5. Measurement and Display Devices

A) Measurements:

1.0 Qualities of Measurements:

Instrumentation is a technology of measurement that serves for science, all branches of engineering, medicine and almost every human endeavor. The knowledge of any parameter is depends on the measurement. It can be easily understood by the measurement of that parameter and further modification can also be obtained.

Measurement is basically used for monitoring the process or operation, and also used for the controlling process. e.g. thermometers, barometers, anemometers are used to indicate the environmental conditions. Similarly water, gas and electric meters are used to keep the track of quantity of commodity used. Also special monitoring equipments are used in the hospitals to monitor the patient's condition.

Whatever may be the nature of application intelligent selection and use of measuring equipment depends on the broad knowledge of what is available and how the performance of the equipment renders itself for the job to be performed. But there are some basic measurement techniques and devices that are useful and will continue to be widely used also. There is always a need for improvement and development of new equipment to solve measurement problems.

The major problem encountered with any measuring instrument is the error. Therefore it is obviously necessary to select the appropriate measuring instrument and measurement method which minimizes error. To avoid errors in any experimental work careful planning execution and evaluation of the experiment are essential.

The basic concern of any measurement is that the measuring instrument should not affect the quantity being measured; in practice this non interference principle is never strictly obeyed. Null measurements with the use of feedback in an instrument minimize these interference effects.

2.0 Static Characteristics:

The knowledge of performance characteristics of an instrument is very much essential for the selection of most suitable instrument for specific measuring jobs. It consists of two basic characteristics: static and dynamic.

The static characteristics of an instrument are considered for the instruments which are used to measure an unvarying process condition.

1. **Instrument:** A device or mechanism used to determine the present value of the quantity under measurement.
2. **Measurement:** The process of determining the amount, degree, or capacity by comparison (direct or indirect) with the accepted standards of the system units being used.
3. **Accuracy:** The degree of exactness (closeness) of a measurement compared to the expected (desired) value.
4. **Resolution:** The smallest change in a measured variable to which an instrument will respond.
5. **Precision:** A measure of the consistency or repeatability of measurements, i.e. successive reading does not differ. (Precision is the consistency of the instrument output for a given value of input).
6. **Expected value:** The design value, i.e. the most probable value that calculations indicate one should expect to measure.
7. **Error:** The deviation of the true value from the desired value.
8. **Sensitivity:** The ratio of the change in output (response) of the instrument to a change of input or measured variable.

3.0 Error in Measurement:

Measurement is the process of comparison of an unknown quantity with the standard one. For measurement of unknown quantity, a measuring instrument is connected into the system under consideration and observing the resulting response on that instrument. Thus measurement is obtained in a quantitative measure called as true value. Since it is very difficult to define the true value, the term expected value is used. Any measurement is affected by many variables; therefore the results rarely reflect the expected value. For example, connecting a measuring instrument into the circuit under consideration always disturbs (changes) the circuit, causing the measurement to differ from the expected value.

Some factors that affect the measurements are related to the measuring instruments themselves. Other factors are related to the person using the instrument. The degree to which a measurement nears the expected value is expressed in terms of the error of measurement.

Error may be expressed either as absolute or percentage of error.

Absolute error may be defined as the difference between expected value and measured value of the variable, or

$$e = Y_n - X_n ------(1)$$

where e = absolute error, Y_n = expected value, X_n = measured value

Therefore

$$\%\,Error = \frac{absolute\ error}{expected\ value} \times 100 = \frac{Y_n - X_n}{Y_n} \times 100 - - - - - (2)$$

But it is more frequently expressed as accuracy rather than error.

Therefore, the relative accuracy ‘A’ is given by,

$$A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right| - - - - - (3)$$

Accuracy is expressed in terms of % accuracy and it is denoted by ‘a’

$$a = 100\% - \%\,error = A \times 100 - - - - - (4)$$

Example-1: The expected value of voltage across a resistor is 80V. However, the measurement gives a value of 79V. Calculate (i) absolute error, (ii) % error, (iii) relative accuracy, and (iv) % accuracy.

Solution:

(i) Absolute error $e = Y_n - X_n = 80 - 79 = 1V.$

(ii) $\%\,Error = \frac{Y_n - X_n}{Y_n} \times 100 = \frac{80-79}{80} \times 100 = 1.25\%.$

(iii) Relative accuracy $A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right| = 1 - \left|\frac{80-79}{80}\right| = 1 - \frac{1}{80} = \frac{79}{80} = 0.9875$

(iv) % accuracy $a = A \times 100 = 0.9875 \times 100 = 98.75\%$

OR $a = 100\% - \%\,error = 100\% - 1.25\% = 98.75\%$

Example-2: The expected value of current through a resistor is 20mA. However, the measurement yields a value of 18mA. Calculate (i) absolute error, (ii) % error, (iii) relative accuracy, and (iv) % accuracy.

Solution:

(i) Absolute error $e = Y_n - X_n = 20mA - 18mA = 2mA.$

(ii) $\%\,Error = \frac{Y_n - X_n}{Y_n} \times 100 = \frac{20mA - 18mA}{20mA} \times 100 = \frac{2mA}{20mA} \times 100 = 10\%.$

(iii) Relative accuracy $A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right| = 1 - \left|\frac{20mA - 18mA}{20mA}\right| = 1 - \frac{2mA}{20mA} = 1 - 0.1 = 0.9$

(iv) % accuracy $a = A \times 100 = 0.9 \times 100 = 90\%$

OR $a = 100\% - \%\ error = 100\% - 10\% = 90\%$

If a measurement is accurate, it must also be precise, i.e. Accuracy means precision. However, a precision measurement may not be accurate. (The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements). Precision can also be expressed mathematically as,

$$P = 1 - \left|\frac{X_n - \bar{X}_n}{\bar{X}_n}\right| ------ (5)$$

where, X_n = value of the n^{th} measurement, $\bar{X}_n$ = average set of measurement

Example-3: The below table gives the set of 10 measurements that were recorded in the laboratory. Calculate the precision of 6^{th} measurement.

Measurement Number	Measurement Value X_n
1	98
2	101
3	102
4	97
5	101
6	100
7	103
8	98
9	106
10	99

Solution:

The average value for the set of measurement is given by,

$$\bar{X}_n = \frac{Sum\ of\ the\ 10\ measurement\ values}{10} = \frac{1005}{10} = 100.5$$

Precision is given by,

$$P = 1 - \left|\frac{X_n - \bar{X}_n}{\bar{X}_n}\right|$$

For 6^{th} reading

$$P = 1 - \left|\frac{100 - 100.5}{100.5}\right| = 1 - \frac{0.5}{100.5} = \frac{100}{100.5} = 99.5$$

The accuracy and precision of measurements depend not only on the quality of the measuring instrument but also on the person using it. However, whatever the quality of the instrument and the case exercised by the user, there is always some error present in the measurement of physical quantities.

4.0 Types of Error:

The error of measuring instrument is the deviation of true value from the expected value. The error can be categorized as gross or human error, systematic error and random error.

4.1 Gross error:

The gross errors are mainly due to human mistakes in reading or in using instruments or errors in recording observations. Errors may also occur due to incorrect adjustment of instruments and computational mistakes. These errors cannot be treated mathematically.

The complete elimination of gross errors is not possible, but one can minimize them. Some errors are easily detected while others may be elusive.

One of the basic gross errors that occur frequently is the improper use of an instrument. The error can be minimized by taking proper care in reading and recording the measurement parameter.

In general, indicating instruments change ambient conditions to some extent when connected into a complete circuit (Refer examples 4 & 5). One should therefore not be completely dependent on one reading only; at least three separate readings should be taken, preferably under conditions in which instruments are switched off and on.

4.2 Systematic error:

The systematic errors occur due to shortcomings of the instrument, such as defective or worn parts, or ageing or effects of the environment on the instrument.

These errors are sometimes referred to as bias, and they influence all measurements of a quantity alike. A constant uniform deviation of the operation of an instrument is known as a systematic error. There are basically three types of systematic errors: i) Instrumental, ii) Environmental, and iii) Observational.

4.2.1 Instrumental error:

Instrumental errors are inherent in measuring instruments, because of their mechanical structure. For example: in D'Arsonval movement, friction in the bearings of various moving components, irregular spring tensions, stretching of the spring; or reduction in tension due to improper handling or overloading of the instrument.

Instrumental errors can be avoided by a) Selecting a suitable instrument for the particular measurement applications. (Refer example 4 & 5) b) Applying correction factors after determining the amount of instrumental error. c) Calibrating the instrument against a standard.

4.2.2 Environmental error:

Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of change in temperature, humidity, barometric pressure or of magnetic or electrostatic fields.

These errors can also be avoided by a) air conditioning, b) hermetically sealing certain components in the instruments, and c) using magnetic shields.

4.2.3 Observational error:

Observational errors are errors introduced by the observer. The most common error is the parallax error introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale. These errors are caused by the habits of individual observers. For example: an observer may always introduce an error by consistently holding his head too far to the left while reading a needle and scale reading.

In general, systematic errors can also be subdivided into static and dynamic errors. Static errors are caused by limitations of the measuring device or the physical laws governing its behavior. Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable.

Example-4: A voltmeter having a sensitivity of 1kΩ/V is connected across an unknown resistance in series with a milliammeter reading 80V on 150V scale. When the milliammeter reads 10mA, calculate i) Apparent resistance of the unknown resistance, ii) Actual resistance of the unknown resistance, iii) Error due to the loading effect of the voltmeter.

Solution:

i) The total resistance of the circuit R_T,

$$R_T = \frac{V_T}{I_T} = \frac{80}{10mA} = 8k\Omega$$

ii) The voltmeter resistance R_V,

$$R_V = 1000\Omega/V \times 150 = 150k\Omega$$

The actual value of unknown resistance R_X,

$$R_X = \frac{R_T \times R_V}{R_V - R_T} = \frac{8k \times 150k}{150k - 8k} = \frac{1200k^2}{142k} = 8.45\Omega$$

iii) % error

$$\%\,error = \frac{Actual\,Value - Apparent\,Value}{Actual\,Value} \times 100 = \frac{8.45k - 8k}{8.45k} \times 100$$

$$\%\,error = 0.053 \times 100 = 5.3\%$$

Example-5: Referring example (4), if the milliammeter reads 600mA and the voltmeter reads 30V on a 150V scale. Calculate i) Apparent resistance of the unknown resistance, ii) Actual resistance of the unknown resistance, iii) Error due to the loading effect of the voltmeter. Comment on the loading effect due to the voltmeter for both examples. (Voltmeter sensitivity is 1kΩ/V)

Solution:

i) The total resistance of the circuit R_T,

$$R_T = \frac{V_T}{I_T} = \frac{80}{0.6} = 50\Omega$$

ii) The voltmeter resistance R_V,

$$R_V = 1000\Omega/V \times 150 = 150k\Omega$$

The actual value of unknown resistance R_X,

$$R_X = \frac{R_T \times R_V}{R_V - R_T} = \frac{50 \times 150k}{150k - 50} = \frac{7500k}{149.95k} = 50.0167\Omega$$

iii) % error

$$\%\,error = \frac{Actual\,Value - Apparent\,Value}{Actual\,Value} \times 100 = \frac{50.0167 - 50}{50.0167} \times 100$$

$$\%\,error = \frac{0.0167}{50.0167} \times 100 = 0.033\%$$

Comment:

In example 4, a well calibrated voltmeter may give a misleading resistance when connected across two points in a high resistance circuit. The same voltmeter, when connected in a low resistance circuit in example 5 may give a more dependable reading. This shows that voltmeters have a loading effect in the circuit during measurement.

4.3 Random error:

These are errors that remain after gross and systematic errors have been substantially reduced or at least accounted for. Random errors are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy. Such errors can be analyzed statistically.

These errors are due to unknown causes, not determinable in the ordinary process of making measurements. Such errors are normally small and follow the laws of probability. Random errors can thus be treated mathematically.

For example, suppose a voltage is being monitored by a voltmeter which is read at 15 minutes intervals. Although the instrument operates under ideal environmental conditions and is accurately calibrated before measurement, it still gives readings that vary slightly over the period of observation. This variation cannot be corrected by any method of calibration or any other known method of control.

4.4 Statistical Analysis:

The statistical analysis of measurement data is important because it allows an analytical determination of the uncertainty of the final test result. To make statistical analysis meaningful a large number of measurements are usually required. Systematic errors should be small compared to random errors, because statistical analysis of data cannot remove a fixed bias contained in all measurements.

4.4.1 Arithmetic Mean:

The most probable value of a measured variable is the arithmetic mean of the number of readings taken. The best approximation is possible when the number of readings of the same quantity is very large. The arithmetic mean of n measurements at a specific count of the variable x is given by the expression

$$\bar{x} = \frac{x_1 + x_2 + x_3 + .. + x_n}{n} = \frac{\sum_{n=1}^{n} x_n}{n}$$

where, $\bar{x} = Arithmetic\ Mean, x_n = n^{th}\ reading\ taken, n = total\ number\ of\ readings$

4.4.2 Deviation from the Mean:

This is the departure of a given reading from the arithmetic mean of the group of readings. If the deviation of the first reading (x_1) is called d_1 and that of the second reading (x_2) is called d_2, so on. The deviations from the mean can be expressed as,

$$d_1 = x_1 - \bar{x}, \qquad d_2 = x_2 - \bar{x}, \dots , \qquad similarly\ \ d_n = x_n - \bar{x}$$

The deviation may be positive or negative. The algebraic sum of all the deviations must be zero.

Example-6: For the given data x_1 = 49.7; x_2 = 50.1; x_3 = 50.2; x_4 = 49.6; x_5 = 49.7, calculate i) Arithmetic mean, ii) Deviation of each value, iii) Algebraic sum of the deviations.

Solution:

i. The arithmetic mean is calculated as,

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5}$$

$$\bar{x} = \frac{49.7 + 50.1 + 50.2 + 49.6 + 49.7}{5} = 49.86$$

ii. The deviations from each value are given by,

$$d_1 = x_1 - \bar{x} = 49.7 - 49.86 = -0.16$$

$$d_2 = x_2 - \bar{x} = 50.1 - 49.86 = +0.24$$

$$d_3 = x_3 - \bar{x} = 50.2 - 49.86 = +0.34$$

$$d_4 = x_4 - \bar{x} = 49.6 - 49.86 = -0.26$$

$$d_5 = x_5 - \bar{x} = 49.7 - 49.86 = -0.16$$

iii. The algebraic sum of the deviations is,

$$d_{total} = -0.16 + 0.24 + 0.34 - 0.26 - 0.16 = +0.58 - 0.58 = 0$$

4.4.3 Average Deviations:

The average deviation is an indication of the precision of the instrument used in measurement. Average deviation is defined as the sum of the absolute values of the deviation divided by the number of readings. The absolute value of the deviation is the value without respect to the sign. Average deviation may be expressed as,

$$D_{av} = \frac{|d_1| + |d_2| + |d_3| +..+ |d_n|}{n} = \frac{\sum|d_n|}{n}$$

where, $D_{av} = average\ deviation$; $|d_1|, |d_2|, |d_3|, .., |d_n| = absolute\ value\ of\ deviation$; n = total number of readings.

Highly precise instruments yield a low average deviation between readings.

Example-7: For the given data x_1 = 49.7; x_2 = 50.1; x_3 = 50.2; x_4 = 49.6; x_5 = 49.7, calculate the average deviation.

Solution:

The average deviation is calculated as,

$$D_{av} = \frac{|d_1| + |d_2| + |d_3| + |d_4| + |d_5|}{5}$$

$$D_{av} = \frac{|-0.16| + |0.24| + |0.34| + |-0.26| + |-0.16|}{5} = \frac{1.16}{5} = 0.232$$

Therefore, the average deviation = 0.232

4.4.4 Standard Deviations:

The standard deviation of an infinite number of data is the Square root of the sum of all the individual deviations squared, divided by the number of readings. It may be expressed as,

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 +..+ d_n^2}{n}}$$

where, $\sigma = standard\ deviation$

The standard deviation is also known as root mean square deviation, and is the most important factor in the statistical analysis of measurement data. Reduction in this quantity effectively means improvement in measurement.

For small readings (n < 30), the denominator is frequently expressed as (n-1) to obtain a more accurate value for the standard deviation.

Example-8: For the given data x_1 = 49.7; x_2 = 50.1; x_3 = 50.2; x_4 = 49.6; x_5 = 49.7, calculate the standard deviation.

Solution:

The standard deviation is calculated as,

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + .. + d_n^2}{n-1}}$$

$$\sigma = \sqrt{\frac{(-0.16)^2 + (0.24)^2 + (0.34)^2 + (-0.26)^2 + (-0.16)^2}{5-1}}$$

$$\sigma = \sqrt{\frac{0.0256 + 0.0576 + 0.1156 + 0.0676 + 0.0256}{4}}$$

$$\sigma = \sqrt{\frac{0.292}{4}} = \sqrt{0.073} = 0.27$$

Therefore, the standard deviation = 0.27

4.4.5 Limiting Errors:

Most manufacturers of measuring instruments specify accuracy within a certain % of a full scale reading. For example, the manufacturer of a certain voltmeter may specify the instrument to be accurate within ± 2% with full scale deflection. This specification is called the limiting error. This means that a full scale deflection reading is guaranteed to be within the limits of 2% of a perfectly accurate reading; however, with a reading less than full scale, the limiting error increases.

Example-9: A 600V voltmeter is specified to be accurate within ± 2% at full scale. Calculate the limiting error when the instrument is used to measure a voltage of 250V.

Solution:

The magnitude of the limiting error is 0.02 x 600 = 12V.

Therefore, the limiting error for 250 V is 12/250 x 100 = 4.8%.

Example-10: A 500mA ammeter is specified to be accurate within ± 2%. Calculate the limiting error when instrument is used to measure 300mA.

Solution:

The magnitude of the limiting error is 0.02 x 500mA = 10mA.

Therefore, the limiting error at 300mA is 10mA/300mA x 100 = 3.33%.

Example-11: A voltmeter reading 70V on its 100V range and an ammeter reading 80mA on its 150mA range are used to determine the power dissipated in a resistor. Both the instruments are guaranteed to be accurate within ± 1.5% at full scale deflection. Determine the limiting error of the power.

Solution:

1) The magnitude of the limiting error for the voltmeter is 0.015 x 100 = 1.5V.
   Therefore, the limiting error at 70V is 1.5/70 x 100 = 2.143%.
2) The magnitude of limiting error of the ammeter is 0.015 x 150mA = 2.25mA.
   Therefore, the limiting error at 80mA is 2.25mA/80mA x 100 = 2.813%.
3) Therefore, the limiting error for the power calculation is the sum of the individual limiting errors involved.
   Therefore, limiting error = 2.143% + 2.813% = 4.956%

B) Display Devices:

The rapid growth of electronic handling of numerical data has bought with it a great demand for simple systems to display the data in a readily understandable form. 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.

Commonly used displays in the digital electronic field are as follows.

1. Cathode Ray Tube (CRT)
2. Light Emitting Diode (LED)
3. Liquid Crystal Display (LCD)
4. Gas discharge plasma displays (Cold cathode displays or Nixies)
5. Electro-Luminescent (EL) displays
6. Incandescent display
7. ElectroPhoretic Image Displays (EPID)
8. Liquid Vapour Display (LVD)

5.0 Light Emitting Diode:

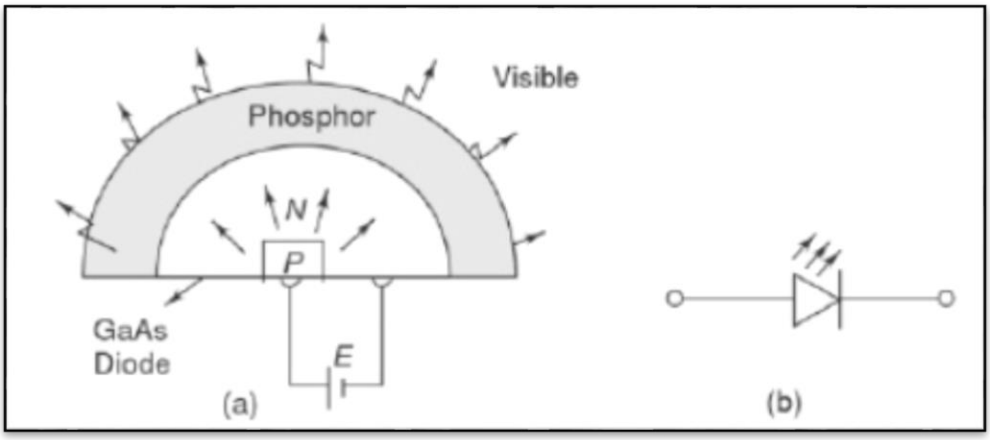

Fig. 1 a) structure of visible PN junction GaAs diode b) Symbol of LED

The LED, Fig.1 a) is basically a semiconductor PN junction diode capable of emitting electromagnetic radiation under forward conductions. The radiation emitted by LEDs can be either in the visible spectrum or in the infra red region, depending on the type of the semiconductor material used. Generally, infra-red emitting LEDs are coated with Phosphor so that, by the excitation of phosphor visible light can be produced. LEDs are useful for electronics display and instrumentation. Fig.1 b) shows the symbol of an LED.

The advantages of using LEDs in electronic displays are as follows.

1. LEDs are very small devices, and can be considered as point sources of light. They can therefore be stacked in a high-density matrix to serve as a numeric and alphanumeric display. (They can have a character density of several thousand per square meter).

2. The light output from an LED is function of the current flowing through it. An LED can therefore, be smoothly controlled by varying the current. This is particularly useful for operating LED displays under different ambient lighting conditions.

3. LEDs are highly efficient emitters of EM radiation. LEDs with light output of different colours, i.e. red, amber, green and yellow are commonly available.

4. LEDs are very fast devices, having a turn ON-OFF time of less than 1ns.

5. The low supply voltage and current requirements of LEDs make them compatible with DTL and TTL, ICs.

In germanium and silicon semiconductors, most of the energy is released in the form of heat. In Gallium Phosphide GaP and Gallium Arsenide Phosphide GaAsP most of the emitted photons have their wavelengths in the visible regions, and therefore these semiconductors are used for the construction of LEDs. The colour of light emitted depends upon the semiconductor material and doping level. Different materials used for doping give out different colours.

1. Gallium Arsenide (GaAs) - red
2. Gallium Arsenide Phosphide (GaAsP) – red or yellow
3. Gallium Phosphide (GaP) – red or green.

Alphanumeric displays using LEDs employ a number of square and oblong emitting areas, arranged either as dot matrix or segmented bar matrix. Alphanumeric LEDs are normally laid out on a single slice of semiconductor material, all the chips being enclosed in a package, similar to an IC, except that the packaging compound is transparent rather than opaque. Fig. 2 c and d gives typical LED packages for single element LEDs.

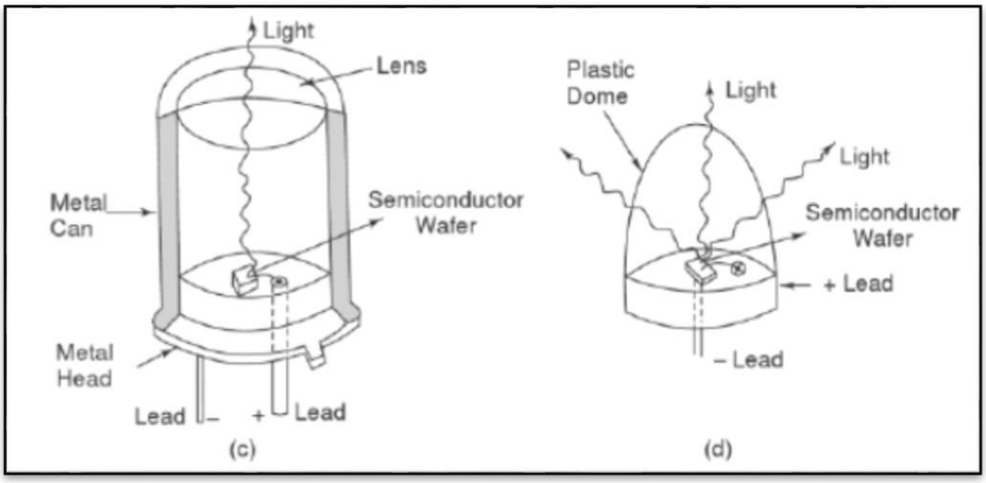

Fig. 1 c) Metal can TO-5 type d) Epoxy type

6.0 Liquid Crystal Display (LCD):

LCDs are passive displays characterized by very low power consumption and good contrast ratio. They have the following characteristics in common.

1. They are light scattering.
2. They can operate in a reflective or transmissive configuration.
3. They do not actively generate light and depend for their operation on ambient or back lighting.

A transmissive LCD has a better visual characteristic than a reflective LCD. The power required by an LCD to scatter or absorb light is extremely small, of the order of a few 11W/cm. LCDs operate at low voltages, ranging from 1-15V. The operation of liquid crystals is based on the utilization of a class of organic materials which remain a regular crystal –like structure even when they have melted. Two liquid crystal materials which are important in display technology are Nematic and Cholesteric, as shown in Fig.2.

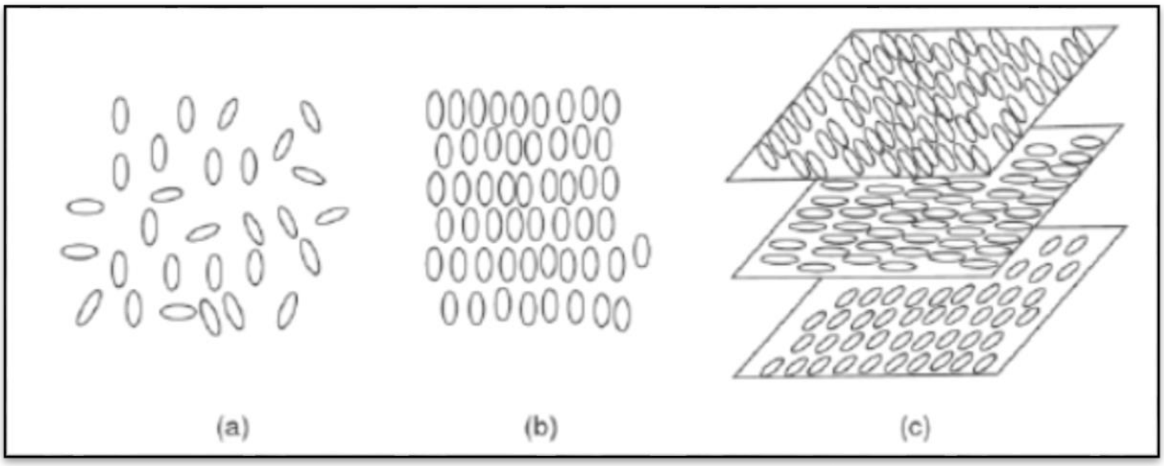

Fig. 2 Liquid Crystal Materials a) Ordinary liquid b) Nematic liquid crystal c) Cholesteric liquid crystal

The most popular liquid crystal structure is the nematic liquid crystal NLC. The liquid is normally transparent, but if it is subjected to a strong electric field, ions move through it and disrupt the well ordered crystal structure, causing the liquid to polarize and hence turn opaque. The removal of the applied field allows the crystals structure to reform and the material regains its transparency. Basically, the LCD comprises of a thin layer of NLC fluid, about 10μ thick, sandwiched between two glass plates having electrodes, at least one of which is transparent. If both are transparent, the LCD is of the transmissive type, where as a reflective LCD has only one electrode transparent. The structure of a typical reflective LCD is shown in Fig.3. The NLC material in Fig.3 has a homogeneous alignment of molecules. While the glass substrate supports the LCD and provides the required transparency, the electrode facilitates electrical connections for the display. The insulating spacers are the hermetic seal.

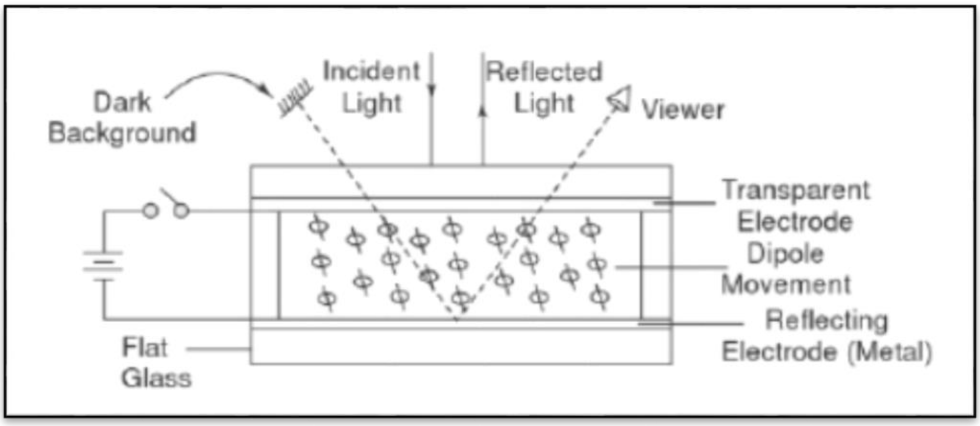

Fig. 3 Reflective display using NLC

The LCD material is held in the centre cell of a glass sandwich the inner surface of which is coated with a very thin conducting layer of tin-oxide which can be either transparent or reflective. The oxide coating on the front sheet of the indicator is etched to produce a single or multi segment pattern of characters and each segment of character is properly insulated from each other.

LCDs can be read easily in any situation even when the ambient light is strong. If the read electrode is made transparent instead of reflective back illumination is possible by a standard indicator lamp. Extending back illumination a step further by adding a lens arrangement. LCDs can be used as the slide in a projection system to obtain an enlarged image.

Important features of LCDs

1. The electric field required to activate LCDs is typically of the order of 10^4 V/cm. This is equivalent to an LCD terminal voltage of 10V when the NLC layer is 10μ thick.
2. NLC materials possess high resistivity > $10^{10}\Omega$. Therefore the current required for scattering light in an NLC is very marginal typically 0.1μA/cm^2.
3. Since the light source for a reflective LCD is the ambient light itself, the only power required is that needed to cause turbulence in the cell, which is very small, typically1μW/cm.
4. LCDs are very slow devices. They have a turn-on time of a few milliseconds, and a turn-off time of tens of milliseconds.

To sum up, LCDs are characterized by low power dissipation, low cost, large area and low operating speed.

LCDs are usually of the seven segment type for numeric use and have one common back electrode and seven transparent front electrodes characters, as shown in Fig. 4.

The back electrode may be reflective or transmissive, depending on the mode of operation of the display device.

Generally arrays of such characters are simultaneously fabricated using thin film or hybrid IC technology for segments and conductors on glass plates, and then filled in with NLC material, followed by hermetic sealing.

LCD arrays utilizing a dot-matrix are also possible, but they are not popular because of theirs low operation.

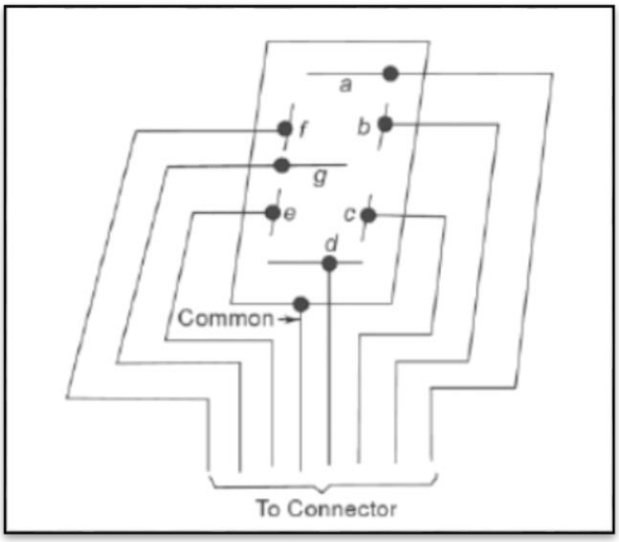

Fig. 4 Seven segment LCD character

2.12.1 Gas Discharge Plasma Displays

These are the most well-known type of alphanumeric displays. Their operation is based on the emission of light in a cold cathode gas filled tube under breakdown condition.

These cold cathode numerical indicators are called Nixies (Numicators and Numbertrons).

This Nixie tube is a numeric indicator based on glow discharge in cold cathode gas filled tubes. It is essentially a multicathode tube filled with a gas such as neon and having a single anode, as shown in Fig. 2.14.

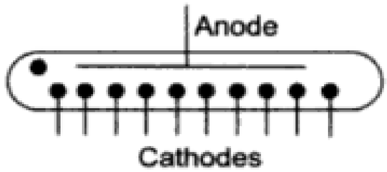

Fig. 2.14 Nixie Tube — Symbolic Representation

Each of the cathodes is made of a thin wire and is shaped in the form of characters to be displayed, for example, numerals 0 to 9. The anode is also in the form of a thin frame.

In its normal operation, the anode is returned to positive supply through a suitable current limiting resistor, the value of the supply being greater than the worst-case breakdown voltage of the gas within the tube. The gas in the vicinity of the appropriate cathode glows when the cathode is switched to ground potential.

(The characteristic orange-red glow in the case of neon covers the selected cathode completely, thereby illuminating the character brightly.)

Since 10 cathodes have to be associated with a single anode inside the glass bulb, they have necessarily to be stacked in different planes. This requires different voltages for different cathodes to enable the glow discharge.

Many Nixie tubes also possess dot-cathodes either on the left or right of the character to serve as decimal points.

The standard Nixie is not the only format used with cold cathode technology—both bar and dot matrix versions are available. The bar types have a cathode which forms the segment and operates in a fashion similar to the standard neon tube. Identical supply voltage and drivers are required. In the dot type display, each dot is in matrix fashion and operates as an individual glow discharge light source. The required dots are selected by an *X-Y* addressing array of thin film metal lines, as shown in Fig. 2.15 (a).

Nixie tubes have the following important characteristics.

1. The numerals are usually large, typically 15–30 mm high, and appear in the same base line for in-line read-out.
2. Nixie tubes are single digit devices with or without a decimal point.
3. They are either side viewing or top viewing (as shown in Figs 2.15 (b) and (c)).

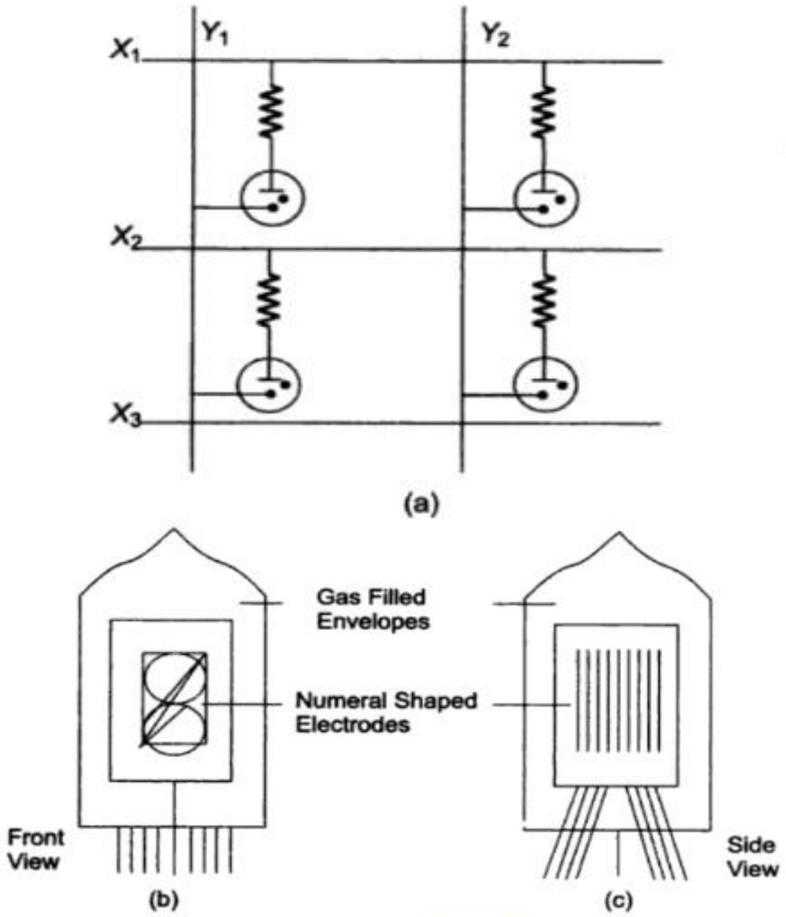

Fig. 2.15 ▬ (a) Matrix Operation of Display Panel Using Gas Filled Devices (b) and (c) Nixie Tube

4. Most Nixie tubes require dc supply of 150–220 V, and the selected cathode carries current in the range of 1–5 mA.
5. The Nixie tube can be pulse operated and hence can be used in multiplexed displays.
6. Alphabetical symbols can also be introduced in the Nixie tube.

2.12.2 Segmented Gas Discharge Displays

Segmented gas discharge displays work on the principle of gas discharge glow, similar to the case of Nixie tubes. They are mostly available in 7 segment or 14 segment form, to display numeric and alphanumeric characters.

Since these devices require high voltages, special ICs are developed to drive them. The construction of a 7 segment Display is shown in Fig. 2.16. Each segment (decimal point) of the 7 segment display formed on a base has a separate cathode. The anode is common to each member of the 7 segment group which is deposited on the covering face plate. The space between the anodes and cathodes contains the gas. For each group of segments, a 'keep alive' cathode is also provided. For improving the switching speeds of the display a small constant current (a few micro amps) is passed through this keep alive cathode, which acts as a source of ions. Pins are connected to the electrodes at the rear of the base plate, with the help of which external connections can be made.

The major disadvantage of this gas discharge tube is that high voltage is required for operating it. Therefore, high voltage transistors, in the range of 150 – 200 V, are required as switches for the cathodes. A major advantage is that the power consumed is extremely small, because a bright display can be obtained even for currents as low as 200 μA.

This display follows a simple construction. Figure 2.17 gives the structure of a typical 7 segment display making use of a gas discharge plasma.

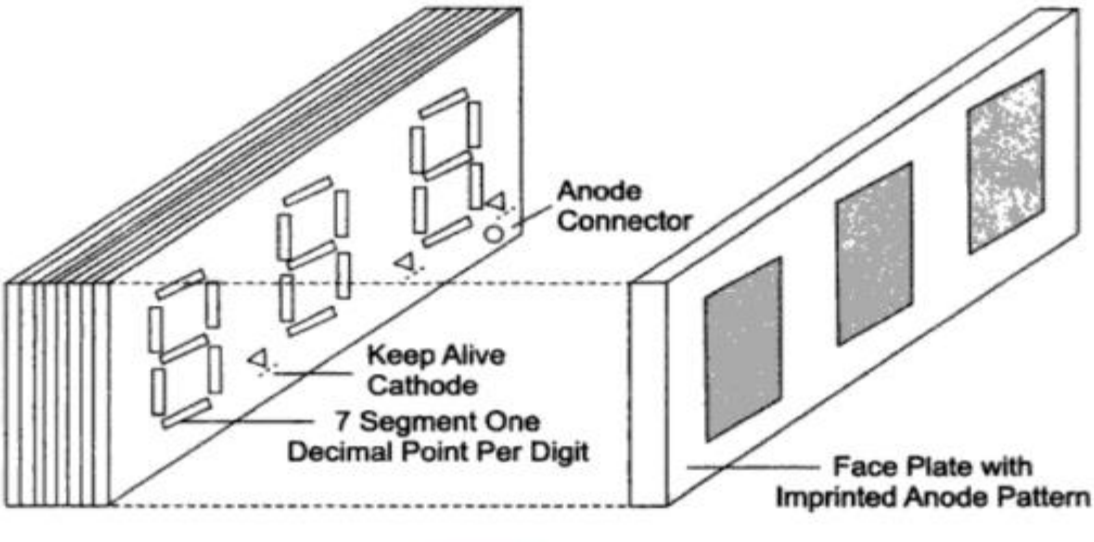

Fig. 2.16 ▬ Seven Segment Display Using Gaseous Discharge

The device uses a glass substrate, shown in Fig. 2.17. Back electrodes of the thick film type serve as cathode segments, and front electrodes of the thin film type serve as transparent anodes. A gas, typically neon, is filled in the discharge space between the cathode and anode segment. The gas is struck between the cathode and anode of a chosen segment so that the cathode glow provides the illumination. All numeric characters can be displayed by activating the appropriate segment.

Display panels of rows or columns of such characters can be easily constructed by extending a single character. The power requirements of such devices are more or less in the same range as those for Nixie tubes.

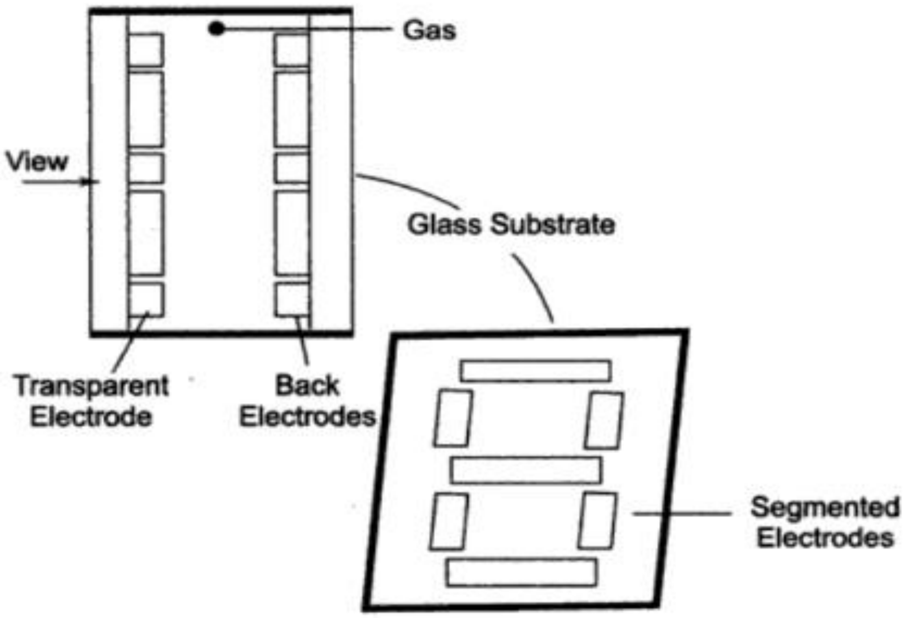

Fig. 2.17 — Seven Segment Gas Filled Character

2.12.3 Segmental Displays using LEDs

In segmental displays, it is usual to employ a single LED for each segment.

For conventional 7 segment LED displays (including the decimal point, i.e. the 8th segment), the wiring pattern is simplified by making one terminal common to all LEDs and other terminals corresponding to different segments. The terminals can be either of the common anode (CA) form or common cathode (CC) form, shown in Figs 2.18 (b) and (c).

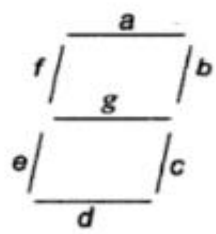

Fig. 2.18 — (a) LED 7 Segment Format

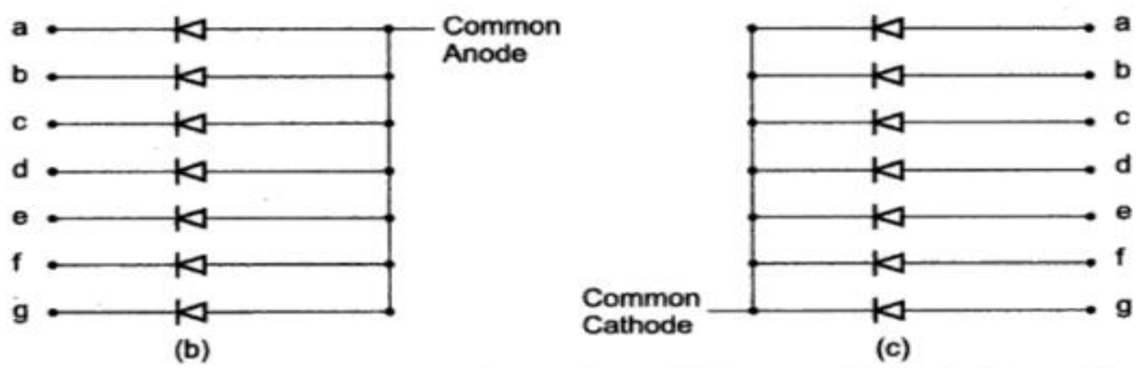

Fig. 2.18 (b) Common Anode Connections (c) Common Cathode Connections

A typical static single digit 7 segment LED display system and multi-digit are shown in Figs. 2.18 (a) and (d).

Multi-digit display system may be static or dynamic.

Common anode type displays require an active low (or current sinking) configuration for code converter circuitry, whereas an active high (or current sourcing) output circuit is necessary for common-cathode LED type display.

Both multi-digit and segmental displays require a code converter; one code converter per character for static display systems and a single code converter for time shared and multiplexed dynamic display systems, which are illuminated one at a time.

The typical circuit schemes described in the figures are only of the decimal numeric character. An 8 digit display system, operating on this principle and suitable for digital instrumentation is given in Fig. 2.18 (d).

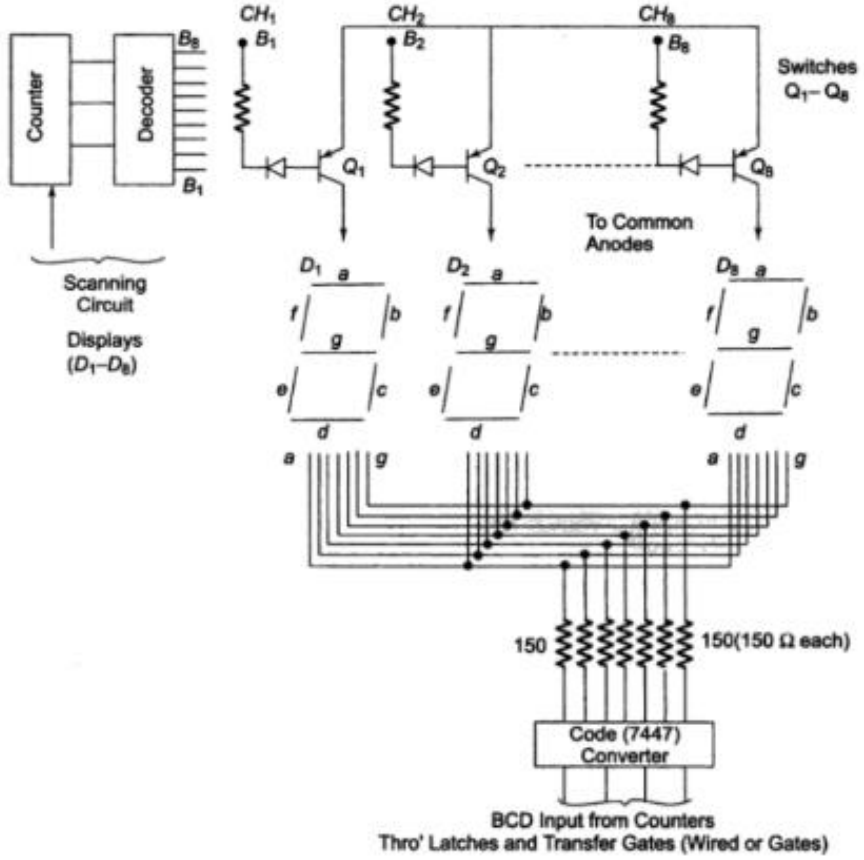

Fig. 2.18 (d) Multi-Digit Display System (8 Digit) Using LED 7 Segment Characters

It is also possible to generate hexadecimal numeric characters and conventional alphanumeric characters using 7 segment and 14 or 16 segment LED display units respectively, with a proper code converter. Both static and dynamic displays can be realised using LCDs, either in a common format (7 segment) or in single or multi character.

A chopped dc supply may be used, for simplicity, but conventionally an ac voltage is applied either to the common electrode or to the segment. Various segmental LCD driver circuits are displayed in Fig. 2.19.

Referring to Figs 2.19 (a) and (b), it is seen that an ac voltage (V_{ac}) is applied to either the common electrode or to the segment. High value resistances ($R > 1M$) are included in the circuit, as shown. The code converter controls the switches (S). V_{ac} is present across the selected segment and the common electrode when S is ON, and the voltage between any other segment (S-OFF) and the common electrode is zero. Hence the desired segments are energised, provided V_{ac} has a magnitude greater than or equal to the operating voltage of the LCD.

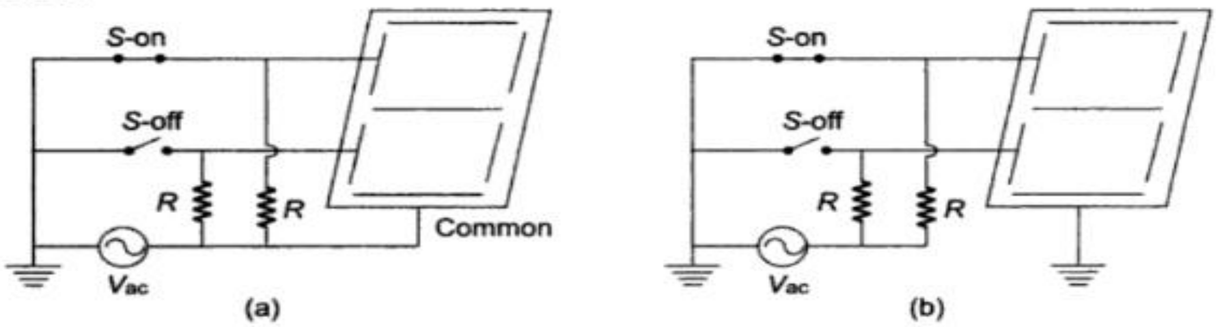

Fig. 2.19 (a) Segments Driving Circuits for LCD, Switching Method Common Electrode (b) Segments Driving Circuits for LCD, Switching Method

The basic operation of the phase shift method for driving the segment is shown in Fig. 2.19 (c). In this circuit, ac voltages of the same amplitude and frequency (not necessarily same phase) are supplied to the common electrode as well as the segments.

There will be a finite voltage drop between a segment and the common electrode only when the ac voltages applied are out of phase, and thus the selected segment is energised. On the other hand, when in-phase voltages are present, the voltage drop between a segment and the common electrode is zero, leading to the off state.

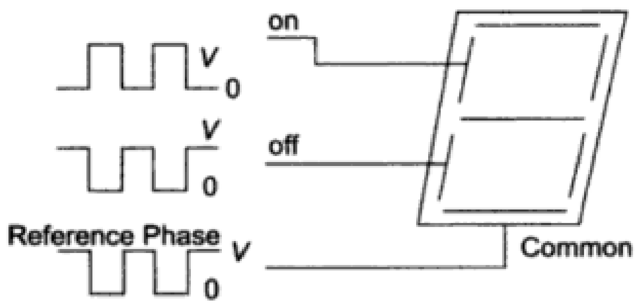

Fig. 2.19 (c) Segments Driving Circuits for LCD, Using Phase Shift Method

2.12.4 Dot Matrix Displays

Excellent alphanumeric characters can be displayed by using dot matrix LEDs with an LED at each dot location. Commonly used dot matrices for the display of prominent characters are 5×7, 5×8, and 7×9, of which 5×7 shown in Fig. 2.20 (a), is very popular due to economic considerations. The two wiring patterns of dotmatrix displays are as follows.

1. Common anode or common cathode connection (uneconomical).
2. $X - Y$ array connection (economical and can be extended vertically or horizontally using a minimum number of wires, Fig. 2.20 (b)).

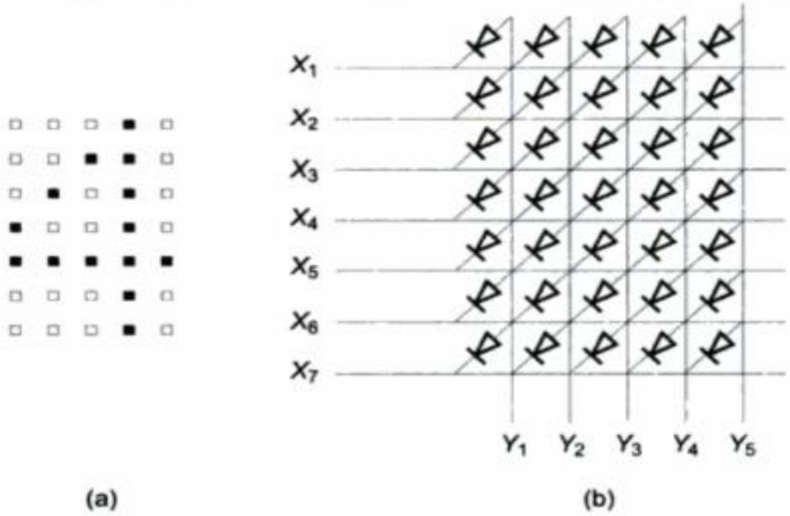

Fig. 2.20 (a) 5 x 7 Dot Matrix Character Using LED
(b) Wiring Pattern for 5 x 7 LED Character

A typical 3 digit alphanumeric character display system using 5×7 dot matrix LEDs is shown in Fig. 2.21.

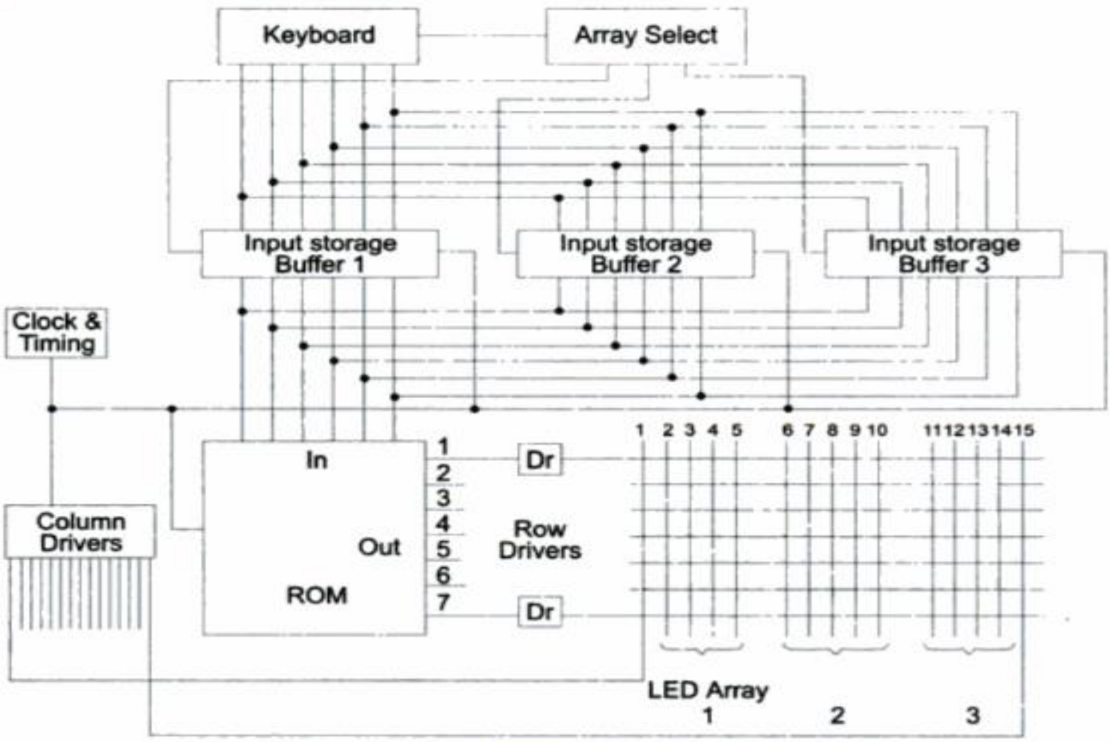

Fig. 2.21 A 3 Digit Alphanumeric Display System Using 5 x 7 Characters

2.12.5 Bar Graph Displays

Bar graph displays are analogue displays which are an alternative to conventional D'Arsonval moving coil meters. They use a closely packed linear array or column of display elements, i.e. "DOT-LED'S", which are independently driven so that the length of the array (or the height of the column) corresponds to the voltage or current being measured. These displays are generally used in the panel meters to accept analog input signals and produce an equivalent display of the input signal level by illuminating the corresponding LEDs, as shown in Fig. 2.22.

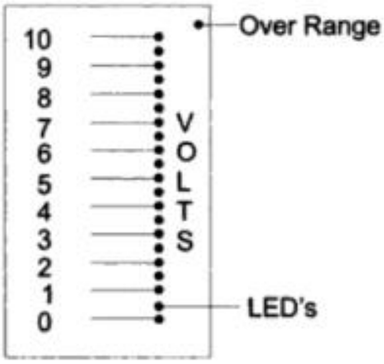

Fig. 2.22 Analog Meter Using Bar Graph of LEDs

2.12.6 Electro Luminescent (EL) Displays

Electro luminescent displays are an important means of light generation. They can be fabricated using polycrystalline semiconductors, and in view of their simple technology, brightness of display and possibility of different colours, are rapidly gaining in popularity.

The semiconductors used for EL displays are essentially phosphor powder or film type structures.

The powder type consist of powder phosphor with some binding material e.g. organic liquids deposited on a sheet of glass. The glass has transparent conductive segments (e.g. 7 segment displays) or dots (dot matrix display) along with the required conductive leads on the side on which phosphor is coated for electrical connections.

A metallic electrode, usually aluminium, is placed over the phosphor in a pressure cell by vacuum evaporation, so as to form an electrical connection on the other side of the phosphor. The resulting device is capacitive, because of poor conduction paths in phosphor. An ac field applied across the chosen segment (or dot) and aluminium electrode excites the phosphor, resulting in emission of light. In film type structures the EL powder structure is replaced by a polycrystalline phosphor film which is deposited on a glass substrate using a vacuum or pressure cell. These devices can be operated by ac as well as dc.

2.12.7 Incandescent Display

Incandescence has been a basic process of light generation for several decades. This process is now down in fully integrated electronic displays.

Incandescent displays using 16 segment as well as 5×7 dot matrix formats fabricated using thin film micro electronics are now available for alphanumeric characters. Such displays are characterised by simple technology, bright output and compatibility with ICs, but at very low operating speeds.

A thin film of tungsten can be made to emit light if its temperature is raised to about 1200°C by electrical excitation. A 5 × 7 character array is formed on a ceramic substrate employing such films in a matrix form and is used as an integrated electronic display unit. Figure 2.23 gives a typical tungsten film or filament suitable for a dot location in the display.

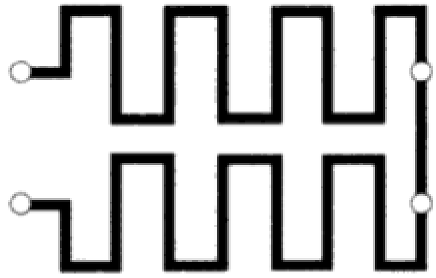

Fig. 2.23 ▬ Tungsten Filament Suitable for Incandescent Display

An array of such filaments can be formed on ceramic substrates using conventional thin film technology commonly used in semiconductor fabrication.

Considering the filament dimensions and the dimensions of commonly available substrates, an array of three characters can be located on a 2.5 cm ceramic substrate.

16 segment incandescent displays are also available, but their display is slow, because of the large thermal time constant associated with the filaments.

2.12.8 Electrophoretic Image Display (EPID)

Electrophoresis is the movement of charged pigment particles suspended in a liquid under the influence of an electric field. This pheonomenon has been utilised in electrophoretic image displays, as shown in Fig. 2.24.

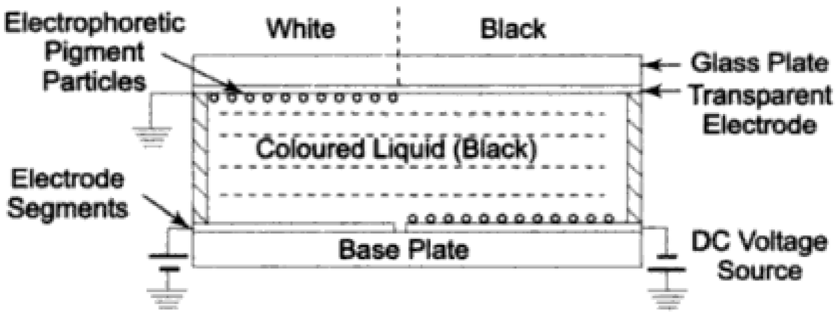

Fig. 2.24 ▬ Structure of an EPID

The basic principle; fabrication and operating characteristics of a reflective type Electrophoretic Image Display (EPID) panel are as follows. These displays are characterised by large character size, low power dissipation and internal memory.

The relatively slow speed of these displays is a major limitation, particularly for use as a dynamic display. The life span of an EPID is a few thousand hours only.

The EPID panel makes use of the electrophoretic migration of charged pigment particles in a supension. The suspension, 25 – 100 μ thick, which largely contains the pigment particles and a suspending liquid, is sandwiched between a pair of electrodes, one of which is transparent.

The application of a dc electric field, across the electrodes, as shown in Fig. 2.24 moves the particles electrophoretically towards either electrode, the movement depending mainly on the polarity of the charge on the particles. The reflective colour of the suspension layer changes on account of this migration. EPID panels generally follow a segmented character format – typically 7 segment for numeric characters.

It is usual to have the transparent electrode as a common electrode. The back electrodes are generally segmented. Two such segments are shown in Fig. 2.24.

During the normal operation of the display, the transparent electrode is maintained at ground potential and the segmented electrodes at the back are given different potentials.

If the pigment particles are white and positively charged in the black suspending liquid, the application of a positive voltage to the chosen segment moves the pigment particles away from it and towards the transparent electrode. This is shown on the left side of Fig. 2.24. Pigment particles appear white in reflective colour as viewed through the transparent electrodes.

On the other hand, when a segment has a negative voltage with reference to the transparent electrode, the white pigment particles go towards it and get immersed in the black suspension. In this case, the viewer sees the reflection from the black liquid itself.

Colour combinations of both the pigment particles and the suspending liquid can be used to achieve a desired colour display.

Moreover, the colours between the displayed pattern and its background can be reversed, by changing the polarities of segment voltages.

In addition, the EPID panel has a memory, because the pigment particles deposited on an electrode surface remain there even after the applied voltage is removed.

2.12.9 Liquid Vapour Display (LVD)

LVDs are the latest in economical display technology. They employ a new reflective passive display principle and depend on the presence of ambient lights for their operation. Figure 2.25 gives the structure of a typical LVD cell.

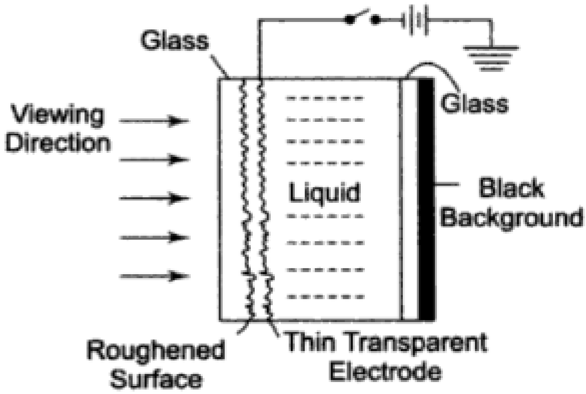

Fig. 2.25 Structure of an LVD Cell

It consists of a transparent volatile liquid encased between two glass plates and side spacers. The rear glass plate has a black background and the front glass surface in contact with the liquid is roughened, so that the liquid wets it, i.e. in its simplest form, an LVD consists of a roughened glass surface wetted with a transparent volatile liquid of the same refractive index as that of the glass. The rear surface is blackened.

The transparent electrode is heated by using a voltage drive, which is the basis for the display function.

In the OFF condition of display with no voltage applied across the transparent electrode, the viewer sees the black background through the front transparent glass electrode and the liquid.

To achieve an ON condition of the display, a voltage is applied to the transparent electrode. This causes sufficient heat in the electrode, which evaporates the liquid in contact with it, and a combination of vapour film and vapour bubbles is formed around the roughened glass surface. As the refractive index of vapour is approximately 1, there is a discontinuity established at the interface between the front glass plate and the liquid, which gives rise to light scattering. This makes it a simple display device.

The organic liquid selected for LVD should have the following features.

1. Refractive index close to that of the glass plate.
2. Minimum energy for vapourising the liquid in contact with the roughened surface.

The electrical heating of a thin film of liquid adjacent to the roughened surface using transparent electrodes and the applied voltage, makes it an unusually good display with a better contrast ratio than an LCD. The speed of operation of LVDs is low.

Introduction, Measurement: qualities of measurements, static characteristics, errors in measurement, types of error, statistical analysis. Display devices: LED, LCD, Gas discharge plasma display, segmented gas discharge display, Segmental display using LED, dot matrix display, bar graph display, Electro-Luminescent display, Incandescent display, ElectroPhoretic Image display, Liquid Vapor Display.