Manonmaniam Sundaranar University,

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OPEN AND DISTANCE LEARNING (ODL) PROGRAMMES

(FOR THOSE WHO JOINED THE PROGRAMMES FROM THE ACADEMIC YEAR 2023–2024)

II YEAR

B.Sc. Physics

Course Material

INSTRUMENTATION PHYSICS-II

Prepared

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INSTRUMENTATION PHYSICS-II

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Oscilloscope - Basic principle - CRT features – Block diagram of oscilloscope - Simple cathode ray oscilloscope.	
TEXT BOOKS	1. Albert D. Helfrick and William D. Cooper, Modern Electronic Instrumentation and Measurement Techniques, Prentice-Hall of India Pvt. Limited, Reprint 2002. 2. M. Arumugam, Biomedical Instrumentation, Anuradha Agencies, Reprint 2002. 3. H.S.Kalsi, Electronic Instrumentation, Tata McGraw Hill Education Pvt. Limited, Reprint 2012.
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UNIT – I

BASIC ELECTRONIC AND DIGITAL INSTRUMENT

Electronic Multimeter: It is one of the most versatile general purpose instruments capable of measuring dc and ac voltages as well as current and resistances. The solid-state electronic multimeter (or VOM) generally consists of the following elements.

(i) A balanced bridge dc amplifier and a PMMC meter.

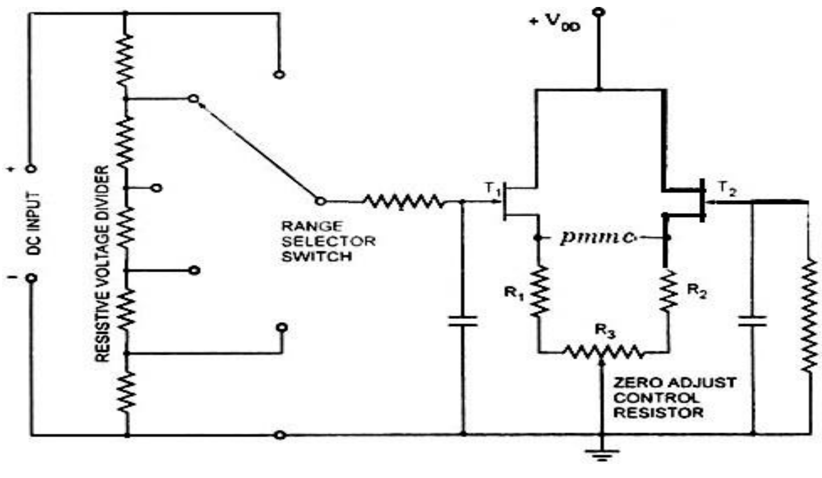
(ii) An attenuator in input stage to select the proper voltage range.

(iii) A rectifier for converting of an ac input voltage to proportionate dc value.

(iv) An internal battery and additional circuitry for providing the capability of resistance measurement.

(v) A function switch for selecting various measurement functions of the meter such as voltage, current or resistance.

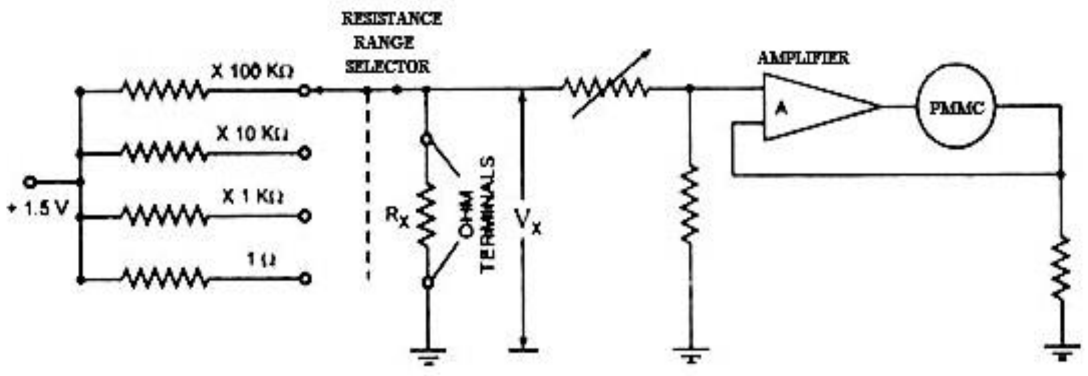
In addition, the instrument is usually provided with a built-in power supply for operation on ac mains and, in most cases, one or more batteries for operation as a portable test instrument. The schematic diagram of a balanced-bridge dc amplifier using two field effect transistors (FETs) is given in fig.1. It is to be noted that two FETs used in circuit should be reasonably well matched for current gain to ensure circuit thermal stability. The two FETs and the source resistors R_x and R_2, together with zero adjust control resistor R_3, constitute a bridge circuit. The PMMC meter is connected between the source terminals of the FETs, representing two opposite corners of the bridge.



Balanced bridge dc amplifier with Input Attenuator and Indicating Meter

In the absence of input signal, the gate terminals of the FETs are at ground potential and the transistors operate under identical quiescent conditions. Ideally no current should flow through the PMMC movement but in practice, on account of some mismatch between the two FETs and slight tolerance differences in the values of various resistors a current does flow and causes the meter movement to deflect from zero position. This current is reduced zero by the adjust control resistor R_3. Now the bridge is balanced. With a positive input signal applied to the gate of input transistor T_1 its drain current creases causing the voltage at the source terminal to rise. The resulting unbalance between the two transistors T_1 and T_2 source voltages is shown by the meter movement, whose scale is calibrated in terms of the magnitude of the applied input voltage. The maximum voltage that can be applied to the gate of input transistor T_1 is determined by its operating range, which is usually of the order of a few volts. The range of the bridge can easily be extended by employing an input attenuator or a range switch, as illustrated in figure.

The unknown dc input voltage is applied through a large resistor in the probe body to a resistive voltage divider. Thus, with the range switch in the 3-V position as illustrated, the voltage at the gate of the input transistor T_1 is developed across 8 MQ resistor of the total resistance of 11.3 MQ and the circuit is so arranged that the PMMC meter gives full scale deflection with 3 V applied to the tip of the probe. With the range switch in 1,200 V position, the gate voltage is developed across 20 kilo ohm of the total divider resistance of 11.3 Mega ohms and an input voltage of 1,200 V will he required to cause the full-scale meter deflection.



Resistance measurement by a Multimeter

Measurement of Resistance by Multimeter or VOM:

When the mustimeter's function switch is placed in the OHM position, the unknown resistor is connected in series with an internal battery, and the PMMC meter simply measure the voltage drop across it (unknown resistor, R_x).

A typical circuit is given in fig. In the given circuit, a separate divider network, employed only for the measurement of resistance, provides a number of different resistance ranges. With the unknown resistor R_x connected to the OHM terminals of the multimeter, the battery supplies current through one of the range resistors and the unknown resistor to ground. Voltage drop across unknown resistor R_x, V_x is applied to the input of the bridge amplifier and the PMMC movement deflects. Since the voltage drop across R_x is directly proportional to its resistance, the meter scale can be calibrated in terms of kilo Ohm.

The worth noting point is that this instrument indicates increasing resistance from left to right whereas the conventional meter, indicates increasing resistance from right to left. This is because the electronic multimeter reads a large resistance as a higher voltage, whereas the conventional multimeter indicates a higher resistance as a smaller current.

Q METER

Q meter was developed by William D. Loughlin at Boonton Radio Corporation in the year 1934 in Boonton, New Jersey. The Q-meter instrument has become more popular in RF impedance measurement. There are different kinds of instruments available based on system usage. These are separated into two types like low-impedance injection & high-impedance injection. This device plays a key role in testing the RF circuits and also replaced in laboratories with other impedance measuring devices, although it is still in use among radio amateurs. This article discusses an overview of the Q meter.

Definition: A device that is used to measure the QF (quality factor) or storage factor or quality factor of the circuit at radio frequencies is called the Q-meter. In the oscillatory system, the QF is one of the essential parameters, used to illustrate the relationships among the dissipated & stored energies.

By using Q value, the overall efficiency can be evaluated for the capacitors as well as coils used in RF applications. The principle of this meter mainly depends on series resonance because the voltage drop is Q times than the applied voltage across the capacitor otherwise coil. When the fixed voltage is applied to an electric circuit, a voltmeter is used to adjust the capacitor's Q value to read directly.

The total efficiency of capacitors & coils used for RF applications can be calculated with the help of Q value.

At resonance $\mathbf{X_L = X_C}$ **and** $\mathbf{E_L = I_{XL}, E_C = I_{XC}, E = I\,R}$

Where 'E' is an applied voltage

'EC' is the capacitor voltage

'EL' is an inductive voltage

'XL' is the inductive reactance

'XC' is the capacitive reactance

'R' is the coil resistance

'I' is circuit current

Thus, $\mathbf{Q = X_L/R = X_c/R = E_{C/}E}$

From the above 'Q'equation, if an applied voltage is kept stable so that the voltage across the capacitor can be calculated using a voltmeter to read 'Q' values directly.

Components of Q Meter

Here are the common components of Q Meter:

- **Meter:** The Quality factor meter has a simple meter to measure the ratio of voltage and current and help to measures the quality factor of the following circuit.
- **Coupling Coil:** It is also a important component of Q meter. It is used to give energy to the meter between circuit being tested. It also measures the quality factor by transferring sufficient energy between them.
- **Detector:** It is also a part of Q meter that is used to measure the quality factor across the circuit being tested and also measure the voltage across the circuit.

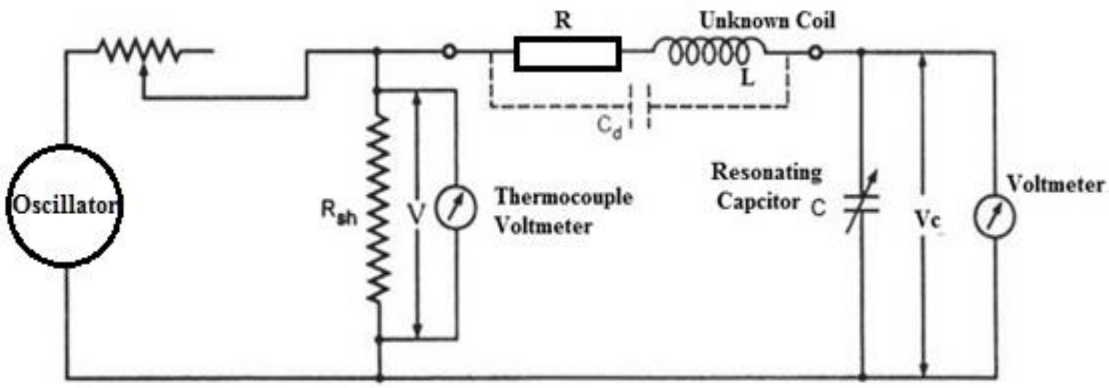
- **Tunable Oscillator:** It is used to produce the signals or frequency for the circuit and compare with the frequency of circuit that tested.
- **Capacitor:** It plays a crucial role to store and release the energy for circuit that tested.
- **Q-Scale**: It is a important measurement scale that used in Q meter, it is used to determine the quality factor of the circuit that tested. It gives a numerical value that tells the efficiency or power of the circuit.

Working Principle

The **working principle of Q meter** is series resonant because the resonant exists within the circuit once the reactance of capacitance & reactance is of the same magnitude. They induce energy to oscillate in between the fields of electric & magnetic of the inductor & capacitor respectively. This meter mainly depends on the feature of the capacitance, inductance & resistance of the resonant series circuit.

Q Meter Circuit

The circuit diagram of the 'Q' meter is shown below. It is designed with an oscillator that uses the frequency that ranges from 50 kHz – 50 MHz. and provides current to a shunt resistance 'Rsh'with 0.02 ohms value.
Here thermocouple meter is used to calculate the voltage across the shunt resistance whereas an electronic voltmeter is used to calculate the voltage across the capacitor. These meters can be calibrated to read 'Q' directly.



q-meter-circuit

In the circuit, the energy of the oscillator can be supplied to the tank circuit. This circuit can be adjusted for the resonance through unstable 'C' until the voltmeter reads the utmost value.

The o/p voltage of resonance is ‘E’, equivalent to ‘Ec’ is E = Q X e and Q = E/e. Because ‘e’ is known so the voltmeter is adjusted to read ‘Q’ value directly.

The coil is connected to the two test terminals of the instrument to determine the coil’s inductance

This circuit is adjusted to resonance through changing either the oscillator frequency otherwise the capacitance. Once the capacitance is changed, then the frequency of the oscillator can be adjusted to a specified frequency & resonance is attained.

If the value of capacitance is already fixed to a preferred value, then the frequency of the oscillator will be changed until resonance takes place.

The reading of ‘Q’ on the o/p meter is multiplied through the setting of an index to get the actual ‘Q’ value. The coil’s inductance is calculated from known values of the coil frequency as well as the resonating capacitor.

The specified Q is not the definite Q, as the losses of the voltmeter, inserted resistance & resonating capacitor are all incorporated in the circuit. Here, the definite ‘Q’ of the calculated coil is a bit larger than the specified Q. This dissimilarity is insignificant except wherever the coil’s resistance is relatively minute compared to the ‘Rsh’ resistance.

Applications of the Q-meter

The applications of Q-meter include the following.

- It is used to measure the quality factor of the inductor.
- By using this meter, unknown impedance can be measured using a series or shunt substitution method. If the impedance is small, the former technique is used and if it is large, then the latter technique is used.
- It is used to measure small capacitor values.
- By using this, inductance, effective resistance, self-capacitance, and bandwidth can be measured.

Q meter is an important and useful electronic device used to calculate the quality factor as well as determine the accuracy, power as well as performance of various electrical circuits. The common components of q meter are meter, detector, tunable oscillator, q scale, coil and capacitor. It works on the principle of resonant frequency to measure the current and voltage which helps us in calculating the quality factor as well as performance. It uses in many industries as well as in telecommunication or radio systems and more.

VECTOR METERS

Trivector Meter:

Trivector meter is an energy meter which accurately measures all the parameters of supply such as voltage, current, power factor, active load, reactive load, apparent load etc., now a days static electronic meters are used for commercial and industrial applications. These electronic meters use micro controllers with their own programming language.

Trivector meter gets the input supply to be measured using CT/PTs. That is current input from Current Transformers and voltage input from Potential Transformers connected in the circuit. It is a true four quadrant measuring instrument. LCD display with annunciators for showing various critical events is used.

The following Measurement Values can be obtained using Trivector meter.

1. Active Energy in MWh
2. Reactive Energy in MVArh
3. Apparent Energy in MVAh
4. Maximum Demand in MVA
5. Voltages of all the phases
6. Currents of all the phases
7. Power factor of all the phases

Principle of Operation:

The principle of operation of trivector energy meter is explained with the help of block diagram.

It mainly consists of the following units.

- **Energy measuring unit:** voltage sampling, current sampling, measuring integrated circuit

An analogue to digital converter is used to sample voltage and current relative to incoming waveform. For getting accurate results the sampling rate should be high.

- **Data processing unit:** Micro Controller Unit [MCU], Memory storage cards

Very highly reliable Read Only Memory [ROM] is used to retain the data for so many years even if there is no power.

- **Power supply unit:** AC power supply, battery
- **Input/output unit:** LCD display, Optical communication, RJ11 port for Remote communication

Data from ROM can either be displayed on the meter LCD or communicated via an optical communication port/RJ11 port on to a hand-held Meter Reading Instrument [MRI].

Major Components of Trivector Meter:

1. Energy Registers:

These are used for measuring Active, Reactive, and Apparent energy. These can be configured according to user’s requirement.

2. Maximum Demand Registers:

Maximum Demand is indicated for a particular time period. The demand is monitored during each demand interval and the maximum value of these demands is stored in the Maximum Demand register.

3. LCD Display:

LCD display is used to show Reading Value indicators, Energy Unit indicators, Phase status indicators, Energy direction indication import or export, and Load status indicators Inductive or Capacitive as shown in the Block diagram.

4. TOD Registers:

These are used to support **Time-of-Day metering,** means to divide a day into certain time slots with tariff rates arranged in such a way so as to encourage consumers to reduce consumption during high demand hours and shift it to lower demand.

Data Communication:

- Local Communication:

Optical port is used to establish communication between meter and Meter Reading Instrument (MRI).

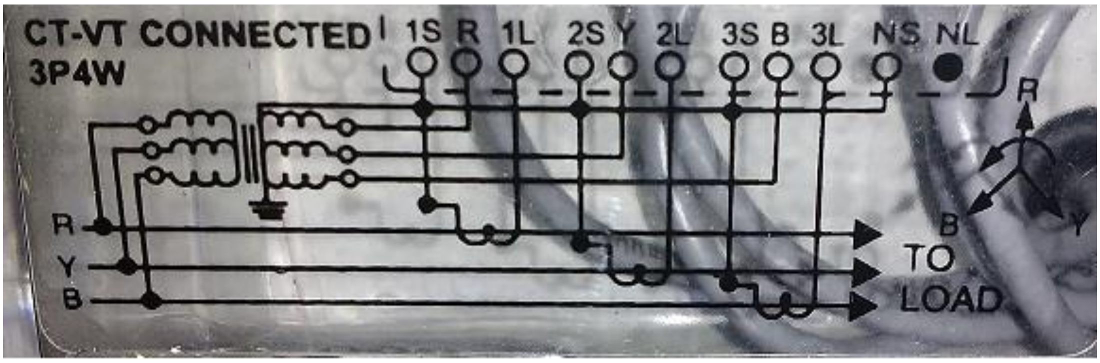
- Remote Communication:

RJ11 port is used to establish communication between meter and a compatible modem which uses Base Computer Software (BCS).

Connection Diagram:

Current Transformer and Potential Transformer operated 3-phase 3 wire trivector meters and 3-phase 4 wire trivector meters are available.

The connection diagram for 3-phase 4 wire meter is as shown in figure below.



RF VOLTAGE AND POWER MEASUREMENTS

RF system's output power level is often the key factor in the design and ultimately the performance of virtually all radio frequency and microwave equipment. For the measurement of average power, a sensor along with a calibrated power meter is connected with the RF transmitter. Initially, if the output of the sensor is switched OFF or not allowed to enter the power meter, the pointer of the power meter is set to zero. Afterward, the sensor is switched

ON and the indication on the power meter is observed which indicates the average power of the transmitter.

It is essential to determine the power for the design and application of RF and Microwave systems. The average power is widely used in specifying almost all of RF and Microwave systems.

RF & Microwave Power Measurement

Generally, there are three methods for measuring power at RF and Microwave frequencies. Each of these methods employs different kinds of devices to convert RF power to measurable dc or low frequency signal. These methods are:

1. Power measurement using a Thermistor.
2. Power measurement using a Thermocouple.
3. Power measurement using a diode detector

Power Measurement using a Thermistor

This is a method that was previously used to measure RF and Microwave power. Currently thermocouple and diode technologies are preferred in most applications because of their increased sensitivities, wider dynamic ranges, and higher power capabilities. Nevertheless, a thermistor is still the sensor of choice in certain applications due to its power substitution capability.

Here, a bolometer which is a temperature-sensitive resistive element whose resistance varies due to change in temperature is used. The change in temperature results from converting RF or Microwave energy into heat within the bolometric element. Principally, two types of bolometers are used – one is the barretter and the other is the thermistor. A barretter is thin wire that has a positive temperature coefficient of resistance, which is not frequently used now. Thermistors are semiconductors with negative temperature coefficient.

Power Measurement using a Thermocouple

Thermocouples work on the principle based on dissimilar metals generating a voltage due to temperature differences at hot and a cold junction of the two metals.

The two main reasons for the development of thermocouples are:

- They exhibit higher sensitivity than the previous thermistor technology.
- They feature inherent square-law detection characteristic (input RF power is proportional to dc voltage out).

Since thermocouples are heat-based sensors, they are true ‘’averaging detectors’’. This is why they are recommended for all types of signal formats from continuous wave to complex digital-phase modulations. Thermocouples are also more rugged than thermistors, make useable power measurements down to 0.3 mW (-30 dBm, full scale) and have lower measurement uncertainty because of better SWR.

Power Measurement Using a Diode Detector

Diodes convert high-frequency energy to dc by way of their rectification properties, which arise from their nonlinear current-voltage (I-V) characteristics. Rectifying diodes have been used as detectors and for relative power measurements at Microwave frequencies. However, for absolute power measurement, diode technology had been limited mainly to RF and low Microwave frequencies.

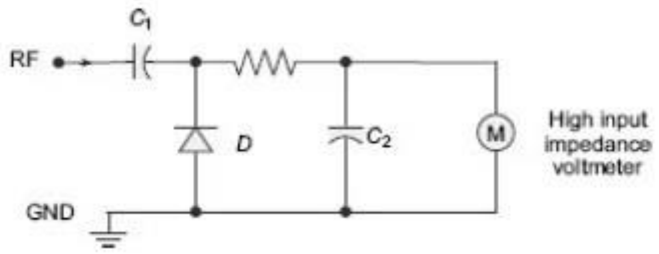
The Measurement of RF Voltages with a Voltmeter

To measure RF voltages, ranging from few hundred millivolts to several hundred millivolts, a voltmeter uses diode detectors. Usually diode detectors follow inverse square law below 100 V. So by taking advantage of this inverse square law, power detectors or voltage detectors are designed.

To achieve best sensitivity, a diode should be matched as closely as possible to source impedance. Simple diode detectors are used for designing RF voltmeter to measure voltages from 100 mV to several hundred mV. In the design of voltmeter, two types of diode detectors are used:

1. Series detector
2. Shunt detector

Out of these two, shunt detectors are mostly suitable for measuring RF and Microwave voltages. In this case, diodes are directly connected to the ground as illustrated in Figure.



COMPARISION OF ANALOG AND DIGITAL TECHNIQUES

Difference Between Digital and Analog System

Analog and digital signals are used to transmit information (such as any audio or video), usually through electric signals. In digital technology, the translation of information is into binary format (either 0 or 1) and information is translated into electric pulses of varying amplitude in analog technology.

Digital System

A digital system is one whose signal has a finite number of discrete values. So, the digital system works on digital signals and is limited to binary values 0 or 1. Digital systems are used to process information in digital form. The digital system has wide applications in digital instruments like calculators, computers, Telephones, etc.

Features of Digital Systems

- **Uses Binary Code:** Digital systems use binary code, which is a combination of zeros and ones, to represent information.
- **Accuracy:** Digital systems are more accurate than analog systems because the information is represented in a precise and consistent manner.
- **Processing Speed:** Digital systems are capable of processing large amounts of data quickly and accurately.
- **Noise Immunity:** Digital systems are immune to noise and interference, which means that the transmitted information is less likely to be corrupted.

Analog System

Analog system is one that uses continous time signal or analog signal which is a sinusoidal waveform. Analog system transmits the output in their raw form reducing the time of translation. The amplitude of the signal varies continuously with the time. Analog signals are used to represent sound, temperature, light intensity etc.

Features of Analog Systems

- **Uses Continuous Signals**: Analog systems use continuous signals to represent information, such as electrical voltages or sound waves.
- **Real-World Representation**: Analog systems are better suited for representing real-world phenomena such as sound and light, which are continuous in nature.
- **Smooth Transitions**: Analog systems provide smooth and continuous transitions between different values, which can be important in certain applications such as music or video.
- **Complexity**: Analog systems can be more complex than digital systems due to the need for additional circuitry to process and transmit the signals.

Similarities Between Digital and Analog Systems

- Both can be used to process and transmit information.
- Both can be used in a variety of applications such as audio, video, and telecommunications.
- Both can be used in combination with each other to achieve certain goals, such as using digital signal processing to enhance analog signals.
- Both require some level of circuitry or hardware to function.

Difference Between Digital and Analog System

	Analog System	**Digital System**
Signal	Analog signal represents physical measurements.	Digital signals are discrete and generated by digital modulation.
Waves	Sine Waves	Square Waves
Representation	Continuous range of values to represent information	Uses discrete values to represent information
Technology	Records waveforms as they are.	Samples analog waveforms into a limited set of numbers and then records them.
Data transmissions	Affected by noise during transmission and write/read cycle.	Noise-immune during transmission and write/read cycle.

Response to Noise	More likely to get affected	Less likely to get affected
Flexibility	Hardware is not flexible.	Hardware is flexible.
Bandwidth	Less bandwidth.	More bandwidth to carry out the same information
Memory	Stored data in the form of wave signal	Stored data in the form of binary bit
Power	Consumes large power	Consumes negligible power
Uses	Best suited for audio and video transmission.	Best suited for Computing and digital electronics.
Cost	Cost is low	Cost is high
Example	Human voice in air, analog electronic devices.	Computers, CDs, DVDs,

DIGITAL VOLTMETER

Working Principle of Digital Voltmeter

A voltmeter is a significant device used in electronics engineering for measuring potential developed across various devices. Depending on the requirements these voltmeters can be designed into two types that being digital and analog. The digital voltmeter can further be divided into certain types and we will discuss them too.

Digital Voltmeter

With the gradual development of technology, there has been a need for more precision while making experimental calculations. This led to the development of digital voltmeters. A digital voltmeter is used for measuring potential differences between two specific points in an electric circuit. Being a digital meter, the values measured either alternating or direct are discrete meaning that output values are more similar to "On" and "Off" values. This results in more precise results ensuring minimum error due to pointer errors.

Types of Voltmeter

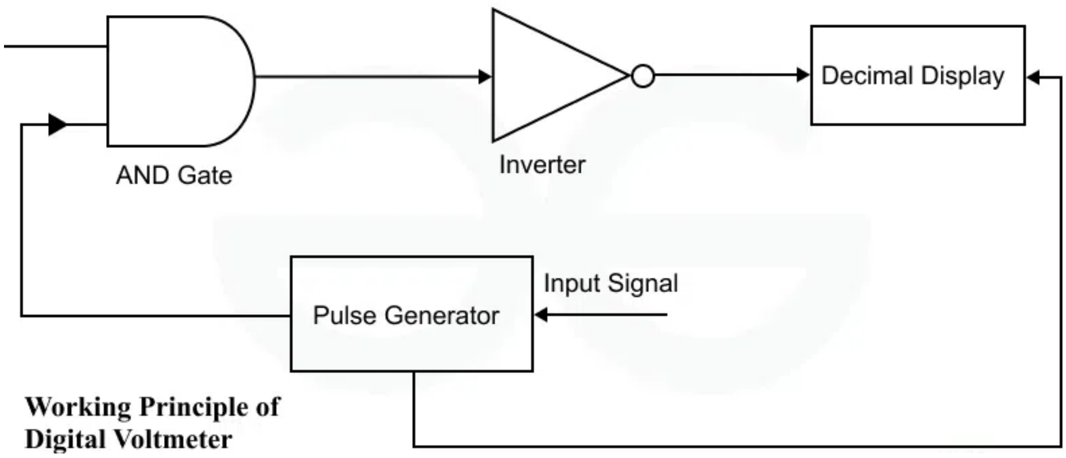
Voltmeters are generally categorized into two types namely digital and analog which have been briefly explained

Digital Voltmeter: A digital voltmeter uses a numeric display to show the exact value of the measurement. This makes digital voltmeters more precise and easier to read. Due to the fragile nature of these voltmeters, they are more expensive than analog voltmeters.

Analog Voltmeter: An analog voltmeter uses a needle that moves along a range of scale to measure the value across instruments. Thus makes analog voltmeters more responsive and durable. That being said ,they are more prone to errors making them less accurate mainly because of interference and parallax errors.

Block Diagram of Digital Voltmeter

Let us see the block diagram of digital voltmeter and see how it works.



Block Diagram of Digital Voltmeter

The voltmeter begins working when it receives an input i.e the **input signal** whose voltage is to be measured. The input signal can not be read as such and thereby is converted in rectangular pulse by the **pulse generator.** The frequency and width of the generated rectangular pulse is selected using digital circuitry present inside the generator. The **AND gate** is added mainly to ensure that train pulses have the same duration as the rectangular pulse. The train pulse and rectangular pulse are fed as the input and the output is high only when both are high.

The **decimal display section** performs the task of counting total number of impulses and the time difference between them. This count is generally displayed on an LED screen after calibration in the required scale.

Types of Digital Voltmeter

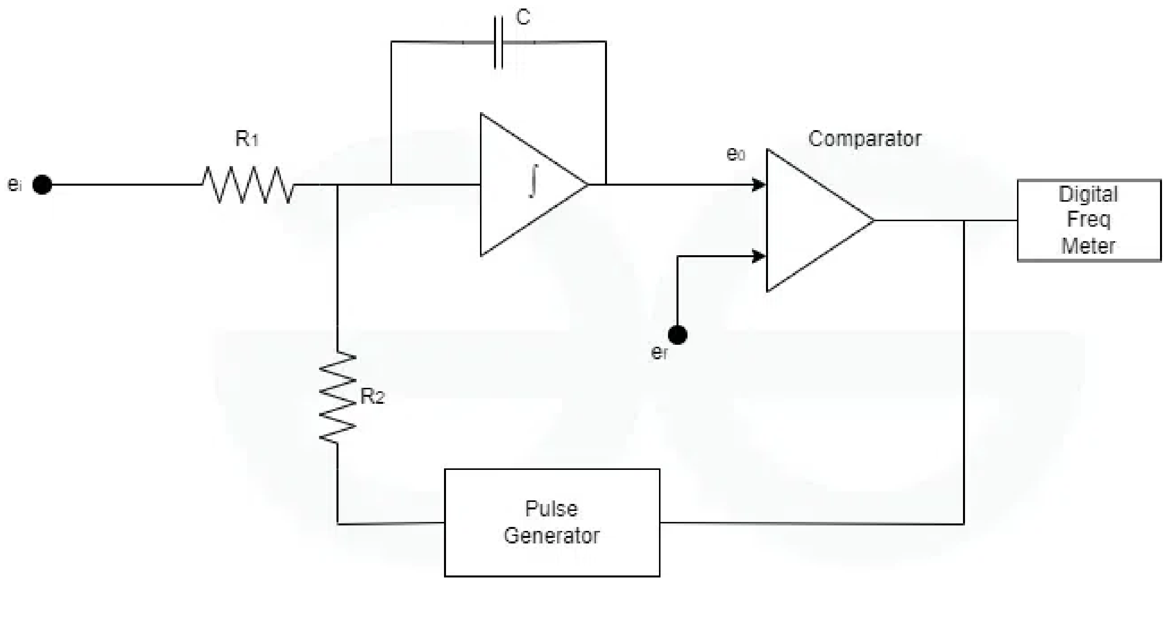
Here are the different types of digital voltmeters:

- Ramp Type Digital Voltmeter
- Integrating Type Digital Voltmeter
- Successive Approximation Digital Voltmeter
- Dual Slope Integrating Digital Voltmeter
-

Ramp Type Digital Voltmeter

There are circuits that generate output signals in the shape of a ramp. The voltmeter used for measuring such ramp signals in Ramp type digital voltmeter. Timing plays an important role in these types of signals. The name of voltmeter is mainly because it measures ramped up signals.

Working: The voltage is measured by providing an unknown input signal to the ranging and attenuation. Depending on the needs, the signal is attenuated or made stronger by amplification. The ramp generator is a device which generates a positive or a negative ramp and our unknown signal is compared to it. The comparator compares input signal to the ramp signal. If the input voltage matches with ramp voltage, then gate is opened with the pulse and after the ramp signal reaches 0, the gate is closed. The time period between two events is called **gating time interval.** This generates the ramp voltage

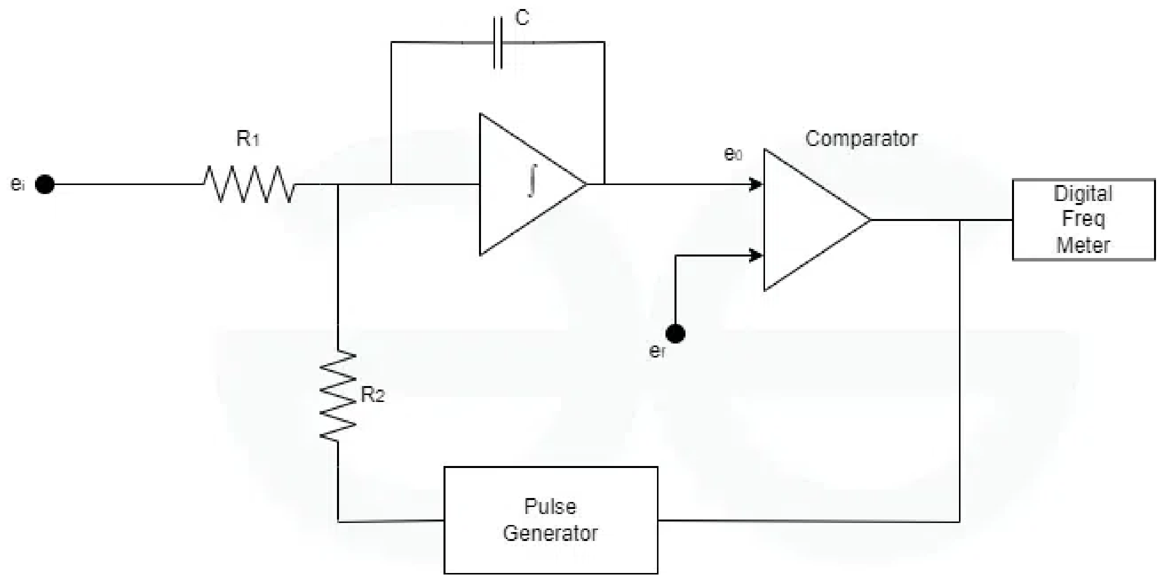


Ramp Type Digital Voltmeter

Integrating Type Digital Voltmeter

This voltmeter measures exact value of input corresponding to the constant of time. This circuit usually uses a voltage-to-frequency converter device which works on the feedback control system. The main characteristic of this voltmeter is that the output from the integrator is compared with the fixed level voltage of reference source.

Working: In this, as soon as the input voltage is applied, the output voltage begins to increase which fed to level detector. After the output voltage reaches a certain value, detector sends a pulse to pulse generator gate. The integrator output is compared to fixed level voltage of the internal reference source resulting in an output pulse. This output pulse from level detector. This pulse opens gate which passes pulse from oscillator to pulse generator. The pulse generator like a **Schmitt trigger**, generates pulses with fixed width and amplitude. So, for each wave a pulse is generated which helps to determine the input voltage.

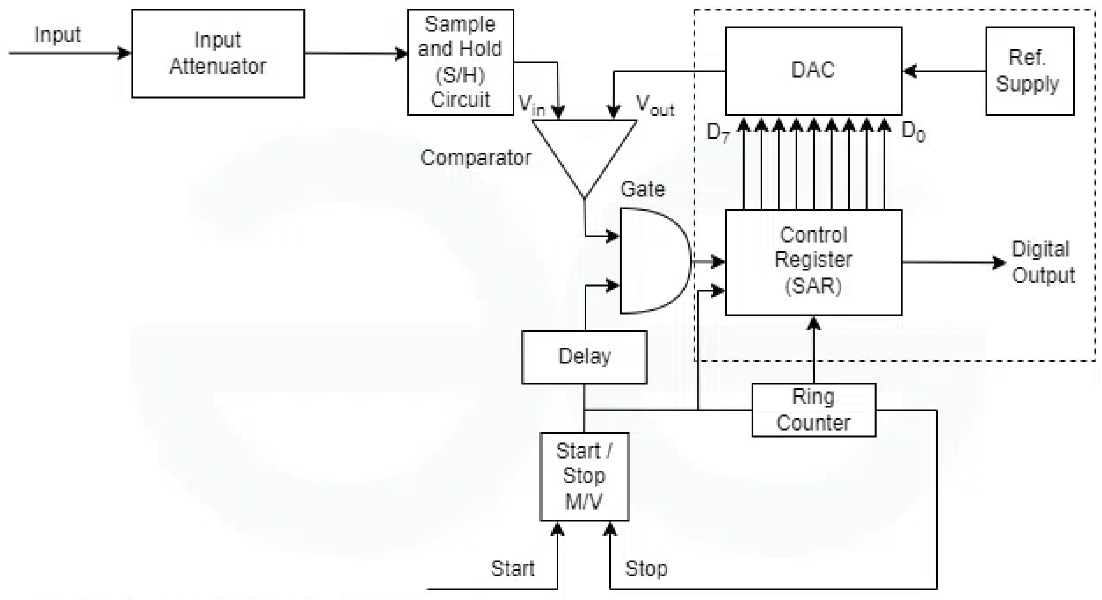


Integrating Type Digital Voltmeter

Successive Approximation Digital Voltmeter

In this voltmeter the output of digital to analog convertor with a certain unknown reference voltage. This meter can measure up to 100 readings per second. The voltmeter uses an amplifier to choose a required range of input voltage and minimize the noise which can cause distortion.

Working: The input amplifier of this device helps to choose a range of input voltage and eliminates any noise. The input is then sent to comparator through an S/H circuit. The comparator generates a signal when it receives the analog signal. This is further sent to AND gat whose output become one if and only if output of comparator is positive. In the end , a digitized digital signal is generated from control registers giving us the required voltage.

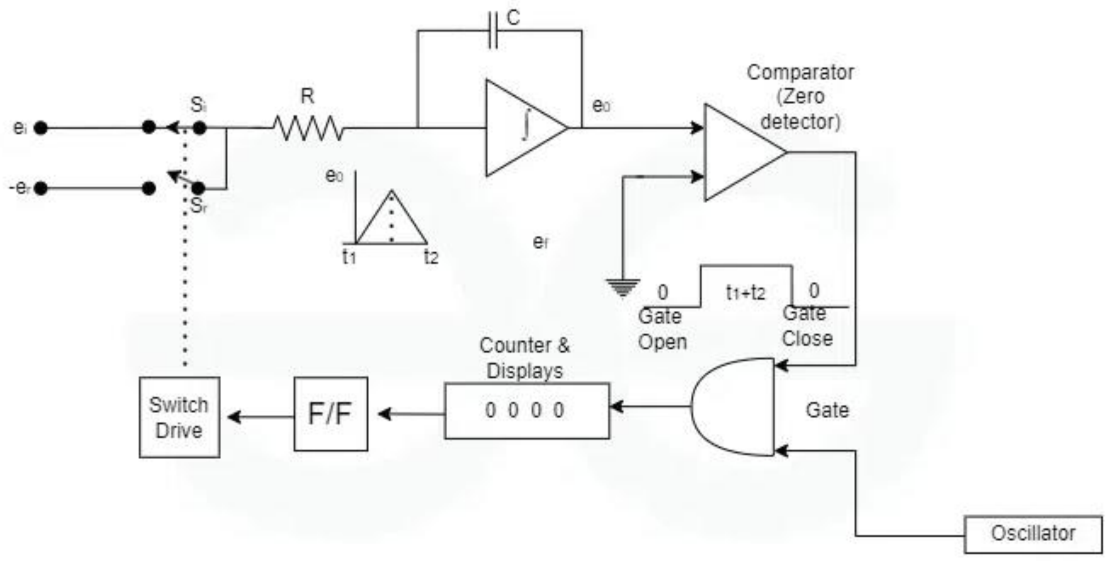


Successive Approximation Digital Voltmeter

Dual Slope Integrating Digital Voltmeter

It consist of an integrator circuit which takes the unknown input for certain time measured using a clock. The circuit consist of comparators ,capacitors ,clock and counters which generate the reference voltage with time. In this way we can measure the required voltage.

Working: In this, the integrator circuit receives an input signal for a specific period of time which is measured using clock frequency. During this time, the capacitor gets charged and the charge is proportional to the input voltage. At the end of this time, the switch is shifted from input voltage to a reference voltage and the charging of capacitor decreases creating a downward linear ramp voltage. This generates the required voltage.



Dual Slope Integrating Digital Voltmeter

Advantages of Digital Voltmeter

Digital voltmeter has various advantages and some of them have been stated below

- Since it does not involve reading from a pointer, it eliminates the human error that are caused by reading at an angle. This means gross errors are now removed giving precise results.
- They are more reliable and stable as compared to analog voltmeters which are comparatively unreliable while making readings.
- The output from DVMs can be provided to memory devices for the purpose of storage. This means that we can directly store the result of digital voltmeter in devices like flip flops.
- We don't require any extra manuals for using digital voltmeters as they are easy to read and give precise and accurate readings.
- Digital voltmeters are more durable than analog voltmeters. We say this because they provide accurate readings without being affected by external factors like atmosphere, temperature and moisture.

Disadvantages of Digital Voltmeter

There are certain limitations of digital voltmeter like:

- They are comparatively fragile than Analog voltmeters and need to be handled with care. They can get heated up on prolonged use and give wrong readings in that case.
- The speed of digital voltmeters is dependent on digitizing circuit being used .This might reduce the operational speed of the voltmeters making them slow.
- There is a certain threshold value associated with digital voltmeter and exceeding that value can damage the voltmeter without any prior warnings.
- In case of fluctuations in the output, digital voltmeter fails to detect them and can even give wrong readings in that case giving wrong output.
- Due to the designing of digital voltmeter in a certain way, it becomes almost impossible to measure transient voltage using this device. Hence measuring transient spikes through this meter is a difficult process.

Applications of Digital Voltmeter

DVM is a useful device and has many applications like:

- It is used in laboratory and labs for determining accurate and precise voltage level across various devices mainly resistors, diodes, capacitors in electronics circuits.
- Often times unknown current values are determined with the help of DVM. As DVM helps to calculate voltage and once voltage level is known we can calculate the corresponding current in the circuit.
- DVM are employed in for verification purposes like they are used in cathode ray tubes to verify the accuracy of the findings and readings. They help in electrical maintenance and inspection of circuits.
- In certain circuits tree ammeter method and the three voltmeter method are used for measuring of power. They are used to calculate the power factor of a specific load in circuit.

- DVM is largely used for the purpose of circuit designing and prototype. They help in measuring and verifying voltage levels at every stage. This is used for designing the required circuit.

DIGITAL MULTIMETER

A digital multimeter or DMM is a test equipment used for resistance, voltage, current measurement, and other electrical parameters.

A Digital Multimeter can measure variety of electrical functions such as Current, Voltage, Resistance etc.

A **digital multimeter** or **DMM** is a test equipment used for resistance, voltage, current measurement, and other electrical parameters as per requirement and displaying the results in the mathematical digits form on an LCD or LED readout. It is a type of multimeter which functions digitally rather giving an analog output.

Digital multimeters are widely accepted worldwide as they have better accuracy levels and ranging from simple 3 ½ to 4 ½ digit handheld DMM to very special system DMM.

Features of Digital Multimeter

The Digital multimeter is the most advanced measuring instrument that makes use of modern Integrated circuits for making electrical measurements. Some of its features which make it famous in the eyes of professional technicians are:

1. It is light in weight.
2. Capable of giving more accurate readings.
3. It measures lots of physical quantities like voltage, current, resistance, frequency, etc.
4. It is less costly.

5. It measures different electrical parameters at high frequencies with the help of special probes.

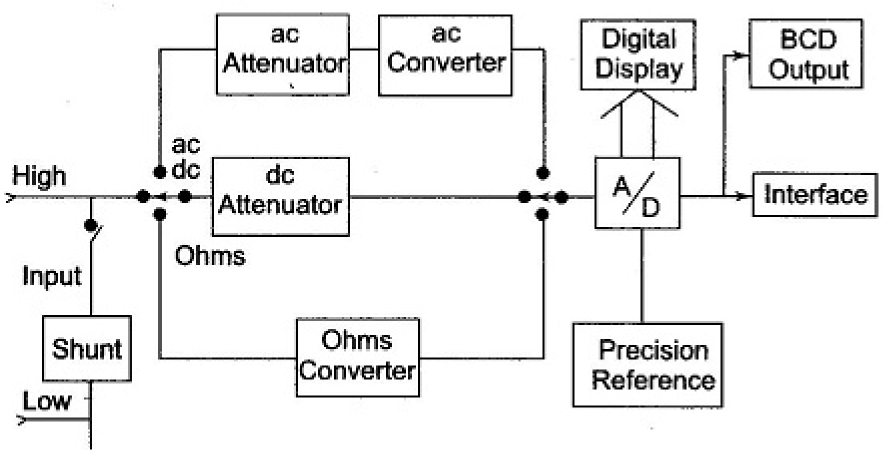
Block diagram of Digital multimeter

The Key process that occurs within a Digital multimeter for any measurement that takes place is that of voltage measurement. If you measure voltage then you can easily measure other electrical parameters with the help of mathematical formulas.

To understand how digital multimeter works, first of all, we have to understand this process.

As we know, Digital multimeters gave output in numeric form due to ADC registers present inside these multimeters. One that is most widely used in digital multimeters, DMMs is known as the successive approximation register or SAR. For better accuracy, these SAR ADCs may have resolution levels of 12 bits.

Generally, a Digital multimeter has resolution levels of 16 bits with speeds of 100k samples per second. These levels of speed are more than adequate for most DMM applications, that's why we are using these registers depending upon the requirement.



As shown in the diagram, the first stage of the process is a sample and hold used to sample the voltage at the input of the Digital multimeter and then to hold it steady. The output of the first stage becomes one of the inputs of the operational amplifier and another input of the op-amp is digital output feedback through the DAC.

The output obtained becomes the input of the SAR which generates results in digital form with a good resolution level. With a steady input voltage, the resister starts at half its full-scale value. It basically sets the most significant bit, MSB to “1” and all the remaining ones to “0”.

To see how it works take the simple example of a 4-bit SAR. Its output will start at 1000. If the voltage is less than half the maximum capability the comparator output will be low and that will force the register to a level of 0100. If the voltage is above this, the register will move to 0110, and so on.

Operation of Digital multimeter

The sample acquisition is done with the help of the sample and hold circuit. Inside the sample and hold circuit the capacitor is present which gets charge to match the input analog voltage known as the acquisition process.

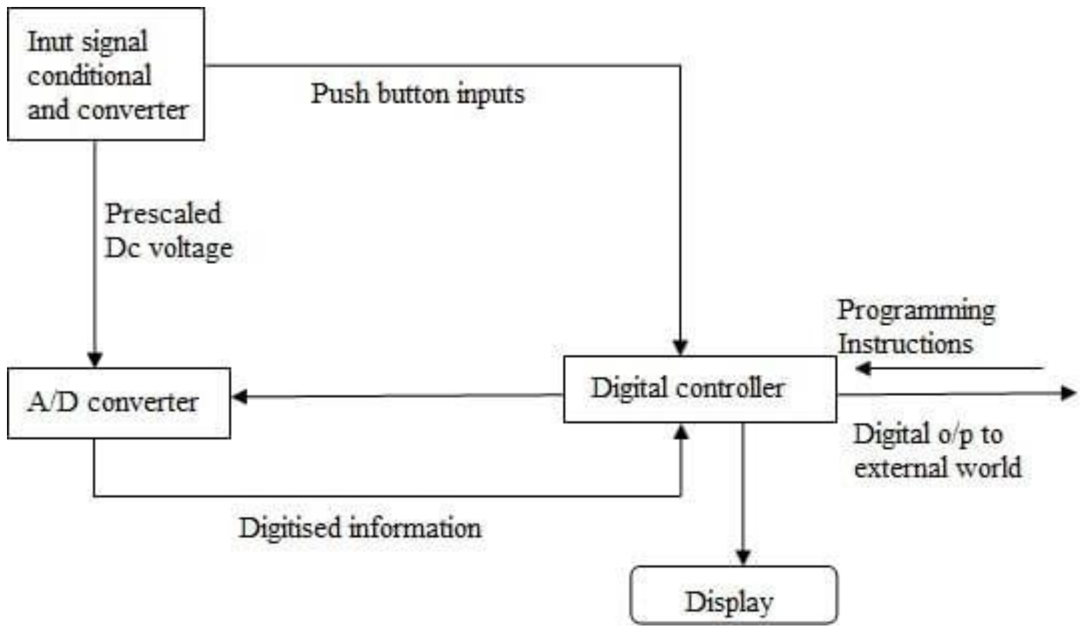
When the capacitor is released from the acquisition circuit then the voltage is considered to be sampled. After this, the noise generally comes which will adversely affect the accuracy of the digital multimeter. To overcome this, we buffered and averaged the samples to achieve high accuracy and resolution.

Working Principle of Digital Multimeter

As shown in the block diagram, in a typical Digital multimeter the input signal i.e. ac or dc voltage, current, resistance, temperature, or any other parameter is converted to dc voltage within the range of the ADC. The analog to digital converter then converts the pre-scaled dc voltage into its equivalent digital numbers which will be displayed on the display unit.

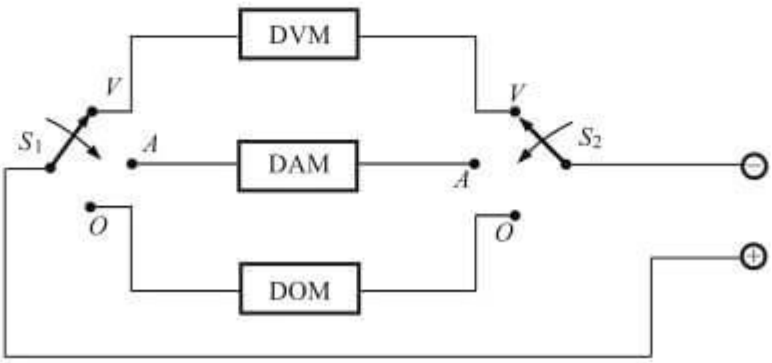
Sometimes, a digital controller block is implemented with a microcontroller or a microprocessor to manage the flow of information within the instrument. This block will coordinate all the internal functions as well as transferring information to external devices such as printers or a personal computer.

In the case of some handheld multimeter, some or all of these blocks may be implemented in a VLSI circuit while the A/D converter and display driver can be in the same IC.



Digital Multimeter as Voltmeter, Ammeter and Digital Ohmmeter

In digital multimeter, we can incorporate many types of meters like ohmmeter, ammeter, a voltmeter for the measurement of electrical parameters. Its block diagram is shown below in the figure. Let us have a look at its working and specification one by one.

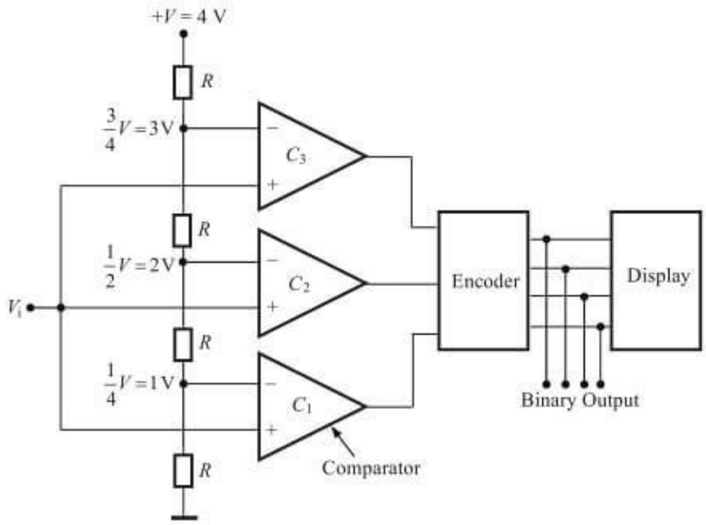


(i) Digital voltmeter (DVM):

Digital voltmeter is the basic instrument used for measurement of voltage through the use of Analog to Digital converter. The basic principle behind digital multimeters is the Analog to digital converter because without this we are not able to convert the analog output into digital form.

There are several ADC available in the market, but we mainly use Flash type ADC due to its simplicity and fastest speed. Let’s have a look at its basic operation.

(a) Flash AD converter: It comprises comparators, encoders, and digital displays. Comparators are driven by a resistor divider network, the encoder converts its inputs to corresponding outputs that drive the digital display.

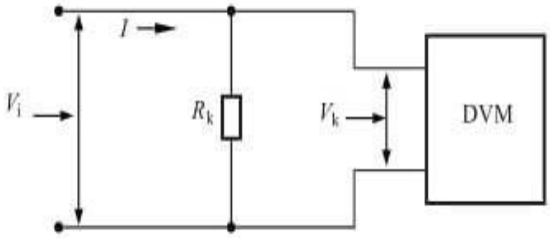


As shown above, three resistors of value R drives the comparators C_1, C_2, C_3. Let the input voltage V_i = 1V, +V= 4V and comparators i.e. C_1 , C_2, C_3 voltages equal to 1V, 2V and 3V respectively. If the output of the C_1 = +1 and C_2=C_3= 0, then we fed 001 as the input to the encoder which further converts it into 0001.

This binary output drives the seven segment display to read 1V on it. With the help of this method, we read the voltages of magnitude 1V, 2V, 3V and we also add more comparators for more accurate readings as per our requirement.

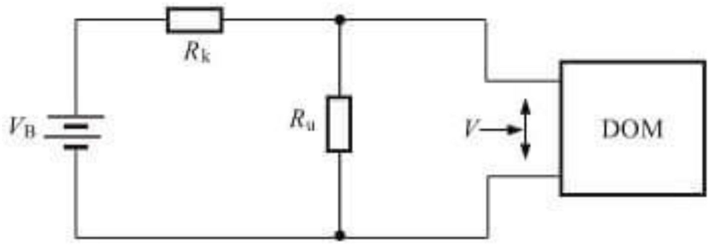
(ii) Digital Ammeter (DAM):

A digital ammeter uses a shunt resistor to produce a calibrated voltage proportional to the current flowing. As shown in the diagram, to read the current we must first convert the current to be measured into a voltage by using a known resistance R_K. The voltage so developed is calibrated to read the input current.



(iii) Digital ohm meter (DOM):

A digital ohmmeter is used to measure electrical resistance which obstructs the path to the flow of current.



As shown in the diagram, a resistance network comprising of a known resistance R_K and unknown resistance R_u used to develop a voltage across the unknown resistance. The voltage is given by:

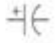
$$\mathbf{V = V_B\, R_u / R_K + R_u}$$

where V_B = Voltage of the built-in battery

After calibrating voltage, the meter can be calibrated in terms of ohms.

Some common Digital multimeter symbols and its description are given in the table below. These symbols are often found on the multimeter & their schematics are designed to symbolize components and reference values of electrical parameters.

Symbol	Measurement Function	Description
~	AC voltage	Measures Ac voltage value in the circuit
═ ═ ═	DC voltage	Measures Dc voltage value in the circuit
Hz	Hertz	Measures Frequency
Ω	Ohm	Measures resistance value in the circuit
⊣▶⊢	Diode	A Device used to control the direction of flow of current
µF	MicroFarad	Unit of capacitor

	Capacitor	A Device used to store electrical charge
	Continuity	Audible indication of continuity for low resistance
A	Ampere	Measures Value of Current in circuit
CE	European Union Directive	It indicates the guarantee of an instrument
	Caution	Refers to the instruction before use and indicates that its misuse results in equipment failure
REL	REL	Measures relative or offset reading
Min/Max	Minimum and Maximum	Shows minimum and maximum recorded readings

DMM Parts and functions

A Digital Multimeter is divided into three parts:

(i) Display: The LCD screen present on the upper portion of the multimeter basically displays four or more digits and also shows a negative value if necessary. A few of today's multimeters have illuminated the display for better viewing in low light situations.

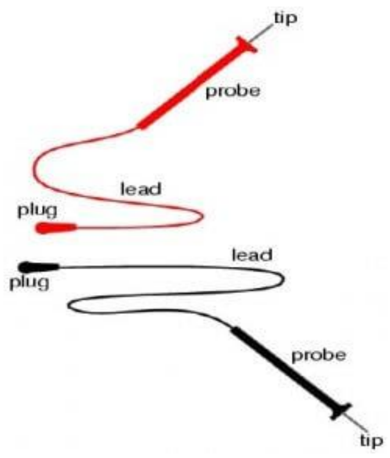
(ii) Selection Dial: It allows the user to set the multimeter to read different electrical parameters such as milliamps (mA) of current, voltage, resistance, capacitance, etc. You can easily turn the dial anywhere for specific parameter measurements.

(iii) Ports: Two ports are available on the front of every multimeter except in some four ports are available for measuring current in mA or A. We plugged two probes into these ports which are of different colors i.e. one is of red color and the other is of black color. Different Ports in multimeter are:

(a) COM: It stands for common and is almost connected to the ground or considered as a -ve connection of a circuit. We generally insert the black color probe into the COM port.

(b) mAVΩ: This port allows the measurement of current (up to 200 mA), voltage and resistance; and is considered as a +ve connection of a circuit. We generally insert the red color probe into the mAVΩ port.

DMM Leads:



In the box of a digital multimeter, we got leads of different colors. Here we are going to explain these leads in detail. DMM leads are subdivided into four parts:

(i) Red lead

1. Connected to voltage, resistance, or ampere port.
2. Considered as a +ve connection of a circuit

(ii) Black lead

1. Connected to the common or ground port
2. Considered as a -ve connection of a circuit

(iii) Probes:

These are the handles used to hold the tip on the tested connection. There are different types of probes available, they are:

- Banana to Alligator Clips: These are great cables for connecting to large wires or pins on a breadboard. Good for performing longer-term tests where you don’t have to hold the probes in place while you manipulate a circuit.
- Banana to IC Hook: IC hooks work well on smaller ICs and legs of ICs.
- Banana to Tweezers: Tweezers are handy if you need to test SMD components.
- Banana to Test Probes: If you ever break a probe, they are cheap to replace.

(iv) Tip:

These are present at the end of the probes and basically, provide a connection point.

Digital Multimeter Measurement Time:

Professional technicians always prefer those instruments whose **time of measurement** plays a crucial role leads to good results with better accuracy. Measurement of time basically depends on the following factors:

i) **Settling time**: When the value to be measured is applied to the input of the circuit it would take a certain time to settle is known as settling time. This will overcome any input capacitance levels when high impedance tests are made.

(ii) **ADC calibration time**: In some DMMs, a calibration is periodically performed must be accounted for especially where measurements are taken under automatic or computer control.

(iii) **Switch time**: The switch time is the time required for the instrument to settle after the input has been switched. This includes the time to settle after a measurement type has been changed, e.g. from voltage to resistance, etc.

(iv) **Auto-zero time**: To ensure accuracy it is necessary to zero the meter when auto-range is selected, or range changes are made.

(v) **Signal measurement time:** This is the basic time required to make the measurement itself. For AC measurements, the frequency of operation must be taken into account because the minimum signal measurement time is based on the minimum frequency required of the measurement.

Digital Multimeter Accuracy

A Digital multimeter is an ideal choice for every professional technician because of its better accuracy. It is the amount by which the displayed reading can differ from the actual input. Digital multimeter usually defines accuracy as a percentage of reading plus a percentage of full-scale value. Accuracy depends upon the specifications of the instrument varies from manufacturer to manufacturer. There are a number of ways in which the **multimeter accuracy** may be expressed:

1. **DMM Accuracy = ±(ppm of reading + ppm of range)**
2. **DMM Accuracy = (% Reading) + (% Range)**
3. **DMM Accuracy = (% Reading) + Offset**

Note: Here ppm refers to parts per million.
Factors affecting the accuracy of Multimeter are:

(i) Temperature: To a large extent, the temperature can affect the accuracy of Digital multimeters. Today many multimeters have an inbuilt temperature feature which eliminates the need for any external device. You can express them as ±(ppm of reading + ppm of range)/°C.

(ii) **Resolution**: Resolution is directly proportional to accuracy. If you want accuracy you have to take care of resolution also. The **resolution of a Digital multimeter** is expressed in terms of the number of digits displayed. Typically this will be a number consisting of an integer and a half i.e.3 ½ digits etc. By convention, a half digit can display either a zero or 1.

DMM Safety Precaution:

Before operating multimeters, we have to follow some safety precautions. Here we are going to explain to you some safety information about DMM.

1. If the DMM test leads are damaged then never use the meter.
2. Always ensures that the test leads and dial are in the right position for the desired measurement.
3. When a test lead is plugged into the 10 A or 300mA input jack then never touch the probes to a voltage source.
4. When power is applied never measure resistance in a circuit.

5. While making measurements always keep your fingers behind the finger guards on the test probes.
6. To avoid damage or injury, never use the meter on circuits that exceed 4800 watts.
7. Replace the battery as soon as possible to avoid false readings which could lead to possible electric shock or personal injury.
8. Be careful when working with voltages above 60 V DC or 30 V AC RMS. Such voltages pose a shock hazard.

UNIT-II

TRANSDUCERS

A transducer is an electronic device that converts energy from one form to another. Common examples include microphones, loudspeakers, thermometers, position and pressure sensors, and antenna. Although not generally thought of as transducers, photocells, LEDs (light-emitting diodes), and even common light bulbs are transducers.

Efficiency is an important consideration in any transducer. Transducer efficiency is defined as the ratio of the power output in the desired form to the total power input. Mathematically, if P represents the total power input and Q represents the power output in the desired form, then the efficiency E, as a ratio between 0 and 1, is given by:

$$E = Q/P$$

If $E_{\%}$ represents the efficiency as a percentage, then:

$$E_{\%} = 100Q/P$$

No transducer is 100 percent efficient; some power is always lost in the conversion process. Usually this loss is manifested in the form of heat. Some antennas approach 100-percent efficiency. A well-designed antenna supplied with 100 watts of radio frequency (RF) power radiates 80 or 90 watts in the form of an electromagnetic field. A few watts are dissipated as heat in the antenna conductors, the feed line conductors and dielectric, and in objects near the antenna. Among the worst transducers, in terms of efficiency, are incandescent lamps. A 100-watt bulb radiates only a few watts in the form of visible light. Most of the power is dissipated as heat; a small amount is radiated in the UV (ultraviolet) spectrum.

Types of Transducers

Major kinds of classification of transducers has been discussed in this article, beginning with the classification based on the principle of operation as follows.

Classification based on Principle of Operation

There is a different working principle involved behind the working of different transducers. Different types of transducers along with their working principle is discussed as under.

- **Piezoelectric Transducers:** The transducers which work upon the piezoelectric effect to convert mechanical stress into an electrical signal. Piezoelectric effect is a phenomenon where certain materials such as quartz generate an electric charge in response to mechanical stress or pressure, and conversely, they deform when an electric field is applied to them. These transducers are used in sensors, actuators, and ultrasound devices.

- **Electromagnetic Transducers:** The working principle of these transducers is electromagnetic induction. These convert the changes in magnetic fields or electric currents into electrical signals or vice versa. Applications of these transducers is found in microphones, speakers, and transformers.
- **Thermoelectric Transducers:** These transducers work upon the thermoelectric effect which is the name given to the phenomenon of generation of electric voltage due to temperature gradient between two different materials. These are widely used in thermocouples to measure temperature differences.
- **Resistive Transducers:** The transducers which suffer a change in their resistance when subjected to pressure and temperature change are called as resistive transducers. Strain gauges are an example of this type of transducers which undergo a change in their electrical resistance when subjected to a mechanical stress.
- **Inductive Transducers:** These transducers undergo a change in inductance when there is a change in the physical quantity being measured. A common example of such type of transducer is a Linear Variable Differential Transformer (LVDT) which converts linear motion into an electrical signal.
- **Capacitive Transducers:** These transducers work on the principle of change in capacitance due to a change in physical quantities such as displacement, pressure, and humidity. These are used in touchscreens, proximity sensing, and pressure measurement.
- **Optical Transducers:** The transducers that convert light energy into electrical signals or vice versa are called as optical transducers. Examples are photodiodes, photovoltaic cells (solar panels), and fiber optic sensors.

Classification Based on Output Signal Type

Transducers are broadly classified into two categories based on output signal type, i.e. analog and digital. These are discussed in brief as follows:

- **Analog Transducers:** Analog transducers produce output signals that vary continuously over time and are proportional to the input quantity being measured. Examples are Voltage output, Current output, Resistance output, and Frequency output transducers.

- **Digital Transducers:** Digital transducers produce output signals that are discrete and quantized which are typically represented in binary format. Some examples are Binary Coded Decimal (BCD) Output, Pulse Width Modulation (PWM) Output Transducers, etc.

Classification based on direction of signal conversion

There are two types of transducers based on direction of signal conversion, i.e. input transducer and output transducer discussed in brief as follows:

- **Input Transducer:** The transducers which convert different physical quantities into an electrical signal for further processing and manipulation are called input transducers. Examples can be found in sensors that measure temperature, pressure, light, sound, humidity, displacement, etc.
- **Output Transducers:** The transducers which take electrical signal as input and convert them into some physical actions to control or manipulate physical processes. Examples are found in actuators such as motors, valves, relays, solenoids, speakers, displays, etc.

Working Principles of Transducers

The basic principle of working of transducers is to convert one form of energy to another. These devices take input of physical quantities such as pressure, temperature, light, or sound, and convert it into a corresponding output signal for measurement and control purposes. A brief explanation of different principles involved behind working of transducers is discussed as under.

- **Sensing Mechanism:** Each transducer has contains a sensing mechanism which that senses the physical quantity for which it is designed to measure. For instance, photodetector serves as a sensor in optical transducers and diaphragm that deforms under pressure changes acts as a sensor in a pressure transducer.

- **Transduction Process:** This process is the main function of a transducer, i.e. converting signal from one form to another after it has been detected through the sensing mechanism. Various principles such as piezoelectricity, thermoelectricity, electromagnetic induction, etc. work behind the transduction process.

- **Output Signal Generation:** The output signal generated should be in well correspondence to the input signal, i.e. originality of the input signal should be maintained efficiently. Generally, the output signal is often electrical in nature because electrical signals are easy to measure, process, and transmit.

- **Application:** The output signal obtained can then further be for various applications, such as monitoring, control, measurement, or feedback in systems and devices across various domains such as automotive, aerospace, medical, industrial, and consumer electronics.

Thus, the working principle of transducers involves the conversion of input physical quantities into corresponding output signals through a transduction process which enables the measurement and control of various physical phenomena in a wide range of applications.

Transducer Efficiency

A transducer converts one form of energy to another using various principles. But some losses are always involved in practice due to factors such as friction, air resistance, etc. Transducer efficiency is the ability of the device to convert one form of energy to another with minimum losses. It is typically expressed as a percentage and calculated using the formula:

$$\textbf{Efficiency (\%)} = \textbf{(Output Energy)/(Input Energy)} \times \textbf{100\%}$$

A higher percentage indicates a more efficient transducer, i.e. it indicates energy wastage is minimized and the desired output is maximized.

Advantages of Converting a Physical Quantity into an Electrical Signal

Transducers are used to convert input signal relating to a physical quantity such as pressure into an electrical signal as output as it offers several advantages listed as follows:

- Electrical signals can be conveniently transmitted over long distances with minimal loss of signal strength, making remote monitoring and control applications easier.
- Electrical signals are easier to manipulate, process, and transmit using the available electronic devices, which makes them versatile for different uses.
- Electrical signals are easier to convert into other different forms such as digital signal making further processing and analysis easier, enhancing the flexibility in system design.
- Electrical signals can be used for real-time monitoring of physical quantities allowing prompt detection of changes and irregularities.

- Electrical signal output transducers and associated electronic equipment are relatively cheaper, making them affordable for various applications.

Piezoelectric, Thermocouple, and Photovoltaic Transducers

Piezoelectric, Thermocouple, and Photovoltaic Transducers are the most commonly used type of transducers. Their different properties are discussed in form of a table below.

Property	Piezoelectric Transducer	Thermocouple Transducer	Photovoltaic Transducer
Operating Principle	Converts mechanical stress or strain into electrical energy, and vice versa.	Converts temperature difference between two different conductors into voltage.	Converts light energy into electrical energy.
Sensing Mechanism	Based on the piezoelectric effect in certain materials such as quartz to generate electrical charge in response to mechanical stress.	Works upon the Seebek effect, where a voltage is generated when a temperature gradient is applied across two dissimilar conductors.	Uses the photovoltaic effect, where semiconductor materials generate an electric current in response to the incident light.
Input Signal	Mechanical stress or strain	Temperature difference	Light Intensity
Output Signal	Electric charge or Voltage	Voltage	Current
Applications	Pressure sensors, accelerometers, ultrasonic transducers	Temperature sensors, thermometers, thermal energy harvesting	Solar panels, solar cells, photodetectors

Applications of Transducers

Transducers find applications in various fields from industrial automation to medical diagnostics, by converting physical quantities into electrical signals for measurement, control, and analysis. Some applications of transducers are discussed as under:

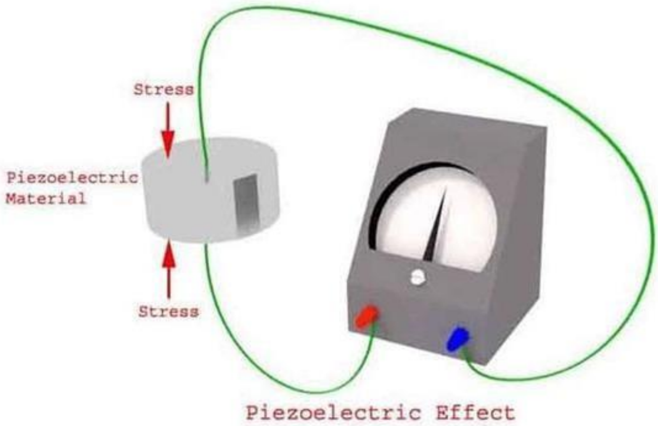
- They are used in field of measurement of parameters such as pressure, temperature, flow, and level in manufacturing processes, ensuring efficient operation and quality control.
- They are used in medical field in form of devices such as thermometers, ultrasound machines, blood pressure monitors, ECG machines, and glucose meters for diagnostic purposes.
- They play an important role in automotive systems for monitoring engine performance, tire pressure, and fuel levels.
- These are also used in aerospace industry for altitude measurement, navigation, and engine monitoring in aircrafts and spacecraft.
- They are widely being used in robotics and automation systems for position sensing, force sensing, object detection, and feedback and control for an efficient operation.

PIEZOELECTRIC TRANSDUCER:

A piezoelectric transducer (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.

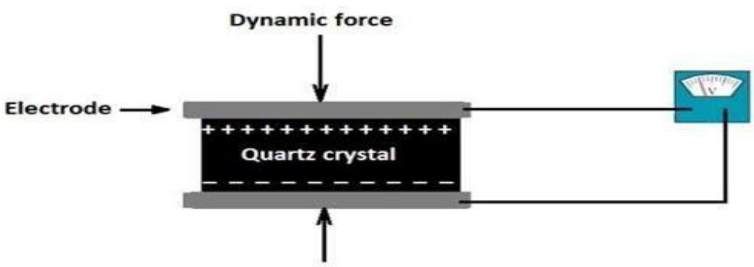
A transducer can be anything that converts one form of energy to another. The piezoelectric material is one kind of transducers. When we squeeze this piezoelectric material or apply any force or pressure, the transducer converts this energy into voltage. This voltage is a function of the force or pressure applied to it.

The electric voltage produced by a piezoelectric transducer can be easily measured by the voltage measuring instruments. Since this voltage will be a function of the force or pressure applied to it, we can infer what the force/pressure was by the voltage reading. In this way, physical quantities like mechanical stress or force can be measured directly by using a piezoelectric transducer is shown in Fig.



Piezoelectric Transducer Working Principle

A quartz crystal exhibits a very important property known as the Piezoelectric Effect. When some mechanical pressure is applied across faces of a quartz crystal, a voltage proportional to the applied mechanical pressure appears across the crystal. Conversely, when a voltage is applied across the crystal surfaces, the crystal is distorted by an amount proportional to the applied voltage. This phenomenon is known as the piezoelectric effect and the material that exhibits this property is known as a piezoelectric material is shown in fig.



Materials for Piezoelectric Transducers

- The materials exhibiting the piezoelectric phenomenon are divided into two groups:
  (i) Natural
  (ii) Synthetic

- The natural group consists of quartz, Rochelle salt and tourmaline.

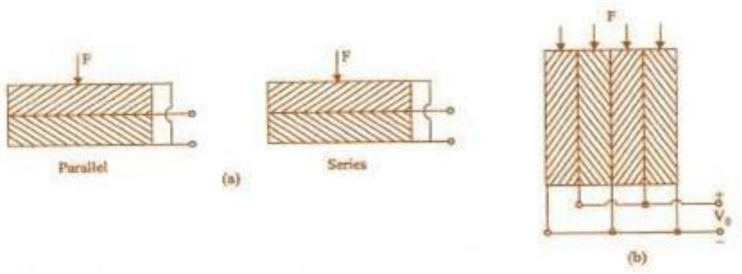
- The synthetic group consists of ammonium dihydrogen phosphate (ADP), lithium sulphate (LS) and Dipotassium Tartarate (DKT).
- Depending on the crystal structure, discs or wafers are-cut and used for measurement of force in one or the other of the modes described.
- Quartz is the most stable material and artificially grown quartz is normally preferred as it is purer than the natural quartz.
- Tourmaline is the only material exhibiting a large sensitivity.
- Rochelle salt is the material that is being produced on industrial scale for producing gramophone pick-ups.and crystal microphones.
- It has the highest relative permittivity among the natural group.
- ADP crystals possess the lowest resistivity which is also temperature dependent. With temperature compensation they are used in acceleration and pressure transducers.
- Lithium sulphate is highly sensitive.

Piezoelectric Force Transducer

- The element can be directly stressed by application of force at one point of the surface. Multiple forces can also be applied at more than one point of the surface and summed by using one single crystal.
- To increase the charge sensitivity, more than one element can be used to form a transducer system and such combinations are known as bimorphs or multimorphs (or piezopile), depending on whether they are of two elements or more.
- The series and connected bimorphs are shown ill Fig.
- A multimorph of four elements, which develops four times the charge of a single element is shown in Fig.
- The four elements are parallel mechanically in series but electrically in parallel and hence the net capacitance of the transducer increases correspondingly.
- When bimorphs are made up of ceramic elements, the direction of polarization of the

two elements should be noted, and then connected so as to develop charges, and voltages under stress as shown in Fig. These are called as Bender-type bimorphs.

- A twister bimorph is shown in Fig., with the force applied at A, while the remaining three corners B, C and D are held rigidly.
- If the four corners can be subjected to concentrated forces as shown in the four-point twister of Fig., the expanding diagonals will be perpendicular to each other, and on opposite sides of the bimorph.



(a) Parallel and Series connected bimorphs (b) Multimorph of four piezoelectric elements.

Piezoelectric Strain Transducer

Any piezoelectric element cemented to the surface of the structure is under stress, the strain in the structure is transmitted to the element.

- A voltage proportional to strain is directly available from the transducer.
- The output is obtained by using the h-coefficient given by

$$V_0 = h\,et$$

Where, e is strain

t is thickness of the element m

- The sensitivity of the transducer is very high.

- Piezo-resistive strain transducers though known to be suited for transient strain measurements are not as sensitive as the piezoelectric type.
- If accuracy and stability are of primary interest, metallic alloy resistive strain gauges are chosen especially when static strain is monitored over a long period of time.

Piezoelectric Pressure Transducers

- Piezoelectric transducers are more suitable for pressure measurements under dynamic conditions only and are often used as microphones, hydrophones and engine pressure indicators.
- In the piezoelectric microphone, the diaphragm and the bimorph are connected together by means of a fine needle (spindle) as shown in Fig.
- The natural frequency of the diaphragm, the bimorph and the associated system should be made higher than the highest frequency to be responded to (10 KHz normally).
- When used in sound level meters, it is essential for microphone to have flat frequency response upto 10 KHz.
- Large pressure variations occurring at frequencies upto 20 KHz in internal combustion engines are measured using multimorphs (piezopile) of quartz elements.

The surfaces of the elements, connecting electrode surfaces in between and the diaphragm or load plate at the extremes, should be optically flat, and no air should be trapped in between as it would reduce the natural frequency of the system.

- The transducer is pre-stressed so as to enable pressure fluctuations about a mean value to be measured.
- The pre-stressing is produced by a thin-walled tube under tension, as shown in Fig.
- A very thin diaphragm of flexible material is used for sealing.
- The preload may also be developed by a stiff diaphragm as shown in Fig.
- The net force F1 to which the piezo pile responds is given by

$$\frac{F_1}{F} = \frac{K_1}{K_1 + K_2}$$

here,

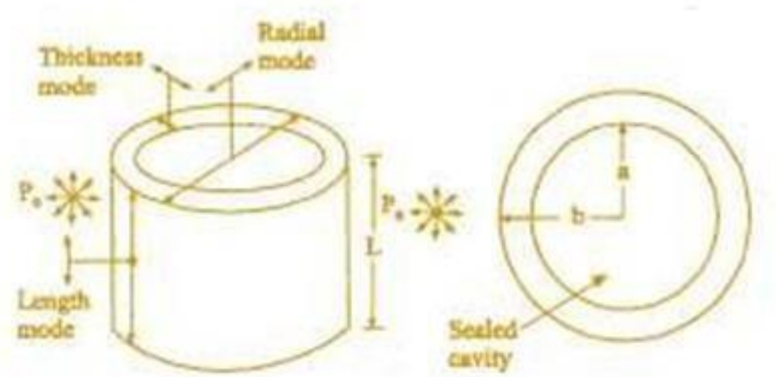
F = Total force acting in the transducer

K_1 = Spring rate of piezopile

K_2 = Spring rate of preloading tube or diaphragm

For the measurement of air-blast pressures and underwater pressure transients.

A small hollow cylinder shown in Fig. is used is most cases.

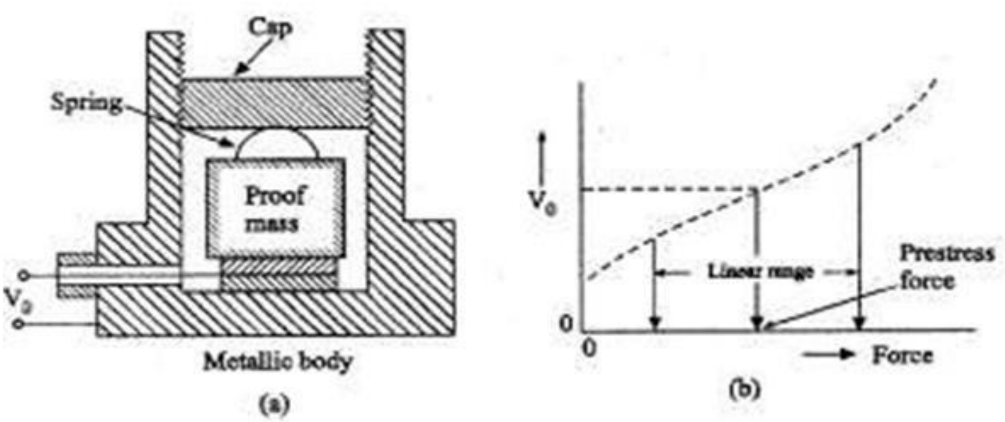


Pressure transducer for under water pressure measurement

- The outer and inner surfaces are metallized and used as electrodes.
- The walls are polarized in a radial direction.
- The tube cavity may be sealed against the external pressure and the blast pressure is applied to the outer surfaces.
- The cylinder responds to the pressure Pe in all the three modes as shown in Fig.

Piezoelectric Acceleration Transducer

- The acceleration transducer design is like that of a force transducer except that a proof mass is added to the acceleration transducer for developing force under acceleration inputs.
- The single crystal or the piezo-pile is pre-stressed by screwing down the cap on the hemispherical spring shown in Fig.
- The input output characteristics of piezoelectric acceleration transducer is shown in Fig.



(a) Piezoelectric acceleration transducer (b) Its input-output Characteristics

PHOTOVOLTAIC TRANSDUCER

A photovoltaic cell works on the same principle as that of the diode, which is to allow the flow of electric current to flow in a single direction and resist the reversal of the same current, i.e, causing only forward bias current.

When light is incident on the surface of a cell, it consists of photons which are absorbed by the semiconductor and electron-hole pairs are liberated to produce an external DC supply.

In a solar cell, the junction area is much bigger than the photovoltaic cell because its main interest is the generation of power but for a photovoltaic cell the main purpose is the generation of electricity.

If the incident energy (hv) is greater than the energy gap of that semiconductor material, these electron-hole pairs are generated at the depletion region of a diode.

When this photon from external radiation hits the diode, these electron-hole pairs disrupt the neutrality of the conductor. If an external current path has been provided then the electrons flowing through the P-side travel towards the N-side, eventually generating a DC current and the magnitude of this electromotive force generated is directly proportional to the intensity of the incident radiation. This is the working of a photovoltaic cell.

PASSIVE TRANSDUCER

Passive transducer is a transducer, which produces the variation in passive element. We will consider the passive elements like resistor, inductor and capacitor. Hence, we will get the following three passive transducers depending on the passive element that we choose.

- Resistive Transducer
- Inductive Transducer
- Capacitive Transducer

Resistive Transducer

A passive transducer is said to be a **resistive transducer**, when it produces the variation (change) in resistance value. the following formula for **resistance**, R of a metal conductor.

$$R = \frac{\rho l}{A}$$

Where,

ρρ is the resistivity of conductor

ll is the length of conductor

AA is the cross-sectional area of the conductor

The resistance value depends on the three parameters ρ,l & A. So, we can make the **resistive transducers** based on the variation in one of the three parameters ρ,l & A. The variation in any one of those three parameters changes the resistance value.

Inductive Transducer

A passive transducer is said to be an **inductive transducer**, when it produces the variation (change) in inductance value. the following formula for **inductance**, L of an inductor.

$$L = \frac{N^2}{S}$$

Where,

NN is the number of turns of coil

SS is the number of turns of coil

the following formula for **reluctance**, S of coil.

$$S = \frac{l}{\mu A}$$

Where,

l is the length of magnetic circuit

μ is the permeability of core

A is the area of magnetic circuit through which flux flows

$$L = \frac{N^2 \mu A}{l}$$

From Equation 1 & Equation 3, we can conclude that the inductance value depends on the three parameters N, S & μ. So, we can make the **inductive transducers** based on the variation in one of the three parameters N,S & μ. Because, the variation in any one of those three parameters changes the inductance value.

- Inductance, L is directly proportional to square of the **number of turns of coil**. So, as number of turns of coil, NN increases the value of inductance, LL also increases. Similarly, as number of turns of coil, NN decreases the value of inductance, LL also decreases.
- Inductance, LL is inversely proportional to **reluctance of coil**, SS. So, as reluctance of coil, SS increases the value of inductance, LL decreases. Similarly, as reluctance of coil, SS decreases the value of inductance, LL increases.
- Inductance, L is directly proportional to **permeability of core**, μμ. So, as permeability of core, μμ increases the value of inductance, L also increases. Similarly, as permeability of core, μμ decreases the value of inductance, L also decreases.
- Capacitive Transducer
- A passive transducer is said to be a **capacitive transducer**, when it produces the variation (change) in capacitance value. the following formula for **capacitance**, C of a parallel plate capacitor.

$$C = \frac{\varepsilon A}{d}$$

Where, ε is the permittivity or the dielectric constant

A is the effective area of two plates

- d is the effective area of two plates
- The capacitance value depends on the three parameters ε, A & d. So, we can make the **capacitive transducers** based on the variation in one of the three parameters ε, A & d. Because, the variation in any one of those three parameters changes the capacitance value.

- Capacitance, C is directly proportional to **permittivity**, ε. So, as permittivity, ε increases the value of capacitance, C also increases. Similarly, as permittivity, ε decreases the value of capacitance, C also decreases.
- Capacitance, C is directly proportional to the **effective area of two plates**, A. So, as effective area of two plates, A increases the value of capacitance, C also increases. Similarly, as effective area of two plates, A decreases the value of capacitance, C also decreases.
- Capacitance, C is inversely proportional to the **distance between two plates**, d. So, as distance between two plates, dd increases the value of capacitance, C decreases. Similarly, as distance between two plates, dd decreases the value of capacitance, C increases.

Difference Between Active Transducer and Passive Transducer

Active Transducer	**Passive Transducer**
It is kind of transducer which generates output in form of voltage or current, without any exterior power supply.	It is a kind of transducer whose interior parameters include capacitance, resistance, The smallest signals and inductance modified or change when it comes in contact with any passive element.
Its working principle includes drawing energy from measured source.	Its working principle includes drawing power from external sources which results in a change in its physical properties.
It has its own power supply for its functioning.	For its functioning, it requires an external power supply.
It has a much simpler design, unlike Passive Transducer.	It has a design that is complex as compared to an Active Transducer.
Smallest change in pressure that it can be detected in its output is very low, i.e it has a low resolution.	It can detect small changes in output easily and more accurately, i.e. it has a high resolution.
The output of active transducers depends on signal which is used for measurement.	The output of passive transducers depends on signal from the external power supply.

Active Transducer	Passive Transducer
These kinds of transducers are also known as self-generating transducers as they do not need any external power source.	These are also known as externally powered transducers as they need an external power supply to perform tasks.

PHOTOELECTRIC TRANSDUCERS

Photoelectric transducers are among the elements used to convert light energy into electrical one.

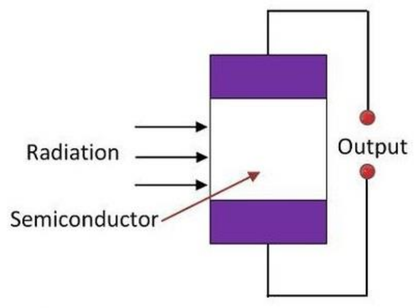
Photoelectric transducer

This transducer type has been designed to convert light energy into electrical energy. Photoelectric transducers are made from semiconductor materials. They use a photosensitive element that is capable of ejecting electrons. This process happens when the photoelectric transducer absorbs a beam of light that shines on the semiconductor material. This discharge results in inducing the current in the system. The total absorbed light is equal to the current's magnitude.

Working of photoelectric transducer

Photoelectric transducers absorb the beam of light and hence, the material's electrons are energized. This process results in the movement of the electrons. This movement creates different situations depending on the desired process:

- A change in the output voltage of the semiconductor may be one of the effects that the mobility of electrons produces.
- A change in the semiconductor's output current is among the effects that can be the result of the electron's movement.
- The final result that can be seen because of the movement of the electrons is a change in the material's resistance.



Photoelectric Transducer

Photo emissive devices work when a beam of light shines on a cathode, separating the electrons from the surface of the cathode. The photoconductive systems work when the illumination causes the resistance of the material to change. And the last principle is for the photovoltaic cells. They generate an output voltage that is related to the radiation intensity. This radiation can be visible light, infrared, gamma rays, ultraviolet, or X-rays.

Different photoelectric transducer types

Transducers have different types, each suitable for specific applications. They include:

- **PhotoJunction**
- **PhotoConductive Cell**
- **Photovoltaic Cell**
- **PhotoEmissive Cell or Tubes**

PhotoJunction

This photoelectric transducer type contains forms: phototransistors and photodiodes.

Phototransistors

Phototransistor transducers contain 3 semi-conducting layers created by two back-to-back diodes. The difference between this transducer and the regular ones is that this type the light intensity is the parameter that triggers the conduction. As soon as the photons meet the base structure, they will be converted to a current flow, resulting in the enabling of the transistor. Their design is in a way that a transparent casing hosts the phototransistor, allowing the light to easily enter the element. They are great for devices with light sensitivities since the light in these elements act as a switch when it’s a bipolar phototransistor.

Photodiodes

Photodiodes are among photoelectric transducers that are reverse-biased PN junction diodes. These transducers convert light into an electrical current with the absorption of the photons in the photodiode. The surface area of these transducers may be small or large. The larger the surface area, the slower the response time. They might also consist of built-in lenses and optical filters. They have a window or optical fiber connection allowing the light to get to the device's sensitive parts.

PhotoConductive Cell

Another photoelectric transducer type is called a photoconductive cell. They, too, convert solar radiation into conductivity. When the beam of light shines on a photoconductive material (Ge, Cadmium Selenide, Si), the resistance of the element changes. When the amount of sunlight reaches a sufficient level for the photoconductive cell, it results in an increase in its conductivity which doubles as a closed switch. When there's no light to shine on the element, it will work as an open switch.

Photovoltaic Cell

This transducer type is also known by the name solar cell. This active transducer generates electricity when it is irradiated by the sunlight. The photovoltaic cell is formed by an N-type material and P-type silicon that are diffused together. The semiconductor crystal absorbs the photons of the light rays whenever it is exposed to the light, resulting in the photovoltaic effect. This process will generate current throughout the semiconductor which is taken across the positive and negative terminal (the PN junction).

PhotoEmissive Cell or Tubes

This transducer type contains a glass envelope, anode, cathode, and some connecting pins. The cathode part of this transducer is a curved plate that is coated with photoemissive material and the anode part is a rode. They are both sealed inside an evacuated envelope. The current that flows in this element is produced throughout the anode and the cathode. This photoelectric transducer also releases electrons when a beam of light shines on the cathode. These electrons will be drawn to the anode part of the element which is kept at a specific positive potential resulting in the rise of a photoelectric current.

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 among a conductor as well as magnetic field induces a voltage within the conductor. The motion among the conductor and the field can be supplied by transforms in the measured. An inductive transducer (electromechanical) is an electrical device used to convert physical motion into modifying within inductance.

Types of Inductive Transducer

There are two kinds of inductive transducers available such as simple inductance & two-coil mutual inductance. The best example of an inductive transducer is LVDT. Please refer to this link to know about **inductive transducer circuit** working and its advantages and disadvantages such as LVDT (linear variable differential transformer).

1). Simple Inductance

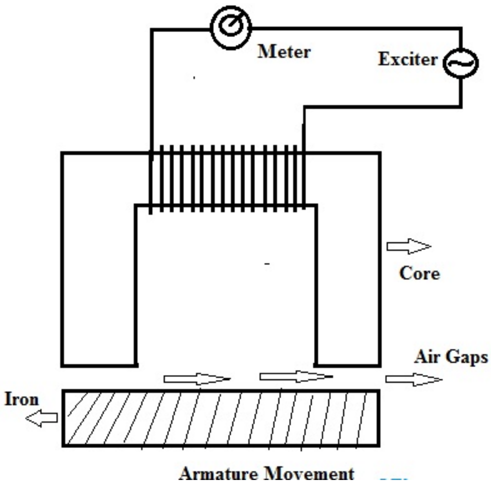
In this type of inductive transducer, a simple single coil is used as the transducer. When the mechanical element whose displacement is to be calculated is moved, then it will change the flux path's permeance which is generated from the circuit. It modifies the inductance of the circuit as well as the equivalent output. The circuit o/p can be directly adjusted against the input value. Therefore, directly it provides the parameter's valve to be calculated.

2). Two-Coil Mutual Inductance

In this type of transducer, there are two different coils are arranged. In the primary coil, the excitation can be generated with external power source whereas in the next coil the output can be attained. Both the mechanical input as well as output are proportional.

Inductive Transducer Working Principle

The working principle of an inductive transducer is the magnetic material's induction. Just like the electrical conductor's resistance, it depends on various factors. The magnetic material's induction can depend on different variables like the twists of the coil over the material, the magnetic material's size, & the flux's permeability.



The magnetic materials are used in the transducers in the path of flux. There is some air gap between them. The change in the circuit inductance can be occurred due to the air gap change. In most of these transducers, it is mainly used to work the instrument properly. The inductive transducer uses three working principles which include the following.

- Self-Inductance Change
- Mutual Inductance Change
- Eddy Current Production

Self-Inductance Change

We know that the coil's self-inductance can be derived by

$$L = \frac{N^2}{R}$$

Where 'N' is the number of twists of coil

'R' is the magnetic circuit's reluctance

The reluctance 'R' can be derived by the following equation

$$R = \frac{1}{\mu A}$$

Thus, inductance equation can become like the following

$$L = \frac{N^2 \mu A}{l}$$

Where

A = It is the Coil's cross-sectional area

l = Coil's length

μ = Permeability

We know that geometric form factor G = A/l, then the inductance equation will become like the following.

$$L = N^2 \mu G$$

The self-inductance is changed by a change in the number of twists, geometric form factor 'G' and permeability 'μ'.
For instance, if some displacement is capable to alter the above factors, then it can be calculated directly in terms of inductance.

Mutual Inductance Change

Here transducers work on the principle of change in mutual inductance. It uses several coils for the purpose of knowing. These coils include their self-inductance which are indicated by L_1 & L_2. The common inductance among these two twists can be derived by the following equation.

$$M = \sqrt{L_1} L_2$$

Therefore common inductance is altered by unstable self-inductance otherwise through the unstable coupling of coefficient 'K'. Here, the coupling coefficient mainly depends on the direction & distance among the two coils. As a result, the displacement can be measured by fixing one coil & make secondary coil movable. This coil can move by the power source whose displacement is to be calculated. The change in mutual inductance can be caused by the change in displacement coefficient coupling distance. This mutual inductance change is adjusted by measurement and displacement.

Eddy Current Production

Whenever a conducting shield is located close to a coil carrying AC (alternating current), then the current flow can be induced within the shield which is known as "EDDY CURRENT". This kind of principle is used in inductive transducers. When a conducting plate is arranged near to a coil carrying AC then eddy currents will be generated within the plate. The plate which carries eddy current will generates their own magnetic field which works against plate magnetic field. So the magnetic flux will be reduced.

As a coil is located near to coil carrying AC, a flowing current can be induced within it which in turn generates its own flux to decrease the flux of the current-carrying coil & therefore coil's inductance will be changed. Here, the coil is arranged nearer to the plate then high eddy current will be generated as well as a high drop within coil inductance. Thus, by changing the distance among the coil and plate, the inductance of the coil will change. The principle like changing the distance of coil or plate with the help of measurand can be used within measurements of displacement.

Inductive Transducer Applications

The applications of these transducers include the following.

- The application of these transducers finds in proximity sensors to measure position, touchpads, dynamic motion, etc.
- Mostly these transducers are used for detecting the kind of metal, to find miss lost parts otherwise counts the objects.
- These transducers are also applicable for detecting the movement of the apparatus which include belt conveyor and bucket elevator etc..

Inductive Transducer Advantages and Disadvantages

The **advantages** of inductive transducer include the following.

- The responsivity of this transducer is high
- Load effects will be reduced.
- Strong against ecological quantities

The **disadvantages** of inductive transducer include the following.

- The operating range will be reduced due to side effects.
- The working temperature should be under the Curie temperature.
- Sensitive to the magnetic field

UNIT -III

MICROSCOPE

MICROSCOPY-PRINCIPLES AND TYPES

Microorganisms are too small to be seen by our unaided eyes and the microscopes are of crucial importance as they help to view the microbes. A microscope is an optical instrument consisting of one or more lenses in order to magnify images of minute objects. Thus it is important to gain a preliminary knowledge about the principles of microscope and its types.

PROPERTIES OF LIGHT

To understand how a light microscope operates, one must know something about the way in which lenses bend and focus light to form images.

When a ray of light passes from one medium to another, **refraction** occurs, i.e., the ray is bent at the interface. The **refractive index** is a measure of how greatly a substance slows the velocity of light, and the direction and magnitude of bending is determined by the refractive indexes of the two media forming the interface.

When light passes from air into glass, a medium with a greater refractive index, it is slowed and bent toward the normal, a line perpendicular to the surface. As light leaves glass and returns to air, a medium with a lower refractive index, it accelerates and is bent away from the normal. Thus a prism bends light because glass has a different refractive index from air, and the light strikes its surface at an angle. Lenses act like a collection of prisms operating as a unit. When the light source is distant so that parallel rays of light strike the lens, a convex lens will focus these rays at a specific point, the **focal point**. The distance between the center of the lens and the focal point is called the **focal length**. Our eyes cannot focus on objects nearer than about 25 cm or 10 inches. This limitation may be overcome by using a convex lens as a simple magnifier (or microscope) and holding it close to an object. A magnifying glass provides a clear image at much closer range, and the object appears larger. Lens strength is related to focal length; a lens with a short focal length will magnify an object more than a weaker lens having a longer focal length.

PRINCIPLES OF LIGHT MICROSCOPY

The light is the primary source on which magnification is based in light microscopes. The magnification is obtained by a system of optical lenses using light waves. Magnification refers the number of times a specimen is appeared to be larger than its original size.

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BASIC UNITS FOR MICROSCOPE

1 meter = 1000 millimeter

1 millimeter = 1000 micrometer (mm) = 10^{-6} meter

1 micrometer = 1000 nanometer (nm) = 10^{-9} meter

1 Angstrom (1 A) = 10^{-10} meter

1 nanometer = 10 Angstrom

Relative size of the microorganisms and their visibility. Man can see about 0.5 mm sized object whereas the light microscopes can be used to visualize upto 1 mm and EM (electron microscopes) can be used to view 1 nm objects.

BASIC QUALITY PARAMETERS OF MICROSCOPIC IMAGES

The microscopic images should have four basic quality parameters, through which the microscopes can be graded.

1. **Focus:** It refers whether the image is well defined or blurry (out of focus). The focus can be adjusted through course and fine adjustment knobs of the microscope which will adjust the focal length to get clear image. The thickness of specimen, slide and coverslip also decide the focus of the image. (Thin specimens will have good focus).

2. **Brightness:** It refers how light or the dark the image is. Brightness of the image is depends on the illumination system and can be adjusted by changing the voltage of the lamp and by condenser diaphragm.

3. **Contrast:** It refers how best the specimen is differentiated from the background or the adjacent area of microscopic field. More the contrast will give good images. It depends on the brightness of illumination and colour of the specimen. The contrast can be achieved by adjusting illumination and diaphragm and by adding colour to the specimen. The phase contrast microscopes are designed in such a way that the contrast can be achieved with out colouring the specimen.

4. **Resolution:** It refers the ability to distinguish two objects close to each other. The resolution depends on the resolving power, which refers minimum distance between the two objects which can be distinguishable.

MAGNIFICATION AND RESOLUTION

The total **magnification** of compound microscope is the product of the magnifications of objective lens and eyepiece. Magnification of about 1500x is the upper limit of compound microscopes. This limit is set because of the resolution.

Resolution refers the ability of microscopes to distinguish two objects close to each other, it depends on resolving power, which refers the minimum distance. Ex : Man has the resolving power of 0.2 mm (meaning that he can distinguish two objects with a distance of 0.2 mm close to each other) If he want to see beyond the limit of his resolving power, further magnification is necessary.

$$Resolution = \frac{\mu}{sin\theta}$$

where, μ is the wave length of light source and n (sin $^{\theta}$) is the numerical aperture (NA).

For compound microscopes, resolving power is μ/2NA. The resolving power of an microscope can be improved either by reducing the wave length of light or by increasing the n(sin $^{\theta}$) value.

Numerical aperture (n sin$^{\theta}$) measures how much light cone spreads out between condenser & specimen. More spread of light gives less resolving power means better resolution. The numerical aperture depends on the objective lens of the microscope. There are two types of objective lenses are available in any compound microscope.

THE LIMIT OF RESOLUTION

The limit of resolution refers the smallest distance by which two objects can be separated and still be distinguishable or visible as two separate objects.

Optical Instrument	**Resolving Power**	**RP in Angstroms**
Human eye	0.2 millimeters (mm)	2,000,000Å
Light microscope	0.20 micrometers (µm)	2000Å
Scanning electron microscope (SEM)	5-10 nanometers (nm)	50-100Å
Transmission electron microscope (TEM)	0.5 nanometers (nm)	5Å

TYPES OF MICROSCOPE

Microbiologists use a variety of microscopes, each with specific advantages and limitations. Microscopes are of two categories.

a. **Light Microscope:** Magnification is obtained by a system of optical lenses using light waves. It includes (i) Bright field (ii) Dark field (iii) Fluorescence (iv) Phase contrast and (v) UV Microscope.

b. **Electron Microscope:** A system of electromagnetic lenses and a short beam of electrons are used to obtain magnification. It is of two types: (I) Transmission electron microscope (TEM) (ii) Scanning electron microscope (SEM).

LIGHT MICROSCOPE

Light microscopy is the corner stone of microbiology for it is through the microscope that most scientists first become acquainted with microorganisms. Light microscopes can be broadly grouped into two categories.

(a) **Simple microscope:** It consists of only one bi-convex lens along with a stage to keep the specimen.

(b) **Compound microscope:** It employs two separate lens systems namely, (i) objective and (ii) ocular (eye piece).

BRIGHT FIELD MICROSCOPE

The compound student microscope is a bright field microscope. It consists of mechanical and optical parts.

1. Mechanical parts

These are secondary but are necessary for working of a microscope. A ‘Base’, which is horsehoe, shaped supports the entire framework for all parts. From the base, a ‘Pillar’ arises. At the top of the pillar through an ‘Inclination Joint’ arm or limb is attached. At the top of the pillar, a stage with a central circular opening called ‘Stage aperture’ is fixed, with a stage clip to fix the microscopic slide. Beneath the stage, there is one stage called ‘sub stage’ which carries the condenser. At the top of the arm, a hollow cylindrical tube of standard diameter is attached in-line with the stage aperture, called ‘body tube’. The body tube moves up and down by two separate arrangements called ‘coarse adjustment’ worked with pinion head and ‘fine adjustment’ worked with micrometer head. At the bottom of the body tube an arrangement called ‘revolving nose-piece’ is present for screwing different objectives. At the top of the body tube eye- piece is fixed.

2.Optical parts

It includes mirror, condenser, objective and ocular lenses. All the optical parts should be kept in perfect optical axis.

a. Objectives: Usually 3 types of magnifying lenses (i) Low power objective (10x) (ii) High dry objective (45x) and (iii) Oil immersion objective (100x)

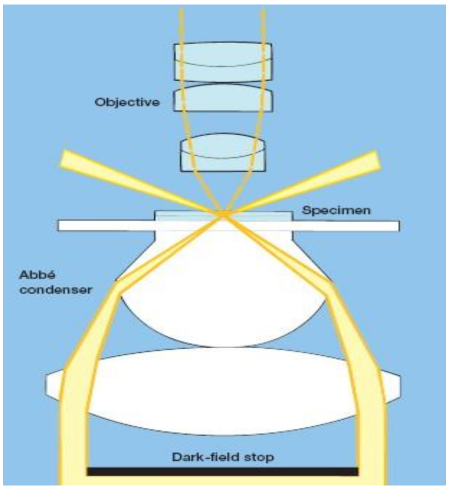
b. Eye-piece: Mostly have standard dimensions and made with different power lenses. (5x, 10x, 15x, 20x). A compound microscope with a single eyepiece is said to be monocular, and one with two eyepieces is said to be binocular.

c. Condenser: Condenses the light waves into a pencil shaped cone thereby preventing the escape of light waves. Also raising or lowering the condenser can control light intensity. To the condenser, iris diaphragm is attached which helps in regulating the light.

d. Mirror: It is mounted on a frame and attached to the pillar in a manner that it can be focused in three different directions. The mirror is made of a lens with one plane surface and another concave surface. Plane surface is used, when the microscope is with a condenser.

DARK-FIELD MICROSCOPE

In dark-field microscopy, specimen is brightly illuminated against a dark background. This type of microscope possesses a special type of condenser, which prevents the parallel and the oblique rays entering in to the objective and thus making the microscopic field dark. In the absence of specimen the entire field will appear as dark. In the presence of specimen, which differs in refractive index, the oblique rays are scattered by reflection and refraction and the scattered rays enter the objective making the specimen brightly illuminated.



Maximum magnification of 1500x and resolution of 0.1 – 0.2 μm can be obtained. It is useful in studying the morphology and motility of microorganisms. Dark field is especially useful for finding cells in suspension. Dark field makes it easy to obtain the correct focal plane at low magnification for small, low contrast specimens. The following are its uses:

a. Initial examination of suspensions of cells such as yeast, bacteria, small protists, or cell and tissue fractions including cheek epithelial cells, chloroplasts, mitochondria, even blood cells (small diameter of pigmented cells makes it tricky to find them sometimes despite the color).

b. Initial survey and observation at low powers of pond water samples, hay or soil infusions, purchased protist or metazoan cultures.

c. Examination of lightly stained prepared slides. Initial location of any specimen of very small size for later viewing at higher power.

d. Determination of motility in cultures.

ELECTRON MICROSCOPE

In electron microscope, short beam of electrons and magnetic condenser lenses are employed to produce the image. The electrons have short wavelength, which helps in better resolution. It is possible to resolve objects as small as 10°A, which is 100 times more than that of light microscope. It can magnify object up to 200,000X.

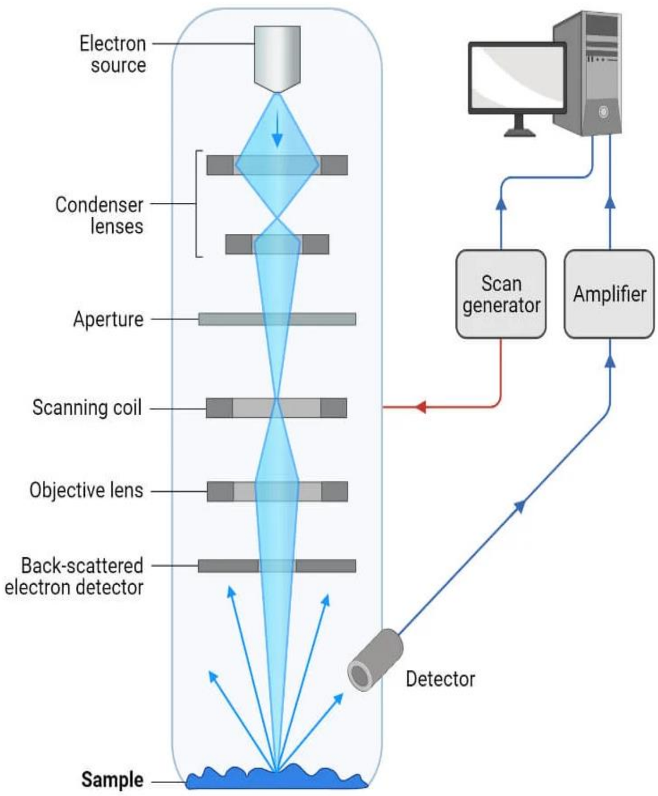
In electron microscope, a hot tungsten filament forms the source of electrons. The object is placed in the path of moving electrons. Since electrons move only in the vacuum, the entire path of electrons should be kept under vacuum. The magnetic condenser lens causes the primary magnification. A second magnetic lens amplifies the primary image and this image is viewed on a fluorescent screen or captured on photographic plates. There are two types of electron microscope.

a. Transmission electron microscope (TEM)
b. Scanning electron microscope (SEM)

Scanning Electron Microscope (SEM) is a type of electron microscope that scans surfaces of microorganisms that uses a beam of electrons moving at low energy to focus and scan specimens. The development of electron microscopes was due to the inefficiency of the wavelength of light microscopes. electron microscopes have very short wavelengths in comparison to the light microscope which enables better resolution power.

Unlike the Transmission Electron Microscope which uses transmitted electrons, the scanning electron Microscope uses emitted electrons. The Scanning electron microscope works on the principle of applying kinetic energy to produce signals on the interaction of the electrons. These electrons are secondary electrons, backscattered electrons, and diffracted backscattered electrons which are used to view crystallized elements and photons. Secondary and backscattered electrons are used to produce an image. The secondary electrons are emitted from the specimen play the primary role of detecting the morphology and topography of the specimen while the backscattered electrons show contrast in the composition of the elements of the specimen.

- The source of the electrons and the electromagnetic lenses are from tungsten filament lamps that are placed at the top of the column and it is similar to those of the transmission electron Microscope.
- The electrons are emitted after thermal energy is applied to the electron source and allowed to move in a fast motion to the anode, which has a positive charge.
- The beam of electrons activates the emission of primary scattered (Primary) electrons at high energy levels and secondary electrons at low-energy levels from the specimen surface. The beam of electrons interacts with the specimen to produce signals that give information about the surface topography and composition of the specimen.
- The specimen does not need special treatment for visualization under the SEM, even air-dried samples can be examined directly. However, microbial specimens need fixation, dehydration, and drying in order to maintain the structural features of the cells and to prevent collapsing of the cells when exposed to the high vacuum of the microscope.



- The samples are mounted and coated with thin layer of heavy metal elements to allow spatial scattering of electric charges on the surface of the specimen allowing better image production, with high clarity.
- Scanning by this microscope is attained by tapering a beam of electrons back and forth over a thin section of the microscope. When the electrons reach the specimen, the surface releases a tiny staw of electrons known as secondary electrons which are then trapped by a special detector apparatus.
- When the secondary electrons reach and enter the detector, they strike a scintillator (a luminescence material that fluoresces when struck by a charged particle or high-energy photon). This emits flashes of light which get converted into an electric current by a photomultiplier, sending a signal to the cathode ray tube. This produces an image that looks like a television picture that can be viewed and photographed.
- The quantity of secondary electrons that enter the detector is highly defined by the nature of the specimen i.e raised surfaces to receive high quantities of electrons, entering the detector while depressed surfaces have fewer electrons reaching the surface and hence fewer electrons enter the detector.
- Therefore raised surfaces will appear brighter on the screen while depressed surfaces appear darker.

The major components of the Scanning Electron Microscope include;

- Electron Source – This is where electrons are produced under thermal heat at a voltage of 1-40kV. the electrons condense into a beam that is used for the creation of an image and analysis. There are three types of electron sources that can be used i. e Tungsten filament, Lanthanum hexaboride, and Field emission gun (FEG)
- Lenses – it has several condenser lenses that focus the beam of electrons from the source through the column forming a narrow beam of electrons that form a spot called a spot size.
- Scanning Coil – they are used to deflect the beam over the specimen surface.
- Detector – It's made up of several detectors that are able to differentiate the secondary electrons, backscattered electrons, and diffracted backscattered electrons. The functioning of the detectors highly depends on the voltage speed, the density of the specimen.

- The display device (data output devices)
- Power supply
- Vacuum system

APPLICATIONS OF SEM

It is used in a variety of fields including Industrial uses, nanoscience studies, Biomedical studies, Microbiology

1. Used for spot chemical analysis in energy-Dispersive X-ray Spectroscopy.
2. Used in the analysis of cosmetic components which are very tiny in size.
3. Used to study the filament structures of microorganisms.
4. Used to study the topography of elements used in industries.

ADVANTAGES OF SEM

5. They are easy to operate and have user-friendly interfaces.
6. They are used in a variety of industrial applications to analyze surfaces of solid objects.
7. Some modern SEMs are able to generate digital data that can be portable.
8. It is easy to acquire data from the SEM, within a short period of time of about 5 minutes.

LIMITATIONS OF SEM

1. They are very expensive to purchase
2. They are bulky to carry
3. They must be used in rooms that are free of vibrations and free of electromagnetic elements
4. They must be maintained with a consistent voltage
5. They should be maintained with access to cooling systems

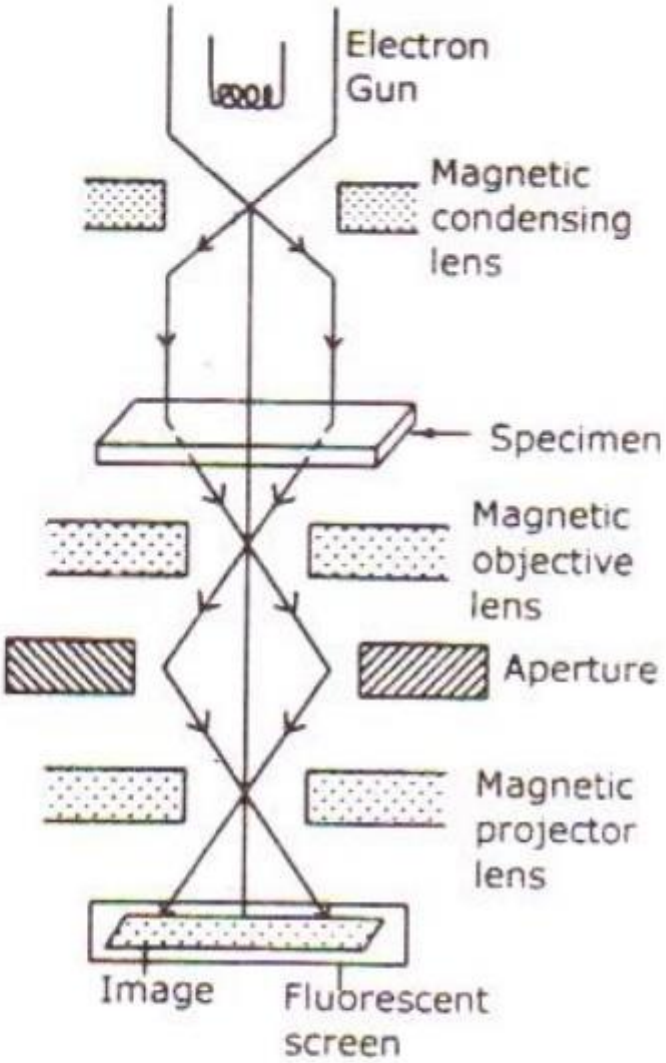
TRANSMISSION ELECTRON MICROSCOPE (TEM)

- This is a powerful electron microscope that uses a beam of electrons to focus on a specimen producing a highly magnified and detailed image of the specimen.

- The magnification power is over 2 million times better than that of the **light microscope,** producing the image of the specimen which enables easy characterization of the image in its morphological features, compositions and crystallization information is also detailed.
- Early discovery of cathode rays like electrons by Louis de Broglie in the early 1920s, paved way into the development of an electron microscope where they used a beam of electrons creating a form of wave motion.
- Magnetic fields were used as lenses for the electrons. With these discoveries, the first electron microscope was later developed by Ernst Ruska and Max Knolls in 1931 and modified into a Transmission Electron Microscope (TEM) by Ernst Ruska along with the Sieman's company, in 1933.
- This TEM microscope has several advantages compared to the light microscope with its efficiency also being very high.
- Among all microscopes both light and electron microscopes, TEM are the most powerful microscopes used in laboratories. It can magnify a mall particle of about 2nm, and therefore they have a resolution limit of 0.2um.
- The working principle of the Transmission Electron Microscope (TEM) is similar to the light microscope. The major difference is that light microscopes use light rays to focus and produce an image while the TEM uses a beam of electrons to focus on the specimen, to produce an image.
- Electrons have a shorter wavelength in comparison to light which has a long wavelength. The mechanism of a light microscope is that an increase in resolution power decreases the wavelength of the light, but in the TEM, when the electron illuminates the specimen, the resolution power increases increasing the wavelength of the electron transmission. The wavelength of the electrons is about 0.005nm which is 100,000X shorter than that of light, hence TEM has better resolution than that of the light microscope, of about 1000times.
- This can accurately be stated that the TEM can be used to detail the internal structures of the smallest particles like a virion particle.

Their **working mechanism** is enabled by the high-resolution power they produce which allows it to be used in a wide variety of fields. It has three working parts which include:

1. Electron gun
2. Image producing system
3. Image recording system



Electron gun

- This is the part of the Transmission Electron Microscope responsible for producing electron beams.
- Electrons are produced by a cathode that is a tungsten filament that is V-shaped and it is normally heated. The tungsten filament is covered by a control grid known as a

Wehnelt cylinder made up of a central hole which lies columnar to the tube. The cathode lies on top of or below the cylindrical column hole. The cathode and the control grid are negatively charged with an end of the anode which is disk-shaped that also has an axial hole.

- When electrons are transmitted from the cathode, they pass through the columnar aperture (hole) to the anode at high voltage with constant energy, which is efficient for focusing the specimen to produce an accurately defined image.
- It also has the condenser lens system which works to focus the electron beam on the specimen by controlling the energy intensity and the column hole of the electron gun. The TEM uses two condenser lenses to converge the beam of electrons to the specimen. The two condenser lens each function to produce an image i.e the first lens which has strong magnification, produces a smaller image of the specimen, to the second condenser lens, directing the image to the objectives.

Image- Producing system

- Its made up of the objective lens, a movable stage or holding the specimen, intermediate and projector lenses. They function by focusing the passing electrons through the specimen forming a highly magnified image.
- The objective has a short focal length of about 1-5mm and it produces an intermediate image from the condenser which are transmitted to the projector lenses for magnification.
- The projector lenses are of two types, i.e the intermediate lens which allows great magnification of the image and the projector lens which gives a generally greater magnification over the intermediate lens.
- To produce efficient high standard images, the objectives and the projector lenses need high power supplies with high stability for the highest standard of resolution.

Image-Recording System

- Its made up of the fluorescent screen used to view and to focus on the image. They also have a digital camera that permanently records the images captured after viewing.

- They have a vacuum system that prevents the bombardment or collision of electrons with air molecules disrupting their movement and ability to focus. A vacuumed system facilitates the straight movement of electrons to the image.
- The vacuumed system is made up of a pump, gauge, valves and a power supply.
- The image that is formed is called a monochromatic image, which is greyish or black and white. The image must be visible to the human eye, and therefore, the electrons are allowed to pass through a fluorescent screen fixed at the base of the microscope.
- The image can also be captured digitally and displayed on a computer and stored in a JPEG or TIFF format. During the storage, the image can be manipulated from its monochromatic state to a colored image depending on the recording apparatus eg use of pixel cameras can store the image in color.
- The presence of colored images allows easy visualization, identification, and characterization of the images.

Applications of Transmission Electron Microscope (TEM)

TEM is used in a wide variety of fields From Biology, Microbiology, Nanotechnology, forensic studies, etc. Some of these applications include:

1. To visualize and study cell structures of bacteria, viruses, and fungi
2. To view bacteria flagella and plasmids
3. To view the shapes and sizes of microbial cell organelles
4. To study and differentiate between plant and animal cells.
5. Its also used in nanotechnology to study nanoparticles such as ZnO nanoparticles
6. It is used to detect and identify fractures, damaged microparticles which further enable repair mechanisms of the particles.

Advantages of Transmission Electron Microscope (TEM)

1. It has a very powerful magnification of about 2 million times that of the Light microscope.
2. It can be used for a variety of applications ranging from basic Biology to Nanotechnology, to education and industrial uses.

3. It can be used to acquire vast information on compounds and their structures.
4. It produces very efficient, high-quality images with high clarity.
5. It can produce permanent images.
6. It is easy to train and use the Transmission Electron Microscope

Limitations of Transmission Electron Microscope (TEM)

1. Generally, the TEMs are very expensive to purchase
2. They are very big to handle.
3. The preparation of specimens to be viewed under the TEM is very tedious.
4. The use of chemical fixations, dehydrators, and embedments can cause the dangers of artifacts.
5. They are laborious to maintain.
6. It requires a constant inflow of voltage to operate.
7. They are extremely sensitive to vibrations and electro-magnetic movements hence they are used in isolated areas, where they are not exposed.
8. It produces monochromatic images, unless they use a fluorescent screen at the end of visualization.

Difference Between Electron Microscope and Light Microscope	
Light Microscope	**Electron Microscope**
Uses light (approx. 400-700 nm) as an illuminating source	Uses electron beams (approx. 1 nm) as an illuminating source
Lower magnification than an electron microscope	Higher magnification
No risk of radiation leakage	Risk of radiation leakage

Specimen preparation takes about a few minutes or an hour	Specimen preparation takes several days
Both live and dead specimens can be seen	Only dead and the dried specimen can be seen
The image formation depends upon the light absorption from the different zones of the specimen	The image formation depends upon the electron scattering
The image is seen through the ocular lens. No screen needed	The image is received on a zinc sulfate fluorescent screen
Useful magnification of 500x to 1500x	Direct magnification as high as 16000x and photographic magnification as high as 1000000x
Low resolution	High resolution
Inexpensive and requires low maintenance cost	Expensive and high maintenance

COMPARISON BETWEEN SEM AND TEM

Signals analyzed	Backscattered electrons, secondary electrons	Transmitted electrons
Image formation mechanism	The beam is scanned across the sample surface and signals are collected in a pixel-by-pixel fashion	Static beam illuminates the sample and a projection image of the transmitted beam is acquired in a single frame
Sample thickness	Any (limited by sample chamber)	<100 nm for most materials
Accelerating voltage	~1-30 kV	~30-300 kV
Type of information in the image	Surface compositional contrast, surface morphology, surface topography (can have 3D appearance)	Phase or diffraction contrast image through sample's surface and internal structure (2D appearance)

Max magnification	Up to 1-2 million times	50 million times or more
Typical field of view	A few µm to several mm’s	A few nm’s up to several µm
Spatial resolution	~1-2 nm	<1 Å
Size of instrument	Smaller, desktop models and floor model options	Larger and taller, takes up entire room
Cost	Less expensive	More expensive
Time-to-image	Fast	Slow

UNIT – IV

ADVANCES IN MEDICAL INSTRUMENTS

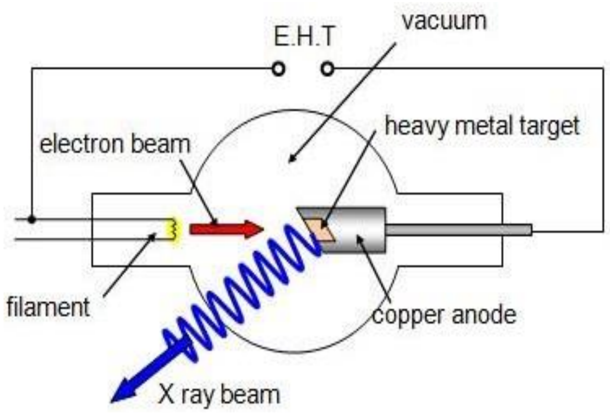
X-RAY MACHINE

Basic X-Ray Machine

It is a special branch that deals with the study and application of imaging technology using X-ray radiations or such other radiation devices for the purpose of obtaining visual information to diagnosing and treatment of diseases. X-ray machines are devices that generate exceedingly high frequency high energy electromagnetic waves that penetrate the body during medical procedures to provide visual information. The x-ray tube working principle and diagram is shown below.

Generation of X-rays in X-ray tubes.

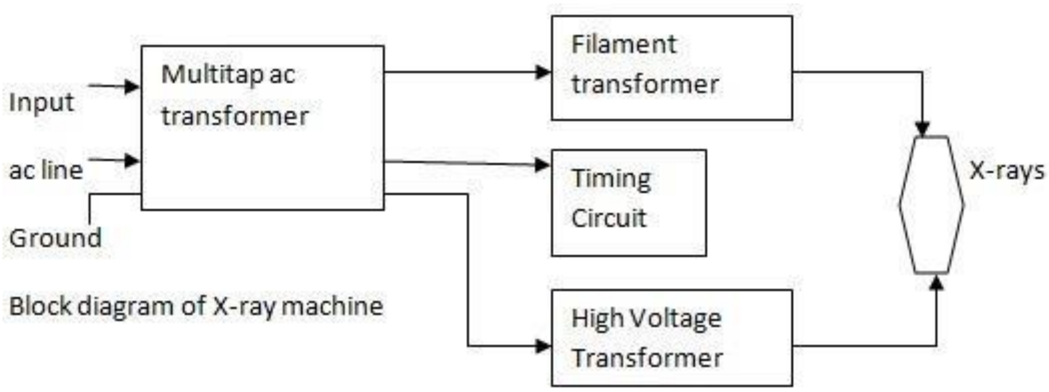
An X-ray generator is a device used to generate X-rays. An X-ray imaging system consists of an X-ray source or generator (X-ray tube) and an image detection system. The X-ray tube (high vacuum diode) operates by emitting electrons from a heated cathode tungsten filament toward a rotating high voltage anode disc. The point where the electrons (beam) strike the target is called the focal spot. At the focal -spot X-ray photons are directed at all directions. X-rays arise from the target disc at right angles and are focused by a collimator. For more viewing contrast we use, photomultipliers. The images are received and viewed on a photographic plate. Here light and dark areas on the film represent high and low tissue penetration. The basic schematic of an X-ray tube is shown below.



X-ray machines work by applying controlled voltage and current to the X-ray tube. So the beam intensity of X-rays can be controlled by controlling voltage or current. The beam is projected on the object. Some of the beams will pass through the object and some are absorbed. The resulting pattern of radiation is detected in a photographic film as told earlier. In an X-ray tube, the rotating anode is used to overcome the overheat problem. Also the anode is made of tungsten alloy which helps in avoiding over heat.

Block Diagram of X-ray Machine

The block diagram of X-ray machine is shown in figure below. The function of each block of an X-ray machine is also explained below.



Block diagram of x-ray machine

1. **Multitap ac transformer**

We use a multi-tap ac transformer in order to select taps to compensate for incoming line variations. The number of outputs is referred to as 'taps' and it may range from 2 outputs to many outputs depending on the type of multi-tap transformer used. The advantage of multi- tap transformer is that it has different taps in different voltages. So we can select a higher voltage tap or lower voltage tap depending on the intensity of X-ray exposure needed. These also permit the operator to choose voltages for specific applications.

2. **X-ray tube filament transformer:**

This transformer transforms the ac line to supply power for heating the cathode filament. This power can be selected by taps to change the filament heat which in turn change the X-ray tube current and total energy delivered to the patient.

3. X-ray tube high voltage transformer and bridge rectifier

This block together transforms the ac line to supply the high dc voltage for accelerating the electrons from cathode to anode. The high dc voltage is selected by taps.

4. Timing circuit

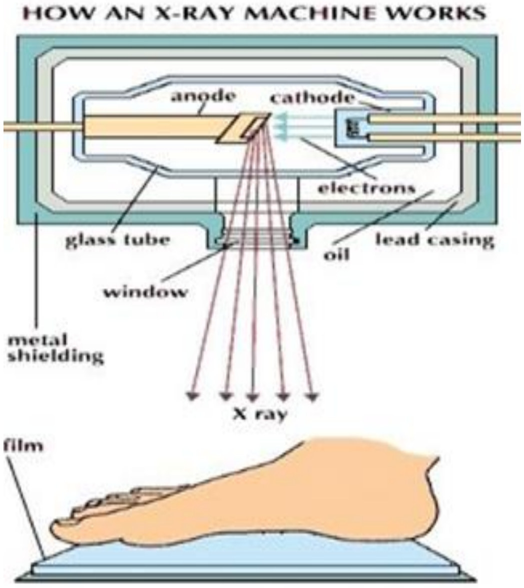
Timing circuit is used to control the turn-on, turn-off and length of X-ray exposure delivered to the patient. It consists of an electronic counter that applies high voltage to the X-ray tube anode for short periods of time.

Advantages of X-rays in medicine:

1. X-ray can be used to produce an image of any body parts.
2. It is also available as a portable unit which can be used in hospitals widely and X-rays can be taken anywhere even in bedside.
3. It is less costly when compared to other imaging models like MRI scan.
4. It can produce fast results.
5. It is a comparatively easy technique.

Applications of X-rays in medicine:

1. X-ray machines are used in healthcare for Visualizing bone structures and other dense tissues such as tumors.
2. The two main fields which use X-ray machines are radiography and dentistry.
3. Radiography is used for fast and highly penetrating images.
4. By using X-rays cancer cells can be treated in radiotherapy.



FLUOROSCOPY

Fluoroscopy is a type of imaging procedure that uses several pulses of an X-ray beam to take real-time footage of tissues inside your body. Healthcare providers use fluoroscopy to help monitor and diagnose certain conditions and as imaging guidance for certain procedures.

Fluoroscopy is a medical imaging procedure that uses several pulses (brief bursts) of an X-ray beam to show internal organs and tissues moving in real time on a computer screen. Standard X-rays are like photographs, whereas fluoroscopy is like a video.

Healthcare providers use fluoroscopy for two main purposes: for diagnostic purposes and to help guide certain treatment procedures (known as interventional guidance), such as surgeries and catheter placements.

Components of a fluoroscopy system

The fundamental components of a modern fluoroscopy system are shown in this figure. Where the x-rays are generated by the x-ray tube and pass through the filters, collimator, anti-scatter grid and finally the remnant beam is measured on a flat panel detector.

1. X-ray tube and Generator: This is the source of the X-rays that are used to produce the images. The X-ray tube is located in the head of the fluoroscopy machine, and it generates X-rays when a high voltage current is passed through it. The generator is the source of the high tube potential in order to power the x-ray tube.

2. Beam Filtration: In many x-ray systems there are beam filters which can be added from the side such that additional beam filtration can be added over areas which have lower attenuation within the anatomy itself.

3. Collimator: This is a device that is used to shape the X-ray beam and control the size and shape of the area being imaged. The collimator is located between the X-ray tube and the patient and can be adjusted to change the size and shape of the beam.

4. Image Receptor (Image Intensifier or Flat Panel Detector (FPD)): The image receptor converts the remnant x-ray beam to a digital image that is displayed on the monitors.

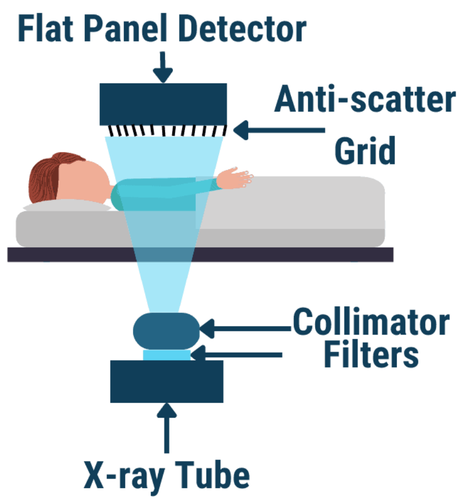
5. Dedicated image processing: The raw image data is typically processed through a number of digital image enhancement algorithms before being displayed to the user.

6. Control panel and footswitch: This is the device that is used to control the fluoroscopy machine and adjust the settings such as the X-ray tube voltage, current, and exposure time. The control panel is typically located on the front of the fluoroscopy machine and includes buttons, switches, and joystick type control that can be used to adjust the settings. The foot pedal is often used also to control the x-ray on and off while the hands are in use.

7. Patient table: This is the table that the patient lies on during the exam. The patient table is typically equipped with a system of motors and gears that allow it to be moved in various directions and positions to help the interventionalist achieve the best possible view of the area being imaged.

8. Gantry: Typically a fluoroscopy system has a C shape gantry that is often called a C-arm. In some specialized configurations two C-arm systems are mounted on the same system in what is termed a bi-plane system as it is possible to achieve two views at once.

9. The x-ray radiation dose is monitored during the acquisition and displayed for the users to read out during the procedure.



RADIOGRAPHY

Originally, screen-film radiography (SFR) was used in which a physical copy of the x-ray film was produced. These have now been replaced by digital radiography. There are two different techniques: computed radiography and digital radiography.

1. Computed radiography

Cassettes are used that have a phosphor screen. When the x-rays hit they form a latent image in the phosphor. The cassette is then placed into a reader with a laser shone on to it which releases the stored photons, collects the signal, and digitises it to be displayed on a display screen.

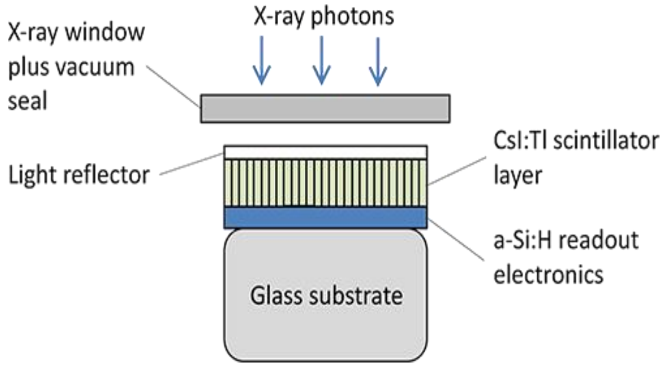
2. Digital radiography

With digital radiography no cassettes are used. The x-rays hit a permanently placed set of hardware, which then sends the digital information directly to a readout mechanism.

- Indirect DR: x-ray photons hit a scintillator layer, which then releases light photons that then hit an active matrix array that digitises the signal
- Direct DR: x-ray photons act directly on a photoconductor layer producing positive and negative charge. The positive charge is attracted to a charge capacitor that stores the latent image. It is then read out by TFT switches pixel by pixel.

Indirect DR

Hardware



Digital radiography hardware

1) Scintillator layer

Most systems use a thin 500 µm layer of **caesium iodide (CsI:TI)** as a scintillator to capture the image which is coated onto the hydrogenated amorphous silicon (a-Si:H) active matrix array (some systems use gadolinium oxysulfide as the scintillator layer). The CsI:TI is a channeled crystal structure that ensures minimum unsharpness caused by scatter of the recorded image. Absorption of an x-ray photon releases ~3000 light photons in the **green** part of the spectrum.

2) Active matrix

This is formed by a **layer of a-Si:H** and forms the readout electronics. The active matrix consists of a high-resolution array of electronic components. Each pixel typically comprises a:

- Photodiode (a light sensor) – amplifies signal from incident light photons
- Charge storage capacitor – stores signal of latent image
- Thin-film transistor (or TFT switch) – latent image read out and transferred to TFT switches that produce a voltage signal that is digitised and converted into the image

This circuitry (TFT and charge storage capacitor) takes up a small area of each pixel preventing image formation in this area. This is calculated by the **fill factor.**

Fill factor = sensitive area / overall area

Decreasing the pixel size (making each area smaller) improves the resolution but, as the circuitry remains the same size, the fill factor and, therefore, the efficiency of the array, decreases.

3) TFT array

This is a device that amplifies the signal then stores it as an electrical charge. The charge can be released and read by applying a high potential. In the array each transistor corresponds to a pixel.

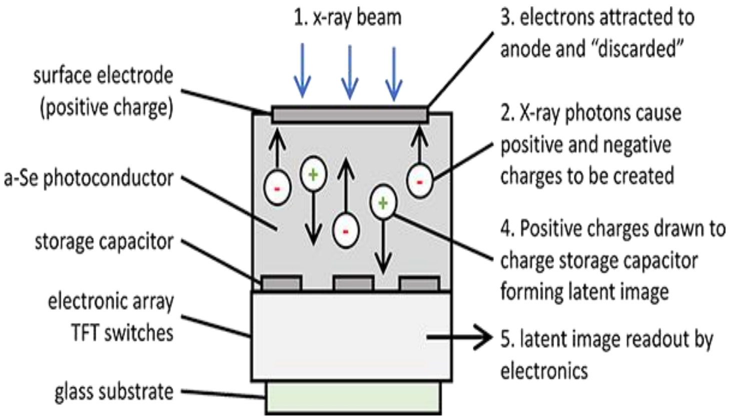
4) X-ray window

The translucent x-ray window is made of aluminium or carbon fibre over the detector entrance to minimise unnecessary absorption and scatter of x-ray photons.

Image formation

1. CsI:TI absorbs x-ray photons and releases light photons
2. These light photons are then absorbed in the photodiodes and the charge stored in the charge storage capacitor at each pixel location
3. The latent image is read out sequentially to a bank of charge sensitive amplifier (TFT switches)
4. The resulting voltage signal is then digitised and transferred to the system computer where the DR image is built up

Direct DR



Direct digital radiography equipment

A layer of x-ray photoconductor material is used instead of an x-ray scintillator.

Photoconductor

This directly converts x-ray photon energy into free electrical charge carriers (electrons and holes) i.e. the "middle-men" or light photons, are cut out. The most commonly used photoconductor is **amorphous selenium (a-Se)**.

Sequence of image formation

1. X-ray photon absorbed by a-Se photoconductor
2. Electrical charge carriers (negative electrons and positive holes) are created in the a-Se

3. A surface electrode at positive potential attracts and discards all the electrons
4. The positive charges are drawn to the charge storage capacitor forming the latent image
5. The latent image is then read out sequentially by gating each row of TFT switches (each TFT corresponds to one pixel) in turn to read the charge pattern and transfer to a bank of charge sensitive amplifiers
6. The resulting voltage signal is then digitised and transferred to the system computer where the DR image is built up
7. Post-processing

Monitor display

Cathode ray tube (CRT)

Visible image generated by scanning a phosphor screen with a focused beam of electrons all contained within an evacuated glass tube.

Flat panel displays

Most display monitors are based on liquid crystal technology. Application of the appropriate voltage distribution to an active matrix modulates light polarisation on a pixel-by-pixel basis varying the light emission that comprises the image seen on the screen. It produces a higher contrast image with greater resolution and less power usage.

Hardcopy

On occasions it is necessary to print a hardcopy image. A hardcopy image is recorded using a laser printer onto a film with silver crystals to create a latent image. This is converted into a visible image by applying heat to the film. This ‘dry’ film processing eliminates the need for traditional chemical processing.

Difference between an X-ray and a fluoroscopy

X-rays and fluoroscopy are medical imaging techniques used to visualize internal body structures. They reveal different details about the body and its condition.

X-ray imaging uses a static image to show bone, tissue, and other structures inside the body that block light. Fluoroscopy uses a live “video” format image to show how organs function in real time as they move through their normal range of motion.

X-rays carry a smaller risk of radiation-related risks than fluoroscopy because they expose patients to less radiation than fluoroscopic imaging.

LASERS IN MEDICINE

The possibility of using light in treating illness has been known for thousands of years. The ancient Greeks and Egyptians used sunlight as a therapy and the two ideas were even tied together in mythology, with the Greek god Apollo taking responsibility for both light and healing.

However, it has only been since the invention of the laser 50 years ago, that the potential of light in medicine has really been revealed.

The special properties of lasers make them much better than sunlight or other light sources at targeting medical applications. Each laser operates within a very narrow wavelength range and the light emitted is coherent. They can also be very powerful. The beams can be focused to a very small point, giving them a high power density. These properties have led to lasers being used in many areas of medical diagnosis and treatment.

Lasers repair skin and eyes

The earliest medical applications for lasers were in ophthalmology and dermatology. Just a year after the invention of the laser in 1960, Leon Goldman demonstrated how a ruby laser, which emits red light, could be used to remove port wine stains, a type of birthmark, and melanomas from the skin.

This application relies on the ability of lasers to operate at a specific wavelength. Lasers are now widely used in dermatology for things like tumor, tattoo, hair, and birthmark removal.

Laser imaging and diagnosis

Lasers have a major role to play in the early detection of cancer as well as many other diseases. For example, in Tel Aviv, Katzir’s group is looking at infrared spectroscopy using IR lasers. This is interesting, according to Katzir, because cancer and healthy tissue may have different transmissions in the IR range. One promising application of the technique is to measure melanomas. With skin cancers, early detection is very important for the patients’ survival rates. Currently melanoma detection is done by eye, so relies on the skill of the physician.

Laser-based systems are also starting to replace the x-rays traditionally used in mammography. Using x-rays poses a challenge: high intensities are needed to be able to detect cancers well, but as the intensity of the x-ray is raised, so is the risk of the x-ray itself causing cancer. The alternative being studied is to use very fast laser pulses to image breasts as well as other parts of the body such as the brain.

OCT for eyes and beyond

There is much enthusiasm about the potential of optical coherence tomography (OCT) in many areas of medicine. This imaging technique can give high-resolution (on the order of microns), cross-sectional, and three-dimensional images of biological tissue in real time, using the coherence properties of laser light. OCT is already used in ophthalmology and can, for example, enable ophthalmologists to see a cross section of the cornea to diagnose retinal disease and glaucoma. It is now beginning to be used in other areas of medicine too.

MAGNETIC RESONANCE IMAGING (MRI)

Magnetic Resonance Imaging (MRI) is a non-invasive imaging technology that produces three dimensional detailed anatomical images. It is often used for disease detection, diagnosis, and treatment monitoring. It is based on sophisticated technology that excites and detects the change in the direction of the rotational axis of protons found in the water that makes up living tissues.

MRIs employ powerful magnets which produce a strong magnetic field that forces protons in the body to align with that field. When a radiofrequency current is then pulsed through the patient, the protons are stimulated, and spin out of equilibrium, straining against the pull of the magnetic field. When the radiofrequency field is turned off, the MRI **sensors** are able to detect the energy released as the protons realign with the magnetic field. The time it takes for the protons to realign with the magnetic field, as well as the amount of energy released, changes depending on the environment and the chemical nature of the molecules. Physicians are able to tell the difference between various types of tissues based on these magnetic properties.

To obtain an MRI image, a patient is placed inside a large magnet and must remain very still during the imaging process in order not to blur the image. Contrast agents (often containing the element Gadolinium) may be given to a patient intravenously before or during the MRI to increase the speed at which protons realign with the magnetic field. The faster the protons realign, the brighter the image.

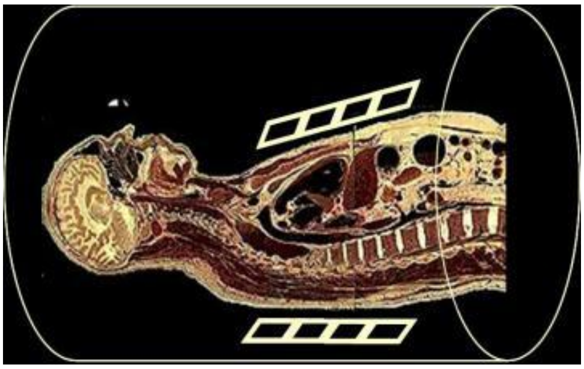
MRI scanners are particularly well suited to image the non-bony parts or soft tissues of the body. They differ from **computed tomography** (CT), in that they do not use the damaging **ionizing radiation** of **x-rays**. The brain, spinal cord and nerves, as well as muscles, ligaments, and tendons are seen much more clearly with MRI than with regular x-rays and CT; for this reason MRI is often used to image knee and shoulder injuries.

In the brain, MRI can differentiate between white matter and grey matter and can also be used to diagnose aneurysms and tumors. Because MRI does not use x-rays or other **radiation,** it is the imaging modality of choice when frequent imaging is required for diagnosis or therapy, especially in the brain. However, MRI is more expensive than x-ray imaging or CT scanning.

One kind of specialized MRI is functional Magnetic Resonance Imaging (fMRI.) This is used to observe brain structures and determine which areas of the brain "activate" (consume more oxygen) during various cognitive tasks. It is used to advance the understanding of brain organization and offers a potential new standard for assessing neurological status and neurosurgical risk.

Although MRI does not emit the **ionizing radiation** that is found in x-ray and CT imaging, it does employ a strong magnetic field. The magnetic field extends beyond the machine and exerts very powerful forces on objects of iron, some steels, and other magnetizable objects; it is strong enough to fling a wheelchair across the room. Patients should notify their physicians of any form of medical or implant prior to an MR scan.

When having an MRI scan, the following should be taken into consideration:



- **People with implants, particularly those containing iron,** — pacemakers, vagus nerve stimulators, implantable cardioverter- defibrillators, loop recorders, insulin pumps, cochlear implants, deep brain stimulators, and capsules from capsule endoscopy should not enter an MRI machine.
- **Noise**—loud noise commonly referred to as clicking and beeping, as well as sound intensity up to 120 decibels in certain MR scanners, may require special ear protection.
- **Nerve Stimulation**—a twitching sensation sometimes results from the rapidly switched fields in the MRI.
- **Contrast agents**—patients with severe renal failure who require dialysis may risk a rare but serious illness called nephrogenic systemic fibrosis that may be linked to the use of certain gadolinium-containing agents, such as gadodiamide and others. Although a causal link has not been established, current guidelines in the United States recommend that dialysis patients should only receive gadolinium agents when essential, and that dialysis should be performed as soon as possible after the scan to remove the agent from the body promptly.
- **Pregnancy**—while no effects have been demonstrated on the fetus, it is recommended that MRI scans be avoided as a precaution especially in the first trimester of pregnancy when the fetus' organs are being formed and contrast agents, if used, could enter the fetal bloodstream.
- **Claustrophobia**—people with even mild claustrophobia may find it difficult to tolerate long scan times inside the machine. Familiarization with the machine and process, as well as visualization techniques, sedation, and anesthesia provide patients with mechanisms to overcome their discomfort. Additional coping mechanisms include listening to music or watching a video or movie, closing or covering the eyes, and holding a panic button. The open MRI is a machine that is open on the sides rather than a tube closed at one end, so it does not fully surround the patient. It was developed to accommodate the needs of patients who are uncomfortable with the narrow tunnel and noises of the traditional MRI and for patients whose size or weight make the traditional MRI impractical. Newer open MRI technology provides high quality images for many but not all types of examinations.

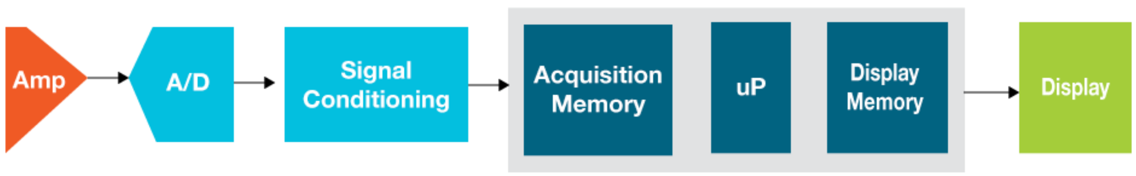
UNIT- V

OSCILLOSCOPE

An oscilloscope, formerly known as an oscillograph (informally scope, oscope, or o-scope), is an instrument that graphically displays electrical signals and shows how those signals change over time. It measures these signals by connecting with a sensor, which is a device that creates an electrical signal in response to physical stimuli like sound, light and heat. For instance, a microphone is a sensor that converts sound into an electrical signal.

Working of oscilloscope

There are three primary oscilloscope systems: vertical, horizontal and trigger systems. Together, these systems provide information about the electrical signal, so the oscilloscope can accurately reconstruct it. The picture below shows the block diagram of an oscilloscope.



The first stage attenuates or amplifies the signal voltage in order to optimize the amplitude of the signal; this is referred to as the vertical system since it depends on the vertical scale control. Then the signal reaches the acquisition block, where the analog-to-digital converter (ADC) is used to sample the signal voltage and convert it in a digital format value. The horizontal system, which contains a sample clock, gives each voltage sample a precise time (horizontal) coordinate. The sample clock drives the ADC and its digital output is stored in the acquisition memory as a record point. The trigger system detects a user-specified condition in the incoming signal stream and applies it as a time reference in the waveform record.

Cathode Ray Oscilloscope

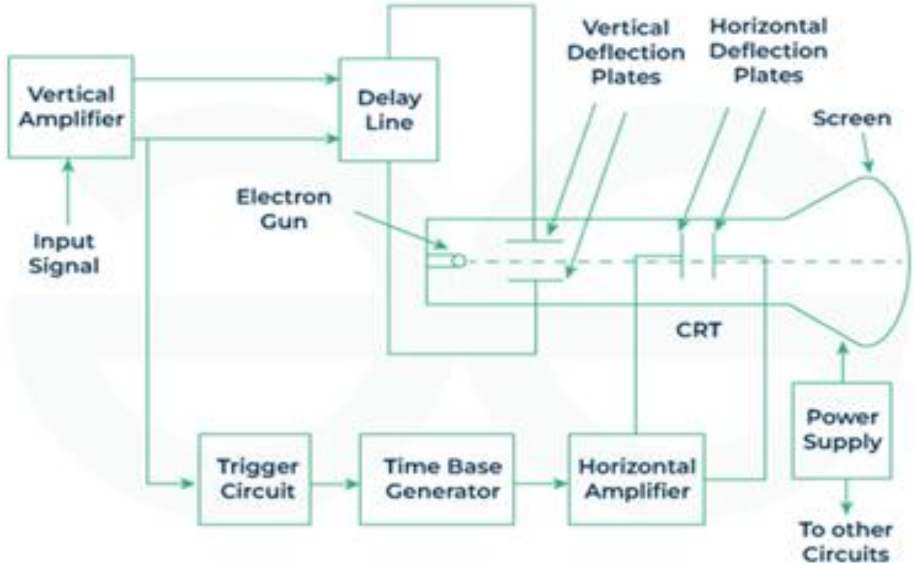
The CRO represents a cathode ray oscilloscope. It is commonly separated into four sections which are show, vertical controllers, horizontal controllers, and Triggers- it is based on the cathode ray tubes which provide a clear image of electrical quantities. The probes that make up the majority of oscilloscopes serve as the instrument's input. We can analyze the waveform by plotting amplitude alongside the x-axis and y-axis. The utilization of CROs is principally engaged with radio and television inputs, likewise in lab work including research and planning. The CRO plays a crucial role in the electronic circuits of modern electronics.

The cathode ray oscilloscope is an electronic test instrument, it is utilized to get waveforms when the different information signals are given. It was originally known as an oscilloscope. The oscilloscope notices the progressions in the electrical signs over the long run, subsequently the voltage and time portray a shape and it is persistently graphed close to a scale. By seeing the waveform, we can break down certain properties like amplitude, frequency, rise time, time interval, distortion, etc.

The cathode ray oscilloscope is mainly worked on voltage and additionally other actual amounts like strain, current; pressure and speed increase are changed into the voltage utilizing the transducer and show on a CRO. This instrument incorporates an iridescent spot or pointer that turns on the showcase locale because of an information voltage. This pointer can be delivered through an electron bar that hits on a fluorescent display. Basically this test is used to perform the waveforms based on the input signals or in response to them. Electron beam and cathode ray tube is used to analyze the waveforms with the help of electrical circuits and thus it plays important role in electronic circuits.

The run of the mill type of the cathode ray oscilloscope utilizes a flat info voltage i.e. inside created incline voltage known as a period. The level voltage moves the pointer occasionally in a flat manner from the passed-on side to one side on the region of the screen. Here the upward voltage is only the voltage below investigation. This voltage moves the pointer up and down on the showcase. When the info voltage moves rapidly on the showcase, then, at that point, it seems idle. Hence, this oscilloscope furnishes the imagining voltage by changing with time.

Hence, the screen creates a noticeable place where the electron strikes hits with it. The electrons can behave like an electrical pencil of light and produce light where it strikes by responding to the electrical signal by detecting the beam above the screen. To get done with this responsibility we want different electrical signals and voltages. This gives the power supply circuit of the oscilloscope. Here we will utilize high voltage and low voltage. The low voltage is utilized for the radiator of the electron firearm to produce the electron beam. A high voltage is expected for the cathode ray tube to speed the beam. The typical voltage supply is important for other control units of the oscilloscope.



The level and vertical plates are put between the electron firearm and the screen, subsequently it can distinguish the shaft as indicated by the info signal. Not long prior to identifying the electron shaft on the screen in the level bearing which is in X-axis a consistent time-subordinate rate, a period base generator is given by the oscillator. The signs are passed from the upward diversion plate through the upward enhancer. In this way, it can amplifier the signal to a level that will be given the diversion of the electron beam. In the event that the electron beam is recognized in the X-axis and the Y-axis a trigger circuit is given for synchronizing these two sorts of location. Consequently, the input signal and the horizontal deflection begin at the same location.

Construction of Cathode Ray Oscilloscope

The construction of cathode ray consist of the following components:

- Cathode Ray Tube
- Electronic Gun
- Deflecting Plate
- Fluorescent Screen For CRT
- Glass Envelope

Cathode Ray Tube

The CRO is the vacuum tube and the fundamental capability of this gadget is to change the sign from electrical to visual. This cylinder incorporates the electron weapon as well as the electrostatic avoidance plates. The primary purpose of this electron gun is to produce a focused, high-frequency electronic ray. The upward redirection plate will turn the beam up and down while the flat beam moved the electrons radiates from the passed on side to the right side. The ray can be positioned anywhere on the monitor because these actions are independent of one another.

Electronic Gun

The fundamental capability of the electron firearm is to transmit the electrons to frame them into a beam. This weapon for the most part incorporates a radiator, a lattice, cathode, and anodes like speeding up, per-speeding up and centering. At the cathode end, the strontium and barium layers are stored to get the high electrons outflow of electrons at the moderate temperature, the layers of barium, and are kept toward the finish of the cathode. After electrons are produced from the cathode grid, they travel through the control grid, which is typically a nickel cylinder, via a coaxial axis located in the center of the CRT. In this way, it controls the strength of the created electrons from the cathode.

At the point when electrons stream all through the control lattice then it advances with the assistance of a high certain potential which is applied to the per-speeding up or speeding up hubs. The electron beam is focused on anodes to stream all through the avoidance plates like flat and vertical and supplies on to the fluorescent light. The anodes like speeding up and per-speeding up are associated with 1500v and the centering terminal can be associated with 500v. The electron beam can be centered around utilizing two procedures like Electrostatic and Electromagnetic centering. Here, a cathode beam oscilloscope uses an electrostatic centering tube.

Deflecting Plate

When the electron beam leaves the electron weapon then this beam will pass all through the two arrangements of the avoiding plate. This set will produce the upward diversion that is known as Y plate's generally vertical diverting plate. The arrangement of the plate is utilized for a level diversion which is known as X plate's generally even redirection.

Fluorescent Screen of CRT

In the CRT, the front face is known as the face-plate, For the CRT screen, it is level and its size is around 100mm×100mm. For larger displays, the CRT screen is slightly bent, and the face plate can be formed by pressing molten glass into a shape and then heating it.

The inward essence of the face-plate is covered by utilizing phosphor precious stone to change the energy from electrical to light. When a hardware beam hits phosphor precious stone, the energy level can be upgraded and subsequently light is created all through phosphorous crystallization, so this event is known as fluorescence.

Glass Envelope

It is an incredibly cleared cone shaped type of development. Within countenances of the CRT among the neck as well as the showcase are covered through the aqua-dag. This material is conductive and functions like a high-voltage electrode. The outer layer of the covering is associated electrically toward the speeding up anode to assist the electron with being the middle.

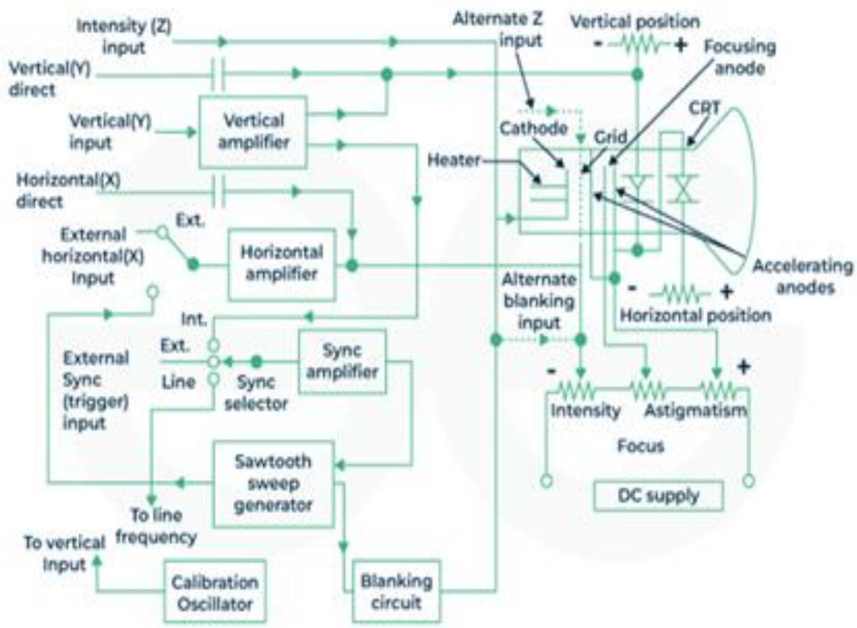
Working of Cathode Ray Oscilloscope

The CRO working principle relies upon the electron ray movement as a result of the electrostatic force. When an electron ray hits a phosphor face, then, at that point, it makes a splendid spot on it. A Cathode ray Oscilloscope applies the electrostatic energy on the electron beam from two vertical ways. The spot on the phosphor screen goes because of the impact of these two electrostatic forces which are opposite together. It moves to make the important waveform of the input signal.

The following circuit diagram shows the fundamental circuit of a cathode ray oscilloscope.

- **Vertical Deflection System :** The primary capability of this amplifier is to amplify the weak signal so the amplified signal can create the ideal signal. To analyze the input signals are entered to the vertical deflection plates through the info attenuate and the quantity of amplifier stages.
- **Horizontal Deflection System :** The vertical and even framework comprises of flat intensifiers to enhance the frail info signals, however it is not quite the same as the upward avoidance framework. The flat diversion plates are entered by a range voltage that gives a period base. The saw-tooth wave generator is triggered by the synchronizing amplifier, as shown in the circuit diagram, while the sweep selector

moves into the internal position. So the trigger saw tooth generator gives the contribution to the even enhancer by following the system. Here we will examine the four kinds of sweeps.



- **Recurrent Sweep :** As the name, itself says that the saw-tooth is individual that is another scope is begun indecently toward the finish of the previous sweep.
- **Triggered Sweep :** In some cases the waveform ought to be seen that it may not be anticipated hence, the ideal that the compass circuit stays out of commission and the scope ought to be started by the waveform under the assessment. In these cases, we will utilize the triggered sweep.
- **Driven Clear :** As a rule, the drive sweep is utilized when the sweep is free-running yet it is triggered by the signal under the test.
- **Non-Saw Tooth Sweep :** The purpose of this sweep is to determine the difference between the two voltages. Non-Saw Tooth Sweep By utilizing the non-saw tooth clear we can analyze the frequency of the input voltages.
- **Synchronization :** The synchronization is finished to create a fixed example. The synchronization is between the sweep and the signal should measure. There are a few

wellsprings of synchronization that can be chosen by the synchronization selector. Which are discussed below.

- **Internal :** In this, the signal is estimated by the upward enhancer and the trigger is avoided by the signal.
- **External :** In the outer trigger, the outside trigger ought to be available.
- **Line :** The line trigger is delivered by the power supply.
- **Intensity Modulation :** This modulation is delivered by embedding the signal between the ground and cathode. This modulation causes by lighting up the display.
- **Positioning Control :** By applying the little autonomous inner direct voltage source to the recognizing plates through the voltmeter the position can be controlled and furthermore we have some control over the place of the sign.
- **Intensity Control :** The intensity has a distinction by changing the network potential as for the cathode.

Controls of Cathode Ray Oscilloscope

The fundamental controls of CRO primarily incorporate position, brightness, focus, astigmatism, blanking and calibration.

- **Position :** In the oscilloscope, the position control handle is mostly utilized for position control of the serious spot from the passed on side to the right side. By directing the handle, one can essentially control the spot from passed on side to the right side.
- **Calibration Circuit :** A calibration circuit for an oscilloscope requires an oscillator. Notwithstanding, the oscillator which is utilized ought to create a square waveform for preset voltage.
- **Focus :** By controlling the applied voltage in the direction of the CRO's center anode, focus can be controlled. The center and different anodes in the district of it can shape the electrostatic focal point. As a result, the voltage across the center anode can be adjusted to change the main length of the lens.
- **Blanking Circuit :** The time base generator present in the oscilloscope created the blanking voltage.

- **Brightness :** The ray's brightness mainly relies upon the power of the electron. The electron intensity of the electron ray is controlled by the control grids. As a result, the electron ray brightness can be adjusted to control the grid voltage.

Electrical Quantities Measurements using Cathode Ray Oscilloscope

Electrical quantities measurements by using CRO should be possible. They are

- Measurement of Amplitude
- Measurement of Time Period
- Measurement of Frequency

Measurement of Amplitude

The display like CRO is used to show the voltage signal like a period capability on its presentation. This signal's amplitude is constant; nonetheless, we can switch the quantity of allotments that cover around the voltage signal inside vertical way by evolving volt/division button on top of the CRO board. Thus, we will secure the signal amplitude, which is there on the CRO screen with the assistance of the below formula.

$A = j * nv$

Where,

- 'A' is the Amplitude
- 'j' is the volt/division value
- 'nv' is the no. of partitions that vertically cover the signal.

Measurement of Time Period

CRO shows the voltage signal as an element of time on its screen. The Time period of that periodic voltage signal is consistent, however we can fluctuate the quantity of divisions that cover one complete pattern of the voltage signal in the flat heading by changing the time/division handle on the CRO panel.

In this way, we will get the Time period of the signal, which is available on the screen of CRO by using the accompanying formula.

$T = k * nh$

Where,

- 'T' is the Time period
- 'j' is the time/division value
- 'nv' is the number of partitions that cover whole cycle of the periodic signal.

Measurement of Frequency

The horizontal scale on the CRO screen makes it simple to measure frequency and tile. To ensure exactness while estimating a recurrence, then, at that point, it helps to upgrade the region of the sign on your CRO show so we can all the more basically convert the waveform.

At first, the time can be counted using the horizontal scale on the CRO and the number of flat partitions from one end of the signal to the other wherever it crosses the flat line. From that point forward, we can foster the quantity of level allotments through the time or division to find the time span of the sign. Numerically the estimation of the recurrence can be connoted as frequency = 1/period.

$f = 1/T$

Applications of Cathode Ray Oscilloscope

The applications of CRO are as follows:

- **Waveform Analysis:** The primary application of CROs is in the visualization and analysis of wave shapes. Researchers and architects can examine the duration, pattern, amount, and structure of electrical signals in the temporal space. This skill is essential for determining how symptoms behave and for identifying problems with electronic circuits. Used for Ensuring signal honesty by identifying wave form distortions, noise, and anomalies.
- **Time Domain Analysis:** The time area involves focusing on the long-term behavior of the signals. CROs provide a graphical representation that aids experts in understanding how signals fluctuate and interact with one another. Used for identifying signal anomalies and transient phenomena for the purpose of troubleshooting electronic circuits.

- **Pulse and Transition Time Measurement:** CROs are utilized to gauge beat widths and change times in computerized circuits. For evaluating digital system performance and timing characteristics, this capability is essential. Used for evaluating the response time of digital devices and verifying the integrity of digital signals.
- **Voltage Measurement:** CROs give a way to exact estimation of voltage levels in a sign. This capacity is central for describing and approving electronic frameworks. Used for measuring voltages, amplitudes, and DC offsets from peak to peak in a variety of electrical signals.
- **Oscillator Testing:** CROs assume a critical part in testing and examining the exhibition of oscillators, which create occasional wave forms. This incorporates evaluating the recurrence steadiness and waveform qualities of oscillators. Used for Checking the appropriate working of oscillators in electronic frameworks.
- **Filter Testing:** Engineers use CROs to assess the exhibition of electronic channels by noticing their impacts on wave forms. This includes evaluating filters' frequency response and attenuation properties. Used for Checking the usefulness and viability of channels in signal handling applications.
- **Frequency Measurement:** CROs take into consideration precise estimation of the recurrence of dreary waveform. The time base settings on the oscilloscope assist with deciding the time span of the sign, empowering exact recurrence estimations. Used for Confirming the recurrence of swaying signals in electronic circuits for legitimate working.
- **Transient Analysis:** CROs are pivotal for catching and breaking down transient peculiarities in electronic circuits. Homeless people are unexpected and fleeting changes in voltage that can affect the security and dependability of a framework. Used for Contemplating and investigating abrupt changes or aggravations in electronic circuits, for example, voltage spikes or errors.
- **Measurement of Phase:** CROs work with the estimation and perception of stage contrasts between different signs. Here the timing connection between signals is critical. It is used for Guaranteeing synchronization and arrangement of signs in correspondence frameworks or control circuits.

- **Sound and Video Applications:** CROs track down applications in the sound and video industry for examining signals connected with sound and picture handling. This includes checking the quality of the video signal or the frequency response of the audio. It is used for Guaranteeing the quality and constancy of sound and video signals in communicating, diversion, and media applications.

Advantages of Cathode Ray Oscilloscope

- **Real-time Visualization:** CRO gives continuous perception of electrical signals, permitting clients to notice wave structures and signal attributes as they happen.
- **Dynamic Signal Observation:** CROs empower the perception of dynamic signal changes, making them important for concentrating on quickly evolving signals, for example, pulse or regulated wave structures.
- **High Accuracy:** CROs are reliable instruments for precise signal analysis because they measure waveform parameters like amplitude, frequency, and phase with high accuracy.
- **Versatility**: Due to their versatility in waveform analysis, CROs can be used in a variety of fields, including electronics, telecommunications, medicine, and physics.
- **Tool for Education:** CROs are useful tools for teaching electronics because they give students a chance to see and understand electrical signals in action.
- **Time Domain Analysis:** CROs are fundamental for time space examination, permitting clients to concentrate on the way of behaving of signals after some time and break down transient peculiarities in electronic circuits.
- **Easy to use**: With current digital CROs, UIs are natural, and highlights like programmed estimations and on-screen menus upgrade client experience, making them open for a great many clients.
- **Quick Troubleshooting:** CROs work with fast recognizable proof and investigating of electronic circuit issues by giving a visual of signals, empowering specialists to pinpoint irregularities.

Disadvantages of Cathode Ray Oscilloscope

- **Susceptibility to Electromagnetic Interference:** CROs can be delicate to electromagnetic obstruction, which might influence signal exactness. Protecting and cautious arrangement are important to limit obstruction.
- **Limited Bandwidth**: Some CRO models might have restricted transmission capacity, limiting their capacity to precisely address high-recurrence signals. High-recurrence applications might require particular oscilloscopes.
- **Cost:** Excellent CROs can be generally costly, particularly those with cutting edge highlights. This cost element might be a thought for spending plan compelled clients or little research facilities.
- **Limited Storage Capacity**: Simple CROs might have restricted capacity limit with regards to waveform information. While computerized CROs offer better information stockpiling, the capacity limit is limited and might be a constraint in specific applications.
- **Mass and Weight:** The weight and bulk of traditional analog CROs can make them difficult to transport. While present day computerized oscilloscopes are more minimal, size and weight can in any case be a worry in specific applications.
- **Risk of Electric Shock:** Cathode ray tubes have high voltages, which can cause electric shock if proper safety precautions are not taken during maintenance or repairs.
- **Complexity for Novice Users:** For inexperienced users, some CROs' advanced features may be overcome. Preparing and experience with the instrument are fundamental for ideal use, particularly in complex applications.