UNIT-1

MEASUREMENT SYSTEM

The measurement of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) & a predefined Standard. Since two quantities are compared, the result is expressed in numerical values.

BASIC REQUIREMENTS OF MEASUREMENT:

i) The standard used for comparison purposes must be accurately defined & should be commonly accepted

ii) The apparatus used & the method adopted must be provable.

MEASURING INSTRUMENT: It may be defined as a device for determining the value or magnitude of a quantity or variable.

ELEMENTS OF A GENERALIZED MEASUREMENT SYSTEM:

Most of the measurement systems contain five main functional elements are

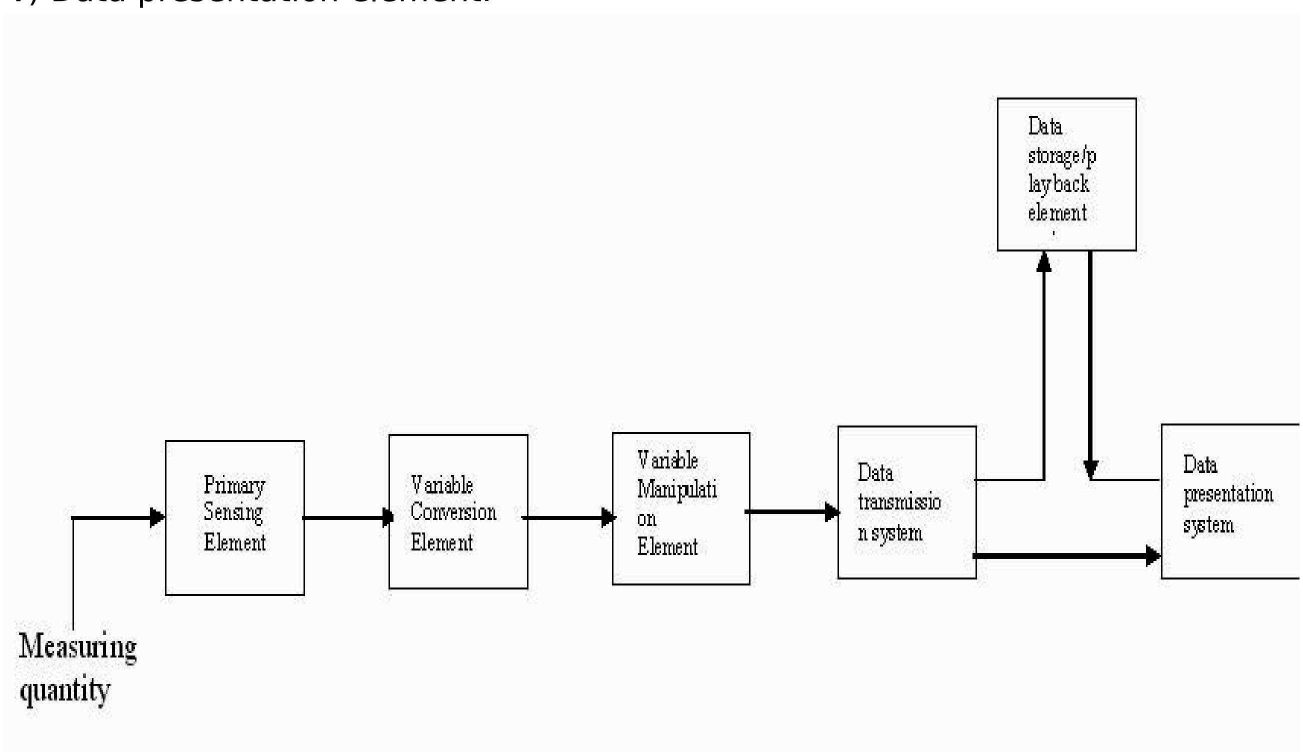
i) Primary sensing element

ii) Variable conversion element

iii) Variable manipulation element

iv) Data transmission system

v) Data presentation element.



Primary sensing element: The quantity under measurement makes its first contact with the primary sensing element of a measurement system. In other words, the measurand (the unknown quantity which is to be measured) is first detected by primary sensor. This act is then immediately followed by the conversion of measurand into an analogous electrical signal. This is done by transducer. A transducer in general, is defined as a device which converts energy from one form to another. The physical quantity to be measured, in the first place is sensed and detected by an element which gives the output in a different analogous form. This output is then converted into an electrical signal by a transducer. First stage of a measurement system is known as a detector Transducer stage.

Variable conversion element: The output of the primary sensing element may be electrical signal of any form; it may be voltage, a frequency or some other electrical parameter. Sometimes this output is not suited for the system. For the instrument to perform the desired function, it may be necessary to convert this output to some other suitable form while preserving the information content of the original signal.

Variable manipulation element: The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. Manipulation here means only a change in numerical value of the signal. It is not necessary that a variable manipulation element should follow the variable conversion element. Some non-linear processes like modulation, detection, sampling, filtering, chopping etc.,are performed on the signal to bring it to the desired form to be accepted by the next stage of measurement system. This process of conversion is called signal conditioning. The term signal conditioning includes many other functions in addition to Variable conversion & Variable manipulation. In fact the element that follows the primary sensing element in any instrument or measurement system is called signal conditioning element.

Data transmission element: When the elements of an instrument are actually physically separated, it becomes necessary to transmit data from one to another. The element that performs this function is called a data transmission element. The signal conditioning stage is commonly known as Intermediate stage.

Data Presentation Element: The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control, or analysis purposes. This function is done by data presentation element. In case data is to be monitored, visual display devices are needed. These devices may be analog or digital indicating instruments like ammeters, voltmeters etc. In case data is to be recorded, recorders like magnetic tapes, high speed camera & TV equipment, CRT, printers may be used. For control & analysis purpose microprocessor or computers may be used. The final stage in a measurement system is known as terminating stage.

PERFORMANCE CHARACTERISTICS

The performance characteristics of an instrument are mainly divided into two categories:
i) Static characteristics
ii) Dynamic characteristics.

Static characteristics:

The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called 'static characteristics'. The various static characteristics are:
i) Accuracy
ii) Precision
iii) Sensitivity
iv) Linearity
v) Reproducibility
vi) Repeatability
vii) Resolution
viii) Threshold
ix) Drift
x) Stability
xi) Tolerance
xii) Range or span
xiii) Hysteresis error

i) Accuracy:

It is the degree of closeness with which the reading approaches the true value of the quantity to be measured. The accuracy can be expressed in following ways:

a) Point accuracy: Such accuracy is specified at only one particular point of scale. It does not give any information about the accuracy at any other Point on the scale.

b) Accuracy as percentage of scale span: When an instrument as uniform scale, its accuracy may be expressed in terms of scale range.

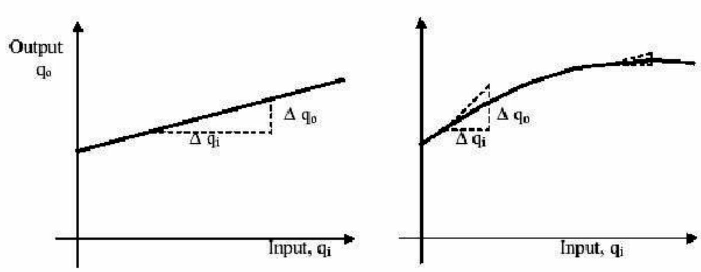
c) Accuracy as percentage of true value: The best way to conceive the idea of accuracy is to specify it in terms of the true value of the quantity being measured.

ii) Precision: It is the measure of reproducibility i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements. The precision is composed of two characteristics:
a) Conformity: Consider a resistor having true value as 2385692 , which is being measured by an ohmmeter. But the reader can read consistently, a value as 2.4 M due to the non availability of proper scale. The error created due to the limitation of the scale reading is a precision error. **b) Number of significant figures:** The precision of the measurement is obtained from the number of significant figures, in which the reading is expressed. The significant figures convey the actual information about the magnitude & the measurement precision of the quantity. The precision can be mathematically expressed as:

$$P=1-\left|\frac{Xn-\overline{Xn}}{\overline{Xn}}\right|$$

Where, P = precision Xn = Value of nth measurement Xn = Average value the set of measurement values.

iii) Sensitivity: The sensitivity denotes the smallest change in the measured variable to which the instrument responds. It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured. Mathematically it is expressed as,



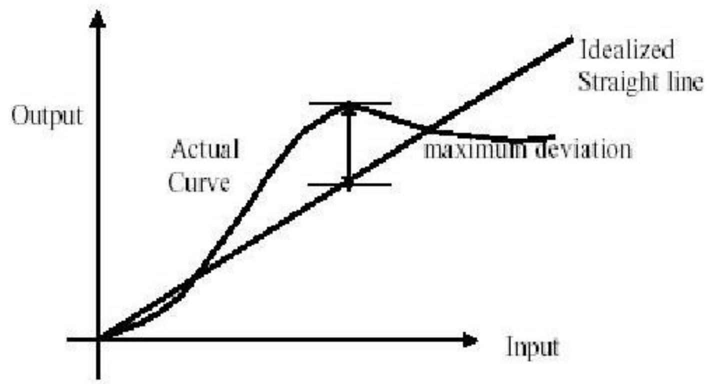
$$\text{Sensitivity}=\frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$=\frac{\Delta qo}{\Delta qi}$$

Thus, if the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve. If the calibration curve is not linear as shown, then the sensitivity varies with the input. Inverse sensitivity or deflection factor is defined as the reciprocal of sensitivity. Inverse sensitivity or deflection factor = 1/ sensitivity.

iv) Linearity

Linearity is defined as, it is the ratio of Maximum deviation of output from idealized straight line to Actual readings. Linearity is simply a measure of the maximum deviation of the calibration points from the ideal straight line. Linearity is defined as the ability of an instrument to reproduce its input linearly.



v) Reproducibility: It is the degree of closeness with which a given value may be repeatedly measured. It is specified in terms of scale readings over a given period of time.

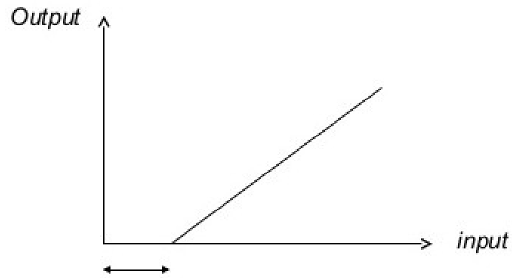
Vi) Repeatability: It is defined as the variation of scale reading & random in nature Drift: Drift may be classified into three categories:

vii) Resolution: The smallest increment in input that can be detected by certainty by an instrument is its resolution.

$$\text{Resolution} = \frac{full\ scall\ reading}{number\ of\ divisions}$$

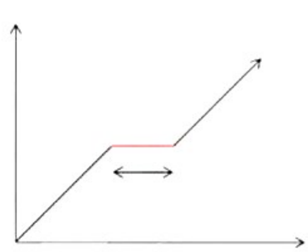
As resolution of an instrument increases, even very a small change in input can be measured very clearly.

viii) Threshold: If the instrument input is increased gradually from zero value, there will be a minimum value is required to give detectable change in output. This minimum defines the instrument threshold.

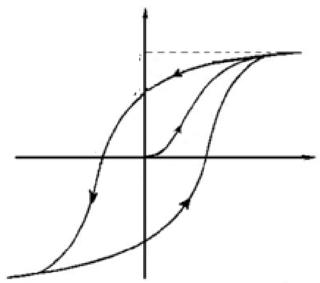


ix) Drift: Drift may be caused because of environment factors like stray electric fields, stray magnetic fields, thermal e.m.fs, changes in temperature, mechanical vibrations etc. The drift is defined as the gradual shift in the indication over a period of time where in the input variable does not change.
Drift is classified into three categories:
a) Zero drift: If the whole calibration gradually shifts due to slippage, permanent set, or due to undue warming up of electronic tube circuits, zero drift sets in.
b) Span drift or sensitivity drift: If there is proportional change in the indication all along the upward scale, the drifts is called span drift or sensitivity drift.
c) Zonal drift: In case the drift occurs only a portion of span of an instrument, it is called zonal drift.

x) Stability: It is the ability of an instrument to retain its performance throughout is specified operating life.
xi) Tolerance: The maximum allowable error in the measurement is specified in terms of some value which is called tolerance.
xii) Range or span: the minimum & maximum value of a quantity for which an instrument is designed to measure is called its range or span.
xiii) Dead zone: It is defined as the largest change off input quantity for which there is no output of the instrument.



xiii) Hystersis error: If an instrument shows less the actual value for asending input value, shows more than actual value for desending input value i.e the meter is giving two different readings for two same input values. This is hystersis error.
Reason: This error is due to the meter have the diferent flux densities for same input while asending and desending times.



DYNAMIC CHARACTERISTICS

The set of criteria defined for the instruments, which are changes rapidly with time, is called dynamic characteristics. The various static characteristics are:
i) Speed of response
ii) Measuring lag
iii) Fidelity
iv) Dynamic error

i) Speed of response: It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.

ii) Measuring lag: It is the retardation or delay in the response of a measurement system to changes in the measured quantity. The measuring lags are of two types:

a) Retardation type: In this case the response of the measurement system begins immediately after the change in measured quantity has occurred.

b) Time delay lag: In this case the response of the measurement system begins after a dead time after the application of the input.

iii) Fidelity: It is defined as the degree to which a measurement system indicates changes in the measurand quantity without dynamic error.

Dynamic error: It is the difference between the true value of the quantity changing with time & the value indicated by the measurement system if no static error is assumed. It is also called measurement error.

TYPES OF ERRORS

Definition: The measurement error is defined as the difference between the true or actual value and the measured value. The true value is the average of the infinite number of measurements, and the measured value is the precise value.

$$dA = A_m - A_t$$

where, dA is the static error A_m is measured value and A_t is true value.

Basically there are three **types of errors** on the basis; they may arise from the source.

Types of Errors in Measurement

The error may arise from the different source and are usually classified into the following types. These types are

I. Gross Errors
II. Systematic Errors
III. Random Errors

Their types are explained below in details.

I. Gross Errors

The gross error occurs because of the human mistakes. For examples consider the person using the instruments takes the wrong reading, or they can record the incorrect data. Such type of error comes under the gross error. The gross error can only be avoided by taking the reading carefully.

For example – The experimenter reads the 31.5ºC reading while the actual reading is 21.5Cº. This happens because of the oversights. The experimenter takes the wrong reading and because of which the error occurs in the measurement.

Such type of error is very common in the measurement. The complete elimination of such type of error is not possible. Some of the gross error easily detected by the experimenter but some of them is difficult to find. Two methods can remove the gross error.

Two methods can remove the gross error. These methods are

- The reading should be taken very carefully.
- Two or more readings should be taken of the measurement quantity. The readings are taken by the different experimenter and at a different point for removing the error.

II. Systematic Errors

The systematic errors are mainly classified into three categories.

A. Instrumental Errors
B. Environmental Errors
C. Observational Errors

Instrumental Errors

These errors mainly arise due to the three main reasons.

(a) Inherent Shortcomings of Instruments **–** Such types of errors are inbuilt in instruments because of their mechanical structure. They may be due to manufacturing, calibration or operation of the device. These errors may cause the error to read too low or too high.

For example – If the instrument uses the weak spring then it gives the high value of measuring quantity. The error occurs in the instrument because of the friction or hysteresis loss.

(b) Misuse of Instrument **–** The error occurs in the instrument because of the fault of the operator. A good instrument used in an unintelligent way may give an enormous result.

For example – the misuse of the instrument may cause the failure to adjust the zero of instruments, poor initial adjustment, using lead to too high resistance. These improper practices may not cause permanent damage to the instrument, but all the same, they cause errors.

(c) Loading Effect – It is the most common type of error which is caused by the instrument in measurement work. For example, when the voltmeter is connected to the high resistance circuit it gives a misleading reading, and when it is connected to the low resistance circuit, it gives the dependable reading. This means the voltmeter has a loading effect on the circuit.

The error caused by the loading effect can be overcome by using the meters intelligently. For example, when measuring a low resistance by the ammeter-voltmeter method, a voltmeter having a very high value of resistance should be used.

Environmental Errors

These errors are due to the external condition of the measuring devices. Such types of errors mainly occur due to the effect of temperature, pressure, humidity, dust, vibration or because of the magnetic or electrostatic field. The corrective measures employed to eliminate or to reduce these undesirable effects are

- The arrangement should be made to keep the conditions as constant as possible.
- Using the equipment which is free from these effects.
- By using the techniques which eliminate the effect of these disturbances.
- By applying the computed corrections.

Observational Errors

Such types of errors are due to the wrong observation of the reading. There are many sources of observational error. For example, the pointer of a voltmeter resets slightly above the surface of the scale. Thus an error **occurs**(because of parallax) unless the line of vision of the observer is exactly above the pointer. To minimise the parallax error highly accurate meters are provided with mirrored scales.

III. Random Errors

The error which is caused by the sudden change in the atmospheric condition, such type of error is called random error. These types of error remain even after the removal of the systematic error. Hence such type of error is also called residual error.

Random errors can be eliminated by using statistical analysis data i.e multi sample data in which the same input value is measured repeatedly by the same instant with single observer or many observers.

Statistical analysis of data:

Suppose we have 'N' measurements of some quantity, X1, X2, X3,……,XN. If there is no systematic error in a set of measurements, the *mean* (or *average*) is the best approximation to the "true" value that we can obtain from a set of measured values:

Mean or Average value **(X')** = $\frac{X1+X2+X3.......+XN}{N}$

Deviation (d)

d1= X1- X'

d2= X2-X'

d3= X3-X'

.

.

dn= XN-X'

Average Deviation (D)

D= $\frac{d1+d2+d3+...+dN}{N}$

Varience:

Standard Deviation (σ)=

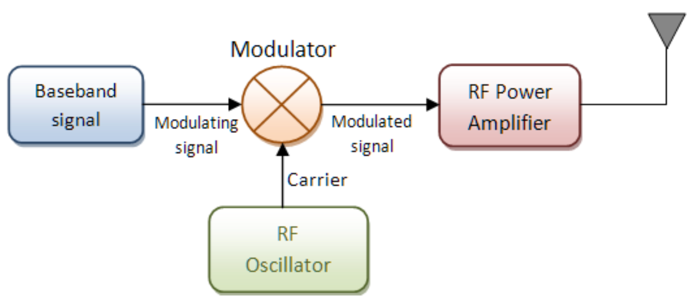
Probable error (r') = ± 0.6745 **σ**

Precession consider random error
Accuracy consider systematic error

MODULATION

Modulation is a process of changing the characteristics of the wave to be transmitted by superimposing the message signal on the high frequency signal. In this process video, voice and other data signals modify high frequency signals – also known as carrier wave. This carrier wave can be DC or AC or pulse chain depending on the application used. Usually high frequency sine wave is used as a carrier wave signal.

Definition: Operation of varying amplitude, frequency or phase of carrier signal accordingly with the instantaneous amplitude of the message signal is called modulation.



Modulation Block Diagram

Here baseband signals come from a audio/video or computer. Baseband signals is also called modulating signal as it modulates carrier signal. Career signals are high frequency radio waves it generally comes from a radio frequency oscillators. These two signals are combined in modulator. Modulator takes the instantaneous amplitude of baseband signal and varies amplitude/frequency/phase of career signal. Resultant signal is a modulated signal. It goes to an RF-amplifier for signal power boosting and then feed to antenna or a co-axial cable.

There are two types of modulation analog and digital. Analog modulation deals with the voice, video and regular waves of base band signals. Whereas digital modulations are with bit streams or symbols from computing devices as base band signals.

Why modulation is used in communication?

- In signal transmission, the signals from various sources are transmitted through a common channel simultaneously by using multiplexers. If these signals are transmitted simultaneously with certain bandwidth, they cause interference. To overcome this, speech signals are modulated to various carrier frequencies in order for the receiver to tune them to desired bandwidth of his own choice within the range of transmission.

- Another technical reason is antenna size; the antenna size is inversely proportional to the frequency of the radiated signal. The order of the antenna aperture size is at least one by tenth of the wavelength of the signal. Its size is not practicable if the signal is 5 KHz; therefore, raising frequency by modulating process will certainly reduce the height of the antenna.
- Modulation is important to transfer the signals over large distances, since it is not possible to send low-frequency signals for longer distances.
- Similarly, modulation is also important to allocate more channels for users and to increase noise immunity.

ANALOG MODULATION

Baseband signal is always analog for this modulation. There are three properties of a carrier signal amplitude, frequency and phase thus there are three basic types of analog modulations.

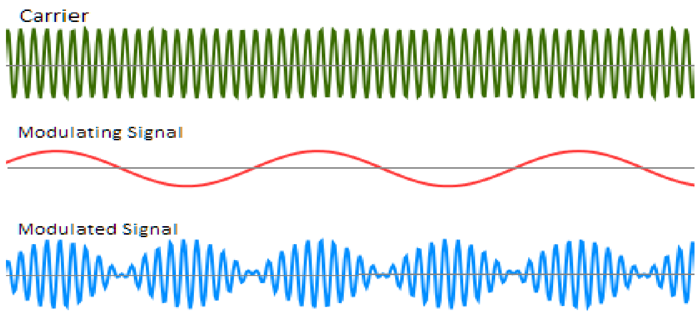
1. **Amplitude Modulation (AM)**
2. **Frequency Modulation (FM)**
3. **Phase modulation (PM)**

Amplitude Modulation

Amplitude modulation or AM is the process of varying the instantaneous amplitude of carrier signal accordingly with instantaneous amplitude of message signal. Thus, if m(t) is the message signal and $c(t)=A\cos w_c t$ then AM signal F(t) is written as

$F(t)= A\cos w_c t+m(t) \cos w_c t$

$F(t)=[A+m(t)] \cos w_c t$



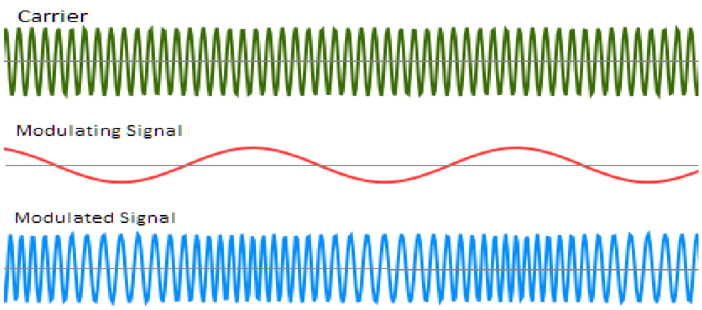
Amplitude Modulation

The modulated signal is shown in the below figure, and its spectrum consists of the lower frequency band, upper frequency band and carrier frequency components. This type of modulation requires more power and greater bandwidth; filtering is very difficult. Amplitude modulation is used in computer modems, VHF aircraft radio, and in portable two-way radio

AM Advantage: AM is the simplest type of modulation. Hardware design of both transmitter and receiver is very simple and less cost effective.
AM Disadvantage: AM is very susceptible to noise.
Application: AM radio broad cast is an example

Frequency modulation

Frequency modulation is the process of varying the in instantaneous frequency of Carrier signal accordingly with instantaneous amplitude of message signal. Thus, if m(t) is the message signal and c(t)=Acosw_ct then FM signal will be
F(t)= $A\cos(w_c t+k_f \int m(\alpha)d\alpha)$



Frequency Modulation

This type of modulation is commonly used for broadcasting music and speech, magnetic tape recording systems, two way radio systems and video transmission systems. When noise occurs naturally in radio systems, frequency modulation with sufficient bandwidth provides an advantage in cancelling the noise.

FM Advantage

Modulation and demodulation does not catch any channel noise.

FM Disadvantage:

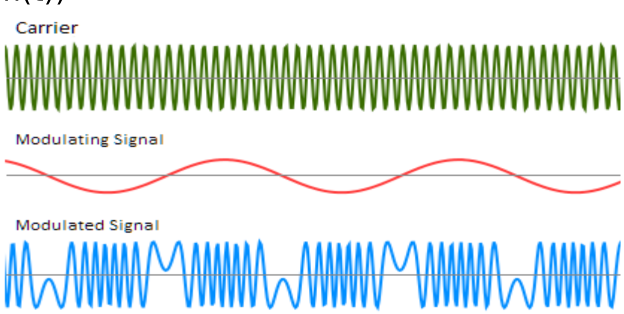
Circuit needed for FM modulation and demodulation is bit complicated than AM

Application:

1) FM radio broad cast is an example

Phase modulation (PM)

Phase modulation is the process of varying the instantaneous phase of Carrier signal accordingly with instantaneous amplitude of message signal. Thus if m(t) is the message signal and c(t)=Acoswct then PM signal will be
F(t)= $A\cos(w_c t+k_p m(t))$



Phase Modulation

Generally, phase modulation is used for transmitting waves. It is an essential part of many digital transmission coding schemes that underlie a wide range of technologies like GSM, WiFi, and satellite television. This type of modulation is used for signal generation in al synthesizers, such as the Yamaha DX7 to implement FM synthesis.

PM Advantage

Modulation and demodulation does not catch any channel noise.

PM Disadvantage: Circuit needed for PM modulation and demodulation is bit complicated than AM and FM

Application: Satellite communication.

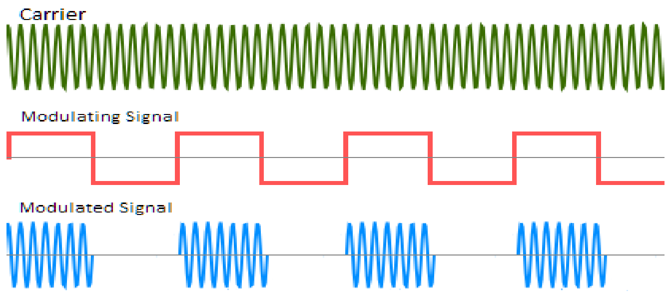
DIGITAL MODULATION

Digital modulation in somewhat similar to the analog modulation except base band signal is of discrete amplitude level. For binary signal it has only two level, either high or logic 1 or low or logic 0. The modulation scheme is mainly three types.

1. ASK or Amplitude shift Key
2. FSK or Frequency shift key
3. PSK or Phase shift key

ASK or Amplitude shift Key:

When the carrier amplitude is varied in proportion to message signal m(t). We have the modulated carrier m(t)cosw$_c$t where cosw$_c$t is the carrier signal. As the information is an on-off signal the output is also an on-off signal where the carrier is present when information is 1 and carrier is absent when information is 0. Thus this modulation scheme is known as on-off keying (OOK) or amplitude shift key.



Amplitude Shift Key

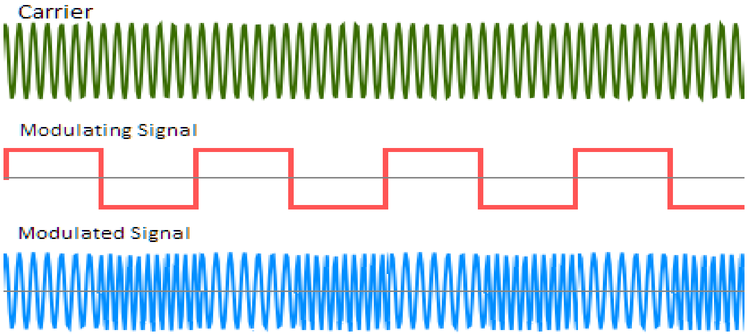
Application:

1. Used in our infrared remote controls
2. Used in fibre optical tranmitter and receiver.

FSK or Frequency shift key:

When Data are transmitted by varying frequency of the carrier, we have the case of frequency shift key. In this modulation carrier has two predefined frequency

w_{c1} and w_{c2}. When information bit is 1 carrier with w_{c1} is transmitted i.e. $\cos w_{c1}$ and When information bit is 0 carrier with w_{c0} is transmitted i.e. $\cos w_{c0}$

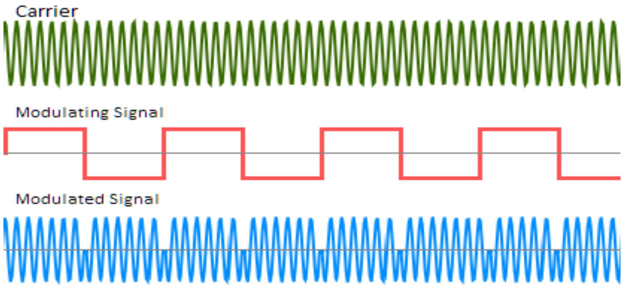


Frequency Shift Key

Application: Many modems used FSK in telemetry systems

PSK or Phase shift key:

The phase of the carrier is shifted for this modulation. If the base band signal m(t) =1 carrier in phase is transmitted. If m(t)=0 carrier with out of phase is transmitted i.e. $\cos(w_c t+\Pi)$. If phase shift is done in 4 different quadrants then 2bit of information can be sent at a time. This scheme is a special case of PSK modulation known as QPSK or Quadrature Phase Shift Key.



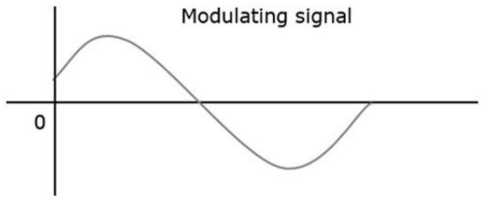
Phase Shift Key

Application:

1. Used in our ADSL broadband modem
2. Used in satellite communication
3. Used in our mobile phones

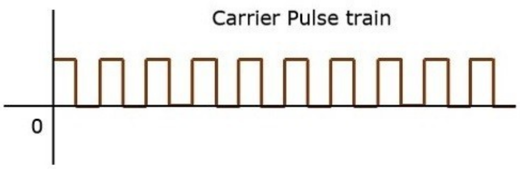
PULSE AMPLITUDE MODULATION

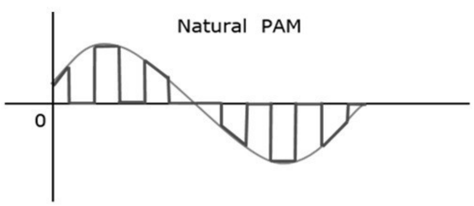
In **Pulse Amplitude Modulation (PAM)** technique, the amplitude of the pulse carrier varies, which is proportional to the instantaneous amplitude of the message signal.



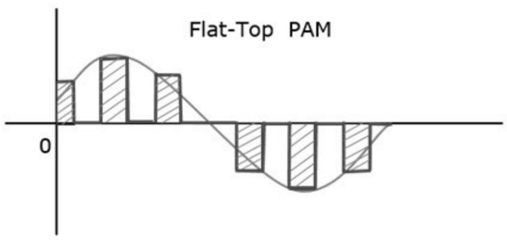
The pulse amplitude modulated signal will follow the amplitude of the original signal, as the signal traces out the path of the whole wave. In natural PAM, a signal sampled at Nyquist rate can be reconstructed, by passing it through an efficient **Low Pass Filter (LPF)** with exact cutoff frequency.

The following figures explain the Pulse Amplitude Modulation.





Though the PAM signal is passed through a LPF, it cannot recover the signal without distortion. Hence, to avoid this noise, use flat-top sampling. The flat-top PAM signal is shown in the following figure.



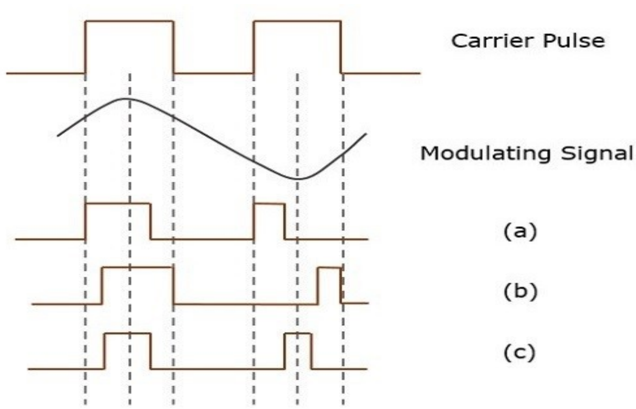
Flat-top sampling is the process in which, the sampled signal can be represented in pulses for which the amplitude of the signal cannot be changed with respect to the analog signal, to be sampled. The tops of amplitude remain flat. This process simplifies the circuit design.

Pulse Width Modulation

In **Pulse Width Modulation (PWM)** or Pulse Duration Modulation (PDM) or Pulse Time Modulation (PTM) technique, the width or the duration or the time of the pulse carrier varies, which is proportional to the instantaneous amplitude of the message signal.

The width of the pulse varies in this method, but the amplitude of the signal remains constant. Amplitude limiters are used to make the amplitude of the signal constant. These circuits clip off the amplitude to a desired level, and hence the noise is limited.

The following figure explains the types of Pulse Width Modulations.



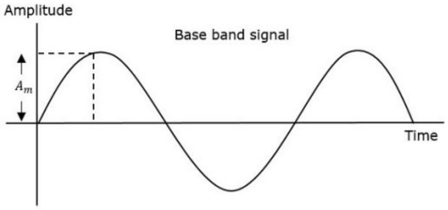
There are three types of PWM.

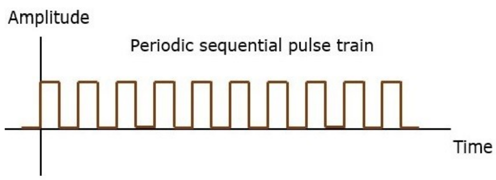
- The leading edge of the pulse being constant, the trailing edge varies according to the message signal. The waveform for this type of PWM is denoted as (a) in the above figure.
- The trailing edge of the pulse being constant, the leading edge varies according to the message signal. The waveform for this type of PWM is denoted as (b) in the above figure.
- The center of the pulse being constant, the leading edge and the trailing edge varies according to the message signal. The waveform for this type of PWM is denoted as (c) shown in the above figure.

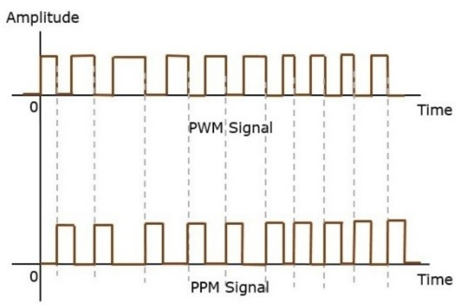
Pulse Position Modulation

Pulse Position Modulation (PPM) is an analog modulation scheme in which, the amplitude and the width of the pulses are kept constant, while the position of each pulse, with reference to the position of a reference pulse varies according to the instantaneous sampled value of the message signal.

The transmitter has to send synchronizing pulses (or simply sync pulses) to keep the transmitter and the receiver in sync. These sync pulses help to maintain the position of the pulses. The following figures explain the Pulse Position Modulation.







Pulse position modulation is done in accordance with the pulse width modulated signal. Each trailing edge of the pulse width modulated signal becomes the starting point for pulses in PPM signal. Hence, the position of these pulses is proportional to the width of the PWM pulses.

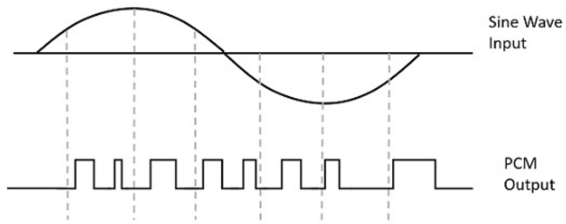
Advantage: As the amplitude and the width are constant, the power handled is also constant.

Disadvantage: The synchronization between the transmitter and the receiver is a must.

PULSE CODE MODULATION

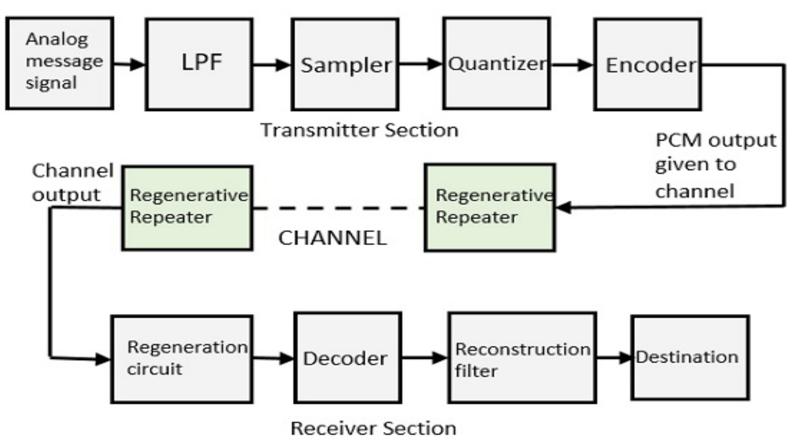
Modulation is the process of varying one or more parameters of a carrier signal in accordance with the instantaneous values of the message signal. The message signal is the signal which is being transmitted for communication and the carrier signal is a high frequency signal which has no data, but is used for long distance transmission. There are many modulation techniques, which are classified according to the type of modulation employed. Of them all, the digital modulation technique used is **Pulse Code Modulation (PCM)**.

A signal is pulse code modulated to convert its analog information into a binary sequence, i.e., **1s** and **0s**. The output of a PCM will resemble a binary sequence. The following figure shows an example of PCM output with respect to instantaneous values of a given sine wave.



Instead of a pulse train, PCM produces a series of numbers or digits, and hence this process is called as **digital**. Each one of these digits, though in binary code, represent the approximate amplitude of the signal sample at that instant. In Pulse Code Modulation, the message signal is represented by a sequence of coded pulses. This message signal is achieved by representing the signal in discrete form in both time and amplitude.

Basic Elements of PCM: The transmitter section of a Pulse Code Modulator circuit consists of Sampling, Quantizing and Encoding, which are performed in the analog-to-digital converter section. The low pass filter prior to sampling prevents aliasing of the message signal. The basic operations in the receiver section are regeneration of impaired signals, decoding, and reconstruction of the quantized pulse train. Following is the block diagram of PCM which represents the basic elements of both the transmitter and the receiver sections.



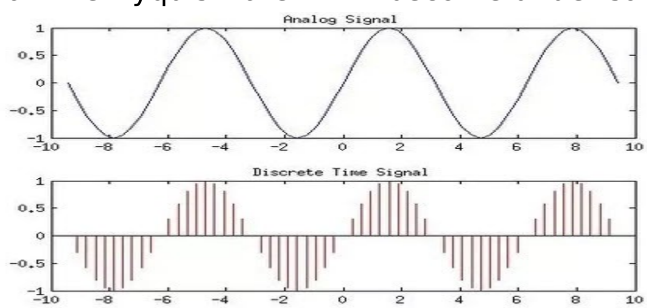
Low Pass Filter

This filter eliminates the high frequency components present in the input analog signal which is greater than the highest frequency of the message signal, to avoid aliasing of the message signal.

Sampler

Sampling is a process of measuring the amplitude of a continuous-time signal at discrete instants, converts the continuous signal into a discrete signal. For example, conversion of a sound wave to a sequence of samples. The Sample is a value or set of values at a point in time or it can be spaced. Sampler extract samples of a continuous signal, it is a subsystem ideal sampler produces samples which are equivalent to the instantaneous value of the continuous signal at the specified various points. The Sampling process generates flat- top Pulse Amplitude Modulated (PAM) signal.

Sampling frequency, Fs is the number of average samples per second also known as sampling rate. According to the Nyquist Theorem sampling rate should be at least 2 times the upper cutoff frequency. Sampling frequency, Fs>=2*fmax to avoid Aliasing Effect. If the sampling frequency is very higher than the Nyquist rate it become Oversampling, theoretically a bandwidth limited signal can be reconstructed if sampled at above the Nyquist rate. If the sampling frequency is less than the Nyquist rate it will become under sampling.



<u>Quantizer:</u> In quantization, an analog sample with amplitude that converted into a digital sample with amplitude that takes one of a specific defined set of quantization values. Quantization is done by dividing the range of possible values of the analog samples into some different levels, and assigning the center value of each level to any sample in quantization interval. Quantization approximates the analog sample values with the nearest quantization values. So almost all the quantized samples will differ from the original samples by a small amount. That amount is called as quantization error. The result of this quantization error is we will hear hissing noise when play a random signal. Converting analog samples into binary numbers that is 0 and 1.

<u>Encoder:</u> The digitization of analog signal is done by the encoder. It designates each quantized level by a binary code. The sampling done here is the sample-and-hold process. These three sections (LPF, Sampler, and Quantizer) will act as an analog to digital converter. Encoding minimizes the bandwidth used.

Regenerative Repeater: This section increases the signal strength. The output of the channel also has one regenerative repeater circuit, to compensate the signal loss and reconstruct the signal, and also to increase its strength.

Decoder: The decoder circuit decodes the pulse coded waveform to reproduce the original signal. This circuit acts as the demodulator.

Reconstruction Filter : After the digital-to-analog conversion is done by the regenerative circuit and the decoder, a low-pass filter is employed, called as the reconstruction filter to get back the original signal. Hence, the Pulse Code Modulator circuit digitizes the given analog signal, codes it and samples it, and then transmits it in an analog form. This whole process is repeated in a reverse pattern to obtain the original signal.

Pulse Code Modulation Advantages

- Analog signal can be transmitted over a high- speed digital communication system.
- Probability of occurring error will reduce by the use of appropriate coding methods.
- PCM is used in Telkom system, digital audio recording, digitized video special effects, digital video, voice mail.
- PCM is also used in Radio control units as transmitter and also receiver for remote controlled cars, boats, planes.
- The PCM signal is more resistant to interference than normal signal.

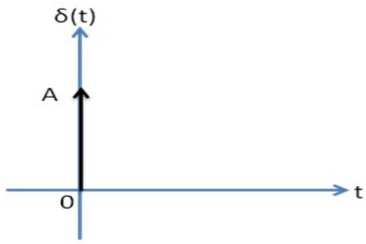
TEST SIGNALS

The dynamic behavior of a system is manipulated and judged under the application and working f standard and **typical test** signals. The characteristics of an input signal are constant acceleration, constant velocity, a sudden change or a sudden shock. There are four types of typical test signals: Impulse Step, Ramp, Parabolic and another important signal is sinusoidal signal.

1. **Impulse Signal:** Impulse response in control system imitates sudden shock quality of actual input signal. Impulse is the output of system when given by small input. Impulse response emphasis on change in the system in reaction to some external change. It is the reply of the system to the direct delta input.

$$\delta(t) = \begin{cases} A & t = 0 \\ 0 & t \neq 0 \end{cases}$$

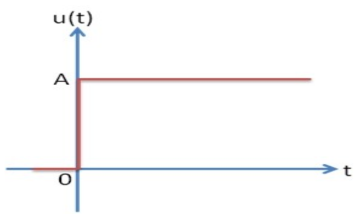
When A=1 then the impulse signal is called Unit impulse signal.



2. **Step Signal**
   The step signal defines the sudden change in properties of actual signal. It is being used to see the transient response of system as it gives you the idea about how the system reply to interruption and somehow the system stability.

$$u(t) = \begin{cases} A & t \geq 0 \\ 0 & t < 0 \end{cases}$$

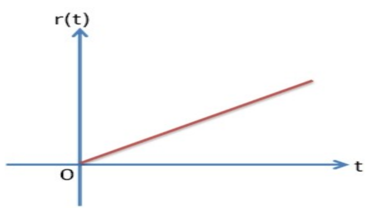
When A=1, the step is called unit step signal.



3. **Ramp Signal**: The ramp signal tells you the constant velocity attribute of actual input signal. It is being used to determine the behavior of system with the velocity factor.

$$r(t) = \begin{cases} At & t \geq 0 \\ 0 & t < 0 \end{cases}$$

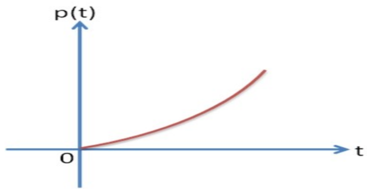
When A=1, ramp signal is called unit ramp signal.



4. **Parabolic Signal**
   Parabolic signal gives the constant acceleration distinction of actual input signal. It gives the idea about how the system will respond along with acceleration.

$$p(t) = \begin{cases} \dfrac{At^2}{2} & t \geq 0 \\ 0 & t < 0 \end{cases}$$

When A=1, the parabolic signal is called unit parabolic signal.



Conclusion

The typical test signals judge the performance and working of a control system in the time domain analysis. We discussed the four times of signals that are Impulse step, ramp, parabolic and sinusoidal. These all have different graphs and different effects. These typical signals determine the behavior and nature of a dynamic system.

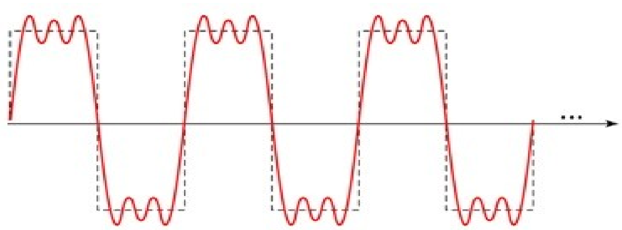
PERIODIC SIGNAL

Definition: A signal is considered to be periodic signal when it is repeated over cycle of time or regular interval of time. This means periodic signal repeats its pattern over a period. The function f(x) can be periodic if it satisfies following equation.

➤f(x + p) = f(x)

Example:

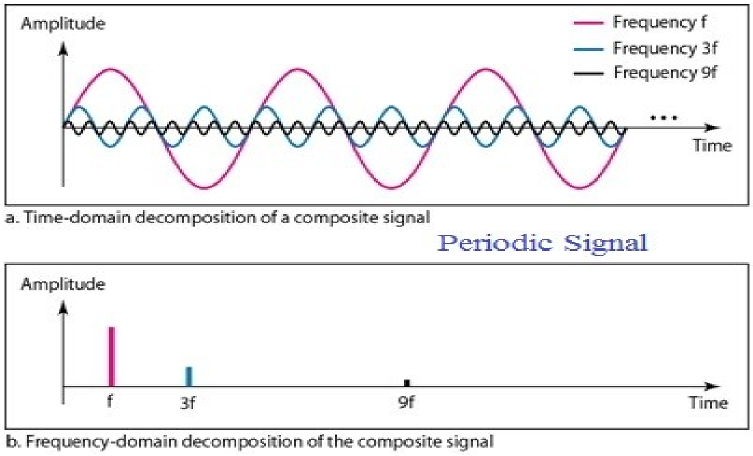
The cosine signal is periodic with periodicity value of 2π.



Composite Periodic Signal

A simple periodic analog signal such as sine wave or cosine wave cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves. The figure-1 depicts typical composite periodic signal. The frequency is rate of change with respect to time. The frequency and period are inverse of each other. Hence following can be implied.

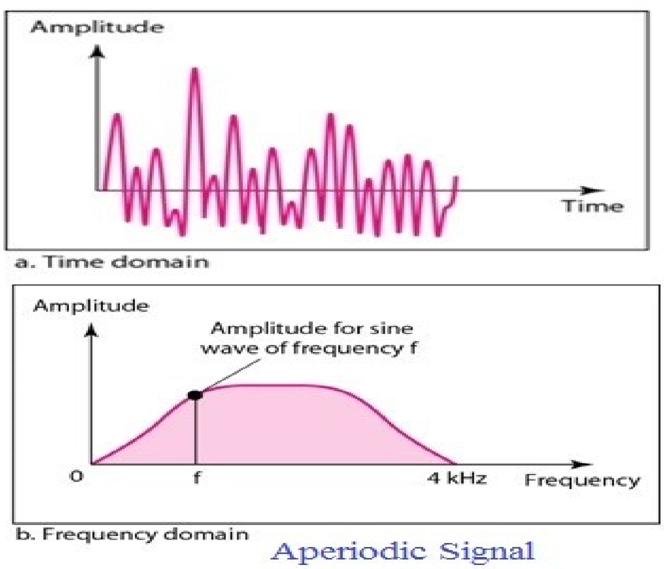
➤ f = 1/T and T = 1/f,



The units such as seconds(s), milliseconds(ms), microseconds(µs), nanoseconds (ns) and picoseconds (ps) are used for time period while units such as Hz, KHz, MHz, GHz and THz are used for frequency. The figure-2 depicts time domain and frequency domain decomposition of the composite periodic signal. This is derived from the fact that a complete sine wave in the time domain can be represented by one single spike in frequency domain.

APERIODIC SIGNAL | NON-PERIODIC SIGNAL

Definition: A signal is considered to be non-periodic or aperiodic signal when it does not repeat its pattern over a period (i.e. interval of time).



The figure-3 depicts time domain and frequency domain decomposition of the composite aperiodic signal. Following is one classic example of aperiodic signal type.

Example#1:

Signal created by microphone or telephone when one or two words are pronounced. In this application, composite signal cannot be periodic in nature. Hence it is referred as aperiodic signal.

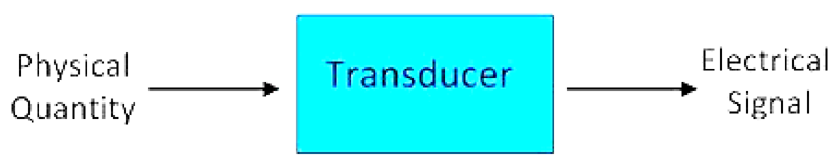
Transducers

Definition: The device which converts the one form of energy into another is known as the transducer. The process of conversion is known as transduction. The conversion is done by sensing and transducing the physical quantities like temperature, pressure, sound, etc.

The electrical transducer converts the mechanical energy into an electric signal. The electrical signal may be voltage, current and frequency. The production of the signal depends on the resistive inductive and capacitive effects of the physical input.

Needs of Transducer

It is quite difficult to determine the exact magnitude of the physical forces like temperature, pressure, etc. But if the physical force is converted into an electrical signal, then their value is easily measured with the help of the meter. The transducers convert the physical forces into an electrical signal which can easily be handled and transmitted for measurement.



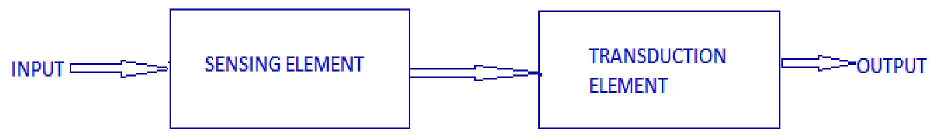
The following are the advantages of converting the physical quantity into an electrical signal.

- The attenuation and amplification of the electrical signals are very easy.
- The electrical signal produces less friction error.
- The small power is required for controlling the electrical systems.
- The electrical signals are easily transmitted and processed for measurement.
- The component used for measuring the electrical signal is very compact and accurate.
- The electrical signals are used in telemetry.

The block diagram of a transducer is given below.

1. **Sensing or Detector Element** – It is the part of the transducers which give the response to the physical sensation. The response of the sensing element depends on the physical phenomenon.
2. **Transduction Element** – The transduction element converts the output of the sensing element into an electrical signal. This element is also called the secondary transducer.

TRANSDUCER BLOCK DIAGRAM



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INPUT - Resistance, Capacitance, Inductance, Stress, Strain, Heat

OUTPUT - Force, Displacement, Pressure, Sound, Magnetic Flux, Voltage, Current

Factors Influencing the Choice of Transducer

The choice of the transducers used for measuring the physical quantity depends on the following factors.

* **Operating Principle** – The transducers are selected by their operating principles. The operating principle may be resistive, inductive, capacitive, optoelectronic, piezoelectric, etc.
* **Sensitivity** – The sensitivity of the transducer is enough for inducing the detectable output.
* **Operating Range** – The transducer must have wide operating ranges so that it does not break during the working.
* **Accuracy** – The transducers gives accuracy after calibration. It has a small value for repeatability which is essentials for the industrial applications.
* **Cross Sensitivity** – The transducers gives variable measured value for the different planes because of the sensitivity. Hence, for the accurate measurement, the cross sensitivity is essential.
* **Errors** – The errors are avoided by taking the input output relations which is obtained by the transfer function.
* **Loading Effect** – The transducers have high input impedance and low output impedance for avoiding the errors.
* **Environmental Compatibility** – The transducers should be able to work in any specified environments like in a corrosive environment. It should be able to work under high pressure and shocks.
* **Insensitivity to Unwanted Signals** – The transducer should be sensitive enough for ignoring the unwanted and high sensitive signals.
* **Usage and Ruggedness –** The durability, size and weight of the transducer must be known before selecting it.
* **Stability and Reliability** – The stability of the transducers should be high enough for the operation and their reliability should be good in case of failure of the transducer.

- **Static characteristic** – The transducer should have a high linearity and resolution, but it has low hysteresis. The transducer is always free from the load and temperature.

Application of the transducers

- ✓ It is used for detecting the movement of muscles which is called acceleromyograph.
- ✓ The transducer measures the load on the engines.
- ✓ It is used as a sensor for knowing the engine knock.
- ✓ The transducers measure the pressure of the gas and liquid by converting it into an electrical signal.
- ✓ It converts the temperature of the devices into an electrical signal or mechanical work.
- ✓ The transducer is used in the ultrasound machine. It receives the sound waves of the patient by emitting their sound waves and pass the signal to the CPU.
- ✓ The transducer is used in the speaker for converting the electrical signal into acoustic sound.
- ✓ It is used in the antenna for converting the electromagnetic waves into an electrical signal.

The classifications of the transducers depend on the various factor like by transduction, the converting electrical signal from AC or DC, etc.

Transducer Characteristics

The characteristics of a transducer are given below that are determined by examining the output response of a transducer to a variety of input signals. Test conditions create definite operating conditions as closely as possible. The methods of computational and standard statistical can be applied to the test data.

1. **Accuracy**: It is defined as the closeness with which the reading approaches an accepted standard value or ideal value or true value, of the variable being measured.
2. **Ruggedness**: The transducer should be mechanically rugged to withstand overloads. It should have overload protection.
3. **Linearity**: The output of the transducer should be linearly proportional to the input quantity under measurement. It should have linear input - output characteristic.
4. **Repeatability:** The output of the transducer must be exactly the same, under same environmental conditions, when the same quantity is applied at the input repeatedly.
5. **High output**: The transducer should give reasonably high output signal so that it can be easily processed and measured. The output must be much larger than noise. Now-a-days, digital output is preferred in many applications.
6. **High Stability and Reliability:** The output of the transducer should be highly stable and reliable so that there will be minimum error in measurement. The output must remain unaffected by environmental conditions such as change in temperature, pressure, etc.

7. **Sensitivity**: The sensitivity of the electrical transducer is defined as the electrical output obtained per unit change in the physical parameter of the input quantity. For example, for a transducer used for temperature measurement, sensitivity will be expressed in mV/’ C. A high sensitivity is always desirable for a given transducer.

8. **Dynamic Range:** For a transducer, the operating range should be wide, so that it can be used over a wide range of measurement conditions.

9**. Size:** The transducer should have smallest possible size and shape with minimal weight and volume. This will make the measurement system very compact.

10. **Speed of Response:** It is the rapidity with which the transducer responds to changes in the measured quantity. The speed of response of the transducer should be as high as practicable.

Resistive Transducer

Definition: The transducer whose resistance varies because of the environmental effects such type of transducer is known as the resistive transducer. The change in resistance is measured by the ac or dc measuring devices. The resistive transducer is used for measuring the physical quantities like temperature, displacement, vibration etc.

The measurement of the physical quantity is quite difficult. The resistive transducer converts the physical quantities into variable resistance which is easily measured by the meters. The process of variation in resistance is widely used in the industrial applications. The resistive transducer can work both as the primary as well as the secondary transducer. The primary transducer changes the physical quantities into a mechanical signal, and secondary transducer directly transforms it into an electrical signal.

The displacement of the slider is converted into an electrical signal.

Working Principle of Resistive Transducer

The resistive transducer element works on the principle that the resistance of the element is directly proportional to the length of the conductor and inversely proportional to the area of the conductor.

$$R = \rho L/A$$

Where R – resistance in ohms.

A – cross-section area of the conductor in meter square.

L – Length of the conductor in meter square.

ρ – the resistivity of the conductor in materials in ohm meter.

The resistive transducer is designed by considering the variation of the length, area and resistivity of the metal.

Basically a resistance potentiometer, or simply a POT, (a resistive potentiometer used for the purposes of voltage division is called a POT) consists of a resistive element provided with a sliding contact. This sliding contact is called a wiper. The motion of the sliding contact may be translatory or rotational. A linear pot and a rotary pot are shown in Figs.(1) and (2)respectively. Some POTS use the combination of the two motions, i.e.; translational as well as rotational. These POTS have their resistive element in the form of a helix and therefore, they are called helipots.

The translational resistive elements are straight devices and have a stroke of 2 mm to 0.5 m. The rotational devices are circular in shape and are used for measurement of angular displacement. They may have a full scale angular displacement as small as 10^0 A full single turn potentiometer may provide accurate measurements up to 357^0. Multi turn potentiometers may measure upto 3500^0 of rotation through use of helipots.

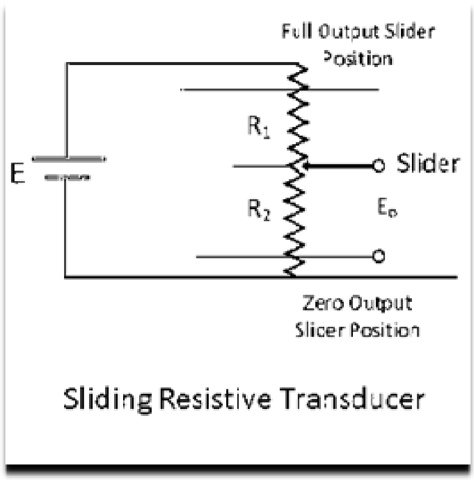


figure: 1

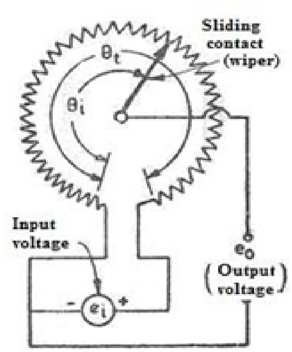


figure: 2

Advantages of Resistive Transducer

The following are the advantages of the resistive transducer.

- Both the AC and DC, current or voltage is appropriate for the measurement of variable resistance.
- The resistive transducer gives the fast response.
- It is available in various sizes and having a high range of resistance.

Applications of Resistive Transducer

The following are the applications of the resistive transducer.

- ✓ **Potentiometer** – The translation and rotatory potentiometer are the examples of the resistive transducers. The resistance of their conductor varies with the variation in their lengths which is used for the measurement of displacement.

- ✓ **Strain gauges –** The resistance of their semiconductor material changes when the strain occurs on it. This property of metals is used for the measurement of the pressure, force-displacement etc.
- ✓ **Resistance Thermometer** – The resistance of the metals changes because of changes in temperature. This property of conductor is used for measuring the temperature.
- ✓ **Thermistor** – It works on the principle that the temperature coefficient of the thermistor material varies with the temperature. The thermistor has the negative temperature coefficient. The Negative temperature coefficient means the temperature is inversely proportional to resistance.

There are a number of ways because of which the resistance of the metal changes with the changed in the physical phenomenon. And this property of conductors is used for measuring the physical quantities of material.

Inductive Transducer

Inductive Transducer Definition may be either of the self generating or the passive type. The self generating type utilizes the basic electrical generator principle, i.e. a motion between a conductor and magnetic field induces a voltage in the conductor (generator action). This relative motion between the field and the conductor is supplied by changes in the measured. An inductive electromechanical transducer is a device that converts physical motion (position change) into a change in inductance.

Transducers of the variable inductance type work upon one of the following principles.

1. **Variation of self inductance**
2. **Variation of mutual inductance**

Inductive Transducer Definition is mainly used for the measurement of displacement. The displacement to be measured is arranged to cause variation in any of three variables

1. **Number of turns**
2. **Permeability of the magnetic material or magnetic circuits**
3. **Variable Reluctance Type Transducer**

For example, let us consider the case of a general inductive transducer. The Inductive Transducer Definition has N turns and a reluctance R**.** When a current i is passed through it, the flux is

$$\phi = \frac{Ni}{R}$$

$$\frac{d\phi}{dt} = \frac{N}{2} \times \frac{di}{dt} - \frac{Ni}{R^2} \times \frac{dR}{dt}$$

If the current varies very rapidly,

$$\frac{d\phi}{dt} = \frac{N}{2} \times \frac{di}{dt}$$

But emf induced in the coil is given by

$$e = N \times d\phi/dt$$

$$e = N \times \frac{N}{2} \times \frac{di}{dt} = \frac{N^2}{R} \times \frac{di}{dt} \qquad (13.9)$$

Also the self inductance is given by

$$L = \frac{e}{di/dt} = \frac{N^2}{R} \qquad (13.10)$$

Therefore, the output from an inductive transducer can be in the form of either a change in voltage or a change in inductance.

CHANGE IN SELF INDUCTANCE WITH NUMBERS OF TURNS

The output may be caused by a change in the number of turns. Figures 13.14(a) and (b) are transducers used for, the measurement of displacement of linear and angular movement respectively

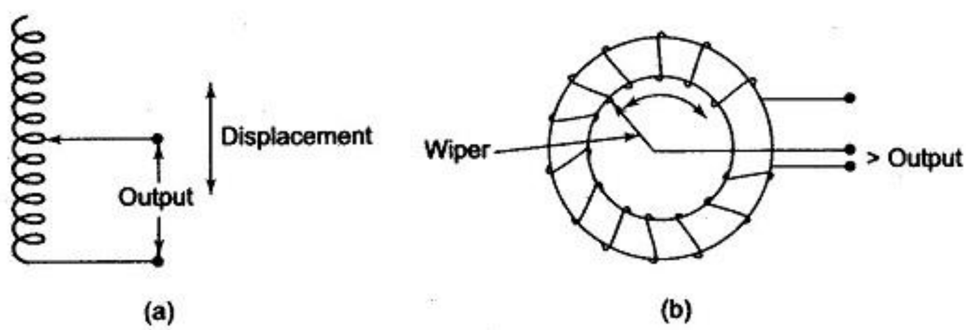


Fig. 13.14 (a) Linear Inductive Transducer (Using Air Core) (b) Angular Inductive Transducer (Using Ferrite Core)

Figure 13.14(a) is an air cored transducer for measurement of linear displacement.

Figure 13.14(b) is an iron cored coil used for the measurement of angular displacement.

In both cases, as the number of turns are changed, the self inductance and the output also changes.

TRANSDUCER WORKING ON THE PRINCIPLE OF CHANGE IN SELF INDUCTANCE WITH CHANGE IN PERMEABILITY

Figure 13.15 shows an Inductive Transducer Definition which works on the principle of the variation of permeability causing a change in self inductance. The iron core is surrounded by a winding. If the iron core is inside the winding, its permeability is increased, and so is the inductance. When the iron core is moved out of the winding, the permeability decreases, resulting in a reduction of the self inductance of the coil. This transducer can be used for measuring displacement.

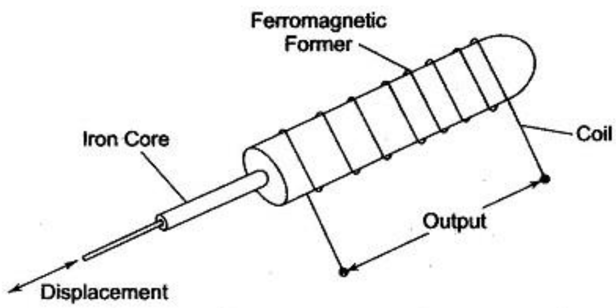


Fig. 13.15 Inductive Transducer Working on the Principle of Variation of Permeability

VARIABLE RELUCTANCE TYPE TRANSDUCER

A transducer of the variable type consists of a coil wound on a ferromagnetic core. The displacement which is to be measured is applied to a ferromagnetic target. The target does not have any physical contact with the core on which it is mounted. The core and the target are separated by an air gap, as shown in Fig. 13.16(a)

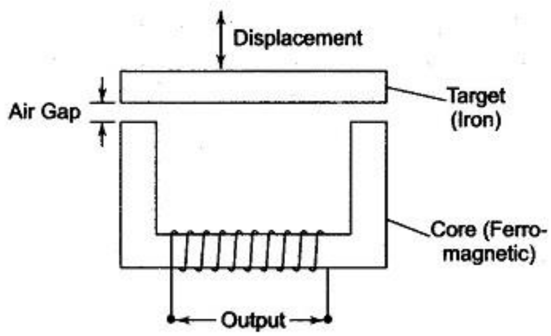


Fig. 13.16(a) Variable Reluctance Transducer

The reluctance of the magnetic path is determined by the size of the air gap. The inductance of the coil depends upon the reluctance of the magnetic circuits. The self inductance of the coil is given by

$$L = \frac{N^2}{R_i + R_g} \qquad (13.11)$$

where N = number of turns

R_i = reluctance of iron parts

R_g = reluctance of air gap

The reluctance of the iron part is negligible compared to that of the air gap.
Therefore

$$L = N^2/R_g \qquad (13.12)$$

But reluctance of the air gap is given by

$$R_g = \frac{l_g}{\mu_o \times A_g} \qquad (13.13)$$

where
l_g = length of the air gap
A_g = area of the flux path through air
μ_o = permeability
R_g is proportional to l_g, as μ_o and A_g are constants.
Hence L is proportional to l/lg, i.e. the self inductance of the coil is inversely proportional to the length of the air gap.

When the target is near the core, the length is small and therefore the self inductance large. But when the target is away from the core the reluctance is large, resulting in a smaller self inductance value. Hence the inductance of the coil is a function of the distance of the target from the core, i.e. the length of the air gap.

Since it is the displacement which changes the length of the air gap, the self inductance is a function of displacement, albeit a non-linear one. A variable reluctance bridge is shown in Fig. 13.16(b). A separate coil is wound on each outside leg of an E core and an iron bar is pivoted on the centre leg. A magnet extends from each outside leg through an air gap and through the iron bar to the centre leg. The moving member is attached to one end of the iron bar and causes the bar to wobble back and forth, thereby varying the size of each air gap. The bridge consists of two transducer coils and a tapped secondary of the input power transformers. It is balanced only when the inductance of the two transducer coils are equal, i.e. when the iron bar is in a nearly exact horizontal position and the air gaps are equal.

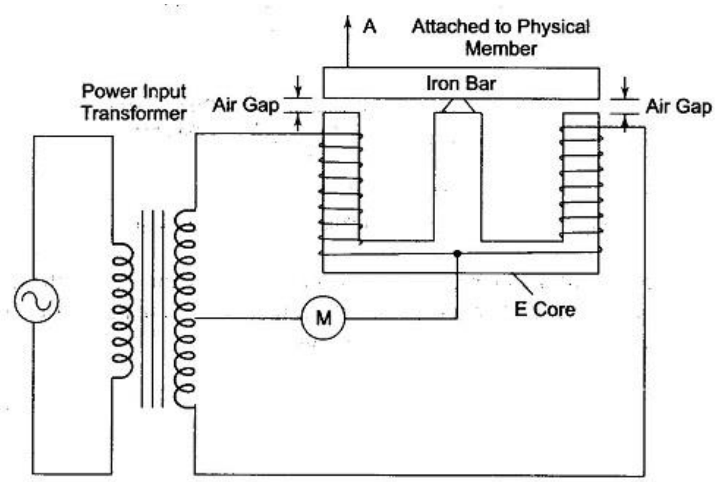


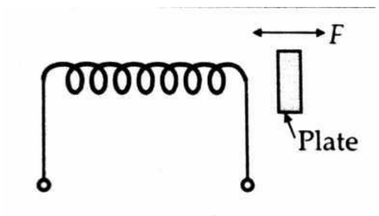
Fig. 13.16(b) Variable Reluctance Bridge Circuit

Whenever the iron bar at point A moves and alters the air gap, the bridge becomes unbalanced by an amount proportional to the change in inductance, which in turn is proportional to the displacement of the moving member.

The increase and decrease of the inductance with varying air gap sizes is non-linear, and so is the output. Also, the flux density within the air gaps is easily affected by external fields.

TRANSDUCERS WORKING ON PRINCIPLE OF PRODUCTION OF EDDY CURRENTS

These inductive transducers work on the principle that if a conducting plate is placed near a coil carrying alternating current, eddy currents are, produced in the conducting plate. The conducting plate acts as a short-circuited secondary winding of a transformer. The eddy currents flowing in the plate produce a magnetic field of their own which acts the magnetic field produced by the coil. This results in reduction of flux and thus the inductance of the coil is reduced. The nearer is the plate to the coil, the higher are the eddy currents and thus higher is the reduction in the inductance of the coil. Thus the inductance of the coil alters with variation of distance between the plate and the coil.



A number of arrangements are possible and two arrangements are shown in Fig. 25.86. The plate may be at right angle to the axis of the coil. The displacement of the plate causes a change in the inductance of the coil. In the other arrangement a conducting sleeve runs in parallel and coaxially over a coil. If the short-circuited sleeve is away from the coil, the inductance of the coil is high while if the sleeve is covering the coil, its inductance is low. The change in inductance is a measure of displacement.

Capacitive Transducer

Definition: The capacitive transducer is used for measuring the displacement, pressure and other physical quantities. It is a passive transducer that means it requires external power for operation. The capacitive transducer works on the principle of variable capacitances. The capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant. The capacitive transducer contains two parallel metal plates. These plates are separated by the dielectric medium which is either air, material, gas or liquid. In the normal capacitor the distance between the plates are fixed, but in capacitive transducer the distance between them are varied.

The capacitive transducer uses the electrical quantity of capacitance for converting the mechanical movement into an electrical signal. The input quantity causes the change of the capacitance which is directly measured by the capacitive transducer.

The capacitors measure both the static and dynamic changes. The displacement is also measured directly by connecting the measurable devices to the movable plate of the capacitor. It works on with both the contacting and non-contacting modes.

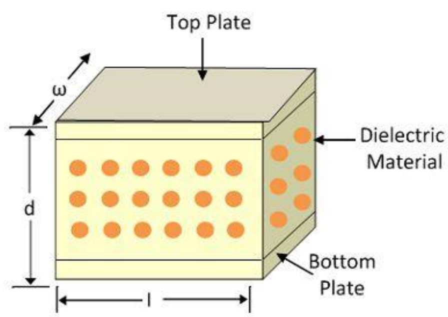
Principle of Operation

The equations below express the capacitance between the plates of a capacitor

$$C = \varepsilon A/d$$

$$C = \varepsilon_r \varepsilon_0 A/d$$

Where A – overlapping area of plates in m^2
d – the distance between two plates in meter
ε – permittivity of the medium in F/m
ε_r – relative permittivity
ε_0 – the permittivity of free space
The schematic diagram of a parallel plate capacitive transducer is shown in the figure below.



Parallel Plate Capacitive Transducer

The change in capacitance occurs because of the physicals variables like displacement, force, pressure, etc. The capacitance of the transducer also changes by the variation in their dielectric constant which is usually because of the measurement of liquid or gas level.

The capacitance of the transducer is measured with the bridge circuit. The output impedance of transducer is given as

$$X_c = 1/2\pi f c$$

Where, C – capacitance
f – frequency of excitation in Hz.
The capacitive transducer is mainly used for measurement of linear displacement. The capacitive transducer uses the following three effects.

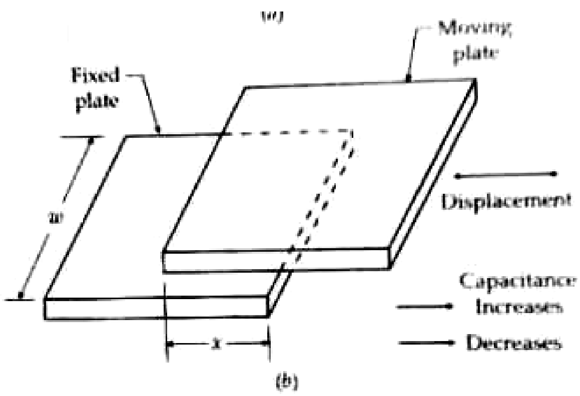
1. Variation in capacitance of transducer is because of the overlapping of capacitor plates.
2. The change in capacitance is because of the change in distances between the plates.
3. The capacitance changes because of dielectric constant.

The following methods are used for the measuring displacement.

1. A TRANSDUCER USING THE CHANGE IN THE AREA OF PLATES

The equation below shows that the capacitance is directly proportional to the area of the plates. The capacitance changes correspondingly with the change in the position of the plates.

The capacitive transducers are used for measuring the large displacement approximately from 1mm to several cms. The area of the capacitive transducer changes linearly with the capacitance and the displacement. Initially, the nonlinearity occurs in the system because of the edges. Otherwise, it gives the linear response.



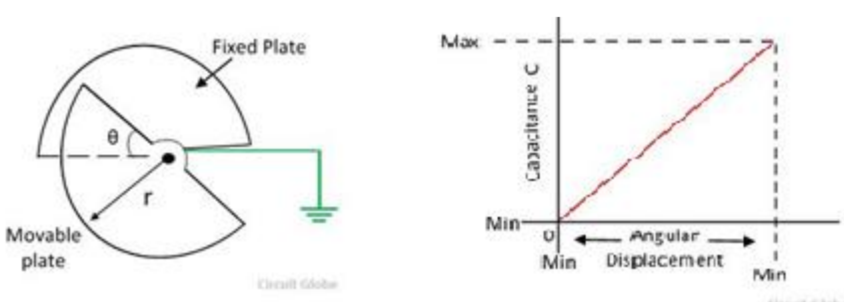
The capacitance of the parallel plates is given as $$C = \frac{\varepsilon A}{d} = \frac{\varepsilon x \omega}{d} F$$

where x – the length of overlapping part of plates
ω – the width of overlapping part of plates.

The sensitivity of the displacement is constant, and therefore it gives the linear relation between the capacitance and displacement.

$$S = \frac{\partial C}{\partial x} = \varepsilon \frac{\omega}{d} F/m$$

The capacitive transducer is used for measuring the angular displacement. It is measured by the movable plates shown below. One of the plates of the transducer is fixed, and the other is movable.



The phasor diagram of the transducer is shown in the figure above. The angular movement changes the capacitance of the transducers. The capacitance between them is maximum when these plates overlap each other. The maximum value of capacitance is expressed as

$$C_{max} = \frac{\varepsilon A}{d} = \frac{\pi \varepsilon r^2}{2d}$$

The capacitance at angle θ is given expressed as,

$$C = \frac{\varepsilon \theta r^2}{2d}$$

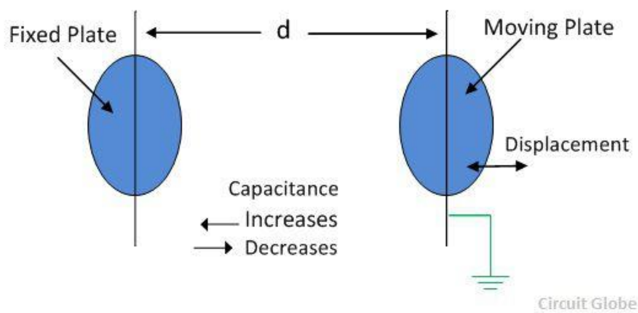
θ – angular displacement in radian. The sensitivity for the change in capacitance is given as

$$S = \frac{\partial C}{\partial \theta} = \frac{\varepsilon r^2}{2d}$$

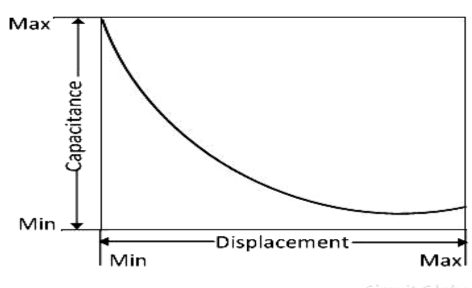
The 180° is the maximum value of the angular displacement of the capacitor.

2. THE TRANSDUCER USING THE CHANGE IN DISTANCE BETWEEN THE PLATES

The capacitance of the transducer is inversely proportional to the distance between the plates. The one plate of the transducer is fixed, and the other is movable. The displacement which is to be measured links to the movable plates.



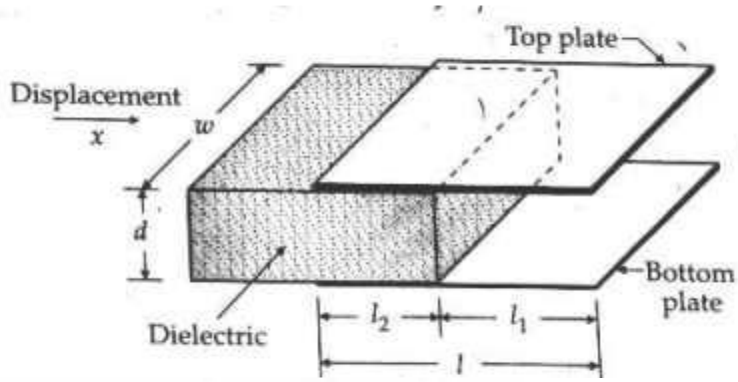
The capacitance is inversely proportional to the distance because of which the capacitor shows the nonlinear response. Such type of transducer is used for measuring the small displacement. The phasor diagram of the capacitor is shown in the figure below.



The sensitivity of the transducer is not constant and varies from places to places.

3. THE CAPACITANCE CHANGES BECAUSE OF DIELECTRIC CONSTANT.

The third principle used in capacitive transducers is the variation of capacitance due to change in dielectric constant. Figure shows a capacitive transducer for measurement of linear displacement working on the above mentioned principle. It has a dielectric of relative permittivity.



Initial capacitance of transducer

$$= C = \varepsilon_0 \frac{wl_1}{d} + \varepsilon_0 \varepsilon_r \frac{wl_2}{d}$$

$$= \varepsilon_0 \frac{w}{d}[l_1 + \varepsilon_r l_2]$$

Let the dielectric be moved through a distance x in the direction indicated. The capacitance changes from C to C + ΔC.

$$\therefore \quad C + \Delta C = \varepsilon_0 \frac{w}{d}(l_1 - x) + \varepsilon_0 \varepsilon_r \frac{w}{d}(l_2 + x)$$

$$= \varepsilon_0 \frac{w}{d}[l_1 - x + \varepsilon_r (l_2 + x)]$$

$$= \varepsilon_0 \frac{w}{d}(l_1 + \varepsilon_r l_2) + \varepsilon_0 \frac{wx}{d}(\varepsilon_r - 1)$$

$$= C + \varepsilon_0 \frac{wx}{d}(\varepsilon_r - 1) \qquad \text{...(25.121)}$$

∴ Change in capacitance

$$\Delta C = \varepsilon_0 \frac{wx}{d}(\varepsilon_r - 1) \qquad \text{...(25.122)}$$

Hence the change in capacitance is proportional to displacement.

Advantage of Capacitive Transducer

The following are the major advantages of capacitive transducers.

- It requires an external force for operation and hence very useful for small systems.
- The capacitive transducer is very sensitive.
- It gives good frequency response because of which it is used for the dynamic study.
- The transducer has high input impedance hence they have a small loading effect.
- It requires small output power for operation.

Disadvantages of capacitive Transducer

The main disadvantages of the transducer are as follows.

* The metallic parts of the transducers require insulation.
* The frame of the capacitor requires earthing for reducing the effect of the stray magnetic field.
* Sometimes the transducer shows the nonlinear behaviors because of the edge effect which is controlled by using the guard ring.
* The cable connecting across the transducer causes an error.

Uses of Capacitive Transducer

The following are the uses of capacitive transducer.

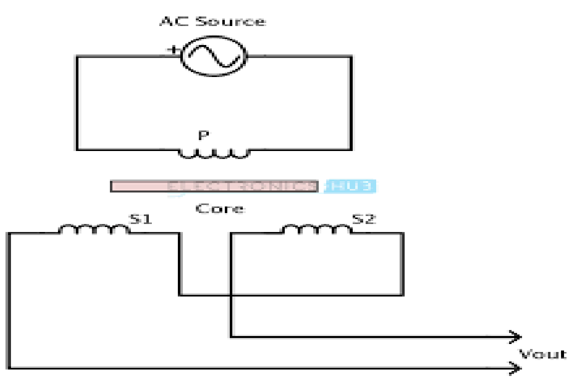
- ✓ The capacitive transducer uses for measurement of both the linear and angular displacement. It is extremely sensitive and used for the measurement of very small distance.
- ✓ It is used for the measurement of the force and pressures. The force or pressure, which is to be measured is first converted into a displacement, and then the displacement changes the capacitances of the transducer.
- ✓ It is used as a pressure transducer in some cases, where the dielectric constant of the transducer changes with the pressure.
- ✓ The humidity in gases is measured through the capacitive transducer.
- ✓ The transducer uses the mechanical modifier for measuring the volume, density, weight etc.

The accuracy of the transducer depends on the variation of temperature to the high level.

Linear Variable Differential Transformer LVDT

Definition of LVDT: The term **LVDT** stands for the **Linear Variable Differential Transformer**. It is the most widely used inductive transducer that coverts the linear motion into the electrical signal.

Main Features of Construction



- The transformer consists of a primary winding P and two secondary windings S_1 and S_2 wound on a cylindrical former (which is hollow in nature and contains the core).

- Both the secondary windings have an equal number of turns, and we place them on either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside astainless steel housing because it will provide electrostatic and electromagnetic shielding.
- The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.

Principle of Operation and Working

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is e_1 and in the secondary S_2 is e_2. So the differential output is,

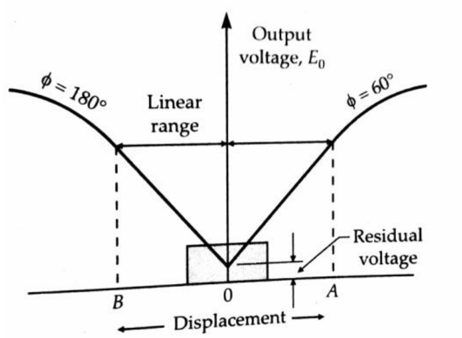
$$Eout = E1 - E2$$

This equation explains the **principle of Operation of LVDT**.

Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

- **CASE I** When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output e_{out} is zero as e_1 and e_2 both are equal. So it shows that no displacement took place.
- **CASE II** When the core is moved to upward of null position (For displacement to the upward of reference point) In the this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this e_1 will be more as that of e_2. Due to this output voltage e_{out} is positive.
- **CASE III** When the core is moved to downward of Null position (for displacement to the downward of the reference point). In this case magnitude of e_2 will be more as that of e_1. Due to this output e_{out} will be negative and shows the output to downward of the reference point.

Output V_S Core Displacement A linear curve shows that output voltage varies linearly with displacement of core.



The output voltage of an LVDT is a linear function of core displacement within a limited range of motion, say, about 5 mm from the null position. Above Figure shows the variation of output voltage against displacement for various positions of core. The curve is practically linear for small displacements (upto about 5 mm as mentioned above). Beyond this range of displacement, the curve starts to deviate from a straight line. The characteristics are linear up to 0-A and 0-B but after then they become non-linear as shown in Fig. Ideally the output voltage at the null position should be equal to zero. However, in actual practice there exists a small voltage at the null position. This may be on account of presence of harmonics in the input supply voltage and also due to harmonics produced in the output voltage on account of use iron core. There may be either an incomplete magnetic or electrical unbalance or both which result in a finite output voltage at the null position. This finite residual voltage is generally less than 1% of the maximum output voltage in the linear range. Other causes of residual voltage are stray magnetic fields and temperature effects. The residual voltage is shown in Fig. However, with improved technological methods and with the use of better a-c. Sources, the residual voltage can be reduced to almost a negligible value.

Some important points about magnitude and sign of voltage induced in LVDT

- The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.
- By noting the output voltage increasing or decreasing the direction of motion can be determined
- The output voltage of an LVDT is linear function of core displacement.

Advantages of LVDT

- **High Range -** The LVDTs have a very high range for measurement of displacement.they can used for measurement of displacements ranging from 1.25 mm to 250 mm
- **No Frictional Losses -** As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.
- **High Input and High Sensitivity -** The output of LVDT is so high that it doesn't need any amplification. The transducer possesses a high sensitivity which is typically about 40V/mm.

- **Low Hysteresis -** LVDTs show a low hysteresis and hence repeatability is excellent under all conditions
- **Low Power Consumption -** The power is about 1W which is very as compared to other transducers.
- **Direct Conversion to Electrical Signals -** They convert the linear displacement to electrical voltage which are easy to process

Disadvantages of LVDT

- LVDT is sensitive to stray magnetic fields so it always requires a setup to protect them from stray magnetic fields.
- LVDT gets affected by vibrations and temperature.

It is concluded that they are advantageous as compared than any other inductive transducer.

Applications of LVDT

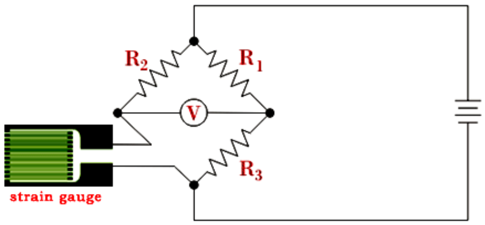
- ✓ We use LVDT in the applications where displacements to be measured are ranging from a fraction of mm to few cms. The **LVDT** acting as a primary transducer converts the displacement to electrical signal directly.
- ✓ The LVDT can also act as a secondary transducer. E.g. the Bourbon tube which acts as a primary transducer and it converts pressure into linear displacement and then LVDT coverts this displacement into an electrical signal which after calibration gives the readings of the pressure of fluid.

Strain Gauge

A **strain gauge** is a resistor used to measure strain on an object. When an external force is applied on an object, due to which there is a deformation occurs in the shape of the object. This deformation in the shape is both compressive or tensile is called strain, and it is measured by the strain gauge. When an object deforms within the limit of elasticity, either it becomes narrower and longer or it become shorter and broadens. As a result of it, there is a change in resistance end-to-end. The strain gauge is sensitive to that small changes occur in the geometry of an object. By measuring the change in resistance of an object, the amount of induced stress can be calculated. The change in resistance normally has very small value, and to sense that small change, strain gauge has a long thin metallic strip arrange in a zigzag pattern on a non-conducting material called the carrier, as shown below, so that it can enlarge the small amount of stress in the group of parallel lines and could be measured with high accuracy. The gauge is literally glued onto the device by an adhesive. When an object shows physical deformation, its electrical resistance gets change and that change is then measured by gage

Strain Gauge Bridge Circuit

Strain gauge bridge circuit shows the measured stress by the degree of discrepancy, and uses a voltmeter in the center of the bridge to provide an accurate measurement of that imbalance:

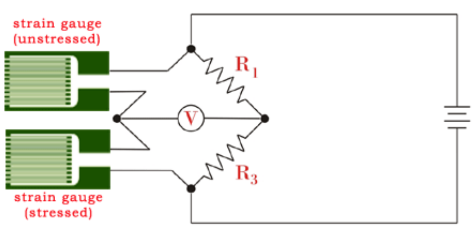


Quarter-bridge strain gauge circuit

In this circuit, R_1 and $R_3$are the ratio arms equal to each other, and R_2 is the rheostat arm has a value equal to the strain gage resistance. When the gauge is unstrained, the bridge is balanced, and voltmeter shows zero value. As there is a change in resistance of strain gauge, the bridge gets unbalanced and producing an indication at the voltmeter. The output voltage from the bridge can be amplified further by a differential amplifier.

Variation of Temperature of Strain Gauge

One more factor that affects the resistance of the gauge is temperature. If the temperature is more resistance will be more and if the temperature is less the resistance will be less. This is a common property of all the conductors. We can overcome this problem by using strain gauges that are self- temperature-compensated or by a dummy strain gauge technique. Most of the strain gauges are made of constantan alloy which cancel out the effect of temperature on the resistance. But some strain gauges are not of an isoelastic alloy. In such cases, dummy gauge is used in the place of R_2 in the quarter bridge strain gauge circuit which acts as a temperature compensation device. Whenever temperature changes, the resistance will change in the same proportion in the both arms of the rheostat, and the bridge remains in the state of balance. Effect of temperature get nullifies. It is good to keep voltage low so that the self-heating of **strain gauge** could be evaded. Self-heating of gauge depends upon its mechanical behavior.



Quarter-bridge strain gauge circuit
with temperature compensation

This arrangement is considered as quarter-bridge. There are two more arrangements half-bridge and full-bridge configurations which give greater sensitivity over the quarter-bridge circuit. Still the quarter-bridge circuit is widely used in strain measurement systems.

Use of Strain Gauge

- ✓ In the field of mechanical engineering development.
- ✓ To measure the stress generated by machinery.
- ✓ In the field of component testing of aircraft like; linkages, structural damage etc.

Theory of Strain Gauges

The change in the value of resistance by straining the gauge may be partly explained by the normal dimensional behavior of elastic material. If a strip of elastic material is subjected to tension, as shown in Figure. or in other words positively strained, its longitudinal dimension will increase while there will be a reduction in the lateral dimension. So when a gauge is subjected

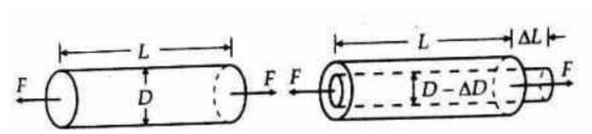


Fig. Change in dimensions of a strain gauge element when subjected to a tensile force.

to a positive strain, its length increases while its area of cross-section decreases as shown in Figure. Since the resistance of a conductor is proportional to its length and inversely proportional to its area of cross-section, the resistance of the gauge increases with positive strain. The change in the value resistance of strained conductor is more than what can be accounted for an increase in resistance due to dimensional changes. The extra change in the value of resistance is attributed to a change in the value of resistivity of a conductor when strained. This property, as described earlier, is known as peizoresistive effect.

Let us consider a strain gauge made of circular wire. The wire has the dimensions:
length = L, area = A, diameter = D before being strained. The material of the wire has a resistivityρ.
Resistance of un strained gauge R =ρL/ A
Let a tensile stress **S** be applied to the wire. This produces a positive strain causing the length to increase and area to decrease as shown in Figure. Thus when the wire is strained there are changes in its dimensions. Let ΔL = change in length, ΔA = change in area, ΔD = change in diameter and ΔR = change in resistance.

In order to find how ΔR depends upon the material physical quantities, the expression for R is differentiated with respect to stress **S.**

Thus we get:

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\partial L}{\partial s} - \frac{\rho L}{A^2}\frac{\rho A}{\partial s} + \frac{L}{A}\frac{\partial \rho}{\partial s} \qquad \text{...(25.59)}$$

Dividing Eqn. 25.59 throughout by resistance $R = \rho L / A$, we have

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{1}{A}\frac{\partial A}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \qquad \text{...(25.60)}$$

It is evident from Eqn. 25.60, that the per unit change in resistance is due to :

(*i*) per unit change in length $= \Delta L / L$,

(*ii*) per unit change in area $= \Delta A / A$, and

(*iii*) per unit change in resistivity $= \Delta\rho / \rho$

Area $\quad A = \frac{\pi}{4} D^2 \quad \therefore \quad \frac{\partial A}{\partial s} = 2.\frac{\pi}{4} D.\frac{\partial D}{ds} \qquad \text{...(25.61)}$

or

$$\frac{1}{A}\frac{dA}{ds} = \frac{(2\pi/4)D}{(\pi/4)D^2}\frac{\partial D}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s} \qquad \text{...(25.62)}$$

$\therefore$ Equation 25.60 can be written as :

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \qquad \text{...(25.63)}$$

Now, Poisson's ratio

$$\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}} = -\frac{\partial D / D}{\partial L / L}$$

...(25.64)

or $\quad \partial D / D = -\nu \times \partial L / L$

$$\therefore \quad \frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \nu\frac{2}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \qquad \text{...(25.65)}$$

For small variations, the above relationship can be written as :

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \qquad \text{...(25.66)}$$

The gauge factor is defined as the ratio of per unit change in resistance to per unit change in length.

Gauge factor $$G_f = \frac{\Delta R / R}{\Delta L / L} \qquad \ldots(25.67)$$

or $$\frac{\Delta R}{R} = G_f \frac{\Delta L}{L} = G_f \times \varepsilon \qquad \ldots(25.68)$$

where $\varepsilon = \text{strain} = \dfrac{\Delta L}{L}$

The gauge factor can be written as :

$$= 1 + 2\nu + \frac{\Delta\rho / \rho}{\varepsilon} \qquad \ldots(25.69)$$

$$= 1 \quad + \quad 2\nu \quad + \quad \frac{\Delta\rho / \rho}{\varepsilon}$$

$= 1$	2ν	$\frac{\Delta\rho / \rho}{\varepsilon}$
Resistance change due to change of length	Resistance change due to change in area	Resistance change due to piezoresistive effect

$$G_f = \frac{\Delta R / R}{\Delta L / L} = 1 + 2\nu + \frac{\Delta\rho / \rho}{\Delta L / L}$$

The strain is usually expressed in terms of microstrain. 1 microstrain = $1\,\mu m / m$.

If the change in the value of resistivity of a material when strained is neglected, the gauge factor is :

$$G_f = 1 + 2\nu \qquad \ldots(25.70)$$

Equation 25.70 is valid only when **Piezoresistive Effect** *i.e.,* change in resistivity due to strain is almost negligible.

The Poisson's ratio for all metals is between 0 and 0.5. This gives a gauge factor of approximately, 2. The common value for Poisson's ratio for wires is 0.3. This gives a value of 1.6 for wire wound strain gauges.

Thermocouple

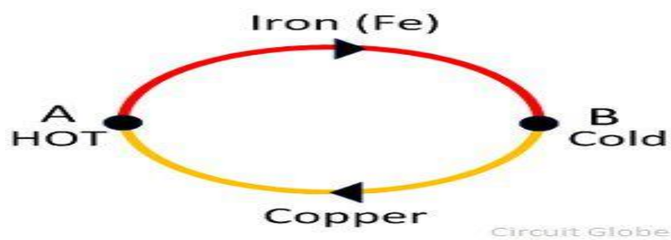
Definition: The thermocouple is a temperature measuring device. It uses for measuring the temperature at one particular point. In other words, it is a type of sensor used for measuring the temperature in the form of an electric current or the EMF.

The thermocouple consists two wires of different metals which are welded together at the ends. The welded portion was creating the junction where the temperature is used to be measured. The variation in temperature of the wire induces the voltages.

Working Principle of Thermocouple

The working principle of the thermocouple depends on the three effects.

See back Effect – The See back effect occurs between two different metals. When the heat provides to any one of the metal, the electrons start flowing from hot metal to cold metal. Thus, direct current induces in the circuit



In short, **it is a phenomenon in which the temperature difference between the two different metals induces the potential differences between them**. The See beck effect produces small voltages for per Kelvin of temperature.

Peltier Effect – The Peltier effect is the inverse of the Seebeck effect. The Peltier effect state that "the temperature difference can be created between any two different conductors by applying the potential difference between them".

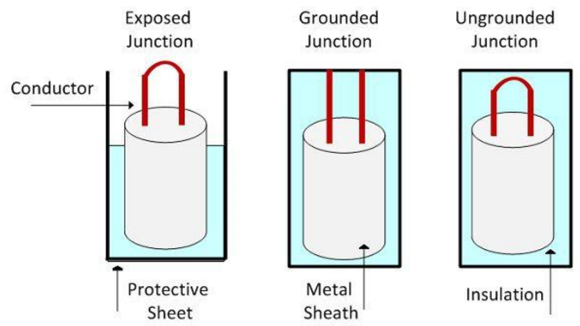
Thompson Effect – The Thompson effect state that **"**when two dissimilar metals join together and if they create two junctions then the voltage induces the entire length of the conductor because of the temperature gradient". The temperature gradient is a physical term which shows the direction and rate of change of temperature at a particular location.

Construction of Thermocouple

The thermocouple consists two dissimilar metals. These metals are welded together at the junction point. This junction considers as the measuring point. The junction point categorises into three types.

1. **Ungrounded Junction** – In ungrounded junction, the conductors are entirely isolated from the protective sheath. It is used for high-pressure application works. The major advantage of using such type of junction is that it reduces the effect of the stray magnetic field.

2. **Grounded Junction** – In such type of junction the metals and protective sheath are welded together**.** The grounded junction use for measuring the temperature in the corrosive environment. This junction provides resistance to the noise.
3. **Exposed Junction** – Such type of junction uses in the places where fast response requires. The exposed junction is used for measuring the temperature of the gas.

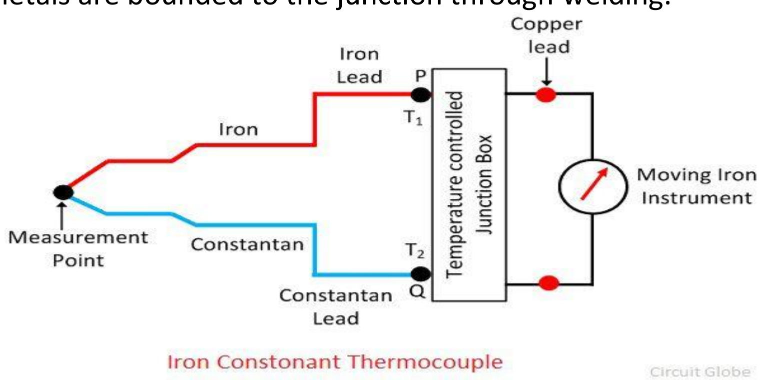


Thermocouple Junctions

The material uses for making the thermocouple depend on the measuring range of temperature.

Working of Thermocouple

The circuit of the thermocouple is shown in the figure below. The circuit consists two dissimilar metals. These metals are joined together in such a manner that they are creating two junctions. The metals are bounded to the junction through welding.



Iron Constonant Thermocouple

Let the P and Q are the two junctions of the thermocouples. The T_1 and T_2 are the temperatures at the junctions. As the temperature of the junctions is different from each other, the EMF generates in the circuit. Thermocouples are used for measurement of temperature up to 1400^0C.

If the temperature at the junction becomes equal, the equal and opposite EMF generates in the circuit, and the zero current flows through it. If the temperatures of the junction become unequal, the potential difference induces in the circuit. The magnitude of the EMF induces in the circuit depends on the types of material used for making the thermocouple. The total current flowing through the circuit is measured through the measuring devices.

The EMF induces in the thermocouple circuit is given by the equation

$$E = a(\Delta\theta) + b(\Delta\theta)^2$$

Where Δθ – temperature difference between the hot thermocouple junction and the reference thermocouple junction. a, b – constants

Measurement of Thermocouple Output

The output EMF obtained from the thermocouples can be measured through the following methods.

1. **Multimeter** – It is a simpler method of measuring the output EMF of the thermocouple. **The multimeter is connected to the cold junctions of the thermocouple**. The deflection of the multimeter pointer is equal to the current flowing through the meter.
2. **Potentiometer** – The output of the thermocouple can also be measured with the help of the DC potentiometer.
3. **Amplifier with Output Devices** – The output obtains from the thermocouples is amplified through an amplifier and then feed to the recording or indicating instrument.

Advantages of Thermocouple

The following are the advantages of the thermocouples.

- The thermocouple is cheaper than the other temperature measuring devices.
- The thermocouple has the fast response time.
- It has a wide temperature range.

Disadvantages of the Thermocouples

- The thermocouple has low accuracy.
- The recalibration of the thermocouple is difficult.

Nickel-alloy, platinum/rhodium alloy, Tungsten/rhenium-alloy, chromel-gold, iron-alloy are the name of the alloys used for making the thermocouple.

Piezo-Electric Transducer

Definition: The Piezoelectric transducer is an **electroacoustic transducer**use for **conversion** of **pressure** or mechanical stress into an alternating **electrical force.** It is used for measuring the physical quantity like force, pressure, stress, etc., which is directly not possible to measure.

The piezo transducer converts the physical quantity into an electrical voltage which is easily measured by analogue and digital meter. The piezoelectric transducer uses the piezoelectric material which has a special property, i.e. the material induces voltage when the pressure or stress applied to it. The material which shows such property is known as the electro-resistive element.

The word piezoelectric means the electricity produces by the pressure. **The Quartz is the examples of the natural piezoelectric crystals,** whereas the **Rochelle salts, ammonium dehydration, phosphate, lithium sulphate, dipotassium tartrate are the examples of the man made crystals.** The ceramic material is also used for piezoelectric transducer.

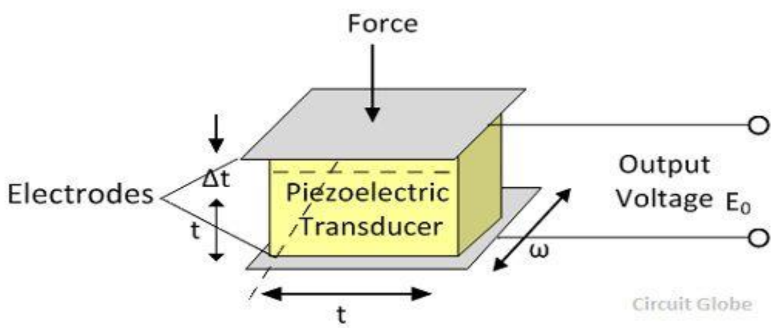
The ceramic material does not have the piezoelectric property. The property is developed on it by special polarizing treatment. The ceramic material has several advantages. It is available in different shapes and sizes. The material has the capability of working at low voltages, and also **it can operate at the temperature more than 3000ºC**

Piezoelectric Effect

The EMF develops because of the displacement of the charges. The effect is changeable, i.e. if the varying potential applies to a piezoelectric transducer, it will change the dimension of the material or deform it. This effect is known as the piezoelectric effect. The pressure is applied to the crystals with the help of the force summing devices for examples the stress is applied through mechanical pressure gauges and pressure sensors, etc. The deformation induces the EMF which determines the value of applied pressure.

Theory of Piezo-Electric Transducer

A piezoelectric crystal is shown in the figure below



The polarity of the charge depends on the direction of the applies forces.

$$Charge\ Q = d\ \times F\ Coulomb$$

Where, d – charge sensitivity of the crystals
F – applied force in Newton
The force changes the thickness of the crystals.

$$F = \frac{AE}{t}\Delta t\ Netwon$$

Where A – area of crystals in meter square
t – the thickness of crystals in meter
E – Young's modulus N/m^2
The young modulus is,

$$E = \frac{stress}{strain} = \left(\frac{F}{A}\right).\frac{1}{\Delta t/t}$$

$$E = \frac{Ft}{A\Delta t}N/m^2$$

$$A = \omega l$$

where ω – width of crystals in meter
l – the length of crystals in meter

On substituting the value of force in the equation of charge, we get

$$Q = dAE(\frac{\Delta t}{t})$$

The output voltage is obtained because of the electrode charges.

$$E_o = \frac{Q}{C_p} = \frac{dF}{\varepsilon_r \varepsilon_0 A/t}$$

$$E_0 = \frac{d}{\varepsilon_r \varepsilon_0} tP$$

$$E_0 = gtP$$

$$g = \frac{d}{\varepsilon_r \varepsilon_0}$$

The g is the voltage sensitivity of the crystals.

$$g = \frac{E_0}{tP} = \frac{E_0/t}{P}$$

Where E_0 – electric field strength, V/m

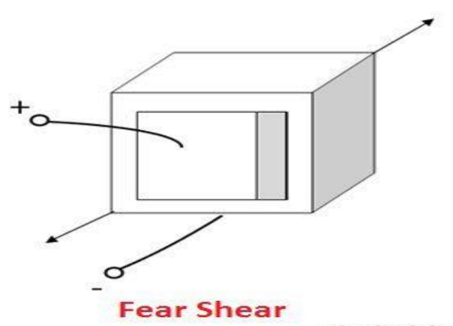
The voltage sensitivity of the crystals is expressed by the ratio of the electric field intensity and pressure.

When the mechanical deformation occurs in the crystals, it generates charges. And this charge develops the voltages across the electrodes.

The Piezoelectric crystal is direction sensitive. The polarity of the voltage depends on the direction of the force which is either tensile or compressive. The magnitude and the polarity of the charges depend on the magnitude and the direction of the applied force.

Modes of Operation of Piezo-Electric Crystal

The Piezoelectric crystals are used in many modes likes, thickness shear, face shear, thickness expansion, Transverse expansion, etc. The figure of the fear shear is shown in the figure below.



Properties of Piezo-electric Crystals

The desirable properties of piezo-electric materials are stability, high output insensitivity to temperature and humidity and the ability to be formed into most desirable shape. Quartz is the most stable piezo-electric material. However, its output is quite small. On the other hand, Rochelle salt provides the highest output but it can be worked over a limited humidity range and has to be protected against moisture. The highest temperature is limited to 45^0C.

Barium titanate has the advantage that it can be formed into a variety of shapes and sizes since it is polycrystalline. It has also a higher dielectric constant. Natural crystals possess the advantages that they have higher mechanical and thermal stability, can withstand higher stresses, have low leakage (their volume resistivity is about 10^{16} 0 - m) and have a good frequency response. The synthetic materials, in general, have higher voltage sensitivity. Uses of Piezoelectric Crystal

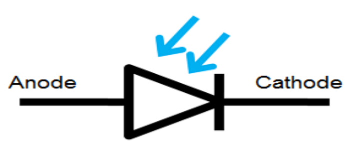
The following are the uses of the Piezoelectric transducers.

- ✓ The piezoelectric material has high stability and hence it is used for stabilizing the electronic oscillator.
- ✓ The ultrasonic generators use the piezoelectric material. This generator is used in SONAR for underwater detection and in industrials apparatus for cleaning.
- ✓ It is used in microphones and speakers for converting the electric signal into sound.
- ✓ The piezoelectric material is used in electric lighter.

Photodiode - Working Principle and Applications

A photodiode is a kind of light detector, which involves the conversion of light into voltage or current, based on the mode of operation of the device.

It consists of built-in lenses and optical filters, and has small or large surface areas. With an increase in their surface areas, photodiodes have a slower response time. Conventional solar cells, used for generating electric solar power, are a typical photodiode with a large surface area. Some photodiodes will look like a light emitting diode. They have two terminals coming from the end. The smaller end of the diode is the cathode terminal, while the longer end of the diode is the anode terminal. See the following schematic diagram for the anode and cathode side. Under forward bias condition, conventional current will flow from the anode to the cathode, following the arrow in the diode symbol. Photocurrent flows in the reverse direction.



Photodiode symbol

A photodiode is a semi-conductor device, with a p-n junction and an intrinsic layer between p and n layers. It produces photocurrent by generating electron-hole pairs, due to the absorption of light in the intrinsic or depletion region. The photocurrent thus generated is proportional to the absorbed light intensity.

Types of Photodiode

Although there are numerous types of photodiode available in the market and they all works on the same basic principles, though some are improved by other effects. The working of different types of photodiodes work in a slightly different way, but the basic operation of these diodes remains the same. The types of the photodiodes can be classified based on its construction and functions as follows.

- PN Photodiode
- Schottky Photo Diode
- PIN Photodiode
- Avalanche Photodiode

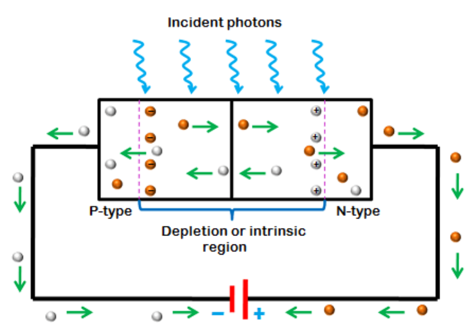
These diodes are widely used in the applications where the detection of the presence of light, color, position, intensity is required. The main features of these diodes include the following.

- The linearity of the diode is good with respect to incident light
- Noise is low.
- The response is wide spectral
- Rugged mechanically
- Light weight and compact
- Long life

Working Principle of Photodiodes

When photons of energy greater than 1.1 eV hit the diode, electron-hole pairs are created. The intensity of photon absorption depends on the energy of photons – the lower the energy of photons, the deeper the absorption is. This process is known as the inner photoelectric effect.

If the absorption occurs in the depletion region of the p-n junction, these hole pairs are swept from the junction - due to the built-in electric field of the depletion region. As a result, the holes move toward the anode and the electrons move toward the cathode, thereby producing photocurrent.



PIN photodiode

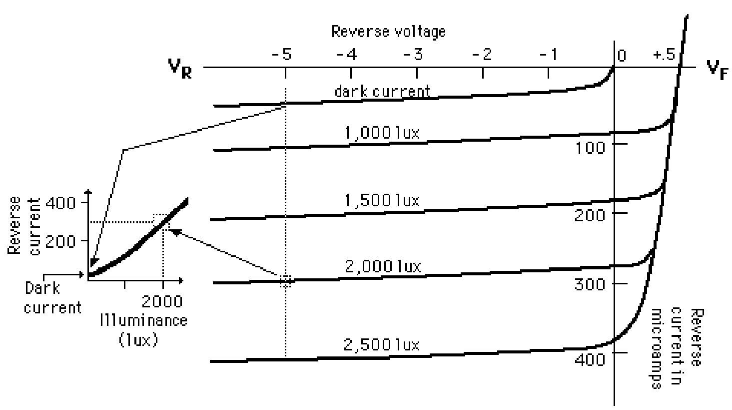
Modes of Operation

Photodiodes can be operated in different modes, which are as follows:

- Photovoltaic mode – It is also known as zero bias mode, in which a voltage is generated by the illuminated photodiode. It provides a very small dynamic range and non-linear dependence of the voltage produced
- Photoconductive mode - The diode used in this mode is more commonly reverse biased. The application of reverse voltage increases the width of the depletion layer, which in turn reduces the response time and capacitance of the junction. This mode is very fast, and exhibits electronic noise
- Avalanche diode mode - Avalanche photodiodes are operated in a high reverse bias condition, which allow multiplication of an avalanche breakdown to each photo-generated electron-hole pair. This results in internal gain within the photodiode, which gradually increases the responsivity of the device

V-I Characteristics of Photodiode

A photodiode continually operates in a reverse bias mode. The characteristics of the photodiode are shown clearly in the following figure, that the photocurrent is nearly independent of reverse bias voltage which is applied. For zero luminance, the photocurrent is almost zero excluding for small dark current. It is of the order of nano amperes. As optical power rises the photo current also rises linearly. The max photocurrent is incomplete by the power dissipation of the photo diode.



APPLICATIONS OF PHOTODIODE

- ✓ The applications of photodiodes involve in similar applications of photodetectors like charge-coupled devices, photoconductors, and photomultiplier tubes.
- ✓ These diodes are used in consumer electronics devices like smoke detectors, compact disc players, and televisions and remote controls in VCRs.

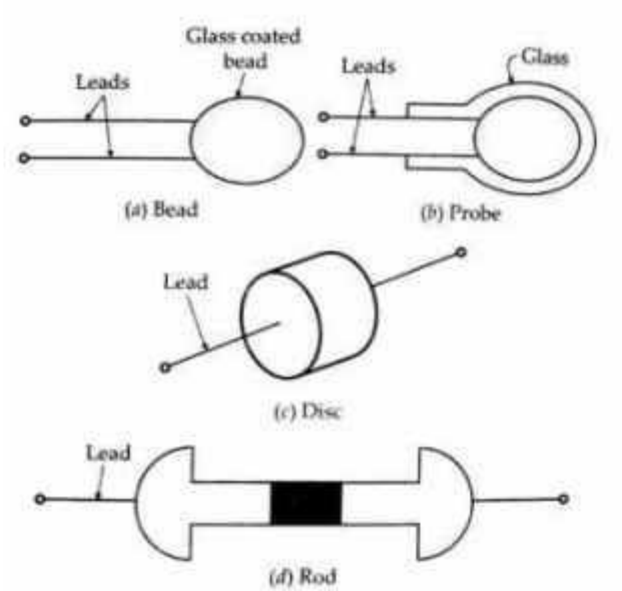
- ✓ In other consumer devices like clock radios, camera light meters, and street lights, photoconductors are more frequently used rather than photodiodes.
- ✓ Photodiodes are frequently used for exact measurement of the intensity of light in science & industry. Generally, they have an enhanced, more linear response than photoconductors.
- ✓ Photodiodes are also widely used in numerous medical applications like instruments to analyze samples, detectors for computed tomography and also used in blood gas monitors.
- ✓ These diodes are much faster & more complex than normal PN junction diodes and hence are frequently used for lighting regulation and in optical communications.

THERMISTORS

Coined from the words "**THER**mally controlled res**ISTOR",** thermistor is a temperature controlled resistor. Thermistors are one of the most commonly used devices for the measurement of temperature. The thermistors are resistors whose resistance changes with the temperature. While for most of the metals the resistance increases with temperature, the thermistors respond negatively to the temperature and their resistance decreases with the increase in temperature. Since the resistance of thermistors is dependent on the temperature, they can be connected in the electrical circuit to measure the temperature of the body. In some cases the resistance of the thermistors at room **temperature may decrease as much as 5 percent for each 1°C rise in temperature.** This **high sensitivity** to temperature changes makes thermistors extremely useful for precision temperature measurements control and compensation**. Thermistors are widely used in applications which involves measurement in the range of -60°C to 15°C. The resistance of thermistors ranges from 0.5Ω to 0.75MΩ.**

Materials used for Thermistors and their Forms

The thermistors are made up of ceramic like semiconducting materials. **They are mostly composed of oxides of manganese, nickel and cobalt having the resistivities if about 100 to 450,000 ohm-cm**. Since the resistivity of the thermistors is very high the resistance of the circuit in which they are connected for measurement of temperature can be measured easily. This resistance is calibrated against, the input quantity, which is the temperature, and its value can be obtained easily. Thermistors are available in various shapes like disc, rod, washer, bead etc. They are of small size and they all can be fitted easily to the body whose temperature has to be measured and also can be connected to the circuit easily. Most of the thermistors are quite cheap.



Principle of Working of Thermistors

The Thermistor's temperature can change either due to external factors or due to internal factors. The most important internal factor is the current flowing through the device. As the current through it increases, it starts self heating its elements. This causes a rise in temperature of the Thermistor. Depending on the type of Thermistor(whether NTC or PTC), its resistance changes with respect to this change in temperature. Externally the Thermistor temperature can be changed by changing the ambient temperature. The resistance and temperature relationship can be approximated by the following equation:

$$R = R_o\, e^{\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)} \qquad \text{..... (1)}$$

Resistance – Temperature Relation Equation of Thermistor

Where,

R = Resistance of Thermistor at the temperature T (in K)
R_0 = Resistance at given temperature T0 (in K)
β = Material specific-constant

In terms of temperature coefficient of resistance this equation can be defined as:

$$R = R_o [1+\alpha(T-T_o)] \;....(2)$$

β is a constant whose value ranges from **3500 to 4500°K depending on the material used for the thermistors and its composition.**

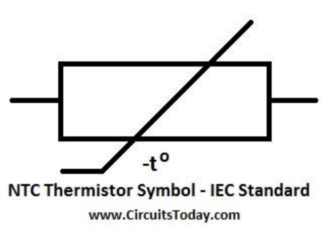
The thermistor acts as the temperature sensor and it is placed on the body whose temperature is to be measured. It is also connected in the electric circuit. When the temperature of the body changes, the resistance of the thermistor also changes, which is indicated by the circuit directly as the temperature since resistance is calibrated against the temperature. The thermistor can also be used for some control which is dependent on the temperature.

Types of Thermistors

As already discussed, temperature dependence of a resistor is defined by its temperature coefficient. According to this, the thermistors are classified into two categories based on the type of temperature coefficient. There are two types of temperature coefficient namely negative temperature coefficient and positive temperature coefficient. The ceramic semiconductor material used for each type of thermistor, differs, as the temperature coefficient is dependent on the material used.

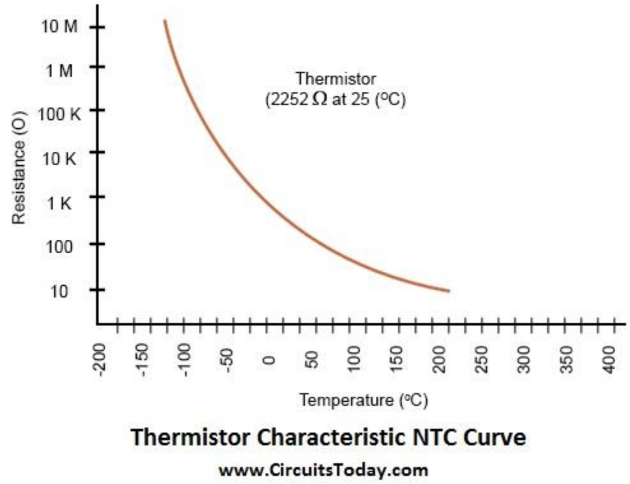
NTC Thermistor:

- ***Definition –*** NTC or negative temperature coefficient thermistor is a device whose resistance decreases with increase in temperature. These types of resistor usually exhibit a large, precise and predictable decrease in resistance with increase in temperature.
- ***Material Used for Construction –*** Unlike other resistors (fixed or variable), these are made of ceramics and polymers, which composed of metal oxides that are dried and sintered to obtain a desired form factor. In case of NTC thermistor, cobalt, nickel, iron and copper oxides are preferred
- ***NTC Thermistor Symbol –*** The symbol for NTC thermistor is given as:



NTC Thermistor Symbol

- ***Characteristic Curve –*** A typical NTC thermistor gives most precise readings in the temperature range of -55°C to 200°C. However some specially designed NTC thermistors are used at absolute zero temperature(-273.15°C) and some can be used above 150°C.The figure below shows the characteristic curve of a NTC thermistor:



Thermistor Characteristic NTC Curve

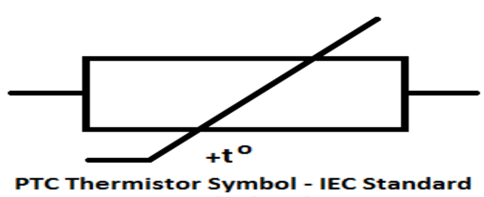
From the figure we can say that they have a steep resistance temperature curve, denoting good temperature sensitivity. However due to the nonlinear relationship between resistance and temperature, some approximations are utilized to design practical system.
Out of all the approximations, the simplest one is:
$\Delta R = k\Delta T$, where k is the negative temperature coefficient of the Thermistor.

PTC Thermistor:

Definition – PTC or Positive temperature coefficient Thermistors are those resistors whose resistance increases with increase in ambient temperature.

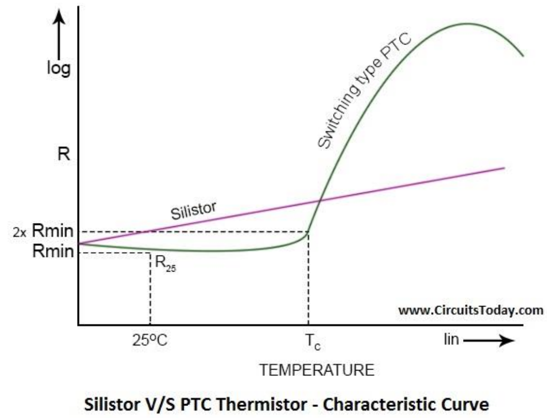
Types of PTC Thermistors – PTC Thermistors are grouped according to their structure, materials used and their manufacturing process. Silistors, are PTC Thermistors that belong to the first group(according to material used and structure). They use silicon as the semiconductor and have linear characteristic. Switching type PTC Thermistors belong to the second category (according to the manufacturing process). This Thermistor has a non linear characteristic curve. As the switching type PTC Thermistor gets heated, initially the resistance starts to decrease, up to a certain critical temperature, after which as the heat is increased, the resistance increases dramatically.

- ***PTC Thermistor Symbol –*** *Th*e following figure shows the symbol used for PTC Thermistors in a circuit diagram.



PTC Thermistor Symbol

- ***Characteristic Curve –*** The following figure shows the characteristic curve of a Silistor and a switching type PTC Thermistor.



Silistor vs PTC Thermistor Characteristic Curve

We see that, a silistor PTC has a linear characteristic. This means that this PTC Thermistor is quite sensitive to the change in temperature. Its resistance increases linearly with increase in temperature. The switching type PTC however, is different. Due to its poly-crystalline ceramic body, has a nonlinear characteristic curve. We see from the figure that upto a certain temperature, lets call it a threshold temperature, the resistance decreases with increase in temperature much like a NTC Thermistor. As the temperature increases beyond the threshold temperature, the resistance starts to increase dramatically with increase in temperature.

ADVANTAGES OF THERMISTORS

Here are some of the advantages of the thermistors

- ✓ When the resistors are connected in the electrical circuit, heat is dissipated in the circuit due to flow of current. This heat tends to increase the temperature of the resistor due to which their resistance changes. For the thermistor the definite value of the resistance is reached at the given ambient conditions due to which the effect of this heat is reduced.
- ✓ In certain cases even the ambient conditions keep on changing, this is compensated by the negative temperature characteristics of the thermistor. This is quite convenient against the materials that have positive resistance characteristics for the temperature.
- ✓ The thermistors are used not only for the measurement of temperature, but also for the measurement of pressure, liquid level, power etc.
- ✓ They are also used as the controls, overload protectors, giving warnings etc.
- ✓ The size of the thermistors is very small and they are very low in cost. However, since their size is small they have to be operated at lower current levels.

SYNCHRO

Definition: The Synchro is a type of transducer which transforms the angular position of the shaft into an electric signal. It is used as an error detector and as a rotary position sensor**.** The error occurs in the system because of the misalignment of the shaft. The transmitter and the control transformer are the two main parts of the synchro.

Synchros System Types

The synchro system is of two types. They are

1. Control Type Synchro.
2. Torque Transmission Type Synchro.

Torque Transmission Type Synchros

This type of synchros has small output torque, and hence they are used for running the very light load like a pointer. The control type Synchro is used for driving the large loads.

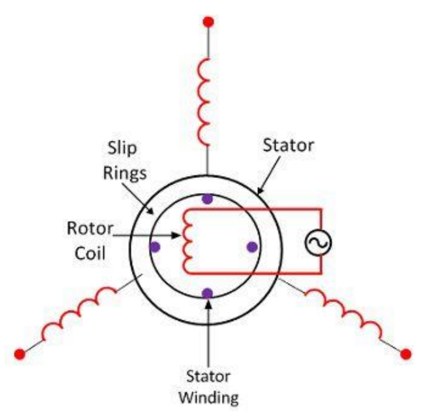
Control Type Synchros System

The controls synchros is used for error detection in positional control systems. Their systems consist two units. They are

1. Synchro Transmitter
2. Synchro receiver

The synchro always works with these two parts. The detail explanation of synchros transmitter and receiver is given below.

Synchros Transmitter – Their construction is similar to the three phase alternator. The stator of the synchros is made of steel for reducing the iron losses. The stator is slotted for housing the three phase windings. The axis of the stator winding is kept 120º apart from each other.



Constructional Feature of Synchros Transmitter

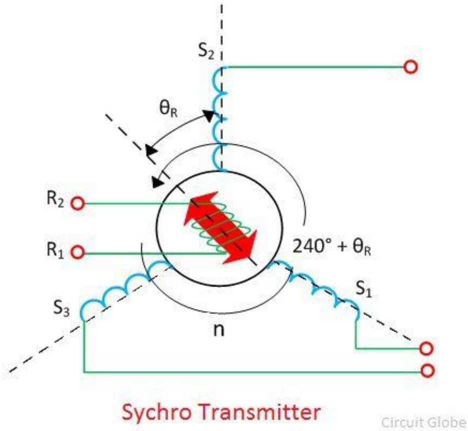
The AC voltage is applied to the rotor of the transmitter and it is expressed as

$$v_r = \sqrt{2}Sin\omega_c t$$

Where V_r – r.ms.value of rotor voltage

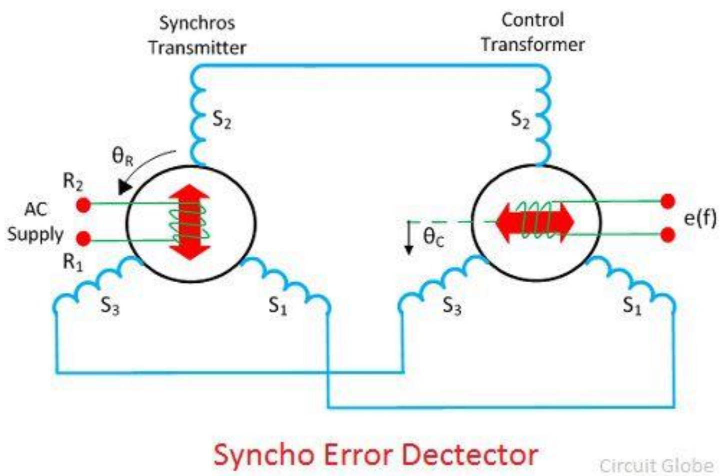
ω_c – carrier frequency

The coils of the stator windings are connected in star. The rotor of the synchros is a dumbbell in shape, and a concentric coil is wound on it. The AC voltage is applied to the rotor with the help of slip rings. The constructional feature of the synchros is shown in the figure below.



Sychro Transmitter

Consider the voltage is applied to the rotor of the transmitter as shown in the figure below.



Syncho Error Dectector

The voltage applied to the rotor induces the magnetizing current and an alternating flux along its axis. The voltage is induced in the stator winding because of the mutual induction between the rotor and stator flux. The flux linked in the stator winding is equal to the cosine of the angle between the rotor and stator. The voltage is induced in the stator winding.

Let V_{s1}, V_{s2}, V_{s3} be the voltages generated in the stator windings S_1, S_2, and S_3 respectively. The figure below shows the rotor position of the synchro transmitter. The rotor axis makes an angle θ_r concerning the stator windings S_2.

$$V_{s1n} = kV_r Sin\omega_c t cos(\theta_R + 120°)$$

$$V_{s2n} = kV_r Sin\omega_c t cos\theta_R$$

$$V_{s1n} = kV_r Sin\omega_c t cos(\theta_R + 240°)$$

$$V_{s1s2} = V_{s1n} - V_{s2n}$$

$$V_{s1s2} = \sqrt{3}kV_r Sin(\theta_R + 240°)Sin\omega_c t$$

$$V_{s3s2} = V_{s2n} - V_{s3n}$$

$$V_{s1s2} = \sqrt{3}kV_r Sin(\theta_R + 120°)Sin\omega_c t$$

$$V_{s3s1} = V_{s3n} - V_{s1n}$$

$$V_{s3s1} = kV_r Sin\omega_c t Sin\theta_R$$

The three terminals of the stator windings are

The variation in the stator terminal axis concerning the rotor is shown in the figure below.

$$e(t) = k'V_r Cos(90° - \theta_R + \theta_C)Sin\omega_c t$$

$$e(t) = k'V_r Sin(\theta_R - \theta_C)Sin\omega_c t$$

When the rotor angle becomes zero, the maximum current is produced in the stator windings S_2. The zero position of the rotor is used as a reference for determining the rotor angular position.

The output of the transmitter is given to stator winding of the control transformer which is shown in the above figure. The current of the same and magnitude flow through the transmitter and control transformer of the synchros. Because of the circulating current, the flux is established between the air gap flux of the control transformer. The flux axis of the control transformer and the transmitter is aligned in the same position. The voltage generates by the rotor of control transformer is equal to the cosine of the angle between the rotors of the transmitter and the controller. The voltage is given as

$$e(t) = k'V_r Cos\emptyset Sin\omega_c t$$

Where ϕ – angular displacement between the rotor axes of transmitter and controller.
Φ – 90º the axis between the rotor of transmitter and control transformer is perpendicular to each other. The above figure shows the zero position of the rotor of transmitter and receiver.

Consider the position of the rotor and the transmitter is changing in the same direction. An angle θ_R deflects the rotor of the transmitter and that of the control transformer is kept θ_C. The total angular separation between the rotors is $\Phi = (90º - \theta_R + \theta_C)$.

The rotor terminal voltage of the Synchro transformer is given as

$$e(t) = k'V_r Cos(90° - \theta_R + \theta_C) Sin\omega_c t$$

$$e(t) = k'V_r Sin(\theta_R - \theta_C) Sin\omega_c t$$

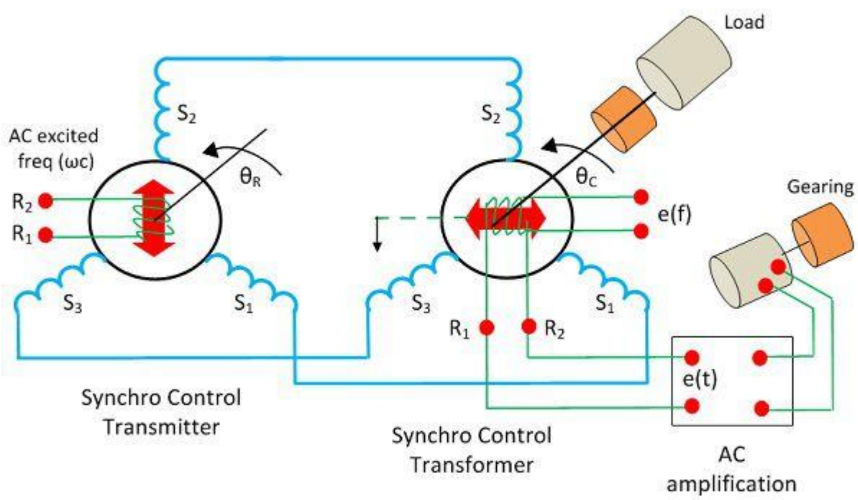
The small angular displacement between their rotor position is given as

$Sin (\theta_R - \theta_C) = (\theta_R - \theta_C)$

On substituting the value of angular displacement in equation (1) we get

$$e(t) = k'V_r Cos\emptyset Sin\omega_c t$$

The synchro transmitter and the control transformer together used for detecting the error. The voltage equation shown above is equal to the shaft position of the rotors of control transformer and



Positional Control System

transmitter.

The error signal is applied to the differential amplifier which gives input to the servo motor. The gear of the servo motor rotates the rotor of the control transformer

The figure above shows the output of the synchro error detector which is a modulated signal. The modulating wave above shown the misalignment between the rotor position and the carrier wave.

$$e(t) = (\theta_R - \theta_C)$$

Where K_s is the error detector.

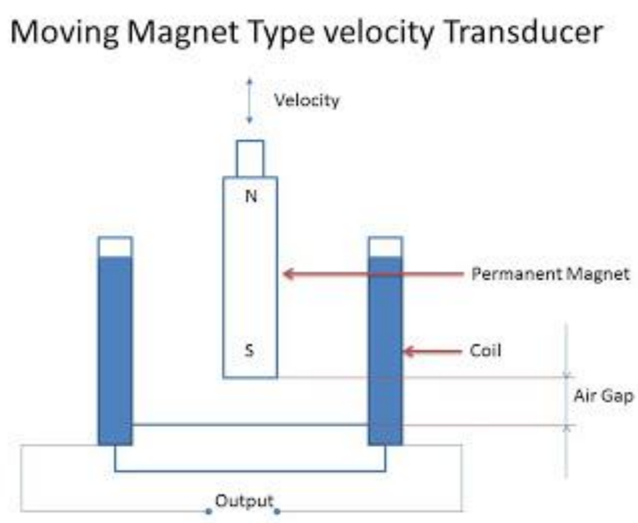
MEASUREMENT OF LINEAR VELOCITY

Moving magnet type velocity Transducer

Basic principle of Moving magnet type velocity Transducer

When a permanent magnet moves inside a coil, the change in the length of the air gap varies the reluctance. Hence the output voltage is directly proportional to the rate of change of the length of the air gap (change in length produced by velocity). Thus the output voltage becomes a measure of the velocity when calibrated.

Description of Moving magnet type velocity Transducer



* The sensing element which is a rod is a permanent magnet.
* The rod is rigidly coupled to the device whose velocity is being measured.
* There is a coil surrounding the permanent magnet.
* The permanent magnet is movable, that is, it can move in and out of the coil.

Operation of Moving magnet type velocity Transducer

- The instrument is fixed to the device whose velocity is to be measured.
- Due to the application of the velocity, the permanent magnet moves in or out of the coil. Due to its motion, the length of the air gap varies.
- The output voltage also varies due to the motion of the magnet and the amplitude of the voltage is directly proportional to velocity.
- The polarity of the output voltages determines the direction of the velocity.

Advantages of Moving magnet type velocity Transducer

- ✓ Its maintenance is negligible.
- ✓ The output voltage is linearly proportional to velocity.
- ✓ Cost of manufacture is less.

Disadvantages of Moving magnet type velocity Transducer

- Performance is affected by stray magnetic fields and hence noise is caused.
- Frequency response is poor.

Application

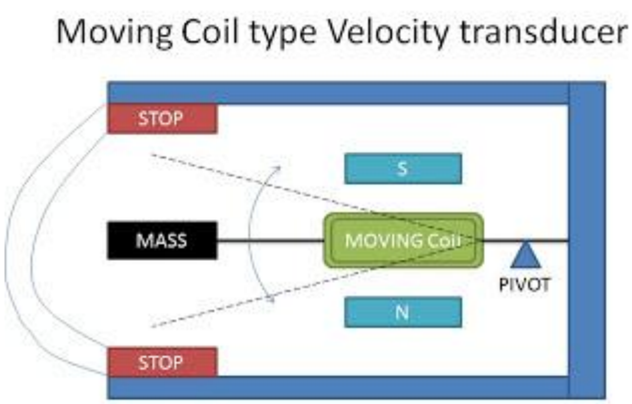
Used as a velocity transducer to convert velocity to measureable voltage.

Moving coil Type Velocity Transducer

Basic Principle of Moving coil Type Velocity Transducer

1. A coil moves in a magnetic field according to the velocity applied.
2. The voltage in the coil becomes a measure of the velocity when calibrated.

Description of Moving coil Type Velocity Transducer



* The instrument has permanent pole pieces which generate the magnetic field.
* There is a pivoted arm on which a coil is mounted.
* There is a mass attached to the end of the coil.
* The whole device is contained in an antimagnetic case.

Operation of Moving coil Type Velocity Transducer

➢ The velocity to be measured is applied to the arm.
➢ Due to this coil moves in the magnetic field.
➢ A voltage is generated on account of motion of the coil in the magnetic field.
➢ The output voltage is proportional to the velocity.

Advantages of Moving coil Type Velocity Transducer

✓ The antimagnetic case reduces the effects of stray magnetic field.
✓ Damping is obtained electrically.
✓ There is high stability under varying temperature conditions.

Applications of Moving coil Type Velocity Transducer

These transducers are used for measuring velocities in linear, sinusoidal or random manner.

Measurement of Angular velocity

The Tachometer use for measuring the rotational speed or angular velocity of the machine which is coupled to it. It works on the principle of relative motion between the magnetic field and shaft of the coupled device. The relative motion induces the EMF in the coil which is placed between the constant magnetic field of the permanent magnet. The developed EMF is directly proportional to the speed of the shaft. Mechanical and electrical are the two types of the tachometer. The mechanical tachometer measures the speed of shaft regarding revolution per minutes.

The electrical tachometer converts the angular velocity into an electrical voltage. The electrical tachometer has more advantages over the mechanical tachometer. Thus it is mostly used for measuring the rotational speed of the shaft.

The tachometers are **classified** as follows:

I. **Mechanical tachometers**

II. **Electrical tachometers**

1. D.C. tachometer generators
2. A.C. tachometer generators
3. Photo-electric tachometers (or Speed-meter)
4. Toothed motor variable reluctance tachometer etc. Electrical tachometers are preferred (as compared to mechanical tachometers) in view of the advantages they offer as **electrical transducers.**

D.C Tachogenerators

Permanent magnet, armature, commutator, brushes, variable resistor, and the moving coil voltmeter are the main parts of the DC tachometer generator. The armature of the D.C Tachogenerator is kept in the permanent magnetic field. The armature of the tachogenerator is coupled to the machine whose speed is to be measured. When the shaft of the machine revolves, the armature of the tachogenerator revolves in the magnetic field producing e.m.f. which is proportional to the product of the flux and speed to be measured. Now as the field of the permanent field is fixed, the e.m.f generated is proportional to the speed directly. The e.m.f induced is measured using moving coil voltmeter with uniform scale calibrated in speed directly. The series resistance is used to limit the current under output short circuit condition. The polarity of output voltage indicates the direction of rotation. The commutator collects current from armature conductors and converts internally induced a.c e.m.f into d.c (unidirectional) e.m.f. while the brushes are used to collect current from commutator and make it available to external circuitry of the d.c tachogenerator.

The emf induces in the dc tachometer generator is given as

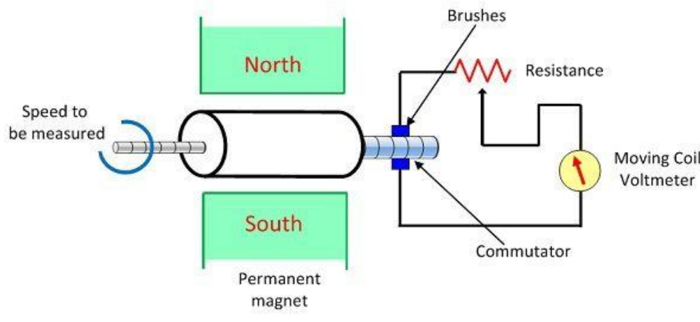
$$E = \frac{\emptyset PN}{60} \times \frac{z}{a}$$

Where, E – generated voltage
Φ – flux per poles in Weber
P- number of poles
N – speed in revolution per minutes
Z – the number of the conductor in armature windings.
a – number of the parallel path in the armature windings.

$$E \; \alpha \; N$$

$$E = KN$$

$$K = Constant = \frac{\emptyset P}{60} \times \frac{z}{a}$$



DC Tachometer Generator

Advantages of the DC Generator
The following are the advantages of the DC Tachometer.

- The polarity of the induces voltages indicates the direction of rotation of the shaft.
- The conventional DC type voltmeter is used for measuring the induced voltage.

Disadvantages of DC Generator

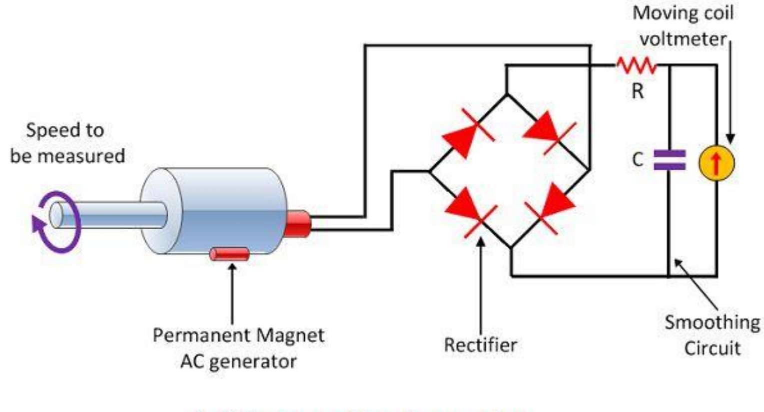
- The commutator and brushes require the periodic maintenance.
- The output resistance of the DC tachometer is kept high as compared to the input resistance. If the large current is induced in the armature conductor, the constant field of the permanent magnet will be distorted.

AC Tachometer Generator

The DC tachometer generator uses the commutator and brushes which have many disadvantages. The AC tachometer generator designs for reducing the problems. The AC tachometer has stationary armature and rotating magnetic field. Thus, the commutator and brushes are absent in AC tachometer generator.

The rotating magnetic field induces the EMF in the stationary coil of the stator. The amplitude and frequency of the induced emf are equivalent to the speed of the shaft. Thus, either amplitude or frequency is used for measuring the angular velocity.

The below mention circuit is used for measuring the speed of the rotor by considering the amplitude of the induced voltage. The induces voltages are rectified and then passes to the capacitor filter for smoothening the ripples of rectified voltages.



A.C Tachometer Generator

Advantages:

- ✓ The output can be calibrated in terms of two parameters namely amplitude and frequency of induced voltage.
- ✓ Commutator and brush contact resistance problems are eliminated as the coil is wound on stator.

Photo-electric Tachometer

Fig. 34 shows a photo-electric tachometer.

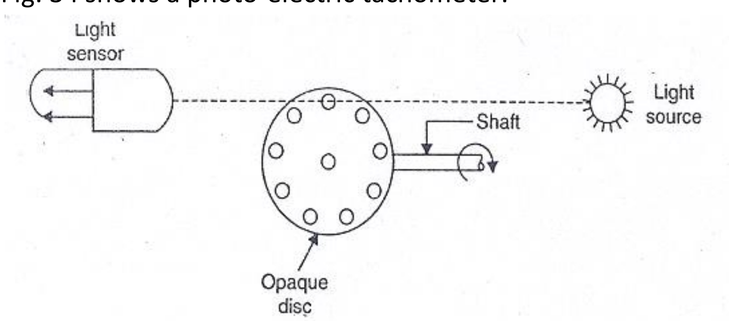


Fig. 34

- It consists of a opaque disc mounted on the shaft whose speed is to be measured. The disc has a number of equivalent holes around the periphery. On one side of the disc there is a source of light (L) while on the other side there is a light sensor (may be a photosensitive device or photo-tube) in line with it (light-source).
- On the rotation of the disc, holes and opaque portions of the disc come alternatory in between the light source and the light sensor. When a hole comes in between the two, light passes through the holes and falls on the light sensor, with the result that an output pulse is generated. But when the opaque portion of the disc comes in between, the light from the source is blocked and hence there is no pulse output. Thus whenever a hole comes in line with the light source and sensor, a pulse is generated. These pulses are counted/measured through an electronic counter.

The number of pulses generated depends upon the foliowing factors:

i. The number of holes in the disc;

ii. The shaft speed.

Since the numbers of holes are fixed, therefore, the number of pulses generated depends on the speed of the shaft only. The electronic counter may therefore be calibrated in terms of speed (r.p.m.)

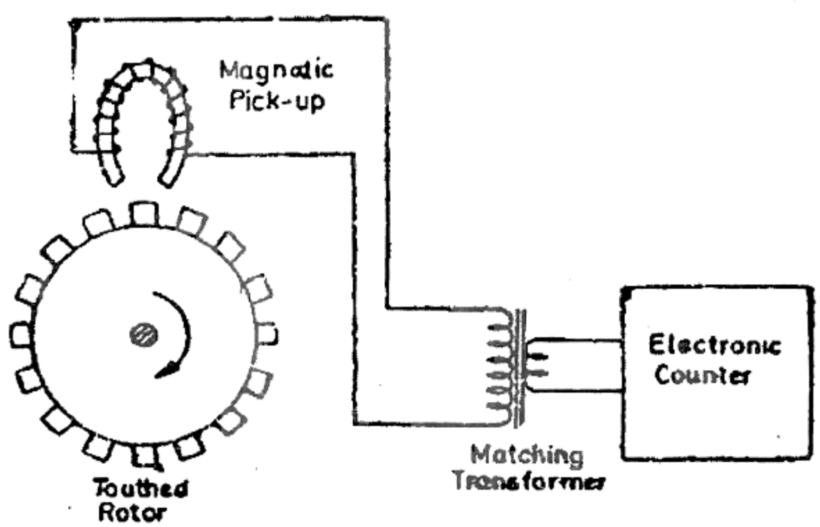
Advantage. It is a digital instrument.

Disadvantage. It is required to replace the light source periodically, and if the grating period is small then errors might creep in the output.

Toothed motor variable reluctance tachometer

A toothed rotor variable reluctance tachometer is described here. This tachometer generator consists of a metallic toothed rotor mounted on the shaft whose speed is to be measured. A magnetic pickup is placed near the toothed rotor. The magnetic pickup consists of a housing containing a small permanent magnet with a coil wound round it. When the rotor rotates, the reluctant e of the air-gap between pickup and the toothed rotor changes giving rise to an indicted e.m.f. in the pickup coil. This output is in the form of pulses, with a variety of wave shapes.

The frequency of the pulses of induced voltage will depend upon the number of teeth of the rotor and its speed of rotation. Since the number of teeth is known, the speed of rotation can be determined by measuring the frequency of pulses with an electronic counter. Suppose the rotor has "T' teeth, the speed of rotation is "n" rps and number of pulses per second is "P". A typical rotor has 60 teeth. Thus if the counter counts the pulse in one second, the counter will directly display the speed in rpm. It is mentioned above that the pulses have a variety of wave shapes. This is immaterial, as this tachometer is always connected to an electronic counter**, whose requirement is merely that the amplitude be great enough to trigger a count.**



Toothed Rotor Tachometer.

Speed = n = $\frac{Pulses\ per\ second}{Number\ of\ teeth}$ **=** $\frac{P}{N}$ **r.p.s =**$\frac{P}{N}$***60 r.p.m**

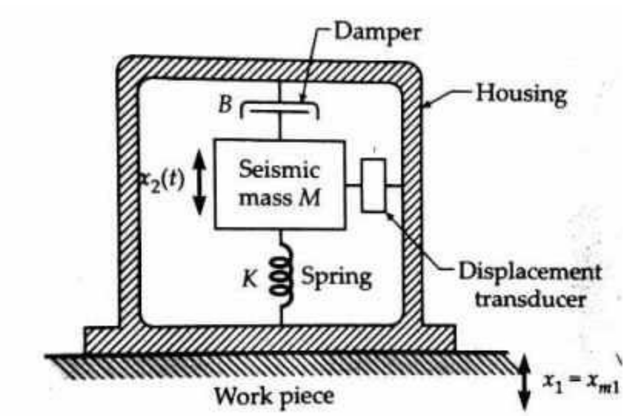
Advantages:

i. Simple is construction and rugged in construction
ii. Maintenance free tachometer
iii. Calibration of tachometer is simple
iv. The transmission of output of tachometer is easy.

MEASUREMENT OF ACCELERATION

SEISMIC TRANSDUCERS

A schematic diagram of a seismic transducer is shown in below Fig. It is called a seismic accelerometer also. The mass is connected through a parallel spring and damper arrangement to a housing frame. The housing frame is connected to the source of vibrations whose characteristics are to be measured.



The mass has the tendency to remain fixed in its spatial position so that the vibrational motion is registered as a relative displacement between mass and housing frame. This displacement is sensed and indicated by an appropriate transducer.

The seismic transducer may be used in two different modes

- A Displacement mode, and
- Acceleration mode.

The mode to be selected depends upon the proper selection of mass, spring and damper combinations. In general, a large mass and a soft spring are suited for displacement mode measurements, while a relatively small mass and a stiff spring are used for acceleration is mode measurements.

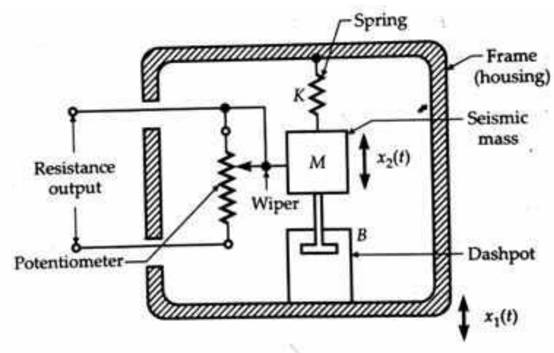
If the device is to be used for acceleration measurements, the input frequency should be much lower than the natural frequency of the accelerometer. In order that **the instrument is used for higher frequencies, it should be designed to have a high natural frequency. This requires a stiff spring (high value of K) and a small mass M.** The most important transducer for vibration, shock and general purpose absolute motion is the accelerometer. The instrument is commercially available in a wide variety of types and ranges in order to meet diverse application requirements.

TYPES OF ACCELEROMETERS

The variety of accelerometers used results from different applications with varied requirement of range of natural frequency and damping. The specification sheet for an accelerometer gives the natural frequency, damping ratio, and a scale factor which relates output with the acceleration input.

POTENTIOMETRIC TYPE ACCELEROMETER

This is the most simple type of accelerometer is shown in below Fig. The seismic mass is attached to the wiper arm or resistance potentiometer. The relative motion of the mass with respect to the transducer frame is sensed either as a change in resistance or as a change in voltage output (if the potentiometer is used as potential divider). The damping may be filling the housing of the accelerometer completely with a viscous fluid or it may be provided by a dashpot. Proper damping is necessary because it increases the range o frequencies over which the transducer may be used.

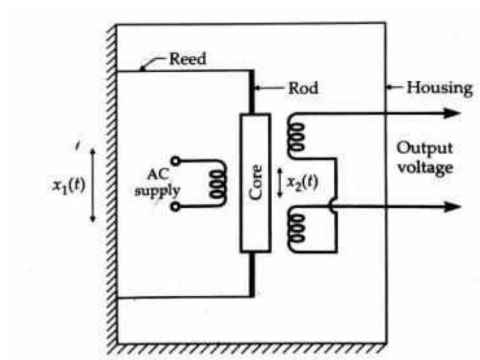


Potentiometric Accelerometer.

The major drawbacks of a seismic accelerometer using resistance potential divider are its limited resolution and a rather low natural frequency. This frequency is generally lower than 100 Hz and hence its application is limited to input frequencies lower than 50 Hz. Hence, this instrument is useful only for low frequency applications. The instrument also gives errors on account of its sliding contacts.

LVDT ACCELEROMETERS

Below Figure shows a seismic accelerometer using a linear voltage differential transformer (LVDT). The core of the LVDT acts as the mass and two flexible reeds, attached at each end of the rods of the core, provide the necessary spring action. The reeds are attached to housing, which is subject to vibrations.



Seismic accelerometer using LVDT.

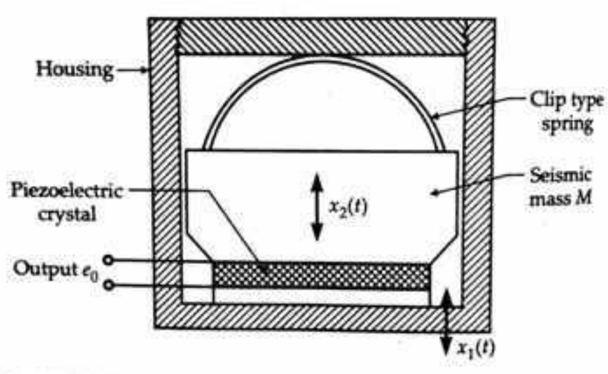
The above arrangement is necessary in order that the core of the LVDT is maintained at its null position. As the sensor moves up and down on account of vibrations, the LVDT secondaries give an a.c. output voltage, first of one phase and then, alternately of the opposite phase. The magnitude of this output signal depends upon the amplitude of the vibrations. The signal may then be rectified producing a voltage that alternately positive and negative. By measuring peak to peak magnitude of this voltage, an indication of the amplitude of the vibrations may be obtained.

The advantages of accelerometers using LVDT are:

- ✓ The LVDT has a much smaller mass and thus has a higher natural frequency. Therefore, it can, be used for measurement of vibrations of higher frequencies.
- ✓ The LVDT offers a lower resistance to the motion than the potentiometer and is capable of a much better resolution.
- ✓ It is a contactless device and is therefore free from problems which arise on account of moving contacts.
- ✓ The LVDT accelerometers are used for steady state and low frequency vibration measurements.

PIEZO-ELECTRIC ACCELEROMETERS

When a force F is applied to a piezo-electric crystal it develops a charge Q = dF coulomb
where d = charge sensitivity of crystal ; C/N.
Through incorporation of a mass, M, in direct contact with the crystal, we have the essential components of an acceleration transducer. By applying a varying acceleration to the mass-crystal assembly, the crystal experiences a varying force.



Piezo-electric type accelerometer.

The force is given by F = m x a
where a = acceleration.
This force generates a varying charge :
Q = dF = dMa
Suppose the crystal has a capacitance, C, the no load output voltage is

$$E_0 = \frac{Q}{C} = \frac{dF}{C} = \frac{dMa}{C}$$

Therefore the output voltage is a measure of the acceleration.
A typical piezo-electric accelerometer is shown in Fig. The piezo-electric crystal is spring loaded

With seismic mass in contact with the crystal. When subjected to an acceleration, the seismic mass stresses the crystal to a force F = Ma, resulting in a voltage generated across the crystal. This force generates an output voltage which is proportional to the acceleration.

Some of the features of piezo-electric accelerometers are:

i. The instrument is quite small in size and has a small weight (Typically 0.025 kg).
ii. The natural frequency is very high. It may be as high as 100 kHz and therefore the accelerometer is useful for high frequency applications. They can be used for any vibration and shock applications.

The primary elements of Importance in shock measurements are that the device should have a natural frequency which is greater than 1 kHz and a range typically greater than 500 g (i.e., g = 9.81 m/s The only accelerometer that can usually satisfy these requirements is the piezo-electric type.

iii. The crystal is a source with high output impedance and in order to avoid loading effect, a voltage monitoring source of high input impedance should be used.

Electrical impedance matching between transducer and readout circuitry is usually a critical matter requiring a very careful design consideration.

iv. These accelerometers are useful for high input frequencies and their response is poor at low frequencies. Therefore, they should not be used for applications where the input frequency is lower than 10 Hz.

MEASUREMENT OF TEMPERACTURE

ELECTRICAL RESISTANCE THERMOMETER

The resistance of metals changes with changes with change in temperature. The resistance thermometer uses the change in electrical resistance of a metallic conductor to determine the temperature. The requirements of a conductor material to be used in resistance thermometers are.

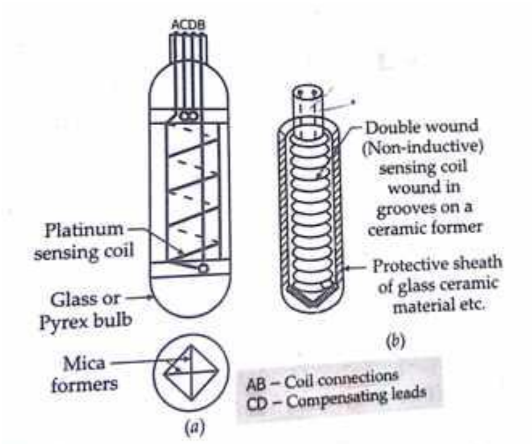
i. The change in resistance of the material per **°C** should be as large as possible, and
ii. The resistance of the material should have a continuous and stable relationship with temperature.
iii. The resistivity of material should be high, hence it requires less material.

The resistance temperature characteristics of nickel, copper and platinum are shown in below Fig.

Platinum Resistance Thermometer

The most commonly used material for metallic resistance thermometer is platinum. The resistance temperature characteristics of pure platinum are very well defined and show a high degree of capability. Therefore, these resistance thermometer elements are used over a wide range to establish the internal temperature scale. Resistance type temperature bulbs use sensing elements in the form of wires or foil. The films deposited on insulating surfaces are also used for temperature sensing. In the wire type, the arrangement is commonly a helical coil wound as a double wire to avoid inductive effects. The laboratory type resistance thermometers have the temperature sensing element wound on a cross mica former and enclosed in a Pyrex tube as shown in Fig. 29.62(a). The tube may be evacuated or filled with in gas to protect the platinum.

The industrial type of thermometer is shown in Fig. 29.62(b) the former being of grooved ceramic and the wire being protected by a glass coating or by a stainless steel tube. The element is normally sealed in glass when used for temperatures up to 150 degree and ceramic for use in temperatures up to 850 degree cen. This sealing has the two-fold advantage of providing structural strength and protection from chemical attack. Resistance thermometers are sometimes u above 850 ^{o}**C** but they have a reduced life. Resistance elements are also available as thin etched grids of metal foil similar in shape to foil type strain gauges. They are constructed of platinum and may be bonded to a plastic backing for attachment to a surface.



Measurement of Resistance of Thermometers

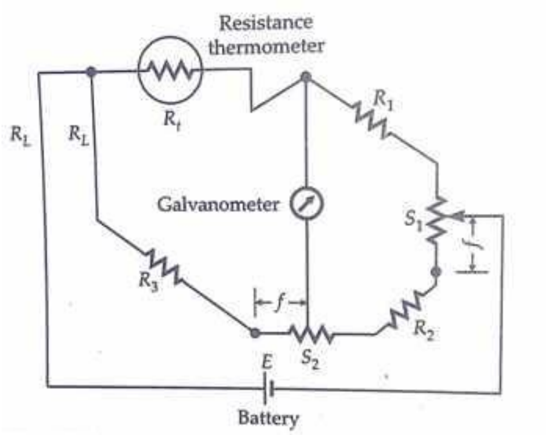
The measurement of change of resistance of thermometer due to temperature changes is measured by Wheatstone bridge. Ordinary Wheatstone bridge is not used for measurement of changes in resistance as it has many disadvantages as explained below:

i. The contact resistance of the adjustable standard resistor may be large enough to produce an error when measuring the change in resistance of thermometer.
ii. The leads from the thermometer to the bridge may introduce an error due to change of their resistance produced by temperature changes.
iii. The current through the thermometer produces a heating effect equal to the product of the current squared and the resistance of thermometer.

Slight modification of the Wheatstone bridge, such as a double slide wire bridge, eliminates most of these problems.

1. **Three Lead Method**

A double slide wire bridge is shown in Fig. 29.63. It has two slide wire resistors S1 and S2 which are tied together so that the fraction of S1 in series with the resistance R2 is equal to the fraction of S2 in series with resistance R3. This fraction is defined as f.



Measurement of temperature with double slide wire bridge and resistance thermometer.

BIMETALLIC THERMOMETERS

Bimetallic thermometers are extensively used in process industries for local temperature measurements. These thermometers use two fundamental principles:

i. All metals expand or contract with change in temperature and,
ii. The temperature co-efficient of expansion is not the same for all metals and therefore their rates of expansion or contraction are different. The difference in thermal expansion rates is used to produce deflections proportional to temperature changes.

A bimetallic thermometer consists of a bimetallic strip which is by bonding together two thin strips of two different metals such that they cannot move relative to each other. Since all metals try to change their physical dimensions at different rates when subjected to same change in temperature, these two metallic strips change their lengths at different rates. The differential change of expansion of two metals results in bending of the bimetallic strip with change in temperature.

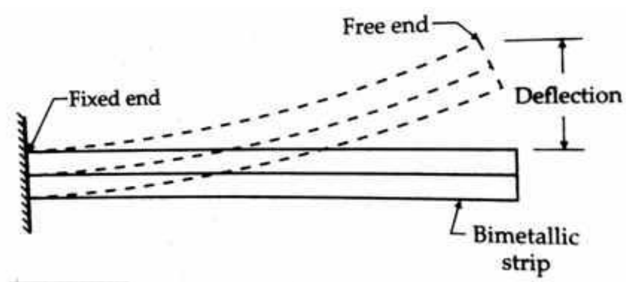


Fig. 29.72 Bimetallic strip fixed at one end.

Figure 29.72 shows a bimetallic strip in the form of a straight cantilever beam. With one end fixed, the "temperature changes cause the free end to deflect. The range over which a linear relationship exists between deflection and temperature depends upon the combination of metals used for the bimetallic strip. The deflection of the free end is directly proportional to the temperature change and square of the length of strip, and inversely proportional to the thickness throughout the linear portion of deflection temperature characteristics.

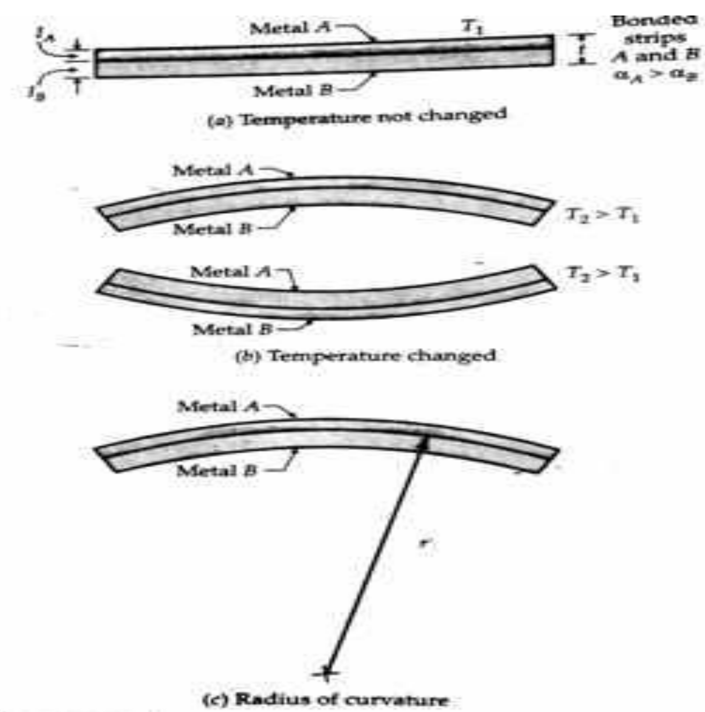


Fig. 29.73 Bonded bimetallic strip (unstrained) and its deflection when subjected to change on temperature.

Figure 29.73 shows a bimetallic strip made up of two metals A and B, having different thermal expansion coefficients, bonded together at a temperature T1. A change in temperature, (T2-T1) causes a differential expansion of the strip and if the motion is unstrained, the strip deflects into a uniform circular arc. The

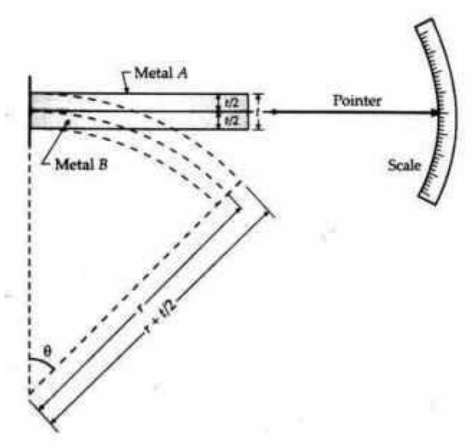
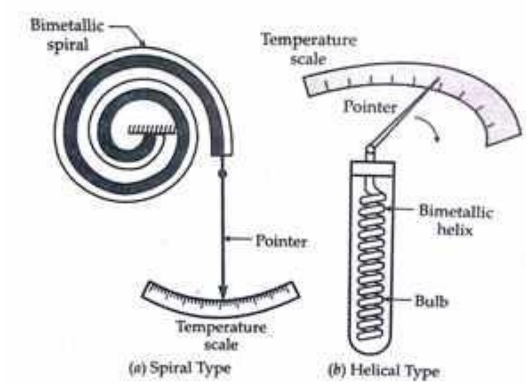


Fig. 29.74 Deflection of Bimetallic Strain.

It is clear from figure that the bimetallic strip bends towards the side whose metal has a lower thermal expansion coefficient when there is increase in temperature and reverse happen when there is decrease in temperature. The bimetallic strip described above is unsuitable for use in industrial applications because the deflection is small and hence the sensitivity is low. The sensitivity can be increased by increasing the length of strip. In order to keep the size of the thermometer within manageable limits, it is formed in the shape of either a spiral or a helix. This arrangement permits a very long length of strip to be compressed into a fairly small space. A bimetallic strip using a spiral is shown in Figure 29.75(a). The curvature of strip varies with temperature thereby causing the pointer to deflect. Figure 29.75(b) shows a bimetallic strip wound in the form of a helix. One end of the helix is fastened to the causing of the bulb and the other end is connected to the pointer. The pointer sweeps over a circular dial to indicate the temperature. The spiral strip is often used in ambient temperature measurement devices and air conditioning thermostats. The helical strip is used for most process applications because of its ability to be manufactured into a small diameter sheath while maintaining ruggedness.



Industrial type bimetallic thermometers.

In making bimetallic thermometers metals are chosen which have widely different thermal expansion co-efficient. Invar (an alloy of nickel and iron) is the mostly commonly used low expansion material. Its thermal expansion co-efficient remains stable over a wide temperature range. Nickel Iron alloys with chromium and manganese added are often used for thermal expansion material. Bimetallic thermometers, like other industrial temperature measuring devices, are usually mounted in wells to provide protection against wear and corrosion. However, the use of protective wells increases the response time.

The advantages of bimetallic thermometers are that they are simple, robust and inexpensive. Their accuracy ranges from ± 0.5% -for laboratory type of about ± 2% for process type instruments. These thermometers, in general can withstand about 50% over-range in temperature.

Bimetallic thermometers are not recommended for use at temperatures above 400^0C for continuous duty of above 550^0C for intermittent duty. All metals have physical limitations and are subject to permanent warp distortion. This means that metals do not return to their normal condition and therefore, temperatures indicated are not correct. Bimetallic thermometers are used for measurement of temperature between 40^0C and 550^0C and are expected to measure with an accuracy of ± 1% when used below 4000C for continuous service.

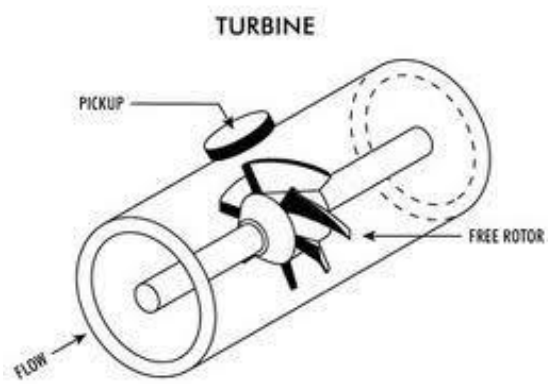
Bimetallic thermometers are used in refineries, oil burners, tire vulcanizers, hot solder tanks, hot wire heaters, tempering tanks, and impregnating tanks.

MEASUREMENT OF FLOW

There are a number of devices for sensing the rate of fluid flow. They mainly operate on the principle of placing an obstruction in the path of fluid causing a change in fluid pressure which is dependent upon the rate of flow. Thus by measuring the difference in pressure before and after the obstruction by means of a differential pressure sensor, the rate of flow may be determined. They are, in fact, mechanical means of measuring rate of liquid flow. The examples of these flow meters are: Orifice plate, venturi tube and Rotameter. These are indirect means of measuring fluid flow. However, there are some direct methods of measuring fluid flow which are described below. These methods employ electrical means directly.

TURBINE METERS

There have been extremely rapid developments in turbine meters in recent years, partly because of the advances in electronics technology and the case with which the output may be used to indicate rate of flow or be integrated to give total flow. An exploded view of the meter is shown in Fig. 29.83.



Turbine flow meters are volumetric flow meters and are available in wide ranges. The output is usually in the form of a digital electrical signal whose frequency is directly proportional to flow rate and whose total count is proportional to the total quantity, as each pulse represents a discrete volume. Above Figure shows a magnetic pickup type of turbine flow meter. A feature of this turbine meter is a hydraulically supported turbine rotor. A permanent magnet sealed inside the rotor body is polarized at 90° to the axis of the rotation. As the rotor rotates so does the magnet and therefore rotating magnetic field is produced. This produces an a.c. voltage pulse in the pick-up coil located external to the meter housing. The frequency of this voltage is directly proportional to the rate of flow. The pulse can be totalized by a counter to give the value of total flow over a particular interval of time.

Advantages:

(i) The output is in electrical digital form which lends itself admirably to line or radio telemetry for recording or control at a distant point.

(ii) Passage of rotor past the pick up coil produces an emf which can be converted to a d.c. analog voltage by a D/A converter for indication on a conventional d.c. instrument or recorded on a potentiometric recorder.
(iii) The pulse output may be summed on a simple counter giving totalized flow without loss of accuracy. The error is approximately ± 0.5%.

Limitations:

* Errors may be caused by excessive frictional torques. Also errors arise on account of wear and corrosion of bearings. This calls for special design of bearings.
* The turbine is subject to variations in performance caused by the characteristics of the liquid, friction or bearings, etc. When the flow rates approach zero, the slippage may amount to 100%, i.e., the turbine stalls and registers zero output. Therefore, at low flow rates, there is a possibility of large errors.

ELECTROMAGNETIC FLOW METERS

Electromagnetic flow meters are particularly suitable for the flow measurements of slurries, sludge and any electrically conducting liquid. A schematic diagram of an electromagnetic flow meter is shown in Fig. 29.84. It consists basically of a pair of insulated electrodes buried flush in the opposite sides of a non-conducting, non-magnetic pipe carrying the liquid whose flow is to be measured.

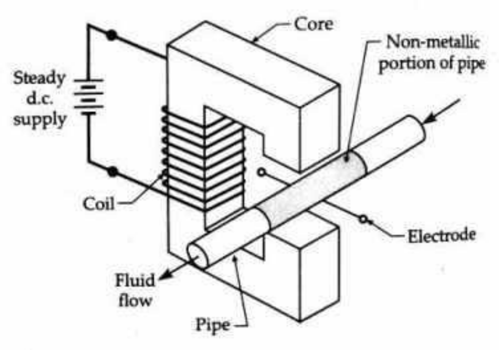


Fig. 29.84 Electromagnetic flow meter.

The pipe is surrounded by an electromagnet which produces a magnetic field. The arrangement is analogous to a conductor moving across a magnetic field— therefore, voltage is induced across the electrodes. This voltage is given by:

E = BLv volt

Where B = flux x density; Wb / m2

L is length of conductor = diameter of pipe; and

v = velocity of conductor (flow) ; m/s

Thus, assuming a constant magnetic field, the magnitude of the voltage appearing across the electrodes will be directly proportional to velocity. Non-conducting pipe has to be used as the output voltage gets short circuited if metallic pipes are used. This is true when liquids of low conductivity are being measured. But when liquids of high conductivity are measured the short circuiting has no effect. Stainless steel pipes can then be used. The voltages produced are small especially at low flow rates.

Therefore, the meter relies greatly on a high gain amplifier to convert the induced voltage into a usable form.

Advantages:

The electromagnetic flow meters may be manufactured to measure flow in pipes of any size provided powerful magnetic field can be produced.

The major advantage from a fluid handling point of view is that with the electro-magnetic flow meter there is no obstruction to flow that may cause pressure drops.

(iii) The output (voltage) is linearly rated to the input (flow rate).

(iv) The output is unaffected by changes is characteristics of liquid such as viscosity, pressure, and temperature.

Limitations:

* The operating costs are high particularly if heavy slurries are handled.
* The conductivity of the liquid being metered should not be less than 10 Q / m. As a general rule it will be found that most aqueous solutions are adequately conductive while majority of hydrocarbon solutions are not sufficiently conductive.

HOT WIRE ANEMOMETERS

The hot wire anemometer is a device that is most often used in research applications to study varying flow conditions. When a fluid flows over a heated surface, heat is transferred from the surface and therefore its (surface's) temperature reduces. The rate of reduction of temperature is related to flow rate. In a hot wire anemometer, heat is supplied electrically to a fine wire placed in the flow stream. The temperature of wire is determined by measuring its resistance with a Wheatstone bridge. One method involves adjusting the current through the wire so that the temperature remains constant, and measuring the heating current. In this way the bridge remains always balanced. The current is measured by finding the voltage drop across a standard resistor connected in series with the heating wire (See Fig. 29.85). The voltage drop is found by using a potentiometer.

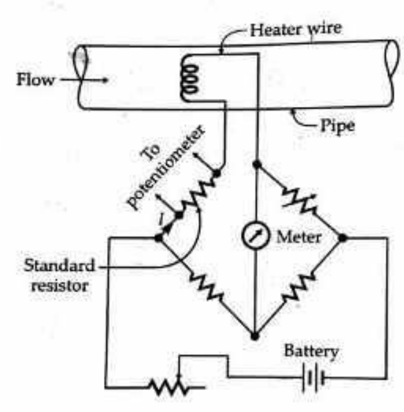


Fig. 29.85 Measurement of rate of fluid flow using a hot wire anemometer.

It can be shown that the loss of heat from the heated wire:

$$= a(v\rho + b)^{1/2} \text{ J/s}$$

Where, **v** = velocity of heat flow, ρ = density of fluid, and **a** and **b** are constants.

Constants **a** and **b** depend upon dimensions and physical properties of wire and fluid. The values of these constants are found by calibrating the instrument against a static pitot tube.

Now supposing a current I flow through the wire having a resistance R. Therefore under equilibrium conditions, **heat generated = heat lost**

Or $I^2 R = a(v\rho + b)^{1/2}$

$= \underline{(1^4 R^2 / a^2 - b)}$

or

Thus if the resistance and the temperature of the wire are kept constant, the rate of fluid flow can be measured by measuring current, I, through the heater wire. The transient conditions may be studied with an oscilloscope. Time constants of the order of 0.1 ms are obtained by using 0.0025 mm diameter platinum and tungsten wires.

FLOW METER USING THERMISTORS

Flow can be measured by using two thermistors connected in two separate arms of a bridge circuit as shown in Fig. 29.86. One thermistor is sealed in a cavity in a brass block and the other thermistor is mounted in a small pipe. When air flows through the pipe, the temperature of the thermistor (place inside the pipe) decreases because of conduction of heat. This thermistor is thus cooled, and its resistance increases which unbalances the bridge causing a current to flow through the meter. The amount of cooling is proportional to the rate of flow of air and the meter may be calibrated to read directly the rate of flow in the pipe.

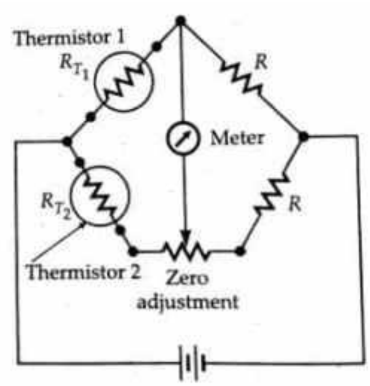


Fig. 29.86 Flow measurements using a bridge circuit having two thermistors.

This instrument can be designed to measure flows as low as $15 \times 10^{12} \text{ m}^3/\text{s}$. The instrument can measure flow rates over a range of 100,000: 1 by switching the resistance in series with the output meter. When the sensing thermistor of the flow meter is placed in free air, the instrument becomes an anemometer which measures velocity of air. It can be calibrated to measure velocities of air from light breeze to supersonic speeds.

ULTRASONIC FLOW TRANSDUCER

Basically an ultrasonic transducer for flow rate consists of two piezoelectric crystals in the liquid or gas by a distance. One of the crystals' acts as a transmitter and the other as a receiver. The transmitter emits an ultrasonic pulse which is received at the receiver a time At later. The transit time in the direction of flow is,

$$\Delta t1= \frac{d}{c+v}$$

where d = distance between transmitter and receiver ; m, c = velocity of sound propagation in medium ; m/s, v = linear velocity of flow ; m/s.

When the signal is travelling in the opposite direction against the flow

$$\Delta t2= \frac{d}{c-v}$$

Similarly, a sinusoidal signal of frequency f Hz travelling in the flow direction has a phase shift of :

$$\Delta\Phi1= \frac{2\pi f d}{c+v}$$

and that travelling against the direction of flow has a phase shift of :

$$\Delta\Phi2= \frac{2\pi f d}{c-v}$$

Velocity can, therefore, be determined by either measuring the transit time or the phase shift.

Figure 29.87 shows a system which can be used external to the pipe carrying the liquid. T and R are respectively transmitting and receiving crystals. They are either pressed to the exterior of pipe or are immersed in the liquid so that the signal is transmitted through the liquid.

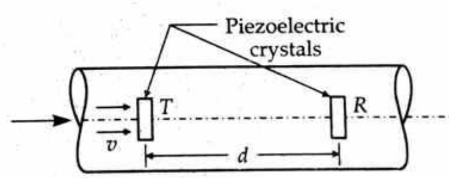


Fig. 29.87 Ultrasonic method for measurement of flow.

The oscillator provides a sinusoid signal of about 100 kHz to crystal T whereas crystal R acts as the receiver. The functions of T and R are reversed periodically by a commutating switch. The difference in transit times is,

$$\Delta t=\Delta t2 - \Delta t1= \frac{2d}{c2+v2}$$

This is measured by a phase sensitive detector driven synchronously with the commutator. Usually c>>v.

$$\Delta t \cong \frac{2dv}{c2}$$

Hence, time Δt is linearly proportional to flow velocity **v**. This system, through gives a linear relationship, is subjected to an error on account of uncertainty of the value of **c**.

Torque Transducers

In all the rotating bodies, it is necessary to ensure that the design of the element rotating is adequate to sustain under shear stresses. This can be done by applying torque measurements. It is also required to measure torque for the measurement of power delivered by rotating shafts.

Dynamic measurement of torque is based on the angular displacement or twist in the shaft in a calibrated length of a torque tube attached to the shaft. Generally torque measurements are based on the methods measuring i) strain produced in a rotating body due to applied torque and ii) reaction force in rotating body.

Torsion Bar

For the measurement of power delivered by a shaft, a torsion bar or torsion tube is inserted in between machine and load. Then by using either strain gauges or other electrical transducer, the output of torsion bar is measured.

A torsion bar is a metallic rod of either circular or rectangular cross section. A torsion Fig. 7.27 Torsion bar bar is connected between the source and load along the axis of rotation in perfect alignment. So when the torque is transmitted by the source, the torsion bar gets strained. Then the torque is measured in terms of the angular displacement of the bar or the surface strain on the bar. A torsion bar with circular cross section is as shown in the Fig. 727.

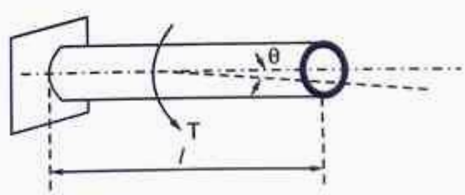


Fig. 7.27 Torsion bar

The angular displacement Φ radian of a hollow cylinder is given by,

$$\phi = \frac{2lT}{\pi G (R_o^4 - r_i^4)}$$

where l = Active length of torsion bar (m)

T = Torque (N-m)

G = Modulus of rigidity (N/m^2)

R_o = outer radius (m)

r_i = Inner radius (m)

Torque Measurement Based on Induced Strain Measurement

Torque measurement based on the induced strain measurement is very much popular as it does not introduce friction torques in the measurement. The typical arrangement with four strain gauges is as shown in the Fig. 7.25.Typically four strain gauges are installed precisely on surface of shaft as shown in the Fig. 7.28. Generally rosette type strain gauges are used. Out of these four gauges, two are in tensile mode while other two are in compressive mode. The gauges are positioned perfectly at 45^0 with the shaft axis. The gauges 1 and 2 and 3 and 4 must be diametrically opposite. The gauges are so mounted that they give maximum sensitivity to the strains produced by the torque. By the theory of two dimensional stress systems, the gauges are strained in direction of their major axis if they are mounted at 45^0 to the axis of shaft.

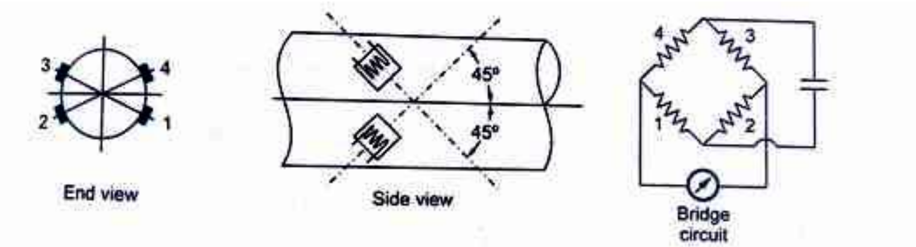


Fig. 7.28 Position of torque measuring strain gauges on shaft

An arrangement with four gauges has following advantages.

i) For given torque, it gives maximum sensitivity ii) It is fully temperature compensated iii) It provides automatic compensation for bending and axial loads.

In spite of all such advantages, there are major difficulties with the use of this arrangement in connecting this arrangement to power source and display unit. To overcome this slip rings are used. The slip rings are the conducting rings attached to the shaft but insulated from it and one of the slip rings is connected to each of the bridge terminals. A contact is made between the rings and the stationary brushes which are connected to the input and output devices.

Piezoelectric Torque Transducer

A measurement of torque is possible by using piezoelectric cantilever type bimorph used as a bender type bimorph. When a small force is transmitted through a lever a twisting moment is generated. A twisting moment can be obtained by connecting driving shaft directly to the bimorph. A piezoelectric torque transducer is as shown in the main advantage of this transducer is a high sensitivity. Hence it is most the measurement of small torques. The most commonly used elements are

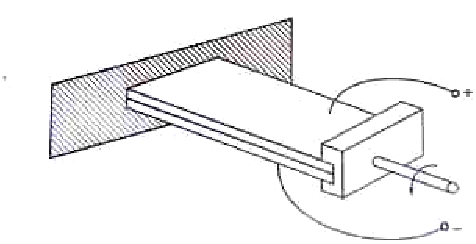


Fig. 7.29 A cantilever type twister bimorph

Optical Torque Measurement

In recent years, a new technique of torque measurement is developed which uses laser diodes and fiber optic transmission system. A simple optical torque measurement set up is as shown in the Fig. 7.30.

At the ends of a rotating shaft, two wheels with black and white strips are mounted. These wheels are properly aligned without applying any torque. A laser diode light source directs light on to the wheels through a pair of fiber optic cables. Under no torque condition, the reflected pulse train is in phase with each other. When the wheels are rotated, the pulses of reflected light are generated.

When the torque is applied to the rotating shaft, the modulation of reflected light takes place. Then the phase difference between the reflected pulse trains is measured using receiver. This phase difference directly gives the torque magnitude directly. The technique is advantageous as its physical size is small and cost of the total set up is relatively small.

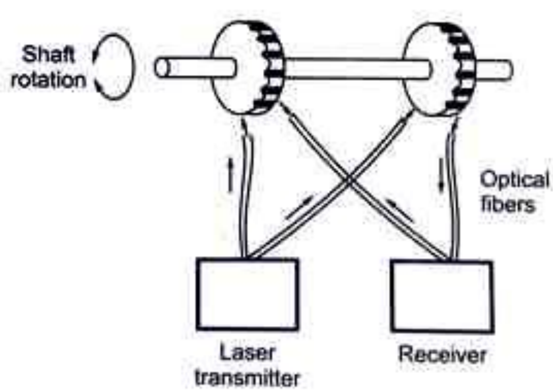


Fig. 7.30 Optical torque measurement

Force Transducer

According to Newton's law, when a force 'F' is applied to a body of mass 'm', it accelerates at a rate 'a'. Mathematically we can write,

$$F=ma$$

From above equation it is clear that, unknown force applied to body of mass m can be measured by measuring acceleration of that body. Another technique is to measure the change in resonant frequency of a vibrating wire under tension due to applied force. The unknown force can be measured by using force measuring sensors i.e. load cells.

Force Measurement using Accelerometer

By using accelerometer of any type, the acceleration of a body of known mass due to the applied force can be measured. Then by using Newton's law of mass acceleration, the applied unknown force can be calculated. But practically use of accelerometers for force measurement is limited because the forces are not free but they are the part of system. It is very difficult to decouple these forces from the system. Also many systems, the body on which forces acting is not free to accelerate. Still this technique is useful in measuring some transient forces. The advanced application of this technique is in calibration of forces produced by thrust motors in the space vehicles.

Force Measurement using Vibrating Wire Sensor

The basic arrangement of vibrating wire sensor is as shown in the Fig. 7.24.
A wire is kept vibrating at its resonant frequency by using variable frequency oscillator. The resonant frequency is given by

$$F=(0.5/L)\sqrt{M}/T$$

F= resonant requency
L = length o wire
M= Mass per unit length of wire
T= tension due to applied force
Thus above equation stated it is clear that when applied force changes, tension changes and hence the output frequency changes. Thus by measuring the output frequency of the local oscillator, the force applied to the wire can be caluculated.

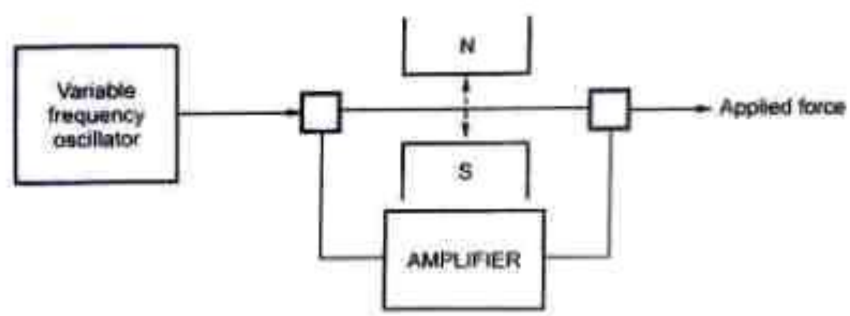


Fig. 7.24 Vibrating wire sensor arrangement

Force Measurement using Load Cell

Basically the load cell is an electromechanical sensor used to measure static and dynamic forces. It is the most widely used transducer used in many industrial applications, which can handle wide range of forces. The material used for load cell should posses linear stress strain relationship up to a fairly large elastic strain limit, low strain hysteresis and very low creep-over during loading period. The various elastic materials suitable for the purpose are medium to high carbon steels of chromium molybdenum and precipitate hardened stainless steel.
Let us study some typical forms of force measuring devices using load cell.

Cantilever Beam Type Load Cell

It is the simplest configuration as shown in the Fig. 7.25.

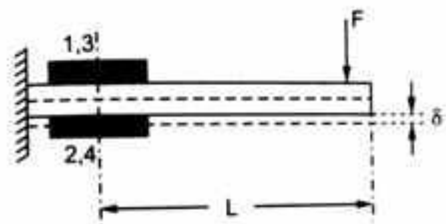


Fig. 7.25 Cantilever beam type load cell

On the top and bottom surfaces of the beam four strain gauges are bonded. On the application of force F, at free end of the cantilever beam, a bending moment develops in the beam which is proportional to the applied force. With reference to the direction of force shown, Fig. 7.25 Cantilever beam type load cell strain gauges 1 and 3 measures tensile strains developed on top surface while strain gauges 2 and 4 measures compressive strains developed at the bottom surface. The maximum deflection (6) occurs at the free end of the beam while the maximum strain (E) develops at the fixed end of the beam. Thus, in cantilever beam type load cell, applied force E can be measured as a function of deflection or strain E.

Column Type Load Cell

The simplest method for measuring unidirectional forces is to use column 01 rod in tension or compression. By using the electrical strain gauges attached to the body, the stress developed due to force on loading can be measured. The column type load cell structure is as shown in the Fig. 7.26.

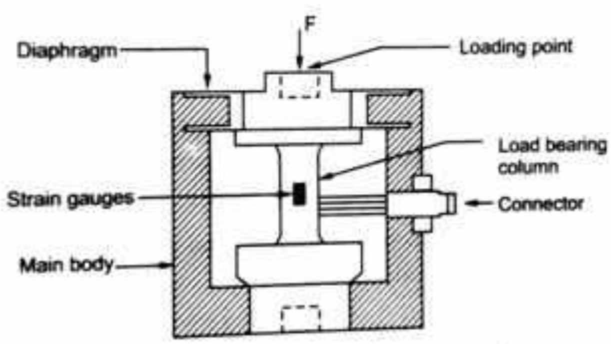


Fig. 7.26 Column type load cell structure

The strain gauges are mounted on exactly opposite faces of each other. Strain gauges 1 and 3 are aligned to measure axial strains while the strain gauges 2 and 4 are alligned to measure circumferential strains only. It is very essential to arrange gauges and the rod symmetrically. Also the column must be loaded as centrally as to avoid bending forces in the columns. For strain measurements, general foil strain gauges are used. Under the adverse industrial conditions, for better operation, the whole load cell assembly is hermetically sealed with electron beam joints welded.

DIGITAL VOLTMETERS

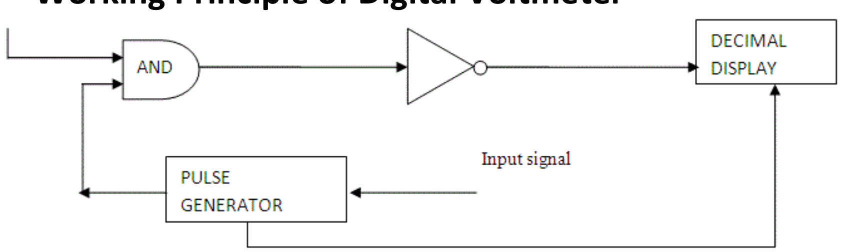
WORKING PRINCIPLE OF DIGITAL VOLTMETER

Voltmeter is an electrical measuring instrument which is used to measure 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. analog and digital. Analog voltmeters generally contain a dial with a needle moving over it according to the measure and hence displaying the value of the same. With the passage of time analog voltmeters are replaced by digital voltmeters due to the same advantages associated with digital systems. Although analog voltmeters are not fully replaced by digital voltmeters, still there are many places where analog voltmeters are preferred over digital voltmeters. Digital voltmeters display the value of AC or DC voltage being measured directly as discrete numerical instead of a pointer deflection on a continuous scale as in analog instruments.

Advantages Associated with Digital Voltmeters

- Read out of **DVMs** is easy as it eliminates observational errors in measurement committed by operators.
- Error on account of parallax and approximation is entirely eliminated.
- Reading can be taken very fast.
- Output can be fed to memory devices for storage and future computations.
- Versatile and accurate
- Compact and cheap
- Low power requirements
- Portability increased

Working Principle of Digital Voltmeter



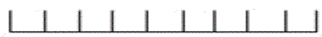
The **block diagram of a simple digital voltmeter** is shown in the figure.

Explanation of various blocks

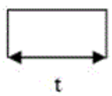
Input signal: It is basically the signal i.e. voltage to be measured.

Pulse generator: Actually it is a voltage source. It uses digital, analog or both techniques to generate a rectangular pulse. The width and frequency of the rectangular pulse is controlled by the digital circuitry inside the generator while amplitude and rise & fall time is controlled by analog circuitry.

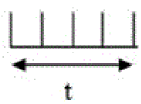
AND gate: It gives high output only when both the inputs are high. When a train pulse is fed to it along with rectangular pulse, it provides us an output having train pulses with duration as same as the rectangular pulse from the pulse generator.



Train pulse



Rectangular pulse



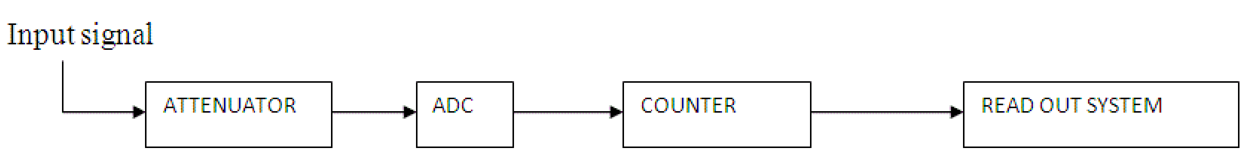
Output of AND gate

Decimal Display: It counts the numbers of impulses and hence the duration and display the value of voltage on LED or LCD display after calibrating it.

Now we are in situation to understand the **working of a digital voltmeter** as follows:

- Unknown voltage signal is fed to the pulse generator which generates a pulse whose width is proportional to the input signal.
- Output of pulse generator is fed to one leg of the AND gate.
- The input signal to the other leg of the AND gate is a train of pulses.
- Output of AND gate is positive triggered train of duration same as the width of the pulse generated by the pulse generator.
- This positive triggered train is fed to the inverter which converts it into a negative triggered train.
- Output of the inverter is fed to a counter which counts the number of triggers in the duration which is proportional to the input signal i.e. voltage under measurement.
- Thus, counter can be calibrated to indicate voltage in volts directly.

We can see the working of digital voltmeter that it is nothing but an analog to digital converter which converts an analog signal into a train of pulses, the number of which is proportional to the input signal. So a **digital voltmeter** can be made by using any one of the A/D conversion methods.



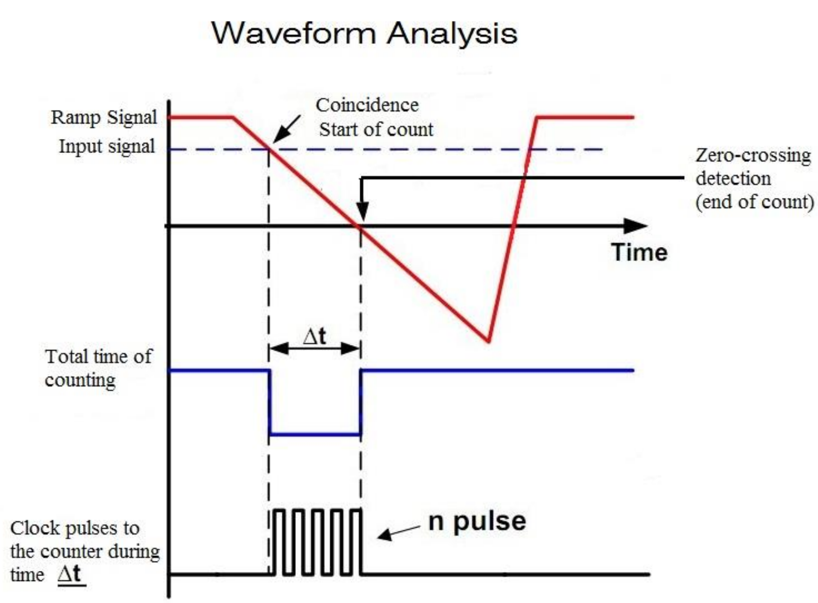
On the basis of A/D conversion method used digital voltmeters can be classified as:

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

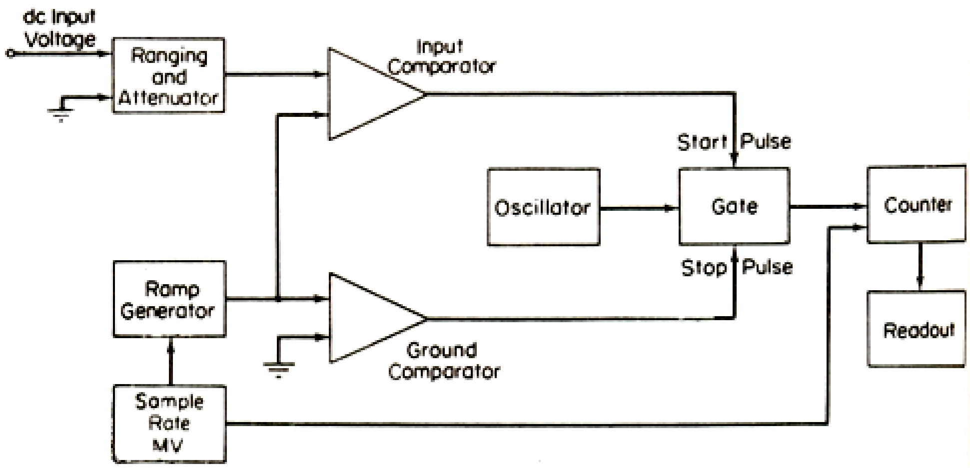
Now-a-days **digital voltmeters** are also replaced by digital millimeters due to its multitasking feature i.e. it can be used for measuring current, voltage and resistance. But still there are some fields where separated digital voltmeters are being used.

1. RAMP-TYPE DVM

The operating principle of the ramp-type DVM 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. Conversion from a voltage to a time interval is illustrated by the waveform diagram of Figure below.



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, shown in Fig. , is continuously compared with the unknown input voltage. At the instant that the ramp voltage equals the unknown voltage, a coincidence circuit, or comparator, generates a pulse which opens a gate. This gate is shown in the block diagram of below figure. The ramp voltage continues to decrease with time until it finally reaches 0 V (or ground potential) and a second comparator 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 (DC Us) 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 multivibrator determines the rate at which the measurement cycles are initiated. The oscillation of this multi vibrator can usually be adjusted by a front-panel control, marked rate, from a few cycles per second to as high as 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 DCU s to their 0 state, removing the display momentarily from the indicator tubes.

2. SUCCESSIVE APPROXIMATIONS

The successive approximations principle can be easily understood using a simple example; the determination of the weight of an object. By using a balance and placing the object on one side and an approximate weight on the other side, the weight of the object is determined. If the weight placed is more than the unknown weight, the weight is removed and another weight of smaller value is placed and again the measurement is performed. Now if it is found that the weight placed is less than that of the object, another weight of smaller value is added to the weight already present, and the measurement is performed. If it is found to be greater than the unknown weight the added weight is removed and another weight of smaller value is added. In this manner by adding and removing the appropriate weight, the weight of the unknown object is determined.

The successive approximation DVM works on the same principle. Its basic block diagram is shown in Fig. 5.10. When the start pulse signal activates the control circuit, the successive approximation register (SAR) is cleared. The output of the SAR is 00000000. V_{out} of the D/A converter is 0. Now, if $V_{in} > V_{out}$ the comparator output is positive. During the first clock pulse, the control circuit sets the D_7 to 1, and V_{out} jumps to the half reference voltage. The SAR output is 10000000. If V_{out} is greater than V_{in} the comparator output is negative and the control circuit resets D_7. However, if V_{in} is greater than V_{out} the comparator output is positive and the control circuits keep D_7 set. Similarly the rest of the bits beginning from D_7 to D_0 are set and tested. Therefore, the measurement is completed in 8 clock pulses.

Table 5.1

$V_{in} = 1\ V$	Operation	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Compare	Output	Voltage
00110011	D_7 Set	1	0	0	0	0	0	0	0	$V_{in} < V_{out}$	D_7 Reset	2.5
,,	D_6 Set	0	1	0	0	0	0	0	0	$V_{in} < V_{out}$	D_6 Reset	1.25
,,	D_5 Set	0	0	1	0	0	0	0	0	$V_{in} > V_{out}$	D_5 Set	0.625
,,	D_4 Set	0	0	1	1	0	0	0	0	$V_{in} > V_{out}$	D_4 Set	0.9375
,,	D_3 Set	0	0	1	1	1	0	0	0	$V_{in} < V_{out}$	D_3 Reset	0.9375
,,	D_2 Set	0	0	1	1	0	1	0	0	$V_{in} < V_{out}$	D_2 Reset	0.9375
,,	D_1 Set	0	0	1	1	0	0	1	0	$V_{in} > V_{out}$	D_1 Set	0.97725
,,	D_0 Set	0	0	1	1	0	0	1	1	$V_{in} > V_{out}$	D_0 Set	0.99785

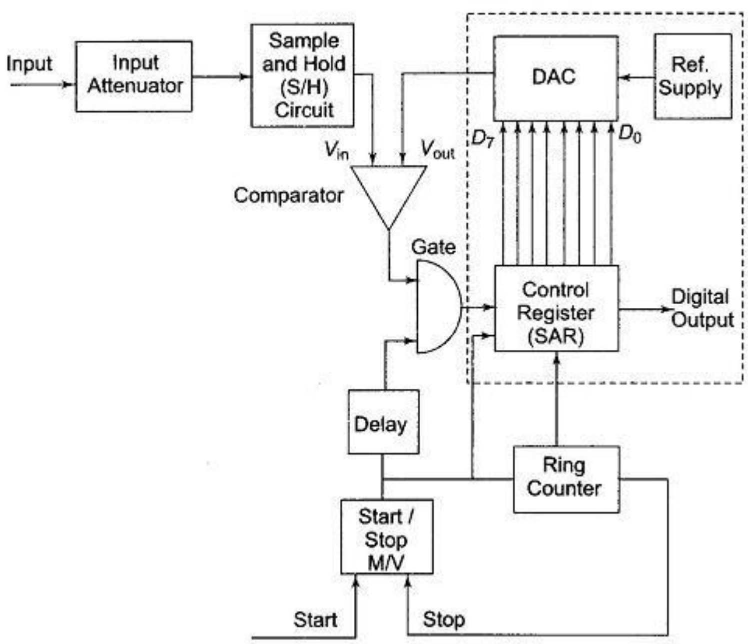


Fig. 5.10 Successive Approximation DVM

At the beginning of the measurement cycle, a start pulse is applied to the start-stop multivibrator. This sets a 1 in the MSB of the control register and a 0 in all bits (assuming an 8-bit control) its reading would be 10000000. This initial setting of the register causes the output of the D/A converter to be half the reference voltage, i.e. 1/2 V. This converter output is compared to the unknown input by the comparator. If the input voltage is greater than the converter reference voltage, the comparator output produces an output that causes the control register to retain the 1 setting in its MSB and the converter continues to supply its reference output voltage of 1/2 V_{ref}.

The ring counter then advances one count, shifting a 1 in the second MSB of the control register and its reading becomes 11000000. This causes the D/A converter to increase its reference output by 1 increment to 1/4 V, i.e. 1/2 V + 1/4 V, and again it is compared with the unknown input. If in this case the total reference voltage exceeds the unknown voltage, the comparator produces an output that causes the control register to reset its second MSB to 0. The converter output then returns to its previous value of 1/2 V and awaits another input from the SAR. When the ring counter advances by 1, the third MSB is set to 1 and the converter output rises by the next increment of 1/2 V + 1/8 V. The measurement cycle thus proceeds through a series of successive approximations. Finally, when the ring counter reaches its final count, the measurement cycle stops and the digital output of the control register represents the final approximation of the unknown input voltage.

3. DUAL SLOPE INTEGRATING TYPE DVM

Dual Slope Integrating Type DVM – In ramp techniques, superimposed noise can cause large errors. In the dual ramp technique, noise is averaged out by the positive and negative ramps using the process of integration.

Principle of Dual Slope Type DVM

As illustrated in Fig. 5.3, the input voltage 'e_i' is integrated, with the slope of the integrator output proportional to the test input voltage. After a fixed time,

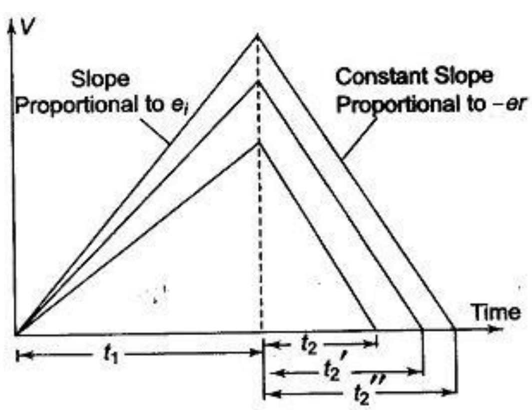


Fig. 5.3 Basic Principle of Dual Slope Type DVM

equal to t_1, the input voltage is disconnected and the integrator input is connected to a negative voltage — e_r The integrator output will have a negative slope which is constant and proportional to the magnitude of the input voltage. The block diagram is given in Fig. 5.4.

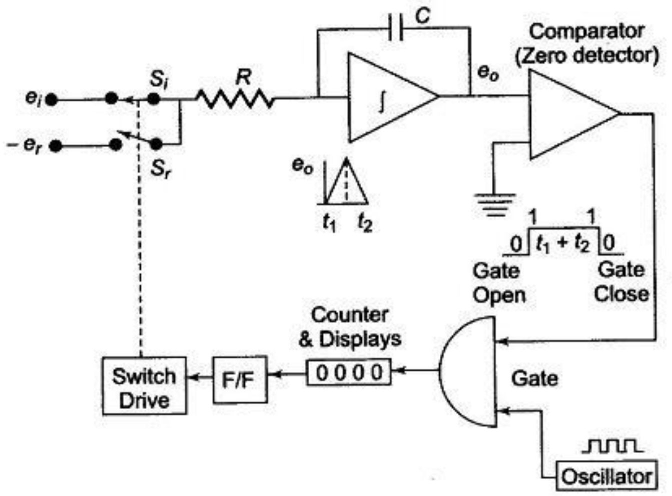


Fig. 5.4 Block Diagram of a Dual Slope Type DVM

At the start a pulse resets the counter and the F/F output to logic level '0'. S_i is closed and S_r is open. The capacitor begins to charge. As soon as the integrator output exceeds zero, the comparator output voltage changes state, which opens the gate so that the oscillator clock pulses are fed to the counter. (When the ramp voltage starts, the comparator goes to state 1, the gate opens and clock pulse drives the counter.) When the counter reaches maximum count, i.e. the counter is made to run for a time 't_1' in this case 9999, on the next clock pulse all digits go to 0000 and the counter activates the F/F to logic level '1'. This activates the switch drive, e_i is disconnected and $-e_r$ is connected to the integrator. The integrator output will have a negative slope which is constant, i.e. integrator output now decreases linearly to 0 volts. Comparator output state changes again and locks the gate. The discharge time t_2 is now proportional to the input voltage. The counter indicates the count during time t_2. When the negative slope of the integrator reaches zero, the comparator switches to state 0 and the gate closes, i.e. the capacitor C is now discharged with a constant slope. As soon as the comparator input (zero detector) finds that e_0, is zero, the counter is stopped. The pulses counted by the counter thus have a direct relation with the input voltage.

During charging

$$e_o = -\frac{1}{RC}\int_0^{t_1} e_i\, dt = -\frac{e_i t_1}{RC} \qquad (5.1)$$

During discharging

$$e_o = \frac{1}{RC}\int_0^{t_2} -e_r\,dt = -\frac{e_r\,t_2}{RC} \qquad (5.2)$$

Subtracting Eqs 5.2 from 5.1 we have

$$e_o - e_o = \frac{-e_r\,t_2}{RC} - \left(\frac{-e_i\,t_1}{RC}\right)$$

$$0 = \frac{-e_r\,t_2}{RC} - \left(\frac{-e_i\,t_1}{RC}\right)$$

$$\frac{e_r\,t_2}{RC} = \frac{e_i\,t_1}{RC}$$

$$e_i = e_r\,\frac{t_2}{t_1} \qquad (5.3)$$

If the oscillator period equals T and the digital counter indicates n_1 and n_2 counts respectively,

$$e_i = \frac{n_2\,T}{n_1\,T}\,e_r \quad \text{i.e.} \quad e_i = \frac{n_2}{n_1}\,e_r \qquad \text{Let } K_1 = \frac{e_r}{n_1}. \text{ Then } e_i = K_1\,n_2 \qquad (5.4)$$

Now, n_1 and e_r are constants.

From Eq. 5.3 it is evident that the accuracy of the measured voltage is independent of the integrator time constant. The times $t_1$and t_2 are measured by the count of the clock given by the numbers n_1 and n_2 respectively. The clock oscillator period equals T and if n_1 and e_r are constants, then Eq. 5.4 indicates that the accuracy of the method is also independent of the oscillator frequency.

The dual slope technique has excellent noise rejection because noise and superimposed ac are averaged out in the process of integration. The speed and accuracy are readily varied according to specific requirements; also an accuracy of ± 0.05% in 100 ms is available.

DIGITAL FREQUENCY METER:

The Principle of Operation of Digital Frequency Meter is given by “The signal waveform is converted to trigger pulses and applied continuously to an AND gate, as shown in Fig. 6.4. A pulse of 1 s is applied to the other terminal, and the number of pulses counted during this period indicates the frequency.”

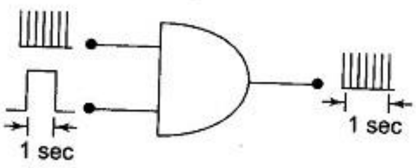


Fig. 6.4 Principle of Digital Frequency Measurement

The signal whose frequency is to be measured is converted into a train of pulses, one pulse for each cycle of the signal. The number of pulses occurring in a definite interval of time is then counted by an electronic counter. Since each pulse represents the cycle of the unknown signal, the number of counts is a direct indication of the frequency of the signal (unknown). Since electronic counters have a high speed of operation, high frequency signals can be measured.

Basic Circuit of a Digital Frequency Meter

The block diagram of a basic circuit of a digital frequency meter is shown in Fig. 6.5.

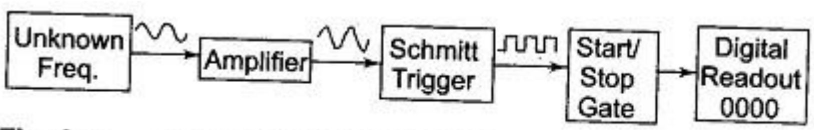


Fig. 6.5 Basic Circuit of a Digital Frequency Meter

The signal may be amplified before being applied to the Schmitt trigger. The Schmitt trigger converts the input signal into a square wave with fast rise and fall times, which is then differentiated and clipped. As a result, the output from the Schmitt trigger is a train of pulses, one pulse for each cycle of the signal. The output pulses from the Schmitt trigger are fed to a START/STOP gate. When this gate is enabled, the input pulses pass through this gate and are fed directly to the electronic counter, which counts the number of pulses.

When this gate is disabled, the counter stops counting the incoming pulses. The counter displays the number of pulses that have passed through it in the time interval between start and stop. If this interval is known, the unknown frequency can be measured.

Basic Circuit for Frequency Measurement

The basic circuit for frequency measurement is as shown in Fig. 6.6. The output of the unknown frequency is applied to a Schmitt trigger, producing positive pulses at the output. These pulses are called the counter signals and are present at point A of the main gate. Positive pulses from the time base selector are present at point B of the START gate and at point B of the STOP gate.

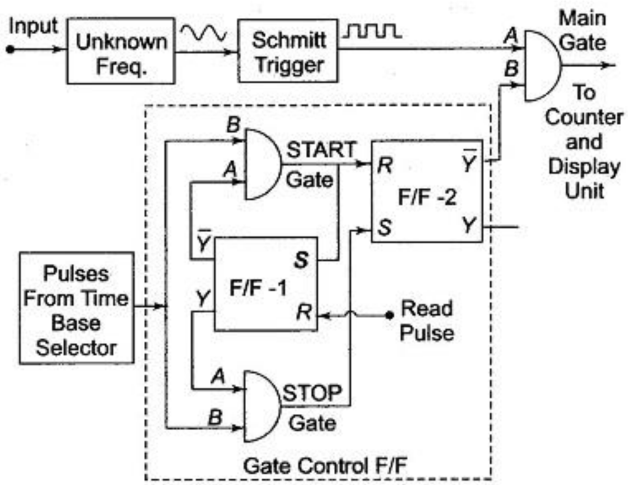


Fig. 6.6 Basic Circuit for Measurement of Frequency Showing Gate Control F/F

Initially the Flip-Flop (F/F-1) is at its logic 1 state. The resulting voltage from output Y is applied to point A of the STOP gate and enables this gate. The logic 0 stage at the output Y of the F/F-1 is applied to the input A of the START gate and disables the gate. As the STOP gate is enabled, the positive pulses from the time base pass through the STOP gate to the Set (S) input of the F/F-2 thereby setting F/F-2 to the 1 state and keeping it there. The resulting 0 output level from Y of F/F-2 is applied to terminal B of the main gate. Hence no pulses from the unknown frequency source can pass through the main gate.

In order to start the operation, a positive pulse is applied to (read input) reset input of F/F-1, thereby causing its state to change. Hence Y = 1, Y= 0, and as a result the STOP gate is disabled and the START gate enabled. This same read pulse is simultaneously applied to the reset input of all decade counters, so that they are reset to 0 and the counting can start. When the next pulse from the time base arrives, it is able to pass through the START gate to reset F/F-2, therefore, the F/F-2 output changes state from 0 to 1, hence Y changes from 0 to 1. This resulting positive voltage from Y called the gating signal, is applied to input B of the main gate thereby enabling the gate.

Now the pulses from the unknown frequency source pass through the main gate to the counter and the counter starts counting. This same pulse from the START gate is applied to the set input of F/F-1, changing its state from 0 to 1. This disables the START gate and enables the STOP gate. However, till the main gate is enabled, pulses from the unknown frequency continue to pass through the main gate to the counter. The next pulse from the time base selector passes through the enabled STOP gate to the set input terminal of F/F-2, changing its output back to 1 and fi = 0. Therefore the main gate is disabled, disconnecting the unknown frequency signal from the counter. The counter counts the number of pulses occurring between two successive pulses from the time base selector. If the time interval between this two successive pulses from the time base selector is 1 second, then the number of pulses counted within this interval is the frequency of the unknown frequency source, in Hertz.

The assembly consisting of two F/Fs and two gates is called a gate control F/F. The block diagram of a digital frequency meter is shown in Fig. 6.7.

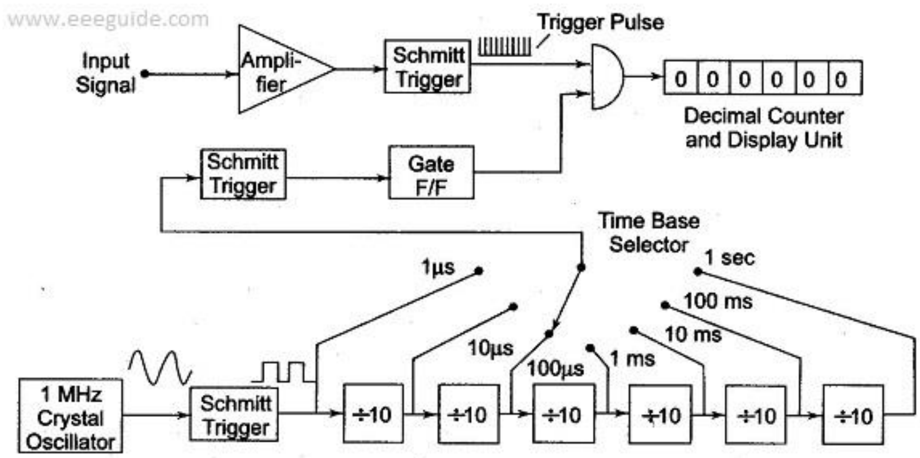


Fig. 6.7 Block Diagram of a Digital Frequency Meter

The input signal is amplified and converted to a square wave by a Schmitt trigger circuit. In this diagram, the square wave is differentiated and clipped to produce a train of pulses, each pulse separated by the period of the input signal. The time base selector output is obtained from an oscillator and is similarly converted into positive pulses.

The first pulse activates the gate control F/F. This gate control F/F provides an enable signal to the AND gate. The trigger pulses of the input signal are allowed to pass through the gate for a selected time period and counted. The second pulse from the decade frequency divider changes the state of the control F/F and removes the enable signal from the AND gate, thereby closing it. The decimal counter and display unit output corresponds to the number of input pulses received during a precise time interval; hence the counter display corresponds to the frequency.

DIGITAL PHASE METER

Digital Phase Meter – The simplest technique to measure the phase difference between two signals employs two flip-flops. The signals to be fed must be of the same frequency. First, the signals must be shaped to a square waveform without any change in their phase positions, by the use of a zero crossing detector. The process of measuring the phase difference can be illustrated by the schematic diagram shown in Fig. 6.26.

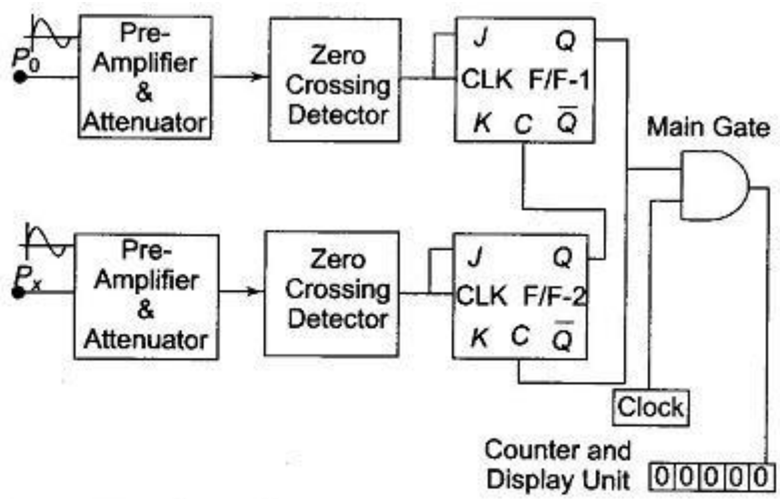


Fig. 6.26 Digital Phase Meter

The block diagram consists of two pairs of preamplifier's, zero crossing detectors, J-K F/Fs, and a single control gate. Two signals having phases P_o and P_x respectively are applied as inputs to the preamplifier and attenuation circuit. The frequency of the two inputs is the same but their phases are different. As the P_o input signal increases in the positive half cycle, the zero crossing detector changes its state when the input crosses zero (0) giving a high (1) level at the output. This causes the J—K F/F-1 to be set (1), that is, the output (Q) of F/F-1 goes high. This high output from the F/F-1 enables the AND gate, and pulses from the clock are fed directly to the counter. The counter starts counting these pulses. Also this high output level of F/F-1 is applied to the clear input of F/F-2 which makes the output of the F/F-2 go to zero (0).

Now as the input P_x which has a phase difference with respect to P_o, crosses zero (0) in the positive half cycle, the zero detector is activated, causing its output to go high (1). This high input in turn toggles the J—K F/F-2, making its output go high. This output (Q) of F/F-2 is connected to the clear input of F/F-1 forcing the F/F-1 to reset. Hence the output of F/F-1 goes to zero (0). The AND gate is thus disabled, and the counter stops counting.

The number of pulses counted while enabling and disabling the AND gate is in direct proportion to the phase difference, hence the display unit gives a direct readout of the phase difference between the two inputs having the same frequency.

Microprocessor Based Ramp Type DVM

A basic block diagram of a Microprocessor Based Ramp Type DVM and its operating waveform is shown in Fig. 5.17 (a) and (b) respectively. Depending on the command fed to the control input of the multiplexer by the microprocessor, input 1 of the comparator can be consecutively connected to the input 1, 2 or 3 of the multiplexer.

The multiplexer has three inputs — input 1 is connected to ground potential, input 2 is the unknown input, and input 3 is the reference voltage input. The comparator has two inputs — input 1 accepts the output signal from the multiplexer and input 2 accepts the ramp voltage from the ramp generator.

The microprocessor remains suspended in the resting state until it receives a command to start conversion. During the resting period, it regularly sends reset signals to the ramp generator. Each time the ramp generator is reset, its capacitor discharges. It produces a ramp, i.e. a sawtooth voltage whose duration, T_r and amplitude, V_m remain constant. The time duration between the consecutive pulses is sufficiently large enough for the capacitor to get discharged.

Whenever a conversion command arrives at the microprocessor at a time t^l, the multiplexer first connects input 1 of the comparator to its input 1 (i.e. ground potential) and brings the former to ground potential.

The microprocessor pauses until another sawtooth pulse begins. When input 2 voltage, arriving from the ramp generator becomes equal to equal to input 1 of the comparator, the comparator sends a signal to the microprocessor, that ramp voltage is zero. The microprocessor measures this time interval Δt_1(shown in Fig. 5.17 (b)), by counting the number of clock pulses supplied by the clock generator during this time interval. Let the count during this time be N_1, which is then stored by the microprocessor. A command from the microprocessor now causes the comparator input 1 to be connected to input 2 of the multiplexer. This connects the unknown voltage, V_x to the input 1 of the comparator. At an instant, when the ramp voltage equals the unknown voltage, the comparator sends a signal to the microprocessor the measure the time interval Δt_2 (Fig. 5.17 (b)). The count N_2, during this time interval is also stored.

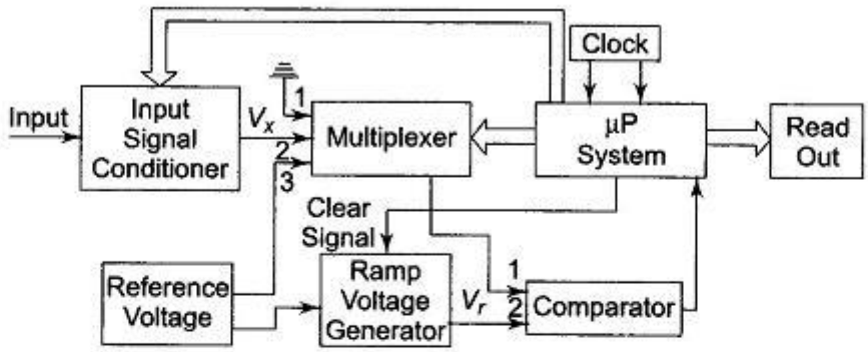


Fig. 5.17 (a) Basic Block Diagram of a Microprocessor-based Ramp Type DVM

Now, the next command from the microprocessor causes the comparator input 1 to be connected to the input 3 of the multiplexer, which is the reference voltage (full scale voltage). The value of the reference voltage sets the upper limit of measurement, that is, full scale value. At the instant, when the ramp voltage equals the reference voltage, a pulse is sent to the microprocessor from the comparator output to measure this time interval, Δt_3 (Fig. 5.17 (b)). The count, N_3 during this time interval is also stored.

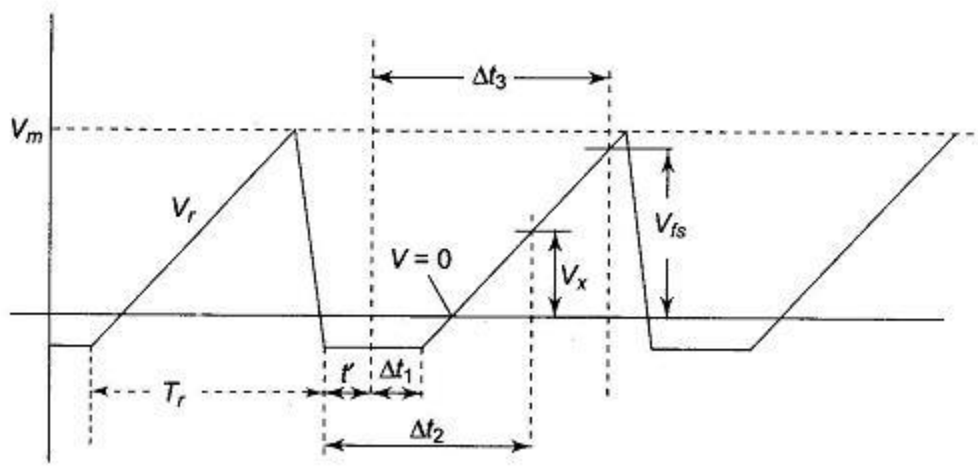


Fig. 5.17 (b) Operating Waveform of a µp-based Ramp Type DVM

The microprocessor then computes the unknown voltage V_x by the equation

$$V_x = C \cdot \frac{(N_2 - N_1)}{(N_3 - N_1)}$$

Where C is the coefficient dependent on the characteristics of the instrument and the units selected to express the result. In this method of measurement, the zero drift has practically no effect on the result, because of the variation of slope of the ramp.

Hence from the Fig. 5.17 (b),

$$\frac{(\Delta t_2 - \Delta t_1)}{(\Delta t_3 - \Delta t_1)} = \frac{V_x}{V_{fs}}$$

$$V_x = V_{fs} \cdot \frac{(\Delta t_2 - \Delta t_1)}{(\Delta t_3 - \Delta t_1)}$$

Since the clock pulse repetition frequency f_c and full scale voltage V_{fs}, are maintained at a very high level of stability and clock pulses allowed to fall within all the time intervals come from a common source, the above equation may be rewritten as

$$V_x = C \cdot \frac{(N_2 - N_1)}{(N_3 - N_1)}$$

where N_1, N_2, N_3 are the counts representing respectively, the zero drift, the unknown voltage, and the full scale voltage.

Advantages

1. Its scale size remains constant due to zero drift correction and maximum
2. The accuracy of the instrument is not affected by the time and temperature instabilities of the circuit element values.
3. There is a good repeatability in switching instants in the presence of noise and interference. This is because the ramp approaches the point at which the comparator operates always the same side and always the same rate.

Disadvantages

1. Noise and interference cannot be suppressed.

Instrumentation

Unit-III

Oscilloscope

* Introduction:

In studying the various electronic, electrical networks and systems, signals which are function of time, are often encountered. Such signals may be periodic or non-periodic in nature. The device which allows, the amplitude of such signals, to be displayed primarily as a function of time, is called "cathod ray oscilloscope", commonly known as CRO.

The oscilloscope is, in fact, a voltmeter. Instead of the mechanical deflection of a metalic pointer as used in the normal voltmeters, the oscilloscope uses the movement of an electron beam against a fluorosent screen, which produces the movement of a visible spot. The movement of a such spot on the screen is proportional to the varying magnitude of the signal, which is under measurement.

The electron beam can be deflected in two directions: the horizontal or X-direction and the vertical or Y-direction. Thus an electron beam producing a spot can be used to produce two dimensional details.

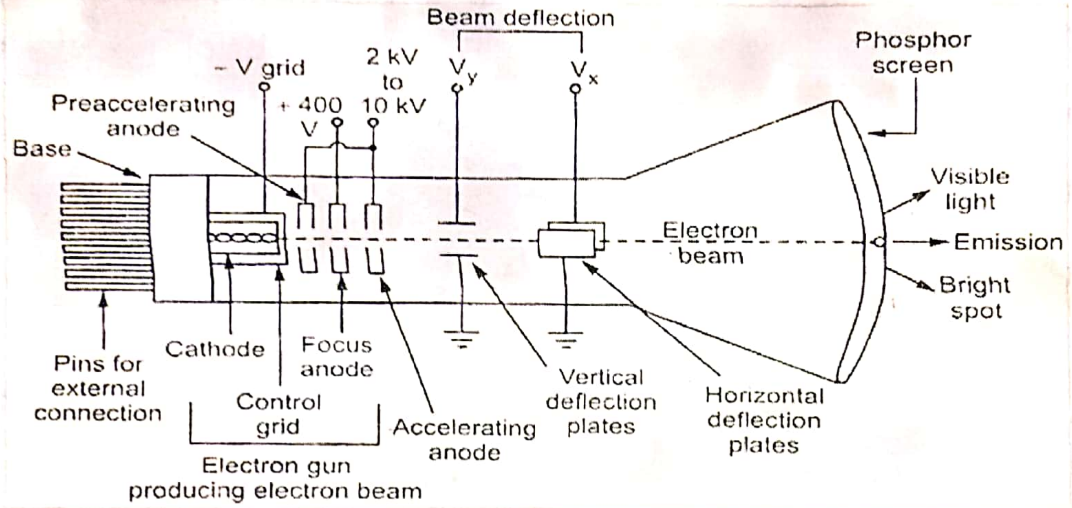
The CRO basically operates on voltages, but it is possible to convert current, pressure, strain, acceleration and other physical quantities into the voltages using transducers and obtain their visual representation on the CRO.

* Cathod Ray Tube (CRT):

The cathod Ray Tube (CRT) is the heart of the CRO. The CRT generates the electron beam, accelerates the beam, deflects the beam and also has a screen where beam becomes visible as a spot. The main parts of the CRT are:

(i) Electron gun
(ii) Deflection system
(iii) Fluorosent screen.
(iv) Glass tube or Envelope
(v) Base.

The schematic diagram of CRT, showing its structure and main components is shown below diagram.



(i) Electron Gun:

The electron gun section of the Cathod ray tube provides a sharply focused electron beam directed towards the fluorocent-coated screen. This section starts from thermally heated cathode, emitting the electrons. The control grid is given negative potential with respect to cathode. This grid controls the number of electrons in the beam, going to the screen.

The momentum of the electrons determines the intensity or brightness of the light emitted from the fluorescent screen due to electron bombardment. The light emitted is usually of the green colour. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid. This negative control voltage can be made variable. A more negative voltage results in less number of electrons in the beam and hence decreased brightness of the beam spot.

Since the electron beam consists of many electrons, the beam tends to diverge. This is because the similar (negative) charges on the electron repel each other. To compensate for such repulsion forces, an adjustable electrostatic field is created between two cylindrical anodes, called the "focusing Anodes.". The variable positive voltage on the second anode is used to adjust the focus & sharpness of the bright beam spot.

The high positive potential also given to the preaccelerating anode and accelerating anodes, which results into the required acceleration of the electrons. The preaccelerating & accelerating anodes are connected to a common positive high voltage which varies between 2kV to 10kV. The focusing anode is connected to a lower positive voltage of about 400V to 500V.

(ii) Deflection System:

When the electron beam is accelerated it passes through the deflection system, with which beam can be positioned anywhere on the screen.

The deflection system of the CRT consists of two pair of parallel plates

(i) Vertical

(ii) Horizontal deflection plates.

One of the plates in each set is connected to ground (0V). To the other plate of each set, the external deflection voltage is applied through an internal adjustable gain amplifier stage. To apply the deflection voltage externally, an external terminal, called the Y input or the X input, is available.

As shown in fig(i), the electron beam passes through these plates. A positive voltage applied to the Y input terminal (V_y) causes the beam to deflect vertically upward due to the vertical force, while a negative voltage applied to the Y input terminal will cause the electron beam to deflect vertically downward, due to the repulsion forces.

Similarly, in X-input terminal, when the voltage is positive, the beam moves horizontally towards right, while the negative voltage applied, the beam deflects horizontally towards left side of the screen. The amount of vertical or horizontal deflection is directly proportional to the correspondingly applied voltage.

When the voltages are applied simultaneously to vertical and horizontal deflecting plates, the electron beam is deflected due to the resultant of these two voltages.

The horizontal deflection produced will be proportional to the horizontal deflection voltage, V_x, applied to X-input.

$$X \alpha V_x$$

$$X = K_x V_x$$

Where K_x = Constant of proportionality.

The deflection produced is measured in cm or as number of divisions, on the scale, in the horizontal direction.

Then $K_x = \frac{X}{V_x}$ where K_x expressed as cm/volt or division/volt.,

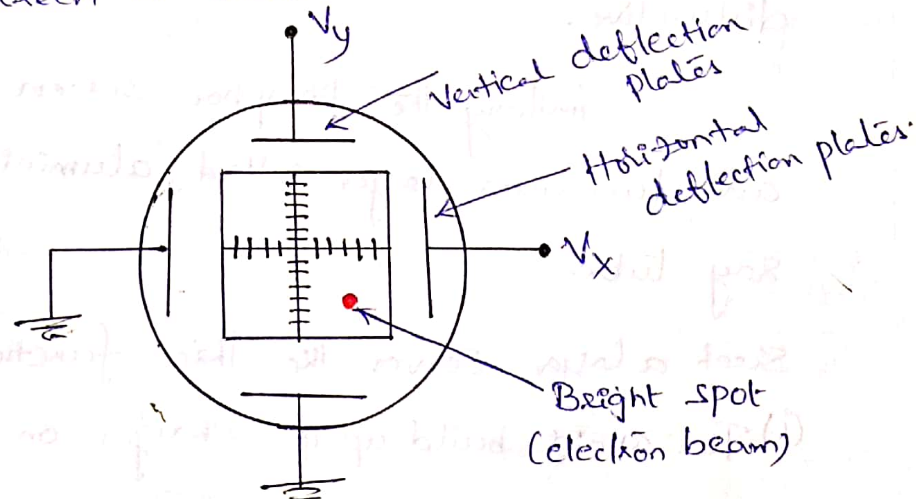
is called "horizontal sensitivity" of the oscilloscope.

Similarly, the vertical deflection (y) produced will be proportional to the vertical deflection voltage, and then write as

$$K_y = \frac{y}{V_y}$$

Where K_y is the "Vertical sensitivity" of the Oscilloscope.

The schematic arrangement of the vertical and the horizontal plates, controlling the position of the spot on the screen is shown below.



(iii) Fluorescent screen:

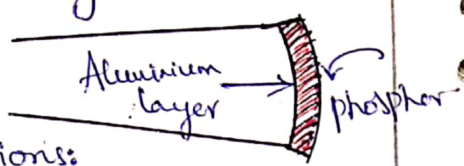
The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero. The time period for which the trace remains on the screen after the signal becomes zero is known as "persistance". The persistance may be as short as a few micro seconds, or as long as tens of seconds or even minutes.

Medium persistance traces are mostly used for general purpose applications. Long persistence traces are used in the study of transients. Short persistance is needed for extremely high speed phenomena.

The screen is coated with a fluorescent material called phosphor which emits light when bombarded by electrons. There are various phosphors available which differ in colour, persistance, and efficiency.

The kinetic energy of the electron beam is converted into both light and heat energy when it hits the screen. The heat so produced gives rise to "phosphor Burn" which is damaging and sometimes distructive.

Similarly the phosphor screen is provided with an aluminium layer called "aluminizing" the cathod ray tube.



Such a layer serves the three functions:

(i) To avoid build up of charges on the phosphor which tend to slow down the electrons and limits the brightness.

(ii) It serves as a light scatter. When the beam strikes the phosphor with aluminized layer, the light emitted back into the tube is reflected back towards the viewer which increases the brightness.

(iii) The aluminium layer acts as a heat sink for the phosphor and thus reduces the chances of the phosphor burning.

The various phosphors and their characteristics are given below table:

Phosphor	Colour		Persistance	Relative luminance	Relative writting speed	Applications.
	Under excitation	After glow				
P_1	Yellow-green	Yellow-green	medium	45	35	General purpose
P_2	blue-green	green	medium	60	70	General purpose.
P_4	white	white	medium to short	50	75	Black & white TV.
P_7	blue-white	Yellow-green	medium-short	45	95	Radar.
P_{11}	blue-Violet	blue	medium-short	25	100	Photographic recording
P_{15}	blue-green	blue-green	Visible-short	15	25	Flying spot Scanners for TV.
P_{19}	orange	orange	Long	25	3	Radar.
P_{31}	green	green	medium-short	100	75	General Purpose.
P_{33}	orange	orange	very long	20	7	Radar.
P_{39}	green	green	medium-long	50	40	Computer graphics.

(iv) Glass Tube:

All the components of a CRT are enclosed in an evacuated glass tube called "envelope". This allows the emitted electrons to move about freely from one end of the ~~other~~ tube to the other end.

(V) Base:

The base is provided to the CRT through which the connections are made to the various parts.

* Time-Base Generator:

The time domain oscilloscopes require a sweep generator that is linear with time for the X-axis display. The motion of spot on the screen from extreme left to extreme right is called "sweep".

The generator which generates a waveform which is responsible for the movement of spot on the screen horizontally is called "time base generator" or "sweep generator". The sweep circuits along with the display gating functions are called "time bases".

The linear sweep moves the spot from left to right while the movement of spot from right to left is not visible. This portion of waveform generated by time base is called flyback or retrace. During this time, the cathode ray tube is blanked.

All the time dependent waveforms needed X-axis to be calibrated as time axis. The sweep generator produces the movement of spot on screen ~~which~~ such that it acts as a time axis or time base for the waveforms to be displayed. Hence the sweep generator is also called "time base generator".

The time base requirements are:

(i) Sweep time variations from 10nsec to 5 sec per division.

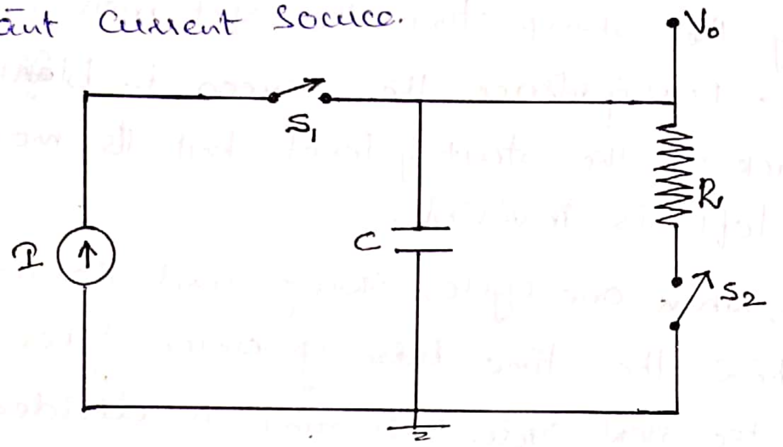
(ii) Time accuracy better than 3%

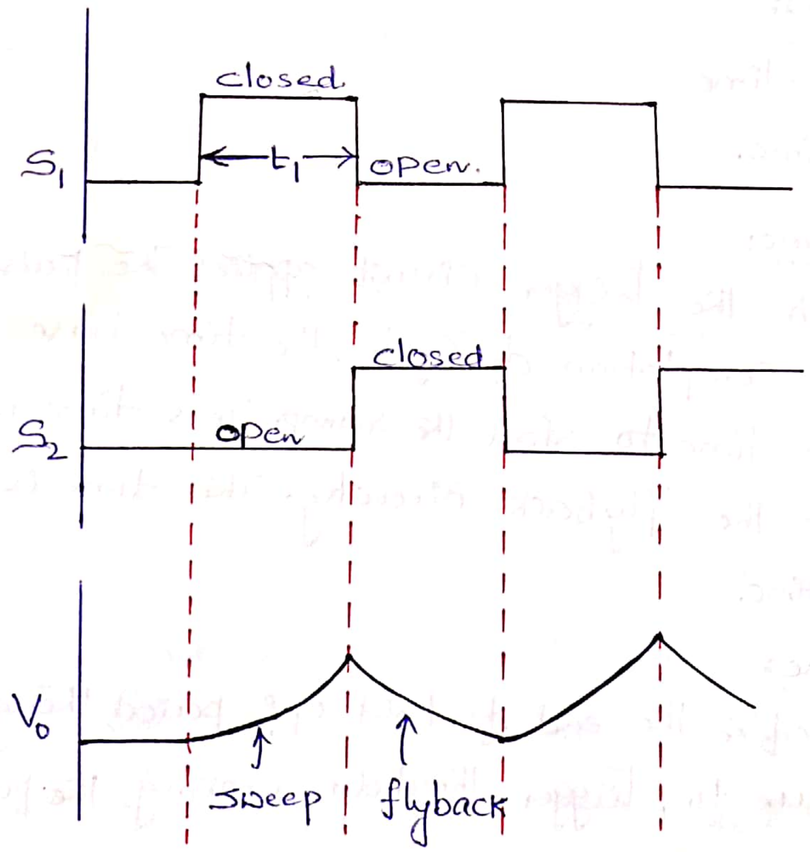
(iii) Linearity better than 1% across the cathode ray tube.

(iv) The speed of the spot should be constant across the entire screen.

(v) The spot should be invisible while tracing from right to left and should be visible only from left to right.

The below figure shows the capacitor charged from a constant current source.





When switch S_1 is closed, S_2 is open capacitor charges to produce linear ramp at the output. The sweep rate can be controlled by changing the value of capacitor or charging current.

Reaching to the maximum value of ramp voltage, the switch S_2 is closed and S_1 open. Thus capacitor gets discharges through the resistance R. This is called flyback or retrace. The time t_1 is called "sweep time."

During the sweep time, the spot moves from left to right. During retrace, the screen is blanked and spot comes back to the starting level but its movement from right to left is invisible.

Now, when one cycle, sweep and retrace is completed then the time base generator takes certain time to start the next cycle. This time is divided into two types as:

(i) Hold off time.
(ii) Waiting time.

(i) Hold Off time:

Though the trigger circuit applies the pulse immediately after completion of cycle, the time base generator takes some time to start the ramp. This time is required to stabilise the flyback circuitry. This time is called "hold off time."

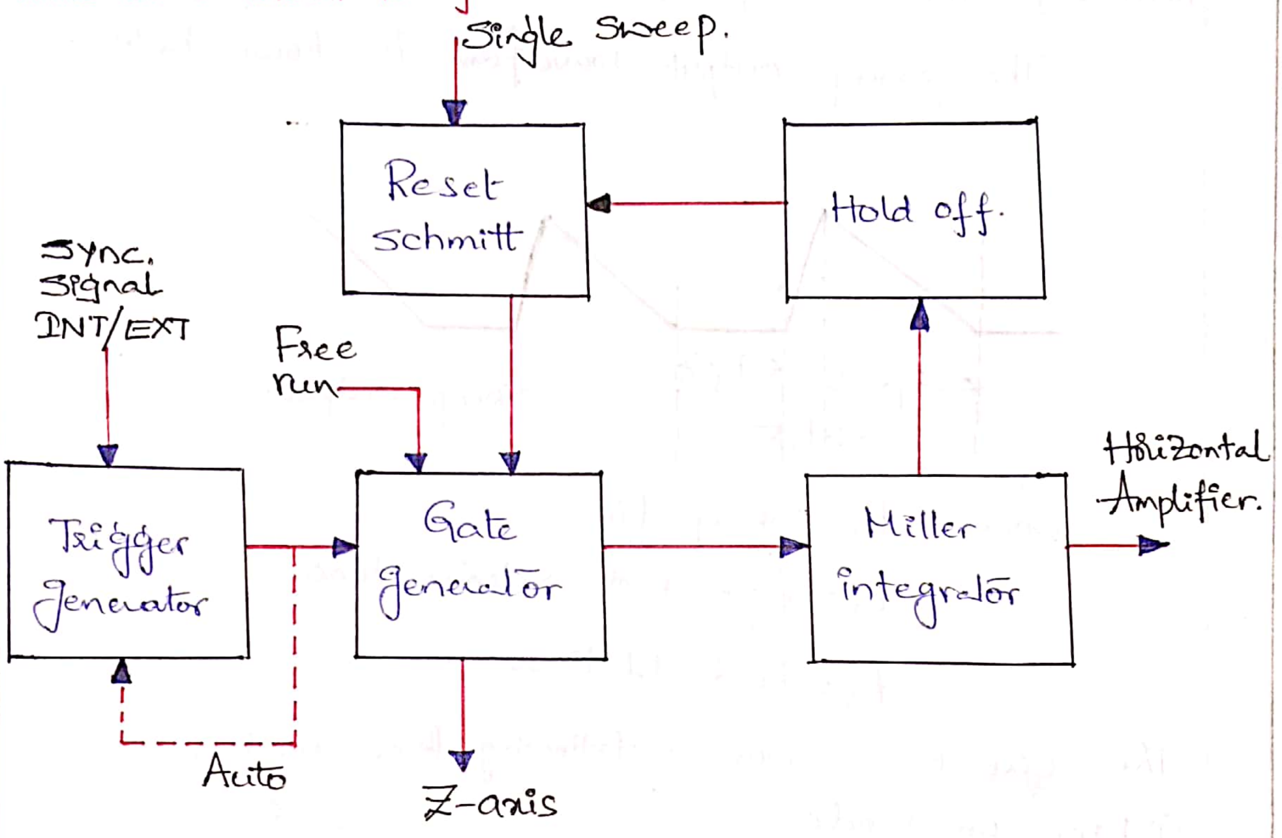
(ii) Waiting time:

Now after the end of hold off period, though circuit is ready, due to trigger threshold crossing, the pulse takes

Some time to activate time base generator. So time required by the triggering pulses to cross the trigger threshold is called "waiting time."

When trigger pulse is generated by trigger circuit, the pulse has to cross certain reference level so as to activate the time base generator. This reference level is called "trigger threshold."

Time Base Block Diagram:

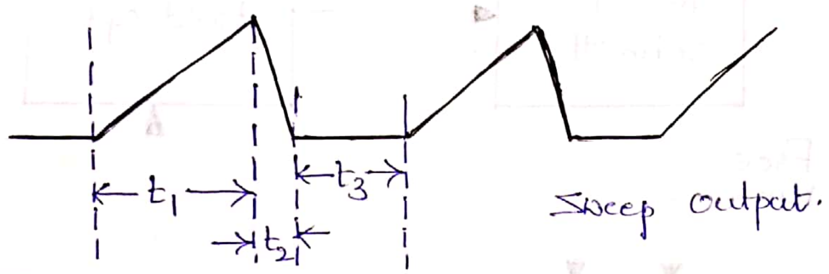


The Miller integrator is the basic time base generator circuit uses commonly in the laboratory oscilloscopes. This ckt has flexibility of choice of capacitor and resistor in the feedback loop. The capacitor can be changed from 10pF to 1μF, while the resistor can be varied from 100kΩ to 50MΩ.

The additional circuitry includes the trigger generator. This uses either internal signal i.e., input applied to the vertical plates to generate trigger pulses or it uses some external signal to generate the trigger pulses.

The trigger generator activates the gate generator which inturn starts the Miller integrator circuit. The hold off time is required to stabilise the Miller integrator circuit when the sweep cycle is completed. The reset schemitt is required which sends a signal to the gate generator whenever the hold off time is completed.

The sweep output waveform is shown below.



where t_1 = Sweep time.

t_2 = flyback or retrace time.

t_3 = hold-off time.

The circuit can work in following three modes:

(i) Free run mode

(ii) Auto mode

(iii) Single sweep mode.

(i) Free run mode: In this mode Miller integrator is started immediately after the hold off time without waiting time. i.e., without waiting for the trigger pulses to cross the trigger threshold.

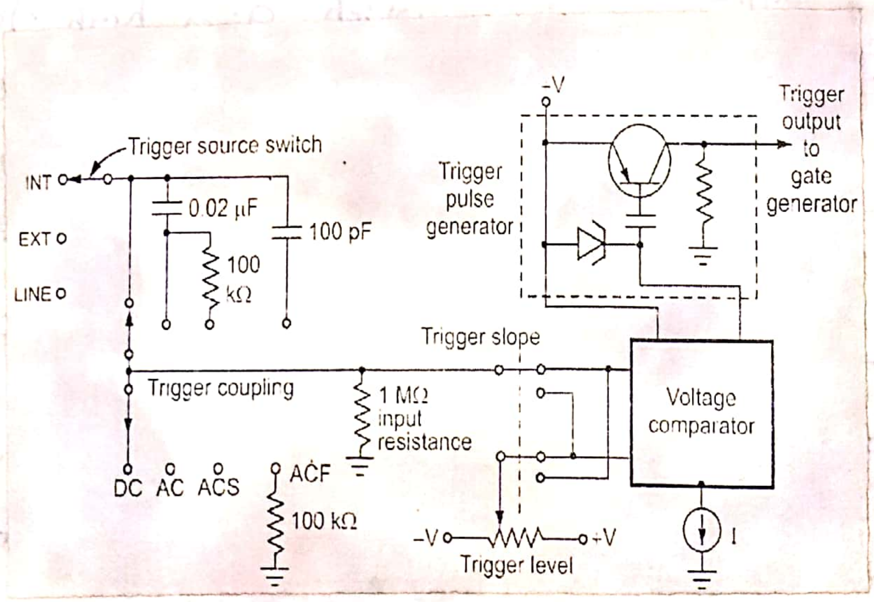
(ii) Auto mode: It senses a length of time after a sweep occurs and automatically provides a trigger pulse if no signal comes either from INT or EXT, after approximately 20 msec. This function - this gives a base line presentation without flicker, in the absence of signal and this allows the easy of verification of the ground level or a base line of a voltage level on the C.R.T.

(III) Single sweep mode:

The sweep runs only once from a trigger pulse after which the gate generator is not reset untill the operator desires. This mode is very useful for displaying and photographing the single occurence events when the time of occurence is undetermined.

Trigger generators:

The circuit which is responsible for starting the sweep at the desired point on a waveform is called trigger generator. The trigger generator includes trigger sources, a generator. The trigger generator includes trigger sources, a variable comparator to set the desired trigger level and a trigger pulse generator. The following shows the trigger generator block.



Trigger generator.

The three typical trigger sources are:

(i) INT: It provides replica of the signal applied to the vertical amplifier. Hence it is internal source

(ii) EXT: It is the external source and it is derived from an external input signal. In this case, the sweep is started at a time determined by an external conditions rather than by a transition of the signal being displayed. This is prefered when the input waveform is of small magnitude.

(iii) Line: It is derived from the power line having 50HZ frequency. This is used when a waveform is having a fixed time relationship with a line frequency.

The trigger coupling has four different positions A.C, D.C., ACS and ACF. With the help of AC and DC coupling and polarity selection, one should able to derive a signal that will give a stable display on the screen.

ACS: This is AC slow which gives the low frequency triggering capability in the presence of high frequency signals.

ACF: This is AC fast which gives high frequency-triggering capability in the presence of low frequency signals. The purpose of ACF is to reject the line frequency hum mixed with the trigger signals.

The trigger level control adjusts the comparator threshold level to allow the selection of the input voltage level which will switch differential comparator. This produces a time controlled trigger pulse at the output.

The trigger pulse slope can be either positive or negative.

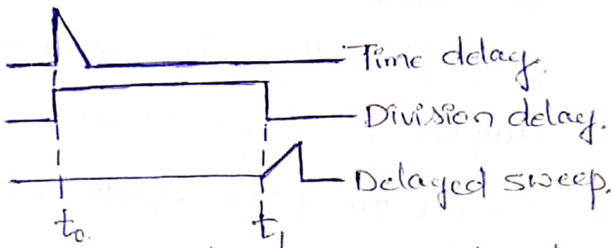
Sweep modes:

Depending upon the sophistication of second time base generator different sweep modes can be obtained which are:

(i) Delayed sweep mode
(ii) Mixed sweep mode
(iii) Switched sweep mode

(i) **Delayed sweep mode:** One time base selects the overall signal by generating the normal sawtooth waveform while the second time base produces delayed sweep due to which it is possible to view small part of the original signal in the expanded manner.

Adv: Increased accuracy as well as high resolution for many time interval measurements.



(ii) **Mixed Sweep Mode:** The main disadvantage of the delayed sweep mode is that the particular portion of the waveform is observed in expanded mode but remaining waveform is lost. In the mixed sweep mode both the signals, the reference signal as well as the signal of interest may be viewed with signal of interest in the expanded fashion.

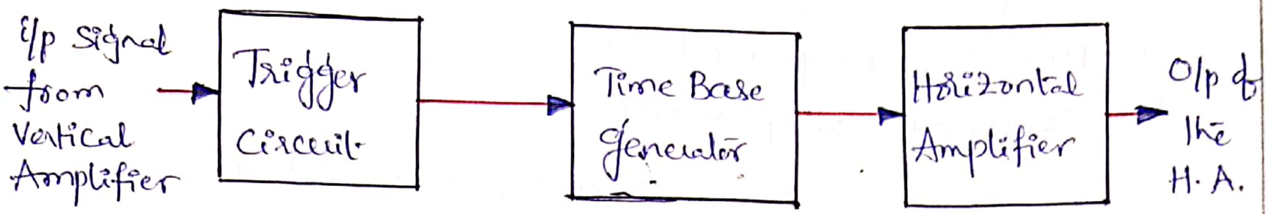
In this mode, the delayed sweep generator is started first. It displays the signal at slower speed. At some time t_1, external trigger or setting time delay, a front panel control activates the delayed sweep generator. This sweep is faster than the first sweep. Thus on the left hand side, the normal waveform displays exists while on the right hand side the expanded display exists.

(iii) **Switched Sweep Mode:** This mode displays two independently variable sweep modes alternately. First the waveforms is displayed with a slower sweep rate while in next scan the same waveform is displayed at faster rate, on the full screen. This is possible by electronically time sharing between the two time bases.

Scanned by CamScanner

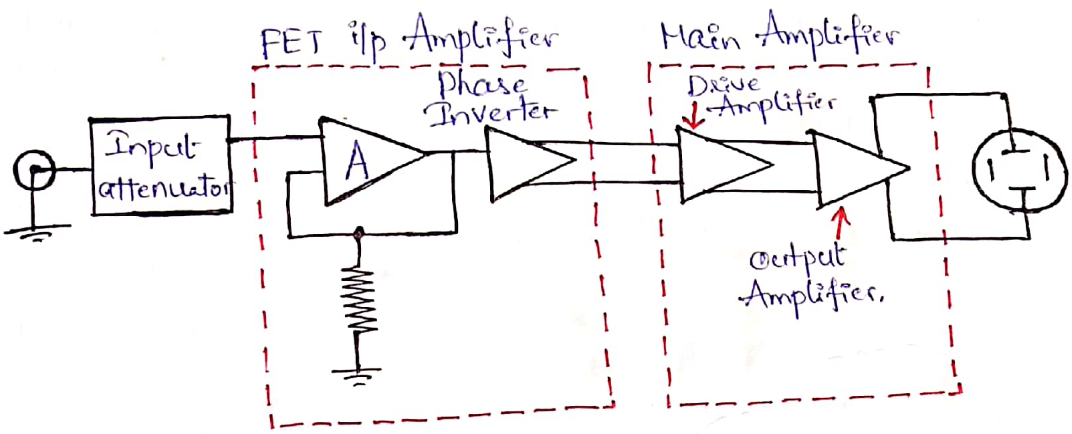
* Horizontal Deflection system:

The horizontal deflection system consisting of a time base generator, a trigger circuit and a horizontal amplifier as shown in below figure.



Vertical Amplifier:

The input signals are generally not strong to provide the measurable deflection on the screen. Hence the vertical amplifier stage is used to amplify the input signals. The amplifier stages used are generally wide band amplifiers so as to pass faithfully the entire band of frequencies to be measured.



It consists of several stages with overall fixed sensitivity. The amplifier can be designed for stability and required bandwidth very easily due to the fixed gain.

The input stage consists of an attenuator follows by FET source follower. It has very high input impedance required to isolate the amplifier from the attenuator.

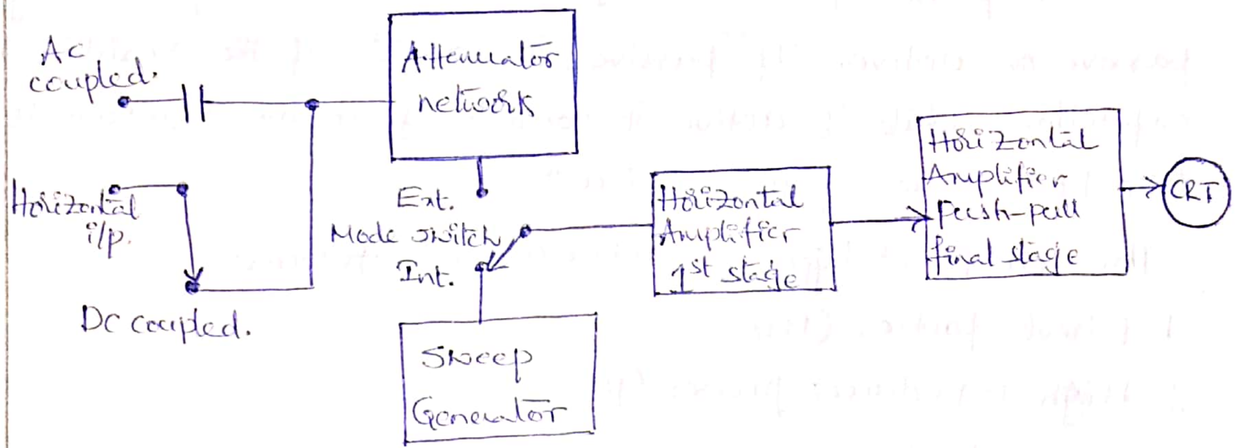
The phase inverter provides two antiphase output signals which are required to operate the push pull output amplifier.

The push pull operation has advantages like better hum voltage cancellation, even harmonic suppression especially large 2nd harmonic, greater power output per tube and reduced number of defocusing and non-linear effects.

Horizontal Amplifier:

Horizontal amplifier basically used for two purposes:

1. It uses to display a signal applied to the vertical input, the horizontal amplifier will amplify the sweep generator output when the oscilloscope is being used in the ordinary mode.
2. The signal applied to the horizontal input terminal be amplified by the horizontal amplifier when the oscilloscope is being used in the X-Y mode.

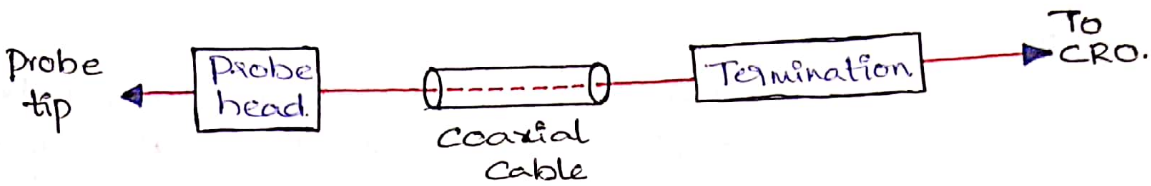


When the oscilloscope is being used in its ordinary mode of operation the gain and bandwidth requirements for the horizontal amplifier are not as same as that of a vertical amplifier. Although vertical amplifier must be able to reproduce faithfully low amplitude, high frequency signals with fast rise time. The horizontal amplifier is required to provide only a faithful reproduction of the sweep signal, which has a relatively high amplitude and a slow rise time. Horizontal amplifier is a push-pull amplifier. The attenuator network given in the figure reduces by voltage division. The amplitude of the horizontal input signal to a level equal to the sensitivity of the horizontal amplifier.

* **CRO probes:**

The probe is used with the oscilloscope to connect the test circuit to the oscilloscope.

While connecting the test circuit, the probe does not alter, load & disturbs the circuit and signal conditions to the analysed. To achieve this, the probes should have high impedance. The probe bandwidth should be as high as possible. Generally it is at least 10 times the bandwidth of the oscilloscope.



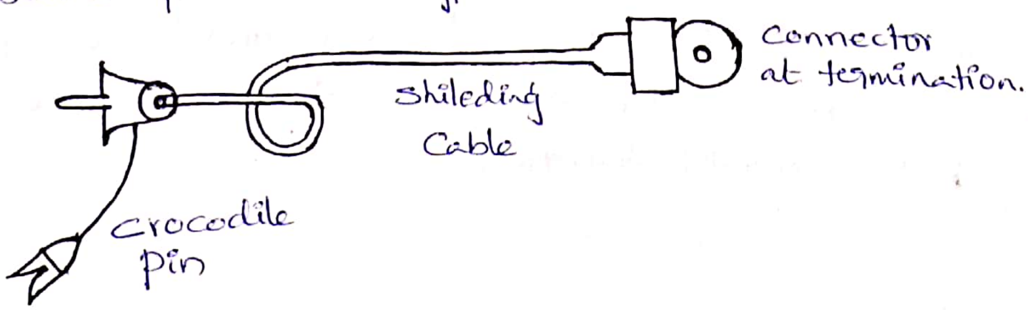
The probe tip is the signal sensing circuitry. It may be passive or active. If passive, it consists of the resistors & capacitors while if active, it consists of active components like FET source follower circuit.

The different types of probes are as follows:

1. Direct probes (1:1)
2. High impedance probes (10X)
3. Active probes.
4. Current probes.
5. Isolation probes.

1. Direct probes (1:1):

These probes are most simplest type of probes. At the oscilloscope end such probes terminate with the lugs, banna tips or other types of tips.



These probes use a shielded co-axial cable. Such probes do not provide any improvement in the input impedance and hence called '1X' probes.

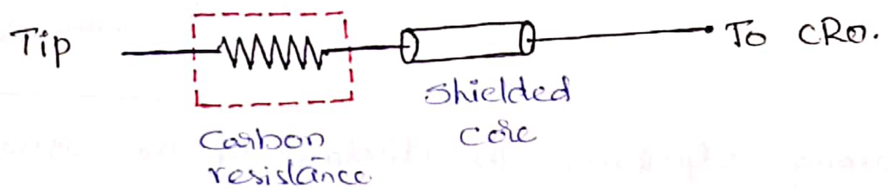
The i/p impedance of the CRO is generally high & it is increased by using the proper probes to avoid the loading effects.

Adv: 1. It is used for low frequencies.

Disadv: 1. This probes are not used for high frequencies, due to its stray capacitance.

2. Isolation probe:

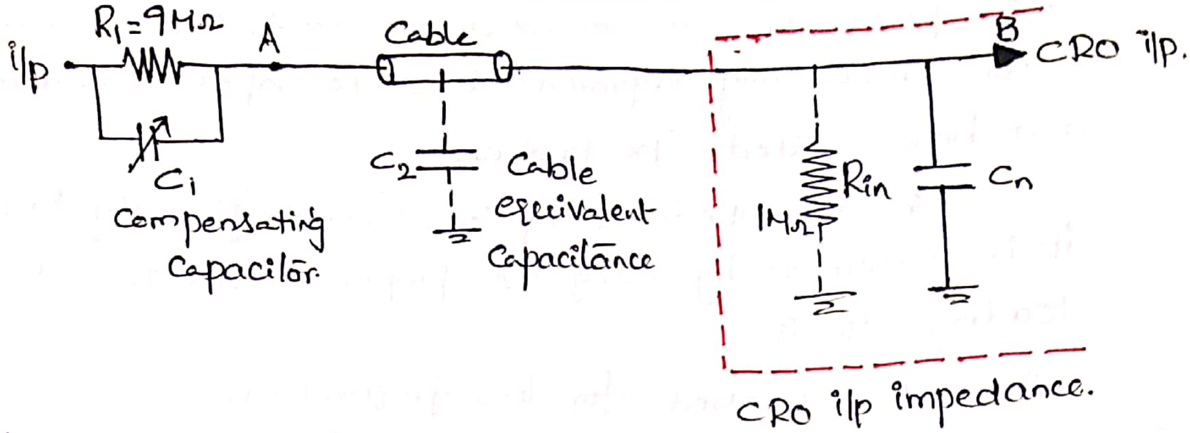
To avoid the shunt capacitance effect of such probe at high frequencies can be reduced by placing a carbon resistor in series with the test leads as shown in below. These probes are called "Isolating probes".

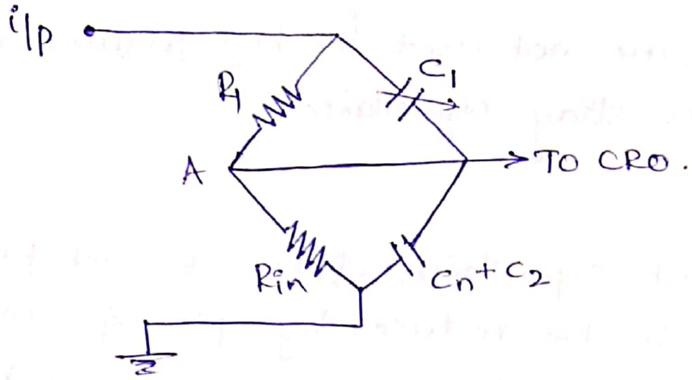


Disadv: slight change occurs in the amplitude of the waveform and slight change in the shape of the input.

3. High impedance probes: (10X)

This probe is also called passive voltage probe. The basic function of this probe is to increase the input impedance and reduce the effective input capacitance of an oscilloscope. This probes head uses a resistor and a capacitor combination. The resistance R_1 is shunted by an adjustable capacitor C_1. This capacitor is called "Compensating Capacitor".





$R_1 X_1 (C_n + C_2) = R_{in} X_{(C_1)}$

$R_1 C_1 = R_{in} (C_2 + C_{in})$.

$\frac{R_1 + R_{in}}{R_{in}} = 10$ and hence the probe is called 10x probe.

$\frac{R_1 + R_{in}}{R_{in}}$ = attenuator* factor

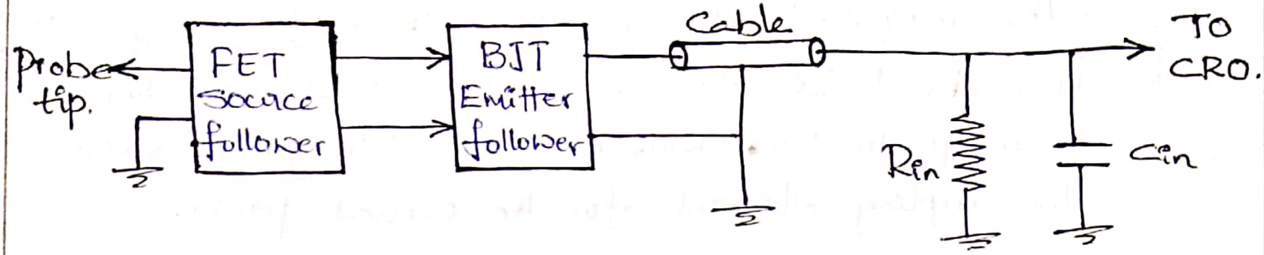
For wrong adjustment, the display of the square wave gets affected adversely.

(4) Active probes:

For connecting fast rising and high frequency signals the active probes are used. These probes are very useful for small signal measurements as their attenuation factor is very small.

The probe consists of active elements like FET source follower circuit and BJT as emitter follower circuit along with a coaxial cable termination. The block diagram of the active probe as shown below.

* To change the magnitude of the signal

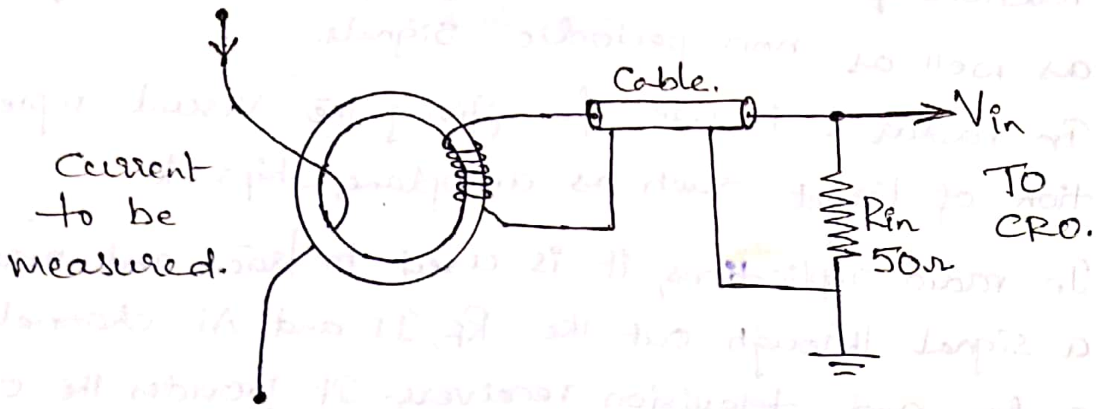


FET is used as an active element to amplify the signal. The voltage gain of FET source follower is unity. The output impedance of FET source follower is very low, this eliminates the loading effect. This emitter follower drives the cable and helps in solving the problems of improper impedance matching.

Adv:

1. No signal attenuation so small signals can be measured.
2. provide high input impedance ~~reading~~ reducing the loading effect.
3. The capacitance of such probes is very low of the order of 2 to 3 pf.
4. High frequency, fast rise time signals can be clearly measured.

(5) Current probes:



The probe provides a method of inductively coupling the signal to the CRO input, thus the direct electrical connection to the test circuit is not necessary.

The magnitude of current with a frequency range from d.c to 50 MHZ can be measured using this probe. A magnetic core with a removable piece is used as the coupling element for the current probe.

The wire carrying current to be measured is inserted in the center of the magnetic core and acts as a primary of a transformer. One coil is wounded on one leg and it is works as secondary of the transformer. Because of electromagnetic induction principle, whenever current flows through primary, the emf gets induced in the secondary. This is fed to the CRO input via termination circuitry.

* Applications of CRO:

There are variety of applications in which CRO is used. Some of these applications are:

(1) It is used to measure a.c as well as d.c. voltages and currents. It is useful to calculate the parameters of the voltages as peak to peak value, rms value, duty cycle etc.

(2) In laboratory to measure the frequency, period, phase, relationships between the signals and to study periodic as well as non-periodic signals.

(3) In radar, it is used for giving the visual representation of target such as aeroplane, ships etc.

(4) In radio applications, it is used to trace and measure a signal through out the RF, IF and AF channels of radio and television receivers. It provides the only effective way of adjusting FM receivers, Broadband high frequency RF amplifiers and automatic frequency control circuits.

(5) In medical applications, it is used to display the cardiograms which are useful for the diagnosis of heart of the patient. Similarly electromyograms are useful to study muscle condition of the patient.

(6) It is used to determine the modulation characteristics and to detect the standing waves in transmission lines.

(7) Curve traces use the oscilloscope technique for testing the active device such as vaccum tubes, transistors and integrated circuits.

* Measurement of Phase and Frequency:

The Lissajous pattern method is the quickest method of measuring the frequency.

In this method, the standard known frequency signal is applied to horizontal plates and simultaneously unknown frequency signal is applied to the vertical plates. The resulting pattern on the screen depends on the integral and phase relationship between the two frequencies.

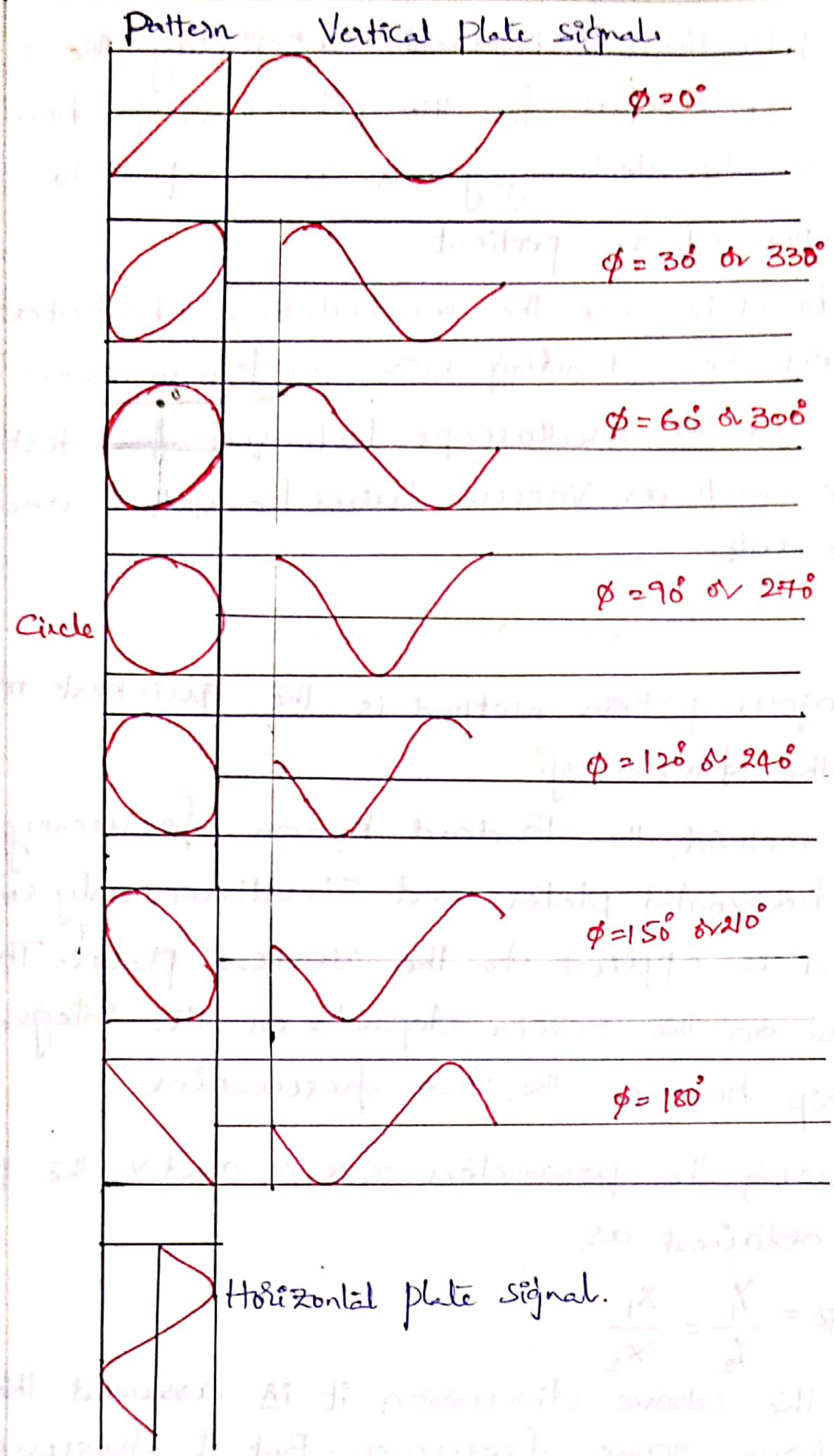
By measuring the parameters X_1, X_2, Y_1 and Y_2 the phase angle can be obtained as,

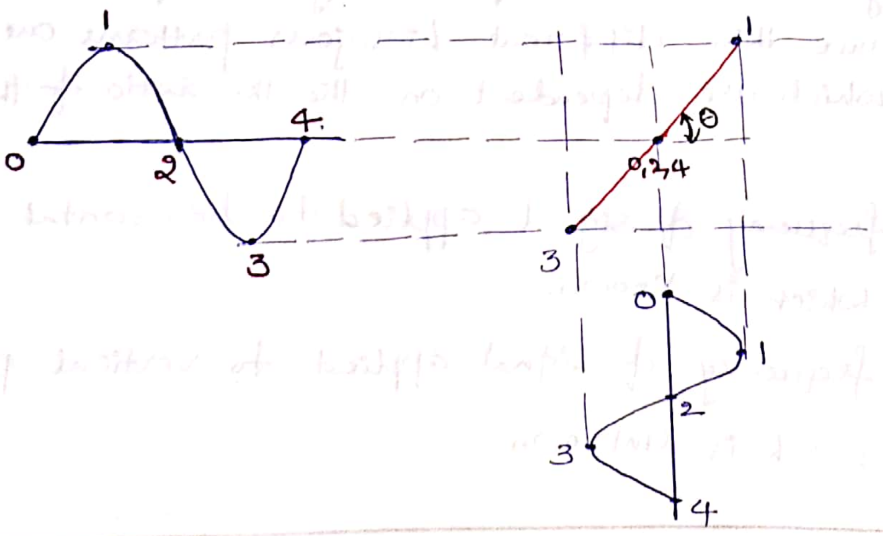
$$\sin\phi = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}$$

Frequency: Now in the above discussion, it is assumed that the two voltages have same frequency. But if frequencies are not same then different Lissajous patterns are obtained on screen which are dependent on the the ratio of the two frequencies.

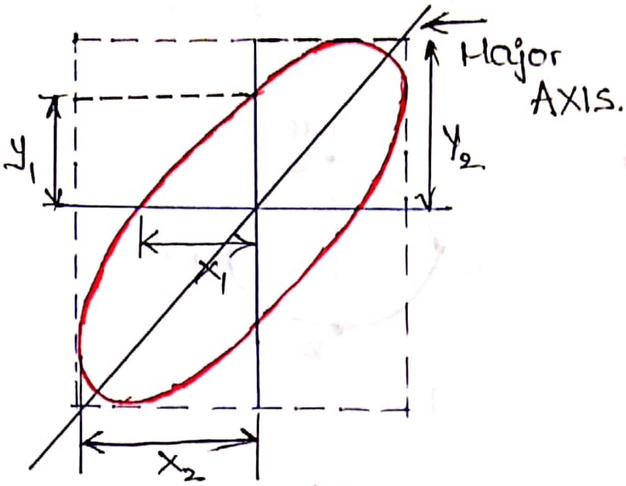
Let f_h = frequency of signal applied to horizontal plates which is known.

f_v = frequency of signal applied to vertical plates which is unknown.


Pattern
Vertical plate signals
φ = 0°
φ = 30° or 330°
φ = 60° or 300°
φ = 90° or 270°
Circle
φ = 120° or 240°
φ = 150° or 210°
φ = 180°
Horizontal plate signal.


1
0
2
3
4.
1
θ
0,2,4
3
0
1
2
3
4.

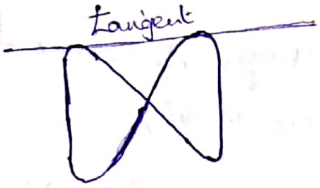
Phase:



$$\text{Phase } \sin\phi = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}.$$

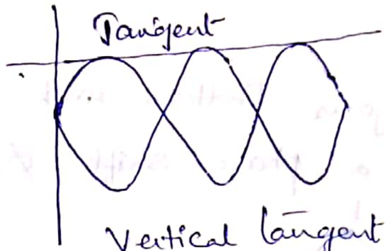
Problems on Frequency Measurement:

(I)



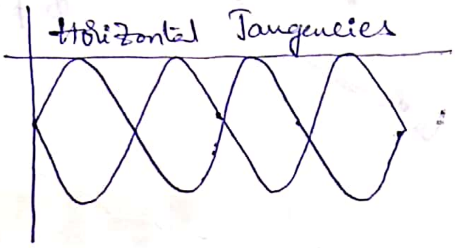
$f_V = 2f_h.$

(II)



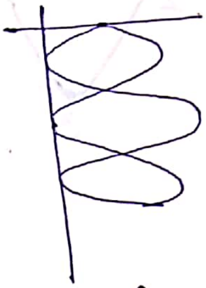
$f_V = 3f_h$

(III)



$f_V = 4f_h.$

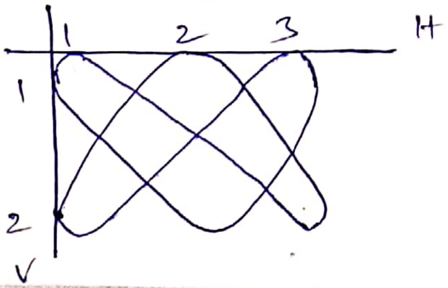
(IV)



$f_V = \frac{1}{3}f_h.$

The ratio of two frequencies can be obtained as,

$$\frac{f_V}{f_h} = \frac{\text{no. of. horizontal tangencies}}{\text{no. of. Vertical tangencies}}.$$

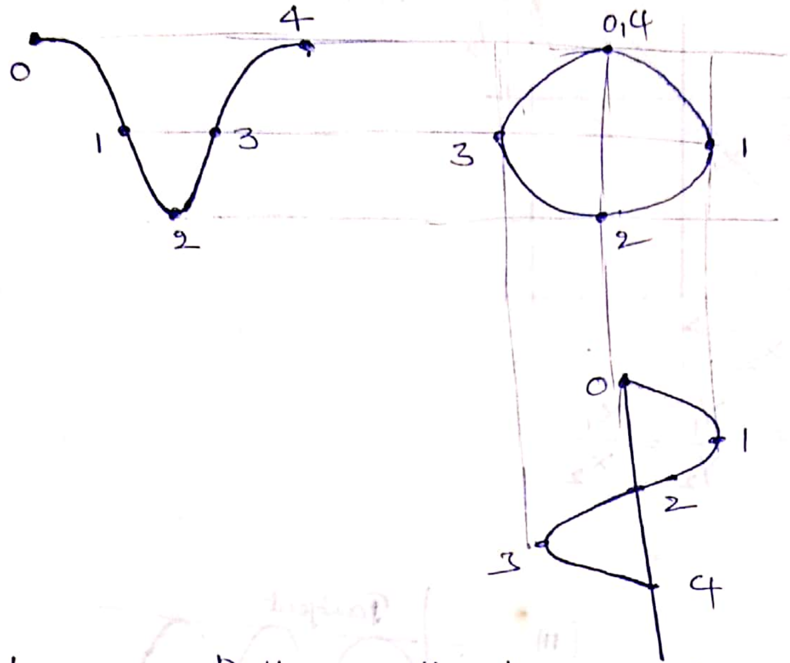


$$\frac{f_V}{f_h} = \frac{3}{2}$$

$$f_V = \frac{3}{2}f_h.$$

Pro: Lissajous Pattern with equal Voltages of equal frequency and a phase of 90°.

Sol.

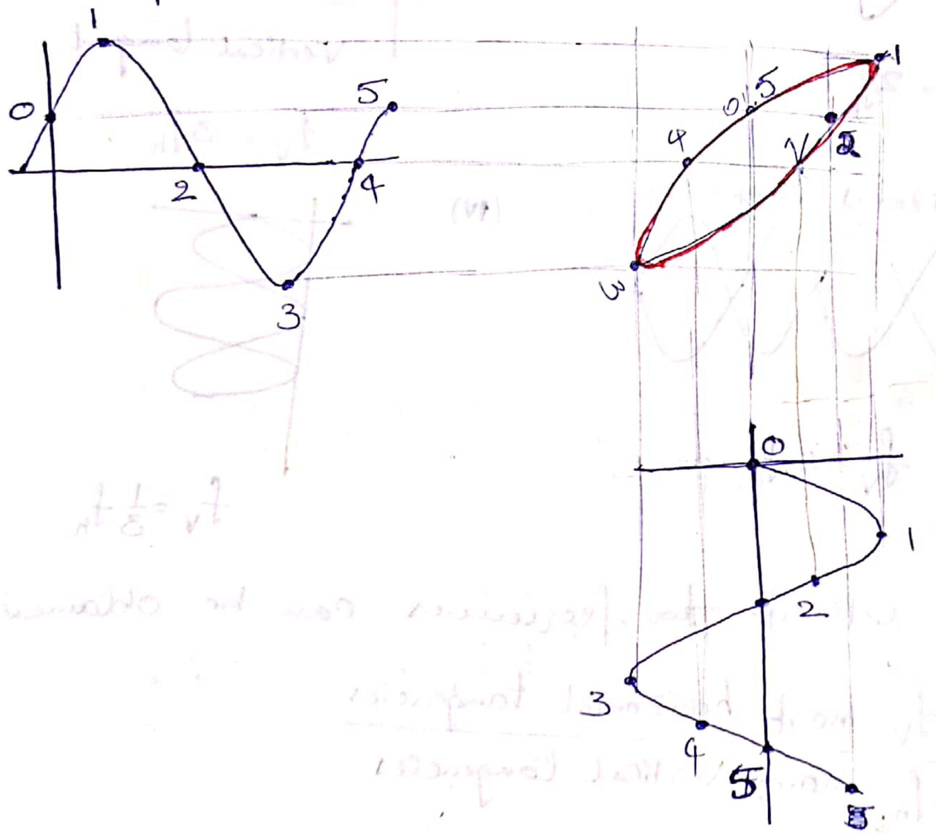


$V_v = V_h$.

$f_v = f_h$

$\phi = 90°$

Pro: Lissajous Pattern with two equal voltages of same frequency and a phase shift ϕ (not equal to zero & 90°).



$V_v = V_h$

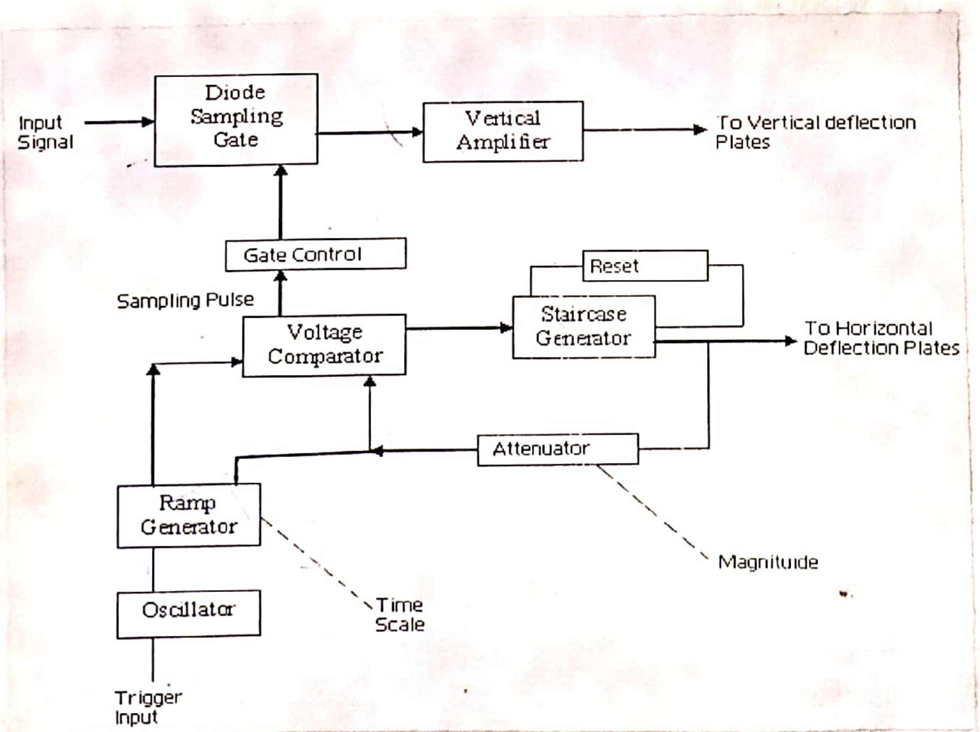
$f_v = f_h$.

$\phi \neq 0° \& 90°$

Sampling oscilloscope:

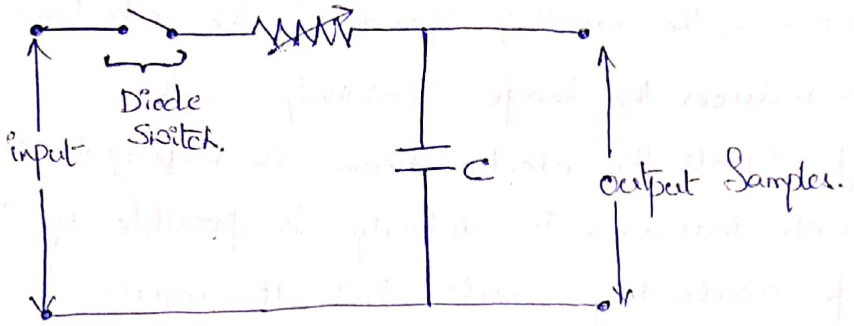
As the frequency of the input signal to the vertical amplifier increases, the writting speed of the electron beam increases. This reduces the image sensitivity on the screen. For high frequency signals the electro beam is required to accelerate more. Such increases in velocity is possible by increasing the voltage of accelerating anodes but it require higher deflection potential and puts higher demands on the vertical amplifier. The Solution to such problem is the Sampling technique. Using this technique, higher frequency signal is converted to low frequency signal.

In this technique, instead of Monitoring the input signal continously, it is sampled at the regular intervals. These samples are presented as on the screen in the form of dots. Many thousands of dots may be displayed on the screen. Such samples are merged to reconstruct the input signal. Due to merging of samples, observer receives a continuous signal on the screen. Thus a very high frequency more than 300MHZ performance can be achieved using this technique.



Block diagram of Sampling oscilloscope.

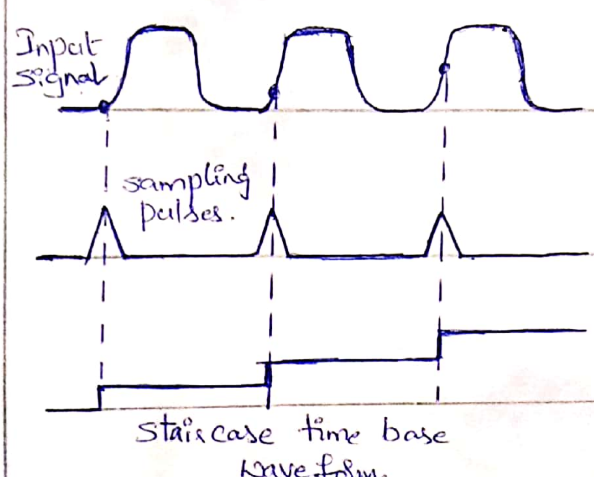
The basic Sampling Circuit which uses a diode switch. This is also called sampling gate.

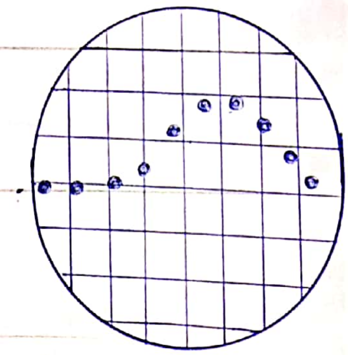


It Consists of a Sampling switch, a series resistor and a shunt capacitor. when switch is closed, the capacitor charging starts. But switch is closed for very short duration of time so that sample of the input signal is presented at the output.

The Sampling pulse is required to turn on the sampling circuit, i.e., to close the switch for very short duration of time. The input voltage at that instant is available at the sampler output and presented as a dot on the CRT screen. The next sample is taken during a subsequent cycle of the input wave-form at a slightly later position. Thus the spot on the screen moves horizontally by a small distance and repositioned to the new value of the input.

In this way, 1000 samples i.e., dots are presented on the screen which together reconstruct the original input signal.





The time base circuit of the sampling oscilloscope is different than the conventional oscilloscope. The time base of sampling oscilloscope has two functions:

(i) To move the dots across the screen.

(ii) To generate the sampling command pulses for the sampling circuit.

It consists of synchronous circuit, which determines the sampling rate and establishes a reference point in time with respect to the input signal.

The time base generates a triggering pulse which activates the oscillator to generate a ramp voltage. Similarly it generates a stair case waveform. The ramp generation is based on the o/p of the synchronous circuit.

Both ramp as well as staircase waveforms are applied to a voltage comparator. This comparator compares the two voltages and whenever these two voltages are equal, it generates a sampling pulse. This pulse then momentarily bias the diodes of the sampling gate in the forward direction and thus diode switch gets closed for short duration of time. The capacitor charges, but for short time, hence it charges to only a small percentage of the input signal value at that instant. This voltage is amplified by using vertical amplifier and then applied to vertical deflecting plates. This is nothing but a sample.

At the same time, the comparator gives a signal to the staircase generator to advance through one step. This is applied to horizontal deflection plates, thus during each step of the staircase waveform, the spot moves across the screen.

Thus the sampling time base is called a "staircase_ramp generator" in case of sampling oscilloscope.

Advantages:

1. Very high frequency performance can be achieved.
2. High speed electrical signals can be analysed.
3. The technique allows the design of the oscilloscope with wide bandwidth, high sensitivity even for low duty cycle pulses.
4. A clear display is produced.
5. Controlling the size of the steps of the staircase generator, the number of samples and hence the resolution can be controlled.

The only limitation of the sampling oscilloscope is that it cannot be used to display the transient waveforms.

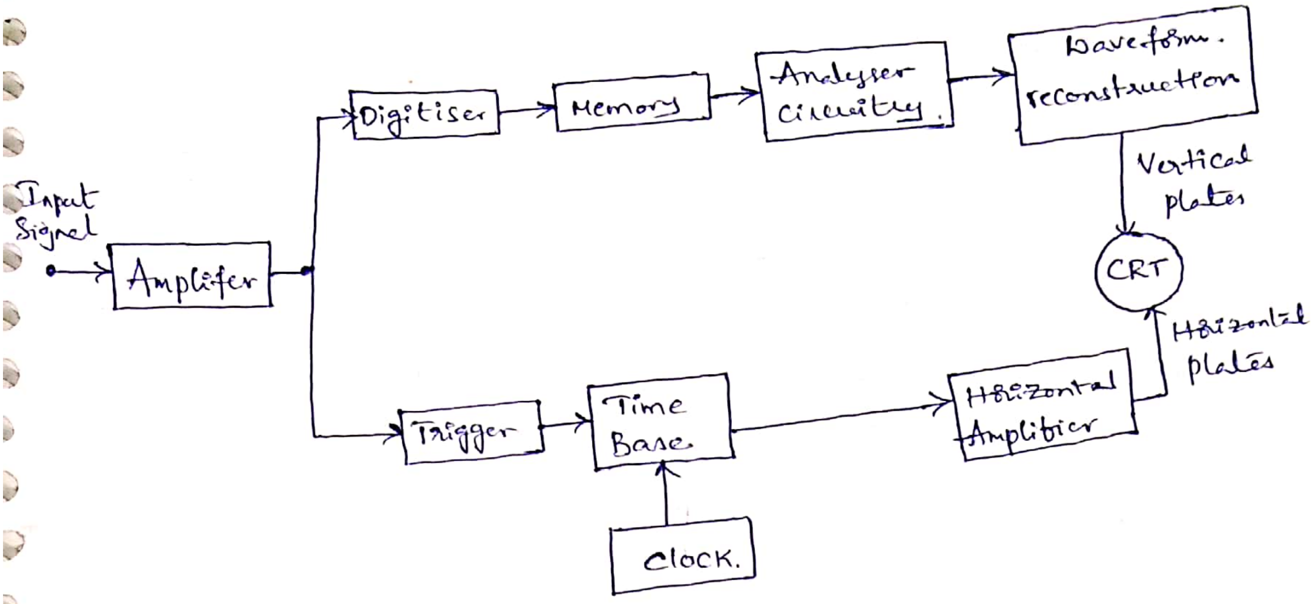
* **Storage oscilloscopes:**

A limitation in conventional CROs is an event that occurs only once, will disappear from the screen after a relatively short interval of time, as the persistance of the phosphor on the screen range only from a few milli sec to several sec. In storage CRO's, the display is retained for a much longer time, sometimes even for some hours, after the image was first traced on the screen.

1. Analog storage oscilloscope.
2. Digital storage oscilloscope.

The Analog storage oscilloscopes use the phenomenon of secondary electron emission to build up and store electrostatic charges on the surface of an insulated target.

* Digital storage oscilloscopes:



It has infinite storage time using its digital memory.

→ Secondary emission Method

→ storage oscilloscopes has Very high persistance upto some hours for transient Mesurements

→ There are two methods for storage oscilloscopes.

  → Variable emission or halftone method or Mesh type

  → bistable emission method.

→ Digitisation in digital storage oscilloscopes:

wave Reconstruction from samples of digital storage oscilloscopes.

(1) Without Interpolation
(2) linear interpolation
(3) Sinusoidal interpolation

} digitilization Methods in digital storage oscilloscopes.

SIGNAL ANALYSERS

INTRODUCTION

The analysis of electrical signals is used in many applications. The different instruments which are used for signal analysis are wave analysers, distortion analysers, spectrum analysers, audio analysers and modulation analysers. All signal analysis instruments measure the basic frequency properties of a signal, but they use different techniques to do so. A spectrum analyser sweeps the signal frequency band and displays a plot of amplitude versus frequency. It has an operating range of about 0.02 Hz—250 GHz. A wave analyser is a voltmeter which can be accurately tuned to measure the amplitude of a single frequency, within a band of about 10 Hz-40 MHz. Distortion analysers operate over a range of 5 Hz—1MHz and give a measure of the energy present in a signal outside a specified frequency band. They therefore tune out the fundamental signal and give an indication of the harmonics. An audio analyser is similar to a distortion analyser but can measure additional functions, such as noise. Modulation analysers tune to the required signal and recover the whole amplitude modulated (a.m.), frequency modulated (f.m.) or phase modulation (p.m.) envelope for display or analysis.

Wave analysers

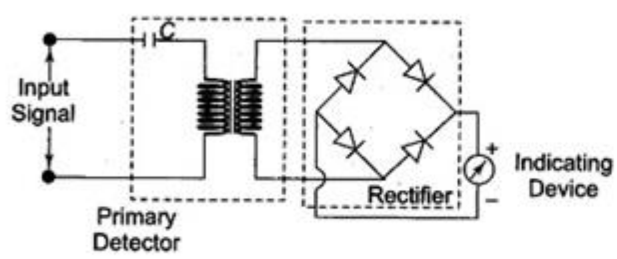
The electronic instrument used to analyze waves is called wave analyzer. It is also called signal analyzer, since the terms signal and wave can be interchangeably used frequently. We can represent the periodic signal as sum of the following two terms.

i. DC component
ii. Series of sinusoidal harmonics

So, analyzation of a periodic signal is analyzation of the harmonics components presents in it.

Basic Wave Analyzer

Basic wave analyzer mainly consists of three blocks − the primary detector, full wave rectifier, and PMMC galvanometer. The block diagram of basic wave analyzer is shown in below figure –



Basic Wave Analyzer

The function of each block present in basic wave analyzer is mentioned below.

Primary Detector − It consists of an LC circuit. We can adjust the values of inductor, L and capacitor, C in such a way that it allows only the desired harmonic frequency component that is to be measured.

Full Wave Rectifier − It converts the AC input into a DC output.

PMMC Galvanometer − It shows the peak value of the signal, which is obtained at the output of Full wave rectifier.

We will get the corresponding circuit diagram, just by replacing each block with the respective component(s) in above block diagram of basic wave analyzer.

This basic wave analyzer can be used for analyzing each and every harmonic frequency component of a periodic signal.

Types of Wave Analyzers

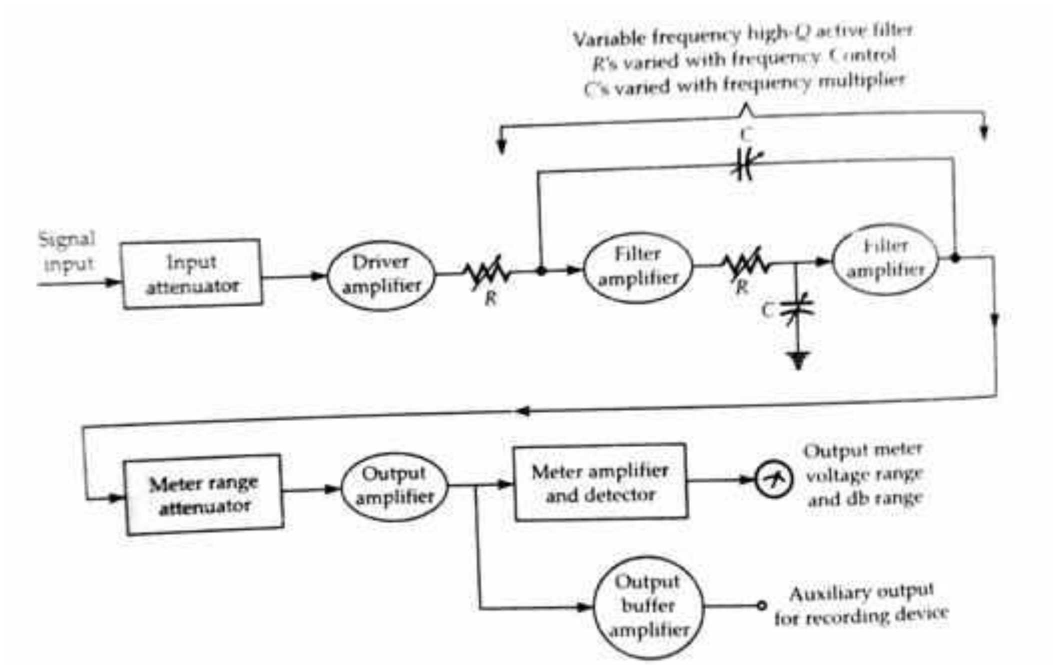
Wave analyzers can be classified into the following two types.

- Frequency Selective Wave Analyzer
- Superheterodyne Wave Analyzer

Now, let us discuss about these two wave analyzers one by one.

Frequency Selective Wave Analyser

The wave analyzer, used for analyzing the signals are of AF range is called frequency selective wave analyzer. The block diagram of frequency selective wave analyzer is shown in below figure.



(a) Block diagram

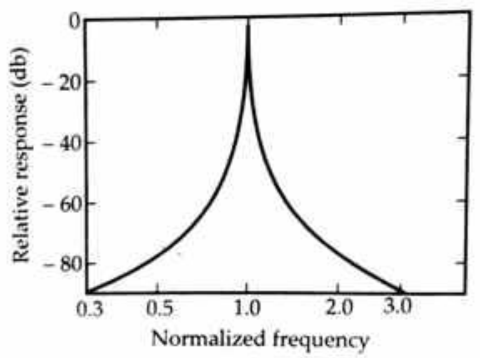
Frequency selective wave analyzer consists a set of blocks. The function of each block is mentioned below.

Input Attenuator − The AF signal, which is to be analyzed is applied to input attenuator. If the signal amplitude is too large, then it can be attenuated by input attenuator.

Driver Amplifier − It amplifies the received signal whenever necessary.

High Q-filter − It is used to select the desired frequency and reject unwanted frequencies. It consists of two RC sections and two filter amplifiers & all these are cascaded with each other. We can vary the capacitance values for changing the range of frequencies in powers of 10. Similarly, we can vary the resistance values in order to change the frequency within a selected range.

Meter Range Attenuator − It gets the selected AF signal as an input & produces an attenuated output, whenever required.
Output Amplifier − It amplifies the selected AF signal if necessary.
Output Buffer − It is used to provide the selected AF signal to output devices.
Meter Circuit − It displays the reading of selected AF signal. We can choose the meter reading in volt range or decibel range.



(b) Attenuation characteristics

Superheterodyne Wave Analyser

The wave analyzer, used to analyze the signals of RF range is called superheterodyne wave analyzer. The following figure shows the block diagram of superheterodyne wave analyzer.

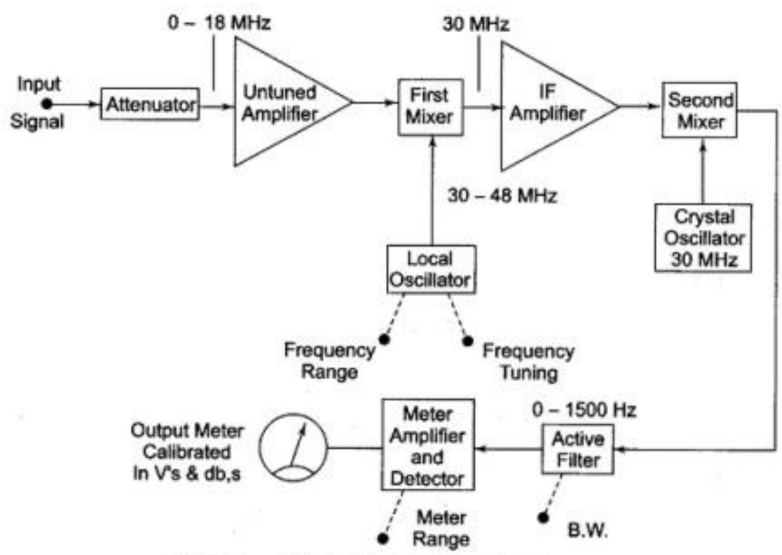


Fig. 9.4 RF Heterodyne Wave Analyzer

The working of superheterodyne wave analyzer is mentioned below.
The RF signal, which is to be analyzed is applied to the input attenuator. If the signal amplitude is too large, then it can be attenuated by input attenuator.
Untuned amplifier amplifies the RF signal whenever necessary and it is applied to first mixer.
The frequency ranges of RF signal & output of Local oscillator are 0-18 MHz & 30-48 MHz respectively.
So, first mixer produces an output, which has frequency of 30 MHz. This is the difference of frequencies of the two signals that are applied to it.

IF amplifier: amplifies the Intermediate Frequency (IF) signal, i.e. the output of first mixer. The amplified IF signal is applied to second mixer.

The frequencies of amplified IF signal & output of Crystal oscillator are same and equal to 30MHz. So, the second mixer produces an output, which has frequency of 0 Hz. This is the difference of frequencies of the two signals that are applied to it.

The cut off frequency of Active Low Pass Filter (LPF) is chosen as 1500 Hz. Hence, this filter allows the output signal of second mixer.

Meter Circuit displays the reading of RF signal. We can choose the meter reading in volt range or decibel range.

So, we can choose a particular wave analyzer based on the frequency range of the signal that is to be analyzed.

Applications of Wave Analysers

Wave analysers have very important applications in the following fields :

i. Electrical measurements
ii. Sound measurements and
iii. Vibration measurements

The wave analysers are applied industrially in the field of reduction of sound and vibrations generated by rotating electrical machines and apparatus. The source of noise and vibrations is first identified by wave analysers before it can be reduced or eliminated A fine spectrum anylsis with a wave analyser shows various discrete frequencies and resonances that can be related to the motion of machines. Once, these sources of sound and vibrations are detected with the help of wave analysers, ways and means can be found to eliminate them.

HARMONIC DISTORTION ANALYSERS

The application of a sinusoidal input signal to an electronic device, such as an amplifier should result in generation of a sinusoidal output waveform. Generally, however, the output waveform is not an exact replica of the input waveform because of various types of distortions that may occur. Distortion may be a result of the inherent non-linear characteristics of different components used in an electronic circuit. Nonlinear behavior of circuit elements introduces harmonics in the output waveform and the resultant distortion is often referred to as harmonic distortion (HD).

Types of Distortion

Distortion is caused by many devices and components which form an electronic circuit. In this section the different types of distortions caused by amplifiers are considered. The various types of distortions which occur are:

i. **Frequency distortion:** This type of distortion occurs because the amplification factor of the amplifier is different for different frequencies.

ii. **Phase distortion**: This distortion occurs on account of the energy storage elements in the system which causes the output signal to be displaced in phase with the input signal. If signals of all frequencies are displaced by the same amount, the phase shift distortion would not be noticed. However, in actual practice, signals at different frequencies are shifted in phase by different angles and therefore the phase shift distortion becomes noticeable.

iii. **Amplitude distortion**: Harmonic distortion occurs due to the fact that the amplifier generates harmonics of the fundamental of the input signal. Harmonics always give rise to amplitude distortion, for example, when an amplifier is overdriven and clips the input signal.

iv. **Intermodulation distortion**: This type of distortion occurs as a consequence of the interaction or heterodyning of two frequencies, giving an output which is sum or difference of the two original frequencies.

v. **Cross-over distortion:** This type of distortion occurs in push-pull amplifiers on account of incorrect boas levels as shown in Fig. 23.3.

TOTAL HARMONIC DISTORTION

A non-linear system produces harmonics of an input sine wave, the harmonics consisting of sine waves with frequencies which are multiples of the fundamental of the input signal. Total harmonic distortion (THD) is measured in terms of the harmonic content of the wave, as given by

$$\text{THD} = \frac{[\Sigma(\text{Harmonics})^2]^{1/2}}{\text{Fundamental}} \qquad ...(23.1)$$

A measure of distortion represented by a particular harmonic is simply the ratio of amplitude of harmonic to that of the fundamental harmonic distortion (HD) is then represented by,

$$D_2 = \frac{E_2}{E_1}, \quad D_3 = \frac{E_3}{E_1}, \quad D_4 = \frac{E_4}{E_1}$$

When Dn(n=2,3,4….) distortion of nth harmonic and En represents the amplitude of nth harmonic.
E1 is the amplitude of fundamental.
Total harmonic distortion (THD) is defined as:

$$\text{THD} = \sqrt{D_2^2 + D_3^2 + D_4^2 + ...} \qquad ...(23.2$$

$$= \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + ...}}{E_1} \qquad ...(23.3$$

Percentage harmonic distortion

$$= \sqrt{D_2^2 + D_3^2 + D_4^2 + ...} \times 100 \qquad ...(23.4)$$

$$= \frac{\sqrt{E_2^2 + E_3^2 + E_4^2 + ...}}{E_1} \times 100 \qquad ...(23.5)$$

In a measurement system noise is read in addition to harmonics, and the total waveform, consisting of harmonics, noise and fundamental, is measured instead of the fundamental alone. Therefore the measured value of total harmonic distortion (THD) is given by Eqn. 23.6.

$$THD_M = \frac{\{\Sigma(H)^2 + (N)^2\}^{1/2}}{\{\Sigma(F)^2 + (H)^2 + (N)^2\}^{1/2}} \quad ...(23.6)$$

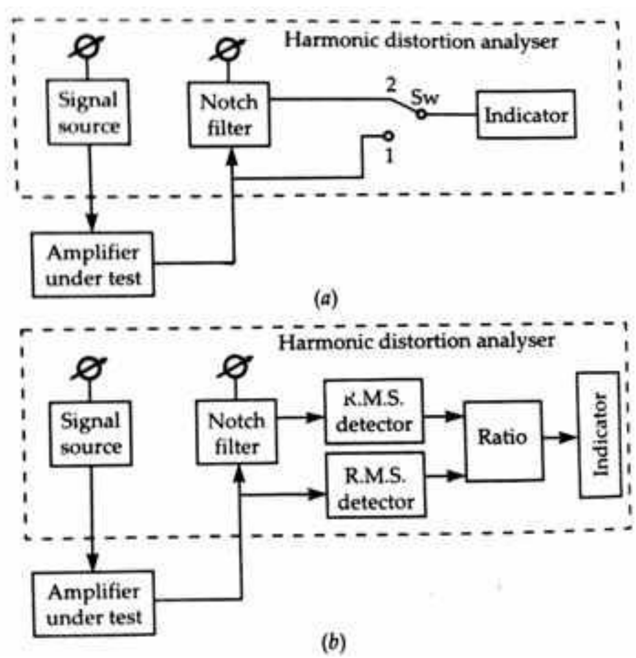
where H = Harmonics ; N = Noise ; F = Fundamental

Where H = Harmonics; N = Noise ; F = Fundamental

Equation 23.6 leads to below 1/2% error, due to the approximation for values of THD below 10%.

Figure 23.4 shows a harmonic distortion analyser which is used to measure THD. The signal source has very low distortion and this can be checked by reading its output distortion by connecting directly into the analyser. The signal from the source is fed into the amplifier under test. This generates harmonics and the original fundamental frequency. The fundamental frequency is removed by the notch filter.

In the manual system of Fig. 23.4(a) the switch Sw is first placed in position 1 and the total content of fundamental and harmonics (Et) is measured. Then the switch is moved to position 2 to measure just the harmonic Eh. The value of THD is then found from equation 23.6 as in equation 23.7



The meter can be calibrated by putting the switch in position 1 and adjusting the reading for full scale deflection. With the switch in position 2 the meter reading is now proportional to THD. Figure 23.4(b) shows an alternative arrangement, where the values of ET and EH are read simultaneously and their ratio calculated and displayed as THD on the indicator. For good accuracy the notch filter must have excellent rejection and high pass characteristics. It should attenuate the fundamental by 100 db or more and the harmonics by less than 1 db. The filter also needs to be tuned accurately to the fundamental of the signal source. This is difficult to achieve manually and most distortion analysers do this automatically. A common form of notch filter is a Wien bridge. This balances at one frequency only and at this frequency the output voltage at the bridge null detector is minimum.

SPECTRUM ANALYSERS

Spectrum analysis is defined as the study of energy distribution across the frequency spectrum of a given electrical signal. The study gives valuable information about bandwidth, effects of different types of modulation and spurious signal generation. The knowledge of the above quantities and phenomena are useful in the design and testing of radio frequency (RF) and pulse circuitry.

The spectrum analysis is divided into two major categories on account of instrumentation limitations and capabilities. They are:

i. Audio frequency (AF) analysis, and
ii. Radio frequency (RF) spectrum analysis.

The RF spectrum analysis covers a frequency range of 10 MHz to 40 GHz, and hence is more important, because it includes the vast majority of communication, navigation, radar, and industrial instrumentation frequency bands.

The spectrum analysers are sophisticated instruments which are capable of portraying graphically the amplitude as a function of frequency in a portion of RF spectrum. These instruments find wide applications for measurement of attenuation, FM deviation, and frequency in pulse studies.

Basic Spectrum Analyser

The basic spectrum analyser is designed to represent graphically, a plot of amplitude versus frequency of a selected portion of the frequency spectrum under study. The modern spectrum analyser basically consists of a narrow band superheterodyne receiver and a CRO. The receiver is electronically tuned by varying the frequency of the local oscillator. A simplified block diagram of a swept frequency spectrum analyser is shown in Fig. 23.9.

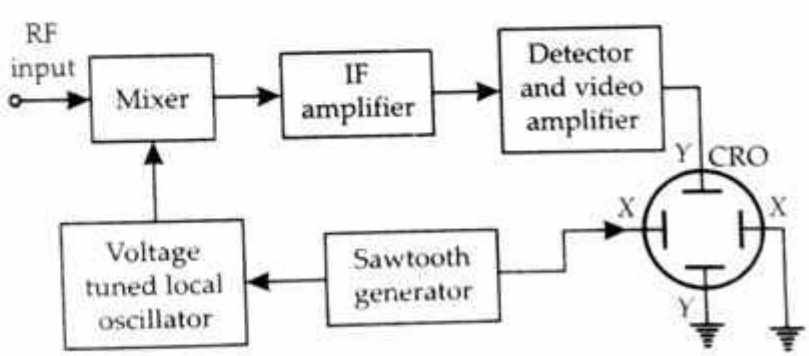


Fig. 23.9 Basic swept receiver spectrum analyser.

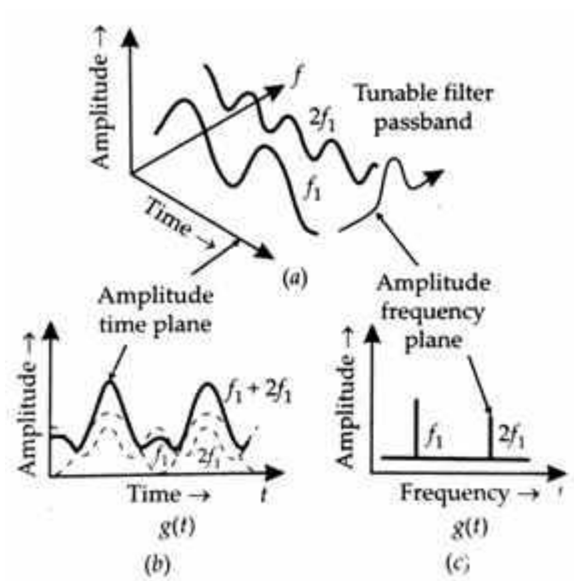
The circuit incorporates a sawtooth generator which supplies a ramp voltage to the frequency control element of the voltage tuned local oscillator. The local oscillator sweep through its frequency band at a recurring linear rate. The same sawtooth voltage is simultaneously applied to the horizontal plates of the CRO. The RF signal to be tested is applied to the input of the mixture stage.

Sawtooth generator makes the local oscillator through its frequency band to beat with the input signal to produce the desired intermediate frequency (IF). An IF component is produced only when the corresponding component is present in the RF input signal. The resulting IF signals are amplified, and then detected. After that they are applied to the vertical deflection plates of the CRO, thereby producing a display of amplitude versus frequency on the screen.

Spectral Displays

Normally a CRO is used for display of electrical signals with respect to time, with the X-axis of CRO calibrated to read directly the rise time, pulse width, and the repetition rate. Such measurements are said to be in Time Domain. However, in the case of spectrum analysers, the signals are broken down into their individual frequency components and displayed along X-axis of the CRO which is calibrated in terms of frequency. Therefore, the signal amplitude is displayed versus frequency. These measurements are then said to be in the Frequency Domain.

A three dimensional representation of a fundamental frequency, f1 and its second harmonic, f2 —2 f1 , is shown in Fig. 23.10. The two signals and the sum instantaneous values, as displayed on a CRO screen are shown in Fig. 23.10(b). The two signals are shown in Fig. 23.10 (c) on amplitude-frequency plane and are portrayed on the CRO as two components of the composite signal, as the window of the spectrum analyser sweeps across the frequency range of the signal.



Spectra of Different Signals

Let us consider some of commonly used signals in order to illustrate the spectra which are displayed on the CRO when they are applied to the spectrum Analyser.

1. **Continuous wave (CW) signals:** When a continuous wave (CW) input signal is slowly swept through by the spectrum analyser's local oscillator, the response displayed on the screen is a plot of the IF amplifier pass band. Since the CW signal has energy at only one frequency and therefore the display on the screen is a single spike. This occurs in case the total RF sweep width or Spectrum Width is wide as compared to the IF band width in the analyser.

2. **Amplitude modulation:** When a continuous wave signal of frequency,fc, is amplitude modulated by an input signal of frequency, fs, two side-band frequencies of fc+ fs and fc—fs are produced. The display on the spectrum analyser screen is a signal of frequency fc, with two side band frequencies whose magnitude relative to the carrier frequency depends upon the percentage of modulation. This is illustrated in figure 23.11.

3. **Frequency modulation:** If a CW signal fc is frequency modulated at a rate fr, it will produce an infinite number of sidebands. These are located at intervals of fc+nfr, where n=integer, 1, 2, 3… In practice, only the sidebands containing significant power are usually considered. A frequency modulated display is shown in figure 23.12.

Vector Impedance Meter

The meter used for complex impedance measurements is called Vector Impedance Meter. It is used to measure the impedances over wide frequency range, from 400 kHz to 110 MHz. The sweep frequency plots i.e. magnitude and phase angle against frequency can also be obtained by vector impedance meter. Such plots provide complete information within the frequency band of interest. With the help of this meter, the magnitude and the phase angle of the impedance can be measured simultaneously. The unknown impedance is simply connected across the input terminals and desired frequency can be selected from the front panel control. Then the two front panel readouts give the magnitude and the phase angle.

The block diagram of vector impedance meter is shown in the Fig.
The measurements taking place in the meter are :

i. Magnitude of impedance determined by measuring current through component applying voltage or by measuring voltage across the component when known current flows through the component.
ii. Phase angle of the impedance is determined by the phase difference between the voltage across the component and current passing through the component.

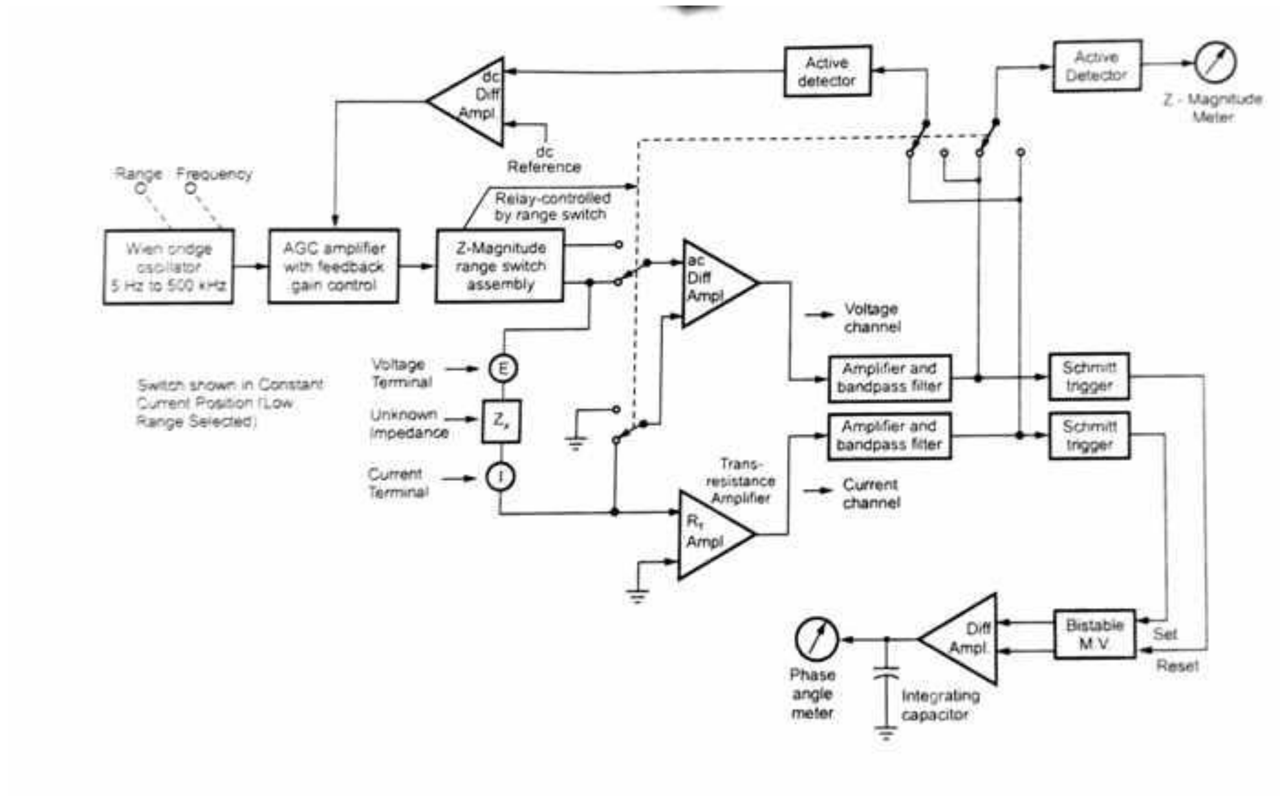


Fig. 5.25 Vector impedance meter

In the vector impedance meter, Wien bridge oscillator is used as a source with two front panel controls. One for selecting the frequency range and other to adjust the selected frequency continuously. The oscillator has a frequency range from 5 Hz to kHz. The oscillator output is given to the AGC (automatic gain control) amplifier which permits the accurate gain adjustment by means of its feedback voltage. The AGC output is connected to impedance range switch which is an internal control with which the gain adjustment is possible. The impedance range switch is an attenuator network which controls the oscillator output voltage.

The impedance range switch operates in two modes. The constant current mode and the constant voltage mode are the two modes of operation. The three lower (Xl, X10 and X100) operate in constant current mode while higher ranges (XIK, XIOK, X100K and XlM)operate in constant voltage mode.

Constant current mode: The unknown component is connected at the input of differential amplifier. The impedance switch decides the current to be supplied to the component. The trans-resistance or RT amplifier maintains this current constant. The RT amplifier is an op-amp whose output voltage is proportional to the input current. The output of the a.c. differential amplifier is fed to amplifier and filter section. The filter section consists of high and low band filters which are changed with the frequency range and restrict the amplifier bandwidth. The filter output is applied to the detector that drives the Z magnitude meter. Since the current is maintained constant, the Z magnitude meter which measures the voltage across the unknown component deflects proportional to the magnitude of the impedance.

Constant voltage mode: The terminal that was connected to the input of trans-resistance amplifier in the constant current mode is now grounded. The other input of a.c. differential amplifier that was connected to the voltage terminal of the unknown component is now connected to a point on Z magnitude range switch which is held at a constant voltage. The voltage across the unknown component is- maintained at the constant level. The current through the unknown component is applied to the trans-resistance amplifier which again produces the output voltage proportional to the input current.

Now this output voltage is applied to the detector and the filter section. The Z magnitude meter deflects proportional to the magnitude of the impedance in the same manner as that in constant current mode. The roles of the a.c. differential amplifier and trans-resistance amplifier are reversed in constant voltage mode.

Phase angle measurement: The phase measurements are carried out simultaneously with the magnitude measurement. The output of the voltage and current channel are applied to the Schmitt triggers. The input to the Schmitt triggers is a sine wave. Thus Schmitt trigger produces a spike whenever input sine wave goes through the zero crossing. These spikes are applied to binary phase detector circuit. It consists of a bistable multivibrator a differential amplifier and integrating capacitor. The positive going pulse from constant current channel sets the multivibrator while pulse from constant voltage channel resets the multivibrator. These set and reset outputs are applied to the differential amplifier. It applies the difference voltage to an integrating capacitor. Thus the voltage across capacitor is directly proportional to the difference between the zero crossings of current and voltage waveforms. This is applied to the phase angle meter which directly indicates the phase difference in degrees.

The calibration of the vector impedance meter is performed by connecting standard components to the input terminals.

The applications of vector impedance meter are,

i. The magnitude and phase angle of unknown impedance can be determined simultaneously.
ii. Using the oscilloscope, displaying the Lissajous pattern, the reactance can be calculated.
iii. Impedance measurement over wide frequency range is possible.

Peak Responding Voltmeter

As the name indicates, this type of meter responds to the peak value of the a.c. input signal. The difference between average responding meter and this meter is the use of storage capacitors with the rectifying diode. The storage capacitor charges through the diode upto the peak value of the a.c. input signal. The d.c. amplifier then amplifies this signal and provides the necessary current for the meter movement proportional to the peak value of the input.

The types of peak responding voltmeters are,

1. DC coupled peak responding voltmeters
2. AC coupled peak responding voltmeters

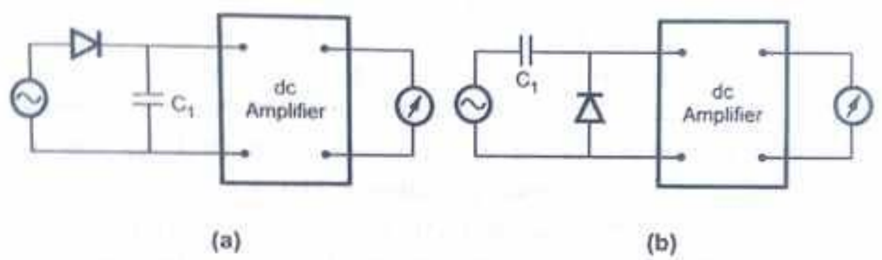


Fig. Peak responding voltmeters

The figure (a) shows the d.c coupled while igure (b) shows the a.c coupled peak responding voltmeter. In d c coupled voltmeter, the capacitor C1, charges to the total peak voltage above the ground reference, In this case, presence of d.c. with a.c. input affects the meter reading. In a.c. coupled peak reading voltmeter, the positions of diode and capacitor are interchanged. The capacitor still charges to the peak value of the a.c input.

In both the meters, a d.c. amplifier having very high Input impedance is used. Due to such high input impedance, the discharging of the capacitor takes place very slowly. Thus the negligible amount of current is supplied by the circuit under test. This keeps the capacitor charged to the peak value of the a.c. input. The d.c. amplifier provides the necessary meter current required for the deflection.

Advantages

i. When a.c. input is strong, the pre amplification of a.c. input is not necessary In such case, the capacitor and diode can be taken out of the instrument and placed in a probe. The measured a.c. signal in this case, travels no further than the diode. The loading effect is thus minimized.
ii. When capacitor and diode are placed in the probe, the frequencies up to hundreds of MHz can be measured.

Disadvantages

i. The harmonic distortion in the input, causes the errors.
ii. The instrument has limited sensitivity due to imperfect and nonlinear diode characteristics.
iii. The error is introduced if input waveform is not symmetrical

True RMS Responding Voltmeter

The r.m.s value means root mean square value. As mentioned earlier it is obtained by squaring the input signal and then calculating square root of its average value. The r.m.s value also called effective value- It compares the heating effect by a-c. And dc.

The true r.m.s, responding voltmeter produces a meter deflection by sensing the of the heating power of the wave form. This heating power is proportional to the square of the input r.m.s value. The measurement of heating power is achieved by the use of the input voltage to be measured is applied to the heater. The heating effect of the heater is sensed by a thermocouple attached to the heater. The thermocouple generates the corresponding voltage. The a.c. input is amplified and given to the heater element to achieve enough heating so that thermocouple can generate enough level of voltage to cause meter deflection. The output voltage is proportional to the r.m.s. value of the a.c input.

For a thermocouple, $$\text{Power} = \frac{E^2_{rms}}{R_{heater}}$$

$$\therefore \quad E_0 \propto \text{heat} \propto \text{power}$$

$$\therefore \quad E_0 = \frac{KE^2_{rms}}{R_{heater}}$$

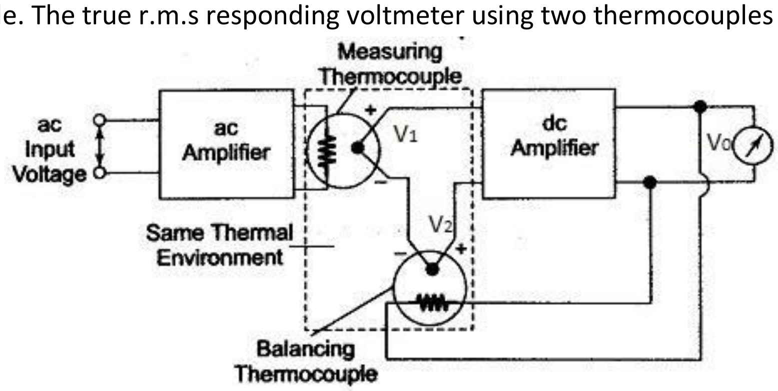
where E_{rms} = r.m.s. value of the a.c. input

E_0 = Output voltage of thermocouple

K = Constant of proportionality

The value of K depends distance between the heater and the thermocouple and also on the materials used in heater and the thermocouple.

The main difficulty in such a meter is the nonlinear characteristics of a thermocouple. In some instruments this difficulty is overcome by placing two thermocouples in the same thermal environment. The effect of the nonlinear behavior of the input thermocouple is cancelled by similar nonlinear effect caused by feedback path. The input thermocouple is called measuring thermocouple is called measuring thermocouple while the thermocouple in the feedback path is called balancing thermocouple. The true r.m.s responding voltmeter using two thermocouples is shown in Figure.



True RMS Voltmeter (Block Diagram)

The two thermocouples, balancing and measuring forms a balanced bridge in the input circuit of the d.c. amplifier. When the a.c. input is applied, the measuring thermocouple produces the voltage V_1 which upsets the balance of the bridge. The d.c. amplifier amplifies the unbalanced voltage. This amplified voltage is feedback to the balancing thermocouple, which heats the heater element to produce V_2 such that the balance of the bridge is re-established.

Thus the d.c. feedback current is the current which is producing same heating effect as that of a.c. input current i.e. the d.c. current is nothing but the r.m.s. value of the input current. The meter deflection is thus proportional to r.m.s or effective value of the a.c. input.

Mathematically we can write,

$$V_0 = A(V_1 - V_2)$$

where A = high gain of d.c. amplifier

$$\therefore \quad V_1 - V_2 = \frac{V_0}{A} = 0$$

In balanced condition of bridge and as A is very high,

$$V_1 = V_2$$

Now V_1 = output of measuring thermocouple

and V_2 = output of balancing thermocouple

$$\therefore \quad V_1 = KE^2_{rms}$$

where E_{rms} = r.m.s. value of the input

and $V_2 = KV_0^2$

where V_0 = output d.c. voltage

As K is same due to same thermal environment used for two thermocouples,

$$E^2_{rms} = V^2_0$$

$$\mathbf{V_0 = E_{rms}}$$

Advantages

i. The nonlinear behavior is avoided by using two thermocouples placed in same thermal environment.

ii. The true r.m.s. value measured is independent of the waveform of the a-c. Input, if the peak amplitude of a.c. input is within the dynamic range of the a.c. amplifier.

iii. Sensitivities in the millivolt region are possible. The voltages throughout a range of 100 gV to 300 V within a frequency range of 10 Hz to 10 MHz can be measured, with good instruments.

However the response of thermocouples is slow hence the overall response of the meter is sluggish. Similarly the crest factor puts the limitation on the meter reading in case of highly nonlinear waveforms. The meter cost is high compared to average and peak responding meters. A typical laboratory type r.m.s. responding voltmeter provides the accurate r.m.s. reading of complex waveforms having a crest factor (ratio of maximum to r.m.s. value) of 10/1.

Q METER

The determination of the storage factor Q is one of the most widely used means in the laboratory for testing radio frequency coils (RFC), inductors and capacitors. The storage factor is equal to Q = WoL/ R where Wo is the resonant angular frequency, L is the inductance and R is the effective resistance of a coil. The effective resistance, R, is never determined directly since its value depends upon the value of frequency. As is well known, the value of effective resistance with a.c. differs from its d.c. value on account of skin effect and eddy current losses. Since the value of R varies in a complex manner with frequency, it is indirectly determined by measuring the value of Q. The Q meter is an instrument which is designed to measure the value of Q directly and as such is very useful in measuring the characteristics of coils and capacitors.

Principle of working: The principle of working of this useful laboratory instrument is based upon the well-known characteristics of a resonant series R, L, C circuit. Figure 24.11(a) shows a coil of resistance R and inductance L in series with a capacitor C.

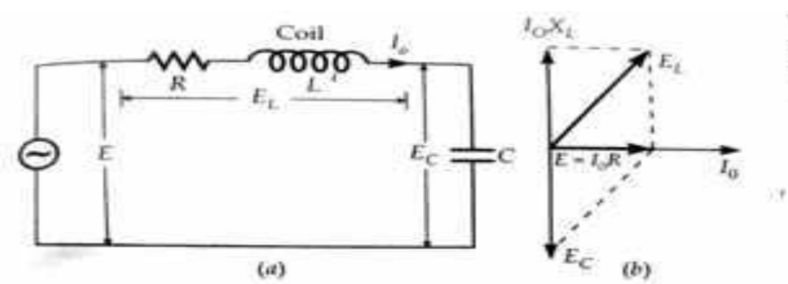


Fig. 24.11 A resonant *RLC* circuit and its phasor diagram.

At resonant frequency f_0, we have,

$$X_C = X_L$$

where capacitive reactance $X_C = 1/2\pi f_0 C = 1/\omega_0 C$

and inductive reactance $X_L = 2\pi f_0 L = \omega_0 L$

resonant frequency $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$

and current at resonance $I_0 = \dfrac{E}{R}$

The phasor diagram is shown in Fig. 24.11(*b*).

Voltage across capacitor, $E_C = I_0 X_C = I_0 X_L = I_0 \omega_0 L$

Input voltage $E = I_0 R$

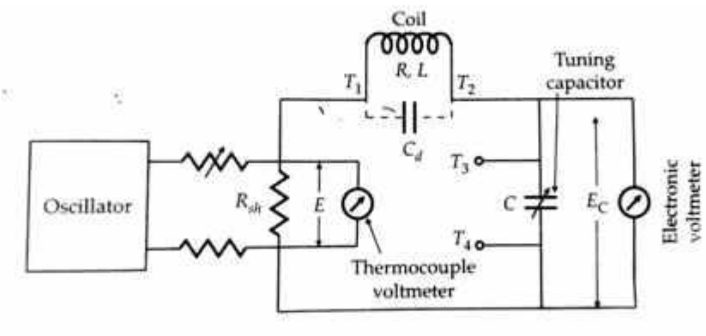
$$\therefore \quad \frac{E_C}{E} = \frac{I_0 \omega_0 L}{I_0 R} = \frac{\omega_0 L}{R} = Q$$

or $$E_0 = QE \qquad \text{...(24.32)}$$

Thus the input voltage E is magnified Q times.

If the input voltage E is kept constant, the voltage appearing across the capacitor is Q times E and a voltmeter connected across the capacitor can be calibrated to read the value of Q directly.

Practical Circuit: A practical Q meter circuit is shown in Fig. 24.12. It consists of a self-contained variable frequency RF oscillator. This oscillator delivers current to a low value shunt resistance Rsh. This low resistance is of the order of a hundredths of an ohm; a typical value may be 0.02Ω. Through this resistance a small value of voltage E is injected into the resonant circuit. This voltage is measured by a thermocouple voltmeter. Since the value of shunt resistance is very low, it introduces almost no resistance into the oscillatory circuit and therefore represents a voltage source of magnitude E, with a very small internal resistance. A calibrated standard variable capacitor C is used for resonating the circuit. An electronic voltmeter is connected across this capacitor. The coil under test is connected to terminals T1 and T2.



Application

1. Measurement of Q. The circuit for measurement of Q is shown in above Fig. The oscillator is set to the desired frequency and then the tuning capacitor is adjusted for maximum value of E. As discussed earlier under these conditions Q = Eo/ E and if the voltage is kept constant, the voltmeter connected across the capacitor may be calibrated to read the value of Q directly. This measured value of Q is commonly regarded as the Q of the coil under test. However, there is an error. The measured value of Q is the Q of whole the circuit and not of the coil. There are errors caused on account of the shunt resistance and also due to the distributed capacitance of the circuit.

Correction for shunt resistance. Measured value,

$$Q_{meas} = \frac{\omega_0 L}{R + R_{sh}}$$

True value $Q_{true} = \omega_0 L / R$

$$\therefore \quad Q_{true} = Q_{meas}\left(1 + \frac{R_{sh}}{R}\right) \qquad \text{...(24.33)}$$

Thus the measured value of Q is smaller than the true value. Now if coils of high resistance (low Q coils) are being measured, the difference between the two values may be negligible. But when measurements are done on low resistance (high Q) coils, the error caused on this account may be serious. Correction for distributed capacitance. The distributed capacitance or self-capacitance of measuring circuit modifies the true value of Q. The measured value of Q is less than the true value by a factor that depends upon the value of the distributed (self) capacitance and the tuning capacitor. It can be shown that

$$Q_{true} = Q_{meas}\left(1 + \frac{C_d}{C}\right) \quad ...(24.34)$$

where C_d = distributed or self-capacitance, and
C = tuning capacitance.

2. Measurement of inductance. The value of inductance is given by L = 1 / $4\pi^2 f0^2C$. The values fo and C are known and therefore the value of inductance may be calculated:
3. Measurement of Effective resistance. The value of the effective resistance may be computed from the relation R = WoL/ Q_{true}
4. **Measurement of self-capacitance:** The self capacitance is measured by making two measurements at different frequencies. The capacitor is set to a high value, and the circuit is resonated by adjustment of the oscillator frequency. Resonance is indicated by the circuit Q meter. Let the values of tuning capacitor be C1 and that of frequency be f1 under these conditions. Therefore,

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

The frequency is now increased to twice its initial value and the circuit is resonated again this time with the help of tuning capacitor. Let the value of tuning capacitor C2 and that of frequency bef2 under these conditions.

Thus,

$$f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$$

Now $f_2 = 2f_1$

$$\therefore \quad \frac{1}{2\pi\sqrt{L(C_2 + C_d)}} = 2 \times \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

or distributed capacitance $C_d = \dfrac{C_1 - 4C_2}{3}$ ...(24.35)

5. **Measurement of bandwidth**: The measurement of bandwidth with a Q meter is similar to the one used for measurement of effective resistance by variation of frequency method. The bandwidth is calculated by using Eqn. BW= fo/Q.
6. **Measurement of capacitance**: For measurement of capacitance a dummy coil is connected across terminal T1 and T2 (Fig. 24.12). The circuit is resonated by varying the value of the tuning capacitor. Let this value be C1. The capacitor under test C is now connected across terminals T3 and T4. This puts the test capacitor in parallel with tuning capacitor. The circuit is resonated again by varying the value of tuning capacitor. Let this value be C2. Therefore value of capacitance under test is CT = C1 — C2