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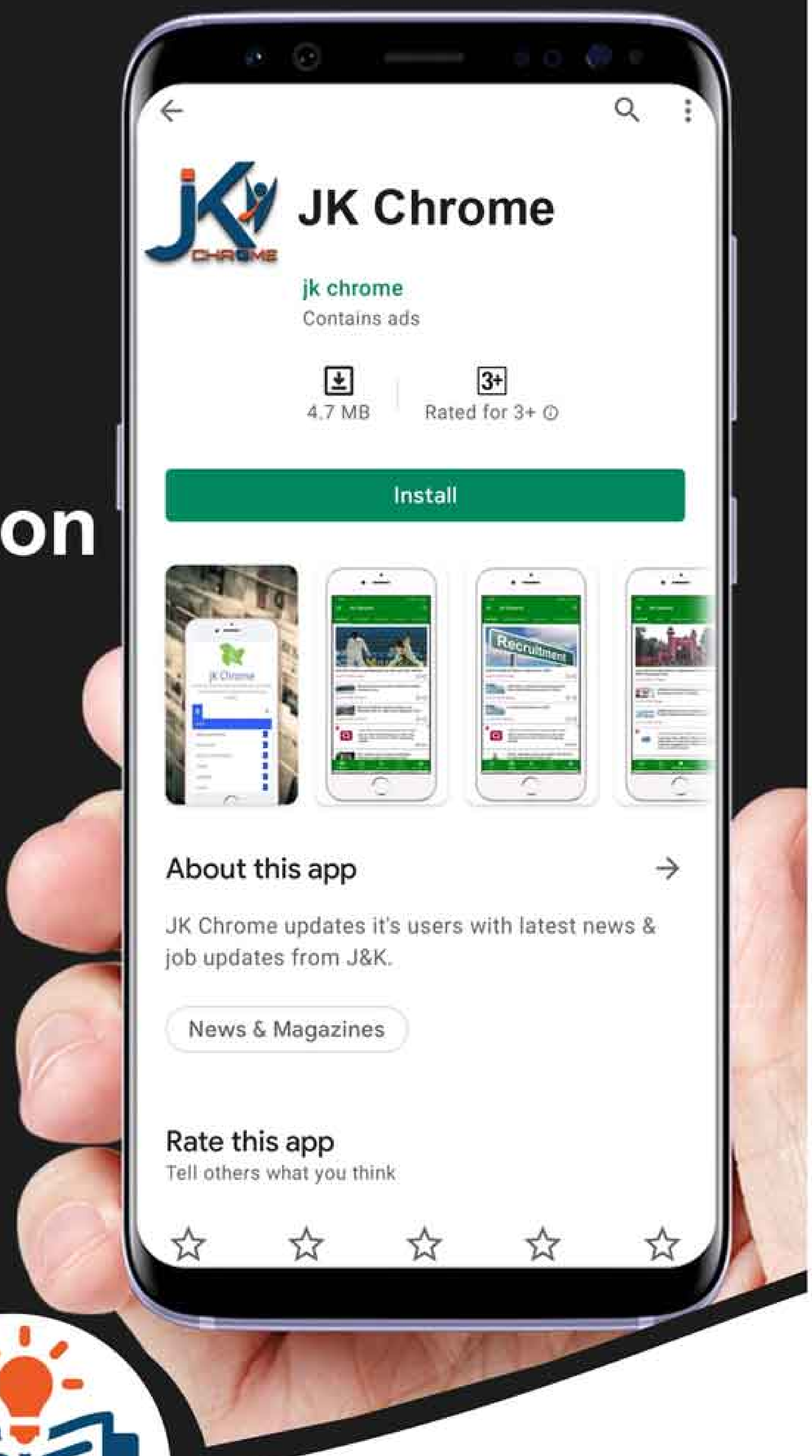

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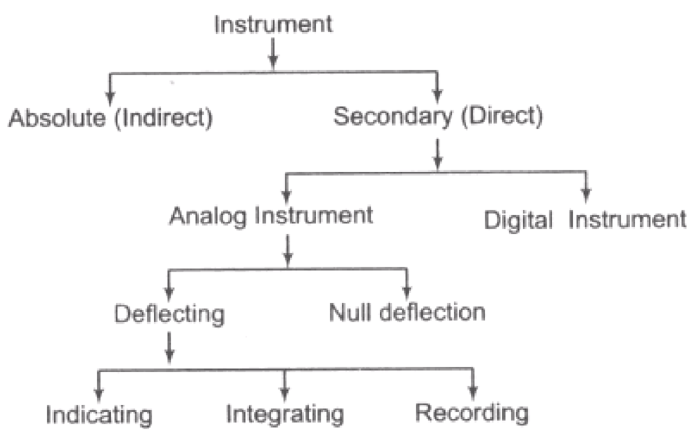
Electrical & Electronic Measurements

Index

Measurement of Voltage & Current

Electrical Instruments and Measurement: Instruments used to measure, current, voltage, power energy, flux, frequency etc., are called electrical measuring instruments.

Classification of Electrical Instrument



Electrical Instrument Classification

Absolute Instrument: It gives the value of the parameters under measurement in terms of the instrument.

e.g., Tangent galvanometer, Rayleigh's current balance.

Secondary Instrument: It gives the value of parameters directly under measurement.

e.g., Voltmeter, thermometer, pressure gauge etc.

Note Absolute instruments are highly accurate than secondary instrument as they contain less few moving mechanical parts resulting in a lower operational of power consumption.

Analog Instrument: Its output varies continuously with respect to time all the while maintaining a constant relationship with the input.

Deflecting Instrument: It gives the value of the parameters under measurement in terms of the deflection of the pointer away from the zero position. e.g., PMMC

Null Deflection: Null deflecting instruments indicate their end of measurement with a zero deflection. e.g., Bridge circuit, DC potentiometer etc.

Note: Null deflecting instrument is highly accurate as the comparison to deflecting instrument as their operational power consumption at zero deflection is zero.

Indicating Instrument: It gives the instantaneous value of the parameters under measurement. e.g., Ammeter, voltmeter, wattmeter, galvanometer.

Integrating Instrument: It gives the sum total of the electrical parameter consumed over a specified period of time. e.g., Energy meter

Recording Instrument: *e.g.*, Recording voltmeter.

Key Points

- PMMC type instruments are used only in DC voltage and current.
- Induction type instruments are used only in AC (voltage and current) measurement.
- An electrodynamometer type instrument can be used to measure DC well as AC voltage.

Principle of Operation of Analog Instrument

- **Electro Magnetic Effect** Moving iron coil type, PMMC type, electrodynamometer type instrument.
- **Induction Effect** Energy meter
- **Heating Effect** Hotwire type, thermocouple, bolometer.
- **Electrostatic Effect** Electrostatic type instrument.
- **Hall's Effect** Flux meter, Poynting vector type wattmeter.

Essentials of Indicating Instrument

Deflecting Torque/Force: Deflecting torque is proportional to quantity under measurement. The utility of this torque is to deflect the pointer away from the zero position.

Controlling Torque/Force (T_C): It controls the deflection by bringing the pointer to rest at the steady-state position.

It brings the pointer back to zero position when the parameter under measurement is removed.

Note: If the control force is absent then the pointer will be deflected beyond the maximum scale.

Damping Torque/Force (T_D): This torque is responsible for damping out the oscillation of the pointer due to inertia.

Construction Details of Indicating Instrument: Moving System Moving system of indicating produces the deflecting torque. Various types of supports for moving system as

Suspension

- Used in galvanometer class instrument.
- Used only in the vertically held instrument.

Taut Suspension: It is used in PMMC type instrument require a low friction and high sensitivity.

Pivot and Jewel Bearing Type Supports: Weight of moving system decides the sensitivity of the instrument.

Note: Torque to weight ratio of the moving system should be high and equal to 0.1

Control System: There are two types of the mechanism is considered here. One is spring control and other is gravity control mechanism as given below.

Spring Control Mechanism

Control torque $T_{CS} = k\theta$

where k = spring constant

θ = deflection

as $T_d \propto I$

at steady state position $T_d = T_c; \theta \propto I$

Spring control has a uniform scale

Gravity Control Mechanism

$T_{cg} = K \sin \theta$

$T_d \propto I$

at steady state position $T_d = T_{cg}$

$I \propto \sin \theta$

Where T_d = Deflection torque

T_{cg} = Control torque of gravity control mechanism

Note: Gravity control mechanism has initially linear scale.

Key Points

- If damping torque Td is absent then pointer oscillate around the mean position.
- Fatigue in spring is avoided by annealing and aging.

Damping System: Damping system is provided in the instrument which helps the moving system of the instrument to reach to the final position at the earliest.

Eddy Current Damping: Mechanism Used in a strong operating field. *e.g.*, PMMC (Permanent Magnet Moving Coil instrument) type.

Air Friction Damping: Used when the operating field is weak as used in moving iron and electro dynamometer type instrument.

Fluid Friction Damping: Used in high voltage measurement. Used in the vertically mounted instrument. e.g., Electrostatic type instrument.

Measuring Current: Ammeters

To measure **current**, the circuit must be broken at the point where we want that current to be measured, and the ammeter inserted at that point. In other words, *an ammeter must be connected in series* with the load under test.

As it's very important that the insertion of the ammeter into a circuit has little effect the circuit's existing resistance and, thus, alter the current normally flowing in the circuit, ammeters are manufactured with *very low* values of internal resistance.

Because ammeters have a very low internal resistance, it is vitally important that they are *never* inadvertently connected in parallel with any circuit component — and especially with the supply. Failure to do so will result in a short-circuit current flowing through the instrument which may damage the ammeter (although most ammeters are fused) or even result in personal injury.

Measuring Voltage: Voltmeters

To measure **potential-difference** or **voltage**, a voltmeter must be connected between *two* points at different potentials. In other words, *a voltmeter must always be connected in parallel* with the part of the circuit under test.

In order to operate, a voltmeter must, of course, draw *some* current from the circuit under test, and this can lead to inaccurate results because it can interfere with the normal condition of the circuit. We call this the 'loading effect' and, to minimize this 'loading effect' (and, therefore, improve the accuracy of a reading), this operating current must be as small as possible and, for this reason, voltmeters are manufactured with a *very high* value of internal resistance — usually many megaohms.

Types of Instruments used for Ammeter and Voltmeter

PMMC (Permanent Magnet Moving Coil) Only for DC current measurement.

Moving Iron Type For both AC and DC

Electro Dynamometer Type For both AC and DC

Electro Thermic Type For both AC and DC

Also for hot wire type, thermocouple type and bolometer.

Induction Type Only for AC measurement.

Electrostatic Type Both AC and DC

Rectifier Type Both AC and DC

Permanent Magnet Moving Coil (PMMC) Type Instrument

It is used for measurement of DC only. Material used for magnet in PMMC is Alnico (Al + Ni + Co) and Alcomax (Al + Co + max….). The field strength in PMMC varies from 0.1 Wb/m^2 to 1Wb/m^2.

- Concentric magnetic construction is used to get longer angular movement of the pointer.
- Due to the strong operating field of the permanent magnet, the eddy current damping mechanism is used to produce the damping torque.
- The control torque in PMMC is provided with spiral-shaped hair type phosphor-bronze spring.
  $T_d = NBIA$ due to magnetic field
  $T_C = K\theta$ due to control spring
  At balance
  As $\theta \propto I$
  The scale of the PMMC instrument is uniform scale

where N = Number of turns of the moving coil

B = Flux density of permanent magnet in Wb/m^2

A = Area of the coil in m2

I = Current in amp

$G = NBA$ = Displacement constant of the galvanometer

Key Points

- The control spring in PMMC has dual utility, they not only produce controlling torque but also used to lead the current into the system.
- Due to strong operating torque at the permanent magnet, an eddy current damping is used to produce damping torque.

Advantages of PMMC

- High torque to weight ratio.
- High accuracy and sensitivity.
- Magnetic shielding not required due to a strong operating field.
- Low power consumption (25 – 200 μ W).

Disadvantages of PMMC

- High cost.
- Used for measurement of DC only.
- Limited current carrying capacity (100 mA) approx.

Sources of Errors

- Ageing effect of the permanent magnet (can be compensated by using a pre-edged magnet.
- Ageing effect of the spring.
- Temperature effect of the coil and the control spring.

Application of PMMC Instrument

Ammeter Shunt

Shunt resistance

Where, Multiplying factor of the shunt

R_{sh} = Shunt resistance (Ω)

R_m = Internal resistance of the movement (Ω)

$I_m = I_{fs}$ = Full scale deflection current of the movement (A)

I = Full-scale current of the ammeter including the shunt.

Key Points

- Shunt should have a small and constant temperature coefficient.
- The materials used for the shunt in PMMC is Magnin as it gives small thermal emf with copper.
- Constanton is used for the construction of shunt in AC ammeter.

Effect of Temperature Change in Ammeter Reading

As temperature increases the resistance of copper increases and this result into a change of reading of the instrument. To reduce the effect of temperature a resistance having very small temperature coefficient made up of Magnin is connected in series with the coil and this is known as swamping resistance.

Multi-Range Ammeters

The combination of a millivoltmeter and shunt employed as an ammeter is readily adaptable to multirange construction either by separate, in interchangeable, single-range shunts or multirange shunts.

By Using Separate Shunts

The circuits have three shunts which can be placed in parallel with the meter movement to give three different ranges I_1, I_2 and I_3.

By Using Universal or Ayrton Shunt

The universal shunt or ayrton shunt is shown in the figure is also used for multi-range ammeters. The advantage of this is that it eliminates the possibility of the meter being in the circuit without shunt.

Moving Iron Instrument Working Operation

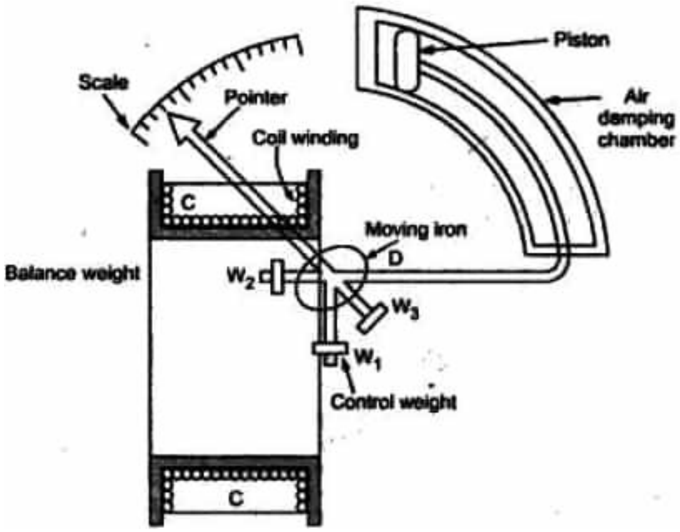
The moving iron instruments are classified as:

1. **Moving iron attraction type instruments**
2. **Moving iron repulsion type instruments**

Attraction Type Instrument Working Operation

Moving Iron Instrument Working Principle: The basic working principle of these instruments is very simple that a soft iron piece if brought near magnet gets attracted by the magnet.

The construction of the **attraction type moving iron instrument** is shown in the below figure.



- It consists of a fixed coil C and moving iron piece D. The oil is flat and has narrow slot like opening.
- The moving iron is a flat disc which is eccentrically mounted on the spindle.The spindle is supported between the jewel bearings.The spindle carries a pointer which moves over a graduated scale.
- The number of turns of the fixed coil are dependent on the range of the instrument. For passing the large current through the coil only a few turns are required.
- The **Controlling Torque** is provided by the **springs but gravity control may also be used** for vertically mounted panel type instruments.
- The **Damping Torque** is provided by the **air friction**.
- A light aluminum piston is attached to the moving system. it moves in a fixed chamber. The chamber is closed at one end. it can also be provided with the help of vane attached to the moving system.

Torque in Moving Iron Instrument

Deflecting torque $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$ Newton meter

Deflection $\theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}$

as $\theta \propto I^2$, the scale is non-linear in moving iron type.

For linear scale $\theta^2 = \frac{I^2}{2K}\left(\theta\frac{dL}{d\theta}\right)$

For scale to be linear $\theta\frac{dL}{d\theta} =$ constant

Where, θ = Deflection of the pointer

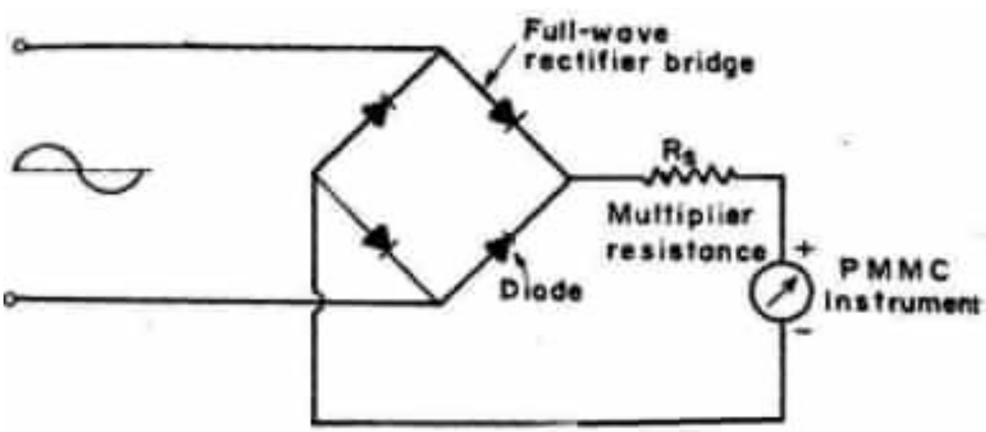
L = Inductance of the coil

I = RMS value of current in the coil

The curve between dL/dθ and θ is a rectangular hyperbola.

Rectifier Type Instrument

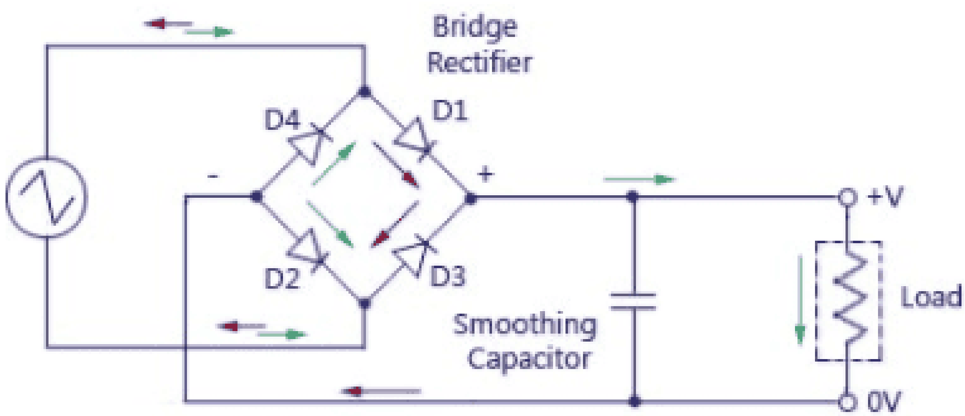
It measures the **alternating voltage and current** with the help of rectifying elements and permanent magnet moving coil type of instruments. However, the primary function of rectifier type of instruments work as voltmeter. Now one question must arises in our mind why we use rectifier type of instruments widely in the industrial world though we have various other AC voltmeter like electrodynamometer type instruments, thermocouple type instruments etc.

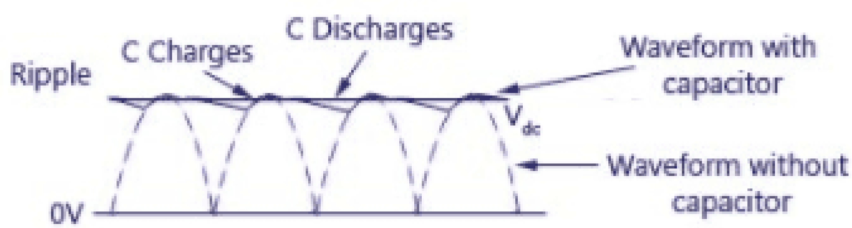


- **Cost** of electrodynamometer type of instruments is quite high than rectifier type of instruments. However rectifier type of instruments as **much accurate** as electrodynamometer type of instruments. So rectifier type of instruments are preferred over electrodynamometer type instruments.
- However, thermocouple type of instruments is more widely used at very high frequencies.

- Before we look at the construction principle and **working of rectifier type instruments**, there is need to discuss in detail about the voltage-current characteristics of ideal and practical rectifier element called diode.
- Now, what is an ideal rectifying element? A rectifying element is one which offers zero resistance if it is forward biased and offers infinite resistance if it is reversed biased.

Factors affecting the Performance of Rectifier type instruments:





- Rectifier type of instruments is calibrated in terms of root mean square values of the sinusoidal wave of voltages and current. The problem is that the input waveform may or may not have same form factor on which the scale of these meter is calibrated.
- There may be some error due to the rectifier circuit as we are not included the resistance of the rectifier bridge circuits in both the case. The nonlinear characteristics of a bridge may distort the current and voltage waveform.
- There may variation in the temperature due to which the electrical resistance of the bridge changes hence in order to compensate this kind of errors we should apply multiplier resistor with a high temperature coefficient.
- Effect of the capacitance of the bridge rectifier: Bridge rectifier has imperfect capacitance thus due to this it by passes the high-frequency currents. Hence there is a decrement in the reading.

The sensitivity of Rectifier type instruments is low in case of **ac** input voltage.

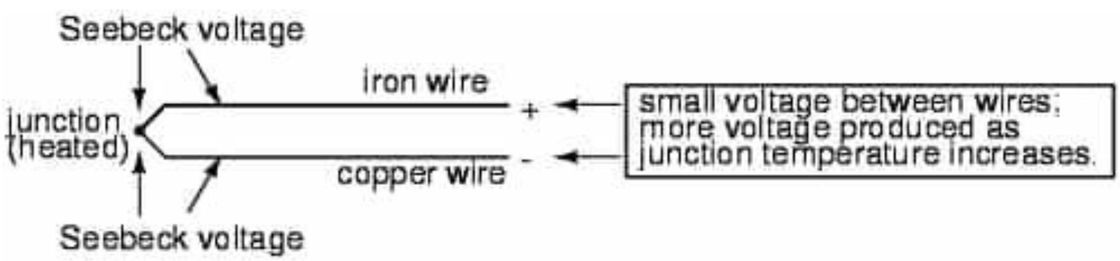
Advantages of Rectifier Type Instruments

Following are the advantages of the rectifier type of instruments:

- The accuracy of rectifier type instrument is about 5 percent under normal operating condition.
- The frequency range of operation can be extended to high value.
- They have uniform scale on the meter.
- They have low operating value of current and voltages.

The **loading effect** of an ac rectifier voltmeter in both the cases (i.e. half wave diode rectifier and full wave diode rectifier) is high as compared to the loading effects of DC voltmeters as the sensitivity of the voltmeter either using in half wave or full wave rectification is less than the sensitivity of DC voltmeters.

Thermocouple Instrument



Principle

The **Seebeck effect** is fairly linear; that is, the voltage produced by a heated junction of two wires is directly proportional to the temperature. This means that the temperature of the metal wire junction can be determined by measuring the voltage produced. Thus, the **Seebeck effect** provides for us an electric method of temperature measurement.

When a pair of dissimilar metals are joined together for the purpose of measuring temperature, the device formed is **called a *thermocouple***. Thermocouples made for instrumentation use metals of high purity for an accurate temperature/voltage relationship.

- The thermocouple instruments are more delicate than the rectifier type of instruments.

- Seebeck voltages are quite small, in the tens of millivolts for most temperature ranges. This makes them somewhat difficult to measure accurately. Also, the fact that *any* junction between dissimilar metals will produce temperature-dependent voltage creates a problem when we try to connect the thermocouple to a voltmeter
- Two thermocouple junctions can be connected in opposition to each other to generate a voltage signal proportional to differential temperature between the two junctions. A collection of junctions so connected for the purpose of generating electricity is **called a *thermopile***.
- When electrons flow through the junctions of a thermopile, heat energy is transferred from one set of junctions to the other. **This is known as the *Peltier Effect*.**
- Multiple thermocouple junctions can be connected in parallel with each other to generate a voltage signal representing the average temperature between the junctions. **"Swamping" resistors** may be connected in series with each thermocouple, to **maintain equality between the junctions**, so the resultant voltage will be more representative of a true average temperature.

Measurement of Power & Energy

Electric power (P) consumed by a load (R) supplied from a dc power supply is the product of the voltage across the load (V_R) and the current flowing through the load (I_R):

$P = V_R \times I_R$

Thus, power measurement in a dc circuit can be carried out using a voltmeter (V) and an ammeter (A) with any one of the arrangements shown in Figure 1.

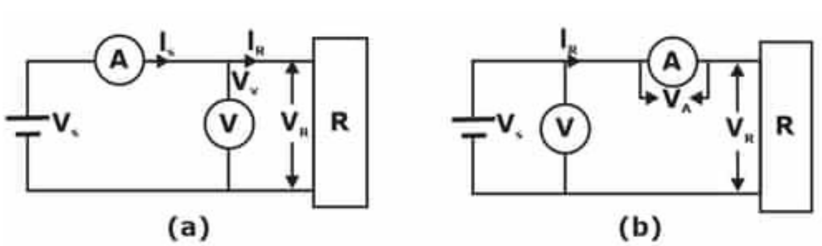


Figure 1. Two arrangements for power measurement in dc circuits

One thing should be kept in mind while using any of the two measuring arrangements shown in Figure 1; that both the voltmeter and the ammeter requires power for their own operations. In the arrangement of Figure 1(a), the voltmeter is connected between the load and the ammeter. The ammeter thus, in this case measures the current flowing into the voltmeter, in addition to the current flowing into the load.

Power consumed by the load= Power indicated by instruments - Power loss in voltmeter

Thus, **Power indicated = Power consumed + Power loss in voltmeter**

In alternating current circuits, the instantaneous power varies continuously as the voltage and current varies. In such case, the power at any instant is given by

$p(t) = v(t) \times i(t)$

where, p(t), v(t), and i(t) are values of instantaneous power, voltage and current respectively.

Thus, if both voltage and current can be assumed to be sinusoidal, with the current lagging the voltage by phase-angle φ, then

$V(t) = V_m \sin(\omega t)$

$i(t) = I_m \sin(\omega t - \varphi)$

where V_m and I_m are peak values of voltage and current respectively, and ω is the angular frequency.

The instantaneous power p(t) is therefore given by,

$p(t) = V_m I_m \sin(\omega t)\sin(\omega t - \varphi)$

Average value of Power over a complete cycle in such a case will be = VI cos φ

where, V and I are rms values of voltage and current respectively and cos j is power factor of the load.

POWER MEASUREMENT IN POLYPHASE SYSTEMS

Blondel's Theorem

The theorem states that 'in an n-phase network, the total power can be obtained by taking summation of the n wattmeter so connected that current elements of the wattmeter are each in one of the n lines and the corresponding voltage element is connected between that line and a common point'.

TWO-WATTMETER METHOD

This is the most common method of measuring three-phase power. It is particularly useful when the load is unbalanced

Star-Connected System

The connections for measurement of power in the case of a star-connected three-phase load are shown in figure 2

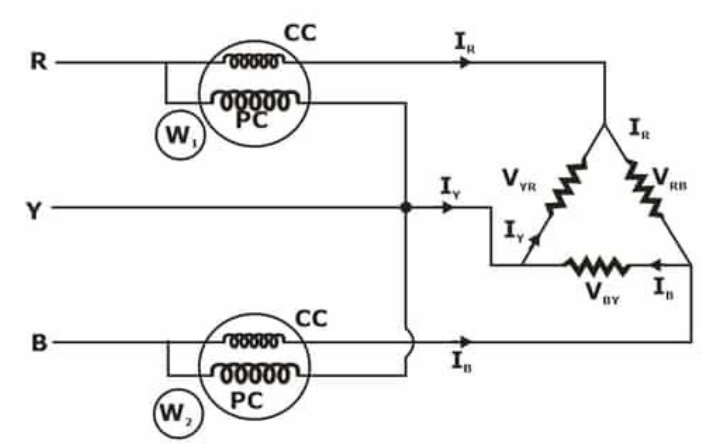


Figure 2: Two-wattmeter method for star-connected load

The current coils of the wattmeter are connected in lines R and B, and their voltage coils are connected between lines R and Y, and B and Y respectively.

Power consumed by the load

$P = V_{RN} \times I_R + V_{YN} \times I_Y + V_{BN} \times I_B$

Reading of wattmeter W_1, $P_1 = V_{RY} \text{ x } I_R = (V_{RN} \times V_{YN}) \text{ X } I_R$

Reading of wattmeter W_2, $P_2 = V_{BY} \text{ x } I_B = (V_{BN} - V_{YN}) \text{ X } I_B$

Summation of the two wattmeter readings:

$= P_1 + P_2 = (V_{RN} - V_{YN}) \text{ x } I_R + (V_{BN} - V_{YN}) \text{ X} I_B$

$= V_{RN} \times I_R + V_{BN} \times I_B - V_{YN} \times (I_R + I_B)$

From Kirchhoff 's law, summation of currents at node N must be zero, i.e.,

$I_R + I_Y + I_B = 0$

$I_R + I_B = -I_Y$

Thus, we can re-write,

$P_1 + P_2 = V_{RN} \times I_R + V_{YN} \times I_Y + V_{BN} \times I_B$

It can thus, be concluded that sum of the two wattmeter readings is equal to the total power consumed by the load. This is irrespective of fact whether the load is balanced or not.

Let, V_{RN}, V_{RN}, and V_{YN} are phase voltages and I_R, I_B is and I_Y are phase currents for the balanced three phase star connected system under study.

For a balanced system, phase voltages, $V_{RN} = V_{BN} = V_{YN} = V$(say)

And, phase currents, $I_R = I_R = I_y = I$ (say)

For a star-connected system,

Line voltages $V_{RN} = V_{BN} = V_{BR} =$ V

Line currents $I_R = I_B = I_Y = I$

Power factor = cos ϕ,

where ϕ is the angle by which each of the phase currents lag the corresponding phase voltages.

Current through the CC of wattmeter W_1 is I_R and voltage across its potential coil is V_{RY}.

The current I_R leads the voltage by V_{RY} an angle (30° − ϕ).

∴ reading of wattmeter W_1 is,

$P_1 = VI\cos(\Phi - 30^o)$

Current through the CC of wattmeter W_2 is I_B and voltage across its potential coil is V_{BY}. The current I_B lags the voltage by V_{BY} an angle (30° + ϕ), as shown above.

∴ reading of wattmeter W_2 is,

$P_2 = VIcos(\Phi - 30^o)$

Sum of these two-wattmeter readings:

$P_1 + P_2 = VIcos(\Phi + 30^o) + VIcos(\Phi - 30^o)$

$= VI[cos(\Phi + 30^o) + cos(\Phi - 30^o)]$

$= VIcos\Phi$

This is the total power consumed by the load, adding together the three individual phases.

Thus, at any power factor, the total power consumed by the load will be, in any case, summation of the two wattmeter readings.

There is way to find out value of the load power factor, if unknown, by a few steps of manipulation.

Consider **$P_1 = W_1$ & $P_2 = W_2$**

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\varphi}{\sqrt{3}\, V_L I_L \cos\varphi}$$

$$\tan\varphi = \sqrt{3}\, \frac{W_1 - W_2}{W_1 + W_2}$$

$$\cos\varphi = \cos\tan^{-1}\sqrt{3}\, \frac{W_1 - W_2}{W_1 + W_2}$$

by using above formula we can easily calculate the condition of Power Factor.

Measurement of Energy

Energy, heat, work and power are four concepts that are often confused. If force is exerted on an object and moves it over a distance, work is done, heat is released (under anything other than unrealistically ideal conditions) and energy is transformed. Energy, heat and work are three facets of the same concept. Energy is the capacity to do (and often the result of doing) work.

- The **SI unit of energy**, heat and work is the ***joule* (J)**. The **British thermal unit (Btu)** or one of its multiples; and the **kilowatt hour (kWh).**
- Power is the rate at which work is done (or heat released, or energy converted).
- A light bulb draws 100 joules of energy per second of electricity, and uses that electricity to emit light and heat (both forms of energy). The rate of one joule per second is called a *watt*. The light bulb, operating at 100 J/s, is drawing power of 100 Watts.

Energy meter or watt hour meter is classified in accordance with several factors such as

- Type of display like analog or digital electric meter.
- Type of metering point like grid, secondary transmission, primary and local distribution.
- End applications like domestic, commercial and industrial.
- Technical like three phases, single phase, HT, LT and accuracy class meters.

Electro-Mechanical induction type Energy meter

- It is the popularly known and most common type of age old watt hour meter.
- It consists of rotating aluminum disc mounted on a spindle between two electro magnets.
- Speed of rotation of disc is proportional to the power and this power is integrated by the use of counter mechanism and gear trains.
- It comprises of two silicon steel laminated electromagnets i.e., series and shunt magnets.

Electronic Energy meters

- These are of accurate, high procession and reliable types of measuring instruments as compared to conventional mechanical meters.
- It consumes less power and starts measuring instantaneously when connected to load.
- These meters might be analog or digital.
- In analog meters, power is converted to proportional frequency or pulse rate and it is integrated by counters placed inside it.
- In digital electric meter power is directly measured by high end processor.
- The power is integrated by logic circuits to get the energy and also for testing and calibration purpose. It is then converted to frequency or pulse rate.

Smart Energy Meters

It is an advanced metering technology involving placing intelligent meters to read, process and feedback the data to customers. It measures energy consumption, remotely switches the supply to customers and remotely controls the maximum electricity consumption. Smart metering system uses the advanced metering infrastructure system technology for better performance.

- These are capable of communicating in both directions.
- They can transmit the data to the utilities like energy consumption, parameter values, alarms, etc and also can receive information from

utilities such as automatic meter reading system, reconnect/disconnect instructions, upgrading of meter software's and other important messages.

Formula to calculate the amount of Energy consumed by a Load

The calculation is as follows:

[number of hours use] x [number of days use] x ([capacity of appliance expressed in watt] / 1,000) = number of kWh

The capacity should be divided by 1,000 to convert the number of watts into the number of kilowatts. This finally gives us the number of kWh (kilowatt-hours).

AC & DC Bridges

AC Bridges: AC bridges are used to measure self-inductance, mutual inductance, capacitance and frequency.

Types of Sources

1. At low frequency, the power line is used as a source.
2. At high frequency, the electronic oscillator is used as a source

Types of Detectors

1. Vibration galvanometer at low power frequency and audio frequency (up to 1000 Hz)
2. Headphones at an audio frequency (250 Hz to 4 kHz)
3. Tunable amplifier for frequency range (10 Hz to 100 kHz)

General Bridge Circuit

At balanced bridge $\overline{Z_1}\,\overline{Z_4} = \overline{Z_2}\,\overline{Z_3}$

Magnitude condition $|Z_1||Z_4| = |Z_2||Z_3|$

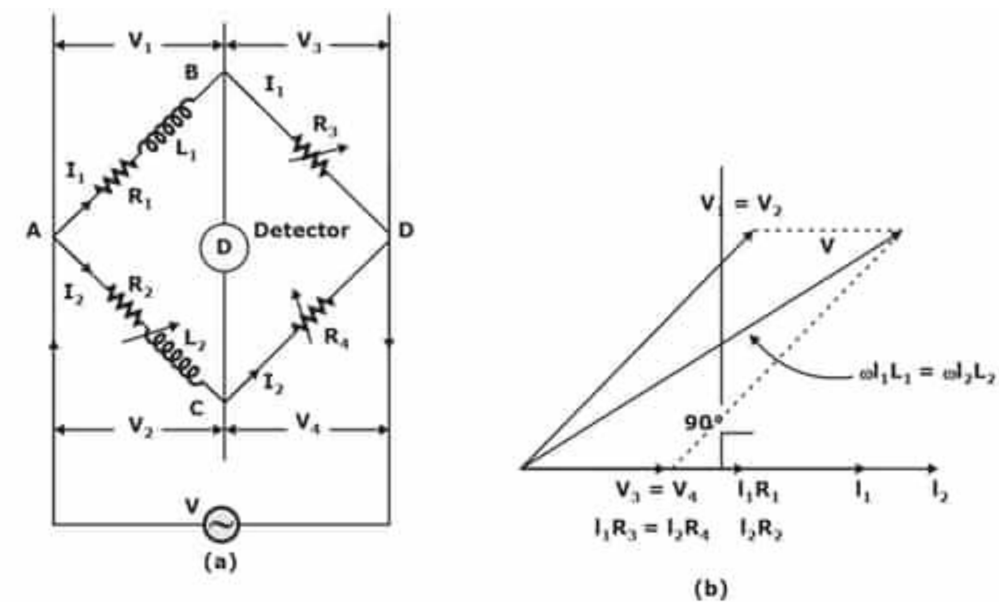
Angle condition $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$

For balanced bridge both the magnitude

Measurement of Self Inductance

- Maxwell's inductance bridge
- Maxwell's inductance-capacitance bridge
- Hay's bridge
- Anderson's bridge
- Owne's bridge

Maxwell's Inductance Bridge



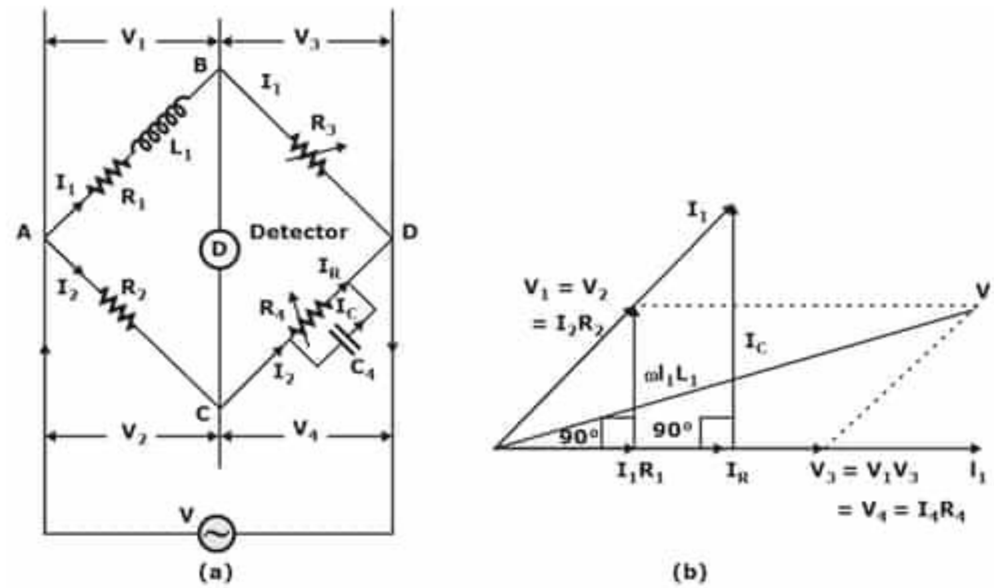
Where, L_1 = Unknown inductance of resistance R_1

L_2 = Variable induactance

R_2 = Standard variable resistance

R_3, R_4 = Fixed non-inductance resistance

Maxwell's Inductance - Capacitance Bridge



Q-factor,

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

Q-factor range 1 < Q < 10, for medium Q-coils

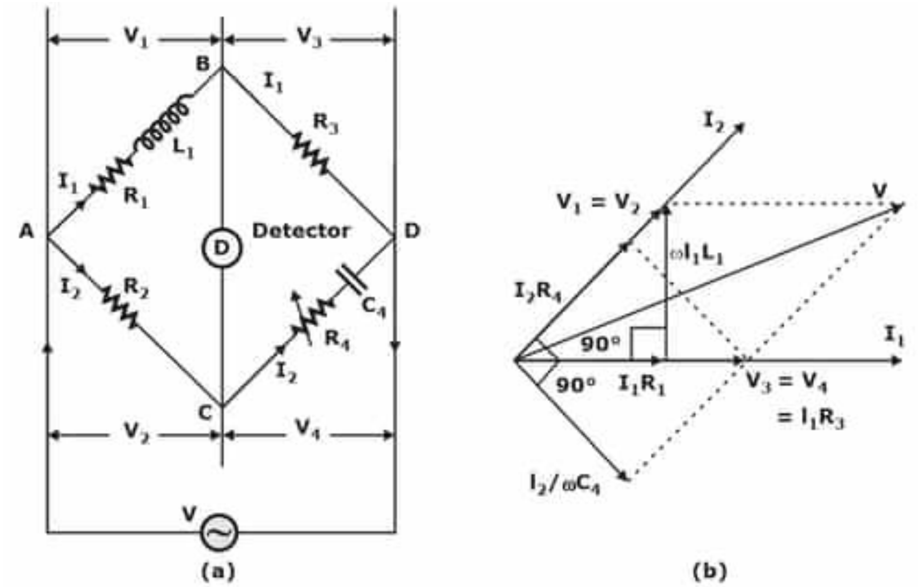
Where, R_4 = Variable non-inductive resistance

C_4 = Standard variable capacitance

Note: If C_4 is fixed, then balanced bridge obtained as

- Either by varying R_2 and R_4.
- Put a resistance in series with L_1 and varying R_4.

Hay's Bridge



$$R_1 = \frac{\omega^2 R_2 R_3 R_4 C_4^2}{1+\omega^2 R_4^2 C_4^2} = \frac{R_2 R_3}{R_4}\left(\frac{1}{1+Q^2}\right)$$

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

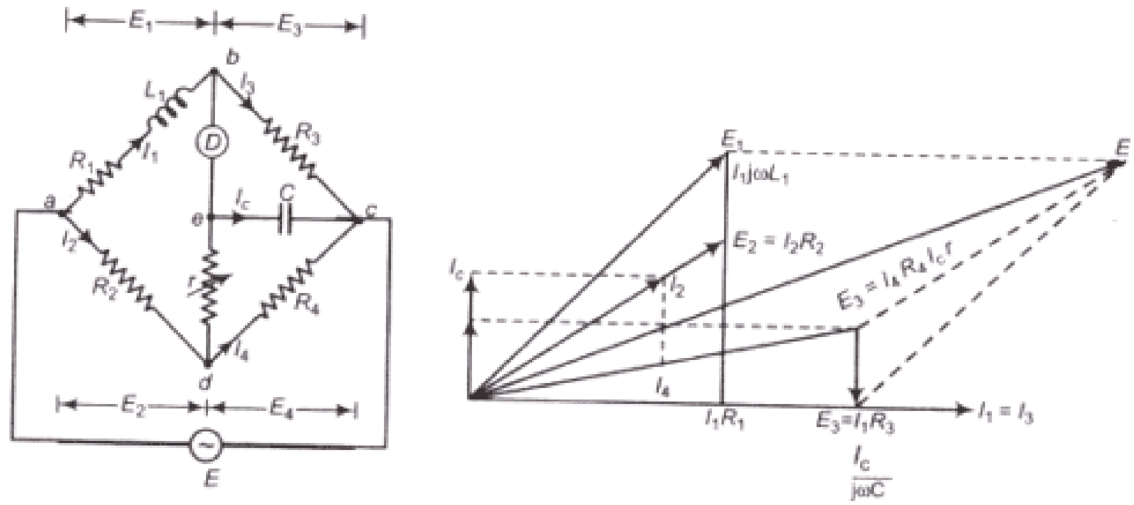
Where, C_4 = Standard capacitance

Q-factor

for Q > 10 *i.e.*, high Q-coils

$L_1 = R_2 R_3 C_4$

Anderson's Bridge



Phasor diagram of Anderson's bridge

Where, L_1 = Unknown self-inductance with an internal resistance R_1

R_2, R_3, R_4 = Fixed standard non-inductive resistance

r = A variable resistance

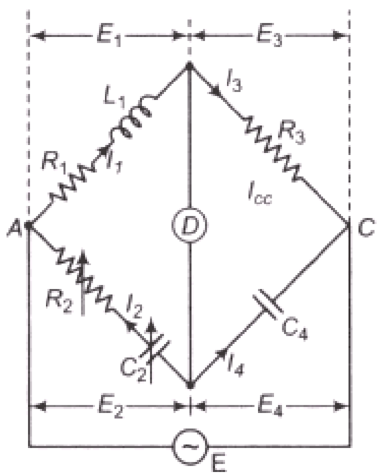
C = A fixed capacitance

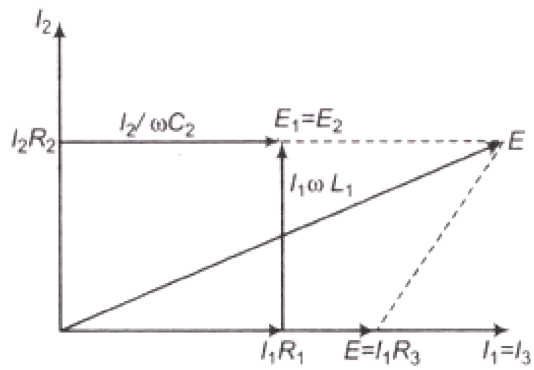
- Anderson's bridge is suitable for small Q-factor *i.e.*, Q < 1.
- It can also be used for the measurement of capacitance in terms of inductance.

Key Points

- Maxwell's bridge is used to measure the inductance of a low Q-inductor.
- Hay bridge is used to measure the inductance of a high Q-inductor.
- Inductance is measured in terms of capacitance, resistance by Anderson's bridge.

Owen's Bridge





Phasor diagram of Owen's bridge

Where, L_1 = Unknown self-inductance with internal resistance R_1

R_2 = Variable non-inductive resistance

R_3 = Fixed standard non-inductive resistance

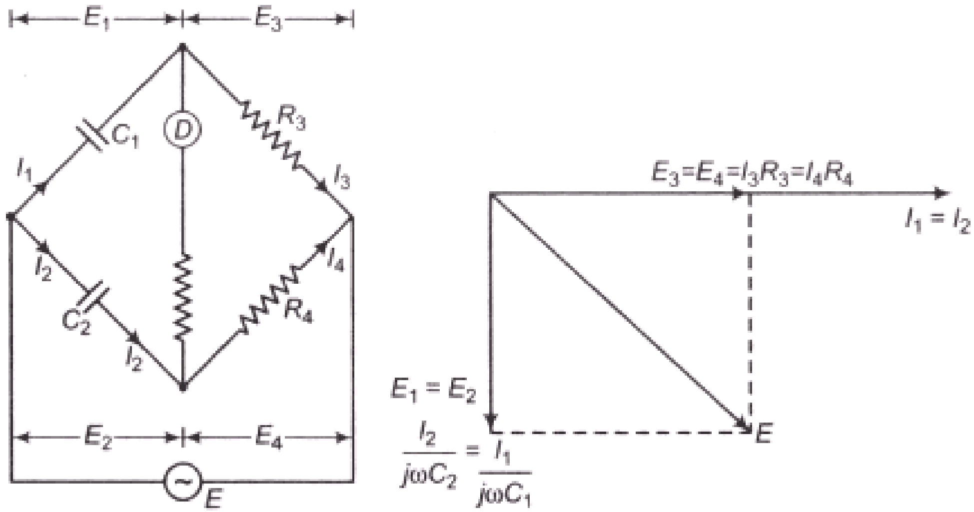
C_2 = Standard variable capacitor

C_4 = Fixed standard capacitor

Measurement of Capacitance

The capacitance can be measured with the help of the following bridges

De-Sauty Bridge



Phase diagram of De-sauty bridge

$$C_1 = \frac{C_2 R_4}{R_3}$$

Where C_1 = Unknown capacitor

C_2 = Standard capacitor

R_3, R_4 = Fixed non-inductive resistance

The de-Sauty bridge can be used for the measurement of either air-cored or gas-filled capacitance only (lossless capacitor).

Schering Bridge

Dissipation factor $D_1 = \tan \delta = \omega C_1 r_1 = \omega C_4 R_4$

Where C_1 = Unknown capacitor with loss component r_1

C_2 = Fixed standard capacitor

R_3 = Fixed standard non-inductive resistance

C_4 = Variable capacitor

R_4 = Variable non-inductive resistance

Key Points

- High voltage Schering bridge is used for the determination of capacitance of insulators, capacitor bushings and insulating oil and other insulating materials.
- Schering bridge is also used to measurement of relative permittivity of dielectric materials.
- The Schering bridge is one of the most widely used AC bridges.
- In order to measure the low value of capacitance Schering bridge is used.

Measurement of Frequency

Frequency by Wein's bridge.

Wein's Bridge

$$\frac{R_4}{R_3} = \frac{C_1}{C_2} + \frac{R_2}{R_1}$$

$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

Frequency,

For $R_1 = R_2 = R$

and $C_1 = C_2 = C$

and $C_1 = C_2 = C$

$$f = \frac{1}{2\pi RC}$$

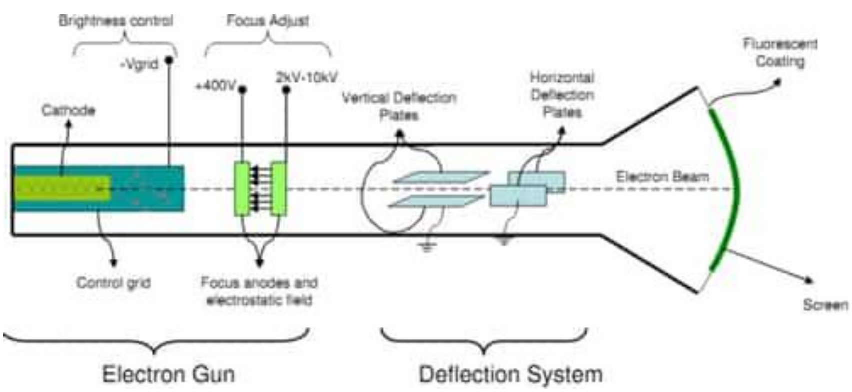
- Wein's bridge used as a notch Filter in harmonic distortion analyzer.
- A frequency isolator in high-frequency oscillator and amplifier circuit.
- A notch filter in a harmonics distortion analyzer where it is used to isolate and eliminate the fundamental frequency component from the output of the amplifier under test.

Comparison between Different Types of Bridges

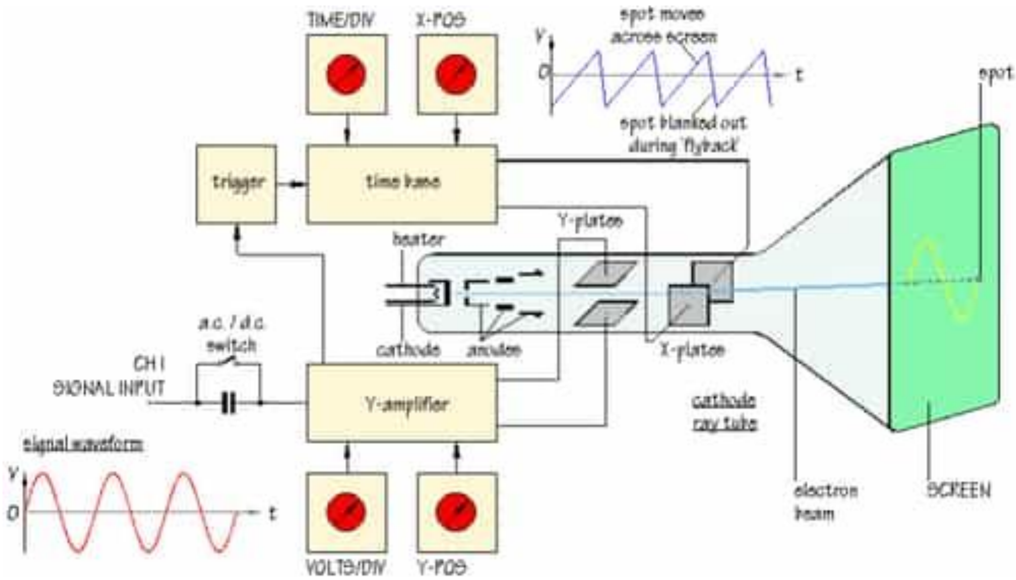
Bridge Type	Measured Parameter
Maxwell's Inductance bridge	Self inductance
Maxwell's inductance capacitance bridge	Same ($1 < Q < 10$)
Hay bridge	Same ($Q > 10$)
Anderson bridge	Same ($Q < 1$)
Owen's bridge	Self inductance in terms of a standard capacitance
De-Sauty's bridge	Capaitavec in terms of standard capacitance
Heavsible bridge	Mutual inductance in terms of a standard mutual inductance
Wein's bridge	Frequency measurement.

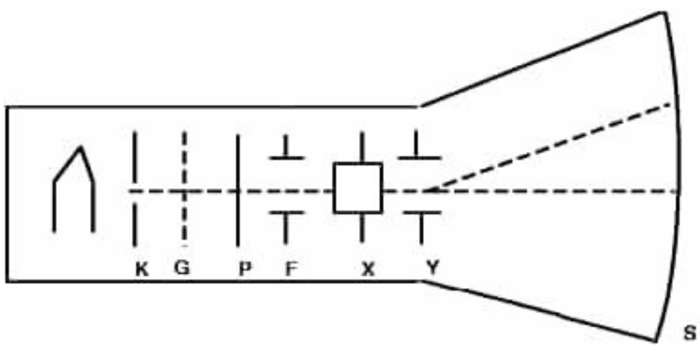
Cathode Ray Tube & Oscilloscope

The Cathode Ray Oscilloscope



The **main part** of the C.R.O. is a **highly evacuated glass tube** housing parts that generate a beam of electrons, accelerates them, shapes them into a narrow beam, and provides external connections to the sets of plates described m above for changing the direction of the beam.





Component of C.R.O

- **K,** an indirectly heated cathode that provides a source of electrons for the beam by "boiling" them out of the cathode.
- **P,** the anode (or plate) which is circular with a small central hole. The potential of P creates an electric field that accelerates the electrons, some of which emerge from the hole as a fine beam. This beam lies along the central axis of the tube.
- **G,** the grid. Controlling the potential of the grid controls the number of electrons for the beam, and hence the intensity of the spot on the screen where the beam hits.
- **F,** the focusing cylinder. This aids in concentrating the electron beam into a thin straight line much as a lens operates in optics.
- **X, Y,** deflection plate pairs. The X plates are used for deflecting the beam left to right (the x-direction) by means of the "ramp" voltage. The Y plates are used for the deflection of the beam in the vertical direction. Voltages

on the X and Y sets of plates determine where the beam will strike the screen and cause a spot of light.
- **S,** the screen. This is coated on the inside with a material that fluoresces with green light (usually) where the electrons are striking.

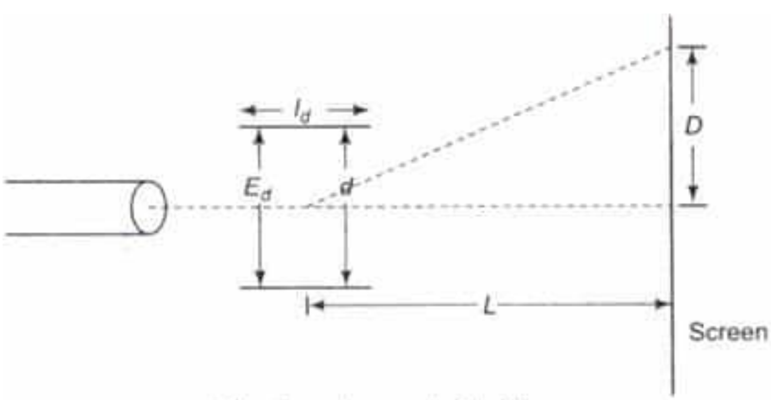
As well as this tube, there are **several electronic circuits required to operate the tube**, all within the C.R.O. along with the tube explained below

- A power supply, operated from the **110 volts 60 cycle per second** electrical "mains". This supply provides all the voltages required for the different circuits within the C.R.O. for operation of the tube.
- A **"sawtooth", or "ramp" signal generator** which makes the spot move left to right on the screen. External controls for this circuit allow variation of the sweep width and the frequency of the sweep signal. Because of the persistence of our vision, this sweep is often fast enough that what we see on the screen is a continuous horizontal line.
- **Amplifiers** for the internally generated ramp signal, and for the "unknown" signal which we hook up to the C.R.O. for the purpose of displaying it.
- **Shift devices** allow us to **control the mean position of the beam; up or down, or left to right.**
- The **synchronizer** circuit. This circuit allows us to **synchronize the "unknown" signal with the ramp signal** such that the **resulting display is a nice clear signal like a snapshot** of the unknown voltage vs. time.

CRO (Cathode Ray Oscilloscope)

CRO is a device that provides accurate time and amplitude of voltage signals over a wide range of frequencies.

Deflection of Electron Beam



Electron beam deflection

Deflection

$$D = \frac{L\, I_d E_d}{2dE_a} metre$$

Where L = distance between the screen and the centre of deflecting plates (m)

I_d = length of deflecting plates (m)

E_d = potential between deflecting plates (V)

d = distance between deflecting plates (m)

E_a = voltage of pre-accelerating anode (V)

Deflection Sensitivity

$$S = \frac{D}{E_d} = \frac{LI_d}{2dE_a}\ m / V$$

Deflection Factor

$$G = \frac{1}{S} = \frac{2dE_a}{LI_d}\ V / m$$

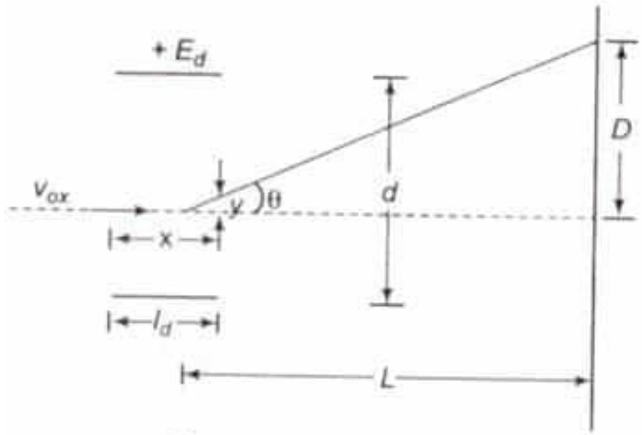
Velocity of Electron Beam

$$v = \sqrt{\frac{2dE_a}{m}}$$

Where, e = charge of electron = 16×10^{-19} C

m = mass of electron = 9.1×10^{-31} kg

Electrostatic Deflection



Electrostatic deflection

$$y = \frac{1}{2}\frac{eEy}{mV_{ox}^2}x^2$$

Where, *y* = displacement in y-direction (m)

e = charge of an electron (C)

m = mass of electron (kg)

x = displacement in X-direction (m)

E_y = electric field intensity in the y-direction (V/m)

V_{ox} = velocity of the electron when entering in the fields of deflecting plates (m/s)

Frequency limit of CRO

$$f_c = \frac{v_{ox}}{4I_d}$$

Where V_{ox} = velocity of the electron beam in X-direction before it enters in deflecting plates

l_d = length of vertical deflection plates

Rising Time of Vertical Amplifier

$$t_r = \frac{0.35}{BW}$$

Where, BW = Bandwidth of oscilloscope (CRO)

Digital Voltmeters

Analog to Digital Conversion

A voltmeter is an electrical measuring instrument that is used to measure the potential difference between two points. The voltage to be measured may be AC or DC. Two types of voltmeters are available for the purpose of voltage measurement i.e. analogue and digital. Analogue voltmeters generally contain a dial with a needle moving over it according to the measure and hence displaying the value of the same.

- These are generally known as **DVM** that use **digital formatting** of the input fed to its input leads. Here, the result of measurement is shown in form of **discrete numbers** for which they employ display devices for the decimal number system.
- **Digital voltmeter** also attains an inherited greater speed of operation. Because output obtained from these instruments comes to be a digital form so it becomes easier to use them directly as an input to many other devices like memory devices so that the result may be used further in future, this is called **storage of data**.
- Because of high accuracy, high-speed operation and greater reliability they are frequently used in laboratories and industries for the purpose of experimentation and obtaining highly accurate results.
- It can be accepted as a **disadvantage of digital voltmeters** that they always need some external power supply for its operation that make it less portable and also bulkier but with the advancements made in the field of integrated circuits, it has become possible to make such digital device very compact, more efficient, low cost and having even greater accuracy.
- This advancement has led to the verge that now some digital devices are there having less cost than their competent analogue ones with the same extent of accuracy.
- A/D converts an analogue signal into the digital code which is proportional to the magnitude of the coming signal.

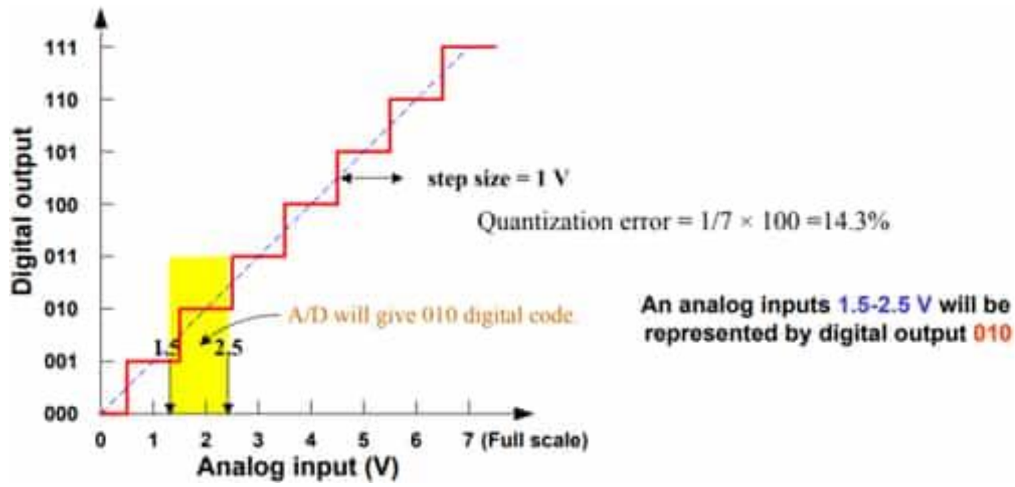
Vin ≈ k ×Digital output

Where k is step size or resolution.

Quantization error or Conversion error of a A/D

$$\text{Quantization error} = \frac{\text{step size}}{\text{full scale}} \times 100 = \frac{1}{2^N - 1} \times 100\%$$

Conversion time, T_c: The time requires to convert an analogue signal to the corresponding digital code.



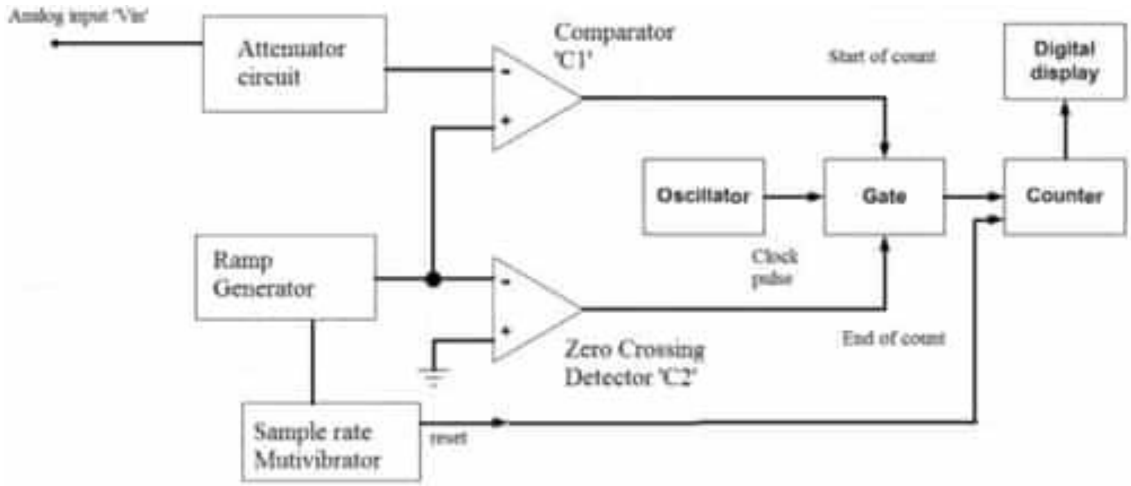
On the basis of the A/D conversion method used digital voltmeters can be classified as:

- Ramp type digital voltmeter
- Integrating type voltmeter
- Potentiometric type digital voltmeters
- Successive approximation type digital voltmeter
- Continuous balance type digital voltmeter

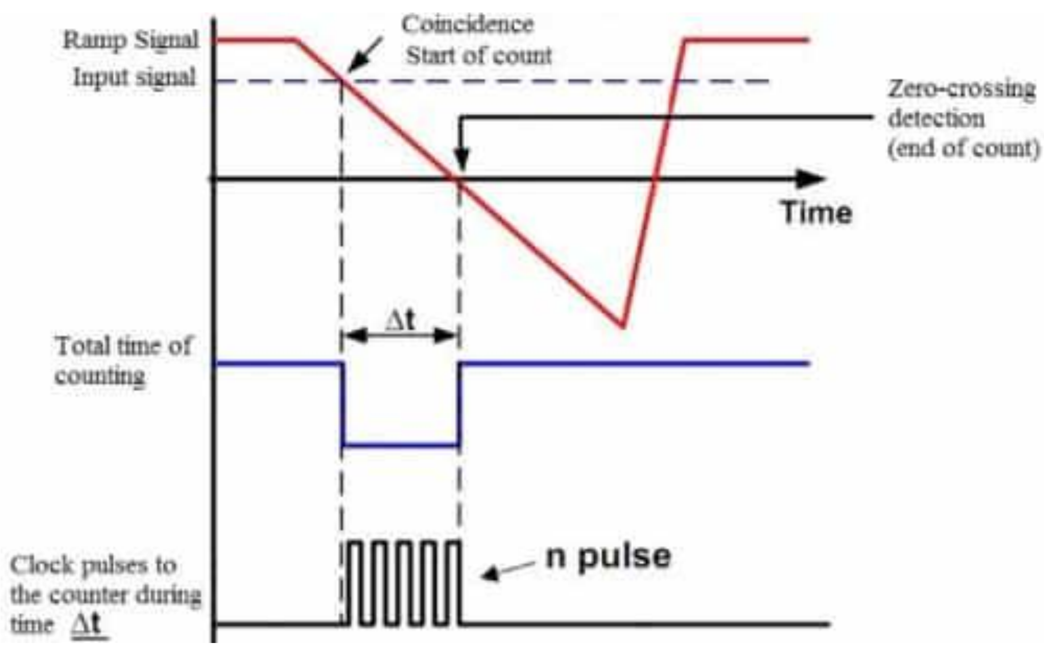
Now-a-days **digital voltmeters** are also replaced by digital millimeters due to its multitasking feature i.e. it can be used for measuring current, voltage and resistance. But still there are some fields where separated digital voltmeters are being used.

Ramp-type Digital Voltmeter

Its Operating principle is based on the measurement of the time it takes for a linear ramp voltage to rise from 0 V to the level of the input voltage, or to decrease from the level of the input voltage to zero. This time interval is measured with an electronic time-interval counter, and the count is displayed as a number of digits on electronic indicating tubes.



The working principle i.e., the Conversion from a voltage to a time interval is illustrated by the waveform



- At the start of the measurement cycle, a ramp voltage is initiated; this voltage can be positive-going or negative-going. The negative-going ramp, is continuously compared with the unknown input voltage.
- At the instant that the ramp voltage equals the unknown voltage, a coincidence circuit, or compactor, generates a pulse which opens a gate.
- The ramp voltage continues to decrease with time until it finally reaches 0 V (or ground potential) and a second compactor generates an output pulse which closes the gate.

- An oscillator generates clock pulses which are allowed to pass through the gate to a number of decade counting units (DCUs) which totalize the number of pulses passed through the gate.
- The decimal number, displayed by the indicator tubes associated with the DCUs, is a measure of the magnitude of the input voltage.
- The sample-rate Multi-vibrator determines the rate at which the measurement cycles are initiated.
- The oscillation of this multivibrator can usually be adjusted by a front-panel control , marked rate , from a few cycles per second to as high 1,000 or more.
- The sample-rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage. At the same time, a reset pulse is generated which returns all the DCUs to their 0 state, removing the display momentarily from the indicator tubes.

V_R ------------ T_R

V_M ---------- T_M

$V_M = (V_R / T_R)^* T_M$

Time period measurement

Let TCLK be time period of clock generator. Let 'n ' be the number of clock pulses between T_1 and T_2

$T_2 - T_1 = T_M = n^* T_{CLK}$

Substitute the value of TM in VM we get

$V_M = (V_R / T_R)^* n ^*T_{CLK}$

FEATURES OF RAMP TYPE DVM

1)CONVERSION TIME

$T_{CONV} = T_M = nT_{CLK}$

Where n is proportional to | V_M | because the number of pulses depends upon V_M

2) NOISE REJECTION

If either AC signal or noise is superimposed on unknown DC voltage then error is introduced in voltage measurement. So noise affect is more. Therefore noise rejection is poor. Since stability of DVM depends on noise condition. Its stability is poor.

3) ACCURACY

Value Internal components of ramp generator changes due to aging then linearity of ramp changes then V_M also changes as shown in the figure and accuracy of measurement is affected.