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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – I – Biosensors and Measurements – SBMA1301

I. Measurement System

Measurement System – Functional elements of an instrumentation system - Static and Dynamic Characteristics - Errors in Measurements and their statistical analysis – Calibration - Primary and secondary standards. Bridge Circuits: Wheatstone bridge, Maxwell's bridge, Wein's bridge and Schering bridge.

1.1 Measurements:

Measurement is defined as the action or act or process of measuring something (any physical quantity). The measurement of a given quantity is essentially an act or the result of comparison between the input quantity (whose magnitude is unknown or the physical parameter is being observed or Measurand) and predefined standard, then the result is expressed in numerical values.

In fact, measurement is the process by which one can convert any physical parameters to meaningful numbers. The numerical value is meaningless unless followed by a unit used, since it (unit) identifies the characteristic or property measured. Figure 1.1 shows the basic process of measurement.

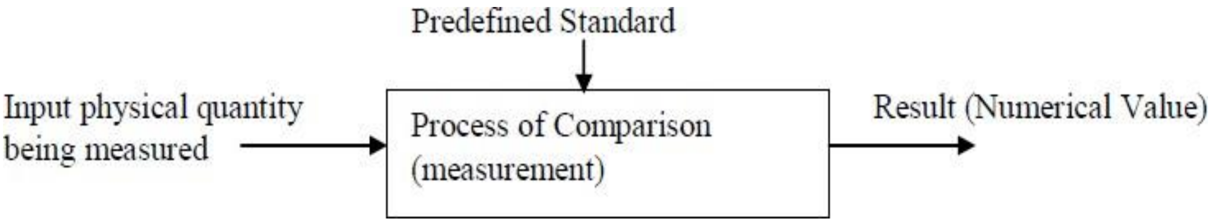


Figure 1.1: Basic Process of Measurement

Examples: To determine the Length of a piece of paper using ruler, Temperature of water and pressure of air etc.

1.1.1 Methods of Measurements:

Methods of measurements are broadly classified into two basic categories.

(1) Direct method of measurement and

(2) Indirect method of measurement

***1)* Direct method of measurement.**

In Direct method of measurement, Unknown Quantity (measurand) is directly compared with predefined standard. The result is expressed as a numerical value and a unit. Direct methods are common for the measurement of physical quantities like length, mass and time.

For Example, to measure the length of an iron bar, we compare the length of an iron bar with a standard ruler. The unit length is metre. An iron bar is so many times long because that many units on our standard having the same length as the bar. Here we have determined the length of paper by direct comparison with standard ruler.

- Direct methods are not always possible, feasible and practicable.
- Most of the cases inaccurate because they involve human factors

- Direct methods are also less sensitive.

Hence direct methods are not preferred for accurate measurements and are rarely used.

***2)* Indirect method of measurement.**

In indirect method of measurement, the physical parameters to be measured is compared with the predefined standard through the use of a calibrated system. (Calibration is the process of checking the accuracy of instrument by comparing the instrument reading with a standard or against a similar meter of known accuracy)

- Indirect methods are used is industries for accurate measurements.
- Example, Temperature measurement using thermocouple in industries.

A measurement system is defined as the system (Group of physical components) which is used for making measurements. It has as its input the quantity being measured and its output the value of that quantity. Generally, a measurement system is used to know the unknown value of a quantity or a variable.

- Measurement involves the use of instruments as a physical means of determining quantities or variable.
- In simple measurement, a measuring instrument consists of a single unit which gives an output reading according to the unknown input quantity applied to it.
- In complex measurement, a measuring instrument may be consisting of several separate elements like sensor/ transducer, signal conditioner and display.
- Because of this modular nature of the elements within it, it is common to refer the measuring instrument as a Measurement system.

1.2 Functions of Measurement systems:

The important three functions of measurement system are i) Indicating Function ii) Recording Function and iii) Controlling Function.

***i)* Indicating Function (Indicating measurement system)**

Instruments and systems use different kind of methods for obtaining information concerning the input unknown quantity under measurement. Mostly this information is obtained as a deflection of pointer of a measuring instrument. In this way the instruments perform a function which known as indicating function.

Example, the speed of automobile is indicated by deflection of pointer of a speedometer, Ammeter, Voltmeter and Wattmeter.

***ii)* Recording Function (Recording measurement system)**

In many cases the system makes a written record on the paper according to given input unknown quantity under measurement against time or against some other variable. Thus, system or instrument performs a recording function.

Example, Monitoring of instantaneous values of temperature records using potentiometric strip chart recorder with respect to time, monitoring of pressure and temperature relationship record for boiler and compressor using X-Y recorder.

***iii)* Controlling Function (Controlling measurement system)**

In this case, the information is used by the instrument or the system to control the original measured input unknown quantity. This controlling function is one of the most important functions used in the field of industrial control processes.

1.3 Elements of a generalized measurement system:

A systematic organization and analysis are more important for measurement systems. The whole operation system can be described in terms of functional elements. The functional elements of generalized measurement system are shown in figure 1.2.

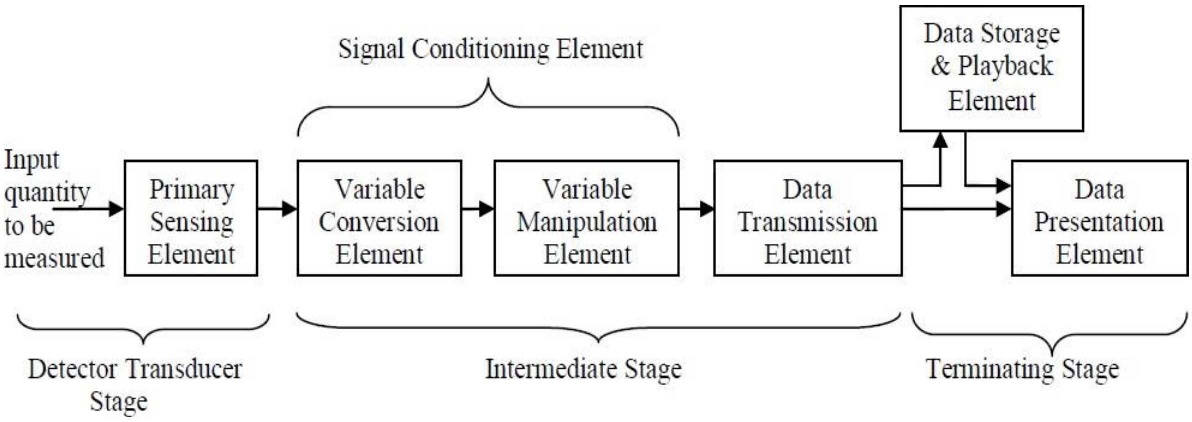


Figure 1.2: Functional elements of generalized measurement system

Most of the measurement system consists of following functional elements.

1. Primary sensing element
2. Variable conversion element
3. Variable manipulation element
4. Data transmission element
5. Data storage and playback element
6. Data presentation element

***1.* Primary Sensing Element**

An element of an instrument which makes first, the contact with the quantity to be measured is called primary sensing element. Thus, first detection of measurand is done by the primary sensing element. In most of the cases, a transducer follows primary sensing element which converts the measurand into a corresponding electrical signal. Transducer is defined as a device which converts a physical quantity into an electrical quantity. In many cases the physical quantity is directly converted into an electrical quantity by a transducer. So, the first stage of a measurement system is known as a detector transducer stage. Example, Pressure transducer with pressure sensor, Temperature sensor etc.

***2.* Variable Conversion Element**

The output of primary sensing element is electrical signal of any form like a voltage, a frequency or some other electrical parameter. Sometime this output not suitable for next level of system. So, it is necessary to convert the output to some other suitable form while preserving the information content of the original signal to perform the desired function of the instrument.

Variable conversion element converts the signal from one physical form to another without changing the information content of the signal.

For example, the output of primary sensing element is in analog form of signal and next stage of system accepts only in digital form of signal. So, we have to convert analog signal into digital form using an A/D converter. Here A/D converter acts as variable conversion element.

3. Variable Manipulation Element

The function of variable manipulation element is to manipulate the signal presented to it preserving the original nature of signal. Here manipulation means only change in the numerical value of signal.

Examples,

1. Voltage amplifier acts as variable manipulation element. Voltage amplifier accepts a small voltage signal as input and produces the voltage with greater magnitude. Here numerical value of voltage magnitude is increased.
2. Attenuator acts as variable manipulation element. It accepts a high voltage signal and produces the voltage or power with lower magnitude. Here numerical value of voltage magnitude is decreased.
   - Linear process manipulation elements: Amplification, attenuation, integration, differentiation, addition and subtraction etc.,
   - Nonlinear process manipulation elements: Modulation, detection, sampling, filtering, chopping and clipping etc.

These are performed on the signal to bring it to desired level to be accepted by the next stage of measurement system. This process of conversion is called signal conditioning. The combination of variable conversion and variable manipulation elements are called as Signal Conditioning Element.

4. Data Transmission Element

The elements of measurement system are actually physically separated; it becomes necessary to transmit the data from one to another. The element which is performs this function is called as data transmission element.

Example, Control signals are transmitted from earth station to Space-crafts by a telemetry system using radio signals.

The combination of Signal conditioning and transmission element is known as Intermediate Stage of measurement system.

5. Data storage and playback element

Some applications require a separate data storage and playback function for easily to rebuild the stored data based on the command. The data storage is made in the form of pen/ink and digital recording. Examples, magnetic tape recorder/ reproducer, X-Y recorder, X-t recorder, Optical Disc recording etc.

6. Data presentation Element

The information about the measured physical quantity is to be presented to a person handling the instrument in the proper form for monitoring, control and analysis purposes. This function is done by data presentation element. If the data is to be monitored then visual display devices are used as data presentation element.

These devices may be analog or digital instruments like ammeter, voltmeter, camera, CRT, printers, analog and digital computers. Computers are used for control and analysis of measured data of measurement system. This Final stage of measurement system is known as Terminating stage.

Example of generalized measurement system

Example 1. Bourdon Tube Pressure Gauge:

The simple pressure measurement system using bourdon tube pressure gauge is shown in figure 1.3. The detail functional elements of this pressure measurement system is given below.

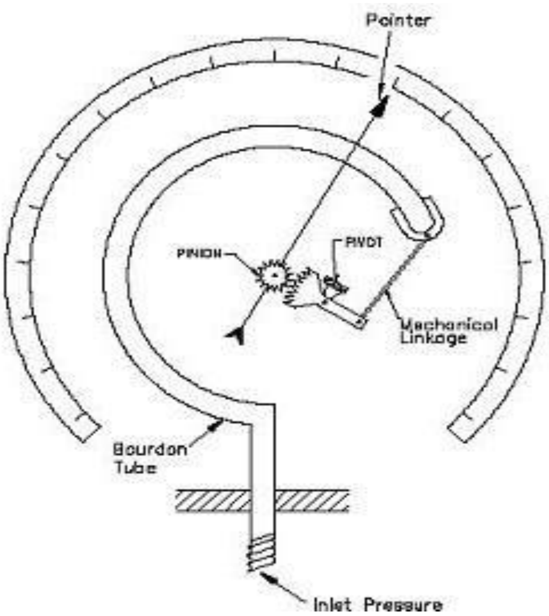


Figure 1.3: Bourdon tube pressure gauge

In this measurement system, bourdon tube acts as primary sensing and variable conversion element. Bourdon tube senses the input pressure and on account of input pressure the closed end of the tube is displaced. Pressure in converted into small displacement. The closed end of bourdon tube is connected through mechanical linkage to a gearing arrangement. The gearing arrangement amplifies the small displacement and makes the pointer to rotate through large angle. The mechanical linkage acts as a data transmission element while the gearing arrangement acts as a data manipulation element. The final data presentation stage consists of pointer & dial arrangement which gives an indication of the pressure signal applied to the bourdon tube. The schematic diagram of this measurement system is given in Fig:1.4

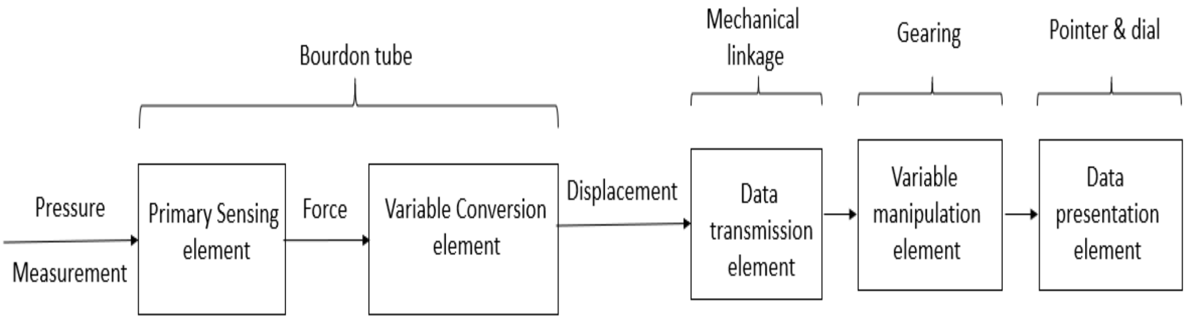


Figure 1.4: Schematic diagram of a Bourdon tube pressure gauge

1.4 Characteristics of Measuring Instruments:

These performance characteristics of an instrument are very important in their selection.

- Static Characteristics: Static characteristics of an instrument are considered for instruments which are used to measure an unvarying process condition. Performance criteria based upon static relations represent the static Characteristics. (The static characteristics are the value or performance given after the steady state condition has reached).
- Dynamic Characteristics: Dynamic characteristics of an instrument are considered for instruments which are used to measure a varying process condition. Performance criteria based upon dynamic relations represent the dynamic Characteristics.

1.4.1 Static Characteristics:

(i)Range and Span

- Range : The region between which the instrument operate is called range. Example: An ammeter whose scale reads from 0 to 1 mA is said to have a range from 0 to 1m A.
- Span is the algebraic difference between the upper and lower limits of the instrument range. Example: span :1mA
- For a thermometer calibrated between 200degree centigrade to 500 degree centigrade, the span is 300 degree centigrade .

(ii) Accuracy

- It is the degree of closeness with which the reading approaches the true value of the quantity to be measured.
- It determines the closeness to true value of instrument reading. The accuracy can be expressed in following ways:
- a) Point accuracy: This is the accuracy of the instrument only at one point on its scale.
- b)Accuracy as percentage of scale range: When an instrument as uniform scale, its accuracy may be expressed in terms of scale range.
- Eg: Accuracy of an instrument is specified by ±5% for the range of 0 to 200ºC in the temperature scale means the reading might be within + or -10ºC of the true reading.
- 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. Eg 5% of true value

(iii) Precision

Precision is the degree of repeatability of a series of the measurement. Precision is measures of the degree of closeness of agreement within a group of measurements are repeatedly made under the prescribed condition.

Precision is used in measurements to describe the stability or reliability or the reproducibility of results.

- The precision is composed of two characteristics:
- a) Conformity: Consider a resistor having true value as 2385692ohm , which is being measured by an ohmmeter. But the reader can read consistently, a value as 2.4 M ohm due to the nonavailability of proper scale.
- 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. More significant figures greater is the precision of an instrument.Eg: 210 V, 210.1V,210.04V

Comparison between accuracy and precision.

S.No	Accuracy	Precision
1.	It refers to degree of closeness of the measured value to the true value.	It refers to the degree of agreement among group of readings
2.	Accuracy gives the maximum error that is maximum departure of the final result from its true value.	Precision of a measuring system gives its capability to reproduce a certain reading with a given accuracy

***iv)* Static Error**

It is defined as the difference between the measured value and the true value of the quantity.

True value:It is the error free value of the measured variable.

True value= Measured value – Static error

***v)* Sensitivity:**

Sensitivity is defined as the ratio of change in output signal (response) to the change in input signal (measurand). It is the relationship indicating how much output changes when input changes.

$$\text{Sensitivity} = \frac{\text{change inoutput}}{\text{change in input}}$$

$$\text{Sensitivity} = \frac{\Delta q_o}{\Delta q_i}$$

If the sensitivity is constant then the system is said to be linear system. If the sensitivity is variable then the system is said to be non linear system.

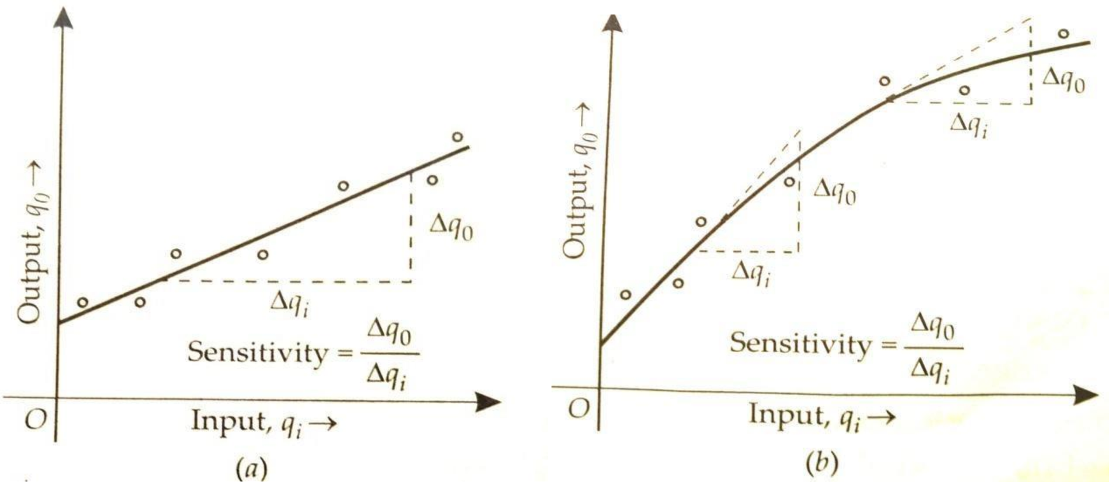
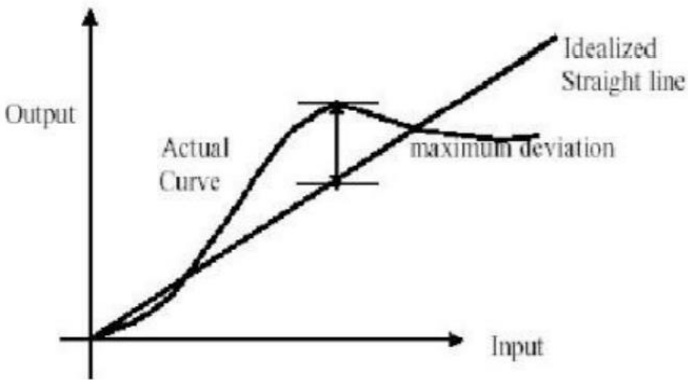


Figure 1.5: Definition of sensitivity for (a) Linear and (b) Non linear instrument

When the calibration curve is linear as in figure 1.5a the sensitivity of the instrument can be defined as in slope of the calibration curve. In this case sensitivity is constant over the entire range of instrument. If the curve is not normally straight line or nonlinear instrument sensitivity varies with the input or varies from on range to another as in figure 1.5b.

(vi) **Linearity**

- Linearity is the best characteristics of an instrument or measurement system.
- Linearity of the instrument refers to the output is linearly or directly proportional to input over the entire range of instrument.
- So the degree of linear (straight line) relationship between the output to input is called as linearity of an instrument.



Nonlinearity: The maximum difference or deviation of output curve from the Specified idealized straight line.

$$\text{Non linearity} = \frac{\text{Maximum deviation of output from the idealized straight line}}{\text{Actual reading or response}} \text{ X } 100$$

(vi) Repeatability

- Repeatability is defined as the ability of an instrument to give the same output for repeated applications of same input value under same environmental condition.

- It is the closeness between successive measurements of the output quantity for the same value of input under the same operating conditions.

(vii) Reproducibility

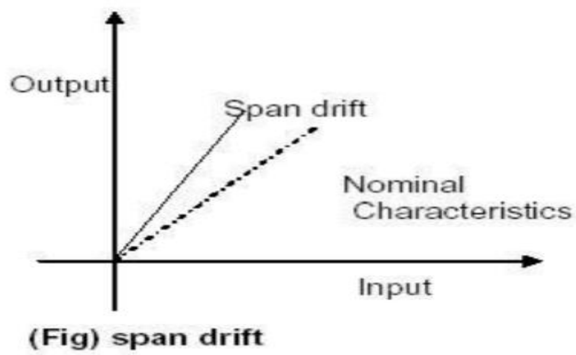
- Reproducibility is defined as the ability of an instrument to reproduce the same output for repeated applications of same input value under different environment condition.
- In case of perfect reproducibility, the instrument satisfies no drift condition

(viii) Drift

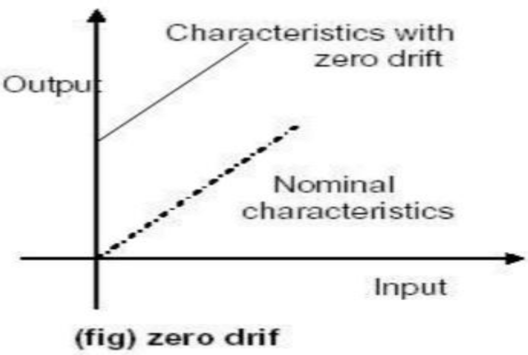
- Drift is an undesirable change in output over a period of time that is unrelated to change in input, operating conditions. (value of input variable, operating conditions does not change)
- Drift is occurred in instruments due to internal temperature variations, ageing effects and high stress etc.
- Drift may be classified into three categories:
- A)zero drift
- B)Span drift
- C)Zonal drift

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.



(Fig) span drift



(fig) zero drif

B)Span drift

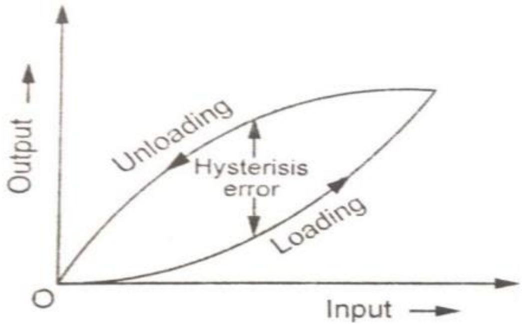
If there is proportional change in the indication all along the upward scale, the drifts is called span drift or sensitivity drift.

C)Zonal drift

In case the drift occurs only a portion of span of an instrument, it is called zonal drift.

(ix) Hysteresis

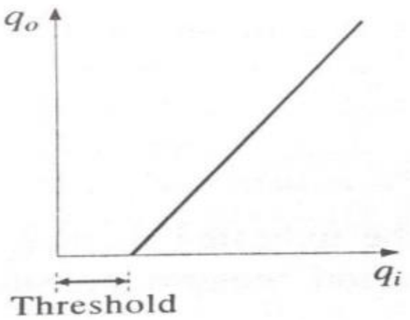
- Hysteresis is Non-coincidence of loading and unloading curves on output.
- When input of an instrument is slowly varied from zero to full scale and then back to zero, its output varies as shown in fig.



- If input is decreases from maximum value and output also decreases but does not follow the same curve, then there is a residual output when input is zero. This phenomenon is called Hysteresis. The difference between increasing change and decreasing change of output values is known as hysteresis error.

(x) Threshold

- The minimum value of input which is necessary to activate an instrument to produce an output is termed its threshold
- Threshold is the minimum value of the input required to cause the pointer to move from zero position
- If the input is increased very gradually from zero, there will be some minimum value below which no output change can be detected.
- This minimum value defines the threshold of an instrument.



(xi) Dead time

- It is the time required by a measurement system to begin to respond to a change in the measurand.

(xii) Dead zone

- Dead zone or dead band is defined as the largest change of input quantity for which there is no output the instrument.

- The region upto which the instrument does not respond for an input change is called dead zone**.**

(xiii) Resolution

Resolution or Discrimination is the smallest change in the input value that is required to cause an appreciable change in the output. (The smallest increment in input or input change which can be detected by an instrument is called as resolution or discrimination). So, if a non-zero quantity is slowly increased, output reading will not increase until some minimum change in the input takes place. The minimum change which causes the change in the output is called discrimination.

(xiii) Loading Effect

- Loading effect is the incapability of the system to faith fully measure, record or control the input signal in accurate form

1.4.2 Dynamic characteristics

- Dynamic characteristics of an instrument are considered for instruments which are used to measure a varying process condition.
- The set of criteria defined for the instruments, which are changes rapidly with time, is called ‘dynamic characteristics.
- As the input varies from instant to instant, output also varies from instant to instant.
- The dynamic behaviour of an instrument is determined by applying some standard form of known and predetermined input to its primary element (sensing element) and then studies the output.
- Generally dynamic behaviour is determined by applying following three types of inputs.

1. Step Input.

2.Linear Input

3.Sinusoidal input

- Step change in which the primary element is subjected to an instantaneous and finite change in measured variable and then remains constant
- Linear Input: Linear change, in which the primary element is, follows a measured variable, changing linearly with time.
- Sinusoidal input: Sinusoidal change, in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude

The dynamic characteristics of an instrument are

- (i) Speed of response

- (ii) Lag
- (iii) Fidelity
- (iv) Dynamic error

(i) **Speed of response**

- It is the rapidity with which an instrument responds to changes in the measured quantity.
- It gives information about how fast the system reacts to the changes in the input.

(ii) **Lag**

- It is the retardation or delay in the response of an instrument to changes in the measured variable. The measuring lags are two types:
  - Retardation type: In this case the response of an instrument begins immediately after a change in measured variable has occurred.
  - Time delay type: In this case the response of an instrument begins after a dead time after the application of the input quantity.

(iii) **Fidelity**

- It is the degree to which an instrument indicates the changes in the measured variable without dynamic error.
- (faithful reproduction or fidelity of an instrument is the ability of reproducing an input signal faithfully (truly)).

(iv) **Dynamic error**

- It is the difference between the true values of a quantity changing with time and the value indicated by the instrument, if no static error is assumed.
- It is also called as *Measurement Error*.

1.5 Errors in Measurements and their statistical analysis

Errors:

The difference between the measured value of quantity and true value (Reference Value) of quantity is called as Error.

Error = Measured value - True

Value $\delta A = A_m - A_t$

1.5.1 Classification of Errors:

All measurement can be made without perfect accuracy (degree of error must always be assumed). In reality, no measurement can ever made with 100% accuracy. It is important to find that actual accuracy and different types of errors can be occurred in measuring instruments. Errors may arise from different sources and usually classified as follows, Classification of Error

- Gross Errors
- Systematic Errors

1. Instrumental errors
    i. Inherent shortcomings of instruments
    ii. Misuse of instruments
    iii. Loading effects
2. Environmental errors
3. Observational errors

- Random Errors

1.Gross Errors

- These gross errors mainly occur due to carelessness or lack of experience of a human being.
- The main source of Gross errors is human mistakes in reading or using instruments and in recording and calculating measured quantity.
- As long as human beings are involved and they may grossly misread the scale reading, then definitely some gross errors will be occurred in measured value.
- Example, (i)Due to an oversight, Experimenter read the voltage as 31.5 V, While the actual reading is 21.5 V
- (ii) The reading may be transposed while recording. For example, 25.8 V actual reading may be recorded as 28.5 V.
- The complete elimination of gross errors is maybe impossible, one should try to predict and correct them.
- Some gross errors are easily identified while others may be very difficult to detect.
- The complete elimination of gross errors is not possible but one can minimize by the following ways.
- Great care should be taken in reading and recording the data.
- Two, three or even more readings should be taken for the quantity being measured by using different experimenters
- So, it is suitable to take a large number of readings as a close agreement between readings assures that no gross error has been occurred in measured values.

2.Systematic Errors

Systematic errors are divided into following three categories.

i. Instrumental Errors
ii. Environmental Errors
iii. Observational Errors

***i)* Instrumental Errors**

These errors are arises due to following three reasons (sources of error).

a) Due to inherent shortcoming of instrument
b) Due to misuse of the instruments, and
c) Due to loading effects of instruments

***a)* Inherent Shortcomings of instruments**

- These errors are inherent in instruments because of their mechanical structure due to construction, calibration or operation of the instruments or measuring devices.

- These errors may cause the instrument to read too low or too high.

  Example, if the spring (used for producing controlling torque) of a permanent magnet instrument has become weak, so the instrument will always read high. Errors may be caused because of friction, hysteresis .

Elimination or reduction methods of these errors,

- The instrument may be re-calibrated carefully.
- The procedure of measurement must be carefully planned. Substitution methods or calibration against standards may be used for the purpose.
- Correction factors should be applied after determining the instrumental errors.

(b) Misuse of the Instruments

- In some cases the errors are occurred in measurement due to the fault of the operator than that of the instrument.
- A good instrument used in an unintelligent way may give wrong results.
- Examples, Misuse of instruments may be failure to do zero adjustment of instrument, poor initial adjustments, using leads of high resistance and ill practices of instrument beyond the manufacturer's instruction and specifications etc.
- Such things do not cause the permanent damage to the instruments but definitely cause errors.

(C) Loading effects of Instruments

- The errors committed by loading effects due to improper use of an instrument for measurement work.
- In measurement system, loading effects are identified and corrections should be made or more suitable instruments can be used.
- Example, a well calibrated voltmeter may give a misleading (may be false) voltage reading when connected across a high resistance circuit. The same voltmeter, when connected across a low resistance circuit may give a more reliable reading (dependable or steady or true value). In this example, voltmeter has a loading effect on the circuit, altering the actual circuit conditions by measurement process.
- So errors caused by loading effect of the meters can be avoided by using them intelligently.

(ii) Environmental Errors

Environmental error occurs due to external environmental conditions of the instrument, such as effects of temperature, pressure, humidity, dust, vibration or external magnetic or electrostatic fields.

Elimination or reduction methods of these undesirable errors are

- Arrangements should be made to keep the conditions as nearly as constant as possible. Example, temperature can be kept constant by keeping the instrument in the temperature-controlled region.

- The device which is used against these environmental effects.
  Example, variations in resistance with temperature can be minimized by using very low resistance temperature co-efficient of resistive material.
- Employing techniques which eliminate the effects of these disturbances. For example, the effect of humidity dust etc., can be entirely eliminated by tightly sealing the equipment.
- The external or electrostatic effects can be eliminated by using magnetic or electrostatic shield on the instrument.
- Applying computed corrections: Efforts are normally made to avoid the use of application of computed corrections, but where these corrections are needed and are necessary, they are incorporated for the computations of the results.

(iii) Observational Errors

There are many sources of observational errors. As an example, the pointer of a voltmeter rests slightly above the surface of the scale. Thus an error on account of PARALLAX will be acquired unless the line of vision of the observer is exactly above the pointer. To minimize parallax errors, highly accurate meters are provided with mirrored scales as shown in figure 1.6.

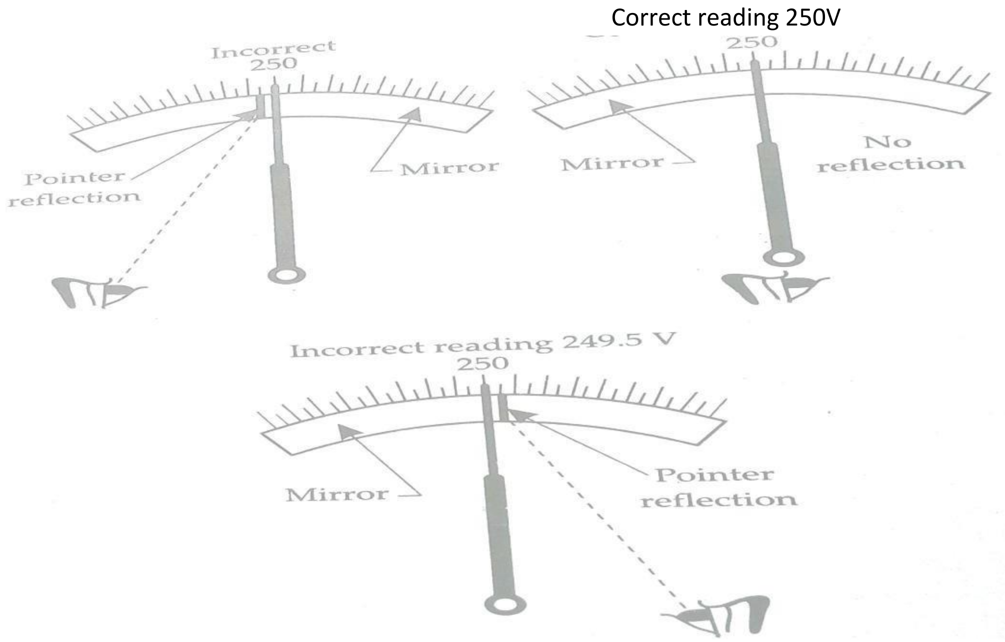


Figure 1.6: Errors due to parallax

When the pointer's image appears hidden by the pointer, observer's eye is directly in line with the pointer. Although a mirrored scale minimizes parallax error, an error is necessarily presented through it may be very small.

So we can eliminate this parallax error by having the pointer and scale in the same plane as shown in figure 1.7

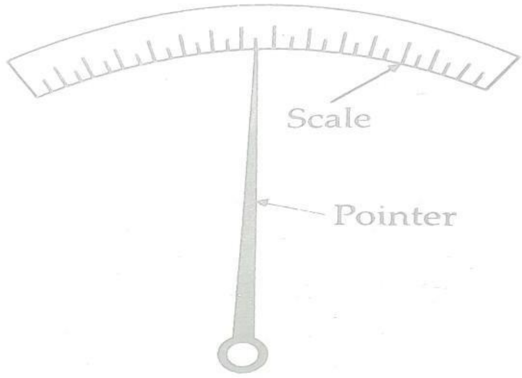


Figure 1.7: Arrangements showing scale and pointer in the same plane

The observational errors are also occurring due to involvement of human factors. For example, there are observational errors in measurements involving timing of an event Different observer may produce different results, especially when sound and light measurement are involved.

The complete elimination of this error can be achieved by using digital display of output.

3. Random Errors

- These errors are occurred due to unknown causes and are observed when the magnitude and polarity of a measurement fluctuate in changeable (random) manner.
- The quantity being measure is affected by many happenings or disturbances and ambient influence about which we are unaware are lumped together and called as Random or Residual. The errors caused by these disturbances are called Random Errors. Since the errors remain even after the systematic errors have been taken care, those errors are called as Residual (Random) Errors
- Random errors cannot normally be predicted or corrected, but they can be minimized by skilled observer and using a well-maintained quality instrument.
- These errors may be reduced by taking the average of a large number of readings.

1.6 Statistical Analysis:

- Statistical Evaluation of measured data is obtained in two methods of tests as shown in below.
  - Multi Sample Test: In multi sample test, repeated measured data have been acquired by different instruments, different methods of measurement and different observers.
  - Single Sample Test: measured data have been acquired by identical conditions (same instrument, methods and observer) excepting time
  - Inorder to get the exact value of the quantity under measurement, tests should be done using many different procedures, techniques and experimenters.
- Statistical Evaluation methods will give the most probable true value of measured quantity. The mathematical background statistical evaluation methods are Arithmetic Mean, Deviation Average Deviation, Standard Deviation and variance.

1.6.1 Arithmetic Mean

- The most probable value of measured reading is the arithmetic mean of the number of reading taken.
- The best approximation is made when the number of readings of the same quantity is very large.
- Arithmetic mean or average of measured variables X is calculated by taking the sum of all readings and dividing by the number of reading.
- The Average is given by,
  $X = (x1 + x2 + x3 + \cdots + xn)/ n = \Sigma x /n$
  Where, X= Arithmetic mean,
  x1, x2....... xn = Readings or variable or samples and
  n= number of readings

1.6.2 Deviation (Deviation from the Average value)

- The Deviation is departure of the observed reading from the arithmetic mean of the group of reading.
- Let the deviation of reading x1 be d1 and that of x2 be d2 etc.,
  d1= x1- X
  d2= x2- X
  .. .. ..
  dn= xn- X
- The algebraic sum deviation is Zero (d1+ d2+....+ dn= 0)
  Algebraic sum of deviations= d1+d2+d3+… +dn
  = (x1- X)+ (x2- X)+ ……..+ (xn- X)
  = (x1+x2+..+xn)-nX=0
  Where (x1+x2+..+xn)= nX

1.6.3 Average Deviation: Average deviation defined as the average of the modulus (without respect to its sign) of the individual deviations and is given by,

- $D = |d1| + |d2| + |d3| + \cdots + |dn|$ n = Σ|d| n
- Where, D= Average Deviation.
- The average deviation is used to identify precision of the instruments which is used in making measurements. Highly precise instruments will give a low average deviation between readings.

1.6.4 Standard Deviation :

- Standard deviation is used to analysis random errors occurred in measurement.
- The standard Deviation of an infinite number of data is defined as the square root of the sum of individual deviations squared, divided by the number of readings (n).

Standard deviation is $S.D = \sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n}} = \sqrt{\frac{\Sigma d^2}{n}}$; for n >20

Standard deviation is $S.D = s = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n-1}} = \sqrt{\frac{\Sigma d^2}{n-1}}$; for n <20

1.6.5 Variance

The variance is the mean square deviation, which is the same as S.D except Square root. Variance is Just the squared standard deviation.

Variance $V = (\text{Standard deviation})^2$

Variance $V = \sigma^2 = \frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n} = \frac{\Sigma d^2}{n}$; for n >20

Variance $V = s^2 = \frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n-1} = \frac{\Sigma d^2}{n-1}$; for n <20

1.6.6 Histogram (Frequency distribution Curve)

- When a number of Multisample observations are taken experimentally there is a scatter of the data about some central value.
- One graphical method to present test results is called histogram. A histogram is also called a frequency distribution curve.
- This histogram indicates the number of occurrences of particular value.
- The ordinate indicates the number of observed readings (frequency of occurrence) of a particular value.
- The steps have smaller increments and we get a smoother curve.

Length (mm)	Number of observed readings (frequency or occurrence)
99.7	1
99.8	4
99.9	12
100.0	19
100.1	10
100.2	3
100.3	1

Example: Table shows a set of 50 readings of length measurement. The most probable or central value of length is 100mm represented as shown in figure 1.8 Histogram.

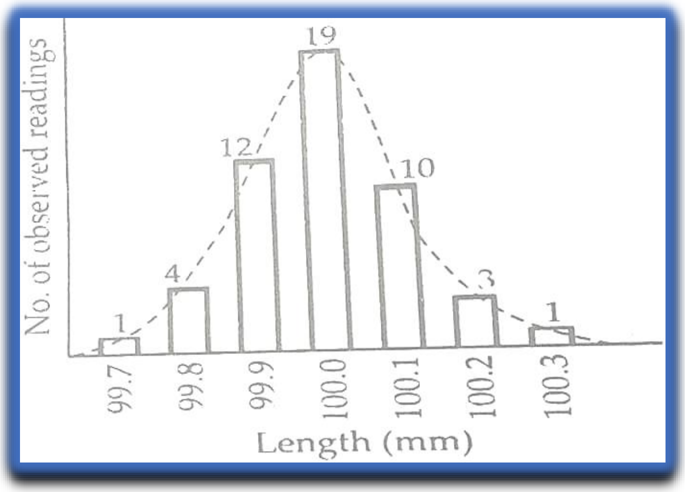


figure 1.8 Histogram.

1.6.7 Measure of Dispersion from the Mean

The property which denotes the extent to which the values are dispersed about the central value is termed as dispersion. The other name of dispersion is *spread or scatter*.

Measure of dispersion from central value is an indication of the degree of consistency (precision) and regularity of the data.

Example: Figure 1.9 shows the two sets of data and curve 1 vary from x_1 to x_2 and curve 2 vary from x_3 to x_4. Curve 1 is having smaller dispersion from central value than the curve 2. Therefore curve 1 is having greater precision than the curve 2.

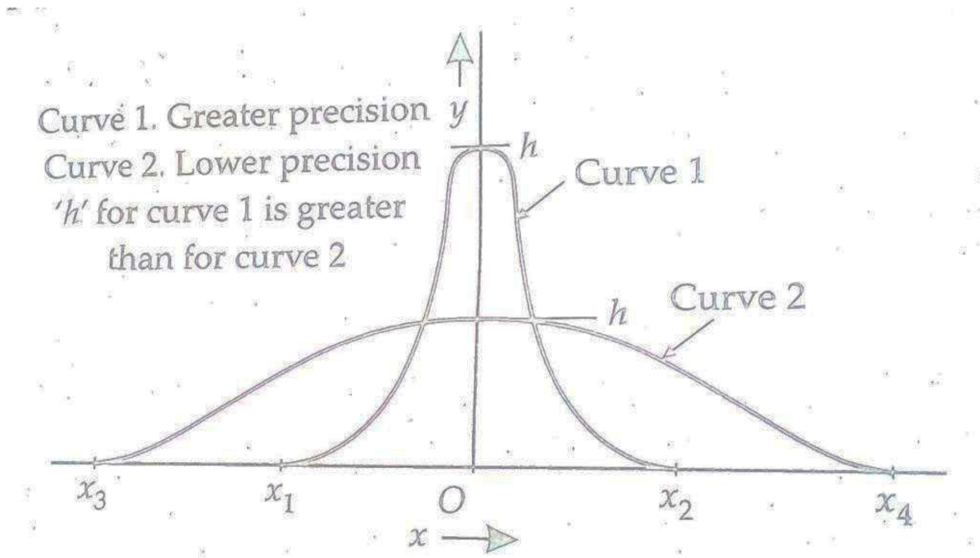


Figure 1.9: Curves showing different ranges and precision index

1.6.8 Probable error of finite number of readings

With a finite number of readings, the probable error is give by,

$$\boxed{e = 0.6745 \sqrt{\frac{\Sigma d^2}{n-1}}}$$

where $\quad d = $ deviation from mean

and $\quad \sigma = \sqrt{\frac{\Sigma d^2}{n-1}}$

$\therefore \quad \boxed{e = 0.6745\,\sigma}$

This is probable error for one reading.

While the average reading has the probable error of,

$$\boxed{e_m = 0.6745 \frac{\sigma}{\sqrt{n-1}}}$$

1.6.9 Limiting error

- In most of the instruments the accuracy is guaranteed to be within a certain percentage of full scale reading.
- The manufacturer has to specify the deviations from the nominal value of a particular quantity.
- The limits of these deviations from the specified value are called as Limiting Errors or Guarantee Errors**.**

Thus the actual value with the limiting error can be expressed mathematically as,

$$\boxed{A_a = A_s \pm \delta A}$$

where $\quad A_a = $ Actual value

$A_s = $ Specified or rated value

$\delta A = $ Limiting error or tolerance

-

Another example is say a resistor is specified by the manufacturer as 4.7 kΩ with a tolerance of ± 5% then the actual value of the resistance is guaranteed to be within the limits.

$$R = 4.7\ k\Omega \pm (5\ \%\ \text{of}\ 4.7\ k\Omega\ ) = 4.7\ k\Omega \pm 0.235\ k\Omega$$

$$= 4.935\ k\Omega \text{ and } 4.465\ k\Omega$$

1.6.10 Relative limiting error

- The relative limiting error is defined as the ratio of the error to the specified (nominal) magnitude of the quantity. This is also called fractional error.

Thus $\boxed{e = \frac{\delta A}{A_s}}$

where e = relative timing error

From the above equation, we can write,

$$\delta A = e \, . \, A_s$$

and

$$A_a = A_s \pm \delta A$$

$$= A_s \pm e \, A_s$$

$$\therefore \quad \boxed{A_a = A_s [1 \pm e]}$$

The percentage relative limiting error is expressed as

$$\boxed{\% \, e = e \times 100}$$

The relative limiting error can be also be expressed as,

$$\boxed{e = \frac{\text{Actual value } (A_a) - \text{Specified value } (A_s)}{\text{Specified value } (A_s)}}$$

Example.1: The set of voltage measurement that were recorded by eight different students in the laboratory as follows: 532V, 548V, 543V, 535V, 546V, 531V, 543V and 536. Calculate the Arithmetic mean, Deviations from mean, average deviation, the standard deviation, variance and probable error on recorded voltage data.

No=	x	$d_i = x_i - X$	d_i^2
1	532	-7.25	52.56
2	548	8.75	76.56
3	543	3.75	14.06
4	535	-4.25	18.06
5	546	6.75	45.56
6	531	-8.25	68.06
7	543	3.75	14.06
8	536	-3.25	10.56
	$\sum x_i = 4314$	$\sum \lvert d_i \rvert = 46$	$\sum d_i^2 = 299.48$

- (i) Arithmetic mean,

  X = $(x1 + x2 + x3 + \cdots + xn)$/ n

  = Σx /n = 4314/8= 539.25 V

- (ii) Average Deviation,

D = $(|d1| + |d2| + |d3| + \cdots + |dn|)$ /n

= Σ|d| /n = 46/8 = 5.75 V

(iii) Standard Deviation, $\sigma = \sqrt{\frac{\Sigma d_i^2}{n-1}}$

$= \sqrt{\frac{299.48}{7}}$

= 6.54V

- (IV) Variance $V = (\text{Standard deviation})^2$

$V = s^2$

V = 6.54*6.54

= 42.77 V

(V) Probable error of one reading = $0.6745\,\sigma$

= 0.6745 * 6.54

= 4.41 V

(VI) e_m = Probable error of mean = $\frac{0.6745\sigma}{\sqrt{n-1}}$

$= \frac{4.41}{\sqrt{8-1}}$

=1.66V

Example 2

Example *The table given below lists a sample of experimental data;*

Value	3	4	5	6	7	8	9	10	11
Frequency of occurrence	1	2	3	6	7	6	4	2	1

Calculate : a) Mean b) Mean deviation c) Standard deviation d) Variance e) Probable error of one reading f) Probable error of mean.

Value x	Frequency f	$x \times f$	Deviation $d_i = x_i - \bar{x}$	$f \times d_i$	d_i^2	$f \times d_i^2$
3	1	3	–4.0625	–4.0625	16.503	16.503
4	2	8	–3.0625	–6.125	9.378	18.7578
5	3	15	–2.0625	–6.1875	4.2539	12.7617
6	6	36	–1.0625	–6.375	1.1289	6.7734
7	7	49	–0.0625	–0.4375	3.9×10^{-3}	0.0273
8	6	48	+0.9375	+5.625	0.8789	5.2734
9	4	36	+1.9375	+7.75	3.7539	15.0156
10	2	20	+2.9375	+5.875	8.6289	17.2578
11	1	11	+3.9375	+3.9375	15.503	15.5039
	n = 32	$\Sigma\ x \times f = 226$		$\Sigma\ \lvert f \times d_i \rvert = 46.375$		$\Sigma\ f d_i^2 = 107.875$

a) Mean, $\bar{x} = \frac{\Sigma x \times f}{n} = \frac{226}{32} = \mathbf{7.0625}$

(b) Mean Deviation = $\frac{\Sigma \lvert f \times d_i \rvert}{n} = \frac{46.375}{32} =$

= 1.45

c) Standard Deviation = $\sigma = \sqrt{\frac{\Sigma f d_i^2}{n}} = \sqrt{\frac{107.875}{32}} =$

=1.836

d) Variance, $\sigma^2 = (1.836)^2$

= 3.3708

e) e = Probable error of one reading

$= 0.6745 \times \sigma = 0.6745 \times 1.836$

= 1.238

f)Probable error of mean

$e_m = \frac{0.6745\sigma}{\sqrt{n}}$

$= \frac{1.238}{\sqrt{32}} =$ 0.22

1.7 Calibration

Calibration is the process of checking the accuracy of instrument by comparing the instrument reading with a standard or against a similar meter of known accuracy. So using calibration is used to find the errors and accuracy of the measurement system or an instrument.

Calibration is an essential process to be undertaken for each instrument and measuring system regularly. The instruments which are actually used for measurement work must be calibrated against some reference instruments in which is having higher accuracy.

Reference instruments must be calibrated against instrument of still higher accuracy or against primary standard or against other standards of known accuracy.

The calibration is better carried out under the predetermined environmental conditions. All industrial grade instruments can be checked for accuracy in the laboratory by using the working standard.

Certification of an instrument manufactured by an industry is undertaken by National Physical Laboratory and other authorizes laboratories where the secondary standards and working standards are kept.

1.7.1 Process of Calibration

The procedure involved in calibration is called as process of calibration. Calibration procedure involves the comparison of particular instrument with either

- A primary standard,
- A secondary standard with higher accuracy than the instrument to be calibrated
- An instrument of known accuracy.

Procedure of calibration as follows.

- Study the construction of the instrument and identify and list all the possible inputs.
- Choose, as best as one can, which of the inputs will be significant in the application for which the instrument is to be calibrated.
- Standard and secure apparatus that will allow all significant inputs to vary over the ranges considered necessary.
- By holding some input constant, varying others and recording the output, develop the desired static input-output relations.

Theory and Principles of Calibration Methods

Calibration methods are classified into following two types,

1) Primary or Absolute method of calibration
2) Secondary or Comparison method of calibration
   i. Direct comparison method of calibration
   ii. Indirect comparison method of calibration

1) Primary or Absolute method of calibration

If the particular test instrument (the instrument to be calibrated) is calibrated against primary standard, then the calibration is called as primary or absolute calibration. After the primary calibration, the instrument can be used as a secondary calibration instrument.

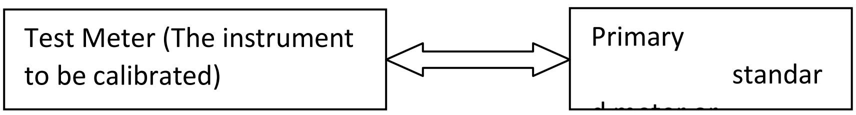


Figure 1.10: Representation of Primary Calibration

2) Secondary or Comparison calibration method

If the instrument is calibrated against secondary standard instrument, then the calibration is called as secondary calibration. This method is used for further calibration of other devices of lesser accuracy. Secondary calibration instruments are used in laboratory practice and also in the industries because they are practical calibration sources.

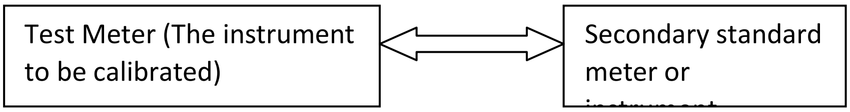


Figure 1.11: Representation of Secondary Calibration

Secondary calibration can be classified further two types,

i) Direct comparison method of Calibration

Direct comparison method of calibration with a known input source with same order of accuracy as primary calibration. So the instrument which is calibrated directly is also used as secondary calibration instruments.

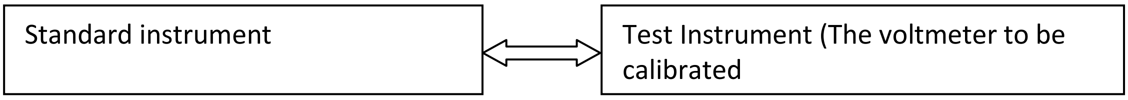


Figure 1.12: Representation of Direct method of Calibration

ii) Indirect comparison method of Calibration

The procedure of indirect method of calibration is based on the equivalence of two different devices with same comparison concept.

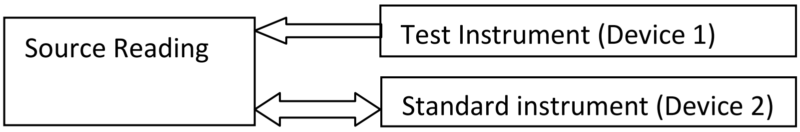


Figure 1.13: Representation of indirect method of Calibration

1.8 Standards of measurement:

- A standard is a physical representation of a unit of measurement. A known accurate measure of physical quantity is termed as standard. These standards are used to determine the accuracy of other physical quantities by the comparison method.
- Example, the fundamental unit of mass in the International System is the Kilogram and defined as the mass of a cubic decimetre of water at its temperature of maximum of density of 4^{o}C.
- Different standards are developed for checking the other units of measurements and all these standards are preserved at the International Bureau of Weight and Measures at Serves, Paris.

1.8.1 Classification of Standards

- Based on the functions and applications, standards are classified into four categories

1)International standards

2) Primary standards

3) Secondary standards

4) Working standards

1)International standards

- International standards are defined and established upon internationally.
- They are maintained at the International Bureau of Weights and measures and are not

accessible to ordinary users for measurements and calibration.

- They are periodically evaluated and checked by absolute measurements in terms of fundamental units of physics.
- International Ohms: It is defined as the resistance offered by a column of mercury having a mass of 14.4521gms, uniform cross sectional area and length of 106.300cm, to the flow of constant current at the melting point of ice.

2)Primary Standards

- Primary standards are maintained by the National Standards Laboratories (NSL) in different parts of the world.
- The principle function of primary standards is the calibration and verification of secondary standards.
- They are not available outside the National Laboratory for calibration.
- These primary standards are absolute standards of high accuracy that can be used as ultimate reference standards.

3)Secondary Standards

- These standards are basic reference standards used by measurement and calibration laboratories in industries.
- These secondary standards are maintained by the particular industry to which they belong.
- Each industry has its own secondary standard.
- Each laboratory periodically sends its secondary standard to the National Standards Laboratory for calibration and comparison against the primary standards.
- After comparison and calibration , the National Standards Laboratory returns the secondary standards to the particular industrial laboratory with a certification of measuring accuracy in terms of primary standards.

4)Working Standards

- The working standards are used for day-to-day use in measurement laboratories. So this standard is the principle tools of a measurement laboratory.
- It is used to check and calibrate laboratory instruments for accuracy and performance.

- Example, manufacturers of electronic components such as capacitors, resistors etc , use a standard called working standard for checking the component values being manufactured, a standard resistor for checking of resistance value manufactured**.**

1.9 Bridge Circuits

- Bridge circuits are used for measurement of resistance, inductance and capacitance.
- It consists of a network of 4 resistance arms forming a closed circuit.
- A source of current is applied to opposite junctions and the current detector is connected to other two junctions.
- It uses the comparison measurement methods and operate on null- indication principle.
- Bridge circuit compares the value of unknown component with that of an accurately known component, so its measurement accuracy is high.
- At balance condition, no current flows through the galvanometer.
- The components to be measured in one branch of the network and the network is adjusted until the detector indicates no output. At this condition, the bridge is said to be balanced.
- Then the unknown value can be found from the known values of the circuit.

1.9.1 Types of bridges

- Two types of bridges
- (i) D.C bridges
- (ii) A.C bridges
- (i) D.C bridges- used for the measurement of resistance, use the d.c voltage as the excitation voltage.
- (ii) A.C bridges- used for the measurement of impedances consisting of inductance and capacitances, use the alternating voltage as the excitation voltage.

1.9.2 Wheatstone bridge (D.C bridge)

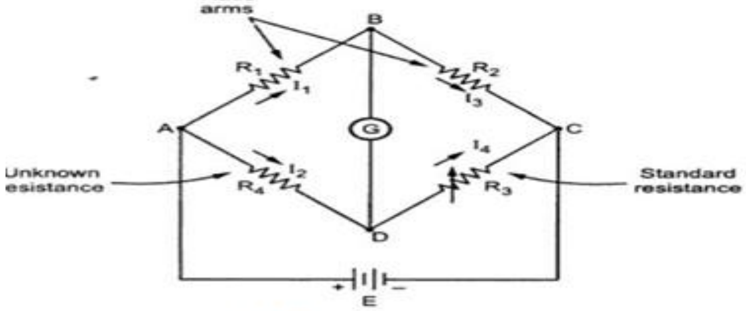


Fig. 1.14 Wheatstone bridge

The bridge consists of four resistive arms together with a source of e.m.f. and a null detector. The galvanometer is used as a null detector.

The Fig. shows the basic Wheatstone bridge circuit.

The arms consisting the resistances R_1 and R_2 are called **ratio arms.** The arm consisting the standard known resistance R_3 is called **standard arm.** The resistance R_4 is the

unknown resistance to be measured. The battery is connected between A and C while galvanometer is connected between B and D.

Balance Condition

When the bridge is balanced, the galvanometer carries zero current and it does not show any deflection. Thus bridge works on the **principle of null deflection** or **null indication.**

To have zero current through galvanometer, the points B and D must be at the same potential. Thus potential across arm AB must be same as the potential across arm AD.

Thus $$I_1 R_1 = I_2 R_4 \qquad \text{... (1)}$$

As galvanometer current is zero,

$$I_1 = I_3 \quad \text{and} \quad I_2 = I_4 \qquad \text{... (2)}$$

Considering the battery path under balanced condition,

$$I_1 = I_3 = \frac{E}{R_1 + R_2} \qquad \text{... (3)}$$

and $$I_2 = I_4 = \frac{E}{R_3 + R_4} \qquad \text{... (4)}$$

Using (3) and (4) in (1),

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

$$\therefore \quad R_1 (R_3 + R_4) = R_4 (R_1 + R_2)$$

$$\therefore R_1 R_3 + R_1 R_4 = R_1 R_4 + R_2 R_4$$

$$\therefore \quad \boxed{R_4 = R_3 \frac{R_1}{R_2}} \qquad \text{... (5)}$$

This is required balance condition of Wheatstone bridge.

Applications of Wheatstone Bridge

The Wheatstone bridge is basically a d.c. bridge and used to measure the resistances in the range 1 Ω to low megaohm.

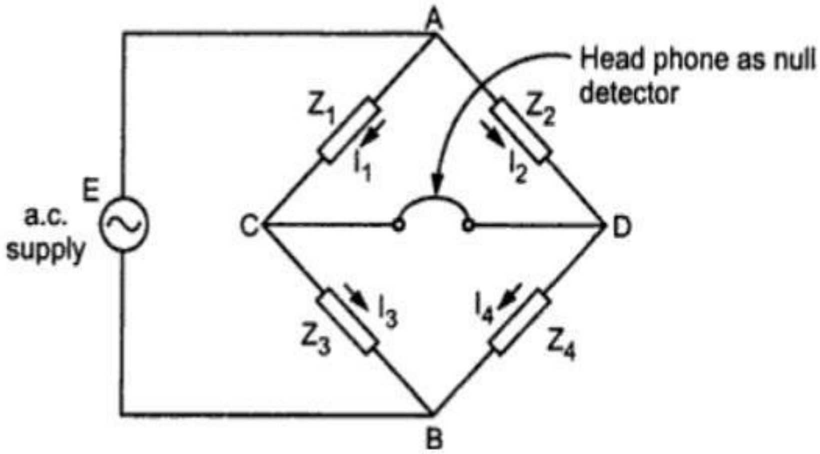
Limitations of Wheatstone Bridge

The bridge cannot be used for high resistance measurement i.e. measurement in high megaohm range. This is because while such measurement the resistance presented by the bridge becomes so large that the galvanometer becomes insensitive to show any imbalance.

Similarly heating effect due to large current also plays a major role. The excessive currents may generate heat which may cause the permanent change in the resistance.

1.9.3 A.C bridges

- Bridge arms are replaced by impedances
- Bridge is excited by an AC source.
- Galvanometer is replaced by detectors (Head phones, vibration galvanometers, tuneable amplifier detectors)



For bridge balance, the potential of point C must be same as the potential of point D. These potentials must be equal interms of amplitude as well as phase.

Thus the drop from A to C must be equal to drop across A to D, in both magnitude and phase for the bridge balance.

$$\therefore \quad \bar{E}_{AC} = \bar{E}_{AD} \quad \ldots (1)$$

The vector notation indicates, both amplitude and phase to be considered.

$$\therefore \quad \overline{I_1 Z_1} = \overline{I_2 Z_2} \quad \ldots (2)$$

When the bridge is balanced, no current flows through the headphones.

$$\therefore \quad \bar{I}_3 = \bar{I}_1 \quad \text{and} \quad \bar{I}_4 = \bar{I}_2$$

$$\text{Now} \quad \bar{I}_1 = \frac{\bar{E}}{\bar{Z}_1 + \bar{Z}_3} \quad \ldots (3)$$

$$\text{and} \quad \bar{I}_2 = \frac{\bar{E}}{\bar{Z}_2 + \bar{Z}_4} \quad \ldots (4)$$

Substituting (3) and (4) into (2) we get,

$$\frac{\bar{E} \cdot \bar{Z}_1}{\bar{Z}_1 + \bar{Z}_3} = \frac{\bar{E} \cdot \bar{Z}_2}{\bar{Z}_2 + \bar{Z}_4}$$

$$\therefore \overline{Z_1 Z_2} + \overline{Z_1 Z_4} = \overline{Z_1 Z_2} + \overline{Z_2 Z_3}$$

$$\therefore \quad \overline{Z_1 Z_4} = \overline{Z_2 Z_3} \quad \ldots (5)$$

The equation (5) is the **balancing equation** in the impedance form.

1.9.3.1 M**axwells inductance bridge**

- The bridge used for the measurement of self-inductance of the circuit is known as the Maxwell bridge.
- It is the advanced form of the Wheatstone bridge.
- The Maxwell bridge works on the principle of the comparison, i.e., the value of unknown inductance is determined by comparing it with the known value or standard value.
- Two methods are used for determining the self-inductance of the circuit. They are
- Maxwell's Inductance Bridge
- Maxwell's inductance Capacitance Bridge

Maxwell's inductance bridge

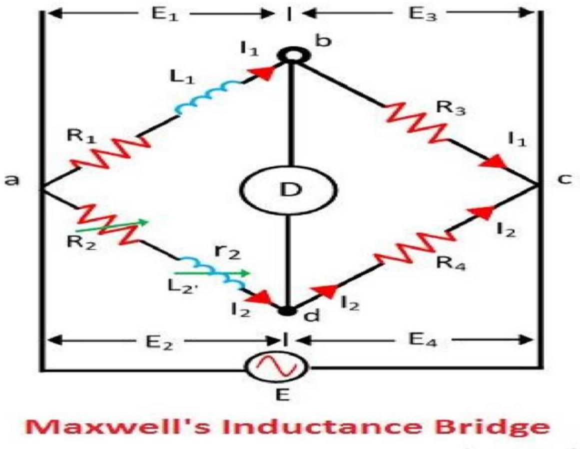


Figure 1.15 Maxwell's inductance Bridge

- the value of unknown inductance is determined by comparing it with the known value of the standard self-inductance.
- Let, L1– unknown inductance of resistance R1.
- L2– Variable inductance of fixed resistance r2 .
- R2 – variable resistance connected in series with inductor L2.
- R3, R4 – known non-inductance resistance

  - Impedance of arm ab, $Z_1 = (R_1 + j\omega L_1)$
  - Impedance of arm ad, $Z_2 = (R_2 + r_2 + j\omega L_2)$
  - Impedance of arm bc, $Z_3 = R_3$
  - Impedance of arm cd, $Z_4 = R_4$
  - Hence for balanced bridge,

$$Z_1 Z_4 = Z_2 Z_3$$

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

- Equating real and imaginary parts
- $R_1 R_4 = (R_2 + r_2) R_3$

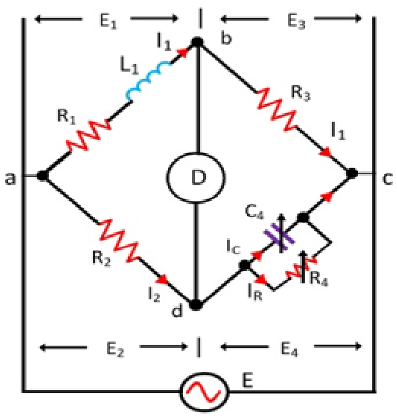
$$\boxed{R_1 = (R_2+r_2)(R_3/R_4)}$$

- $L_1 R_4 = L_2 R_3$

$$\boxed{L_1 = L_2 (R_3 / R_4)}$$

- Thus unknown inductance L_1 and its resistance R_1 may be calculated.

1.9.3.2 Maxwell's Inductance Capacitance Bridge



- the unknown inductance is measured with the help of the standard variable capacitance.
- L_1 = Unknown inductance with resistance R_1
- C_4 =variable standard capacitor
- R_2, R_3, R_4 = Known non inductive resistances

Figure 1.16 Maxwell's inductance Capacitance Bridge

- Impedance of arm ab, $Z_1 = (R_1 + j\omega L_1)$
- Impedance of arm ad, $Z_2 = R_2$
- Impedance of arm bc, $Z_3 = R_3$
- Impedance of arm cd, $Z_4 = 1/Y_4$ (R_4 parallel to C_4)
- $Y_4 = (1/R_4) + j\omega C_4$

Hence for balanced bridge,

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_1 (1/Y_4) = Z_2 Z_3$$

$$Z_1 = Z_2 Z_3 Y_4$$

$$(R_1 + j\omega L_1) = R_2 R_3 ((1/R_4) + j\omega C_4)$$

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

- Equating real and imaginary parts
- $R_1 = (R_2 R_3 / R_4)$
- $L_1 = C_4 R_2 R_3$
- Thus unknown inductance L1 and its resistance R1 may be calculated.

1.9.3.3 Schering Bridge

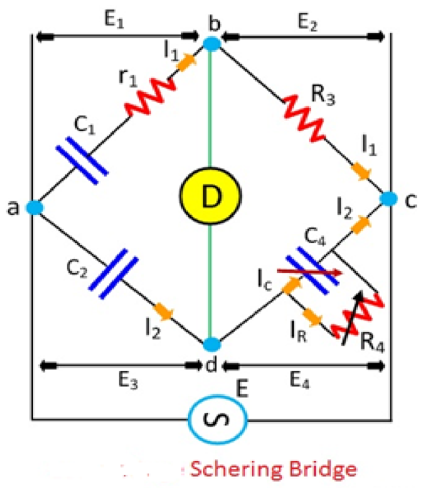


Figure 1.17 Schering Bridge

- use for measuring the capacitance
- Let C_1 – capacitor whose capacitance is to be determined,
  r_1 – a series resistance, representing the loss of the capacitor C_1.
  C_2 – a standard capacitor

  R_3 – a non-inductive resistance

  C_4 – a variable capacitor.

  R_4 – a variable non-inductive resistance

parallel with variable capacitor C_4.

- Impedance of arm ab, $Z_1 = r_1 + (1/j\omega C_1)$
- Impedance of arm ad, $Z_2 = 1/j\omega C_2$
- Impedance of arm bc, $Z_3 = R_3$
- Impedance of arm cd, $Z_4 = 1/Y_4$ (R_4 parallel to C_4)
- $Y_4 = (1/R_4) + j\omega C_4$
- Hence for balanced bridge,

$$Z_1 Z_4 = Z_2 Z_3$$

$$Z_1 (1/Y_4) = Z_2 Z_3$$

$$Z_1 = Z_2 Z_3 Y_4$$

- $r_1 + (1/j\omega C_1) = (1/j\omega C_2) R_3[(1/R_4) + j\omega C_4]$
- $r_1 + (1/j\omega C_1) = (R_3 / j\omega C_2 R_4) + (R_3 C_4 / C_2)$
- $r_1 - (j/\omega C_1) = (-jR_3 / \omega C_2 R_4) + (R_3 C_4 / C_2)$

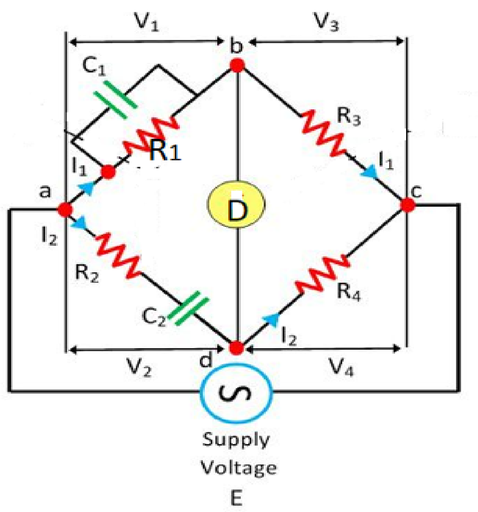
Equating real and imaginary parts

$$r_1 = (R_3\, C_4 / C_2)$$

$$(1/C_1) = (R_3 / C_2\, R_4)$$

$$C_1 = C_2\, (R_4 / R_3)$$

1.9.3.4 Wien's bridge



- The Wien's bridge is known as a frequency determining bridge and can be used for the measurement of capacitance also.
- Used in audio and high frequency oscillators as the frequency determining device
- resistance R_1 is connected in parallel with capacitance C_1
- resistance R_2 is connected in series with capacitance C_2
- R_3, R_4 – known non-inductance resistance

Figure 1.18 Wien's Bridge

- Impedance of arm ab, $Z_1 = 1/Y_1$ (R_1 parallel to C_1)
- $Y_1 = (1/R_1) + j\omega\, C_1$
- Impedance of arm ad, $Z_2 = R_2 + (1/j\omega C_2)$
- Impedance of arm bc, $Z_3 = R_3$
- Impedance of arm cd, $Z_4 = R_4$
- Hence for balanced bridge,

$$Z_1 Z_4 = Z_2\, Z_3$$

$$(1/Y_1)\, Z_4 = Z_2\, Z_3$$

$$Z_4 = Z_2\, Z_3\, Y_1$$

$$R_4 = (R_2 + (1/j\omega C_2))\;\; R_3\;\; ((1/R_1) + j\omega\, C_1)$$

$$R_4 / R_3 = (R_2 - j/\omega C_2)\;\; ((1/R_1) + j\omega\, C_1)$$

$$R4 / R3 = (R_2 / R_1) - (j/\omega C_2 R_1) + j\omega\, C_1\, R_2 + (C_1/C_2)$$

Equating real and imaginary parts

$R4 / R3 = (R_2 / R_1) + (C_1/C_2)$ ------------(1)

$-(1/\omega C_2 R_1) + \omega C_1 R_2 = 0$

$-1 + \omega^2 C_2 R_1 C_1 R_2 = 0$

$$R_2 \omega^2 C_2 C_1 R_1 = 1$$

$$\omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

By substituting the value of $\omega = 2\pi f$,

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

- In most wien bridges,
- $R_1 = R_2 = R$ and $C_1 = C_2 = C$
- Eqn (1) reduces to $R4 / R3 = 2$

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

TEXT / REFERENCE BOOKS

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DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – II – Biosensors and Measurements – SBMA1301

II.Passive and Active Transducers

Classification of transducers and characteristics for selection of transducers - Resistive transducers-Strain Gauge, Capacitive transducer - various arrangements, Inductive transducer, LVDT, Passive types: RTD materials & range, relative resistance vs. temperature characteristics, thermistor characteristics, Active type: Thermocouple - characteristics. Piezoelectric active transducer- Equivalent circuit and its characteristics. photo multiplier tube (PMT), photovoltaic, photo conductive cells, photo diodes, phototransistor, Optical displacement sensors and optical encoders.

2.1Transducer

Transducer is defined as a device, which converts energy or information from one form to another. It is a device which converts a physical quantity into an electrical signal.

2.1.1 Classification of transducers

The transducers may be classified in various ways such as on the basis of electrical principles involved, methods of application, methods of energy conversion used, nature of output signal etc

- On the basis of transduction form used
- Primary and Secondary Transducers
- Active and Passive Transducers
- Analog and Digital Transducers
- Transducers and Inverse Transducers

(i)On the basis of transduction form used

- Depending upon how they convert the input quantity into resistance, inductance or capacitance.
- Resistive, inductive, capacitive etc.

(ii)Primary and Secondary Transducers

- Some transducers consist of mechanical device along with the electrical device.
- In such transducer’s mechanical device acts as a primary transducer and converts physical quantity into mechanical signal.
- The electrical device that converts mechanical signal produced by primary transducer into an electrical signal acts as a secondary transducer.

- For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT. In this case LVDT is secondary transducer.

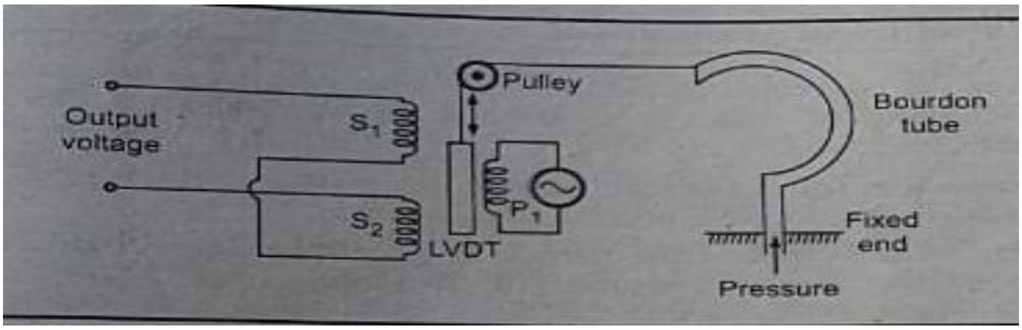


Figure 2.1 Pressure measurement

(iii)Active and Passive Transducers

- Active transducers- These transducers do not require any external source or power for their operation. So they are called as self-generating type.eg) Piezo electric crystal.
- Passive transducers- do not generate electrical signals by themselves. To obtain an electric signal for such transducers an extrernal power source is essential. They are also known as externally power-driven transducers. Eg. POT, LVDT

(iv)Analog and Digital Transducers

- Transducers, on the basis of nature of output signal, may be classified into analog and digital transducers.
- Analog transducer converts input signal into output signal, which is a continuous function of time such as thermistor, strain gauge, LVDT, thermo-couple etc.
- Digital transducer converts input signal into the output signal of the form of pulse e.g. it gives discrete output.

(v)Transducers and Inverse Transducers

- Transducer, as already defined, is a device that converts a non-electrical quantity into an electrical quantity.
- An inverse transducer is a device that converts an electrical quantity into a non-electrical quantity. (e.g) Loudspeaker converts electrical signal to sound signal. An ammeter or voltmeter converts electric current into mechanical movement.

2.2 Characteristics for selection of transducers

- **Operating Range:** Choice of transducer depends upon the useful range of input quantity.
- **Type of Input:** The type of input, which can be any physical quantity, is generally determined in advance .

- **Loading Effect :** The transducer, that is selected for a particular application should ideally exact NO force, power or energy from the quantity under measurement in order that is measured accurately
- **Response of transducer to environmental influences:** It should not be subjected to any disturbances like stray electromagnetic and electrostatic fields, mechanical shocks and vibrations temperature changes, pressure and humidity changes, changes in supply voltage and improper mechanical mountings.
- **Accuracy & repeatability :**High accuracy ensures that frequent calibration is not required and errors are less. Repeatability is more important than accuracy
- **Type of Electrical Output:** The type of output which may be available from the transducers may be available from the transducers may be a voltage, current , impedance or a time function of these amplitudes.
- **Sensitivity :** The transducers must be sensitive enough to produce detectable output.
- **Stability and reliability:** The transducer should exhibit a high degree of stability during its operation and storage life
- **ruggedness :**The ruggedness both of mechanical and electrical intensities of the transducer versus its size and weight must be considered. To withstand overloads**.**

  Static characteristics-low hysteresis, low non-linearity, high resolution

2.3 Resistive Transducer

- Resistive transducers are those in which the resistance changes due to a change in some physical phenomenon.
- In general, the resistance of a metal conductor is given by,
- $R = \rho L/A$.
- Where L is the length ,
- A is cross sectional area and
- ρ is resistivity of the resistance material.
- resistance can be changed if any of these value ρ,L or A is changed.

  Physical phenomenon (i.e) input signal to the transducer causes variation in resistance by changing anyone of the quantities ρ,L or A.

2.3.1 Potentiometers

- Principle Of Operation
- The resistance of their conductor varies with the variation in their lengths which is used for the measurement of displacement.
- A resistance potentiometer consists of a wire wound resistive element provided with a sliding contact.

- This sliding contact is called as wiper.
- A wire is generally made up of platinum or nickel alloy and has diameter as small as 0.01 mm. Thus, this wire is wound on insulating former.
- The resistance elements are also made up of cermet, hot moulded carbon,carbon film.
- With the help of potentiometric resistance transducers mechanical displacement is converted into an electrical output.
- The displacement either linear or angular is applied to the sliding contact and then the corresponding change in resistance is converted into voltage or current.

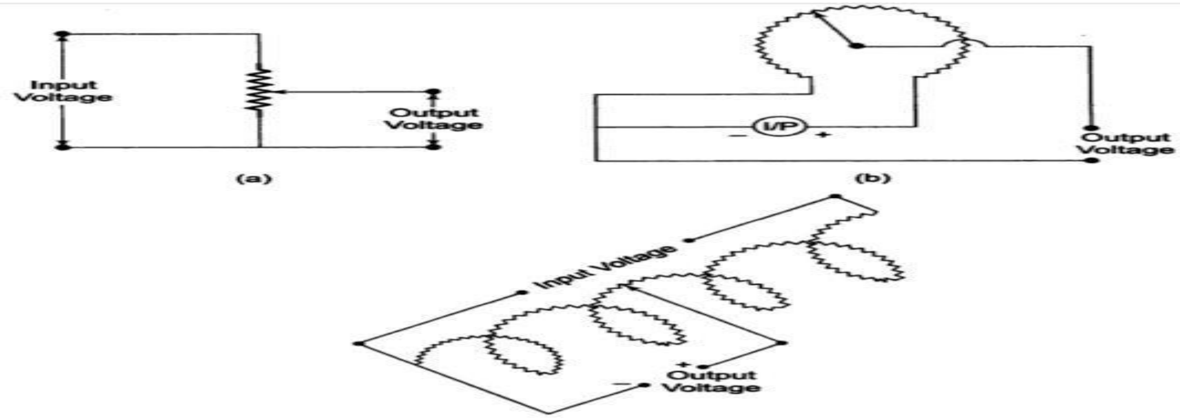


Figure 2.2 (a) Translatory Type (b) Rotational Type (c) Helipot (Rotational)

- POT - It’s a Passive Transducer.
- Linear Pot –Translational Motion
- Rotary Pot-Rotational Motion
- Helipots- Combination of the two motions (translational as well as rotational).

Advantages

- Cost-effective
- Simple design and simple working
- Can be used for measuring even large displacements.
- The device produces a large output and hence can be used for control purposes without further amplification steps. Thus the whole operation is bounded to a single device.
- Can produce a high electrical efficiency.

Disadvantages

- A huge force may be required for the slider movement.
- Can produce unwanted noise due to alignment problems, wear and tear of the sliding contact. This may also affect the total life of the device.

2.3.2 Strain Gauge

- When an external force is applied to an elastic material, stress is generated, which Subsequently deforms the material.
- At this time if applied force is a tensile force, the length L of the material extends to L+DL. The ratio of DL to L, that is DL/L, is called strain.
- (Precisely, this is called normal strain or longitudinal strain.) On the other hand, if a compressive force is applied, the length L is reduced to L- DL. Strain at this time is (-DL)/L.
- Strain is usually represented as e.
- Passive transducer
- Uses the variation in electrical resistance in wires to sense the strain produced by a force on the wires.

If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both the length and diameter of the conductor changes. Also, there is a change in the value of the resistivity of the conductor when subjected to strain, a property called the *piezo-resistive effect*. Therefore, resistance strain gauges are also known as *piezo resistive gauges*.

WORKING

- The strain gauge is connected into a Wheatstone Bridge circuit. The change in resistance is proportional to applied strain and is measured with Wheatstone bridge.

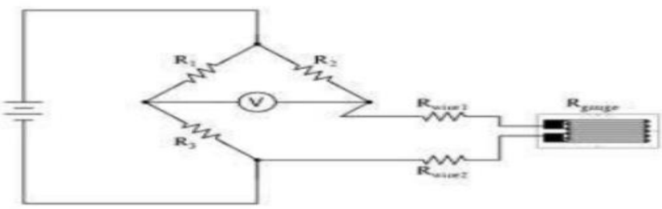


Figure 2.3 Strain gauge connected to a wheatstone bridge

The sensitivity of a strain gauge is described in terms of a characteristic called the gauge factor, defined as unit change in resistance per unit change in length, or

$$K = \frac{\Delta R/R}{\Delta l/l}$$

Gauge factor is related to Poisson's ratio μ by,

$$K=1+2\ \mu$$

2.3.2.1Types of strain gauges

- Wire strain gauges

a. Unbonded resistance wire Strain Gauge

b. Bonded resistance wire Strain Gauge

- Foil strain gauges
- Semiconductor strain gauges
- Wire strain gauges

Unbonded Metal Strain Gauge

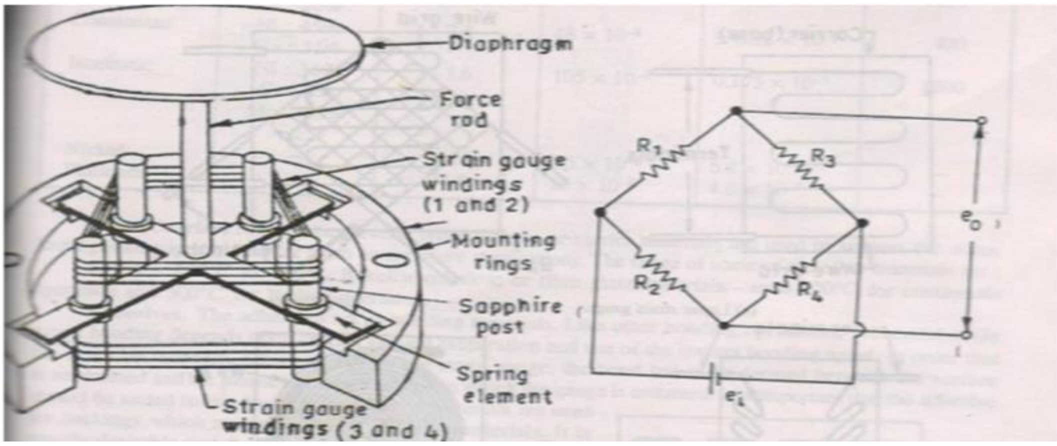


Figure:2.4 Unbonded strain gauge and measurement with a wheatstone bridge

- Used almost exclusively in transducer applications.
- At initial preload , the strains and resistances of the four arms are normally equal, with the result the output voltage of the bridge, e0=0.
- Application of pressure produces a small displacement , the displacement increases tension in 2 wires and decreasing the resistance of the remaining 2 wires.
- This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure.

Bonded Metal Wire Strain Gauge

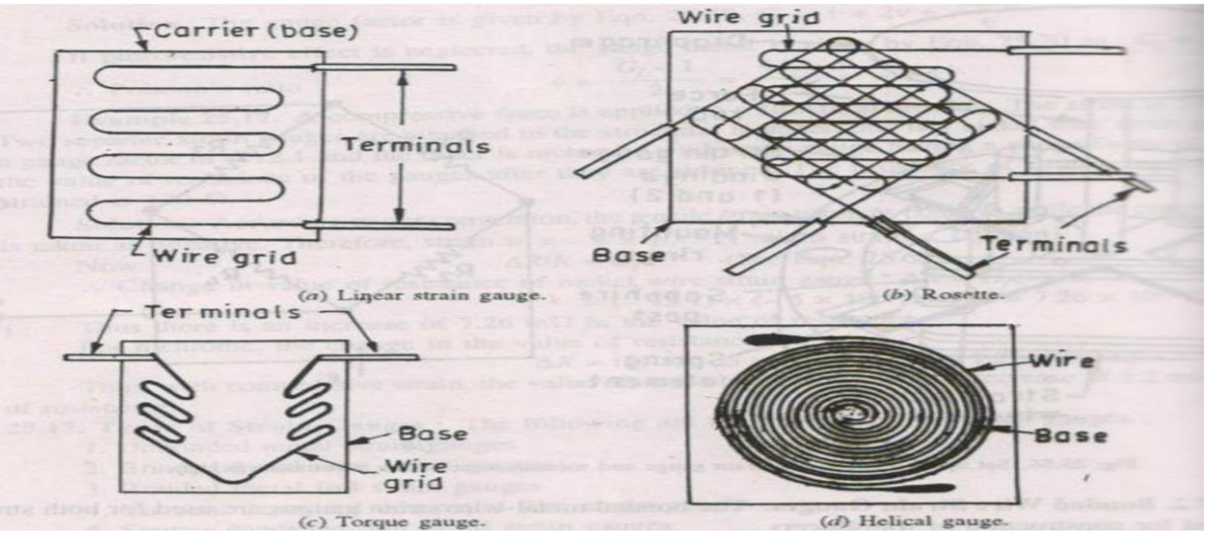


Figure:2.5 Bonded metal wire strain gauge

It consist of a grid of fine resistance wire of diameter of about 0.025mm.

- The wire is cemented to a base.
- The base – thin sheet of paper or bakelite.
- Wire is covered with a thin sheet of material so that it is not damaged mechanically.

The spreading of wire permits a uniform distribution of stress over a grid.

Bonded Metal Foil Strain Gauge

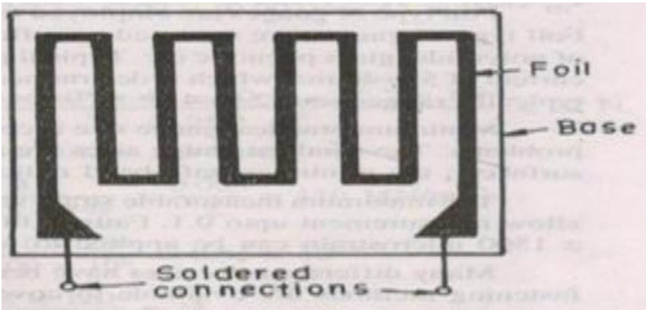


Figure 2.6: Bonded metal foil strain gauge

- Extension of the bonded metal wire strain gauge.
- The bonded metal wire strain gauge have been completely superseded by bonded foil strain gauge.
- Mostly used for the purpose of stress analysis and for many transducers.
- It have a much greater heat dissipation capacity due to larger surface area.
- They can be used for higher operating temperature range**.**

Semiconductor strain gauges

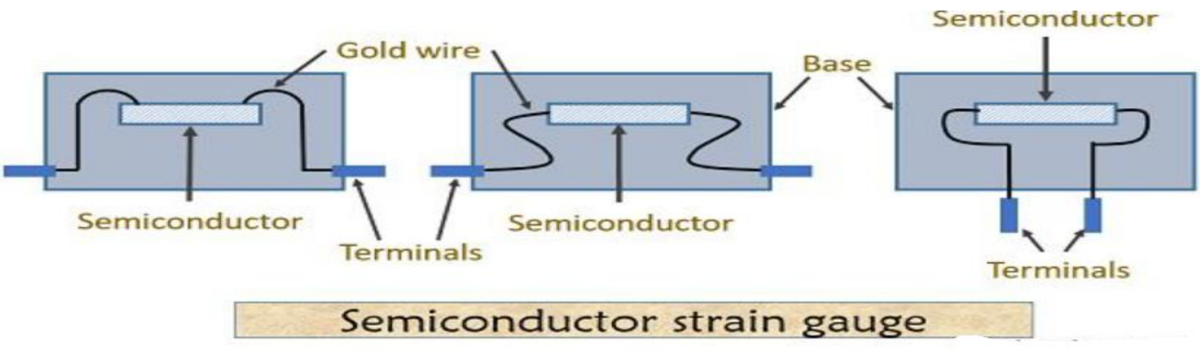


Figure 2.7: Semiconductor strain gauge

- In order to have a high sensitivity, a high value of gauge factor is desirable.
- A high gauge factor means a relatively higher change in resistance which can be easily measured with a good degree of accuracy.

- Semiconductor strain gauges are used where a very high gauge factor is required.
- The basic principle of operation of the semiconductor strain gauge is the piezoresistive effect(i.e) the change in value of resistance due to change in reistivity of the semiconductor because of strain applied.
- Semi-conducting materials such as silicon and germanium are used as resistive materials for semi-conductor strain gauges.
- A typical semiconductor strain gauge is formed by the semiconductor technology i.e., the semiconducting wafers or filaments of length varying from 2 mm to 10 mm and thickness of 0.05 mm are bonded on suitable insulating substrates (for example Teflon).
- The gold leads are usually employed for making electrical contacts.

2.4 Capacitive transducer

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 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. In the instruments using capacitance transducers the value of the capacitance changes due to change in the value of the input quantity that is to be measured.

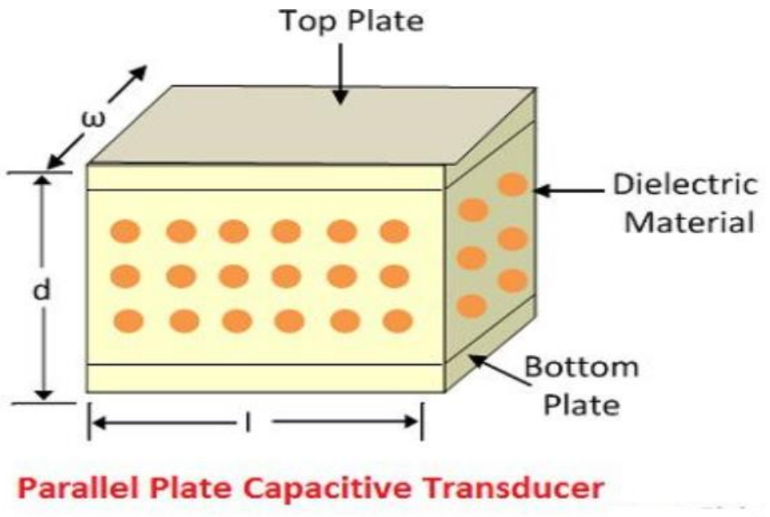


Figure 2.8: Capacitive transducer

The capacitance C between the two plates of capacitive transducers is given by:

$$C = \varepsilon A/d$$

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

Where A – overlapping area of plates in m^2

d – the distance between two plates in m

ε – permittivity of the medium in F/m

ε_r – relative permittivity

ε_0 – the permittivity of free space; $8.854*10^{-12}$ F/m.

Thus the capacitance of the variable capacitance transducer can change with the

(i) change in the area of the plates

(ii) change of the dielectric material and

(iii) the distance between the plates.

These changes are caused by physical variables like displacement, force and pressure in most of the cases. The change in capacitance may be caused by change in dielectric constant as is the case in measurement of liquid or gas levels.

Depending on the parameter that changes for the capacitive transducers, they are of three types as mentioned below.

(i)Changing Area of the Plates of Capacitive Transducers

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 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.

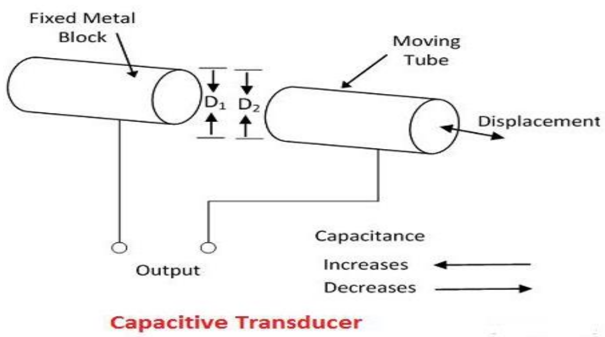


Figure 2.9: Capacitive transducer

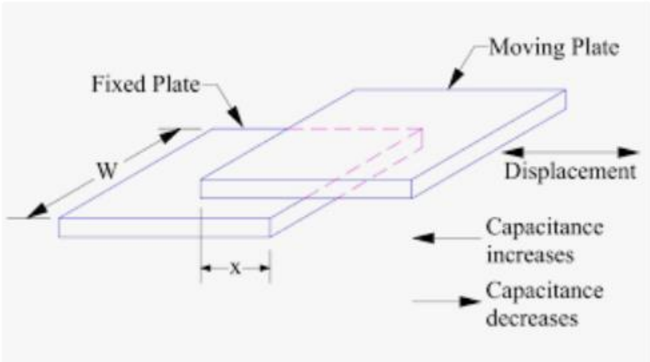


Figure 2.10: Changing Area of the Plates of Capacitive transducer

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 angular movement changes the capacitance of the transducers. The capacitance between them is maximum when these plates overlap each other.

Figure 2.11: Angular displacement

(ii) Changing Distance between the Plates of Capacitive Transducers

In these capacitive transducers the distance between the plates is variable, while the area of the plates and the dielectric constant remain constant. A Capacitive Transducer can also be designed to respond to linear displacement by attaching one of the plates of capacitor to the moving object and keeping the other plate fixed. When the object moves, the distance between the plate changes and hence the capacitance changes.

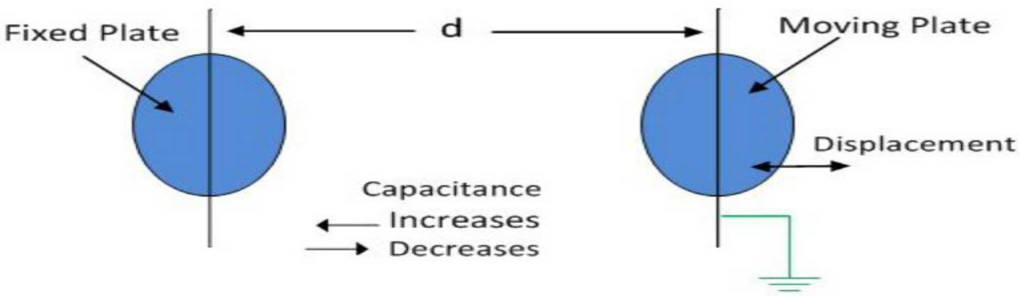
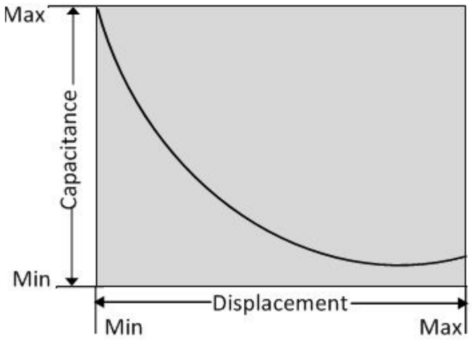


Figure 2.12: Changing Distance between the Plates of Capacitive Transducers

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.



(iii) Changing Dielectric Constant type of Capacitive Transducers

In this capacitive transducer the dielectric material between the two plates changes, due to which the capacitance of the transducer also changes. When the input quantity to be measured changes the value of the dielectric constant also changes so the capacitance of the instrument changes.

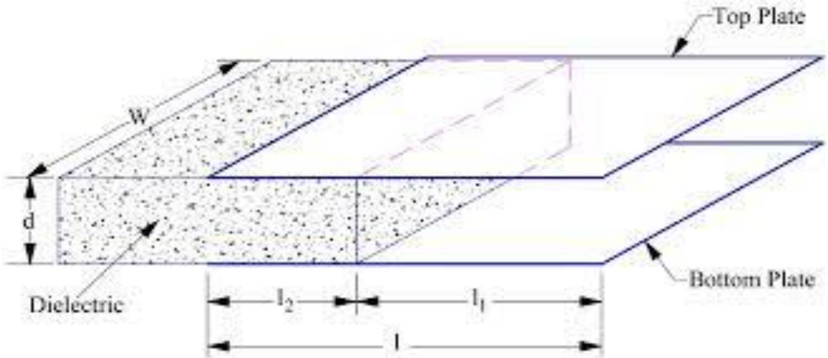


Figure 2.13: Changing Dielectric Constant type of Capacitive Transducers

The plates of capacitor are fixed. However, a moving object having some dielectric constant ε_r is moving into the plates. We want to measure the displacement of the object. At any intermediate stage, let the l_2 length of object is inside the plates. Therefore, up to l_2 length, the capacitor is filled up with dielectric having dielectric constant ε_r whereas l_1 length have air. The capacitance in this combination can be found as shown below.

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

From the above expression, it is clear that, as the object moves into the capacitor, the value of l_2 increases and hence the capacitance C increases. By measuring this capacitance, the linear displacement can be predicted.

Advantages

- This transducer requires very small force to operate
- They are very sensitive.
- The loading effect is minimum.

- Measurement of Inductive Transducer is affected by the stray magnetic field whereas a capacitive transducer is not affected.
- The power requirement of capacitive transducer is less as they require less force to operate.

Disadvantages

- Capacitive Transducer requires its metallic part to be insulated from each other.
- The capacitance may change due to dust, moisture etc.
- They are temperature sensitive and therefore, any change in temperature adversely affects their performance.

2.4.1 Capacitive pressure transducers

The capacitive pressure transducer is based on the principle that when the distance between the two parallel plate changes, capacitance of the parallel plate capacitor changes. Here , the diaphragm acts as one of the plates of a two plate capacitor , while other plate is fixed. The fixed plate and the diaphragm are separated by a dielectric material. When the force is applied to the diaphragm, it changes its position from initial static position obtained with no force applied. Due to this, the distance of separation between the fixed plate and the diaphragm

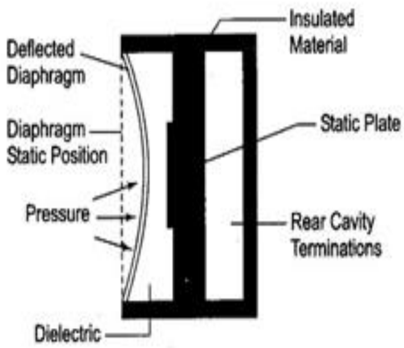


Figure 2.14 Capacitive pressure transducers

changes, hence the capacitance also changes. The change in capacitance can be measured by using any simple a.c bridge.

2.5 Inductive transducer

Inductive Transducer is the self-generating type otherwise the passive type transducer. The first type like self-generating uses the principle of fundamental electrical generator. The electric generator principle is when a motion between a conductor as well as magnetic field induces a voltage within the conductor. This motion between the conductor and the field is supplied by changes in the measurand. An inductive transducer is an electromechanical device used to convert physical motion into change in inductance.

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

i)Variation of self inductance

ii) Variation of mutual inductance

The property of self-inductance is a particular form of electromagnetic induction. Self inductance is defined as the induction of a voltage in a current-carrying wire when the current in the wire itself is changing. In the case of self-inductance, the magnetic field created by a changing current in the circuit itself induces a voltage in the same circuit. Therefore, the voltage is self-induced.

Mutual Inductance is the interaction of one coils magnetic field on another coil as it induces a voltage in the adjacent coil. when the emf is induced into an adjacent coil situated within the same magnetic field, the emf is said to be induced magnetically, inductively or by **Mutual induction**, symbol (M). Then when two or more coils are magnetically linked together by a common magnetic flux they are said to have the property of **Mutual Inductance**.

2.5.1 Linear Variable Differential Transformer (LVDT)

The LVDT converts the displacement into an electrical signal. LVDT consists of one primary winding (P) and two secondary windings (S1 and S2) with equal number of turns wound on a hollow cylindrical former. The two secondary windings are connected in series opposition and are placed identically on either side of primary winding to which an AC excitation voltage is connected. A movable soft iron core is placed within the cylindrical former. When the displacement to be measured is applied to the arm of the core, the LVDT converts this displacement into an electrical signal.

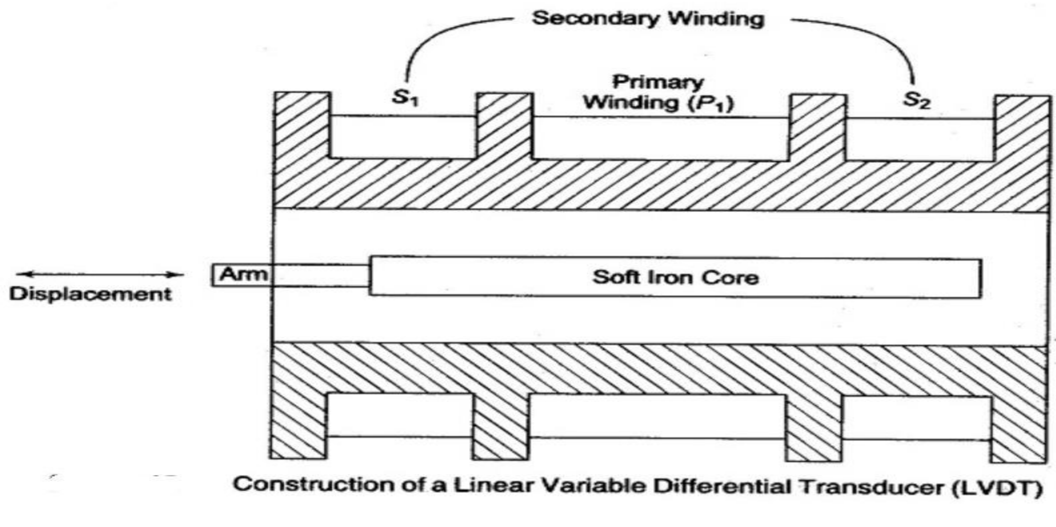


Figure 2.15 Linear Variable Differential transsformer

The operating principle of LVDT:-

The operating principle of LVDT depends on mutual inductance. In the LVDT when the primary winding is supplied with A.C. supply voltage, it generates alternating magnetic field. Due to this magnetic field an alternating voltage will be induced in the two secondary windings. Es1 is the output voltage of secondary winding S1 and Es2 is the output voltage of secondary winding S2. In order to get single differential output voltage two secondary windings are connected in series opposition. Thus the differential output voltage is given by,

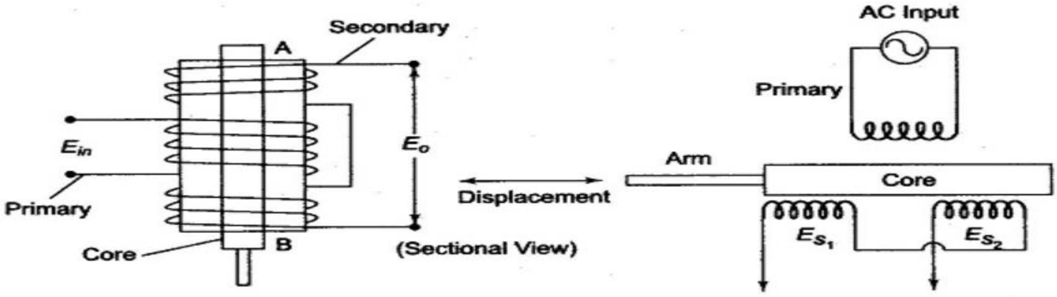
$E0=Es1-Es2$

When the core is placed symmetrically with respect to two secondary windings an equal amount of voltage will be induced in both windings. Therefore esl - es2 and the output voltage is '0'. Hence, this position is known as null position.

Now if the core is moved towards up from null position, more magnetic field links with secondary winding S1, and small field links with secondary winding S2. Therefore more voltage will be induced in S1 and less in S2 i .e .,Es1 will be larger than Es2 . Hence the differential output voltage is E0 = Es1-Es2 and is in phase with primary voltage.

But when the core is moved towards down from null position more magnetic field links with secondary winding S2 and small field links with secondary winding S1. Therefore, more voltage will be induced in S2 and less in S1, i.e., Es2 will be larger than Es1. Hence, the differential output voltage is E0 = Es2 – Es1 and is 180° out of phase with primary voltage. Thus, the output voltage E0 position of the core and hence the displacement applied to the arm of the core.

By noting which output is increasing or decreasing, the direction of motion could be determined. Hence amplitude is a function of distance the core has moved and polarity or phase indicates the direction of motion.



(a) Construction (b) Basic Circuit

Secondary Winding Connected for Differential Output

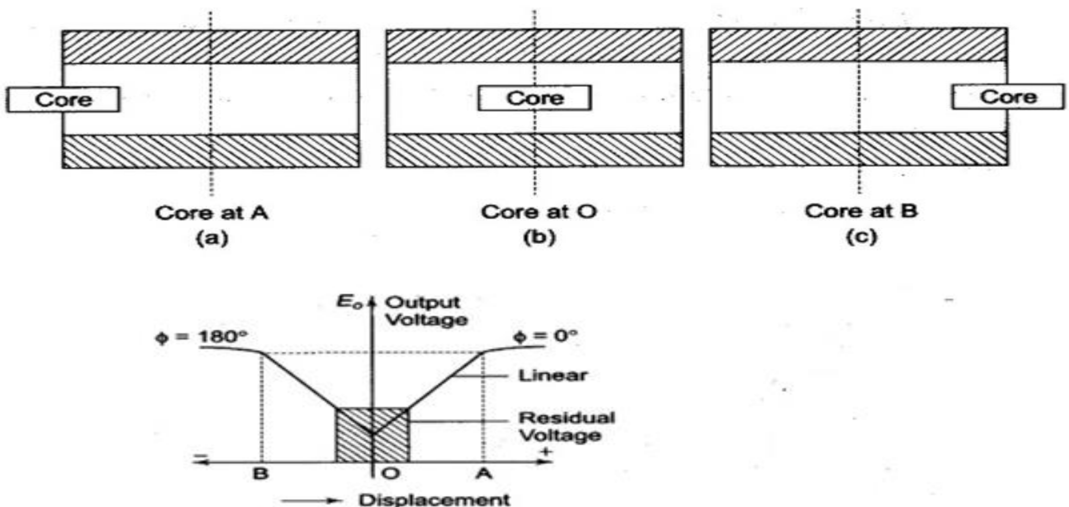


Figure 2.16 (a). (b). (c) Various Core Position of LVDT
(d) Variation of Output Voltage vs Displacement

Advantages of LVDT

- High Range: the LVDTs has a very high range for measurement of displacement This can be used for measurement of displacement ranging from 1.25 mm to 2.50 mm
- Immunity from External Effects
- high sensitivity
- Ruggedness: The transducer can usually tolerate high degree of shock and vibration
- Low Hysteresis
- Low Power consumption
- Linearity

Disadvantages

- They are sensitive to stray magnetic fields (but shielding is possible).
- Many times, the transducer performance is affected by vibrations.
- The efficiency of the device is easily affected by temperature.

2.6 Passive types:

2.6.1 RTD(Resistance Temperature Detector)

- The resistance of a conductor changes when its temperature is changed. This property is used for measurement of temperature.
- The Resistance Thermometer Connected in Bridge Circuit uses the change in electrical resistance of conductor to determine the temperature.
- Platinum, Nickel and Copper are the metals most commonly used to measure temperature.
- Almost all, metals have a positive temperature coefficient of resistance so that their resistance increases with increase in temperature. The carbon and germanium have low temperature coefficient which shows that their resistance is inversely proportional to temperature.
- Platinum has the temperature range of 650^{o}C, and then the Copper and Nickel have 120^{o}C and 300^{o}C respectively.

The relationship between temperature and resistance of conductors can be calculated from the equation.

$$R = R_0\,(1 + \alpha\,\Delta T)$$

<u>**Where**</u>

R = The resistance of the conductor at temperature t ($^\circ$C)

R_o = The resistance at the reference temperature, usually 0°C

α = The temperature coefficient of resistance

Δ T = The difference between the operating and the reference Temperature

Construction of Resistive Thermometer

- The resistance thermometer is placed inside the protective tube for providing the protection against damage.
- The resistive element is formed by placing the platinum wire on the ceramic bobbin.
- This resistance element is placed inside the tube which is made up of stainless steel or copper steel.

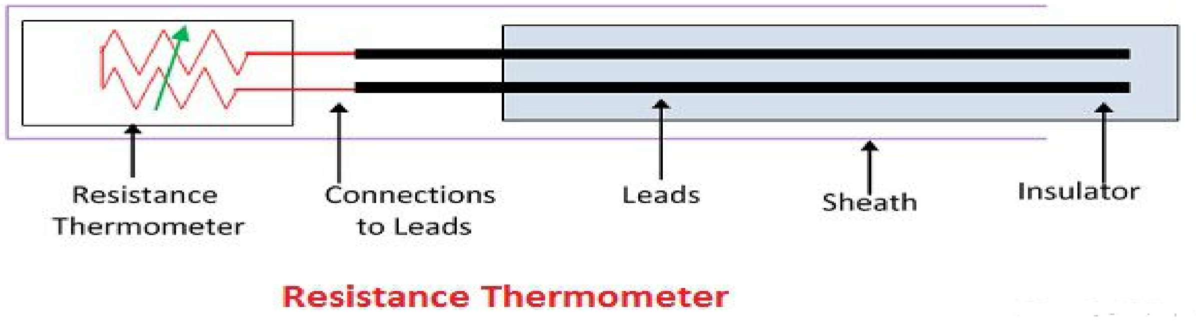


Figure 2.17 Resistance thermometer

- The lead wire is used for connecting the resistance element with the external lead.
- The lead wire is covered by the insulated tube which protects it from short circuit.
- The ceramic material is used as an insulator for high-temperature material and for low-temperature fibre or glass is used.

Working

- The tip of the resistance thermometer is placed near the measurand heat source.
- The sheath quickly reaches the temperature of the medium.
- This change in temperature causes the platinum wire inside the sheath to heat or cool, resulting in a proportional change in the wire's resistance.
- The RTD is connected by leads   to a wheatstone bridge.

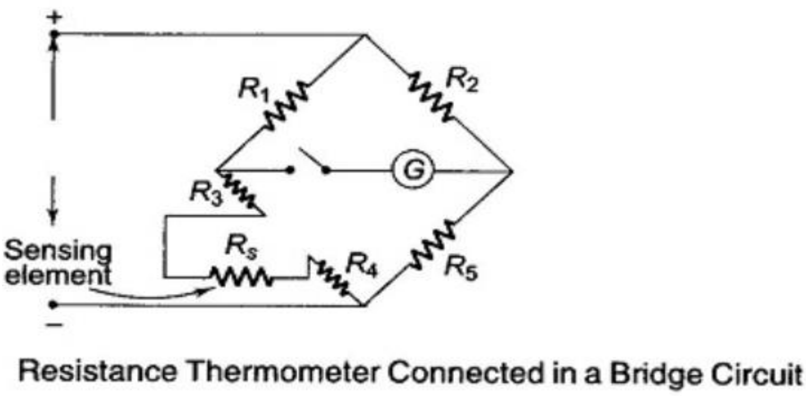


Figure 2.18 Resistance thermometer connected in a bridge circuit

- The bridge consisting of a sensing element Rs having high temperature coefficient and resistance R1, R2, R5 whose values do not alter with change of temperature.
- R3 and R4 are the lead wire resistance of the sensing element.
- At balanced condition

$$\frac{R_1}{R_2} = \frac{R_s + R_3 + R_4}{R_5}$$

When resistance Rs changes, the wheatstone bridge becomes unbalanced and thus galvanometer will give deflection which can be calibrated to give suitable temperature scale.

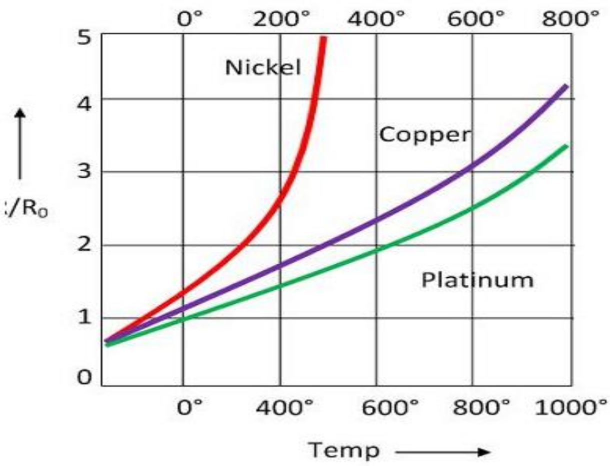


Figure 2.19 Characteristics of materials used for resistance thermometers

Advantages

1. High accuracy
2. Simplicity
3. Fast in response
4. Suitable for precision applications
5. Good reproducibility
6. Temperature compensation not required

Limitation

High cost

Need for bridge and power source

2.6.2 Thermistor

- Thermistor (Thermally sensitive resistors.)
- All resistors vary with temperature, but thermistors are constructed of semiconductor material with a resistivity that is especially sensitive to temperature.

- Generally, the resistance increases with the temperature for most of the metals but the thermistors respond negatively i.e. the resistance of the thermistors decrease with the increase in temperature.
- They are suitable upto 800 degree centigrade**.**

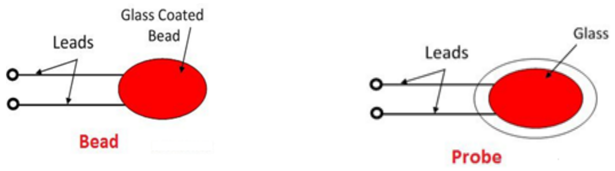
Types of Thermistor

- The thermistor is classified into types. They are the negative temperature coefficient and the positive temperature coefficient thermistor.

1. **Negative Temperature Coefficient Thermistor –** In this type of thermistor the temperature increases with the decrease of the resistance. The resistance of the negative temperature coefficient thermistor is very large due to which it detects the small variation in temperature.
2. **Positive Temperature Coefficient Thermistor –** The resistance of the thermistor increases with the increases in temperature.

Construction of Thermistor

- The thermistor is made with the sintered mixture of metallic oxides like manganese, cobalt, nickel, cobalt, copper, iron, uranium, etc. It is available in the form of the bead, rod and disc. The different types of the thermistor are
- The bead form of the thermistor is smallest in shape, and it is enclosed inside the solid glass rod to form probes.



- The disc shape is made by pressing material under high pressure with diameter range from 2.5 mm to 25mm.

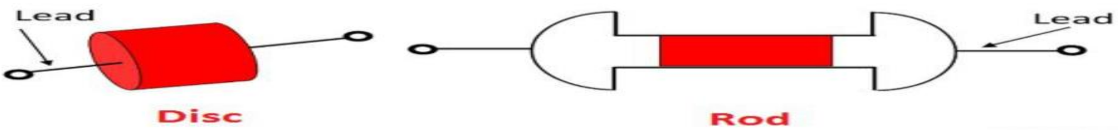


Figure 2.20 Thermistors

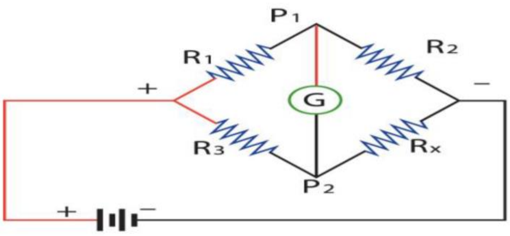


Figure 2.21 Thermistor connected in bridge circuit

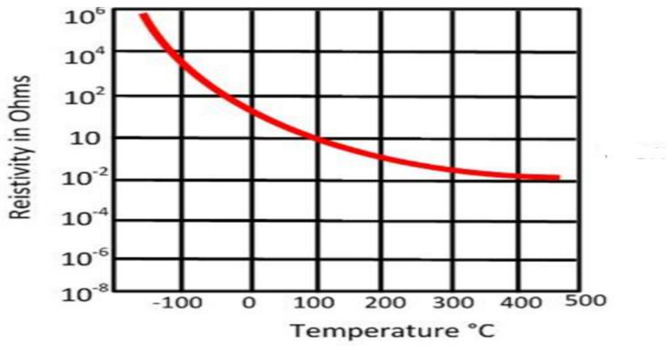


Figure 2.22 Resistance Temperature Characteristic of Thermistor

Advantages

- Small size and fast response
- Cost is low
- Greater sensitivity
- High stability

Disadvantages

- Temperature Vs resistance curve is nonlinear.
- Unsuitable for wide temperature range.
- Applications
- Thermal sensor, Respiration sensor

2.7 Active type: Thermocouple

- Principle-Thermoelectric effect or Seebeck effect
- A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature.

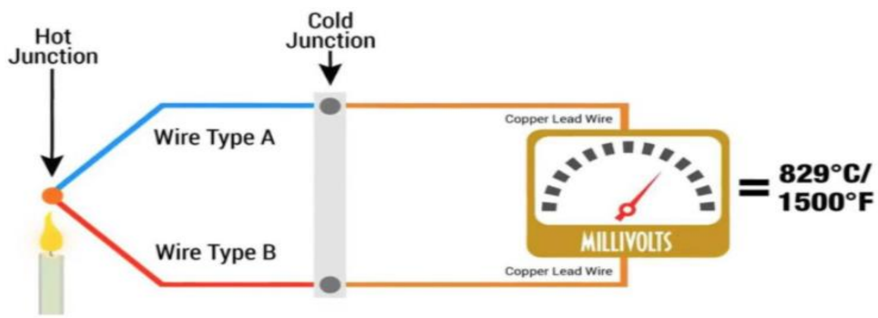


Figure 2.23 Thermocouple

- A thermocouple is a sensor that measures temperature.
- It consists of two different types of metals, joined together at one end.
- When the junction of the two metals is heated or cooled, a voltage is created that can be correlated back to the temperature.

A thermocouple is a simple, robust and cost-effective temperature sensor used in a wide range of temperature measurement processes.

Thermocouple materials and Characteristics

Type	Positive lead	Negative lead	Temperature range	Temperature coeff.variation µv/°C	Most linear range and sensitivity in the range
R	Platinum-Rhodium (87% Pt, 13% Rh)	Platinum	0-1500 C	5.25-14.1	1100-1500 C 13.6-14.1 µv/ C
S	Platinum-Rhodium (90% Pt, 10% Rh)	Platinum	0-1500 C	5.4-12.2	1100-1500 C 13.6-14.1 µv/ C
K	Chromel (90%Ni, 10% Cr)	Alumel ($Ni_{94}Al_2Mn_3Si$)	-200-1300 C	15.2-42.6	0-1000 C 38-42.9 µv/ C
E	Chromel	Constantan (57%Cu, 43%Ni)	-200-1000 C	25.1-80.8	300-800 C 77.9-80.8 µv/°C
T	Copper	Constantan	-200-350°C	15.8-61.8	nonlinear
J	Iron	Constantan	-150-750 C	21.8-64.6	100-500 C 54.4-55.9

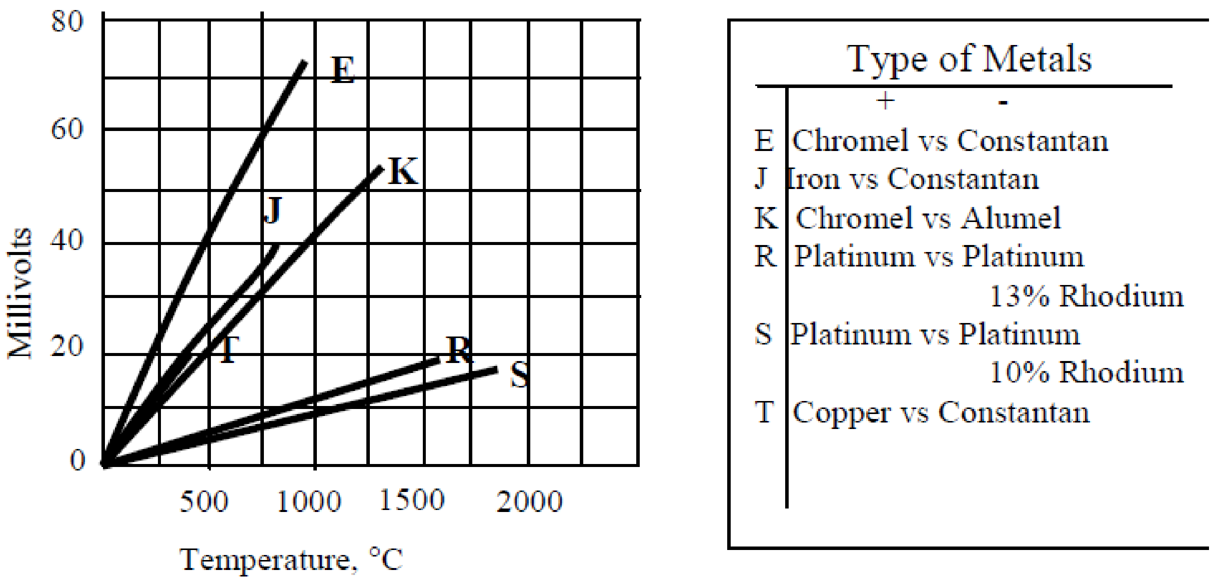


Figure 2.24 Thermocouple characteristics of different metals

Advantages

1.The thermocouple is cheaper than the other temperature measuring devices.

2.The thermocouple has the fast response time.

3.It has a wide temperature range.

4.Good reproducibility.

5. Inexpensive, no need of bridge circuit, good accuracy

Disadvantages

Nonlinear

Reference junction compensation is needed.

2.8 Piezoelectric active transducer

- Piezo electric transducer is a device in which an electric potential is developed when the dimensions of the piezoelectric crystal are changed by the application of mechanical force.
- This potential is developed due to displacement of charges.
- This effect is reversible. (ie) if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it. This phenomenon is known as Piezoelectric effect.
- Piezoelectric materials-Quartz, Rochelle salt, Barium titanate etc.

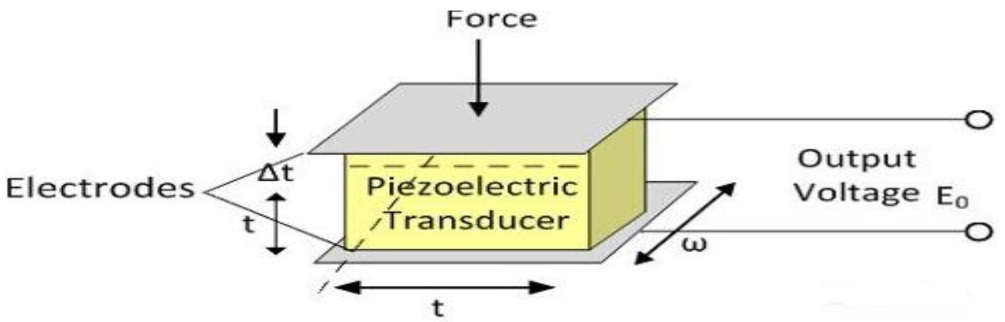


Figure 2.25 Principle of Piezoelectric transducer

- The piezoelectric effect can be made to respond to mechanical deformations of the material in many different modes.
- The modes can be

(a) Thickness expansion

(b) transverse expansion

(c) Thickness shear

(d) face shear

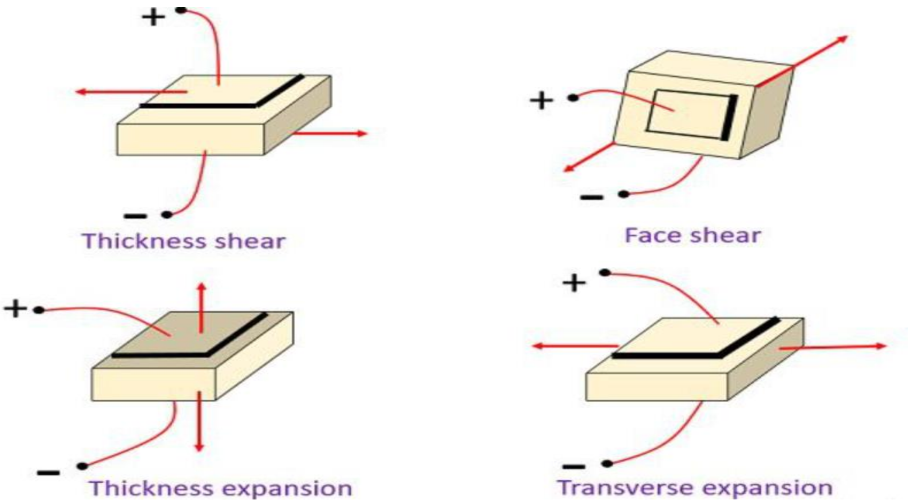


Figure 2.26 Different modes of Piezoelectric transducer

Piezoelectric transducer

- Mechanical deformation generates a charge and this charge appears as a voltage across the electrodes.
- The output voltage Eo= Q/C
- This piezo electric effect is direction sensitive.
- A tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity.

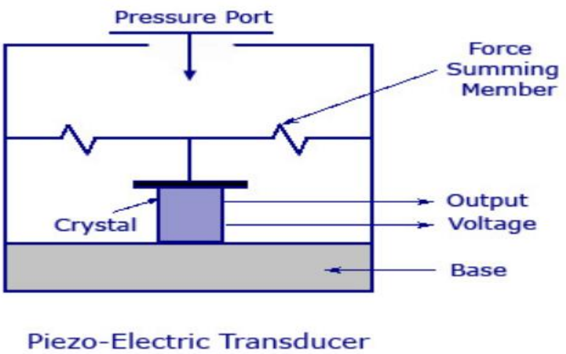


Figure 2.27 Piezoelectric transducer

- A crystal is place between a solid base and force summing member.
- An externally applied force, entering the transducer through its pressure port applies pressure to the top of a crystal.
- Metal electrodes plated on the faces of piezoelectric crystal are taken out to measure output.
- The electrodes become plate of the parallel plate capacitor.
- Thus it can be considered as charge generator.
- The output voltage is given by

- Eo= Q/C

Equivalent circuit of piezoelectric transducers

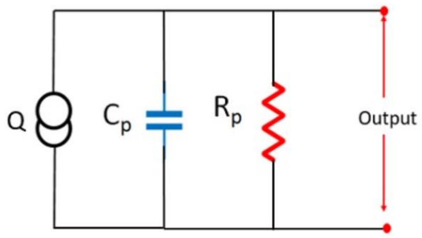


Figure 2.28 Equivalent circuit of Piezoelectric transducer

- Here, ***Q = dF***
- Charge generated is across C_p and R_p is the leakage resistance

$$E_o = \frac{Q}{C_p} = \frac{dF}{C_p}$$

Advantages

1. Due to its small size, it is easy to handle.
2. It shows high frequency respectively as the parameter changes rapidly.
3. It does not require any external force.

Disadvantges

- Output voltage is affected by temperature variations of the crystal.
- It can be used for dynamic measurements only.

2.9 Photo multiplier tube (PMT)

- It is most widely used photo emissive device having the better characteristics to detect the very low intensity light.
- The Photomultiplier tube consists of an evacuated glass envelope containing a photo cathode, an anode and several additional electrodes caller dynodes, each at a higher voltage.
- The beam of incident light is first made to strike a photoemissive material coated photocathode. As a result, electrons are emitted.
- Electrons emitted by the cathode are attracted to another electrode called dynode.

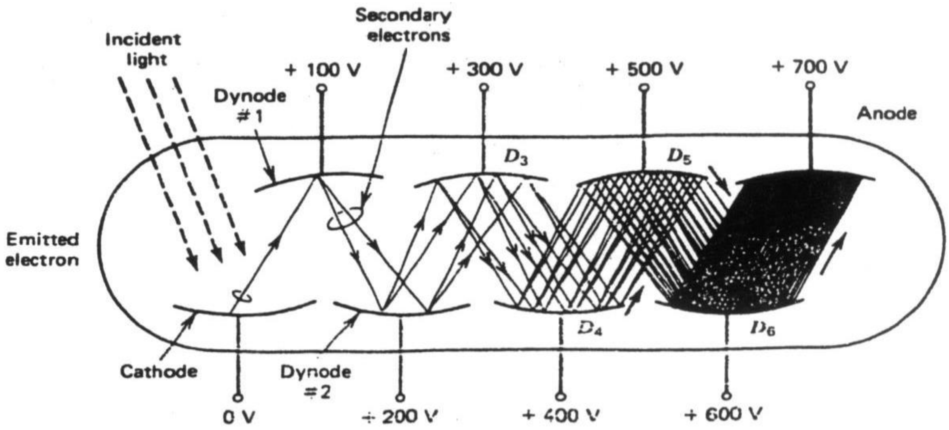


Figure 2.29 Photo multiplier tube

- The electrons are subsequently accelerated with a high voltage (hundreds of volts) to a first dynode (an electrode), where they generate several secondary electrons. Those are accelerated towards further dynodes, where the number of electrons is getting several times larger each time.
- Thus at each dynode , the electrons are multiplied in number and finally all are collected at anode.
- Finally, a strongly amplified photocurrent is collected with an anode near the last dynode.

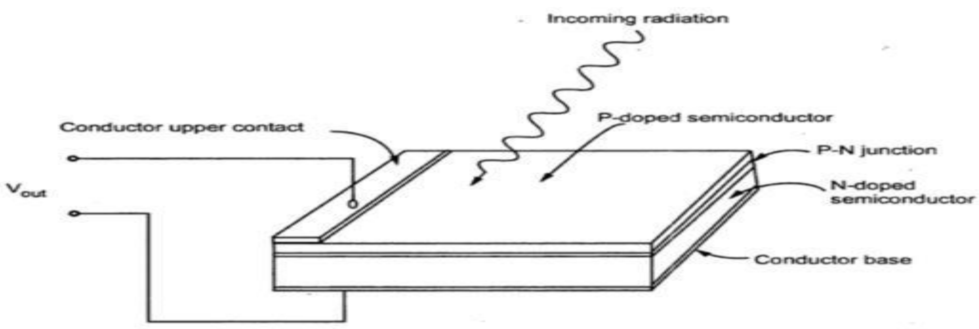
  It has very rapid response time

2.10 Photo voltaic cell

- An active transducer which converts light energy into electrical energy.
- Generates a voltage proportional to light intensity**.**

Photovoltaic Transducers

When an open circuited p-n junction is illuminated, large number of electron-hole pairs are generated in the region near junction. Typically a small voltage appears across its terminals, hence acts as a voltage source. This phenomenon in which light energy is converted to electrical energy is called **photovoltaic effect.** Photovoltaic cell is the common example of this type.



Structure of photovoltaic cell

Figure 2.30 Photo voltaic transducers

Fig. shows structure of photovoltaic cell. It shows that cell is actually a P-N junction diode with appropriately doped semiconductors. When photons strike on the thin p-doped upper layer, they are absorbed by the electrons in the n-layer; which causes formation of conduction electrons and holes. These conduction electrons and holes are separated by depletion region potential of the p-n junction. When a load is connected across the cell, the depletion region potential causes the photocurrent to flow through the load.

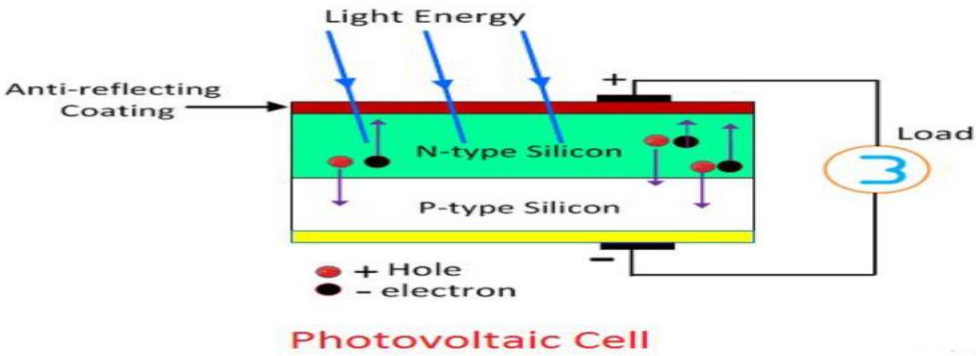


Figure 2.31 Photo voltaic cell

2.11 Photo conductive cells (or) Photo cells

- The electrical resistance of the material varies with the amount of light.
- Light striking the surface of a material can provide sufficient energy to cause electrons within the material to break away from their atoms.
- Thus, free electrons and holes (charge carriers) are created within the material, and consequently its resistance is reduced. This is known as the Photoconductive effect.
- When the photoconductive semiconductor element is subjected to radiations, its resistance decreases, if decreases). Due to this, the flow of current through the cell increases.
- Photoconductive materials are calcium sulphide, calcium selenide or calcium sulphoselenide.
- It is deposited in zigzag pattern, separating two metal coated areas acting as electrodes, on a insulating base made of ceramic**.**
- The assembly is enclosed by a metal case and with a glass window.

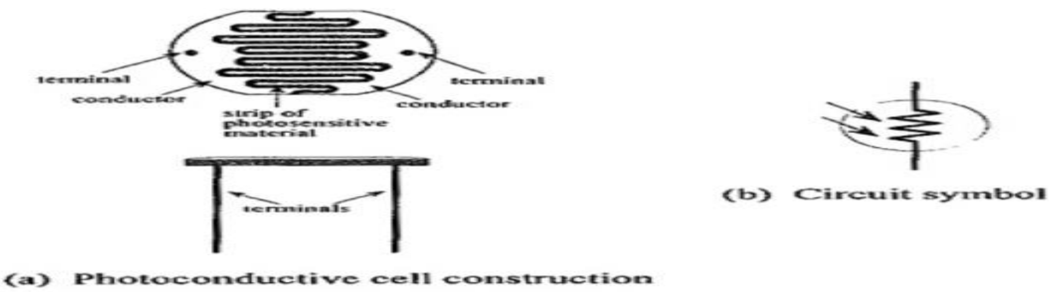


Figure 2.32 Photo conductive cell construction

- When photocell has appropriate light on it, resistance is low and current is high.
- When light is interrupted on it, resistance is high and current is low.

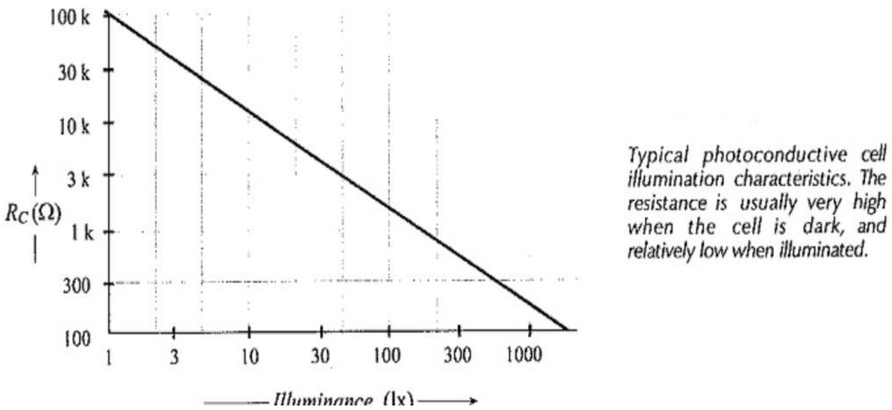


Figure 2.33 Photo conductive cell illumination characteristics

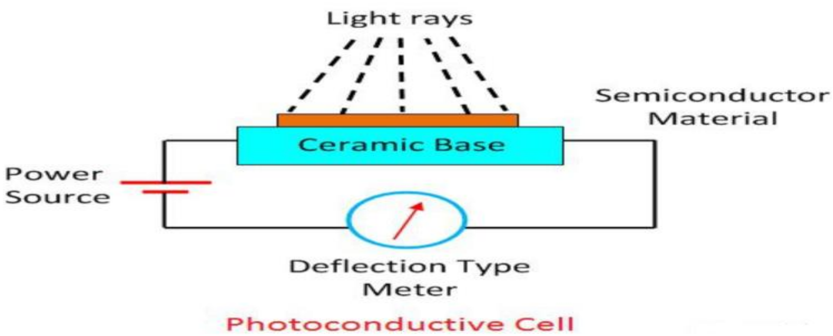
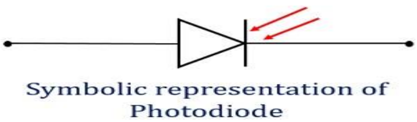


Figure 2.34Photo conductive cell

2.12 Photo diode

- A special type of PN junction device that generates current when exposed to light is known as Photodiode.
- It is also known as photodetector or photosensor.
- It operates in reverse biased mode and converts light energy into electrical energy.



- In a normal diode, under reverse biased condition, the reverse current is due to the minority charge carriers in p-type and n-type regions. This current is limited to few microamperes.

- Now, the junction of the device is illuminated with light. As the light falls on the surface of the junction, then the temperature of the junction gets increased. This causes the electron and hole to get separated from each other.

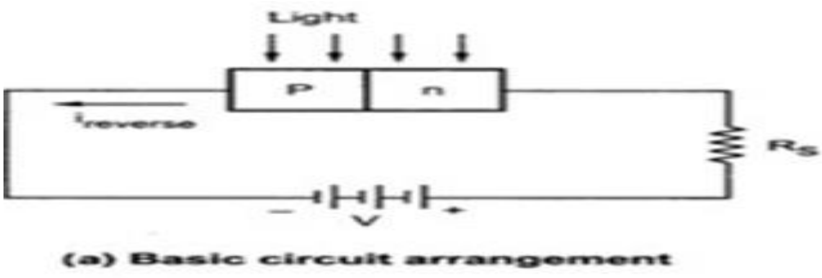


Figure 2.35 Photo diode

- At the two gets separated then electrons from n side gets attracted towards the positive potential of the battery. Similarly, holes present in the p side get attracted to the negative potential of the battery.
- This movement then generates high reverse current through the device.

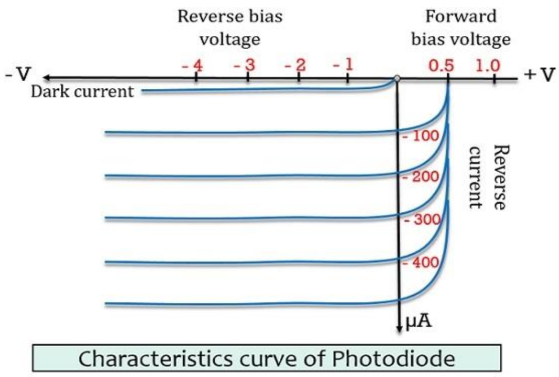


Figure 2.36 Characteristics curve of Photo diode

Here, the vertical line represents the reverse current flowing through the device and the horizontal line represents the reverse-biased potential.

The first curve represents the dark current that generates due to minority carriers in the absence of light.

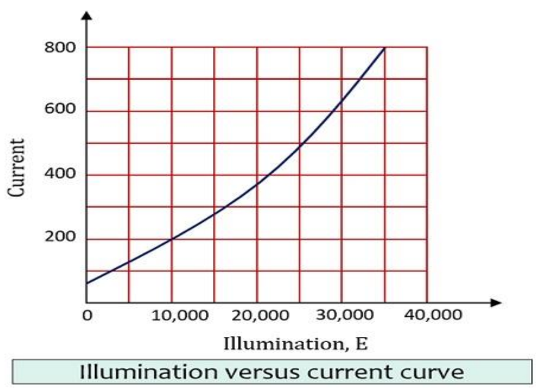
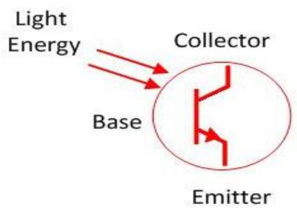


Figure 2.37 Illumination verses current curve

- From the characteristics it is clear that for same increment in luminous flux, there is same increase in the reverse current.
- Thus the characteristics of current versus luminous flux are linear.
- When operated without reverse voltage, it operates as photo voltaic cell or photo voltaic diode or solar cell.

2.13 Photo transistor

- The phototransistor is a type of transistor which converts the light energy into an electric current or voltage.
- It is a special designs transistor which has a light-sensitive base region.
- When the light incident at the base of NPN transistor the base current develops.
- The magnitude of current depends on the intensity of the light incident on it.
- The phototransistor amplifies the input light, and the output current is obtained from the collector of the transistor.
- The circuit symbol of the photo-transistor is shown in the figure below.
- The arrow shows the light energy incident on their base surface.

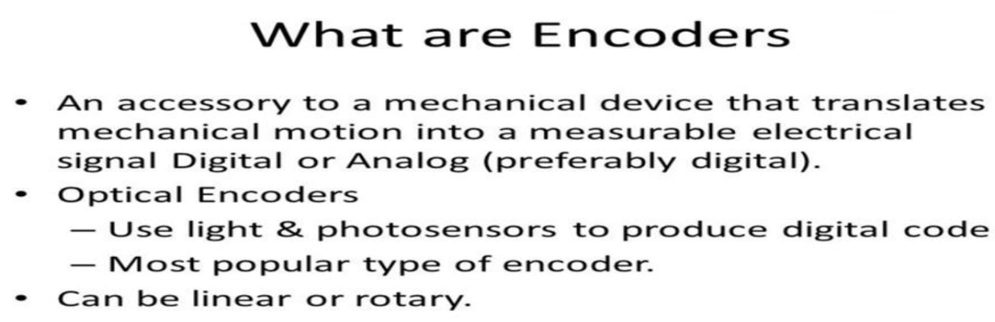


- It is usually connected in the common emitter configuration with base open for the illumination.
- A lens focusses the light on the base collector junction.
- The collector region of the phototransistor is large as compared to the ordinary transistor because it is made up of heavy diffuse semiconductor material.
- When the base of the phototransistor absorbs light, they release the electron-hole pairs.
- Because of this hole pair, the depletion layer of the diode decreases and electron starts moving from the emitter to the collector region.
- For the small amount of light energy, the transistor amplifies the large collector current.

The graph below shows the magnitude of current increases along with the intensity of light.

2.14 Optical displacement sensors & Optical encoders

- Digital encoding transducers or digitisers enable a linear or rotary displacement to be directly converted into digital form. Such digitisers are known as digital encoders.
- By the use of a digital code, it is possible to identify the position of a movable test piece in terms of a binary number. The position is converted into a train of pulses. This is achieved by a digital transducer and is also termed as encoder.
- Since the binary system uses only two states, 0 or 1, it can be easily represented by two different types of systems, optical or electrical. Digital transducers using optical methods are called Optical encoders, while those using electrical methods are called resistive electrical encoders.



2.14.1Optical encoders

- A sector may be designed with a pattern of opaque and translucent areas. A photo sensor and a light source is placed on the two sides of the sector.
- The displacement is applied to the sector and therefore changes the amount of light falling on the photo electric sensor. The pattern of the illuminated sensor then carries the information to the location of the sector.

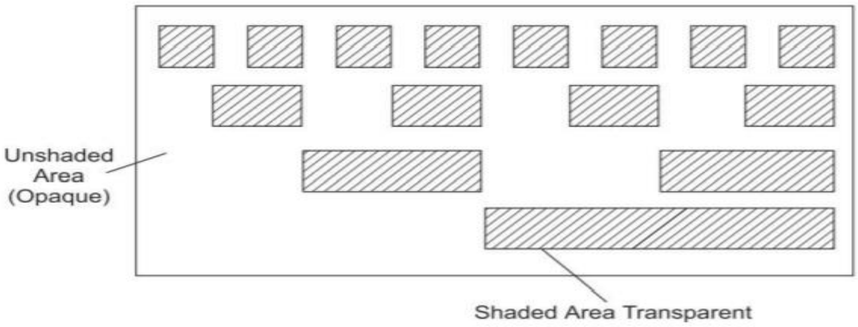


Figure 2.38 Optical encoder

- Figure shows a possible pattern on sector of opaque and translucent areas. The number of levels in the encoder determines the accuracy with which the device operates.

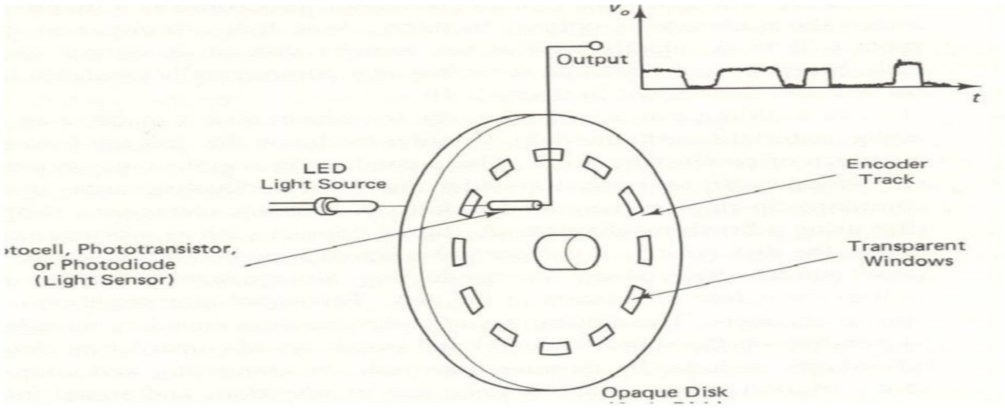
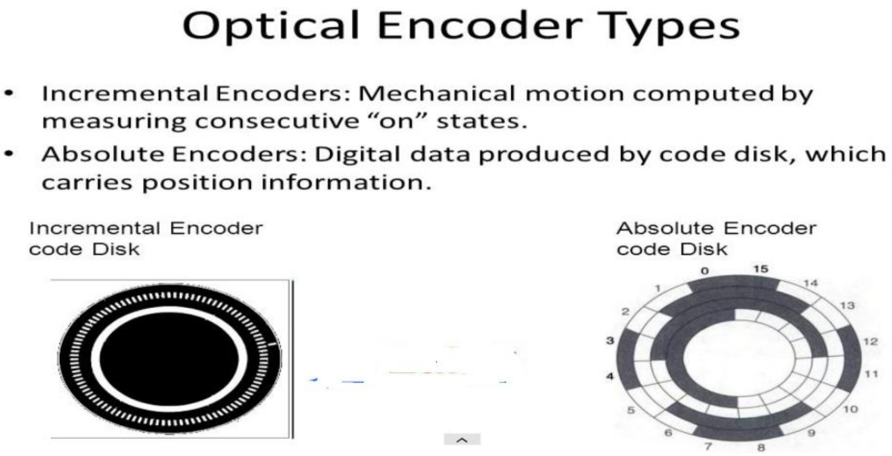


Figure 2.39 Optical encoder

- The optical encoder uses an opaque disk that has one or more circular tracks, with some arrangement of identical transparent windows.
- A parallel beam of light is projected to all tracks from one side of the disk
- The light sensor could be a silicon photodiode, a phototransistor, or a photovoltaic cell.
- The light from the source is interrupted by the opaque areas of the track, the output signal from the probe is a series of voltage pulses



Advantages

- 1. They give a true digital readout
- 2. No mechanical contact is involved and therefore problems of wear and tear and alignment are not present

Disadvantages

- 1. Light sources burn out. (However, the life of the light is about 50,000 hours.)

TEXT / REFERENCE BOOKS

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DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – III– Biosensors and Measurements – SBMA1301

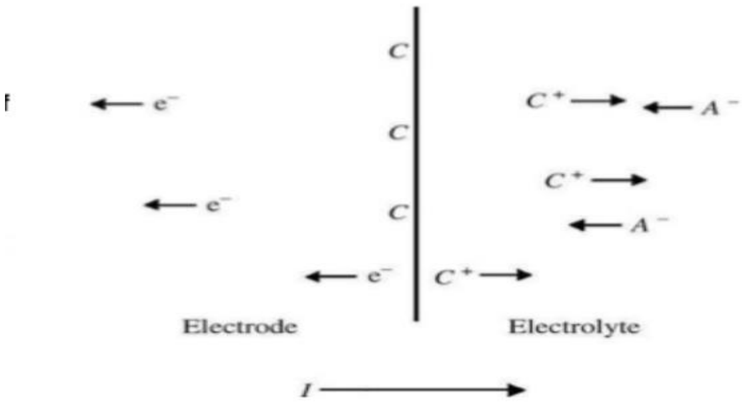
III. Biopotential Electrodes and Chemical Sensors

Electrodes Electrolyte Interface, Half-Cell Potential, Polarization, Polarizable and Non Polarizable, Electrodes, Reference Electrode, Hydrogen Electrode, Electrode Skin-Interface and Motion Artifact. Surface Electrodes. Oxygen electrodes, CO2 electrodes, enzyme electrode, construction, ISFET for glucose, urea etc. fiber optic sensors.

3.1 Biopotential Electrodes

- Electrodes that are capable of picking up the electrical signals of the body are called as biopotential electrodes.
- Signals are developed due to chemical activity in the cells/ biological system.
- Chemical activity is brought about by Na+, K+ and Cl- ions concentration gradient and unbalanced conditions lead to chemical activity in the human body.
- Current flows in the measuring circuit for at least a fraction of the period of time over which the measurement is made.
- Bioelectric potential generated in the body are ionic potential.
- Electrode carries out a transducing function, because current is
- carried in the body by ions, whereas it is carried in the electrode
- and its lead wire by electrons.
- A transducer that convert the body ionic current in the body into the traditional electronic current flowing in the electrode.
- Able to conduct small current across the interface between the body and the electronic measuring circuit.

3.2 Electrodes-Electrolyte interface



$$C \rightleftarrows C^{n+} + ne^{-} \qquad A^{m-} \rightleftarrows A + me^{-}$$

where *n* is the valence of C and *m* is valence of A

Figure 3.1 Electrodes – Electrolyte interface

A net current (I) that crosses the interface passing from the electrode to electrolyte consists of
1. e- moving in opposite to current in electrode

2. Cations c+ moving in same direction of current

3. Anions A- moving in opposite to current in electrolyte

Electrode consists metallic atomC . Electrolyte consists cations C+ & anions A- .

- The electrode is made up of some atoms of the same material as the cations and that this material in the electrode at the interface can become oxidized to form a cation and one or more free electrons.
- The cation is discharged into the electrolyte; the electron remains as a charge carrier in the electrode.
- These ions are reduced when the process occurs in the reverse direction
- an anion coming to the electrode–electrolyte interface can be oxidized to a neutral atom, giving off one or more free electrons to the electrode.
- Oxidation reaction causes atom to lose electron
- Reduction reaction causes atom to gain electron
- Oxidation is dominant when current flow from electrode to electrolyte and reduction dominate when the current flow is in the opposite.

3.3 Half cell potential

- Voltage developed at electrode-electrolyte interface is called half cell potential or electrode potential.
- In the case of a metal solution interface, an electrode potential results from the difference in rates between two opposing forces
- the passage of ions from the metal into the solution.
- The combination of metallic ions in solution with electrons in the metal to form atoms of the metal.
- So, when a metal electrode comes into contact with an electrolyte (body fluid), there is a tendency for the electrode to discharge ions into solution and for ions in the electrolyte to combine with the electrode.
- The net result is the creation of a charge gradient, the spatial arrangement of which is called the electrical double layer.
- Electrodes in which no net transfer of charge occurs across the metal electrolyte interface is called as perfectly polarised electrodes.
- Electrodes in which unhindered exchange of charge is possible across the metal electrolyte interface are called nonpolarizable electrodes.

3.3 Polarizable and non-polarizable electrodes

Perfectly polarizable electrodes

- Electrodes in which no net transfer of charge occurs across the metal electrolyte interface when a current is applied is called as perfectly polarised electrodes. Example: Platinum Electrode
- The electrode behaves like a capacitor and overpotential is due to concentration.

Non polarizable electrodes

- Electrodes in which current passes freely across the electrode- electrolyte interface are called nonpolarizable electrodes.
- Electrodes in which unhindered exchange of charge is possible across the metal electrolyte interface are called nonpolarizable electrodes.
- Here current flows freely across the interface and energy is not required for it. Example: Ag/AgCl electrode.
- Thus, for perfectly non-polarizable electrodes there are no over-potentials.
- Electrode interface impedance is represented as a resistor.

3.4 Polarization

Half cell potential is altered when there is current flowing in the electrode due to electrode polarization. Overpotential is the difference between the observed half-cell potential with current flow and the equilibrium zero-current half-cell potential.

Mechanism Contributed to overpotential –

Ohmic overpotential: voltage drop along the path of the current, and current changes resistance of electrolyte and thus, a voltage drop does not follow ohm's law.

Concentration overpotential: Current changes the distribution of ions at the electrode-electrolyte interface

Activation overpotential: current changes the rate of oxidation and reduction. Since the activation energy barriers for oxidation and reduction are different, the net activation energy depends on the direction of current and this difference appear as voltage.

$$V_p = V_R + V_c + V_A$$

These three mechanisms of polarization are additive.

Thus the net over-potential of an electrode is given by

$$Vp = E° + V_R + V_c + V_A$$

where Vp = total potential, or polarization potential, of the electrode

E° = half-cell potential

V_R = ohmic overpotential

V_c = concentration overpotential

V_A = activation overpotential

3.5 Resting potential

- In a cell membrane the outside fluid is extra-cellular fluid and inside fluid is intra-cellular fluid.
- The extra-cellular fluid has a large concentration of sodium ions and chloride ions but less concentration of potassium ions.
- The intra-cellular fluid has a high concentration of potassium ions than the sodium ions.
- Cells surrounded by semipermeable membrane permits some substances to pass through and some kept out.
- Cells surrounded by body fluids containing ions.
- Principal ions are (Na+), (K+) and (Cl-).
- When a cell does not send a signal, it is at "resting state".
- Membrane permits the entry of potassium (K+) and chloride (Cl-) ions and stops Sodium ions (Na+).
- sodium ion concentration inside the cell becomes much lower than the outside the cell.
- Inside the cell, potassium and chloride ion concentration is more than the outside the cell.
- Thus the charge balance is not achieved.
- However, an equilibrium is reached with a potential difference across the membrane such that the negative potential on the inside and positive on the outside.
- This membrane potential caused by the different concentration of ions is known as resting potential.
- The cell membrane is negative inside and positive outside.
- The difference in ion concentration results in the Resting Membrane Potential of the cell.
- The value of resting potential is between - 60mV to - 100mV.
- At the resting state, the cell is polarised.

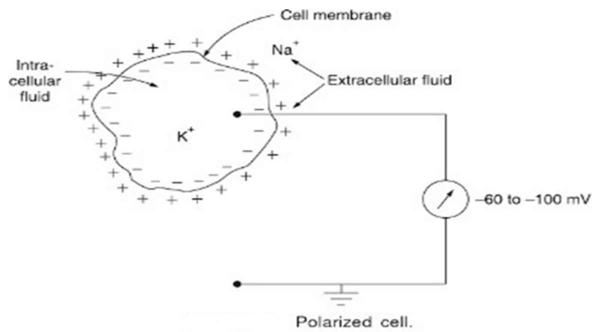


Figure 3.2 Resting potential

3.6 Action potential

- When a section of the cell membrane is excited by some form of applied energy, the permeability of the membrane changes and begins to allow some of the sodium ions to enter.
- Movement of sodium ions into the cell constitutes an ionic current and this reduces the membrane barrier.
- Sodium ions rushes into the cell and try to balance with the ions outside.
- Meanwhile, potassium ions flow outside the cell but unable to move rapidly as sodium ions.
- Thus, the cell has positive potential inside the cell due to the imbalance of potassium ions.
- The positive potential of the cell membrane during excitation is called as action Membrane Potential.
- The value of action potential is 20mV.
- As long as action potential exists, the cell is said to be depolarised.

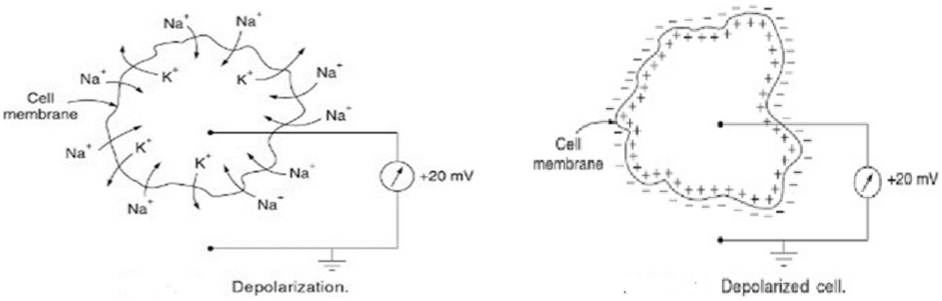


Figure 3.3 Action potential

- Process of changing from resting state to action potential is called as depolarization.
- Once equilibrium is again reached, membrane gets back to semipermeable state and stops entry of sodium ions.
- By a process of sodium pump, all sodium ions are transported outside of the cell and resting potential is attained. This process is called repolarization.

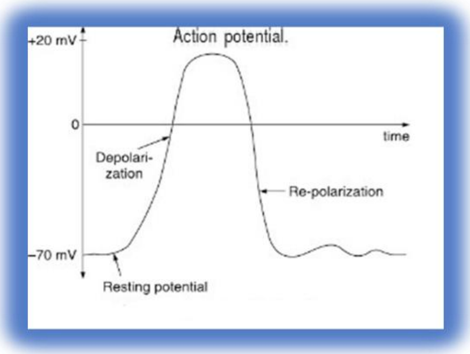


Figure 3.4 Action and resting potential

- All or nothing law- Action potential is always the same for any given cell regardless of the excitation method or intensity of stimulus.
- Absolute refractory period- A brief period of time during which the cell cannot respond to any new stimulus.(1msec in nerve cell)
- Relative refractory period- After Absolute refractory period, during which another action potential can be triggered, but a much more stronger stimulation is required.
- Propagation rate- Rate at which action potential is propagated from cell to cell(conduction velocity or nerve conduction rate).

3.7 Types of electrodes

1.Micro electrodes

- To measure biopotential signals within a single cell
- Metal microelectrode
- Micropipet

2. Depth and needle electrodes

Electrodes penetrate into the skin to record signals. These electrodes are used to measure bio-potential at highly localized extracellular region.

3.Surface electrodes

Measures signal from the surface of the skin

- Metal plate
- Suction cup
- Adhesive tape
- Multipoint
- Floating

4.Chemical electrodes

Measures Ph, pO2, pCo2 of blood

Hydrogen electrode

Reference electrode

Ph, pO2, pCo2 electrode

1.Micro electrode

- Used to measure potential near or within a single cell
- Also called intracellular electrode.
- Small in diameter so that they do not damage cells during insertion.

- Microelectrodes are placed within cell and reference electrodes are placed outside cell.
- Tip diameter range from 0.05 to 10 micrometer
- Two types of micro electrodes
- i) metal micro electrodes
- (ii) micropipet or nonmetal micro electrode

(i)Metal micro electrodes

- These electrodes are made of fine tungsten or stainless steel wire.
- They are formed by electrolytically etching the tip of the tungsten or stainless steel wire to a fine point. This technique is known as electro pointing.
- This etched metal wire is then supported by a larger metallic shaft.
- This metallic shaft acts as a

  - Sturdy mechanical support for the microelectrode.

  -Means of connecting the micro electrode to its lead wire.

- The micro electrode and the supporting shaft is insulated by a polymer material or varnish.
- The extreme tip of the micro electrode is left without insulation.
- The bioelectric potential measured is actually the difference in instantaneous potential of the measuring micro electrode and reference electrode.

Structure of Metal Microelectrode

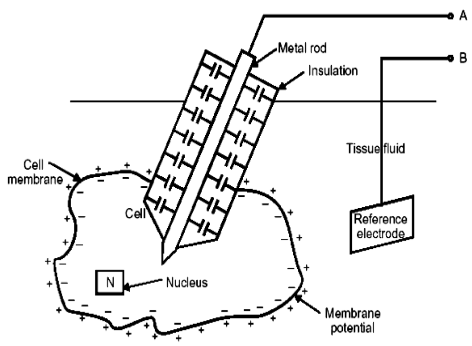


Figure 3.5 Metal micro electrodes

Bioelectric potential is given by,

$E = E_A+E_B+E_C$

E – Bio-potential

E_A – Metal electrode - electrolyte potential at the micro electrode tip

E_B – Reference electrode - electrolyte potential

E_C – Variable cell membrane potential

(ii) Micropipet (or) Non metal electrode

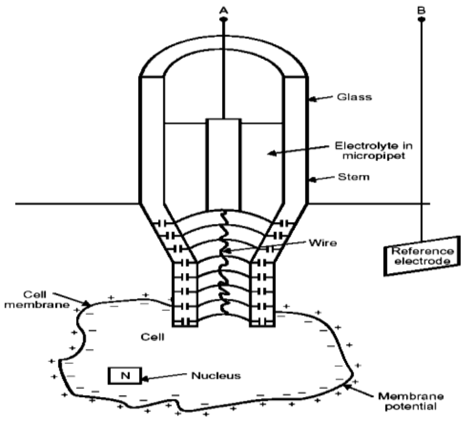


Figure 3.6 Non Metal electrodes

- It consists of a glass Micropipet whose tip's diameter is about 1 micrometer.
- A thin, flexible metal wire made of silver, stainless steel or tungsten is inserted into the stem of the micropipet.
- One end of the metal wire is mounted to a rigid support and the other free end through the stem of the micropipet is resting on the cell to pick up bio-electric potential.
- It is filled with an electrolyte(3 M KCl)
- Here bio-electric potential is given as
- $E = E_A+E_B+E_C+E_D$
- E – Bio-electric Potential
- E_A – Potential between the metal wire and electrolyte filled in the micropipet.
- E_B – Potential between the reference electrode and the extra cellularfluid
- E_C – Variable cell membrane potential
- E_D – Potential existing at the tip due to different electrolytes present in the pipet and the cell.

2.Depth and needle electrodes

- These type of electrodes are used to measure and record bio-electric events from highly localized extra cellular regions.
- They are of two types namely,

i. Depth electrode

ii. Needle electrode

(i)Depth electrode

- Used to study electrical activity of neurons in the superficial layers of the brain.
- Also called as implantable electrodes.
- These are made of a bundle of Teflon insulated platinum 90%- iridium 10% alloy wires
- These wires act as individual electrodes and supported by a stainless steel wire.
- This stainless steel supporting wire is rounded off at the tip for easy insertion into the top layers of the brain.
- The electrode rests on the sub-cortical nerve cells.
- The active area of depth electrode is 0.5 mm^2

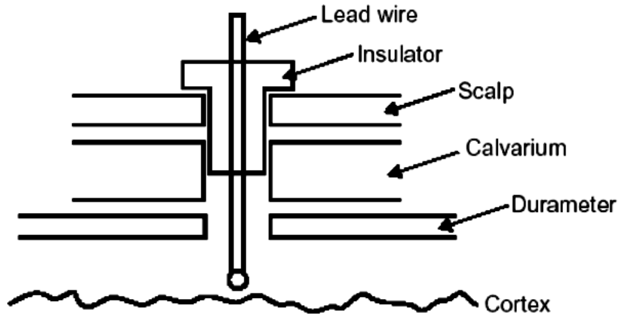


Figure 3.6 Depth electrodes

- The supporting stainless-steel wire can itself act as an electrode if an appropriate varnish is used.
- The supporting wire if made in the form of a capillary tube can be used to inject medicines into the brain.
- Silver sphere cortical surface potential is an example of a implantable depth electrode.
- It has 2mm diameter silver sphere located at tip of cylindrical Teflon insulator through which lead wire passes.
- Calvarium is exposed through incision in scalp.
- Ag sphere introduced and rests on cerebral cortex.

(ii)Needle electrode:

- The needle electrode is used to measure action potentials of peripheral nerves.
- Used to reduce movement artifacts and interface impedance.
- Here a needle is used to make a lumen through which a short length metal wire is inserted.
- This short length metal wire is bent at one end and inserted through the lumen into the muscles.
- This wire picks up the electrical activity of the biological system.
- If one wire is used as a measuring electrode and another separate reference electrode is used then it is called mono-polar needle electrode.
- If two insulated wires are used one as reference and the other as measuring electrode through the lumen of the needle then such an electrode system is called bipolarneedle electrode.

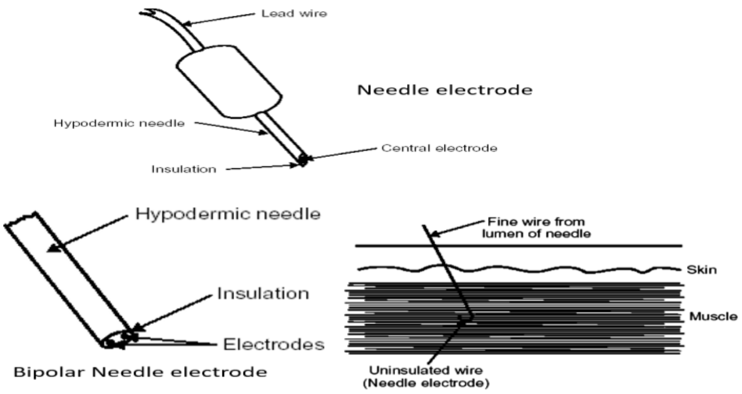


Figure 3.7 Needle electrodes

3.Surface electrodes

- Electrodes used to obtain bioelectric potentials from surface of the body.
- Surface electrodes are used to record ECG, EMG and EEG signals.
- Larger surface area, surface electrodes are used for ECG measurement.
- Smaller surface area, surface electrodes are used for EEG and EMG measurement.

(i)Metal plate surface electrodes (Limb Electrodes)

- Simplest of all surface electrodes and frequently used.
- It consists of a metallic conductor in contact with the skin making use of an electrolyte gel.
- It is mostly used as limb electrodes in ECG measurement.
- It is made up of a flat metal plate that is bent into a cylindrical segment.
- There is a terminal on the cylindrical segment on its outer surface, to attach the lead wire to the electrocardiograph.

- There is also a post placed on the same side of the segment near the Centre. This post is used to connect a rubber strap to the electrode and hold it in place on the arm or leg.
- The electrode is generally made of germanium silver, nickel plated steel, nickel etc.
- There are basically two types of metal plate surface electrodes namely,
- Rectangular
- Circular
- The active surface area of a rectangular surface electrode is normally 3.5 cm* 5 cm.
- The active surface area of the circular surface electrode is 17.6cm^2 (4.75 cm – Diameter)
- The inner surface of the electrode is covered with gel or an electrolyte soaked pad is kept which will maintain the electrode contact with the skin.
- In circular metal disk electrodes the lead wire is soldered to the back surface. The connection between lead wire and electrode is protected by a layer of insulating material such as epoxy or polyvinyl chloride.
- Disk electrodes used for ECG measurements are made of silver and has an electrolytically deposited layer of AgCl on its contacting surface.
- It is also coated with electrolyte gel and placed on the patient's chest wall.
- Disk electrodes used for EMG recordings are made of stainless steel, platinum or gold plated disks.

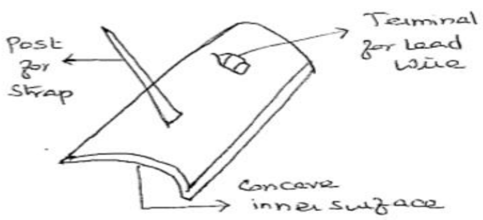


Figure 3.8 Cylindrical metal plate surface electrode

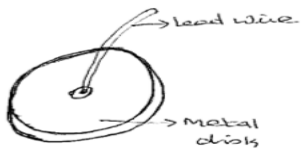


Figure 3.9 Circular metal plate surface electrode

(ii)Suction Cup electrode:

- Suction cup electrodes can be called as modified metal plate electrodes.
- These electrodes do not require straps or adhesives to hold them to a particular location.

- These electrodes are mostly used as chest lead electrodes for ECG measurement.
- They consist of a hollow metallic cylindrical electrode that makes contact with the skin at its base.
- A terminal is present on the metal cylinder for lead wire attachment.
- A rubber suction bulb is fitted to the other base of the cylinder metal electrode.
- The rubber bulb is squeezed and placed on the body, the bulb releases and applies suction against the skin, thus holding the electrode to the body.
- This electrode can be used for only short periods of time because the suction and pressure can cause irritation to the skin.
- These electrodes are generally used as ECG limb electrodes.
- These electrodes are well suited for attachment to flat surfaces of the body.

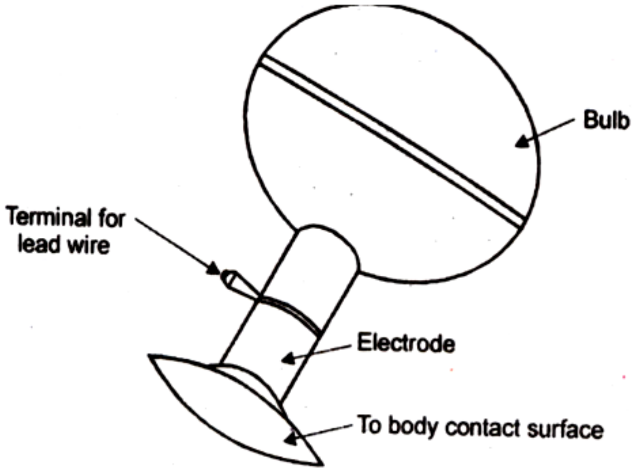


Figure 3.10 suction cup electrode

(iii)Adhesive tape electrode (Pre-gelled Disposable Electrode)

- When surface electrodes are used, the pressure applied on it across the body squeezes the gel or electrode paste out.
- Such a problem is avoided with the use of adhesive tape electrode.
- It consists of a large disk of plastic foam material with a silverplated disk on one side and silverplated snap on the other side.
- The silverplated disk serves as the electrode and may be coated with silver chloride layer.
- A layer of electrolyte gel covers the disk.
- A lead wire is snapped onto the electrode and connected to the ECG apparatus.
- The electrode side of the foam is covered with an adhesive material, which is covered with a protective foil material.

- To apply the electrode, the skin is cleaned, the protective material is removed and pressed against the patient.

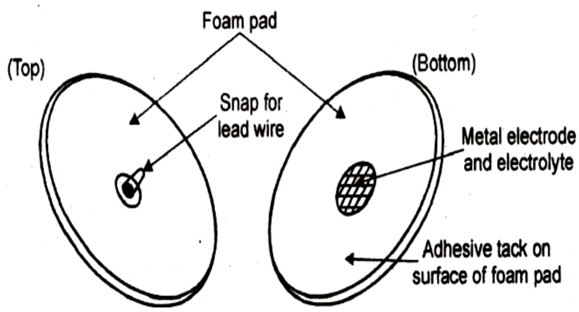


Figure 3.11 Adhesive tape electrode

iv)Multipoint electrodes:

- Multipoint electrodes contains nearly 1000 fine active contact points.
- Since the active surface area is very small, a very low resistance contact is established in these type of surface electrodes.
- These types of electrodes are used on subjects where the region of interest is covered with hair.
- These electrodes can be used under any environmental conditions.
- The multipoint electrode is a very practical electrode for ECG measurement.

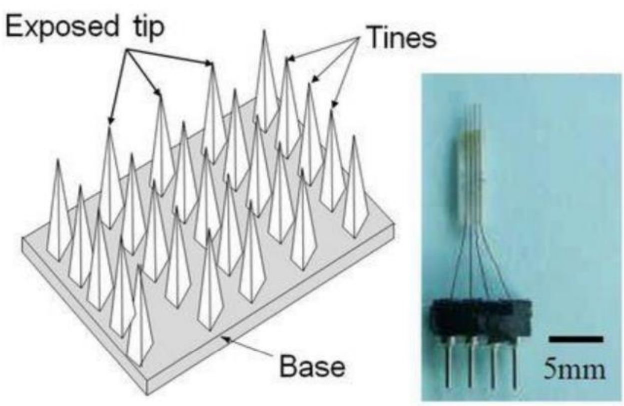


Figure 3.12 Multipoint electrode

4.Chemical Electrodes

- To measure the bioelectric potential, there is a reference electrode with constant potential and a measuring electrode, difference between them give the biopotential.
- In electrochemical measurements, it is necessary to keep one of the electrodes in the electrochemical cell at a constant potential.

3.8 Reference electrode

- The electrode which has a known potential (constant potential) is called as reference electrode.
- Reference electrodes are of two types

  (i)Primary reference electrodes

  (ii)Secondary reference electrodes

(i)Primary reference electrodes

- The reference electrode whose potential is taken as zero is called as primary reference electrode.
- E.g Standard Hydrogen Electrode (SHE)

Hydrogen Electrode

- Primary electrode to which all electrochemical measurements are referred to hydrogen electrode.
- Standard hydrogen electrode consists of a platinum wire sealed in a glass tube and carrying a platinum foil which is coated with platinum black at one end.
- The electrode is placed in a solution of an acid having 1 Molar concentration of hydrogen ions.
- Hydrogen gas at 1 atm pressure is continuously bubbled through the solution at 298 K through the side arm in such a way that the platinum foil is half immersed in Hcl while upper half is surrounded by H_2 gas.
- A redox reaction occurs when the electrode is placed in the solution.
- The oxidation or reduction takes place at the Platinum foil.
- A difference in potential occurs when hydrogen gas moves into the solution and the concentration of hydrogen concentration increases.

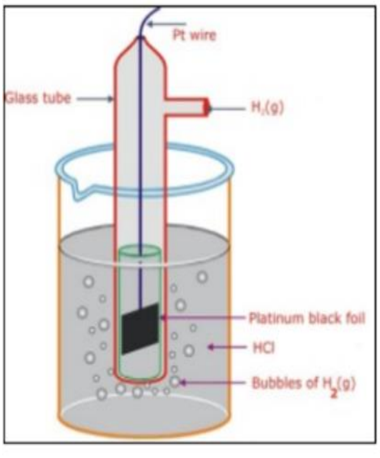


Figure 3.13 Hydrogen electrode

It is represented as Pt, H_2(latm)/H-(1M)

In a cell when the standard hydrogen electrode acts as anode, the electrode reaction can be written as

$$H_{2(g)} \longrightarrow 2H^+ + 2e^-$$

When the standard hydrogen electrode acts as cathode, the electrode reaction can be written as

$$2H^+ + 2e^- \longrightarrow H_{2(g)}$$

Based on the electrode potential obtained with reference to hydrogen, electrochemical series is obtained.

- Platinum is usually used as it readily adsorb hydrogen and is a good conductor.

Limitations

1)It is rather difficult to regulate the pressure of the H2 gas to be at exactly 1atm throughout the experiment.

2) In such a system, it is difficult to maintain the concentration of HCl at 1M.

3)Platinum foil gets easily poisoned by the impurities present in the gas and HCl

Applications

To measure pH of body fluid.

(ii)Secondary Reference Electrode

- The reference electrode whose potential is not zero but exactly known, and the electrode potential value depends on the concentration of solution in which it is dipped.
- Two types
  - ❖ Calomel electrode
  - ❖ Silver-Silver chloride electrode
- **Secondary Reference (or) Calomel Electrode**
- It consists of pure Hg at the bottom of the glass tube and covered by the paste of Mercury chloride(Calomel) and a known value of kCl.
- One side arm is used to introduce the kCl above the mercury chloride paste
- A platinum wire is sealed into a glass tube serves to make electrical contact of the electrode with the external circuit
- This act as anode or cathode depending upon the electrode which it is coupled with.
- If the electrode act as cathode

$$Hg_2cl_2 \rightleftharpoons Hg_2{}^{2+} + 2cl^-$$

$$Hg_2{}^{2+} + 2e^- \rightleftharpoons 2Hg\text{-----Reduction}$$

Hg_2cl_2 accepts electrons.

- Increase in concentration of chloride ions.

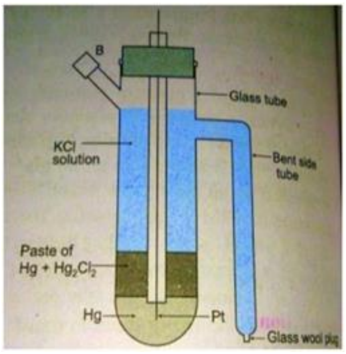


Figure 3.14 Calomel electrode

- The electrode acts as anode it would liberate electrons and Hg_2^{2+} ions into solution. These ions combine with cl- ions forming Hg_2 cl2. result is fall in concentration of chloride ions in the solution.

$$2Hg \rightleftharpoons Hg_2^{2+} + 2e^- \text{ -----Oxidation}$$
$$Hg_2^{2+} + 2cl^- \rightleftharpoons Hg_2cl2$$

- The calomel electrode can be represented as

$$Hg_{(1)} \mid Hg_2\,cl_{2(s)} \mid Kcl_{(xM)}$$

- Used as reference electrode in Ph measurement.
- Potential of calomel electrode depends on concentration of KCl solution.

- **Silver/Silver chloride electrode**
- The internal tube is replaced by a silver wire that is coated with silver chloride
- The wire is immersed in a pottassium chloride solution of known concentration usually of 1.0 M and saturated with silver chloride
- $Ag + Cl^- \rightleftharpoons AgCl + \text{electron } (e^-)$

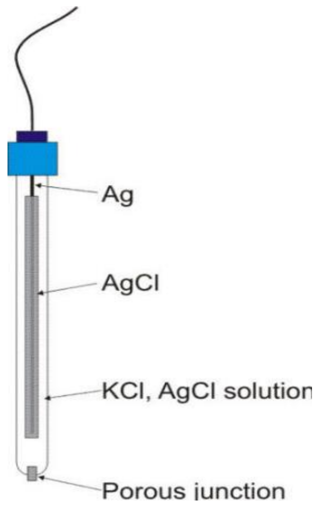


Figure 3.15 Silver/silver chloride electrode

Advantages

Easy to use, Difficult to repair

3.9 Ph Electrode

- pH of blood and otherbody fluid helps in identifying chemical balance of the body.
- ❖ pH is a measure of hydrogen ion concentration in a solution.
- ❖ pH = - log (H^+)
- ❖ Two electrodes which are involved in the measurement of pH, are

1. The glass electrode (Indicating Electrode or Sensing Electrode or Measuring Electrode)
2. The reference electrode (Calomel Electrode)

- For pH measurement silver – silver chloride electrode is used as the measuring electrode.
- ❖ The bulb provides a thin glass membrane which permits the passage of only hydrogen ions in the form of $H3O^+$.
- ❖ This glass bulb has the Ag/ AgCl electrode immersed in chloride buffer solution.
- ❖ Chloride buffer solution is nothing but KCl in 0.1M HCl.
- A calomel electrode is used as the reference electrode.
- ❖ The calomel electrode is made of a glass inner tube filled with mercurous chloride [Hg2Cl2] paste.
- ❖ This glass tube has a porous plug at the bottom.
- ❖ A platinum wire is inserted through this which is the lead wire.
- ❖ On top of the Hg2Cl2 paste an elemental mercury layer is formed.
- ❖ This whole inner glass set up is now placed in an outer bigger glass tube with the porous plug at the bottom.
- The porous plug at the bottom of the electrode assembly is used to make contact between the internal KCl electrolyte and the unknown pH test solution into which the electrode is immersed.
- ❖ The potential between this electrode and the glass measurement electrode gives the pH of the unknown solution.
- ❖ Since a salt bridge is formed between the KCl in measuring electrode – unknown test solution – KCl in reference electrode.
- ❖ It with the internal electrolyte solution, (KCl), makes contact with the sample solution via a porous glass

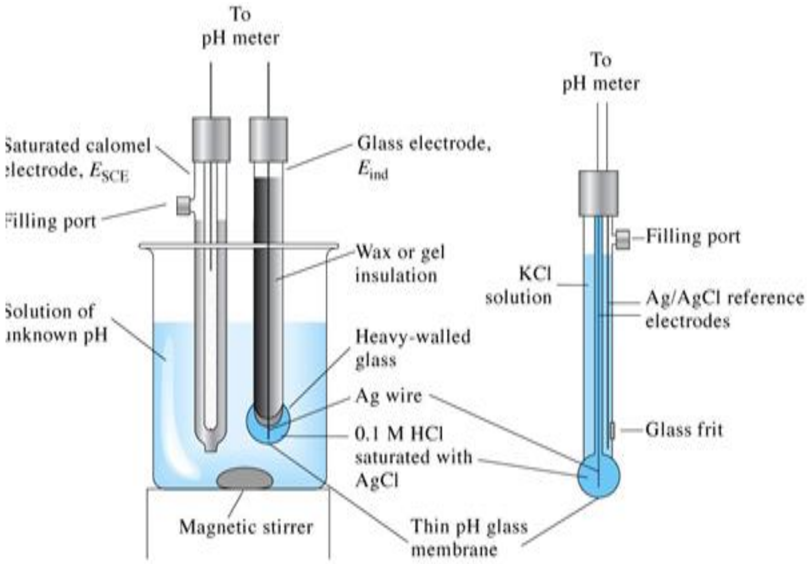


Figure 3.16 Measurement of pH

3.10 Carbondioxide electrode

- The blood pCO2 is the partial pressure of carbondioxide of blood taken anaerobically. It is expressed in mm of Hg.
- *pCO2 = Barometric pressure – Water vaporpressure * (% CO2/ 100)*
- The pCO2 electrode consists of pH sensitive glass electrode.
- The electrode is enclosed by a permeable rubber membrane.
- A thin film of water surrounds the glass electrode in between the rubber membrane and separates the membrane from the electrode.
- The whole set up is kept in the solution whose CO2 concentration is to be found out.
- The technique is based on the fact that the dissolved CO2 changes the pH of an aqueous solution.
- CO2 from the solution diffuses through the rubber membrane and reaches the water film.
- The CO2 from blood sample defuses through the membrane to form H2CO3, which dissociates into (H+) and (HCO3-) ions.
- CO2 from the solution diffuses through the rubber membrane and reaches the water film.
- The pH of the water film which is measured with the help of the silver/ silver chloride electrode (pH measurement electrode) gets disturbed and changes depending on the diffused CO2.
- The resultant change in pH is thus a function of the CO2 concentration in the sample.

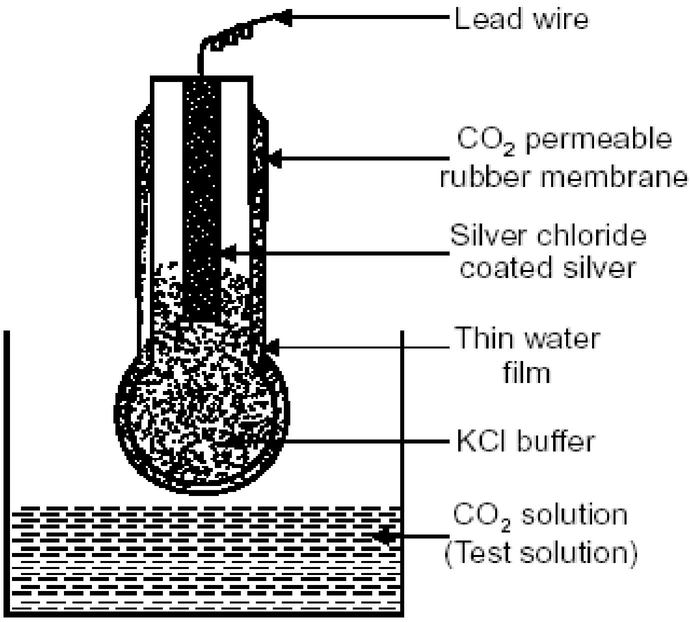


Figure 3.17 pCO2 electrode

- An alternate modified form of the electrode used for pCO2 measurement includes a thin film of an aqueous sodium bicarbonate (NaHCO3) solution instead of the water layer.
- *The* rubber membrane was also replaced by a thin Teflon membrane, which is permeable to CO2 but not to any other ions, which might alter the pH of the bicarbonate solution.
- Co2 diffuses into bicarbonate solution and causes a drop in Ph.
- Hence, the pH change is a linear function of the logarithm of the CO2 tension.
- Twice as sensitive as older version.
- Instead of Silver/ Silverchloride electrode a calomel electrode can also be used.

3.11 Oxygen electrode

- The partial pressure of oxygen in the blood or plasma indicates the extent of oxygen exchange between the lungs and the blood
- Common Po2 electrode is a clark electrode.
- The cathode is a Pt wire embedded in an insulating glass holder with end exposed into electrolyte.
- a silver/ silver chloride –anode(ref electrode)
- Electrolyte Kcl
- Permeable membrane a polypropylene membrane, only to oxygen is attached to the bottom of the cell.

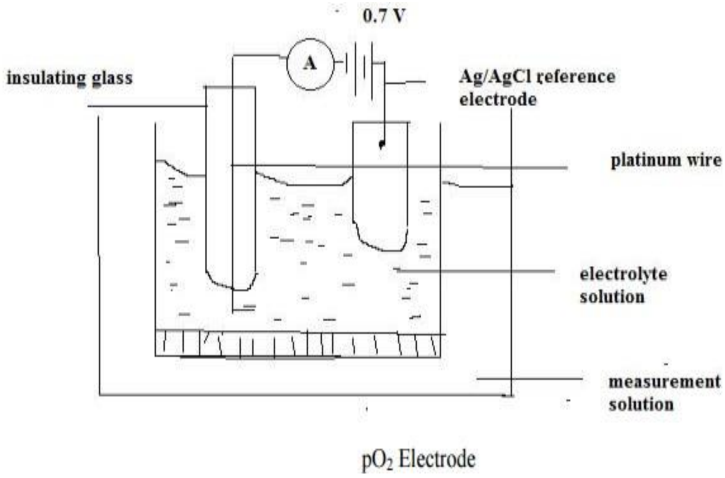


Figure 3.18 pCO2 electrode

- The entire unit is inserted into the solution under measurement. Oxygen diffuses across the polypropylene membrane into the electrolyte filling solution and is reduced at the cathode. At the anode silver is oxidized and the magnitude of the resulting current indicates the partial pressure of oxygen.
- The reactions occurring at the anode and cathode are:
- Cathode Reaction:
- O2 + 2H2O + $4e^-$ à 4 OH^-
- Anode Reaction:
- 4Ag à $4Ag^+$ + $4e^-$

3.12 Electrode Skin-Interface

- Outer layer of skin is very dry and not conductive.
- An electrode paste/ gel is applied to obtain a good electric contact.
- The skin is cleaned, paste is applied and electrode is held in position with a rubber strap.
- The electrode paste decreases the impedance and also reduces the artifacts due to electrode or patients.
- Conductivity of skin is directly proportional to moisture for the skin.
- For eg: for dry skin, contact impedance-100kohm
- With electrode paste , contact impedance- 10kohm
- Transparent electrolyte gel containing Cl- is used to maintain good electric
- Contact between the electrode and the skin.
- For good conductivity, gel must have particular chloride ion concentration about (1%)

- Electrode jelly can be replaced by a conducting plastic.

3.13 Motion Artifact

- Due to movement of electrodes or patients
- When the electrode moves with respect to the electrolyte, the distribution of the double layer charge on polarizable electrode interface changes. This changes the half-cell potential temporarily.
- If a pair of electrodes is in an electrolyte and one moves with respect to the other, a potential difference appears across the electrodes known as motion artifact.
- This is a source of noise and interference in biopotential measurements.
- Motion artifact is minimal for non-polarizable electrodes.
- Can be reduced by using floating electrodes.
- Distortion is usually reduced by using large surface area electrodes.

3.14 ISFET (Ion sensitive field effect transistor)

An ISFET (Ion sensitive field effect transistor) selectively measures ion activity in an electrolyte. An ion-sensitive field-effect transistor (ISFET) is a field-effect transistor used for measuring ion concentrations in solution; when the ion concentration (such as H+,) changes, the current through the transistor will change accordingly. It is a special type of MOSFET (metal-oxide-semiconductor field-effect transistor), and shares the same basic structure, but with the metal gate replaced by an ion-sensitive membrane, electrolyte solution and reference electrode. ISFET is produced by removal of the metal gate region that is normally present on a FET. A MOSFET (metal-oxide-semiconductor field-effect transistor) is composed of two diodes separated by a gate region. The gate is a thin insulator usually silicon dioxide upon which a metallic material is deposited. Voltage applied to the gate controls the electric field in the dielectric and thus the charge on the silicon surface. High input impedance results from the gate insulator which is essential for the operation of ISFET. ISFET with the sample under measurement in contact with an ion selective membrane and a reference electrode.

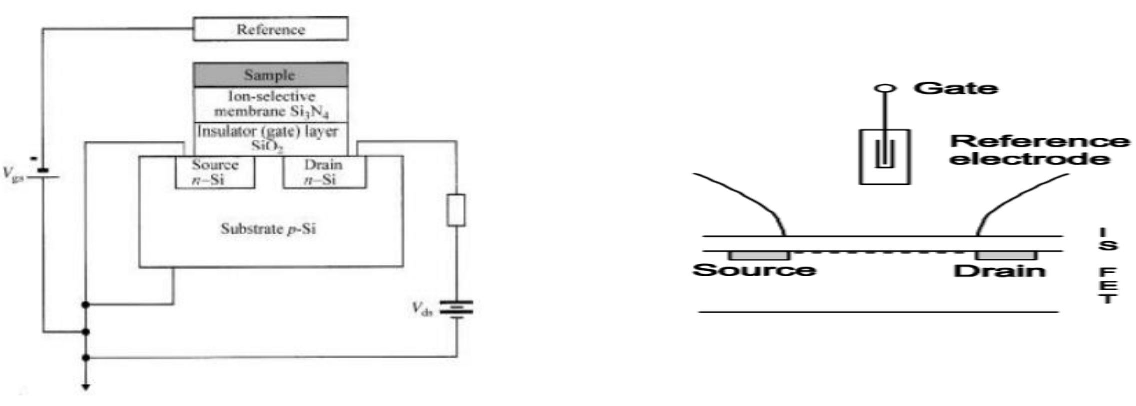


Figure 3.19 ISFET

- The potential developed across the insulator depends on the electrolyte concentration of the solution in contact with the ion selective membrane.
- The ISFET measures the potential at the gate.
- This potential is derived through an ion selective process; in which ions passing through the ion selective membrane modulate the current between the source and the drain.
- The voltage across the gate region changes and thus the field effect current flows.

Advantages

- Microminiature sensors
- Lowcost
- Small size
- Measurement speed is fast.

3.14.1 ISFET for glucose

- ISFET with an immobilized enzyme membrane has been developed, with the ion concentration change accompanying the enzymatic reaction detected by the isfet.
- Used for measuring blood glucose in diabetic patients.
- Immobilised enzyme is held between inner and outer membrane .
- Presence of glucose by changing the value of oxygen.

$$\beta\text{ - D - glucose} + H_2O + O_2 \xrightarrow{\text{glucose oxidase}} \text{gluconic acid} + H_2O_2$$

- glucose oxidase, (GOD) is immobilized at the bottom of the biosensor.
- When glucose reacts with glucose oxidase, oxygen is released.
- This oxygen passes through the oxygen permeable membrane and interacts with the platinum electrode as a result of which electrons will be produced.
- Due to the electron flow in electrodes current will be created

3.14.2 ISFET for Urea

- Immobilized enzyme (gel layer) is attached to the surface of the electrode.
- Urease fixed in the acrylamide gel.
- Enzyme urease reacts with the urea and allows the ammonium ions to pass through it.
- Detected by internal electrode.
- As the pH changes the electrolyte oxide interface potential also change and due to this the threshold voltage of the ISFET changes. This variation of threshold voltage causes

the change in drain current

$$NH_2\text{-}CO\text{-}NH_2(\text{urea}) + H_2O \xrightarrow{\text{urease}} 2NH_4^+ + CO_2 + 2OH^-$$

3.15 Enzyme electrode

- Enzyme electrodes invariably refer to such devices that sense and analyze biological informations.
- Enzyme electrode is a miniature chemical transducer which functions by combining an electrochemical procedure with immobilized enzyme activity.
- Ion selective electrodes used in conjunction with immobilized enzymes can serve as the basis of electrodes that are selective for specific enzyme substrates.
- Enzymes are proteins that catalyses specific reactions to a high a degree of specificity
- The reactants are the substrates.
- Electrochemical enzyme-based biosensors are widely used because of their practical advantages, which include their
- low fabrication cost,
- simplicity of operation,
- high selectivity,
- and their ability to perform real-time detection.
- Types

  (i) Amperometric enzyme electrode

  (ii)Potentiometric enzyme electrode

  (iii)Conductimetric enzyme electrode

(i)Amperometric enzyme electrode

- Amperometric biosensors measure the electric current associated with electron flow resulting from redox reactions.
- They typically rely on an enzyme system that catalytically converts electrochemically non-active analytes into products that can be oxidized or reduced at a working electrode.
- This electrode is maintained at a specific potential with respect to a reference electrode.
- The current produced is linearly proportional to the concentration of the electroactive product, which in turn is proportional to the nonelectroactive enzyme substrate.
- The “substrate” here is any substance on which an enzyme acts.
- Enzymes typically used in amperometric biosensors are oxidases that catalyze the following class of reactions:

- Substrate + O_2 → Product + H_2O_2
- As a result of the enzyme-catalyzed reaction, the substrate (analyte) concentration can be determined by amperometric detection of oxygen or hydrogen peroxide (H_2O_2).
- An example of this configuration would be an oxygen-consuming enzyme coupled to an oxygen-sensing electrode.
- The ambient oxygen concentration is then continuously monitored as it diffuses through a semi-permeable membrane and is reduced at a platinum (Pt) electrode.
- Other common configurations include the use of oxidases specific to various substrates to produce H_2O_2.
- During measurement, the working electrode may act as an anode or a cathode, according to the nature of the analyte.
- For example, a glucose-sensitive biosensor that uses glucose oxidase could detect the H_2O_2 produced by the enzymatic reaction by polarising the working electrode to a positive potential (+0.6V vs. SCE), or by polarising the working electrode to a negative potential (-0.65V vs. SCE) to monitor oxygen.

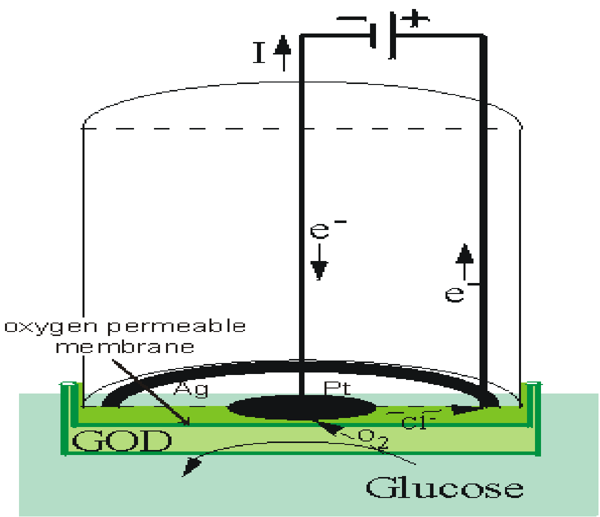
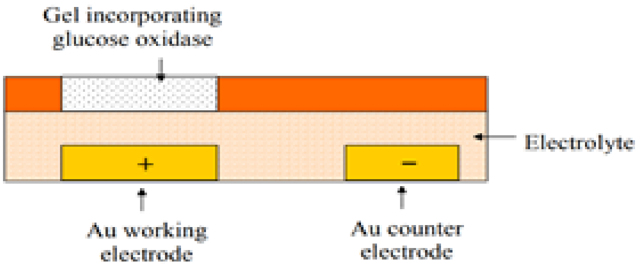


Figure 3.20 Glucose Enzyme Electrode

- A potential is applied between the central platinum cathode and the annular silver anode.
- This generates a current (I) which is carried between the electrodes by means of a saturated solution of KCl.
- This electrode compartment is separated from the biocatalyst (here shown glucose oxidase, GOD) by a thin plastic membrane, permeable only to oxygen
- Higher the glucose content higher the oxygen consumption.

- Used to measure glucose content in the blood sample.
- glucose oxidase, (GOD) is immobilized at the bottom of the biosensor.
- When glucose reacts with glucose oxidase , oxygen is released.
- This oxygen passes through the oxygen permeable membrane and interacts with the platinum electrode as a result of which electrons will be produced.
- Due to the electron flow in electrodes current will be created



$$\text{Glucose} + O_2 + H_2O \xrightarrow[\text{GOD}]{} \text{Gluconic acid} + H_2O_2$$

$$\text{Anodic: } H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$$

current passed thru
working electrode

(ii)Potentiometric enzyme electrode

- Potentiometric biosensors use ion selective electrodes to determine changes in the concentration of chosen ions.
- The basic principle behind potentiometric sensor measurements is the development of a voltage related to the analyte activity (concentration) [A] in the sample through the Nernst relation:

$$E = -\frac{RT}{nF}\ln\left(\frac{a_1}{a_2}\right).$$

- where E is the potential measured,
- R is the universal gas constant,
- T is the absolute temperature, n is the valence of the ion,

  and a1 and a2 are the activities of the ions on each side of the membrane.
- Potentiometric sensors will generally require a reference electrode as well as the indicator (working) electrode to be in contact with the test sample solution.

- The use of ion-selective membranes can make these sensors sensitive to various ions (e.g, hydrogen, fluorine, iodine,chlorine ions) in addition to gases such as carbon dioxide and ammonia.
- Enzyme systems,that change the concentration of any of these ions or gases, can also be incorporated into the sensor in order to be able to measure enzyme substrate concentrations, or to detect inhibitors

  (e.g., heavy metal ions, insecticides) or modulators of the enzyme.
- Development of voltage related to analyte concentration in sample
- Ideally, the potential difference between the indicator and reference electrode is proportional to the logarithm of the ion activity

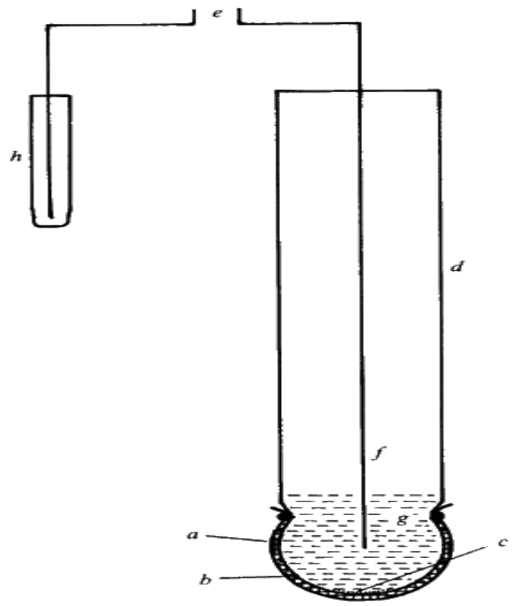


Figure 3.21 A simple potentiometric biosensor

A semi-permeable membrane (a) surrounds the biocatalyst (b) entrapped next to the active glass membrane (c) of a pH probe (d).

The electrical potential (e) is generated between the internal Ag/AgCl electrode (f) bathed in dilute HCl (g) and an external reference electrode (h).

- Consider the hydrolysis of substrate urea in the presence of enzyme urease
- A urea electrode can be prepared by immobilizing urease in a gel coating it on the surface of a cation sensitive type glass electrode (that respond to monovalent cation)
- when the electrode is dipped in the solution containing urea, the urea diffuses into the gel layer and the enzyme

$$\boxed{NH_2\text{-}CO\text{-}NH_2(\text{urea}) + H_2O \xrightarrow{\text{urease}} 2NH_4^+ + CO_2 + 2OH^-}$$

- When Co2 reacts with ph electrode, it alters the ph of the solution in the ph electrode and this causes potential difference.
- These ions diffuse to the surface of the electrode where they are sensed by cation sensitive glass to give a potential reading .
- After about 30 to 60 second , steady state reading is reached which over a certain working range is a linear function of the logarithm if the urea concentration .
- By appropriate choice of immobilized enzyme and electrode a number of substrate selective enzyme electrode have been described

(iii) Conductimetric enzyme electrode

- Measure changes in the conductivity of medium as a result of enzyme reactions that change its ionic composition.
- Conductance is directly related to the amount of ions in a medium, and since many enzyme-linked reactions result in a change in ion concentration they are suitable for conductometric biosensors.
- Enzyme reactions that produce or consume ionic species depend on the total ionic strength of the medium and changes in its conductance/capacitance can be relatively small
- Urea sensor
- Sensing enzymes can be immobilised onto the electrodes in a paste or gel form. An example of this is a urea sensor,using the enzyme urease to catalyze the hydrolysis of urea and produce ionic species (ammonium, bicarbonate and hydroxyl ions):

$$\text{urea} + 3H_2O \xrightarrow{\text{urease}} 2NH_4^+ + HCO_3^- + OH^-$$

3.16 Fiber optics

- Fiber optics (optical fibers) are long, thin strands of very pure glass about the diameter of a human hair.
- They are arranged in bundles called optical cables and used to transmit light signals over long distances.
- Core - Thin glass center of the fiber where the light travels
- Cladding - Outer optical material surrounding the core that reflects the light back into the core
- Buffer coating - Plastic coating that protects the fiber from damage and moisture
- Hundreds or thousands of these optical fibers are arranged in bundles in optical cables. The bundles are protected by the cable's outer covering, called a jacket.
- The light in a fiber-optic cable travels through the core (hallway) by constantly bouncing from the cladding (mirror-lined walls), a principle called total internal

reflection. Because the cladding does not absorb any light from the core, the light wave can travel great distances.

- **Advantages**
- Less expensive , Thinner, Less signal degradation , Low power , Digital signals , Non-flammable, Lightweight,flexible
- **Applications**
- Medical imaging - in bronchoscopes, endoscopes, laparoscopes
- Mechanical imaging - inspecting mechanical welds in pipes and engines (in airplanes, rockets, space shuttles, cars)
- Plumbing - to inspect sewer lines
- telecommunications and computer networks
- Chemical fibrosensors offer several desirable features.
- They can be made small in size.
- Multiple sensors can be introduced together, through a catheter, for intracranial or intravascular measurements.
- Because optical measurements are being made, there are no electric hazards to the patient.
- The measurements are immune to external electric interference, provided that the electronic instrumentation is properly shielded.
- No reference electrode is necessary.
- 6.high degree of flexibility ,good thermal stability, and low-cost manufacturing

3.16.1 Fiber optic pH sensor

- This pH sensor uses two single-strand optical fibres P and D .
- The distal ends of the fibres are adjacent and parallel and fit inside a cellulose dialysis hollow fibre (0.25 mm in diameter).
- The proximal end of one fibre (P) is attached to a light source.
- The other fibre (D) is used for detection.
- The cellulose hollow fibre is filled with an indicator dye, phenol red adjacent to the sealed cut ends of the optic fibre.

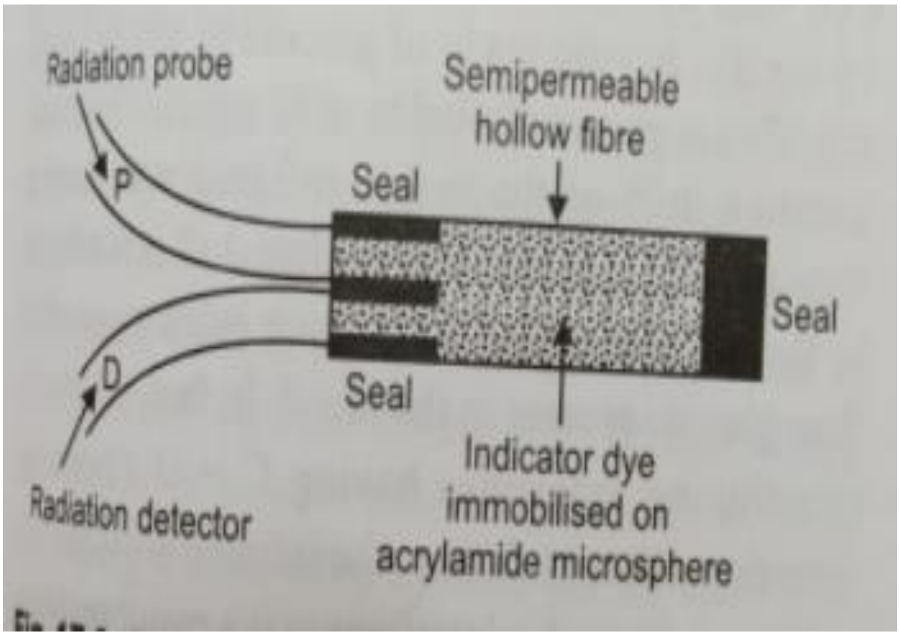


Figure 3.22 Fiber optic pH sensor

- The indicator is trapped inside the membrane by bonding it to polyacrylamide gel microspheres.
- Hydrogen ions diffusing across the cellulose fibre membrane cause the dye to change colour.
- The absorbance or colour change is quantitatively measured by the intensity of green light (550 nm) transmitted through the fibre.
- Green and red light is passed into the cell from one optical fibre.
- The green light is partially absorbed by the dye, while the red light that is not absorbed act as a reference beam.
- A separate optical fibre collects the emitted light and passes it to a photodetector for processing.

3.16.2 Optical–FiberTemperature sensors

- Temperature sensors, such as thermistor or thermocouples require metallic components and connecting wires, which disturbs the incident electromagnetic fields and may even cause localized heating spots and the temperature readings may even be erratic due to interference.
- This problem is overcome by using temperature sensors, based on fiber-optics.
- These fiber optic devices utilize externally induced changes in transmission characteristics of the optical fibers and offer typical advantages of optical fibers such as, flexibility, small dimensions and immunity from electro-magnetic interference.
- Simplest type of temperature sensors consists of a layer of liquid crystal at the end of optical fibers, giving a variation in light scattering with temperature at a particular wavelength

- A temperature sensor, which utilizes a silica-core, silicon clad fiber, with an unclad terminal portion immersed in a liquid which replace the clad.
- Temperature rise causes e reduction in refractive index in liquid, clad fiber section.
- Therefore, light travelling from the silicon clad fiber to liquid clad fiber undergoes an attenuation, which decreases by increased temperature.
- The light from an 860mm LED is coupled into the fiber.
- The light reflected backwards is sent along the same fibers and light amplitude modulation, induced by thereto sensitive cladding applied on the distal end of fiber, is detected and processed.
- One more type of temperature sensor is based on the temperature dependence of band edge absorption of infrared light in GaAs crystal.
- In this temperature measuring system light is emitted by a LED, transmitted to and from the crystal via optical fiber and measured by a photo detector.
- No metal parts are used in the temperature probe design, resulting in transparency of the probe to electromagnetic fields.

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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – IV– Biosensors and Measurements – SBMA1301

IV. Biosensors

Biological Sensors: Study of various corpuscles like Pacinian, functions and modelling, Chemoreceptor, hot and cold receptors, baro- receptors, sensors for smell, sound, vision, osmolality and taste.

Biosensors: Introduction, Advantages and limitations, various components of Biosensors, Biocatalysts based biosensors, bio-affinity based biosensors & microorganisms based biosensors, Types of membranes used in biosensor constructions, Electronic Nose.

4.1 Biological Sensors: Study of various corpuscles like Pacinian, functions and modelling

- Pacinian corpuscle- an encapsulated ending of a sensory nerve that acts as a receptor for pressure and vibration.
- They are nerve endings in the skin responsible for sensitivity to vibration and pressure.
- They respond only to sudden disturbances and are especially sensitive to vibration.
- Pacinian corpuscles are also found in the pancreas, where they detect vibration and possibly very low frequency sounds.
- Pacinian corpuscles act as very rapidly adapting mechanoreceptors.
- The human skin is highly sensitive to changes in the external environment.
- These receptors detect the external stimulus and signal the CNS to take necessary actions to cope with the changing external environment.
- Pacinian corpuscles or lamellar corpuscles
- They are not only found in skin but are also seen in the walls of organs like the pancreas, urinary bladder, and rectum, etc. here, these corpuscles detect the pressure created by distortion of the surrounding tissue and make the higher centers aware of it.

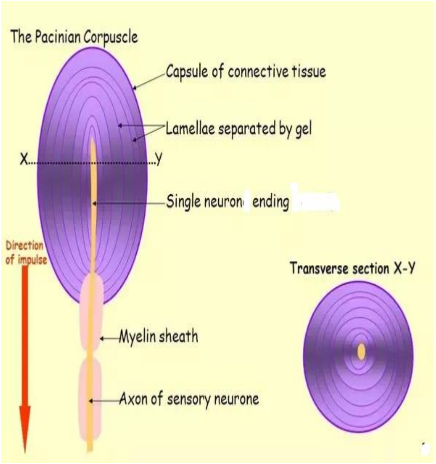

Figure 4.1 Pacinian Corpuscle

- Pacinian corpuscles are the capsulated endings of sensory neurons. They are large oval structures that are 0.5 to 1 mm in diameter. These corpuscles are found deep in the skin within the layers of reticular dermis and hypodermis.
- Pacinian corpuscles have a single axonal fiber at the center surrounded by 15-20 lamella arranged in a concentric pattern. The entire structure is also surrounded by a connective tissue capsule. A fluid of certain nature is also present in between the lamella of the corpuscle.
- The myelinated fiber enters a peripheral sensory nerve.
- Pacinian corpuscles are responsible for detecting pressure and vibration stimuli.
- Any pressure or change in pressure is detected by the change in the position or shape of the lamella of Pacinian corpuscles.
- When pressure is applied to the skin, the lamella of Pacinian corpuscles gets deformed.
- This causes stress on the membrane of sensory neuron and potential is generated, called the generator potential or receptor potential.
- The basic reason of receptor potential is the change in the membrane permeability of different ions caused by the stress on the sensory axon.
- It causes the ions to diffuse into the cell at a different rate, resulting in a change in transmembrane potential.

4.1.1 Generation of Action Potential

- compressed anywhere, it will result in elongation, bending, or deformation of the central fiber.
- When a small area of the axonal fiber is compressed due to the deformation of the corpuscle, certain ion channels open causing the positively charged sodium ions to diffuse into the axon.
- These positive ions cause depolarization of the fiber creating a potential called receptor potential.
- This receptor potential also creates local circuits of current flow that spread throughout the length of the fiber.
- The first node of Ranvier is located inside the capsule.
- When the local current circuits reach this node, the membrane becomes depolarized.
- The action potential now leaves the corpuscle and travels from node to node, along the sensory nerve.
- The action potential is only generated when the receptor potential is greater than the threshold potential of the sensory fiber.

- The strength of the receptor potential is related to the intensity of the stimulus
- The increased influx of sodium ions causes a stronger receptor potential.
- The receptor has an extreme range of responses, from very weak to very strong. The receptor is more sensitive to the weak sensory stimuli.
- If a continuous stimulus is applied to a sensory receptor, it first generates impulses at a very rapid rate. The response rate progressively decreases finally reaching a level when only a few or no impulses are generated. This phenomenon is known as adaptation.
- Pacinian corpuscles are a good example of rate receptors or phasic receptors.
- The rapidly adapting receptors cannot be used to send continuous signals as they are stimulated only when the strength of the stimulus changes.
- As they react only in response to an actual change, they are termed as rate receptors, phasic receptors, or movement receptors.
- When a sudden pressure is applied to a tissue, it excites the Pacinian corpuscles for a few milliseconds.
- The excitation is over soon, although the pressure is still there. A signal is transmitted again when the pressure is released.
- Thus, it keeps the nervous system aware of the changing deformation of tissues but is useless in the case of the constant deformation state of the body.

4.1.2 Functions of Pacinian Corpuscles

(i) Detection of Pressure and Vibration Changes

- It is the primary function of Pacinian corpuscles.
- They detect any pressure change applied to the skin.
- The changing pressure stimuli create a sense of vibration.
- They have pressure-sensitive sodium channels that are opened in response to the changing pressure on the skin.
- An action potential is initiated that is carried to the higher centers of the brain via the ascending pathways in the spinal cord.

(ii) Detection of Pressure in Internal Organs

- Pacinian corpuscles are also present in the walls of some viscera like the rectum and urinary bladder.
- Here, the detect the pressure created due to the filling of the organ. As a result, a signal is sent to the CNS that makes us aware of the filled state of the organ.

- The CNS also make necessary arrangements to empty the filled urinary bladder or rectum. Thus, they have an important role in processes like urination and defecation.

4.2 Chemo receptors

- Chemoreceptors are stimulated by a change in the chemical composition of their immediate environment.
- There are many types of chemoreceptor spread throughout the body which help to control different processes including taste, smell and breathing, control the pH, partial pressure of oxygen (pO2) and partial pressure of carbon dioxide (pCO2) within our blood

4.2.1 Peripheral Chemoreceptors

- Located in both the carotid body and the aortic body, these receptors detect large changes in pO2 as the arterial blood supply leaves the heart.
- If an abnormally low pO2 is detected, afferent impulses travel to the respiratory centres in the brainstem.
- A number of responses are then coordinated which aim to increase the pO2 again.
- These include:
- Increasing the respiratory rate and tidal volume, to allow more oxygen to enter the lungs and subsequently diffuse into the blood
- Directing blood flow towards the kidneys and the brain (as these organs are the most sensitive to hypoxia)
- Increasing Cardiac Output in order to maintain blood flow, and therefore oxygen supply to the body's tissues.

4.2.2 Central Chemoreceptors

- Located in the medulla oblongata of the brainstem, these receptors are more sensitive and detect smaller changes in arterial pCO_2.
- controls our respiratory system
- An increase in pCO_2 leads to an increase in ventilation. This results in more CO_2 being blown off and so the pCO_2 returns to normal
- A decrease in pCO_2 leads to a decrease in ventilation. This results in more CO_2 being retained in our lungs and so the pCO_2 returns to normal.
- these receptors actually detect changes in the pH of the Cerebral Spinal Fluid (CSF).
- The pH of the CSF is established by the ratio of pCO_2 : [HCO3–].

- The HCO3– levels remain relatively constant, whereas CO2 freely diffuses across the blood brain barrier (from the arterial blood supply into the CSF).
- This means, in the short term, the pH of the CSF is approximately inversely proportional to the arterial pCO_2. As described above, a small drop in pCO2¬leads to an increase in pH of the CSF and subsequently stimulates the respiratory centres to decrease ventilation and vice versa.
- However, if pCO_2 levels stay abnormal over a substantial period of time, e.g. three days or more, specialised cells (called choroid plexus cells) within the blood brain barrier allow HCO3– ions to enter the CSF.
- As such the system can be 'reset' to a different pCO_2 by manipulating the pH – which can be relevant in certain diseases, such as Chronic Obstructive Pulmonary Disease (COPD).

4.3 Hot and Cold receptors

- thermoreceptor: a nerve cell that is sensitive to changes in temperature
- Thermoreceptors can include: Krause end bulbs, which detect cold and are defined by capsules; Ruffini endings, which detect warmth and are defined by enlarged dendritic endings; and warm and cold receptors present on free nerve endings which can detect a range of temperature.
- The cold receptors present on free nerve endings, that can be either lightly-myelinated or unmyelinated, have a maximum sensitivity at ~ 27°C and will signal temperatures above 17°C.
- The warm receptors present on free nerve endings are unmyelinated fibers that have a maximum senstivity of ~45°C and will signal temperature above 30°C.
- Mammals have at least two types of sensors: those that detect heat (i.e., temperatures above body temperature) and those that detect cold (i.e., temperatures below body temperature).
- A thermoreceptor is a sensory receptor or, more accurately, the receptive portion of a sensory neuron that codes absolute and relative changes in temperature, primarily within the innocuous range.
- The adequate stimulus for a warm receptor is warming, which results in an increase in their action potential discharge rate; cooling results in a decrease in warm receptor discharge rate.

- For cold receptors, their firing rate increases during cooling and decreases during warming. The types of receptors capable of detecting changes in temperature can vary.
- There are thermoreceptors that are located in the dermis, skeletal muscles, liver, and hypothalamus that are activated by different temperatures.
- These thermoreceptors, which have free nerve endings, include only two types of thermoreceptors that signal innocuous warmth and cooling respectively in our skin.
- The warm receptors show a maximum sensitivity at ~ 45°C, signal temperatures between 30 and 45°C, and cannot unambiguously signal temperatures higher than 45°C; they are unmyelinated.
- The cold receptors have their maximum sensitivity at ~ 27°C, signal temperatures above 17°C, and some consist of lightly-myelinated fibers, while others are unmyelinated.
- Our sense of temperature comes from the comparison of the signals from the warm and cold receptors. Thermoreceptors are poor indicators of absolute temperature, but are very sensitive to changes in skin temperature.
- The thermoreceptor pathway in the brain runs from the spinal cord through the thalamus to the primary somatosensory cortex. Warmth and cold information from the face travels through one of the cranial nerves to the brain.
- Any stimulus that is too intense can be perceived as pain because temperature sensations are conducted along the same pathways that carry pain sensations.

4.4 Baroreceptors

The best known of nervous mechanisms for arterial pressure control (baroreceptor reflex). Baroreceptors are stretch receptors found in the carotid body, aortic body and the wall of all large arteries of the neck and thorax. Respond progressively at 60-180 mm Hg. Respond more to a rapidly changing pressure than stationary pressure. Baroreceptors are sensors located in the blood vessels of the human body. They are a type of mechanoreceptor that detect the pressure of blood flowing through them, and can send messages to the CNS to increase or decrease total peripheral resistance and cardiac output. Baroreceptors act immediately as part of a negative feedback system called the baroreflex, as soon as there is a change from the usual blood pressure mean arterial blood pressure, returning the pressure to a normal level. In the walls of the bifurcation region of the carotid arteries in the neck, and also in the arch of the aorta in the thorax, are many baroreceptors, which are stimulated by stretch of the arterial wall.

4.4.1 The mechanism

- When the arterial pressure rises too high, the baroreceptors send barrages of nerve impulses to the medulla of the brain.
- Here these impulses inhibit the vasomotor center, which in turn decreases the number of impulses transmitted from the vasomotor center through the sympathetic nervous system to the heart and blood vessels.
- Lack of these impulses causes diminished pumping activity by the heart and also dilation of the peripheral blood vessels, allowing increased blood flow through the vessels.
- Both of these effects decrease the arterial pressure back toward normal.
- Conversely, a decrease in arterial pressure below normal relaxes the stretch receptors, allowing the vasomotor center to become more active than usual, thereby causing vasoconstriction and increased heart pumping, and raising arterial pressure back toward normal.

4.4.2 High Pressure Baroreceptors

- Arterial baroreceptors are present in the aortic arch and the carotid sinuses of the left and right internal carotid arteries.
- Arterial baroreceptors are stimulated by pressure changes in the arteries.
- The baroreceptors can identify the changes in the blood pressure which can increase or decrease the heart rate.
- A change in the mean arterial pressure induces depolarization of these sensory endings which results in action potentials.
- These action potentials are conducted to the central nervous system by axons and have a direct effect on the cardiovascular system through autonomic neurons.
- Hormone secretions which target the heart and blood vessels are affected by the stimulaton of baroreceptors
- If blood pressure falls, such as in hypovolaemic shock, baroreceptor firing rate decreases.
- Signals from the carotid baroreceptors are sent via the glossopharyngeal nerve (cranial nerve IX).
- Signals from the aortic baroreceptors travel through the vagus nerve (cranial nerve X). If the arterial pressure is severely lowered, the baroreflex is activated.

- Baroreceptors respond very quickly to maintain a stable blood pressure, but they only respond to short term changes.
- Over a period of 1–2 days they will reset to a new value.
- Thus, in people with essential hypertension the baroreceptors behave as if the elevated blood pressure is normal and aim to maintain this high blood pressure. The receptors then become less sensitive to change.
- Low Pressure Baroreceptors The low-pressure baroreceptors, or cardiopulmonary receptors, are found in large systemic veins, pulmonary vessels, and in the walls of the right atrium and ventricles of the heart.
- The low pressure baroreceptors are involved with the regulation of blood volume throughout the system, in particular in the venous side where most of the blood is held. The blood volume determines the mean pressure .
- The low-pressure baroreceptors have both circulatory and renal effects, they produce changes in hormone secretion which have profound effects on the retention of salt and water and also influence intake of salt and water. The renal effects allow the receptors to change the mean pressure in the system in the long term.

4.5 Sensors for smell

4.5.1 Electronic nose

Electronic noses are engineered to mimic the mammalian olfactory system. Instrument designed to allow repeatable identifications and classifications of aroma mixtures. Determines the various characteristics properties of the odour while eliminating operator fatigue. e-sensing refers to the capability of reproducing human senses using sensor arrays and pattern recognition systems.

Figure 4.2 Electronic nose

- Device intended to detect odors or flavors.
- Can be seen as arrays of sensors able to generate electrical signals in response to either simple or complex volatile compounds present in the gaseous sample.

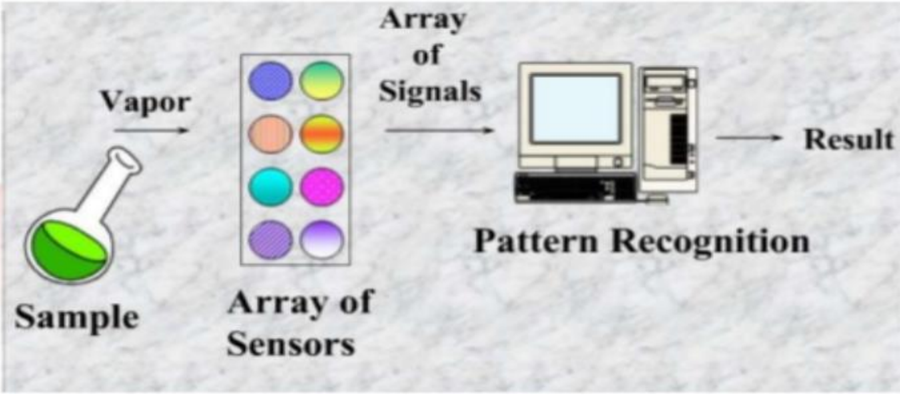

Figure 4.3 Basic design of an e-nose

- Each and every part of the electronic nose is similar to human nose

Biological Nose	E-Nose
Inhaling	Pump
Mucus	Filter
Binding with proteins	Interaction
Enzymatic proteins	Reaction
Cell membrane depolarized	Signal
Nerve impulses	Circuitry and neural network

Table 4.1 Comparison table

- The human sniffers are costly when compared to electronic nose.
- Speedy, reliable new technology of the gas sensors are used in the electronic nose.
- Detection of hazardous or poisonous gas is not possible with a human sniffer.
- An e-nose also overcomes other problems associated with the human olfactory system.
- There lies a great chance of difference in the values got by each individual.
- An air sample is pulled by a vacuum pump.
- It is led through a tube into a small chamber consisting of electronic sensor array.
- A transient response is produced as the volatile organic compounds in the sample interact with the surface of the sensor's active material.
- A steady state response is reached within few minutes. This response is then sent to a signal processing unit.

- Electronic noses include three major parts:

  I. a sample delivery system

  II. a detection system I

  II. a computing system

I. Sample delivery system

- Enables the generation of the headspace (volatile compounds) of a sample.
- The system then injects this headspace into the detection system of the e-nose.

II. Detection system

- Consists of a sensor set, is the "reactive" part of the instrument.
- Adsorption of volatile compounds on the sensor surface causes a physical change of the sensor; they experience a change of electrical properties.
- A specific response is recorded by the electronic interface transforming the signal into a digital value.
- Recorded data are then computed based on statistical models.

III. Computing system

Works to combine the responses of all the sensors.

- The sensor array is clearly the key element. It forms the primary step in the detection or identification of an odorant.
- The most commonly used sensors in electronic nose are:

1.Conductivity sensors

(i) Metal oxide sensors(MOS)

(ii)Conducting polymers

(2) Piezoelectric sensors

(3) MOSFET sensors

(4) Optical sensors Sensor technology

1 (i) MOS (Metal oxide sensors)

- Adsorption of gas molecules provoke changes in conductivity .

- This conductivity change is the measure of the amount of volatile organic compounds adsorbed.

(1) (ii) Conducting polymers

- Conducting or conductive polymer gas sensors operate based on changes in electrical resistance caused by adsorption of gases onto the sensor surface.

(2) Piezoelectric sensors-

• Adsorption of gas onto the surface of the polymer leads to change in mass on the sensor surface.

• This in turn produces a change in the resonant frequency of the crystal.

• This change in frequency is proportional to the concentration of the test material.

(3) MOSFET (Metal Oxide Silicon Field Effect Transistor)sensors-

- A volatile organic compound produces a reaction in the sensing layer(gate).
- This causes the physical property of the gate to change.
- Thereby the threshold voltage is changed and thus the channel conductivity.

4) Optical sensors-

- Optical sensor systems are somewhat more complex than typical sensor- array systems having transduction mechanisms based on changes in electrical resistance.
- Optical sensors work by means of light modulation measurements.

Performing an analysis with an e-nose

- As a first step, an e-nose needs to be trained with qualified samples so as to build a database of reference.
- Then the instrument can recognize new samples by comparing volatile compounds fingerprint to those contained in its database.
- Thus they can perform the analysis.

Applications of e-nose

Respiratory disease diagnosis,Medical diagnosis and health monitoring ,Environmental monitoring ,Application in food industry ,Detection of explosives.

4.6 Sensors For Sound

Sound detection sensor works similarly to our Ears, having diaphragm which converts vibration into signals. However, what's different as that a sound sensor consists of an in-built capacitive microphone, peak detector and an amplifier (LM386, LM393, etc.) that's highly sensitive to sound. With these components, it allows for the sensor to work:

1. Sound waves propagate through air molecules

2. Such sound waves cause the diaphragm in the microphone to vibrate, resulting in capacitance change

3. Capacitance change is then amplified and digitalized for processing of sound intensity

4.6.1 Microphones

These are used to translate wave motion in air into electrical signal. Usual types are: (i) carbon button which changes resistance with air pressure, (ii) electrodynamic where a voltage is induced in a coil by its motion relative to a magnet, (iii) condenser where capacitance of a condenser is varied by the vibration of one of the condenser plates.

- The sound sensor has a thin piece of material called a diaphragm that vibrates when hit by sound waves (similar to how your eardrum vibrates when hearing sound).
- The vibration of the diaphragm is converted by the sensor into an electrical signal

4.6.2 Dynamic moving coil microphone sound transducer

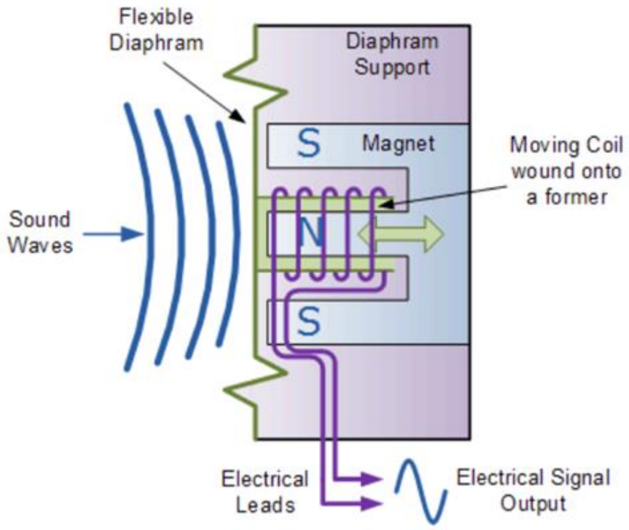

Figure 4.4 Dynamic moving coil microphone

- The construction of a dynamic microphone resembles that of a loudspeaker, but in reverse.
- It is a moving coil type microphone which uses electromagnetic induction to convert the sound waves into an electrical signal.
- It has a very small coil of thin wire suspended within the magnetic field of a permanent magnet.
- As the sound wave hits the flexible diaphragm, the diaphragm moves back and forth in response to the sound pressure acting upon it causing the attached coil of wire to move within the magnetic field of the magnet.
- The movement of the coil within the magnetic field causes a voltage to be induced in the coil as defined by Faraday's law of Electromagnetic Induction.
- The resultant output voltage signal from the coil is proportional to the pressure of the sound wave acting upon the diaphragm so the louder or stronger the sound wave the larger the output signal will be, making this type of microphone design pressure sensitive.

4.6.3 Electret Microphone

- an electret condenser microphone which consists of a very light diaphragm (moving plate) and back plate (stationary or static plate) and has a permanent charge implanted in an electret material to provide polarizing voltage.
- The principle of operation is that sound waves impinging on the diaphragm cause the capacitance between it and the back plate to change synchronously, this in turn induces an AC voltage on the back plate.
- The AC signal is amplified in an amplifier which consists of a single JFET transistor, with the gate connected to the pick-up plate, the source connected to ground, and the signal appearing on the drain. The JFET in this electret microphone is designed for low-noise applications.

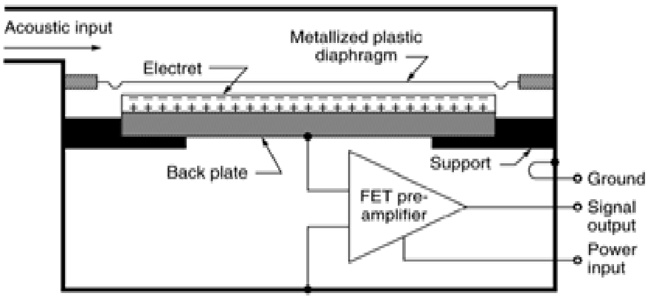

Figure 4.5 Electret microphone

4.6.4 Heart sound measurement

- Heart sounds are diagnostically useful Sounds produced by healthy hearts are very much identical Whereas abnormal sounds always correlate to specific physical abnormalities.
- The heart sounds may be due to movement of heart wall, closure of walls, flow of blood, leakage of blood etc.
- The principal instrument used for the clinical detection of heart sounds is the acoustical stethoscope.
- An improvement over the acoustical stethoscope is the electronic stethoscope consisting of a microphone, an amplifier and a head set.
- Electronic stethoscopes can detect heart sounds which are too low in intensity or too high in frequency to he heard in a purely acoustical instrument.
- The phonocardiograph is an instrument used for detecting and recording the sounds connected with the pumping action (mechanical action) of the heart.
- This helps in indicating heart rate and rhythmicity of heart beat, efficiency of pumping of blood, valve action etc.
- the phonocardiograph consists of a microphone, an amplifier and the recorder
- There are two types' microphones that are used for recording phonocardiogram, 1) Crystal and 2) Dynamic.
- The crystal microphone consists of a piezo electric material which generates potentials when subjected to mechanical stresses due to heart sounds.
- The dynamic type microphone consists of a moving coil having a fixed magnetic core inside it.
- The coil moves with the heart sounds and produces a voltage because of its interaction with the magnetic flux.
- The amplifier used fora phonocardiograph has wide bandwidth with a frequency of range about 20 to 2000 Hz.
- Filters permit selection of suitable frequency bands, so that particular heart sound frequencies can be recorded.
- The phonocardiogram requires a recording system capable of responding to 2000 Hz. Galvanometer recorders, direct writing recorders, inkjet recorders, electrostatic recorders or thermal recorders can be used to record PCG (Phono Cardio Gram) waves.

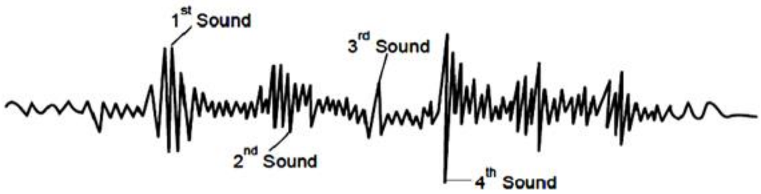

Figure 4.6 Typical phonocardiogram

- The first sound is due to the closure of mitral and tricuspid valves. This sound corresponds to the R wave of the ECG.
- Any abnormality in the first sound thus relates to relaxation of atria or contraction of ventricles.
- The normal sounds are longer in duration, lower in frequency and greater in intensity than the second sound.
- The frequencies of these sounds range between 30 to 100 Hz and duration range from 50 to 100ms.
- The second sound is higher in pitch with duration 25 to 50 ms and frequency 100 Hz.
- this sound is produced due to the closure of aortic and pulmonary valves.
- The third sound is produced by the inflow of blood to the ventricles.
- The fourth sound is produced due to the contraction of the atria.

4.6.5 Hearing Aid

- A hearing aid or deaf aid is an electro acoustic device which is designed to amplify sound for the wearer, usually with the aim of making speech more intelligible.
- Microphone: pick up sound and convert to electrical impulses.
- Amplifier: magnifies electrical impulses
- Receivers: convert electrical impulses back to sound
- Microphone
  The microphone picks up sounds from the air and convert them into electrical signals.
- Amplifier
  The amplifier increases the intensity of the signals from the microphone. Filters modify the sounds so that only sounds which are relevant for the person are amplified.
- 'Loudspeaker'(Receiver)
  The third basic component is the 'loudspeaker' (receiver). It converts electrical signals into acoustic signals, which the person then hears.
- Smallcomputer(Digital)
  These three components exist in all hearing aids. Furthermore, in digital hearing aids a

small computer can be programmed to manipulate the signals to fit the hearing loss of the individual hearing-impaired person.

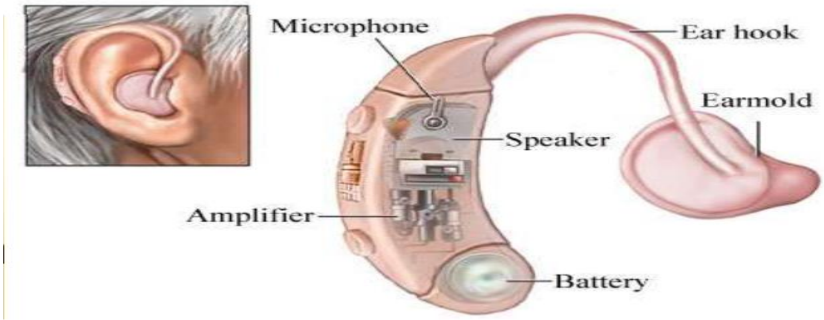

Figure 4.7 Hearing aid

4.7 Sensors for Osmolality

- Osmolality is the concentration of particles (solutes) dissolved in a solution.
- osmolality of many solutions, including serum, urine, plasma, and biologics.
- An osmometer is a device for measuring the osmotic strength of a solution, colloid, or compound.
- Osmometers are useful for determining the total concentration of dissolved salts and sugars in blood or urine samples.
- There are several different techniques employed in osmometry:
- Vapor pressure osmometers determine the concentration of osmotically active particles that reduce the vapor pressure of a solution.
- Membrane osmometers measure the osmotic pressure of a solution separated from pure solvent by a semipermeable membrane.
- Freezing point depression osmometers may also be used to determine the osmotic strength of a solution, as osmotically active compounds depress the freezing point of a solution.

4.7.1 Freezing point depression osmometers

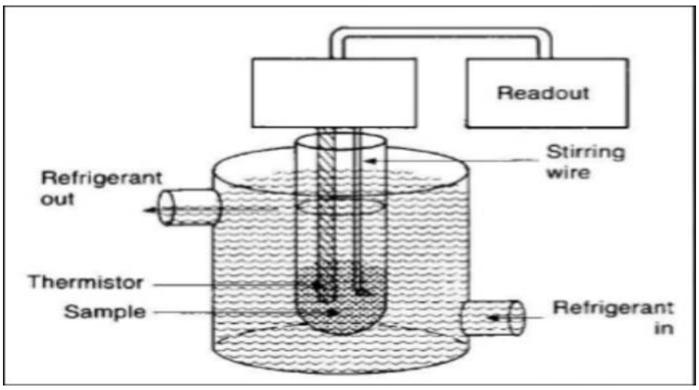

Figure 4.8 Freezing point depression osmometers

- Principle : the freezing point of a solution is related to the osmotic concentration of that solution.
- If concentration of the solute is increased, it will lower its freezing point
- The sample in a small tube is lowered into a chamber with cold refrigerant circulating from a cooling point.
- A thermistor is immersed in the sample.
- To measure temperature, a wire is used to gently stir the sample until it is cooled to several degrees below its freezing point.
- It is possible to cool water to as low as -40°C and still have liquid water, provided no crystals or particulate matter is present—supercooled solution.
- Freezing can also be started by "seeding" a supercooled solution with crystals.
- When the supercooled solution starts to freeze as a result of the rapid stirring, a slush is formed and the solution actually warms to its freezing point temperature.
- The slush will remain at the freezing point temperature until the sample freezes solid and drops below its freezing point.
- Most commonly used method for measuring the osmolality of serum or urine in clinical laboratory.

4.7.2 Vapor Pressure Osmometer

- Measurement related to the decrease in dew point of temp of pure solvent (water) caused by decrease in vapor pressure of solvent by the solute.
- Drawback: measurement of any of volatile solute in serum not better. (volatile gases if present will increase the vapor pressure of solvent)
- Hence not recommended for clinical laboratory

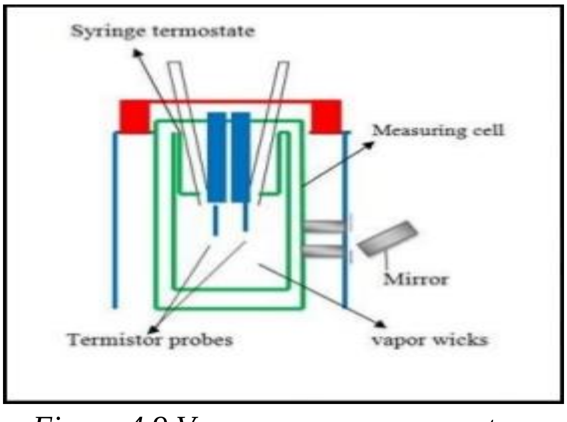

Figure 4.9 Vapor pressure osmometers

4.7.3 Membrane osmometers

- It is a device used to indirectly measure the number average molecular weight of a polymer sample.
- One chamber contains the pure solvent and other a solution in which the solute polymer with unknown MW.
- The osmotic pressure of the solvent across the semipermeable is measured.
- solvent is permitted through the membrane, a change in concentration causes the solvent to diffuse to the solute side of the chamber through the membrane separating it.
- As this occurs, the pressure of the solvent decreases until the pressure difference across the membrane just counteracts the chemical potential difference caused by the solute.
- Hence, this change in pressure is measured.

4.8 Sensors for vision

- The purpose of image sensors are to convert incoming light (photons) into an electrical signal that can be viewed, analyzed, or stored.
- Image sensors built into today's digital cameras and mobile phones mostly use either the CCD (charge coupled device) or CMOS technology.
- digital cameras use solid-state device called image sensor.
- Image sensors contain millions of photosensitive diodes known as photosites.
- When you take a picture, the camera's shutter opens briefly and each photo site on the image sensor records the brightness of the light that falls on it by accumulating photons.
- The more light that hits a photo site, the more photons it records.

4.8.1Types of Image Sensors

- An image sensor is typically of two types:
- (i) Charged Coupled Device (CCD)
- (ii) Complementary Metal Oxide Semiconductor (CMOS)

(i)Charged Coupled Device (CCD)

- Charge-coupled devices (CCDs) are silicon-based integrated circuits consisting of a dense matrix of photodiodes that operate by converting light energy in the form of photons into an electronic charge.

• Electrons generated by the interaction of photons with silicon atoms are stored in a potential well and can subsequently be transferred across the chip through registers and output to an amplifier.

• In a CCD for capturing images, there is a photoactive region, and a transmission region made out of a shift register.

• An image is projected by a lens on the capacitor array (the photoactive region), causing each capacitor to accumulate an electric charge proportional to the light intensity at that location

• The CCD sensor is itself an analog device, but the output is immediately converted to a digital signal by means of an analog-to-digital converter (ADC) in digital cameras, either on or off chip.

• Once the array has been exposed to the image, a control circuit causes each capacitor to transfer its contents to its neighbour.

• The last capacitor in the array dumps its charge into a charge amplifier, which converts the charge into a voltage.

• By repeating this process, the controlling circuit converts the entire semiconductor contents of the array to a sequence of voltages, which it samples, digitizes and stores in some form of memory.

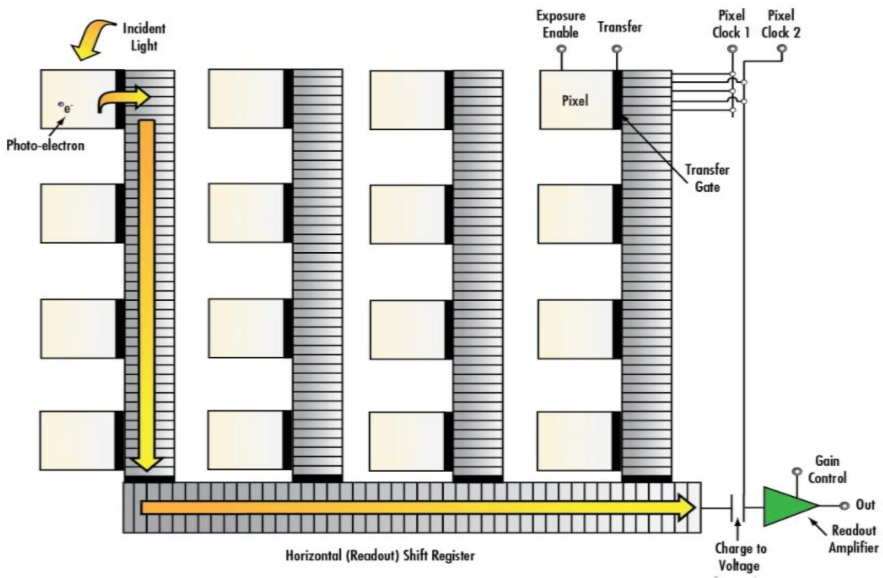

Figure 4.10 charged coupled device

(ii) Complementary Metal Oxide Semiconductor (CMOS)

- CMOS" refers to both a particular style of digital circuitry design, and the family of processes used to implement that circuitry on integrated circuits (chips)
- CMOS circuits use a combination of p-type and n-type metal–oxide–semiconductor field-effect transistors (MOSFETs) to implement logic gates and other digital circuits found in computers, telecommunications equipment, and signal processing equipment
- In most CMOS devices, there are several transistors at each pixel that amplify and move the charge using wires.
- The CMOS approach is more flexible because each pixel can be read individually.
- In a CMOS sensor, each pixel has its own charge-to-voltage conversion, and the sensor often also includes amplifiers, noise-correction, and digitization circuits, so that the chip outputs digital bits.
- With each pixel doing its own conversion, uniformity is lower.

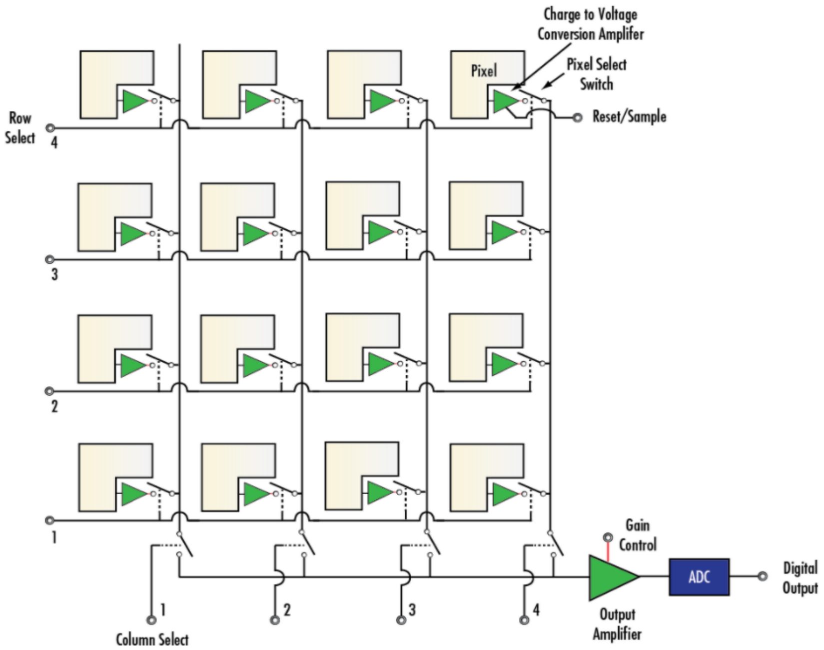

Figure 4.11 Complementary metal oxide semiconductor

- The CMOS image sensor consists of a large pixel matrix that takes care of the registration of incoming light.
- The electrical voltages that this matrix produces are buffered by column-amplifiers and sent to the on-chip ADC.
- So, in case of the CMOS sensor, the charge to voltage conversion as well as the voltage amplification is carried out in the pixel itself.

- So, the processing speed of the CMOS sensor will be much higher than the CCD sensor.
- CMOS image sensors can incorporate other circuits on the same chip, eliminating the many separate chips required for a CCD.
- The overall power consumption of this CCD sensor will be high.
- While in case of this CMOS sensor, it requires the single power supply.
- Overall size of CCD sensor is high.
- Hence CMOS sensor are preferred over CCD sensors.

4.8.2 Electronic EYE system

- a prosthesis which is used to replace a missing or damaged eye.
- In order to accomplish the goal of creating a visual prosthesis, scientists had to develop a camera which could interact with the brain by stimulating the optic nerve.
- In damaged or dysfunctional retina, the photoreceptors stop working, causing blindness**.**

❖ What happens when we look at an object?

- Scattered light from the object enters through the cornea.
- The light is projected onto the retina.
- The retina sends messages to the brain through the optic nerve.
- The brain interprets what the object is.

❖ how brain works after seeing an image?

- After seeing an image, the brain takes information from the outside world and encodes it in patterns of electrical activity.
- After the creating pattern the brain gets an visualization of an image. That can we actually seeing the image from our eyes.

4.8.2.1 ARGUS-II device

- The Argus II Retinal Prosthesis System ("Argus II") is the world's first approved device intended to restore some functional vision for people suffering from blindness.
- transmits images from a small, eye-glass- mounted camera wirelessly to a microelectrode array implanted on a patient's damaged retina.
- The System has three parts:
- a small electronic device implanted in and around the eye,
- a tiny video camera attached to a pair of glasses,

and a video processing unit that is worn or carried by the patient

Figure 4.12 Electronic eye system

- The camera used for this is the CMOS image sensor.
- This camera is placed on the goggles.
- The battery required for this is provided from the video processing unit.
- Video Processing Unit acts as a optogenic transducer unit which simplifies the image as spots of light and then reduces the image to the number of photodiodes.

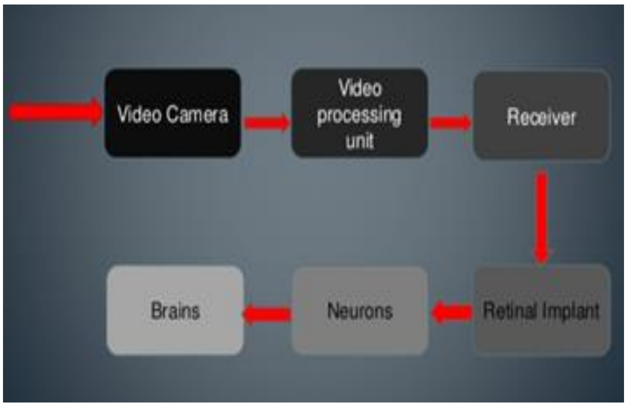

Figure 4.13 Block diagram of Electronic eye system

- The patient wears glasses with an attached video camera that captures images of the surrounding area.
- These images become an electrical signal which is processed by the video processing unit.
- The signal is then wirelessly delivered to the eye stimulating the retina.
- This electrical stimulation of the retina is recognized by the brain as spots of light.
- The camera captures images and sends to retina implant.
- It stimulates neurons.
- The stimulated neurons send information to brain via optic nerves.
- identify the location or movement of objects and people;
- recognize large letters, words, or Sentences.
- and helped in other activities of daily life.

4.9 Sensors for taste

4.9.1 Electronic tongue

- The electronic tongue is an instrument that measures and compares tastes.
- It is an analytical instrument comprising an array of non-specific, low selective chemical sensors with cross-sensitivity to different components in solution, and an appropriate method of pattern recognition and/or multivariate calibration for the data processing.
- Chemical compounds responsible for taste are detected by human taste receptors, and the seven sensors of electronic instruments detect the same dissolved organic and inorganic compounds.
- Like human receptors, each sensor has a spectrum of reactions different from the other.
- The information given by each sensor is complementary and the combination of all sensors' results generates a unique fingerprint.
- Most of the detection thresholds of sensors are similar to or better than those of human receptors.
- In the biological mechanism, taste signals are transducted by nerves in the brain into electric signals.
- E-tongue sensors process is similar: they generate electric signals as potentiometric variations.
- Taste quality perception and recognition is based on building or recognition of activated sensory nerve patterns by the brain and on the taste fingerprint of the product.
- This step is achieved by the etongue’s statistical software which interprets the sensor data into taste patterns.
- Liquid samples are directly analyzed without any preparation, whereas solids require a preliminary dissolution before measurement. Reference electrode and sensors are dipped in a beaker containing a test solution.
- A voltage is applied between each sensor and a reference electrode, and a measurable current response results that is consistent with the Cottrell equation.
- This current response is a result of oxidizing reactions that take place in the solution due to the voltage difference, and can be amplified through catalytic surface treatments.
- The response is measured and recorded by the e-tongue's software. These data represent the input for mathematical treatment that will deliver results.

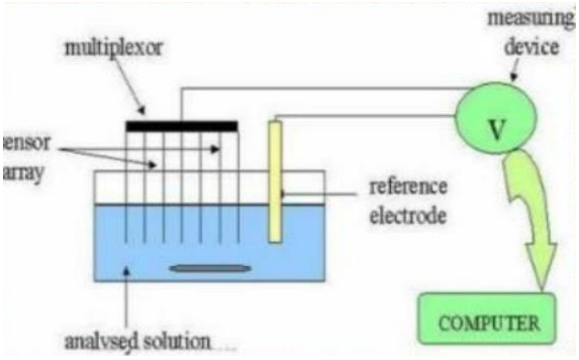

Figure 4.14Block diagram of Electronic tongue

- Chemical sensors are small devices that perform transformation of chemical or biochemical information of a qualitative or quantitative type into an analytical useful signal by the process of chemical interaction between sample and sensors.
- Currently these technologies are based on electrochemical sensors(potentiometric).
- The detecting sensor part consist of lipid/polymer membranes and act as the working electrodes.
- The reference electrodes -Ag/AgCI.
- Electrode charge density of the lipid/polymer membrane-surface and ion distribution near the surface of the membrane is changed due to sample.
- Therefore, the total electric charge on the lipid membrane gives the response membrane electric potential for the substances.
- The acquisition system establishes the communication between the sensor array and data processing system.
- Converts the electrical signals from sensor array to digital signals with less distortion.
- Amplifier must be present as the electrical signals from the sensors are always small.
- Electronic tongues have several applications in various industrial areas: the pharmaceutical industry, food and beverage sector, etc. It can be used to:
- analyze flavor ageing in beverages (for instance fruit juice, alcoholic or non alcoholic drinks, flavored milks...)
- quantify bitterness or “spicy level” of drinks or dissolved compounds (e.g. bitterness measurement and prediction of teas)
- quantify taste masking efficiency of formulations (tablets, syrups, powders, capsules, lozenges...)
- analyze medicines stability in terms of taste, monitor biological and biochemical processes.

- The electronic tongue uses taste sensors to receive information from chemicals on the tongue and send it to a pattern recognition system.
- The result is the detection of the tastes that compose the human palate.
- The types of taste that is generated is divided into five categories sourness, saltiness, bitterness, sweetness, and umami (savoriness).
- Sourness, which includes hydrogen chloride, acetic acid, and citric acid, is created by hydrogen ions.
- Saltiness is registered as sodium chloride, sweetness by sugars, bitterness, which includes chemicals such as quinine and caffeine is detected through magnesium chloride, and umami by monosodium glutamate from seaweed, or disodium guanylate in meat/fish/mushrooms.

4.10 Biosensors

- A biosensor is an analytical device which converts the biological signal into a measurable electrical signal.
- Professor Leland C Clark is the father of Biosenor.
- It detects, records and transmits information regarding a physiological change or process.
- It determines the presence and concentration of a specific substance in any test solution.
- Biosensor is a special type of bioelectronic device commonly used in bio-analysis.
- A sensor can be viewed as the "primary element of a measurement chain, which converts the input variable into a signal suitable for measurement.
- Biosensor is an analytical device for the detection of an analyte that combines a biological component with a physiochemical detector.
- A device incorporating a biological sensing element connected to a transducer.
- Two fundamental operating principles of a biosensor are "biological recognition" and "sensing."
- Therefore, a biosensor can be generally defined as a device that consists of three basic components connected in series:
- (1) a biological recognition system, often called a bioreceptor, (2) a transducer, and (3) microelectronics.
- The basic principle of a biosensor is to detect this molecular recognition and to transform it into another type of signal using a transducer.

4.10.1 Basic Principle of Biosensor

- Basic priciple of biosensor involved in three element :-
- First biological recognization element which highly specific towards the biological material analytes produces.
- Second transducers detect and transduces signal from biological target -receptor molecule to electrical signal which is due to reaction occur.
- Third after transduction signal from biological to electrical signal where its amplification is necessary and takes place and read out in detector after processing the values are displayed for monitor and controlling the system.

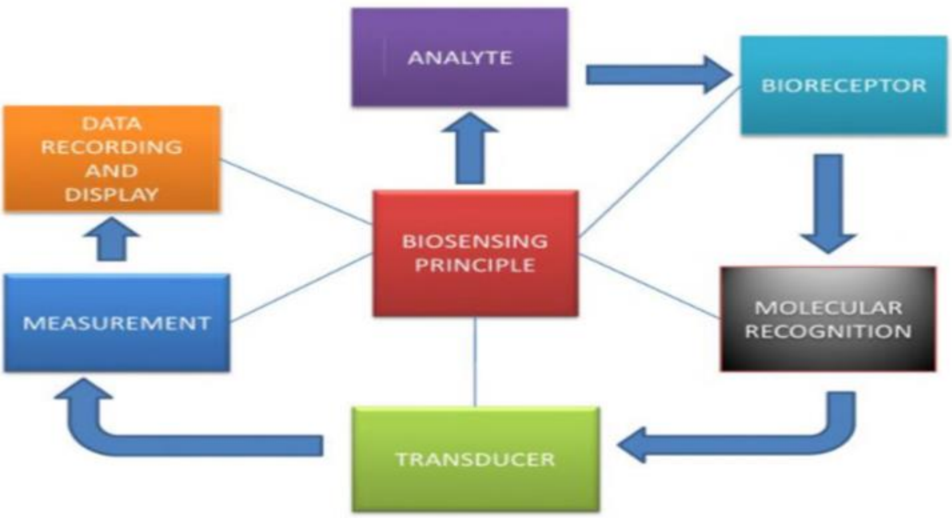

Figure 4.15Basic principle of Biosensor

- The term biosensor is short for biological sensor and is a device made up of a transducer and a biological element that may be an enzyme, an antibody, or a nucleic acid.
- The biological element or bioelement interacts with the analyte being tested and the biological response is converted into an electrical signal by the transducer.
- Every biosensor has a biological component that acts as the sensor and an electronic component that detects and transmits the signal.
- In other words, the biological material is immobilized and a contact is made between the immobilized biological material and the transducer**.**
- The analyte binds to the biological material to form a bound analyte, which in turn produces the electronic response that can be measured.

- Sometimes the analyte is converted to a product that could be associated with the release of heat, gas (oxygen), electrons, or hydrogen ions.
- The transducer then converts the product-linked changes into electrical signals, which can be amplified and measured.

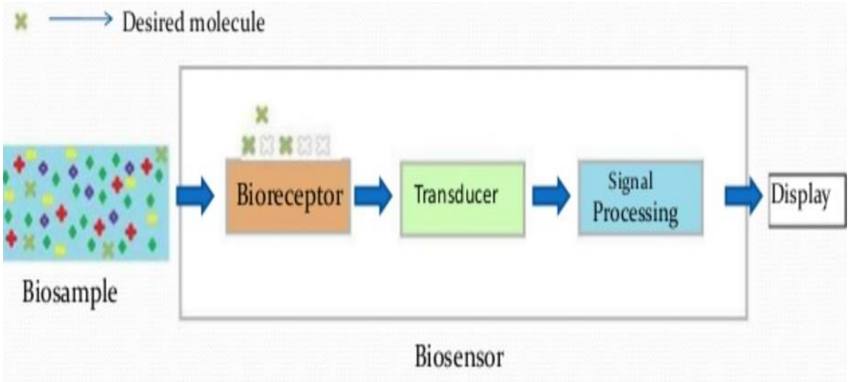

Figure 4.16 Block diagram of Biosensor

4.10.2 Components of Biosensor

- A biosensor consists of three main elements:
- a bioreceptor, a transducer, and a signal pro-cessing .
- Biosensors can be classified by their bioreceptor or their transducer types.
- Analyte: A substance of interest that needs detection. A substance whose chemical constituents are being identified and measured. For instance, glucose is an 'analyte' in a biosensor designed to detect glucose.
- Bioreceptor: A molecule that specifically recognises the analyte is known as a bioreceptor. Enzymes, cells, nucleic acid, antibodies are some examples of bioreceptors.
- The process of signal generation (in the form of light, heat, pH, charge or mass change, etc.) upon interaction of the bioreceptor with the analyte is termed bio-recognition.
- Transducer or detector element:
- It transforms the signal resulting from the interaction of the analyte with biological element into another signal that can be more easily measured or quantified.
- Biosensor reader device:
- It associates with electronics or signal processor that are responsible for the display of the results.

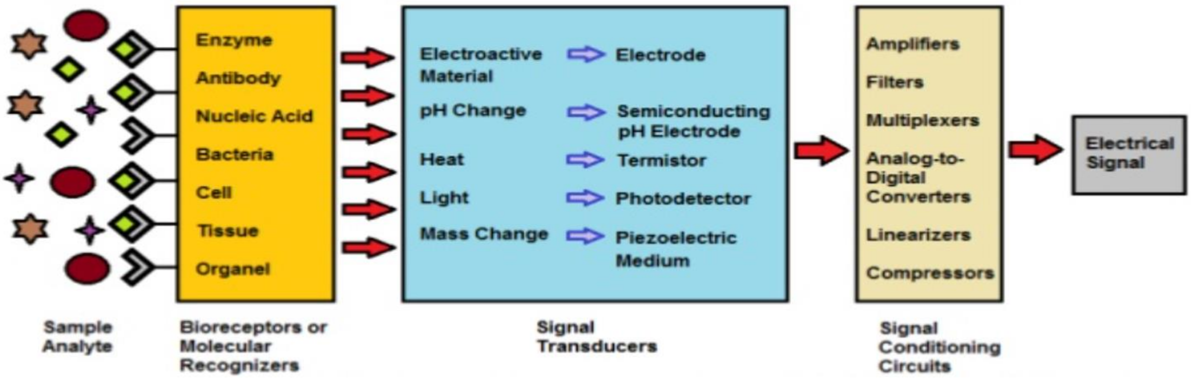

Figure 4.17 Components of Biosensor

- Analyte diffuses from the solution to the surface of the Biosensor.
- Analyte reacts specifically & efficiently with the Biological Component of the Biosensor.
- This reaction changes the physicochemical properties of the Transducer surface.
- This leads to a change in the optical/electronic properties of the Transducer Surface.
- The change in the optical/electronic properties is measured/converted into electrical signal, which is detected.
- These are the major selective element in biosensors. These substances attach themselves to one particular substrate but not to others. There are four main biological elements namely

  a)Enzymes

  b)Antibodies

  c)Nucleic Acid

  d)Receptors

  a)Enzymes

(a) Enzymes

- It is used in purified form and it is present in microorganisms.
- It is also present in slice of intact tissues.
- They are biological catalyst for particular reaction.
- Catalysts are those which will speed up the reaction and do not undergo any change itself.
- This catalytic action is made use in the biosensor.
- They can bind themselves to specific substrate.

- **Advantage**:
- They bind to the subject.
- They are highly selective.
- They have catalytic activity thus improving selectivity.
- They are fairly fast acting.
- They are the most commonly used biological component
- Disadvantages:
- They are expensive because of cost extracting, isolating and purifying is high
- There is loss of activity when they are immobilized to a transducer.
- They tend to lose activity after a short period of time.

(b) Anitbodies

- Antibodies bind specifically with the corresponding antigen.
- They have no catalytic effect.
- They involve with the substrate directly and provide a signal for the transducer.
- Advantages:
- They are very selective.
- They are very sensitive.
- They bind very powerfully. Disadvantage:
- There is no catalytic effect
- **Advantages**
- Can be integrated on one chip and are useful for measuring various substances in small amounts of sample solution simultaneously.
- Since semiconductor fabrication technology is applied to micro-biosensors, it is possible to develop disposable transducers for biosensors through mass production.
- Rapid and convenient detection
- Direct measurement of real sample
- Very specific detection

c)Nuclei acids

- Nucleic acids are the main information-carrying molecules of the cell, and, by directing the process of protein synthesis, they determine the inherited characteristics of every living thing. The two main classes of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

- These operate selectively because of their base-pairing characteristics. They are used in identifying genetic disorder in children.

d) Receptors

- Receptors are proteins, usually cell surface receptors, which bind to ligands and cause responses in the immune system, including cytokine receptors, growth factor receptors and Fc receptor.
- Receptors can be found in various immune cells like B cells, T cells, NK cells, monocytes and stem cells.
- Receptors are proteins present inside the lipid bilayer plasma membrane surrounding a cell.
- They traverse the full breadth of the membrane and have molecular recognition property.
- They bind solutes with a degree of affinity and specificity matching antibodies.
- The biological component has to be properly attached to the transducer to make a good biosensor. This process of attaching the biological component with the transducer is known as Immobilisation.

4.11 Advantages of Biosensors

- The purpose of a biosensor is to provide rapid, real-time, accurate, and reliable information about the analyte of interrogation.
- Ideally, it is a device that is capable of responding continuously, reversibly, and does not perturb the sample.
- Easy to use, linear response
- High sensitivity, high specificity, bind to analyte, low sample requirements
- Portable, inexpensive

4.12 Limitations of Biosensors

- Ph parameter , temperature parameter influences the performance of biosensor sensitivity .
- Tedious measurement conditions
- Requirement for sample preparation
- Requires the identification of analyte

4.13 Applications of biosensors

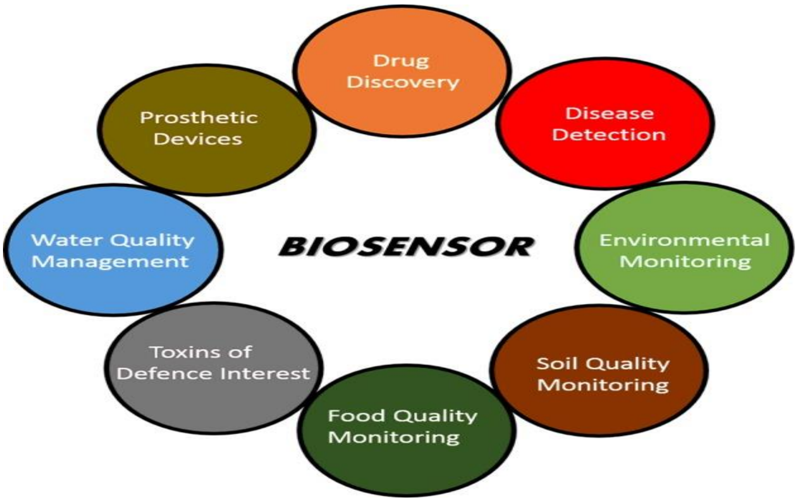

Figure 4.18 Applications of Biosensor

4.14 Types of membranes used in biosensor constructions

- A variety of membranes can be used in the construction of biosensors depending on the need. The membranes are constructed from a variety of sources/materials; hydrophilic, hydrophobic, conducting, non-conducting and so on.
- Various types of membranes used in the construction of biosensors include :
- Membranes made from synthetic polymers with high water regaining capacity. eg: hydrogels like Polyacrylamides
- Hydrophobic Membranes that are impermeable to high molecular weight watersoluble compounds, but are permeable to ions and gases. Polytetrafluoroethylene, Polyvinylchloride membranes are used in the making of Ion Selective Electodes (ISE's).
- Membranes constructed from biologically derived materials such as cellulose, collagen etc. Membranes derived from these materilas posses good properties for immobilizing biological materilas (such as porosity).
- Non-Conducting Polymer Films such as Polyphenol are used as membranes for biosensors.
- Conducting Polymer Films such as Polypyrrole and Polyaniline are also used as membranes in biosensors.
- Heterogenous multilayer membranes are used in certain cases. They contain multiple membranes. Each membrane has a different biological material and thus a different function.
- Microfiltrarion membranes such as Polycarbonate membranes are also used in Biosensors.
- The choice of the membrane used for a biosensor is made taking into consideration, the analyte, the method of detection of the reaction/signal at/from the biological element.

- For example :Ion selective membranes are used in the making of Potentiometric biosensors.
- PolyTetraFluoroEthylene and Teflon membranes are used in the glucose biosensor for seperating the electrode from the bulk reaction mixture.
- PolyVinylAlcohol membrane for Glucose and Lactate Biosensors.

4.14 Types of biosensors

(i) On The Basis of Transducing Element

1. Calorimetric biosensor: They measure change in temperature due to either release (exothermic) or absorption (endothermic) of heat. ex. Temperature biosensors.

2. Potentiometric biosensors: They measure potential difference arising during a redox reaction. ex. Urea biosensor.

3. Amperometric biosensor: They measure current (flow of electrons) arising during a reaction. ex. Glucose biosensor.

4. Conductometric biosensors: These measure changes in electrical conductivity arising during a reaction. Ex. urea biosensor.

5. Acoustic wave biosensor: they measure electric field developed by piezoelectric effects. Ex. Cocaine biosensor.

6. Optical biosensors: They measure light arising from the action of enzyme luciferase (firefly). ex. Detection of bacteria

(ii) Classification based on biorecognition element

(a) Biocatalysts based biosensors

(b) Bio-affinity based biosensors

(c) Microorganisms based biosensors

4.14.1Biocatalysts based biosensors

- These are also known as metabolism sensors and are kinetic devices based on the achievement of a steady state concentration of a transducer detectable species.
- The progress of the biocatalyzed reaction is related to the concentration of the analyte, which can be measured by monitoring the rate of formation of product, the disappearance of a reactant, or the inhibition of the reaction.

- The biocatalyst can be an isolated enzyme, a microorganism, a sub cellular organelle, or a tissue slice.
- Catalysts are substances that speed up chemical reactions. Organic/bio-catalysts are called enzymes.
- Reactions with enzymes are up to 10 billion times faster than those without enzymes
- Enzymatic (or metabolism) biosensors employ immobilized enzymes as receptors. Enzymes are catalysts, substances that enable biochemical processes to proceed. The enzymatic reaction makes it possible for a signal to be produced by the transducer.
- Enzymatic sensors are based on the catalytic chemical reaction of the enzyme and substrate. The reaction products, the charge exchange, or the heat generation may be the bases for the indirect transduction.
- The enzyme-based biosensor is a chemical sensor in which the catalytic property of an enzyme is utilized.
- In biosensors, immobilized enzymes are generally used.
- Enzyme-based biosensors can be formed by different sensing principles, such as electrochemical, electromagnetic, optical, thermal, and gravimetric ones.
- The amperometric principle has been widely used in enzyme electrodes. For example, glucose can be measured selectively by detecting the consumption of oxygen or the formation of hydrogen peroxide produced by the enzymatic reaction of glucose oxidase (GOx).

$$\text{Glucose} + O_2 \xrightarrow{\text{GOx}} \text{Gluconolactone} + H_2O_2$$

- Enzyme based biosensors are used in different analysers for quantification of glucose (PO2 electrode) ,urea, creatinine etc where the enzyme is immobilized on the sensor.
- ISFET
- In a potentiometric enzyme electrode, the product of the enzymatic reaction is measured by the potentiometric method.
- For example the hydrolysation of urea is catalysed by urease as

$$Urea + 2H_2O + H^+ \xrightarrow{urease} 2NH_4^+ + HCO_3^-$$

and then NH_3 is formed by

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$$

4.14.2 Bio-affinity based biosensors

- In these, the receptor molecule binds the analyte "irreversibly" and non-catalytically.
- .Receptor molecules are Antibodies,Nucleic acids,Hormone receptors
- Affinity biosensors are based on specific chemical binding.
- In immunosensors, this means the antigen-antibody reaction.
- They employ the phenomenon that the immunosystem of living things produces specific antigens against foreign objects (bacteria, viruses, molecules, etc.) that are able to form stable complexes for biological recognition.
- In DNA sensors (also called DNA chips), the selective chemical binding is the hybridization of molecule clusters with DNA molecules to form a double structure.
- The immunosensor is a type of chemical sensor in which the antigen—antibody reaction is utilized so as to realize highly specific and sensitive measurements
- The antigen, Ag, and the antibody, Ab, form an antigen—antibody complex, AgAb.
- When Ag is introduced, but the amount of Ab remains unchanged, the amount of introduced Ag can be determined by the increment of AgAb.
- If the antibody Ab is immobilized and fixed on the sensor surface, formation of AgAb will cause some change in the sensing element, which can be measured by many different ways such as electrochemical, acoustic, gravimetric, and optical techniques.
- Highly sensitive immunosensors can be formed by utilizing an enzymatic reaction, in which a sample with a fixed amount of enzyme-labeled antigen is introduced onto the sensing element with immobilized antibody to which labeled or unlabeled antigens can be bound.
- After removing the free antigen, enzyme activity is measured by introducing a substrate and detecting the change of the product by an appropriate technique such as the electrochemical, gravimetric, or optical method. The binding reactions of labeled and unlabeled antigens are competitive: When the concentration of unlabeled antigen

is increased, more antibodies are occupied by unlabeled antigens so that the amount of antibodies bound by labelled antigens decrease and consequently, after separating the free antigen, the resulting enzyme activity will decrease.

- This leads to the formation of a sandwich complex (Ab:Ag:Ab). After washing out unbound labeled antibody, the amount of labeled antibody remaining is proportional to that of the antigen in the sample.
- The DNA sensor is a device for detecting DNA molecules having specific base sequence.
- To recognize the specific base sequence among the sample DNA, the hybridization technique is employed.
- A single strand DNA segment is hybridized to another single strand DNA segment forming a double strand structure when the base sequence is matched.
- In order to detect DNA segment having a spe-cific base sequence (target), another DNA segment having a complementary base sequence (probe) is used so that the target is hybridized with the probe and forms a hybrid. Hybridization is a conse-quence of a reaction given by
- Probe + Target —> Hybrid
- The concentration of target can be predicted by measuring the amount of hybrid.
- To detect the result of hybridization, different sensing principles have been used such as amperometric, potentiometric,electrochemical, acoustic, gravimetric,.

4.14.3 Microorganisms based biosensors

- microbial sensor is a type of chemical sensor in which immobilized microorganisms are incorporated so that microbe-catalyzed reactions can occur.
- Living bacterial cells was fixed in place of isolated enzymes on the surface of electrochemical sensor to form a microbial electrode.
- While the selectivity of a microbial sensor for substrates is realized by the enzymes in incorporated microorganisms, there are particular advantages in using microorganisms versus using isolated enzymes;

- (1) microbial sensors are less sensitive to inhibition by solutes and are more tolerant of suboptimal pH,
- (2) they have a longer lifetime than enzyme electrodes, and
- (3) they are cheaper because an active enzyme does not need to be isolated
- On the other hand, there are disadvantages; (1) some microbial sensors have a longer response time than enzyme electrodes, (2) they need more time to return to the base line level after use, and (3) microorganisms contain many enzymes and care must be taken to ensure selectivity
- Most microbial sensors are classified into two types; the respiration-measuring type and the metabolite-measuring type. The respiration-measuring types of microbial sensors consist of immobilized aerobic microorganisms and an oxygen electrode. When a substrate, which can be metabolized by the microorganism, is contained in a solution saturated by oxygen, a metabolic reaction occurs by consuming dissolved oxygen, and thus the substrate can be measured from the decrease in oxygen tension.
- By means of respiration-measuring types of microbial sensors, many substances such as glucose, assimilable sugars, acetic acid, ammonia, and alcohols are measured selectively by using different microorganisms
- The metabolite-measurement type of microbial sensor consists of immobilized microorganisms and a sensor, which detects the metabolite that is produced by the reaction catalysed by that microorganism.
- Using different types of gas and ion sensors, many kinds of substances can be measured by detecting different metabolites. For example, the fuel cell electrode is used to detect H2 for measuring formic acid, the CO, electrode for glutamic acid or lysine, and the pH electrode for cephalosporin and nicotinic acid
- Some bacteria, called luminous bacteria, exhibit luminescence. If luminous bacteria are immobilized and combined with a photo detector, substances that affect the bioluminescence can be measured by detecting the change in luminescence.
- Such a type of sensor is called the photo microbial sensor. While some substances, such as glucose, may increase luminescence, many toxic substances such as benzalkonium chloride, sodium dodecyl sulphate, chromium, and mercury decrease

luminescence, and thus the photomicrobial sensors are applicable to environmental monitoring

- The combination of a microbial sensor and an immobilized enzyme membrane is effective in some cases, and such a sensor is called a hybrid biosensor.
- For example, a urea sensor can be formed by combining an immobilized urease membrane and a microbial NH3 sensor using nitrifying bacteria.
- In this sensor, higher selectivity is realized by using an immobilized enzyme.
- The microbial NH3 sensor is superior to the potentiometric ammonium electrode in the sense that interference from ions or volatile compounds such as amines is less common.

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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOMEDICAL ENGINEERING

UNIT – V– Biosensors and Measurements – SBMA1301

V. Display and recording devices

Digital Display System and Indicators: Classification of display devices, DOT Matrix display, Digital voltmeter, Multimeter, Digital storage oscilloscope, LCD monitor, PMMC writing systems. Recorders: Graphic recorders, strip chart recorders, Galvanometer type recorders and self-balancing type potentiometric recorders, Magnetic tape recorders and Disc recorders.

5.1 Digital Display System and Indicators

- The display devices are output devices to display the information in visual form by means of various types of display systems.
- In digital instruments, the output device of the instrument indicates the value of measured quantity using the digital display device.
- Display devices provide a visual display of numbers, letters, and symbols in response to electrical input, and serve as constituents of an electronic display system.

5.2 Classification of display devices

- Cathode ray tube
- Light Emitting Diode (LED)
- Liquid Crystal Display (LCD)
- Nixie Tube or Cold Cathode Displays
- Incandescent Displays
- Electroluminescent displays
- Liquid Vapour Display
- Electrophoretic image Displays (EPID)
- In general, displays are classified in a number of ways, as follows.

❖ **On methods of conversion of electrical data into visible light**

- (a) Active displays
- Light emitters – Incandescent, i.e. due to temperature, lumines-cence, i.e. due to non-thermal means or physio-thermal, and gas discharge-glow of light around the cathode.) CRTs, Gas discharge plasma, LEDs, etc.
- (b) Passive displays
- Light controllers, LCDs, EPIDs, etc.

❖ **On the applications**

- (a) Analog displays — Bar graph displays (CRT)
- (b) Digital displays — Nixies, Alphanumeric, LEDs, etc.

❖ **According to the display size and physical dimensions**

- (a) Symbolic displays — Alphanumeric, Nixie tubes, LEDs, etc.
- (b) Console displays — CRTs, LEDs, etc.
- (c) Large screen display— Enlarged projection system

❖ **According to the display format**

- (a) Direct view type (Flat panel planar) — Segmental, dotmatrix —CRTs
- (b) Stacked electrode non-planar type — Nixie

❖ **In terms of resolution and legibility of characters**

- (a) Simple single element indicator
- (b) Multi-element displays

5.3 DOT Matrix display

A dot matrix display is a display device used to display information on machines, clocks,railway departure indicators and many and other devices requiring a simple display device of limited resolution. The display consists of a matrix of lights or mechanical indicators arranged in a rectangular configuration. The rectangular arrangements are called arrays of LEDs. By switching ON or OFF the selected LEDs, text or Graphics can be displayed. A matrix driver or controller converts the instructions from a processor into signals which turns ON or OFF LEDs in the matrix, so as to obtain the required display. A dot matrix controller converts instructions from a processor into signals which turns on or off lights in the matrix so that the required display is produced. The common sizes of dot matrix displays are 128 × 16 (Two lined), 128 × 32 (Four Lined) and 192 × 64 (Eight Lined). While a common size for a character is 5 × 7 pixels. This is seen on most of the graphic calculators. The dot matrix displays are used in Varity of applications such as rolling advertisement boards, railway timing, reservation charts, temperature indication outside observatory digital clocks, calculators, digital diaries, microwave oven etc.

Figure 5.1 Display of alphabetic character

- 5 × 7 Dot Matrix Display
- In a 5 × 7 dot matrix display, 5 columns and 7 rows of LEDs. The dot matrix may be in round or square shape .

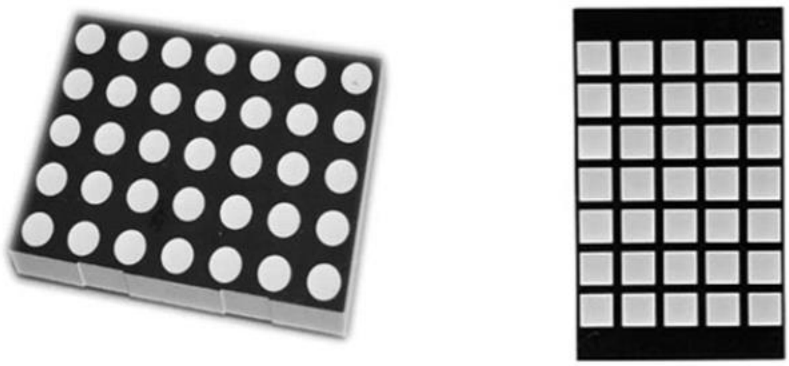

Figure 5.2 Round shape and square shape dot matrix display

- Depending upon the required character, the corresponding LEDs switched ON, in this display.

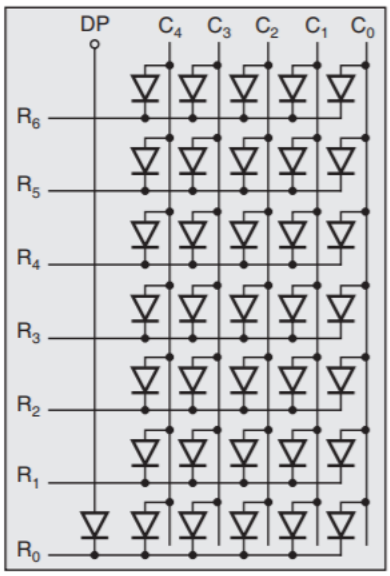

Figure 5.3 Circuit connection of 5 × 7 dot matrix display

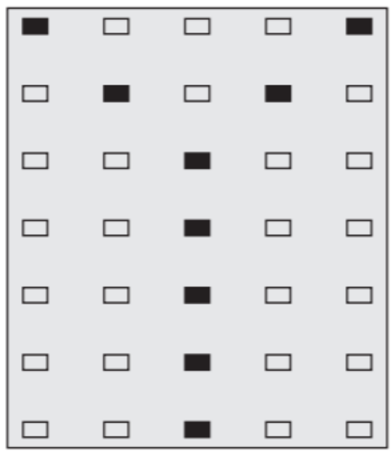

Figure 5.4 display of character "Y".

5.4 Digital voltmeter

The digital voltmeter systems are measuring instruments that convert analog voltage signals into a digital or numeric readout. A digital voltmeter is also called digital electronic voltmeter, it measures and displays dc or ac voltages as discrete number instead of a pointer deflection on a continuous scale. Such a voltmeter displays measurements of dc or ac voltages as discrete numerals instead of pointer deflections on a continuous scale as in analog instruments.

5.4.1 Types of Digital Voltmeter

1. Ramp type DVM

2. Dual-slope integrating type DVM.

3. Successive-approximation DVM

4. Potentiometer type DVM

Advantages of Digital Voltmeter

Although there are several advantages of DVMs yet the following are important from the subject point of view:

1. Due to digital display the human errors like parallax are removed

2. The accuracy is upto ± 0.005 % of the reading.

3. The reading speed is high due to digital display.

4. Compatibility with other digital equipment for further processing and recording.

5. Due to small size, portable.

1. Ramp type DVM

It consists of voltage-to-time conversion unit and a time measurement unit.The operating principle of the ramp type DVM is based on the measurement of the time taken by the DVM for a linear ramp voltage to rise from 0 V to the level of the input voltage, or to decrease from level of the input voltage to zero. This time period is measured with an electronic time-interval counter, and the count is displayed as a number of digits on digital display.

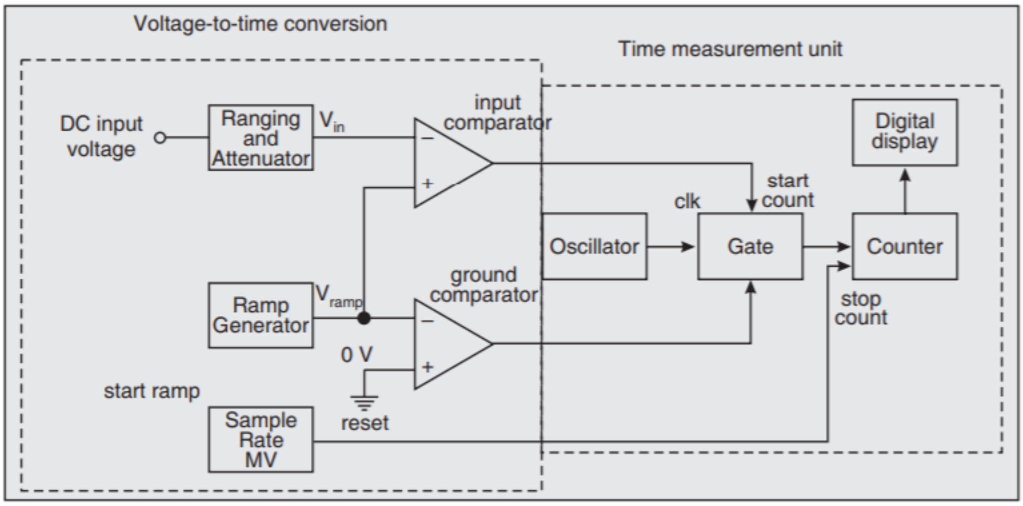

Figure 5.5 Ramp type DVM

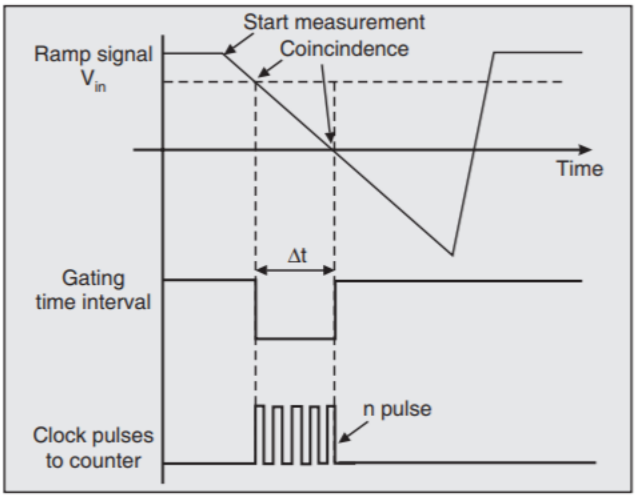

Figure 5.6 Voltage to time conversion

At the start of measurement a ramp voltage is initiated. The ramp voltage can be negative or positive. with a negative going ramp, this ramp is continuously compared with the unknown input voltage. At the instant that the ramp voltage equals to the unknown voltage to be measured, a coincidence circuit or comparator generates a pulse to open the gate. The ramp voltage continues to decrease with time until it finally reaches 0 V. At this instant the ground comparator generate an output pulse to close the gate. The time between opening and closing of the gate is Δt. During this time interval pulses from a clock pulse generator pass through the gate and are counted and displayed. An oscillator generates clock pulses which are allowed to pass through the gate to a number of counting units which totalize the number of pulses passed through the gate. The sampling rate multivibrator determines the rate at which the measurement cycles are initiated. The sample-rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage.

Advantages of Ramp-Type

1. Circuit is easy to design and low in cost.

2. Output pulse can be transmitted over long distance.

Disadvantages of Ramp-Type DVM

1. Single ramp requires excellent characteristics regarding linearity of ramp and time measurement.

2. Large errors are possible when noise is superimposed on the input signal.

3. Input filter are required for this type of converter.

2. 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

The input voltage 'e_i ' is integrated, with the slope of the integrator output proportional to the test input voltage. After a fixed time, equal to t1, 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.

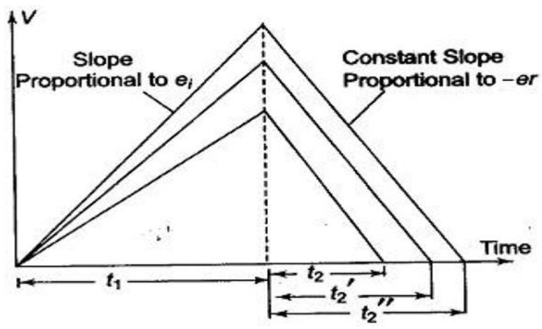

Figure 5.7 Basic principle of dual slope type DVM

At the start a pulse resets the counter and the F/F output to logic level '0'. Si is closed and Sr 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 't1' 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, ei is disconnected and –er 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 t2 is now proportional to the input voltage. The counter indicates the count during time t2. 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_o is zero, the counter is stopped. The pulses counted by the counter thus have a direct relation with the input voltage.

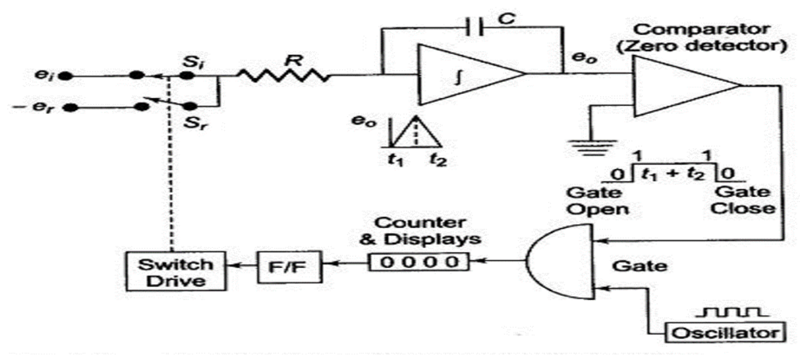

Figure 5.8 Block diagram of dual slope integrating type DVM

Advantages

1. Excellent noise rejection as noise and superimposed ac are averaged out during the process of integration.
2. The RC time constant does not affect the input voltage measurement.
3. Sample and hold circuit is not necessary.
4. The accuracy is high and can be readily varied according to the specific requirements.

Disadvantage

The speed of DVM is very slow, as compare to other DVMs.

3. Successive-approximation DVM

The output of the DAC is compared with the unknown voltage by the comparator. The output of the comparator is applied to the control circuit. The control circuit generates the sequence of code which is applied to DAC. Conversion time is fixed (not depend on the signal magnitude) and relatively fast. The operation is similar to the example of determination of weight of the object. The object is placed on one side of the balance and approximate weight on the other side of the balance to determine the weight of the unknown object.

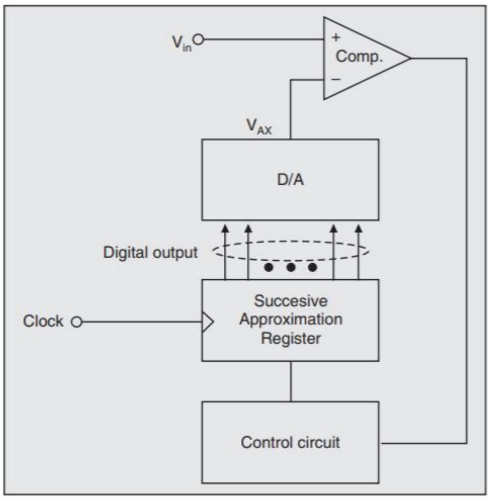

Figure 5.9 Block diagram of successive approximation type DVM

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. By such procedure of adding and removing the appropriate weight, the weight of the unknown object is determined. In successive approximation type DVM, the comparator compares the output of digital to analog converter with the unknown voltage. The comparator provides logic high or low signals. The digital to analog converter successively generates the set of pattern signals. The procedure continues till the output of the digital to analog converter becomes equal to the unknown voltage.

Advantages:

1. Very high speed of the order of 100 readings per second possible.
2. Resolution upto 5 significant digits is possible.
3. Accuracy is high.

Disadvantages

1. Circuit is complex.
2. Digital to Analog is required.
3. Input impedence is variable.
4. Noise can be cause error.

5.5 Digital Multimeter

A digital multimeter (DMM) displays the quantity measured as a number, its eliminates parallax errors. The information from analog input signal passes through the various analog signal conversion circuits which convert the measured quantity to a dc voltage equivalent. Then the A/D converts the dc value to digital form and display unit display the value. The DMM is made up of following three basic elements: (a) Signal conditioning (b) Analog-to-digital (A/D) conversation (c) Numeric digital display

5.5.1 Features of Basic Digital Multimeter

The main features of any digital multimeter is the types of measurement and the ranges over which it will operate. Most DMMs will offer a variety of measurements.

The basic measurements will include:

(a) Current (DC)

(b) Current (AC)

(c) Voltage (DC)

(d) Voltage (AC)

(e) Resistance

The digital multimeter can measure ac voltage, dc voltage, ac current, dc current and resistance over several ranges.

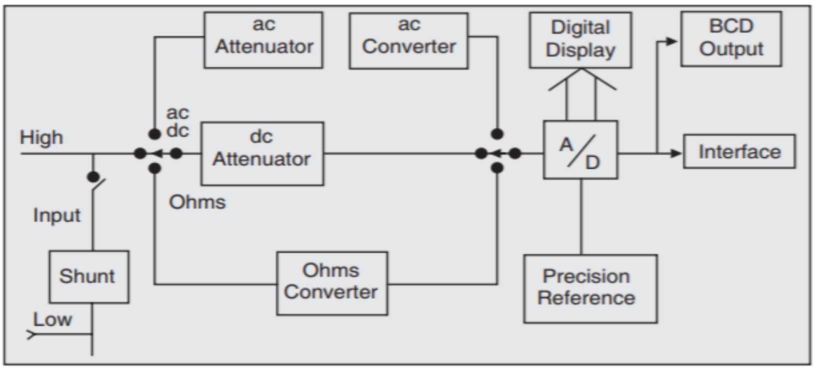

Figure 5.10 Digital multimeter

For D.C. voltage measurement

For DC voltage measurement by DMM, a wide range of DC voltage inputs is scaled to the limited range of the A/D Converter. A resistive divider and switching are generally used for this function.

For A.C. voltage measurement

The signal is converted to a DC equivalent before sending it to the A/D Converter.

For D.C. and AC current measurement

It is necessary to convert the current at the input to a voltage. This is done through a series of switched resistors, called shunts. AC current is converted into DC by rectifiers and filters circuit.

For resistance measurement

It is necessary to create a voltage proportional to the resistance because A/D Converter measures only DC volts. The DMM input circuit must provide a DC current flowing through the resistor and then measure the resulting voltage.

To measure the unknown current with DMM we have to first convert the current to the voltage with current to voltage converter. The current to voltage circuit is implemented in DMM. The known current is applied at the input of the op-amp. When the input current of op-amp is zero, the current IR is almost same as I1. This current IR causes the voltage drop, which is proportional to the current to be measured. This voltage drop is the analog input to the analog to digital converter.

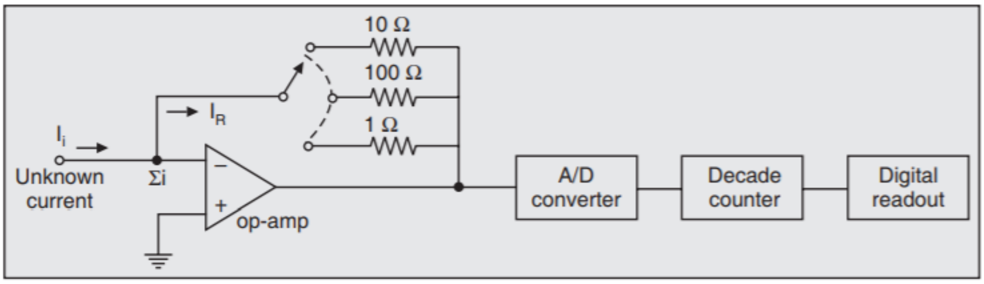

Figure 5.11 Current to voltage converter

Advantage of Digital Multimeter (DMM)

1. DMM offer high measurement accuracy.
2. These instruments have a high input impedance.
3. They are smaller in size.
4. These meters eliminate observational, parallax and approximation errors.
5. The output of these instruments can be directly feed to a computer for further analysis and use.

5.6 Digital Storage Oscilloscope

The digital storage oscilloscope is an instrument which gives the storage of a digital waveform or the digital copy of the waveform. It allows us to store the signal or the waveform in the digital format, and in the digital memory also it allows us to do the digital signal processing techniques over that signal. The maximum frequency measured on the digital signal oscilloscope depends upon two things they are: sampling rate of the scope and the nature of the converter. The traces in DSO are bright, highly defined, and displayed within seconds.

The block diagram of the digital storage oscilloscope consists of an amplifier, digitizer, memory, analyzer circuitry. Waveform reconstruction, vertical plates, horizontal plates, cathode ray tube (CRT), horizontal amplifier, time base circuitry, trigger, and clock.

at first digital storage oscilloscope digitizes the analog input signal, then the analog input signal is amplified by amplifier if it has any weak signal. After amplification, the signal is digitized by the digitizer and that digitized signal stores in memory. The analyzer circuit process the digital signal after that the waveform is reconstructed (again the digital signal is converted into an analog form) and then that signal is applied to vertical plates of the cathode ray tube (CRT).

The cathode ray tube has two inputs they are vertical input and horizontal input. The vertical input signal is the 'Y' axis and the horizontal input signal is the 'X' axis. The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal. Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate. On the CRT screen, we will get the waveform of the input signal versus time.

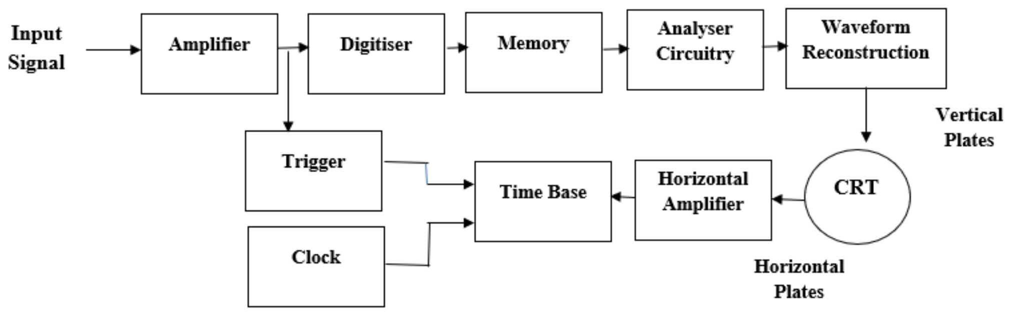

Figure 5.12 Block diagram of digital storage oscilloscope

The digitizing occurs by taking a sample of the input waveform at periodic intervals. At the periodic time interval means, when half of the time cycle is completed then we are taking the samples of the signal. The process of digitizing or sampling should follow the sampling theorem. The sampling theorem says that the rate at which the samples are taken should be greater than twice the highest frequency present in the input signal. When the analog signal is not properly converted into digital then there occurs an aliasing effect.

When the analog signal is properly converted into digital then the resolution of the A/D converter will be decreased. When the input signals stored in analog store registers can be read out at a much slower rate by the A/D converter, then the digital output of the A/D converter stored in the digital store, and it allows operation up to 100 mega samples per second. This is the working principle of a digital storage oscilloscope.

The digital storage oscilloscope works in three modes of operations they are roll mode, store mode, and hold or save mode.

Roll Mode: In roll mode, very fast varying signals are displayed on the display screen.

Store Mode: In the store mode the signals stores in memory.

Hold or Save Mode: In hold or save mode, some part of the signal will hold for some time and then they will be stored in memory.

Advantages:

1. Since the DSO uses digital memory, it can store the waveforms for longer time. But in the normal CRO this cannot happen.

2. In the DSO, we can store and view the part or full waveforms before the actual trigger happens. But this is not possible in the conventional CRO.

3. In the DSO, the stored waveform can be positioned anywhere in the screen. We can actually adjust the vertical and horizontal scales of the waveform. This is not possible in the normal CRO.

Applications

- It checks faulty components in circuits
- Used in the medical field
- Used to measure capacitor, inductance, time interval between signals, frequency and time period
- Used to observe transistors and diodes V-I characteristics
- Used to analyze TV waveforms
- Used in video and audio recording equipment’s

5.7 LCD monitors

LCD (Liquid Crystal Display) monitors use liquid crystal, instead of a cathode ray tube, to display information on the screen. LCD monitors and LCD displays are a type of flat-panel display. A flat-panel display has a lightweight, compact screen that consumes less than one-third of the power as compare to CRT monitor. This feature makes the LCD monitors and displays ideal for mobile users. LCD monitors typically are more expensive than CRT monitors. LCD monitors are also available in a variety of sizes, the most common being 15, 17, 18 and 20 inches. LCD monitors typically are more expensive than CRT monitors. Notebook and handheld computers often use LCD displays. LCD monitors and displays produce colour using either passive matrix or active matrix technology. An active-matrix display, also known as a thin-film transistor (TFT) display, can display high-quality colour that is viewable from all angles because it uses separate transistor for each colour pixel. Active-matrix displays require more power than passive-matrix displays because they use many transistors. A passive-matrix display, often called a dual-scan display, uses fewer transistors and requires less power than an active-matrix display. The colour on a passive-matrix display is often not as bright as an active-matrix display. You can best view images on a passive-matrix display, when working directly in front of the display. Passive-matrix displays are less expensive than active-matrix displays.

The Liquid Crystal Display (LCD) has been one of the enabling technologies of the current electronic revolution. It is an essential part of every mobile phone, every laptop and every personal organiser. Liquid crystal is an organic compound that polarises any light that passes through it. A liquid crystal also responds to an applied electric field by changing the alignment of its molecules, and in so doing changing the direction of the light polarisation that it introduces. Liquid crystals can be trapped between two parallel sheets of glass, with a matching pattern of transparent electrode on each sheet. When a voltage is applied to the electrodes, the optical character of the crystal changes and the electrode pattern appears in the crystal. A huge range of LCDs has been developed, including those based on sevensegment digits or dot matrix formats, as well as a variety of graphical forms. Many general-purpose displays are available commercially.

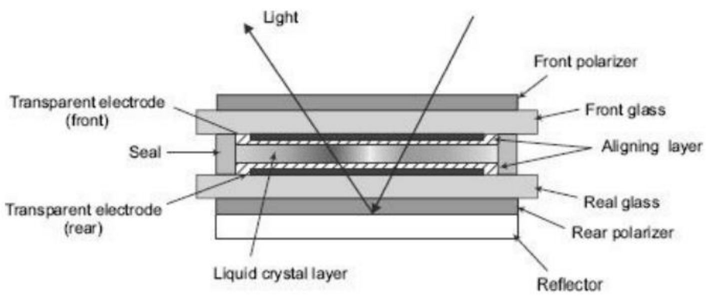

Figure 5.13 Different layers of a typical lcd display

The liquid crystal fluid is the active medium that is used to create an image. It consists of a very large number of elongated crystals suspended in a fluid. This reservoir is sandwiched between two thin sheets of glass. Each piece of glass has a transparent conductive pattern bonded to it. The crystals are aligned in a spiral pattern until an electric field is impressed on the conductors. A sheet of polarising material is bonded to the outside surfaces of both the front and rear glass covers. As incident light of random polarisation enters the top polarizer, it is stopped except for that which is polarised in the proper direction. With no electric field applied, the light is twisted or its polarisation is changed by the spiral pattern of the crystals. The bottom polariser is aligned opposite of the top one but the “twisted” light is now aligned with the bottom polariser and passes through. The display is now transparent and appears light.

Recorder

A recorder is an instrument to record the electrical and non-electrical quantities as a function of time. The record shows how a variable varies with respect to another with time. The electrical quantities such as voltage and current are measured directly. A recorder is a device whose function is to record the value of a quantity as it is being measured. Recording preserves the experimental data in a manageable and usable form. A recording system is very useful in industries as (i) it preserves information which could be obtained at an instant from indicating instruments and (ii) it gives information about waveforms and transient behavior or phase relations in different parts of a circuit. A recorder records both electrical and non-electrical quantities as a function of time or relates two signals to each other. Electrical quantities, such as current voltage etc can be recorded directly while non-electrical quantities, such as pressure, temperature, speed etc are recorded indirectly by first converting them into the form of electrical signal with the help of sensors and transducers. When working with the analog system the analog recording techniques should be used while working with a digital system, digital recording devices should be used.

There are many ways for classifying recorders; the popular one is according to the type of signal to be recorded, which is as follows:

1. Analog recorders

a. Graphic recorder

- i. Strip chart recorder
  - Galvanometer type
  - Null type
    - Potentiometric recorders
    - Bridge recorders
    - LVDT recorders
- ii. Circular chart recorders
- iii. X-Y Recorders

b. Magnetic tape recorders

c. Oscillographic recorders

d. Others [hybrid, paperless, ultraviolet and thermal dot matrix recorder]

2. Digital recorders

5.8 Graphic Recorder

The graphic instrument displays and stores the physical quantity being measured. It uses basic elements as chart paper for displaying and storing the quantity and pen for marking the variation in physical quantity. The pen is also called stylus.

There are three types of graphic recorders:

1. Strip Chart Recorder
2. Circular Chart Recorder
3. X-Y Tape recorder

5.8.1. Strip Chart Recorder

A chart recorder is an electromechanical device that records an electrical or mechanical input trend onto a piece of paper (the chart). Chart recorders may record several inputs using different color pens and may record onto strip charts or circular charts. Chart recorders may be entirely mechanical with clockwork mechanisms or electro-mechanical with an electrical clockwork mechanism for driving the chart (with mechanical or pressure inputs) or entirely electronic with no mechanical components at all (a virtual chart recorder). The strip chart recorder often used for the application which require monitoring the quantity. A roll of paper is continuously moved under the pen and a continuous record is maintained. Strip chart recorders are generally multirange voltmeter with a speed range selector to control the paper feed. A strip-chart recorder plots one or more parameters as a function of time. A strip is a ribbon of paper moved through the instrument at uniform speed by an electric motor.

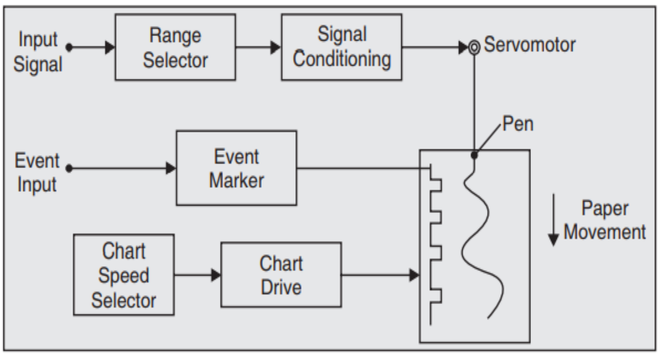

Figure 5.14 Strip chart recorder

The basic element of this recorder is pen for making and chart paper for recording data. The quantity to be measured is given as to the input to the range selector. The range selector switch keeps data within the limit. The stylus moved along the calibrated scale in accordance with input data. To get proper record of input data signal conditioning block is used which gives proper input signal along calibrated scale. The chart paper moves vertically at a uniform speed. The speed selector selects the required speed of the chart paper movement.

- **Mechanism for Marking**

There are many mechanisms for marking the marks on the chart paper. These are explained below:

(a) Pen and Ink Stylus: The ink is filled in the stylus using gravity of capillary action. Any color is used to record data as per color coding. There are several types of pens, including the bucket pen, the V-pen, the fiber-tipped pen, and the ballpoint pen. Various types of capillary feeding systems, both pressurized and gravimetric, are mostly used. For ordinary chart speed ranges, V-pen, fountain pen, large-reservoir capillary-fed recording tips are common.

(b) Impact Printing: In this a carbon ribbon is placed between the paper and pointer mechanism. The carbon provides ink for recording data. The marking is done by pressing pointer on the paper.

(c) Chopper Bar Printing: The marking is done with chopper bar. This chopper bar applies pressure on the special purpose pressure sensitive paper.

(d) Thermal Writing: In this method, the recording is done by marking on a special paper with heated stylus. The special movable pen is heated by passing an eclectic current through it. During marking the color on the special paper changes as heated stylus moves. In some systems a black paper with white wax coating is used. During recording the heated stylus melts thin white coating wax. Because of this we get high contrast marking on the special paper.

(e) Electrical Writing: In this method, a paper base with a layer of colored dye and thin surface of aluminum coating is used. The stylus consists of a conducting wire moving over aluminum surface. As the paper is current sensitive, when the current is conducted from stylus, we get traces on the paper with removal of aluminum and keeping color dye at those traces.

(f) Optical Writing: In this method, a photosensitive paper is used. A beam of ultraviolet is used to record data on the paper. We can have higher resolution with higher frequencies and large paper rolling speeds.

The strip chart recorder has a number of advantages.:

1. Relatively large amount of paper can be inserted at one time.

2. Data conversion is easier with rectangular coordinates system

3. The rate of movement of the chart can be easily changed.

4. More than one separate variable can be recorded on a strip chart.

Strip Chart recorder has some disadvantages also.

1. Mechanism is more complicated than is required to drive a circular chart.

2. Observing behavior several hours or days back is not as easy as picking out one circular chart which covers the desired period of time.

Application of Strip Chart Recorder

- In temperature recorder
- Sound level recording
- Recording amplifier drift

5.8.2 Galvanometer Type Strip Chart Recorder

This is a type of strip chart recorder. It operates on the deflection principle. The deflection is produced by a galvanometer (D'Arsonval). It produces a torque on account of a current passing through its coil. The current is proportion to the quantity to be measured. The moving coil pointer is in strong magnetic field. The pen-ink system is fitted to the pointer for recording the input signal. The pen-ink system consists of a recording pen at one end while ink reservoir is at other end. Both are connected to each other through bore tube. Ink flow from reservoir to pen by gravity action. The paper is pulled from the roll and the signal is traced on the paper as the paper moves across the pen, when pen is deflected.

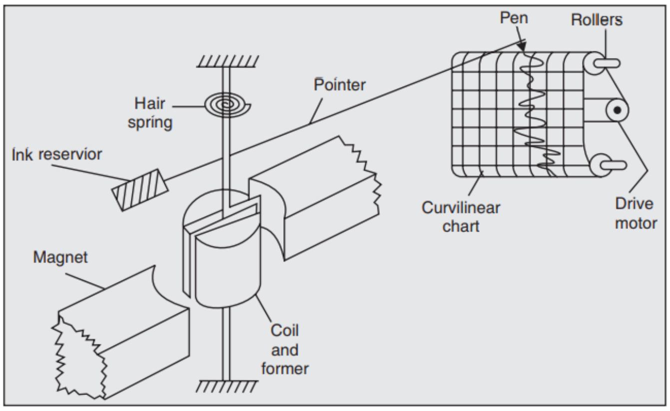

Figure 5.15 Galvanometer type Strip chart recorder

The pointer deflects according to the current flow through the coil. The magnetic field is varying according to the input current. This change in magnetic field interacts with magnetic field produced by the permanent magnet used. This causes the moving coil to move in angular direction. As this coil is moving as per variation in the signal current, the pen is correspondingly deflected across the paper. Thus, the input signal gets recorded. The grater the amplitude of the input signal, the greater will be deflection.

Advantages

1. The system is comparatively inexpensive.
2. It records very low frequency a.c. signals.
3. We can change the speed of paper as per requirement.

Disadvantages

1. It cannot record fast varying signals such as current, voltage or power.
2. The performance is affected by fraction losses due to moving coil and stylus.

5.8.3 Self-Balancing Potentiometer Type Strip Chart Recorder

When the input signal given by sensor or transducer is applied to the measuring unit of the recorder, the balanced condition of the instrument gets disturbed. This unbalanced signal produces error signal. Error signal is the difference of input signal and reference potentiometer voltage. The error signal is amplified and subsequently the field coil of DC motor is energized. The error current either flows in clockwise or in anticlockwise direction depending on the value of the voltage. The motor turn in such direction that it reduces the error signal to achieve balanced condition. As the error signal reduces, the motor slows down and stops completely. When error becomes zero, the balance condition is achieved.

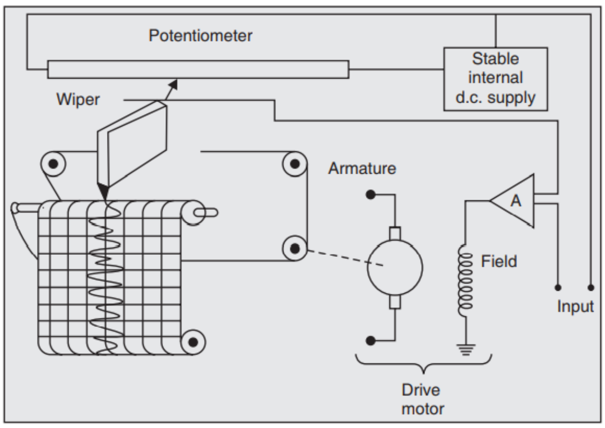

Figure 5.16 Self balancing type Strip chart recorder

Notice that the pen is mechanically coupled to a wiper, which is turn is mechanically coupled to the armature of the DC motor. Thus the wiper moves according to the error signal, so the pen also moves in the same direction. The pen records the input signal variations moving across the paper.

The main application of potentiometer recorder is for recording and control of process temperatures. It is automatic and eliminates the constant operation of an operator. The recorder draw the curve of the quantity of being measured with the help of recording mechanism.

5.9 Magnetic tape recorders

The major advantage of using a magnetic tape recorder is that once the data is recorded, it can be replayed an almost indefinite number of times. The recording period may vary from a few minutes to several days. Speed translation of the data captured can be provided, i.e. fast data can be slowed down and slow data speeded up by using different record and reproduce speeds. The recorders described earlier have a poor high frequency response. Magnetic tape recorder, on the other hand, have a good response to high frequency, i.e. they can be used to record high frequency signals. Hence, magnetic tape recorders are widely used in instrumentation systems.

Basic Components of a Tape Recorder

A magnetic tape recorder consists of the following basic components.

1. Recording Head

2. Magnetic Head

3. Reproducing Head

4. Tape transport mechanism

5. Conditioning devices

Magnetic Recording

The magnetic tape is made of a thin sheet of tough, dimensionally stable plastic, one side of which is coated with a magnetic material. Some form of fi nely powdered iron oxide is usually cemented on the plastic tape with a suitable binder. As the tape is transferred from one reel, it passes across a magnetising head that impresses a residual magnetic pattern upon it in response to an amplified input signal. The methods employed in recording data on to the magnetic tape include direct recording, frequency modulation (FM) and pulse code modulation (PCM). Modulation of the current in the recording head by the signal to be recorded linearly modulates the magneticflux in the recording gap.

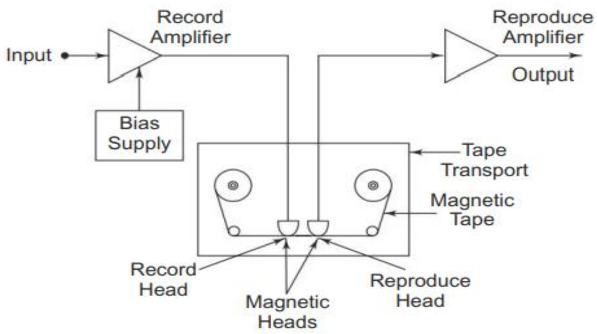

Figure 5.17 Elementary magnetic tape recorder

As the tape moves under the recording head, the magnetic particles retain a state of permanent magnetisation proportional to the flux in the gap. The input signal is thus converted to a spatial variation of the magnetisation of the particles on the tape. The reproduce head detects these changes as changes in the reluctance of its magnetic circuit which induce a voltage in its winding. This voltage is proportional to the rate of change of flux. The reproduce head amplifier integrates the signal to provide a fl at frequency characteristics. Since the reproduce head generates a signal which is proportional to the rate of change of flux, the direct recording method cannot be used down to dc. The lower limit is around 100 Hz and the upper limit for direct recording, around 2 MHz. The upper frequency limit occurs when the induced variation in magnetisation varies over a distance smaller than the gap in the reproduce head.

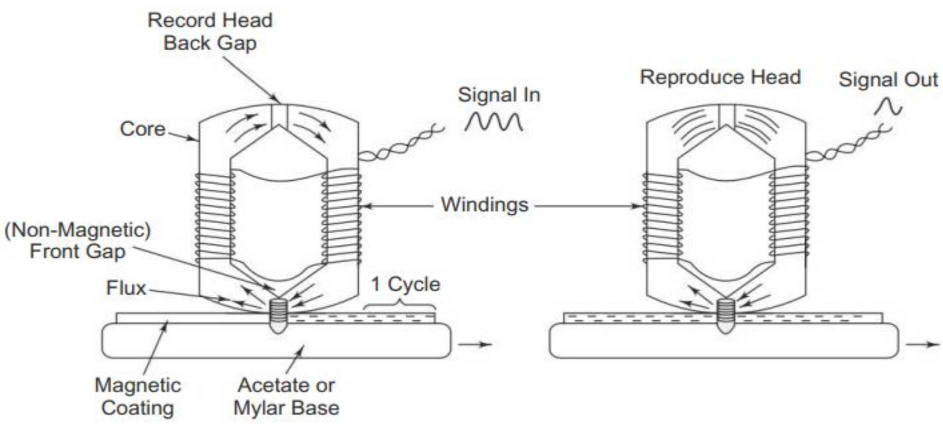

Figure 5.18 Magnetisation of tape

The signal on an exposed tape can be retrieved and played out at any time by pulling the tape across the magnetic head, in which a voltage is induced. It is possible to magnetise the tape longitudinally or along either of the other two main axis, but longitudinal magnetisation is the best choice. If a magnetic fi eld is applied to any one of the iron oxide particles in a tape and removed, a residual flux remains. The relationship between the residual flux and the recording fi eld is determined by the previous state of magnetisation and by the magnetisation curves of the particular magnetic recording medium.

A simple magnetic particle on the tape might have the B – H curve where H is the magnetising force and B the flux density in the particle. Consider the material with no flux at all, i.e. the condition at point 0. Now if the current in the coil of the recording head is increased from 0 in a direction that gives positive values of H, the flux density increases along the path 0 – 1– 2, until the material is eventually saturated. If the operating point is brought from 0 only as far as 1, and H is brought back to 0, B follows a minor hysteresis loop back to point 6. A greater value of coil current would leave a higher residual flux, and a lower current a lower residual; a very simple recording process results.

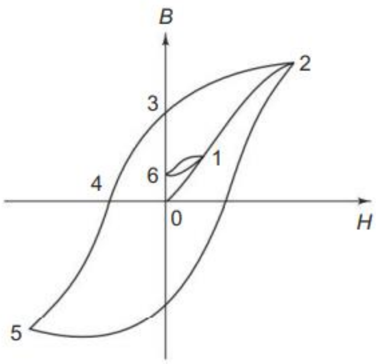

Figure 5.19 Magnetisation curve

However, the linearity between residual flux and recording current is very poor. Hence to obtain linearity in direct recording, FM is used. In all systems, the signal is reproduced by passing the magnetised tape over a magnetic head similar to the recording head. The magnetisation of the particles on the tape induces a varying flux in the reproducing head and a voltage is induced in the coil, proportional to the rate of change of flux.

Methods of Recording

There are three methods of magnetic tape recording which are used for instrumentation purposes.

1. Direct recording

2. FM recording

3. Pulse Duration Modulation recording (PDM)

FM recorders are generally used for instrumentation purposes. PDM recording is used in instrumentation for special applications where a large number of slowly changing variables have to be recorded simultaneously.

5.10 Disc recorders

Although there are many different types of optical disks, they can be grouped into three main categories.

I. Read-only memory (ROM) disks, like the audio CD, are used for the distribution of standard program and data files. These are mass-produced by mechanical pressing from a master die. The information is actually stored as physical indentations on the surface of the CD. Recently low-cost equipment has been introduced in the market to make one-off CD-ROMs, putting them into the next category.

2. Write-once read-many (WORM disks: Some optical disks can be recorded once. The information stored on the disk cannot be changed or erased. Generally, the disk has a thin reflective film deposited on the surface. A strong laser beam is focused on selected spots on the surface and pulsed. The energy melts the film at that point, producing a non-reflective void. In the read mode, a low power laser is directed at the disk. and the bit information is recovered by sensing the presence or absence of a reflected beam from the disk.

3. Re-writeable, write-many read-many (WMRM) disks, just like the magnetic storage disks, allows information to be recorded and erased many times. Usually, there is a separate erase cycle although this may be transparent to the user. Some modem devices have this accomplished with one over-write cycle. These devices are also called direct-read-after-write (DRAW) disks.

The CD-ROM, together with the audio compact disk are examples of technologically advanced products that have been mass-produced and made readily available to the general public. For the computer industry, the read-only CD-ROM is gaining importance as a delivery medium for software. The large storage capacity and low cost of manufacture makes it a very attractive means of distributing software which is getting larger all the time. Also machine-readable documentation can be included on the same disk or on a separate disk. Software available on CD-ROMs now include many games which have large graphics and audio files, graphics software with clip-art, and operating systems like Unix and OS/2.

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