3$

Measurement of Resistance, Inductance, and Capacitance Using AC Bridge :

Let us consider an ac bridge with four arms and a detector as shown below.



Let,

- L_1 = Unknown inductance to be measured
- R_1 = Internal resistance of the unknown inductor
- L_2 = Standard known inductance
- R_2, R_3 & R_4 = Standard non-inductive resistances.

From the balance condition of the bridge, we know that,

$$Z_1 Z_4 = Z_2 Z_3$$

$$(R_1 + j\omega L_1)R_4 = (R_2 + j\omega L_2)R_3$$

$$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega L_2 R_3$$

Equating real and imaginary parts on both sides, we get,

$$R_1 R_4 = R_2 R_3$$

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

$$and \quad L_1 R_4 = L_2 R_3$$

$$L_1 = \frac{R_3}{R_4} \times L_2$$

Hence both the values of R_1 and L_1 depend upon the ratio of R_3 and R_4 (i.e., R_3/R_4). So, if we choose R_3 and R_4 as variable elements, then to obtain balance once R_3 is adjusted then R_4 is adjusted and again R_3 is adjusted till the bridge comes nearer to balance then R_4 is adjusted.

In this way, the balance point shifts or slides with the number of adjustments of R_3 and R_4. This is termed has sliding balance. Hence, if we choose R_3 and R_4 as variable elements then the two balancing equations will be dependent and convergence of balance becomes very poor and thus the sliding balance effect appears.

So, in order to satisfy both the balance equations and for convenience of manipulation only one element is chosen as the variable for one balance equation. So that the two balance equations are independent of each other. As R_2 and L_2 appear in different balance equations, they can be selected as variable elements.

Thus L_2 and R_2 are varied alternatively till the balance is obtained. By this, the condition of interaction between two controls is avoided. Also, the convergence to balance point is best as both R_2 and L_2 are in the same arm.

Errors in AC Bridges :

The different sources of errors in AC bridges are,

Stray Conductance Effects :

If there is no proper insulation between various components of a bridge circuit, errors may arise because of leakage currents from one arm to another. This mainly happens for a high impedance bridge. To overcome this variable components and other pieces of apparatus are mounted on an insulating stand.

Eddy Current Errors :

The induced eddy currents in the standard resistors and inductors change the standard values of the bridge, causing errors. To avoid such errors. The materials with large conductivity masses should not be placed near the bridge.

Errors due to Electrostatic Coupling :

The Inter-capacitance effect arises if the adjacent branches of a bridge network are at a different potential. In other words, the electric field of the branches interacts thus introducing errors. Effective shielding by means of covering elements with earthed metallic shields can minimize this error.

Errors due to Electromagnetic Coupling :

If there is electromagnetic coupling between the source and detector, an emf is induced in the detector directly from the source. The zero indication of the detector is obtained only when the bridge supplies the voltage which is equal in magnitude and opposite in phase as that of induced emf.

Residual Errors :

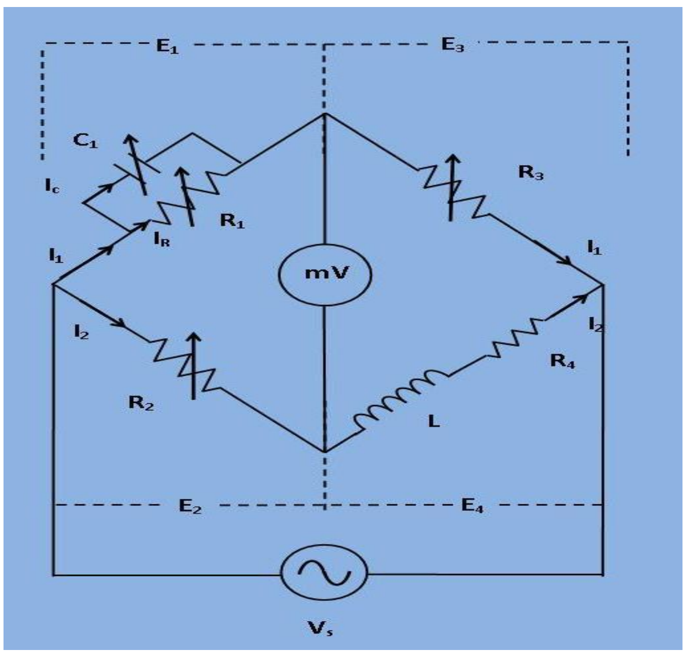
Residues mean small inherent inductance or capacitance that are used in bridge circuits and are assumed to be non-inductive and non-capacitive but in practice, their inductance and capacitance are never zero. So, it is necessary to evaluate these components otherwise these errors will creep in.

Frequency Errors :

The frequency of the supply system plays a vital role in causing errors in the supply system i.e., the presence of harmonics in supply causes variations in the sinusoidal waveform due to which the appreciable crosses are generated.

Objective: Measurement of Self-Inductance by Maxwell's Bridge.

In this bridge, an inductance is measured by comparison with a standard variable capacitance. The connection is shown in Figure 1.



[Fig 1: Circuit diagram for Maxwell's Bridge]

Here,

L = Unknown Inductance,

R_4 = Effective resistance of unknown Inductance coil,

R_1, R_2, R_3 = Known non inductive resistance,

C_1 = Standard variable capacitor.

The balance equation for the branch can be written as:

$$(R_4 + j\omega L) * (\frac{R_1}{1 + j\omega C_1 R_1}) = R_2 R_3;$$

$$R_1 R_4 + j\omega L R_1 = R_2 R_3 + j\omega R_2 R_3 C_1 R_1;$$

Equating the real and imaginary parts,

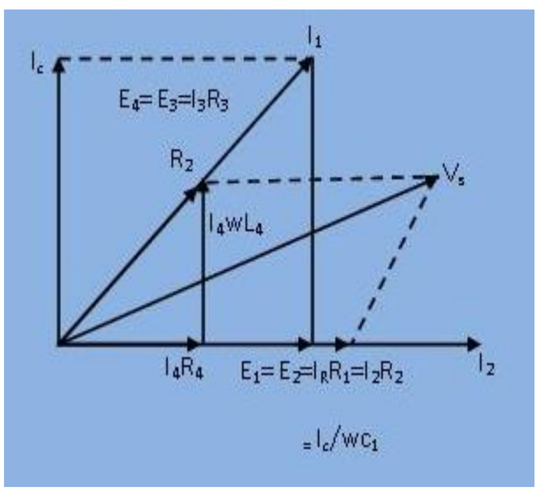
$$R_4 = \frac{R_2 R_3}{R_1} \ldots\ldots (1)$$

$$L = R_2 R_3 C_1 \ldots\ldots (2)$$

Two variables R_1 and C_1 which appear in one of the two balance equations (i.e. equation (1) and (2)) and hence the two equations are independent. The expression for Q factor can be written as:

$$Q = \frac{\omega L}{R_4} = \omega C_1 R_1$$

Phasor Diagram:



[Fig 2: Phasor diagram for the circuit shown in Figure 1]

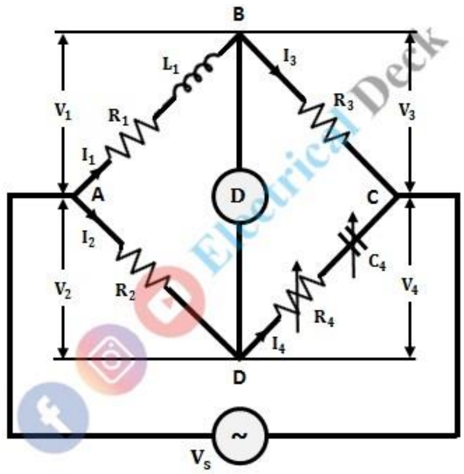
Hay's Bridge - Construction, Equation, Phasor Diagram & Advantages

Hay's bridge is the electrical circuit used for the measurement of self-inductance. It is an alternating current bridge similar to Maxwell's bridge with small modifications.

The main difference between Hay's bridge and Maxwell's bridge is that Hay's bridge employs a resistance in series with the standard capacitor, whereas Maxwell's bridge uses a resistor in parallel with the standard capacitor.

Construction of Hay’s Bridge :

The Hay's bridge is a modified form of Maxwell's inductance-capacitance bridge. It measures inductance by comparing it with a standard variable capacitance. The circuit diagram of Hay's bridge is shown below.



It consists of an inductor with an inductance L_1 and internal resistance R_1 in arm AB and non-inductive standard resistances R_2 and R_3 in arms AD and BC respectively, and a known variable standard capacitance C_4 in series with known non-inductive variable standard resistance R_4 in arm CD.

Operation and Theory of Hay’s Bridge :

The bridge can be balanced by adjusting the values of R_4 and C_4. From the above figure,

$$Z_{ab} = R_1 + j\omega L_1$$

$$Z_{bc} = R_3$$

$$Z_{cd} = R_4 - j\frac{1}{\omega C_4}$$

$$Z_{ad} = R_2$$

Under balanced condition, we have,

$$Z_{ab}\,Z_{cd} = Z_{bc}\,Z_{ad}$$

$$(R_1 + j\omega L_1)\left(R_4 - j\frac{1}{\omega C_4}\right) = R_3\,R_2$$

$$R_1\,R_4 + \frac{L_1}{C_4} + j\left(\omega R_4 L_1 - \frac{R_1}{\omega C_4}\right) = R_2\,R_3$$

Equating real and imaginary terms on both sides, we get,

$$R_1\,R_4 + \frac{L_1}{C_4} = R_2\,R_3 \dots (1)$$

$$and \quad \omega R_4 L_1 - \frac{R_1}{\omega C_4} = 0$$

$$R_1 = \omega^2 R_4 L_1 C_4 \dots (2)$$

Substituting equation 2 in 1, we get,

$$(\omega^2 R_4 L_1 C_4)R_4 + \frac{L_1}{C_4} = R_2\,R_3$$

$$L_1\left(\omega^2 {R_4}^2 C_4 + \frac{1}{C_4}\right) = R_2\,R_3$$

$$L_1\left(\frac{1 + \omega^2 {R_4}^2 {C_4}^2}{C_4}\right) = R_2\,R_3$$

$$L_1 + \frac{R_2\,R_3 C_4}{1 + \omega^2 {R_4}^2 {C_4}^2} \dots (3)$$

Substituting equation 3 in 2, we get,

$$R_1 = \frac{\omega^2 R_2\,R_3\,R_4\,{C_4}^2}{1 + \omega^2 {R_4}^2 {C_4}^2} \dots (4)$$

Now, the quality factor of an inductor is given by,

$$Q = \frac{\omega L_1}{R_1}$$

$$Substituting\ equations\ 3\ and\ 4$$

$$Q = \frac{1}{\omega R_4 C_4}$$

$$\omega R_4 C_4 = \frac{1}{Q}$$

$$\omega^2 R_4{}^2 C_4{}^2 = \frac{1}{Q^2} \ldots (5)$$

Substituting equation 5 in 3, we have,

$$L_1 = \frac{R_2\ R_3\ C_4}{1 + \frac{1}{Q^2}}$$

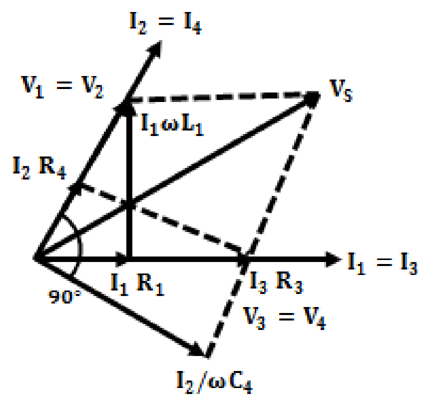
For high Q coils i.e., Q > 10, $1/Q^2$ is almost negligible. Hence the above equation reduces to,

$L_1 = R_2 R_3 C_4$

From the above equations, we can say that for high Q coils the expression for L_1 is free from the frequency term. For low Q coils, $1/Q^2$ cannot be neglected and hence to find L_1, the frequency of source is to be accurately known. Therefore, the bridge suits only for the measurements of inductance of high Q coils.

Phasor Diagram of Hay's Bridge :

The below shows the phasor diagram of the bridge under balanced conditions. By taking inductor current I_1 as the reference phasor. It is the current of arm AB, then the voltage drop across R_1 will $I_1 R_1$ which will be in-phase with I_1. Similarly, the voltage drop across L_1 will be $I_1\ \omega L_1$ which leads the current I_1 with 90°. Now the total voltage drop V_1 of arm AB will be the sum of voltage drops across R_1 and L_1.



Phasor Diagram of Hay's Bridge

When the bridge is balanced, B and D will be at the same potential and there will be a null-deflection i.e., $V_1 = V_2$ and $V_3 = V_4$, also $I_1 = I_3$ and $I_2 = I_4$. Therefore, the phasor V_2 lies along with V_1 with equal magnitude, and the voltage drop $I_2 R_2$ (in AD arm) and current I_2 will be in-phase with V_2.

Also, when the bridge is balanced I_4 lies along with I_2 and I_3 with I_1. Similarly, the voltage drop along the BC arm will be $I_3 R_3$ and will be in-phase with I_3. Thus $I_3 R_3$ lies along phasor I_3 which is nothing but V_3, and V_4 will be equal to V_3 under balanced condition.

Now the voltage drop in arm CD is the sum of voltage drops across capacitor and resistor i.e., $I_4 R_4 + I_4/\omega C_4$. Due to capacitance, the drop $I_4/\omega C_4$ lags behind the I_4 by 90° and $I_4 R_4$ lies along with I_4. Therefore, the resultant of drop $I_4 R_4$ and $I_4/\omega C_4$ will be V_4 (also equal to V_3). The resultant of V_1 and V_3 will be the V_s since V_s will be equal to $(V_1 + V_3)$ or $(V_2 + V_4)$.

Advantages of Hay's Bridge :

- The expression obtained for the Q-factor of the coil using Hay's bridge is not a complicated one.

$$Q - factor = \frac{1}{\omega R_4 C_4}$$

- From the above expression, it can be seen that the resistance R_4 is inversely proportional to the Q-factor. Lower the resistance higher the Q-factor. Thus for high Q coils, the value of resistance R_4 should be quite small. Hence, the bridge requires the resistance of low value.
- Hay's bridge is suitable for coils whose quality factor is greater than 10 (Q > 10). Also, it gives a simple expression for unknown inductance for high Q coils.

Disadvantages of Hay's Bridge :

The major drawback of Hay's bridge is that it cannot be used for measuring coils having a Q-factor less than 10. We have,

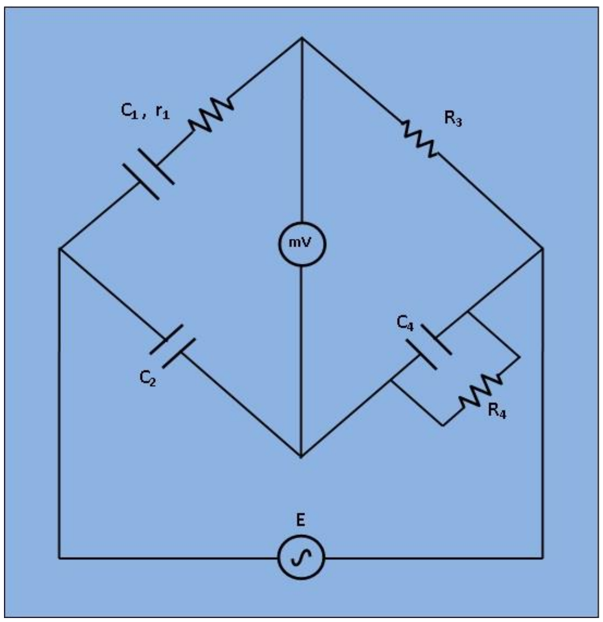
$$L_1 = \frac{R_2\, R_3\, C_4}{1 + \frac{1}{Q^2}}$$

For lower values of Q(<10) the term $(1/Q)^2$ in the above expression cannot be neglected. Hence this bridge cannot be used for coils that have a Q-factor less than 10. For such coils, Maxwell's bridge can be used.

Objective:

Measurement the Capacitance by Schering Bridge.

Circuit Diagram:



[Fig 1: Circuit diagram for measurement of Capacitance by Schering Bridge]

Let, C_1 =capacitor whose capacitance is to be measured.

r_1 = a series resistance representing the loss in the capacitor C_1.

C_2 = a standard capacitor.

R_3 = a non inductive resistance.

C_4 = a variable capacitor.

R_4 = a variable non inductive resistance.

At balance,

$$\left(r_1 + \frac{1}{j\omega C_1}\right) \cdot \left(\frac{R_4}{j\omega C_4 R_4 + 1}\right) = \frac{R_3}{j\omega C_2} \text{......(1)}$$

$$r_1 R_4 - \frac{jR_4}{\omega C_1} = -\frac{jR_3}{\omega C_2} + \frac{R_3 R_4 C_4}{C_2} \text{......(2)}$$

Or Equating the real and imaginary terms in equa. (2), we obtain

$$r_1 = R_3 \cdot \frac{C_4}{C_2} \text{......(3)}$$

$$C_1 = R_4 \cdot \frac{C_2}{R_3} \text{......(4)}$$

And, Two independent balance equations (3) and (4) are obatined if C_4 and R_4 are chosen as the variable elements.
Dissipation factor

$$D_1 = \omega C_1 r_1 \text{......(5)}$$

Measurement of Low, Medium & High Resistance - Various Methods

Resistance is one of the important parameter in electrical parameters. Thus it is essential to known the resistance of any circuit to understand the behavior of any element in the circuit. Measurement of resistance is also used for the measurement of other electrical quantities. Depending upon the value of resistance they are classified into three categories,

- Low Resistance - Resistance of the order of 1Ω and below are classified as low resistance.
- Medium Resistance - Resistance ranging from 1Ω to 100Ω are classified as medium resistances
- High Resistance - Resistance of the order of 100kΩ and above are classified as high resistances

Even though there are multimeters for the measurement of resistance. In order to obtain accurate value, suppose if the resistance is very low and very high various methods are implemented. Hence for the measurement of resistance, the above classification is done and different techniques are applied for low, medium, and high values of resistances.

Measurement of Low Resistance (<1Ω) :

The various methods that can be employed for the measurement of low resistance are,

- Ammeter-voltmeter Method
- Kelvin's Double Bridge Method
- Potentiometer Method

Ammeter-voltmeter Method :

This method is the simplest of all. It only requires an ammeter and a voltmeter which is easily available in the laboratory. However, it is not so accurate because of the voltage drop across the ammeter and the shunting effect of the voltmeter.

Kelvin's Double Bridge Method :

This method is most accurate compared to other methods. It eliminates the error, due to the contact and lead resistances.

Potentiometer Method :

It is also one of the accurate method of obtaining the value of resistance, but the accuracy of this method depends on the availability of a stable dc supply.

Measurement of Medium Resistance (1Ω to 100kΩ) :

The various methods that can be employed for the measurement of medium value resistance are,

- Ammeter-voltmeter Method
- Substitution Method
- Wheatstone Bridge Method
- Ohmmeter Method

Ammeter-voltmeter Method :

The ammeter-voltmeter method being simple can also be used for the measurement of medium resistance, but the accuracy is again less owing to the same reason as that of low resistance measurement.

Substitution Method :

Compared to the ammeter-voltmeter method, the substitution method is quite accurate. The error due to ammeter voltage drop and voltmeter shunts are not present in this method. Even though the above errors are eliminated, there are many other causes of errors in this method, i.e., error due to variations in battery emf, error due to sensitivity of the instrument, etc. Hence this method is not used frequently.

Wheatstone Bridge Method :

This is one of the most common and popular method used for the measurement of medium resistance. It is the most accurate and reliable method of measuring the resistance. However, errors due to thermo emf and heating effect are present in it. Also, the cost of the Wheatstone bridge is quite high.

Ohmmeter Method :

The value of resistance can be directly measured by using an ohmmeter. The accuracy of an ohmmeter is moderate. But it is very simple and easy to use.

Measurement of High Resistance (>100kΩ) :

The various methods that can be employed for the measurement of high value resistance are,

- Direct Deflection Method
- Loss of Charge Method
- Megger

Direct Deflection Method :

In this method, the resistance to be measured is obtained according to the deflection of the galvanometer. The galvanometer used here must be very sensitive and should have high resistance. It is quite costly, as it requires a high degree of insulation to avoid leakage currents.

Loss of Charge Method :

This method is the simplest of all, as it requires a voltmeter and a capacitor to determine the unknown resistance R. Also it is the most effective method for the measurement of high insulation resistance. However, this method is time consuming and the results are not so accurate due to the internal resistance of the voltmeter and leakage resistance of the capacitor.

Megger :

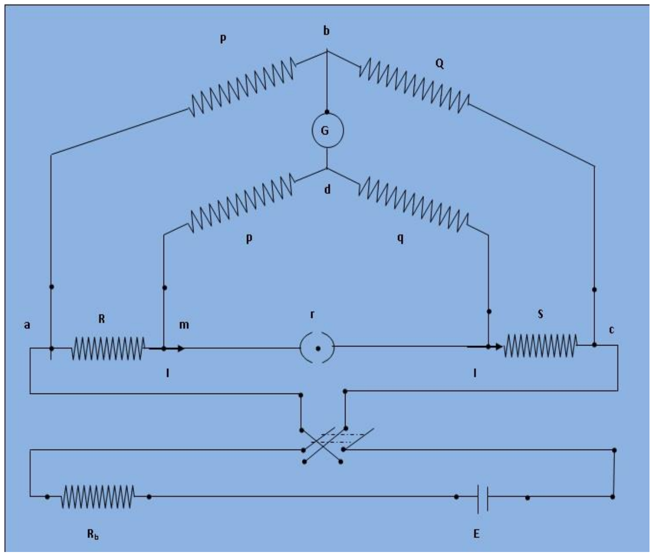
It is a portable instrument for measuring high resistances in which the voltage range can be controlled by using a voltage selector switch. It is not only used for the measurement of high resistances (insulation resistance) but also can be used for testing the insulation resistance.

The added advantage of this method is that the deflection of the instrument is independent of the field strength of the magnet. Megger is also used for testing the continuity between two points in a circuit.

To study the Kelvin Double Bridge for Low resistance measurement

Kelvin's double bridge may be used for precision mesurement of four-terminal low resistances. Four terminal resistors have two current leading terminals and two potential terminals across which the resistance equals the marked nominal value. This is because, the current must enter and leave the resistor in a fashion that there is same or equivalent distribution of current density between the particular equipotent surfaces used to define the resistance. The additional points also eliminated any contact resistance at the current lead-in terminals.

Circuit Diagram



[Fig 1: Schematic diagram for measurement of low resistance by Kelvin double bridge]

The kelvin double bridge incorporates the idea of a second set of ratio arms - hence the name double bridge- and the use of four terminal resistors for the low resistance arms. Figure 1 shows the schematic diagram of kelvin bridge. The first ratio arms is P and Q. The second set of ratio arms p and q is used to connect the galvanometer to a point d at the appropriate potential between points m and n to eliminate the effect of connecting lead resistance r between the unknown resistance R and the standard resistance S.

The ratio p/q is made equal to P/Q. Under balance conditions there is no current through the galvanometer which means that the voltage drop between a and b, E_{ab} is equal to voltage drops E_{amd} between a and c.

`E_(ab) = P* E_(ac)/(P+Q)` and `E_(ac) = I*{R + S + r*(p + q)/(p+q+r)}`

`E_(amd)= I*{R+(p/(p+q))*(r*(p+q)/(p+q+r))} = I*(R+pr/(p+q+r))`

for zero galvanometer deflection, $E_{ab}=E_{amd}$

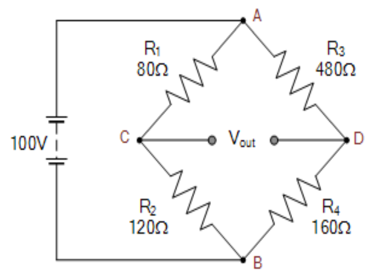
$$\frac{PI}{P+Q}[R+S+\frac{(p+q)r}{p+q+r}]=I[R+\frac{pr}{p+q+r}]$$
$$or\ R=\frac{P}{Q}S+\frac{qr}{p+q+r}[\frac{P}{Q}-\frac{p}{q}] \text{ ------------ } (1)$$

$$\text{now if } \frac{P}{Q}=\frac{p}{q}\ Eq\ (1)\ becomes,\ R=\frac{P}{Q}S \text{ --------- } (2)$$

Eq (2) is the usual working equation for the kelvin bridge. It indicates that the resistance of connecting lead, r, has no effect on the measurement, provided that the two sets of ratio arms have equal ratios.

Measurement of resistance by Wheatstone bridge

The following unbalanced Wheatstone Bridge is constructed. Calculate the output voltage across points C and D and the value of resistor R_4 required to balance the bridge circuit.



For the first series arm, ACB

$$V_C = \frac{R_2}{(R_1+R_2)} \times V_S$$

$$V_C = \frac{120\Omega}{80\Omega + 120\Omega} \times 100 = 60\text{volts}$$

For the second series arm, ADB

$$V_D = \frac{R_4}{(R_3+R_4)} \times V_S$$

$$V_D = \frac{160\Omega}{480\Omega + 160\Omega} \times 100 = 25\text{volts}$$

The voltage across points C-D is given as:

$$V_{OUT} = V_C - V_D$$

$$\therefore V_{OUT} = 60 - 25 = 35\text{volts}$$

The value of resistor, R_4 required to balance the bridge is given as:

$$R_4 = \frac{R_2 R_3}{R_1} = \frac{120\Omega \times 480\Omega}{80\Omega} = 720\Omega$$

We have seen above that the Wheatstone Bridge has two input terminals (A-B) and two output terminals (C-D). When the bridge is balanced, the voltage across the output terminals is 0 volts. When the bridge is unbalanced, however, the output voltage may be either positive or negative depending upon the direction of unbalance.

Difference between Wattmeter and Energy Meter

A **wattmeter** is an electrical measuring device used for measuring the active power in an electric circuit. The wattmeter is a type of **indicating instrument** that means it measure the electrical power in the circuit, only when the current flowing in the circuit.

A typical wattmeter consists of two coils namely **current coil** and **pressure coil**. The current coil of the wattmeter is connected in series with the electrical load, while the pressure coil is connected in parallel with the load. Therefore, the load current flows through the current coil and the load voltage appears across the pressure coil. The load current through the current coil produces a magnetic field which is directly proportional to the current through the coil. This magnetic field can produce a torque in the pressure coil. A pointer is attached to the pressure coil can move over a scale to the show the power reading.

What is an Energy Meter?

A type of electrical measuring instrument which measures the total amount of energy consumed by an electrical load over a certain period of time is known as **energy meter**. The energy meter is a type of **integrating instrument** as it maintains the record of measurement over a period. In practice, the energy meters are generally calibrated to measure the electrical energy in **kWh (kilo Watt hours).**

An **electromechanical induction type energy meter** consists of a disc made of aluminium mounted on a spindle and is placed between two electromagnets. The speed of rotation of the disc is directly proportional to the power consumed and this power is integrated over a certain period of time by using a counter and gear train mechanism.

Difference between Wattmeter and Energy Meter

The following table highlights all the major differences between a wattmeter and an energy meter −

Basis of Difference	Wattmeter	Energy Meter
Definition	An electric measuring device which shows reading of the power consumed by a load in the circuit is called wattmeter.	An electrical measuring device that shows the value of electrical energy consumed by a load in a certain period is called energy meter.
Circuit symbol		

Quantity measured	A wattmeter measures active (or real) power in an electric circuit.	Energy meters measures the total average power consumed over a period, called energy.
Types	There are two types of wattmeter namely 'electrodynamometer type wattmeter' and 'induction type wattmeter'.	Types of energy meters are: 'electromechanical induction type energy meter', 'electronic energy meter' and 'smart energy meter'.
Measuring unit	A typical wattmeter shows the reading of electrical power in watts.	A typical energy meter shows the energy reading in kWh (kilo Watt hours).
Major parts	The major parts of a wattmeter are: current coil, pressure coil, damping system, control mechanism, scale and pointer.	The major parts of an energy meter are: current coil, voltage coil, rotating aluminium disc, breaking system, counting mechanism.
Instrument type	A wattmeter is an indicating type instrument.	An energy meter is an integrating type instrument.
Applications	Wattmeter is used with electrical devices to measure their power ratings and consumption, and also used in labs to perform experiments.	Energy meters are extensively to measure electrical energy consumed for billing and monitoring purposes.