Bridge Circuit

A bridge circuit is a topology of electrical circuitry in which two circuit branches (usually in parallel with each other) are "bridged" by a third branch connected between the first two branches at some intermediate point along them. Simply if the electrical components are arranged in the form a ring structure, then that electrical circuit is called a bridge. In general, bridge forms a loop with a set of four arms or branches. Each branch may contain one or two electrical components. The bridge was originally developed for laboratory measurement purposes and one of the intermediate bridging points is often adjustable when so used.

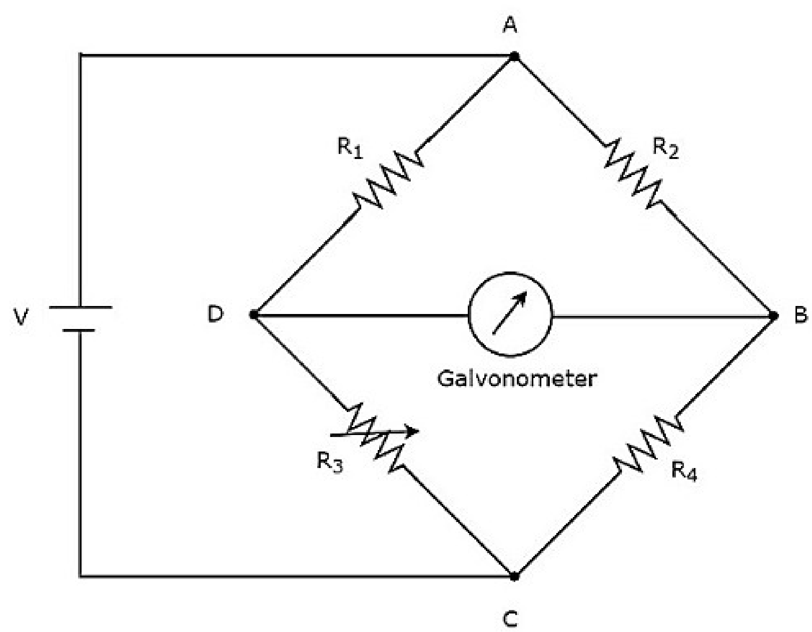
Types of Bridges

We can classify the bridge circuits or bridges into the following two categories based on the voltage signal with which those can be operated.

- DC Bridges
- AC Bridges

DC Bridges

If the bridge circuit can be operated with only DC voltage signal, then it is a DC Bridge circuit or simply DC Bridge. DC bridges are used to measure the value of unknown resistance. The circuit diagram of DC Bridge looks like as shown in below figure.



The above DC Bridge has four arms and each arm consists of a resistor. Among which, two resistors have fixed resistance values, one resistor is a variable resistor and the other one has an unknown resistance value.

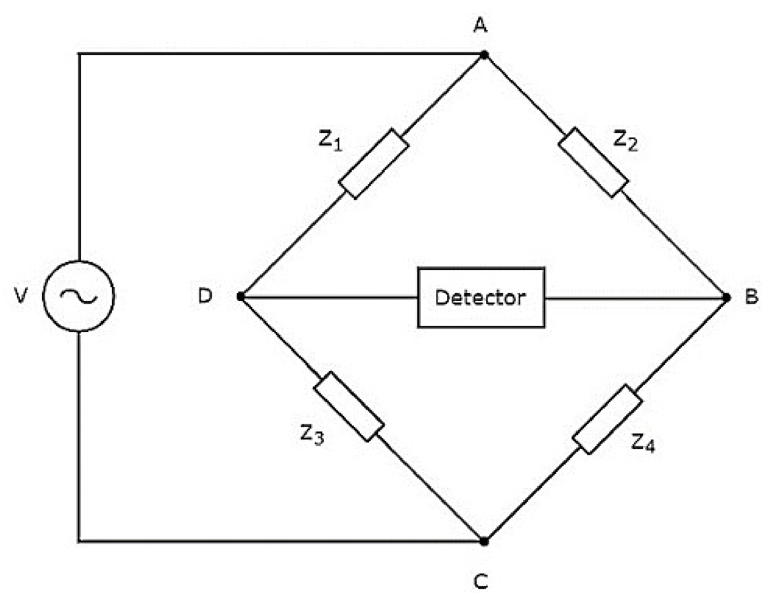
The above DC bridge circuit can be excited with a DC voltage source by placing it in one diagonal. The galvanometer is placed in other diagonal of DC Bridge. It shows some deflection as long as the bridge is unbalanced.
Vary the resistance value of variable resistor until the galvanometer shows null (zero) deflection. Now, the above DC Bridge is said to be a balanced one. So, we can find the value of unknown resistance by using nodal equations.

The types of D.C bridges are-

- Wheatstone Bridge
- Kelvin Bridge
- Megohm Bridge

AC Bridges

If the bridge circuit can be operated with only AC voltage signal, then it is said to be AC bridge circuit or simply AC Bridge. AC bridges are used to measure the value of unknown inductance, capacitance and frequency.
The circuit diagram of AC Bridge looks like as shown in below figure.



The circuit diagram of AC Bridge is similar to that of DC Bridge. The above AC Bridge has four arms and each arm consists of some impedance. That means, each arm will be having either single or combination of passive elements such as resistor, inductor and capacitor.
Among the four impedances, two impedances have fixed values, one of these is variable and the other one is unknown impedance.
The above AC bridge circuit can be excited with an AC voltage source by placing it in one diagonal. A detector is placed in other diagonal of AC Bridge. It shows some deflection as long as the bridge is unbalanced.
The above AC bridge circuit can be excited with an AC voltage source by placing it in one diagonal. A detector is placed in other diagonal of AC Bridge. It shows some deflection as long as the bridge is unbalanced.

Vary the impedance value of variable impedance until the detector shows null (zero) deflection. Now, the above AC Bridge is said to be a balanced one. So, we can find the value of unknown impedance by using balanced condition.

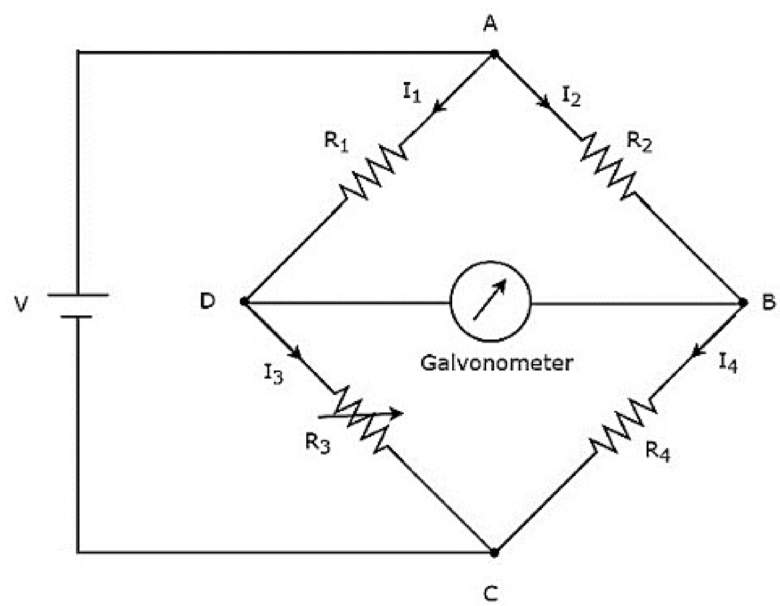
The various types of A.C Bridges are,

1. Maxwell's Bridge
2. Hay's Bridge
3. Anderson Bridge
4. Schering Bridge
5. Wien Bridge
6. Campbell Bridge
7. Carey Foster Bridge

Wheatstone's bridge

Wheatstone's bridge is a simple DC bridge, which is mainly having four arms. These four arms form a rhombus or square shape and each arm consists of one resistor. To find the value of unknown resistance, we need the galvanometer and DC voltage source. Hence, one of these two is placed in one diagonal of Wheatstone's bridge and the other one is placed in another diagonal of Wheatstone's bridge.

Wheatstone's bridge is used to measure the value of medium resistance. The circuit diagram of Wheatstone's bridge is shown in below figure.



In above circuit, the arms AB, BC, CD and DA together form a rhombus or square shape. They consist of resistors R_2, R_4, R_3 and R_1 respectively. Let the current flowing through these resistor arms is I_2, I_4, I_3 and I_1 respectively and the directions of these currents are shown in the figure.

The diagonal arms DB and AC consist of galvanometer and DC voltage source of V volts respectively. Here, the resistor, R_3 is a standard variable resistor and the resistor, R_4 is an unknown resistor. We can balance the bridge, by varying the resistance value of resistor, R_3.

The above bridge circuit is balanced when no current flows through the diagonal arm, DB. That means, there is no deflection in the galvanometer, when the bridge is balanced.

The bridge will be balanced, when the following two conditions are satisfied.

- The voltage across arm AD is equal to the voltage across arm AB. i.e.,

$$V_{AD} = V_{AB}$$
$$\Rightarrow \quad I_1R_1 = I_2R_2$$

- The voltage across arm DC is equal to the voltage across arm BC. i.e.,

$$V_{DC} = V_{BC}$$
$$\Rightarrow \quad I_3R_3 = I_4R_4$$

From above two balancing conditions, we will get the following two conclusions.

- The current flowing through the arm AD will be equal to that of arm DC. i.e.,
  $$I_1 = I_3$$
- The current flowing through the arm AB will be equal to that of arm BC. i.e.,
  $$I_2 = I_4$$

Take the ratio of upper two equations

$$I_1R_1/I_3R_3 = I_2R_2/I_4R_4$$

Substitute, $I_1=I_3$ and $I_2=I_4$.

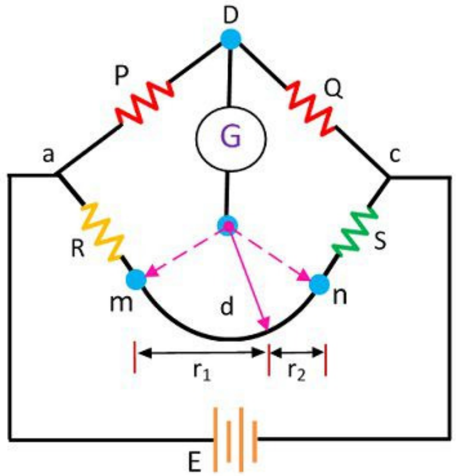
$$I_3R_1/I_3R_3 = I_4R_2/I_4R_4$$
$$\Rightarrow \quad R_1/R_3 = R_2/R_4$$
$$\Rightarrow \quad R_4 = R_2\,(R_3/R_1)$$

By substituting the known values of resistors R_1, R_2 and R_3 in above equation, we will get the value of resistor, R4.

Kelvin Bridge

In a case where the resistance value is less than 1 ohm, it will be difficult to measure the value of resistor using Wheatstone's bridge. A Kelvin bridge circuit is used to measure unknown electrical resistors, beneath1 Ohm. Hence, we shunt a lower value of the unknown resistors, 2 precision resistors, and a high current ammeter to form four-terminal resistors, where the current flows through the circuit, then the voltage drop across the resistors can be measured using a galvanometer, which together is a four-terminal resistor called Kelvin bridge.

In Wheatstone bridge, while measuring the low-value resistance, the resistance of their lead and contacts increases the resistance of their total measured value. This can easily be understood with the help of the circuit diagram.



The r is the resistance of the contacts that connect the unknown resistance R to the standard resistance S. The ‘m’ and ‘n’ show the range between which the galvanometer is connected for obtaining a null point.

When the galvanometer is connected to point ‘m’, the lead resistance r is added to the standard resistance S. Thereby the very low indication obtains for unknown resistance R. And if the galvanometer is connected to point n then the r adds to the R, and hence the high value of unknown resistance is obtained. Thus, at point n and m either very high or very low value of unknown resistance is obtained.

So, instead of connecting the galvanometer from point, m and n we chose any intermediate point say d where the resistance of lead r is divided into two equal parts, i.e., r_1 and r_2

$$\frac{r_1}{r_2} = \frac{P}{Q} \dots \dots \dots equ(1)$$

The presence of r_1 causes no error in the measurement of unknown resistance.

$$R + r_1 = \frac{P}{Q}.(S + r_2)$$

From equation (1), we get

$$\frac{r_1}{r_1 + r_2} = \frac{P}{P + Q}$$

$$r_1 = \frac{P}{P + Q}.r$$

As

$$r_1 + r_2 = r$$

$$r_2 = \frac{Q}{P + Q}.r$$

So

$$R + \frac{P}{P+Q}.r = \frac{P}{Q}\left(S + \frac{Q}{P+Q}r\right)$$

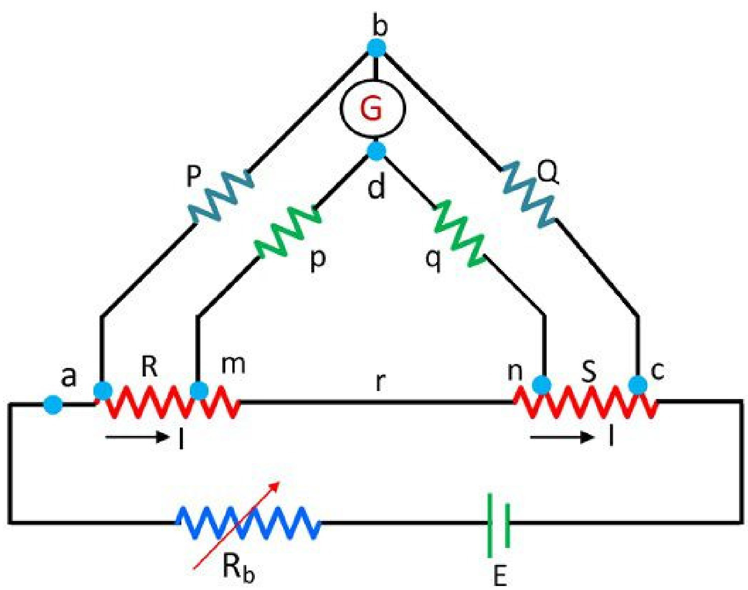
$$R = \frac{P}{Q}.S$$

The above equation shows that if the galvanometer connects at point d then the resistance of lead will not affect their results.

The above mention process is practically not possible to implement. For obtaining the desired result, the actual resistance of exact ratio connects between the point m and n and the galvanometer connects at the junction of the resistor.

Kelvin Double Bridge Circuit

The ratio of the arms p and q are used to connect the galvanometer at the right place between the point j and k. The j and k reduce the effect of connecting lead. The P and Q is the first ratio of the arm and p and q is the second arm ratio.



The galvanometer is connected between the arms p and q at a point d. The point d places at the centre of the resistance r between the point m and n for removing the effect of the connecting lead resistance which is placed between the unknown resistance R and standard resistance S.

The ratio of p/q is made equal to the P/Q. Under balance condition zero current flows through the galvanometer. The potential difference between the point a and b is equivalent to the voltage drop between the points E_{amd}.

Now,

$$E_{ab} = \frac{P}{P+Q} E_{ac}$$

$$E_{ac} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right] \ldots\ldots\ldots .\, equ(1)$$

$$E_{amd} = I\left[R + \frac{p}{(p+q)}\left\{\frac{(p+q)r}{p+q+r}\right\}\right]$$

$$E_{ac} = I\left[\frac{pr}{p+q+r}\right] \ldots\ldots\ldots ..\, equ(2)$$

For zero galvanometer deflection,

$$E_{ac} = E_{amd}$$

$$\frac{P}{P+Q} . I\left[R + \frac{p}{(p+q)}\left\{\frac{(p+q)r}{p+q+r}\right\}\right] = I\left[\frac{pr}{p+q+r}\right]$$

$$R = \frac{P}{Q} . S + \frac{pr}{p+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right]$$

As we known, P/Q = p/q then above equation becomes

$$R = \frac{P}{Q} . S$$

The above equation is the working equations of the Kelvin's bridge. The equation shows that the result obtains from the Kelvin double bridge are free from the impact of the connecting lead resistance.

For obtaining the appropriate result, it is very essentials that the ratio of their arms is equal. The unequal arm ratio causes the error in the result. Also, the value of resistance r should be kept minimum for obtaining the exact result.

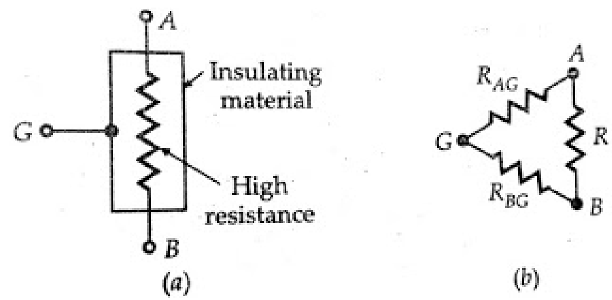
The thermo-electric EMF induces in the bridge during the reading. This effect can be reduced by measuring the resistance with the reverse battery connection. The real value of the resistance obtains by takings the means of the two.

Limitations of Kelvin's Bridge

1. The sensitive galvanometer is used for detecting the balance condition.
2. The high measurement current is required for obtaining the good sensitivity.

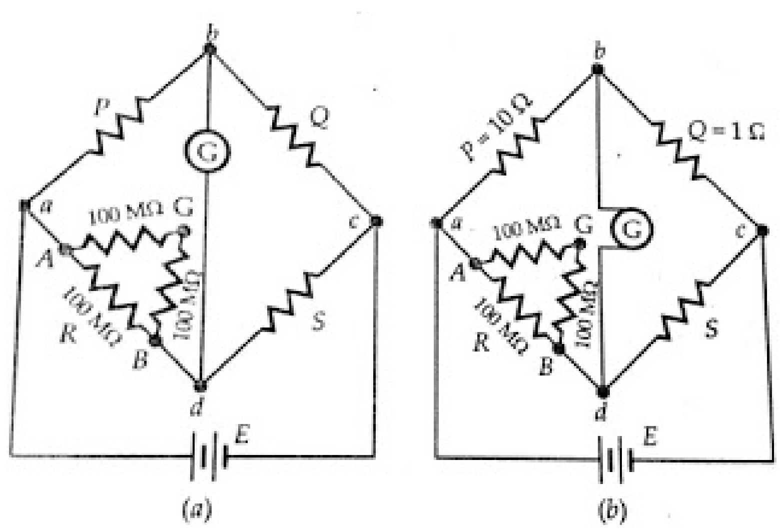
Megohm Bridge Method

We have seen many methods to find low and medium resistances but now let us discuss methods for high resistance measurement. So now I will explain Megohm bridge method. The below figure (a) shows a very high resistance R with its two main terminals A and B, and a guard terminal, which is put on the insulation. This high resistance may be diagrammatically represented as in figure (b). The resistance R is between main terminals A and B and the leakage resistances RAG and RBG between the main terminals A and B of from a "Three-terminal resistance".



Let us consider the hypothetical case of a 100 MΩ resistance. We assume that each of the leakage resistances is 100 MΩ, i.e., RAG = RBG =100 MΩ. Let this resistance be measured by an ordinary Wheatstone bridge as shown in the figure (a) below. It is clear that the Wheatstone bridge will measure a resistance of $\frac{100*100}{100+200}=67M\Omega$ instead of 100 MΩ thus giving an error of 33 percent.

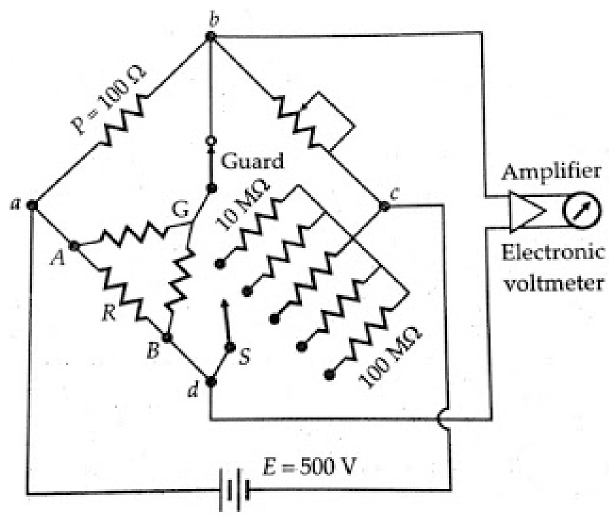
Megohm Bridge Circuit:



However if the same resistance is measured by a modified Wheatstone bridge as shown in the figure (b) above with the guard connection G connected as indicated, the error in measurement is considerably reduced. For the arrangement shown in figure (b) above resistance, RBG is put in parallel with the galvanometer and thus it has no effect on the balance and only affects the sensitivity of the galvanometer slightly.

The resistance RAG =100 MΩ is put in parallel with a resistance P =100 kΩ and therefore for the arrangement shown the measured value has an error of only 0.01 percent and this error is entirely negligible for measurements of this type.

The arrangement of the below figure illustrates the operation of a Megohm bridge. The below figure shows the circuit of a completely self-contained Megohm bridge which includes power supplies, bridge a members, amplifiers, and indicating instrument. It has a range from 0.1 MΩ to 10^6 MΩ. The accuracy is within 3% for the lower part of the range to possible 10% above 10,000 MΩ.



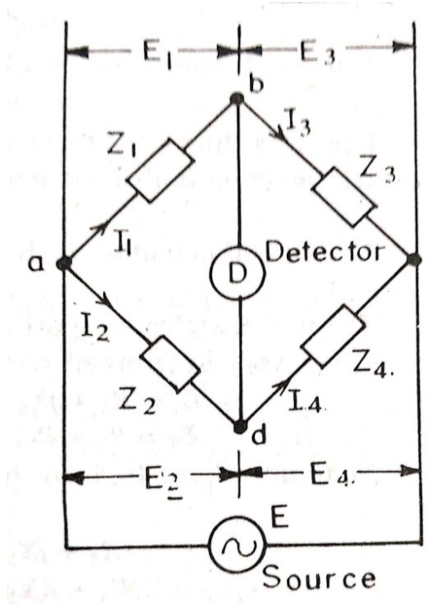
Sensitivity for balancing against high resistance is obtained by use of adjustable high voltage supplies of 500 V or 1000 V and the use of a sensitive null indicating arrangement such as a high gain amplifier with an electronic voltmeter or a CRO. The dial on Q is calibrated 1 - 10 - 100 - 1000 MΩ, with main decade 1 - 10 occupying the greater part of the dial space.

Since unknown resistance R= P.S/Q the arm Q is made, tapered, so that the dial calibration is approximately logarithmic in the main decade, 1 - 10. Arm S gives five multipliers, 0.1, 1, 10, 100 and 1000.The junction of ratio arms P and Q is brought on the main panel and is designated as 'Guard' terminal.

AC Bridge

General Equation for AC Bridge Balance:

The figure shows a basic ac bridge. The four arms of the bridge are impedances Z1, Z2, Z3 & Z4.



The conditions for the balance of bridge require that there should be no current through the detector. This requires that the potential difference between point's b and d should be zero. This will be the case when the voltage drop from a to b equals to voltage drop from a to d, both in magnitude and phase. In complex notation we can, thus, write:

$$E_1 = E_2$$

$$I_1 Z_1 = I_2 Z_2$$

Also at balance,

$$I_1 = I_3 = \frac{E}{Z_1 + Z_3}$$

$$I_2 = I_4 = \frac{E}{Z_2 + Z_4}$$

On Substitutions we get,

$$Z_1 Z_4 = Z_2 Z_3$$

Or when using admittances instead of impedances

$$Y_1 Y_4 = Y_2 Y_3$$

Above two equations represent the basic equations for the balance of an ac bridge.

Equation $Z_1Z_4 = Z_2Z_3$ is convenient to use when dealing with series elements of a bridge while equation $Y_1Y_4 = Y_2Y_3$ is useful when dealing with parallel elements.

Equation $Z_1Z_4 = Z_2Z_3$ states that the product of impedances of one pair opposite arms must equal the product of impedances of the other pair of opposite arms expressed in complex notation. This means that both magnitudes and the phase angles of the impedances must be taken into account.

Considering the polar form, the impedance can be written as $Z = Z\angle\theta$, where Z represents the magnitude and θ represent the phase angle of the complex impedance. Now that equation can be re-written in the form

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

Thus for balance, we must have,

$$Z_1Z_4 \angle\theta_1+\theta_4 = Z_2Z_3\angle\theta_{2+}\theta_3$$

The above equation shows that two conditions must be satisfied simultaneously when balancing an ac bridge. The first condition is that the magnitude of impedances satisfies the relationship:

$$Z_1Z_4 = Z_2Z_3$$

The second condition is that the phase angles of impedances satisfy the relationship:

$$\angle\theta_1+\theta_4 = \angle\theta_{2+}\theta$$

The phase angles are positive for inductive impedance and negative for capacitive impedance.
If we work in terms of rectangular coordinates, we have

$Z_1= R_1 + jX_1$; $\qquad$ $Z_2= R_2 + jX_2$

$Z_3= R_3 + jX_3$ $\qquad$ and $\qquad$ $Z_4= R_4 + jX_4$

For balance, $\quad Z_1Z_4 = Z_2Z_3$

Or $\quad (R_1 + jX_1)\ (R_4 + jX_4) = (R_2 + jX_2)\ (R_3 + jX_3)$

Or $\quad R_1R_4 - X_1X_4 + j\ (X_1R_4 + X_4R_1) = R_2\ R_3 - X_1\ X_4 + j\ (X_2R_3 + X_3R_2)$

The above equation is a complex equation and a complex equation is satisfied only if real and imaginary parts of each side of the equation are separately equal. Thus, for balance,

$$R_1R_4 - X_1X_4 = R_2\ R_3 - X_1\ X_4$$
$$X_1R_4 + X_4R_1 = X_2R_3 + X_3R_2$$

Thus there are two independent conditions for balance and both of them must be satisfied for the *Ac Bridge* to be balanced.

Maxwell's Bridge

The bridge used for the measurement of self-inductance of the circuit is known as the Maxwell Bridge. It is the advanced form of the Wheatstone 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.

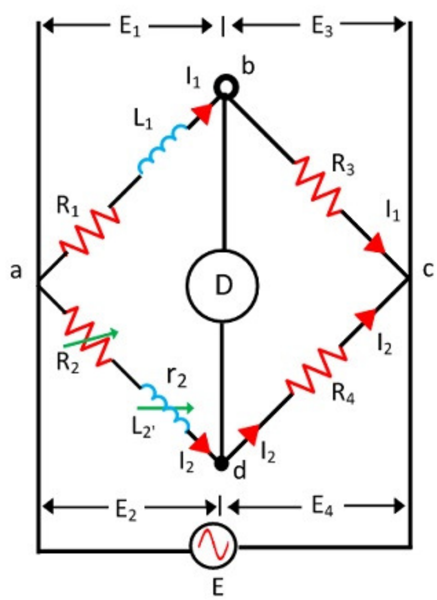
Types of Maxwell's Bridge

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

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

Maxwell's Inductance Bridge

In such type of bridges, the value of unknown resistance is determined by comparing it with the known value of the standard self-inductance. The connection diagram for the balance Maxwell Bridge is shown in the figure below.



Let,

L_1 = unknown inductance of resistance R_1.

L_2 = Variable inductance of fixed resistance r_2.

R_2 = variable resistance connected in series with inductor L_2.

R_3, R_4 = known non-inductance resistance

At balance, $Z_1Z_4 = Z_2Z_3$

Or $(R_1 + jX_1) R_4 = (R_2 + r_2 + jX_2) R_3$

Or $(R_1 + j\omega L_1) R_4 = (R_2 + r_2 + j\omega L_2) R_3$

Or $R_1 R_4 + j\omega L_1 R_4 = (R_2 + r_2) R_3 + j\omega L_2 R_3$

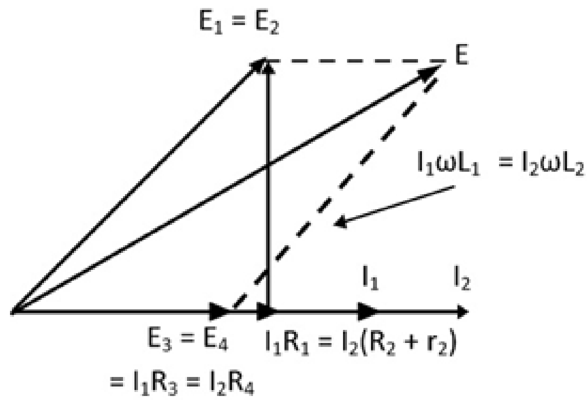
Comparing Real part, $R_1 R_4 = (R_2 + r_2) R_3$

Or $R_1 = (R_3/R_4) (R_2 + r_2)$

Comparing imaginary parts,

$$\omega L_1 R_4 = \omega L_2 R_3$$

$$L_1 = L_2 R_3 / R_4$$



Phasor Diagram of Maxwell's Inductance Bridge

So,

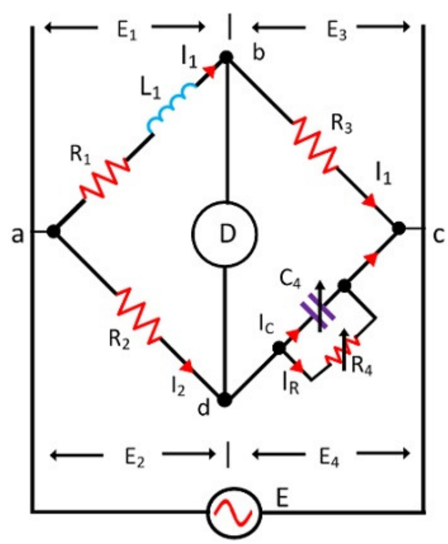
$$L_1 = \frac{R_3}{R_4} L_2$$

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

The value of the R_3 and the R_4 resistance varies from 10 to 1000 ohms with the help of the resistance box. Sometimes for balancing the bridge, the additional resistance is also inserted into the circuit.

Maxwell's Inductance Capacitance Bridge

In this type of bridges, the unknown resistance is measured with the help of the standard variable capacitance. The connection diagram of the Maxwell Bridge is shown in the figure below.



Let,

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, $Z_1Z_4 = Z_2Z_3$

Or $(R_1 + jX_1)\ (R_4 \parallel jX_2) = R_2R_3$

Or
$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2R_3$$

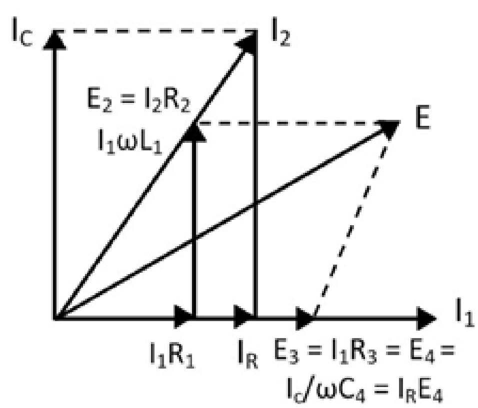
Or
$$R_1R_4 + j\omega L_1 R_4 = R_2R_3 + j\omega C_4 R_4 R_2 R_3$$

Comparing Real part, $R_1\ R_4 = R_2\ R_3$

Or $R_1 = R_2R_3/R_4$

Comparing imaginary parts,

$$\omega L_1\ R_4 = \omega R_2R_3R_4C_4$$
$$L_1 = R_2R_3C_4$$



Phasor Diagram of Maxwell's Inductance Capacitance Bridge

So,

$$R_1 = \frac{R_2R_3}{R_4}$$

$$L_1 = R_2R_3C_4$$

The above equation shows that the bridges have two variables R_4 and C_4 which appear in one of the two equations and hence both the equations are independent.

The circuit quality factor is expressed as

$$Q = \frac{\omega L_1}{R_1} = \omega C_4 R_4$$

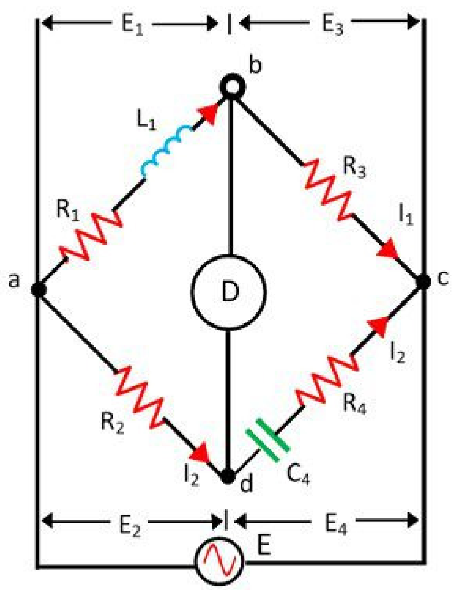
Hay's Bridge

The Hay's bridge is used for determining the self-inductance of the circuit. The bridge is the advanced form of Maxwell's bridge. The Maxwell's bridge is only appropriate for measuring the medium quality factor. Hence, for measuring the high-quality factor the Hays Bridge is used in the circuit.

In Hay's bridge, the capacitor is connected in series with the resistance, the voltage drop across the capacitance and resistance are varied. Thus, the magnitude of a voltage pass through the resistance and capacitor is equal.

Construction of Hay's Bridge

The unknown inductor L_1 is placed in the arm ab along with the resistance R_1. This unknown inductor is compared with the standard capacitor C_4 connected across the arm cd. The resistance R_4 is connected in series with the capacitor C_4. The other two non-inductive resistors R_2 and R_3 are connected in the arm ad and bc respectively.



The C_4 and R_4 are adjusted for making the bridge in the balanced condition. When the bridge is in a balanced condition, no current flows through the detector which is connected to point b and c respectively. The potential drops across the arm ad and cd are equal and similarly, the potential across the arm ab and bc are equal.

Let,

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,

$$(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2 R_3$$

$$R_1 R_4 + \frac{L_1}{C_4} + j\omega L_1 R_4 - \frac{jR_1}{\omega C_4} = R_2 R_3$$

Separating the real and imaginary term, we obtain

$$R_1 R_4 + \frac{L_1}{C_4} = R_2 R_3 \quad and\; L_1 = \frac{-\ R_1}{\omega^2 R_4 C_4}$$

Solving the above equation, we have

$$L_1 = \frac{R_2 R_3 C_4}{1 + \omega^2 R_4^2 C_4^2}$$

$$R_1 = \frac{\omega^2 C_4^2 R_2 R_3 R_4}{1 + \omega^2 R_4^2 C_4^2}$$

The quality factor of the coil is

$$Q = \frac{\omega L_1}{R_1} = \frac{1}{\omega^2 C_4 R_4}$$

The equation of the unknown inductance and capacitance consists frequency term. Thus for finding the value of unknown inductance the frequency of the supply must be known.

For the high-quality factor, the frequency does not play an important role.

$$Q = \frac{1}{\omega^2 C_4 R_4}$$

Substituting the value of Q in the equation of unknown inductance, we get

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

For greater value of Q the 1/Q is neglected and hence the equation become

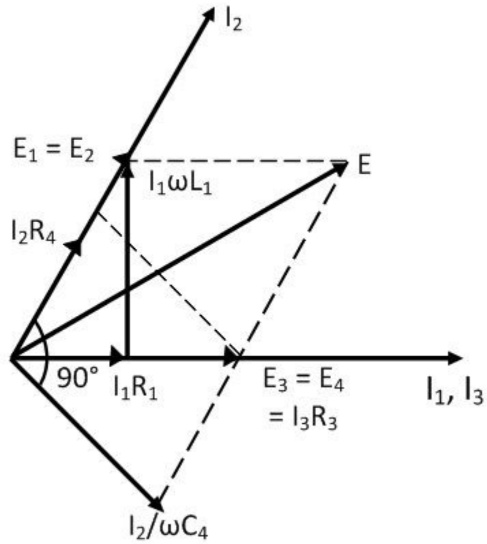
$$L_1 = R_2 R_3 C_4$$

Phasor Diagram of Hay’s Bridge

The phasor diagram of the Hay’s bridge is shown in the figure below. The magnitude and the phase of the E_3 and E_4 are equal and hence they are overlapping each other and draw on the horizontal axis. The current I_1 flow through the purely resistive arm bd. The current I_1 and the potential $E_3 = I_3R_3$ are in the same phase and represented on the horizontal axis.

The current passes through the arm ab produces a potential drop I_1R_1 which is also in the same phase of I_1. The total voltage drop across the arm ab is determined by adding the voltage I_1R_1 and ωI_1L_1.

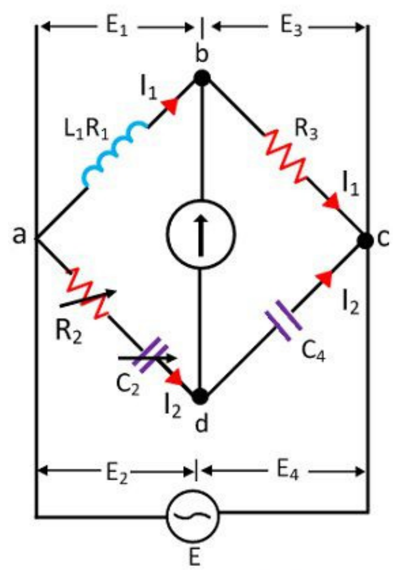
The voltage drops across the arm ab and ad are equal. The voltage drop E_1 and E_2 are equal in magnitude and phase and hence overlap each other. The current I_2 and E_2 are in the same phase as shown in the figure.



The current I_2 flows through the arms cd and produces the I_2R_4 voltage drops across the resistance and $I_2/\omega C_4$ voltage drops across the capacitor C_4. The capacitance C_4 lags by the currents 90º. The voltage drops across the resistance C_4 and R_4 gives the total voltage drops across the arm cd. The sum of the voltage E_1 and E_3 or E_2 and E_4 gives the voltage drops E.

Owen's Bridge

The bridge which measures the inductance in terms of capacitance is known as Owen's bridge. It works on the principle of comparison i.e., the value of the unknown inductor is compared with the standard capacitor. The connection diagram of Owen's bridge is shown in the figure.

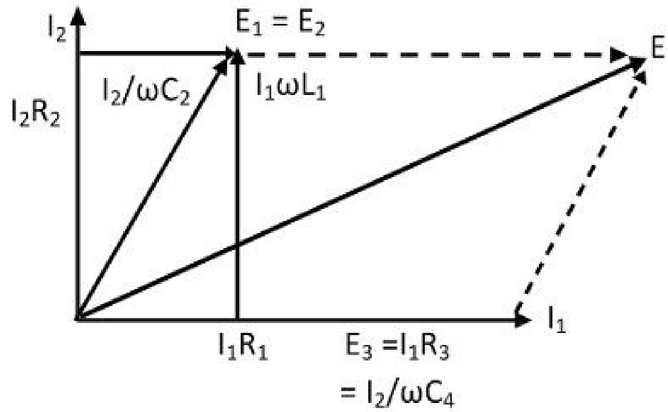


The ab, bc, cd and da are the four arms of Owen's bridge. The arms ab is purely inductive and the arm bc is purely resistive in nature. The arm cd has fixed capacitor and the arm ad consists the variable resistor and capacitor connected in series with the circuit.

The unknown inductor L_1 of arm ab is compared with the known capacitor C_4 connected to the arm cd. The bridge is kept in balanced condition by independently varying the resistor R_2 and the capacitor C_2. At the balanced condition, no current flows through the detector. The end points (b and c) of the detector are at the same potential.

Phasor Diagram of Owen's Bridge

The phasor diagram of Owen's bridge is shown in the figure below.



The current I_1, $E_3 = I_3R_3$ and $E_4 = \omega I_2C_4$ are all on the same phases and are represented on the horizontal axis. The voltage drop I_1R_1 in the arm ab is also represented on the horizontal axis.

The sum of the inductive voltage drop ωL_1I_1 and the resistive voltage drop I_1R_1 gives the voltage drop E_1 of the arm ab. When the bridge is in the balanced condition the potential E_1 and E_2 across the arm ab and ad are equal. Thus, it is shown on the same axis.

The voltage drop V_2 is the summation of the resistive voltage drop I_2R_2 and capacitive voltage drop I_2/wC_2. The I_2 of the arm ad lead by 90º with the voltage drop V_4 of the arm cd because of the fixed capacitor C_4.

The current I_2 and the voltage I_2R_2 are represented on the vertical phases shown in the figure above. The supply voltage is obtained by adding the voltage V_1 and V_3.

Theory of Owen's Bridge

Let,

L_1 = unknown self-inductance of resistance R_1

R_2 = variable non-inductive resistance

R_3 = fixed non-inductive resistance

C_2 = variable standard capacitor

C_4 = fixed standard capacitor

At balance condition,

$$(R_1 + j\omega L_1)\left(\frac{1}{j\omega C_4}\right) = \left(R_2 + \frac{1}{j\omega C_2}\right)R_3$$

On separating the real and imaginary part we get,

$$L_1 = R_2R_3C_4$$

And,

$$R_1 = R_3\frac{C_4}{C_2}$$

Schering Bridge

The Schering Bridge is used for measuring the capacitance of the capacitor, dissipation factor, properties of an insulator, capacitor bushing, insulating oil and other insulating materials. It is one of the most commonly used AC Bridge. The Schering Bridge works on the principle of balancing the load on its arm.

Let,

C_1 = capacitor whose capacitance is to be determined,

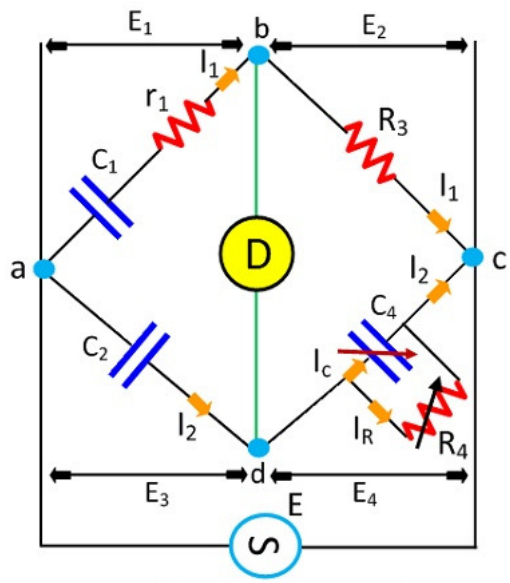
r_1 = a series resistance, representing the loss of the capacitor C_1.

C_2 = a standard capacitor (The term standard capacitor means the capacitor is free from loss)

R_3 = a non-inductive resistance

C_4 = a variable capacitor.

R_4 = a variable non-inductive resistance parallel with variable capacitor C_4.



When the bridge is in the balanced condition, zero current passes through the detector, which shows that the potential across the detector is zero.

At balance condition, $Z_1/Z_2 = Z_3/Z_4$

Or $Z_1Z_4 = Z_2Z_3$

So,

$$\left(r_1 + \frac{1}{jwC_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2}.R_3$$

$$\left(r_1 + \frac{1}{jwC_1}\right)R_4 = \frac{R_3}{jwC_2}(1 + j\omega C_4 R_4)$$

$$r_1 R_4 - \frac{jR_4}{\omega C_1} = -j\frac{R_3}{\omega C_1} + \frac{R_3 R_4 C_4}{C_2}$$

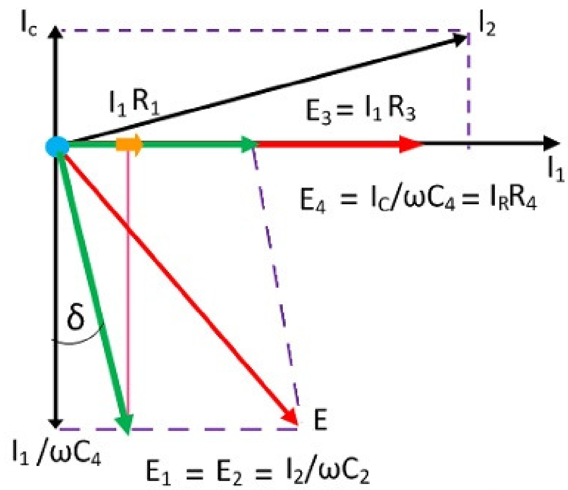
Equating the real and imaginary equations, we get

$$r_1 = \frac{R_3 C_4}{C_2} \dots \dots \dots . equ(1)$$

$$C_1 = C_2 \left({R_4}/{R_3} \right) \dots \dots \dots equ(2)$$

The equation (1) and (2) are the balanced equation, and it is free from the frequency.

The dissipation factor obtains with the help of the phasor diagram. The dissipation factor determines the rate of loss of energy that occurs because of the oscillations of the electrical and mechanical instrument.



$$D_1 = tan\delta = \omega C_1 r_1 = \omega(C_1 r_1) = \omega(C_2 R_4/R_3) \times (R_3 C_4/C_2)$$

$$D_1 = \omega C_4 R_4$$

By the help of the above equation, we can calculate the value of tanδ which is the dissipation factor of the Schering Bridge.

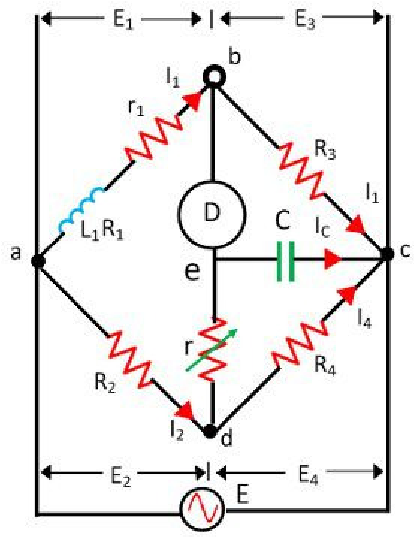
Anderson's Bridge

The Anderson's bridge gives the accurate measurement of self-inductance of the circuit. The bridge is the advanced form of Maxwell's inductance capacitance bridge. In Anderson bridge, the unknown inductance is compared with the standard fixed capacitance which is connected between the two arms of the bridge.

Constructions of Anderson's Bridge

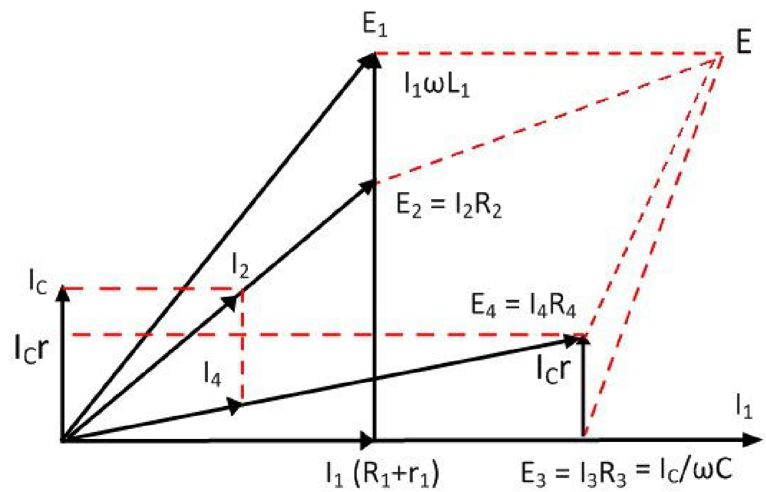
The bridge has fours arms ab, bc, cd, and ad. The arm ab consist unknown inductance along with the resistance. And the other three arms consists the purely resistive arms connected in series with the circuit.

The static capacitor and the variable resistor are connected in series and placed in parallel with the cd arm. The voltage source is applied to the terminal a and c.



Phasor Diagram of Anderson's Bridge

The phasor diagram of the Anderson Bridge is shown in the figure below. The current I_1 and the E_3 are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm bc and ec are equal.



The current enters into the bridge is divided into the two parts I_1 and I_2. The I_1 is entered into the arm ab and causes the voltage drop $I_1(R_1+R)$ which is in phase with the I_1. As the bridge is in the balanced condition, the same current is passed through the arms bc and ec.

The voltage drop E_4 is equal to the sum of the $I_C/\omega C$ and the $I_C r$. The current I_4 and the voltage E_4 are in the same phase and representing on the same line of the phasor diagram. The sum of the current I_C and I_4 will give rise to the current I_2 in the arm ad.

When the bridge is at balance condition the emf across the arm ab and the point a, d and e are equal. The phasor sum of the voltage across the arms ac and de will give rise the voltage drops across the arm ab.

The V_1 is also obtained by adding the $I_1(R_1+r_1)$ with the voltage drop $\omega I_1 L_1$ in the arm AB. The phasor sum of the E_1 and E_3 or E_2 and E_4 will give the supply voltage.

Theory of Anderson Bridge

Let,

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,

$$I_1 = I_3 \; and \; I_2 = I_C + I_4$$

Now,

$$I_1 R_3 = I_C \times \frac{1}{j\omega C}$$

$$I_C = I_1 \omega C R_3$$

The other balance condition equation is expressed as

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_C r$$

$$I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_C) R_4$$

By substituting the value of I_c in the above equation we get,

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

and

$$I_1(R_3 + j\omega R_3 R_4 + j\omega C R_3 r) = I_2 R_4$$

On equating the equation, we get

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1(\frac{R_1 R_2}{R_3} + \frac{j\omega C R_3 r R_2}{R_4} + j\omega C R_3 R_2)$$

Equating the real and the imaginary part, we get

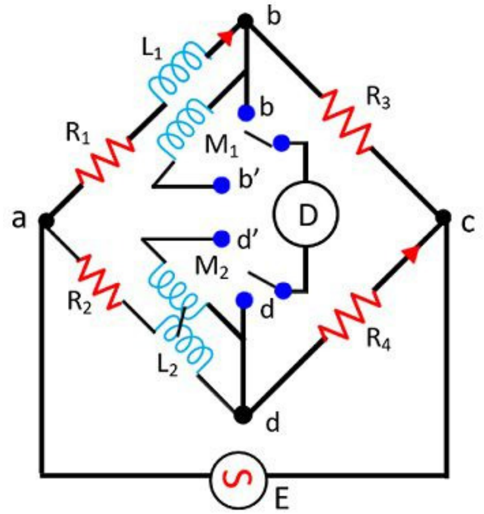
$$R_1 = \frac{R_1 R_3}{R_4} - r_1$$

$$L_1 = C\frac{R_3}{R_4}\left[4(R_4 + R_2) + R_2 R_4\right]$$

Campbell's Bridge

The bridge which measures the unknown mutual inductance regarding mutual inductance such type of bridge is known as the Campbell Bridge. The mutual inductance is the phenomenon in which the variation of current in one coil induces the current in the nearer coil. The bridge also used for measuring the frequency by adjusting the mutual inductance until the null point is not obtained.

Consider the figure below shows the mutual inductance.



Let,

M_1 = unknown mutual inductance

L_1 = self-inductance of secondary of mutual inductance M_1

M_2 = variable standard mutual inductance

L_2 = self-inductance of secondary of mutual inductance M_2

R_1, R_2, R_3, R_4 = non-inductive resistance

The two steps are required for obtaining the balanced position of the bridge.

1. The detector is connected between points 'b' and, 'd'. The circuit behaves like a simple self-inductance commercial bridge. The condition requires for obtaining the balanced position of a bridge is

$$\frac{L_1}{L_2} = \frac{R_1}{R_2} = \frac{R_3}{R_4}$$

The bridge is in balanced condition by adjustment the R_3 or R_4 and R_1 and R_2.

2. The detector is connected between the b' and d'. Along with the step-1 adjustment if the mutual inductance M_2 is varied, then the balance point is obtained.

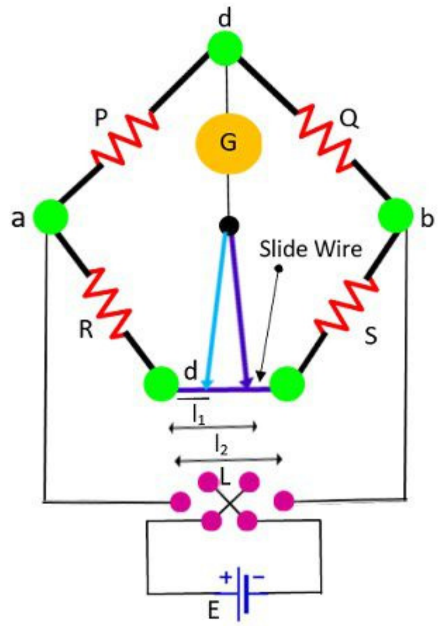
$$\frac{M_1}{M_2} = \frac{R_3}{R_4}$$

$$M_1 = \frac{M_2 R_3}{R_4}$$

Carey-Foster Slide-Wire Bridge

The Carey Foster Bridge is used for measuring the low resistance or for the comparison of two nearly equal resistances. The working principle of the Carey foster bridge is similar to the Wheatstone bridge.

The circuit for the Carey foster bridge is shown in the figure below.



Let P, Q, R and S are the four resistors used in the bridge. The resistances of P and R are known while the R and S are the unknown resistors. The slide wire of length L is placed between the resistance R and S. The resistor P and Q are adjusted so that the ratio of P/Q is equivalent to the R/S. The ratio of the resistance is equivalent by sliding the contact on the sliding wiring.

Let l_1 is the distance from the left at which the balanced is obtained. Now the R and S are interchanged, and this time the balanced is obtained by sliding the contact at the distance of l_2.

Consider the equation for first balance

$$\frac{P}{Q} = \frac{R + l_1 r}{S + (L - l_1)r}$$

The r is the resistance per unit length of the sliding wire.

After interchanging the R and S, the balance equation of the bridge is

$$\frac{P}{Q} = \frac{S + l_2 r}{R + (L - l_2)}$$

For the first balance equation

$$\frac{P}{Q} + 1 = \frac{R + l_1 r + S + (L - l_1)r}{S + (L - l_1)r} \dots\dots\dots..(1)$$

$$\frac{P}{Q} = \frac{R + S + l_1 r}{S + (L - l_1)r}$$

And for the second balance equation

$$\frac{P}{Q}+1=\frac{S+l_2r+R+(L-l_1)r}{R+(L-l_2)r} \dots\dots\dots\dots (2)$$

$$\frac{P}{Q}+1=\frac{S+R+Lr}{R+(L-l_2)r}$$

From equation (1) and (2)

$$S+(L-l_1)r=R+(L-l_1)r$$

$$\text{S - R} = (\, l_1 - l_2)$$

The difference between the resistance of S and R is obtained from a distance between the lengths of the slide-wire, i.e., $l_1 - l_2$ at balance condition.

Calibration of Slide Wire

The calibration of the sliding wire can be done by placing the resistance R or S in parallel with the slide wire of known resistance. Let S is known and S' is its values when shunted by known resistance.

$$\text{S - R} = (\, l_1 - l_2)r \text{ and } S' - \text{R} = (\, l'_1 - l'_2)r$$

$$\frac{S-R}{(l_1-\;l_2)}=\;\frac{S'-R}{(l'_1-\;l'_2)}$$

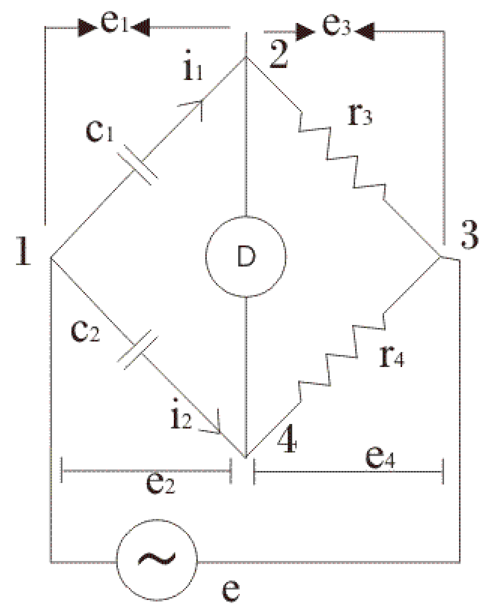
By solving the above equation, we get

$$R=\;\frac{S(l'_1-\;l'_2)-S(l_1-\;l_2)}{(l'_1-\;l'_2-l_1+\;l_2)} \dots\dots\dots..(3)$$

By the help of the Carey foster bridge, the direct comparison between the resistance R and S regarding length can be done. The resistance of other components like the resistance of P, Q and sliding contact are completely eliminated.

De-Sauty's Bridge

This bridge provides us the most suitable method for comparing the two values of capacitor if we neglect dielectric losses in the bridge circuit. The circuit of De Sauty's bridge is shown below.



Battery is applied between terminals marked as 1 and 4. The arm 1-2 consists of capacitor c_1 (whose value is unknown) which carries current i_1 as shown, arm 2-4 consists of pure resistor (here pure resistor means we assuming it non inductive in nature), arm 3-4 also consists of pure resistor and arm 4-1 consists of standard capacitor whose value is already known to us. Let us derive the expression for capacitor c_1 in terms of standard capacitor and resistors.

At balance condition we have,

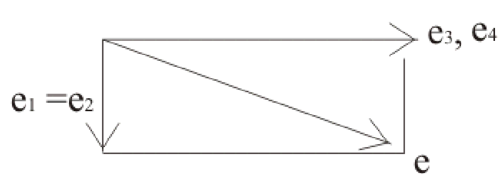
$$\frac{1}{j\omega c_1} \times r_4 = \frac{1}{j\omega c_2} \times r_3$$

It implies that the value of capacitor is given by the expression

$$c_1 = c_2 \times \frac{r_4}{r_3}$$

In order to obtain the balance point we must adjust the values of either r_3 or r_4 without disturbing any other element of the bridge. This is the most efficient method of comparing the two values of capacitor if all the dielectric losses are neglected from the circuit.

Now let us draw and study the phasor diagram of this bridge. Phasor diagram of De Sauty Bridge is shown below:

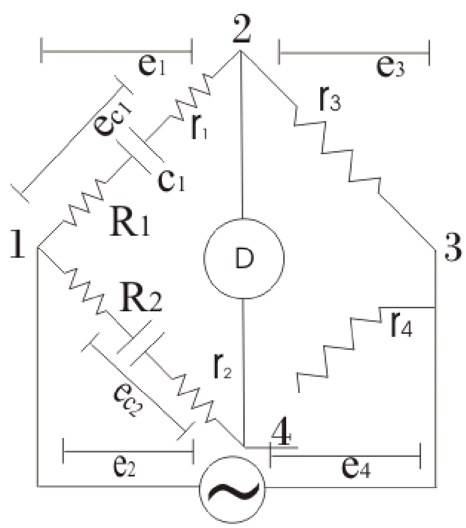


Phasor diagram

Let us mark the current drop across unknown capacitor as e_1, voltage drop across the resistor r_3 be e_3, voltage drop across arm 3-4 be e_4 and voltage drop across arm 4-1 be e_2. At balance condition the current flows through 2-4 path will be zero and also voltage drops e_1 and e_3 be equal to voltage drops e_2 and e_4 respectively.

In order to draw the phasor diagram we have taken e_3 (or e_4) reference axis, e_1 and e_2 are shown at right angle to e_1 (or e_2). Why they are at right angle to each other? Answer to this question is very simple as capacitor is connected there; therefore phase difference angle obtained is 90^o. Now instead of some advantages like bridge is quite simple and provides easy calculations, there are some disadvantages of this bridge because this bridge give inaccurate results for imperfect capacitor (here imperfect means capacitors which not free from dielectric losses). Hence we can use this bridge only for comparing perfect capacitors.

Here we interested in modify the De Sauty's bridge; we want to have such a kind of bridge that will gives us accurate results for imperfect capacitors also. This modification is done by Grover. The modified circuit diagram is shown below:



Here Grover has introduced electrical resistances r_1 and r_2 as shown in above on arms 1-2 and 4-1 respectively, in order to include the dielectric losses. Also he has connected resistances R_1 and R_2 respectively in the arms 1-2 and 4-1. Let us derive the expression capacitor c_1 whose value is unknown to us. Again we connected standard capacitor on the same arm 1-4 as we have done in De Sauty's bridge. At balance point on equating the voltage drops we have:

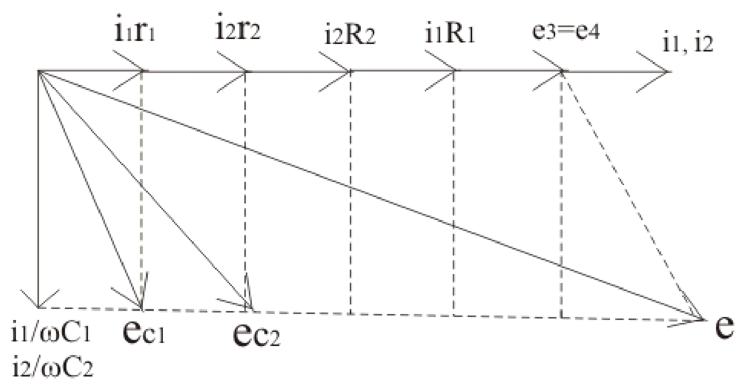
$$\left(R_1 + r_1 + \frac{1}{j\omega c_1}\right) r_4 \;=\; \left(R_2 + r_2 + \frac{1}{j\omega c_2}\right) r_3 \cdots\cdots\cdots (1)$$

On solving above equation we get:

$$\frac{c_1}{c_2} \;=\; \frac{R_2 + r_2}{R_1 + r_1} \;=\; r_4 r_3$$

This is the required equation.

By making the phasor diagram we can calculate dissipation factor. Phasor diagram for the above circuit is shown below



Let us mark δ_1 and δ_2 be phase angles of the capacitors c_1 and c_2 capacitors respectively. From the phasor diagram we have tan (δ_1) = dissipation factor = $\omega c_1 r_1$ and similarly we have tan (δ_2) = $\omega c_2 r_2$.

From equation (1) we have

$$c_2 r_2 - c_1 r_1 = c_1 R_1 - c_2 R_2$$

On multiplying ω both sides we have

$$\omega c_2 r_2 - \omega c_1 r_1 \ = \ \omega(c_1 R_1 - c_2 R_2)$$

But,

$$\frac{c_1}{c_2} \ = \ \frac{r_4}{r_3}$$

Therefore the final expression for the dissipation factor is written

$$tan(\delta_1) - tan(\delta_2) \ = \ \omega c_2 \left(R_1 \frac{r_4}{r_3} - R_2 \right)$$

Hence if dissipation factor for one capacitor is known. However this method is gives quite inaccurate results for dissipation factor.

Potentiometer (POT)

The instrument designs for measuring the unknown voltage by comparing it with the known voltage, such type of instrument is known as the potentiometer. In other words, the potentiometer is the three terminal device used for measuring the potential differences by manually varying the resistances. The known voltage is drawn by the cell or any other supply sources.
The potentiometer uses the comparative method which is more accurate than the deflection method. So, it is mostly used in the places where higher accuracy is required or where no current flows from the source under test. The potentiometer is used in the electronic circuit, especially for controlling the volume.

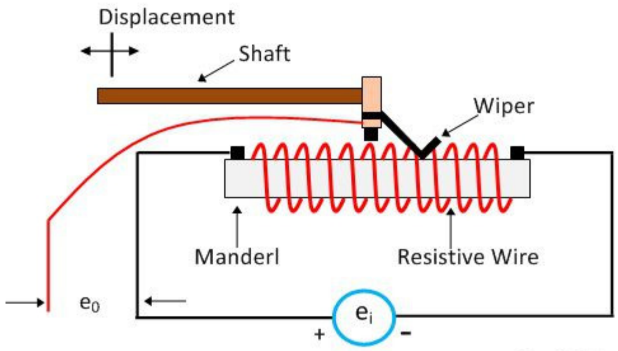
Characteristics of Potentiometer

The following are the important characteristics of the potentiometer.

1. The potentiometer is very accurate because its works on the comparing method rather than the deflection pointer method for determining the unknown voltages.
2. It measures the null or balance point which does not require power for the measurement.
3. The working of the potentiometer is free from the source resistance because no current flows through the potentiometer when it is balanced.

Construction of Potentiometer

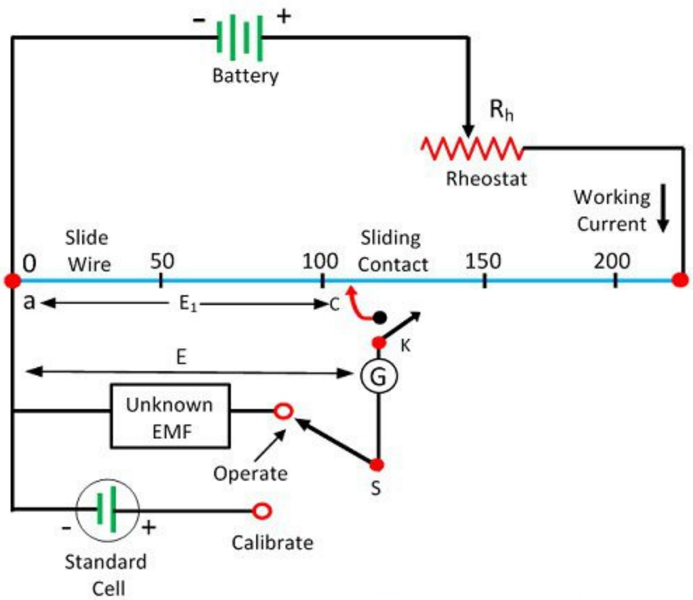
The construction of the potentiometer is categorized into two parts. They are the sliding and non-sliding parts. The sliding contact is a called wiper. The motion of the sliding contacts is either translatory or rotational. Some potentiometer uses both the translatory and rotational motions. Such type of potentiometer uses the resistor in the form of a helix, and hence they are called heliports.



The potentiometer has three terminals, the two terminals are connected to the resistor, and the third terminal is connected to the wiper which is movable with the wire. Because of this moving wire, the variable potential is tapped off. The third terminal is used for controlling the variable resistor. The potential of the third terminal is controlled by changing the applying potential at the end of the resistor. The body of the potentiometer is made up of resistive material, and the wire is wound on it.

Working of Potentiometer

The working principle of the potentiometer is explained through the circuit shown below. Consider S is the switch used for connecting or disconnecting the galvanometer from the potentiometer. The batteries through the rheostat and slide wire supply the working current. The working current may vary by changing the setting of the rheostat.



The method of findings the unknown voltage depends on the sliding position of the contact at which the galvanometer shows the zero deflection. The zero or null deflection of galvanometer shows that the potential of the unknown source E and the voltage drops E_1 across the sliding wires are equal. Thus, the potential of the unknown voltage is evaluated by knowing the voltage drop across the ac portion of the sliding wire.

The slide wire has the uniform cross-section and resistance across the entire length. As the resistance of the sliding wire is known, then it is easily controlled by adjusting the working current. The process of equalizing the working voltage as that of voltage drop is known as the standardization.

AC Potentiometer

The potentiometer which is used for measuring the phase and the magnitude of the unknown emf by comparing it with the known emf such type of potentiometer is known as the AC potentiometer. The working principle of the AC potentiometer is same as that of the DC potentiometer, i.e., the unknown voltage is determined by comparing it with the known voltage. And when both of them are equal the galvanometer indicates the null point. Hence the value of the unknown emf is known.

The operation of the AC potentiometer is quite complicated as compared to the DC potentiometer. The following are the important factor which must be considered for their operation.

1. In AC potentiometer, the frequency and the waveform of the current must be same as that of the voltage being measured. Thus, in AC potentiometer the potential is transferred from the same source as the current or voltage is measured.

2. The non-inductive element is used for making the sliding wire and the resistance coil of the AC potentiometer which reduces the reading error.
3. The reading of the AC potentiometer is affected by the external magnetic field. So, they are eliminated at the time of measurement.
4. The supply source should be sinusoidal and free from harmonics because in the presence of the harmonics the balanced is not easily achieved.

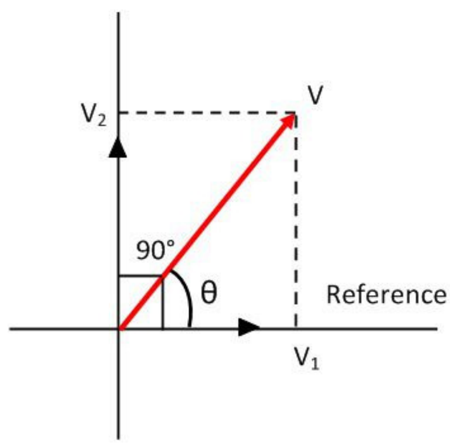
Types of AC Potentiometer

The AC potentiometers are classified by the value measured by the potentiometer dial and scales. The AC potentiometer may be broadly classified as-

1. Polar type potentiometer
2. Coordinate type potentiometer

Polar Type Potentiometer

In this potentiometer, the magnitude of the unknown voltage is measured from one scale, and its phase angle is directly on the second scale. The arrangement is made to read phase angles up to 360°. The voltage is read in the form of $V\angle\theta$.



Coordinate Type Potentiometer

The coordinate type potentiometer has two scales to read the in phase V_1 component, and the quadrature component V_2 of the unknown voltage V. These voltages are 90° out of phase with each other. The potentiometer is constructed in such a way so that the potentiometer read both the positive and negative value of V_1 and V_2 and covered the entire angle up to 360°.

Applications of Potentiometer

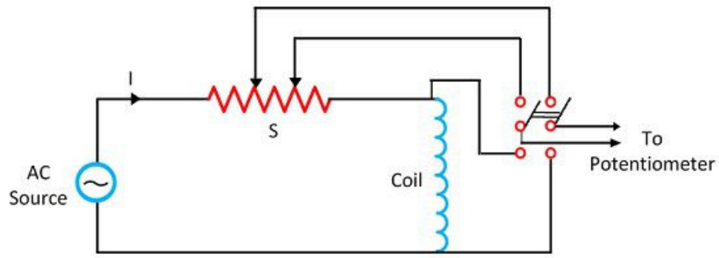
The AC potentiometer has numerous applications. The few of them are explained below in details.

1. **Voltmeter Calibration** – The AC potentiometer directly measures the low voltages up to 1.5V. The higher voltage is measured by either using the volt box ratio or two capacitors in series with the potentiometer.

2. **Ammeter Calibration** – The measurement of the alternating current may be measured by the use of non-inductive standard resistor with the potentiometer.

3. **Wattmeter and Energy Meter Testing –** The testing circuit of the Wattmeter and the energy meter is same as that of the DC measurements. The phase shifting transformer is connected to the potentiometer to vary the phase of the voltage on the current. Thus, the voltage and current may vary at different power factor.

4. **Measurements of Self Reactant of a Coil –** The standard reactance is placed in series with the coil whose reactance is to be measured.



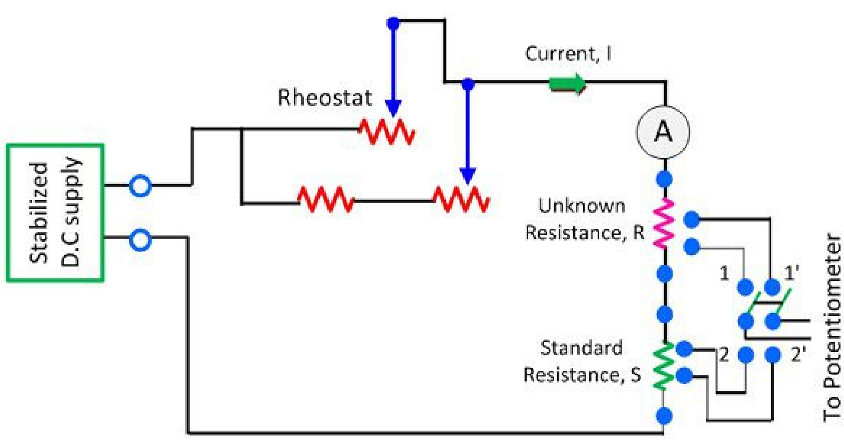
Measurement of Self Reactance of Coil

5**. Other Applications –** The AC potentiometer is used for engineering measurement in which the accuracy of 0.5 to 1% is essentials. The AC potentiometer is also used for measuring the voltage which must be resolved into two components. It gives the accurate results in magnetic testing and precise testing of instrument transformers.

Measurement of Resistance using Potentiometer

The DC potentiometer method of measurement of resistance is used for measuring the unknown resistance of low value. This can be done by comparing the unknown resistance with the standard resistance. The voltage drop across the known and unknown resistance is measured and by comparison the value of known resistance is determined.

Let understand this with the help of the circuit diagram. The R is the unknown resistance whose value is needed to be measured. The S is the standard resistance from which the value of unknown resistance is compared. The rheostat is used for controlling the magnitude of current into the circuit.



The double pole double throw switch is used in the circuit. The switch, when moves to position 1, 1´the unknown resistance connects to the circuit, and when it moves to position 2, 2´ the standard resistance connects to the circuit.

Consider that when the switch is in position 1,1 the voltage drop across the unknown resistance is V_r

$$V_R = IR$$

And when it is in 2, 2 the voltage drop across the resistance is V_s

$$V_S = IS$$

On equating the equation (1) and (2), we get

$$\frac{V_R}{V_S} = \frac{IR}{IS}$$

$$\frac{V_R}{V_S} = \frac{R}{S}$$

$$R = \frac{V_R}{V_S}.S$$

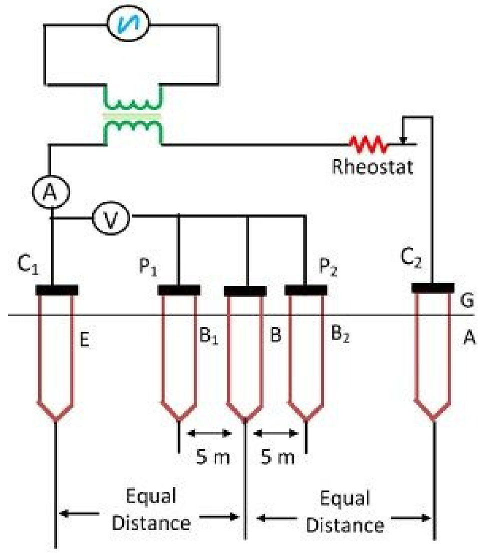
The accuracy of unknown resistance depends on the value of standard resistance.

The accuracy of the unknown resistance also depends on the magnitude of the current at the time of the readings. If the magnitude of current remains same, the circuit gives the accurate result. The ammeter is used in the circuit for determining the magnitude of current passing through resistor during the reading.

The magnitude of the current is adjusted in such a way that the voltage drop across the resistance is equal to 1 volt.

Measurement of Earth Resistance

The measurement of earth resistance is made by the potential fall method. The resistance area of the earth electrode is the area of the soil around which a voltage gradient is measured with a commercial instrument. In the figure shown below E is the earth electrode under rest, and A is an auxiliary earth electrode positioned so that two resistance areas do not overlap. B is the second auxiliary electrode which is placed between E and A.



An alternating current of steady state value passes through the earth path from E to A and the voltage drop between E and B is measured.

$$R_e = \frac{Voltage\ drop\ between\ E\ and\ B}{Current\ through\ earth\ path}$$

$$R_e = \frac{V}{I}$$

The electrode B is moved from position B_1 and B_2 respectively so that the resistances do not overlap. If the resistance values determined is of approximately the same in all three cases, the mean of the three readings can be taken as the earth resistance of the earth electrode.

The auxiliary earth electrode A must be driven in at a point further away from E and the above test repeated until the groups of three readings obtained are in good agreement. The alternating current source is used to eliminate the electrolytic effect.

The test can be performed, with current at power frequency from a double wound transformer, using a voltmeter and an ammeter as shown in the figure above by mean of an earth tester.

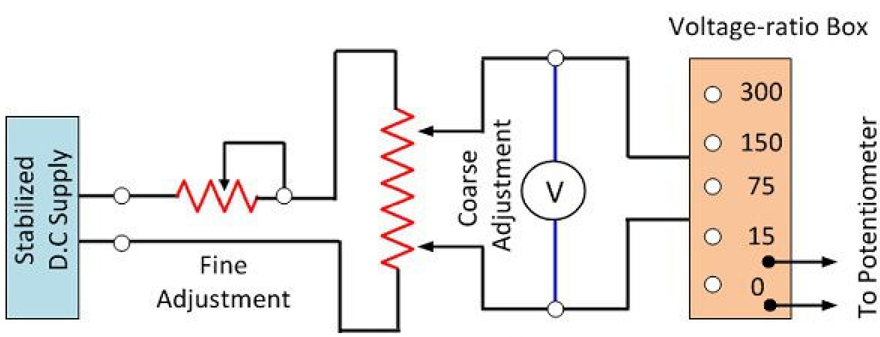
The earth tester is a special type of Megger, which sends AC through earth and DC through the measuring instrument. It has got four terminals. Two terminals are shorted to form a common point which is connected to the earth electrode under test. The other two terminals are connected to the auxiliary electrode A and B respectively. The value of the earth resistance is indicated by the instrument directly when its handle is turned at a uniform speed.

Calibration of Voltmeter, Ammeter & Wattmeter using Potentiometer

The calibration is the process of checking the accuracy of the result by comparing it with the standard value. In other words, calibration checks the correctness of the instrument by comparing it with the reference standard. It helps us in determining the error occurs in the reading and adjusts the voltages for getting the ideal reading.

Calibration of Voltmeter

The circuit for the calibration of the voltmeter is shown in the figure below.

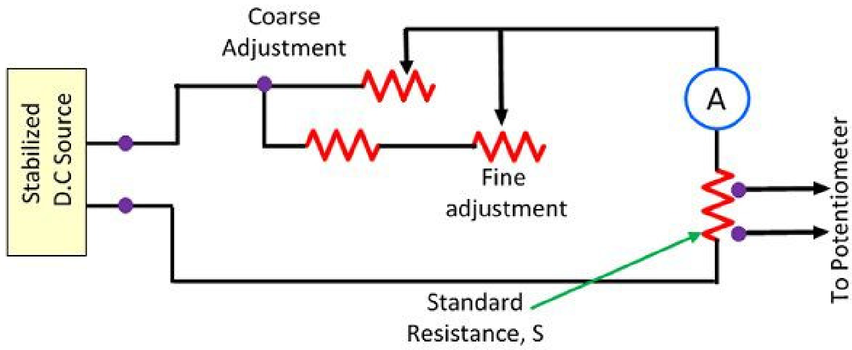


The circuit requires two rheostats, one for controlling the voltage and another for adjustment. The voltage ratio box is used to step-down the voltage to a suitable value. The accurate value of the voltmeter is determined by measuring the value of the voltage to the maximum possible range of the potentiometer.

The potentiometer measures the maximum possible value of voltages. The negative and positive error occurs in the readings of the voltmeter if the readings of the potentiometer and the voltmeter are not equal.

Calibration of Ammeter

The figure below shows the circuit for the calibration of the ammeter.



The standard resistance is connected in series with the ammeter which is to be calibrated. The potentiometer is used for measuring the voltage across the standard resistor. The below mention formula determines the current through the standard resistance.

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

Where,

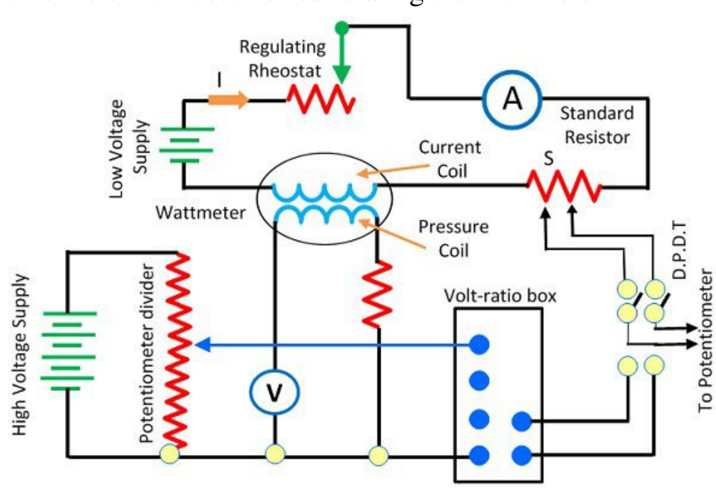
V_s = voltage across the standard resistor as indicated by the potentiometer.

S = Resistance of standard resistor

This method of calibration of the ammeter is very accurate because in this method the value of standard resistance and the voltage across the potentiometer is exactly known by the instrument.

Calibrating of Wattmeter

The figure below shows the circuit used for calibrating the Wattmeter.



The standard resistance is connected in series with the Wattmeter which is to be calibrated. The low voltage supply is given to the current coil of the Wattmeter. The rheostat is connected in series with the coil for adjusting the value of current.
The potential circuit is supplied from the supply. The volt-ratio box is used to step-down the voltage so that the potentiometer can easily read the voltage. The actual value of the actual value of voltage and current is measured by using a double pole double throw switch. The accurate value VI and the value of Wattmeter are compared.

Reactive Power Measurement

The power which exists in the circuit when the voltage and current are out of phase to each other, such type of power is known as the reactive power. The formula measures the reactive power in the circuit

$$Q = VIsin\emptyset$$

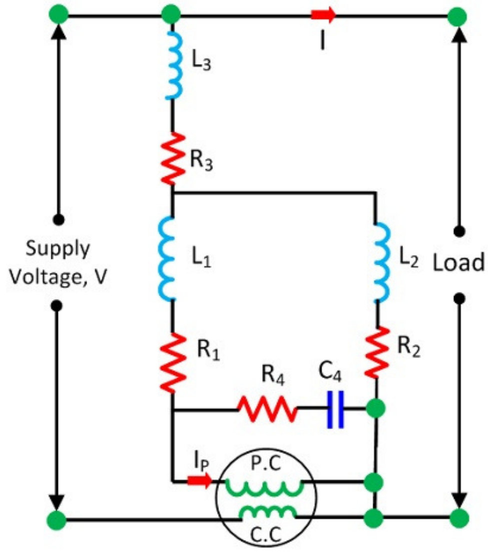
The measurement of reactive power is essential because the value of reactive power shows the total power loss in the circuit. If the value of reactive power is low, the power factor of the load becomes poorer and more loss occurs in the system. The electrical system is classified by the number of phases used in the circuit, and according to these phases, the VAR meter is categorized into two types.

1. Single Phase VAR meter
2. Poly-phase VAR meter

Single Phase VAR meter
The reactive power of the single phase circuit is measured by the VAR meter (Volt ampere reactive meter). The VAR meter is a type of the Electrodynamometer Wattmeter in which the pressure coil of the meter is made highly inductive. The terms "highly inductive" means, the voltage of the pressure coils lags at an angle of 90° with that of the current coil.
The current which passes through the current coil is the load current. The load current has a phase difference of 90° concerning that of the supply voltage, and it is given by the equation shown below.

$$VI\ \mathrm{Cos}(90^{\circ} - \emptyset) = VIsin\emptyset = reactive\ power$$

The circuit diagram of the single phase VAR meter is shown in the figure below.

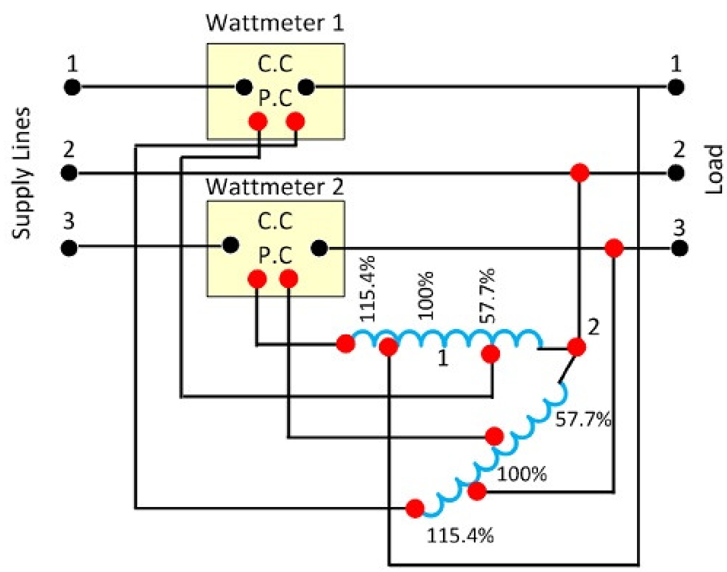


Single phase Varmeter

The Single Phase VAR meter gives the incorrect result because of the presence of harmonics. If the VAR meter measures the reading at a different frequency from that which we used during the calibration then also the VAR meter gives the inaccurate result.

Poly-phase VAR meter

The reactive power exists in the circuit because of the phase displacement between the voltage and current. And this phase shifting is obtained from the phase shifting transformer. The phase shifting transformer consists two open circuit transformer which is connected in open delta configuration. The current coil is connected in series with the line. The pressure coil is connected to the common terminals of both the auto-transformer.

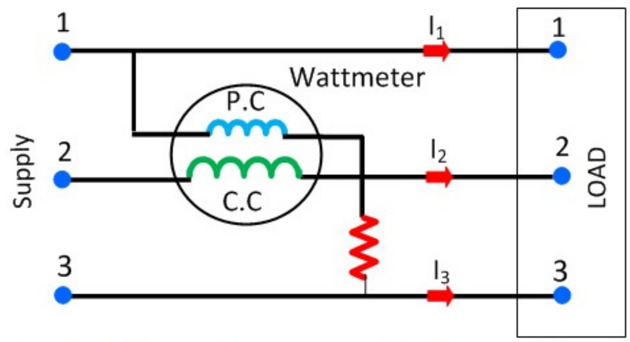


Reactive Power Measurement with Two Auto-Transformer

The 57.7%, 100%, and 115.4% shows the tapping of the auto-transformer. The auto-transformer shows the maximum line voltage of 115.4%. The pressure coil of one of the Wattmeter is connected to the 115.4% tapping of auto-transformer, while the other is connected to the 57.7%. The voltage produces the pressure coil of wattmeter which is equal to the line voltage, but they have a phase shift of an angle of 90º. Similarly, the pressure coil of the Wattmeter 2 has the phase difference of 90º. The arithmetic reading of both the Wattmeters gives the total reactive power of the circuit.

Reactive Power Measurement in Balanced Three-Phase Circuit

The single wattmeter method is used for measuring the power of the balanced three-phase circuit. The current coil of the Wattmeter is connected to one phase, and the pressure coil is connected to the other phase of the line.



Reactive Power Measurement with One Wattmeter

Let,

The current through the current coil – I_2

Voltage across the pressure coil – V_{13}

$$Reading\ of\ Wattmeter = V_{13} I_2 \operatorname{Cos}(90^\circ + \emptyset)$$

$$= \sqrt{3} VI \operatorname{Cos}(90^\circ + \emptyset)$$

$$= \sqrt{3} VI Sin 90^\circ$$

Total reactive volt amperes of the circuit

$$Q = 3VISin\emptyset$$

$$= (-\sqrt{3}) \times reading\ of\ Wattmeter$$

The phase angle

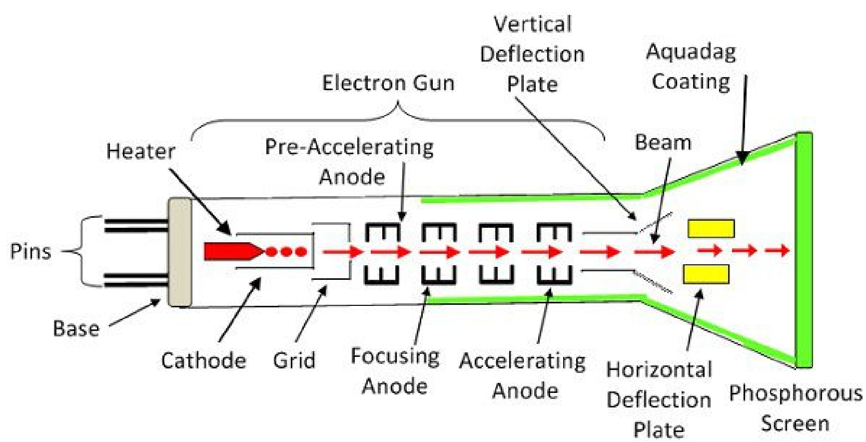
$$\emptyset = \tan^{-1}\frac{Q}{P}$$

Cathode Ray Tube (CRT)

The CRT is a display screen which produces images in the form of the video signal. It is a type of vacuum tube which displays images when the electron beams through electron guns are strikes on the phosphorescent surface. In other Words, the CRT generates the beams, accelerates it at high velocity and deflects it for creating the images on the phosphorous screen so that the beam becomes visible.

Working of CRT

The working of CRT depends on the movement of electrons beams. The electron guns generate sharply focused electrons which are accelerated at high voltage. This high-velocity electron beam when a strike on the fluorescent screen creates luminous spot



After exiting from the electron gun, the beam passes through the pairs of electrostatic deflection plate. These plates deflected the beams when the voltage applied across it. The one pair of plate moves the beam upward and the second pair of plate moves the beam from one side to another. The horizontal and vertical movement of the electron are independent of each other, and hence the electron beam positioned anywhere on the screen.

The working parts of a CRT are enclosed in a vacuum glass envelope so that the emitted electron can easily move freely from one end of the tube to the other.

Construction of CRT

The Electrons Gun Assembly, Deflection Plate Assembly, Fluorescent Screen, Glass Envelope, Base are the important parts of the CRT. The electron gun emits the electron beam, and through deflecting plates, it is strikes on the phosphorous screen. The detail explanation of their parts is explained below.

Electrons Gun Assembly

The electron gun is the source of the electron beams. The electron gun has a heater, cathode, grid, pre-accelerating anode, focusing anode and accelerating anode. The electrons are emitted from the highly emitted cathode. The cathode is cylindrical in shape, and at the end of it, the layer of strontium and barium oxide is deposited which emit the high emission of electrons at the end of the tube.

The electron passes through the electron in the small grid. This control grid is made up of nickel material with a centrally located hole which is coaxial with the CRT axis. The electron which is emitted from the electron gun and passes through the control grid have high positive potential which is applied across the pre-accelerating and accelerating anodes.

The beam is focused by focusing anode. The accelerating and focusing electrodes are cylindrical in shape which has a small opening in the centre of each electrode. After exiting the focusing anode, the beam passes through the vertical and horizontal deflecting plates.

The pre-accelerating and accelerating anode are connected to the positive high voltage of about 1500V and the focusing anode are connected to the lower voltage of about 500V.There are two methods of focusing the electron beam. They are the Electrostatic Focusing Beam and the Electromagnetic Focusing.

Electrostatic Deflection Plates

The deflection plate produces the uniform electrostatic field only in the one direction. The electron beam entering into the deflection plates will accelerate only in the one direction, and hence electrons will not move in the other directions.

Screen for CRT

The front of the CRT is called the face plate. The face plate of the CRT is made up of entirely fiber optics which has special characteristics. The internal surface of the faceplate is coated with the phosphor. The phosphorous converts the electrical energy into light energy. The energy level of the phosphorous crystal rises when the electron beams strike on it. This phenomenon is called cathodoluminescence.

The light which is emitted through phosphorous excitation is called fluorescence. When the electron beam stop, the phosphorous crystal regain their original position and release a quantum of light energy which is called phosphorescence or persistence.

Aquadag

The Aquadag is the aqueous solution of graphite which is connected to the secondary of the anode. The Aquadag collects the secondary emitted electrons which are necessary for keeping the CRT screen in the state of electrical equilibrium.

Cathode Ray Oscilloscope (CRO)

The cathode ray oscilloscope (CRO) is a type of electrical instrument which is used for showing the measurement and analysis of waveforms and others electronic and electrical phenomenon. It is a very fast X-Y plotter shows the input signal versus another signal or versus time. The CROs are used to analyze the waveforms, transient, phenomena, and other time-varying quantities from a very low-frequency range to the radio frequencies.

The CRO is mainly operated on voltages. Thus, the other physical quantities like current, strain, acceleration, pressure, are converted into the voltage with the help of the transducer and thus represent on a CRO. It is also used for knowing the waveforms, transient phenomenon, and other time-varying quantity from a very low-frequency range to the radio frequencies.

The CRO has Stylus (i.e., a luminous spot) which moves over the display area in response to an input voltage. This luminous spot is produced by a beam of electrons striking on a fluorescent screen. The normal form of the CRO uses a horizontal input voltage which is an internally generated ramp voltage called “time base”.

The horizontal voltage moves the luminous spot periodically in a horizontal direction from left to right over the display area or screen. The vertical voltage is the voltage under investigation. The vertical voltage moves the luminous spot up and down on the screen. When the input voltage moves very fast on the screen, the display on the screen appears stationary. Thus, CRO provides a means of the visualizing time-varying voltage.

Construction of Cathode Ray Oscilloscope

The main parts of the cathode ray oscilloscope are as follows.

1. Cathode Ray Tube
2. Electronic Gun Assembly
3. Deflecting Plate
4. Fluorescent Screen For CRT
5. Glass Envelop

Their parts are explained below in details.

Cathode Ray Tube

The cathode ray tube is the vacuum tube which converts the electrical signal into the visual signal. The cathode ray tube mainly consist the electron gun and the electrostatic deflection plates (vertical and horizontal).The electron gun produces a focused beam of the electron which is accelerated to high frequency.

The vertical deflection plate moves the beams up and down and the horizontal beam moved the electrons beams left to right. These movements are independent to each other and hence the beam may be positioned anywhere on the screen.

Electronic Gun Assembly

The electron gun emits the electrons and forms them into a beam. The electron gun mainly consist a heater, cathode, a grid, a pre-accelerating anode, a focusing anode and an accelerating anode. For gaining the high emission of electrons at the moderate temperature, the layers of barium and strontium is deposited on the end of the cathode.

After the emission of an electron from the cathode grid, it passes through the control grid. The control grid is usually a nickel cylinder with a centrally located co-axial with the CRT axis. It controls the intensity of the emitted electron from the cathode.

The electron while passing through the control grid is accelerated by a high positive potential which is applied to the pre-accelerating or accelerating nodes.

The electron beam is focused on focusing electrodes and then passes through the vertical and horizontal deflection plates and then goes on to the fluorescent lamp. The pre-accelerating and accelerating anode are connected to 1500v, and the focusing electrode is connected to 500 v. There are two methods of focusing on the electron beam. These methods are

- Electrostatic focusing
- Electromagnetic focusing.

The CRO uses an electrostatic focusing tube.

Deflecting Plate

The electron beam after leaving the electron gun passes through the two pairs of the deflecting plates. The pair of plate producing the vertical deflection is called a vertical deflecting plate or Y plates, and the pair of the plate which is used for horizontal deflection is called horizontal deflection plate or X plates.

Fluorescent Screen for CRT

The front of the CRT is called the face plate. It is flat for screen sized up to about 100mm×100mm. The screen of the CRT is slightly curved for larger displays. The face plate is formed by pressing the molten glass into a mould and then annealing it.

The inside surface of the faceplate is coated with phosphor crystal. The phosphor converts electrical energy into light energy. When an electronics beam strike phosphor crystal, it raises their energy level and hence light is emitted during phosphorous crystallization. This phenomenon is called fluorescence.

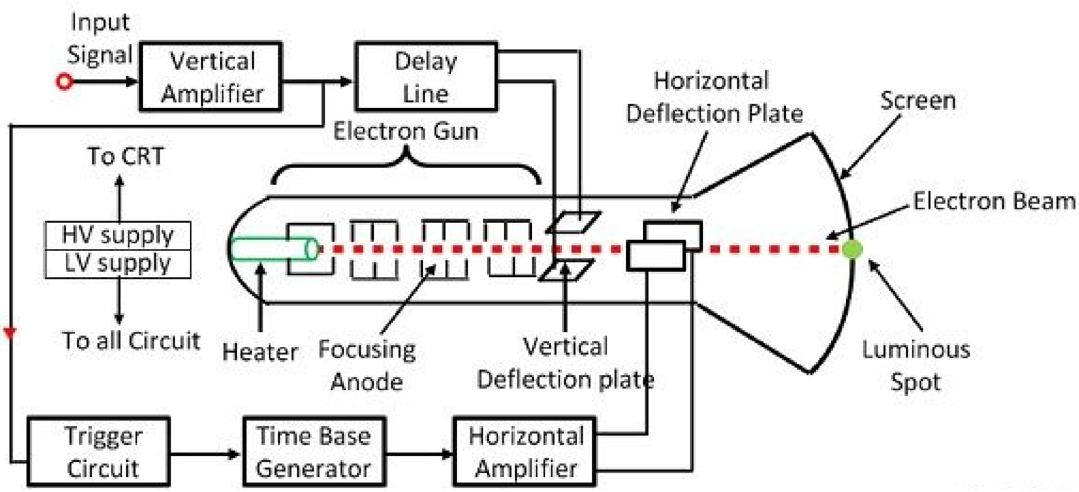
Glass Envelope

It is a highly evacuated conical shape structure. The inner surface of the CRT between the neck and the screen is coated with the Aquadag. The Aquadag is a conducting material and act as a high-voltage electrode. The coating surface is electrically connected to the accelerating anode and hence helps the electron to be the focus.

Working of Cathode Ray Oscilloscope

When the electron is injected through the electron gun, it passes through the control grid. The control grid controls the intensity of electron in the vacuum tube. If the control grid has high negative potential, then it allows only a few electrons to pass through it. Thus, the dim spot is produced on the lightning screen. If the negative potential on the control grid is low, then the bright spot is produced. Hence the intensity of light depends on the negative potential of the control grid.

After moving the control grid, the electron beam passing through the focusing and accelerating anodes. The accelerating anodes are at a high positive potential and hence they converge the beam at a point on the screen.



After moving from the accelerating anode, the beam comes under the effect of the deflecting plates. When the deflecting plate is at zero potential, the beam produces a spot at the centre. If the voltage is applied to the vertical deflecting plate, the electron beam focuses at the upward and when the voltage is applied horizontally the spot of light will be deflected horizontally.

Sampling Oscilloscope

The sampling oscilloscope is a special type of digital sampling oscilloscope which is used to examine a very fast signal. In other words, the sampling oscilloscope receives various electrical signals and then together displays the signals on the screen.

It works on the principle of stroboscopic light in which sample is taken at different portions of the waveform, over successive cycles, and then the total picture is stretched, amplified by relatively low bandwidth amplifiers, and display as the continuous wave on the screen.

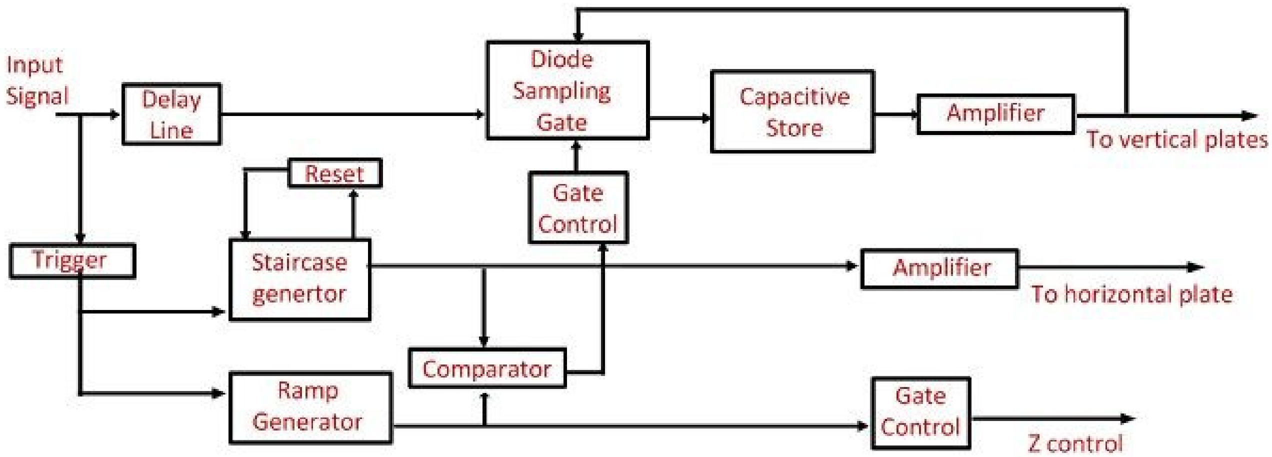
The advantage of the sampling oscilloscope is that it can measure the very high-speed event with the help of the instrument having lower bandwidth. The disadvantage of the oscilloscope is are that it can only measure the repetitive or continuous signal. The frequency range of the oscilloscopes depends on their design.

The sampling techniques of the oscilloscope convert the input signal into the low-frequency domain. The low-frequency signal has a highly efficient domain. The sampling oscilloscopes in not used for displaying the transient signals.

Block Diagram of Sampling Oscilloscope

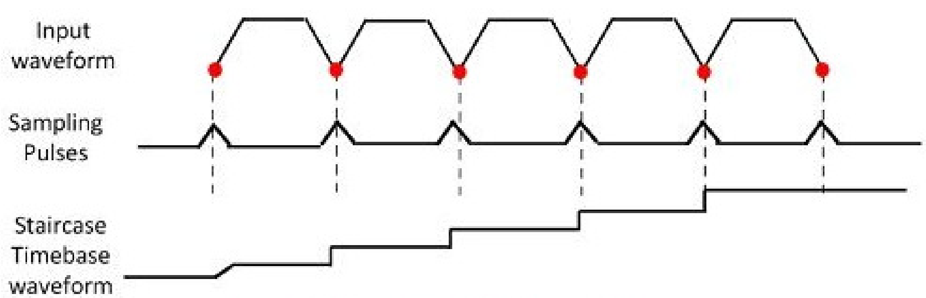
The block diagram of the sampling scope is shown in the figure below. The input signal is applied to the delay line where the signal is delayed. The signal delay means the precise time difference develops between the input and output signal.

The output obtains from the delay line passes to the diode sampling gate. The sampled signal received from the diode gate stores in the capacitor. Then it is fed to the amplifier for amplification and then given to the vertical axis of the display screen.



The single feedback is used from the amplifier to the diode gate. The feedback shows that the voltage stored on the capacitor increases only by the change in internal signal between each sample.

The staircase waveform is shown in the figure below. The waveform shows that it is reset after several numbers of steps. Thus, more than 1000 points are used on the screen for creating the waveform. The staircase waveform is used in the cathode ray tube. It is used for removing the spot on the screen.



Principle of Sampling Oscilloscopes

Delayed Sweep in sampling Oscilloscope

It is a technique of adding a time between the starting and the triggering point of the scope sweep. It increases the flexibility of the instrument. By the help of the delayed sweep oscilloscope, it is possible to amplify the undelayed signal. It is also helpful in many other applications like for measuring the rise time of the waveform or for measuring their pulse time modulation.

Dual Trace Oscilloscope

In dual trace oscilloscope, a single electron beam generates 2 traces, that undergo deflection by two independent sources. In order to produce two separate traces, basically, 2 methods are used, known as alternate and chopped mode.

These are also known as the two operating modes of the switch.

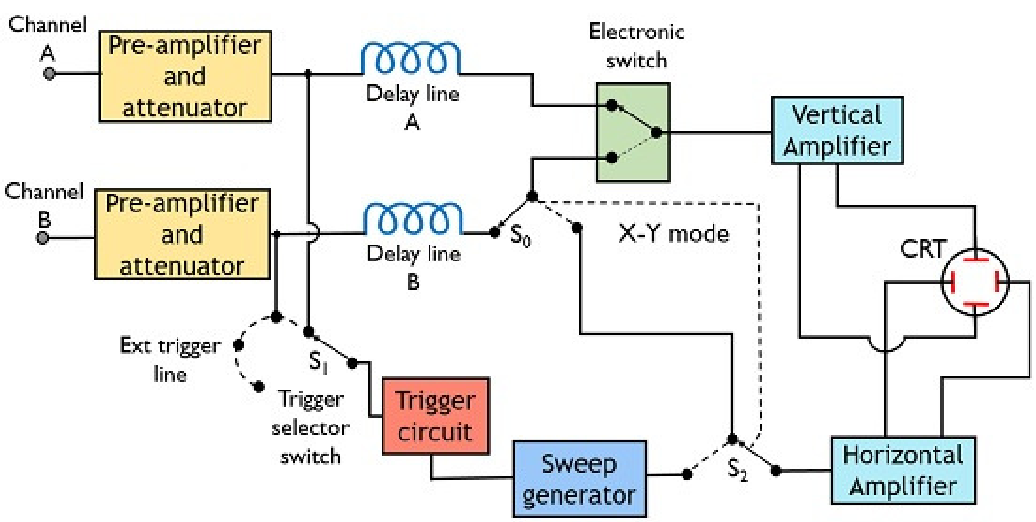
So, we know to analyze or study multiple electronic circuits, the comparison between their voltages is really important. Hence to compare the different circuits, one can use multiple oscilloscopes.

But simultaneously triggering the sweep of each oscilloscope is a quite difficult task.

Thus we have used dual trace oscilloscope provides two traces by making use of a single electron beam.

Block diagram and Working of Dual Trace Oscilloscope

The figure below shows the block diagram of a dual trace oscilloscope:



Block Diagram of Dual Trace Oscilloscope

As we can see in the above figure that it has two individual vertical input channels namely A and B.

Both the inputs are separately fed to the preamplifier and attenuator stage. The outputs of the two separate preamplifiers and attenuator stage are then provided to the electronic switch. This switch only passes a single channel input particularly at a time to the vertical amplifier.

The circuit also has a trigger selector switch that permits the circuit triggering with either A or B channel input or with the externally applied signal.

The signal from the horizontal amplifier is fed to the electronic switch by either sweep generator or channel B by switch S_0 and S_2.

In this way, the vertical signal from channel A and horizontal signal from channel B is provided to the CRT for the operation of the oscilloscope.

This is the X-Y mode of the oscilloscope and permits accurate X-Y measurements.

Basically, the modes of operation of the oscilloscope rely on the choice of front panel controls. Like either the trace of channel A is needed, channel B is needed or separately traces of channel A or B is required.

As we have already discussed that there exist two modes of operation of dual trace oscilloscope.

Let us have a look at both the methods separately.

ALTERNATE MODE OF DUAL TRACE OSCILLOSCOPE

Whenever we activate the alternate mode, then it permits the connection between both the channels alternately. This alternation or switching between the channels A and B takes place at the beginning of each upcoming sweep.

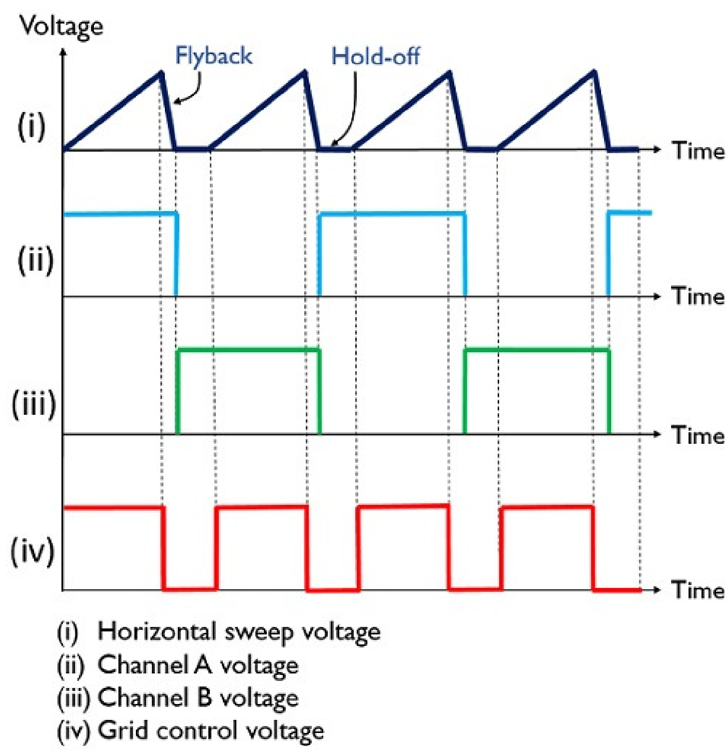
Also, there exists synchronization between the switching rate and the sweep rate. This leads to the spotting of traces of each channel on one sweep. Like in first sweep traces of channel A will be spotted, then in the next sweep traces of channel B will be considered by the CRT.

In this way, the alternate connection of the two-channel input with the vertical amplifier is performed.

The change in the electronic switch from one channel to the other occurs at fly back sweep duration. At the flyback period, the electron beam will be invisible and so the changeover from one channel to other.

Hence a complete sweep signal from one vertical channel will be displayed at the screen. While for the next sweep, the signal from another vertical channel will be displayed.

The figure below represents the waveform the oscilloscope output operating in alternate mode:



Waveform for Alternate Mode

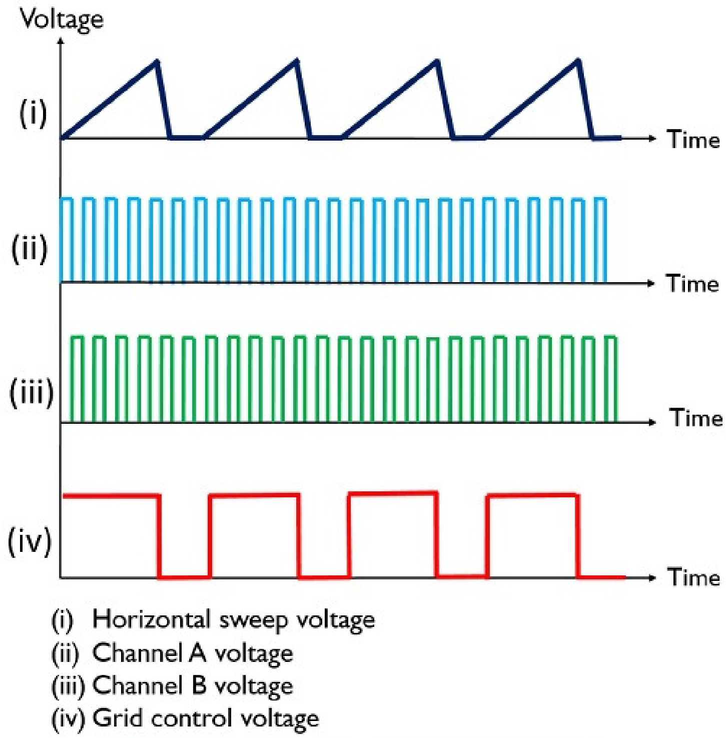
This method allows us to maintain the proper phase relationship between signals of channel A and B. However, along with advantage, a disadvantageous factor is also associated with this mode.

Alternate mode leads to a display that will show the occurrence of both the signals at different time. But in actual practice, the two events occur simultaneously. Also, the method cannot be used for the representation of the low-frequency signal.

CHOPPED MODE OF DUAL TRACE OSCILLOSCOPE

In this mode of operation during a single sweep, several times switching between the two channels occurs. And this switching is so quick that even for the very small segment the display is available at the screen.

The figure below shows the waveform representation in case of chopped mode:



Waveform for Chopped Mode

Here, the electronic switch undergoes free running at a very high frequency of about 100 KHz to 500 KHz. And the frequency of electronic switch does not rely on the frequency of the sweep generator.

Hence in this way, the small segments of the two channels get connected to the amplifier in a continuous manner.

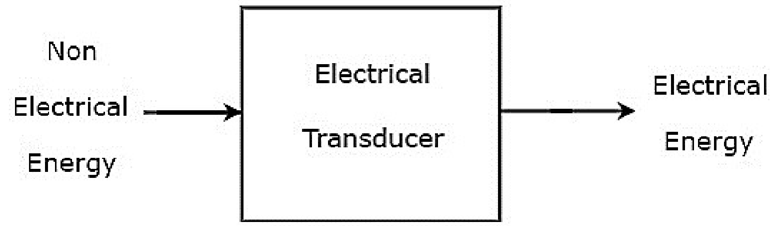
When the chopping rate is faster than the rate of horizontal sweep, then the separately chopped segments will be merged and recombine to form originally applied channel A and B waveform at the screen of CRT.

However, if the chopping rate is lesser than the sweep rate then it will definitely lead to discontinuity in the display. Therefore, in such case alternate mode is more suitable.

The dual trace oscillator permits the choice of respective mode of operation through the front panel of the instrument.

Transducers

Transducer converts one form of energy into another form of energy. The transducer, which converts non-electrical form of energy into electrical form of energy, is known as electrical transducer. The block diagram of electrical transducer is shown in below figure.



As shown in the figure, electrical transducer will produce an output, which has electrical energy. The output of electrical transducer is equivalent to the input, which has non-electrical energy.

Types of Electrical Transducers

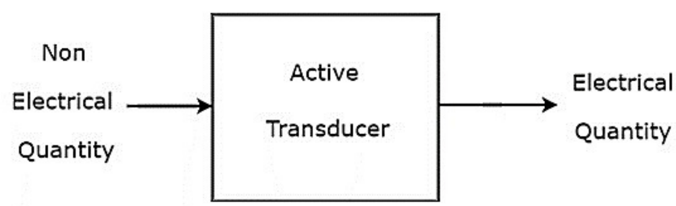
Mainly, the electrical transducers can be classified into the following two types.

- Active Transducers
- Passive Transducers

Active Transducers

The transducer, which can produce one of the electrical quantities such as voltage and current, is known as active transducer. It is also called self-generating transducer, since it doesn't require any external power supply.

The block diagram of active transducer is shown in below figure.



As shown in the figure, active transducer will produce an electrical quantity (or signal), which is equivalent to the non-electrical input quantity (or signal).

Following are the examples of active transducers.

- Piezo Electric Transducer
- Photo Electric Transducer
- Thermo Electric Transducer

Passive Transducers

The transducer, which can't produce the electrical quantities such as voltage and current, is known as passive transducer. But, it produces the variation in one of passive elements like resistor (R), inductor (L) and capacitor (C). Passive transducer requires external power supply.

The block diagram of passive transducer is shown in below figure.

ERROR: stackunderflow
OFFENDING COMMAND: ~

STACK: