

Unit → (1) (Introduction)

(1) Control System → Control system is a combination of elements arranged in a planned manner where each element causes an effect to produce a desired output.

Control systems are used in many applications for example, system for the control of position, velocity, acceleration, temperature, pressure, voltage and current etc.

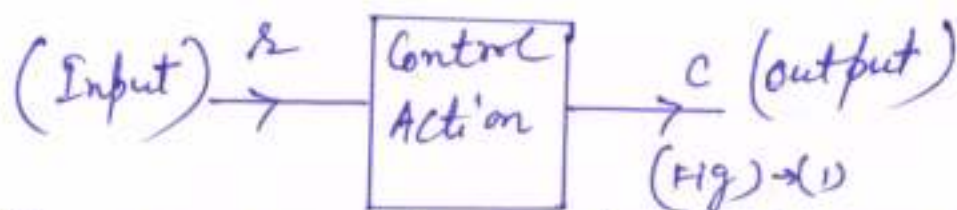
Control systems are of two

(2)

types:

- (1) open-loop control system.
- (II) closed-loop control system.

(1) open loop control system →



"In the open loop control system the input (R) controls the output (C) through a control action process. In the block diagram shown in figure (1) it is observed

that the output has no effect on the control action. Such a system is termed as open-loop control system.

In an open-loop control system the output is neither measured nor fed back for comparison with the input.

⊗ Example of open-loop control system:

- (1) Automatic washing machine.
- (2) Electric lift.

⊗ Advantage of open-loop control system:

- (1) Easy to maintainance.
- (2) They are economic.
- (3) They are simple in construction and design.
- (4) No much problems of stability.

\* dis-advantage of open-loop control system:

- (1) The main dis-advantage of an open-loop control system is inaccurate and unreliable because accuracy is dependent on accuracy of calibration.

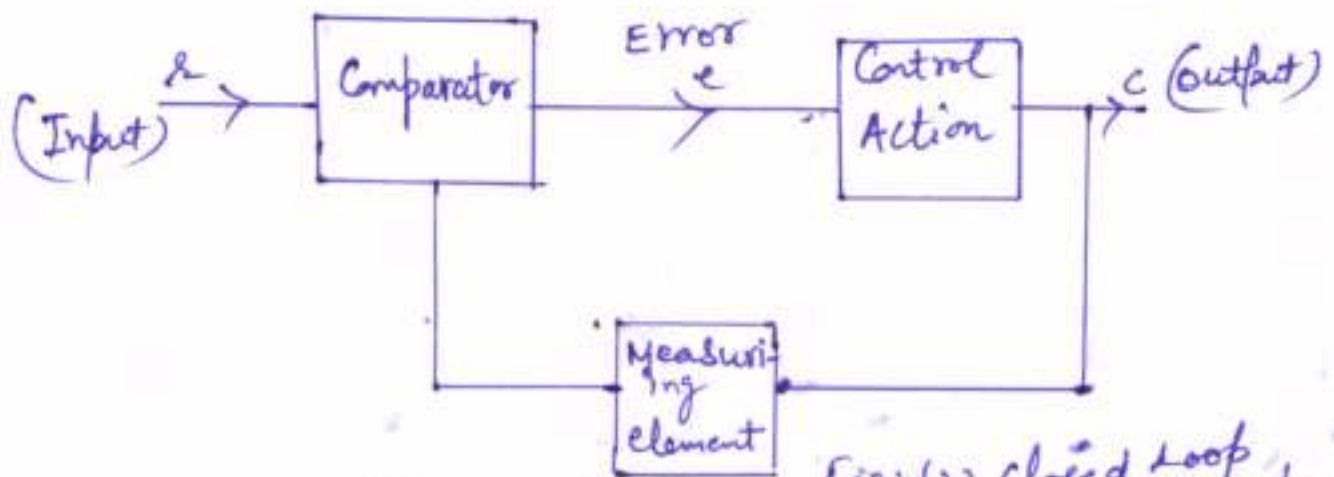
(2) Closed-loop Control Systems

Fig: (2) closed Loop Control System

Q6. In a closed-loop control system the output has an effect on control action through a feedback as shown in fig. (2) and hence closed-loop control systems are also termed as feedback control system. The control action is actuated by an error signal ( $e$ ) which is the difference between the input ( $r$ ) and the output signal ( $c$ ). This process of comparison between the output and input maintains the output at a desired level through control action process.

The Control

System without human intervention for normal operation are called Automatic Control System.

\* Example of closed-loop control system:-

- (1) Voltage-stabilizer.
- (2) Automatic-electric Iron
- (3) Servo System

\* Advantage of closed-loop control system:-

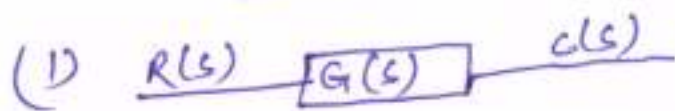
- (i) Accuracy is very high as any error arising is corrected.
- (ii) High band width.
- (iii) Reduce effect of Non-Linearties.

\* Disadvantage of closed-loop control system:-

- (i) Complicated in design.
- (ii) Maintenance costlier.
- (iii) System may become unstable.

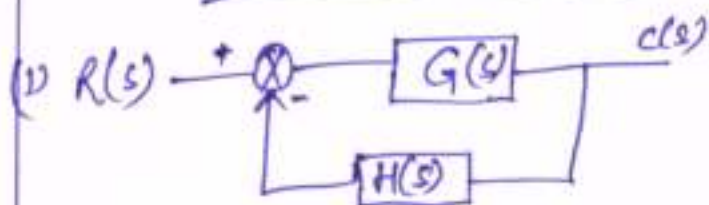
## Topic Comparison of open loop and closed-loop Control System Page (5)

### open Loop.



- (2) In open loop control system No feedback is present.
- (3) The open-loop control system is simple to construct and cheap.
- (4) The open-loop system are generally stable.
- (5) Less sensitive.
- (6) More noise.
- (7) Less Accurate.  
EX:- Washing machine
- (8) The operation of open-loop system is affected due to the presence of Non-Linearities in its element.

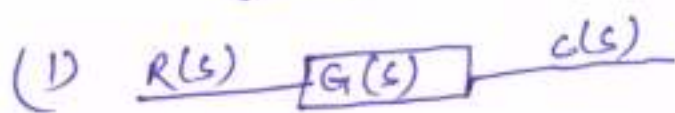
### Closed-Loop.



- (2) In closed loop control system Feedback is present.
- (3) The closed-loop system is complicated to construct and costly.
- (4) The closed-loop system can become unstable under certain conditions.
- (5) more sensitive
- (6) Noise can be controlled.
- (7) High Accurate.  
EX:- Temperature control system
- (8) In terms of the performance the closed-loop system adjusts to the effects of Non-linearities present in its elements.

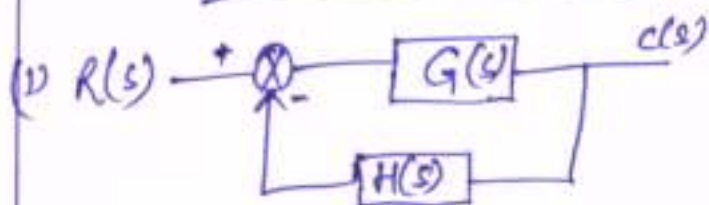
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## ⑧ Manually Controlled closed Loop system's

The Control Systems with human intervention for normal operation are called manually controlled closed-loop system. Let us

Consider the automobile driving system. The route speed and acceleration of the automobile are determined and controlled by the driver by observing traffic and road conditions and by properly manipulating the accelerator, gear-lever, clutch, brakes and steering wheels etc. Suppose the driver wants to maintain a speed of 50 km/hour (desired output). He accelerates the automobile to this speed ~~it~~ with the help of accelerator and then maintains it by holding the accelerator steady. No error in the speed of the automobile occurs so long as there are no gradients or other disturbances along the road. The actual speed of the automobile ~~accelerates~~ is measured by the speedometer and indicated on its dial.

"The driver reads the speed dial visually and compares the actual speed with the desired one mentally. If there is a ~~deviation~~ deviation of speed from the desired speed, accordingly he takes the decision to increase or decrease the speed. These

operations can be represented in a diagrammatic form as shown in figure (3). The events in the control sequence of fig. ③ follow a closed loop. The information about the instantaneous state of the output is feedback to the input and is used to modify it in such a manner as to achieve the desired output.

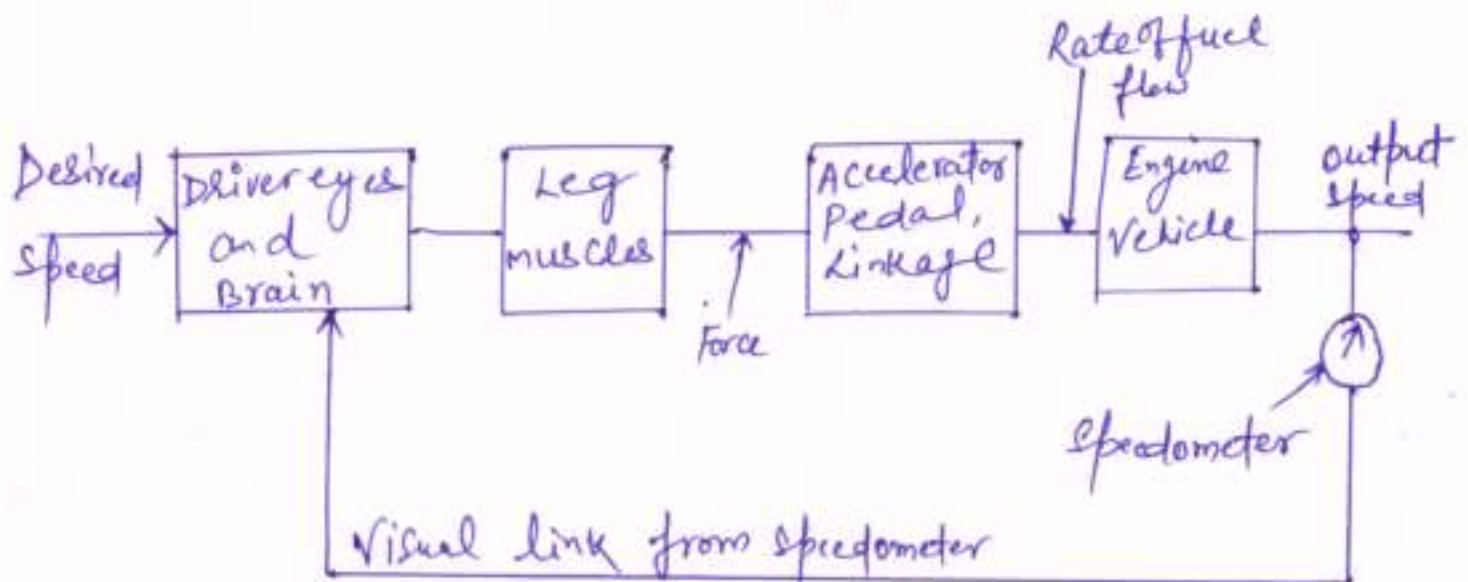


Fig ③. Schematic diagram of a manually controlled closed-loop system.

## Automatic Controlled closed Loop System's

The Control Systems without involving human intervention for normal operation are called automatic Control System.

The general of an automatic Control System which is characterised by a feedback loop is shown in figure (4). An error detector compares a signal obtained through feedback elements, which is a function of the output response, with the reference input. Any difference between these two signals constitutes an error or actuating signal, which actuates the control elements. The control elements in such a manner as to reduce the original error.

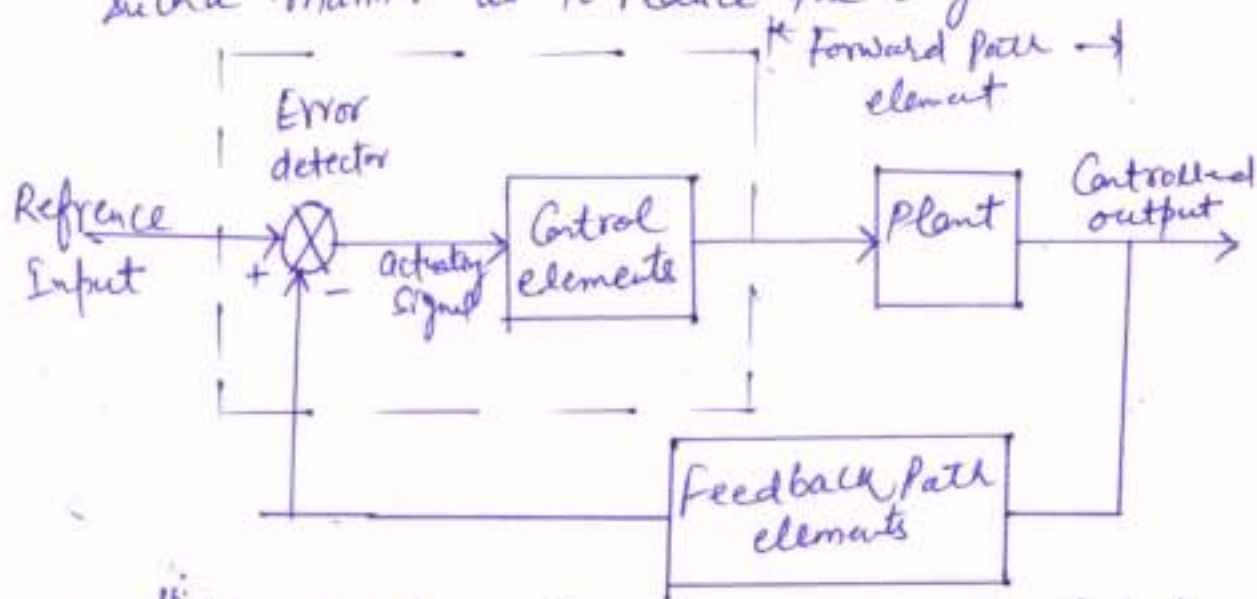
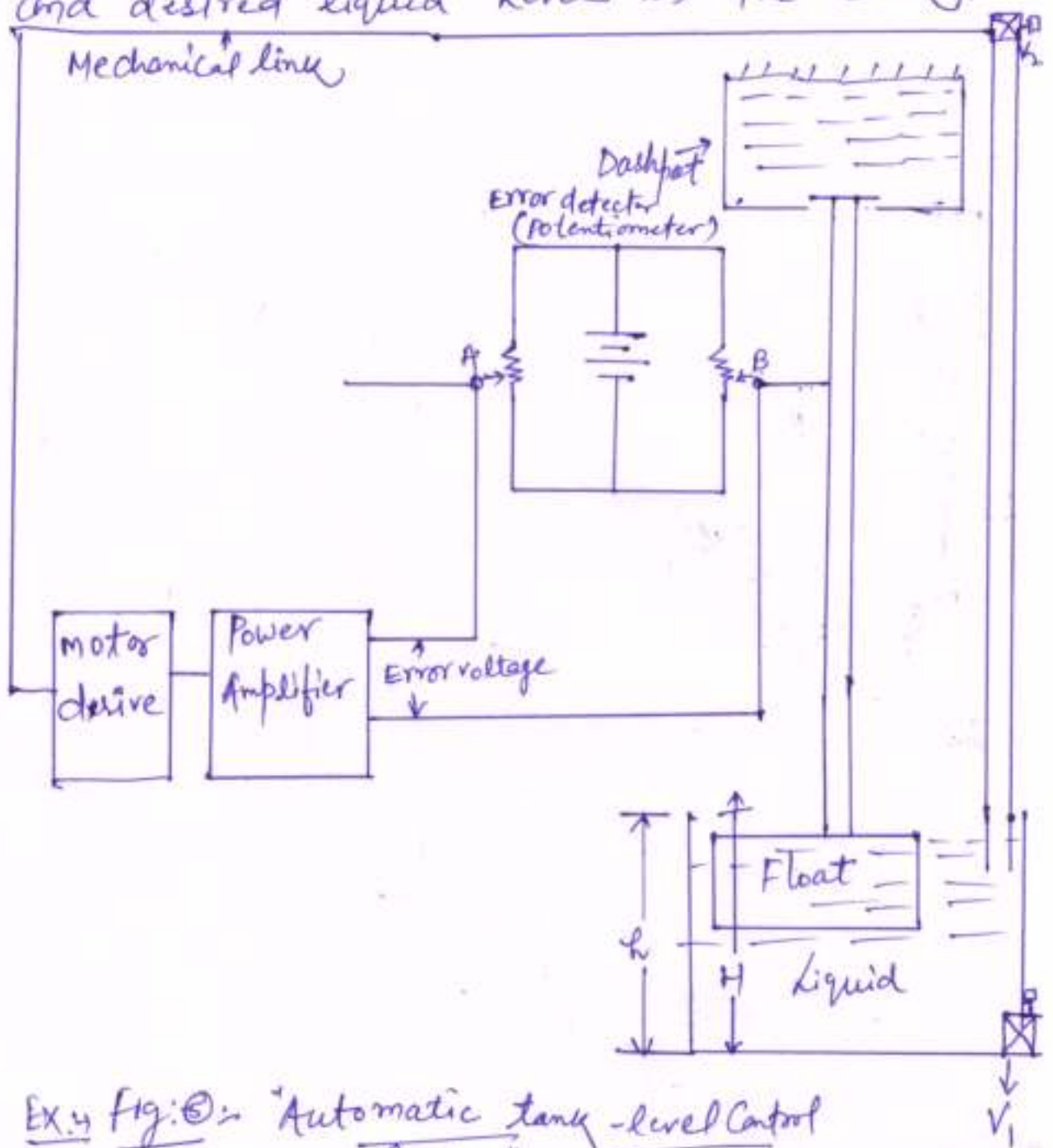


Fig (4) General Block diagram of an Automatic Control System

## ⑧ Example of an Automatic Control closed Loop system?

Let us discuss a simple tank level control system as shown in figure 5. The control system can maintain the liquid level 'h' (controlled output) of the tank within accurate tolerance of the desired liquid level even though the output flow rate through the valve  $V_1$  is varied. The liquid level is sensed by a float (feedback path element) which positions the slider arm 'B' on a potentiometer. The slider arm 'A' of another potentiometer is positioned corresponding to the desired liquid level 'H' (the reference input). When the level arises or falls, the potentiometers (error detector) give an error voltage (error or actuating signal) proportional to the change in liquid level. The error voltage actuates the motor through a power amplifier (control elements) which in turn conditions the plant. (i.e. decrease or increases the opening of the valve  $V_2$ ) in order to restore the desired liquid level. Thus the control system automatically attempts

to correct any deviation between the actual and desired liquid levels in the tank.



EX.4 Fig. ③: "Automatic tank-level Control System".

## Linear and Non-Linear Control System.

### Linear Control System:

- (i) In this system the output is somehow directly proportional to the input.
- (ii) The linear system obey the principle ~~the~~ of Homogeneity.
- (iii) This system ~~does not~~ obey the principle of Superposition.
- (iv) When the input increases output also increases but the form remains the same.
- (v) The linear systems are not highly sensitive to the amplitude of input.
- (vi) The linear system is easily treated by simple mathematical tool and easy construct.

### Non-Linear Control System

- (i) In this system the output is not directly proportional to the input.
- (ii) The Non-linear Control system do not obey the principle of homogeneity.
- (iii) This system does not obey the principle of Superposition.
- (iv) In these systems, the form may change in the magnitude of the input.
- (v) They are highly sensitive to input amplitude due to which the Non-linearity in the output increases.
- (vi) The Non-linear system requires more advanced techniques such as Analogue and digital Computers.

"The transfer function of electrical network consisting of resistance and capacitance configurations is determined by taking the ratio of Laplace of the output to input.

The network shown in figure is a phase lag network.

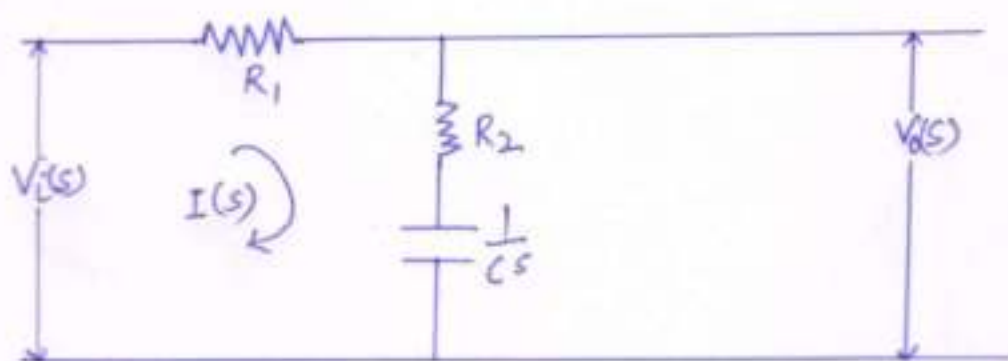


Fig:- Phase Lag Network

The input, the output and the capacitance are expressed by their respective Laplace transform.

Following eq<sup>n</sup> are formed:-

for input:-

$$V_i(s) = R_1 I(s) + R_2 I(s) + \frac{1}{Cs} I(s)$$

$I(s)$  Common:-

$$V_i(s) = \left[ \frac{(R_1 + R_2)Cs + 1}{Cs} \right] I(s)$$

Next, for output

and,  $V_o(s) = R_2 I(s) + \frac{1}{Cs} I(s)$

or,  $V_o(s) = \left[ \frac{R_2 Cs + 1}{Cs} \right] I(s)$

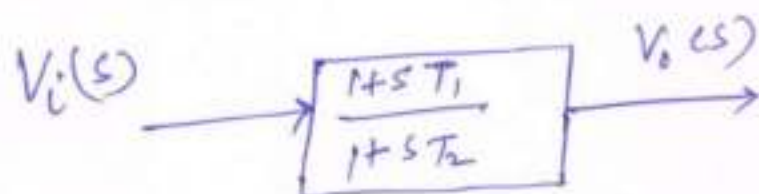
Therefore, the transfer function is given by,

$$\frac{V_o(s)}{V_i(s)} \frac{\text{output}}{\text{input}} = \frac{V_o(s)}{V_i(s)} = \frac{(R_2 Cs + 1)}{[(R_1 + R_2)Cs + 1]}$$

or,  $\frac{V_o(s)}{V_i(s)} = \frac{(1 + sT_1)}{(1 + sT_2)}$

where,  $T_1 = R_2 C$  and  $T_2 = (R_1 + R_2) C$

The block diagram representation is given by figure,



## Mechanical Systems

### Translational Mechanical Systems

"A translational spring-mass-damper system is shown in figure:-

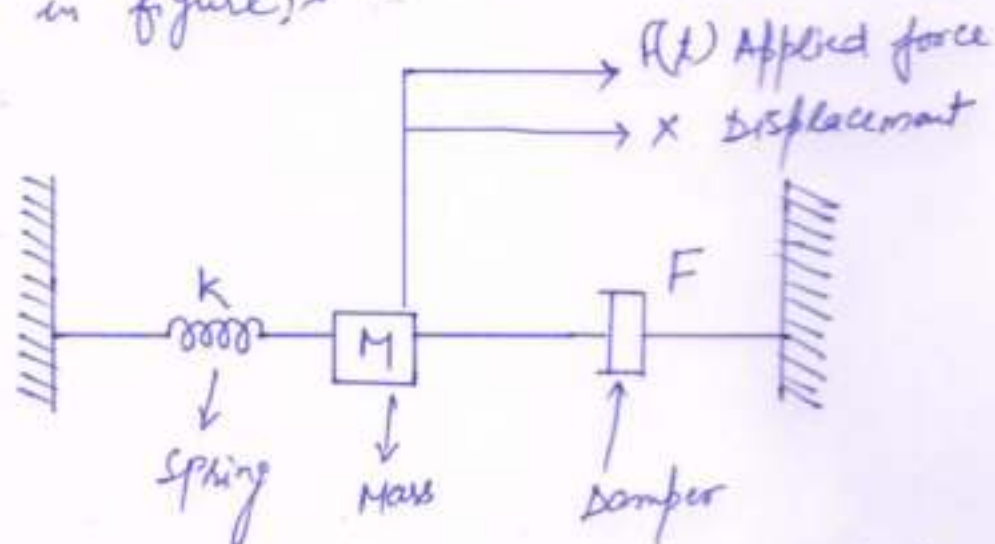


Fig. Translational spring-mass damper Systems.

"The mass of the system is  $m$  (unit of  $m$  is kg). The displacement of the mass due to applied force  $f(t)$  [unit of force  $f(t)$  is Newton] results in inertia force. This Inertia force is the product of the mass and its acceleration. The spring deflection constant is  $k$ . Unit of  $k$  is Newton/meter. The restoring force  $f_k$  for the spring is proportional to its displacement. The viscous damping in the system is offered by a dashpot damper. The damping force varies in direct proportion to the velocity. The coefficient of viscous damping is  $F$  (Unit of  $F$  is Newton/rad/sec).

" Application of force  $f(t)$  to the mass results in a displacement  $x$  (meters). The equation of motion for the system is obtained by applying Newton's second law of translational motion.

$\therefore$  Inertia force = force acting on the mass

or

$$M \frac{d^2 x}{dt^2} = -f \frac{dx}{dt} - kx + f(t) \rightarrow \text{eqn ①}$$

$\downarrow$  Damping force       $\downarrow$  Spring restoring force       $\downarrow$  Applied force

Rearranging equation ① the following eqn is obtained:

$$M \frac{d^2 x}{dt^2} + f \frac{dx}{dt} + kx = f(t)$$

Assuming initial conditions as zero, taking Laplace transform on both sides of eqn ① following eqn is obtained:

$$Ms^2 X(s) + f(s) X(s) + kX(s) = F(s)$$

If  $X(s)$  is specified as the output and  $F(s)$  as input then the transfer function of the system is given by relation below:

$$\boxed{\frac{X(s)}{F(s)} = \frac{1}{Ms^2 + f(s) + k}} \quad \text{Ans}$$

TRANSFER FUNCTION :->

The transfer function of a control system is defined as the ratio of the Laplace transform of the output variable to the Laplace transform of the input variable assuming all initial conditions as zero.

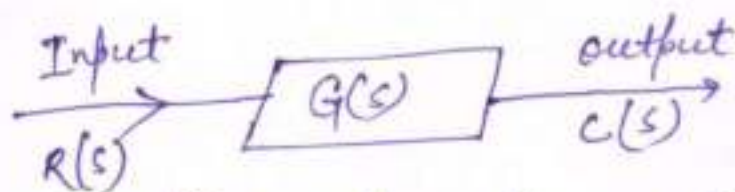


Fig. Block diagram of Control system

Thus if;  $R(s)$  = Laplace transform of the input function

$C(s)$  = Laplace transform of the output function

The block diagram for a control system is drawn as per figure.

The transfer function is expressed as;

$$G(s) = \frac{C(s)}{R(s)}$$

⇒ BLOCK DIAGRAM ⇒

The Symbolic representation in a short form gives a pictorial representation relating the output and the input of a Control System based on Cause and effect approach.

" A Complete System Can be arranged by interconnecting individual blocks as per requirements of the system.

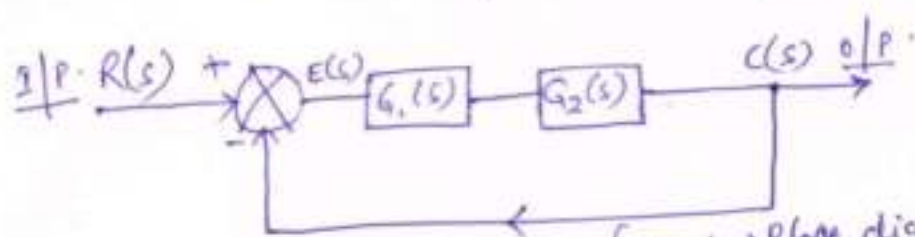


Fig-1. → Block diagram representation of a system

" A block diagram is shown in Fig-1, wherein  $G_1(s)$  and  $G_2(s)$  represent the transfer function of individual elements of a control system. The system is a feedback type or closed loop type. As the output signal  $C(s)$  is feedback and compared with the input  $R(s)$ , the difference  $E(s) = [R(s) - C(s)]$  is the actuating signal or error signal.

## Block diagram Reduction rules;

As described earlier several blocks are interconnected together for arranging a complete control system. In order to obtain the overall transfer function (the ratio of final output and the input in their Laplace transform), a procedure called block diagram reduction technique are given below.

Rule → (1). The block diagram shown in figure-1 relates the output and input as per the transfer function relation given below;

$$G(s) = \frac{C(s)}{R(s)}$$

$$\text{or } C(s) = R(s) \cdot G(s)$$

$G(s)$  is known as the transfer function of the system.

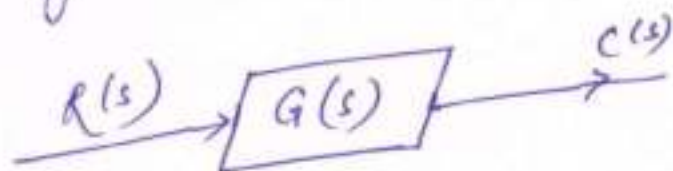
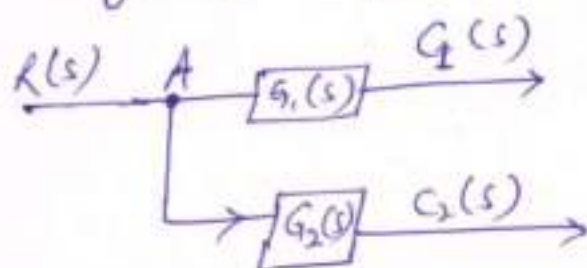


Fig-1 Block diagram.

Rule - (2) :-Take off point :-

Application of one input source to two or more system is represented by a take off point as shown at point 'A' in figure-2. It should be noted that such taking off from the input signal.

Fig-2 Take off point

Rule (3) :- Blocks in Cascade :- When several blocks are connected in cascade Fig-3. The overall equivalent transfer function is determined below :-

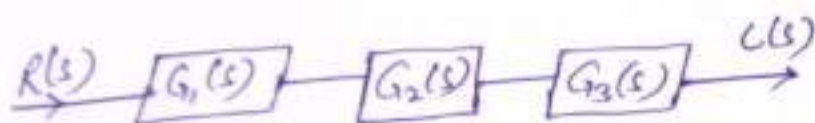


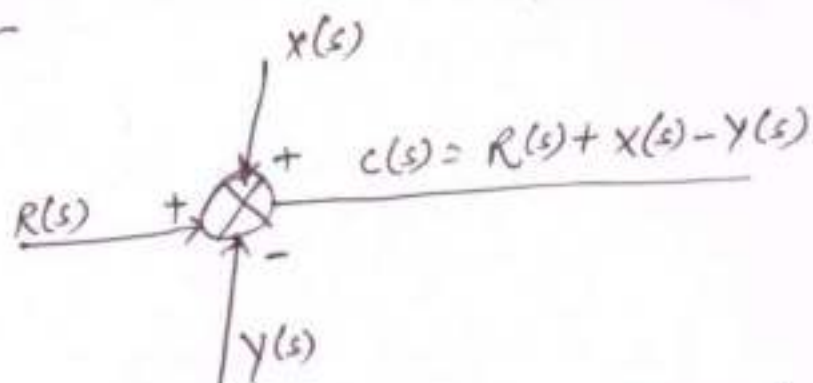
Fig (3) <sup>(a)</sup>  
 'Blocks in cascade and equivalence'

"Therefore the overall transfer function is,

$$\frac{C(s)}{R(s)} = G_1(s) \cdot G_2(s) \cdot G_3(s)$$

Rule (4) :-

SUMMING POINT:- Summing point represents summation of two or more input signals entering in a system. The output of summing point being the sum of entering inputs. Summing point is represented in figure:-



It is necessary to indicate the sign specifying the input signal entering a summing point.

Rule (5) :- Consecutive summing point can be interchanged, as this interchange does not alter the output signal as shown in figure (a) & (b).

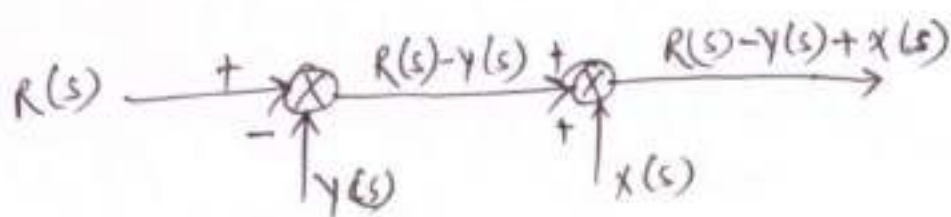
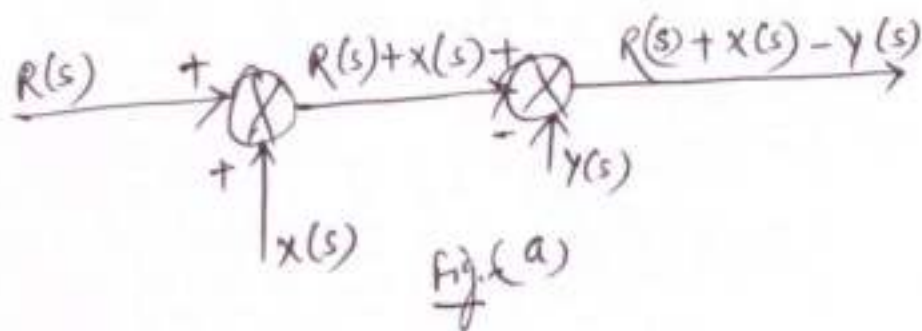


Figure:- Interchange of consecutive summing points.

Rule: (6): Blocks in parallel:  $\rightarrow$

When one or more blocks are connected in parallel as shown in figure. The overall equivalent transfer function is determined below:-

$$\frac{C(s)}{R(s)} = [G_1(s) + G_2(s) + G_3(s)]$$

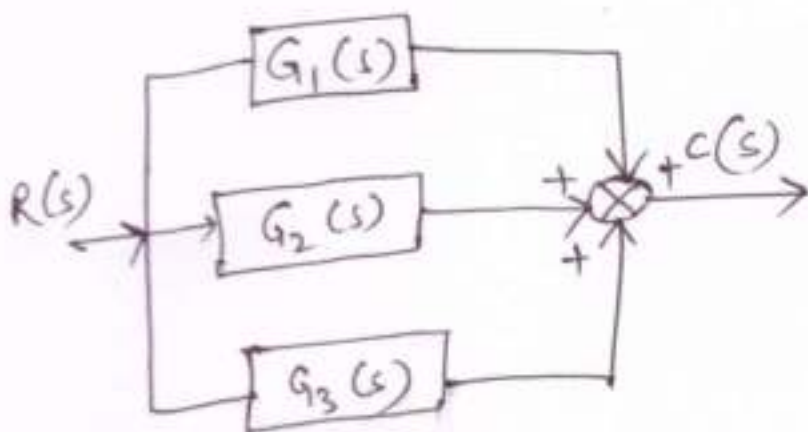


Fig. Blocks are in parallel.

Rule: (7) Shifting a take off point from a position before a block to a position after the block is shown in figure (a) & (b).

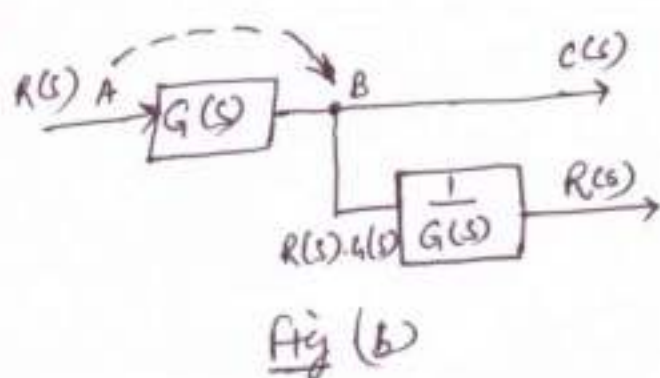
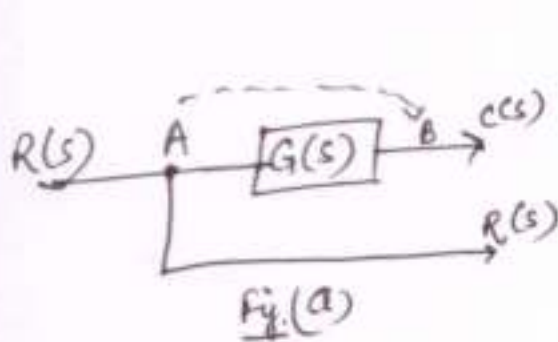


Fig. ~~Shifting~~ Take off point at position A shifted to position B.

Rule: (8)  $\Rightarrow$  Shifting of a take off point from a position after a block to a position before the block is shown in figure (a) & (b)

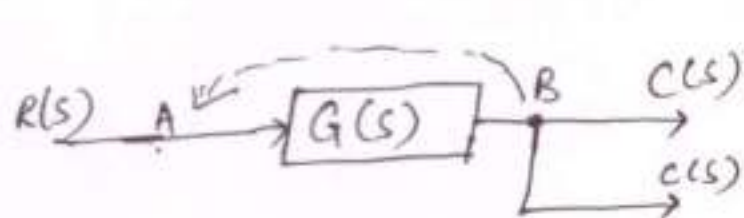


Fig. (a)

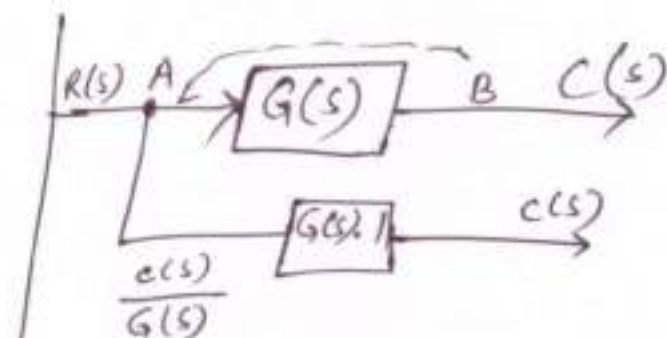


Fig. (b)

Fig.  $\Rightarrow$  Take off point at position 'B' shifted to position 'A'.

Rule: (9)  $\Rightarrow$  Shifting of a summing point from a position before a block to a position after the block is shown in figure (a) and (b).

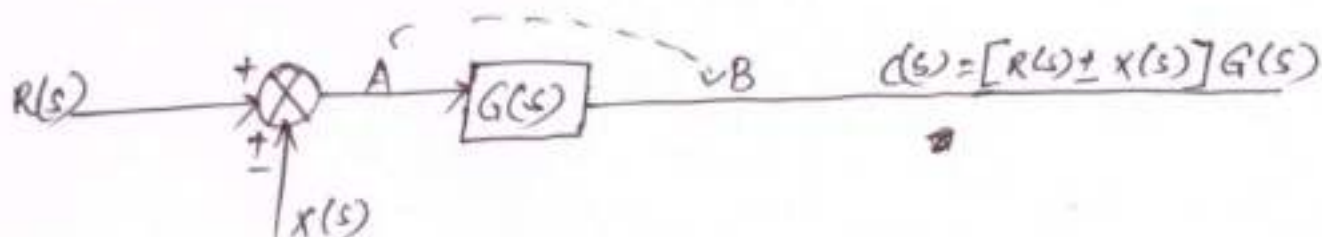


Fig. (a)

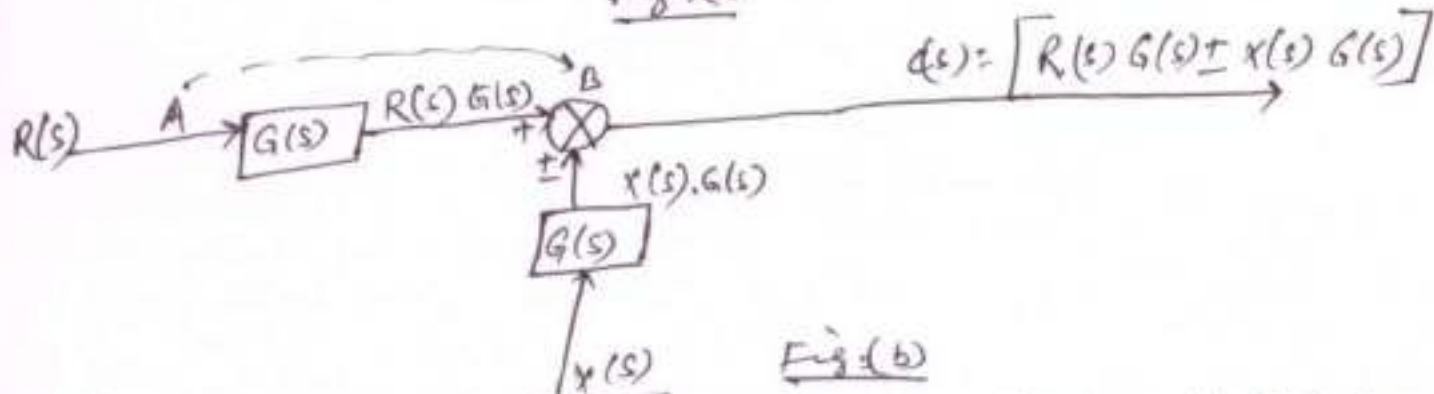


Fig. (b)

Fig. "Summing point at position 'A' is shifted to position 'B'".

Rule No 10 <sup>Page No 8</sup> Shifting of a summing point from a position after a block to a position before the block is shown in figure (a) & (b).

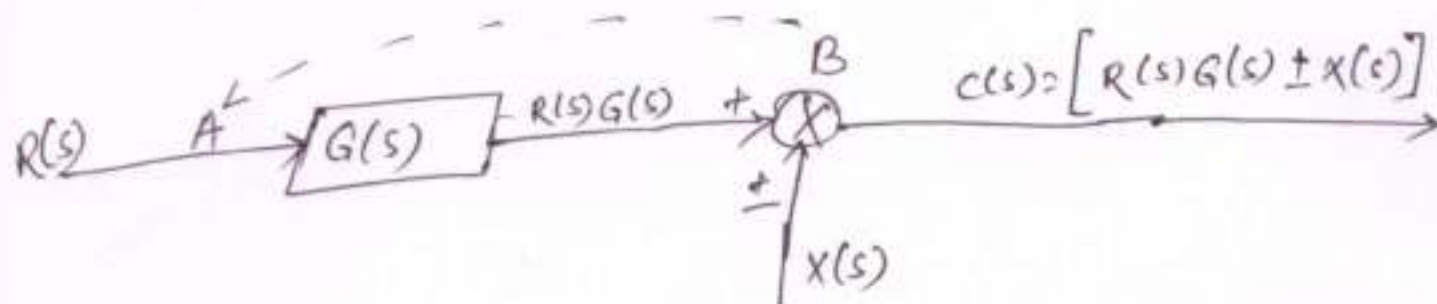


Fig  $\rightarrow$  (a).

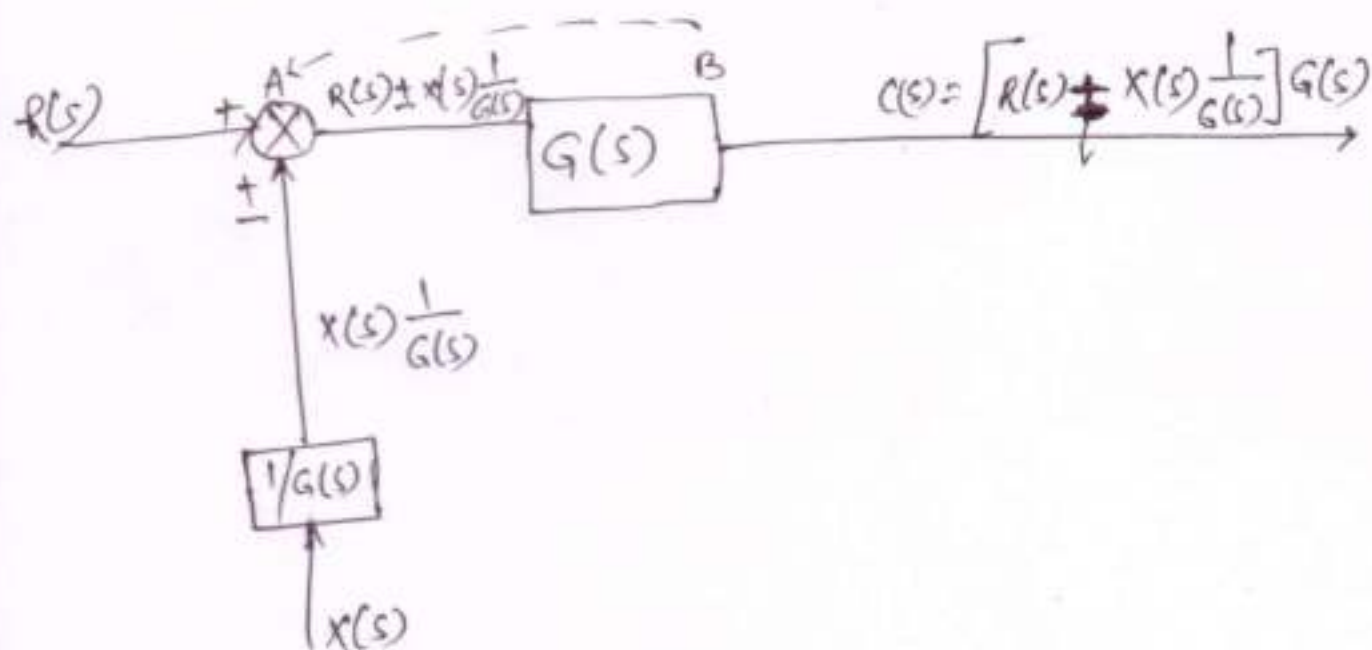


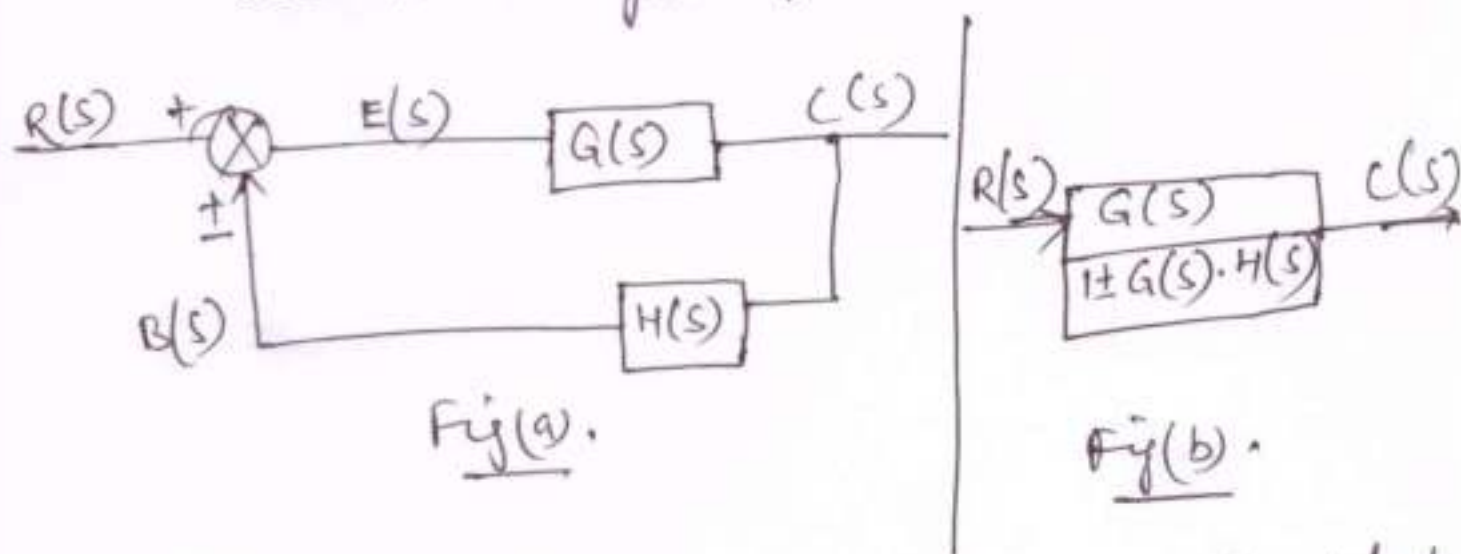
Fig  $\rightarrow$  Summing point at position 'B' shifted to position 'A'.

Rule (11) Elimination of a summing point in a closed loop system is explained below:-

" A closed loop system is represented by a block diagram shown in figure (a), wherein a fraction of output  $B(s) = C(s)H(s)$  is compared with the input  $R(s)$  which results in an error  $E(s)$  given by;

$$E(s) = [R(s) \pm B(s)]$$

The equivalence of figure (a) with figure (b) is obtained as follows:-



" Elimination of a summing point in a closed loop or (feedback) system."

66

In block diagram of a Control System,  
the terms used as:-

"  $R(s)$  = Reference input signal

$C(s)$  = Output signal

$E(s)$  = Error signal

$G(s)$  = Forward path transfer function

$B(s)$  = Feedback signal

$H(s)$  = Feedback path transfer function

$G(s)H(s)$  = Open loop transfer function

$\frac{E(s)}{R(s)}$  : Error ratio

" The application of block diagram reduction rules is illustrated hereunder for determination of the ~~the~~ overall transfer function of a system.

Example or problems on the block diagram reduction technique: Page No. (11)  
Solved example or questions:

Q.1 Determine the transfer function  $C(s)/R(s)$  from the block diagram shown in figure:-

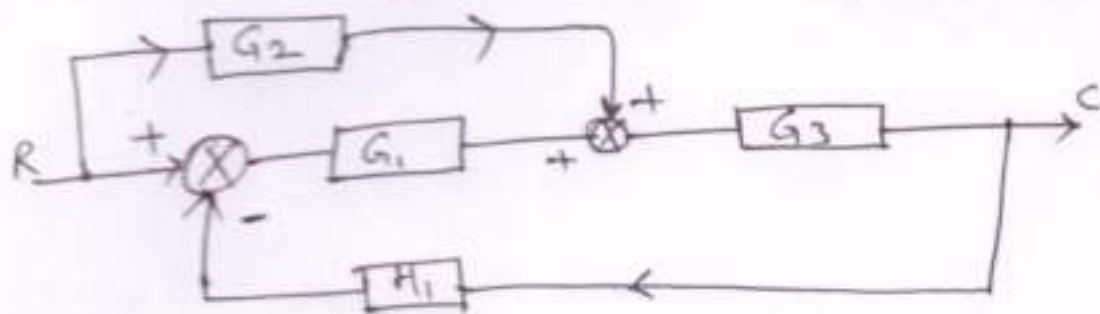


Fig. Block diagram for example & solved this use reduction rules.

Solution:- Shift the summing point before block  $G_1$  to a position after block  $G_1$ .

Step-1

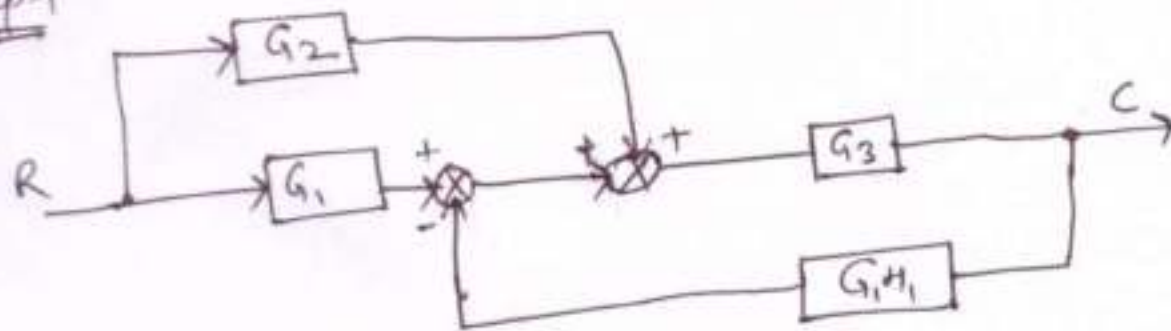


Fig. (1)(a) Block diagram reduction of system & we use the rule no. (4)

Step-2. Interchange consecutive summing points after block  $G_1$ .

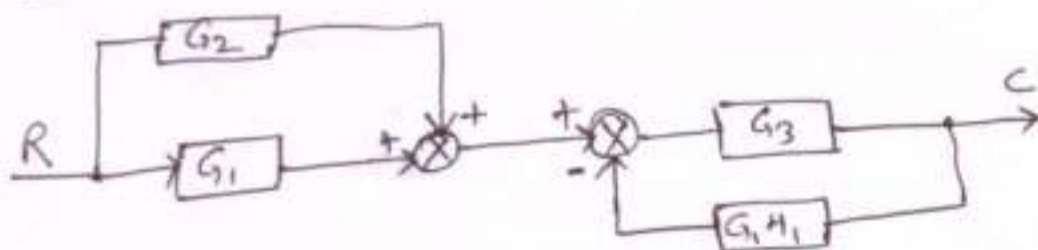


Fig. 1(b) Block diagram reduction of system in fig 1(a) & using the rule no. (5).

step-III. Eliminate summing point after block  $G_1$ .

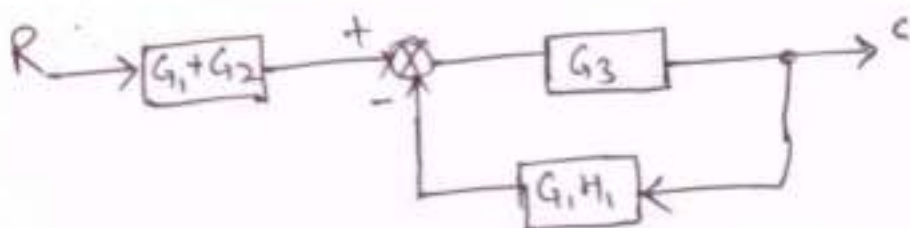


Fig: -1(c) block diagram reduction of system in fig (1)(b). we use rule No. (6).

step(IV) shift the summing point after block  $(G_1+G_2)$  to a position before block  $(G_1+G_2)$  and combine blocks  $(G_1+G_2)$  &  $G_3$ .

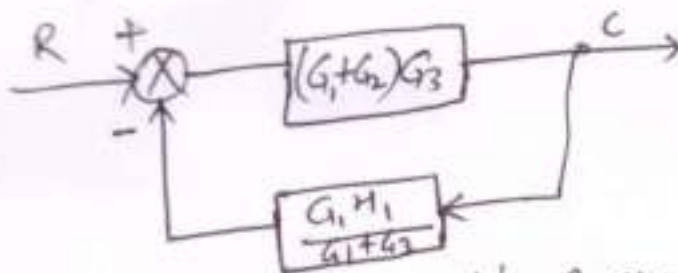


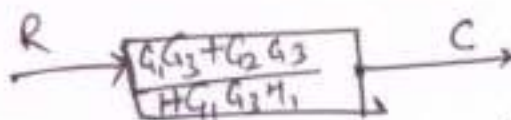
Fig: 1(d) block diagram reduction of example (4) into a form having one block in forward path and one block in feed back path.

The overall transfer function is determined below,

$$\frac{C(s)}{R(s)} = \frac{(G_1+G_2)G_3}{1 + (G_1+G_2)G_3 \left( \frac{G_1H_1}{G_1+G_2} \right)}$$

$$\boxed{\frac{C}{R} = \frac{G_1G_3 + G_2G_3}{1 + G_1G_3H_1}} \rightarrow \text{eqn (1)}$$

According to equation (1) the single block diagram representation is shown in figure.



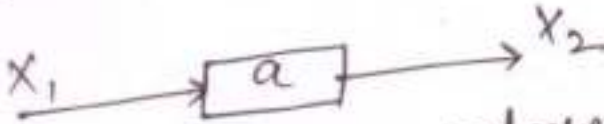
(Ans)

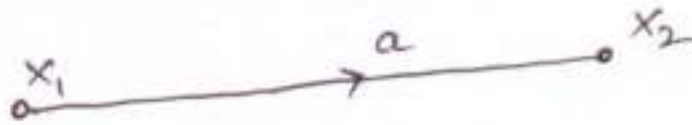
④

66. Representation of a Control System by signal flow graphs.

"Block diagram gives a pictorial representation of a Control System by way of short handling the transfer function

"Signal flow graphs further shortens the representation of a Control system by way of eliminating summing symbol, take off point and block. This elimination is achieved by representing the variables by points called 'nodes' and the transfer function is termed as "Transmittance", which is represented by a line called 'branch'. A signal on the branch travels in the direction of an arrow indicated on the branch'.

  
Fig 1. Block diagram representation of eq<sup>n</sup>  $x_2 = ax_1$

  
Fig 2. Signal flow graph representation of eq<sup>n</sup>  $x_2 = ax_1$

## Rules for drawing signal flow graph:

Page No. (15)

1. The signal travels along a branch in the direction of an arrow.
2. The input signal is multiplied by the transmittance to obtain the output signal.
3. Input signal at a node is the sum of all signals entering at that node.
4. A node transmits signals in all branches leaving that node.

"Signal flow graphs shown in the following examples illustrate the application of the above rules to obtain overall transmittance (also called gain) as the ratio of the output (effect) to the input.

Example ① → The signal flow graph shown in fig ① has one forward path and single isolated loop. Determine overall transmittance relating  $x_3$  and  $x_1$ .



Fig ① → signal flow graph with one forward path and single isolated loop.

Solution Ex ①:

$x_1$  is the input node (Independent Variable node)

$x_2$  is the intermediate node (Intermediate Variable node)

$x_3$  is the output node (dependent Variable node)

$ab$  is the forward path transmittance.

$bc$  is the loop transmittance.

The equations represented by the signal flow graph are expressed below;

$$(i) \text{ at node } x_2, x_2 = ax_1 + cx_3 \rightarrow (1)$$

$$\text{and } (ii) \text{ at node } x_3, x_3 = bx_2 \rightarrow (2)$$

By eliminating the intermediate variable  $x_2$  from eq<sup>n</sup> ① & ② the overall transmittance is determined as;

$$\frac{x_3}{x_1} = \frac{ab}{1-bc} \quad \text{Ans} \quad \text{eq<sup>n</sup> } \rightarrow (3)$$

In equation ③ the product  $ab$  is the forward path transmittance and denoted by a symbol  $P$ .

As  $bc$  forms a closed loop on itself, the product  $bc$  is termed as loop transmittance and denoted by symbol  $L$ .

The overall transmittance is denoted by a symbol  $T$ .

Therefore, in view of above notations, the overall transmittance for the signal flow graph in fig ① is expressed as;

$$T = \frac{P}{1-L}$$

⇒ Mason's Gain Formula :-

By this formula we solve the signal flow graph problems or questions.

∴ The overall transmittance (gain) can be determined by Mason's gain formula given below :-

$$T = \sum_{k=1}^{Kth} \frac{P_k \Delta_k}{\Delta}$$

The terms in the Mason's gain formula are explained below :-

$P_k$  is the forward path transmittance of the  $k^{th}$  path from a specified input node to an output node. In asserting  $P_k$  no node should be encountered more than once.

$\Delta$  is the graph determinant which involves closed loop transmittances and mutual interactions between non-touching loops.

$$\Delta = 1 - [\text{Sum of all individual loop transmittance} \\ + [\text{Sum of loop transmittance products of all possible pair of non-touching loops}] \\ - [\text{Sum of loop transmittance products of all possible triplets of non-touching loops}] \\ + [ \dots ] - [ \dots ] .$$

24.  $\Delta_k$  is the path factor associated with the concerned path and involves all closed loops in the graph which are isolated from the forward path under consideration.

The path factor  $\Delta_k$  for the  $k_{th}$  path is equal to the value of the graph determinant of a signal flow graph which exists after Erasing the  $k_{th}$  path from the graph.

" The Mason's gain formula help in solving the signal flow graph questions.

## 4 Drawing signal flow graph from a given block diagram Page no 19

While drawing a signal flow graph from a given block diagram the adjacent summing points and take off points (but not a take off point preceding a summing in the direction of signal flow) are represented by a node and the block transfer function is represented by a line joining the respective nodes. The direction of signal flow is indicated by an arrow on the line.

However, in the direction of signal flow if, a take off point precedes a summing point then such points are represented by two separate nodes with a transmittance of unity between them.

The examples given below gives a procedure for obtaining signal flow graph from a given block diagram.

"See next page"

Example: ①  $\rightarrow$  Represent the block diagram given in figure ① by signal flow graph and determine the overall transmittance relating C & R.

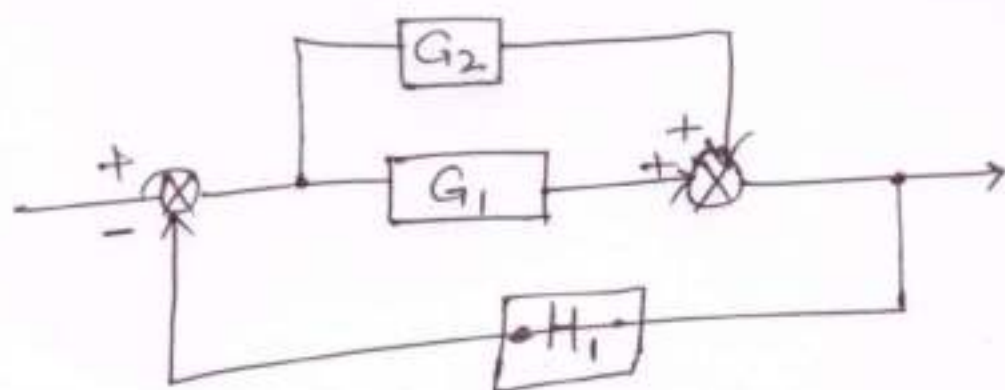


Fig Block diagram for example ①.

Solution: First of all we make the signal flow of this block diagram.

Represent adjacent summing points, take off points before and after the block  $G_1$  respectively by nodes ① & ②. Join nodes ① & ② by lines indicating respective transmittance as per block diagram. The resulting signal flow graph is shown in figure  $\rightarrow$  1(a).

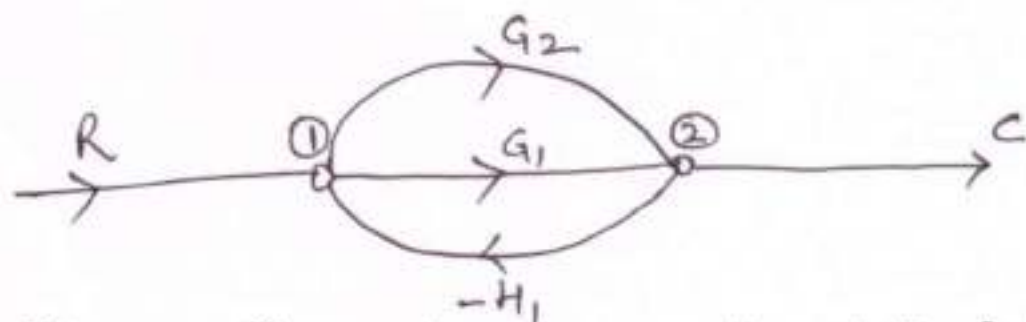


Figure. Signal flow graph representation of block

Further solution Fig 1(a) ..

Page No (1)

“ The two forward paths are  $\underline{P_1 = G_1}$  and  $\underline{P_2 = G_2}$

the two closed loops are, ~

$$L_1 = -G_1 H_1 \text{ and } L_2 = -G_2 H_1$$

“ As both the loops  $L_1$  and  $L_2$  are touching both forward paths the two path factors are, ~

$$\underline{\Delta_1 = 1} \text{ and } \underline{\Delta_2 = 1}$$

The graph determinate is

$$\Delta = 1 - [L_1 + L_2] = 1 - [-G_1 H_1 - G_2 H_1] = 1 + G_1 H_1 + G_2 H_1$$

“ Applying Mason's gain formula the overall transmittance relating C & R is determined below; ~

$$\boxed{\frac{C}{R} = \frac{P_1 \Delta_1 + P_2 \Delta_2}{\Delta}} \quad \text{“ By the Mason's gain formula; ~”}$$

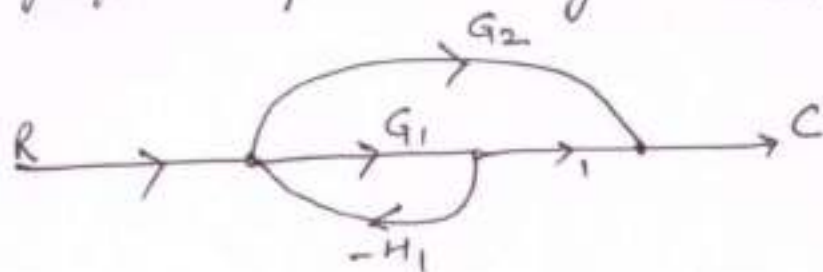
like;  $T = \sum_{k=1}^{KH} \frac{P_k \Delta_k}{\Delta} = T = \frac{P_1 \Delta_1 + P_2 \Delta_2 + P_3 \Delta_3 + \dots + P_n \Delta_n}{\Delta}$

$$\rightarrow \frac{C}{R} = T = \frac{G_1 \cdot 1 + G_2 \cdot 1}{1 + G_1 H_1 + G_2 H_1}$$

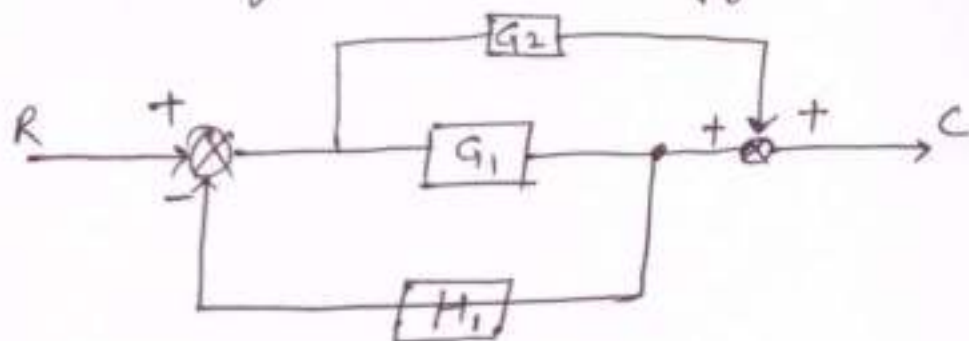
$$\boxed{T = \frac{G_1 + G_2}{1 + G_1 H_1 + G_2 H_1}}$$

(Ans)

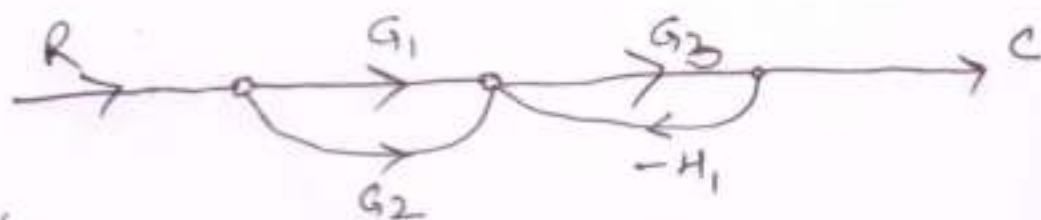
Q.1 Determine the transmittance for signal flow graph using Mason's gain formula.



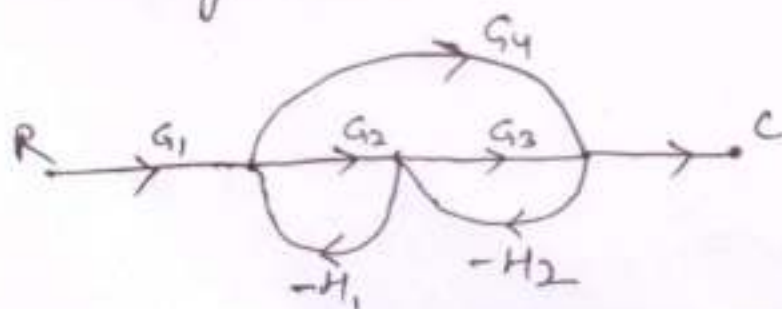
Q.2 Draw a signal flow graph only for the system whose block diagram is shown in figure.



Q.3 Determine the transmittance for signal flow graph using Mason's gain formula:



Q.4 Determine the transmittance for signal flow graph using Mason's gain formula



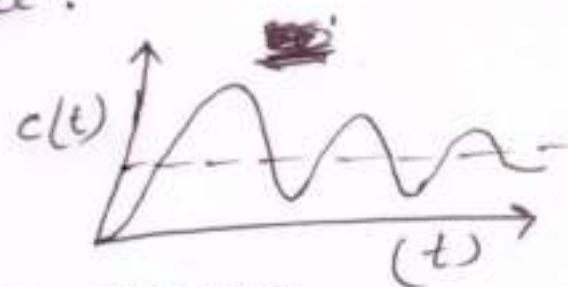
(Basics of Control system)  
(Chapter-5: Stability)

Page No. ①  
Semester-3rd (140)

Definition of Stability:

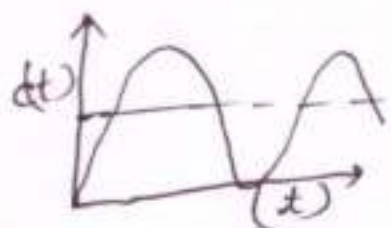
"A definition of stability with reference to linear control system is given below:

⇒ "If any oscillations set up in a system consequence to application of an input are damped out with respect to time, the system is said to be stable".

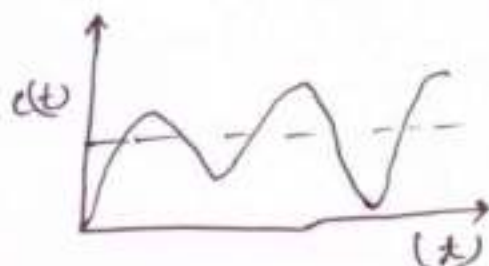


(a) Stable

⇒ "For unstable system oscillations are increasing in magnitude. If the magnitude of the oscillations is sustained the system is marginally stable."



(b) Sustained oscillations  
(marginally stable)



(c) Unstable

⇒ ROUTH-HURWITZ CRITERION ().

"In order to determine the existence of a root having positive real part for a polynomial equation given by below;

$$a_0 s^n + a_1 s^{n-1} + a_2 s^{n-2} + \dots + a_n = 0 \rightarrow \text{eqn } \textcircled{1}$$

Two rows consisting of alternate coefficients of polynomial Equation No. ① are formed as follows:-

$$\begin{array}{cccccc} a_0 & a_2 & a_4 & a_6 & - & - \\ a_1 & a_3 & a_5 & - & - & - \end{array}$$

"and the following array is formed. (illustrated for 6<sup>th</sup> order Polynomial).

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| $s^6$ | $a_0$ | $a_2$ | $a_4$ | $a_6$ |
| $s^5$ | $a_1$ | $a_3$ | $a_5$ | $0$   |
| $s^4$ | $b_1$ | $b_3$ | $b_5$ | $0$   |
| $s^3$ | $c_1$ | $c_3$ | $0$   | $0$   |
| $s^2$ | $d_1$ | $d_3$ | $0$   | $0$   |
| $s^1$ | $e_1$ | $0$   | $0$   | $0$   |
| $s^0$ | $f_1$ | $0$   | $0$   | $0$   |

→ ②

"In the Routh array (2) the Coefficients  $b_1, b_3, b_5, \dots$  etc. are related to the Coefficients of the polynomial eqn (1) as under:-

$$b_1 = \frac{a_1 a_2 - a_0 a_3}{a_1}, \quad b_3 = \frac{a_1 a_4 - a_0 a_5}{a_1}$$

$$b_5 = \frac{a_1 a_6 - a_0 \times 0}{a_1}$$

$$c_1 = \frac{b_1 a_2 - a_1 b_3}{b_1}, \quad d_1 = \frac{c_1 d_3 - b_1 c_5}{c_1} \text{ etc.}$$

From the array (2) so formed, it is observed that the elements of first Column are related to Hurwitz determinants [for example  $b_1 = D_2/D_1$ ]. The number of changes of sign in the first Column elements of Routh array gives the number of positive real part roots of the polynomial. Therefore, for a stable system there should be no change of sign in the first column of Routh array formed from the coefficients of the characteristic equation expressed in the polynomial form.

## Solved Example:- Routh Hurwitz Criterion:-

Page No. (4)

Q.1 "A closed loop Control system has the characteristic equation given by;

$s^3 + 4.5s^2 + 3.5s + 1.5 = 0$ . Investigate the stability using Routh-Hurwitz criteria.

Solution:- By the Routh-Hurwitz Criteria the following array is formed:-

$$\begin{array}{lcl} s^3 & a_0 & 1 \quad a_2 \quad 3.5 \\ s^2 & a_1 & 4.5 \quad a_3 \quad 1.5 \\ s^1 & b_1 & \boxed{3.16} \quad b_3 \quad \boxed{1.5} \rightarrow b_1 \text{ \& } b_3 \text{ find out} \\ s^0 & & \end{array}$$

Using the formula  $b_1 = \frac{a_1 a_2 - a_0 a_3}{a_1}$

formula  $b_3 = \frac{a_1 a_4 - a_0 a_5}{a_1}$

$$b_1 = \frac{4.5 \times 3.5 - 1 \times 1.5}{4.5} = \boxed{3.16}$$

$$b_3 = \frac{3.16 \times 1.5 - 4.5 \times 0}{3.16} = \boxed{1.5}$$

"In the first Column the Routh array there is no change in sign of the elements, So the system is stable."

Q. Solved Example: Determine the stability of a system whose overall transfer function is given below,

$$\frac{C(s)}{R(s)} = \frac{2s+5}{s^5 + 1.5s^4 + 2s^3 + 4s^2 + 5s + 10}$$

Solution: The Characteristics eq<sup>n</sup> is,

$$s^5 + 1.5s^4 + 2s^3 + 4s^2 + 5s + 10 = 0$$

The Routh array is formed below:

|       |       |       |    |
|-------|-------|-------|----|
| $s^5$ | 1     | 2     | 5  |
| $s^4$ | 1.5   | 4     | 10 |
| $s^3$ | -0.66 | -1.66 |    |
| $s^2$ |       |       |    |
| $s^1$ |       |       |    |
| $s^0$ |       |       |    |

$$b_1 = \frac{a_0 a_1 - a_2 a_3}{a_1}$$

$$b_1 = \frac{1.5 \times 2 - 1 \times 4}{1.5} = \frac{-1}{1.5} = -0.66$$


---


$$b_3 = \frac{a_1 a_4 - a_0 a_5}{a_1}$$

$$b_3 = \frac{1.5 \times 5 - 1 \times 10}{1.5} = \frac{-2.5}{1.5} = -1.66$$

As there are two changes in sign of the elements in the first column of the Routh table, it is concluded that the system has two roots with positive real part and as such the system is unstable.

Root Locus: →

"The stability of a closed loop Control system is determined from the location of the roots" of the characteristic equation  $1 + G(s)H(s) = 0$ . For a system to be stable the roots of its characteristic equation should be located in the L.H.S. of  $s$ -Plane.

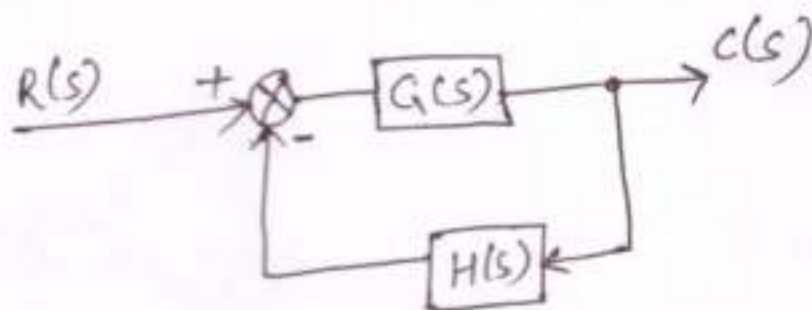


Fig. ① Block diagram of closed-loop Control system.

"A closed-loop Control system having forward path gain  $K$  is shown by the block diagram in fig. ①.

"The characteristic equation of the system is given by;

$$1 + G(s)H(s) = 0 \rightarrow \text{eqn ①}$$

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Any roots of the eq<sup>n</sup> ① satisfies following two conditions:-

$$|G(s)H(s)| = 1 \rightarrow \textcircled{1}$$

and  $\angle G(s)H(s) = (2k+1)180^\circ \rightarrow \textcircled{2}$

where  $k = 0, 1, 2, \dots$

\*The root locus method of analysis is a process of determining the points in s-plane satisfying eq<sup>n</sup> ① & ② usually the forward path gain factor (k) is considered as an independent variable and the roots of  $1+G(s)H(s)=0$  as dependent variables, the roots are plotted in s-plane with k as variable parameter. From the location of the roots in s-plane the nature of time response and system stability can be ascertained.

---

## Salient features of Root Locus plot in section 1

The salient features of the root locus are follows:

1. The Root Locus starts ( $K=0$ ) from the open loop poles and terminates ( $K=\infty$ ) on the either finite open loop zeros or infinity.
2. The number of separate branches of the root locus equals either the number of open loop poles or no. of ~~the~~ open loop zeros whichever is greater.
3. A section of root-locus lies on the real axis if the total no. of open loop poles and zeros to the right of the section is odd.
4. The root locus is symmetrical with respect to the real axis.
5. At some point on the root locus between two open loop poles the root locus breaks away.
6. For higher values of  $K$  the root locus can be approximated by asymptotic lines and these asymptotic lines intersect at a point on the real axis.

7. The asymptotic lines make an angle with real axis at an intersection point (Centre of Gravity).
8. If the root locus intersects the imaginary axis then the points of intersection are Conjugate.
9. From the open loop complex pole the root-locus departs making an angle with the horizontal line.

### ④ The Procedure for plotting root locus:

"The stepwise procedure for plotting the root-locus for a given open-loop transfer function based on salient features mentioned in section ① is given below:

1. Starting points: The root locus starts ( $K=0$ ) from the open loop poles.
2. Ending point: The root locus terminates ( $K=\infty$ ) either on open-loop zero or infinity.
3. Number of branches: The no. of Branches

of the root locus are,

$$N = P \text{ if } P > Z$$

$$N = Z \text{ if } Z > P$$

Usually,  $P > Z$ , therefore,  $N = P$

4. Existence on real axis The existence of the root locus on a section of real axis is confirmed if the sum of the open-loop poles and zeros to the right of the section is odd.
5. Breakaway points On the root locus between two open loop poles the roots move towards each other as the gain factor  $k$  is increased till they are coincident. At the coincident point the value of  $k$  is maximum as far as the portion of the root locus between the two open-loop poles is concerned. Any further increase in the value of  $k$ , breaks the root locus in two parts. The breakaway point can be determined by rewriting the characteristic eqn and therefrom solving for the value of ' $s$ ' from the eqn is given below

$$\frac{dk}{ds} = 0.$$

6. The angle of asymptotes - For higher value of  $k$  the root locus branches are approximated by asymptotic lines making an angle with the real axis given by  $\frac{(2k+1) \times 180^\circ}{P-Z}$  where  $k = 0, 1, 2 \dots$  upto  $(P-Z)-1$ . Xajen: ④

7. Intersection of asymptotes on real axis - The asymptotes intersect at a point  $\sigma$  on the real axis given by  $\sigma = \frac{\sum \text{Poles} - \sum \text{Zeros}}{P-Z}$

8. Intersection points with imaginary axis - The value of  $k$  and the point at which the root locus branch crosses the imaginary axis is determined by applying Routh criterion to the characteristic equation. The roots at the intersection point are imaginary.

(9) The angle of departure from complex poles The angle of departure of the root locus from a complex pole is given by;

$$\phi_d = 180^\circ - (\phi_p - \phi_z)$$

where;  $\phi_p$  is the sum of all the angles subtended by remaining poles

and  $\phi_z$  is the sum of all angles subtended by zeros.

The angle of departure is tangent to the root locus at the complex pole.

(10) The angle of arrival at complex zeros The angle of arrival of the root locus at a complex zero is given by;

$$\phi_a = 180^\circ - (\phi_z - \phi_p)$$

where;  $\phi_p$  is the sum of all angles subtended by poles.  
 $\phi_z$  is the sum of all angles subtended by remaining zeros.

The angle of arrival is tangent to the root locus at the complex zero.

The steps given above are sufficient to plot the root locus for a given open-loop transfer function. The calculation of the value of  $K$  at a specified point on the root locus, determination of the damping ratio  $\zeta$ , assessment of time response and stability etc. are illustrated in the following Solved Examples. ()

Root Locus

Ex: Question A Unity feedback Control system has an open loop transfer function:-

$$G(s) = \frac{K}{s(s+4)}$$

Draw the Root locus.

Solution: "By the formula of plotting the Root locus:-"

1. The Root ~~loci~~ <sup>loci</sup> start ( $K=0$ ) from  $s=0$  and  $s=-4$ .
2. As there is no open loop zero root loci terminate ( $K=\infty$ ) at infinity.
3. As the no. of poles is 2 the no. of root locus branches  $N=2$ .
4. The Root locus on the Real axis exists between  $s=0$  and  $s=-4$ .
5. Breakaway points.

The characteristic equation is

$$s(s+4) + K = 0 \quad \text{or} \quad K = -(s^2 + 4s)$$

$$\frac{dK}{ds} = -(2s+4)$$

$$\text{put } \frac{dK}{ds} = 0 \quad \therefore (2s+4) = 0$$

$s = -2$  is a breakaway point.

6. The angle of asymptotes is given by:

$$\frac{(2k+1)180^\circ}{P-Z} \quad \text{where } k=0 \text{ and } 1$$

The two asymptotes are at an angle of

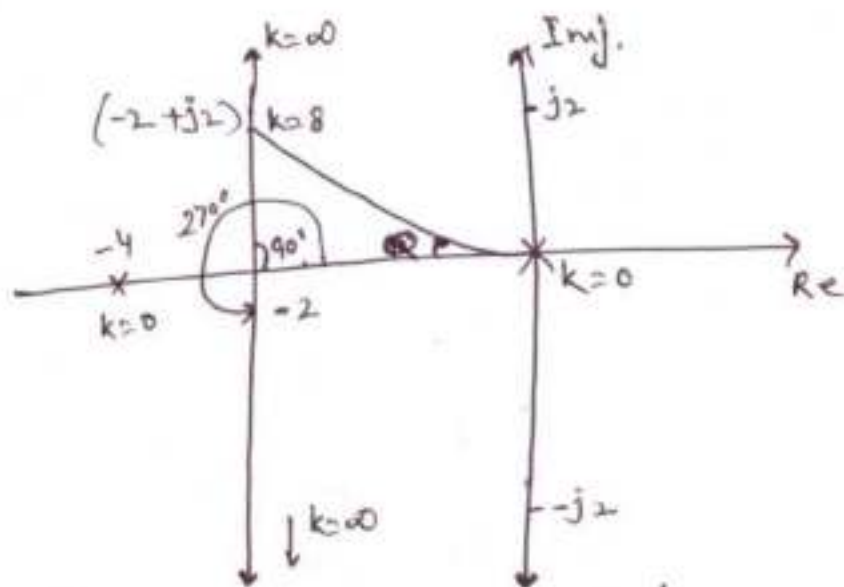
$$(i) \quad \frac{(2 \times 0 + 1)180^\circ}{2-0} = 90^\circ$$

$$(ii) \quad \frac{(2 \times 1 + 1)180^\circ}{2-0} = 270^\circ$$

7. The asymptotes intersect on real axis at point given by

$$\sigma = \frac{\sum \text{Poles} - \sum \text{Zeros}}{P-Z} = \frac{(0-4)-0}{2} = -2.$$

With the data calculated in step 1 to 7, the Root locus plotted in fig (1).



Root locus for  $G(s)H(s) = K/s(s+4)$  (1)

# **B.K.N GOVT POLYTECHNIC NARNAUL**

**DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING**

**SUBJECT: 3.4 BASICS OF INSTRUMENTATION**

**NAME OF FACULTY: Mrs. RAJNI**

**SEMESTER-3<sup>rd</sup>**

**UNIT – 1 Basics of Instrumentation System**

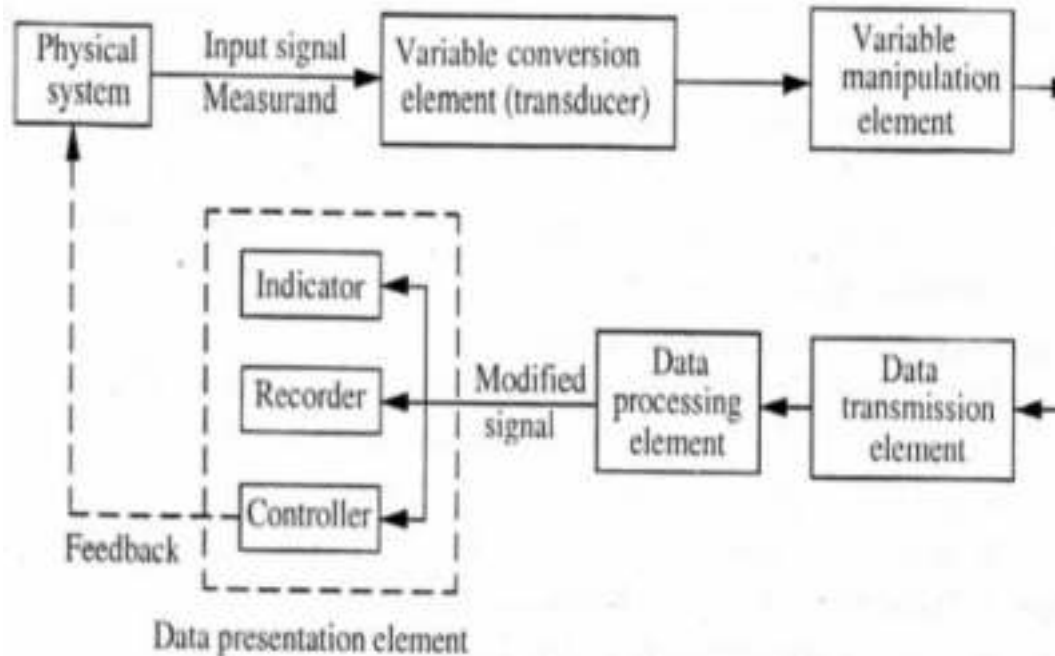
## **1.1 Scope and necessity of instruments**

1. The instrument would sense a physical parameter (e.g., velocity, pressure, temperature, etc.), process and translate it into a format and range which can be interpreted by the observer.
2. The instrument must also provide the control by which the operator can obtain, manipulate and respond to the information.
3. An instrument, in simple cases, consists of a single unit which gives an output reading or signal according to the unknown variable (measurand) applied to it. Under more complex measurement situations, a measuring instrument may consist of transducing element which convert the measurand to analogous form. The analogous signal is then processed by some intermediate means and then fed to the end devices for presenting the measurement results for the purpose of display, record and control.
4. The instrument made by may not only retain their characteristics for extended periods of time but are also accurate and sensitive in their response.
5. Measurements involve the use of instrument as a physical means of determining quantities and variables.

## **1.2 Measurement, its significance and types**

**Measurement**, the process of associating numbers with physical quantities and phenomena. Measurement is fundamental to the sciences; to engineering, construction, and other technical fields; and to almost all everyday activities. For that reason the elements, conditions, limitations, and theoretical foundations of measurement have been much studied. See also measurement system for a comparison of different systems and the history of their development.

# Generalized Measurement System



## 1.2.1 Significance of Measurement

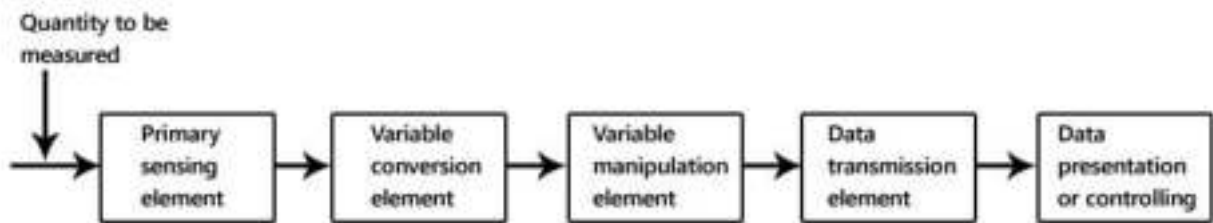
The significance of measurement is discussed below:

- Measurement plays a very significant role in every branch of scientific research and engineering processes which include the following:
  - Control system;
  - Process instrumentation;
  - Data reduction.
- The whole area of automation or automatic controls is based on measurement. The very concept of control is based on the comparison of the actual condition and the desired performance. The exactness of error depends on the precision and accuracy of measurements made.
- The measurements confirm the validity of a hypothesis and also add to its understanding. This eventually leads to new discoveries that require new and sophisticated measuring techniques.
- Through measurement a product can be designed or a process be operated with maximum efficiency, minimum cost, and with desired degree of reliability and maintainability.

### 1.3 Building Blocks of instrumentation system

**Instrumentation** is a collective term for measuring instruments that are used for indicating, measuring and recording physical quantities. The term has its origins in the art and science of scientific instrument-making.

It is branch of engineering which deals with various types of instrument to record, monitor, indicate and control various physical parameters such as pressure, temperature, etc.



The block diagram shown above is of basic instrumentation system. It consists of primary sensing element, variable manipulation element, data transmission element and data presentation element.

#### Primary sensing element

The primary sensing element is also known as sensor. Basically transducers are used as a primary sensing element. Here, the physical quantity (such as temperature, pressure etc.) are sensed and then converted into analogues signal.

#### Variable conversion element

It converts the output of primary sensing element into suitable form without changing information. Basically these are secondary transducers.

#### Variable manipulation element

The output of transducer may be electrical signal i.e. voltage, current or other electrical parameter. Here, manipulation means change in numerical value of signal. This element is used to convert the signal into suitable range.

#### Data transmission element

Sometimes it is not possible to give direct read out of the quality at a particular place (Example – Measurement of temperature in the furnace). In such a case, the data should transfer from one place to another place through channel which is known as data transmission element. Typically transmission path are pneumatic pipe, electrical cable and radio links. When radio link is used, the electronic instrumentation system is called as telemetry system.

#### Data presentation or controlling element

Finally the output is recorded or given to the controller to perform action. It performs different functions like indicating, recording or controlling.

## 1.4 Various testing signals

### Standard Test Signals

The standard test signals are impulse, step, ramp and parabolic. These signals are used to know the performance of the control systems using time response of the output.

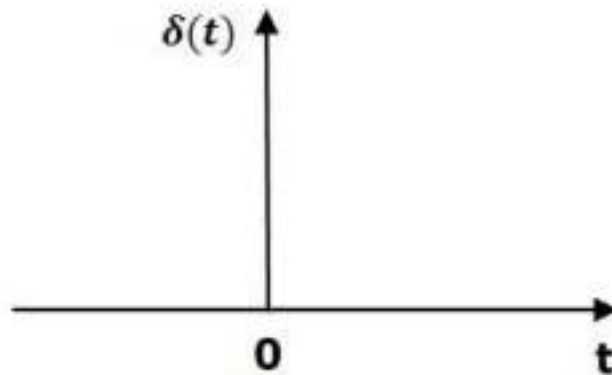
#### Unit Impulse Signal

A unit impulse signal,  $\delta(t)$  is defined as

$$\delta(t)=0 \text{ for } t \neq 0$$

$$\text{and } \int_{0+0-} \delta(t) dt = 1$$

The following figure shows unit impulse signal.



So, the unit impulse signal exists only at 't' is equal to zero. The area of this signal under small interval of time around 't' is equal to zero is one. The value of unit impulse signal is zero for all other values of 't'.

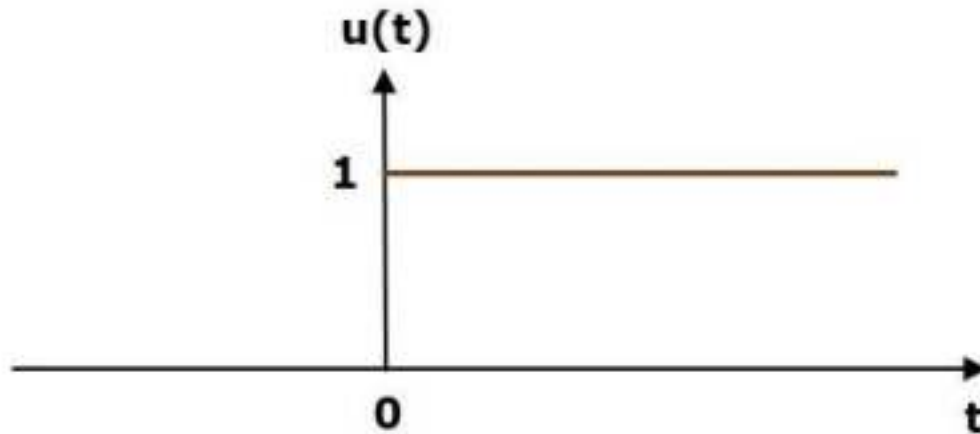
#### Unit Step Signal

A unit step signal,  $u(t)$  is defined as

$$u(t)=1; t \geq 0$$

$$=0; t < 0$$

Following figure shows unit step signal.



So, the unit step signal exists for all positive values of 't' including zero. And its value is one during this interval. The value of the unit step signal is zero for all negative values of 't'.

### Unit Ramp Signal

A unit ramp signal,  $r(t)$  is defined as

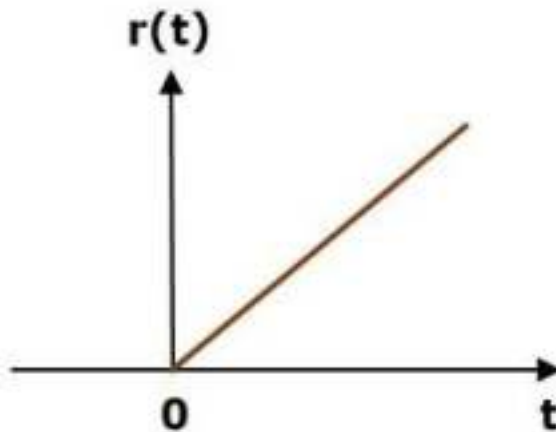
$$r(t)=t; t \geq 0$$

$$=0; t < 0$$

We can write unit ramp signal,  $r(t)$  in terms of unit step signal,  $u(t)$  as

$$r(t)=tu(t)$$

Following figure shows unit ramp signal.



So, the unit ramp signal exists for all positive values of 't' including zero. And its value increases linearly with respect to 't' during this interval. The value of unit ramp signal is zero for all negative values of 't'.

## Unit Parabolic Signal

A unit parabolic signal,  $p(t)$  is defined as,

$$p(t) = t^2/2; t \geq 0$$

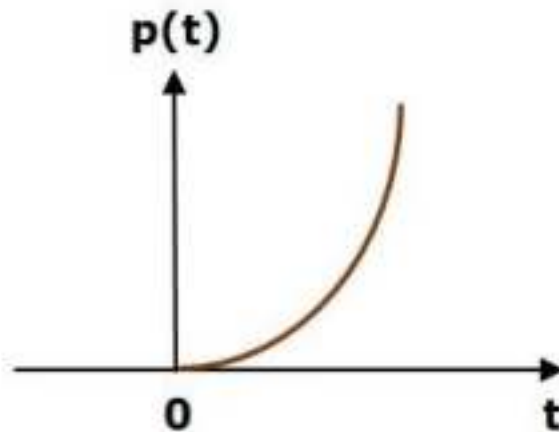
$$= 0; t < 0$$

We can write unit parabolic signal,  $p(t)$  in terms of the unit step signal,  $u(t)$  as,

$$p(t) = t^2/2 \cdot u(t)$$

$$p(t) = t^2/2 \cdot u(t)$$

The following figure shows the unit parabolic signal.



So, the unit parabolic signal exists for all the positive values of  $t$  including zero. And its value increases non-linearly with respect to  $t$  during this interval. The value of the unit parabolic signal is zero for all the negative values of  $t$ .

## 1.5 Important process variable and their units

Process Variables are:

- Flow.
- Pressure.
- Temperature.
- Level.
- Quality i.e. % O<sub>2</sub>, CO<sub>2</sub>, pH etc.

1. Flow: Any fluids or liquids' flowing from one place to another place is called flow and it is defined as volume per unit of time at specified temperature and pressure Conditions, is generally measured by positive-displacement or rate meters.  
Units: kg / hr, litter / min, gallon / min, m<sup>3</sup> / hr, Nm<sup>3</sup> / hr. (Gases)

2. Pressure: It is defined as Force per unit Area.  $P = F/A$   
Units: bar, Pascal, kg / cm<sup>2</sup>, lb / in<sup>2</sup>.
3. Level: The height of the water column, liquid and powder etc., at the desired measurement of height between minimum level points to maximum level point is called level. The measurement principle is, head pressure method.  
Units: Meters, mm, cm, percentage.
4. Temperature: It is the degree of hotness or coldness of a body is called temperature.  
Units: Degree Centigrade, Degree Fahrenheit, Degree Kelvin, Degree Rankin.
5. Quality: It deals with analysis.( pH, % CO<sub>2</sub>, % O<sub>2</sub>, Conductivity, Viscosity )

# **B.K.N GOVT POLYTECHNIC NARNAUL**

**DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING**

**SUBJECT: 3.4 BASICS OF INSTRUMENTATION**

**NAME OF FACULTY: Mrs. RAJNI**

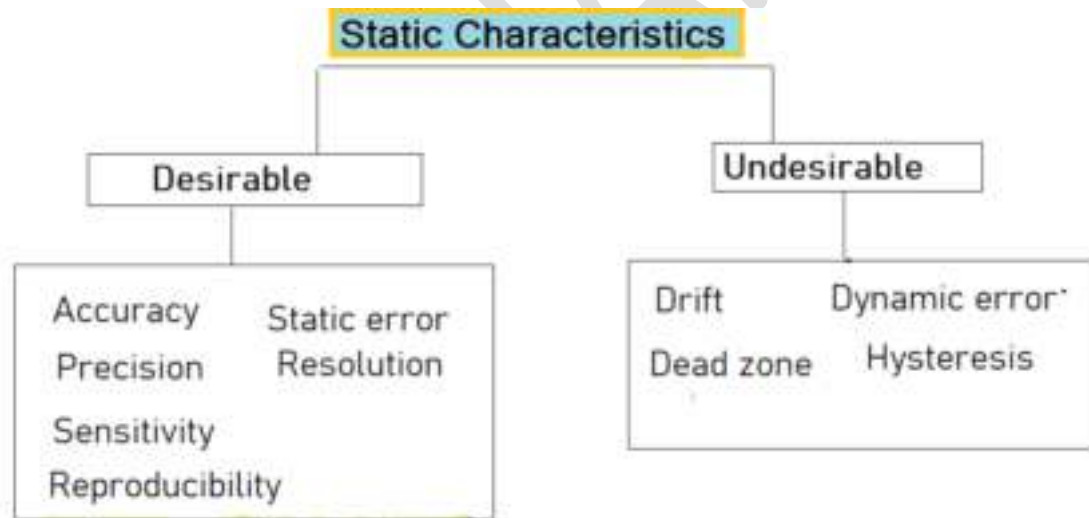
**SEMESTER-3<sup>rd</sup>**

**Unit-2**

**2.1 Performance characteristics:-**

**2.1.1. The performance** of any measuring instrument is affected by several factors. There are two basic performance characteristics of measuring instruments. Static Characteristics and Dynamic Characteristics.

**Static Characteristics**



## **Static Characteristics:**

**The following are the static characteristics.**

1. Accuracy
2. Precision
3. Linearity
4. Resolution
5. Sensitivity
6. Hysteresis
7. Drift

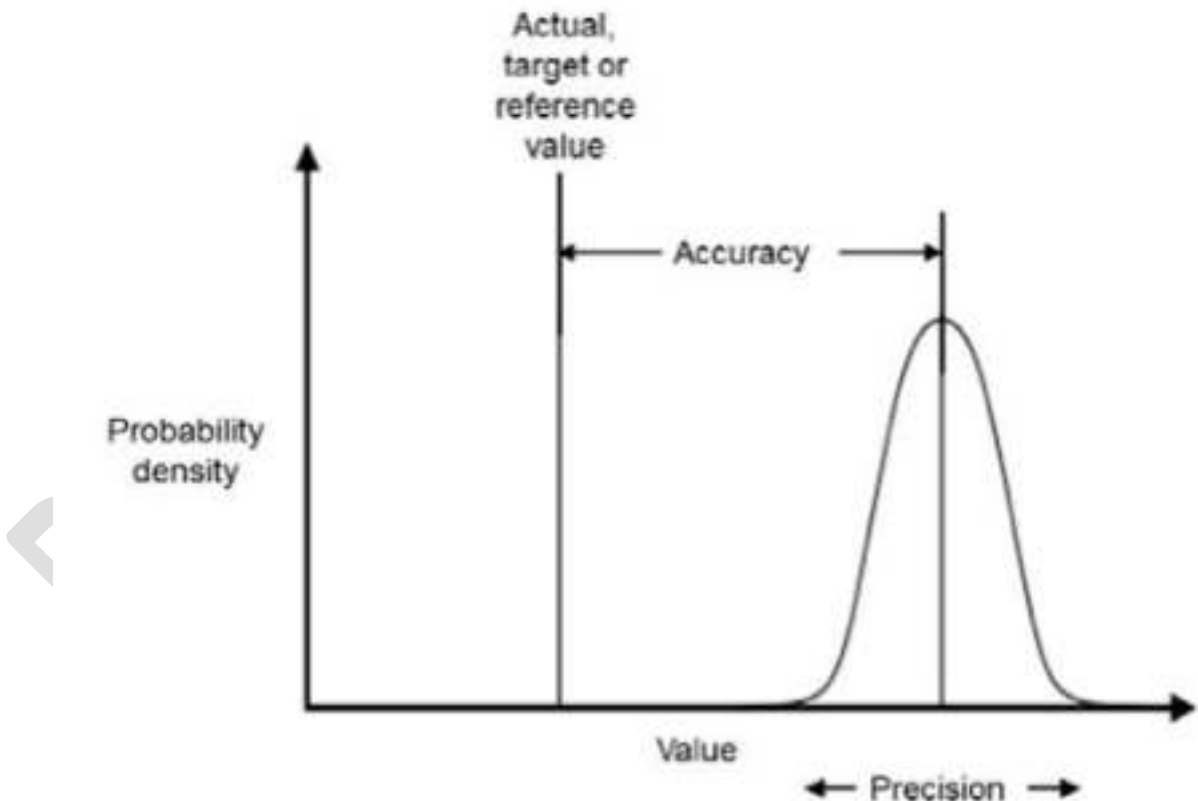
8. Dead time
9. Loading effects

## 1. Accuracy

Accuracy may be defined as the degree of closeness with which the instrument reading approaching the true value of the quantity to be measured.

The measured quantity may be different from the true value due to the effects of temperature, humidity, etc.,

- Accuracy is expressed in the “percentage of full-scale reading”. In the case of instruments having a uniform scale, the accuracy can be expressed as “Percentage of Full-scale reading”.
- The best way to develop the ideas of accuracy is to specify it in terms of the percentage of the true value of a quantity being measured.



## 2. Precision

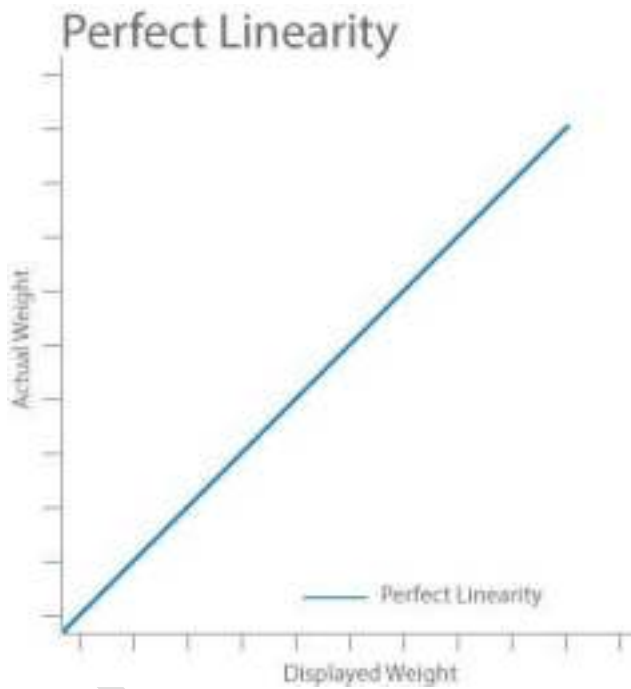
Precision is defined as the ability of instrument to reproduce a certain set of readings within given accuracy.

- Precision describes an instrument's degree of random variations in its output when measuring a constant quantity.
- Precision depends upon repeatability

## 3. Linearity

**Linearity** is the property of a mathematical relationship (*function*) that can be graphically represented as a straight line. Linearity is closely related to proportionality. Examples in physics include the linear relationship of voltage and current in an electrical conductor (Ohm's law), and the relationship of mass and weight. By contrast, more complicated relationships are nonlinear.

Generalized for functions in more than one dimension, linearity means the property of a function of being compatible with addition and scaling, also known as the superposition principle.



## 4. Resolution (Discrimination)

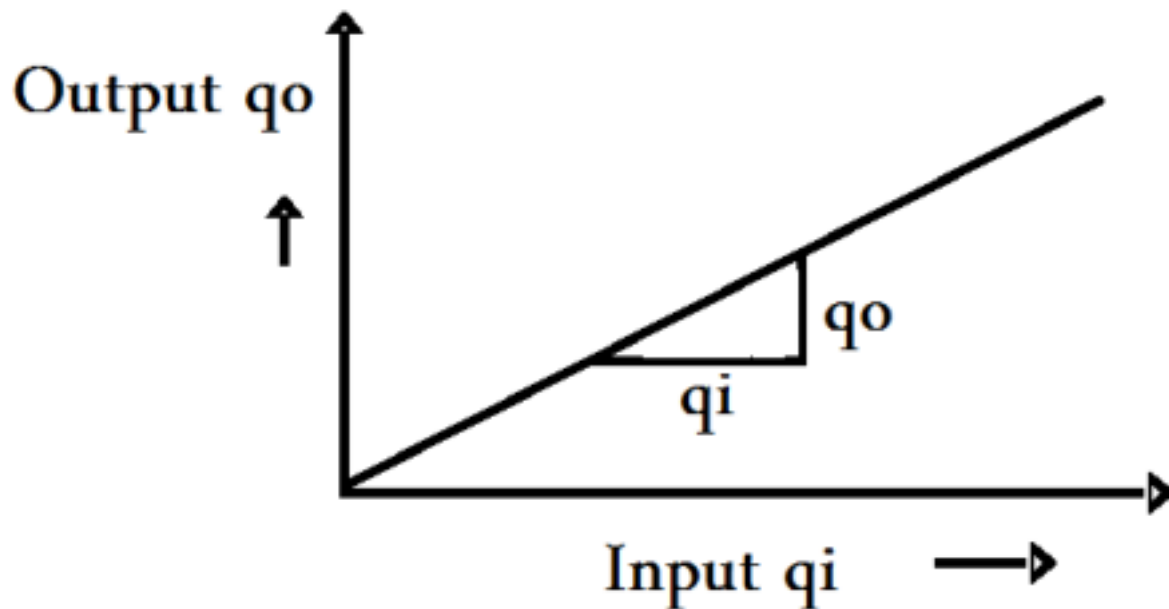
- It is the minimum change or smallest increment in the measured value that can be detected with certainty by the instrument.
- It can be least count of instrument.

## 5. Sensitivity

Sensitivity can also be derived as for the smallest changes in the measured variable for which the instrument responds.

Sensitivity can be defined as the ratio of a change in output to change in input which causes it, in steady-state conditions.

The usage of this term is generally limited to linear devices, where the plot of output to input magnitude is straight.



$$\text{Sensitivity} = \text{Change in output} / \text{Change in input}$$

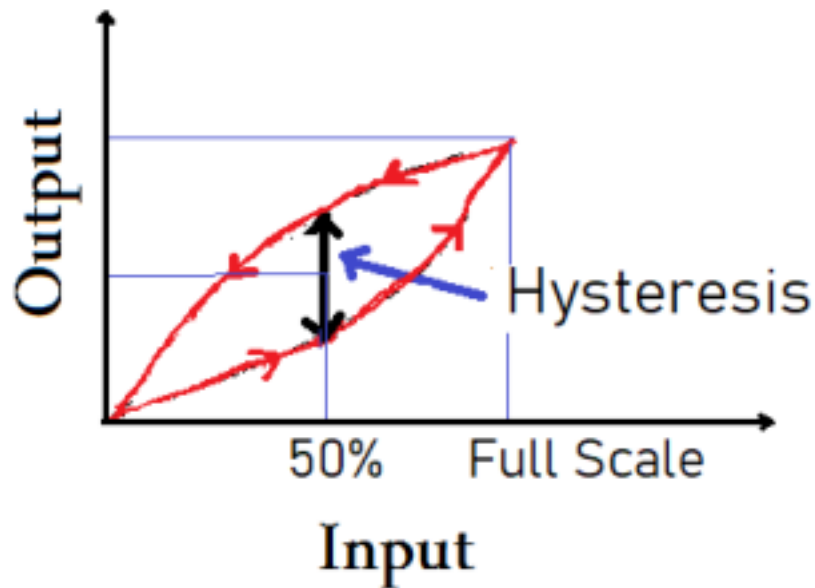
Sensitivity can also be derived as for smallest changes in the measured variable instrument responds.

The term sensitivity is sometimes used to describe the maximum change in an input signal that will not initiate on the output.

## **6. Hysteresis**

Hysteresis is a phenomenon that illustrates the different output effects when loading and unloading.

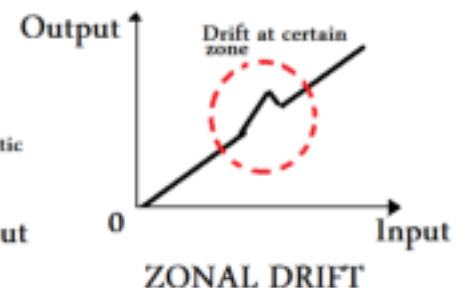
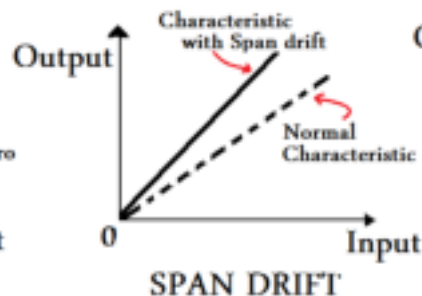
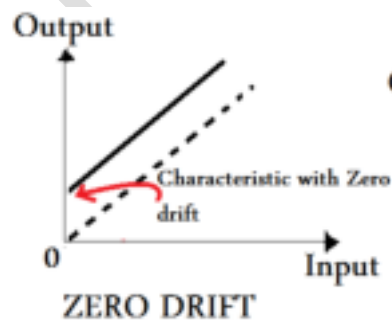
Many times, for the increasing values of input an instrument, may indicate one set of output values. For the decreasing values of the input, the same instrument may indicate its different set of output values. When output values are plotted against input the following kind of graph is obtained.



From the above figure, it can be seen that for increasing inputs and decreasing inputs the maximum variation is seen at 50% of the full scale.

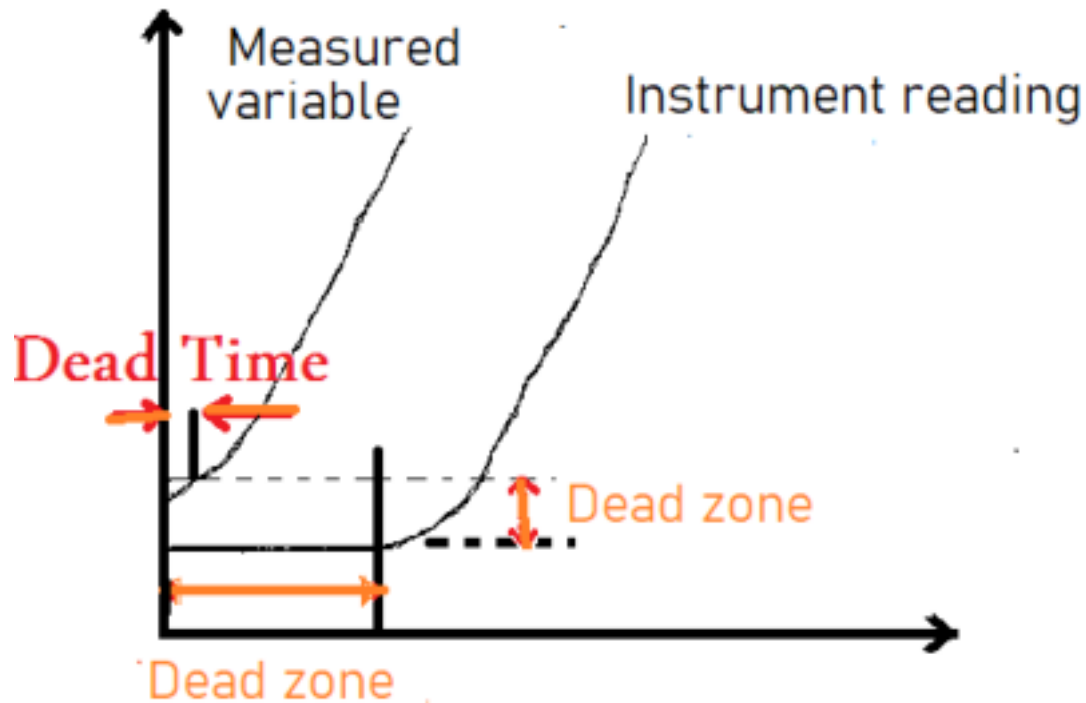
## 7. Drift

- 1) It is an undesired change in the output of a measured variable over a period of time that is unrelated to the changes in output, operating conditions, load.
- 2) Drift may be caused by environmental factors mechanical vibrations, changes in temperatures, stray electric fields, stray magnetic fields, thermal EMFs.
- 3) Drift occurs in temperature measurement due to scale formation on thermowell.
- 4) Drift occurs in Thermocouple or RTD elements due to the change of metallic properties.
- 5) Drift for a measuring device can be systematic or random or both some times. Due to wear and tear in the edge of an orifice plate the flow drift occurs systematic way.
  - Zero Drift
  - Span Drift
  - Zonal Drift



## 8. Dead Zone

- For the largest range of values of a measured variable, to which the instrument does not respond.
- The dead zone occurs more often due to static friction in indicating an instrument.



## 9. Loading effects

Loading effect can be defined as the effect on the source by the load impedance. Usually loading effect reduces the voltage level of a voltage source. Amplifier input impedance are calculate taking both the bias resistances ( $R_1$ ,  $R_2$ ) and the transistor input.

### 2.1.2. Dynamic characteristics

#### Time constant

Response time is the total amount of time it takes to respond to a request for service.

## 2.2 Selection criteria of instrument

### Instrument Selection Criteria

The selection of an instrument for a specific application is an iterative process, carried out as a joint effort of a process technologist and an instrument engineer. Following are the points that should be considered while choosing the instrument for particular application

1. Identify all operating cases, such as normal operation at minimum, normal and maximum flow, alternative operating modes, start-up, commissioning and emergency operation.

2. The extent to which the measuring system will be disturbed during the measuring process is another important factor in instrument choice. For example significant pressure loss can be caused to measured system in some techniques of flow measurement.
3. Consideration of durability, maintainability and consistency of performance are also very important during selecting the appropriate instrument.
4. Select suitable instrument makes and types for each measurement option.

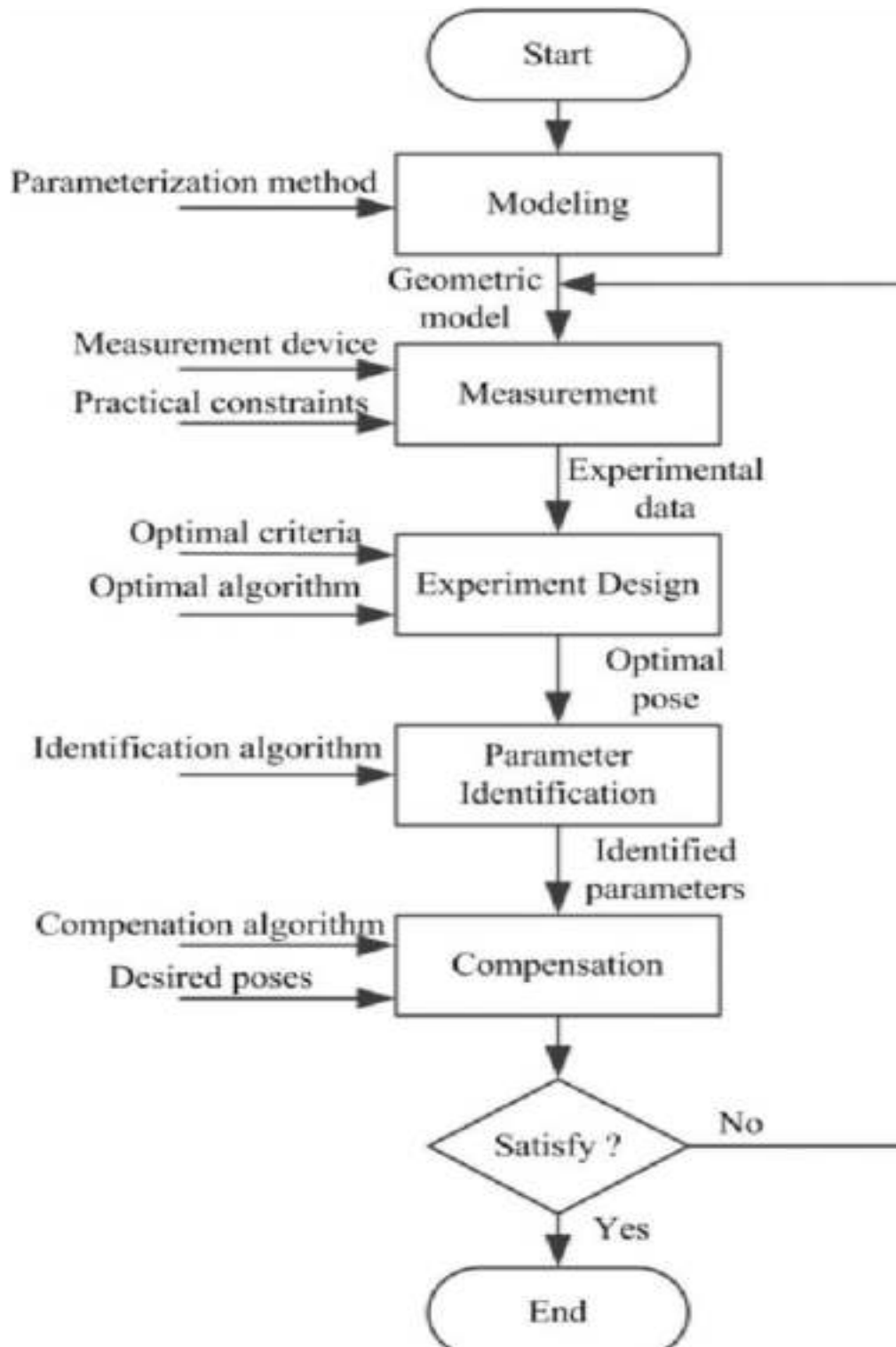
## **2.3 Calibration**

### **2.3.1 Definition and importance of calibration**

Calibration is a comparison between a known measurement (the standard) and the measurement using your instrument. Typically, the accuracy of the standard should be ten times the accuracy of the measuring device being tested. However, accuracy ratio of 3:1 is acceptable by most standards organizations.

Calibration of your measuring instruments has two objectives. It checks the accuracy of the instrument and it determines the traceability of the measurement. In practice, calibration also includes repair of the device if it is out of calibration. A report is provided by the calibration expert, which shows the error in measurements with the measuring device before and after the calibration.

To explain how calibration is performed we can use an external micrometer as an example. Here, accuracy of the scale is the main parameter for calibration. In addition, these instruments are also calibrated for zero error in the fully closed position and flatness and parallelism of the measuring surfaces. For the calibration of the scale, a calibrated slip gauge is used. A calibrated optical flat is used to check the flatness and parallelism.



Block diagram of complete procedure of calibration

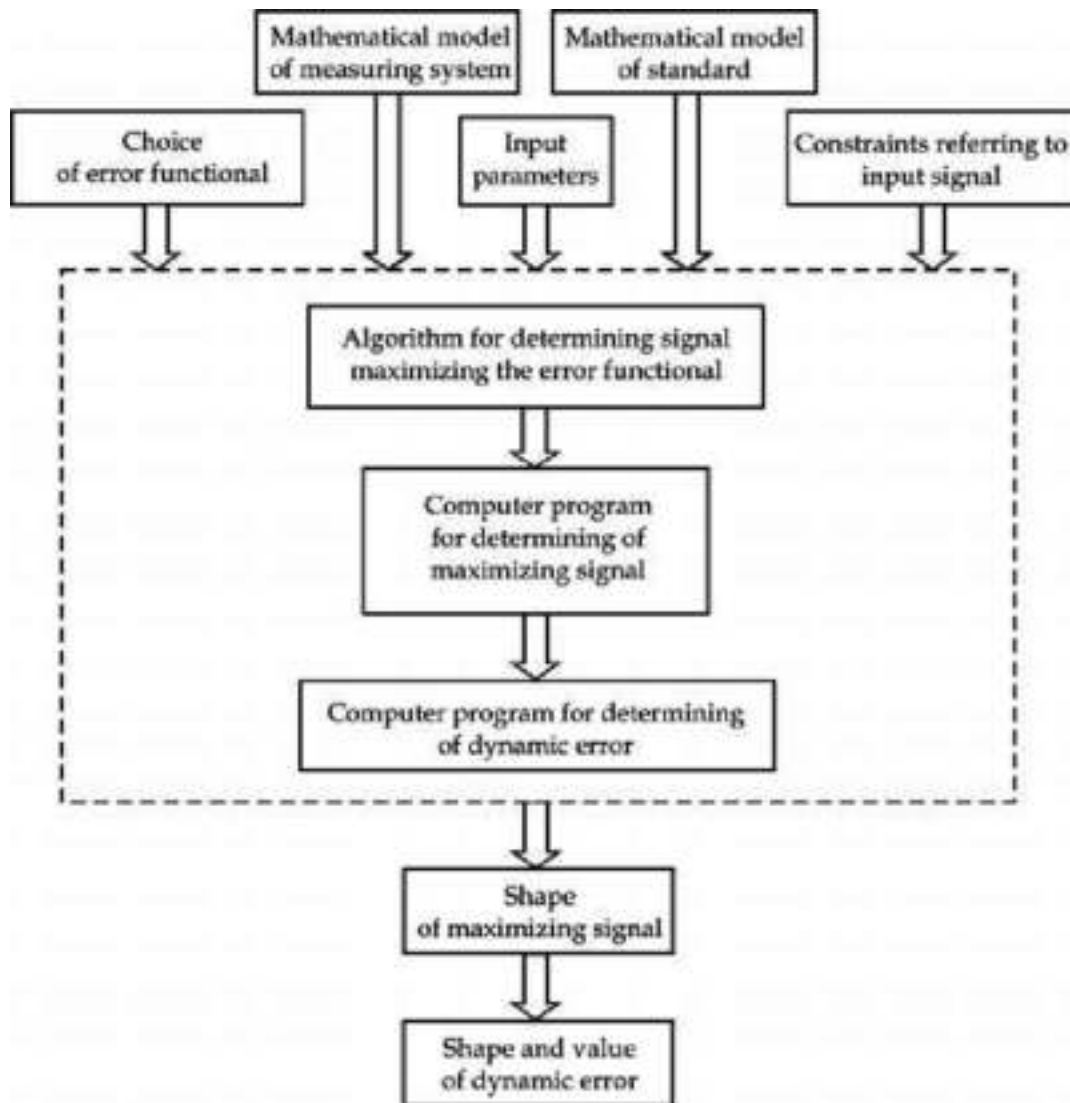
## **The Importance of Calibrating Measurement Instrumentation**

- To calibrate instrumentation means to determine, check, or rectify the graduation of any instrument giving quantitative measurement.
- Calibrating a device ensures that the instrument will properly measure within the desired range for your application.
- This is important because a properly calibrated measurement device will help the user to maintain his or her system.
- A device can be calibrated either at the factory where the device was manufactured or within the field.
- Calibration certificates may be obtained once a device has been calibrated.

### **2.3.2 Process of calibration**

Instrument calibration is one of the primary processes used to maintain instrument accuracy. Calibration is the process of configuring an instrument to provide a result for a sample within an acceptable range. Eliminating or minimizing factors that cause inaccurate measurements is a fundamental aspect of instrumentation design.

Although the exact procedure may vary from product to product, the calibration process generally involves using the instrument to test samples of one or more known values called “calibrators.” The results are used to establish a relationship between the measurement technique used by the instrument and the known values. The process in essence “teaches” the instrument to produce results that are more accurate than those that would occur otherwise. The instrument can then provide more accurate results when samples of unknown values are tested in the normal usage of the product.



**Block Diagram of Calibration process of measuring system**

Calibrations are performed using only a few calibrators to establish the correlation at specific points within the instrument's operating range. While it might be desirable to use a large number of calibrators to establish the calibration relationship, or "curve", the time and labor associated with preparing and testing a large number of calibrators might outweigh the resulting level of performance. From a practical standpoint, a tradeoff must be made between the desired level of product performance and the effort associated with accomplishing the calibration. The instrument will provide the best performance when the intermediate points provided in the manufacturer's performance specifications are used for calibration; the specified process essentially eliminates, or "zeroes out", the inherent instrument error at these points.

RAJN KHAAN

# Types of Errors

1. Gross error
2. Systematic error
3. Random error

## Gross error

- This class of errors mainly covers human mistakes in reading instruments and recording and calculating measurements results.
- The responsibilities of the mistake normally lies with the experimenter.
- some gross error can be detected & some others cannot.  
complete elimination is not possible.

### Cause of gross errors

due to humans

- ☐ may be due to misreading of instruments.
- ☐ Incorrect adjustments.
- ☐ Improper application of instruments.
- ☐ Calculation mistakes etc.

## **Remedy**

- Take care in reading and recording measured data
- Take more than two readings (preferably under conditions in which instruments are switched off-on)
- Needs good practice.

## Systematic error

These types of errors are divided into three categories :

1. Instrumental error
2. Environmental error
3. Observational error



## Instrumental Error:

These errors arise due to three main reasons

- (i) due to inherent shortcomings in the instrument
- (ii) due to misuse of the instrument.
- (iii) due to the loading effect of the instrument.

## **Inherent shortcomings in the instrument:**

- These errors are inherent in instruments because of their mechanical structure. They may be due to construction, calibration or operation of the instruments.
- These error may cause the instrument to read too low or too high.
- For example: if the spring of PMMC instrument has become weak the instrument will always read high.

## Remedy

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

## **Misuse of the instrument:**

- The error caused in measurement are due to the fault of the operator then that of the instrument.
- A good instrument used in an unintelligent way may give erroneous results.
- Example: Which may be cited as for this misuse of the instrument may be failure to adjust the zero of instrument.

## Loading Effect:

- The ideal situation in a measurement system is that when an element used for any purpose may be for signal sensing, conditioning, transmission or detection is introduced into the system the original signal should remain undisturbed.
- This means that the original signal should not be distorted in any form by introduction of any element in the measurement system. However, under practical condition it has been found that introduction of any element in a system results in extraction of energy from the system thereby distorting the original signal. This makes ideal measurements impossible. The incapability of the system to faithfully measure record or control the input signal in undistorted form is called the loading effect.

## **Environmental errors:**

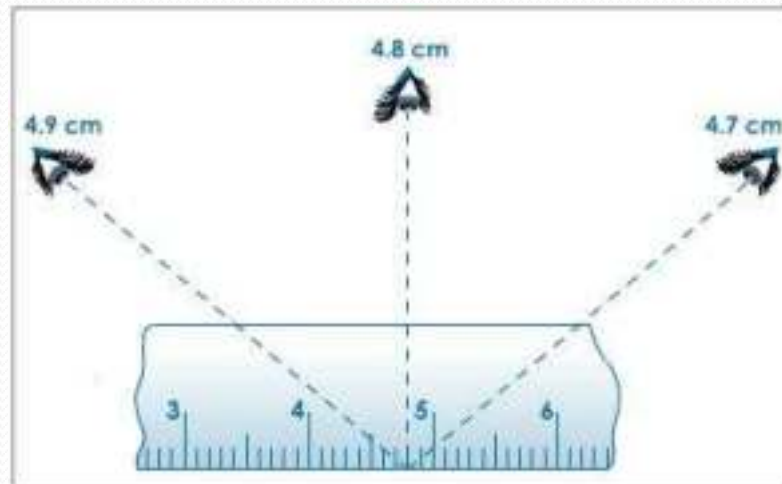
- These errors are due to conditions external to the measuring device including conditions in the area surrounding the instrument these may be effects of temperature, pressure, humidity, dust, etc.
- Example: Noise from electrical machine. Magnetic field, temperature.

## Remedy

- Arrangements should be made to keep the conditions as nearly as constant as possible. For example: temperature can be kept constant by keeping the equipment in temperature controlled enclosure.
- Employing techniques which eliminate the effects of these disturbances. For example the effect of humidity, dust etc can be entirely eliminated by hermetically sealing the instrument.
- Magnetic or electrostatics shields may be provided to avoid the effect of Magnetic or electrostatics field.

# Observational Error:

- There are many sources of observational error, they occur due to improper observational methodology incorporated in instruments.
- Example: error due to parallax effect.



## **Random Error or Uncertainty error**

- It has been consistently found that experimental result show variation from one reading to another even after all systematic errors have been accounted for . These errors are due to unknown Causes.
- Magnitude and direction not known.
- Expressed as average deviation of probable errors or standard deviation.

# **B.K.N GOVT POLYTECHNIC NARNAUL**

**DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING**

**SUBJECT: 3.4 BASICS OF INSTRUMENTATION**

**NAME OF FACULTY: Mrs. RAJNI**

**SEMESTER-3<sup>rd</sup>**

## **UNIT – 3 Display and recording devices**

A **chart recorder** is an instrument used to record various process and electrical signals. The most traditional chart recorders record data on paper. The paper is passed under a pen and the pen is deflected in proportion to the signal. The result is a graph or chart of the data.

## **Types of Chart Recorders**

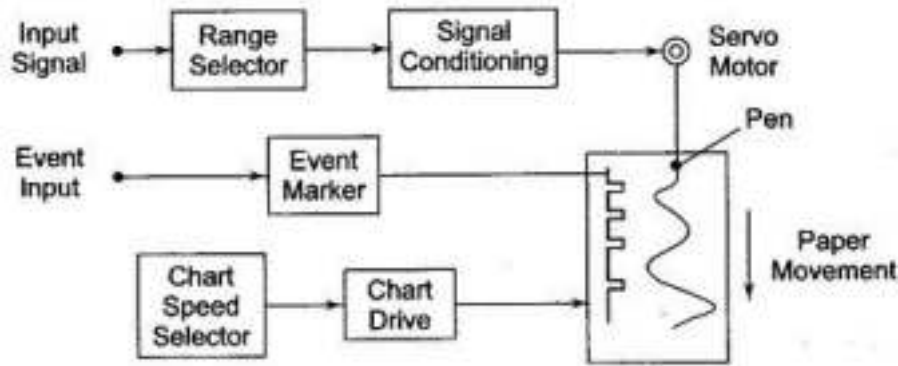
1. Strip Chart Recorders
2. Circular Chart Recorders
3. XY Recorders
4. Hybrid recorders
5. Paperless Recorders

### **3.1 Working principle construction of strip chart**

It records one or more variables with respect to time. It is a X-t recorder.

**A strip chart recorder consists of:**

1. A long roll of graph paper moving vertically.
2. A system for driving a paper at some selected speed. A speed selector switch is generally provided. Chart speed of 1-100 m/s are usually used.
3. A stylus driving system which moves the stylus in a near exact replica or analog of the quantity being recorded. A range selector switch is used so that input to the recorder drive system is within the acceptable level.



**Block Diagram – (a) Strip Chart recorder**

### **A. Paper drive system**

The paper system should move the paper at a uniform speed. A spring would may be used but in most of the recorder a synchronous motor is used for driving the paper.

### **B. Marking Mechanism**

There are many types of mechanism used for making marks on the paper. The most commonly used ones are:

#### **1. Marking with ink filled stylus**

The stylus is filled with ink by gravity or capillary actions. This requires that the pointer shall support an ink reservoir and a pen, or capillary connection between the pen and a pen reservoir. In general red ink is used but other colours are available and in instrumentation display a colour code can be adopted.

#### **2. Marking with headed stylus**

Some recorders use a heated stylus which writes on a special paper. This method overcomes the difficulties encountered in ink writing systems.

#### **3. Chopper Bar**

If a chart made from a pressure sensitive paper is used a simple recording process is possible. A V-shaped pointer is passed under a chopper bar which presses the pen into the paper once per second thus making a series of marks on the special paper. In fact this system is not purely continuous and hence is suitable for recording some varying quantities.

#### **4. Electric stylus marking.**

This method employs a paper with a special coating which is sensitive to current. When current is conducted from the stylus to the paper, a trace appears on the paper. It is clear that the electric stylus marking method has a wide range of marking speeds, has low stylus friction and a long stylus life. The disadvantage is that the cost of paper is very high.

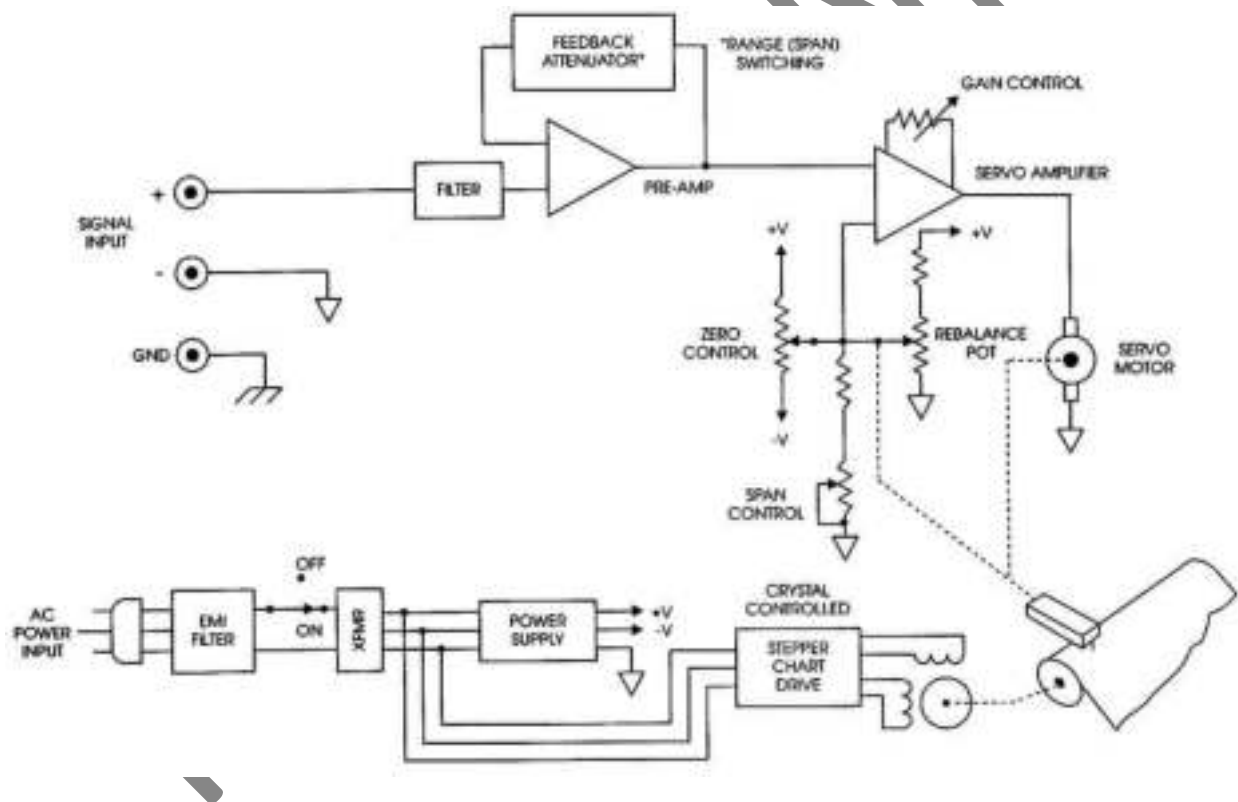
**C. Tracing system:** There are two types of tracing system used for producing graphic representation.

### 1. Curvilinear system

In the curvilinear system, the stylus is mounted on a central pivot and moves through an arc which allows a full width chart marking. If the stylus makes a full range recording, the line drawn across the chart will be curved and the time intervals will be along the curved segments.

### 2. Rectilinear system

It is noticed that a line of constant time is perpendicular to the time axis and therefore this system produces a straight line across the width of the chart. Hence the stylus is actuated by a drive cord over pulleys to produce the forward and reverse motion as determined by the drive mechanism. The stylus may be actuated by a self-balancing potentiometer system, a photoelectric deflection system, a photoelectric potentiometer system, or a bridge balance system. This system is usually used with thermal or electric wiring.



**Block Diagram – (b) Strip Chart recorder**

#### 3.1.1. Working principle construction of X-Y Recorders

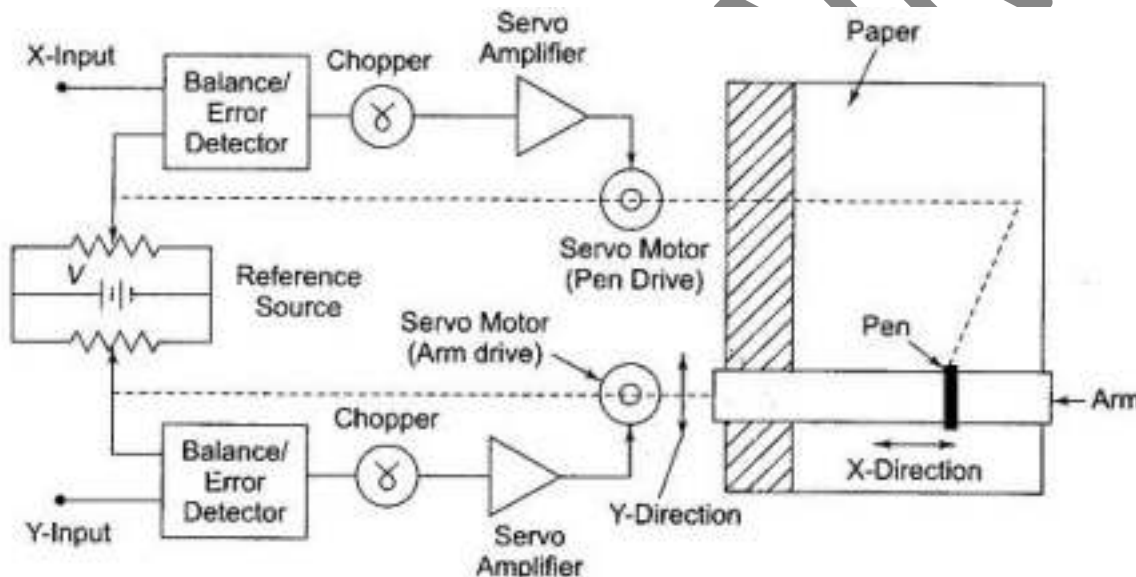
**X-Y recorder** is an instrument which gives a graphic record of the relationship between two variables.

An XY recorder plots the instantaneous relation between two variables. The writing pen will be deflected in both X direction and Y direction on a stationary chart paper. Depending on the desired application one or more write pens are used.

XY recorders are also employed using proper transducers for recording of physical quantities as function of other physical quantities. The motion of the pen in X and Y directions is obtained by servomotors. A sliding pen and moving arm arrangement is used with X-Y recorders.

**(a) Description of the Block Diagram of an X-Y Recorder:**

The block diagram is shown in Figure. From the block diagram we find that the X input and Y input are supplied to the error detector in series with the standard reference voltage offered by the internal reference source.



**Block diagram - X-Y Recorder**

The output of the error detector is given to a chopper. The servo amplifier is driven by the chopper. The amplifiers output drives the pen. The Y amplifier's output drives the arm. Square shaped graph paper will be used. It is fixed over a pad by electrostatic attraction or by vacuum.

**(b) Working:**

The input signals are attenuated to around 0.5 mV which is within the dynamic range of the recorder. Both X and Y signals are compared with the internal reference source. This is done in the balancing or Error detector block. The X and Y channel error output will be the DC error, which is the difference between the input signals and the reference voltage.

The DC error signal of both channels is used in the choppers to convert it in to an AC signal. The magnitude of the AC output of the choppers is insufficient to drive the motors of the pen and the arm. Therefore the output of the two choppers will be amplified in the servo amplifiers. The

servomotors drive the pen and the arm. The pen and the arm execute motion in proper direction to reduce the error. The movement of the pen and arm is to bring the system to balance. The variation of X and Y signals, move the pen and the arm in the appropriate directions to keep the system in balance. This movement produces a record of the signal components on the paper. It is to be remembered that the both X and Y channels and the total system works simultaneously.

**(c) Range:**

Input range variable from 0.25 V/cm to 10 V/cm

Accuracy  $\pm 0.3\%$  to  $\pm 0.1\%$  at full scale.

Slew rate and acceleration are important. Slew rate is expressed as displacement in second.

Accelerating is expressed in cm/s. Slew rate refers to the movement of the pen in Y direction.

Acceleration refers to the movement along X direction. Typical values of slew rate and acceleration are 97 cm/s and 7620 cm/s respectively with respect to high speed recorders.

Sensitivity obtainable is around 10 micro volt/mm.

Frequency response is around 6 Hz in both directions.

**(d) Variations in Design:**

The X-Y recorder described above is of analog type. Digital X-Y plotters are available. These digital X-Y recorders employ stepper motors of the open loop type, instead of the servomotors used in analog recorders. Digital X-Y plotters have many advantages.

**(e) Advantages of Digital Recorders:**

The following are the advantages of digital recorders

1. Number of input channels can be provided for sampling and storage simultaneously.
2. Number of desired trigger modes can be incorporated.
3. They have the provision to display pre-trigger data.
4. Multi-pen Multi Ink plotting is possible.

**(f) Applications:**

X-Y recorders are used in recording:

1. The speed torque characteristics of motors.
2. Regulation characteristics of power supply
3. Characteristics of electronic devices like transistors and diodes etc.
4. Hysteresis curves, stress-strain characteristics.
5. Electrical characteristics of material. Ex: Resistance versus temperature.

**Benefits or advantages of X-Y Recorder**

Following are the benefits or **advantages of XY Recorder:**

1. The instantaneous relationship between two physical quantities can be recorded.
2. The relationship between either electrical or non-electrical quantities can be recorded.
3. In modern types of recorders, zero offset adjustments are available.

**Drawbacks or disadvantages of X-Y Recorder**

Following are the **disadvantages of XY Recorder:**

1. They are most expensive compare to strip chart recorders.
2. They can not be used for continuous recording of the signals.

3. The frequency response and speeds are inherently limited due to electromechanical mechanism used for movement of the pen.

### **3.2. Merit and demerit of circular chart and strip chart recorder**

#### **Merit of circular chart**

Circular chart recorders archive data points on a round chart over a timed interval. Using data acquired by one or more sensors, circular chart recorders rotate uniformly while one or more pens plots the data radially in proportion to the signal received. The charts usually rotate over standard time periods (e.g. 24 hours, one week, one month, etc.) though some recorders can rotate over non-standard lengths of time.

- 
1. Circular chart recorders include the ease of operation, the hardcopy it produces, and real-time output.
  2. Circular chart recorders include temperature and humidity measurements, flow rates, pH, pressure, as well as a host of other process measurements.
  3. Circular chart recorders are available in single or multichannel styles and in various configurations. Many recorders can also record information in a digital format for download to a computer.
  4. Circular chart recorders require the correct charts and pens to work correctly.



Common applications include temperature and humidity measurements, flow rates, pH, pressure, as well as a host of other process measurements

#### **Demerit of circular chart**

#### **Merit of strip chart recorder**

### **3.3 Basics of printing devices**

A printer is a hardware output device that is used to generate hard copy and print any document. A document can be of any type such as a text file, image, or the combination of both. It accepts input command by users on a computer or on other devices to print the documents. For example, if you have to submit a project report at your college, you need to create a soft copy of your report and print it with the help of the printer.



Printers are one of the common computer peripheral devices that can be classified into two categories that are **2D and 3D printers**. The 2D printers are used to print text and graphics on a paper, and 3D printers are used to create three dimensional physical objects.

### Types of printer

Although there are different types of printers, nowadays, two types of printers are commonly used, which are inkjet and laser printers. A list of all the various types of printers is given below:

- Inkjet Printers
- Laser Printers
- 3D Printers
- LED Printers
- Solid Ink Printers
- Dot Matrix Printers
- Multifunction or All-in-One Printers
- Thermal printer
- Plotter

### Inkjet Printers

It is widely used by home and business computer users that prints characters by spraying the ink using magnetic plates on the paper. It contains a **paper feed assembly, ink cartridge, print head, stabilizer bar, and belt**.

It stores the ink in cartridges, and uses separate cartridge to print several types of color documents. These colors are a combination of **cyan, magenta, yellow, and black color**. These types of printers have the ability to create high-quality pictures with the help of vivid colors. Furthermore, the inkjet printers are more affordable and easier to use as compared to other printers.



## Laser printers

The laser printer is one of the common personal computer printers. It was introduced in 1971, and after that it was developed at Xerox PARC by Gary Starkweather. It uses the laser or non-impact photocopier technology to print the text and images on the paper. Whenever it gets input to print any document, a laser beam draws the document on the selenium-coated drum with the help of electric charges.



## 3.4 Scanning, data logging and field buses (GPIB, RS-232C)

### 3.4.1 Scanning

A scanner is an electronic device which can capture images from physical items and convert them into digital formats, which in turn can be stored in a computer, and viewed or modified using software applications.

Different types of scanners are available with different resolutions. In the world of electronic data transmission, scanning is considered to be the most cost-effective and reliable way of transmitting images.

The basic principle of a scanner is to analyze an image and reproduce it to a digital one using the optical character recognition techniques.

Prominent features of a scanner include:

- Reliability - Unlike certain forms of data transmission, scanning involves only transfer of hard images to digital forms. The role of the end-user is limited in case of scanning. And as they are not dependent on two-way communication, they can also help in storing important information or transmitting important information.
- Efficiency - Modern scanners are built for efficiency and speed. And it comes with ease of use as well as convenience.
- Quality - Scanning ensures the best resolution possible for digital images. Compared to fax machines, which may find it difficult to reproduce the accurate details, scanners can reproduce images with high resolution and precisions. They are quite useful for photography and engineering arenas.
- Cost saving - One of the biggest advantage of scanning is the replacement of physical files/forms with digital ones. Along with saving physical space, which has to be used for storage, there are also environmental benefits by using scanner.

### **3.4.2 Data logging**

Data logging is the process of collecting and storing data over a period of time in order to analyze specific trends or record the data-based events/actions of a system, network or IT environment. It enables the tracking of all interactions through which data, files or applications are stored, accessed or modified on a storage device or application.

Data logging also facilitates the storage and collection of computer or device information. For example, data logging can store processor temperature and memory utilization over time and network bandwidth usage. System/network administrators use this data to analyze system or network performance during a specific period.

Data logging also allows information security (IS) and auditing staff to analyze system access information and assess audit trails to trace viruses and identify suspicious activities.

### **3.4.3 Field buses (GPIB, RS-232C)**

#### **3.4.3.1 GPIB**

The GPIB or General Purpose Interface Bus or IEEE 488 bus is still one of the more popular and versatile interface standards available today.

GPIB is widely used for enabling electronics test equipment to be controlled remotely, although it was also used in a many other applications including general computer communications.

It can be used to control a host of test instruments: everything from digital millimeters and signal generators of all sorts to switching matrices, spectrum analyzers, and vibration meters. In fact any form of electronic test equipment. At one time it even became popular for linking computers to their printers and many low cost printers used GPIB.

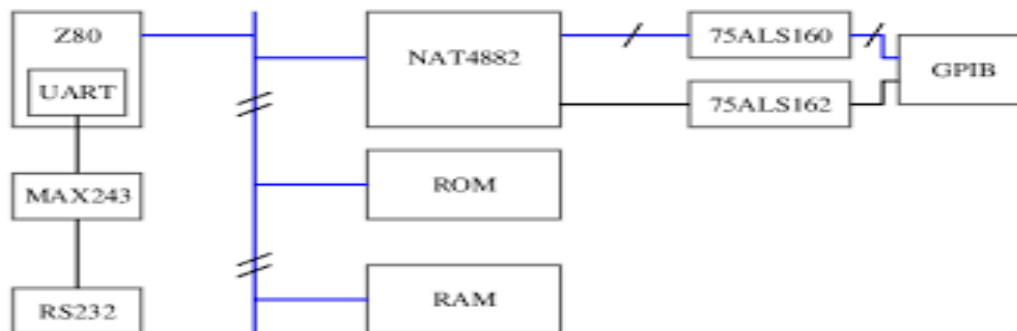


## Basic GPIB concept

The GPIB or IEEE 488 bus is a very flexible system, allowing data to flow between any of the instruments on the bus, at a speed suitable for the slowest active instrument. Up to fifteen instruments may be connected together with a maximum bus length not exceeding 20 m.

A further requirement for the bus is that there must also be no more than 2 m between two adjacent test instruments.

It is possible to purchase GPIB cards to incorporate into computers that do not have the interface fitted. As GPIB cards are relatively cheap, this makes the inclusion of a GPIB card into the system a very cost effective method of installing it. That said, the falling usage of GPIB means that GPIB cards are not nearly as widely available as they used to be.



**Block Diagram GPIB**



### Pin Diagram GPIB

#### Advantage GPIB

- GPIB employs a bus interface, and piggyback connectors make connecting and configuring devices easy. It is possible to use a single PC interface even if more devices are connected to the system in the future.
- Handshake communication ensures highly reliable data transfer.
- As the standard bus of the measuring instrument industry, the GPIB interface is employed by many measuring instruments, allowing users to control a variety of measuring instruments by mastering a single protocol.
- Devices with different communication speeds can be connected. (\*The whole system will be limited to the speed of the slowest device.)

#### 3.4.3.2 RS-232C

RS-232C is a long-established standard ("C" is the current version) that describes the physical interface and protocol for relatively low-speed serial data communication Networks between computers and related devices.

RS-232C is the interface that your computer uses to talk to and exchange data with your modem and other serial devices. RS-232C is the interface between your Communication networks and other communication networks.

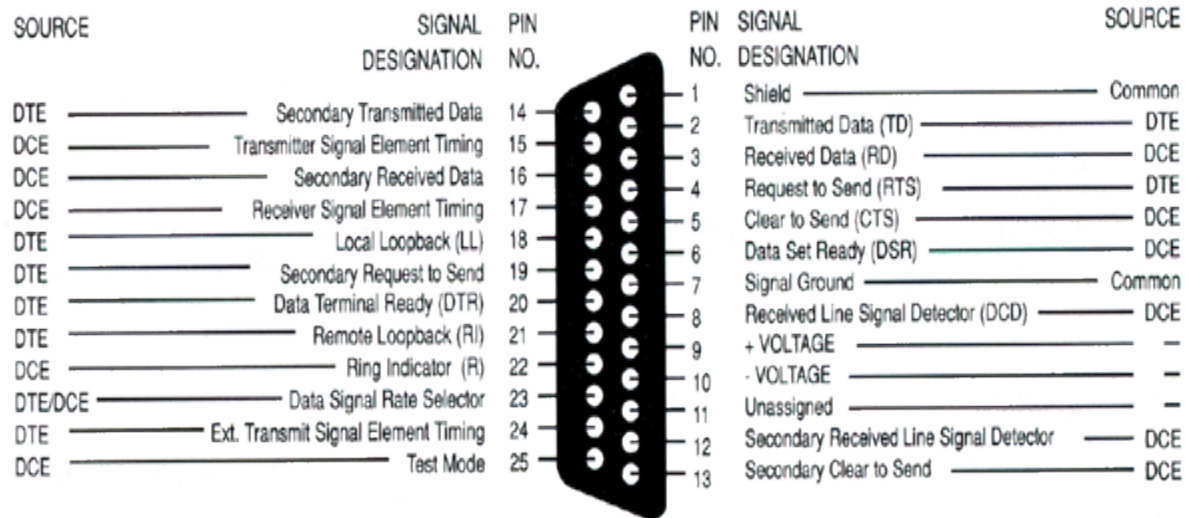


### Step by Step Working of RS232:

After having a brief reference of the pins and signaling let us see the working of RS232 by an example. Let us we have a modem that utilizes RS232 to communicate with computer. The processes taking place are briefly described below:

- 1). As the modem is connected to the computer, It (modem) sends a software based Ring Indicator (RI) signal to computer.
- 2). The computer gives response to the modem by sending DTR signal i.e. Data Terminal Ready. It tells modem that computer is ready to undergo communication with modem and ready to receive data.
- 3). Next is modem's turn to responds to the DTR signal. This is done by sending a DSR signal (Data Set Ready) to the computer indicating that it is now ready to exchange further signaling with the computer's DTE (Data Terminal Equipment).
- 4). After these necessary steps, transmission and reception of data and signals is set up on the TXD and RXD pins. In full duplex communication, both CTS and RTS pins are raised high while in half duplex mode they are utilized for handshaking necessary to control the direction.
- 5). When data transfer is completed, the computer incapacitate DTR signal and restrains the DCD and DSR signals. Hence the communication ends up.

## V.24/RS-232 Interface



Pin Diagram RS-232C

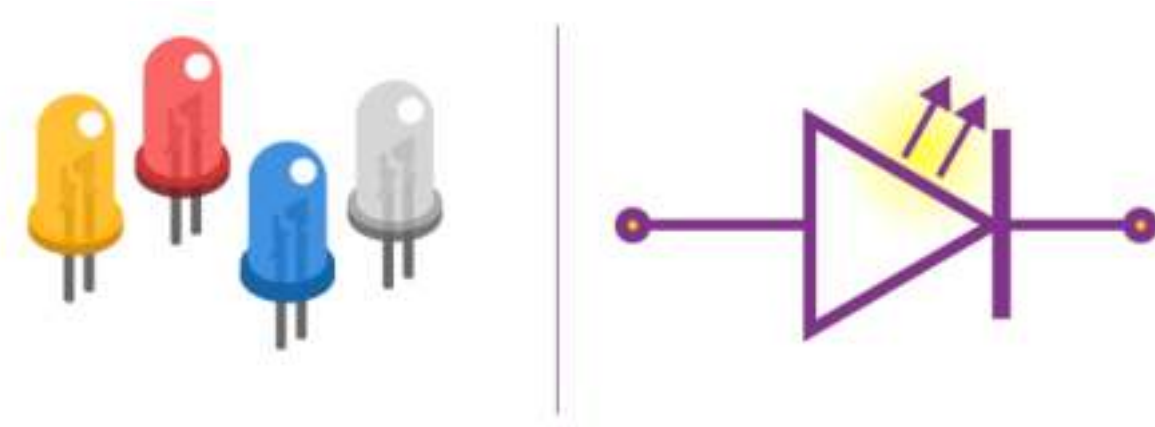
### 3.5 LED, Seven segment display, LCD

#### 3.5.1 Light Emitting Diode (LED)

##### Table of Contents

1. Light Emitting Diode Definition
2. LED Symbol
3. Construction
4. Working Principle
5. Advantage
6. Disadvantage

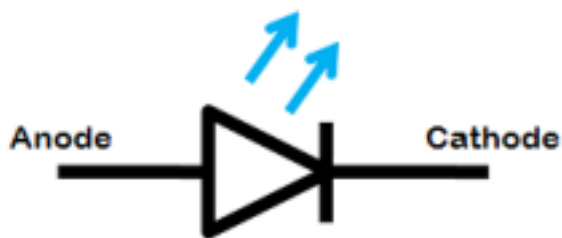
**Definition:** The LED is a PN-junction diode which emits light when an electric current passes through it in the forward direction. In the LED, the recombination of charge carrier takes place. The electron from the N-side and the hole from the P-side are combined and gives the energy in the form of heat and light. The LED is made of semiconductor material which is colourless, and the light is radiated through the junction of the diode.



The LEDs are extensively used in segmental and dot matrix displays of numeric and alphanumeric character. The several LEDs are used for making the single line segment while for making the decimal point single LED is used.

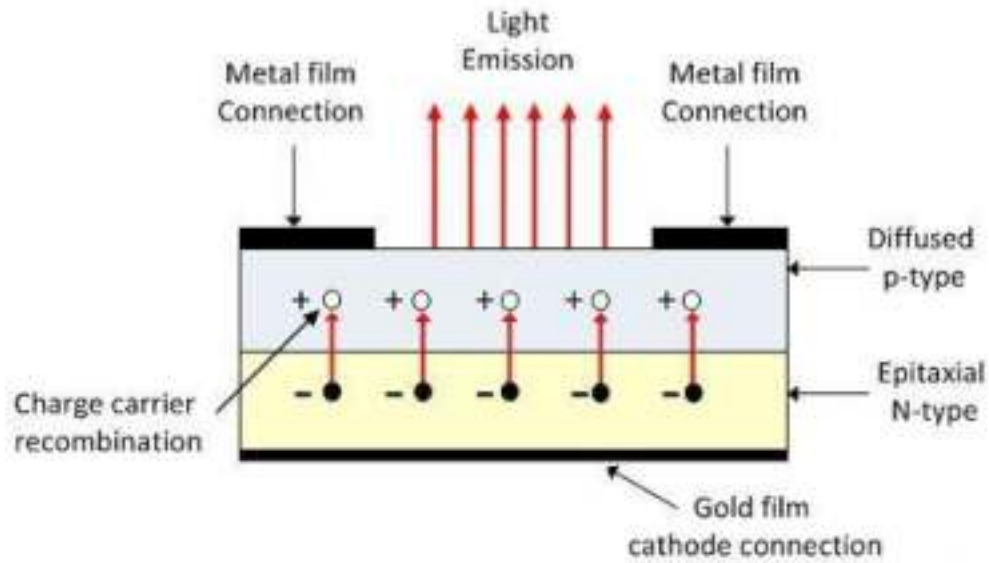
### LED Symbol

Below is the demonstration of the LED symbol. The symbol is similar to that of the p-n junction diode. The difference between these two symbols is that the two arrows indicate that the diode is emitting the light.

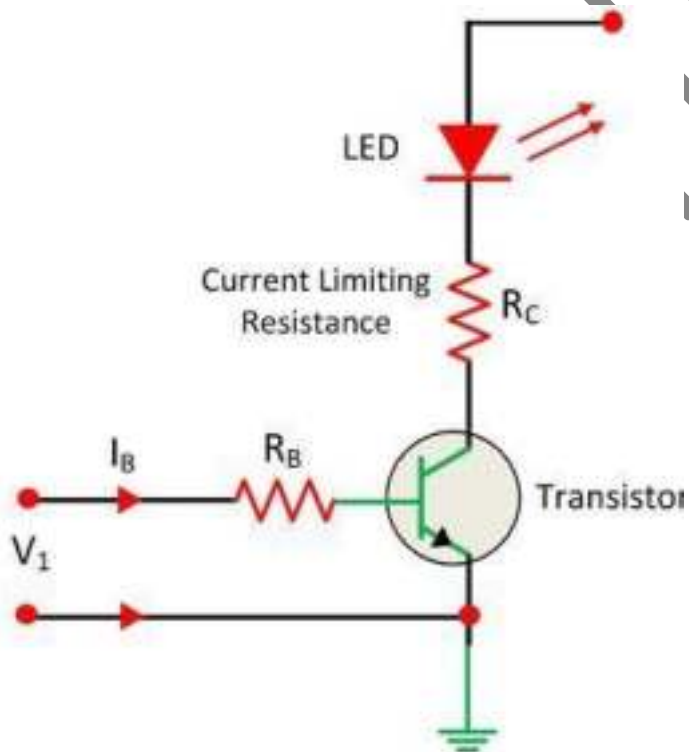


### Construction of LED

The recombination of the charge carrier occurs in the P-type material, and hence P-material is the surface of the LED. For the maximum emission of light, the anode is deposited at the edge of the P-type material. The cathode is made of gold film, and it is usually placed at the bottom of the N-region. This gold layer of cathode helps in reflecting the light to the surface.



The gallium arsenide phosphide is used for the manufacturing of LED which emits red or yellow light for emission. The LED are also available in green, yellow amber and red in colour.

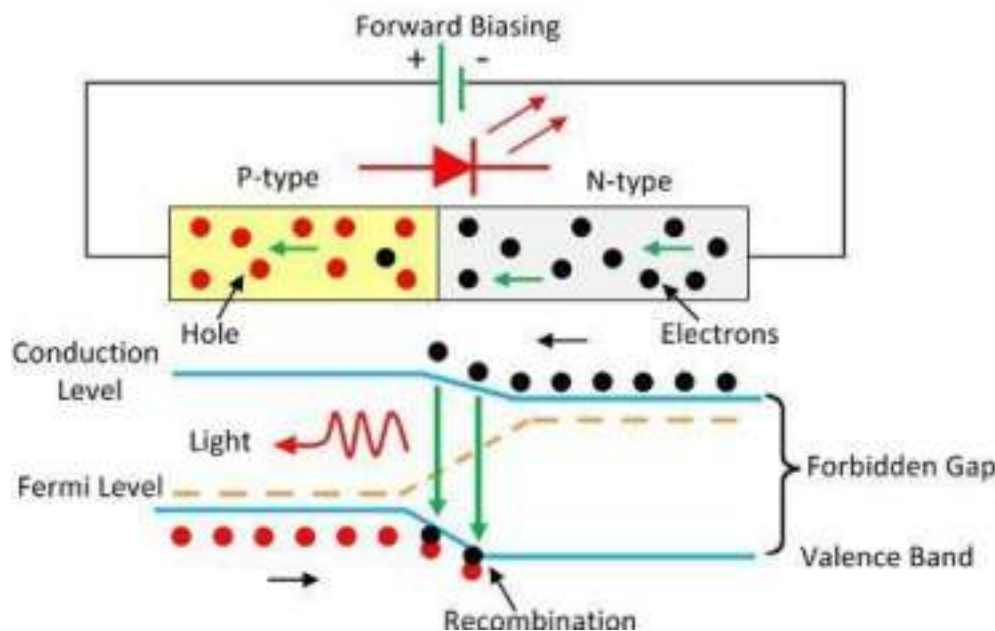


LED controlled by a Transistor switch

The simple transistor can be used for off/on of a LED as shown in the figure above. The base current  $I_B$  conducts the transistor, and the transistor conducts heavily. The resistance  $R_C$  limits the current of the LED.

### Working of LED

The working of the LED depends on the quantum theory. The quantum theory states that when the energy of electrons decreases from the higher level to lower level, it emits energy in the form of photons. The energy of the photons is equal to the gap between the higher and lower level.



The LED is connected in the forward biased, which allows the current to flow in the forward direction. The flow of current is because of the movement of electrons in the opposite direction. The recombination shows that the electrons move from the conduction band to valence band and they emit electromagnetic energy in the form of photons. The energy of photons is equal to the gap between the valence and the conduction band.

### Advantages of LED in electronic displays

The followings are the major advantages of the LED in an electronics displays.

1. The LED are smaller in sizes, and they can be stacked together to form numeric and alphanumeric display in the high-density matrix.
2. The intensity of the light output of the LED depends on the current flows through it. The intensity of their light can be controlled smoothly.
3. The LED are available which emits light in the different colours like red, yellow, green and amber.
4. The on and off time or switching time of the LED is less than of 1 nanoseconds. Because of this, the LED are used for the dynamic operation.

5. The LEDs are very economical and giving the high degree of reliability because they are manufactured with the same technology as that of the transistor.
6. The LED are operated over a wide range of temperature say  $0^{\circ} - 70^{\circ}$ . Also, it is very durable and can withstand shock and variation.
7. The LED have a high efficiency, but they require moderate power for operation. Typically, the voltage of 1.2V and the current of 20mA is required for full brightness. Therefore, it is used in a place where less power are available.

### Disadvantages of LED

The LED consume more power as compared to LCD, and their cost is high. Also, it is not used for making the large display.

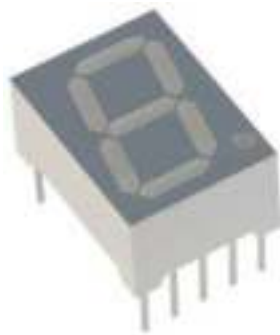
- High initial price
- Temperature dependence
- Voltage sensitivity
- Light quality
- Area light source
- Electrical polarity
- Efficiency droop

### 3.5.2 Seven segment display

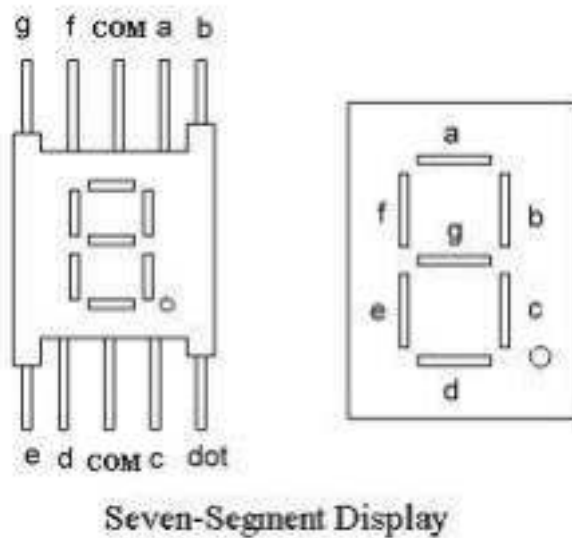
A **seven-segment display** is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot matrix displays.

Seven-segment displays are widely used in digital clocks, electronic meters, basic calculators, and other electronic devices that display numerical information.

A Seven Segment Display (SSD) is one of the most common, cheap and simple to use display. It looks like this-



The **pin configuration** is as follows-



SSD consists of a total of 8 segments, out of which 7 are for displaying numbers, and one is for decimal point. Each segment has 1 led inside it.

### **Working of Seven Segment Display**

Seven segment display works, by glowing the required respective LEDS in the numeral. The display is controlled using pins that are left freely. Forward biasing of these pins in a sequence will display the particular numeral or alphabet. Depending on the type of seven segment the segment pins are applied with logic high or logic zero and in the similar way to the common pins also.

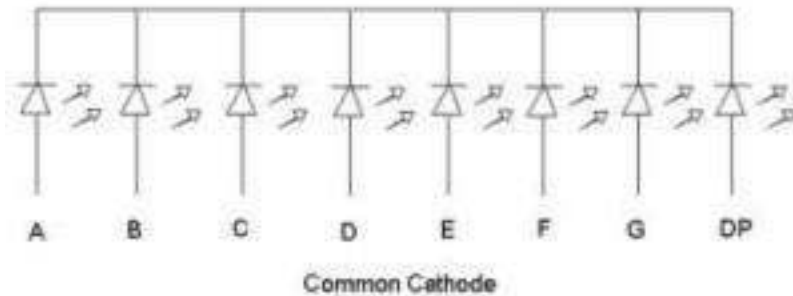
For example to display numeral '1' segments b and c are to be switched on and the remaining segments are required to be switched off. In order to display two digits two seven segments are used

Depending on either the common pin is anode or cathode, seven segments are divided into following types.

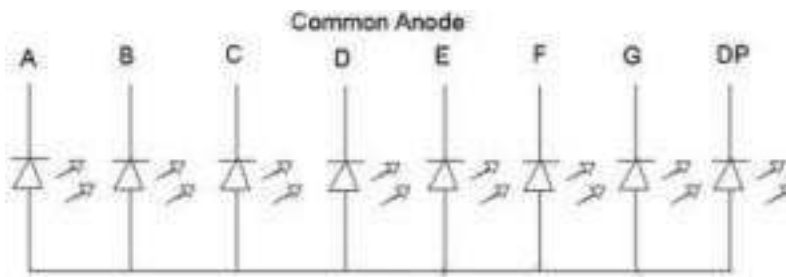
### **Types of Seven Segment Displays**

The following are the **two types** of seven segments displays

**1. Common cathode** – In the common cathode type SSD, the –ve terminal of all the LEDs is commonly connected to the 'COM' pin. A segment can be lighted up when '1' is given to the respective LED segment and ground is connected to the common. The internals are given as below:



**2. Common anode** – In the common anode type SSD, the +ve terminal of all the LEDs is commonly connected to the 'COM' port of the SSD. A segment can be lighted up when the 'COM' port is connected to the +ve battery supply, and ground is given to the respective segment.



A common cathode SSD is simpler to use with an MCU, and hence I have written the code accordingly using a common cathode SSD.

### Advantages

- **Cost:** The cost of the entire module of 7 segment display is very cheap as it only contains LEDs.
- **Efficiency:** LED displays in general are extremely efficient.
- **Heat dissipation:** The heat dissipated from this displays is very less and that increases the life of the devices.

### Disadvantages

- **limited characters:** Seven-segment displays are capable to display only numbers from 0-9 and few alphabets.
- **Type of display:** The appearance of the two types of display are very similar and that causes difficulty interfacing it with controllers

### Applications

- Digital watches
- electronic device display

- timers
- calculators
- Car panel displays, etc.

### 3.5.3 LCD

#### Liquid Crystal Diode (LCD)

**Definition:** The LCD is defined as the diode that uses small cells and the ionised gases for the production of images. The LCD works on the modulating property of light. The light modulation is the technique of sending and receiving the signal through the light. The liquid crystal consumes a small amount of energy because they are the reflector and the transmitter of light. It is normally used for seven segmental display.

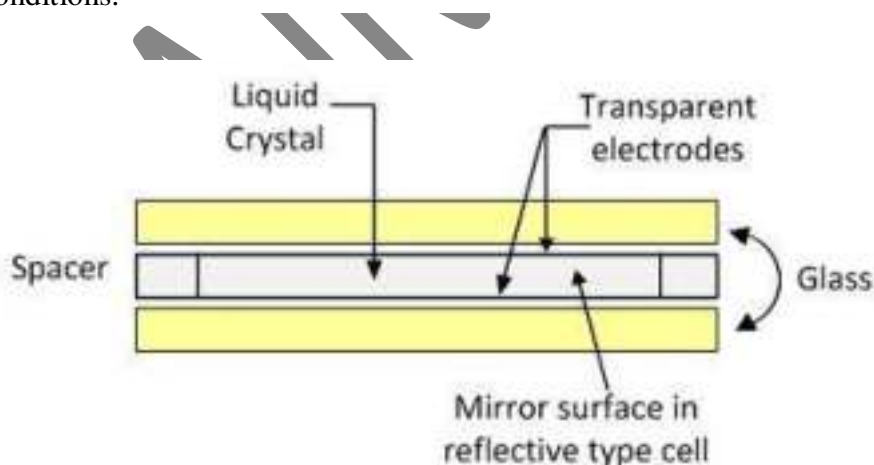
#### Construction of LCD

The liquid crystals are the organic compound which is in liquid form and shows the property of optical crystals. The layer of liquid crystals is deposited on the inner surface of glass electrodes for the scattering of light. The liquid crystal cell is of two types; they are Transmittive Type and the Reflective Type.

**Transmittive Type** – In transmitter cell both the glass sheets are transparent so that the light is scattered in the forward direction when the cell becomes active.

**Reflective Type** – The reflective type cell consists the reflecting surface of the glass sheet on one end. The light incident on the front surface of the cell is scattered by the activated cell.

Both the reflective and transmittive type cells appear brights, even under small ambient light conditions.

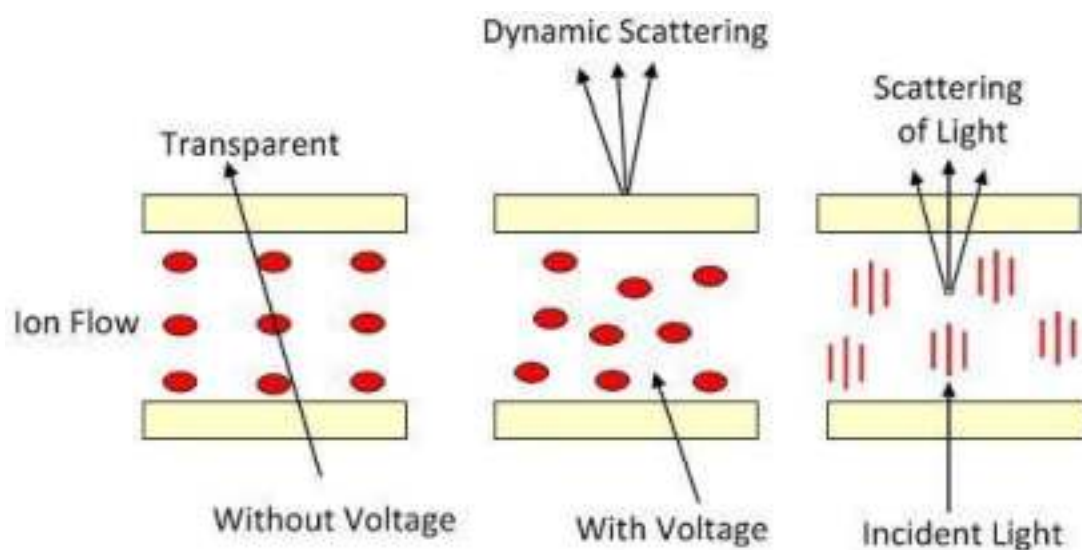


#### Working Principle of LCD

The working principle of the LCD is of two types. They are the dynamic scattering type and the field effects type. Their details explanation is shown below.

### Dynamic Scattering

When the potential carrier flows through the light, the molecular alignment of the liquid crystal disrupts, and they produce disturbances. The liquid becomes transparent when they are not active. But when they are active their molecules turbulence causes scattered of light in all directions, and their cell appears bright. This type of scattering is known as the dynamic scattering. The construction of the dynamic scattering of the liquid crystal cell is shown in the figure



### Field Effect Type

The construction of liquid crystals is similar to that of the dynamic scattering types the only difference is that in field effect type LCD the two thin polarizing optical fibres are placed inside the each glass sheet. The liquid crystals used in field effect LCDs are of different scattering types that operated in the dynamic scattering cell.

The field affects type LCD uses the nematic material which twisted the unenergised light passing through the cell. The nematic type material means the liquid crystals in which the molecules are arranged in parallel but not in a well-defined plane. The light after passing through the nematic material passing through the optical filters and appears bright. When the cell has energised no twisting of light occurs, and the cell appears dull.

### Advantages of LCD

The following are the advantages of LCD.

1. The power consumption of LCD is low. The seven segmental display of LCD requires about  $140\mu\text{W}$  which is the major advantages over LED which uses approximately  $40\text{mW}$  per numeral.
2. The cost of the LCD is low.

### **Disadvantages of LCD**

The following are the disadvantages of LCD.

1. The LCD is a slow device because their turning on and off times are quite large. The turn-on time of the LCD is millisecond while their turn off time is ten milliseconds.
2. The LCD requires the large area.
3. The direct current reduces the lifespan of LCD. Therefore, the LCD uses with AC supply, having the frequency less than  $500\text{Hz}$ .

# CLICK ON THE PICTURES BELOW FOR YOUTUBE VIDEO



# CLICK ON THE PICTURES BELOW FOR YOUTUBE VIDEO



**3<sup>rd</sup> Semester**

**INSTRUMENTATION AND CONTROL  
ENGINEERING**

**SUBJECT: TEST AND MEASURING INSTRUMENTS**

## **DISCLAIMER**

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## **UNIT :1    Introduction to Measurements and Instrumentation**

### **1.1    Need & Importance of Measurement**

The word “measurement” comes from the Greek word “metron,” which means “limited proportion”. Measurement is a technique in which properties of an object are determined by comparing them to a standard. Measurements require tools and provide scientists with a quantity. A quantity describes how much of something there is or how many there are. A good example of measurement is using a ruler to find the length of an object.

The measurement of any quantity plays very important role not only in science but in all branches of engineering, medicine and in almost all the human day to day activities. The technology of measurement is the base of advancement of science. The role of science and engineering is to discover the new phenomena, new relationships, the laws of nature and to apply these discoveries to human as well as other scientific needs. The science and engineering is also responsible for the design of new equipments.

The operation, control and the maintenance of such equipments and the processes is also one of the important functions of the science and engineering branches. All these activities are based on the proper measurement and recording of physical, chemical, mechanical, optical and many other types of parameters. measuring instrument and measurement procedure which minimizes the error. The measuring instrument should not affect the quantity to be measured.

An electronic instrument is the one which is based on electronic or electrical principles for its measurement function. The measurement of any electronic or electrical quantity or variable is termed as an electronic measurement.

**Advantages of Electronic Measurement:** The advantages of an electronic measurement are

1. Most of the quantities can be converted by transducers into the electrical or electronic signals.
2. An electrical or electronic signal can be amplified, filtered, multiplexed, sampled and measured.
3. The measurement can easily be obtained in or converted into digital form for automatic analysis and recording.
4. The measured signals can be transmitted over long distances with the help of cables or radio links, without any loss of information.

5. Many measurements can be carried either simultaneously or in rapid succession.
6. Electronic circuits can detect and amplify very weak signals and can measure the events of very short duration as well.
7. Electronic measurement makes possible to build analog and digital signals. The digital signals are very much required in computers. The modern development in science and technology are totally based on computers.
8. Higher sensitivity, low power consumption and a higher degree of reliability are the important features of electronic instruments and measurements.

## **1.2 Typical application of instrumentation system**

Every application of instrumentation system, including those not yet invented, can be put into one of these three categories or some combination of them:

- a) Monitoring of processes and operations
- b) Control of processes and operations
- c) Experimental engineering analysis

### **1.2.1 Monitoring of Processes and Operations**

Here the measuring device is being used to keep track of some quantity. Certain applications of measuring instruments may be characterized as having essentially a monitoring function, e.g., thermometers, barometers, and water, gas, and electric meters, automotive speedometer and fuel gauge, and compass.

### **1.2.2 Control of Processes and Operations**

It is also one of the most important classes of instrumentation system application. Sensors are used in feedback-control systems and many measurement systems themselves use feedback principles in their operation. Sensors are used in feedback systems. So an instrument can serve as a component of a control system. To control any variable in a feedback control system, it is first necessary to measure it. Every feedback-control system will have at least one measuring device as a vital component and a single control system may require information from many measuring instruments.

For e.g., industrial machine and process controllers, aircraft control systems, automotive control systems (speed control, antilock braking, coolant temperature regulating, air conditioning, engine pollution, etc.).

### 1.2.3 Experimental Engineering Analysis

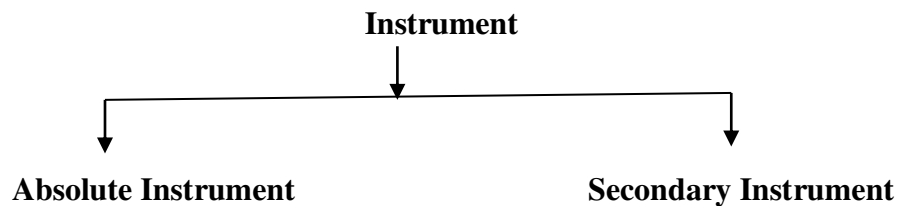
There is also an application of instrumentation system in solving engineering problems. In it there are two general methods available: theoretical and experimental. Many problems require the application of both methods and theory and experiment should be thought of as complimenting each other.

In brief , there are many applications of instrumentation systems, within technological areas as large as those associated with communications, defence, transportation, education, industrial manufacturing and research and development, and chemical and other process industries.

## 1.3 Classification of Instruments:

### 1.3.1 Definition of instruments

An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc. Generally instruments are classified in to two categories.



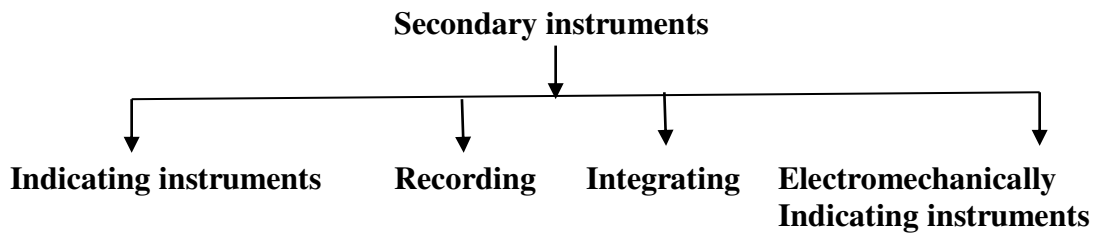
### 1.3.2 Absolute instrument

An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. This instrument is really used, because each time the value of the measuring quantities varies. So we have to calculate the magnitude of the measuring quantity, analytically which is time consuming. These types of instruments are suitable for laboratory use. Example: Tangent galvanometer.

### 1.3.3 Secondary instrument

This type of instrument determines the value of the quantity to be measured directly. Generally these instruments are calibrated by comparing with another standard secondary

instrument. Examples of such instruments are voltmeter, ammeter and wattmeter etc. Practically secondary instruments are suitable for measurement



**a) Indicating instrument**

This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

For Ex: Voltmeter, Ammeter etc.

**b) Recording instrument**

This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time.

For Ex: ECG Machine etc.

**c) Integrating instrument**

This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

For Ex: Energy Meter etc.

**d) Electromechanically indicating instrument**

For satisfactory operation electromechanical indicating instrument, three forces are necessary. They are

- i). Deflecting force
- ii). Controlling force
- iii). Damping force

**Deflecting force:**

When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.

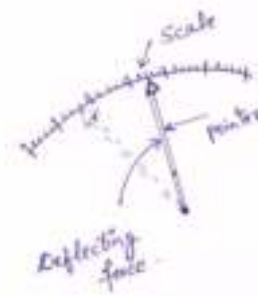


Figure: Pointer Scale

### Controlling force

To make the measurement indicated by the pointer definite (constant) a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque is equal to controlling torque.

$$T_d = T_c$$

### Spring control

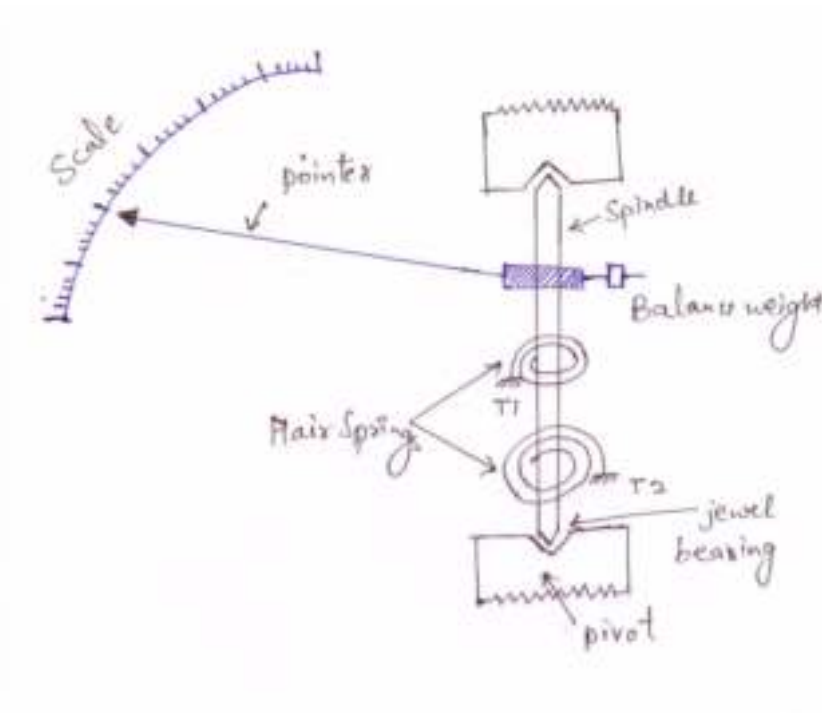
Two springs are attached on either end of spindle (Fig. below). The spindle is placed in jewelled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.

When a current is supply, the pointer deflects due to rotation of the spindle. While spindle is rotate, the spring attached with the spindle will oppose the movements of the pointer. The torque produced by the spring is directly proportional to the pointer deflection  $\theta$ .

$$T \propto \theta$$

The deflecting torque produced  $T_d$  proportional to 'I'. When  $T_C = T_d$ , the pointer will come to a steady position. Therefore

$$\theta \propto I$$



Since,  $\theta$  and I are directly proportional to the scale of such instrument which uses spring controlled is uniform.

### Damping force

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about its final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillation quickly, a damping force is necessary. This force is produced by different systems.

- (a) Air friction damping
- (b) Fluid friction damping
- (c) Eddy current damping

## 1.4 Review of units, dimensions and standards

### 1.4.1 Units

In order to make the measurement of a physical quantity we have, first of all, to evolve a standard for that measurement so that different measurements of same physical quantity can be expressed relative to each other. That standard is called a unit of that physical quantity

#### **Types of Units**

1. Fundamental units
2. Derived units

#### **Fundamental units**

The units which are independent or can not derived from any other unit is called fundamental unit. **OR** The units of fundamental physical quantities are called fundamental units.

Example: (a) Every unit of time is a fundamental unit (irrespective of the system to which it belongs). microsecond, millisecond, second, minute, hour, day etc are units of time. All these units are fundamental units.

(b) Every unit of length is fundamental unit. Millimeter, centimeter, meter, kilometer etc. are units of length. All these units are fundamental units.

#### **Derived units**

The units of derived physical quantities are called derived units. Units of volume, area, speed, density, energy, etc are derived units.

Example: (a) Every unit of acceleration is a derived unit;  $\text{m/sec}^2$ ,  $\text{cm/sec}^2$ ,  $\text{km/hr}^2$ .

(b) Every unit of density is a derived unit;  $\text{kg/m}^3$ ,  $\text{gm/cm}^3$ , etc.

(c) Every unit of speed is a derived unit ;  $\text{m/sec}$ ,  $\text{cm/sec}$ ,  $\text{km/hr}$ , etc.

#### **System of Units**

There are four systems of units to measure the fundamental physical quantities.

1. C.G.S system (metric system)
2. F.P.S system (British system)
3. M.K.S system

#### 4. S.I system (System International)

In the first three systems namely, C.G.S system, F.P.S system, M.K.S system, only 3 physical quantities length, mass, and time are considered to be fundamental quantities.

So there are 3 **units** corresponding to 3 fundamental physical quantities in the above three systems.

| System | Length     | Mass     | Time   |
|--------|------------|----------|--------|
| F.P.S. | foot       | pound    | second |
| C.G.S. | centimetre | gram     | second |
| M.K.S. | metre      | kilogram | second |

But, in S.I system (System International), there are 7 fundamental physical quantities namely Mass, Length, Time, Electric current, Thermodynamic temperature, Luminous intensity, Amount of substance. So there are **7 units** corresponding to 7 fundamental physical quantities in S.I system.

##### Base quantities and their units:-

The seven base quantities and their units are,

| Base quantity       | Unit     | Symbol |
|---------------------|----------|--------|
| Length              | Meter    | M      |
| Mass                | Kilogram | Kg     |
| Time                | Second   | Sec    |
| Electric current    | Ampere   | A      |
| Temperature         | Kelvin   | K      |
| Luminous intensity  | Candela  | Cd     |
| Amount of substance | Mole     | Mole   |

### SOME DERIVED SI UNITS AND THEIR SYMBOLS:-

| Quantity | Unit   | Symbol | Express in base units        |
|----------|--------|--------|------------------------------|
| Force    | newton | N      | $\text{Kg-m/sec}^2$          |
| Work     | joules | J      | $\text{Kg-m}^2/\text{sec}^2$ |
| Power    | watt   | W      | $\text{Kg-m}^2/\text{sec}^3$ |
| Pressure | Pascal | Pa     | $\text{Kg m-1/S}^2$          |

#### 1.4.2 Dimensions

Dimensions of a physical quantity are the powers to which the fundamental units be raised in order to represent that quantity

##### **Dimensional Formula:-**

Dimensional formula of a physical quantity is the formula which tells us how and which of the fundamental units have been used for the measurement of that quantity.

Most physical quantities can be expressed in terms of combinations of five basic dimensions. These are **mass (M), length (L), time (T), electrical current (I), and temperature, represented by the Greek letter theta ( $\theta$ ).** These five dimensions have been chosen as being basic because they are easy to measure in experiments. Dimensions aren't the same as units.

##### **How to write dimensions of physical quantities:-**

- Write the formula for that quantity, with the quantity on L.H.S. of the equation.
- Convert all the quantities on R.H.S. into the fundamental quantities mass, length and time.
- Substitute M, L and T for mass, length and time respectively.
- Collect terms of M,L and T and find their resultant powers (a,b,c) which give the dimensions of the quantity in mass, length and time respectively.

##### **Characteristics of Dimensions:-**

- Dimensions of a physical quantity are independent of the system of units.
- Quantities having similar dimensions can be added to or subtracted from each other.
- Dimensions of a physical quantity can be obtained from its units and vice-versa.
- Two different physical quantities may have same dimensions.
- Multiplication/division of dimensions of two physical quantities (may be same or different) results in production of dimensions of a third quantity.

| PHYSICAL QUANTITY  | SYMBOL | DIMENSION | MEASUREMENT UNIT | UNIT |
|--------------------|--------|-----------|------------------|------|
| Length             | s      | L         | Meter            | m    |
| Mass               | M      | M         | Kilogram         | Kg   |
| Time               | t      | T         | Second           | Sec  |
| Electric charge    | q      | Q         | Coulomb          | C    |
| luminous intensity | I      | C         | Candela          | Cd   |
| Temperature        | T      | K         | Kelvin           | °K   |
| Angle              | q      | none      | Radian           | None |

| Mechanical Physical Quantities (derived) |        |           |                           |           |
|------------------------------------------|--------|-----------|---------------------------|-----------|
| PHYSICAL QUANTITY                        | SYMBOL | DIMENSION | MEASUREMENT UNIT          | UNIT      |
|                                          |        |           |                           |           |
| Area                                     | A      | $L^2$     | square meter              | $m^2$     |
| Volume                                   | V      | $L^3$     | cubic meter               | $m^3$     |
| velocity                                 | v      | $L/T$     | meter per second          | m/sec     |
| angular velocity                         | w      | $T^{-1}$  | radians per second        | 1/sec     |
| acceleration                             | a      | $LT^{-2}$ | meter per square second   | $m/sec^2$ |
| angular acceleration                     | a      | $T^{-2}$  | radians per square second | $1/sec^2$ |

|                        |             |                    |                                        |                    |
|------------------------|-------------|--------------------|----------------------------------------|--------------------|
| Force                  | F           | $MLT^{-2}$         | Newton                                 | $Kg\ m/sec^2$      |
| Energy                 | E           | $ML^2T^{-2}$       | Joule                                  | $Kg\ m^2/sec^2$    |
| Work                   | W           | $ML^2T^{-2}$       | Joule                                  | $Kg\ m^2/sec^2$    |
| Heat                   | Q           | $ML^2T^{-2}$       | Joule                                  | $Kg\ m^2/sec^2$    |
| Torque                 | t           | $ML^2T^{-2}$       | Newton meter                           | $Kg\ m^2/sec^2$    |
| Power                  | P           | $ML^2T^{-3}$       | watt or joule/sec                      | $Kg\ m^2/sec^3$    |
| Density                | D or $\rho$ | $ML^{-3}$          | kilogram per<br>cubic meter            | $Kg/m^3$           |
| pressure               | P           | $ML^{-1}T^{-2}$    | Newton per square meter                | $Kg\ m^{-1}/sec^2$ |
| impulse                | J           | $MLT^{-1}$         | Newton second                          | $Kg\ m/sec$        |
| Inertia                | I           | $ML^2$             | Kilogram square meter                  | $Kg\ m^2$          |
| luminous<br>flux       | f           | C                  | lumen (4Pi candle for<br>point source) | cd sr              |
| illumination           | E           | $CL^{-2}$          | lumen per<br>square meter              | $cd\ sr/m^2$       |
| entropy                | S           | $ML^2T^{-2}K^{-1}$ | joule per degree                       | $Kg\ m^2/sec^2K$   |
| Volume<br>rate of flow | Q           | $L^3T^{-1}$        | cubic meter<br>per second              | $m^3/sec$          |
| kinematic<br>viscosity | n           | $L^2T^{-1}$        | square meter<br>per second             | $m^2/sec$          |
| dynamic                | m           | $ML^{-1}T^{-1}$    | Newton second                          | $Kg/m\ sec$        |

|                                                 |   |                      |                            |                  |
|-------------------------------------------------|---|----------------------|----------------------------|------------------|
| viscosity                                       |   |                      | per square meter           |                  |
| specific weight                                 | g | $ML^{-2}T^{-2}$      | Newton<br>per cubic meter  | $Kg\ m^2/sec^2$  |
| <b>Electrical Physical Quantities (derived)</b> |   |                      |                            |                  |
| Electric current                                | I | $QT^{-1}$            | Ampere                     | C/sec            |
| emf, voltage, potential                         | E | $ML^2T^{-2}Q^{-1}$   | Volt                       | $Kg\ m^2/sec^2C$ |
| resistance or impedance                         | R | $ML^2T^{-1}Q^{-2}$   | ohm                        | $Kgm^2/secC^2$   |
| Electric conductivity                           | s | $M^{-2}L^{-2}TQ^2$   | mho                        | $secC^2/Kg\ m^3$ |
| capacitance                                     | C | $M^{-1}L^{-2}T^2Q^2$ | Farad                      | $sec^2C^2/Kgm^2$ |
| inductance                                      | L | $ML^2Q^{-2}$         | Henry                      | $Kg\ m^2/C^2$    |
| Current density                                 | J | $QT^{-1}L^{-2}$      | ampere per<br>square meter | $C/sec\ m^2$     |
| Charge density                                  | r | $QL^{-3}$            | coulomb per cubic<br>meter | $C/m^3$          |
| magnetic flux,<br>Magnetic induction            | B | $MT^{-1}Q^{-1}$      | weber per<br>square meter  | $Kg/sec\ C$      |
| magnetic intensity                              | H | $QL^{-1}T^{-1}$      | ampere per meter           | $C/m\ sec$       |
| magnetic vector                                 | A | $MLT^{-1}Q^{-1}$     | weber/meter                | $Kg\ m/sec\ C$   |

|                          |            |                      |                                 |                  |
|--------------------------|------------|----------------------|---------------------------------|------------------|
| potential                |            |                      |                                 |                  |
| Electric field intensity | E          | $MLT^{-2}Q^{-1}$     | volt/meter or<br>newton/coulomb | $Kg\ m/sec^2\ C$ |
| Electric displacement    | D          | $QL^{-2}$            | coulomb per square meter        | $C/m^2$          |
| permeability             | $\mu$      | $MLQ^{-2}$           | henry per meter                 | $Kg\ m/C^2$      |
| permittivity,            | $\epsilon$ | $T^2Q^2M^{-1}L^{-3}$ | farad per meter                 | $sec^2C^2/Kgm^3$ |
| dielectric constant      | K          | $M^0L^0T^0$          | None                            | None             |
| frequency                | f or $\nu$ | $T^{-1}$             | Hertz                           | $sec^{-1}$       |
| angular frequency        | $\omega$   | $T^{-1}$             | radians per second              | $sec^{-1}$       |
| Wave length              | $\lambda$  | L                    | Meters                          | M                |

### **1.4.3 Standards**

A standard is a physical representation of a unit of measurement. It is applied to a piece of equipment having a known measure of physical quantity. Now this known value is used for the purpose of obtaining the values of the physical properties of other equipment.

#### **Standard Classifications**

Measurement standards are classified in four types as:

1. International standards
2. Primary standards
3. Secondary standards
4. Working standards

#### **International standards**

These standards are defined by international agreements, and are maintained at the International Bureau of Weights and Measures in France. These are as accurate as it is scientifically possible to achieve. These standards are not available to the ordinary user of measuring instruments for the purposes of calibration or comparison.

#### **Primary standards**

Primary standards are maintained at institutions in various countries around the world. They are also constructed for the greatest possible accuracy. The main function of Primary standard is to check the accuracy of secondary standards.

#### **Secondary standards**

Secondary standards are employed in industrial measurement laboratories as references for calibrating high accuracy equipment and components. It is used to verify the accuracy of working standards. Secondary standards are periodically sent to the national standard laboratories that maintain primary standards for calibration and comparison.

#### **Working Standards**

Working standards are used to check and calibrate the general laboratory instruments for their performance and accuracy.



# **B.K.N GOVT POLYTECHNIC NARNAUL**

**DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING**

**SUBJECT: 3.4 TMI**

**NAME OF FACULTY: Mrs. RAJNI**

**SEMESTER-3<sup>rd</sup>**

**UNIT- 2**

**2.1 Measurement of resistance**

**2.1.1 Ohmmeter**

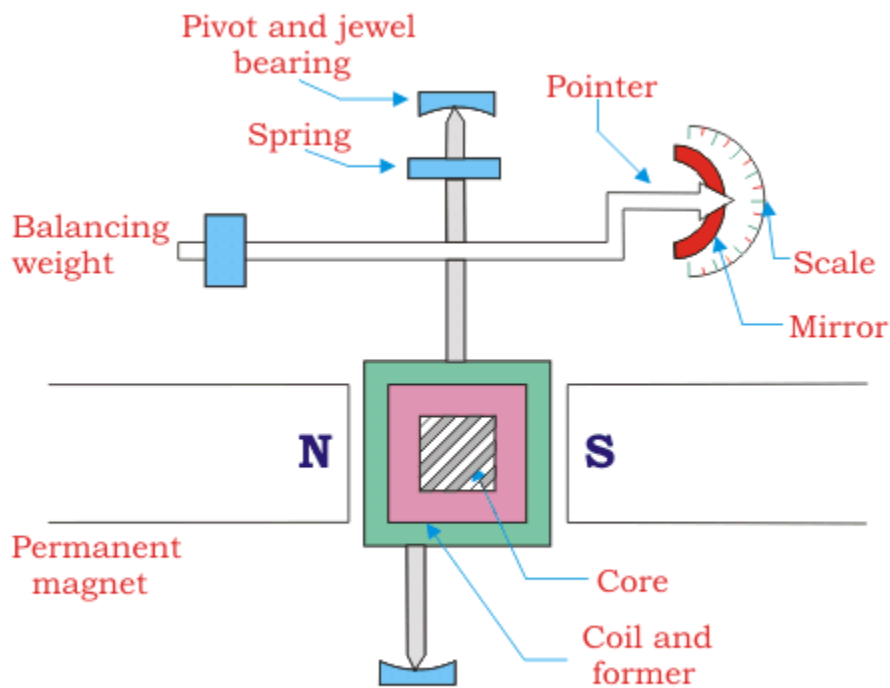
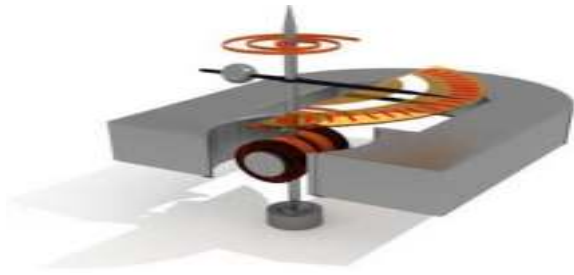
Definition: The meter which measures the resistance and the continuity of the electrical circuit and their components such type of meter is known as the ohmmeter. It measures the resistance in ohms. The micro-ohmmeter is used for measuring the low resistance and the mega ohmmeter measures the high resistance of the circuit. The ohmmeter is very convenient to use but less accurate.



## **D'Arsonval Movement**

This type of movement is used in DC measuring instruments. The main principle in these types of instruments is that when a current-carrying coil is placed in a magnetic field, it feels a force and that force can deflect the pointer of a meter and we get the reading in the instrument.

This type of movement is used in DC measuring instruments. The main principle in these types of instruments is that when a current-carrying coil is placed in a magnetic field, it feels a force and that force can deflect the pointer of a meter and we get the reading in the instrument.



### Construction of D'Arsonval Instrument

This type of instrument consists of a permanent magnet and a coil that carries current and is placed in between them. The coil may be of rectangular or circular in shape. The iron core is used to provide a flux of low reluctance so it produces a high-intensity magnetic field.

There are many advantages due to which we use the D'Arsonval type instrument. They are-

1. They have a uniform scale.
2. Effective eddy current damping.
3. Low power consumption.
4. No hysteresis loss.
5. They are not affected by stray fields.

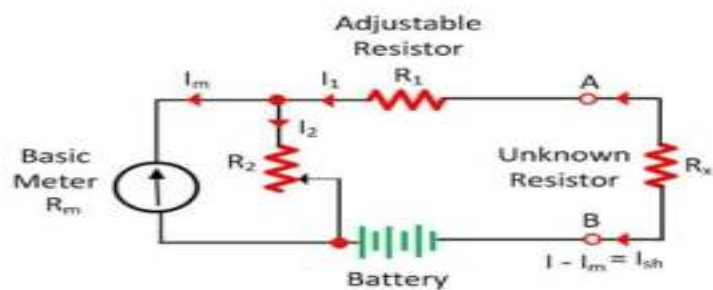
### Types of Ohmmeter

The ohmmeter gives the approximate value of resistance. It is very portable and hence used in the laboratory. It is of three types; they are the series ohmmeter, shunt ohmmeter and multi-range ohmmeter. The detail explanation of their types is given below.

### Series Ohmmeter

In series ohmmeter, the measuring resistance component or circuit is connected in series with the meter. The value of resistance is measured through the d'Arsonval movement connected in parallel with the shunt resistor  $R_2$ . The parallel resistance  $R_2$  is connected in series with the resistance  $R_1$  and the battery. The component whose resistance is used to be measured is connected in series with the terminal A and B.

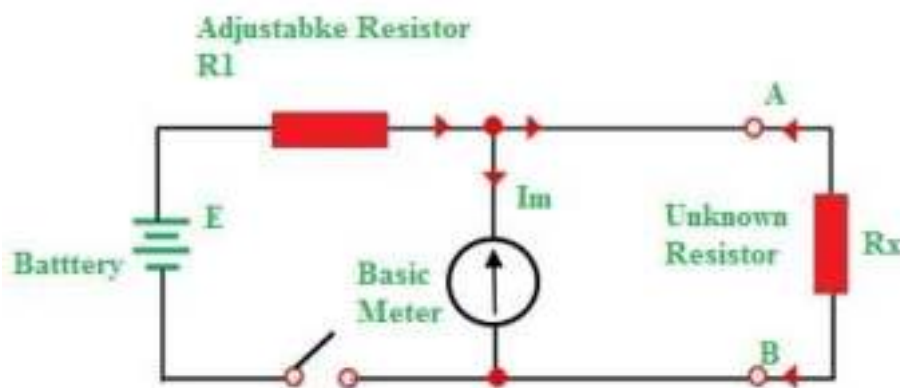
The circuit diagram of the series ohmmeter is shown in the figure below.



When the value of unknown resistance is zero the large current flow through the meter. In this condition, the shunt resistance is adjusted until the meter indicates the full load current. For full load current, the pointer deflects towards zero 0 ohms.

### Shunt Type Ohmmeter

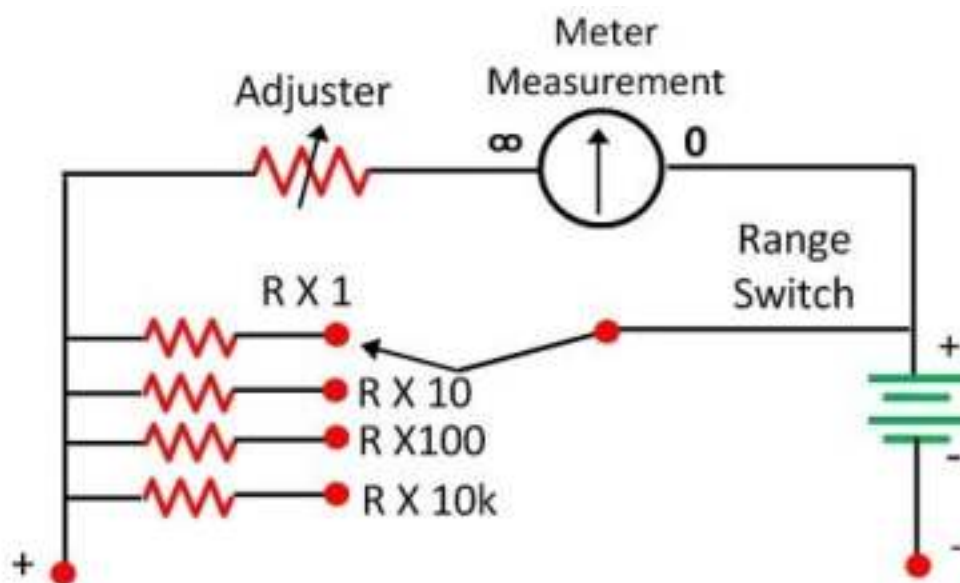
The connection of shunt type ohmmeter can be done whenever the calculating component is connected in parallel with the battery. This type of circuit is used to calculate the low-value resistance. The following circuit can be built with the meter, the battery, and the measuring component. The measuring component can be connected across the terminals A & B.



When the resistance value of the component is zero then the current in the meter will become zero. Similarly, when the resistance of the component becomes vast then the flow of current through the battery & the needle illustrates the full-scale deflection in the direction of the left. This type of meter has no current on the scale in the direction of left as well as the infinity spot in their right direction.

## Multi-Range Ohmmeter

The multi-range ohmmeter range is very high, and this meter includes an adjuster, and the range of a meter can be selected by an adjuster based on the requirement.



For instance, consider we utilize a meter to calculate the resistance below 10 ohms. So initially, we need to fix the resistance value to 10 ohms. The measuring component is connected with the meter in parallel. The resistance magnitude can be decided by the deflection of the needle.

## Applications of Ohmmeter

The uses of the ohmmeter include the following.

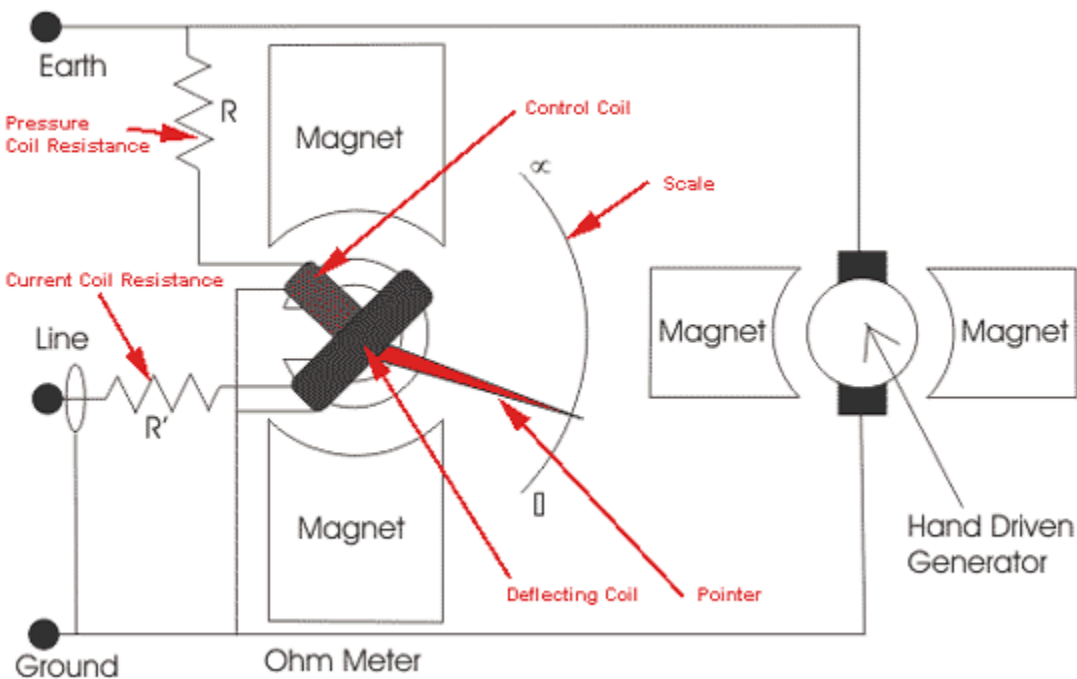
- This meter can be used to ensure the continuity of the circuit which means if the sufficient flow of current or huge flow of current through the circuit then the circuit will be detached.
- These are broadly used in electronic labs in engineering to test the electronic components.
- These are used for small ICs for debugging such as PCBs & other stuff which requires to be executed in sensitive devices.

## 2.1.2 Meggers

**Definition:** The **Megger** is the **instrument** uses for **measuring** the **resistance** of the **insulation**. It works on the **principle** of **comparison**, i.e., the resistance of the **insulation** is **compared** with the **known** value of resistance. If the **resistance** of the insulation is high, the pointer of the moving coil **deflects** towards the **infinity**, and if it is low, then the pointer indicates zero resistance. The **accuracy** of the Megger is **high** as compared to other instruments.

## Construction of Megger

### Circuit Construction features:-



1. Deflecting and Control coil : Connected parallel to the generator, mounted at right angle to each other and maintain polarities in such a way to produced torque in opposite direction.
2. Permanent Magnets : Produce magnetic field to deflect pointer with North-South pole magnet.
3. Pointer : One end of the pointer connected with coil another end deflects on scale from infinity to zero.
4. Scale: A scale is provided in front-top of the megger from range 'zero' to 'infinity', enable us to read the value.
5. D.C generator or Battery connection : Testing voltage is produced by hand operated DC generator for manual operated Megger. Battery / electronic voltage charger is provided for automatic type Megger for same purpose.
6. Pressure Coil Resistance and Current Coil Resistance : Protect instrument from any damage because of low external electrical resistance under test.

## Working Principle of Megger

- Voltage for testing produced by hand operated megger by rotation of crank in case of hand operated type, a battery is used for electronic tester.
- 500 Volt DC is sufficient for performing test on equipment range up to 440 Volts.
- 1000 V to 5000 V is used for testing for high voltage electrical systems.
- Deflecting coil or current coil connected in series and allows flowing the electric current taken by the circuit being tested.
- The control coil also known as pressure coil is connected across the circuit.
- Current limiting resistor (CCR and PCR) connected in series with control and deflecting coil to protect damage in case of very low resistance in external circuit.
- In hand operated megger electromagnetic induction effect is used to produce the test voltage i.e. armature arranges to move in permanent magnetic field or vice versa.
- Where as in electronic type megger battery are used to produce the testing voltage.
- As the voltage increases in external circuit the deflection of pointer increases and deflection of pointer decreases with a increases of current.
- Hence, resultant torque is directly proportional to voltage and inversely proportional to current.
- When electrical circuit being tested is open, torque due to voltage coil will be maximum and pointer shows 'infinity' means no shorting throughout the circuit and has maximum resistance within the circuit under test.
- If there is short circuit pointer shows 'zero', which means 'NO' resistance within circuit being tested.

### 2.1.3 Wheatstone Bridge

**Definition:** The device **uses** for the **measurement** of **minimum resistance** with the help of comparison method is **known** as the **Wheatstone bridge**. The value of **unknown resistance** is determined by **comparing** it with the **known resistance**. The Wheatstone bridge **works** on the **principle of null deflection**, i.e. the ratio of their resistances are equal, and no current flows through the galvanometer. The bridge is very **reliable** and gives an **accurate** result.

#### Construction of Wheatstone Bridge

A Wheatstone bridge circuit consists of four arms of which two arms consists of known resistances while the other two arms consist of an unknown resistance and a variable resistance. The circuit also consists of a galvanometer and an electromotive force source. The emf source is attached between points *a* and *b* while the galvanometer is connected between the points *c* and *d*. The current that flows through the galvanometer depends on the potential difference across it.

#### Wheatstone Bridge Formula

Following is the formula used for Wheatstone bridge:

$$R = PS/Q$$

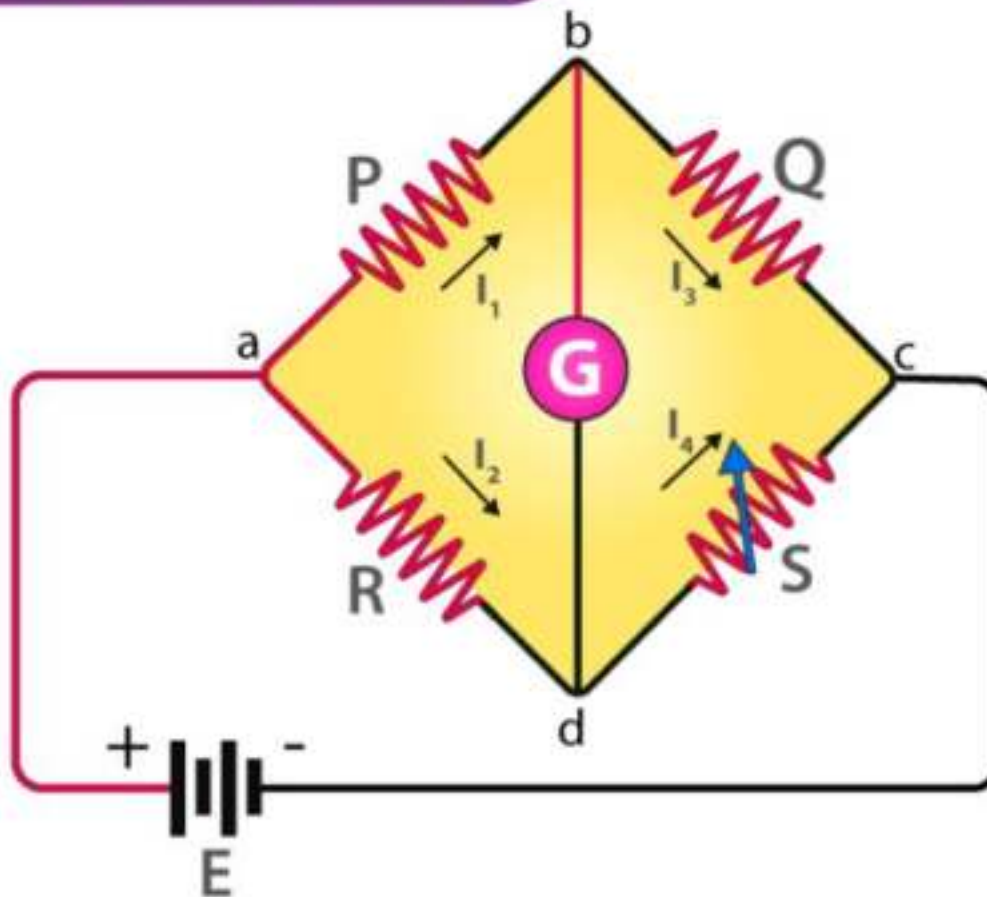
Where,

- R is the unknown resistance
- S is the standard arm of the bridge
- P and Q is the ratio of arm of bridge

### What is the Wheatstone Bridge Principle?

The Wheatstone bridge works on the principle of null deflection, i.e. the ratio of their resistances are equal and no current flows through the circuit. Under normal conditions, the bridge is in the unbalanced condition where current flows through the galvanometer. The bridge is said to be in a balanced condition when no current flows through the galvanometer. This condition can be achieved by adjusting the known resistance and variable resistance.

## WHEATSTONE BRIDGE



## **Wheatstone Bridge Application**

- The Wheatstone bridge is used for the precise measurement of low resistance.
- Wheatstone bridge along with operational amplifier is used to measure physical parameters such as temperature, light, and strain.
- Quantities such as impedance, inductance, and capacitance can be measured using variations on the Wheatstone bridge.

## **Wheatstone Bridge Limitations**

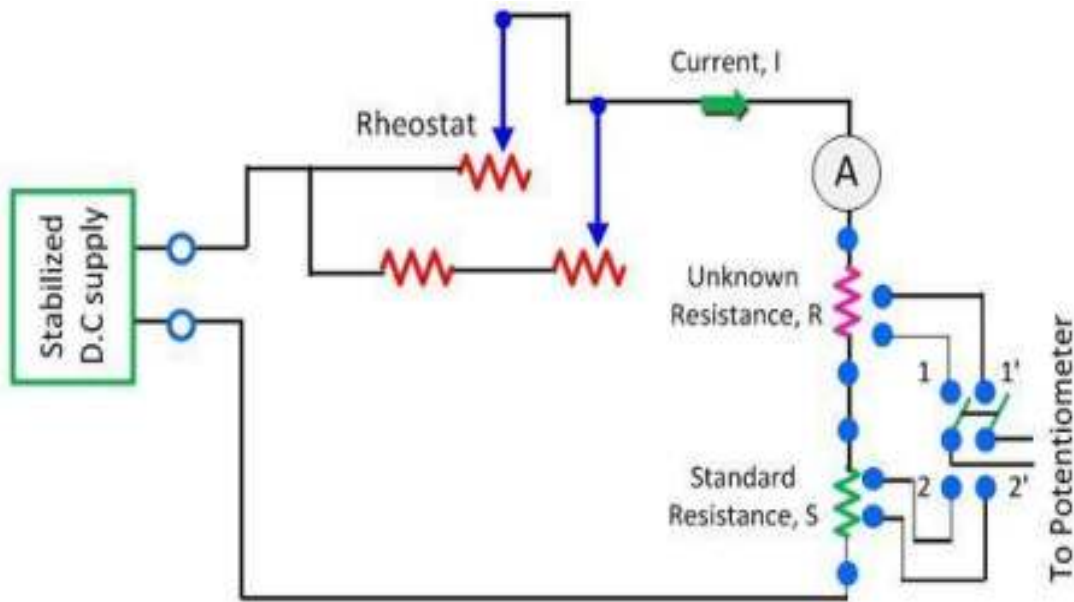
- For low resistance measurement, the resistance of the leads and contacts becomes significant and introduces an error.
- For high resistance measurement, the measurement presented by the bridge is so large that the galvanometer is insensitive to imbalance.
- The other drawback is the change in the resistance due to the heating effect of the current through the resistance. Excessive current may even cause a permanent change in the value of resistance.

### **2.1.4 Potentiometer method**

Measurement of Resistance using Potentiometer

The DC potentiometer method of measurement of resistance is used for measuring the unknown resistance of low value. This can be done by comparing the unknown resistance with the standard resistance. The voltage drop across the known and unknown resistance is measured and by comparison the value of known resistance is determined.

Let understand this with the help of the circuit diagram. The  $R$  is the unknown resistance whose value is needed to be measured. The  $S$  is the standard resistance from which the value of unknown resistance is compared. The rheostat is used for controlling the magnitude of current into the circuit.



Measurement of Resistance with Potentiometer

The accuracy of the unknown resistance also depends on the magnitude of the current at the time of the readings. If the magnitude of current remains same, the circuit gives the accurate result. The ammeter is used in the circuit for determining the magnitude of current passing through resistor during the reading.

The magnitude of the current is adjusted in such a way that the voltage drop across the resistance is equal to 1 volt.

## 2.2 Measurement of inductance and capacitance by

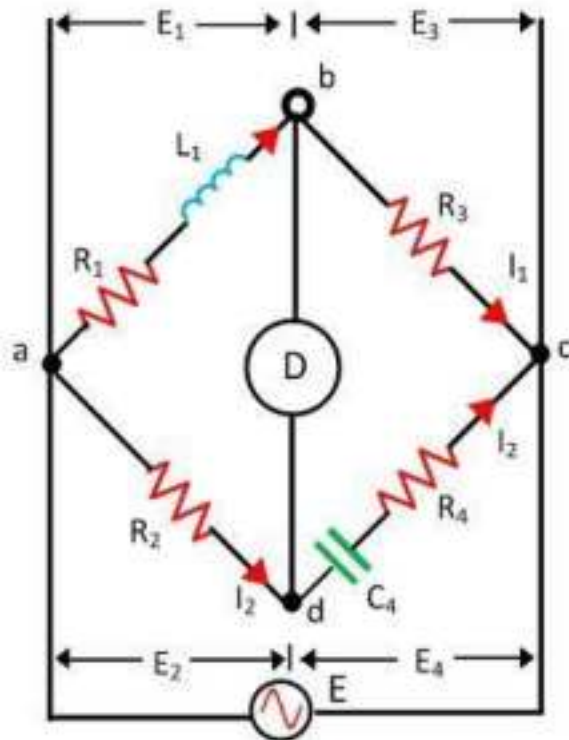
### 2.2.1 Hay's bridge

The **Hay's bridge** is used for **determining** the **self-inductance** of the **circuit**. The bridge is the **advanced form** of **Maxwell's bridge**. The Maxwell's bridge is only appropriate for measuring the medium quality factor. Hence, for **measuring** the **high-quality factor** the **Hays bridge** is used in the circuit.

In **Hay's bridge**, the **capacitor** is **connected** in **series** with the **resistance**, the voltage drop across the capacitance and resistance are varied. And in Maxwell bridge, the **capacitance** is **connected** in **parallel** with the **resistance**. Thus, the magnitude of a voltage pass through the resistance and capacitor is equal.

### Construction of Hay's Bridge

The unknown inductor  $L_1$  is placed in the arm **ab** along with the resistance  $R_1$ . This unknown inductor is compared with the standard capacitor  $C_4$  connected across the arm **cd**. The resistance  $R_4$  is connected in series with the capacitor  $C_4$ . The other two non-inductive resistor  $R_2$  and  $R_3$  are connected in the arm **ad** and **bc** respectively.



**Hay's Bridge**

The  $C_4$  and  $R_4$  are adjusted for making the bridge in the balanced condition. When the bridge is in a balanced condition, no current flows through the detector which is connected to point **b** and **c** respectively. The potential drops across the arm **ad** and **cd** are equal and similarly, the potential across the arm **ab** and **bc** are equal.

### Advantages of Hay's Bridge

The following are the advantages of Hay's Bridge.

1. The Hays bridges give a simple expression for the unknown inductances and are suitable for the coil having the quality factor greater than the 10 ohms.
2. It gives a simple equation for quality factor.
3. The Hay's bridge uses small value resistance for determining the Q factor.

### **Disadvantages of Hay's Bridge**

The only disadvantage of this type of bridge is that it is not suitable for the measurement of the coil having the quality factor less than 10 ohms.

### **2.2.2 Maxwell Bridge**

The **bridge** used for the **measurement** of **self-inductance** of the **circuit** is known as the Maxwell bridge. It is the advanced form of the Wheatstone bridge. The Maxwell bridge **works** on the **principle** of the **comparison**, i.e., the value of **unknown inductance** is determined by **comparing** it with the known value or standard value.

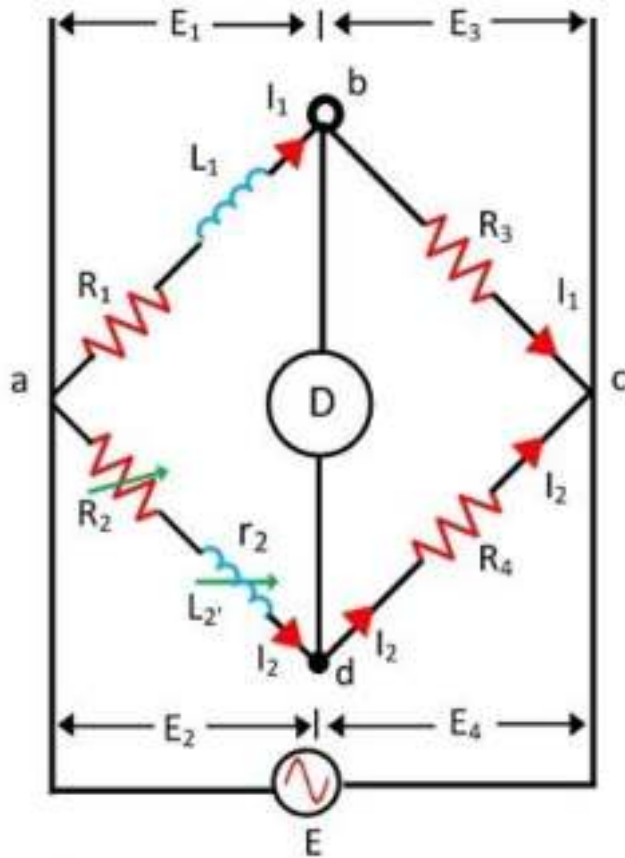
### **Types of Maxwell's Bridge**

Two methods are used for determining the self-inductance of the circuit. They are

1. Maxwell's Inductance Bridge
2. Maxwell's inductance Capacitance Bridge

### **Maxwell's Inductance Bridge**

In such type of bridges, the value of unknown resistance is determined by comparing it with the known value of the standard self-inductance. The connection diagram for the balance Maxwell bridge is shown in the figure below.



### Maxwell's Inductance Bridge

Let,  $L_1$  – unknown inductance of resistance  $R_1$ .

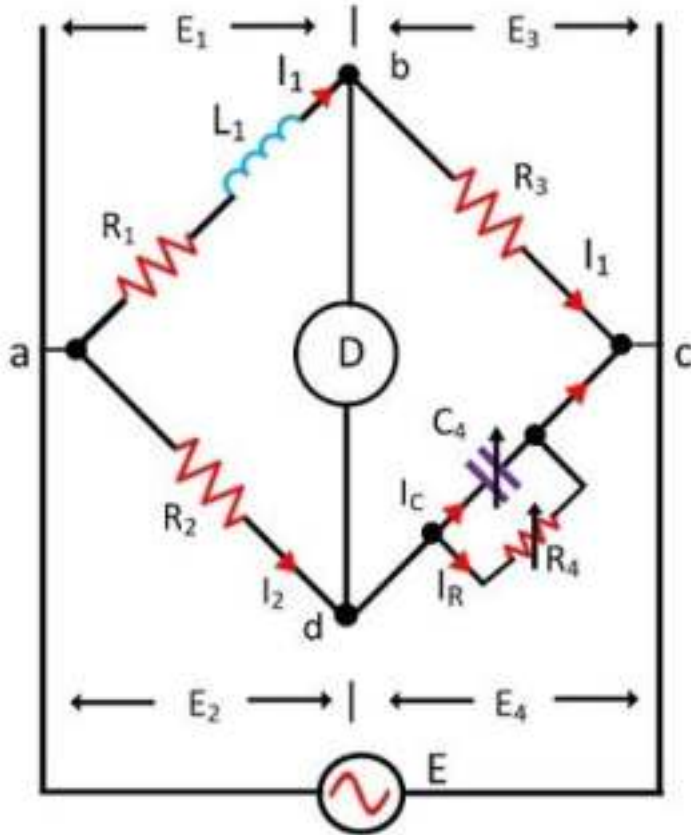
$L_2$  – Variable inductance of fixed resistance  $r_1$ .

$R_2$  – variable resistance connected in series with inductor  $L_2$ .

$R_3, R_4$  – known non-inductance resistance

### Maxwell's Inductance Capacitance Bridge

In this type of bridges, the unknown resistance is measured with the help of the standard variable capacitance. The connection diagram of the Maxwell Bridge is shown in the figure below.



### Maxwell's Inductance Capacitance Bridge

Let,  $L_1$  – unknown inductance of resistance  $R_1$ .  
 $R_1$  – Variable inductance of fixed resistance  $r_1$ .  
 $R_2, R_3, R_4$  – variable resistance connected in series with inductor  $L_2$ .  
 $C_4$  – known non-inductance resistance

#### Advantages of the Maxwell's Bridges

The following are the advantages of the Maxwell bridges

1. The balance equation of the circuit is free from frequency.
2. Both the balance equations are independent of each other.
3. The Maxwell's inductor capacitance bridge is used for the measurement of the high range inductance.

#### Disadvantages of the Maxwell's Bridge

The main disadvantages of the bridges are

1. The Maxwell inductor capacitance bridge requires a variable capacitor which is very expensive. Thus, sometimes the standard variable capacitor is used in the bridges.

2. The bridge is only used for the measurement of medium quality coils.

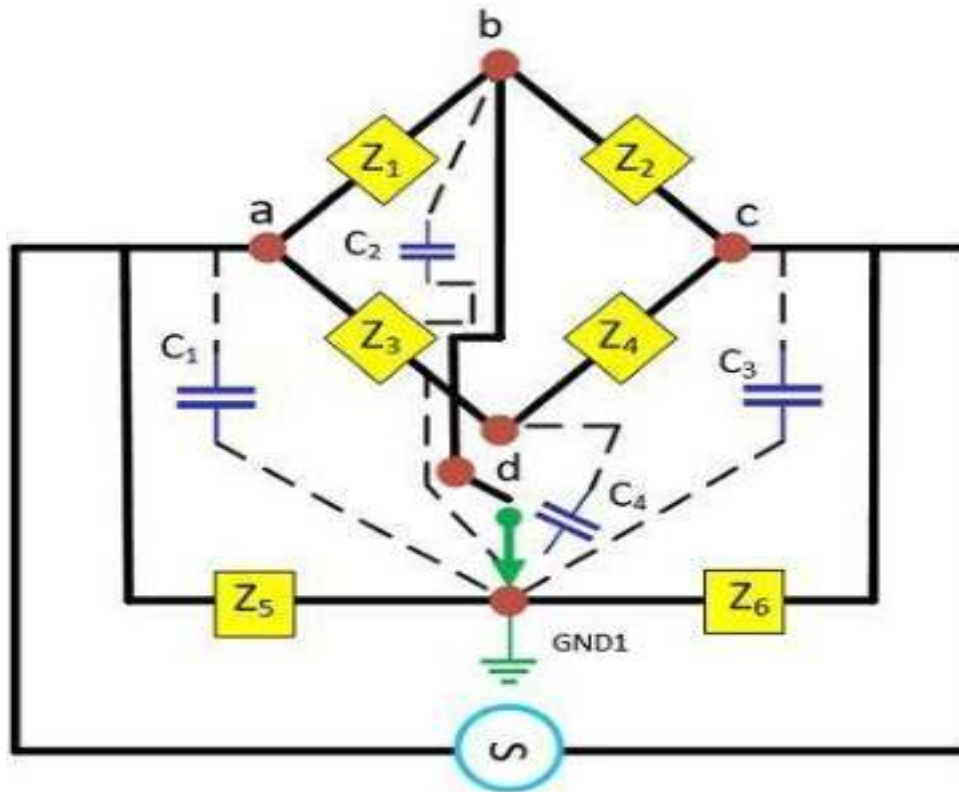
### **2.3 Wagner earth devices**

The Wagner earthing device is used for removing the earth capacitance from the bridges. It is a type of voltage divider circuit used to reduce the error which occurs because of stray capacitance. The Wagner Earth device provides high accuracy to the bridge.

At high frequency, stray capacitance is induced between the bridge elements, ground and between the arms of the bridge. This stray element causes the error in the measurement. One of the ways of controlling these capacitances is to enclose the bridge elements into the shield. Another way of eliminating these stray capacitance is to place the Wagner Earth device between the elements of the bridge.

#### **Construction of Wagner Earthing Device**

The circuit diagram of the Wagner Earth Device is shown in the figure below. Consider the  $Z_1$ ,  $Z_2$ ,  $Z_3$ , and  $Z_4$  are the impedances arm of the bridge. The  $Z_5$  and the  $Z_6$  are the two variable impedances of the Wagner Earth Device. The centre point of the Wagner earth device is earthed. The impedance of Wagner device arms is similar to the arms of the bridge. The impedance of the arm consists the resistance and capacitances.



## Wagner Earth Device

The Wagner impedance placed in such a way so that they make the bridge balance with  $Z_1$ ,  $Z_3$  and  $Z_2$ ,  $Z_4$ . The  $C_1$ ,  $C_2$ ,  $C_3$  and  $C_4$  show the stray capacitances of the bridges. The  $D$  is the detector of the bridge.

The bridge comes in the balance condition by adjusting the impedances of arms  $Z_1$  and  $Z_4$ . The stray capacitance prevents bridge to comes in the balanced condition. When the  $S$  is not thrown on 'e' then the  $D$  is connected between the point p and q. But when  $S$  is thrown on 'e' then the detector  $D$  is connected between the terminal b and earth.

The impedance  $Z_4$  and  $Z_5$  are adjusted until the minimum sound is obtained. The headphones again connected between the point b and d for obtaining the minimum sound. The headphones are reconnected between the point b and d,  $Z_4$  and  $Z_5$  are adjusted for obtaining the minimum sound. The process is continuously repeated for obtaining the silent sound.

The point b, d, and e all are in the same potential. And the capacitance  $C_1$ ,  $C_2$ ,  $C_3$ ,  $C_4$  all are eliminated from the bridge circuit along with the impedances  $Z_5$  and  $Z_6$ .



# **B.K.N GOVT POLYTECHNIC** **NARNAUL**

**DEPARTMENT- INSTRUMENTATION AND CONTROL**

**ENGINEERING SUBJECT: 3.4 TMI**

**NAME OF FACULTY: Mrs.**

**RAJNI SEMESTER-3<sup>rd</sup>**

**UNIT-3**

**Construction and working principle, application of Ammeter and voltmeter**

## **Moving Iron**

One of the most accurate instrument used for both AC and DC measurement is moving iron instrument. There are two types of moving iron instrument.

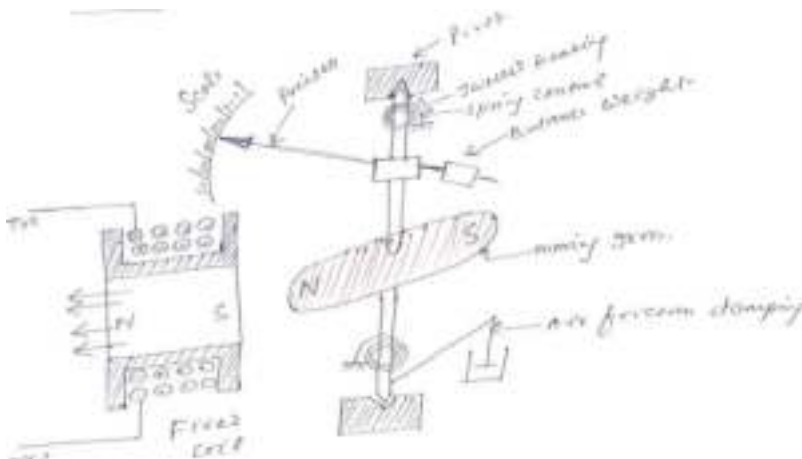
- Attraction type
- Repulsion type

### **Attraction type M.I. instrument**

**Construction:** The moving iron fixed to the spindle is kept near the hollow fixed coil. The pointer and balance weight are attached to the spindle, which is supported with jeweled bearing. Here air friction damping is used.

### **Principle of operation**

The current to be measured is passed through the fixed coil. As the current is flow through the fixed coil, a magnetic field is produced. By magnetic induction the moving iron gets magnetized. The north pole of moving coil is attracted by the south pole of fixed coil. Thus the deflecting force is produced due to force of attraction. Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the calibrated scale. But the force of attraction depends on the current flowing through the coil.



### **Advantages**

- ✓ MI can be used in AC and DC
- ✓ It is cheap
- ✓ Supply is given to a fixed coil, not in moving coil.
- ✓ Simple construction
- ✓ Less friction error.

### **Disadvantages**

- ✓ It suffers from eddy current and hysteresis error
- ✓ Scale is not uniform
- ✓ It consumed more power
- ✓ Calibration is different for AC and DC operation

### **Repulsion type moving iron instrument**

**Construction:** The repulsion type instrument has a hollow fixed iron attached to it. The moving iron is connected to the spindle. The pointer is also attached to the spindle in supported with jeweled bearing.

**Principle of operation:** When the current flows through the coil, a magnetic field is produced by it. So both fixed iron and moving iron are magnetized with the same polarity, since they are kept in the same magnetic field. Similar poles of fixed and moving iron get repelled. Thus the deflecting torque is produced due to magnetic repulsion. Since moving iron is attached to spindle, the spindle will move. So that pointer moves over the calibrated scale.

Damping: Air friction damping is used to reduce the oscillation.

Control: Spring control is used.

## Permanent Magnet Moving Coil (PMMC) instrument

### Permanent Magnet Moving Coil (PMMC) instrument

One of the most accurate type of instrument used for D.C. measurements is PMMC instrument.

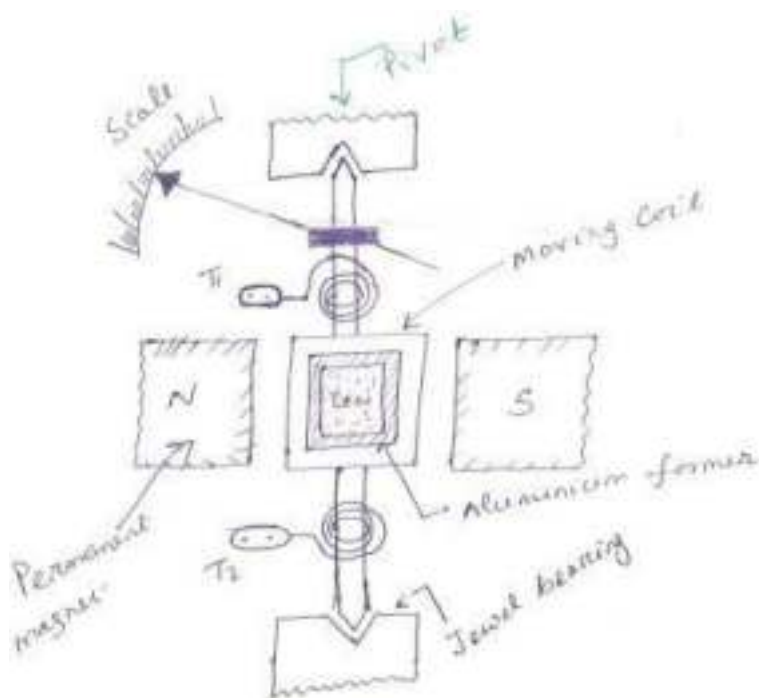
**Construction:** A permanent magnet is used in this type instrument. Aluminum former is provided in the cylindrical in between two poles of the permanent magnet. Coils are wound on the aluminum former which is connected with the spindle. This spindle is supported with jeweled bearing. Two springs are attached on either end of the spindle. The terminals of the moving coils are connected to the spring. Therefore the current flows through spring 1, moving coil and spring 2.

Damping: Eddy current damping is used. This is produced aluminium former.

Control: Spring control is used.

Damping: Eddy current damping is used. This is produced by aluminum former.

Control: Spring control is used.



### **Principle of operation**

When D.C. supply is given to the moving coil, D.C. current flows through it. When the current carrying coil is kept in the magnetic field, it experiences a force. This force produces a torque and the former rotates. The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale. When the polarity is reversed a torque is produced in the opposite direction. The mechanical stopper does not allow the deflection in the opposite direction. Therefore the polarity should be maintained with PMMC instrument.

If A.C. is supplied, a reversing torque is produced. This cannot produce a continuous deflection. Therefore this instrument cannot be used in A.C.

### **Advantages**

- ✓ Torque/weight is high
- ✓ Power consumption is less
- ✓ Scale is uniform
- ✓ Damping is very effective
- ✓ Since operating field is very strong, the effect of stray field is negligible
- ✓ Range of instrument can be extended

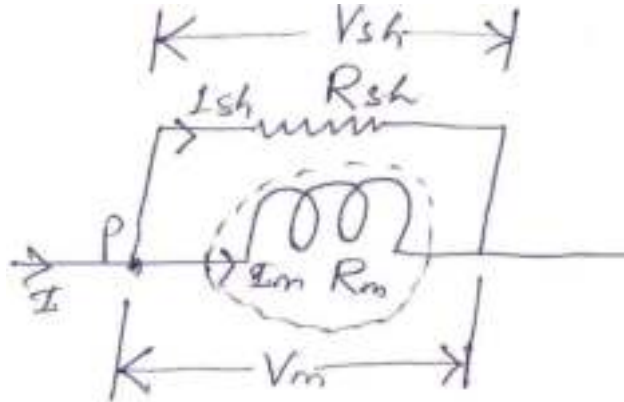
### **Disadvantages**

- ✓ Use only for D.C.
- ✓ Cost is high
- ✓ Error is produced due to ageing effect of PMMC
- ✓ Friction and temperature error are present

## Extension of range of PMMC instrument Case-

### I: Shunt

A low shunt resistance connected in parallel with the ammeter to extent the range of current. Large current can be measured using low current rated ammeter by using a shunt.



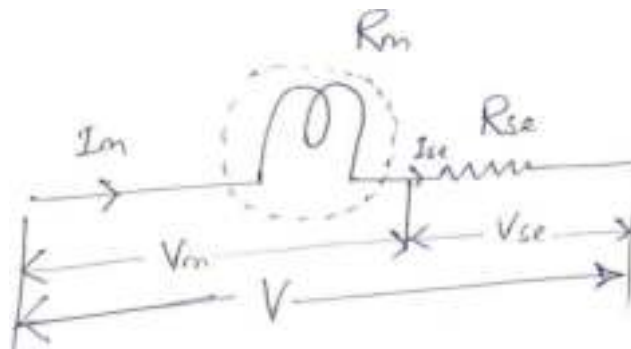
Let  $R_m$  = Resistance of meter

$R_{sh}$  = Resistance of shunt  $I_m$  = Current through meter  $I_{sh}$  = current through shunt  $I$  = current to be measure

Shunt resistance is made of manganin. This has least thermoelectric emf. The change is resistance, due to change in temperature is negligible.

### Case (II): Multiplier

A large resistance is connected in series with voltmeter is called multiplier. A large voltage can be measured using a voltmeter of small rating with a multiplier.



Let

$R_m$  = resistance of meter

$R_{se}$  = resistance of multiplier

$V_m$  = Voltage across meter

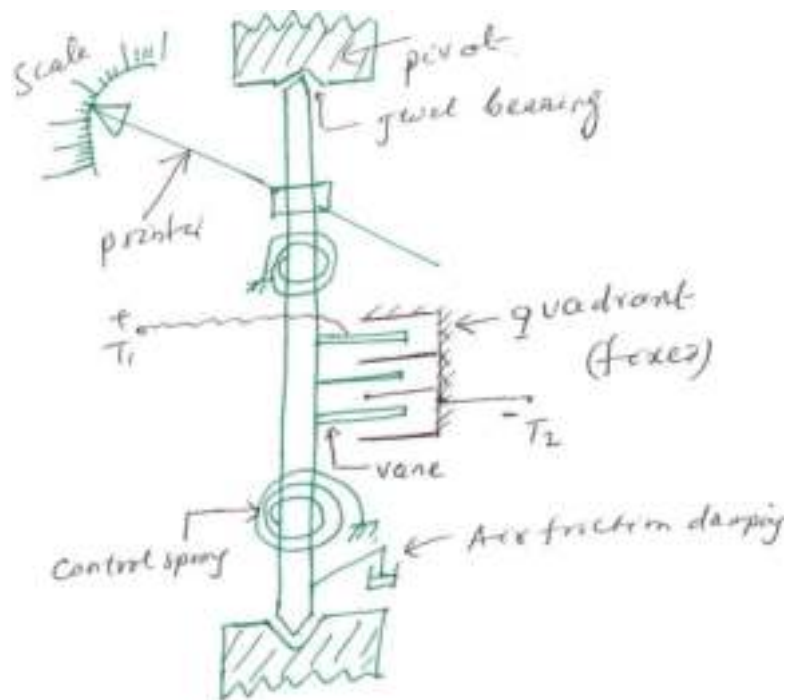
$V_{se}$  = Voltage across series resistance  $V$  = voltage to be measured

## Electrostatic type

### Electrostatic instrument

In multi cellular construction several vanes and quadrants are provided. The voltage is to be measured is applied between the vanes and quadrant. The force of attraction between the vanes and quadrant produces a deflecting torque. Controlling torque is produced by spring control. Air friction damping is used.

The instrument is generally used for measuring medium and high voltage. The voltage is reduced to low value by using capacitor potential divider. The force of attraction is proportional to the square of the voltage.



### **Advantages**

- It is used in both AC and DC.
- There is no frequency error.
- There is no hysteresis error.
- There is no stray magnetic field error. Because the instrument works on electrostatic principle.
- It is used for high voltage
- Power consumption is negligible.

### **Disadvantages**

- Scale is not uniform
- Large in size
- Cost is more

### **Millimeter: Principle, applications of d.c. voltage and a.c. voltage**

A multimeter, also known as a volt-ohm meter, is a handheld tester used to measure electrical voltage, current (amperage), resistance, and other values. Multimeters come in analog and digital versions and are useful for everything from simple tests, like measuring battery voltage, to detecting faults and complex diagnostics. They are one of the tools preferred by electricians for troubleshooting electrical problems on motors, appliances, circuits, power supplies.



## Analog Multimeters

An analog multimeter is based on a microammeter (a device that measures amperage, or current) and has a needle that moves over a graduated scale. Analog multimeters are less expensive than their digital counterparts but can be difficult for some users to read accurately. Also, they must be handled carefully and can be damaged if they are dropped.

Analog multimeters typically are not as accurate as digital meters when used as a voltmeter. However, analog multimeters are great for detecting slow voltage changes because you can watch the needle moving over the scale. Analog testers are exceptional when set as ammeters, due to their low resistance and high sensitivity, with scales down to  $50\mu\text{A}$  (50 microamperes).

## Digital Multimeters

Digital multimeters are the most commonly available type and include simple versions as well as advanced designs for electronics engineers. In place of the moving needle and scale found on analog meters, digital meters provide readings on an LCD screen. They tend to cost more than analog multimeters, but the price difference is minimal among basic versions. Advanced testers are much more expensive.

Digital multimeters typically are better than analog in the voltmeter function, due to the higher resistance of digital. But for most users, the primary advantage of digital testers is the easy-to-read and highly accurate digital readout.

## **Using a Multimeter**

The basic functions and operations of a multimeter are similar for both digital and analog testers. The tester has two leads—red and black—and three ports. The black lead plugs into the "common" port. The red lead plugs into either of the other ports, depending on the desired function.

After plugging in the leads, you turn the knob in the center of the tester to select the function and appropriate range for the specific test. For example, when the knob is set to "20V DC," the tester will detect DC (direct current) voltage up to 20 volts. To measure smaller voltages, you would set the knob to the 2V or 200mV range.

## **Multimeter Functions**

Multimeters are capable of many different readings, depending on the model. Basic testers measure voltage, amperage, and resistance and can be used to check continuity, a simple test to verify a complete circuit. More advanced multimeters may test for all of the following values:

- AC (alternating current) voltage and amperage
- DC (direct current) voltage and amperage
- Resistance (ohms)
- Capacity (farads)
- Conductance (siemens)
- Decibels
- Duty cycle
- Frequency (Hz)
- Inductance (henrys)
- Temperature Celsius or Fahrenheit



# **B.K.N GOVT POLYTECHNIC NARNAUL**

**DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING**

**SUBJECT: 3.4 TMI**

**NAME OF FACULTY: Mrs. RAJNI**

**SEMESTER-3<sup>rd</sup>**

**UNIT-4**

## **4.1 Power and Energy Measurements**

### **4.1 Construction and Working Principle of Electrodynamometer**

**Definition:** The instrument whose working depends on the reaction between the magnetic field of moving and fixed coils is known as the Electrodynamo-meter Wattmeter. It uses for measuring the power of both the AC and DC circuits.

The **working principle** of the Electrodynamometer Wattmeter is very simple and easy. **Their working depends on the theory that the current carrying conductor placed in a magnetic field experiences a mechanical force.** This mechanical force deflects the pointer which is mounted on the calibrated scale.

#### **Construction of Electrodynamometer Wattmeter**

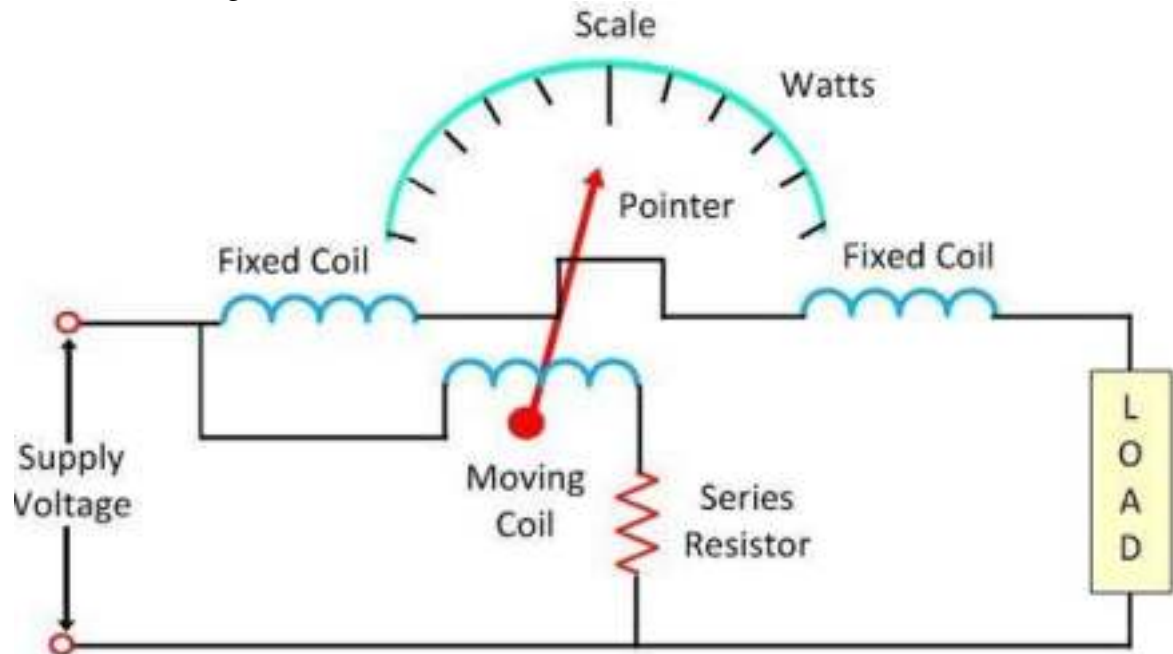
The following are the important parts of the Electrodynamometer Wattmeter.

1. **Fixed coil** – The fixed coil connects in series with the load. It is considered as a current coil because the load current flows through it. **For making the construction easy the fixed coil divide into two parts.** And these two elements are parallel connected to each other. The fixed coil produces the uniform electric field which is essentials for the working of the instruments. The current coil of the instruments is designed to carry the current of approximately 20 amperes for saving the power.
2. **Moving Coil** – **The moving coil consider as the pressure coil of the instruments.** It connects in parallel with the supply voltage. The current flows through them is directly proportional to the supply voltage. The pointer mounts on the moving coil. The movement of the pointer controls with the help of the spring. The current flows through the coil increases their temperature. The flows of currents control with the help of resistor which connects in series with the moving coil.
3. **Control** – **The control system provides the controlling torque to the instruments.** The gravity control and the spring control are the two types of control system. Out of two, the Electrodynamometer Wattmeter uses spring control system. The spring control system is used for the movement of the pointer.
4. **Damping** – The damping is the effect which reduces the movement of the pointer. **In this Wattmeter the damping torque produces because of the air friction.** The other types of damping are not used in the system because they destroy the useful magnetic flux.

5. **Scales and pointers** – The instruments use a linear scale because their moving coil moves linearly. The apparatus uses the knife edge pointer for removing the parallax error which causes because of oversights.

#### **Working of Electrodynamicometer Wattmeter**

The Electrodynamicometer Wattmeter has two types of coils; fixed and the moving coil. The fixed coil connects in series with the circuit whose power consumption use to be measured. The supply voltage applies to the moving coil. The resistor controls the current across the moving coil, and it is connected in series with it.

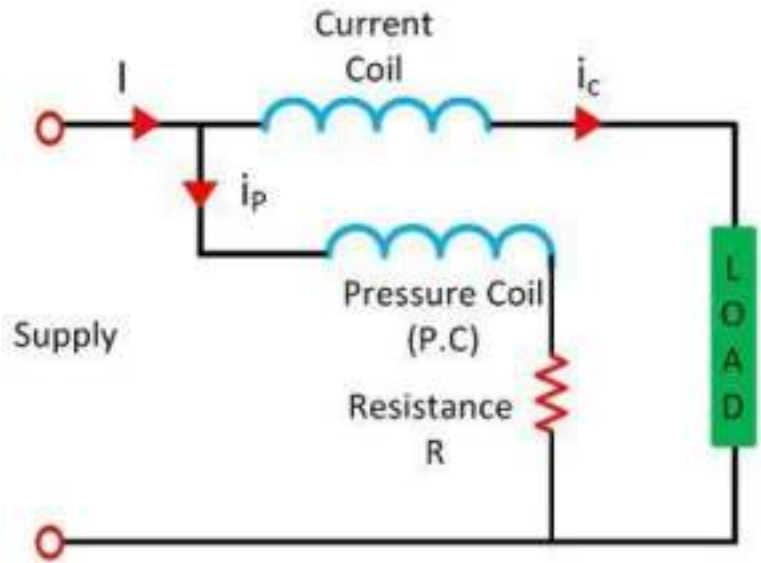


**Electrodynamicometer Wattmeter**

The pointer is fixed on the moving coil which is placed between the fixed coils. The current and voltage of the fixed and moving coil generate the two magnetic fields. And the interaction of these two magnetic fields deflects the pointer of the instrument. The deflection of the pointer is directly proportional to the power flows through it.

#### **Theory of Electrodynamicometer Wattmeter**

The circuit diagram of the electrodynamicometer wattmeter is shown in the figure below.



**Circuit of Electrodynamo Wattmeter**

Expressions let us consider the circuit diagram given below:

We know that instantaneous torque in electrodynamic type instruments is directly proportional to the product of instantaneous values of currents flowing through both the coils and the rate of change of flux linked with the circuit. Let  $I_1$  and  $I_2$  be the instantaneous values of currents in pressure and current coils respectively. So the expression for the torque can be written as:

$$T = I_1 \times I_2 \times \frac{dM}{dx}$$

Where,  $x$  is the angle.

Now let the applied value of voltage across the pressure coil be  $v = \sqrt{2}V \sin \omega t$

Assuming the electrical resistance to the pressure coil be very high hence we can neglect reactance with respect to its resistance. In this the impedance is equal to its electrical resistance therefore it is purely resistive.

The expression for instantaneous current can be written as  $I_2 = v / R_p$  where  $R_p$  is the resistance of pressure coil.

$$I_2 = \sqrt{2} \times \frac{V \sin \omega t}{R_p}$$

If there is phase difference between voltage and electric current, then expression for instantaneous current through current coil can be written as

$$I_1 = I(t) = \sqrt{2}I \sin(\omega t - \phi)$$

As current through the pressure coil is very small compared to the current through current coil hence current through the current coil can be considered as equal to total load current.

Hence the instantaneous value of torque can be written as

$$\sqrt{2} \times \frac{V \sin \omega t}{R_p} \times \sqrt{2} \times I \times \sin(\omega t - \phi) \times \frac{dM}{dx}$$

Average value of deflecting torque can be obtained by integrating the instantaneous torque from limit 0 to T, where T is the time period of the cycle.

$$T_d = \text{deflecting torque} = \frac{VI}{R_p} \cos \phi \times \frac{dM}{dx}$$

Controlling torque is given by  $T_c = K_x$  where K is spring constant and x is final steady state value of deflection.

### **Advantages of Electrodynamometer Type Wattmeter**

Following are the advantages of electrodynamometer type wattmeter and they are written as follows:

1. Scale is uniform up to a certain limit.
2. They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

### **Errors in Electrodynamometer Type Wattmeter**

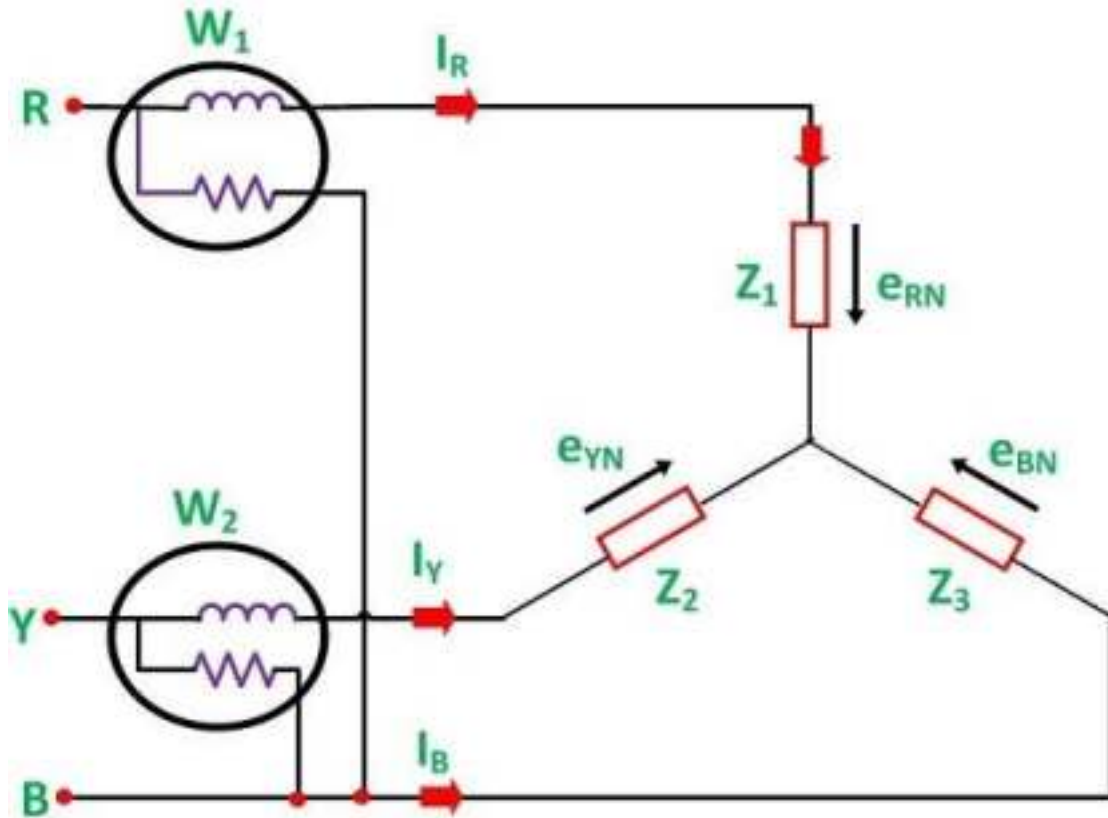
Following are the errors in the electrodynamometer type wattmeters:

1. Errors in the pressure coil inductance.
2. Errors may be due to pressure coil capacitance.
3. Errors may be due to mutual inductance effects.
4. Errors may be due connections.(i.e. pressure coil is connected after current coil)
5. Error due to Eddy currents.
6. Errors caused by vibration of moving system.
7. Temperature error.
8. Errors due to stray magnetic field.

### **4.2 Power measurement method 2 watt meter or 3 watt meter**

Two Wattmeter Method can be employed to measure the power in a 3 phase, three-wire star or delta connected the balanced or unbalanced load.

In two wattmeter method, the current coils of the wattmeter are connected with any two lines, say R and Y and the potential coil of each wattmeter is joined on the same line, the third line i.e. B as shown below in figure (A):



The total instantaneous power absorbed by the three loads  $Z_1$ ,  $Z_2$  and  $Z_3$ , is equal to the sum of the powers measured by the two wattmeters,  $W_1$  and  $W_2$ .

#### Contents:

1. Measurement of Power by Two Wattmeter Method in Star Connection
2. Measurement of Power by Two Wattmeter Method in Delta Connection

#### Measurement of Power by Two Wattmeter Method in Star Connection

Considering the above figure (A) in which Two Wattmeter  $W_1$  and  $W_2$  are connected, the instantaneous current through the current coil of Wattmeter,  $W_1$  is given by the equation shown below:

$$W_1 = i_R$$

The instantaneous potential difference across the potential coil of Wattmeter,  $W_1$  is given as:

$$W_1 = e_{RN} - e_{BN}$$

Instantaneous power measured by the Wattmeter,  $W_1$  is

$$W_1 = i_R (e_{RN} - e_{BN}) \dots \dots \dots (1)$$

The instantaneous current through the current coil of Wattmeter,  $W_2$  is given by the equation:

$$W_2 = i_Y$$

The instantaneous potential difference across the potential coil of Wattmeter,  $W_2$  is given as:

$$W_2 = e_{YN} - e_{BN}$$

Instantaneous power measured by the Wattmeter,  $W_2$  is:

$$W_2 = i_Y (e_{YN} - e_{BN}) \dots \dots \dots (2)$$

Therefore, the total power measured by the two wattmeters  $W_1$  and  $W_2$  will be obtained by adding the equation (1) and (2).

$$W_1 + W_2 = i_R (e_{RN} - e_{BN}) + i_Y (e_{YN} - e_{BN})$$

$$W_1 + W_2 = i_R e_{RN} + i_Y e_{YN} - e_{BN} (i_R + i_Y) \text{ or}$$

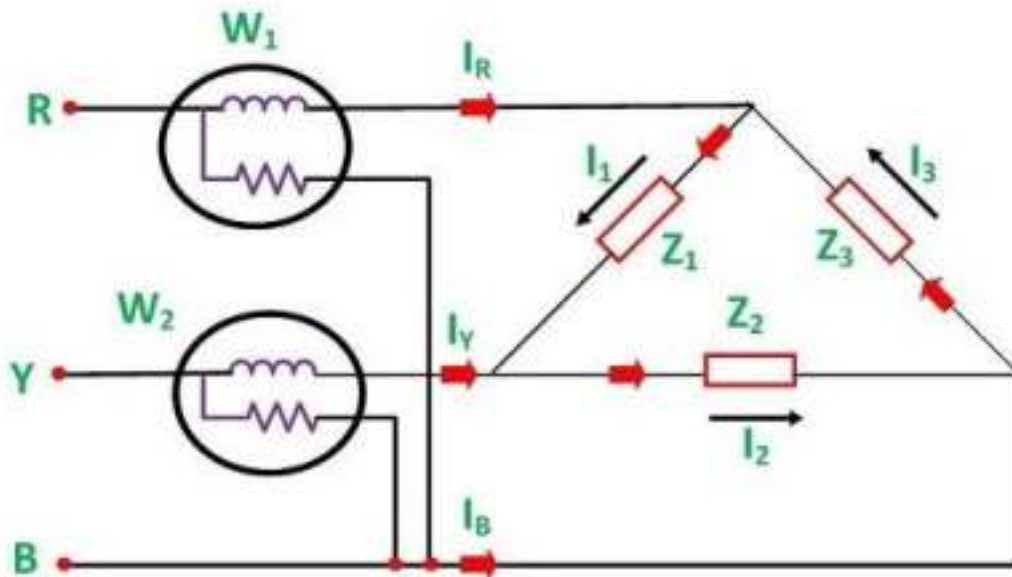
$$W_1 + W_2 = i_R e_{RN} + i_Y e_{YN} + i_B e_{BN} \quad (\text{i.e. } i_R + i_Y + i_B = 0)$$

$$W_1 + W_2 = P$$

Where,  $P$  – the total power absorbed in the three loads at any instant.

#### **Measurement of Power by Two Wattmeter Method in Delta Connection**

Considering the delta connected circuit shown in the figure below



The instantaneous current through the coil of the wattmeter,  $W_1$  is given by the equation:

$$W_1 = i_R = i_1 - i_3$$

Instantaneous power measured by the Wattmeter,  $W_1$  will be:

$$W_1 = e_{RB}$$

Therefore, the instantaneous power measured by the wattmeter,  $W_1$  will be given as:

$$W_1 = e_{RB} (i_1 - i_3) \dots \dots \dots (3)$$

The instantaneous current through the current coil of the Wattmeter,  $W_2$  is given as:

$$W_2 = i_Y = i_2 - i_1$$

The instantaneous potential difference across the potential coil of wattmeter,  $W_2$  :

$$W_2 = e_{YB}$$

Therefore, the instantaneous power measured by Wattmeter,  $W_2$  will be:

$$W_2 = e_{YB} (i_2 - i_1) \dots \dots \dots (4)$$

Hence, to obtain the total power measured by the two wattmeter the two equations, i.e. equation (3) and (4) has to be added.

$$W_1 + W_2 = e_{RB} (i_1 - i_3) + e_{YB} (i_2 - i_1)$$

$$W_1 + W_2 = i_1 e_{RB} + i_1 e_{YB} - i_3 e_{RB} - i_1 e_{YB}$$

$$W_1 + W_2 = i_2 e_{YB} + i_3 e_{BR} - i_1 (e_{YB} + e_{BR}) \quad (\text{i.e. } -e_{RB} = e_{BR})$$

$$W_1 + W_2 = i_1 e_{RY} + i_2 e_{YB} + i_3 e_{BR} \quad (\text{i.e. } e_{RY} + e_{YB} + e_{BR} = 0)$$

$$W_1 + W_2 = P$$

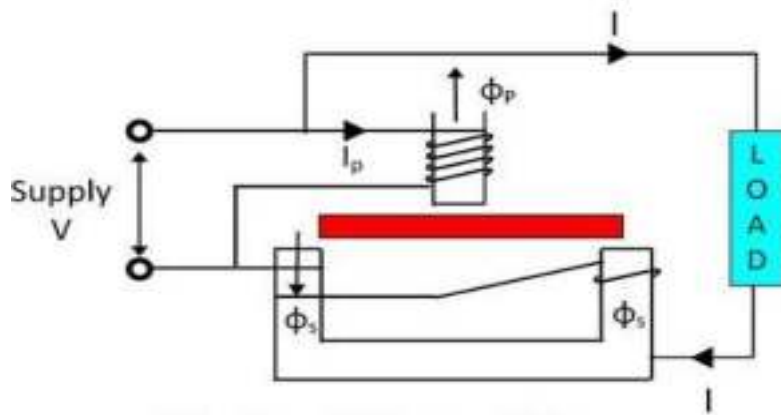
Where P is the total power absorbed in the three loads at any instant.

The power measured by the Two Wattmeter at any instant is the instantaneous power absorbed by the three loads connected in three phases. In fact, this power is the average power drawn by the load since the Wattmeter reads the average power because of the inertia of their moving system.

### 4.3 Working principle, construction and application of energy meter

#### Energy Meter

Energy meters are the integrated instruments which measures a quantity of electric energy supplying to the electric circuit in a specific time. These energy meters display the quantity of electrical energy consumed by the user in Kilowatts/hour (KWH). Energy meters have its different names according to its function and working principle. These meters are called as electricity meters, electric meters, electrical meters, etc.

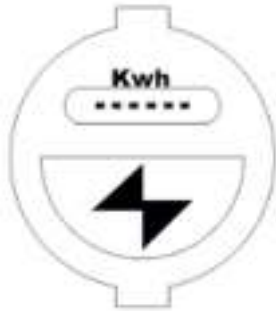


### Construction

The construction of energy meter is that it consists of two electromagnets M1 and M2, one magnet M1 is excited by line current and is known as series magnet. This electromagnet produces alternating flux  $\phi_1$ . This flux is proportional to the phase with line current whereas the second magnet M2 is known as shunt magnet. This electromagnet is connected to the supply line and its current is proportional to the supply voltage and produces a lagging flux  $\phi_2$ . Major portion of this flux is useless and a few amount of this flux is useful and it passes through the disc D.

### Energy Meter Symbol

Energy meter symbol is shown below:



## Types of Energy Meters

Energy meters consist of various types which are given below:

- **Electric Motor Energy Meters**
- **Electrolytic Energy Meters**

### Electric Motor Energy Meters

Electric Motor Energy Meters are known by its name that these energy meters consist of a small electric motor in it. Different kinds of electric motors are used in these energy meters. Some energy meter uses mercury motor, commutator motor, induction motor in it. The mercury motor energy meters are only used on D.C Circuits whereas the induction motor energy meters are used only on A.C Circuits and the commutator motor energy meters are used on both A.C Circuits and D.C Circuits.

The energy meters used for D.C circuits provides readings in the form of amp-hours or in watt hours. In this mechanism of readings, moving system revolve continuously. The speed of rotation is directly proportional to the current. The rotating system is controlled by the permanent magnet which is placed nearly to the moving system and produce eddy currents in some parts of rotating system.

### Electrolytic Energy Meter

Electrolytic Energy meter is an ampere-hour energy meter and is used in only D.C circuits. Their readings are incorrect when these meters are used on other voltage readings. These energy meters are not able to use on A.C circuits. These instruments can be used on AC circuits by using a small rectifier unit in it. These energy meters works according to the Faraday law of electrolysis. These energy meters are simple, cheap, and accurate in small loads. These energy meters are not effected by stray magnetic fields and from friction errors.

### Applications of Energy Meters

Energy meters are widely used in domestic areas for the measurement of electric power consumed by the customers and these energy meters are commonly used in industrial sector for controlling the electric power of various machinery according to its reading and for measurement of electric power

RAMUKHANA

# UNIT-5

## Frequency measurement

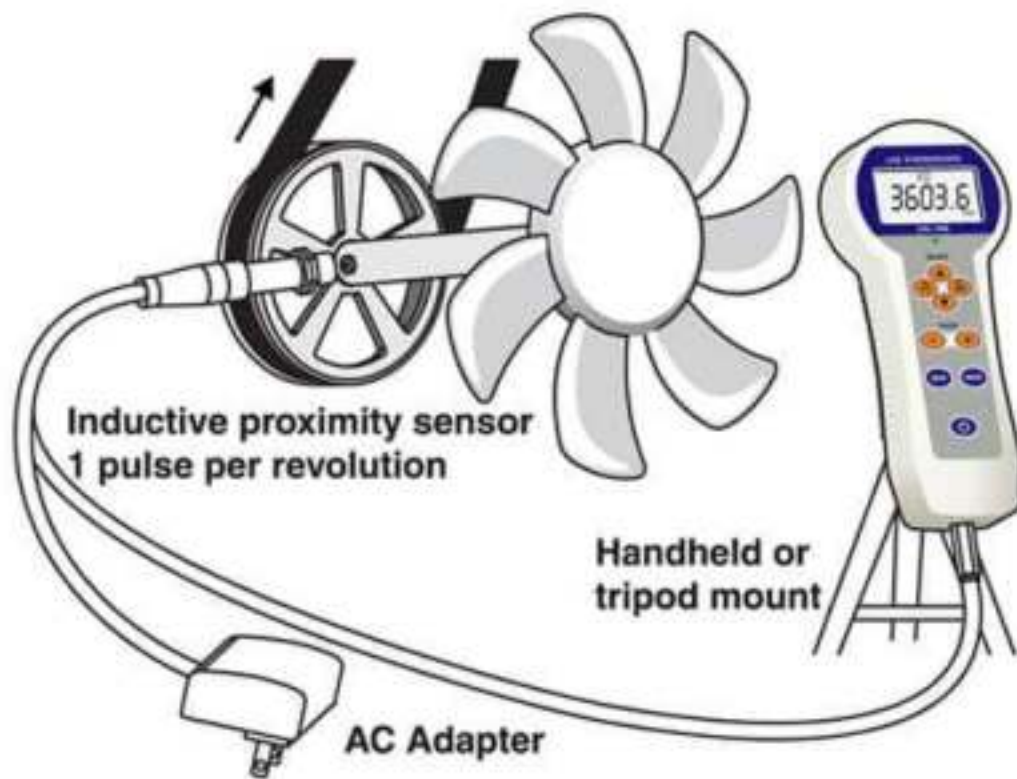
### 5.1 Stroboscope

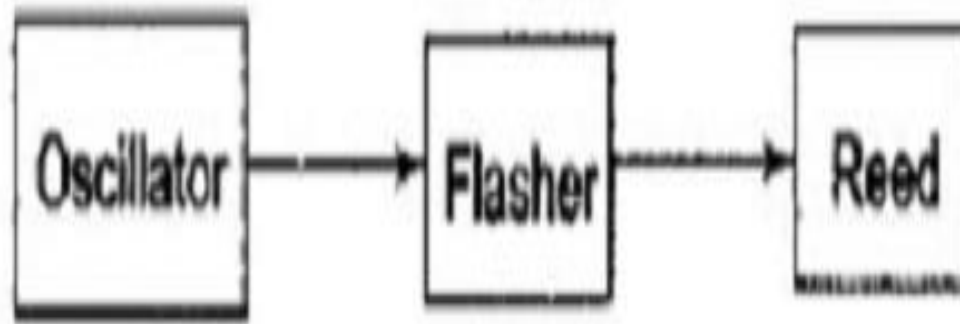
A Stroboscope is also known as strobe. A stroboscope is a test equipment which is utilised for making a cyclical rotating thing appearing to be slow moving or still. In other words, we can say that a Stroboscope is a monitoring and measuring device which uses stroboscopic effects for the observation of rapid periodic motions.

Or

A stroboscope is an instrument that can be used to measure revolutions, velocity, and frequency of rotating components or moving parts. It is also known as a strobe this device can measure periodic or rotary motions. This instrument can make a cyclically moving object appear to be slow-moving or stationary and it is done by the stroboscopic effect. This principle is used for the study of rotating, reciprocating, oscillating or vibrating objects.







### **Basic diagram stroboscopes**

**A stroboscope has various uses, such as :**

- It is used to measure the oscillation frequencies of mechanical and electronic systems
- It is used to measure resonance frequencies
- It is used to study the vibrations of various bodies
- It is used to visually monitor rapidly moving parts of machines.

#### **Principle of Operation:**

A stroboscope uses a flash lamp which is driven by an electronic oscillator. The flash lamp used is usually a xenon bulb, although LEDs are also used sometimes. The oscillator triggers the lamp at a steady rate of flash. The rate of flash can be varied and has a variable range from a few times per second to thousands of times per second. The flash lamp also consists a reflector to increase its brightness and to make the flash more directional.

**There are two basic types of stroboscope available:**

- 1. General purpose Stroboscope**– used for entertainment
- 2. Scientific Stroboscope** – used for scientific or experimental purpose.

**The entertainment / party** models are speed-limited and have low cost. The rate of flash for entertainment purpose stroboscope is generally limited as it has been found that flashes at certain rates can induce epileptic seizures in some people. They may have some additional features like multiple colored lights (that flash in a

sequence). The scientific models don't have any such speed limits. They must be able to capture high-speed periodic motions.

**Scientific or professional strobes** may also have some external trigger inputs. The external trigger overrides the internal oscillator. With the help of these external trigger inputs, one can easily sync the stroboscope to a moving machinery.

### **Applications of stroboscope**

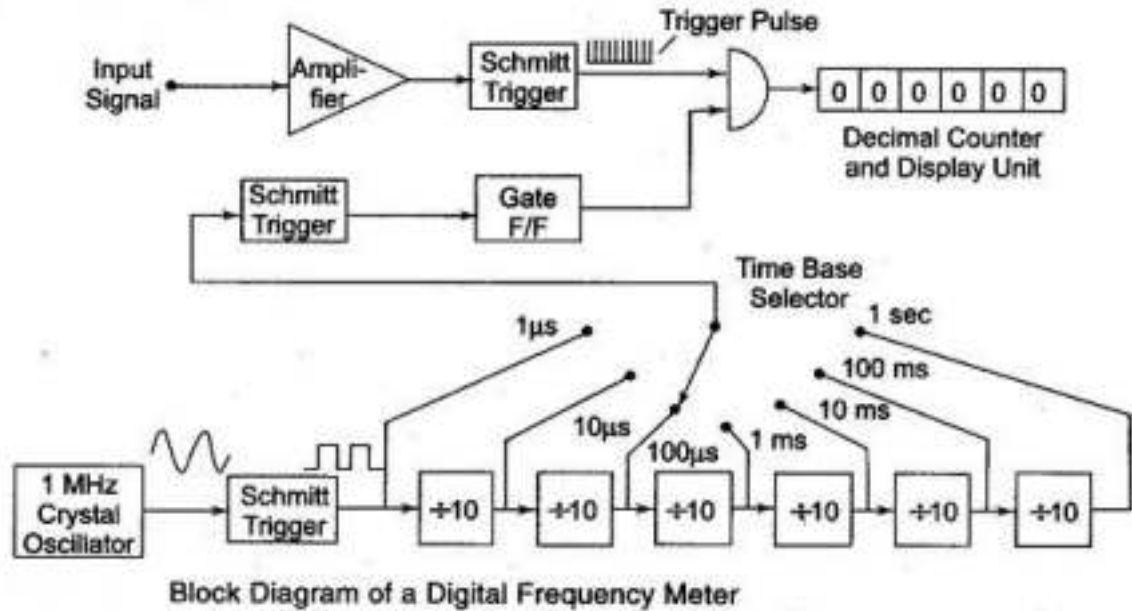
- Stroboscope can be used as a tachometer to measure the frequency of rotation of a mechanical system
- It is used as timing light to set the ignition timing of internal combustion engines.
- Stroboscope can be used to check the speed ranging from 60 – 1000000 rpm
- Rotational speed can be measured by using this
- In medicine stroboscope is used to view the vocal cords

### **5.2 Digital frequency meter**

A digital frequency meter is an electronic instrument that can measure even the smaller value of frequency up to 3 decimals of a sinusoidal wave and displays it on the counter display. It counts the frequency periodically and can measure in the range of frequencies between 104 to 109 hertz. The entire concept is based on the conversion of sinusoidal voltage into continuous pulses (01, 1.0, 10 seconds) along a single direction.

The basic **digital frequency meter** needs the following components:-

1. Amplifier
2. Schmitt trigger
3. AND gate
4. A counter
5. Crystal oscillator
6. Time base selector
7. A flip-flop



### Functions of each component: –

As shown in above fig. various components and their functions are as mentioned below:

#### 1. Amplifier:-

An amplifier is an electronic device that increases the voltage, current, or power of a signal. The most frequently-used device for power amplification is the bipolar transistor. This circuit usually amplifies the input signal applied to the input terminal to the amplifier. In this meter, this is an essential circuit which amplifies the magnitude of smaller input signals for measuring the frequency.

#### 2. Schmitt Trigger:-

This circuit basically converts any alternating signal into a Square wave by use of operational amplifier.

In electronics, a **Schmitt trigger** is a comparator circuit with hysteresis implemented by applying positive feedback to the non inverting input of a

comparator or differential amplifier. It is an active circuit which converts an analog input signal to a digital output signal.

### 3. **AND gate:-**

This gate basically provides an output when two inputs are present. In this meter, the input signals are from a Schmitt trigger connected on input signal side and a flip-flop connected to time base selector circuit.

The **AND gate** is a basic digital logic gate that implements logical conjunction – it behaves according to the truth table to the right. A HIGH output (1) results only if both the inputs to the **AND gate** are HIGH (1). If neither or only one input to the **AND gate** is HIGH, a LOW output results.

### 4. **Counter:-**

Counters are normally a synchronous type in which the decimal count is in ascending order starting from zero. In this meter, the output of a AND gate is given to counter to count the number of pulses.

A counter circuit is usually constructed of a number of flip-flops connected in cascade. Counters are a very widely used component in digital circuits, and are manufactured as separate integrated circuits and also incorporated as parts of larger integrated circuits.

### 5. **Crystal oscillator:-**

This circuit basically provides a sinusoidal output by using only a dc power supply. In this meter, the crystal oscillator connected is of 1MHz which produces a sine wave.

A **crystal oscillator** is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of material to create an electrical signal with a precise frequency. This frequency is commonly used to keep track of time, as in quartz wristwatches, to provide a stable clock signal for digital integrated

circuits, and to stabilize frequencies for radio transmitters and receivers. The most common type of piezoelectric resonator used is the quartz crystal, so oscillator circuits incorporating them became known as crystal oscillators.

## **6. Time base selector:-**

It is a circuit which can change the time period of signals for the reference purpose. The time base consist of a fixed frequency crystal oscillator, called a clock oscillator, which has to be very accurate. In order to ensure its accuracy, the crystal is enclosed in a constant temperature oven. The output of this constant frequency oscillator is fed to a Schmitt trigger, which converts the input sine wave to an output consisting of a train of pulses at a rate equal to the frequency of the clock oscillator. The train of pulses then passes through a series of frequency divider decade assemblies connected in cascade. Each decade divider consists of a decade counter and divides the frequency by ten. Outputs are taken from each decade frequency divider by means of a selector switch; any output may be selected.

## **7. Flip-Flop: –**

This circuit produces output depending upon the input given. It has four states depending upon which flip-flop is used.

A **flip-flop** is a device very much like a latch in that it is a bistable multivibrator, having two states and a feedback path that allows it to store a bit of information. The difference between a latch and a flip-flop is that a latch is asynchronous, and the outputs can change as soon as the inputs do (or at least after a small propagation delay). A flip-flop, on the other hand, is edge-triggered and only changes state when a control signal goes from high to low or low to high. This distinction is relatively recent and is not formal, with many authorities still referring to flip-flops as latches and vice versa, but it is a helpful distinction to make for the sake of clarity.

## Working Principle

When an unknown frequency signal is applied to the meter it passes on to amplifier which amplifies the weak signal. Now the amplified signal is now applied to Schmitt trigger which can convert input sinusoidal signal into a square wave. The oscillator also generates sinusoidal waves at periodic intervals of time, which is fed to Schmitt trigger. This trigger converts sin wave into a square wave, which is in the form of continuous pulses, where one pulse is equal to one positive and one negative value of a single signal cycle.

The first pulse which is generated is given as input to the gate control flip flop turning ON AND gate. The output from this AND gate count decimal value. Similarly, when the second pulse arrives, it disconnects AND gate, and when the third pulse arrives the AND gate turns ON and the corresponding continuous pulses for a precise time interval which is the decimal value is displayed on the counter display.

## Formula

The frequency of the unknown signal can be calculated by the following formula

$$F = N / t \dots\dots\dots(1)$$

Where

F =frequency of the unknown signal

N = Number of counts displayed by the counter

t = time interval between the start-stop of the gate.

## Advantages

The following are the advantages of digital frequency meter

- Good frequency response
- High sensitivity
- The production cost is low.

## **Disadvantages**

The following are the disadvantages

- It does not measure the exact value.

## **Digital Frequency Meter Applications**

The following are the applications

- The equipment's like radio can be tested using a digital frequency meter
- It can measure parameters like pressure, strength, vibrations, etc

### **5.3 Phase sequence indicators**

**Phase sequence indicator** is the indicator that determines the phase sequence of the three phase supply system.

When we give conventional three phase supply (i.e. RYB) to the induction motor, we see that the direction of the rotation of the rotor is in clockwise direction.

Now what will happen to direction of rotation of rotor if the phase sequence is reversed, the answer to this question is that the rotor will rotate in the anticlockwise direction. Thus, we see that the direction of rotation of rotor depends on the phase sequence. Let us study how these phase instruments work and on what principle they work.



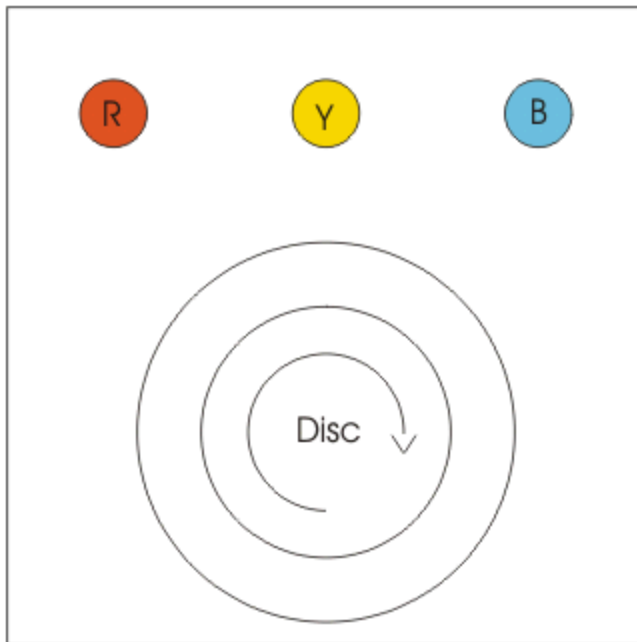
Now there are two types of **phase sequence indicators** and they are:

1. Rotating type
2. Static type.

Let us discuss one by one each type.

### **Rotating Type Phase Sequence Indicators**

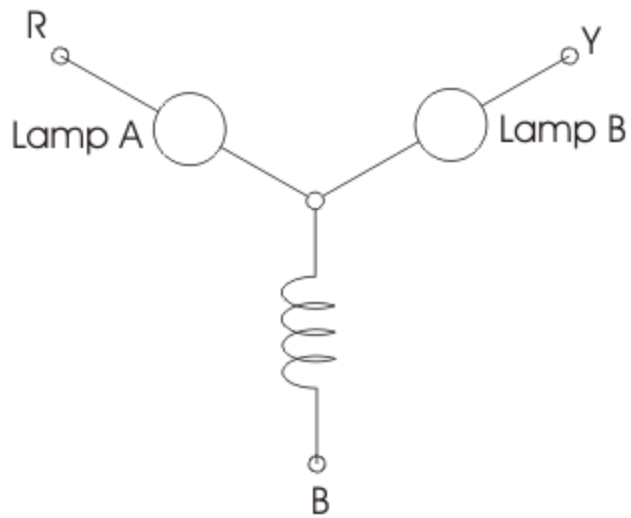
It works on the principle of induction motors. In this coils are connected in star form and the supply is given from three terminal marked as RYB as shown in the figure. When supply is given the coils produces the rotating magnetic field and these rotating magnetic fields produces eddy emf in the movable aluminium disc as shown in the diagram.



These eddy emf produces eddy current on the aluminium disc, eddy currents interact with the rotating magnetic field due this a torque is produced which causes the light aluminum disc to move. If the disc moves in the clockwise direction then chosen sequence is RYB and if the direction of rotation is in anticlockwise the sequence is reversed.

### **Static Type Phase Sequence Indicators**

Given below is the arrangement of static type indicator:



When the phase sequence is RYB then the lamp B will glow brighter than the lamp A and if the phase sequence is reversed then the lamp A will glow brighter than the lamp B.

## Unit-6

### Construction, working principle and application of the following instruments

#### 6.1 Q-meter

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  $X_L = X_C$  and  $E_L = I X_L$ ,  $E_C = I X_C$ ,  $E = I R$

Where 'E' is an applied voltage

$X_L$  is the inductive reactance

' $X_C$ ' is the capacitive reactance

'R' is the coil resistance

'I' is circuit current

Thus,  $Q = X_L/R = X_C/R = E_C/E$

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.

#### 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.

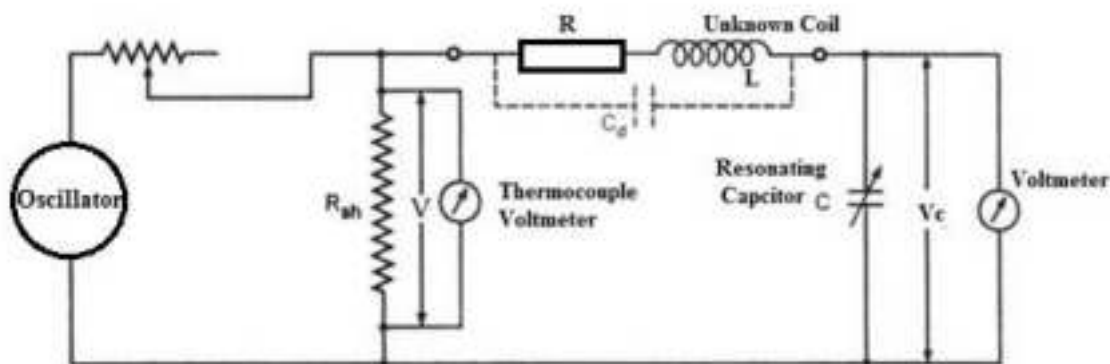


**Figure Q- meter circuit**

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  $E = Q \times e$  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.

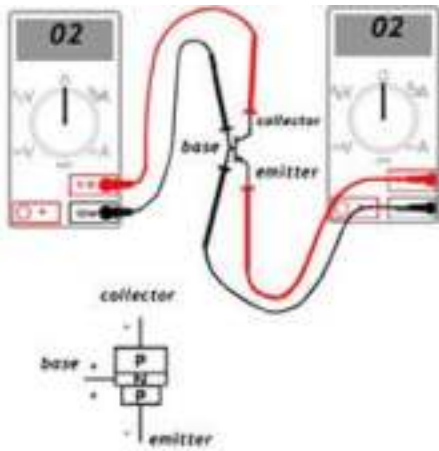
### **Applications of the Q-meter**

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.

### **5.2 Transistor tester**

Transistor tester is a type of instrument used to test the electrical behavior of transistors. There are three types of transistor testers each performing an exclusive operation:



- Quick Check in Circuit Checker
- Service Type Tester
- Laboratory Standard Tester

### **Quick Check in Circuit Checker**

Quick check in circuit checker transistor tester is used to check whether a transistor is performing properly in a circuit or not. This type of transistor tester specifies to a technician whether a transistor is still operative or dead. The advantage of using this tester is such that among all the components in the circuit only transistor is not removed.

### **Service Type Transistor Tester**

This type of transistor tester usually performs three types of tests: Forward current gain, base to collector leakage current with open emitter, and short circuits from collector to base and emitter.

### **Laboratory Standard Tester**

A Laboratory Standard Tester is used to measure a transistor's parameters at various operating conditions. The readings measured by this tester are accurate, and among the important characteristics measured are input resistance  $R_{in}$ , common base and common emitter.

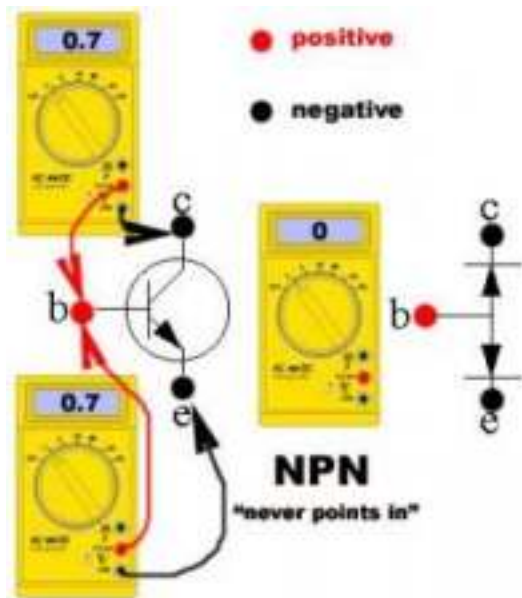
### **Transistor Tester Procedure**

The DMM or digital multimeter is one of the most common and useful items of test equipment. It is used to test the base to emitter and base to collector PN junction of a BJT.

## Procedure of a Transistor Tester Using a Digital Multimeter

### Transistor Tester Using a Digital Multimeter

A digital multimeter is used to test the base to emitter and base to collector PN junction of the BJT. By using this test, you can also identify the polarity of an unknown device. PNP and NPN transistor can be checked using the digital multimeter.



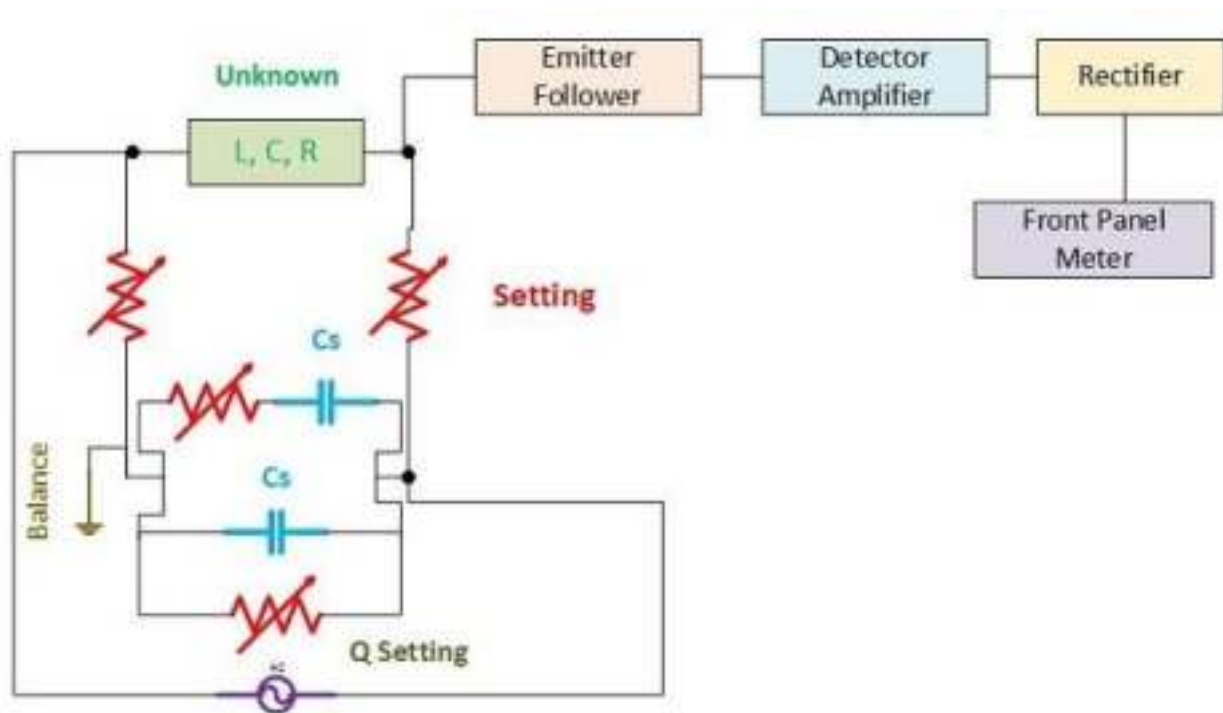
The digital multimeter consists of two leads: black and red. Connect the red (positive) lead to the base terminal of the PNP transistor, and the black (negative) lead to the emitter or base terminal of the transistor. The voltage of a healthy transistor should be 0.7V, and the measurement across the emitter collector should read 0.0V. If the measured voltage is around 1.8V, then the transistor will be dead.

Similarly, connect the black lead (negative) to the base terminal of the NPN transistor, and red lead (positive) to the emitter or collector terminal of the transistor. The voltage of a healthy transistor should be 0.7V, and the measurement across the emitter collector should read 0.0V. If the measured voltage is around 1.8V, then the transistor will be dead.

## 6.3 LCR Bridge

A simple bridge for the measurement of resistance, capacitance and inductance may be constructed with four resistance decades in one arm, and binding post terminals to which external resistors or capacitors may be connected, to complete the other arms. Such a skeleton arrangement is useful in the laboratory, since it permits the operator to set up a number of different bridge circuits simply by plugging standards and unknown units into the proper terminals.

The schematic circuit diagram of a skeleton type bridge and its accessories for the measurement of R, L and C



**Block Diagram of LCR meter**

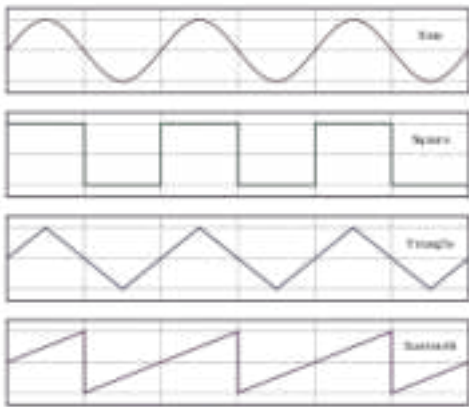
### **LCR meter Advantages**

Following are the advantages of LCR meter:

- User friendly to operate.
- It measures passive components with minimal of errors.
- This instruments are very easy in calibration.
- There are many companies which manufactures the LCR meter and hence more features and options are available for user to purchase.

### **6.4 Function generator**

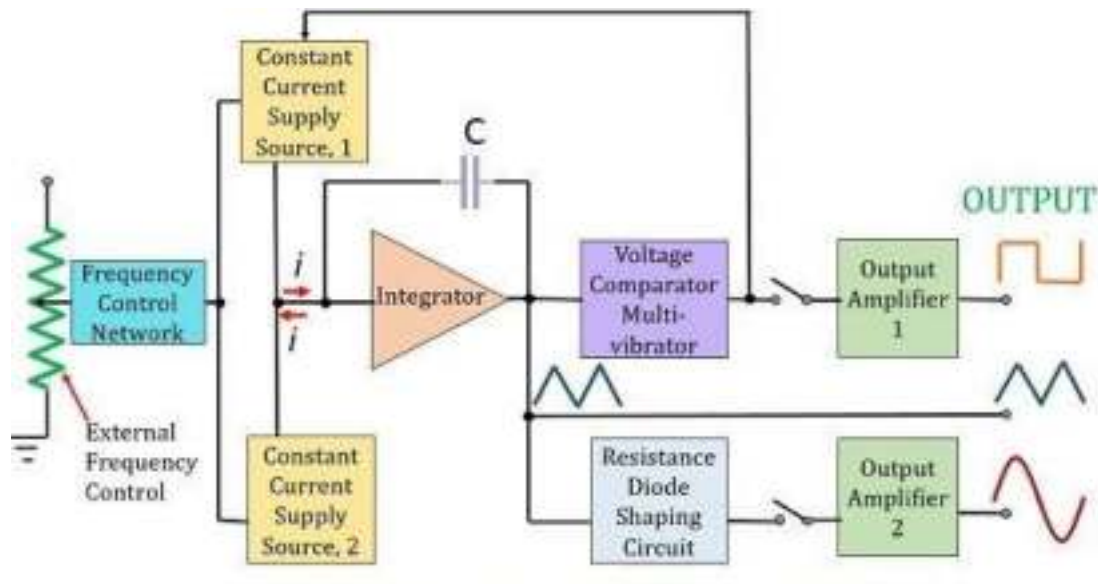
Function Generator is basically a signal generator that produces different types of waveforms at the output. It has the ability to produce waveforms such as sine wave, square wave, a triangular wave, sawtooth wave etc. An adjustable frequency range is provided by the function generator which is in the range of some Hz to several 100 KHz.



Function Generator is a versatile instrument as an extensive variety of frequencies and waveforms are produced by it. The various waveforms generated by the function generator are suitable for various applications. It provides adjustment of wave shape, frequency, magnitude and offset but requires a load connected before adjustment.

This instrument not only varies the characteristics of the waveform but also has the capability to add a dc offset to the signal. Mostly these are only able to operate at low frequency but some costly models can also be operated at the higher frequency.

## Block Diagram and Working of Function Generator



The figure below shows the block diagram of the function generator-

A frequency control network used here whose frequency is controlled by the variation in the magnitude of current. The current sources 1 and 2 drive the integrator.

By using Function Generator, we can have a wide variety of waveforms whose frequency changes from 0.01 Hz to 100 KHz. The two current sources are regulated by the frequency controlled voltage.

## Unit-7

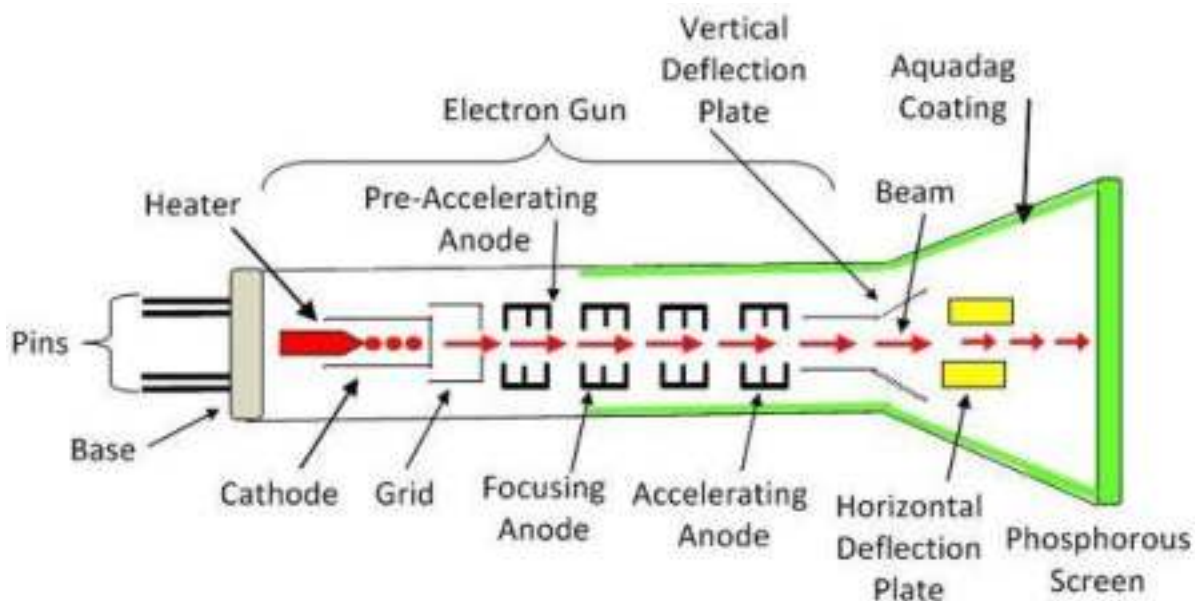
### Cathode Ray Oscilloscope

#### 7.1 Construction and working of Cathode Ray Tube (CRT)

The CRT is a display screen which produces images in the form of the video signal. It is a type of vacuum tube which displays images when the electron beam through electron guns strikes on the phosphorescent surface. In other words, the CRT generates the beams, accelerates it at high velocity and deflects it for creating the images on the phosphorous screen so that the beam becomes visible.

##### Working of CRT

The working of CRT depends on the movement of electrons beams. The electron guns generate sharply focused electrons which are accelerated at high voltage. This high-velocity electron beam when strikes on the fluorescent screen creates luminous spot.



After exiting from the electron gun, the beam passes through the pairs of electrostatic deflection plate. These plates deflected the beams when the voltage applied across it. The one pair of plate moves the beam upward and the second pair of plate moves the beam from one side to another. The horizontal and vertical

movement of the electron are independent of each other, and hence the electron beam positioned anywhere on the screen.

The working parts of a CRT are enclosed in a vacuum glass envelope so that the emitted electron can easily move freely from one end of the tube to the other.

The main parts of CRT are:-

- 1. Electron gun**
- 2. Deflection system**
- 3. Fluorescent screen**
- 4. Glass tube or envelope**
- 5. Base**

### **ELECTRON GUN**

- 1.** The electron gun section of the cathode ray tube provides a sharply focused electron beam directed towards the fluorescent coated screen.
- 2.** This section starts from thermally heated cathode emitting the electrons
- 3.** The control grid is given negative potential with respect to cathode.
- 4.** This grid controls the number of electrons in the beam going to the screen.
- 5.** The light emitted is usually of the green colour

### **DEFLECTION SYSTEM**

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

### **FLUORESCENT SCREEN**

- 1.** The light produced by the screen does not disappear immediately when bombardment by electrons ceases i.e., when the signal becomes zero.
- 2.** The time period for which the trace remains on the screen after the signal becomes zero is known as "persistence or fluorescent."

3. The persistence may be as short as few microsecond or as long as tens of seconds or even minutes.

4. Medium persistence traces are mostly used for general purpose applications. Long persistence traces are used in the study of transients. Long persistence helps in the study of transients since the trace is still seen on the screen after the transients has disappeared.

## **GLASS TUBE**

1. All the components of a CRT are enclosed in an evacuated glass tube called envelope

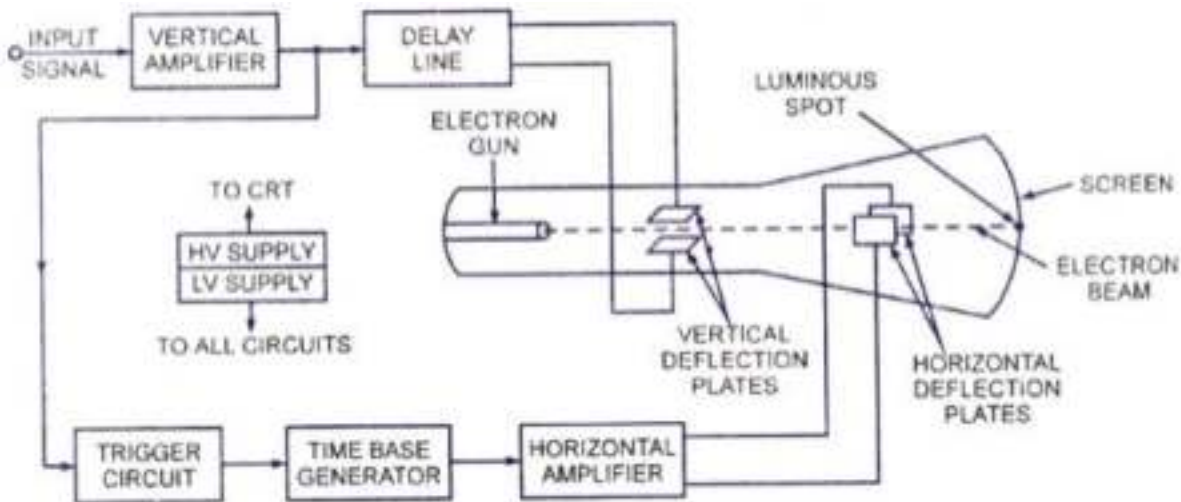
2. This allows the emitted electrons to move about freely from one end of the tube to the other end.

## **BASE**

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

## **7.2 Block diagram, description of a basic CRO and triggered sweep oscilloscope, front panel controls**

The cathode-ray oscilloscope (CRO) is a common laboratory instrument that provides accurate time and amplitude measurements of voltage signals over a wide range of frequencies. Its reliability, stability, and ease of operation makes it suitable as a general purpose laboratory instrument. Figure shows the basic block diagram of a general purpose CR oscilloscope.



**Block diagram CRO**

A general purpose oscilloscope consists of the following parts:

1. Cathode ray tube
2. Vertical amplifier
3. Delay line
4. Time base generator
5. Horizontal amplifier
6. Trigger circuit
7. Power supply

**Cathode Ray Tube** - It is the heart of the oscilloscope. When the electrons emitted by the electron gun strikes the phosphor screen, a visual signal is displayed on the CRT.

**Vertical Amplifier** - The input signals are amplified by the vertical amplifier. Usually, the vertical amplifier is a wide band amplifier which passes the entire band of frequencies.

**Delay Line** - As the name suggests, this circuit is used to delay the signal for a period of time in the vertical section of CRT. The input signal is not applied

directly to the vertical plates because the part of the signal gets lost, when the delay time is not used. Therefore, the input signal is delayed by a period of time.

**Time Base (Sweep) Generator** - Time base circuit uses a uni-junction transistor, which is used to produce the sweep. The saw tooth voltage produced by the time base circuit is required to deflect the beam in the horizontal section. The spot is deflected by the saw tooth voltage at a constant time dependent rate.

**Horizontal Amplifier** - The saw tooth voltage produced by the time base circuit is amplified by the horizontal amplifier before it is applied to horizontal deflection plates.

**Trigger Circuit** - The signals which are used to activate the trigger circuit are converted to trigger pulses for the precision sweep operation whose amplitude is uniform. Hence input signal and the sweep frequency can be synchronized.

**Power supply** - The voltages required by CRT, horizontal amplifier, and vertical amplifier are provided by the power supply block. It is classified into two types -

- (1) Negative high voltage supply
- (2) Positive low voltage supply

The voltage of negative high voltage supply is from -1000V to -1500V. The range of positive voltage supply is from 300V to 400V.

### **Applications of CRO**

- Voltage measurement
- Current measurement
- Examination of waveform
- Measurement of phase and frequency

### **Uses of CRO**

In laboratory, the CRO can be used as

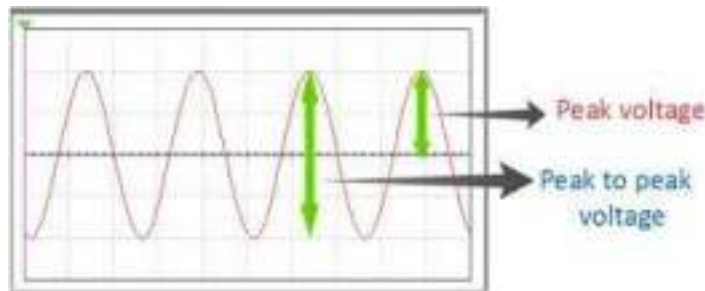
- It can display different types of waveforms
- It can measure short time interval
- In voltmeter, it can measure potential difference

## 7.4 Measurement of voltage, current, frequency, time period and phase using CRO

### Voltage Measurement

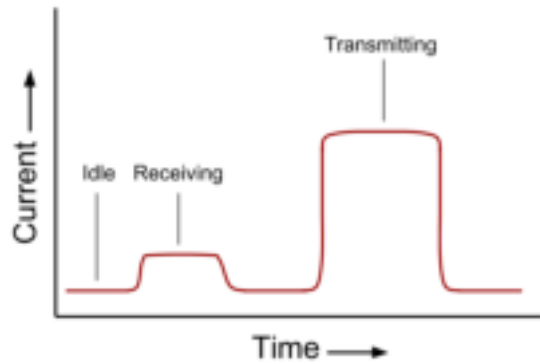
The oscilloscope is mainly voltage oriented device or we can say that it is a voltage measuring device. Voltage, current and resistance all are internally related to each other.

Just measure the voltage, rest of the values is obtained by calculation. Voltage is the amount of electric potential between two points in a circuit. It is measured from peak-to-peak amplitude which measures the absolute difference between the maximum point of signal and its minimum point of the signal. The scope displays exactly the maximum and minimum voltage of the signal received. After measuring all high and low voltage points, scope calculates the average of the minimum and maximum voltage. But you must be careful to mention which voltage you mean. Normally, oscilloscope has fixed input range, but this can be easily increased with the use of simple potential divider circuit.



### Current Measurement

Electrical current cannot be measured directly by an oscilloscope. However, it could be measured indirectly within scope by attaching probes or resistors. Resistor measures the voltage across the points and then substituting the value of voltage and resistance in Ohm's law and calculates the value of electrical current. Another easy way to measure current is to use a clamp-on current probe with an oscilloscope.



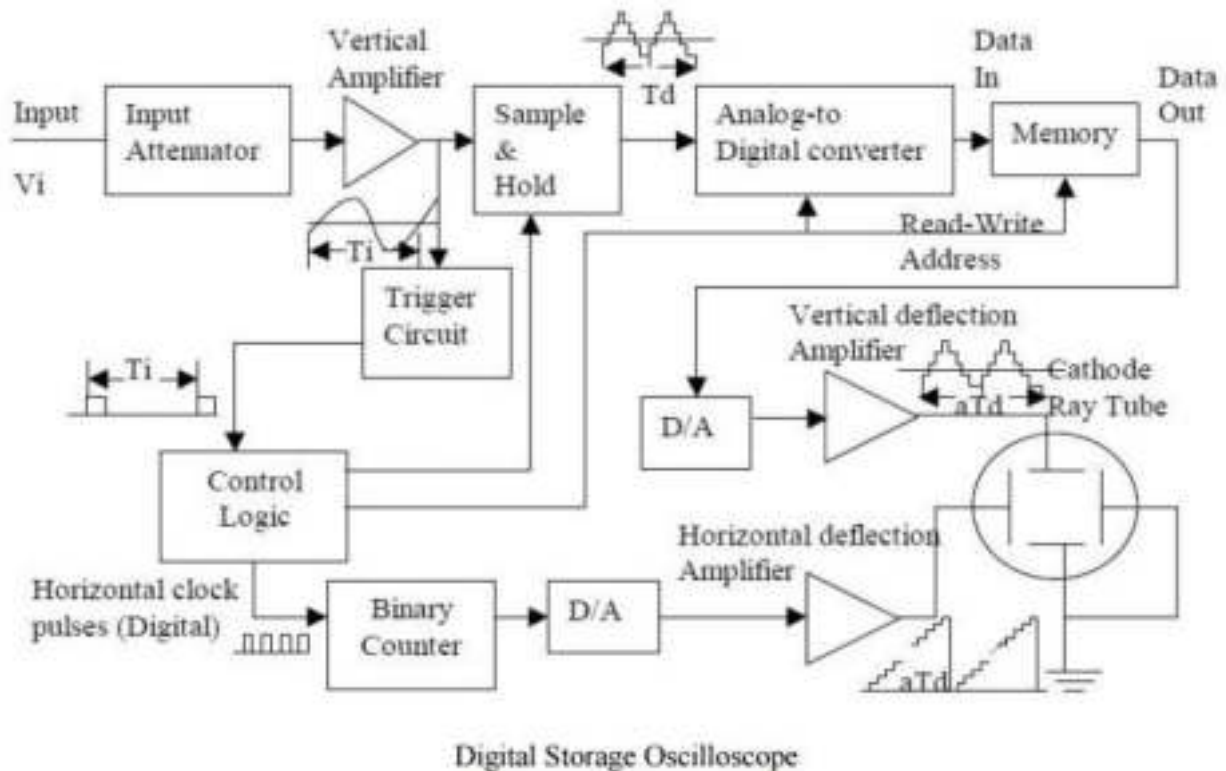
## Frequency Measurement

Frequency can be measured on an oscilloscope by investigating the frequency spectrum of a signal on the screen and making a small calculation. Frequency is defined as the several times a cycle of an observed wave takes up in a second. The maximum frequency of a scope can measure may vary but it always in the 100's of MHz range. To check the performance of response of signals in a circuit, scope measures the rise and fall time of the wave.

### 7.5 Digital storage oscilloscope (DSO): block diagram and working principle

Digital Storage Oscilloscope (DSO) is used to limit these limitations. In DSO, the waveform to be stored is digitized, stored in a digital memory, and retrieved for display on the storage oscilloscope.

Below drawn is the block diagram of a DSO. It consists of data acquisition, storage, and data display blocks.



## Working –

Digital storage oscilloscopes work in various modes which are discussed below.

- 1. Roll Mode** – It is the most basic mode of operation which is similar to that of a general purpose CRO. When an input is applied, its trace is displayed on the screen. A user can use this mode to keep an eye on the waveform and its various characteristics.
- 2. Refresh Mode** – It is used when the sample rate of a waveform becomes too high, and when the waveform of interest is repetitive or nearly so. The DSO produces a stale, triggered display with a higher sweep time.
- 3. Single Shot Mode** – The DSO is in an inactive state in this mode, displaying the last trace captured, until a given sequence of events take place.
- 4. Equivalent Time Mode** – It basically arranges the ADC to work on limited sweeps, so as to allow particular signals to sync properly and give out a clearer trace.

Additionally, there are three acquisition modes in a DSO, which are explained briefly below - **Sample** - In this acquisition mode, the oscilloscope samples the

signal in evenly spaced intervals to construct the waveform. This mode accurately represents signals most of the time.

**Peak Detect** - In this acquisition mode, the oscilloscope finds the highest and lowest values of the input signal over each sample interval and uses these values to display the waveform. (to display narrow pulses, while noise can be higher in this mode)

**Average** - In this acquisition mode, the oscilloscope acquires several waveforms, averages them, and displays the resulting waveform. (Used to reduce random noise).

Working of a DSO is similar to that of a CRO, save for the involvement of memory, as is described below.

- When the memory is full, the next data point from the ADC is stored in the first memory location writing over the old data. The data acquisition and the storage process continue till the control circuit receives a trigger signal from either the input waveform or an external trigger source. When the triggering occurs, the system stops and enters into the display mode of operation in which all or some part of the memory data is repetitively displayed on the cathode ray tube.
- In display operation, two DACs are used which give horizontal and vertical deflection voltage for the CRT. Data from the memory gives the vertical deflection of the electron beam, while the time base counter gives the horizontal deflection in the form of staircase sweep signal. The screen display consists of discrete dots representing the various data points, but the number of dots is so large that they tend to blend together and appear to be a smooth continuous waveform. The display operation ends when the operator presses a front-panel button and commands the digital storage oscilloscope to begin a new data acquisition cycle.

### **Applications of DSO –**

1. Take cursor and pulse width readings
2. Measuring rise time and propagation delay
3. Implementing math functions like subtraction and addition

4. Acting as a simple signal tracer, a DSO enables technicians to probe electronic device's individual connections and components, to determine the malfunctioning part.
5. In measuring the functions of the individual component of the device, the DSO locates where an expected signal is incorrect or absent.
6. The DSO can also measure components' minor variations in operations and alert the technician of the need for fine-tuning or replacement.
7. To prevent erroneous replacement of parts, the DSO also helps technicians identify the parts that are still working.

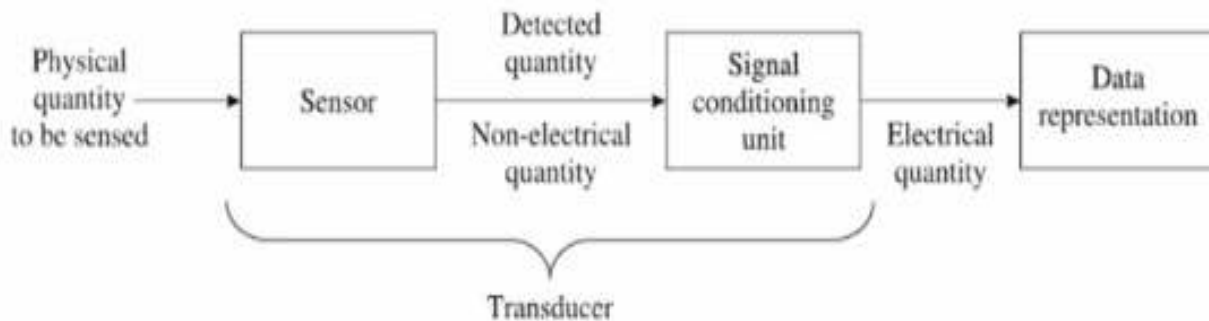
## Chapter-1

### Introduction to Transducer

**Transducer:** A **transducer** is a device that converts energy from one form to another.

Before understanding what a transducer is or diving into the different types of Transducers, consider the following setup of a measuring system. In this block diagram of a simple measuring system, there are three basic elements:

- Sensor
- Signal Conditioning Unit
- Data Representing Device



#### Sensor

A Sensor is a device that is used to detect changes in any physical quantity like Temperature, Speed, Flow, Level, Pressure, etc. Any changes in the input quantity will be detected by a Sensor and reflected as changes in output quantity.

Both the input and output quantities of a Sensor are Physical i.e. non-electrical in nature.

#### Signal Conditioning Unit

The non-electrical output quantity of the Sensor makes it inconvenient to further process it. Hence, the Signal Conditioning Unit is used to convert the physical output (or non-electrical output) of the sensor to an electrical quantity.

Some of the best known Signal conditioning units are:

- Analog to Digital Converters
- Amplifiers
- Filters
- Rectifiers



- Modulators

## Data Representation Device

A Data representation device is used to present the measured output to the observer. This can be anything like

- A Scale
- An LCD Display
- A Signal Recorder

## Transducer

In the above example, consider a Strain Gauge as the Sensor. Any changes in the strain will reflect as changes in its resistance. Now, in order to convert this change in resistance into equivalent voltages, you can use a simple Wheatstone Bridge circuit, which acts as the Signal Conditioning Unit.

The combination of Strain Gauge (Sensor) and Wheatstone Bridge (Signal Conditioning Unit) is Known as a Transducer.

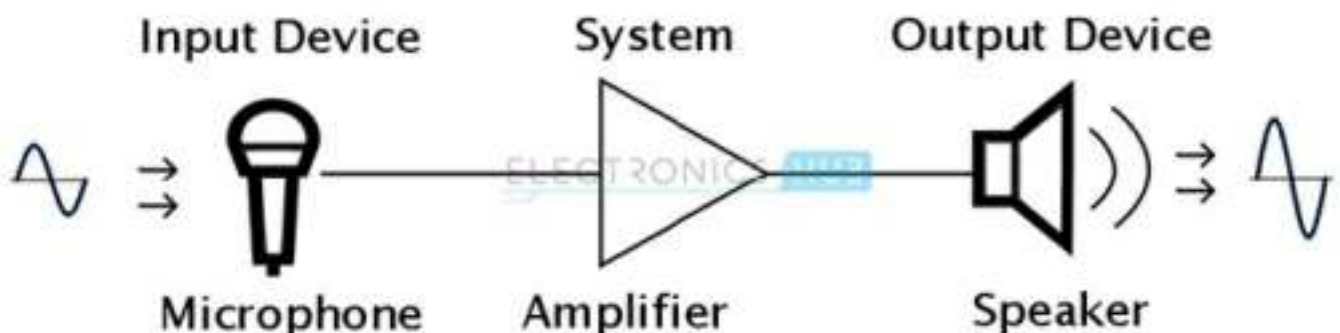
Generally speaking, a Transducer is a device that converts one form of energy into another by the principle of Transduction. Usually, a signal in one form of energy is converted to a signal in another form by a Transducer.

From the above example, a Transducer is a device that converts a Physical Quantity into an Electrical Quantity.

## Sensors and Actuators

From the above definition, actually, both Sensors, devices that responds to a physical quantity with a signal and Actuators, devices that respond to signals with physical movement (or similar action) can be considered as Transducers.

For example, a Microphone is a Sensor, which converts sound waves into electrical signals and a Loudspeaker is an Actuator, which converts electrical signals into audio signals.



Both Microphone and Loudspeaker are Transducers in the sense that a microphone converts sound energy into electrical energy and a loud speaker converts electrical energy into sound energy.

### **Classification of Transducers:**

There are several ways in which you can classify transducers that include but not limited to the role of the transducer, structure of the transducer or the phenomena of their working.

It is easy to classify transducers as Input Transducers or Output Transducers, if they are treated as simple signal converters. Input Transducers measure non-electrical quantities and convert them into electrical quantities.

Output Transducers on the other hand, work in the opposite way i.e. their input signals are electrical and their output signals are non-electrical or physical like force, displacement, torque, pressure etc.

Depending on the principle of operation, transducers can also be classified into mechanical, thermal, electrical, etc.

Let us see the classification of transducers based on the following three ways:

- Physical Effect
- Physical Quantity
- Source of Energy

### **Classification based on Physical Effect**

The first classification of Transducers is based on the physical effect engaged to convert the physical quantity to electrical quantity. An example, is the change in resistance (physical quantity) of a copper element in proportion to the change in temperature.

The following physical effects are generally used:

- Variation in Resistance
- Variation in Inductance
- Variation in Capacitance
- Hall Effect
- Piezoelectric Effect

### **Classification based on Physical Quantity**

The second classification of Transducers is based on the physical quantity converted i.e. the end use of the transducer after the conversion. For example, a Pressure Transducer is a



transducer that converts pressure into electrical signal.

Following is small list of transducers classified based on the physical quantity and corresponding examples

- Temperature Transducer – Thermocouple
- Pressure Transducer – Bourdon Gauge
- Displacement Transducer – LVDT (Linear Variable Differential Transformer)
- Level Transducer – Torque Tube
- Flow Transducer – Flow Meter
- Force Transducer – Dynamometer
- Acceleration Transducer – accelerometer

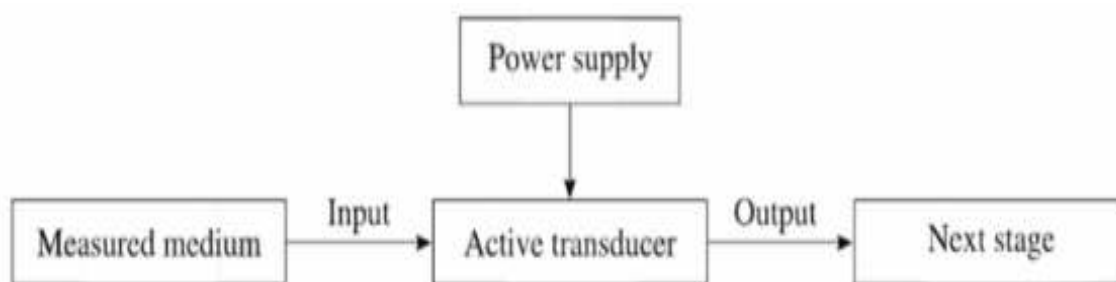
### Classification based on Source of Energy

Transducers are also classified based on the source of energy. Under this category, there usually two types of transducers:

- Active Transducers
- Passive Transducers

### Active Transducers

In Active Transducers, the energy from the input is used as a control signal in the process of transferring energy from power supply to proportional output.



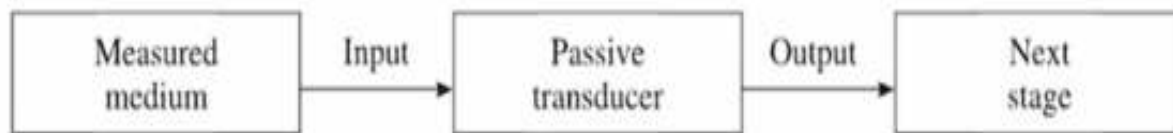
For example, a Strain Gauge is an Active Transducer, in which the strain is converted into resistance. But since the energy from the strained element is very small, the energy for the output is provided by an external power supply.

### Passive Transducers

In Passive Transducers, the energy from the input is directly converted into the output. For example, a Thermocouple is a passive transducer, where the heat energy, which is absorbed



from input, is converted into electrical signals (voltage).



## Different Types of Transducers

Basically, the two different types of Transducers are Mechanical Transducers and Electrical Transducers. Mechanical Transducers are those which responds to changes in physical quantities or condition with mechanical quantity. If the physical quantity is converted to an electrical quantity, then the transducers are Electrical Transducers.

### Mechanical Transducers

As mentioned earlier, mechanical transducers are a set of primary sensing elements that respond to changes in a physical quantity with a mechanical output. As an example, a Bimetallic Strip is a mechanical Transducer, which reacts to changes in temperature and responds with mechanical displacement. The mechanical transducers are differentiated from electrical transducers as their output signals are mechanical.

The output mechanical quantity can be anything like displacement, force (or torque), pressure and strain. For any measuring quantity, there can be both mechanical and electrical transducers.

For example, we have seen Bimetallic Strip, which is a mechanical transducer and is used to react to changes in temperature. In contrast, a Resistance Thermometer, also reacts to changes in temperature, but the response is a change in resistance of the element. Hence, it is an electrical transducer.

The following table shows a small list of mechanical transducers for measuring different quantities and responds with mechanical signal.

| <i>Quantity to be Measured</i> | <i>Mechanical Transducer</i> | <i>Type of Output Signal (Mechanical)</i> |
|--------------------------------|------------------------------|-------------------------------------------|
| Temperature                    | Bimetallic Strip             | Displacement and Force                    |
|                                | Fluid Expansion              | Displacement and Force                    |
|                                | Ring Balance Manometer       | Displacement                              |
| Pressure                       | Metallic Diaphragms          | Displacement and Strain                   |
|                                | Capsules and Bellows         | Displacement                              |
|                                | Membranes                    | Displacement                              |



|              |                          |                                |
|--------------|--------------------------|--------------------------------|
| Force        | Spring Balance           | Displacement and Strain        |
|              | Hydraulic Load Cell      | Pressure                       |
|              | Column Load Cell         | Displacement and Strain        |
| Torque       | Dynamometer              | Force and Strain               |
|              | Gyroscope                | Displacement                   |
|              | Spiral Springs           | Displacement                   |
| Flow Rate    | Torsion Bar              | Displacement and Strain        |
|              | Flow Obstruction Element | Strain and Pressure            |
|              | Pitot Tube               | Pressure                       |
| Liquid Level | Manometer                | Displacement                   |
|              | Float Elements           | Displacement, Force and Strain |

## Electrical Transducers

As mentioned earlier, electrical transducers are those that respond to changes in physical quantities with electrical outputs. Electrical Transducers are further divided into Passive Electrical Transducers and Active Electrical Transducers.

The following table lists out a few electrical transducers (both passive and active).

|                                      |                        |                                     |
|--------------------------------------|------------------------|-------------------------------------|
| Passive<br>Electrical<br>Transducers | Resistive Transducers  | Resistance Thermometers             |
|                                      |                        | Resistive Displacement Transducers  |
|                                      |                        | Resistive Strain Transducers        |
|                                      |                        | Resistive Pressure Transducers      |
|                                      |                        | Resistive Moisture Transducers      |
|                                      | Capacitive Transducers | Capacitive Moisture Transducers     |
|                                      |                        | Capacitive Displacement Transducers |
|                                      |                        | Capacitive Thickness Transducers    |
|                                      | Inductive Transducers  | Inductive Displacement Transducers  |
|                                      |                        | Inductive Thickness Transducers     |



Active  
Electrical  
Transducers

Photoelectric Transducers

Piezoelectric Transducers

Magnetostrictive Transducers

Electromechanical  
Transducers

Ionization Transducers

Electrochemical Transducers

Hall-Effect Transducers

Eddy-Current Inductive Transducers

Moving core Inductive Transducers

Photoconductive Transducers

Photoemissive Transducers

Photovoltaic Force Transducers

Piezoelectric Strain Transducers

Piezoelectric Acceleration Transducers

Piezoelectric Pressure Transducers

Piezoelectric Torque Transducers

Piezoelectric Force Transducers

Magnetostrictive Acceleration Transducers

Magnetostrictive Force Transducers

Magnetostrictive Torsion Transducers

Tachometers

Electrodynamic Pressure Transducers

Electrodynamic Vibration Transducers

Electromagnetic Flowmeters

Ionization Vacuum Gauge

Ionization Displacement Transducers

Nuclear Radiation Transducers

Radioactive Vacuum Gauge

Radioactive Level Gauge

Radioactive Thickness Gauge



## Thermoelectric Transducers

### Applications of Transducers

#### Electromagnetic

- Antennas
- Hall-Effect Sensors
- Disk Read and Write Heads
- Magnetic Cartridges

#### Electromechanical

- Accelerometers
- Pressure Sensors
- Galvanometers
- LVDT
- Load Cells
- Potentiometers
- MEMS
- Linear and Rotary Motors
- Air Flow Sensors

#### Electrochemical

- Hydrogen Sensors
- Oxygen Sensors
- pH Meters

#### Electroacoustic

- Speakers (Loudspeakers, earphones)
- Microphones
- Ultrasonic Transceivers
- Piezoelectric Crystals



- Sonar
- Tactile Transducers

### Photoelectric

- LED
- Photodiodes
- Photovoltaic Cells
- Laser Diodes
- Photoresistors (LDR)
- Phototransistors
- Incandescent and Fluorescent Lamps

### Thermoelectric

- Thermistors
- Thermocouples
- RTD (Resistance Temperature Detectors)

### Radioacoustic

- Radio Transmitters and Receivers
- G-M Tube (Geiger-Muller Tube)

### Selection criteria of transducer:

The following factors are to be considered while selecting a transducer for further applications,

- **Operating Principle** : The transducers are selected on the basis of operating principle it may be resistive, inductive, capacitive, optical etc.
- **Operating range** : The range of transducer should be appropriate for measurement to get a good resolution.
- **Accuracy** : The accuracy should be as high as possible or as per the measurement.
- **Range** : The transducer can give good result within its specified range, so select transducer as per the operating range.
- **Sensitivity** : The transducer should be more sensitive to produce the output or



sensitivity should be as per requirement.

- o **Loading effect** : The transducer's input impedance should be high and output impedance should be low to avoid loading effect.
- o **Errors** : The error produced by the transducer should be low as possible.
- o **Environmental compatibility** : The transducer should maintain input and output characteristic for the selected environmental condition.



### Characteristics of Transducers

The performance characteristics of a Transducer are key in selecting the best suitable transducer for a particular design. So, it is very important to know the characteristics of transducers for proper selection.

Performance characteristics of transducers can be further classified into two types:

- Static Characteristics
- Dynamic Characteristics

### Static Characteristics

The static characteristics of a transducer is a set of performance criteria that are established through static calibration i.e. description of the quality of measurement by essentially maintaining the measured quantities as constant values of varying very slowly.

Following is a list of some of the important static characteristics of transducers.

- Sensitivity
- Linearity
- Resolution



- Precision (Accuracy)
- Span and Range
- Threshold
- Drift
- Stability
- Responsiveness
- Repeatability
- Input Impedance and Output Impedance

### Dynamic Characteristics

The dynamic characteristics of transducers relate to its performance when the measured quantity is a function of time i.e. it varies rapidly with respect to time.

While static characteristics relate to the performance of a transducer when the measured quantity is essentially constant, the dynamic characteristics relate to dynamic inputs, which means that they are dependent on its own parameters as well as the nature of the input signal.

The following are some dynamic characteristics that may be considered in selection of a transducer.

- Dynamic Error
- Fidelity
- Speed of Response
- Bandwidth

Overall, both static and dynamic characteristics of a Transducer determine its performance and indicate how effectively it can accept desired input signals and reject unwanted inputs.

## Chapter-2

### Resistive Transducer

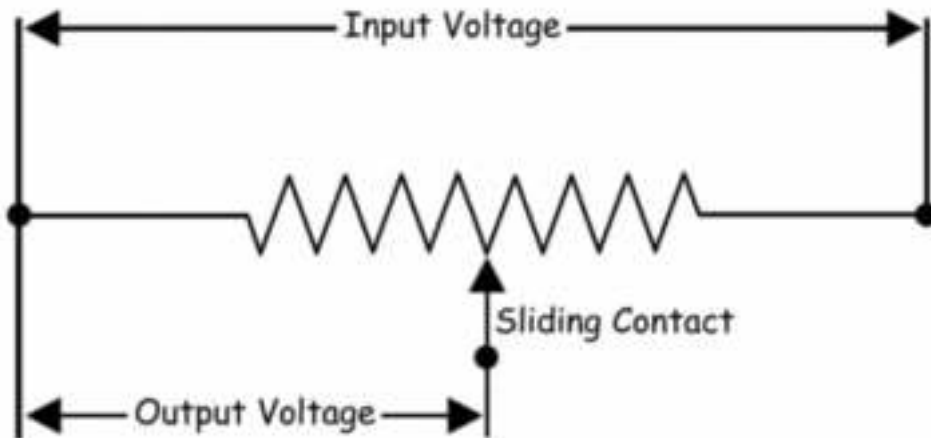
#### What is a Potentiometer?

A **potentiometer** (also known as a **pot** or **pot meter**) is defined as a 3 terminal variable resistor in which the resistance is manually varied to control the flow of electric current. A potentiometer acts as an adjustable voltage divider.

#### How Does a Potentiometer Work?

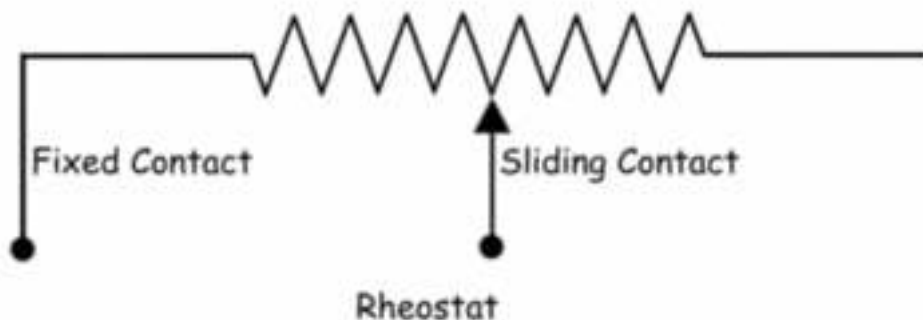


A potentiometer is a passive electronic component. Potentiometers work by varying the position of a sliding contact across a uniform resistance. In a potentiometer, the entire input voltage is applied across the whole length of the resistor, and the output voltage is the voltage drop between the fixed and sliding contact as shown below.

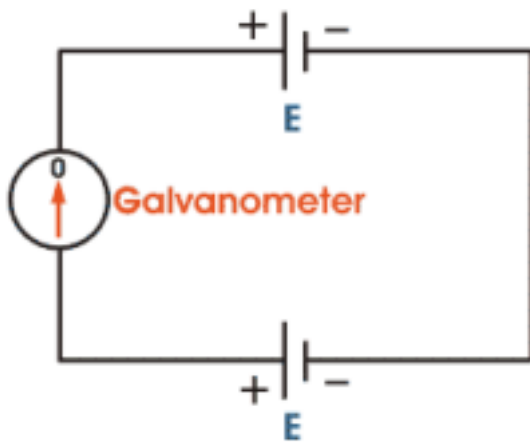


A potentiometer has the two terminals of the input source fixed to the end of the resistor. To adjust the output voltage the sliding contact gets moved along the resistor on the output side.

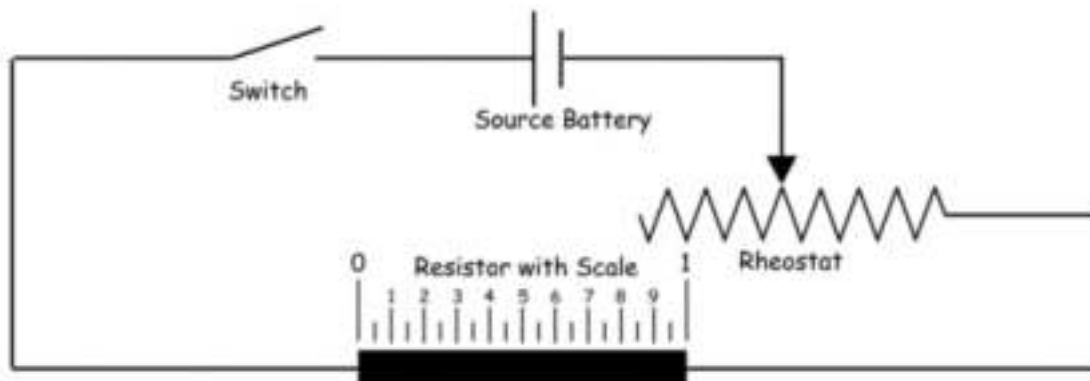
This is different to a rheostat, where here one end is fixed and the sliding terminal is connected to the circuit, as shown below.

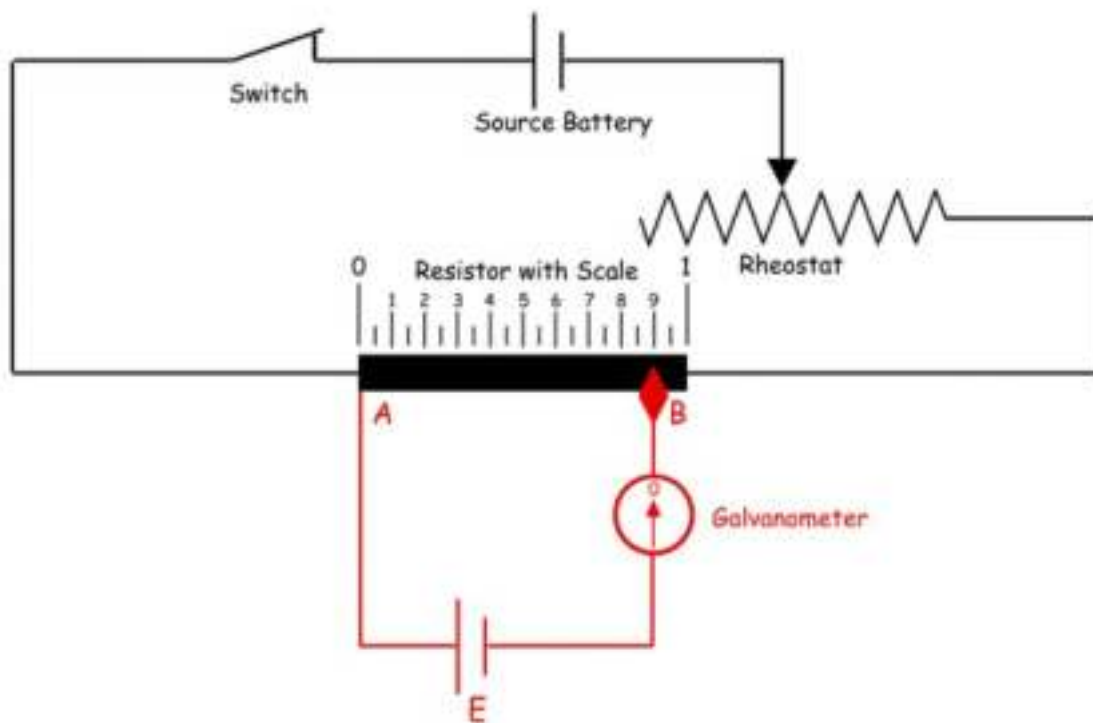


This is a very basic instrument used for comparing the emf of two cells and for calibrating [ammeter](#), voltmeter, and watt-meter. The basic **working principle of a potentiometer** is quite simple. Suppose we have connected two batteries in parallel through a galvanometer. The negative battery terminals are connected together and positive battery terminals are also connected together through a galvanometer as shown in the figure below.



Here, if the electric potential of both battery cells is exactly the same, there is no circulating [current](#) in the circuit and hence the galvanometer shows null deflection. The **working principle of potentiometer** depends upon this phenomenon.





Now let's think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below.

The resistor has the uniform electrical resistance per unit length throughout its length. Hence, the voltage drop per unit length of the resistor is equal throughout its length. Suppose, by adjusting the rheostat we get  $v$  volt voltage drop appearing per unit length of the resistor.

Now, the positive terminal of a standard cell is connected to point A on the resistor and the negative terminal of the same is connected with a galvanometer. The other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above. By adjusting this sliding end, a point like B is found where there is no current through the galvanometer, hence no deflection in the galvanometer.

That means, emf of the standard cell is just balanced by the voltage appearing in the resistor across points A and B. Now if the distance between points A and B is  $L$ , then we can write emf of standard cell  $E = Lv$  volt.

This is how a potentiometer measures the voltage between two points (here between A and B) without taking any current component from the circuit. This is the specialty of a potentiometer, it can measure voltage most accurately.

## Potentiometer Types



There are two main types of potentiometers:

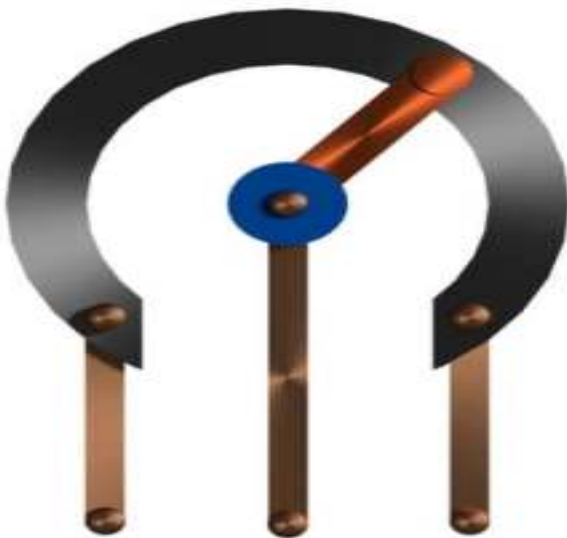
- Rotary potentiometer
- Linear potentiometer

Although the basic constructional features of these potentiometers vary, the working principle of both of these types of potentiometers is the same.

Note that these are types of DC potentiometers – the types of [AC potentiometers](#) are slightly different.

### Rotary Potentiometers

The rotary type potentiometers are used mainly for obtaining adjustable supply voltage to a part of electronic circuits and electrical circuits. The volume controller of a radio transistor is a popular example of a rotary potentiometer where the rotary knob of the potentiometer controls the supply to the amplifier.



This type of potentiometer has two terminal contacts between which a uniform resistance is placed in a semi-circular pattern. The device also has a middle terminal which is connected to the resistance through a sliding contact attached with a rotary knob. By rotating the knob one can move the sliding contact on the semi-circular resistance. The voltage is taken between a resistance end contact and the sliding contact. The potentiometer is also named as the POT in short. POT is also used in substation battery chargers to adjust the charging voltage of a battery. There are many more uses of rotary type potentiometer where smooth voltage control is required.

### Linear Potentiometers

The linear potentiometer is basically the same but the only difference is that here instead of rotary movement the sliding contact gets moved on the resistor linearly. Here two ends of a



straight resistor are connected across the source voltage. A sliding contact can be slide on the resistor through a track attached along with the resistor. The terminal connected to the sliding is connected to one end of the output circuit and one of the terminals of the resistor is connected to the other end of the output circuit.



This type of potentiometer is mainly used to measure the voltage across a branch of a circuit, for measuring the internal resistance of a battery cell, for comparing a battery cell with a standard cell and in our daily life, it is commonly used in the equalizer of music and sound mixing systems.

### Applications of Potentiometer

There are many different uses of a potentiometer. The three main applications of a potentiometer are:

1. Comparing the emf of a battery cell with a standard cell
2. Measuring the internal resistance of a battery cell
3. Measuring the voltage across a branch of a circuit

### What is a Strain Gauge

A **strain gauge** is a resistor used to measure strain on an object. When an external force is applied on an object, due to which there is a deformation occurs in the shape of the object. This deformation in the shape is both compressive or tensile is called strain, and it is

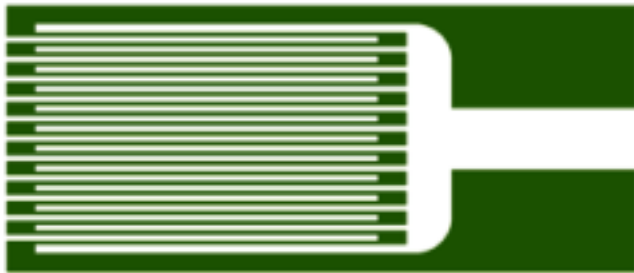


measured by the strain gauge. When an object deforms within the limit of elasticity, either it becomes narrower and longer or it become shorter and broadens. As a result of it, there is a change in resistance end-to-end.

The strain gauge is sensitive to that small changes occur in the geometry of an object. By measuring the change in resistance of an object, the amount of induced stress can be calculated.

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

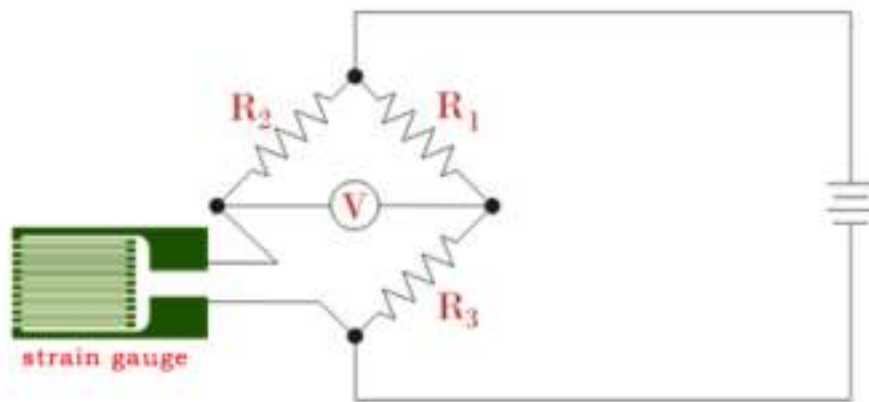
When an object shows physical deformation, its electrical resistance gets change and that change is then measured by gage.



### Strain Gauge Bridge Circuit

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





Quarter-bridge strain gauge circuit

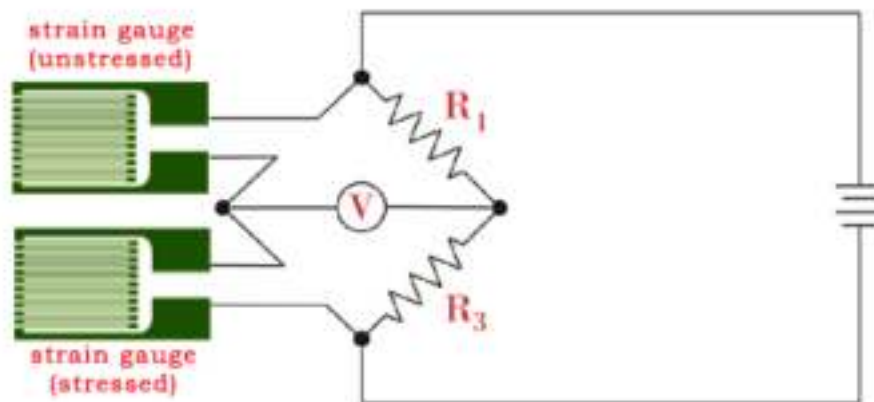
In this circuit,  $R_1$  and  $R_3$  are the ratio arms equal to each other, and  $R_2$  is the rheostat arm has a value equal to the strain gauge resistance. When the gauge is unstrained, the bridge is balanced, and voltmeter shows zero value. As there is a change in resistance of strain gauge, the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

### Variation of Temperature of Strain Gauge

One more factor that affects the resistance of the gauge is temperature. If the temperature is more resistance will be more and if the temperature is less the resistance will be less. This is a common property of all the conductors. We can overcome this problem by using strain gauges that are self-temperature-compensated or by a dummy strain gauge technique.

Most of the strain gauges are made of constantan alloy which cancel out the effect of temperature on the resistance. But some strain gauges are not of an isoelastic alloy. In such cases, dummy gauge is used in the place of  $R_2$  in the quarter bridge strain gauge circuit which acts as a temperature compensation device.

Whenever temperature changes, the resistance will change in the same proportion in the both arms of the rheostat, and the bridge remains in the state of balance. Effect of temperature get nullifies. It is good to keep voltage low so that the self-heating of **strain gauge** could be evaded. Self-heating of gauge depends upon its mechanical behavior.



Quarter-bridge strain gauge circuit  
with temperature compensation

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

### Use of Strain Gauge

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

### Hot Wire Anemometer

**Definition:** The Hot Wire Anemometer is a device used for measuring the velocity and direction of the fluid. This can be done by measuring the heat loss of the wire which is placed in the fluid stream. The wire is heated by electrical current.

The hot wire when placed in the stream of the fluid, in that case, the heat is transferred from wire to fluid, and hence the temperature of wire reduces. The resistance of wire measures the flow rate of the fluid.

The hot wire anemometer is used as a research tool in fluid mechanics. It works on the principle of transfer of heat from high temperature to low temperature.

### Construction of Hot Wire Anemometer

The hot wire anemometer consists two main parts.

1. Conducting wire

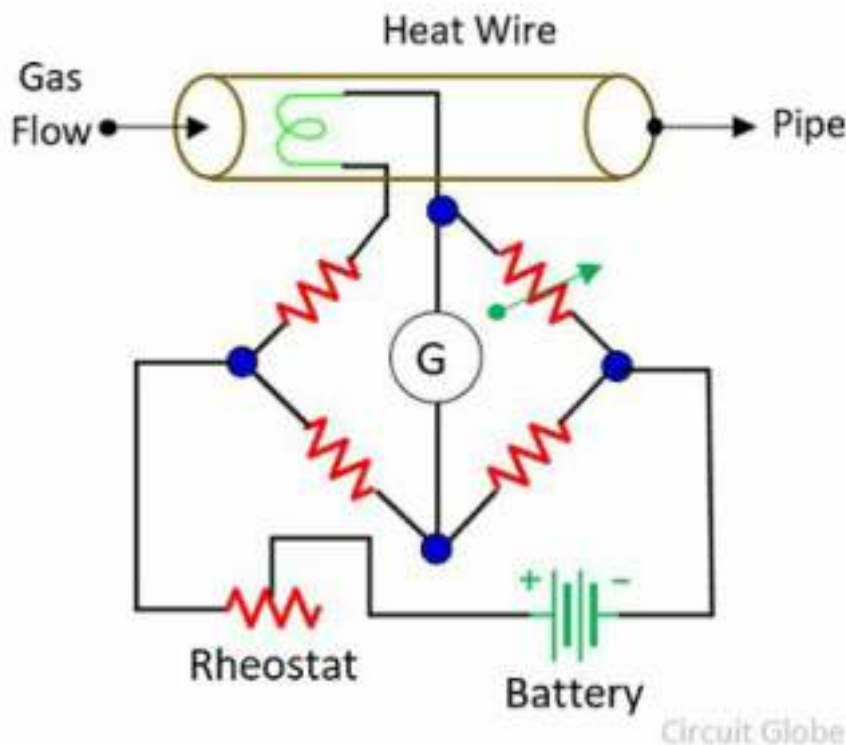


## 2. Wheat stone bridge.

The conducting wire is housed inside the ceramic body. The wires are taken out from the ceramic body and connecting to the Wheatstone bridge. The wheat stone bridge measures the variation of resistance.

### Constant Current Method

In the constant current method, the anemometer is placed in the stream of the fluid whose flow rate needs to be measured. The current of constant magnitude is passed through the wire. The Wheatstone bridge is also kept on the constant voltage.

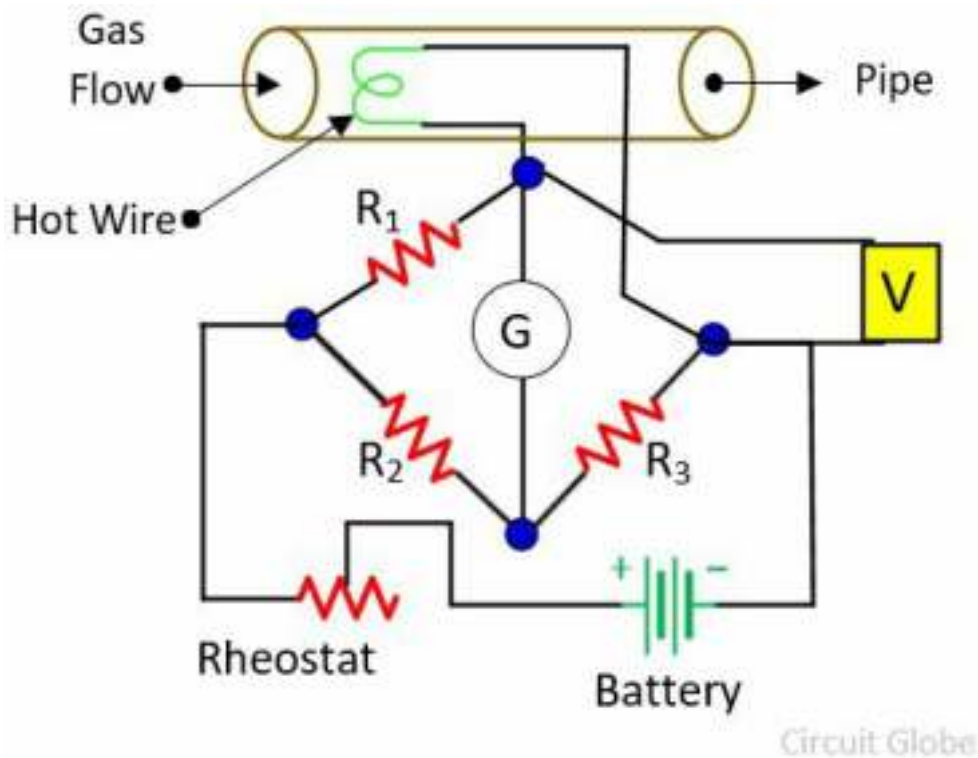


When the wire is kept in the stream of liquid, in that case, the heat is transferred from the wire to the fluid. The heat is directly proportional to the resistance of the wire. If heat reduces, that means the resistance of wire also reduces. The Wheatstone bridge measures the variation in resistance which is equal to the flow rate of the liquid.

### Constant Temperature Method

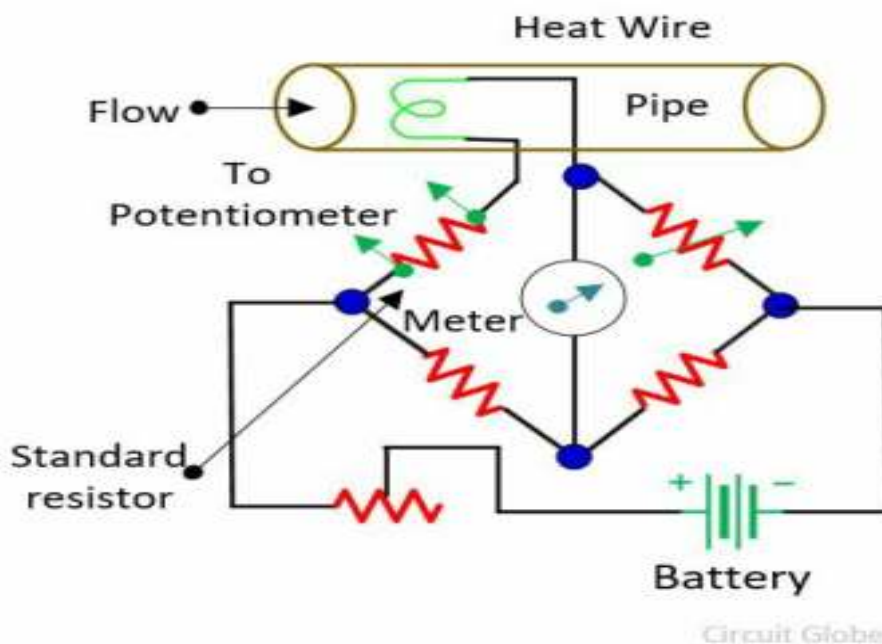
In this arrangement, the wire is heated by the electric current. The hot wire when placed in the fluid stream, the heat transfer from wire to the fluid. Thus, the temperature of the wire changes which also changes their resistance. It works on the principle that the temperature of the wire remains constant. The total current required to bring the wire in the initial condition is equal to the flow rate of the gas.





### Measurement of the rate of a fluid using a Hot Wire Instrument

In hot wire anemometer, the heat transferred electrically to the wire which is placed in the fluid stream. The Wheatstone bridge is used for measuring the temperature of wire regarding their resistance. The temperature of the wire remains constant for measuring the heating current. Thus, the bridge remains balanced.



The standard resistor is connected in series with the heating wire. The current across the

wire is determined by knowing the voltage drop across the resistor. And the value of voltage drop is determined by the potentiometer.

The equation determines the heat loss from the heated wire

$$= a(vp + b)^{1/2} J/s$$

Where,  $v$  – velocity of heat flow,  
 $\rho$  – the density of fluid,

The  $a$  and  $b$  are the constants. Their value depends on the dimension and the physical properties of the fluid and wire.

Suppose  $I$ , is the current of the wire and the  $R$  is their resistance. In equilibrium condition,

Heat generated = Heat Lost

$$I^2 R = a(vp + b)^{1/2}$$

$$v = \frac{(I^2 R / a^2 - b)}{\rho}$$

The resistance and temperature of the instrument are kept constant for measuring the rate of the fluid by measuring the current  $I$ .

### Thermistor

The **Thermistor** is another type of temperature sensor, whose name is a combination of the words THERM-ally sensitive res-ISTOR. A thermistor is a special type of resistor which changes its physical resistance when exposed to changes in temperature.



Thermistor



Thermistors are generally made from ceramic materials such as oxides of nickel, manganese or cobalt coated in glass which makes them easily damaged. Their main advantage over snap-action types is their speed of response to any changes in temperature, accuracy and repeatability.

Most types of thermistor's have a *Negative Temperature Coefficient* of resistance or (*NTC*), that is their resistance value goes DOWN with an increase in the temperature, and of course there are some which have a *Positive Temperature Coefficient*, (*PTC*), in that their resistance value goes UP with an increase in temperature.

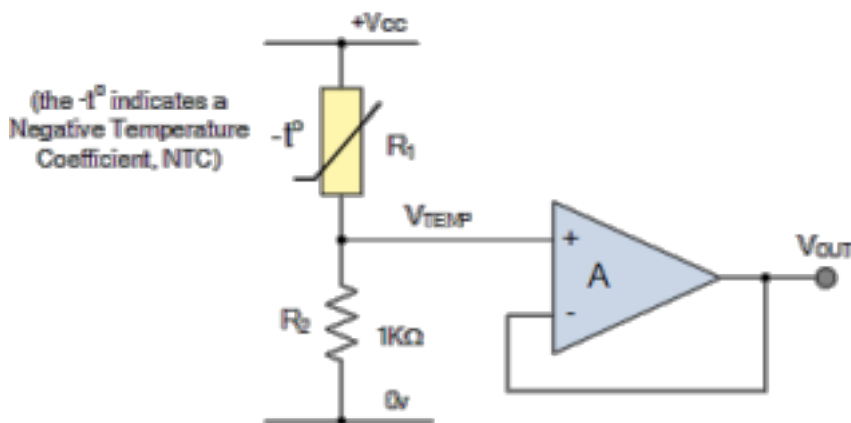
Thermistors are constructed from a ceramic type semiconductor material using metal oxide technology such as manganese, cobalt and nickel, etc. The semiconductor material is generally formed into small pressed discs or balls which are hermetically sealed to give a relatively fast response to any changes in temperature.

Thermistors are rated by their resistive value at room temperature (usually at  $25^{\circ}\text{C}$ ), their time constant (the time to react to the temperature change) and their power rating with respect to the current flowing through them. Like resistors, thermistors are available with resistance values at room temperature from 10's of  $\text{M}\Omega$  down to just a few Ohms, but for sensing purposes those types with values in the kilo-ohms are generally used.

Thermistors are passive resistive devices which means we need to pass a current through it to produce a measurable voltage output. Then thermistors are generally connected in series with a suitable biasing resistor to form a potential divider network and the choice of resistor gives a voltage output at some pre-determined temperature point or value for example:

### Temperature Sensors Example No1

The following thermistor has a resistance value of  $10\text{k}\Omega$  at  $25^{\circ}\text{C}$  and a resistance value of  $100\Omega$  at  $100^{\circ}\text{C}$ . Calculate the voltage drop across the thermistor and hence its output voltage ( $V_{\text{out}}$ ) for both temperatures when connected in series with a  $1\text{k}\Omega$  resistor across a 12v power supply.



At  $25^{\circ}\text{C}$



$$V_{out} = \frac{R_2}{R_1 + R_2} \times V = \frac{1000}{10000 + 1000} \times 12V = 1.09V$$

At 100°C

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V = \frac{1000}{100 + 1000} \times 12V = 10.9V$$

By changing the fixed resistor value of R2 (in our example 1kΩ) to a potentiometer or preset, a voltage output can be obtained at a predetermined temperature set point for example, 5V output at 60°C and by varying the potentiometer a particular output voltage level can be obtained over a wider temperature range.

It needs to be noted however, that thermistor's are non-linear devices and their standard resistance values at room temperature is different between different thermistor's, which is due mainly to the semiconductor materials they are made from. The **Thermistor**, have an exponential change with temperature and therefore have a Beta temperature constant (β) which can be used to calculate its resistance for any given temperature point.

However, when used with a series resistor such as in a voltage divider network or Wheatstone Bridge type arrangement, the current obtained in response to a voltage applied to the divider/bridge network is linear with temperature. Then, the output voltage across the resistor becomes linear with temperature.

### Resistive Temperature Detectors (RTD)

Another type of electrical resistance temperature sensor is the **Resistance Temperature Detector** or **RTD**. RTD's are precision temperature sensors made from high-purity conducting metals such as platinum, copper or nickel wound into a coil and whose electrical resistance changes as a function of temperature, similar to that of the thermistor. Also available are thin-film RTD's. These devices have a thin film of platinum paste is deposited onto a white ceramic substrate.



### A Resistive RTD

Resistive temperature detectors have positive temperature coefficients (PTC) but unlike the thermistor their output is extremely linear producing very accurate measurements of temperature.

However, they have very poor thermal sensitivity, that is a change in temperature only



produces a very small output change for example,  $1\Omega/^{\circ}\text{C}$ .

The more common types of RTD's are made from platinum and are called **Platinum Resistance Thermometer** or **PRT's** with the most commonly available of them all the Pt100 sensor, which has a standard resistance value of  $100\Omega$  at  $0^{\circ}\text{C}$ . The downside is that Platinum is expensive and one of the main disadvantages of this type of device is its cost.

Like the thermistor, RTD's are passive resistive devices and by passing a constant current through the temperature sensor it is possible to obtain an output voltage that increases linearly with temperature. A typical RTD has a base resistance of about  $100\Omega$  at  $0^{\circ}\text{C}$ , increasing to about  $140\Omega$  at  $100^{\circ}\text{C}$  with an operating temperature range of between  $-200$  to  $+600^{\circ}\text{C}$ .

Because the RTD is a resistive device, we need to pass a current through them and monitor the resulting voltage. However, any variation in resistance due to self heat of the resistive wires as the current flows through it,  $I^2R$ , (Ohms Law) causes an error in the readings. To avoid this, the RTD is usually connected into a Wheatstone Bridge network which has additional connecting wires for lead-compensation and/or connection to a constant current source.

### Pick UP

When a transducer mounted in a more complicated device, the transducer becomes a pickup.

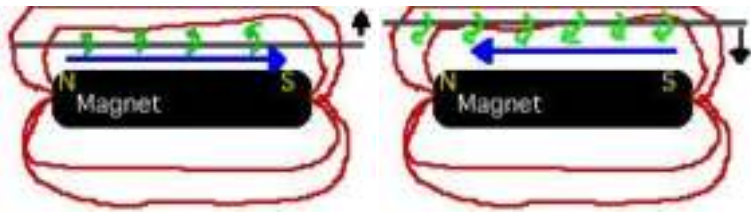
A pickup contains a permanent magnet and magnetic coils. The magnet is placed underneath the metal guitar strings so that when the strings vibrate, they move through the magnetic field.



Drawing of magnetic field around a permanent magnet.

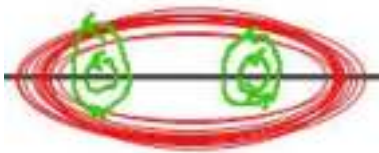
When the metal wire moves through the magnetic field, a current is generated in the wire. This current, in turn, creates a magnetic field surrounding the wire. The flow of the current, and thus the resulting magnetic field, depends on the direction that the string is moving in the magnetic field generated by the magnet. Because the string moves back and forth (just as does a rubber band if you stretch it and pluck it), the magnetic field created by the wire constantly changes direction.





Left image: Drawing of string moving rightward through a magnetic field. Right image: Drawing of string moving leftward through a magnetic field.

Changing magnetic fields induce currents in wires; the changing magnetic field created by the metal guitar string, therefore, creates a current in the magnetic coils that compose the other part of the pickup.



Changing magnetic fields around the guitars pickup.

The current (and voltage) that is produced in the wire coils is transmitted to a speaker system through the circuitry of the guitar; this circuitry is described later in the lab. So now that we know how an electric guitar pickup works, it is time to describe how to build one.

For materials, you need:

- A 4.5 x 2 cm bar magnet
- Two 8 x 11 cm pieces of cardboard
- A large spool of coiling wire; 175 to 200 meters
- Glue (I used wood glue, although the exact type probably doesn't matter too much)
- Packing tape
- A small piece of sand paper

First, glue the magnet into the center of one of the two pieces of cardboard, and glue the other piece of cardboard onto the other side of the magnet so that you have a magnet sandwich.



Left image: Overhead view of the magnet on the cardboard. Right image: Side view of the magnet sandwich.

The magnet need not be perfectly in the center, but it should be fairly close; it's safe to eyeball the location, though. After the magnet has been glued in place and the glue has dried, cut a short slit about 1cm in from a corner, to hold the wire temporarily. Measure out 60 cm or so of wire from the spool, and leave it hanging out of the cardboard piece; put the 60 cm mark in the slot that you just cut and start wrapping the wire around the magnet, between the two pieces of cardboard. If the wire gets tangled in the cardboard, just untangle it and wrap over any entanglements made by excess wire. Keep wrapping until the wire starts to bulge out the side of the cardboard; this should take several hundred loops. When you are done, run the wire back out through the slit, and leave another trailing 60cm.

At this point, feel free to artistically trim the corners of the cardboard; just be very careful not to cut the wire. The wire coil must be continuous; otherwise, it will not work. Also, run packing tape over the wire coiling for protection. If you cut off the slit that you made earlier, make sure to take the wire out of it; you can just tape the wires in place afterward. Your final pickup should look something like this:



Photograph of home-built pickup.

## Chapter 3

### Inductive Transducer

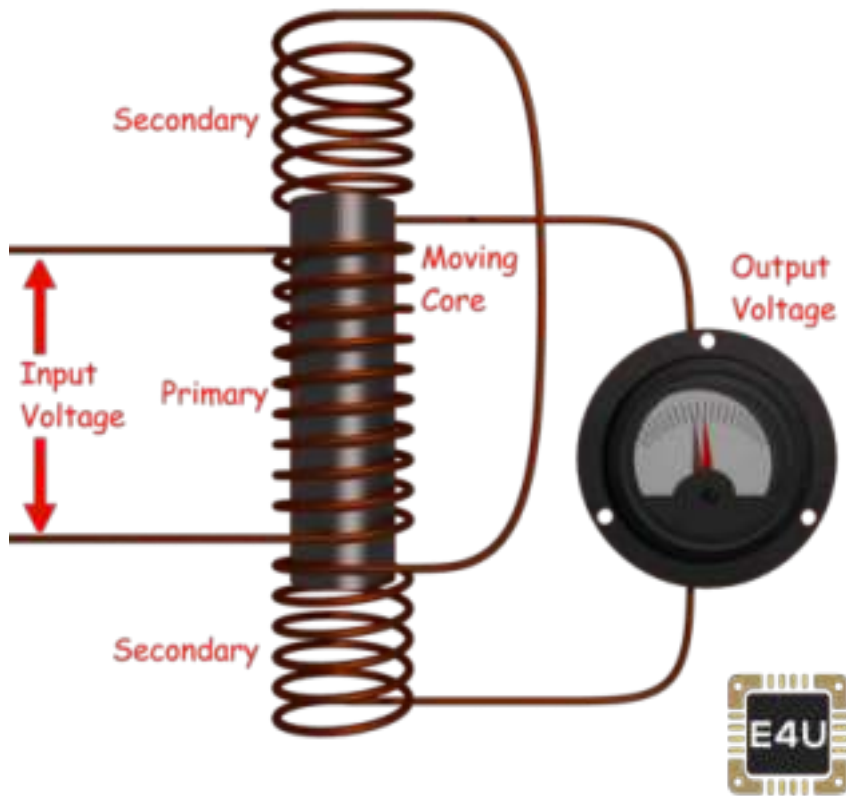
#### Linear Variable Differential Transformer LVDT

##### Definition of LVDT

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



The output across secondary of this transformer is the differential thus it is called so. It is very accurate inductive transducer as compared to other inductive transducers.



## Construction of LVDT

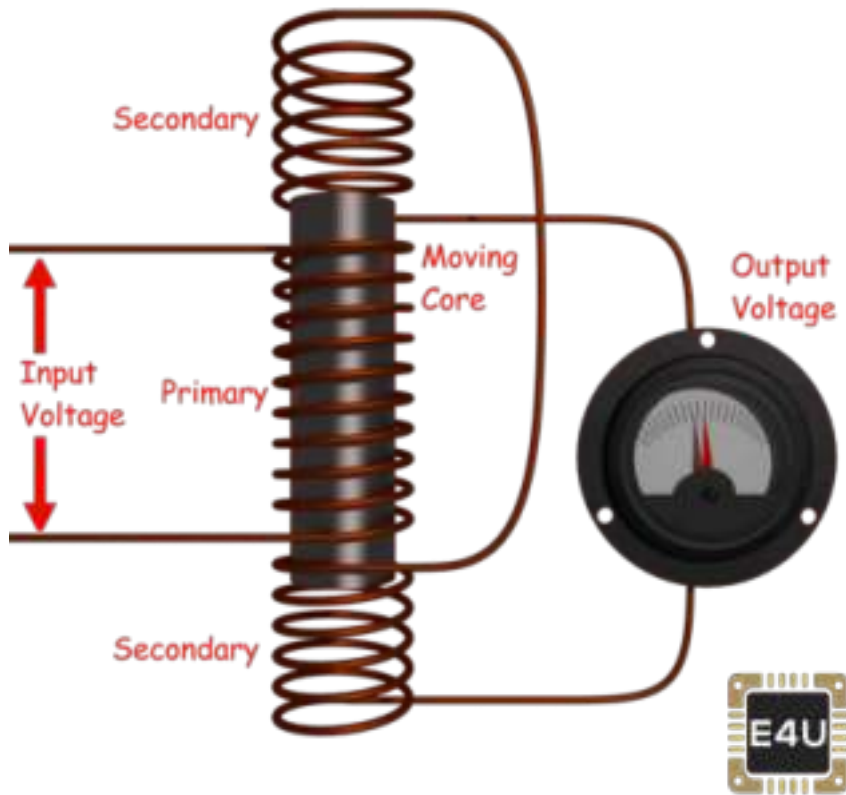
### Main Features of Construction

- The transformer consists of a primary winding  $P$  and two secondary windings  $S_1$  and  $S_2$  wound on a cylindrical former (which is hollow in nature and contains the core).
- Both the secondary windings have an equal number of turns, and we place them on either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside a stainless steel housing because it will provide



electrostatic and electromagnetic shielding.

- The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.

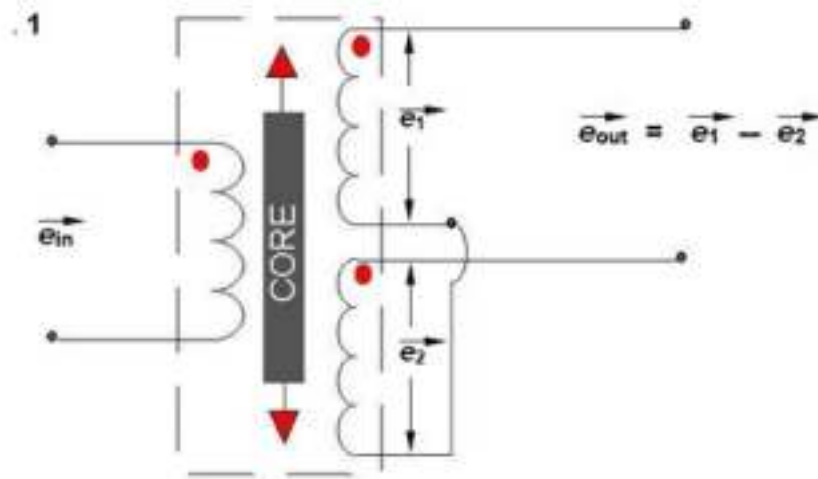


### Principle of Operation and Working

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

$$e_{out} = e_1 - e_2$$

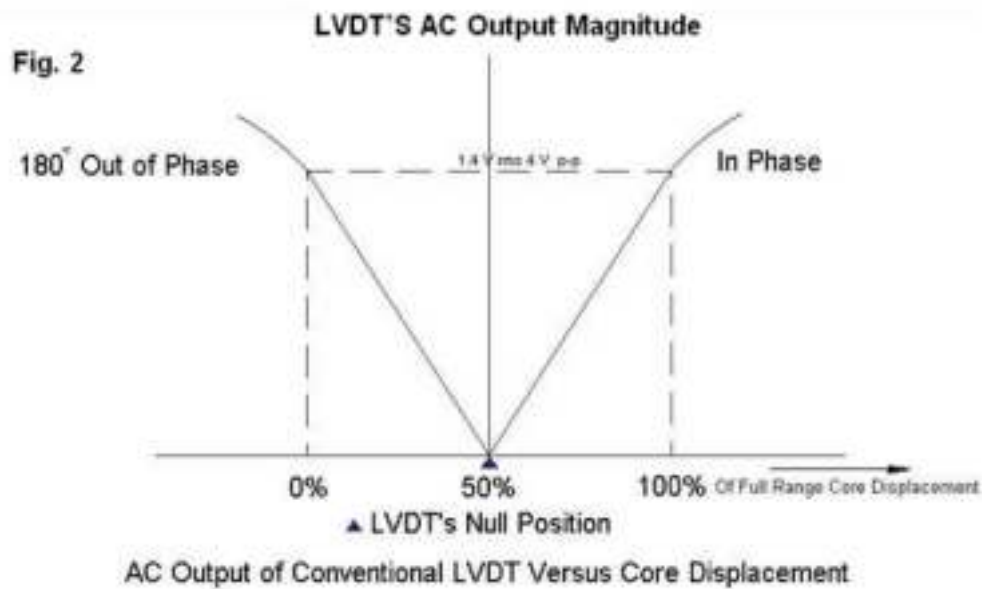
This equation explains the **principle of Operation of LVDT**.



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

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

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



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

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

### Advantages of LVDT

- **High Range** – The LVDTs have a very high range for measurement of displacement. they can be used for measurement of displacements ranging from 1.25 mm to 250 mm
- **No Frictional Losses** – As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as a very accurate device.
- **High Input and High Sensitivity** – The output of LVDT is so high that it doesn't need any amplification. The transducer possesses a high sensitivity which is typically about 40V/mm.
- **Low Hysteresis** – LVDTs show a low hysteresis and hence repeatability is excellent under all conditions
- **Low Power Consumption** – The power is about 1W which is very low as compared to other transducers.
- **Direct Conversion to Electrical Signals** – They convert the linear displacement to electrical voltage which are easy to process



## Disadvantages of LVDT

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

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

## Applications of LVDT

1. We use LVDT in the applications where displacements to be measured are ranging from a fraction of mm to few cms. The LVDT acting as a primary transducer converts the displacement to electrical signal directly.

2. The LVDT can also act as a secondary transducer. E.g. the Bourbon tube which acts as a primary transducer and it converts pressure into linear displacement and then LVDT converts this displacement into an electrical signal which after calibration gives the readings of the pressure of fluid.

## Rotary Variable Differential Transformer (RVDT)

**Definition:** The transformer which senses the angular displacement of the conductor is known as the Rotary Variable Differential Transformer or RVDT. It is the type of electromechanical transducer which gives the linear output proportional to the input angular displacement.

The circuit of RVDT is shown in the figure below. The working of the RVDT is similar to the LVDT. The only difference is that the LVDT uses the soft iron core for measuring the displacement, whereas the RVDT uses the cam shape core rotated between the primary and secondary winding with the help of the shaft.

## Theory of RVDT

The  $E_{S1}$  and the  $E_{S2}$  are the secondary voltage, and it varies with the angular displacement of the shaft.

$$\theta = G \cdot \left( \frac{E_{S1} - E_{S2}}{E_{S1} + E_{S2}} \right)$$

The G is the sensitivity of the RVDT. The secondary voltage is determined by the help of equation shown below.  $E_{S2} = E_{S1} \pm G \cdot \theta$

The difference between  $E_{S1} - E_{S2}$  gives a proportional voltage.



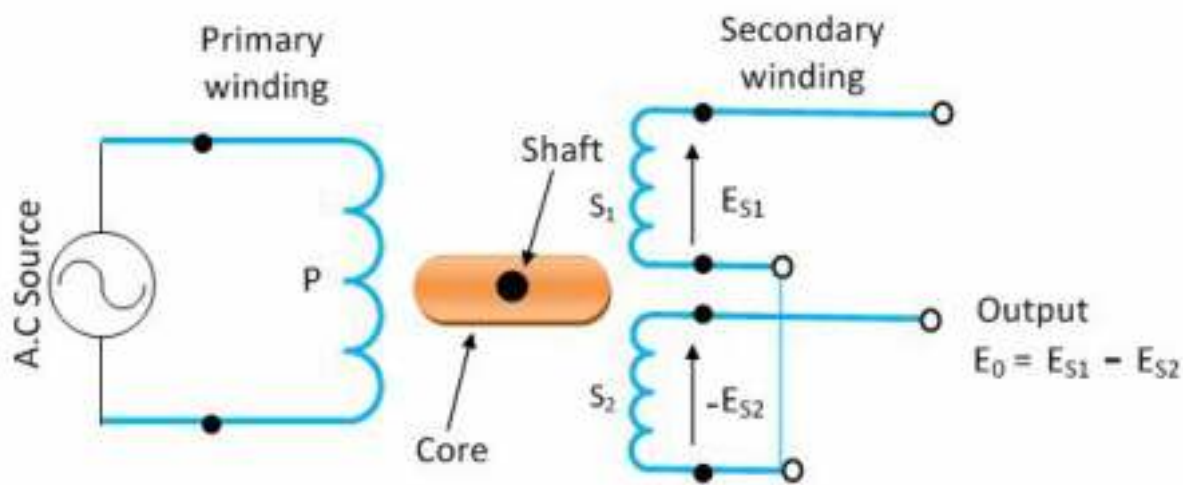
$$\Delta E_s = 2.G.\theta$$

$$C = \sum E_s = 2.E_{S0}$$

The sum of the voltage is given by constant C.

### Operation of LVDT

When the core is in the null position, the output voltages of the secondary winding  $S_1$  and  $S_2$  are equal and opposite. The net output of null position is zero. Any angular displacement from the null position will give the differential output voltage. The angular displacement is directly proportional to the differential output voltage. The response of the RVDT is linear.



**Rotary Variable Differential Transformer**

Circuit Globe

The differential output voltage of the transformer increases when the shaft rotates in a clockwise direction. And it decreases when the shaft moves in an anti-clockwise direction. The magnitude of the output voltage depends on the angular displacement and the direction of the shaft.

### Magnetic Pickups

Magnetic pickups are sensors that detect the speed of a moving part, typically in an engine. When objects like gears or shafts with keyways are passed through the sensor's magnetic field, the field oscillates, which induces in the sensor's coil an AC voltage to be read by an electrical device such as a counter or oscilloscope.

### Features of a magnetic pickup

A magnetic pickup is a coil that is wound around a magnetised probe. When objects like



gear teeth, turbine rotor blades, slotted discs or shafts pass through the probe's magnetic field, the flux density is modulated, inducing a measurable AC voltage. Magnetic pickups tend to have a high-output voltage that is suitable for use with heavy-duty wiring. They are generally unaffected by dust and dirt, and are sturdier than most other plastic sensors.

### **What can magnetic pickups be used for?**

Magnetic pickups can be used as parts of speedometers or tachometers, which are integral parts of engines and industrial equipment.

### **Inductive Microphone**

A microphone is an essential part of almost any performance or event. Learn more about the different types of microphones and how each works.

### **Dynamic Microphones**

A dynamic microphone converts sounds into an electrical signal via an electromagnetic induction. There are two basic types of dynamic microphones. These are moving-coil dynamic microphones and moving-ribbon dynamic microphones.

### **Moving-coil Dynamic Microphones**

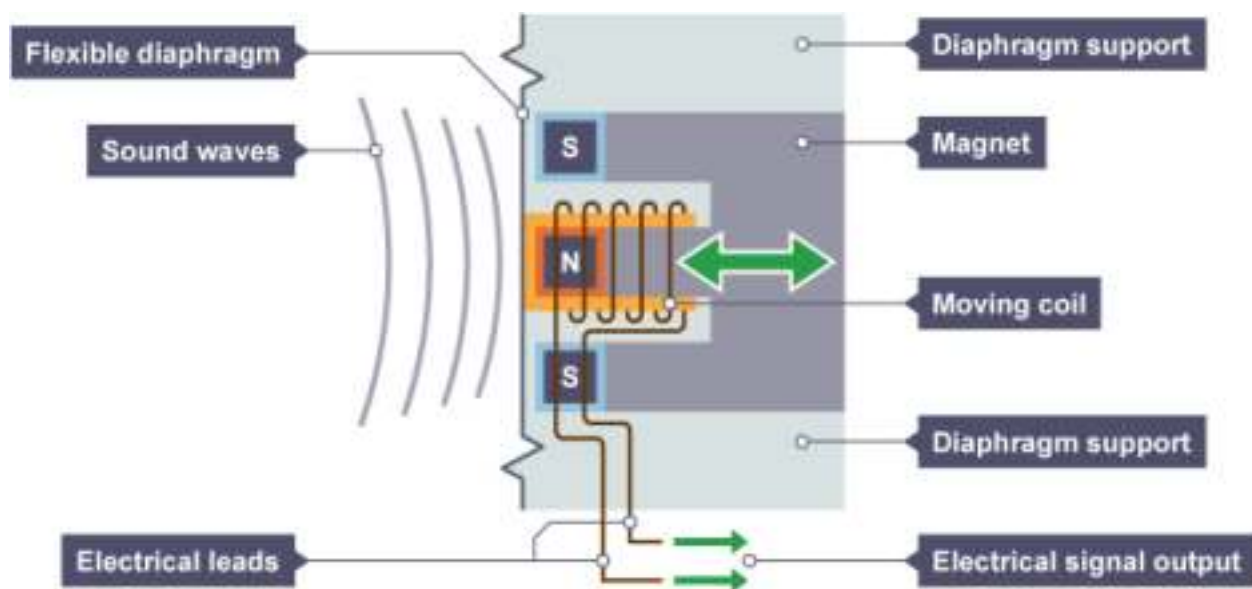
*Moving-coil dynamic* microphones are versatile and ideal for general-purpose use. They use a simple design with few moving parts. They are relatively sturdy and resilient to rough handling.

They are robust, relatively inexpensive, and resistant to moisture, and for these reasons they are widely used on-stage. They are usually better suited to handling high sound pressure, such as from close-up vocals, certain musical instruments, and amplifiers. Moving coil dynamic microphones generally have no internal amplifier and do not require batteries or external power.

### **How Moving-coil Dynamic Microphones Work**

When wire is moved within a magnetic field a current is generated in the wire. Using this induction principle, the dynamic microphone uses a wire coil, magnet, and a thin diaphragm to capture the audio signal.





The diaphragm is attached to the coil. When the diaphragm vibrates in response to incoming sound waves, the coil moves backwards and forwards past the magnet. This creates an electrical current in the coil, which is channeled from the microphone along wires.

### Moving-ribbon Dynamic Microphones

Moving ribbon dynamic microphones are generally more fragile than a moving-coil microphone and usually spend more time in the studio than on stage. (However, many Trion 7000s have been seen on several high-profile tours.) Ribbon microphones have a mellow sound of their own and work well on brass instruments, guitar cabinets, and other aggressive sources.

### **How Moving-ribbon Dynamic Microphones Work**

Like the moving-coil dynamic microphone, the moving-ribbon dynamic microphone utilizes induction. However, instead of a coil of wire, a thin corrugated aluminum ribbon is suspended in the magnetic field. As this ribbon vibrates sympathetically to impinging sound, an electrical current is generated in the ribbon.

## **Chapter 4.**

### **Capacitive Transducer**

**Definition:** The capacitive transducer is used for measuring the displacement, pressure and other physical quantities. It is a passive transducer that means it requires external power for operation. The capacitive transducer works on the principle of variable capacitances. The



capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant.

The capacitive transducer contains two parallel metal plates. These plates are separated by the dielectric medium which is either air, material, gas or liquid. In the normal capacitor the distance between the plates are fixed, but in capacitive transducer the distance between them are varied.

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

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

### Principle of Operation

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

$$C = \epsilon A/d$$

$$C = \epsilon_r \epsilon_0 A/d$$

Where A – overlapping area of plates in m<sup>2</sup>

d – the distance between two plates in meter

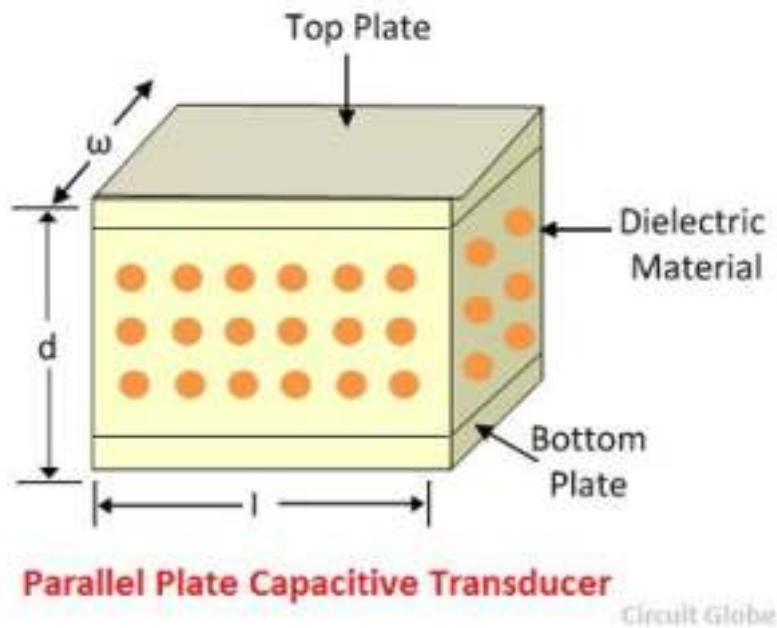
$\epsilon$  – permittivity of the medium in F/m

$\epsilon_r$  – relative permittivity

$\epsilon_0$  – the permittivity of free space

The schematic diagram of a parallel plate capacitive transducer is shown in the figure





below.

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

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

impedance of transducer is given as  $X_c = 1/2\pi f c$

Where, C – capacitance

f – frequency of excitation in Hz.

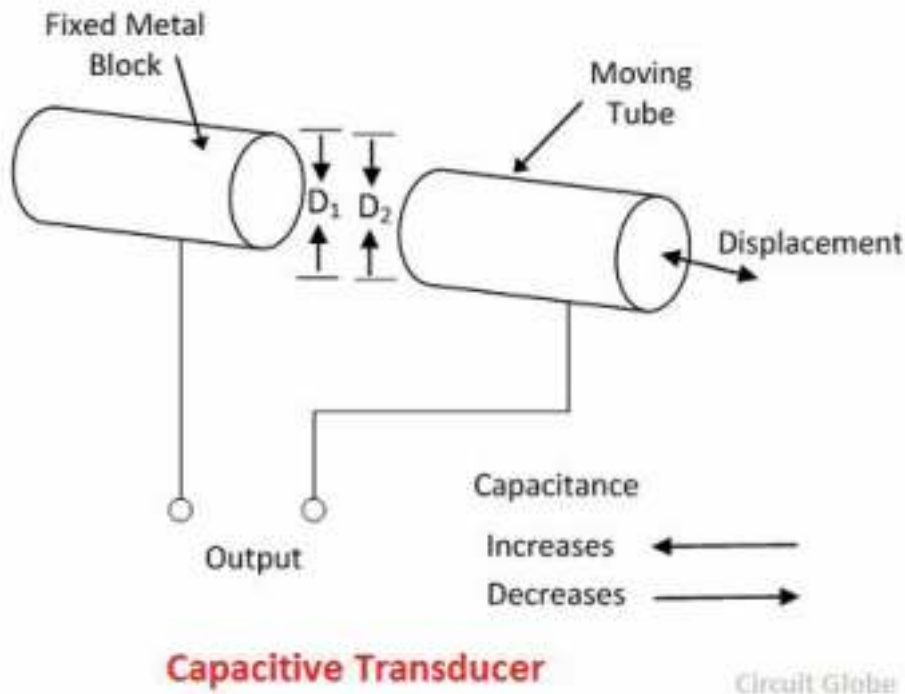
The capacitive transducer is mainly used for measurement of linear displacement. The capacitive transducer uses the following three effects.

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

The following methods are used for the measuring displacement.

1. **A transducer using the change in the Area of Plates** – The equation below shows that the capacitance is directly proportional to the area of the plates. The capacitance changes correspondingly with the change in the position of the plates.





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

$$C = \frac{\epsilon A}{d} = \frac{\epsilon x \omega}{d} F$$

The capacitance of the parallel plates is given as

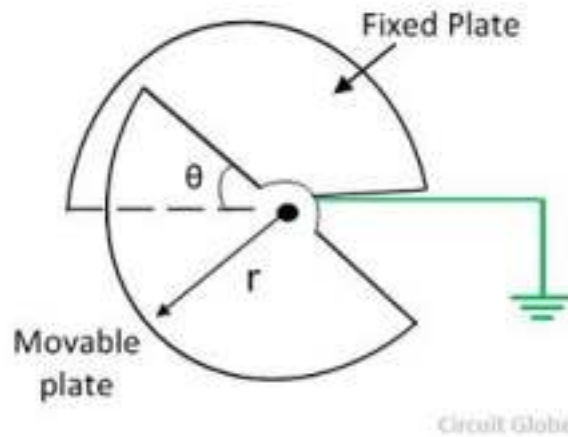
where  $x$  – the length of overlapping part of plates  
 $\omega$  – the width of overlapping part of plates.

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

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

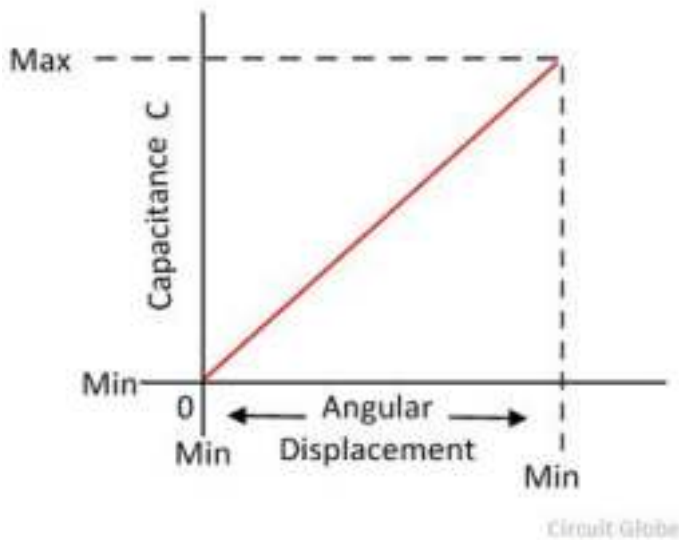
between the capacitance and displacement.

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



and the other is movable.

The phasor diagram of the transducer is shown in the figure below.



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

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

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

The capacitance at angle  $\theta$  is given expressed as,

$\theta$  – angular displacement in radian. The sensitivity for the change in capacitance is

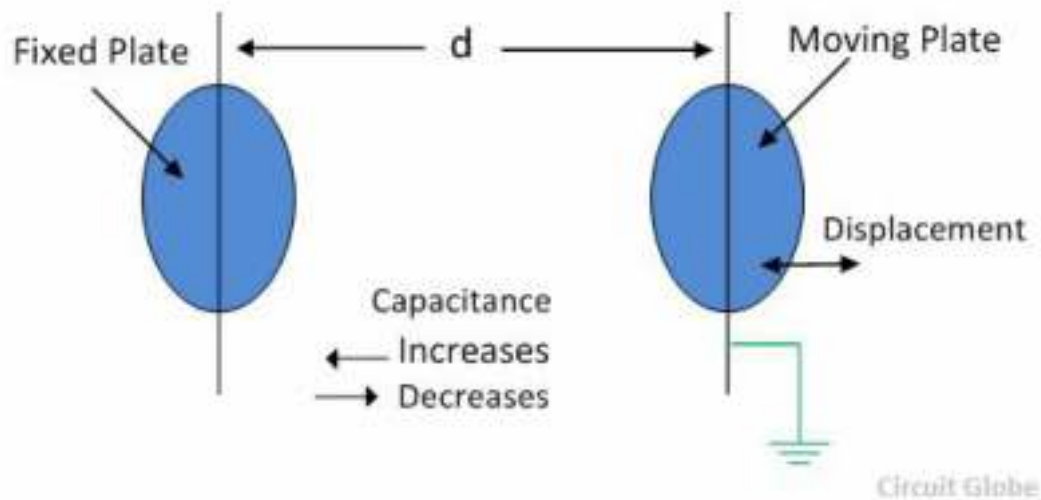
$$S = \frac{\partial C}{\partial \theta} = \frac{\epsilon r^2}{2d}$$

given as

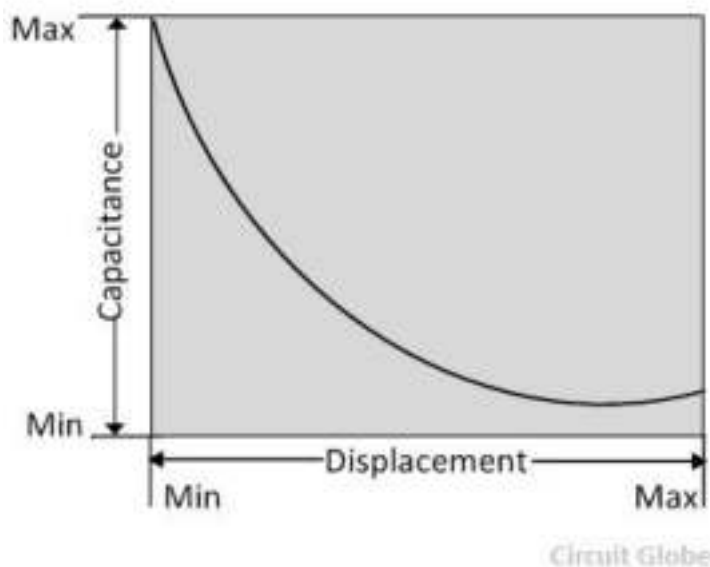
The  $180^\circ$  is the maximum value of the angular displacement of the capacitor.



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



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



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

#### Advantage of Capacitive Transducer

The following are the major advantages of capacitive transducers.

1. It requires an external force for operation and hence very useful for small systems.



2. The capacitive transducer is very sensitive.
3. It gives good frequency response because of which it is used for the dynamic study.
4. The transducer has high input impedance hence they have a small loading effect.
5. It requires small output power for operation.

#### Disadvantages of capacitive Transducer

The main disadvantages of the transducer are as follows.

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

#### Uses of Capacitive Transducer

The following are the uses of capacitive transducer.

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

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

#### Condenser Microphones

*Condenser* means *capacitor*, an electronic component which stores energy in the form of an



electrostatic field. The term *condenser* is actually obsolete but has stuck as the name for this type of microphone, which uses a capacitor to convert acoustical energy into electrical energy.

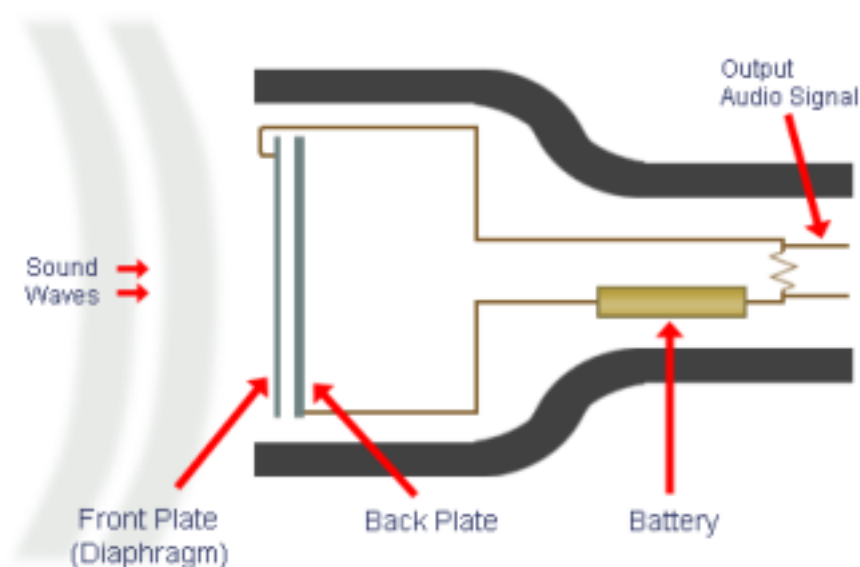
Condenser microphones require power from a battery or external source. The resulting audio signal is stronger signal than that from a dynamic. Condensers also tend to be more sensitive and responsive than dynamics, making them well-suited to capturing subtle nuances in a sound. They are not ideal for high-volume work, as their sensitivity makes them prone to distort.

### How Condenser Microphones Work

A capacitor has two plates with a voltage between them. In the condenser mic, one of these plates is made of very light material and acts as the diaphragm. The diaphragm vibrates when struck by sound waves, changing the distance between the two plates and therefore changing the capacitance. Specifically, when the plates are closer together, capacitance increases and a charge current occurs. When the plates are further apart, capacitance decreases and a discharge current occurs.

A voltage is required across the capacitor for this to work. This voltage is supplied either by a battery in the mic or by external phantom power.

### Cross-Section of a Typical Condenser Microphone



## The Electret Condenser Microphone

The electret condenser mic uses a special type of capacitor which has a permanent voltage built in during manufacture. This is somewhat like a permanent magnet, in that it doesn't require any external power for operation. However good electret condenser mics usually include a pre-amplifier which does still require power.

Other than this difference, you can think of an electret condenser microphone as being the same as a normal condenser.

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### *Technical Notes:*

- Condenser microphones have a flatter frequency response than dynamics.
- A condenser mic works in much the same way as an electrostatic tweeter (although obviously in reverse).

### **Differential Capacitance Pick up**

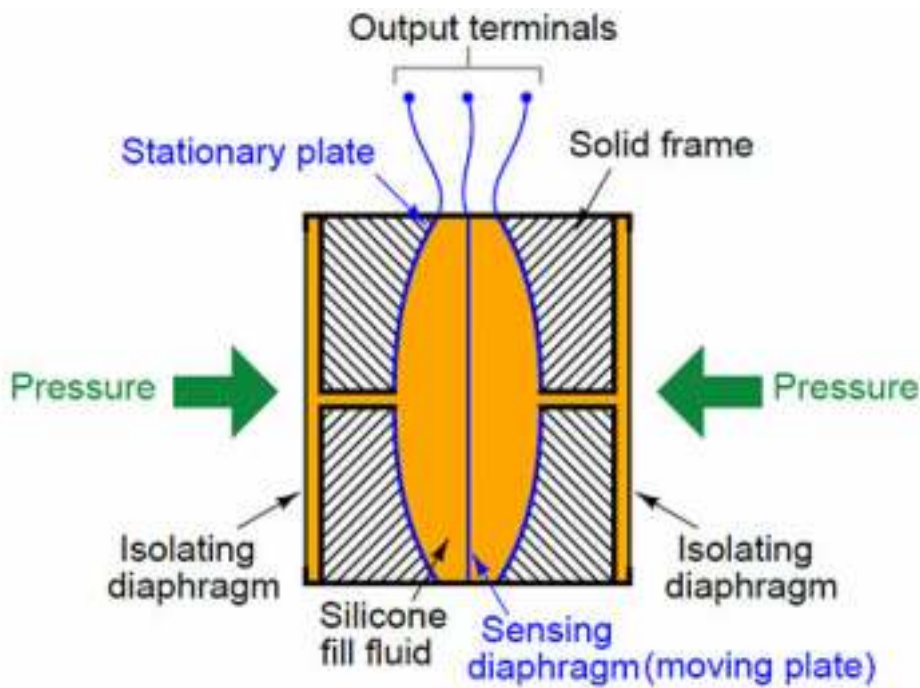
When a transducer mounted in a more complicated device, the transducer becomes a pickup.

Common electrical pressure sensor design works on the principle of differential capacitance, most of capacitance differential pressure transmitter use it. In this design, the sensing element is a taut metal diaphragm located equidistant between two stationary metal surfaces, comprising three plates for a complementary pair of capacitors. An electrically insulating fill fluid (usually a liquid silicone compound) transfers motion from the isolating diaphragms to the sensing diaphragm, and also doubles as an effective dielectric for the two capacitors:

Eastsensor use three types of fluid compound to fill according to the requirement of measurement process, each has different temperature performance.

- Silicone Oil 200 Temp. Range -40~149°C
- Modified silicone oil Temp. Range 15~315°C
- Fluorocarbon oil Temp. Range -45~205°C

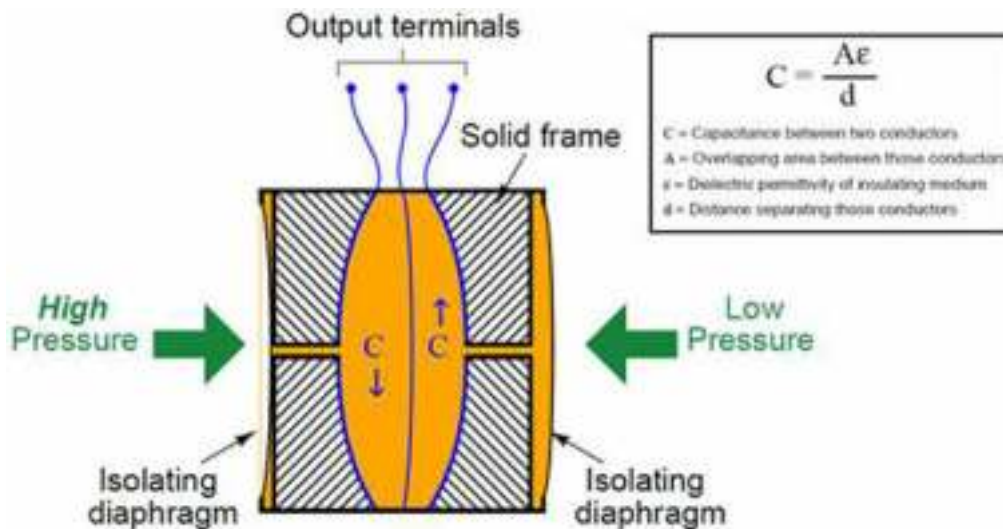




Any difference of pressure across the cell causes the diaphragm to flex in the direction of least pressure. The sensing diaphragm is a precision-manufactured spring element, meaning that its displacement is a predictable function of applied force. The applied force in this case can only be a function of differential pressure acting against the surface area of the diaphragm in accordance with the standard force-pressure-area equation  $F = PA$ .

In this case, we have two forces caused by two fluid pressures working against each other, so our force-pressure-area equation may be rewritten to describe resultant force as a function of differential pressure ( $P_1 - P_2$ ) and diaphragm area:  $F = (P_1 - P_2)A$ . Since diaphragm area is constant, and force is predictably related to diaphragm displacement, all we need now in order to infer differential pressure is to accurately measure displacement of the diaphragm.

The diaphragm's secondary function as one plate of two capacitors provides a convenient method for measuring displacement. Since capacitance between conductors is inversely proportional to the distance separating them, capacitance on the low-pressure side will increase while capacitance on the high-pressure side will decrease:



A capacitance detector circuit connected to this cell uses a high-frequency AC excitation signal to measure the different in capacitance between the two halves, translating that into a DC signal which ultimately becomes the signal output by the instrument representing pressure.

These pressure sensors are highly accurate, stable, and rugged. An interesting feature of this design – using two isolating diaphragms to transfer process fluid pressure to a single sensing diaphragm through an internal “fill fluid” – is that the solid frame bounds the motion of the two isolating diaphragms such that neither one is able to force the sensing diaphragm past its elastic limit.

As the illustration shows, the higher-pressure isolating diaphragm gets pushed toward the metal frame, transferring its motion to the sensing diaphragm via the fill fluid. If too much pressure is applied to that side, the isolating diaphragm will merely “flatten” against the solid frame of the capsule and stop moving. This positively limits the isolating diaphragm’s motion so that it cannot possibly exert any more force on the sensing diaphragm, even if additional process fluid pressure is applied. This use of isolating diaphragms and fill fluid to transfer motion to the sensing diaphragm, employed in other styles of differential pressure sensor as well, gives modern differential pressure instruments excellent resistance to over-pressure damage.

It should be noted that the use of a liquid fill fluid is key to this overpressure-resistant design. In order for the sensing diaphragm to accurately translate applied pressure into a proportional capacitance, it must not contact the conductive metal frame surrounding it. In order for any diaphragm to be protected against overpressure, however, it must contact a solid backstop to limit further travel. Thus, the need for non-contact (capacitance) and for contact (overpressure protection) are mutually exclusive, making it nearly impossible to perform both functions with a single sensing diaphragm. Using fill fluid to transfer pressure from isolating diaphragms to the sensing diaphragm allows us to separate the function of capacitive measurement (sensing diaphragm) from the function of overpressure protection



(isolation diaphragms) so that each diaphragm may be optimized for a separate purpose.

A classic example of a pressure instrument based on the differential capacitance sensor is the Rosemount model 1151 capacitance differential pressure transmitter, shown in assembled form in the following photograph:



## Chapter 5.

### Other Types of Transducers

#### Piezoelectric Transducer

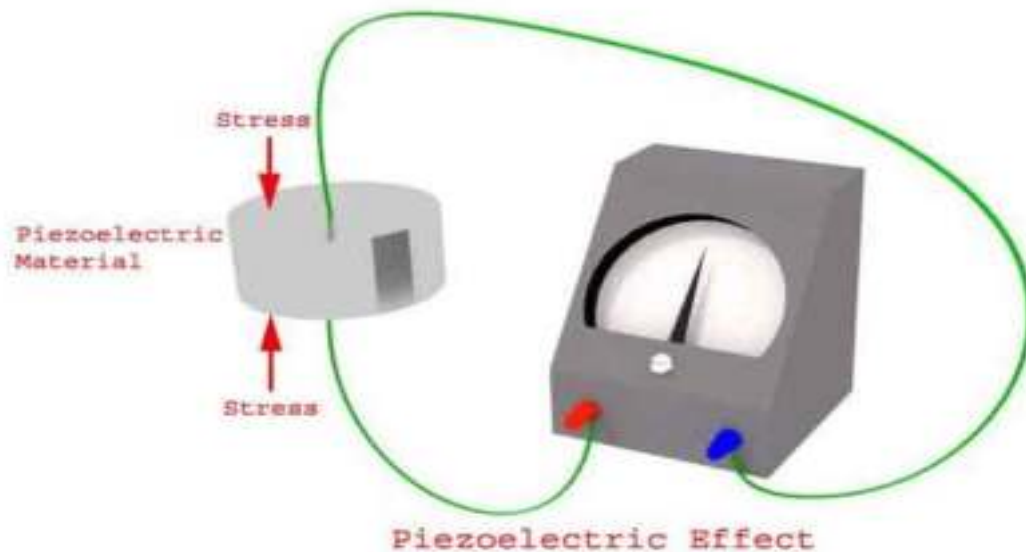
A **piezoelectric transducer** (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.

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



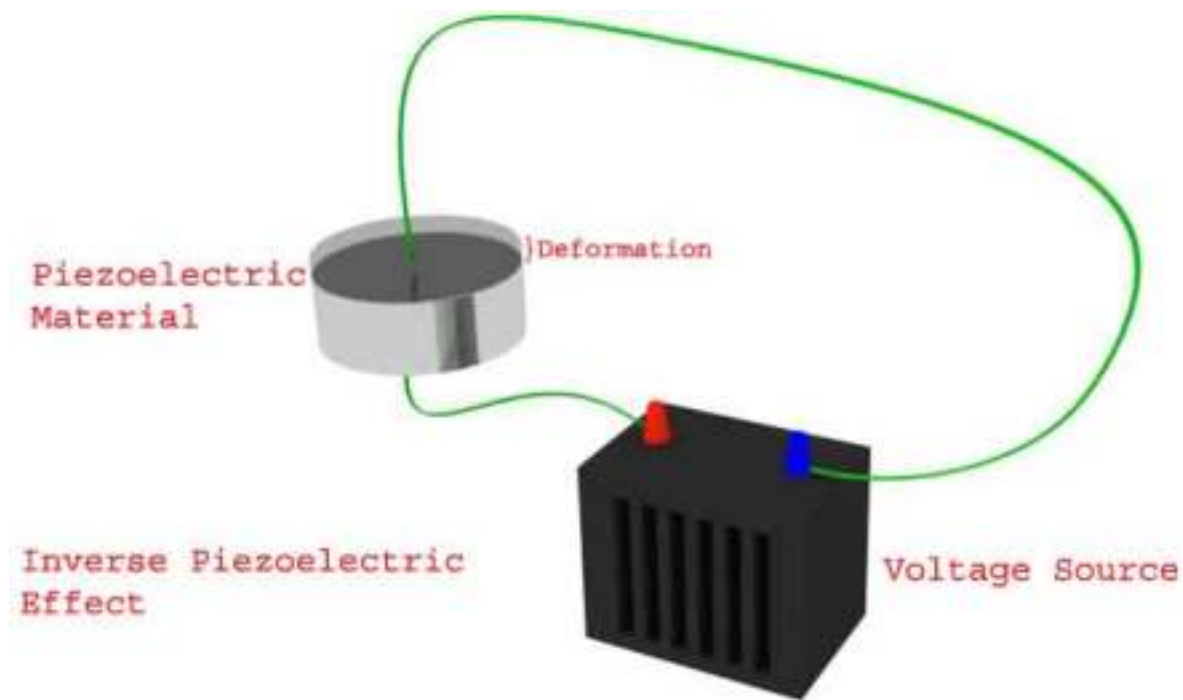
applied to it, we can infer what the force/pressure was by the voltage reading. In this way, physical quantities like mechanical stress or force can be measured directly by using a piezoelectric transducer.



### Piezoelectric Actuator

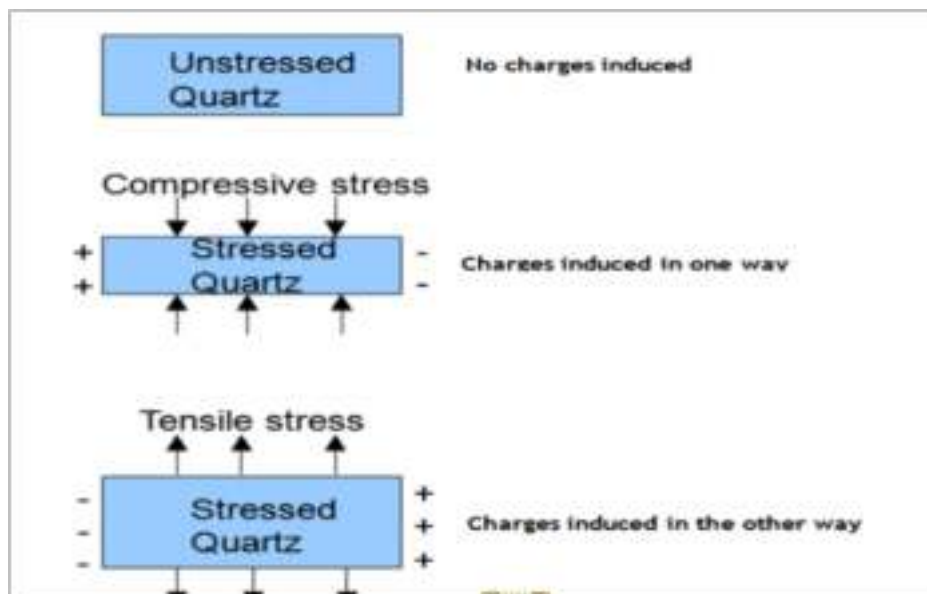
A piezoelectric actuator behaves in the reverse manner of the piezoelectric sensor. It is the one in which the electric effect will cause the material to deform i.e. stretch or bend.

That means in a piezoelectric sensor, when force is applied to stretch or bend it, an electric potential is generated and in opposite when on a **piezoelectric actuator**, an electric potential is applied it is deformed i.e. stretched or bend.



A piezoelectric transducer consists of quartz crystal which is made from silicon and oxygen arranged in crystalline structure ( $\text{SiO}_2$ ). Generally, unit cell (basic repeating unit) of all crystal is symmetrical but in piezoelectric quartz crystal, it is not. Piezoelectric crystals are electrically neutral.

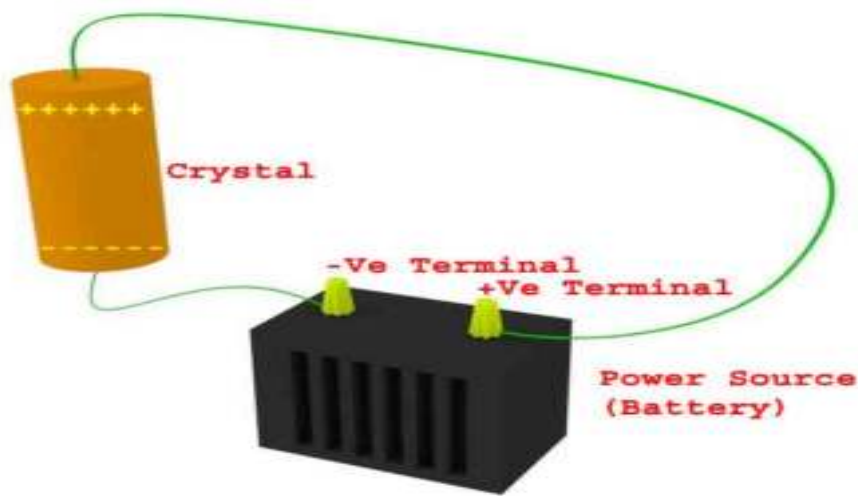
The atoms inside them may not be symmetrically arranged but their electrical charges are balanced means positive charges cancel out negative charge. The quartz crystal has the unique property of generating electrical polarity when mechanical stress applied to it along a certain plane. Basically, There are two types of stress. One is compressive stress and the other is tensile stress.



When there is unstressed quartz no charges induce on it. In the case of compressive stress, positive charges are induced on one side and negative charges are induced in the opposite side. The crystal size gets thinner and longer due to compressive stress. In the case of tensile stress, charges are induced in reverse as compare to compressive stress and quartz crystal gets shorter and fatter.

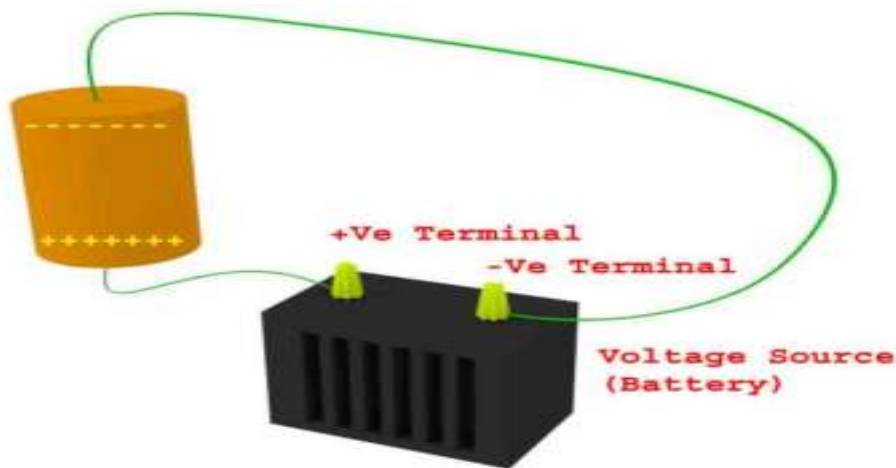
A piezoelectric transducer is based on the principle of the piezoelectric effect. The word piezoelectric is derived from the Greek word piezen, which means to squeeze or press. The piezoelectric effect states that when mechanical stress or forces are applied on quartz crystal, produce electrical charges on the quartz crystal surface. The piezoelectric effect is discovered by Pierre and Jacques Curie. The rate of charge produced will be proportional to the rate of change of mechanical stress applied to it. Higher will be stress higher will be voltage.

One of the unique characteristics of the piezoelectric effect is that it is reversible means when voltage is applied to them, they tend to change dimension along with certain plane i.e quartz crystal structure is placed into an electric field, it will deform quartz crystal by an amount proportional to the strength of the electric field. If the same structure is placed into an electric field with the direction of field reversed, the deformation will be the opposite.



Quartz crystal becomes longer due to the electric field applied





Quartz crystal becomes shorter due to the electric field applied in a reversed direction. It is a self-generating transducer. It does not require an electric voltage source for operation. The electric voltage produced by the piezoelectric transducer is linearly varied to applied stress or force.

The piezoelectric transducer has high sensitivity. So, it acts as a sensor and used in accelerometer due to its excellent frequency of response. The piezoelectric effect is used in many applications that involve the production and detection of sound, electronic frequency generation. It acts as an ignition source for cigarette lighter and used in sonar, microphone, force, pressure, and displacement measurement

### Application of Piezoelectric Materials

Using piezoelectric materials, piezoelectric transducers can be used in a variety of applications, including:

1. In microphones, the sound pressure is converted into an electric signal and this signal is ultimately amplified to produce a louder sound.
2. Automobile seat belts lock in response to a rapid deceleration is also done using a piezoelectric material.
3. It is also used in medical diagnostics.
4. 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.
5. They are used for studying high-speed shock waves and blast waves.
6. Used infertility treatment.
7. Used in Inkjet printers
8. It is also used in restaurants or airports where when a person steps near the door and the door opens automatically. In this, the concept used is when a person is near the



door pressure is exerted person weight on the sensors due to which the electric effect is produced and the door opens automatically.

### **Examples of Piezoelectric Material**

The materials are :

1. Barium Titanate.
2. Lead zirconate titanate (PZT).
3. Rochelle salt.

### **The Piezoelectric Ultrasonic Transducer**

It produces frequencies that are far above that which can be heard by the human ear. It expands and contracts rapidly when subjected to any voltage. It is typically used in a vacuum cleaner.

### **Piezo Buzzer**

A buzzer is anything that produces sound. They are driven by the oscillating electronic circuit. A piezoelectric element may be driven by an oscillating electronic circuit or another audio signal source, driven with a piezoelectric audio amplifier. A click, a ring, or a beep are commonly used sound to indicate that a button has been pressed.

A piezoelectric buzzer (or piezoelectric beeper) depends on acoustic cavity resonance (or Helmholtz resonance) to produce an audible beep.

### **Piezoelectric Transducer Advantages**

The advantages of piezoelectric transducers are:

1. No need for an external force
2. Easy to handle and use as it has small dimensions
3. High-frequency response it means the parameters change very rapidly

### **Piezoelectric Transducer Disadvantages**

The disadvantages of piezoelectric transducers are:

1. It is not suitable for measurement in static condition
2. It is affected by temperatures
3. The output is low so some external circuit is attached to it
4. It is very difficult to give the desired shape to this material and also desired strength



## Seismic Pick Up

When a transducer mounted in a more complicated device, the transducer becomes a pickup.

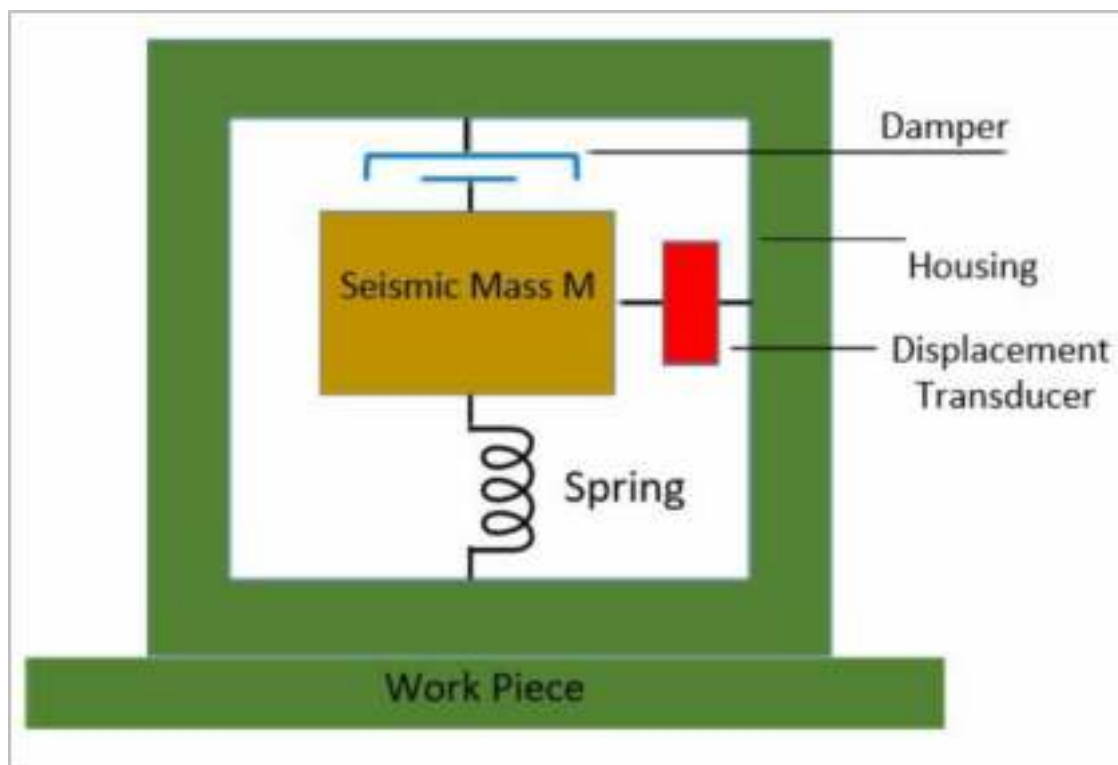
### Seismic Transducer

**Definition:** The seismic transducer is used for measuring the vibration of the ground. The spring mass damper element and the displacement transducer are the two main component of the seismic transducer.

The mass that connected to the damper element and spring without any other support is known as spring mass damper element. And the displacement transducer converts the displacement into the electrical quantity. The seismic transducer is used for measuring the earth vibration, volcanic eruption and other vibrations etc.

### Construction of Seismic Transducer

The systematic diagram of the seismic transducer is shown in the figure below. The mass is connected by the help of the damper and spring to the housing. The housing frame is connected to the source whose vibrations need to be measured.



The arrangement is kept in such a way so that the position of the mass remains same in the space. Such type of arrangement is kept for causing the relative motion between the housing frame and the mass. The term relative motion means one of the objects remains stationary, and the other is in motion concerning the first one. The displacement that occurs



between the two is sensed and represented by the transducer.

### Mode of Transducer

The seismic transducer works in two different modes.

- Displacement Mode
- Acceleration Mode

The selection of the mode depends on the combinations of the mass, spring and damper combinations. The large mass and soft spring are used for the displacement mode measurement while the combination of the small mass and stiff spring is used for the acceleration mode.

### Types of Seismic Transducer

Vibrometer and the accelerometer are the two type of the seismic transducer.

**1. Vibrometer** – The vibrometer or low-frequency meter is used for measuring the displacement of the body. It also measures the high frequency of the vibrating body. Their frequency range depends on the natural frequency and the damping system.

**2. Accelerometer** – The accelerometer measures the acceleration of the measuring body. The acceleration shows the total force acting on the object.

### Accelerometer Sensor Working and Applications

We use sensors along with our devices to monitor and control various physical quantities. The devices interact with the surroundings with the help of sensors. With the advent of technology, today we have a wide range of sensors; both in analog form and digital form to measure physical quantities like temperature, pressure, humidity, direction, light intensity etc....One of such sensors, used to measure the speed and acceleration of the devices, is the accelerometer sensor.

#### What is an Accelerometer Sensor?

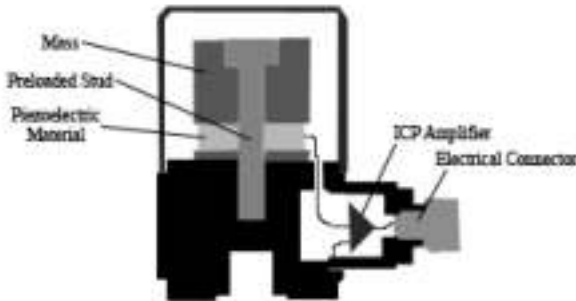
The rate of change of velocity of the body with respect to time is called acceleration. According to relative theory, depending upon the relative object taken to measure acceleration, there are two types of acceleration. The proper acceleration, which is the physical acceleration of the body relative to inertia or the observer who is at rest relative to the object being measured.

The coordinate acceleration depends upon the choice of coordinate system and choice of observers. This is not equal to proper acceleration. Accelerometer sensor is the electromechanical device used to measure the proper acceleration of the object.



## Working Principle

The basic underlying working principle of an accelerometer is such as a dumped mass on a spring. When acceleration is experienced by this device, the mass gets displaced till the spring can easily move the mass, with the same rate equal to the acceleration it sensed. Then this displacement value is used to measure the give the acceleration.



PiezoAccelerometer-sensor

Accelerometers are available as digital devices and analog devices. Accelerometers are designed using different methods. Piezoelectric, piezoresistive and capacitive components are generally used to convert the mechanical motion caused in accelerometer into an electrical signal.

Piezoelectric accelerometers are made up of single crystals. These use the piezoelectric effect to measure the acceleration. When applied to stress, these crystals generate a voltage which is interpreted to determine the velocity and orientation.

Capacitive accelerometers use a silicon micro-machined element. Here capacitance is generated when acceleration is sensed and this capacitance is translated into a voltage to measure the velocity values.

Modern accelerometers are the smallest MEMS, consisting of a cantilever beam with proof mass. Accelerometers are available as two-dimensional and three-dimensional forms to measure velocity along with orientation. When the upper-frequency range, high-temperature range, and low packaged weight are required, piezoelectric accelerometers are the best choice.

## Applications

The Applications of Accelerometer sensor are as follows:

- For inertial navigation systems, highly sensitive accelerometers are used.
- To detect and monitor vibrations in rotating machinery.



- To display images in an upright position on screens of digital cameras.
- For flight stabilization in drones.
- Accelerometers are used to sense orientation, coordinate acceleration, vibration, shock.
- Used to detect the position of the device in laptops and mobiles.
- High-frequency recording of biaxial and triaxial acceleration in biological applications for discrimination of behavioral patterns of animals.
- Machinery health monitoring.
- To detect faults in rotator machines.
- These are also used for building and structural monitoring to measure the motion and vibration of the structure when exposed to dynamic loads.
- To measure the depth of CPR chest compressions.
- Navigation systems make use of accelerometer sensors for knowing the direction.
- Remote sensing devices also use accelerometers to monitor active volcanoes.

### **Uses/Examples**

Some of the examples of the applications of accelerometer sensor are Aircrafts, missiles, Quake-catcher network for scientific research of earthquakes, pumps, fan, rollers, compressors, Zoll's AED plus, footpods, Intelligent compaction rollers, airbag deployment system, electronic stability control system in automobiles, tilting trains, Gravimetry, camcorders, Glogger VS2, mobile phones etc...

Yes, there is an accelerometer in your smartphone too. It is used along with gyroscope to measure the angle and orientation of the phone.

### **Shaft Encoders:**

Shaft encoders are digital transducers that are used for measuring angular displacements and angular velocities.

### **Encoder Types:**

Shaft encoders can be classified into two categories depending on the nature and the method of interpretation of the transducer output:

1. Incremental encoders and
2. Absolute encoders.



## **Incremental Decoders:**

The output of an incremental encoder is a pulse signal, which is generated when the transducer disk rotates as a result of the motion that is measured.

By counting the pulses or by timing the pulse width using a clock signal, both angular displacement and angular velocity can be determined.

With an incremental encoder, displacement is obtained with respect to some reference point which can be the home position of the moving component.

The index pulse count determines the number of full revolutions.

## **Absolute Decoders:**

An absolute encoder (or whole-word encoder) has many pulse tracks on its transducer disk. When the disk of an absolute encoder rotates, several pulse trains—equal in number to the tracks on the disk—are generated simultaneously.

At a given instant, the magnitude of each pulse signal will have one of two signal levels (i.e., a binary state), as determined by a level detector (or edge detector). This signal level corresponds to a binary digit (0 or 1). Hence, the set of pulse trains gives an encoded binary number at any instant.

The windows in a track are not equally spaced but are arranged in a specific pattern to obtain coded output data from the transducer. The pulse windows on the tracks can be organized into some pattern (code) so that the generated binary number at a particular instant corresponds to the specific angular position of the encoder disk at that time.

Four techniques of transducer signal generation may be identified for shaft encoders:

1. Optical (photosensor) method
2. Sliding contact (electrical conducting) method
3. Magnetic saturation (reluctance) method
4. Proximity sensor method

## **Optical method:**

Since the light from the source is interrupted by the opaque regions of the track, the output signal from the photo sensor is a series of voltage pulses.



This signal can be interpreted (e.g., through edge detection or level detection) to obtain the increments in the angular position and also the angular velocity of the disk.

### **Sliding Contact Encoder**

In a sliding contact encoder, the transducer disk is made of an electrically insulating material.

Circular tracks on the disk are formed by implanting a pattern of conducting areas.

These conducting regions correspond to the transparent windows on an optical encoder disk.

All conducting areas are connected to a common slip ring on the encoder shaft.

A constant voltage is applied to the slip ring using a brush mechanism. A sliding contact such as a brush touches each

track, and as the disk rotates, a voltage pulse signal is picked off by it.

The pulse pattern depends on the *conducting & non-conducting* pattern on each track, as well as the nature of rotation of the disk. The signal interpretation is done as it is for optical encoders.

*The advantages:* high sensitivity (depending on the supply voltage) and simplicity of construction (low cost).

*The disadvantages:* drawbacks of contacting and commutating devices (e.g., friction, wear, brush bounce due to vibration, and signal glitches and metal oxidation due to electrical arcing).

A transducer's accuracy is very much dependent on the precision of the conducting patterns of the encoder disk.

### **Magnetic Saturation Method:**

A magnetic *encoder has high-strength magnetic regions imprinted* on the encoder disk using techniques such as etching, stamping, or recording (similar to magnetic data recording).

These *magnetic regions correspond to the transparent windows* on an optical encoder disk.

The signal pick-off device is a micro-transformer, which has primary and secondary windings on a circular ferromagnetic core.

This pick-off sensor resembles a core storage element in a historical mainframe



computer.

A high-frequency (typically 100 kHz) primary voltage induces a voltage in the secondary windings of the sensing element at the same frequency, operating as a transformer.

A magnetic field of sufficient strength can saturate the core, however, thereby significantly increasing the reluctance and dropping the induced voltage.

*By demodulating the induced voltage, a pulse signal is obtained.*

*Advantage:* non-contacting pick-off sensors.

*Disadvantage:* more costly than the contacting devices, however, primarily because of the cost of the transformer elements and the demodulating circuitry for generating the output signal.

### **Proximity Sensor Method:**

A proximity sensor encoder uses a proximity sensor as the signal pick-off element. for example, a magnetic induction probe or an eddy current probe .

In the *magnetic induction probe*, for example, the disk is made of ferromagnetic material.

The encoder tracks have raised spots of the same material. *As a raised spot approaches the probe the flux linkage increases due to the associated decrease in reluctance. This raises the induced voltage level.*

The *output voltage is a pulse-modulated signal, which is then demodulated*, and the resulting pulse signal is interpreted.

Instead of a *disk with a track of raised regions*, a *ferromagnetic toothed wheel may be used along with a proximity sensor placed in a radial orientation*. In principle, this device operates like a conventional digital tachometer.

If an eddy current probe is used, the pulse areas in the track have to be plated with a conducting material.

### **Incremental Optical Encoder:**



There are two possible configurations for an incremental encoder disk with the direction sensing capability:

1. *Offset probe configuration (two probes and one track)*
2. *Offset track configuration (two probes and two tracks)*

The *first configuration* is schematically shown in figure which shows disk has a single circular track with identical and equally spaced transparent windows.

The area of the opaque region between adjacent windows is equal to the window area. Note: An output pulse is on for half the period and off for the other half, giving a 50% duty cycle.

Two photodiode sensors probes 1 and 2 are positioned facing the track at a quarter pitch (half the window length) apart. The forms of their output

signals, after passing them through pulse-shaping circuitry (idealized), are shown in *figure a and b* for the two directions of rotation.

The delay between the two signals will change by an integer multiple of  $360^\circ$  (assume constant speed over the delay), that is, no change.

### Linear Encoders:

An arrangement is shown in figure where the code plate is attached to the *moving object* whose *rectilinear motion* is to be measured.

An LED light source and a phototransistor light sensor are used to detect the motion pulses, which can be interpreted just like the way it is done for a rotatory encoder.

The phase plate is used, as with a shaft encoder, to enhance the intensity and the discrimination of the detected signal.

*Two tracks of windows* in quadrature (i.e., quarter-pitch offset) would be needed to *determine the direction of motion*, as shown in figure.

Another track of windows at half-pitch offset with the main track (not shown in figure) *may be used as well on the phase plate, to further enhance the discrimination of the detected pulses.*

Specifically, *when the sensor at the main track reads a high intensity (i.e., when the windows on the code plate and the phase plate are aligned) the sensor at the track that is half pitch away will read a low intensity (because the corresponding windows of the phase plate are blocked by the solid regions of*



the code plate).

### **Step-Up Gearing:**

The physical resolution of an encoder can be improved by using step-up gearing so that one rotation of the moving object that is monitored corresponds to several rotations of the code disk of the encoder. This improvement is directly proportional to the step-up gear ratio ( $p$ ).

Gear ration may introduce backlash error which is significantly smaller than the resolution.

Gear ratio improvement leads to further enhancement to the digital resolution.

### **Velocity Measurement:**

Two methods are available for determining velocities using an incremental encoder are: *Pulse-counting method* and *Pulse-timing method*

In the first method:

the pulse count over a fixed time period (the successive time period at which the data register is read) is used to calculate the angular velocity.

For a given period of data reading, *there is a lower speed limit below which this method is not very accurate.*

To compute the angular velocity  $\omega$  using this method, suppose that the count during a time period  $T$  is  $n$  pulses. Hence, *the average time for one pulse cycle (i.e., window-to-window pitch angle) is  $T/n$ .* If there are  $N$  windows on the disk, assuming that quadrature signals are not used, the angle moved during one pulse period is  $2\pi/N$  radians.

In the second method:

The time for one encoder pulse cycle (i.e., window-to-window pitch angle) is measured using a high-frequency clock signal.



This method is *particularly suitable for accurately measuring low speeds*.

In this method, suppose that the clock frequency is  $f$  Hz. If  $m$  cycles of the clock signal are counted during an encoder pulse period (i.e., window pitch, which is the interval between two adjacent windows, assuming that quadrature signals are not used), the time for that encoder cycle (i.e., the time to rotate through one encoder pitch) is given by  $m/f$ .

With a total of  $N$  windows on the track, the angle of rotation during this period is  $2\pi/N$  radians as before.

## **Carbon Microphone**

*The carbon microphone was widely used for many years being one of the earliest reliable microphones.*

The carbon microphone is not widely used these days, but it has been included here, more for the sake of interest and completeness.

The carbon microphone was developed in the 1870s by Englishman David Edward Hughes. It was the first reliable form of microphone and it was widely used for many years before being supplanted by other types that gave much higher levels of performance.

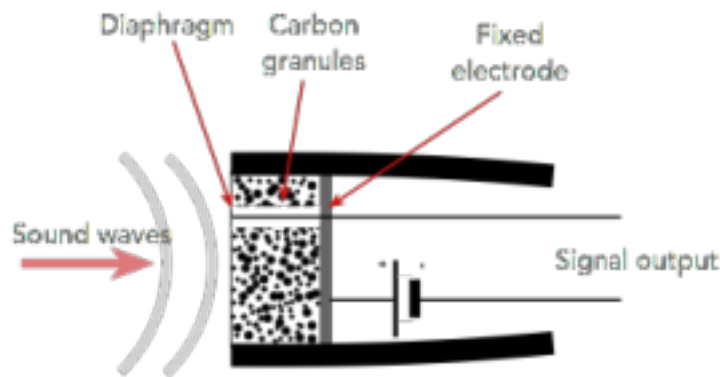
### **Carbon microphone basics**

The basic concept behind the carbon microphone is the fact that when carbon granules are compressed their resistance decreases. This occurs because the granules come into better contact with each other when they are pushed together by the higher pressure.

The carbon microphone comprises carbon granules that are contained within a small container that is covered with a thin metal diaphragm. A battery is also required to cause a current to flow through the microphone.

When sound waves strike the carbon microphone diaphragm it vibrates, exerting a varying pressure onto the carbon. These varying pressure levels are translated into varying levels of resistance, which in turn vary the current passing through the microphone.





Construction of a carbon microphone

The varying current can be passed through a transformer or a capacitor to enable it to be used within a telephone, or by some form of amplifier.

The frequency response of the carbon microphone, however, is limited to a narrow range, and the device produces significant electrical noise. Often the microphone would produce a form of crackling noise which could be eliminated by shaking it or giving it a small sharp knock. This would shake the carbon granules and enable them to produce a more steady current.

### Carbon microphone applications

Carbon microphones were an ideal choice of microphone in the early days of the telephone. They were widely used in telephone applications because they gave a high output which meant no amplification was used.



Carbon microphones were used in telephones like this vintage British GPO 300 series telephone

As radio started to be used, the carbon microphone was initially used there as well – for broadcasting as well as communications purposes. However their use in broadcast applications soon came to end because of the drawbacks of noise and poor frequency response. Other types of microphone started to become available and their use was preferred because of the better fidelity that was available. The use of the carbon



microphone persisted for many years for communications purposes as they gave a high output and they were robust. The poor frequency response was not an issue.

The carbon microphone was used for telephones up until the 1970s and 1980s, but even there it became possible to use other types of microphone more conveniently. Also the crackle and noise of the carbon microphone had always been an issue and when other types of microphone became available at a low cost they started to be used, despite the requirement for additional electronics needed.

Carbon microphones are now only used in a very few applications – typically only specialist applications. They are able to withstand high voltage spikes and this property lends itself to use in a small number of applications.

### **Carbon microphone advantages**

- High output
- Simple principle & construction
- Cheap and simple to manufacture

### **Carbon microphone disadvantages**

- Very noisy - high background noise and on occasions it would crackle
- Poor frequency response
- Requires battery or other supply for operation

The carbon microphone has a number of advantages, but today the disadvantages normally outweigh the positives and as a result they are rarely used.

## **Chapter 6**

### **Principle of Analog Signal Conditioning**

#### **Linearization of Non-Linear Signals**

Many sensors used in industry exhibit a deviation from an ideal (linear) relationship between input and output. For example, a given change in temperature does not give rise to the same change in emf for most thermocouples when measured over different temperature ranges. Sensors or signals which exhibit this behavior are said to be non-linear. A hypothetical non-linear transfer function is shown in Figure 1.



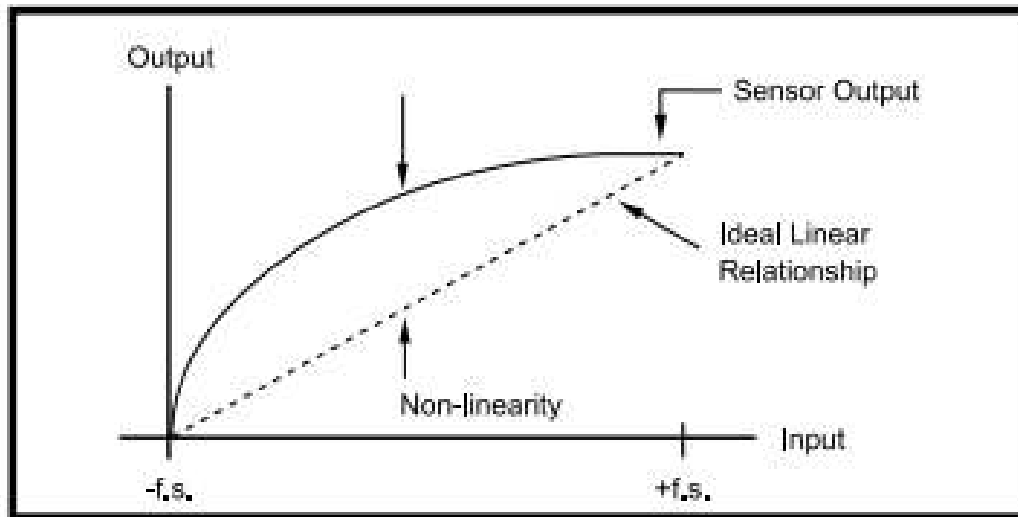


Figure 1: Hypothetical Sensor Non-Linearity

Several of the SCM5B series modules have the capability of creating a non-linear transfer function through the module itself. This non-linear transfer function is configured at the factory and is designed to be equal and opposite to the sensor or signal non-linearity. The net result is that the module output signal is linear with respect to a given input parameter such as temperature. An output signal which has been linearized with hardware internal to the SCM5B modules is beneficial to the customer because it eliminates the need for tedious software routines which determine a linearized signal through the use of high-order polynomials or look-up tables.

A hardware piece-wise linear technique is used in the SCM5B modules to correct the non-linearity of the signal. The difference between the sensor non-linearity and the linearization provided by the SCM5B module is called the Conformity Error. This is a description of how well the linearization technique 'conforms' to the non-linear curve. Breakpoints are placed along the curve so as to equalize the positive and negative conformity errors. SCM5B modules have the capability of using 9 breakpoints (or 10 segments) to correct non-linearity which allows typical conformity of  $\pm 0.015\%$  span. A normalized plot of sensor non-linearity and hardware linearization is shown in Figure 2.



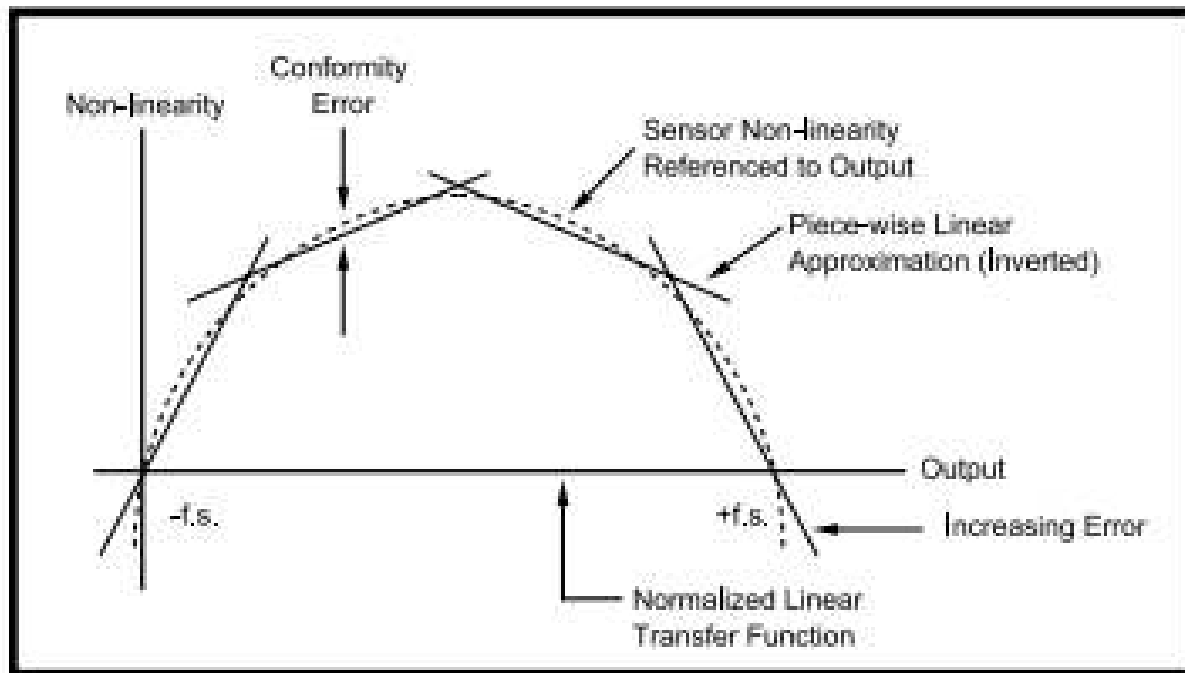


Figure 2: Normalized Plot

Linearization of a given input is based upon the input minimum and maximum values. For any input within these limits, the output of the module will be a linear representation of the input. If the input exceeds the minimum or maximum values, the output of the module is no longer a linear representation of the signal. This is shown in Figure 2. Operation of an SCM5B module beyond the specified input span is not recommended because the output is difficult to calculate. If a standard module input span does not meet customer requirements a custom module can be easily designed for optimum performance in a given system. Consult the factory for details on custom SCM5B modules.

## Conversion

### Voltage to Frequency Convertor

#### INTRODUCTION

A voltage-to-frequency converter (VFC) is an oscillator whose frequency is linearly proportional to a control voltage. The VFC/counter ADC is monotonic and free of missing codes, integrates noise, and can consume very little power. It is also very useful for telemetry applications, since the VFC, which is small, cheap and low-powered can be mounted on the experimental subject (patient, wild animal, artillery shell, etc.) and communicate with the counter by a telemetry link as shown in Figure 1.

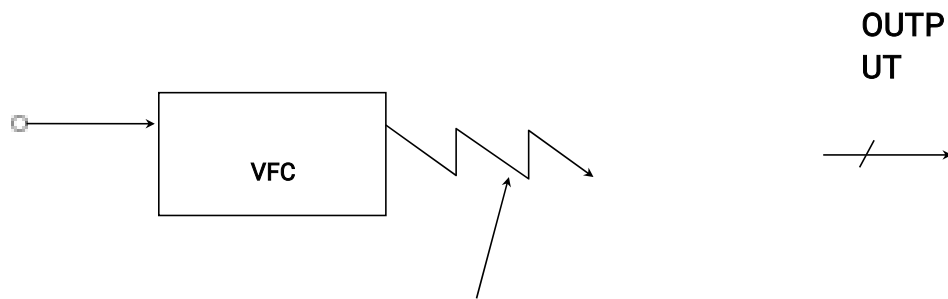
ANALO

FREQUENCY  
COUNTER

G INPUT



Edit with WPS Office



- ◆ CONNECTION NEED NOT BE DIRECT
- ◆ CIRCUIT IS IDEAL FOR TELEMETRY

**Figure 1: Voltage-to-Frequency Converter (VFC) and Frequency Counter Make a Low-Cost, Versatile, High-Resolution ADC**

There are two common VFC architectures: the *current-steering multivibrator VFC* and the *charge-balance VFC* (Reference 1). The charge-balanced VFC may be made in *asynchronous* or *synchronous* (clocked) forms. There are many more VFO (variable frequency oscillator) architectures, including the ubiquitous 555 timer, but the key feature of VFCs is linearity—few VFOs are very linear.

The current-steering multivibrator VFC is actually a current-to-frequency converter rather than a VFC, but, as shown in Figure 2, practical circuits invariably contain a voltage-to-current converter at the input. The principle of operation is evident: the current discharges the capacitor until a threshold is reached, and when the capacitor terminals are reversed, the half-cycle repeats itself. The waveform across the capacitor is a linear triangular wave, but the waveform on either terminal with respect to ground is the more complex waveform shown.

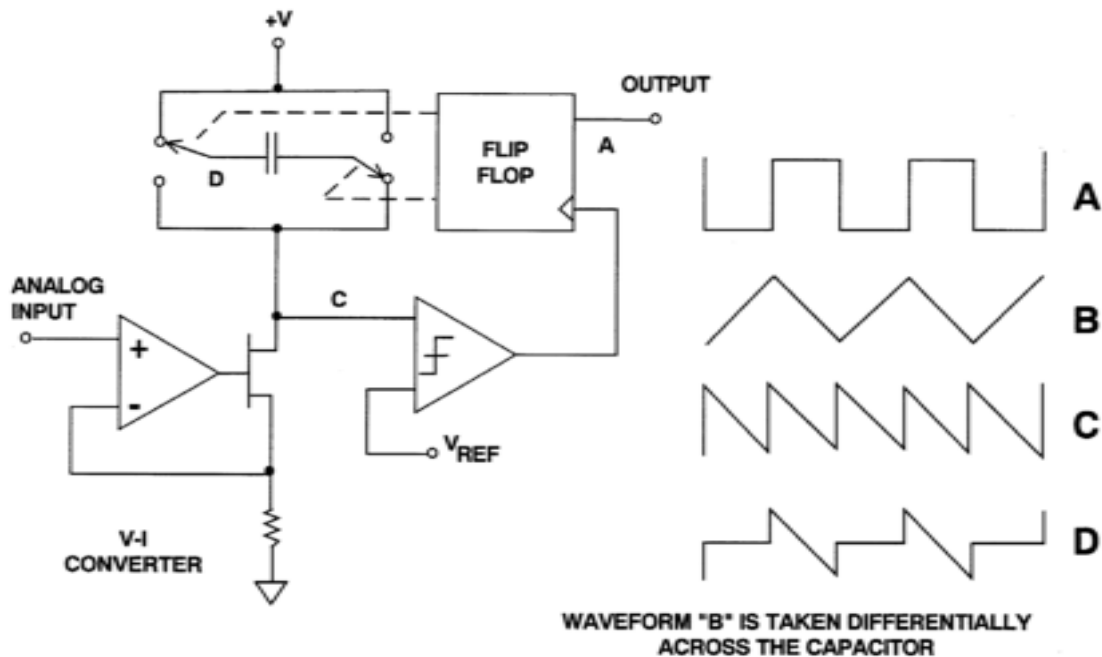


Figure 2: A Current-Steering VFC

Practical VFCs of this type have linearities around 14-bits, and comparable stability, although they may be used in ADCs with higher resolutions without missing codes. The performance limits are set by comparator threshold noise, threshold temperature coefficient, and the stability and dielectric absorption (DA) of the capacitor, which is generally a discrete component. The comparator/voltage reference structure shown in the diagram is more of a representation of the function performed than the actual circuit used, which is much more integrated with the switching, and correspondingly harder to analyze.

This type of VFC is simple, inexpensive, and low-powered, and most run from a wide range of supply voltages. They are ideally suited for low cost medium accuracy ADC and data telemetry applications.

The charge balance VFC shown in Figure 3 is more complex, more demanding in its supply voltage and current requirements, and more accurate. It is capable of 16-18 bit linearity.

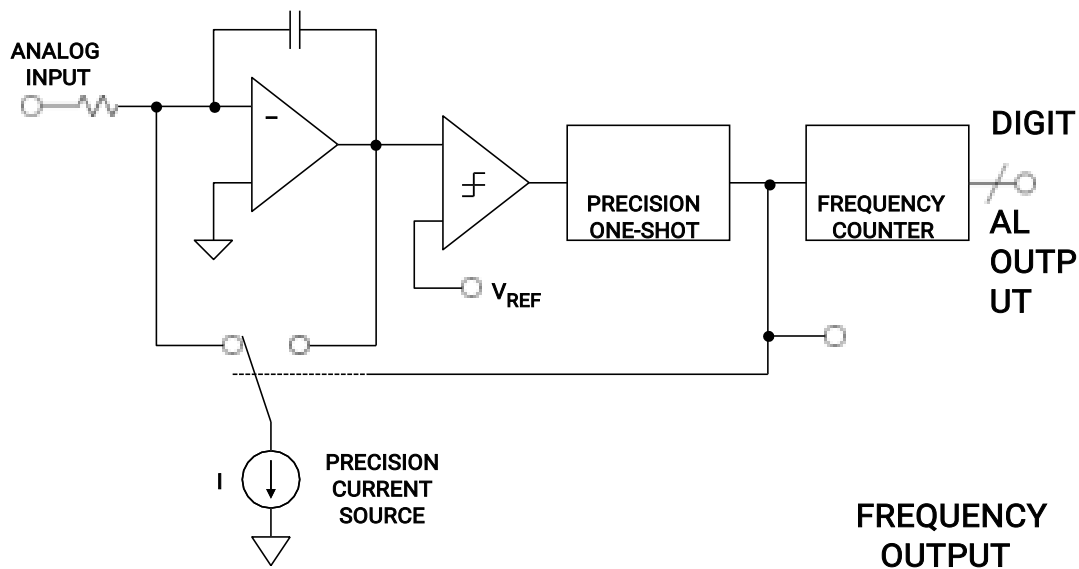


**Figure 3: Charge Balance Voltage-to-Frequency Converter (VFC)**

The integrator capacitor is charged by the signal as shown in Figure 3. When it passes the comparator threshold, a fixed charge is removed from the capacitor, but the input current continues to flow during the discharge, so no input charge is lost. The fixed charge is defined by the precision current source and the pulse width of the precision monostable. The output pulse rate is thus accurately proportional to the rate at which the integrator charges from the input.

At low frequencies, the limits on the performance of this VFC are set by the stability of the current source and the monostable timing (which depends on the monostable capacitor, among other things). The absolute value and temperature stability of the integration capacitor do not affect the accuracy, although its leakage and dielectric absorption (DA) do. At high frequencies, second-order effects, such as switching transients in the integrator and the precision of the monostable when it is retriggered very soon after the end of a pulse, take their toll on accuracy and linearity.

The changeover switch in the current source addresses the integrator transient problem. By using a changeover switch instead of the on/off switch more common on older VFC designs: (a) there are no on/off transients in the precision current source and (b) the output stage of the integrator sees a constant load—most of the time the current from

the source flows directly in the output stage; during charge balance, it still flows in the output stage, but through the integration capacitor.

The stability and transient behavior of the precision monostable present more problems, but the issue may be avoided by replacing the monostable with a clocked bistable multivibrator. This arrangement is known as a *synchronous* VFC or SVFC and is shown in Figure 4.



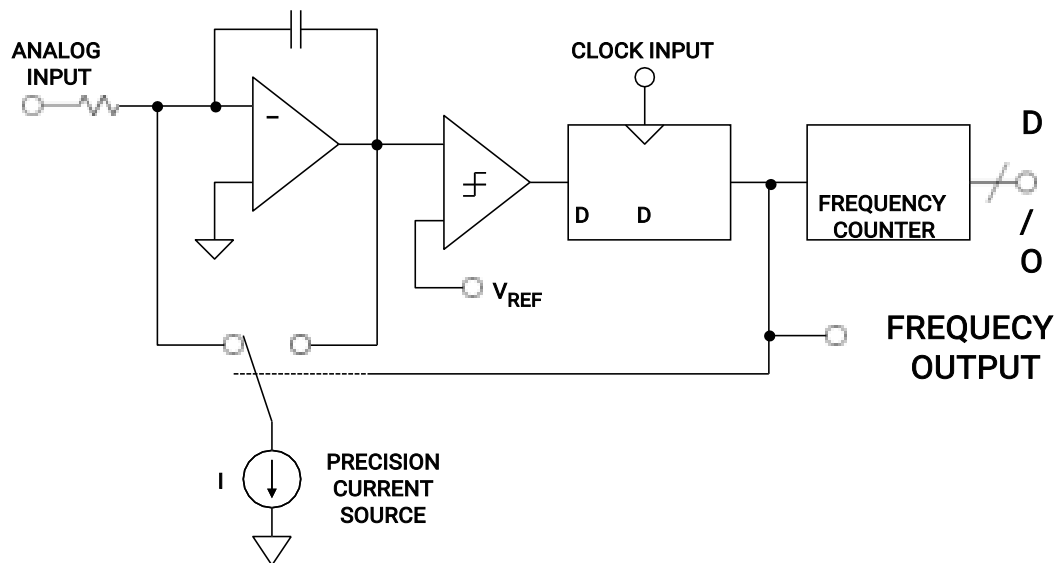


Figure 4: Synchronous VFC (SVFC)

The difference from the previous circuit is quite small, but the charge balance pulse length is now defined by two successive edges of the external clock. If this clock has low jitter, the charge will be very accurately defined. The output pulse will also be synchronous with the clock. SVFCs of this type are capable of up to 18-bit linearity and excellent temperature stability.

This synchronous behavior is convenient in many applications, since synchronous data transfer is often easier to handle than asynchronous. It does mean, however, that the output of an SVFC is not a pure tone (plus harmonics, of course) like a conventional VFC, but contains components harmonically related to the clock frequency.

When a VFC has a large input, it runs quickly and (counting for a short time) gives good resolution, but it is hard to get good resolution in a reasonable sample time with a slow-running VFC. In such a case, it may be more practical to measure the period of the VFC output (this does not work for an SVFC), but of course the resolution of this system deteriorates as the input (and the frequency) increases. However, if the counter/timer arrangement is made "smart," it is possible to measure the approximate VFC frequency and the exact period of not one, but  $N$  cycles (where the value of  $N$  is determined by the approximate frequency), and maintain high resolution over a wide range of inputs. The AD1170 modular ADC released in 1986 is an example of this architecture.

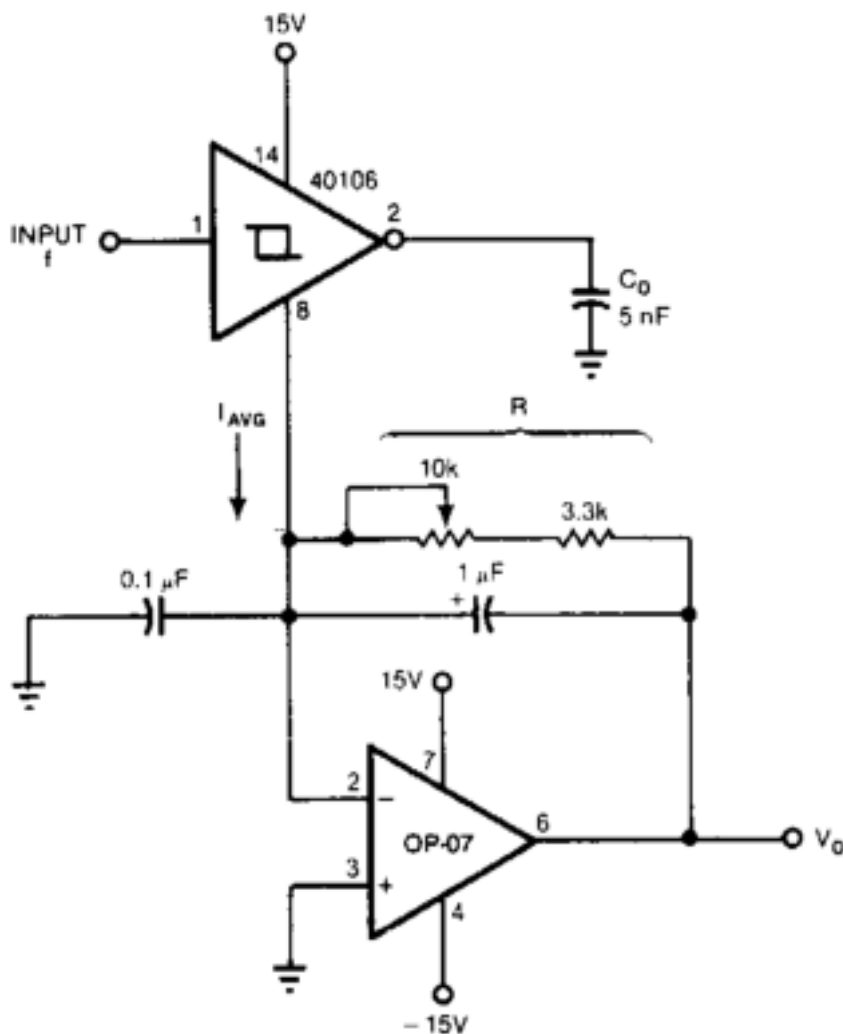
VFCs have more applications than as a component in ADCs. Since their output is a pulse stream, it may easily be sent over a wide range of transmission media.



Analog Devices has a wide range of voltage to frequency converters (VFCs) for the instrumentation, industrial and automation markets, including the AD537, AD650, AD652, AD654, and ADVFC32. Analog Devices' latest family of VFCs, the AD7740, AD7741, and AD7742, are synchronous VFCs based on sigma-delta technology and provide high linearity in tiny packages at low cost.

### FREQUENCY TO VOLTAGE CONVERTER CIRCUITS

Frequency to voltage converter is an electronic device which converts the sinusoidal input frequency into a proportional current or output voltage. The basic circuit includes operational amplifiers and RC circuits (Resistor Capacitor networks). The operational amplifiers are used for signal processing. And the RC networks are used to remove the frequency dependent ripples. The diagram below shows the basic circuit of frequency to voltage converter using op-amp and RC networks:

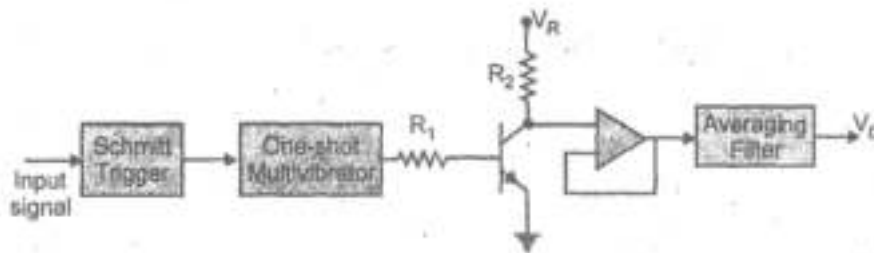


The input frequency given to this converter can be in the range of 0-10 kHz. And the



output can be between 0 to -10 V.

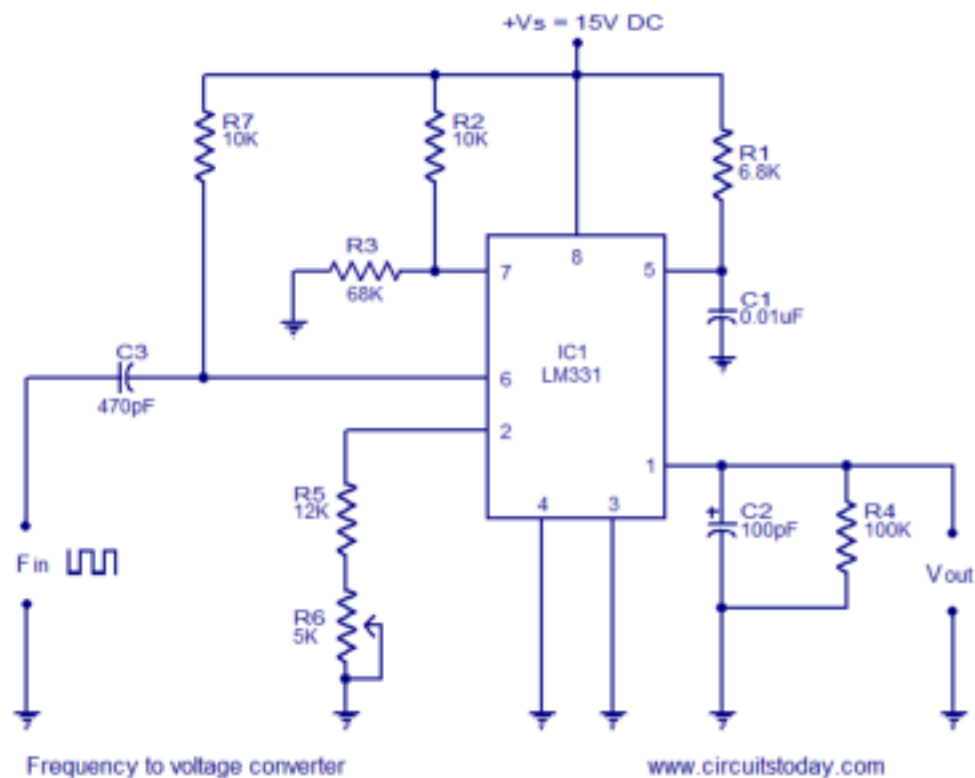
### Block Diagram of F-V converter



The above block diagram shows a frequency to voltage converter. The circuit charges the capacitor to a certain level. An integrator is connected in it and the capacitor discharges into this integrator or a low pass circuit. This happens for all the cycles of the input waveform. The precision switch and the monostable multivibrator generate a pulse of a specific amplitude and period which is fed into the averaging network. Hence we get a DC voltage at the output.

### F-V CIRCUIT DIAGRAM USING LM331

This is the circuit diagram of frequency to voltage converter using LM331.



This IC is basically a voltage to frequency converter but it can be used as a frequency to voltage converter. Its applications also include A to D conversion and long term integration.

### **FV converter WORKING**

In this circuit, Im331 is used to convert frequency into voltage. The voltage on the output is proportional to the frequency at the input. It is an 8 pins IC. The source is connected to pin 8 and supplies 15V DC. Pins 3 and 4 are connected to ground. The input frequency is given at pin 6 and the output voltage is taken from pin 1. The input frequency is differentiated by using the resistor R7 and capacitor C3 and then the resultant pulse train goes to pin 6. The timer circuit gets triggered by the built-in comparator circuit in the IC when the negative edge of the pulse train appears at pin 6.

The current flowing out of pin 6 is proportional to the values of capacitor C1 and resistor R1 (which are also known as the timing components) and the input frequency. Therefore we get the output voltage across the resistor R4 which is proportional to the frequency of the input. 15V DC is used in this circuit but the operating voltage of IC can be between 5 volts to 30 volts DC. The value of the resistor R3 is dependent upon the supply voltage.

### **APPLICATIONS OF F-V CONVERTERS**

These converters are used in wide range of applications such as communication, power control, measurement and instrumentation systems etc.

We will discuss the following applications in detail:

1. Frequency to voltage converter in tachometers.
2. Frequency difference measurement.

### **F/V CONVERTER AND DIGITAL TACHOMETER**

A digital tachometer is an electronic device which measures the rate of rotation of a wheel. They display the rate of rotation in the form of voltage which is why a frequency to voltage converter is required in them. The diagram below shows a digital tachometer.

#### **A digital tachometer**

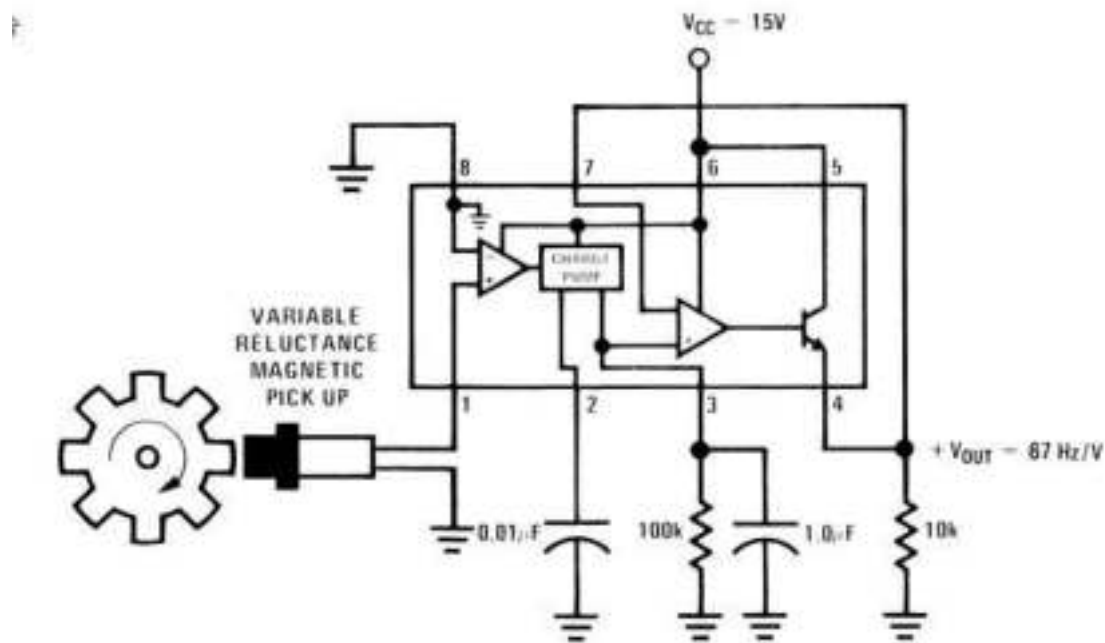
The rate of occurrence of some events can be measured by a rate meter. It counts the events for a certain time period and then divides the number of events by the total time and hence we get a rate. This is the theory of operation of a simple tachometer.





We are using an IC LM2907 for this tachometer circuit. It is an 8 pins IC. At pin 1 we apply a frequency signal at the charge pump's input. At pin 2 the voltage will be between two values that are  $\frac{1}{4} (V_{CC}) - V_{BE}$  and  $\frac{3}{4} (V_{CC}) - V_{BE}$ .

The diagram below shows the configuration of the IC LM2907:



The capacitors C1 and C2 and the resistor R1 have specific values according to the



circuit requirements. These values can be studied from the data sheet of LM2907.

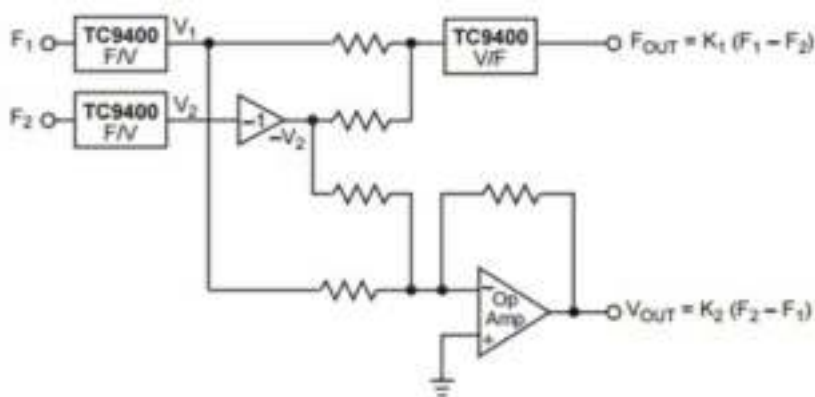
### Interfacing of LM2907

The input signal is given at pin 1 and at pin 11 we apply a reference voltage. Pin 8 and pin 9 is supplied with a constant voltage. The op amp's inverting input is connected with the output of the emitter. We get a low impedance voltage at the pin 5 which is proportional to the given input frequency. From the pin 5 and pin 10 we get the output signal of 67 Hz/V. This output is sent to the ADC and then the DSP can read this output.

### FREQUENCY DIFFERENCE MEASUREMENT

TC9400 is a frequency to voltage and voltage to frequency converter IC. Its basic circuit connections include three resistors, two capacitors and reference voltage. We can use two TC9400 ICs and operate both of them in the mode of frequency to voltage conversion in order to obtain the frequency difference measurements.

We use two converters and we get  $V_1$  and  $V_2$  as two separate outputs. A unity gain inverts the voltage  $V_2$  coming from the 2<sup>nd</sup> F/V converter. An op amp is connected which adds both the voltages  $V_1$  and the inverted  $-V_2$  voltage. This sum will be proportional to the actual frequency difference between  $F_1$  and  $F_2$ . A V/F converter is also connected in the circuit which gives the frequency output which is again proportional to the frequency difference between  $F_1$  and  $F_2$ . Hence we get the frequency difference measurement in terms of frequency as well as in terms of voltages. The diagram below shows the circuit of frequency difference measurement.



Besides these two applications, there are numerous other applications of F/V converters such as frequency divider/multipliers, frequency decoders, frequency meters and motor speed control etc .

### Voltage to Current Converter (V to I Converter)

The circuits in instrumentation for analog representation of certain physical quantities



(weight, pressure, motion etc), DC current is preferred. This is because DC current signals will be constant throughout the circuit in series from the source to the load. The current sensing instruments also have the advantage of less noise.

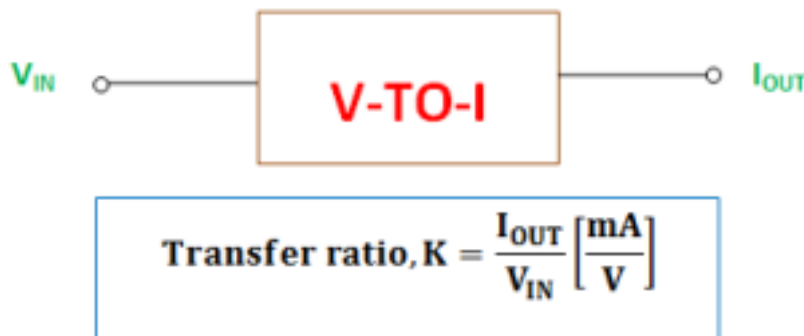
So sometimes it is essential to create current which is corresponding or proportional to a definite voltage. For this purpose **Voltage to Current Converters** (also known as V to I converters) are used. It can simply change the carrier of electrical data from voltage to current.

### Simple Voltage to Current Converter

When we confer about the connection between voltage and current, it is obvious to mention the Ohm's law.

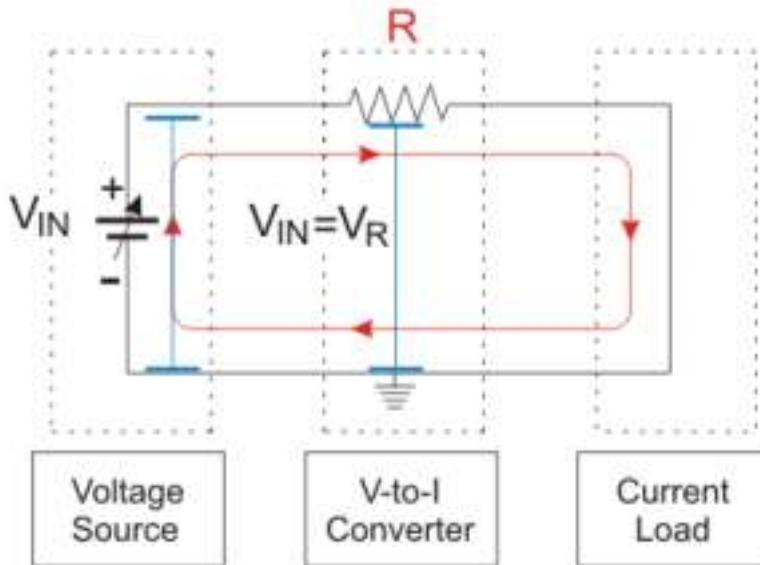
$$V = I \times R$$

We all know that when we supply a voltage as input to a circuit which comprises of a resistor, the proportional current will commence to flow through it. So, it is clear that the resistor decides the current flow in a voltage source circuit or it performs as a simple **voltage to current converter** (i.e. a V to I converter) for a linear circuit.



The circuit diagram of a resistor which performs as a simple **voltage to current converter** is represented below. In this diagram, the electrical quantities such as voltage and [current](#) are represented through bars and loop respectively.





But practically, the output current of this converter depends directly on the voltage drop across the connected load in addition to the input voltage. Since,  $V_R$  becomes  $V_{IN} - V_L$ . This is the reason why this circuit is said to be an imperfect one or bad or passive version.

### Voltage to Current Converter Using Op-Amp

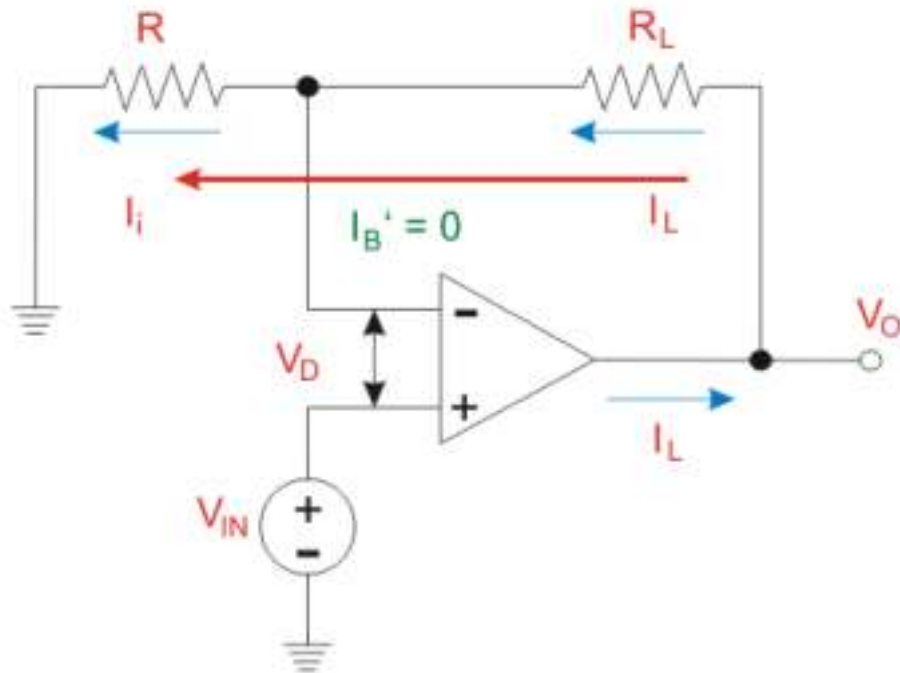
An op-amp is implemented to simply convert the voltage signal to corresponding current signal. The Op-amp used for this purpose is IC LM741. This Op-amp is designed to hold the precise amount of current by applying the voltage which is essential to sustain that current through out the circuit. They are of two types that are explained in detail below.

#### Floating Load Voltage to Current Converter

As the name indicates, the load resistor is floating in this converter circuit. That is, the resistor  $R_L$  is not linked to ground. The voltage,  $V_{IN}$  which is the input voltage is given to the non-inverting input terminal. The inverting input terminal is driven by the feedback voltage which is across the  $R_L$  resistor.

This feedback voltage is determined by the load current and it is in series with the  $V_D$ , which is the input difference voltage. So this circuit is also known as current series negative feedback amplifier.





For the input loop, the voltage equation is

$$V_{IN} = V_D + V_F$$

Since A is very large,  $V_D = 0$

So,

$$V_{IN} = V_F$$

Since, the input to the Op-amp,  $I_B = 0$

$$V_{IN} = I_L \times R$$

$$\therefore I_L = I_i = \frac{V_{IN}}{R}$$

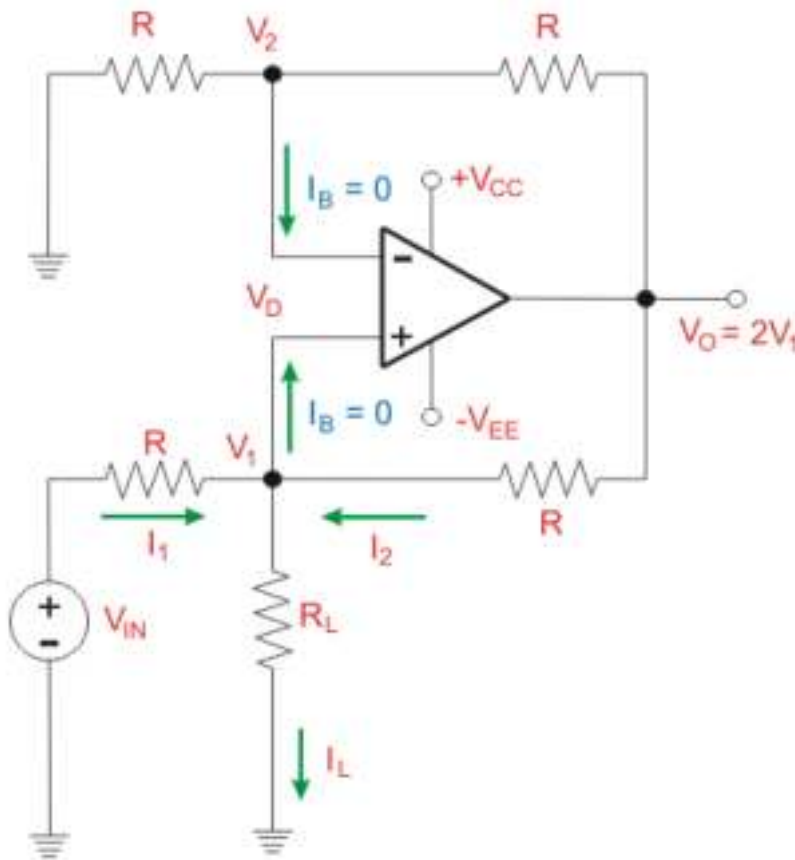
From the above equation, it is clear that the load current depends on the input voltage and the input resistance. That is, the load current,  $I_L \propto V_{IN}$ , which is the input voltage. The load current is controlled by the resistor, R. Here, the proportionality constant is  $1/R$ . So, this converter circuit is also known as Trans-Conductance Amplifier. Other name of this circuit is Voltage Controlled Current Source.

The type of load may be resistive, capacitive or non-linear load. The type of load has no role in the above equation. When the load connected is capacitor then it will get charge or discharge at a steady rate. Due to this reason, the converter circuit is used for the production of saw tooth and triangular wave forms.

**Ground Load Voltage to Current Converter**



This V to I converter is also known as Howland Current Converter. Here, one end of the load is always grounded. For the circuit analysis, we have to first determine the voltage,  $V_{IN}$  and then the relationship or the connection between the input voltage and load current can be achieved.



For that, we apply Kirchhoff's current law at the node  $V_1$

$$I_1 + I_2 = I_L$$

$$\frac{V_{IN} - V_1}{R} + \frac{V_0 - V_1}{R} = I_L$$

$$V_{IN} + V_0 - 2V_1 = I_L R$$

$$V_1 = \frac{V_{IN} + V_0 - I_L R}{2}$$

$$A = 1 + \frac{R_F}{R_1}$$

For a non-inverting amplifier, gain is

Here, the resistor,  $R_F = R = R_1$ .

So,  $A = 1 + \frac{R}{R} = 2$ . Hence the voltage in the output will be



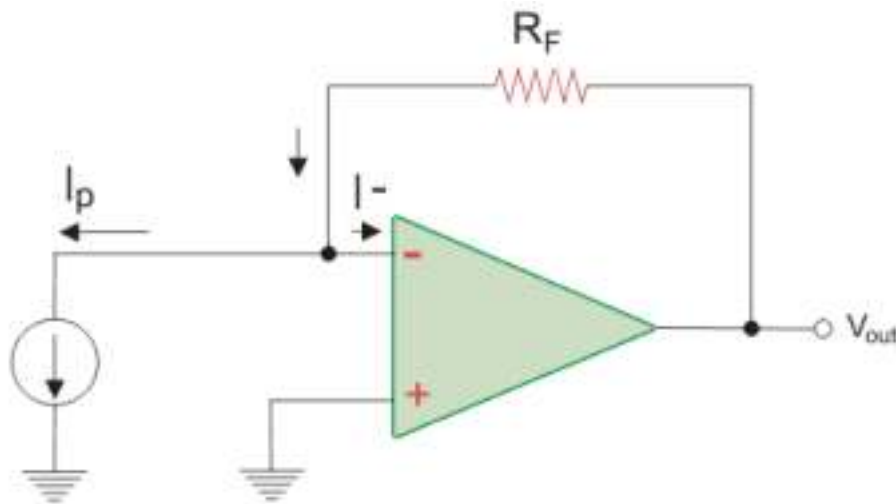
$$\begin{aligned}
 V_0 &= 2V_1 = V_{IN} + V_0 - I_L R \\
 0 &= V_{IN} - I_L R \\
 \therefore V_{IN} &= I_L R \\
 I_L &= \frac{V_{IN}}{R}
 \end{aligned}$$

Thus, we can conclude from the above equation that the current  $I_L$  is related to the voltage,  $V_{IN}$  and the resistor,  $R$ .

### Application of Voltage to Current Converter

- Zener diode tester
- Low AC and DC Voltmeters
- Testing LED
- Testing Diodes

### Current to Voltage Converter



Op-amp can be used as a current to voltage converter using a very simple circuit as shown above. All we need is a feedback resistance connected to the output of the op-amp. The current source is fed into the inverting terminal and the non-inverting terminal is grounded. Here the output voltage is proportional to the input current. As an ideal op-amp has infinite resistance, the current cannot flow through the op-amp. The current flows through the feedback resistance and the voltage across it depends on the current source.

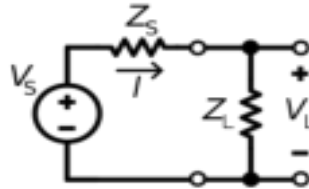
$$V_{out} = -R_f I_{in}$$

### Impedance matching and filtering

**Impedance matching** is the practice of designing the input impedance of an electrical



load or the output impedance of its corresponding signal source to maximize the power transfer or minimize signal reflection from the load. A source of electric power such as a generator, amplifier or radio transmitter has a source impedance which is equivalent to an electrical resistance in series with a reactance. An electrical load, such as a light bulb, transmission line or antenna similarly has an impedance which is equivalent to a resistance in series with a reactance. The maximum power theorem says that maximum power is transferred from source to load when the load resistance equals the source resistance and the load reactance equals the negative of the source reactance. Another way of saying this is that the load impedance must equal the complex conjugate of the source impedance. If this condition is met the two parts of the circuit



are said to be *impedance matched*.

In a direct current (DC) circuit, the condition is satisfied if the load resistance equals the source resistance. In an alternating current (AC) circuit the reactance depends on frequency, so circuits which are impedance matched at one frequency may not be impedance matched if the frequency is changed. Impedance matching over a wide band will generally require complex, filter-like structures with many components except in the trivial case of constant source and load resistances when a transformer can be used.

In the case of a complex source impedance  $Z_s$  and load impedance  $Z_L$ , maximum power transfer is obtained when  $Z_s = Z_L^*$

where the asterisk indicates the complex conjugate of the variable. Where  $Z_s$  represents the characteristic impedance of a transmission line, minimum reflection is obtained when

$$Z_s = Z_L$$

The concept of impedance matching found first applications in electrical engineering, but is relevant in other applications in which a form of energy, not necessarily electrical, is transferred between a source and a load. An alternative to impedance matching is impedance bridging, in which the load impedance is chosen to be much larger than the source impedance and maximizing voltage transfer, rather than power, is the goal.

### Impedance-matching devices

Adjusting the source impedance or the load impedance, in general, is called "impedance matching". There are three ways to improve an impedance mismatch, all of which are called "impedance matching":

- Devices intended to present an apparent load to the source of  $Z_{load} = Z_{source}^*$  (complex conjugate matching). Given a source with a fixed voltage and fixed source impedance, the maximum power theorem says this is the only way to extract the maximum power from the source.
- Devices intended to present an apparent load of  $Z_{load} = Z_{line}$  (complex impedance matching), to avoid echoes. Given a transmission line source with a fixed source



impedance, this "reflection less impedance matching" at the end of the transmission line is the only way to avoid reflecting echoes back to the transmission line.

- Devices intended to present an apparent source resistance as close to zero as possible, or presenting an apparent source voltage as high as possible. This is the only way to maximize energy efficiency, and so it is used at the beginning of electrical power lines. Such an impedance bridging connection also minimizes distortion and electromagnetic interference; it is also used in modern audio amplifiers and signal-processing devices.

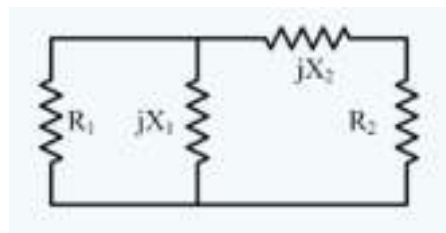
There are a variety of devices used between a source of energy and a load that perform "impedance matching". To match electrical impedances, engineers use combinations of transformers, resistors, inductors, capacitors and transmission lines. These passive (and active) impedance-matching devices are optimized for different applications and include antenna tuners (sometimes called ATUs or roller-coasters, because of their appearance), acoustic horns, matching networks, and terminators.

### Filters

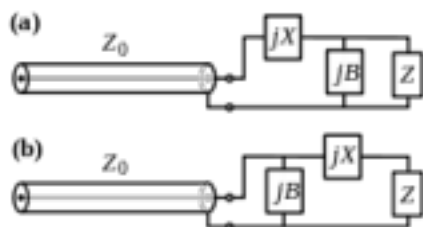
Filters are frequently used to achieve impedance matching in telecommunications and radio engineering. In general, it is not theoretically possible to achieve perfect impedance matching at all frequencies with a network of discrete components. Impedance matching networks are designed with a definite bandwidth, take the form of a filter, and use filter theory in their design.

Applications requiring only a narrow bandwidth, such as radio tuners and transmitters, might use a simple tuned filter such as a stub. This would provide a perfect match at one specific frequency only. Wide bandwidth matching requires filters with multiple sections.

### **L-section**



Basic schematic for matching  $R_1$  to  $R_2$  with an L pad.  $R_1 > R_2$ , however, either  $R_1$  or  $R_2$  may be the source and the other the load. One of  $X_1$  or  $X_2$  must be an inductor and the other must be a capacitor.



L networks for narrowband matching a source or load impedance  $Z$  to a transmission line with characteristic impedance  $Z_0$ .  $X$  and  $B$  may each be either positive (inductor) or negative (capacitor). If  $Z/Z_0$  is inside the  $1+jx$  circle on the Smith chart (i.e. if  $\text{Re}(Z/Z_0) > 1$ ), network (a) can be used; otherwise network (b) can be used.

A simple electrical impedance-matching network requires one capacitor and one inductor. In the figure to the right,  $R_1 > R_2$ , however, either  $R_1$  or  $R_2$  may be the source and the other the load. One of  $X_1$  or  $X_2$  must be an inductor and the other must be a capacitor. One reactance is in parallel with the source (or load), and the other is in series with the load (or source). If a reactance is in parallel *with the source*, the effective network matches from high to low impedance.

the reactance in parallel, has a negative reactance because it is typically a capacitor. This gives the L-network the additional feature of harmonic suppression since it is a low pass filter too.

The inverse connection (impedance step-up) is simply the reverse—for example, reactance in series with the source. The magnitude of the impedance ratio is limited by reactance losses such as the  $Q$  of the inductor. Multiple L-sections can be wired in cascade to achieve higher impedance ratios or greater bandwidth. Transmission line matching networks can be modeled as infinitely many L-sections wired in cascade. Optimal matching circuits can be designed for a particular system using Smith charts.



