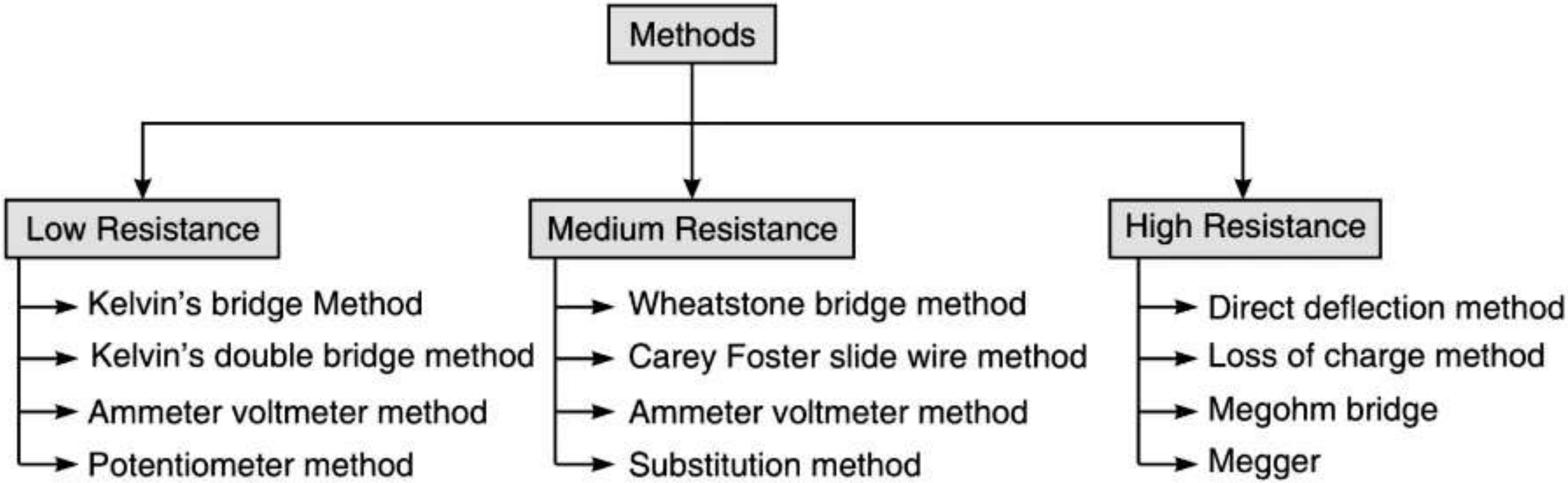
DSE 4A CLASS

Lecture-4

13/05/2021

Classification of Resistance Measurements

- Low resistances (0-1) Ω
- Medium resistances (1-0.1M)Ω
- High resistances (≥ 0.1MΩ)


Methods
Low Resistance
Medium Resistance
High Resistance
Kelvin's bridge Method
Kelvin's double bridge method
Ammeter voltmeter method
Potentiometer method
Wheatstone bridge method
Carey Foster slide wire method
Ammeter voltmeter method
Substitution method
Direct deflection method
Loss of charge method
Megohm bridge
Megger

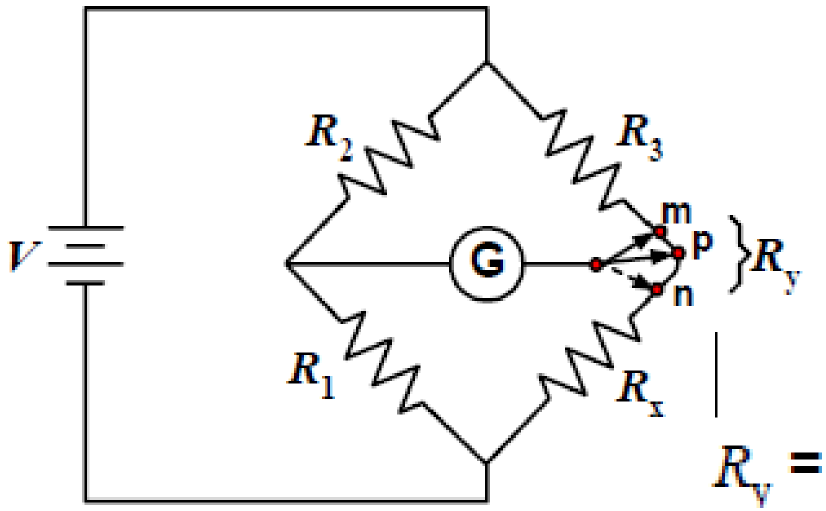
Kelvin Bridge

Wheatstone bridge use for measuring the resistance from a few ohms to several kilo-ohms.

But error occurs when it is used for measuring the low resistance due to the contact resistances.

Kelvin bridge or Thompson bridge is modification of Wheatstone bridge.

The Kelvin bridge is suitable for measuring the low resistance $< 1\ \Omega$.



The effects of the connecting lead and the connecting terminals are prominent when the value of *resistance to be measured* decreases to a few Ohms

R_y = resistance of the connecting lead between *mn*

If the galvanometer is connected to m — R_y is added to the unknown R_x

If the galvanometer is connected to n — R_y is added to R_3

At point *p*: $$R_x + R_{np} = \left(R_3 + R_{mp}\right)\frac{R_1}{R_2}$$

$$R_x = R_3\frac{R_1}{R_2} + R_{mp}\frac{R_1}{R_2} - R_{np}$$

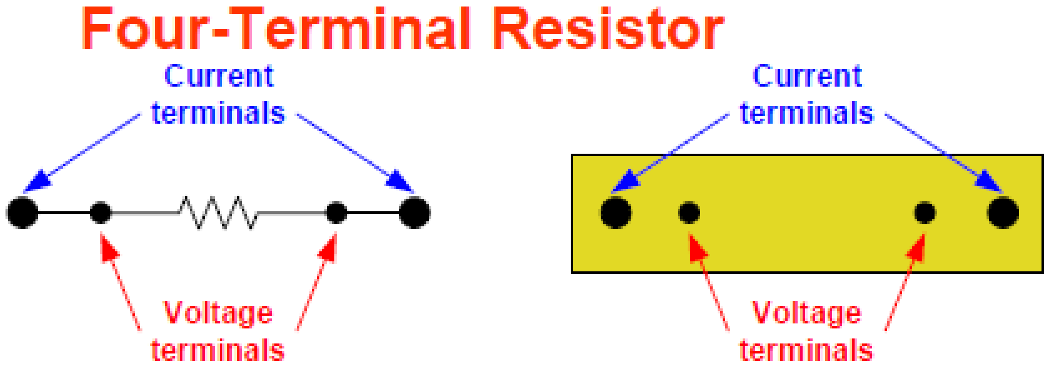
Effect of connecting leads will be cancelled if 2nd and 3rd terms add to zero

$$R_{mp}\frac{R_1}{R_2} - R_{np} = 0 \text{ or } \frac{R_{np}}{R_{mp}} = \frac{R_1}{R_2}$$

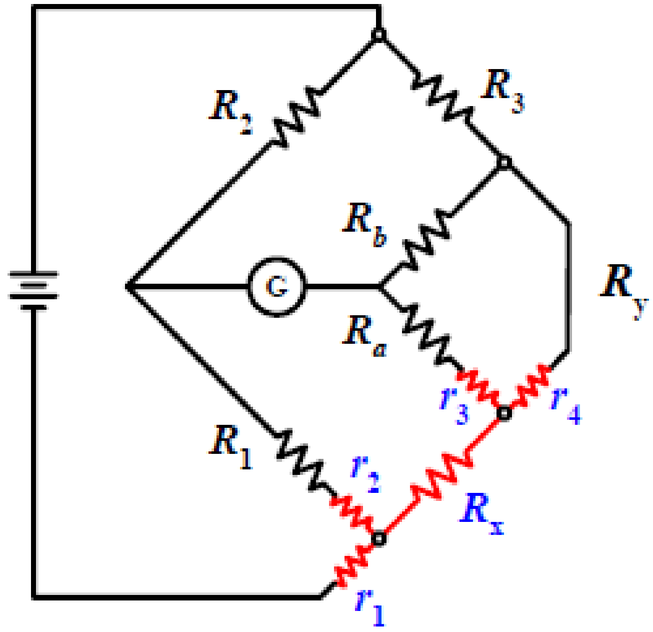
Disadvantage of Kelvin Bridge

There is a trouble in determining the correct point for galvanometer connection ie. to find the perfect point *p* in the circuit

The **Kelvin Double Bridge** incorporates the a second set of ratio arms, hence the name of double bridge.
Use four terminal resistors for the low resistance arms.

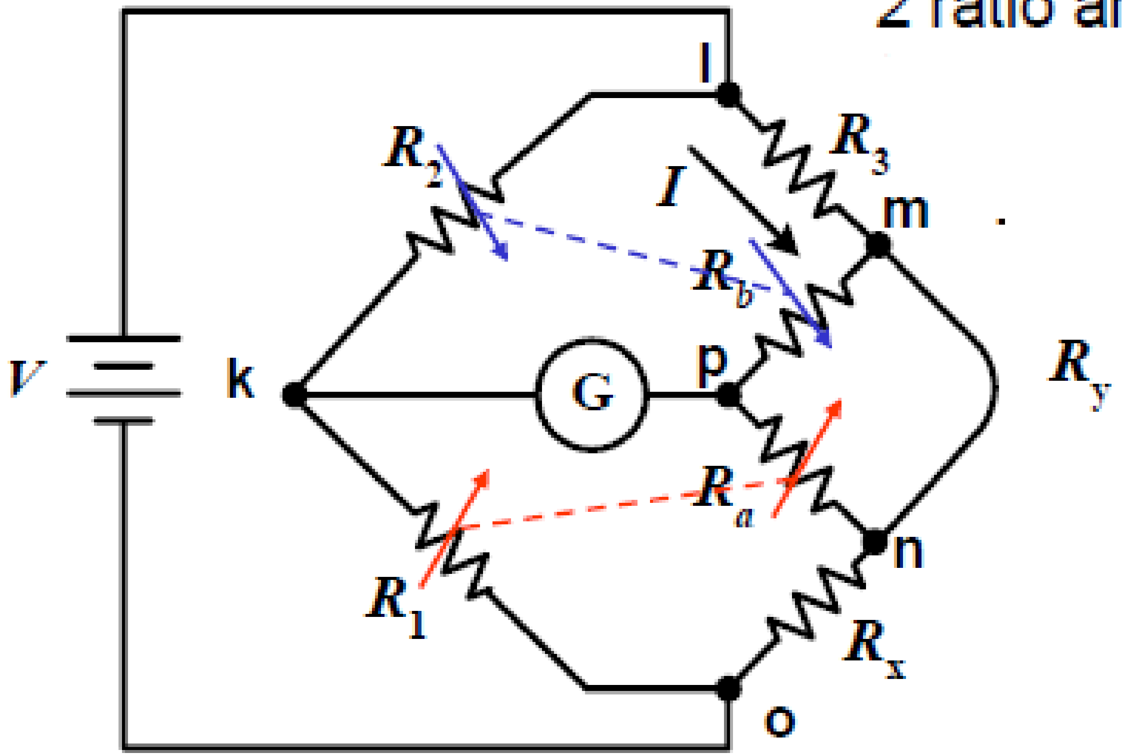


Kelvin Double Bridge



- r_1 causes no effect on the balance condition.
- The effects of r_2 and r_3 could be minimized, if $R_1 >> r_2$ and $R_a >> r_3$.
- The main error comes from r_4, even though this value is very small.

2 ratio arms: R_1-R_2 and R_a-R_b



The balance conditions: $V_{lk} = V_{lmp}$ or $V_{ok} = V_{onp}$

$$V_{lk} = \frac{R_2}{R_1 + R_2} V \qquad V = IR_{lo} = I[R_3 + R_x + (R_a + R_b) // R_y]$$

$$V_{lmp} = I\left[R_3 + \frac{R_y}{R_a + R_b + R_y} R_b \right]$$

$$V_{lk} = V_{lmp}$$

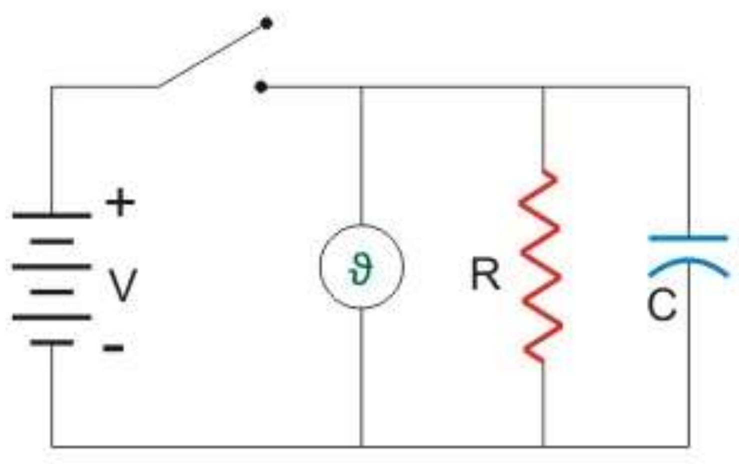
$$R_x = R_3 \frac{R_1}{R_2} + \frac{R_b R_y}{R_a + R_b + R_y} \left(\frac{R_1}{R_2} - \frac{R_a}{R_b} \right)$$

If the second term of the right hand side is zero then the above equation represents the standard Wheatstone bridge balance equation.

$$R_x = R_3 \frac{R_1}{R_2}$$

Loss of Charge Method

Unknown resistance is connected in parallel with the capacitor and electrostatic voltmeter.
The capacitor is initially charged to some suitable voltage by means of a battery of voltage V and then allowed to discharge through the resistance.

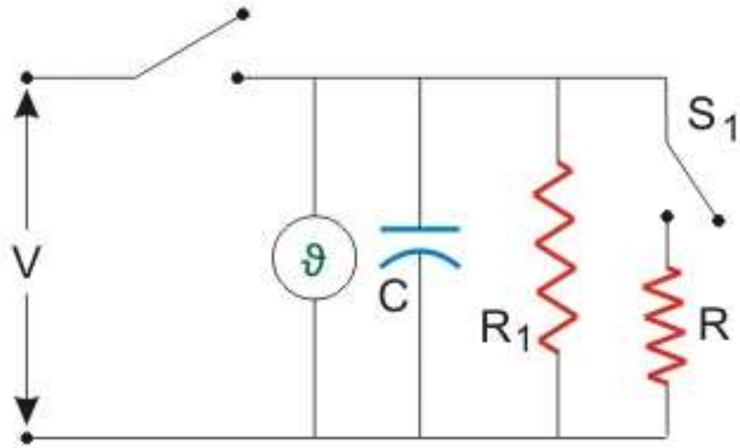


$$v = V e^{\frac{-t}{RC}}$$

$$R = \frac{0.4343t}{C\ log_{10} V/v}$$

From the equation above, it follows that if V, v, C and t are known the value of R can be computed.

The above case assumes no leakage resistance of the capacitor.



R_1 is the leakage resistance of C and R is the unknown resistance.

We follow the same procedure but first with switch S_1 closed and next with switch S_1 open.

For the first case

$$R' = \frac{0.4343t}{C\ log_{10} V/v}$$

$$Where,\ R' = \frac{RR_1}{R + R_1}$$

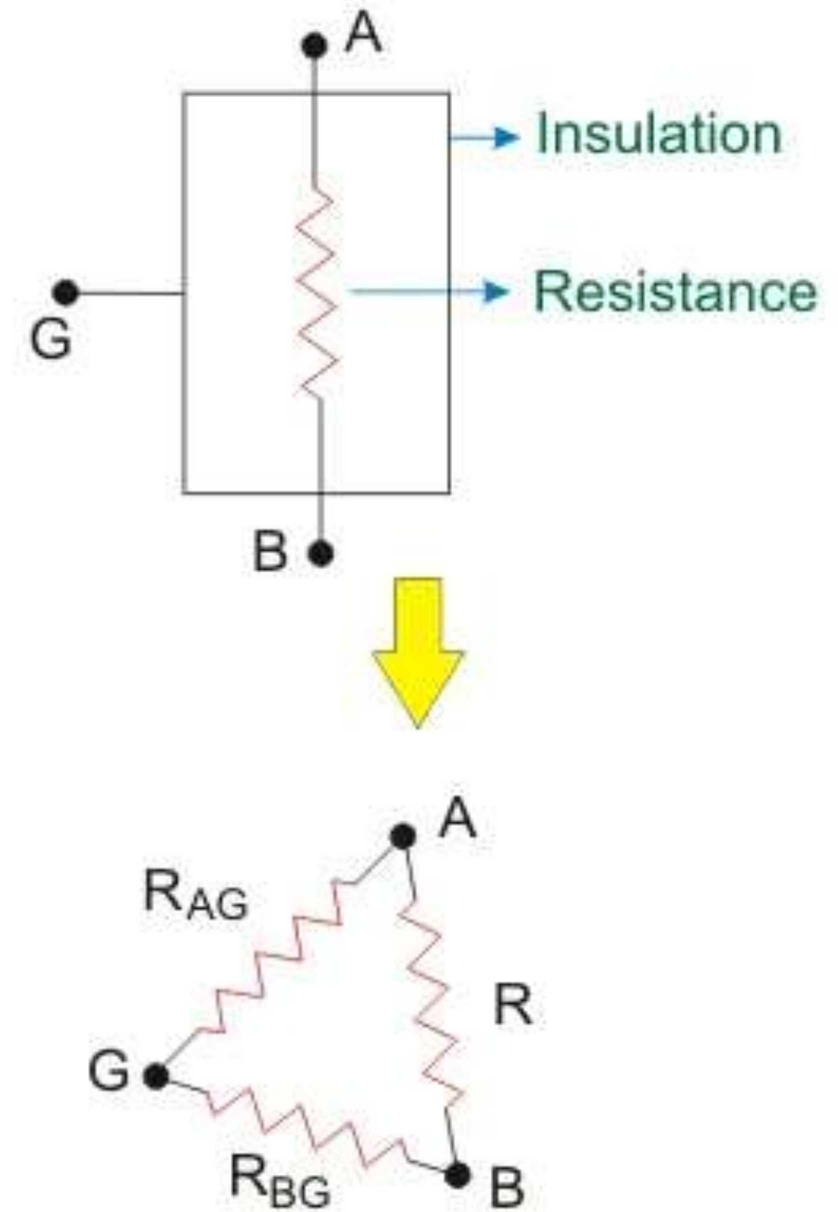
For second case with switch open

$$R_1 = \frac{0.4343t}{C\ log_{10} V/v}$$

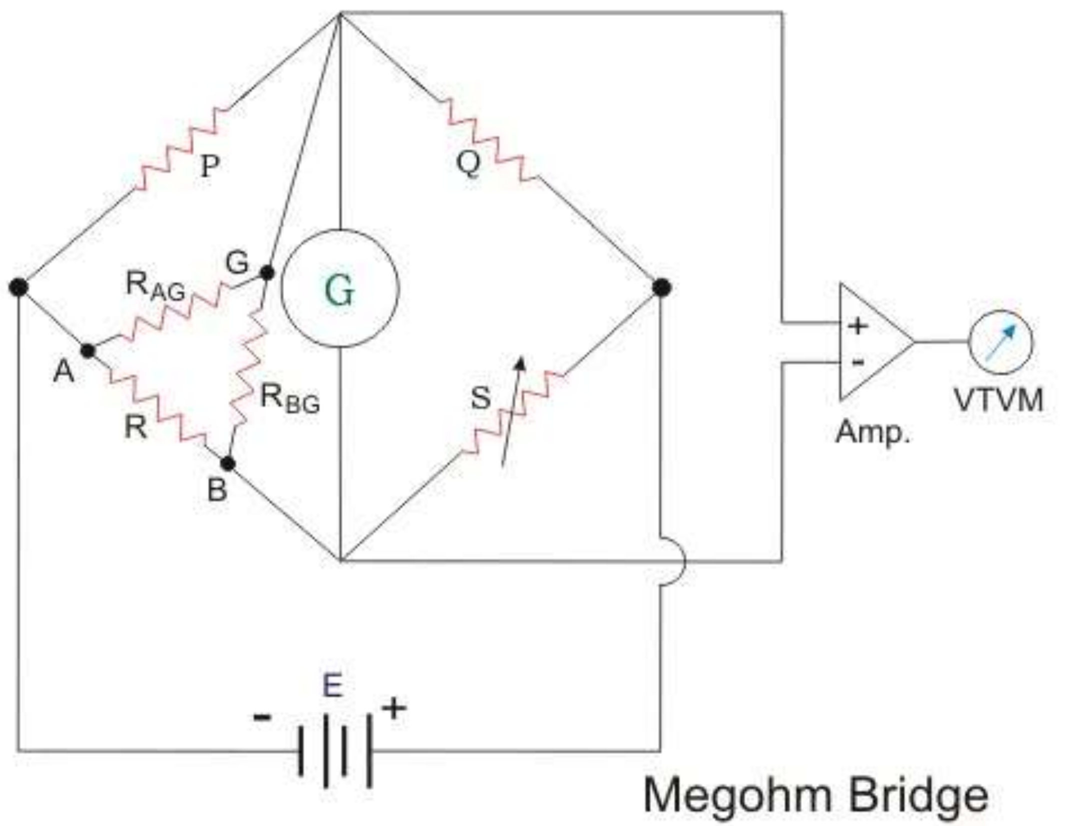
Using R_1 from above equation in equation for R' we can find R.

Megohm Bridge Method

A very high resistance R with its two main terminals A and B, and a guard terminal



The resistance R is between main terminals A and B and the leakage resistances R_{AG} and R_{BG} between the main terminals A and B of from a "Three-terminal resistance".



$R_{AG} \,//\, R_P \approx R_P$ since $R_{AG} >> R_P$

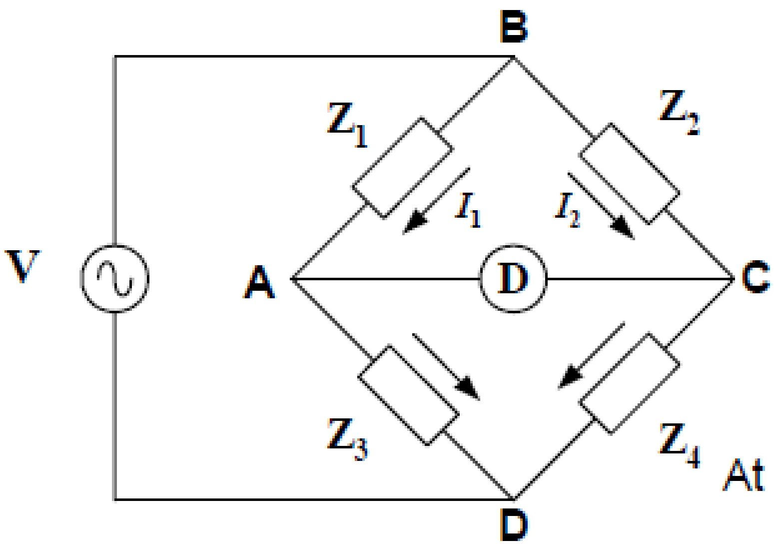
$R_{BG} \,//\, R_g \approx R_g$ since $R_2 >> R_g$

AC BRIDGES AND THEIR APPLICATIONS

Alternating current bridges are most popular, convenient and accurate instruments for measurement of unknown inductance, capacitance and some other related quantities.

In its simplest form, ac bridges can be thought of to be derived from the conventional dc Wheatstone bridge.

AC Bridge: Balance Condition



- all four arms are considered as impedance (frequency dependent components)
- The detector is an ac responding device: headphone, ac meter
- Source: an ac voltage at desired frequency

$\mathbf{Z_1}$, $\mathbf{Z_2}$, $\mathbf{Z_3}$ and $\mathbf{Z_4}$ are the impedance of bridge arms

At balance point: $\mathbf{E_{BA}} = \mathbf{E_{BC}}$ or $\mathbf{I_1Z_1} = \mathbf{I_2Z_2}$

$$\mathbf{I_1} = \frac{\mathbf{V}}{\mathbf{Z_1} + \mathbf{Z_3}} \text{ and } \mathbf{I_2} = \frac{\mathbf{V}}{\mathbf{Z_2} + \mathbf{Z_4}}$$

General Form of the ac Bridge

Complex Form: $\mathbf{Z_1Z_4} = \mathbf{Z_2Z_3}$

Polar Form:

$$Z_1Z_4(\angle\theta_1 + \angle\theta_4) = Z_2Z_3(\angle\theta_2 + \angle\theta_3)$$

Magnitude balance: $Z_1Z_4 = Z_2Z_3$

Phase balance: $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$

Two conditions must be satisfied for bridge balance.

(i) The product of the magnitudes of the opposite arms must be equal.

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

The value of phase angles depends on the type of components of individual impedance.

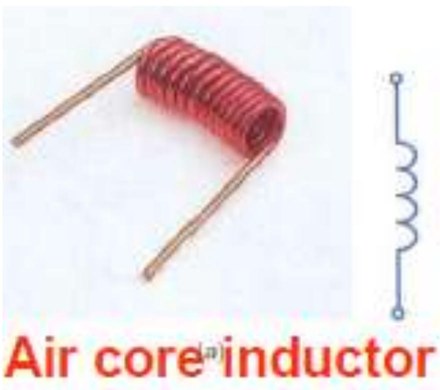
For inductive impedance the phase angles are positive and for capacitive impedance the phase angles are negative.

MEASUREMENT OF SELF-INDUCTANCE

Comparison Bridge:

Measure an unknown inductance or capacitance by comparing with it with a known inductance or capacitance.

Inductance – the ability of a conductor to produce induced voltage
when the current varies.



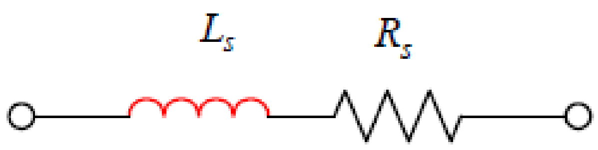
Toroidal inductor

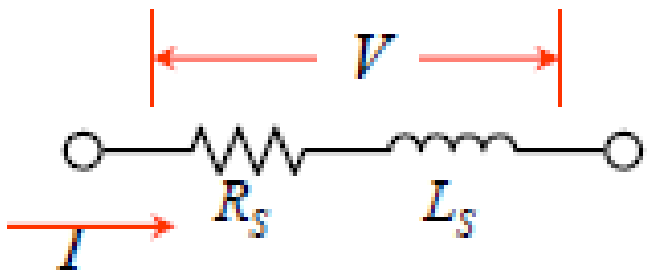
A simple winding

Ferromagnetic materials, such as ferrite or iron, as the core material

Magnetic material as the core substance to which the wire is wound in circular ring shape.

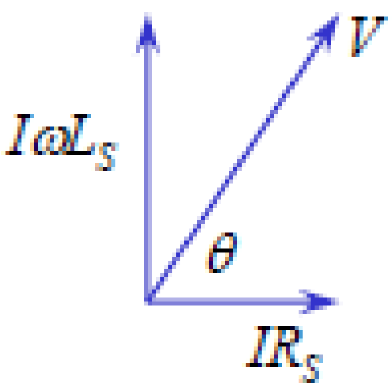
Equivalent circuit of Inductance





Quality factor of a coil: the ratio of reactance to resistance

$$Q = \frac{X_s}{R_s} = \frac{\omega L_s}{R_s}$$

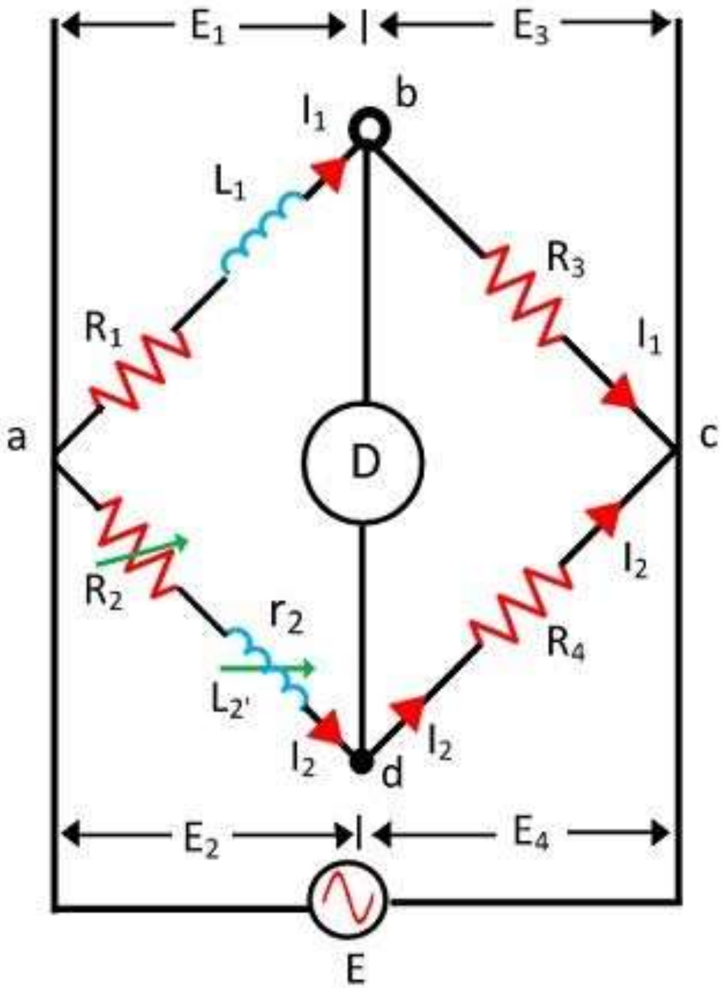


Maxwell's Bridge

The Maxwell bridge **works** on the **principle** of the **comparison**, i.e., the value of **unknown inductance** is determined by **comparing** it with the known value or standard value.

Two methods are used for determining self-inductance of the circuit.

1. **Maxwell's Inductance Bridge**
2. **Maxwell's inductance Capacitance Bridge**



Maxwell's Inductance Bridge

L_1 — unknown inductance of resistance R_1.

L_2 — Variable inductance of fixed resistance r_1.

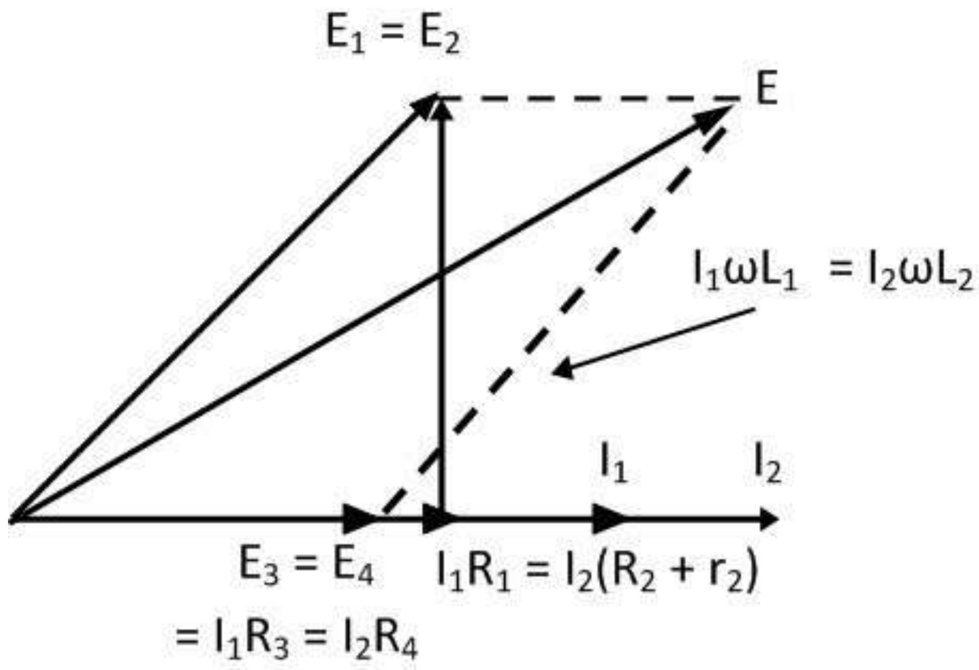
R_2 — variable resistance connected in series with inductor L_2.

R_3, R_4 — known non-inductance resistance

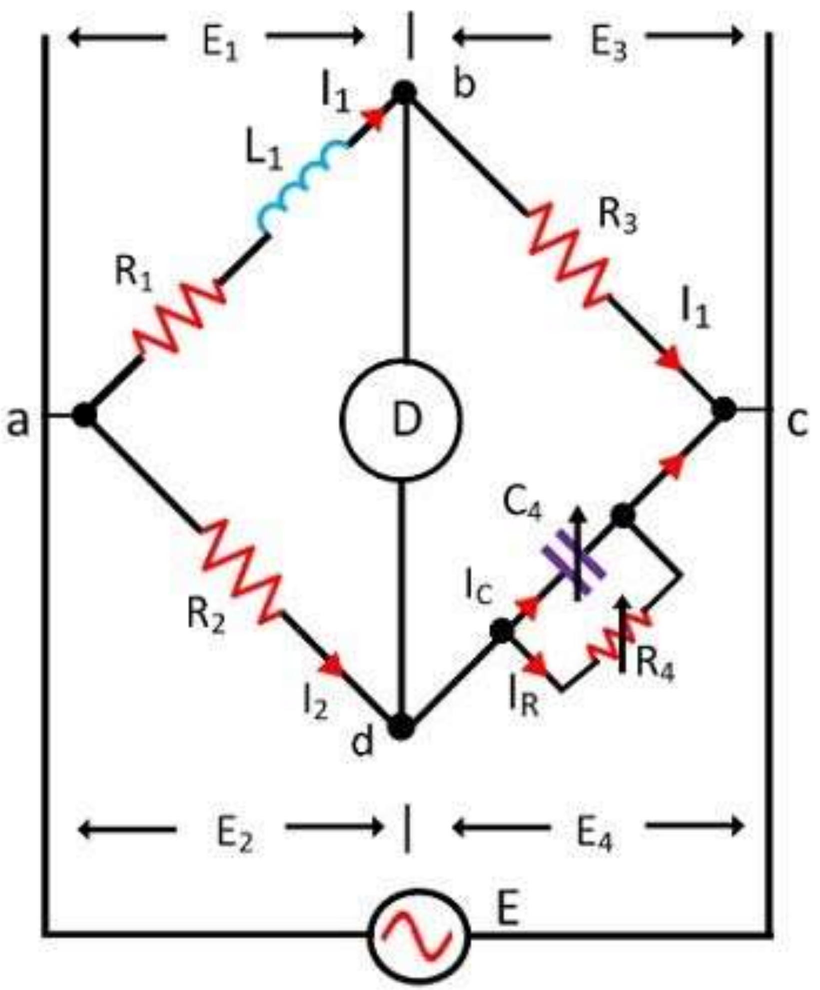
At balance $\boldsymbol{Z_1 Z_4 = Z_2 Z_3}$

Separation of the real and imaginary terms yields:

$$L_1 = \frac{R_3}{R_4} L_2 \qquad R_1 = \frac{R_3}{R_4}(R_2 + r_2)$$



Phasor Diagram of Maxewell Inductance Bridge



Maxwell's Inductance Capacitance Bridge

L_1 – unknown inductance of resistance R_1.

R_1 – Variable inductance of fixed resistance r_1.

R_2, R_3, R_4 – variable resistance connected in series with inductor L_2.

C_4 – known non-inductance resistance

At balance condition,

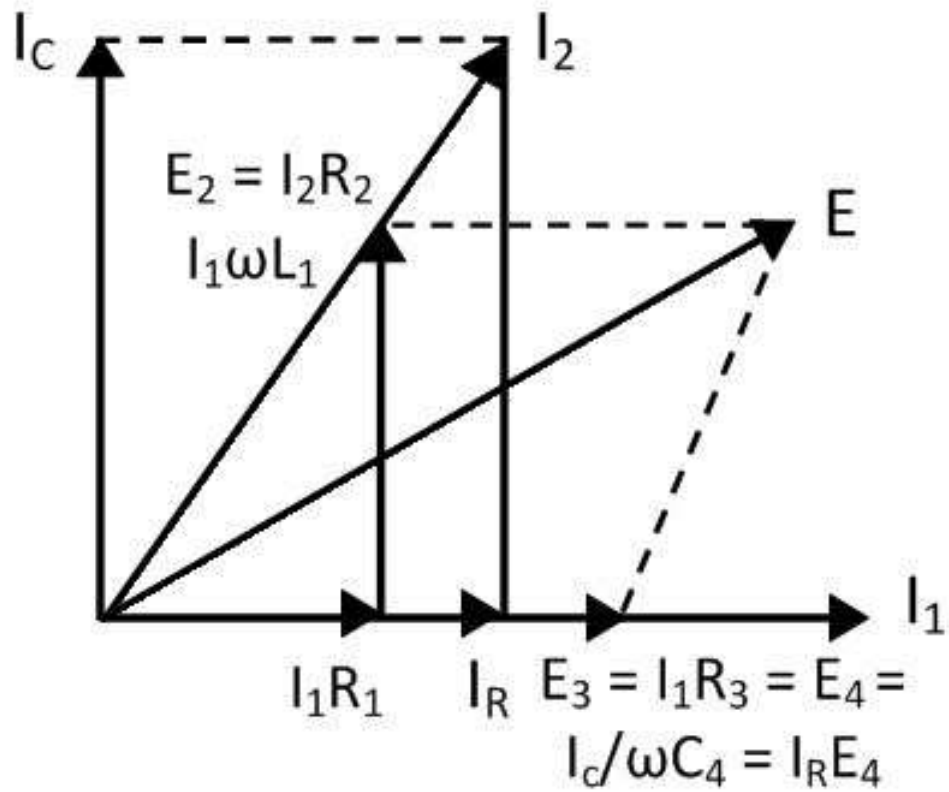
$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3$$

$$R_1 R_4 = j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_4 R_2 R_3$$

By separating the real and imaginary equation

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

$$L_1 = R_2 R_3 C_4$$



Phasor Diagram of Inductance Capacitance Bridge

The circuit quality factor is

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

Advantages of the Maxwell's Bridges

The following are the advantages of the Maxwell bridges

1.The balance equation of the circuit is free from frequency.

2.Both the balance equations are independent of each other.

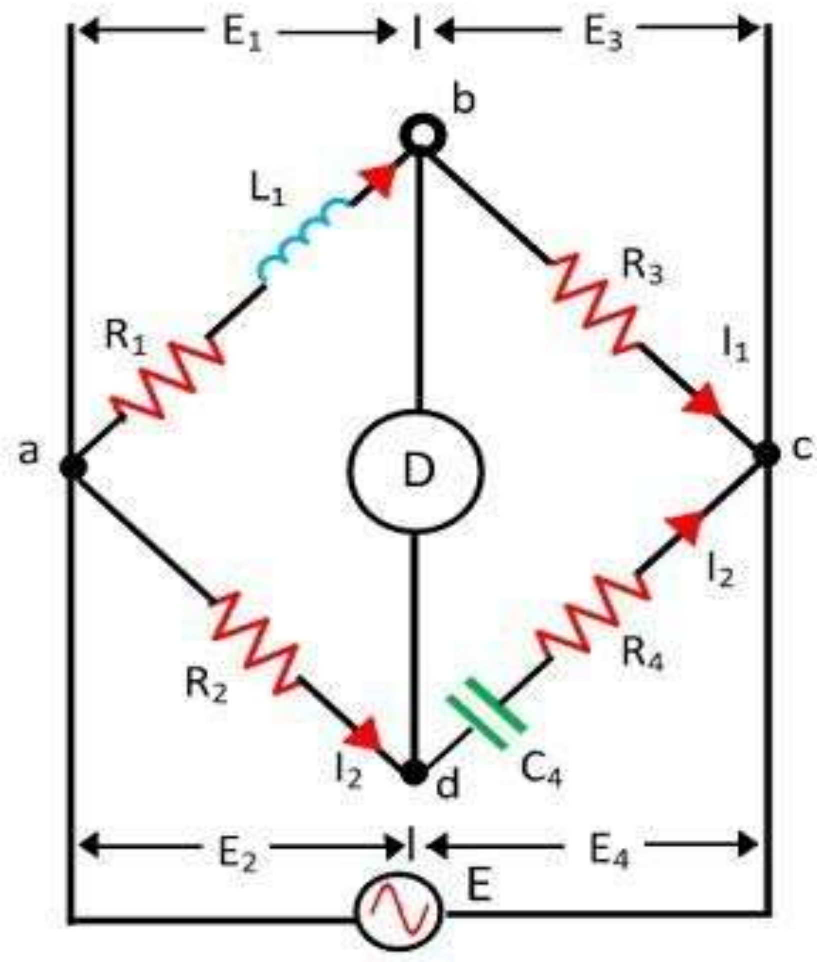
3.The Maxwell's inductor capacitance bridge is used for the measurement of the high range inductance.

Disadvantages of the Maxwell's Bridge

The main disadvantages of the bridges are

1.The Maxwell inductor capacitance bridge requires a variable capacitor which is very expensive.

2.The bridge is only used for the measurement of medium quality coils ($1 < Q < 10$).



Hay's Bridge

L_1 – unknown inductance having a resistance R_1

R_2, R_3, R_4 – known non-inductive resistance.

C_4 – standard capacitor

At balance condition,

$$(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2R_3$$

$$R_1R_4 + \frac{L_1}{C_4} + j\omega L_1R_4 - \frac{jR_1}{\omega C_4} = R_2R_3$$

By separating the real and imaginary equation

$$R_1R_4 + \frac{L_1}{C_4} = R_2R_3 \quad and \; L_1 = \frac{-\,R_1}{\omega^2 R_4 C_4}$$

$$L_1 = \frac{R_2R_3C_4}{1 + \omega^2 R_4^2 C_4^2}$$

$$R_1 = \frac{\omega^2 C_4^2 R_2R_3R_4}{1 + \omega^2 R_4^2 C_4^2}$$

Advantages

- This bridge is used for the unknown inductances to provide a simple expression. It is appropriate for the coil that has a high Q factor > 10.
- It uses a small resistance value to determine the quality factor.

Disadvantages

- It is not applicable for the measurement of the coil which has less than 10 Q factor.
- The balanced equation of the bridge depends on operating frequency and thus the frequency change will influence the measurements.