EET203
MODULE V

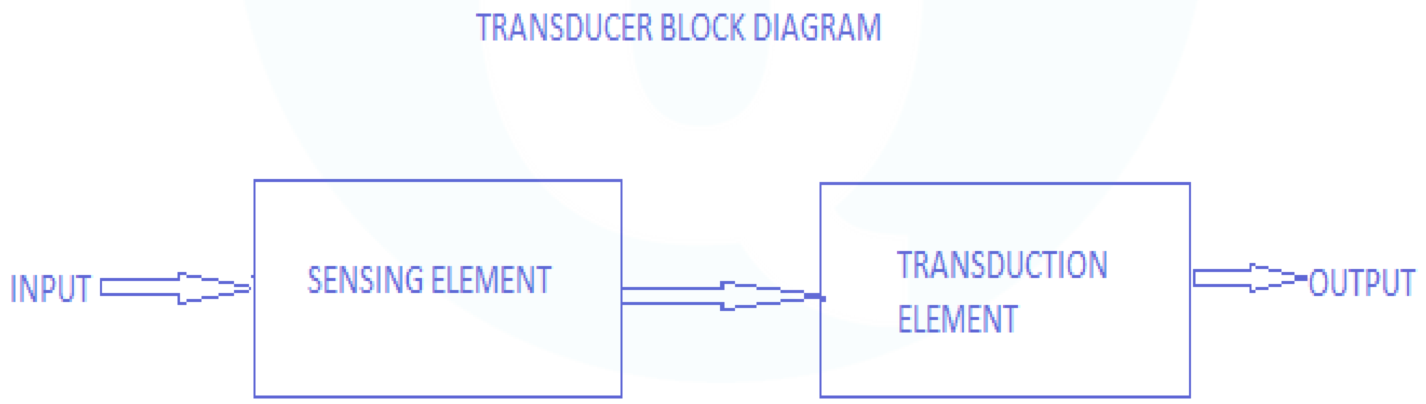
KtuQbank

Syllabus

- Transducers - Definition and classification. LVDT, Electromagnetic and Ultrasonic flow meters, Piezoelectric transducers-modes of operation-force transducer, Load cell, Strain gauge.
- Oscilloscopes- Principal of operation of general purpose CRO- basics of vertical and horizontal deflection system, sweep generator etc. DSO-Characteristics-Probes and Probing techniques.
- Digital voltmeters and frequency meters using electronic counters, DMM, Clamp on meters.
- Phasor Measurement Unit (PMU) (description only).
- Introduction to Virtual Instrumentation systems- Simulation software's (description only)

Transducer

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



Parts of Transducer

- The transducer consists two important parts.

  1)Sensing Element

  2)Transduction Element
- The transducer has many other parts like amplifiers, signal processing equipment, power supplies, calibrating and reference sources, etc.
- **Sensing or Detector Element** – It is the part of the transducers which give the response to the physical sensation. The response of the sensing element depends on the physical phenomenon.
- **Transduction Element** – The transduction element converts the output of the sensing element into an electrical signal.

Transducer Types

- The transducer is of many types, and they can be classified by the following criteria:

1) By transduction used
2) as a primary and secondary transducer
3) as a passive and active transducer
4) as analog and digital transducer
5) as transducer and inverse transducer

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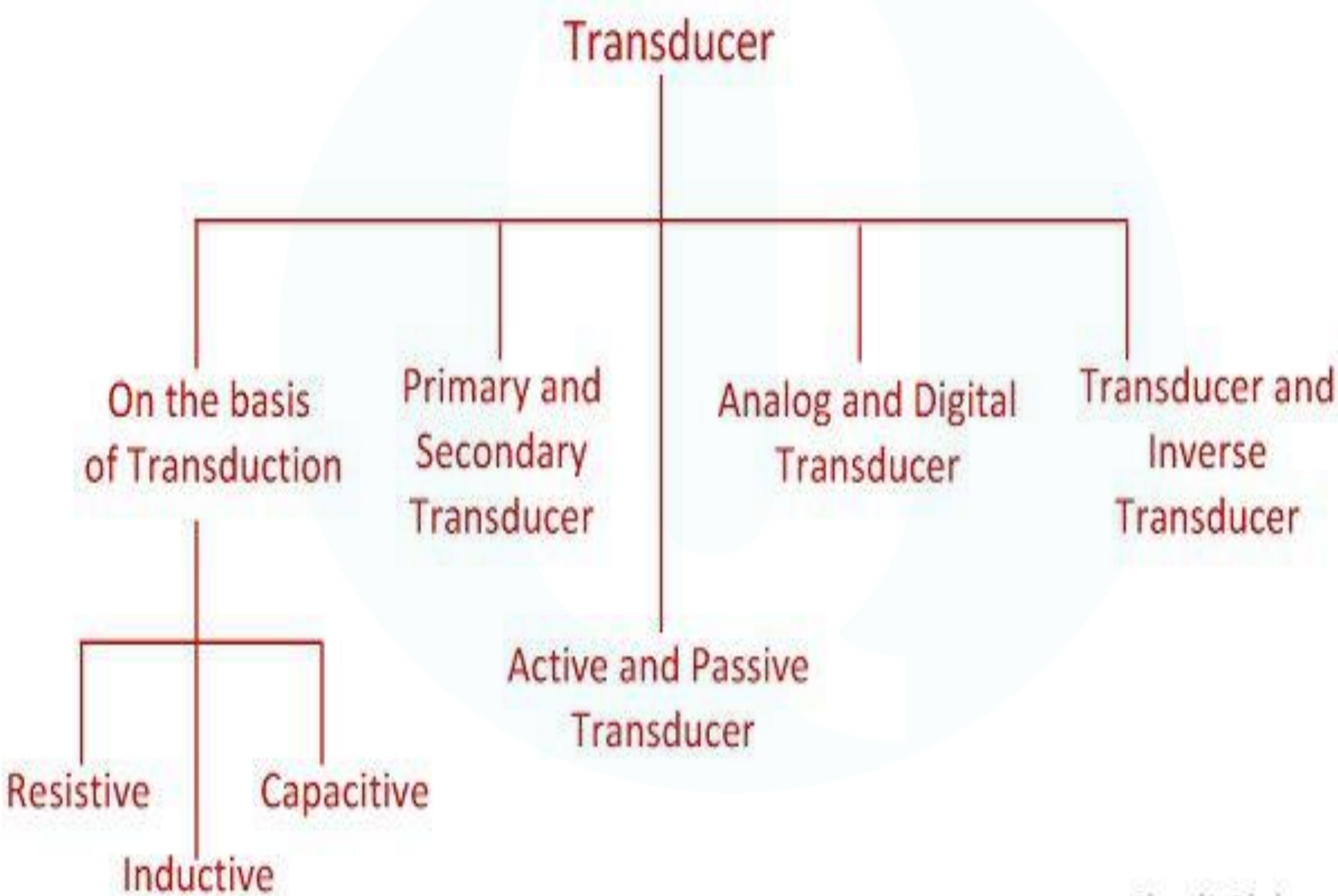
Transducer
On the basis of Transduction
Primary and Secondary Transducer
Analog and Digital Transducer
Transducer and Inverse Transducer
Active and Passive Transducer
Resistive
Capacitive
Inductive

1. **Classification based on the Principle of Transduction**

- The transducer is classified by the transduction medium.
- The transduction medium may be resistive, inductive or capacitive depending on the conversion process that how input transducer converts the input signal into resistance, inductance and capacitance respectively.

2. Primary and Secondary Transducer

- Primary Transducer –Input signal is directly sensed by the transducer and physical phenomenon is converted into electrical form directly.
- Secondary Transducer – Input signal is first sensed by some sensor & then its output being of some form other than input signal is given as input to a transducer for conversion into electrical form.

3. Passive and Active Transducer

- Passive Transducer – The transducer which requires the power from an external supply source is known as the passive transducer.
- They are also known as the external power transducer.
- The capacitive, resistive and inductive transducers are the example of the passive transducer.
- Active Transducer – The transducer which does not require the external power source is known as the active transducer.
- Such type of transducer develops theirs own voltage or current, hence known as a self-generating transducer.
- The piezoelectric crystal, photo-voltaic cell, thermocouples, photovoltaic cell are the examples of the active transducers.

4. Analog and Digital Transducer

- Analog Transducer – The Analog transducer changes the input quantity into a continuous function.
- The strain gauge, L.V.D.T, thermocouple, thermistor are the examples of the analog transducer.
- Digital Transducer – These transducers convert an input quantity into a digital signal or in the form of the pulse.

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5. Transducer and Inverse Transducer

- Transducer – The device which converts the non-electrical quantity into an electric quantity is known as the transducer.
- Inverse Transducer – The transducer which converts the electric quantity into a physical quantity, such type of transducers is known as the inverse transducer.

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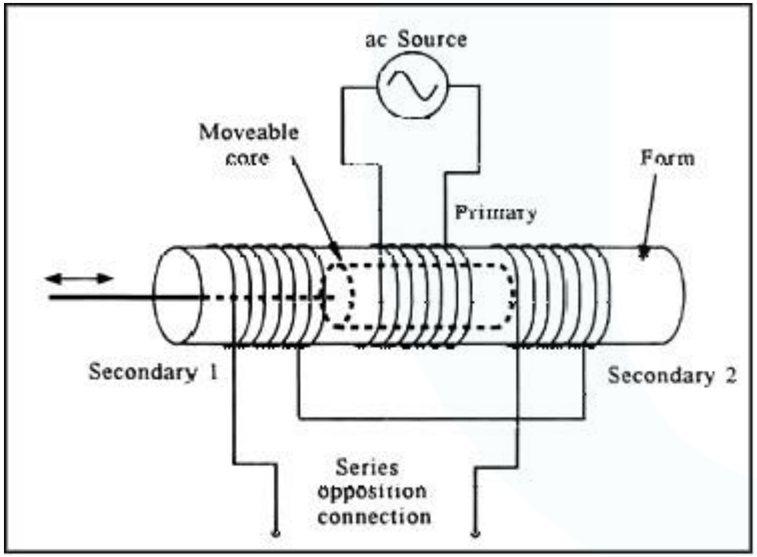
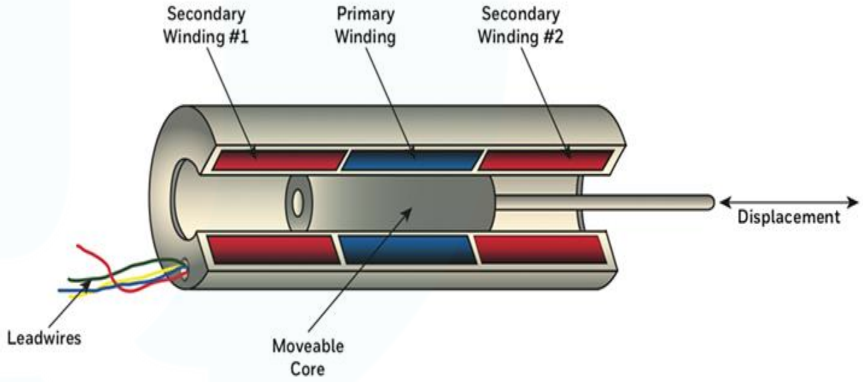
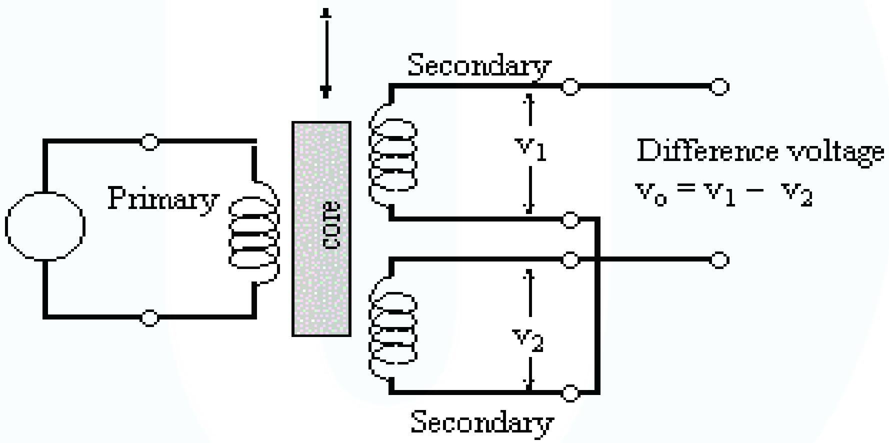
LVDT

- Linear Variable Differential Transformer



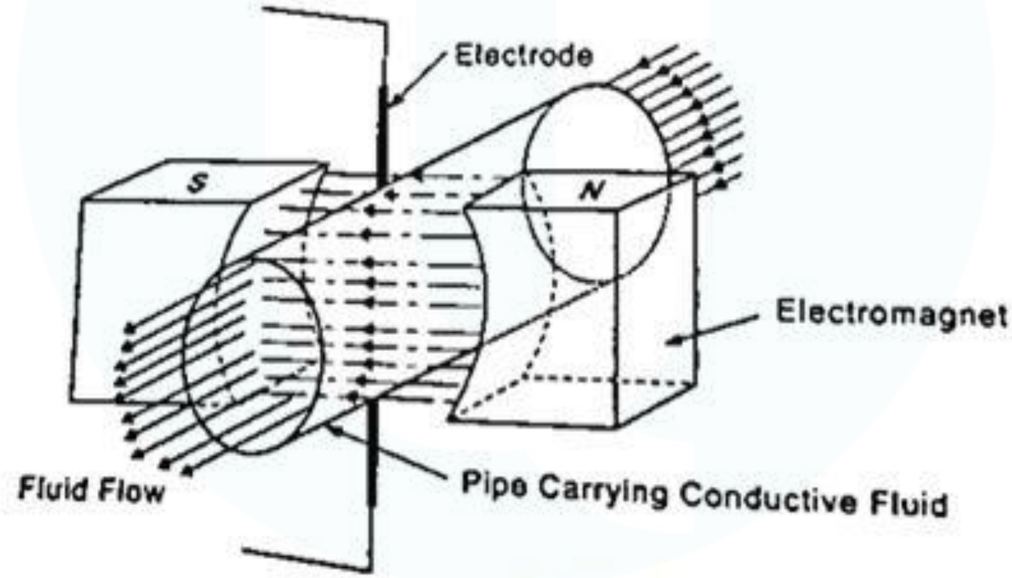


- Refer A.K Sawhney page 788-791



FLOW MEASUREMENT

- ELECTROMAGNETIC FLOW METER
- (A.K Sawhney page 1028)



Electromagnetic Flow Meter

- Electromagnetic flow meters use Faraday’s law of electromagnetic induction for making flow measurement.
- Faraday’s law states that, whenever a conductor of length ‘l’ moves with a velocity ‘v’ perpendicular to a magnetic field ‘B’, an emf ‘e’ is induced in a mutually perpendicular direction which is given by

$$\mathbf{e = B\, l\, v}$$

where

B = Magnetic flux density (Wb/m^2)
l = length of conductor (m)
v = Velocity of the conductor (m/s)

- The volume flow rate Q is given by

$$Q = (\pi d^2/4)\ v$$

where
d = diameter of the pipe
v = average velocity of flow (conductor velocity)

From equation

$$v = e/Bl$$

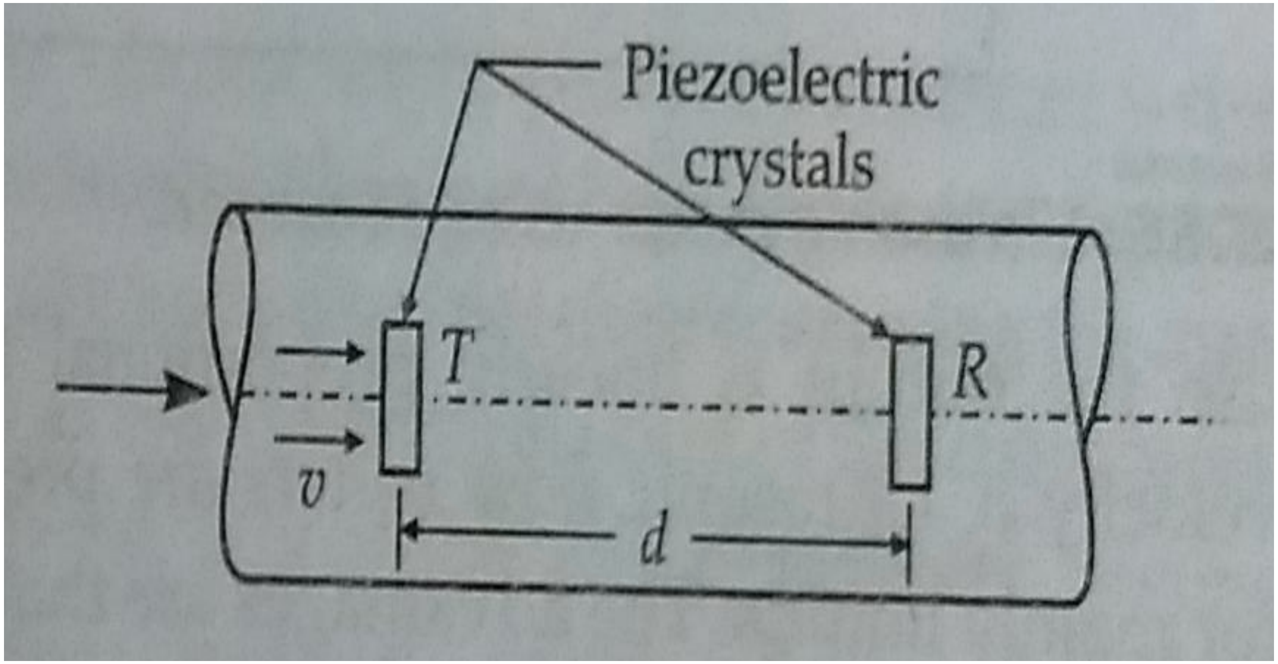
$$Q = \pi d^2 e/4Bl$$

$$Q = Ke$$

where K is a meter constant.

- Thus the **volume flow rate is proportional to the induced emf**

Ultrasonic flowmeters



Basically an ultrasonic transducer for flow rate consists of two piezoelectric crystals in the liquid or gas separated by a distance. One of the crystals' acts as a transmitter and the other as a receiver.

The transmitter emits an ultrasonic pulse which is received at the receiver a time Δt later. The transit time in the direction of flow is,

$$\Delta t_1 = \frac{d}{c+v} \quad \text{...(29.80)}$$

where d = distance between transmitter and receiver ; m,

c = velocity of sound propagation in medium ; m/s,

v = linear velocity of flow ; m/s.

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

$$\Delta t_2 = \frac{d}{c-v} \quad \text{...(29.81)}$$

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

$$\Delta\phi_1 = \frac{2\pi f d}{c+v} \text{ rad} \quad \text{...(29.82)}$$

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

$$\Delta\phi_2 = \frac{2\pi f d}{c-v} \text{ rad} \quad \text{...(29.83)}$$

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

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

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

$$\Delta t = \Delta t_2 - \Delta t_1 = \frac{2dv}{c^2 - v^2} \qquad \text{...(29.84)}$$

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

$$\therefore \qquad \Delta t \approx \frac{2dv}{c^2} \qquad \text{...(29.85)}$$

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

A system based upon f

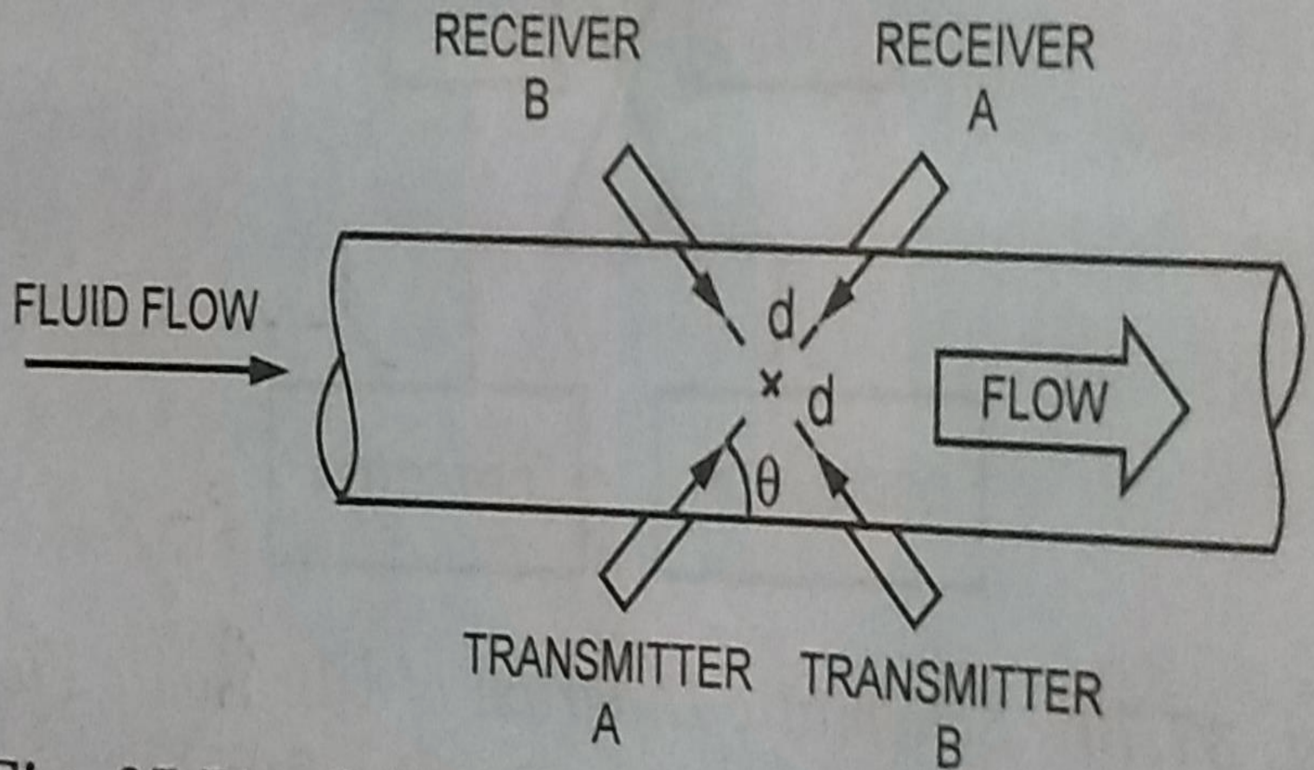


Fig. 37.71 *Schematic Diagram of Transit Time Ultrasonic Flow meter*

The schematic diagram of an ultrasonic flow meter
operating on second principle is illustrated in Fig. 37.71.
Such a flow meter is called the *transit time flow meter* or
leading-edge meter. In this arrangement two sets of
piezocrystals (a transmitter and a receiver as a set) are
mounted as shown in the figure and wave trains are sent
at an angle θ with the direction of fluid flow in either way.

The velocity of the ultrasonic signal from the trans-
mitter A to the receiver A is increased while that from the
transmitter B to receiver B is decreased because of fluid
flow velocity in the direction or in opposite direction of sound
path.

If C is the sound propagation velocity in medium in
m/s, *v* is the fluid flow velocity in m/s, *d* is the distance
between the transmitter and receiver in metres and θ is
the angle between the sound path and the pipe wall, the
repetition frequencies in the upstream side and downstream
side will be

$$f_a = \frac{C + v\cos\theta}{d} \text{ and } f_b = \frac{C - v\cos\theta}{d} \text{ respectively}$$

The difference in frequency is given by

$$\Delta f = f_a - f_b = \frac{2v\cos\theta}{d} \qquad \ldots(37.45)$$

By measuring the difference in the repetition frequency Δf, and knowing the values of θ and d, the velocity of the fluid flow can be determined. Alternatively, the flow velocity can be determined by measuring the time difference between the two pulse trains in either direction as $\Delta t = 1/\Delta f$.

Equation (37.45) shows that output is independent of C, therefore, the effects of pressure and temperature are avoided. Also the output is linearly proportional to the velocity of fluid flow. The measurement is insensitive to viscosity, pressure and temperature variations. The other advantages are no obstruction to flow, bidirectional measuring capabilities, good accuracy, fast response, wide frequency range and its versatility in that it can be employed for any pipe size.

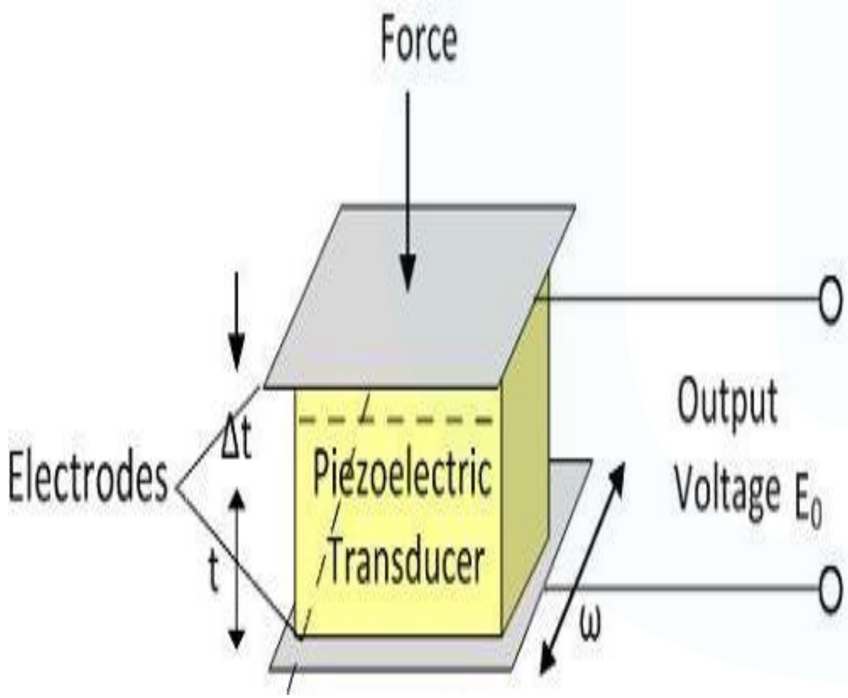
However, the complexity and relatively high cost limit its use for individual applications.

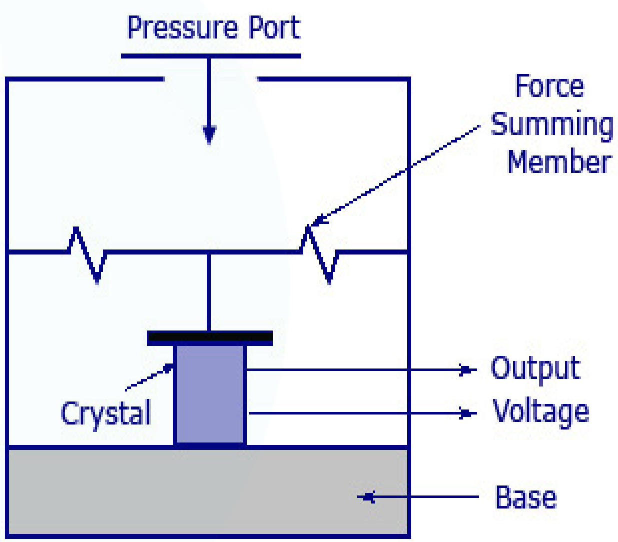
Piezoelectric Transducer

- Device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.
- 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.
- A piezoelectric transducer is based on the principle of the piezoelectric effect.
- The word piezoelectric is derived from the Greek word piezen, which means to squeeze or press.
- The piezoelectric effect states that when mechanical stress or forces are applied on quartz crystal, produce electrical charges on the quartz crystal surface.
- The rate of charge produced will be proportional to the rate of change of mechanical stress applied to it.
- Higher the stress higher will be voltage.

- A piezo-electric material is one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force.
- This potential is produced by the displacement of charges.
- The effect is reversible, i.e. conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it.
- This effect is known as piezo-electric effect.
- A piezo-electric element used for converting mechanical motion to electrical signals may be thought as charge generator and a capacitor.
- Mechanical deformation generates a charge and this charge appears as a voltage across the electrodes.
- The voltage is $\mathbf{E = Q/C_p}$

- A piezoelectric transducer consists of quartz crystal which is made from silicon and oxygen arranged in crystalline structure (SiO_2).
- Generally, unit cell (basic repeating unit) of all crystal is symmetrical but in piezoelectric quartz crystal, it is not.
- Piezoelectric crystals are electrically neutral.
- The atoms inside them may not be symmetrically arranged but their electrical charges are balanced means positive charges cancel out negative charge.
- The quartz crystal has the unique property of generating electrical polarity when mechanical stress applied to it along a certain plane.





Piezo-Electric Transducer

- The magnitude and polarity of the induced surface charges are proportional to the magnitude and direction of the applied force F.
- Charge **Q= dF**

  where d=charge sensitivity of the crystal

  (It is constant for a given crystal)

  F=applied force
- The charge at the electrodes gives rise to an output voltage E_o.

  $$\mathbf{E_o = Q/C_p}$$

  where C_p=capacitance between electrodes
- Capacitance between electrodes $\mathbf{C_p = \in A/t}$

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Where A- Area and t- thickness

- Thus $E_o = Q/C_p$

$E_o = dFt / \in A$

- But F/A = P ,Pressure or stress in N/m^2

$E_o = gPt$

Where $g = d/ \in$

g=voltage sensitivity of crystal

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Modes of operation

- The piezo-electric effect is direction sensitive. A ·tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity.
- The piezo-electric effect can be made to respond to mechanical deformations of the material in many different modes.
- The modes can be : a)thickness expansion b)transverse expansion, c)thickness shear and d)face shear.
- The mode of motion effected depends on the shape of the body relative to the crystal axis and location of the electrodes.

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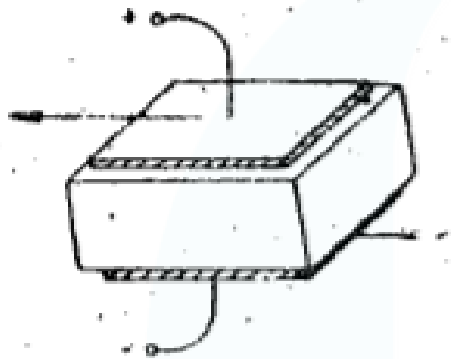
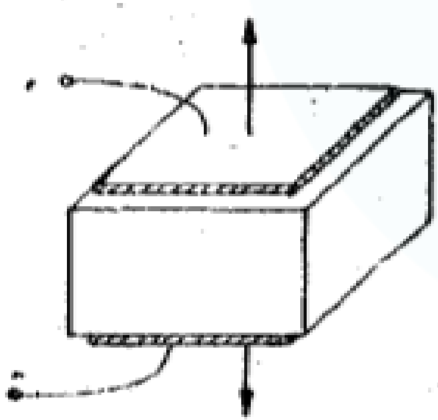
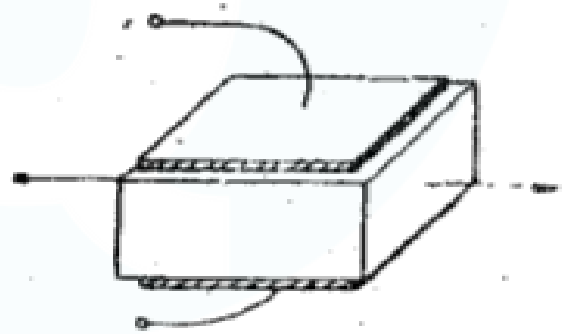


a) Thickness shear

b) Face shear



c) Thickness expansion



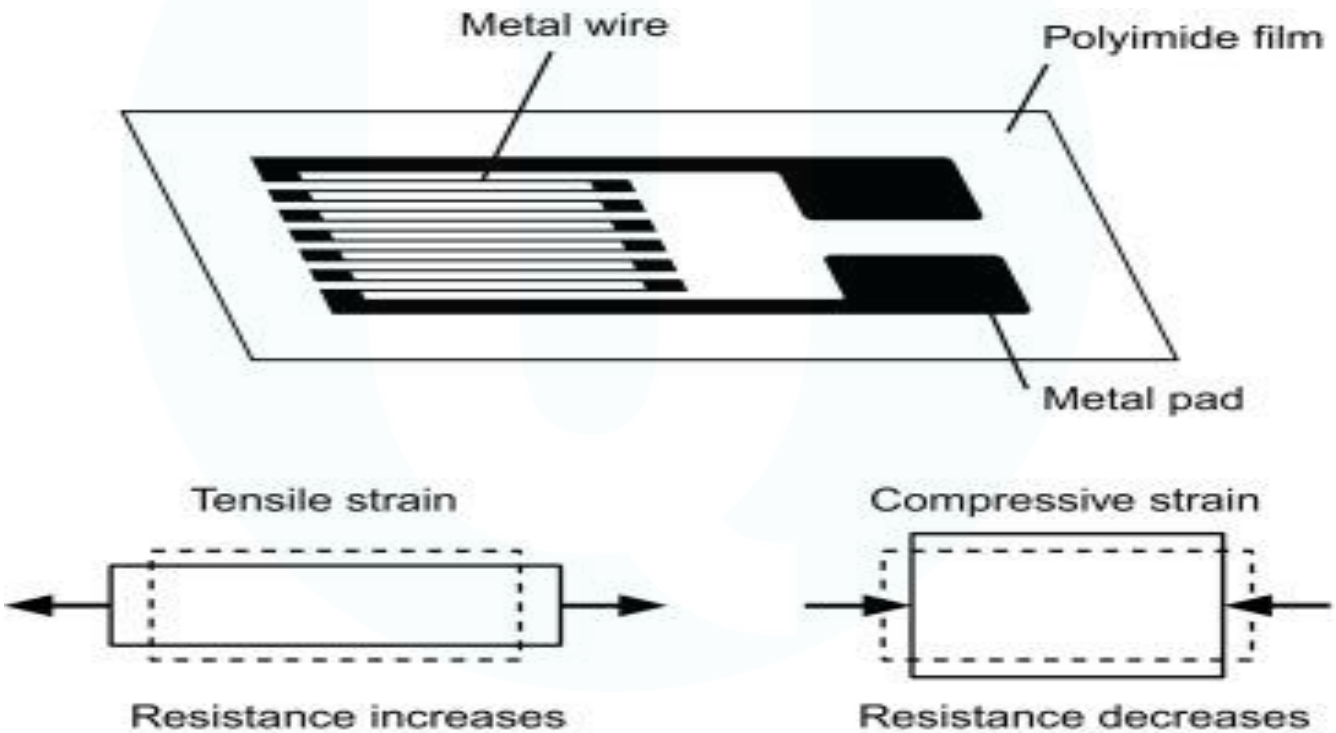
d) Transverse expansion

Applications:

- In microphones, the sound pressure is converted into an electric signal and this signal is ultimately amplified to produce a louder sound.
- Automobile seat belts lock in response to a rapid deceleration is also done using a piezoelectric material.
- It is also used in medical diagnostics.
- It is used in electric lighter used in kitchens. The pressure made on piezoelectric sensor creates an electric signal which ultimately causes the flash to fire up.

Strain Gauge

- Transducer used to measure strain on an object.
- When an external force is applied on an object, due to which there is a deformation occurs in the shape of the object. This deformation in the shape is both compressive or tensile is called strain, and it is measured by the strain gauge.
- When an object deforms within the limit of elasticity, either it becomes narrower and longer or it become shorter and broadens. As a result of it, there is a change in resistance.
- If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both length and diameter of conductor change.
- Also there is a change in the value of resistivity of the conductor when it is strained and this property is called piezo resistive effect. Therefore, resistance strain gauges are also known as piezoresistive gauges


Metal wire
Polyimide film
Metal pad
Tensile strain
Compressive strain
Resistance increases
Resistance decreases

- The strain gauge is sensitive to that small changes occur in the geometry of an object.
- By measuring the change in resistance of an object, the amount of induced stress can be calculated.
- The change in resistance normally has very small value, and to sense that small change, strain gauge has a long thin metallic strip arrange in a zigzag pattern on a non-conducting material called the carrier so that it can enlarge the small amount of stress in the group of parallel lines and could be measured with high accuracy.
- The gauge is literally glued onto the device by an adhesive.

A.K Sawhney page 765

Strain Gauges

If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both length and diameter of conductor change. Also there is a change in the value of resistivity of the conductor when it is strained and this property is called **piezo resistive effect.** Therefore, resistance strain gauges are also known as **piezoresistive gauges.** the strain gauges are used for measurement of strain and associated stress in experimental stress analysis. Secondly, many other detectors and transducers, notably the load cells, torque meters, diaphragm type pressure gauges, temperature sensors, accelerometers and flow meters, employ strain gauges as secondary transducers.

Theory of Strain Gauges. The change in the value of resistance by straining the gauge may be partly explained by the normal dimensional behaviour of elastic material. If a strip of elastic material is subjected to tension, or in other words positively strained, its longitudinal dimension will increase while there will be a reduction in the lateral dimension So when a gauge is subjected to a positive strain, its length increases while its area of cross-section decreases. Since the resistance of a conductor is proportional to its length and inversely proportional to its area of cross-section, the resistance of the gauge increases with positive strain. The change in the value resistance of strained conductor is more than what can be accounted for an increase in resistance due to dimensional changes.

The extra change in the value of resistance is attributed to a change in the value of resistivity of a conductor when strained. This property, as described earlier, is known as **peizoresistive effect.**

Let us consider a strain gauge made of circular wire. The wire has the dimensions: length $=L$, area $=A$, diameter $=D$ before being strained. The material of the wire has a resistivity ρ.

$\therefore$ Resistance of unstrained gauge $R=\rho L/A$.

Let a tensile stress s be applied to the wire. This produces a positive strain causing the length to increase and area to decrease. Thus when the wire is strained there are changes in its dimensions. Let $\Delta L=$change in length, $\Delta A=$change in area, $\Delta D=$change in diameter and $\Delta R=$change in resistance.

In order to find how ΔR depends upon the meterial physical quantities, the expression for R is differentited with respect to stress s. Thus we get :

$$\frac{dR}{ds}=\frac{\rho}{A}\quad\frac{\partial L}{\partial s}-\frac{\rho L}{A^2}\quad\frac{\partial A}{\partial s}+\frac{L}{A}\quad\frac{\partial\rho}{\partial s} \qquad ...(25\cdot20)$$

Dividing Eqn. 25·20 throughout by resistance $R=\rho L/A$, we have

$$\frac{1}{R}\quad\frac{dR}{ds}=\frac{1}{L}\quad\frac{\partial L}{\partial s}-\frac{1}{A}\quad\frac{\partial A}{\partial s}+\frac{1}{\rho}\quad\frac{\partial\rho}{\partial s} \qquad ...(25\cdot21)$$

It is evident from Eqn. 25·21, that the per unit change in resistance is due to :

(*i*) per unit change in length$=\Delta L/L$. (*ii*) per unit change in area$=\Delta A/A$.

Area $\qquad A=\frac{\pi}{4}D^2 \qquad \therefore \quad \frac{\partial A}{\partial s}=2.\frac{\pi}{4}D.\frac{\partial D}{ds} \qquad ...(25\cdot22)$

or

$$\frac{1}{A}\quad\frac{dA}{ds}=\frac{(2\pi/4)D}{(\pi/4)D^2}\quad\frac{\partial D}{\partial s}=\frac{2}{D}\quad\frac{\partial D}{\partial s} \qquad ...(25\cdot23)$$

$\therefore$ Eqn. 25·21 can be written as :

$$\frac{1}{R}\quad\frac{dR}{ds}=\frac{1}{L}\quad\frac{\partial L}{\partial s}-\frac{2}{D}\quad\frac{\partial D}{\partial s}+\frac{1}{\rho}\quad\frac{\partial\rho}{\partial s} \qquad ...(25\cdot24)$$

Now, Poisson's ratio $\qquad \nu=\frac{\text{lateral strain}}{\text{longitudinal strain}}=-\frac{\partial D/D}{\partial L/L} \qquad ...(25\cdot25)$

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

$$\therefore \qquad \frac{1}{R}\quad\frac{dR}{ds}=\frac{1}{L}\quad\frac{\partial L}{\partial s}+\nu\quad\frac{2}{L}\quad\frac{\partial L}{\partial s}+\frac{1}{\rho}\quad\frac{\partial\rho}{\partial s} \qquad ...(25\cdot26)$$

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

$$\frac{\Delta R}{R}=\frac{\Delta L}{L}+2\nu\quad\frac{\Delta L}{L}+\frac{\Delta\rho}{\rho} \qquad ...(25\cdot27)$$

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

Gauge factor $$G_f = \frac{\Delta R/R}{\Delta L/L} \quad \text{...(25·28)}$$

or $$\frac{\Delta R}{R} = G_f \frac{\Delta L}{L} = G_f \times \epsilon \quad \text{...(25·29)}$$

where $$\epsilon = \text{strain} = \frac{\Delta L}{L}$$

The gauge factor can be written as :

$$G_f = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\nu + \frac{\Delta \rho/\rho}{\Delta L/L} = 1 + 2\nu + \frac{\Delta \rho/\rho}{\epsilon} \quad \text{...(25·30)}$$

The strain is usually expressed in terms of microstrain. 1 microstrain = 1 μm/m.

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

$$G_f = 1 + 2\nu \quad \text{...(25·31)}$$

Types of strain guage

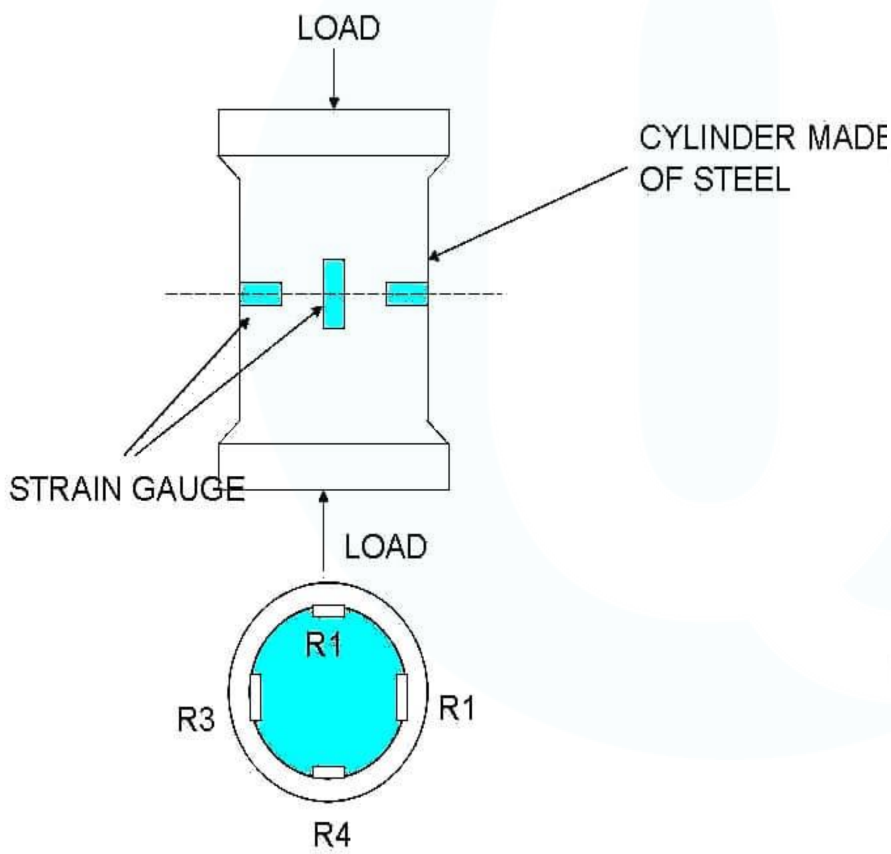
- Wire wound type (resistance strain guage)
  1) Unbonded type   2) Bonded type
- Foil type
- Semi conductor type

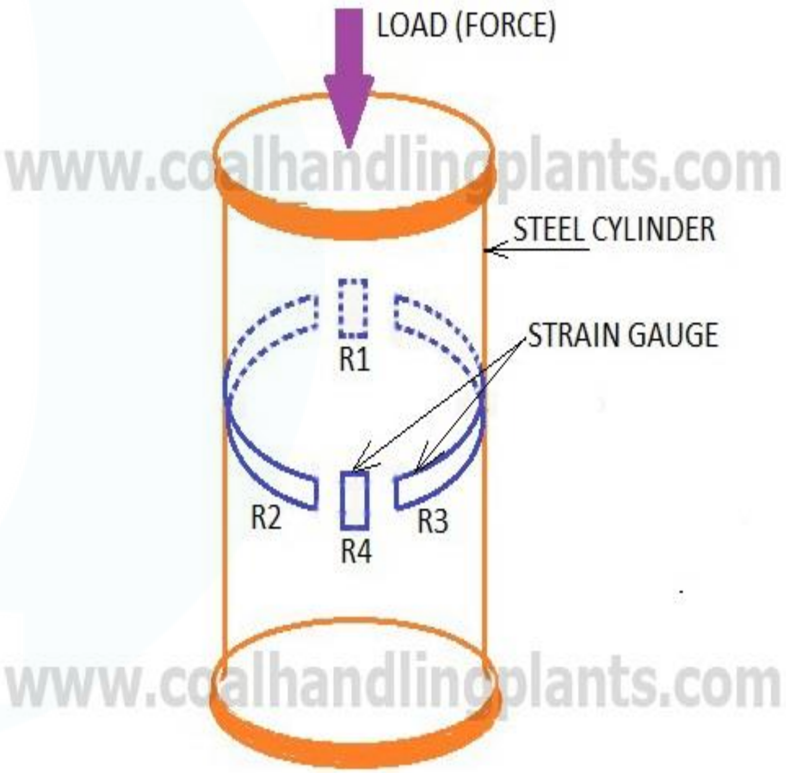
- Refer A.K Sawhney page.767

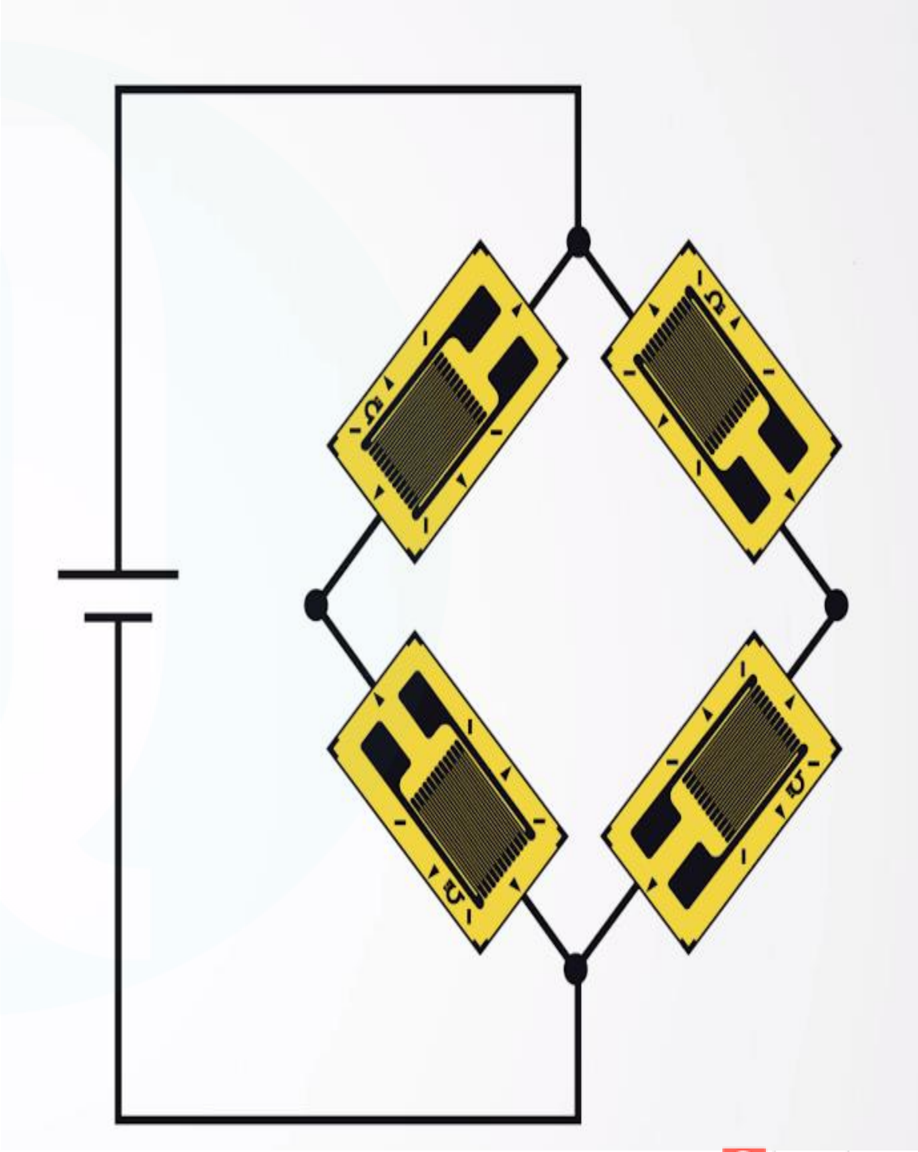
Load cells

- A load cell is a force transducer.
- It converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured and standardized.
- As the force applied to the load cell increases, the electrical signal changes proportionally.
- The most common types of load cell used are strain gauges, pneumatic and hydraulic.

Construction of Strain Gauge Load Cell







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Separate notes given for

- CRO
- DSO
- DVM
- DMM
- PMU
- Clamp on meters

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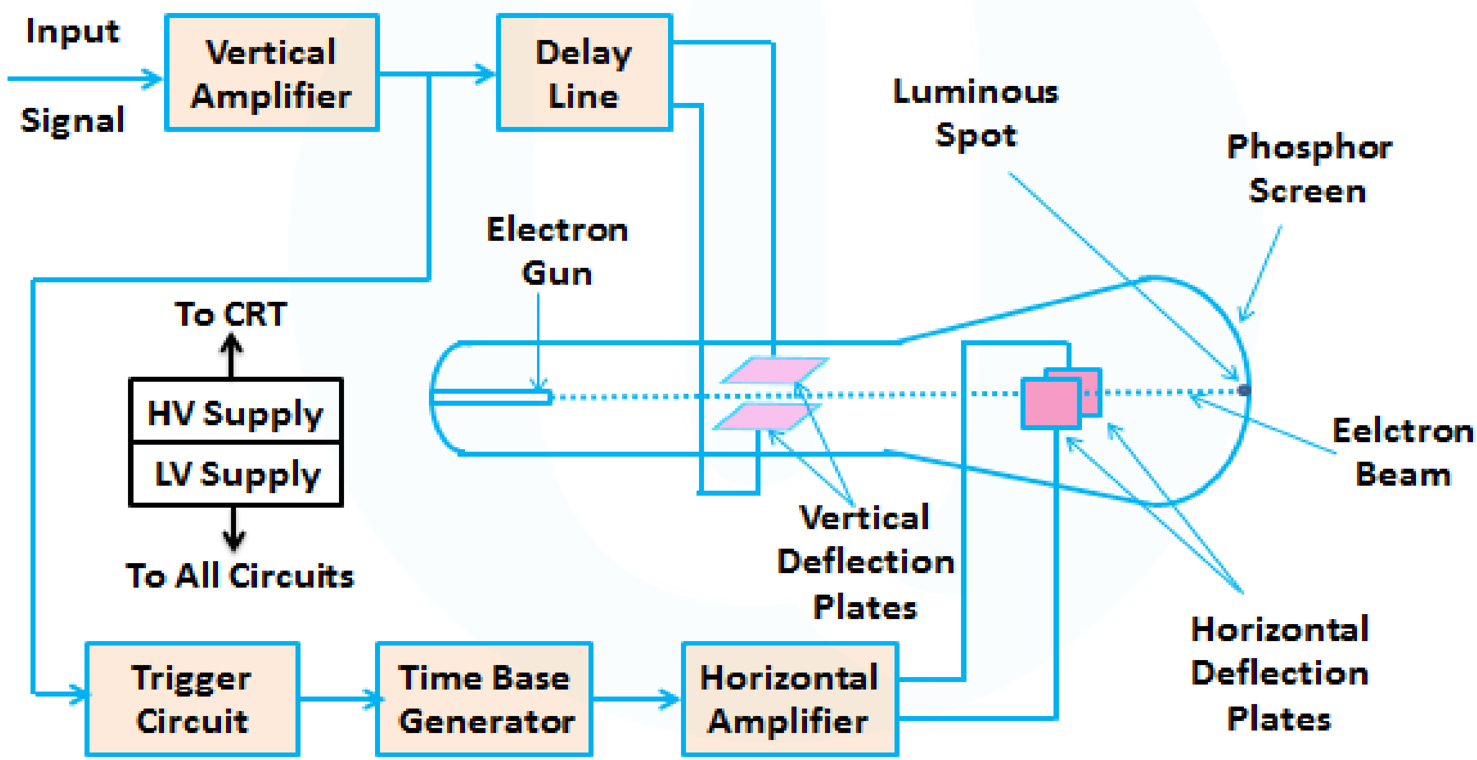
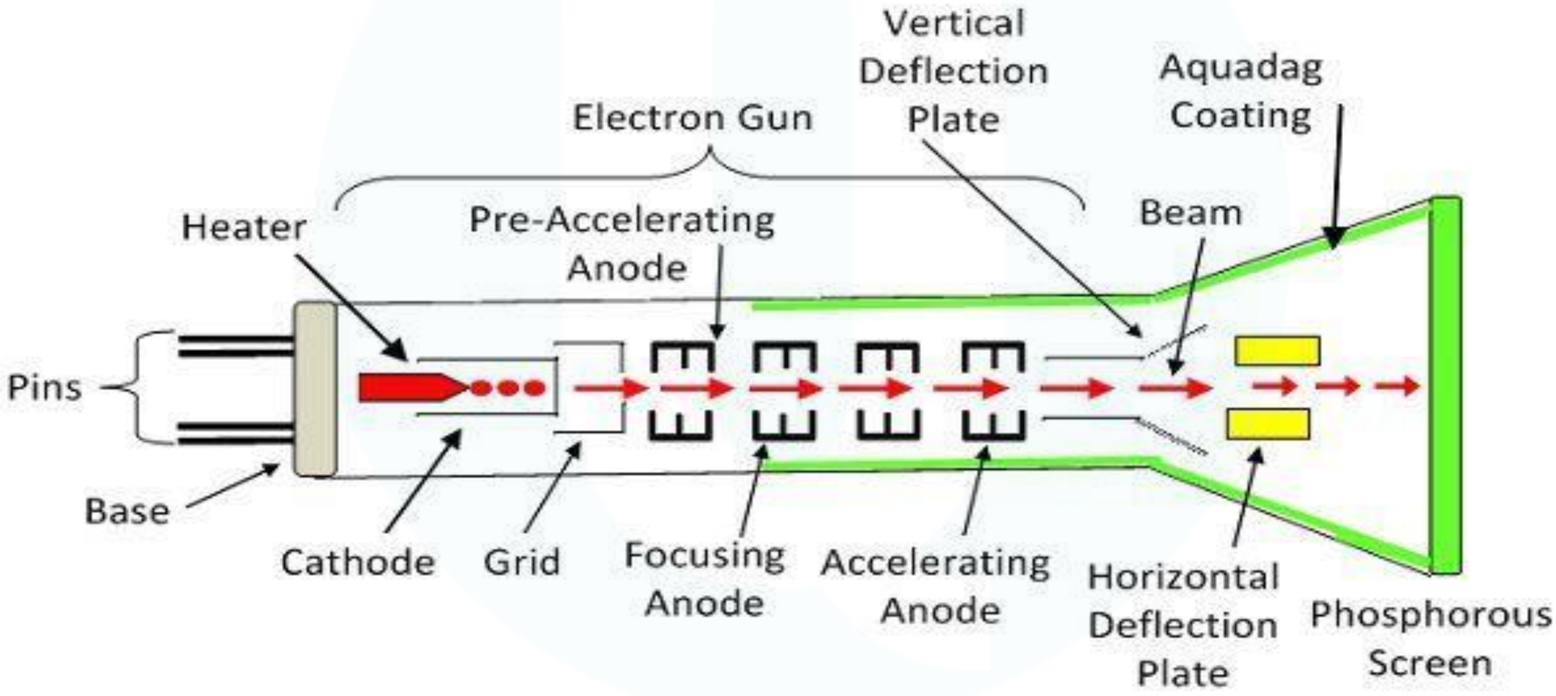
CRO



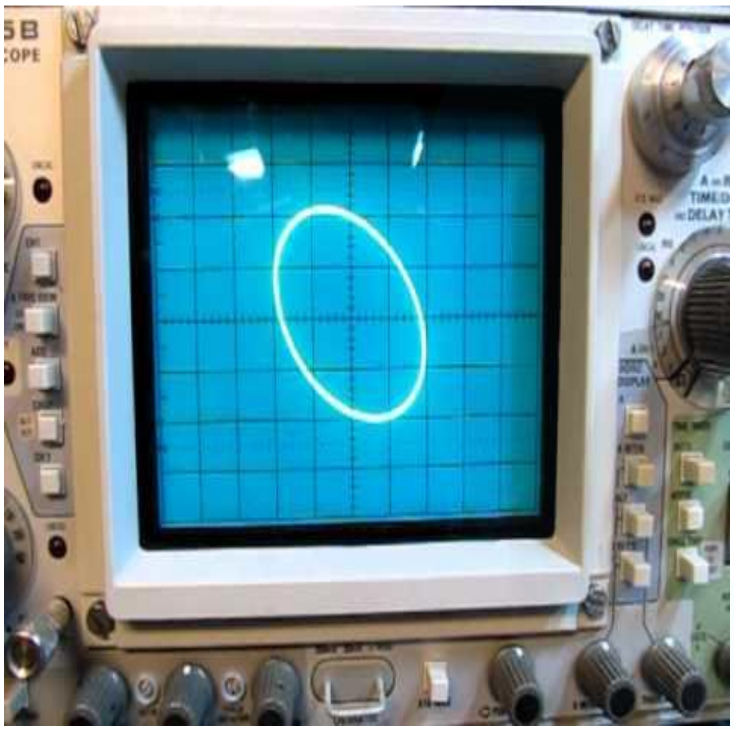
Block Diagram of Cathode Ray Oscilloscope (CRO)

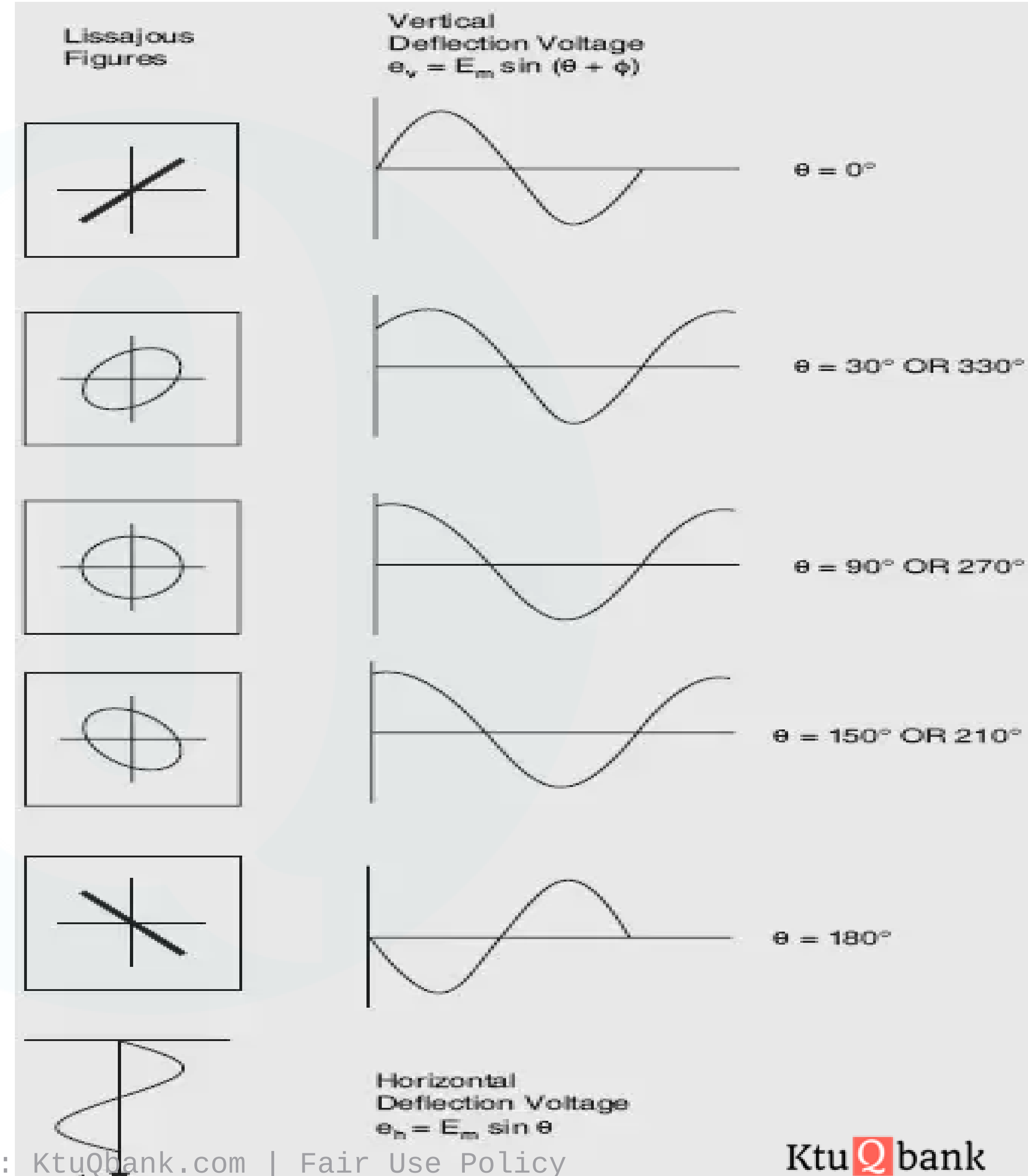


Cathode Ray Tube

Lissajous figures

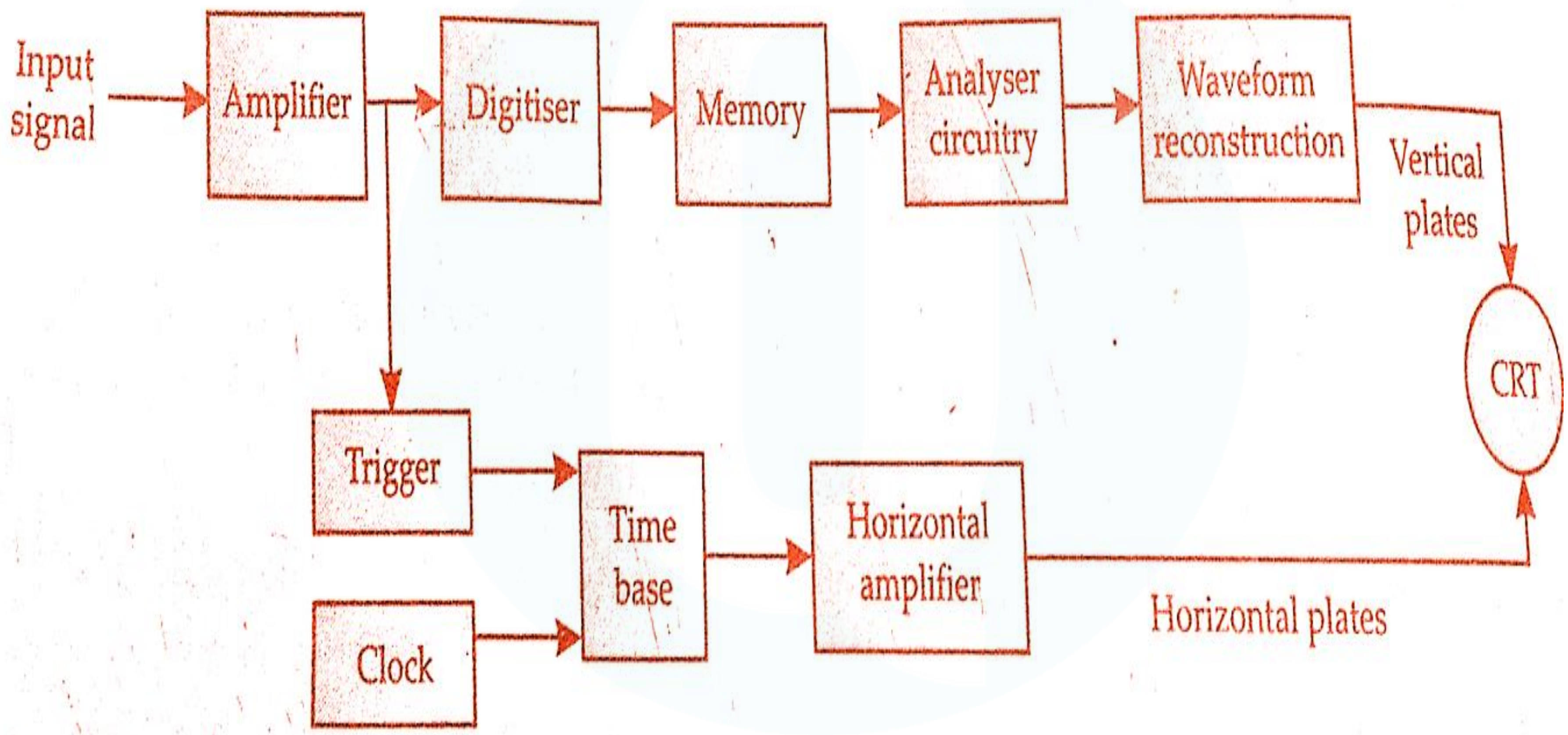
- When both pairs of the deflection plates (horizontal deflection plates and vertical deflection plates) of CRO are connected to two sinusoidal voltages, the patterns appear at CRO screen are called the **Lissajous pattern**.



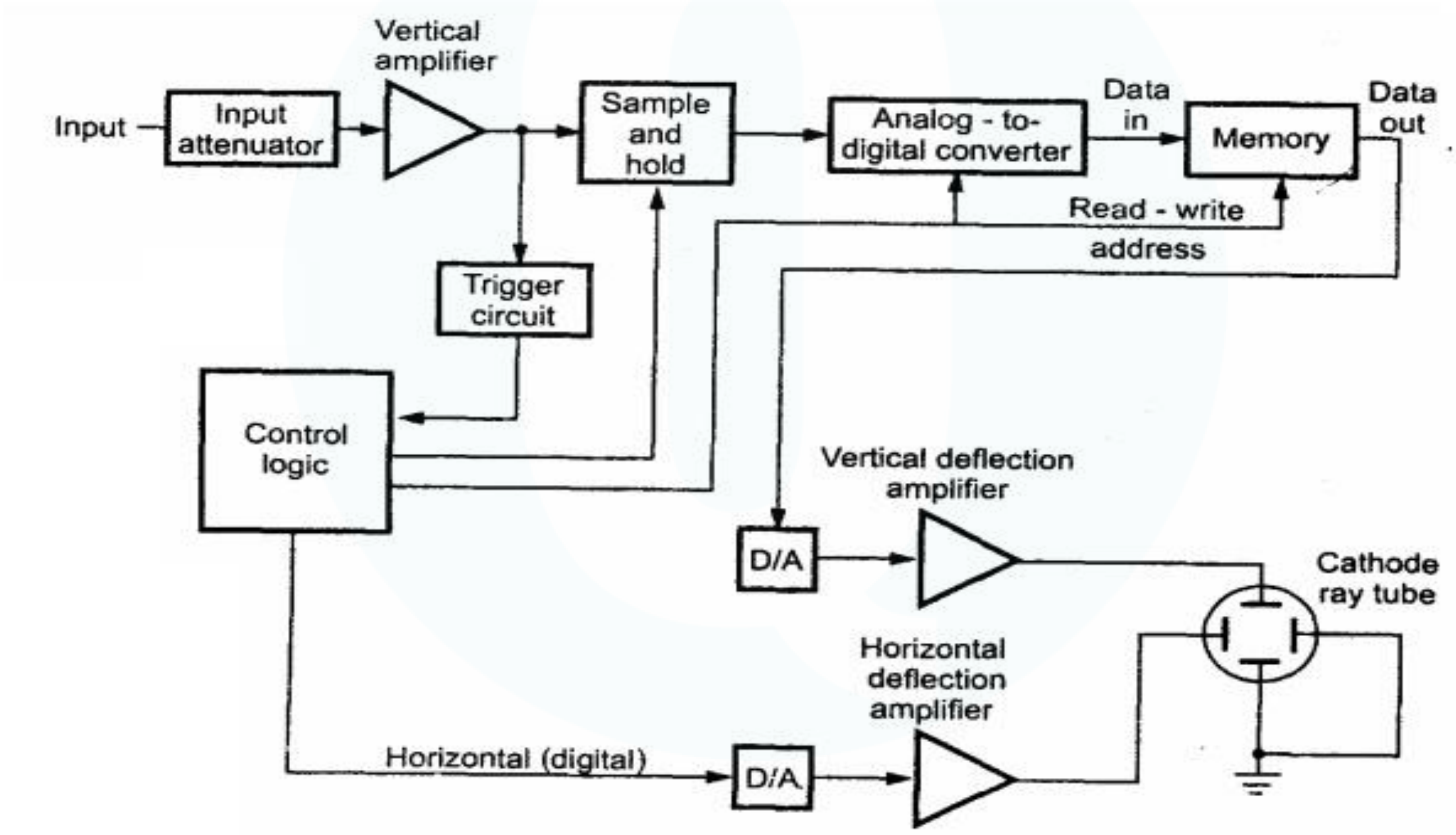


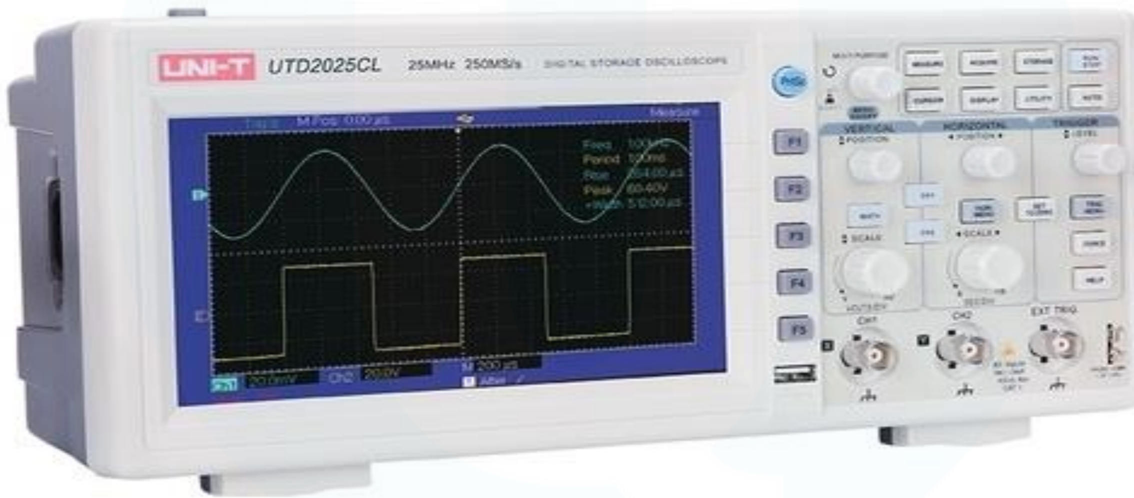
Lissajous Figures
Vertical Deflection Voltage
$e_v = E_m \sin(\theta + \phi)$
$\theta = 0°$
$\theta = 30°$ OR $330°$
$\theta = 90°$ OR $270°$
$\theta = 150°$ OR $210°$
$\theta = 180°$
Horizontal Deflection Voltage
$e_h = E_m \sin \theta$
t

Digital Storage Oscilloscope (DSO)



Detailed block diagram of DSO




UNI-T
UTD2025CL
25MHz 250MS/s
DIGITAL STORAGE OSCILLOSCOPE
F1
F2
F3
F4
F5
CH1
CH2
EXT TRIG

DSO probes

- **Passive probes** are the most commonly used probes for taking general-purpose measurements.
- Passive probes are constructed using wires, connectors, a housing, and, if required, compensation or attenuation resistors or capacitors.
- No active components such as transistors or amplifiers are used within these types of probes.
- Generally speaking, passive probes are easy to use, relatively inexpensive, and fairly rugged.

- Passive probes are typically available in the following configurations:
- 1×: no attenuation
- 10×: factor-of-10 attenuation
- 100×: factor-of-100 attenuation
- 1000×: factor-of-1000 attenuation
- As an example, a typical 10× probe houses an internal 9 MΩ resistor that, when used with a 1 MΩ scope, creates a 10:1 attenuation ratio at the scope's input channel.
- This means that the displayed signal on the scope will be 1/10th the magnitude of the actual measured signal.

- **Active probes** contain active components, such as FETs or amplifiers .
- Active probes are commonly used for taking high-speed measurements (>500 MHz) or on high-impedance circuits.
- **Differential probes** measure differential signals.
- That is, they measure the difference between any two points.
- This is in contrast to a **single-ended probe**, which measures the difference between a single point and ground.
- Differential probes are especially popular for measuring high-frequency signals or signals of very low amplitude (i.e., approaching the noise floor).
- Differential probes use a differential amplifier to convert the difference between two signals into a voltage that can be sent to a typical single-ended scope input.

Virtual Instrumentation system

- Virtual Instrumentation is the use of customizable software and modular measurement hardware to create user-defined measurement systems called virtual instruments.
- Virtual instrumentation combines mainstream commercial technologies such as C, with flexible software and a wide variety of measurement and control hardware, so engineers and scientists can create user defined systems that meet their exact application needs.
- With virtual instrumentation, engineers and scientists reduce development time, design higher quality products, and lower their design costs.

Components

- An industry standard computer or workstation
- Powerful user friendly application software
- Cost effective hardware such as plug-in boards
- Driver software

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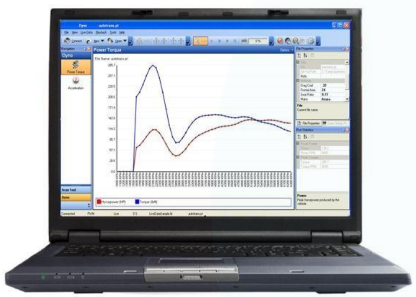

Computer

Software

Hardware

Why is Virtual Instrumentation necessary?

- It delivers instrumentation with the rapid adaptability required for today's concept, product, and process design, development and delivery.
- Only with virtual instrumentation can engineers and scientists create the user-defined instruments required to keep up with the world's demands.
- The only way to meet these demands is to use test and control architectures that are also software centric.
- Because virtual instrumentation uses highly productive software, modular I/O, and commercial platforms, it is uniquely positioned to keep pace with the required new idea and product development rate.

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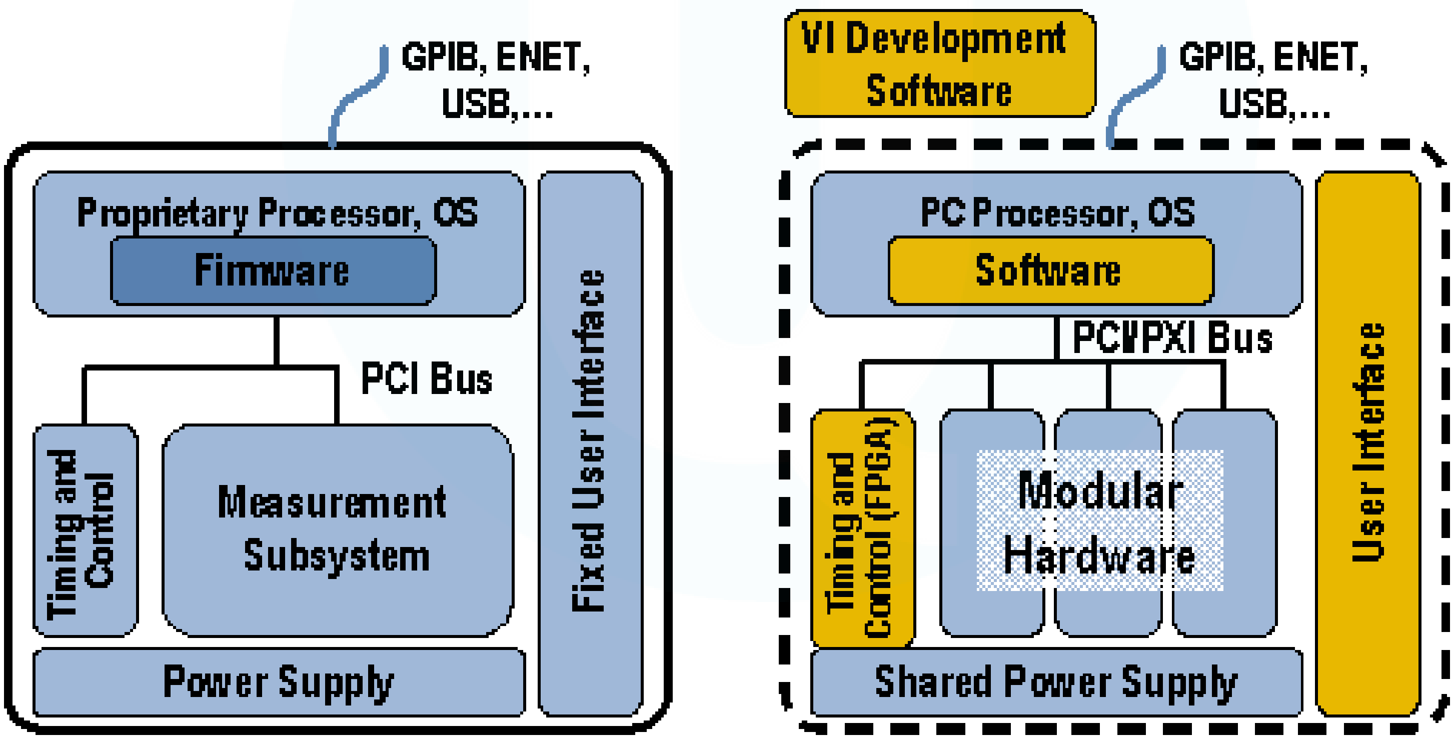
Virtual instrument vs Traditional instrument

- Every virtual instrument consists of two parts – software and hardware.
- A virtual instrument typically has a sticker price comparable to and many times less than a similar traditional instrument for the current measurement task.
- A traditional instrument provides them with all software and measurement circuitry packaged into a product with a finite list of fixed-functionality using the instrument front panel.
- A virtual instrument provides all the software and hardware needed to accomplish the measurement or control task.
- In addition, with a virtual instrument, engineers and scientists can customize the acquisition, analysis, storage, sharing, and presentation functionality using productive, powerful software.

- Traditional instruments (left) and software based virtual instruments (right) largely share the same architectural components, but radically different philosophies



Traditional instruments

- Very large and cumbersome
- High power consumption
- Pre- defined hardware components
- Limited functionality due to hardcoded functions
- Re-calibration is needed

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Advantages of Virtual instrumentation

- **Flexibility**

You can easily add additional functions such as a filter routine or a new data view to a virtual instrument.

- **Storage**

Today's personal computers have hard disks that can store dozens of gigabytes which is an absolute plus if you want to process mass data like audio or video.

- **Display**

Computer monitors usually have better colour depth and pixel resolution than traditional instruments. Also you can switch easily between different views of the data (graphical, numerical).

- **Costs**

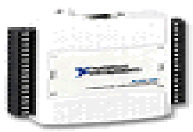
PC add-in boards for signal acquisition and software mostly cost a fraction of the traditional hardware they emulate.

Layers of Virtual Instrumentation

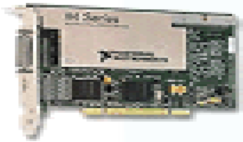
- Application Software: Most people think immediately of the application software layer. This is the primary development environment for building an application.
- Test and Data Management Software: Above the application software layer the test executive and data management software layer. This layer of software incorporates all of the functionality developed by the application layer and provides system-wide data management.
- Measurement and Control Services Software: The last layer is often overlooked, yet critical to maintaining software development productivity.

On which hardware I/O and platforms does virtual instrumentation software run?

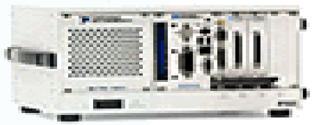
- Standard hardware platforms that house the I/O are important to I/O modularity. Laptop and desktop computers provide an excellent platform where virtual instrumentation can make the most of existing standards such as the USB, PCI, Ethernet, and PCMCIA buses
- for example, USB 2.0 and PCI Express



USB data acquisition starting at $145
• Pocket-sized for ultimate portability
• Powered by the USB connection
• Onboard precision voltage reference



M Series Plug-In Measurement Hardware
• 24 new devices
• Up to 18-bit resolution and 1.25 MS/s
• Starting at less than $7/channel



PXI Modular Instrumentation
• Open, multivendor standard
• Rackmount, portable and benchtop options
• 10X performance increase over ordinary instrumentation