EC4231OE

ELECTRONIC MEASUREMENTS AND INSTRUMENTATION

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UNIT –I

Block Schematics of Measuring Systems

INTRODUCTION

- Instrumentation is a technology of measurement which serves sciences, engineering, medicine and etc.

- Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.

- Instrument is a device for determining the value or magnitude of a quantity or variable.

- Electronic instrument is based on electrical or electronic principles for its measurement functions.

FUNCTION AND ADVANTAGES

- The 3 basic functions of instrumentation :-
  - Indicating – visualize the process/operation
  - Recording – observe and save the measurement reading
  - Controlling – to control measurement and process

- Advantages of electronic measurement
  - Results high sensitivity rating – the use of amplifier
  - Increase the input impedance – thus lower loading effects
  - Ability to monitor remote signal

PERFORMANCE CHARACTERISTICS

- Performance Characteristics - characteristics that show the performance of an instrument.
  - Eg: accuracy, precision, resolution, sensitivity.
- Allows users to select the most suitable instrument for a specific measuring jobs.
- Two basic characteristics :
  - Static – measuring a constant process condition.
  - Dynamic - measuring a varying process condition.

PERFORMANCE CHARACTERISTICS

- Accuracy – the degree of exactness (closeness) of measurement compared to the expected (desired) value.
- Resolution – the smallest change in a measurement variable to which an instrument will respond.
- Precision – a measure of consistency or repeatability of measurement, i.e successive reading do not differ.
- Sensitivity – ratio of change in the output (response) of instrument to a change of input or measured variable.
- Expected value – the design value or the most probable value that expect to obtain.
- Error – the deviation of the true value from the desired value.

ERROR IN MEASUREMENT

- Measurement always introduce error
- Error may be expressed either as absolute or percentage of error

Absolute error, e = $Y_n - X_n$

where Y_n – expected value

X_n – measured value

% error = $\left|\frac{Y_n - X_n}{Y_n}\right| \times 100$

ERROR IN MEASUREMENT

Relative accuracy, $A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right|$

% Accuracy, a = 100% - % error

= $A \times 100$

Precision, P = $1 - \left| \frac{X_n - \overline{X_n}}{\overline{X_n}} \right|$

where X_n - value of the n[th] measurement

$\overline{X_n}$ - average set of measurement

PRECISION

- The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements.

Example

Given expected voltage value across a resistor is 80V.

The measurement is 79V. Calculate,

i. The absolute error
ii. The % of error
iii. The relative accuracy
iv. The % of accuracy

LIMITING ERROR

- The accuracy of measuring instrument is guaranteed within a certain percentage (%) of full scale reading
- E.g manufacturer may specify the instrument to be accurate at ±2 % with full scale deflection
- For reading less than full scale, the limiting error increases

Significant Figures

- Significant figures convey actual information regarding the magnitude and precision of quantity
- More significant figure represent greater precision of measurement

Example 1.3

Find the precision value of X_1 and X_2?

$$X_n = 101$$

$$X_1 = 98 \quad ===>> 2\ s.f$$

$$X_2 = 98.5 \quad ===>> 3\ s.f$$

TYPES OF STATIC ERROR

- Types of static error

  1) Gross error/human error
  2) Systematic Error
  3) Random Error

TYPES OF STATIC ERROR

1) **Gross Error**

- cause by human mistakes in reading/using instruments
- may also occur due to incorrect adjustment of the instrument and the computational mistakes
- cannot be treated mathematically
- cannot eliminate but can minimize
- Eg: Improper use of an instrument.
- This error can be minimized by taking proper care in reading and recording measurement parameter.
- In general, indicating instruments change ambient conditions to some extent when connected into a complete circuit.
- Therefore, several readings (at three readings) must be taken to minimize the effect of ambient condition changes.

TYPES OF STATIC ERROR (cont)

2) Systematic Error

- due to shortcomings of the instrument (such as defective or worn parts, ageing or effects of the environment on the instrument)

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

TYPES OF STATIC ERROR (cont)

3 types of systematic error :-

(i) Instrumental error

(ii) Environmental error

(iii) Observational error

TYPES OF STATIC ERROR (cont)

(i) Instrumental error

Inherent while measuring instrument because of their mechanical structure (eg: in a D'Arsonval meter, friction in the bearings of various moving component, irregular spring tension, stretching of spring, etc)

Error can be avoid by:

(a) selecting a suitable instrument for the particular measurement application

(b) apply correction factor by determining instrumental error

(c) calibrate the instrument against standard

TYPES OF STATIC ERROR (cont)

(ii) Environmental error

- due to external condition effecting the measurement including surrounding area condition such as change in temperature, humidity, barometer pressure, etc
- to avoid the error :-
  (a) use air conditioner
  (b) sealing certain component in the instruments
  (c) use magnetic shields

(iii) Observational error

- introduce by the observer
- most common : parallax error and estimation error (while reading the scale)
- Eg: an observer who tend to hold his head too far to the left while reading the position of the needle on the scale.

Dynamic Characteristics

- Dynamic – measuring a varying process condition.
- Instruments rarely respond instantaneously to changes in the measured variables due to such things as mass, thermal capacitance, fluid capacitance or electrical capacitance.
- Pure delay in time is often encountered where the instrument waits for some reaction to take place.
- Such industrial instruments are nearly always used for measuring quantities that fluctuate with time.
- Therefore, the dynamic and transient behavior of the instrument is important.

Dynamic Characteristics

- The dynamic behavior of an instrument is determined by subjecting its primary element (sensing element) to some unknown and predetermined variations in the measured quantity.

- The three most common variations in the measured quantity:
  - Step change
  - Linear change
  - Sinusoidal change

Dynamic Characteristics

- **Step change-**in which the primary element is subjected to an instantaneous and finite change in measured variable.

- **Linear change-**in which the primary element is following the measured variable, changing linearly with time.
- **Sinusoidal change-**in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude.

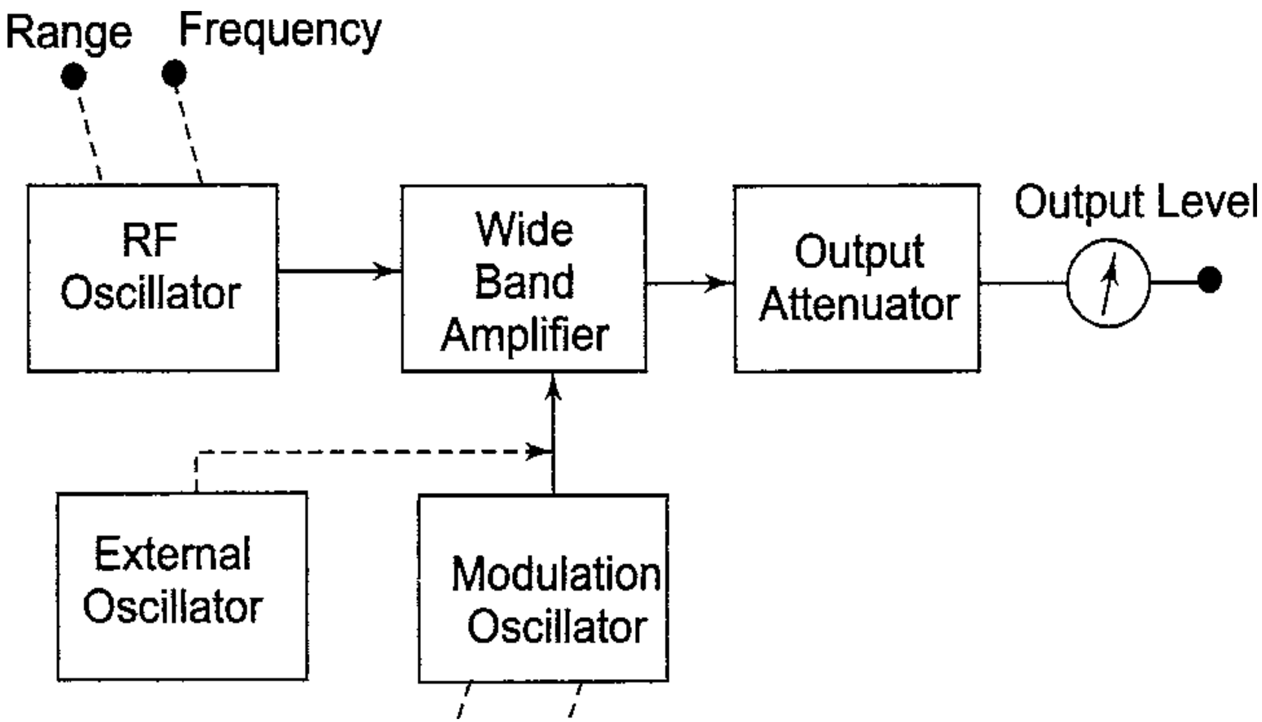
The rapidity with which aninstrument responds changes in measured quantity.

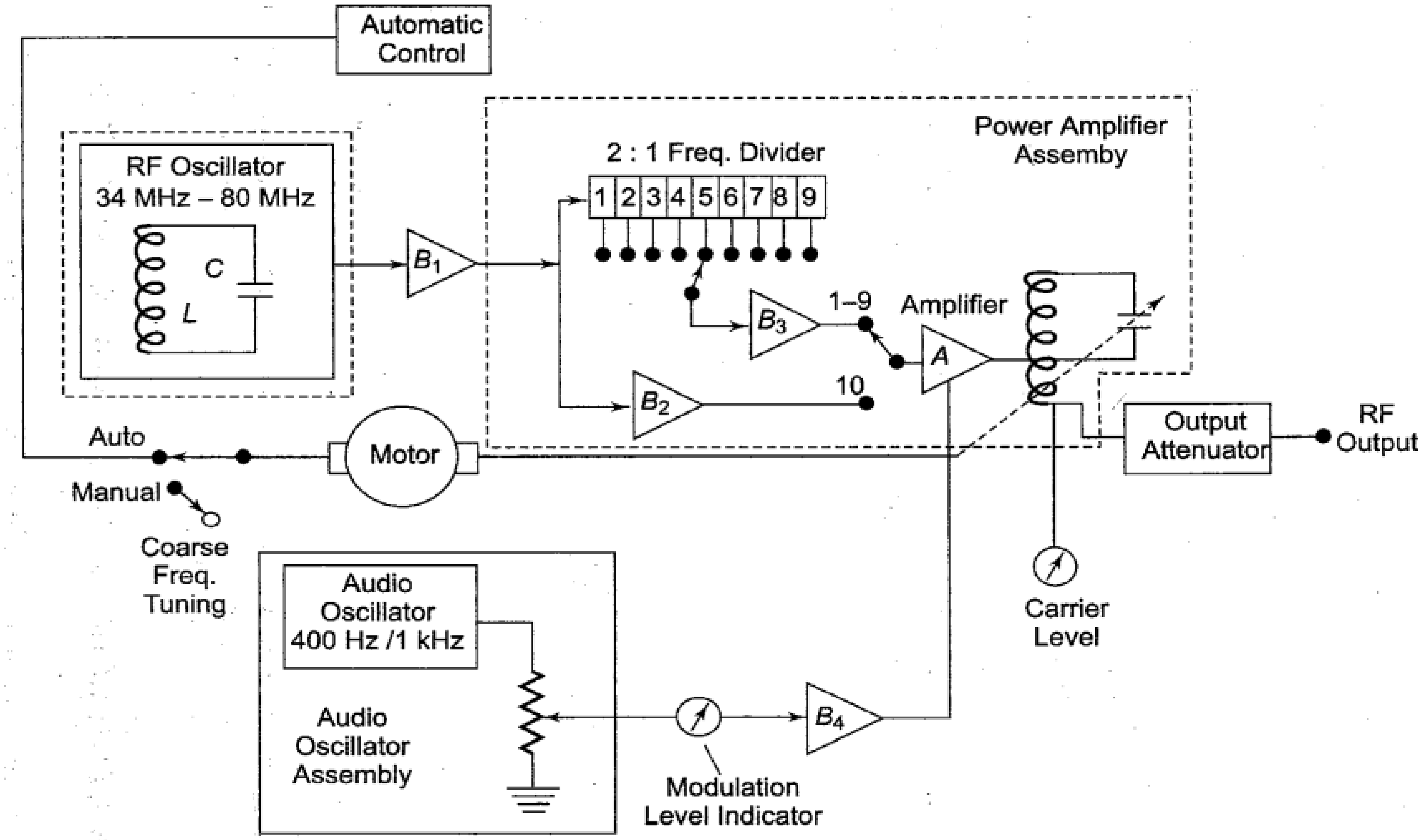
- Dynamic error-The difference between the true and measured value with no static error.
- Lag – delay in the response of an instrument to changes in the measured variable.
- Fidelity – the degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction).

UNIT-II

Signal Generators

Signal Generator





Automatic Control
RF Oscillator 34 MHz – 80 MHz
C
L
B1
2 : 1 Freq. Divider
1 2 3 4 5 6 7 8 9
Power Amplifier Assemby
B3
1–9
Amplifier
A
B2
10
Auto
Manual
Motor
Coarse Freq. Tuning
Output Attenuator
RF Output
Carrier Level
Audio Oscillator 400 Hz /1 kHz
Audio Oscillator Assembly
B4
Modulation Level Indicator

- Highest freq. ranges are provided by RF Oscillator (34MHz –
- 80MHz).
- „ Lowest freq. ranges are obtained by using **frequency divider.**
  - ‰ 34MHz – 80MHz divided by 512 (2^9) Æ 67kHz – 156kHz.
- „ Buffer amplifiers (B_1, B_2, B_3) provide isolation between the master oscillator and power amplifier.
- ‰ Eliminates frequency effects (signal distortion) between input and output circuits.

- Compared to conventional std. signal gen, modern signal generator uses same oscillator on all bands.‰

- Eliminates range switching effects.

‰ Master oscillator is tuned by a motor driven variable capacitor.

,, Coarse freq. tuning – 7% frequency changes per second.

,, Fine tuning – at 0.01% of the main dial.

,, Modulation process is done at the power amplifier stage.

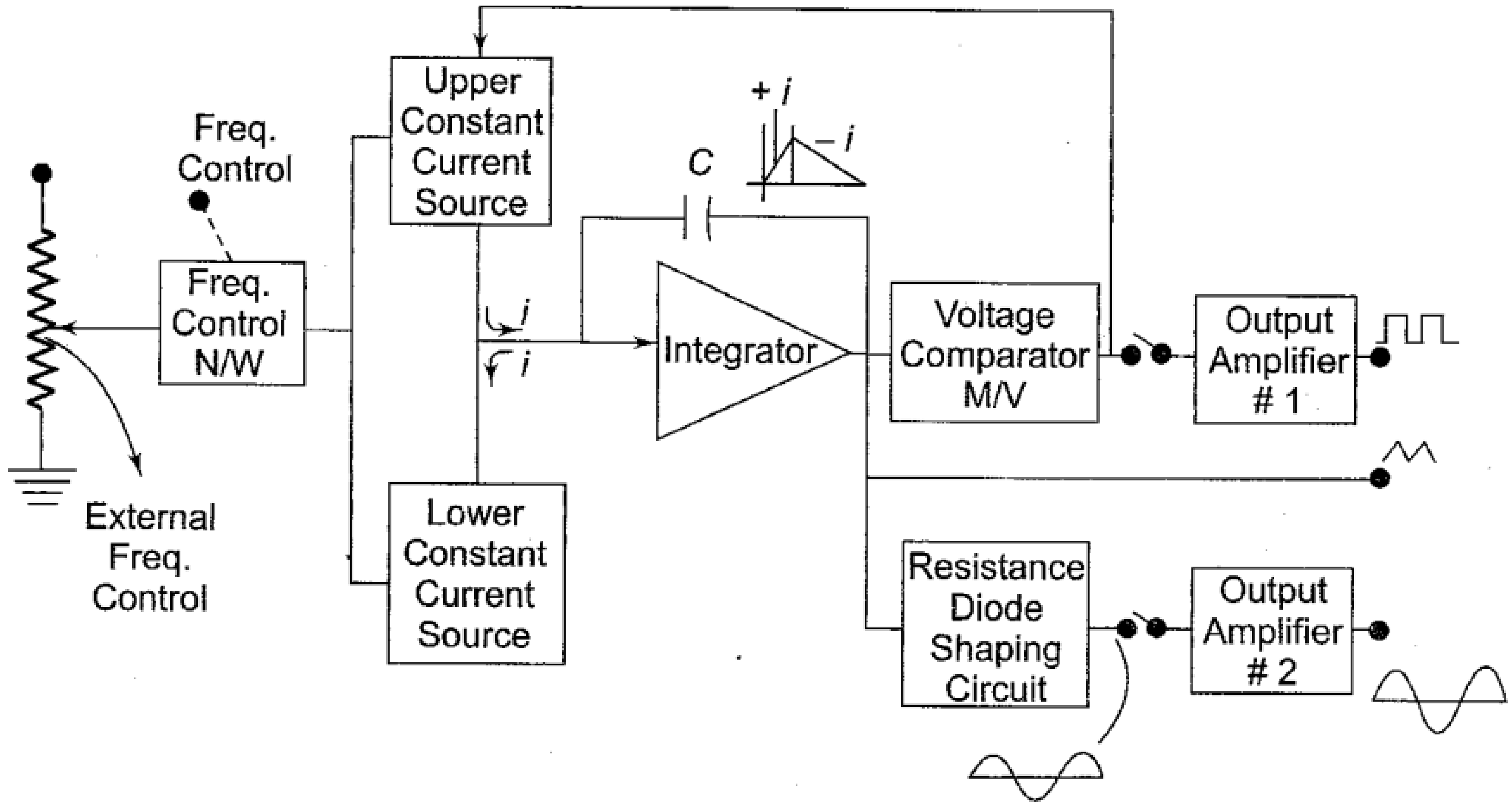
‰ Two internally generated signal are used (400Hz &1kHz) for modulation.

FUNCTION GENERATOR

- ,,A **function generator** produces different waveforms of
- adjustable frequency.
- The common output waveforms are the sine, square, triangular.

- ,,Theblock diagram of a function generator is shown in Figure 3.
- Freq. Control – regulates two currents sources (control the freq).
- Upper current source – supplies constant current to the integrator, produces an output voltage .
- Lower current source – supplies a reverse current to the
- integrator so that its output decreases linearly with time.

FUNCTION GENERATOR



- Frequency is controlled by varying upper and lower currents.
- An increase or decrease in the current will increase or decrease the slope of the output voltage, hence controls the frequency.

- The **voltage comparator –** changes states at a pre-determined maximum and minimum level of the integrator output voltage.
- ‰ When the pre-determined level is reached, it changes the state and switches the current source.

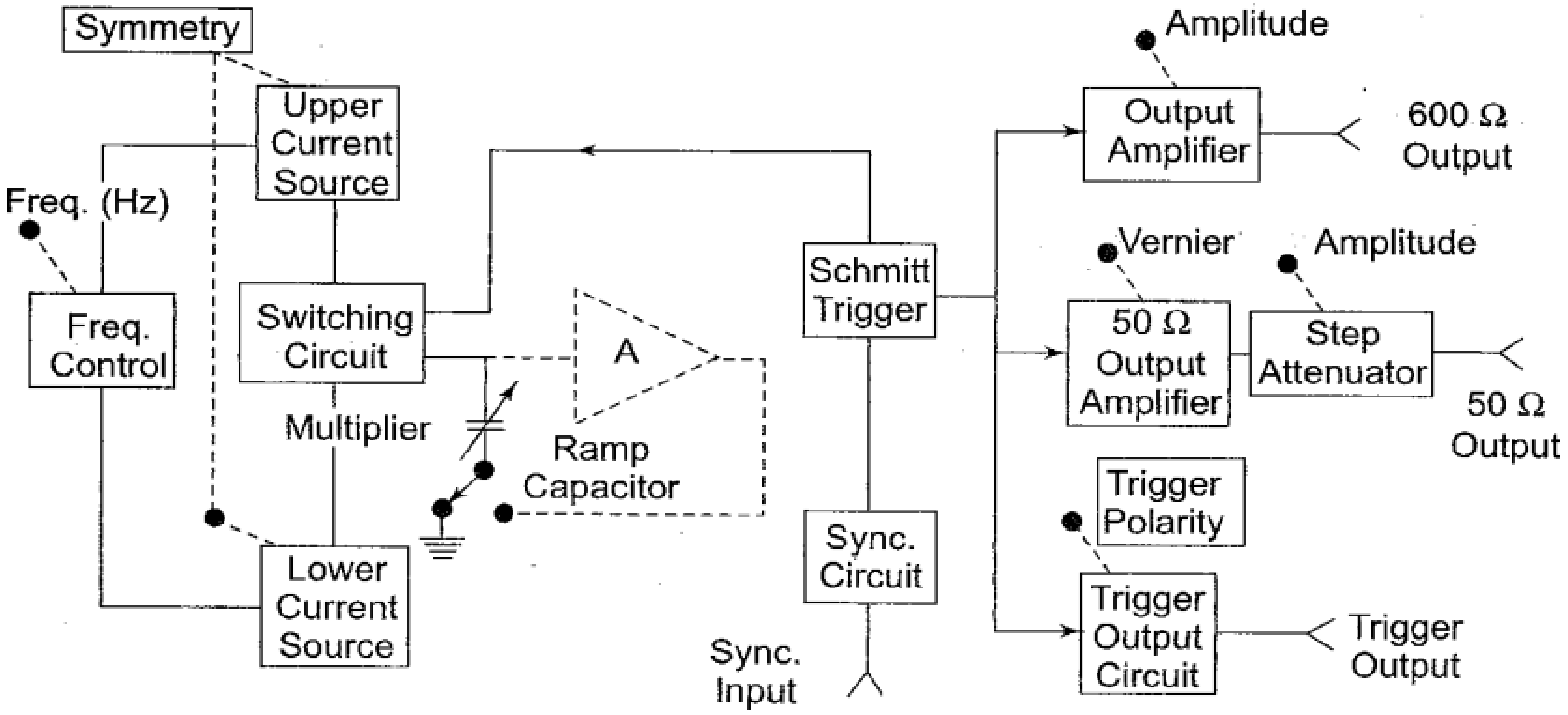
- ‰ Produces a square wave.

- The **integrator** output is a triangular waveform whose frequency is determined by the magnitude of the constant current sources.
- he **comparator** output delivers a square wave of the same frequency.
- The **resistance diode network** produces a sine wave from the triangular wave with less than 1% distortion.

PULSE GENERATOR

- **Pulse generators** are instruments that produce a rectangular waveform similar to a square wave but with a different duty cycle.
- Duty cycle = pulse width/pulse period,,
- A square wave generator has a 50% duty cycle.
- The basic circuit for pulse generation is the **asymmetrical multi-vibrator**.
- Figure . shows block diagram of a pulse generator.

PULSE GENERATOR



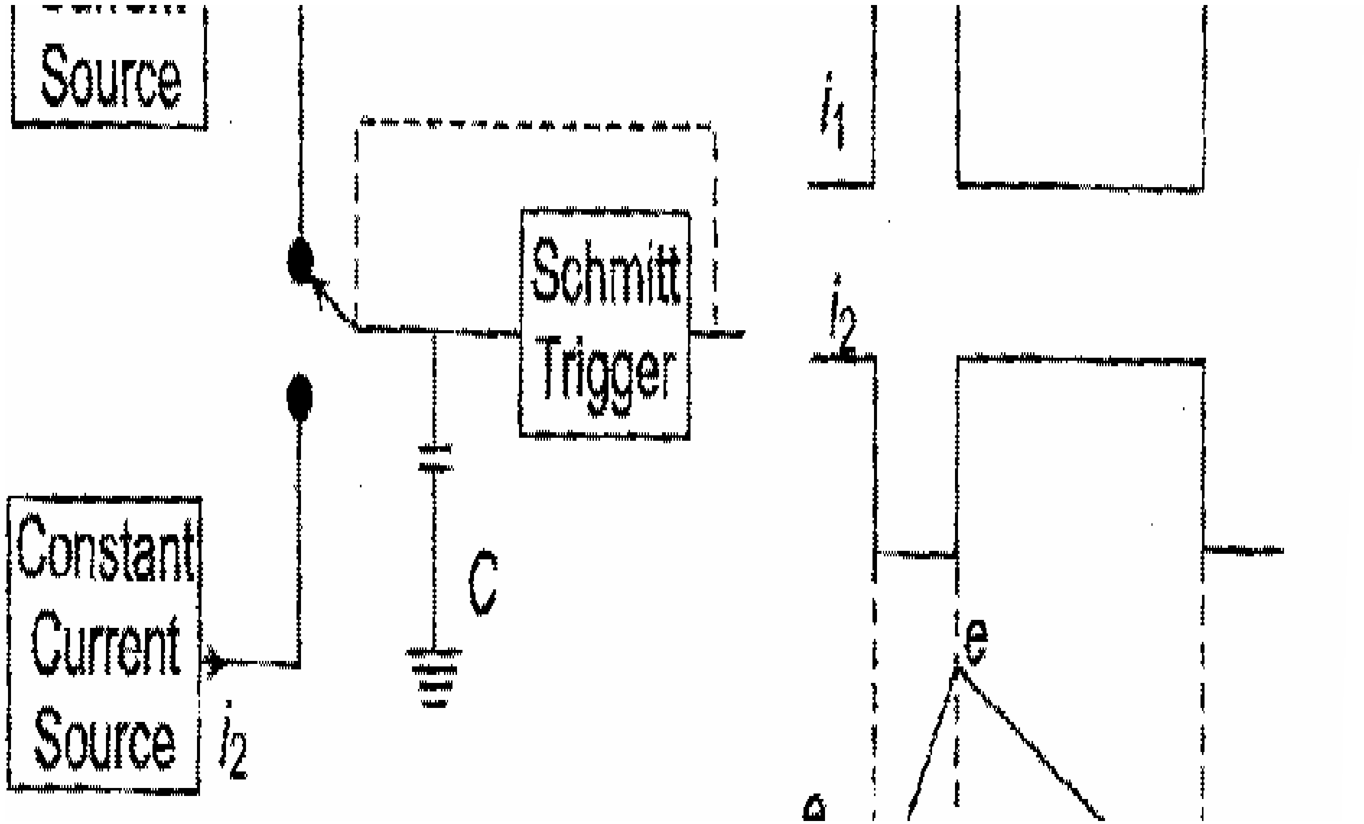
- ,,Theduty cycle can be varied from 25 to 75%
- Two independent outputs:
- 50Ω - supplies pulses with a rise and fall time of 5ns at 5Vp.
- 600Ω-supplies pulses with a rise and fall time of 70ns at 30Vp.
- The instrument can operate as a free-running or can be

Basic generating loop consists of the current sources, the

ramp capacitor, the Schmitt trigger, and the current switching

circuit

PULSE GENERATOR



PULSE GENERATOR

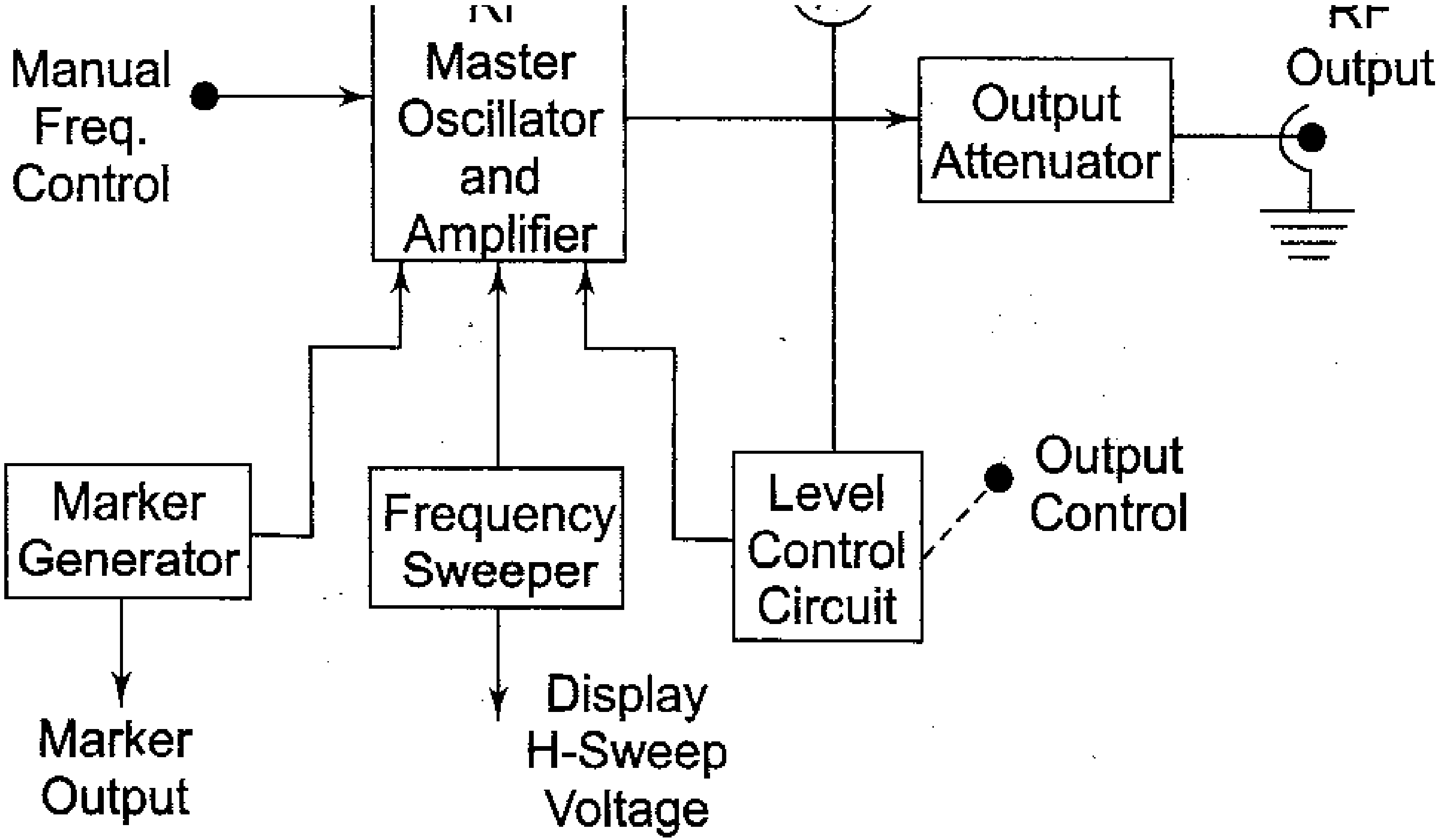
- „Uppercurrent source – supplies a constant current to the ramp capacitor and the capacitor voltage increases linearly.
- When the positive slope of the ramp reaches the upper limit
- Schmitt trigger will change a state
- Reverses the condition of the current switch.
- Capacitor discharges linearly. (lower current source takes part)
- When the negative slope of the ramp reaches the lower limit, upper current will control the circuit.
- The process is repeated.
- The ratio i_1/i_2 determines the duty cycle, and is controlled by **symmetry control**.The sum of i_1 and i_2 determines the frequency.
- The size of the capacitor is selected by the **multiplier switch**.

SWEEP GENERATOR

- **Sweep frequency generators** are instruments that provide a sine wave in the RF range.
- Its frequency can be varied smoothly and continuously over an entire frequency band.
- Figure 8 shows the block diagram of the sweep generator.
- The **frequency sweeper** provides a varying sweep voltage for synchronization to drive the horizontal deflection plates of the CRO.

- ,, A sweep rate can be of the order of 20 sweeps/sec.
- ,, Figure 9 shows the modulated sinewave by a **voltage- controlled oscillator** (VCO).

SWEEP GENERATOR



- Radio Frequency Generator
- **Radio frequency generators** are designed to provide an output signal over a wide range of frequencies from approximately 30 kHz to nearly 3000 MHz.
- Contain a precision output attenuator network that permits selection of output voltages from 1 uV to 3V in precise steps.

output impedance= 50Ω.

- „Figure. shows a block diagram for a basic RF signal generator.
- The frequency range is selected with the **band selector** and exact freq. is selected with the Vernier freq. selector.
- Broadband amplifier – provides buffering between the oscillator and the load connected to the output terminal.
- The output of the attenuator is monitored by the output meter.

UNIT-III

MEASURING INSTRUMENTS

INTRODUCTION:

- The cathode-ray oscilloscope (CRO) is a multipurpose display instrument used for the observation, measurement , and analysis of waveforms by plotting amplitude along *y-axis and time along x-axis*.
- *CRO is generally* an *x-y plotter; on a single screen it can display different signals applied to different channels. It can measure* amplitude, frequencies and phase shift of various signals. Many physical quantities like temperature, pressure
- and strain can be converted into electrical signals by the use of transducers, and the signals can be displayed on the CRO.
- A moving luminous spot over the screen displays the signal. CROs are used to study waveforms, and other time-varying phenomena from very low to very high frequencies.
- The central unit of the oscilloscope is the cathode-ray tube (CRT), and the remaining part of the CRO consists of the circuitry required to operate the cathode-ray tube.

Objectives:

- This final chapter discusses the key instruments of electronic measurement with special emphasis on the most versatile instrument of electronic measurement—the cathode-ray oscilloscope (CRO).
- The objective of this book will remain unrealized without a discussion on the CRO.
- The chapter begins with the details of construction of the CRO, and proceeds to examine the active and passive mode input–output waveforms for filter circuits and lead-lag network delay.
- This will be followed by a detailed study of the dual beam CRO and its uses in op-amp circuit integrator, differentiator, inverting and non-inverting circuits, comparative waveform study, and accurate measurement with impeccable visual display.
- In addition to the CRO, the chapter also examines the sweep frequency generator, the function generator, the sine wave generator, the square wave generator and the AF signal generator.

VOLTMETER LOADING EFFECTS

- When a voltmeter is used to measure the voltage across a circuit component, the voltmeter circuit itself is in parallel with the circuit component.
- Total resistance will decrease, so the voltage across component will also decrease. This is called voltmeter loading.
- The resulting error is called a loading error.
- The voltmeter loading can be reduced by using a high sensitivity voltmeter.
- How about ammeter??

AMMETER INSERTION EFFECTS

- Inserting Ammeter in a circuit always increases the resistance of the circuit and, thus always reduces the current in the circuit. The expected current:

$$I_e = \frac{E}{R_1}$$

- Placing the meter in series with R1 causes the current to reduce to a value equal to:

$$I_m = \frac{E}{R_1 + R_m}$$

AMMETER INSERTION EFFECTS

- Dividing equation 1 by 2 yields:

$$\frac{I_m}{I_e} = \frac{R_1}{R_1 + R_m}$$

- The Ammeter insertion error is given by :

Insertion Error

$$= \left|\left(1 - \frac{I_m}{I_e}\right)\right| X\ 100$$

OHMMETER (Series Type)

- Current flowing through meter movements depends on the magnitude of the unknown resistance.
- The meter deflection is non-linearly related to the value of the unknown Resistance, R_x.
- A major drawback – as the internal voltage decreases, reduces the currentand meter will not get zero Ohm.
- R_2 counteracts the voltage drop to achieve zero ohm. How do you get zero Ohm?
- R_1 and R_2 are determined by the value of $R_x = R_h$ where R_h = half of full scale deflection resistance.

$$R_h = R_1 + (R_2 \,//\, R_m) = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

- The total current of the circuit, $It=V/R_h$
- The shunt current through R2 is $I_2=I_t-I_{fsd}$

OHMMETER (Series Type)

- The voltage across the shunt, Vsh= Vm

So, $I_2 R_2 = I_{fsd} R_m$

Since $I_2 = I_t - I_{fsd}$

Then,

$$R_2 = \frac{I_{fsd} R_m}{I_t - I_{fsd}}$$

Since $I_t = V/R_h$

So,

$$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h}$$

$$R_1 = R_h - \frac{I_{fsd} R_m R_h}{V}$$

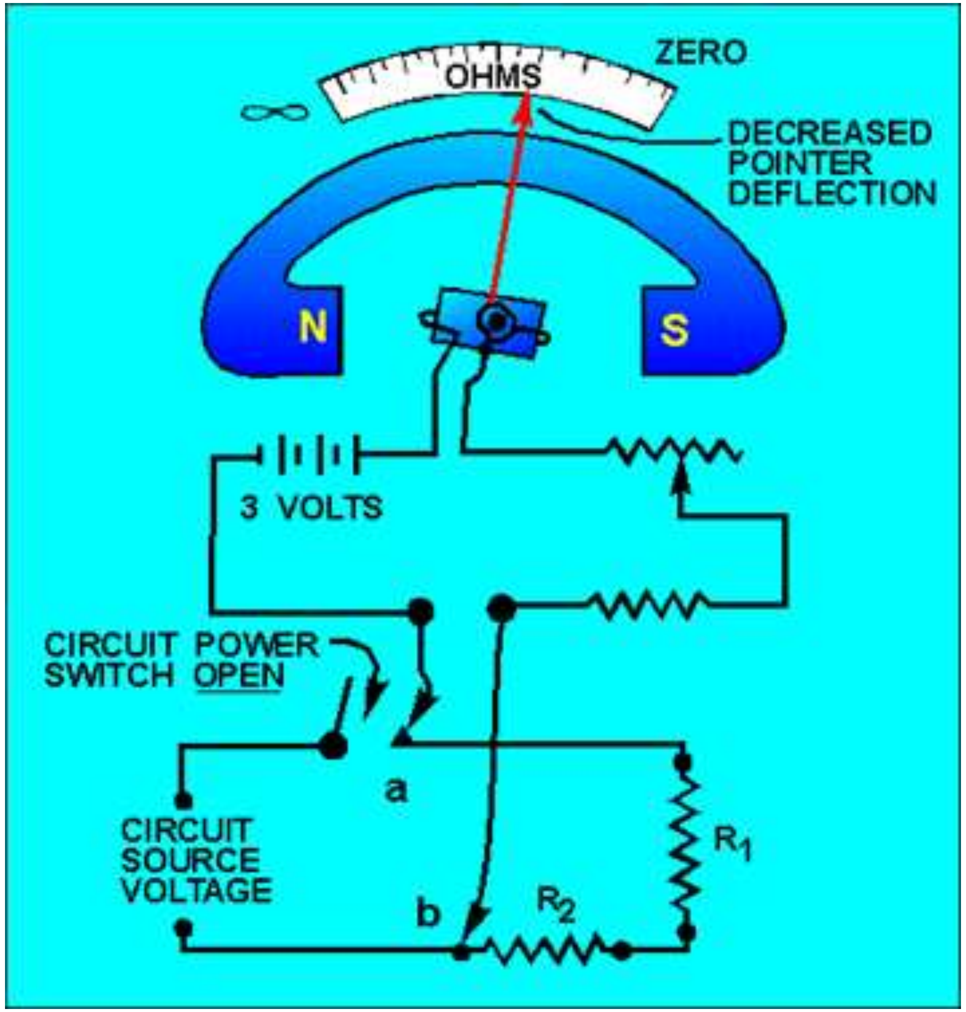


Figure : Measuring circuit resistance with an ohmmeter

MULTIMETER

- Multimeter consists of an ammeter, voltmeter and ohmmeter in one unit.
- It has a function switch to connect the appropriate circuit to the D'Arsonval movement.
- Fig.4.33 (in text book) shows DC miliammeter, DC voltmeter, AC voltmeter, microammeter and ohmmeter.

AC VOLTMETER USING HALF-WAVE RECTIFIER

- The D'Arsonval meter movement can be used to measure alternating current by the use of a diode rectifier to produce unidirectional current flow.
- In case of a half wave rectifier, if given input voltage, Ein = 10 Vrms, then:

Peak voltage,

$$E_p = 10V_{rms} \times 1.414 = 14.14V$$

Average voltage,

$$E_{ave} = E_{dc} = 0.636 \times E_p = 8.99V$$

- Since the diode conducts only during the positive half cycle as shown in Fig 4.18(in text book), the average voltage is given by:

$$E_{ave} / 2 = 4.5V$$

AC VOLTMETER USING HALF-WAVE RECTIFIER

- Therefore, the pointer will deflect for a full scale if 10 Vdc is applied and only 4.5 V when a 10 Vrms sinusoidal signal is applied.
- The DC voltmeter sensitivity is given by:

$$S_{dc} = \frac{1}{I_m} = \frac{1}{1mA} = 1k\Omega/V$$

- For the circuit in Figure 4.18, the AC voltmeter sensitivity is given by:

$$S_{ac} = 0.45 S_{dc} = 0.45 k\Omega /V$$

- This means that an AC voltmeter is not as sensitive as a DC voltmeter.

AC VOLTMETER USING HALF-WAVE RECTIFIER

- Toget the multiplier resistor, Rs value:

$$E_{dc} = 0.45 \times E_{rms}$$

$$R_s = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.45 \times E_{rms}}{I_{dc}} - R_m$$

o The AC meter scale is usually calibrated to give the RMS value of analternating sine wave input.

- A more general AC voltmeter circuit is shown in Fig. 4.17 (in text book)
- A shunt resistor, Rsh is used to draw more current from the diode D1 to move its operating point to a linear region.
- Diode D2 is used to conduct the current during the negative half cycle.
- The sensitivity of AC voltmeter can be doubled by using a full wave rectifier.

Sensitivity, Span, Precision

- *Sensitivity* is a parameter extracted from the instrument response (based on the assumption that the response is linear). If *input quantity* changes by ΔQ_{INP}, resulting in the *output quantity* change of ΔQ_{OUT}, then the sensitivity is

$$S = \frac{\Delta Q_{out}}{\Delta Q_{inp}}$$

- *Span* of the Instrument is the difference between the upper and the lower limits of operation

span = Upper – Lower

- *Precision Measurement* requires a measurement system capable of resolving very small signals, (say, one part in 10^7). In other words, the precise measurement is such for which

Span / Resolution » 1

Block diagram of a cathode-ray oscilloscope:

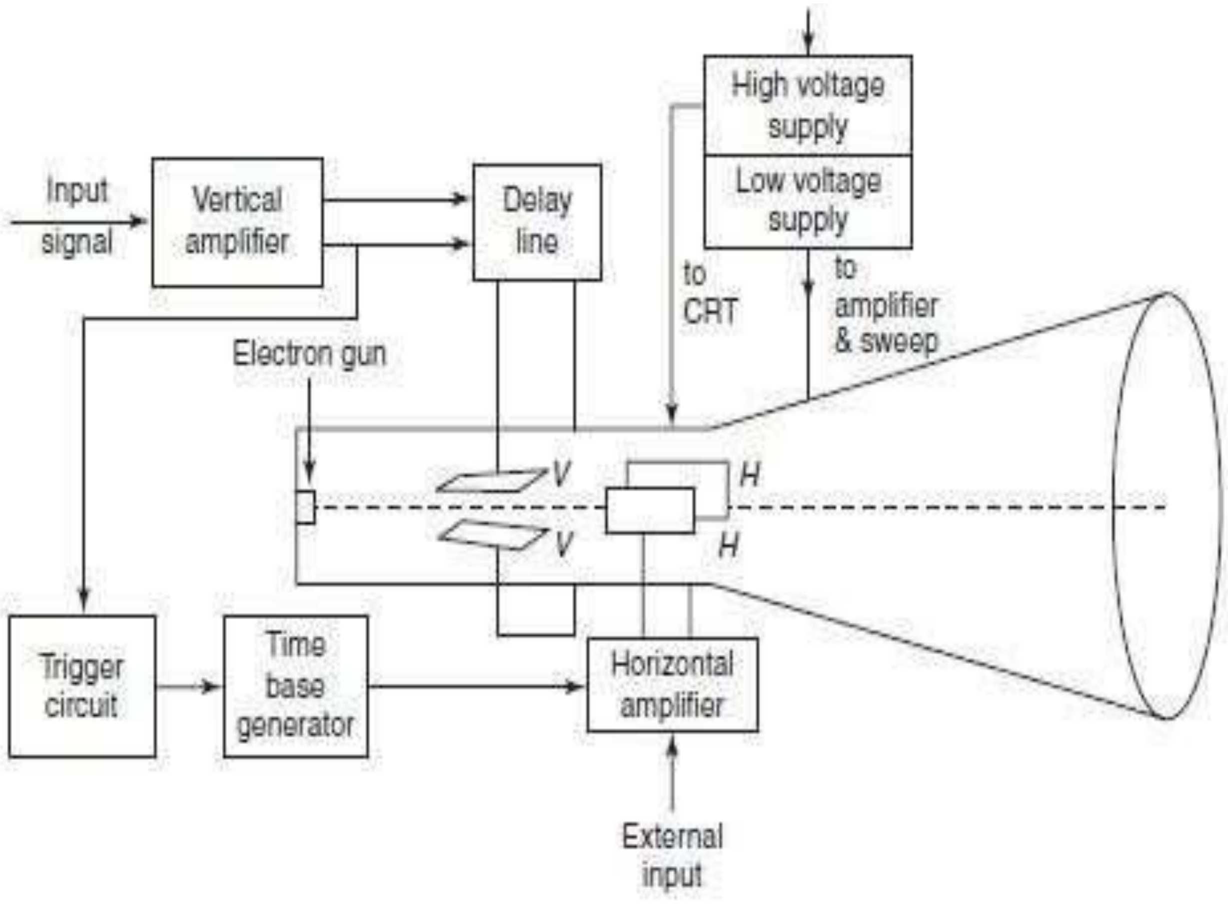


Figure 14-1 Block diagram of a cathode-ray oscilloscope

COMPONENTS OF THE CATHODE-RAY OSCILLOSCOPE:

The CRO consists of the following:

- (i) CRT
- (ii) Vertical amplifier
- (iii) Delay line
- (iv) Horizontal amplifier
- (v) Time-base generator
- (vi) Triggering circuit
- (vii) Power supply

CATHODE-RAY TUBE

- The **electron gun or electron emitter, the deflecting system and the fluorescent screen** are the three major components of a general purpose CRT. A detailed diagram of the cathode-ray oscilloscope is given in Fig. 14-2.

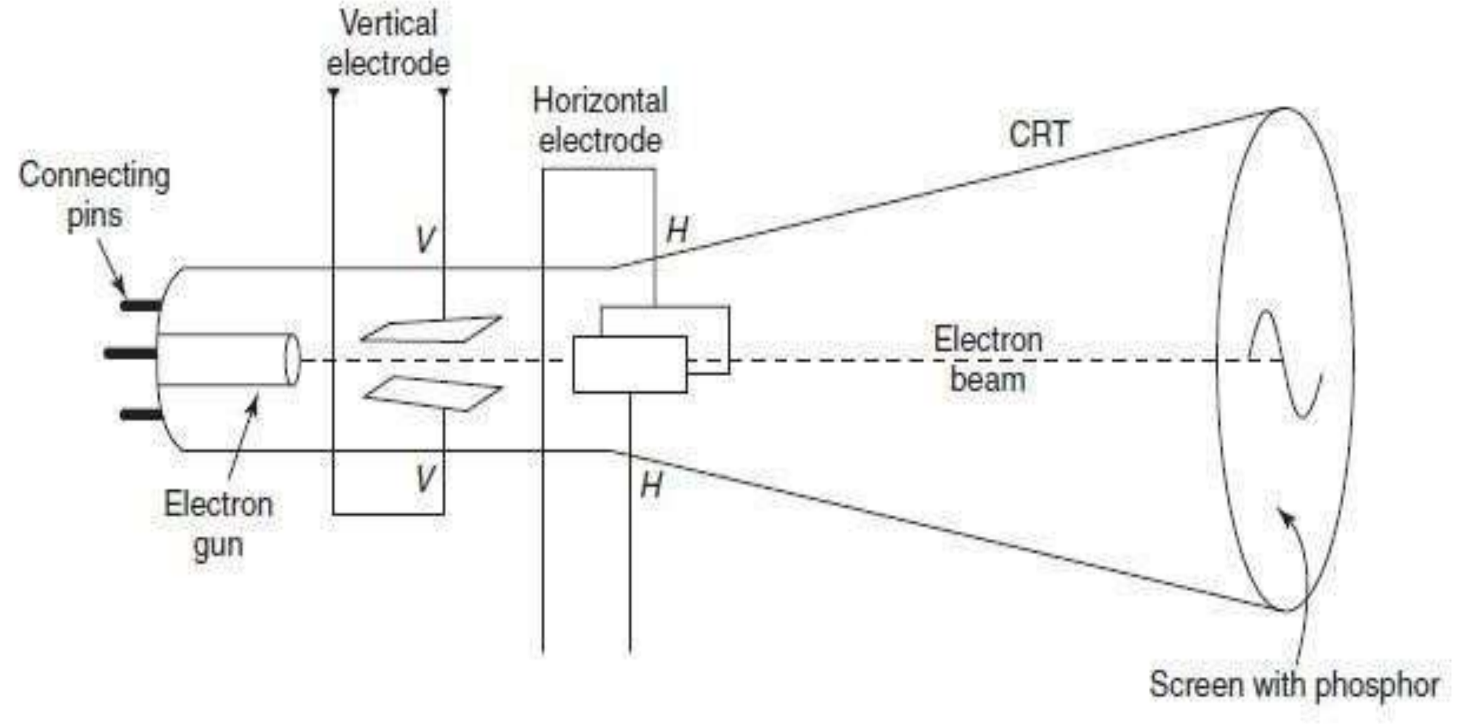


Figure 14-2 Components of a cathode-ray oscilloscope

Electron Gun:

- In the electron gun of the CRT, electrons are emitted, converted into a sharp beam and focused upon the fluorescent screen.

- The electron beam consists of an indirectly heated cathode, a control grid, an accelerating electrode and a focusing anode.

- The electrodes are connected to the base pins. The cathode emitting the electrons is surrounded by a control grid with a fine hole at its center.

- The accelerated electron beam passes through the fine hole.
- The negative voltage at the control grid controls the flow of electrons in the electron beam, and consequently, the brightness of the spot on the CRO screen is controlled.

Deflection Systems:

- Electrostatic deflection of an electron beam is used in a general purpose oscilloscope. The deflecting system consists of a pair of horizontal and vertical deflecting plates.

- Let us consider two parallel vertical deflecting plates *P1 and P2. The beam is focused at point O on the screen in the absence of a deflecting plate voltage.*

- *If a* positive voltage is applied to plate *P1 with respect to plate P2, the negatively charged electrons are attracted towards* the positive plate *P1, and these electrons will come to focus at point Y1 on the fluorescent screen.*

Deflection Systems:

- To deflect the beam horizontally, an alternating voltage is applied to the horizontal deflecting plates and the spot on the screen horizontally, as shown in Fig. 14-3(b).
- The electrons will focus at point *X2. By changing the polarity* of *voltage, the beam will focus at point X1. Thus, the* horizontal movement is controlled along *X1OX2 line.*

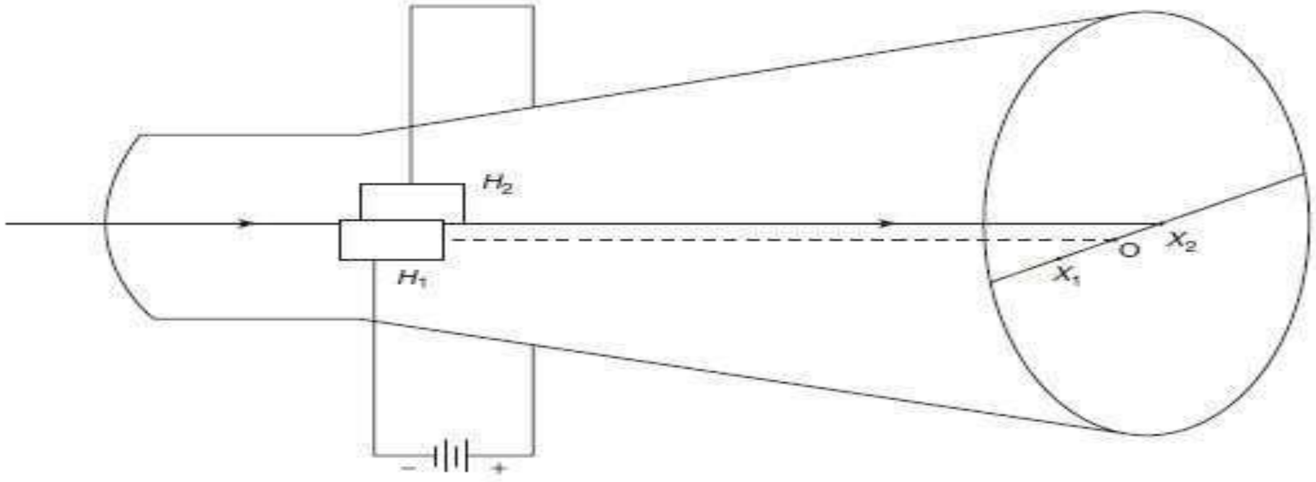


Figure 14-3(b) Deflecting system using parallel horizontal plate

Electrostatic Deflection:

Electrostatic Deflection

s = separation between deflecting plates

P = distance between the plate and screen S

l = length of each deflecting plate

V_d = deflecting voltage applied across the plates

m = mass of the electron

e = charge of the electron

v = velocity of the entering electron

V_a = accelerating anode voltage

Thus:

$$\frac{1}{2}mv^2 = eV_a \tag{14-2}$$

$$v^2 = \frac{2eV_a}{m} \tag{14-3}$$

Force exerted on the electron towards the positive deflecting plate is:

$$F.s = eV_d$$

$$F = \frac{eV_d}{s} \tag{14-4}$$

Fluorescent Screen:

- Phosphor is used as screen material on the inner surface of a CRT. Phosphor absorbs the energy of the incident electrons. The spot of light is produced on the screen where the electron beam hits.
- The bombarding electrons striking the screen, release secondary emission electrons. These electrons are collected or trapped by an aqueous solution of graphite called ―Aquadag‖ which is connected to the second anode.
- Collection of the secondary electrons is necessary to keep the screen in a state of electrical equilibrium.
- The type of phosphor used, determines the color of the light spot. The brightest available phosphor isotope, P31, produces yellow–green light with relative luminance of 99.99%.

Triangular wave form

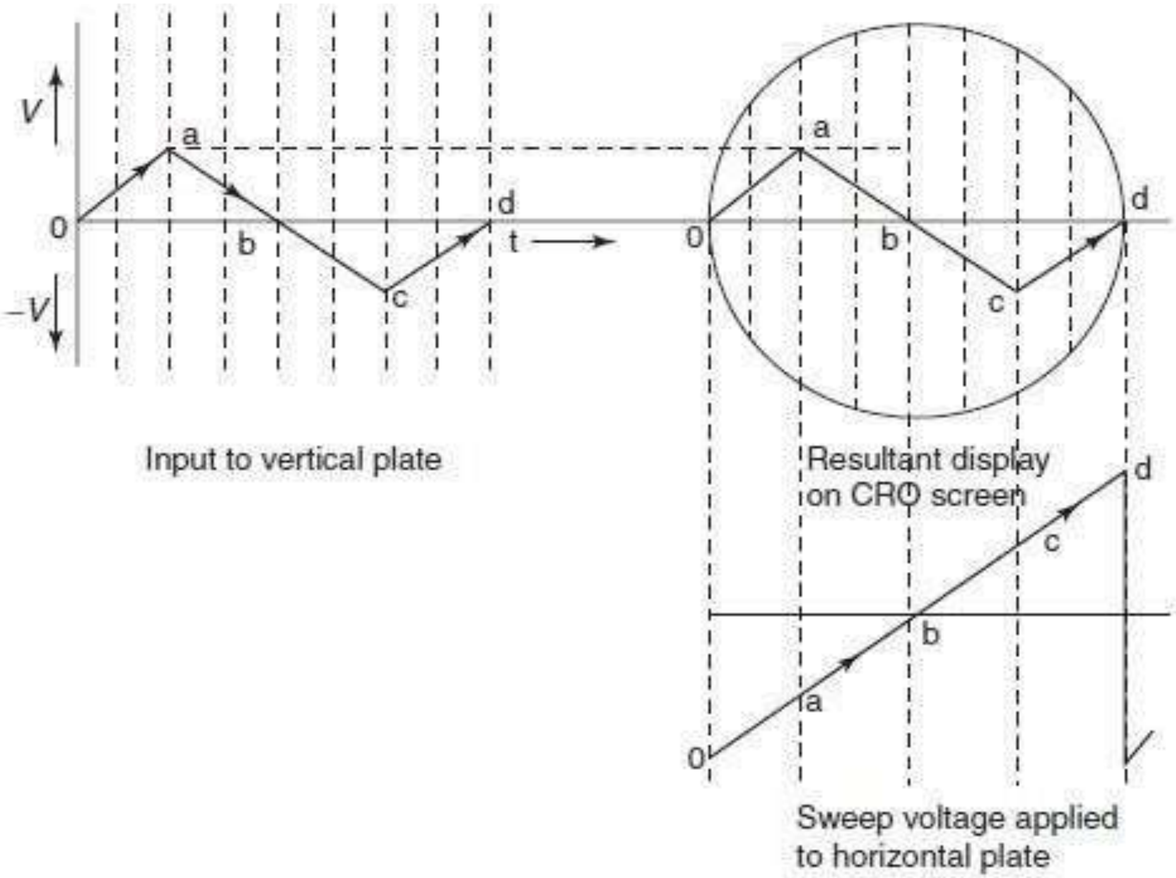


Figure 14-5(b) Triangular waveform input applied to the vertical deflecting plates of CRO

TIME-BASE GENERATORS

be accurately reproduced, the beam should have a constant horizontal velocity.

- As the beam velocity is a function of the deflecting voltage, the deflecting voltage must increase linearly with time.
- A voltage with such characteristics is called a ramp voltage. If the voltage decreases rapidly to zero—with the waveform repeatedly produced, as shown in Fig. 14-6—we observe a pattern which is generally called a saw-tooth waveform.
- The time taken to return to its initial value is known as fly back or return time.

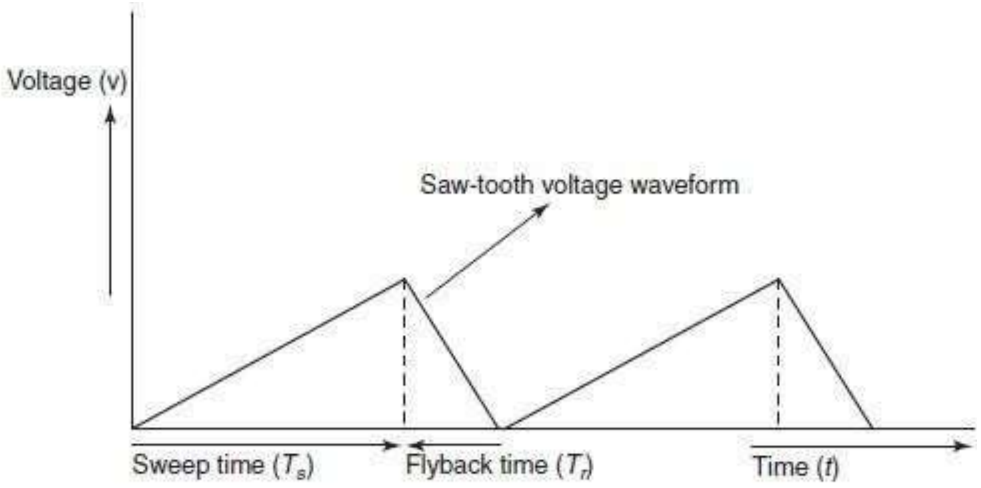


Figure 14-6 Typical saw-tooth waveform applied to the horizontal deflection plates

Simple saw-tooth generator & associated waveforms:

- The circuit shown in Fig. 14-7(a) is a simple sweep circuit, in which the capacitor *C charges through the* resistor *R.*
- *The capacitor discharges periodically through the transistor T1, which causes the waveform shown* in Fig. 14-7(b) to appear across the capacitor.
- The signal voltage, *Vi which must be applied to the base of the* transistor to turn it ON for short time intervals is also shown in Fig. 14-7(b).

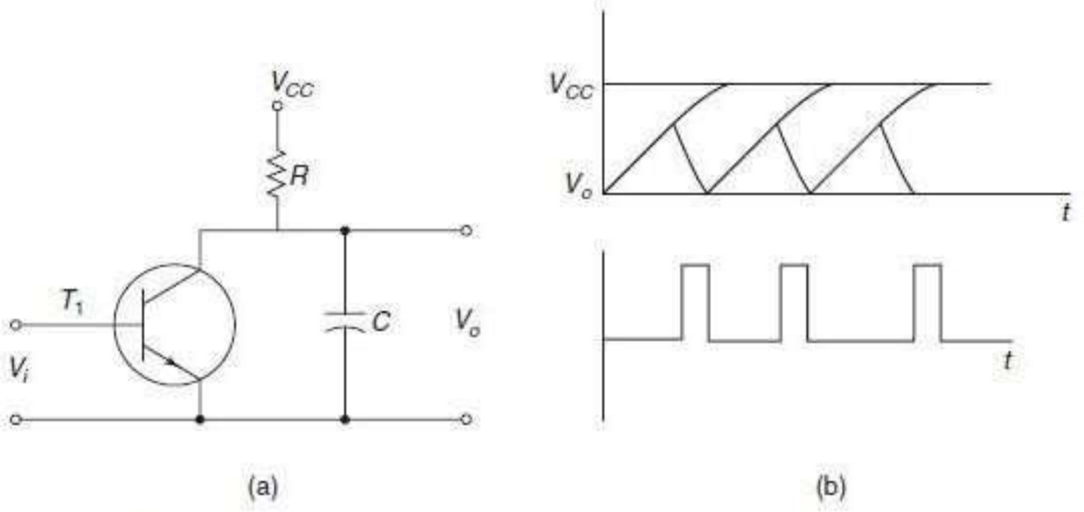


Figure 14-7: (a) simple saw-tooth generator (b) associated waveforms.

Time-base generator using UJT:

- The continuous sweep CRO uses the UJT as a time-base generator. When power is first applied to the UJT,it is in the OFF state and *CT changes exponentially through RT .*
- *The UJT emitter* voltage *VE rises towards VBB and VE reaches the plate voltage VP.*
- The emitter-to-base diode becomes forward biased and the UJT triggers ON. This provides a low resistance discharge path and the capacitor discharges rapidly.
- When the emitter voltage *VE reaches* the minimum value rapidly, the UJT goes OFF. The capacitor recharges and the cycles repeat.

- Toimprove the sweep linearity, two separate voltage supplies are used; a low voltage supply for the UJT and a high voltage supply for the *RTCT circuit. This circuit is as shown in Fig. 14-7(c).*

- *RT is used for continuous control of frequency within a range and CT is varied or changed in steps. They are sometimes known as*

timing resistor and timing capacitor.

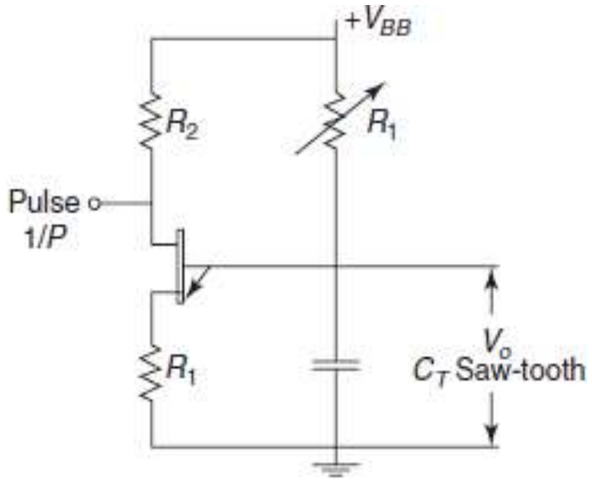


Figure 14-7 (c) Time-base generator using UJT

Oscilloscope Amplifiers:

- The purpose of an oscilloscope is to produce a faithful representation of the signals applied to its input terminals.
- Considerable attention has to be paid to the design of these amplifiers for this purpose. The oscillographic amplifiers can be classified into two major categories.

  (i) AC-coupled amplifiers

  (ii) DC-coupled amplifiers

- The low-cost oscilloscopes generally use ac-coupled amplifiers. The ac amplifiers, used in oscilloscopes, are required for laboratory purposes. The dc-coupled amplifiers are quite expensive. They

  offer the advantage of responding to dc voltages, so it is possible to measure dc voltages as pure signals

  and ac signals superimposed upon the dc signals.

- DC-coupled amplifiers have another advantage. They eliminate the problems of low-frequency phase shift and waveform distortion while observing low-frequency pulse train.
- The amplifiers can be classified according to bandwidth use also:

  (i) Narrow-bandwidth amplifiers

  (ii) Broad-bandwidth amplifiers

Vertical Amplifiers:

- Vertical amplifiers determines the sensitivity and bandwidth of an oscilloscope. Sensitivity, which is expressed in terms of V/cm of vertical deflection at the mid-band frequency.

- The gain of the vertical amplifier determines the smallest signal that the oscilloscope can satisfactorily measure by reproducing it on the CRT screen.

- The sensitivity of an oscilloscope is directly proportional to the gain of the vertical amplifier. So, as the gain increases the sensitivity also increases.

- The vertical sensitivity measures how much the electron beam will be deflected for a specified input signal. The CRT screen is covered with a plastic grid pattern called a graticule.

- The spacing between the grids lines is typically 10 mm. Vertical sensitivity is generally expressed in volts per division.

- The vertical sensitivity of an oscilloscope measures the smallest deflection factor that can be selected with the rotary switch.

Frequency response:

- The bandwidth of an oscilloscope detects the range of frequencies that can be accurately reproduced on the CRT screen. The greater the bandwidth, the wider is the range of observed frequencies.
- The bandwidth of an oscilloscope is the range of frequencies over which the gain of the vertical amplifier stays within 3 db of the mid-band frequency gain, as shown in Fig. 14-8.
- Rise time is defined as the time required for the edge to rise from 10–90% of its maximum amplitude. An approximate relation is given as follows:

$$t_r \times BW = 0.35$$

where, t_r is the rise time in seconds and BW is the band width in Hertz.

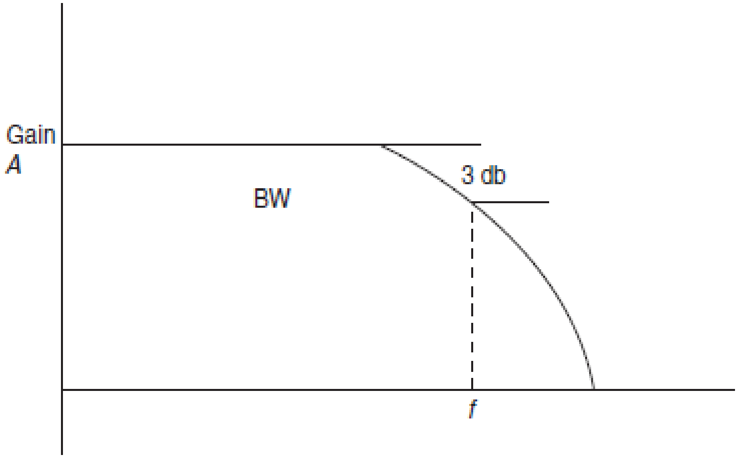


Figure 14-8 Frequency response graphs

• **2) Measurement of Phase:**

The phase difference of two different waveforms displayed on the CRT screen can be found from the time axis. Two sinusoidal signals of time period T are in the same phase at time t_1 and t_2 respectively, and the phase difference between them is expressed as:

$$\varphi = \frac{2\pi}{T}(t_1 - t_2) \tag{14-16}$$

Figure 14-10 shows the phase difference of two different waveforms.

• **3 Measurement of Phase Using Lissajous Figures:**

Lissajous figures are used to measure the phase difference between two sinusoidal voltages of the same amplitude and frequency. The signals are applied simultaneously to the horizontal and vertical deflection plates. The values of the deflection voltages are given by:

$$v_y = A \sin(\omega t + \varphi) \tag{14-17}$$

and

$$v_x = A \sin \omega t \tag{14-18}$$

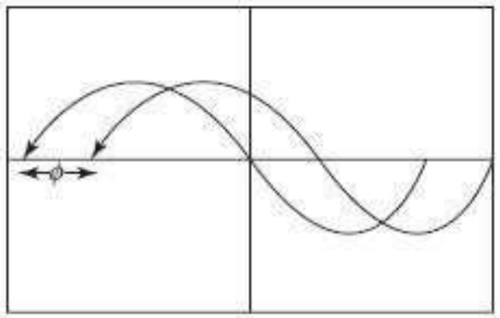


Figure 14-10 Measurement of phase difference

Measurement of Phase Using Lissajous Fig

The values of the deflection voltages are given by:

$$v_y = \text{A} \sin (\omega t + \varphi)$$

$$v_x = \text{A} \sin \omega t$$

Here A is the amplitude, ω is the angular frequency and φ is the phase angle by which v_y leads v_x. Eq. (14-17) can be expanded as:

$$v_y = A \sin \omega t \cos \varphi + A \cos \omega t \sin \varphi \qquad (14\text{-}19)$$

Equation (14-18) yields:

$$A \cos \omega t = \sqrt{A^2 - v_x^2} \qquad (14\text{-}20)$$

Substituting the sine and cosine terms from Eqs. (14-17) and (14-18) in Eq. (14-19), we get:

$$v_y = A \sin \omega t \cos \varphi + \sqrt{A^2 - v_x^2} \sin \varphi$$

$$v_y = v_x \cos \varphi + \sqrt{A^2 - v_x^2} \sin \varphi$$

$$v_y - v_x \cos \varphi = \sqrt{A^2 - v_x^2} \sin \varphi$$

$$(v_y - v_x \cos \varphi)^2 = (A^2 - v_x^2) \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 \cos^2 \varphi = A^2 \sin^2 \varphi - v_x^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 \cos^2 \varphi\, v_x^2 \sin^2 \varphi = A^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 (\cos^2 \varphi + \sin^2 \varphi) = A^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 = A^2 \sin^2 \varphi$$

$$v_x^2 + v_y^2 - 2v_x v_y \cos\varphi = A^2 \sin^2 \varphi. \qquad (14.21)$$

The Lissajous figure is thus, an ellipse represented by Eq. (14-21). The ellipse is depicted in Fig. 14-9.

Measurement of Phase Using Lissajous Figures:

Case I: When $\varphi = 0°$, $\cos\varphi = 1$, $\sin\varphi = 0$

Then, Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 - 2v_x v_y = 0$$

$$(v_x - v_y)^2 = 0$$

$$v_x = v_y \qquad (14\text{-}22)$$

Equation (14-22) represents a straight line with slope 45°, i.e., $m = 1$. The straight line diagram is shown in Fig. 14-11(a).

Case II: When $0 < \varphi < 90$, $\varphi = 45°$, $\cos\varphi = \frac{1}{\sqrt{2}}$, $\sin\varphi = \frac{1}{\sqrt{2}}$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 - \sqrt{2}v_x v_y = \frac{A^2}{2} \qquad (14\text{-}23)$$

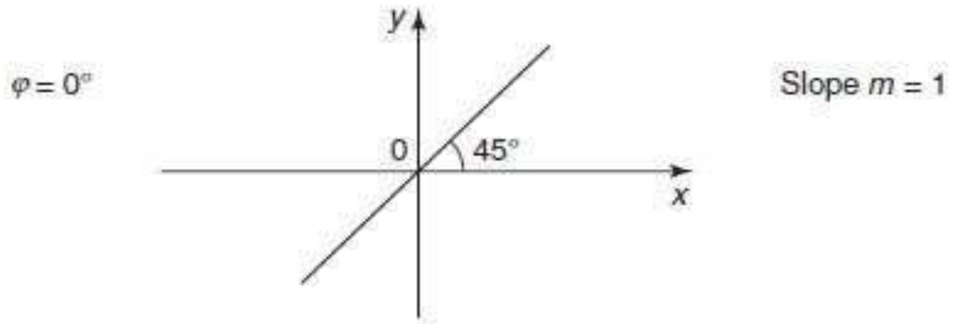


Figure 14-11(a) Lissajous figure at $\varphi = 0°$ is a straight line with slope $m = 1$

Measurement of Phase Using Lissajous Figures:

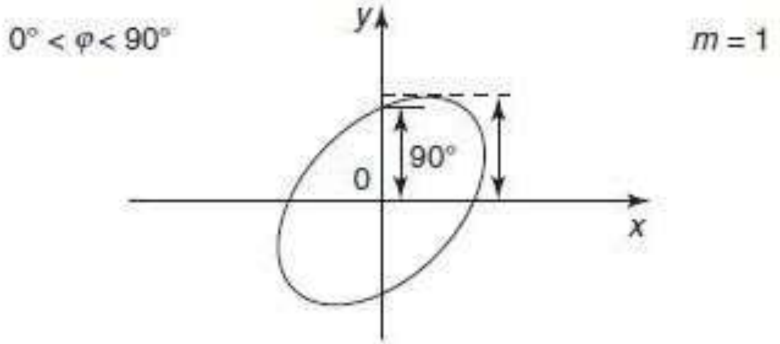


Figure 14-11(b) Lissajous figure at $0° < \varphi < 90$ takes the shape of an ellipse

Equation (14-11) represents an ellipse, as shown in Fig. 14-11(b).

Case III: When $\varphi = 90°$, $\cos\varphi = 0$, $\sin\varphi = 1$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 = A^2 \quad (14\text{-}24)$$

Equation (14-24) represents a circle shown in Fig. 14-12.

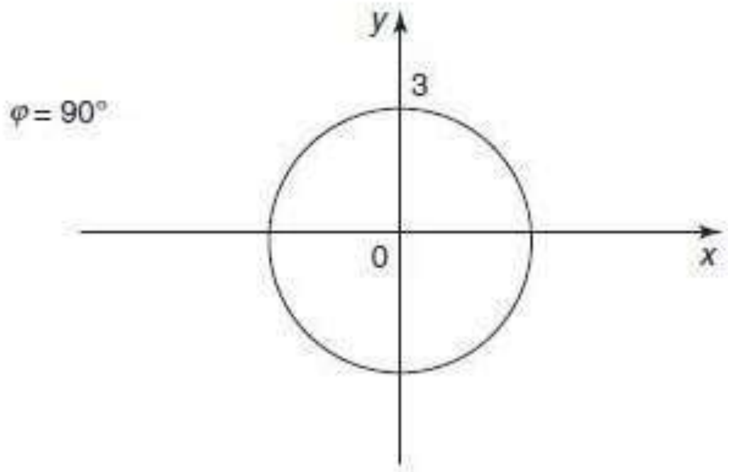


Figure 14-12 Lissajous figure at $\varphi = 90°$: it forms a circle

Case IV: When $90 < \varphi < 180$; say $\varphi = 135°$,

$\cos\varphi = -\frac{1}{\sqrt{2}}$, $\sin\varphi = \frac{1}{\sqrt{2}}$

Measurement of Phase Using Lissajous Figures:

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 + \sqrt{2}v_x v_y = \frac{A^2}{2} \qquad (14\text{-}25)$$

Equation (14-25) represents an ellipse shown in Fig. 14-13.

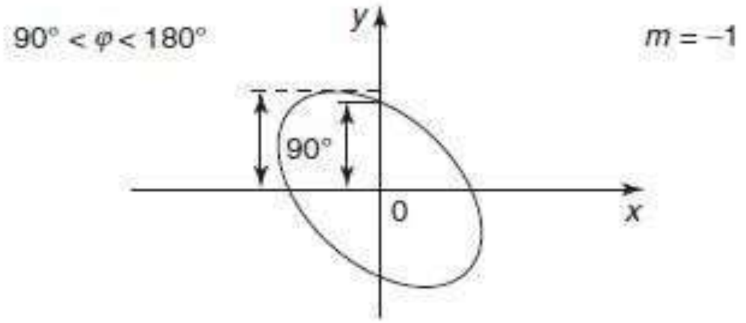


Figure 14-13 Lissajous figure when $90 < \varphi < 180$

Case V: $\varphi = 180°$, $\cos\varphi = -1$, $\sin\varphi = 0$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 + 2v_x v_y = 0$$

$$(v_x + v_y)^2 = 0$$

$$v_x = -v_y \qquad (14\text{-}26)$$

Equation (14-26) represents a straight line with slope $m = -1$; a slope of 45° in the negative direction of the x-axis, as shown in Fig. (14-14).

The maximum y-displacement, A, and the vertical displacement, V_y, at time $t = 0$ can be measured from the vertical scale of the CRO. Putting $t = 0$ in Eq. (14-17), we get:

$$v_{y0} = A\sin\varphi \qquad (14\text{-}27)$$

$$\sin\varphi = \frac{v_{y0}}{A} \qquad (14\text{-}28)$$

Thus, the phase angle can be found from Eq. (14-28) using any form of the Lissajous figure.

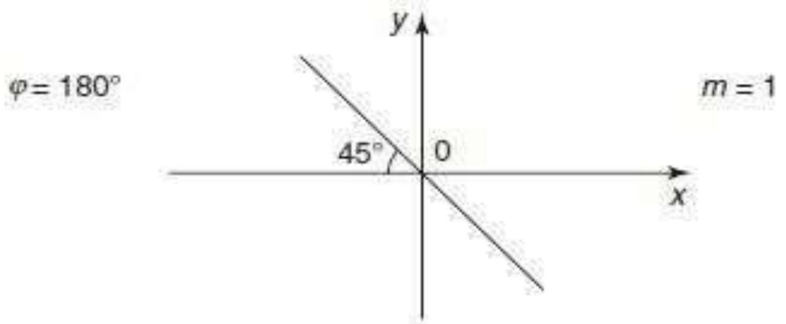


Figure 14-14 Lissajous figure at $\varphi = 180°$ with negative slope $m = -1$

Applications of the Sweep Frequency

1. Sweep frequency generators are used to display the response curve of the various stages of frequency of television or radio receivers.
2. Sweep frequency generators can be used to determine the characteristics of a device over a wide continuous range of frequencies.

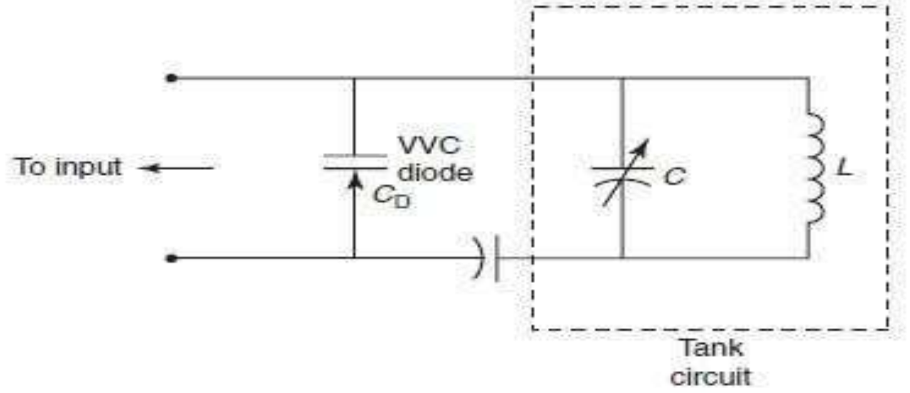


Figure 14-16 Oscillator tank circuit

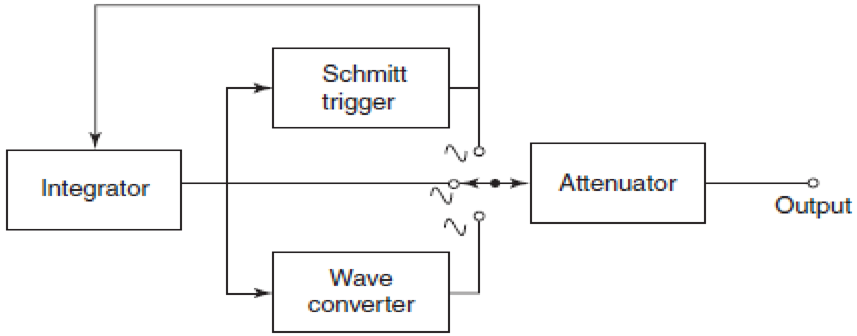


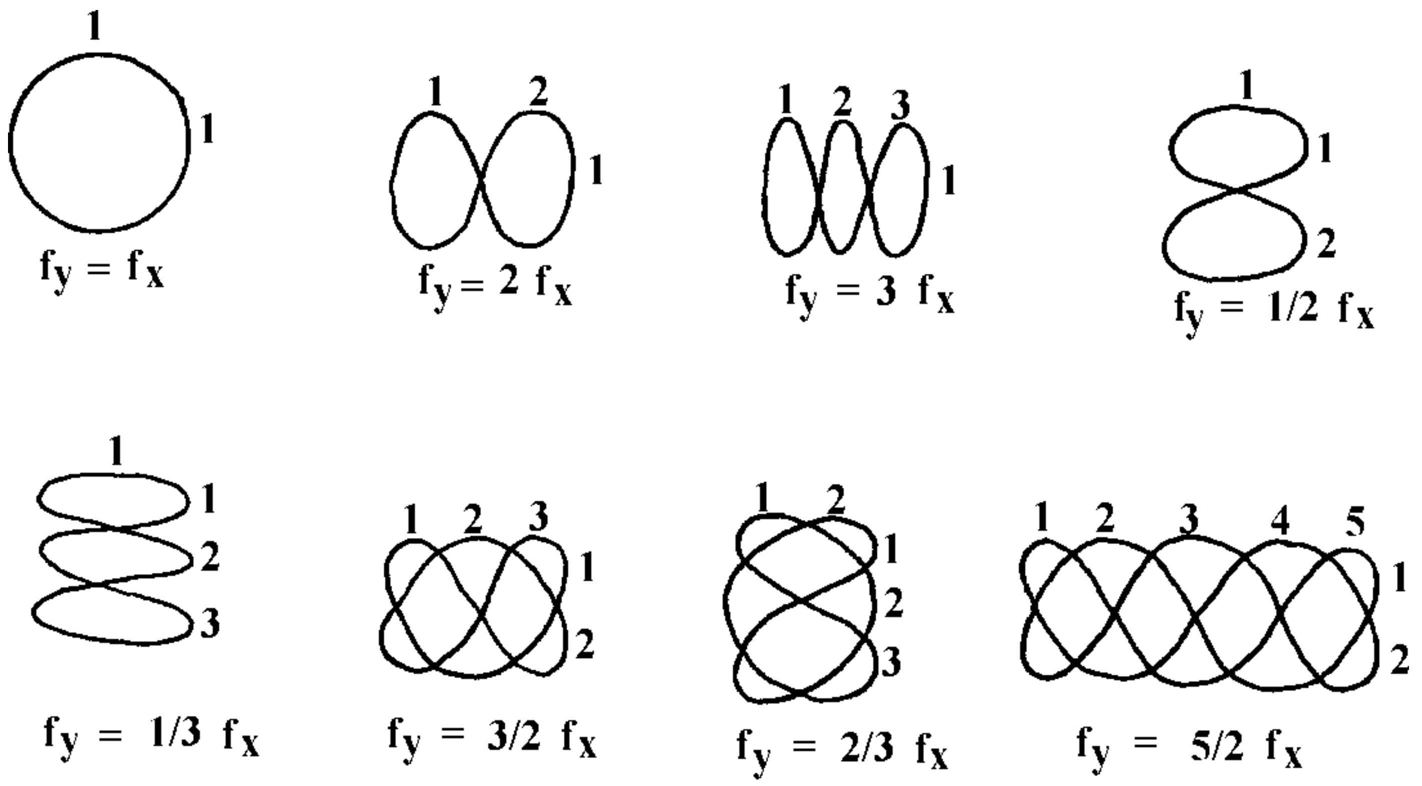
Figure 14-17 Block diagram of a function generator

Lissajous' Figures

- Lissajous' figure can be displayed by applying two a.c. signals simultaneously to the X-plates and Y-plates of an oscilloscope.
- As the frequency, amplitude and phase difference are altered, different patterns are seen on the screen of the CRO.

Lissajous' Figures

Same amplitude but different frequencies



POINTS TO REMEMBER:

- 1. CRO is used to study waveforms.
- 2. CRT is the main component of a CRO.
- 3. Prosperous P31 is used for the fluorescent screen of a CRO.
- 4. A CRO has the following components:
- (a) Electron gun
- (b) Deflecting system
- (c) Florescent screen
- 5. Lissajous figures are used to measure frequency and phase of the waves under study.
- 6. A time-base generator produces saw-tooth voltage.
- 7. An oscilloscope amplifier is used to provide a faithful representation of input signal applied to its input terminals.

IMPORTANT FORMULAE:

1. The deflection sensitivity of the CRT is:

$$S = \frac{l_{total}}{V_d} = \frac{lL}{2sV_a} \text{ m/V}$$

2. The deflection factor of the CRT is:

$$G = \frac{1}{S} = \frac{2sV_a}{lL} \text{ V/m}$$

3. Phase angle is given by:

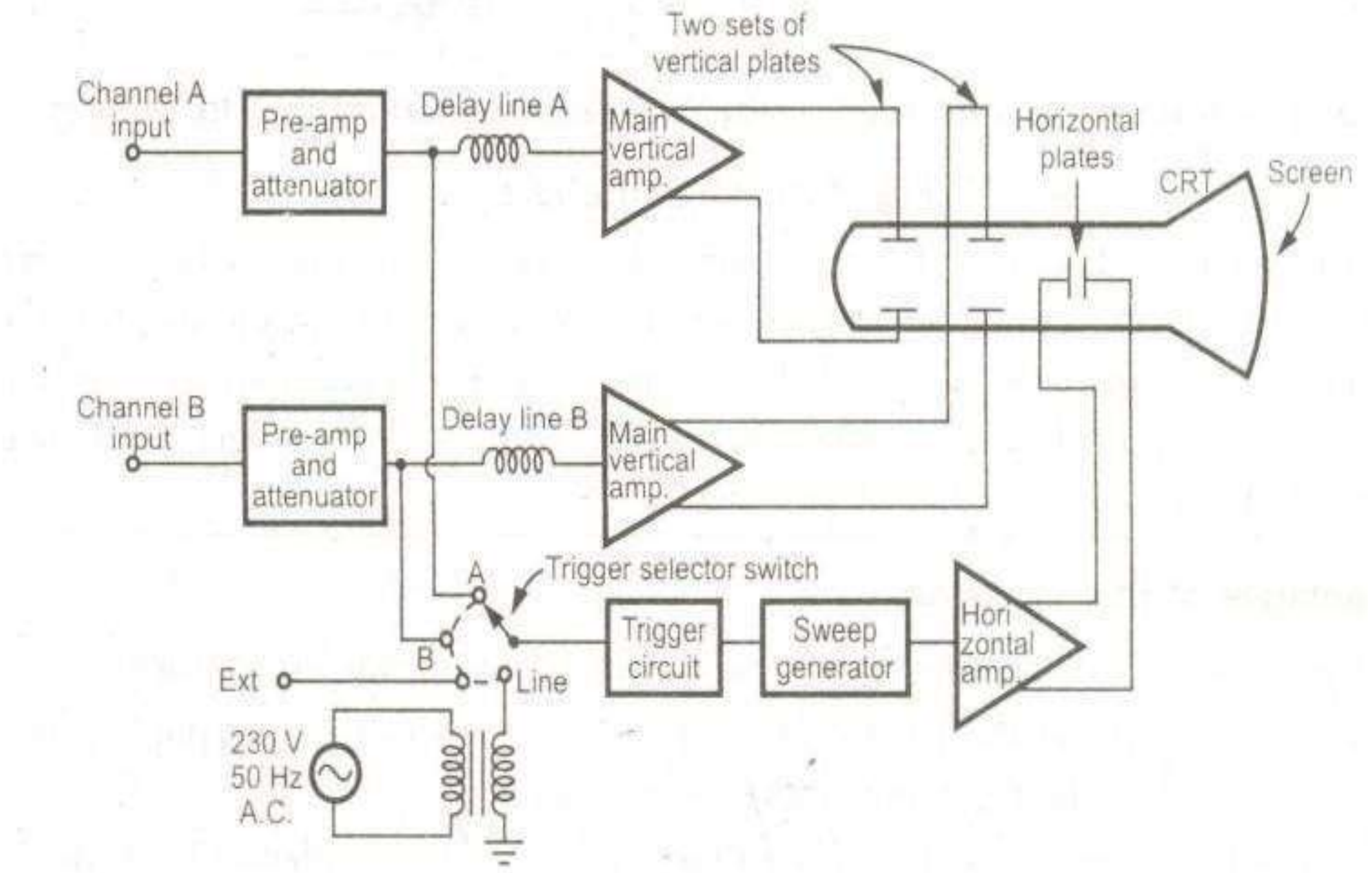
$$\varphi = \frac{2\pi}{T}(t_1 - t_2)$$

4. Lissajous equation is given by:

$$v_x^2 + v_y^2 - 2v_x v_y \cos\varphi = A^2 \sin^2\varphi$$

SPECIAL PURPOSE OSCILLOSCOPES

DUAL BEAM OSCILLOSCOPE



- This is the Another method of studying two voltages simultaneously on the screen is to use special cathode ray

- Tube having two separate electron guns generating two separate beam Each electron beam has its

- Own vertical deflection plates.
- But the two beams are deflected horizontally by the common set of horizontal plate\ The time base circuit may be same or different. Such an oscilloscope is called **Dual** Beam Oscilloscope.
- The oscilloscope has two vertical deflection plates and two separate channels A and B for the two
- separate input signals. Each channel consists of a preamplifier and an attenuator. A delay line,

- main vertical amplifier and a set of vertical deflection plates together forms a single channel. There is a single set of horizontal plates and single time base circuit.

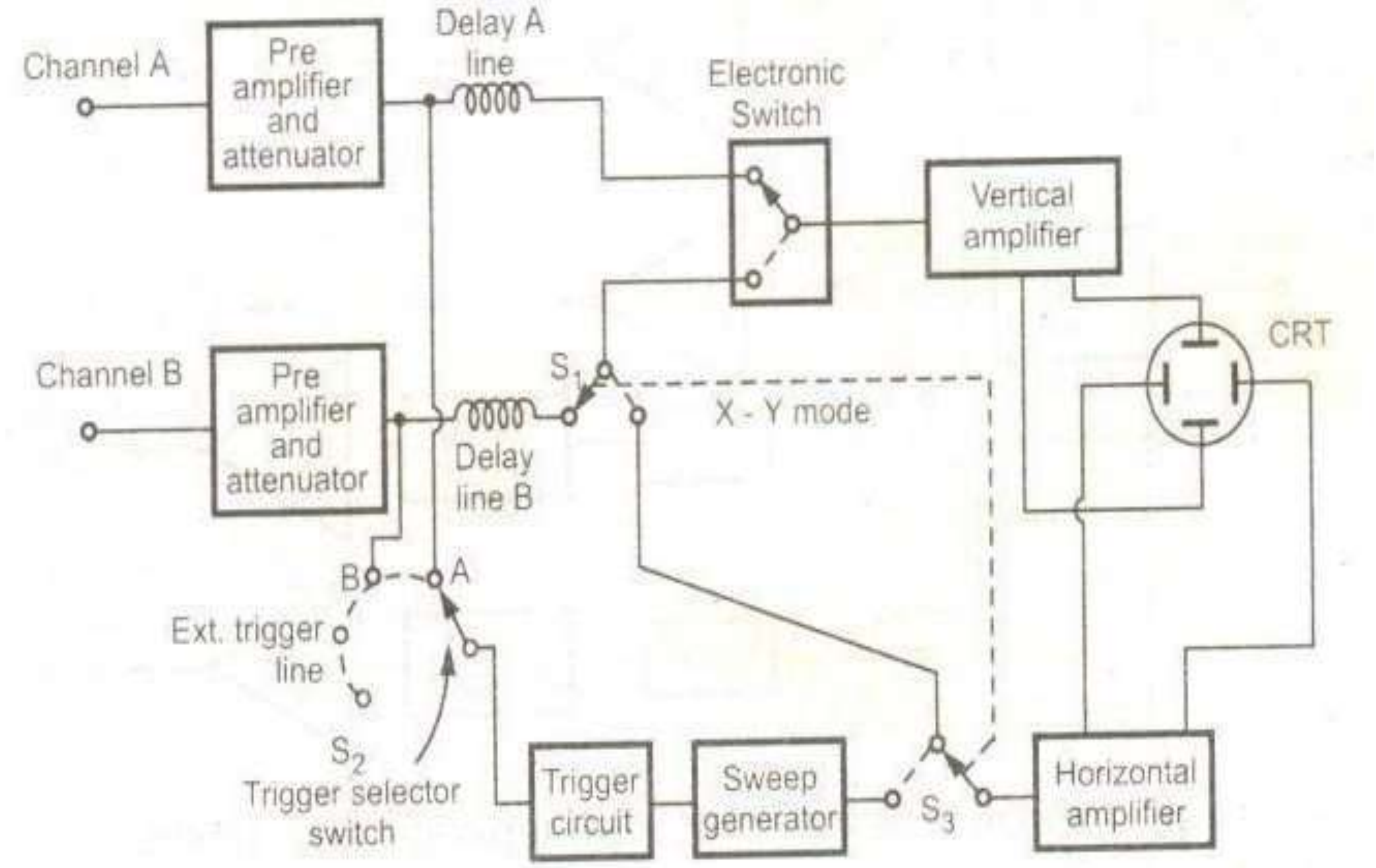
- The sweep generator drives the horizontal amplifier which in turn drives the plates. The' horizontal plates sweep both the beams across the screen at the same rate. The sweep generator can be triggered internally by the channel A signal or .channel B signal. Similarly it' can also be triggered from an external signal or line frequency signal. This is possible with the help of trigger selector switch, a front panel control.

- Such an oscilloscope may have separate time base circuit for separate channel. This allows

- different sweep rates for the two channels but increases the size and

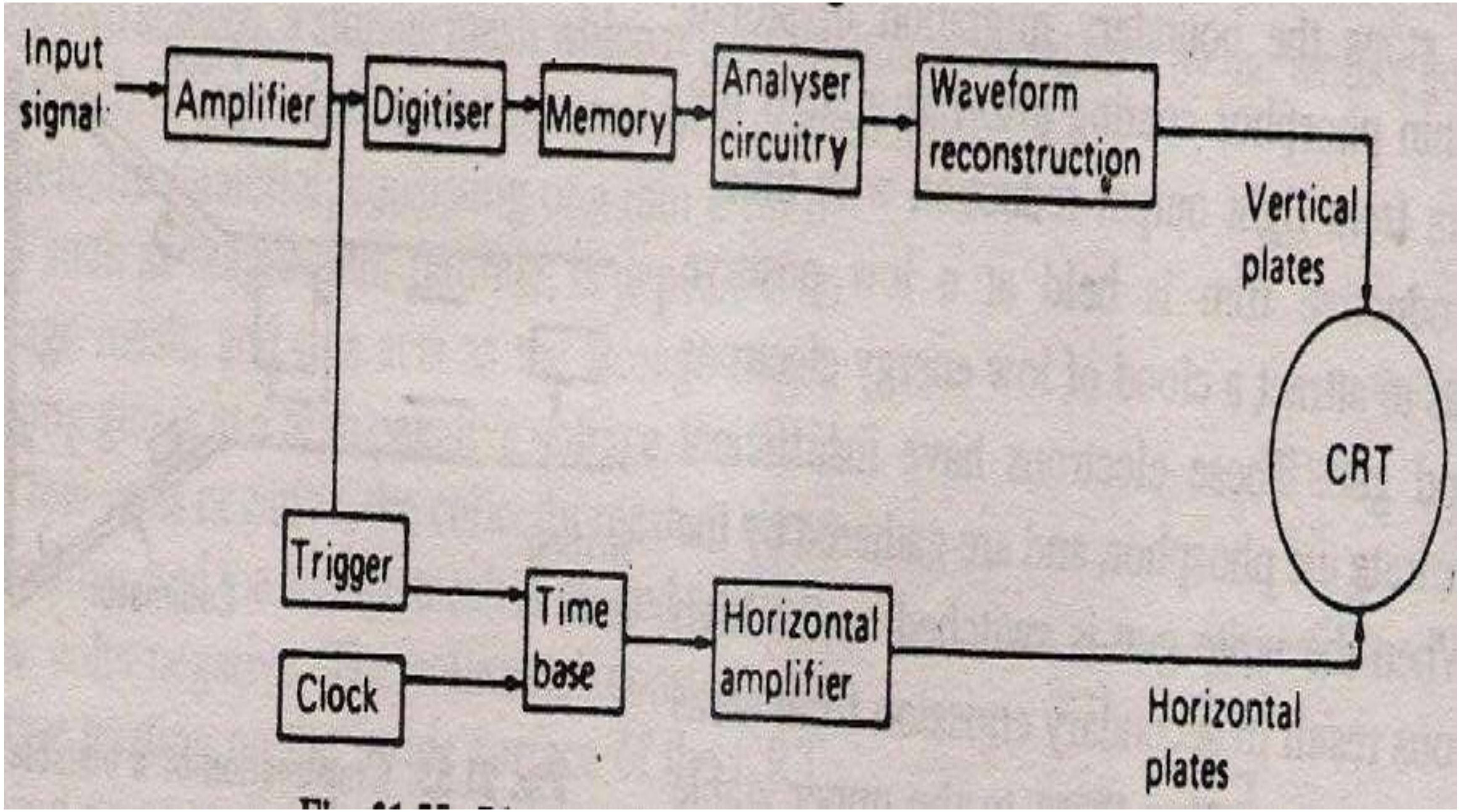
- weight of the oscilloscope.

DUAL TRACE OSCILLOSCOPE



- The comparison of two or more voltages is very much ,necessary in the analysis and study of many electronic circuits and systems.
- This is possible by using more than one oscilloscope but in such a case it is difficult to trigger the sweep of each oscilloscope precisely at the same time.
- Acommon and less costly method to solve this problem is to use dual trace or multi trace oscilloscopes.
- In this method, the same electron beam is used to generate two traces which can be deflected from two independent vertical sources.
- The methods are used to generate two independent traces which the alternate sweep method and other is chop method.

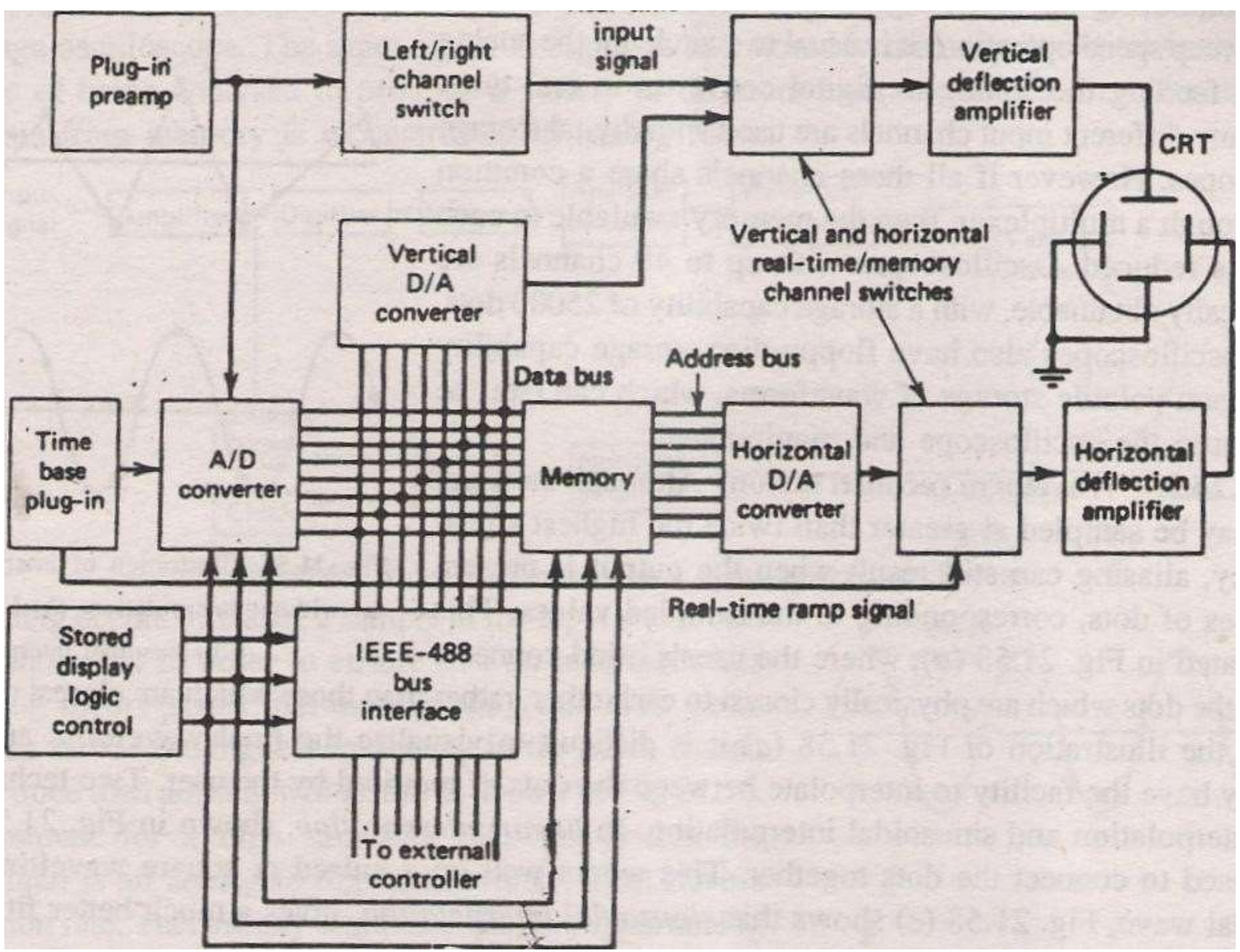
DIGITAL STORAGE OSCILLOSCOPE



- The input signal is digitized and stored in memory in digital form.
- In this state it is capable of being analyzed to produce a varietyof different information.
- Toview the display on the CRT the data from memory is reconstructed in analog form.
- The analog input voltage is sampled at adjustable rates (up to 100,000 samples per
- second) and data points are read onto the memory.

- If the memory is read out rapidly and repetitively, an input event which is a single shot transient becomes a repetitive or continuous waveform that can be observed easily on an ordinary scope (not a storage scope).
- The digital memory also may be read directly (without going through DAC) to, say, a computer where a stored program can manipulate the data in almost any way desired

COMPLETE BLOCK DIAGRAM OF DSO



SAMPLING OSCILLOSCOPE

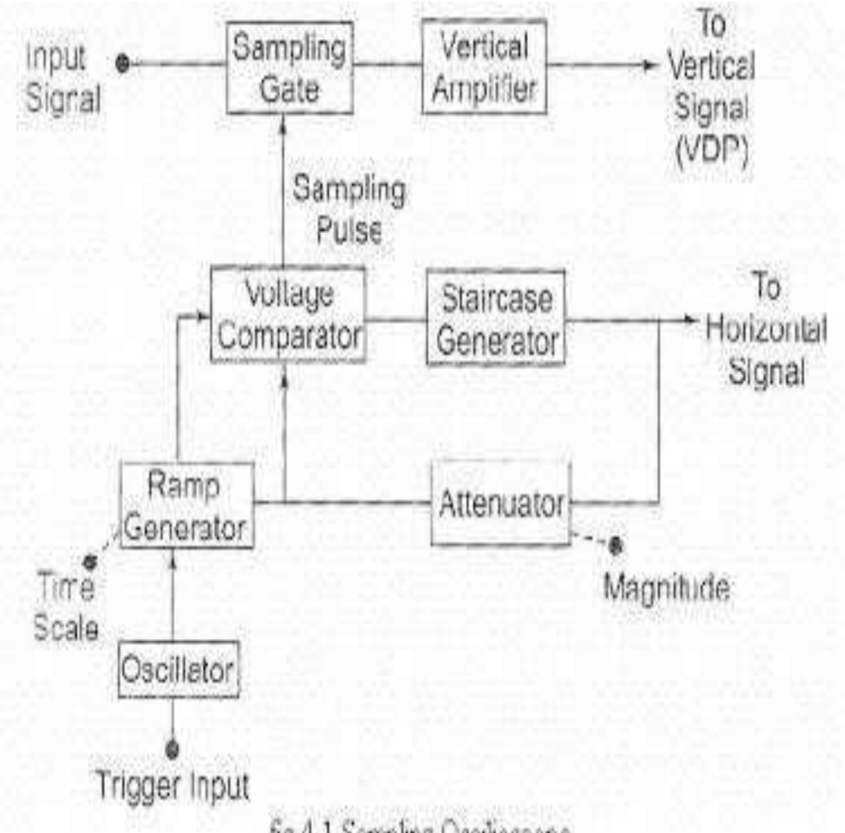


fig.4.1 Sampling Oscilloscope

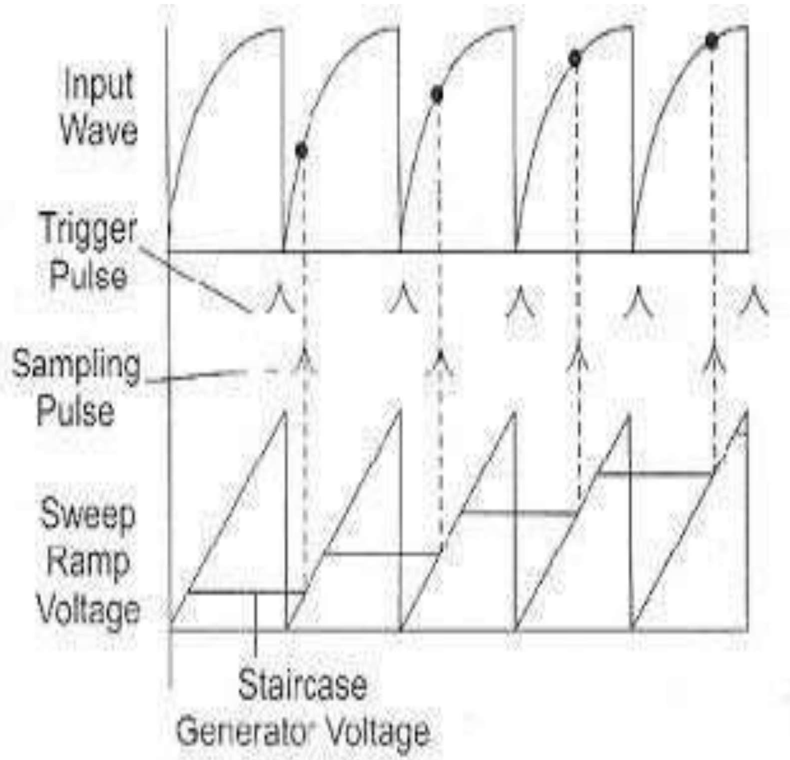


fig 4.2 Various Wave Forms at each block of oscilloscope

- An ordinary oscilloscope has a B.W. of 10 MHz the HF performance can be improved by means of sampling the input waveform and reconstructing its shape from the sample, i.e. the signal to be observed is sampled and after a few cycles sampling point is advanced and another sample is taken.
- The shape of the wave form is reconstructed by joining the sample levels together. The sampling frequency may be as low as 1/10th of the input signal frequency (if the input signal frequency is 100 MHz, the bandwidth of the CRO vertical amplifier can be as low as 10 MHz). As many as 1000 samples are used to reconstruct the original waveform.

- The input is applied to the sampling gate. The input waveform is sampled whenever a sampling pulse opens the sampling gate.
- The sampling must be synchronized with the input signal frequency.
- The signal is delayed in the vertical amplifier, allowing the horizontal sweep to be initiated by the input signal.
- At the beginning of each sampling cycle, the trigger pulse activates an oscillator and a linear ramp voltage is generated.

- This ramp voltage is applied to a voltage comparator which compares the ramp voltage to a staircase generate-When the two voltages are equal in amplitude, the staircase advances one step and a sampling pulse is generated, which opens the sampling gate for a sample of input voltage.
- The resolution of the final image depends upon the size of the steps of the staircase generator. The smaller the size of the steps the larger the number of samples and higher the resolution of the image.

UNIT-4

RECORDERS

Introduction

Recorders are devices or systems used to capture and document measurement data over time. These instruments are designed to continuously or periodically record readings from sensors or measuring devices, often in graphical or digital form, for later analysis and review. Recorders are essential in various applications where ongoing or long-term monitoring is required, such as in industrial control systems, laboratory experiments, environmental monitoring, or quality control.

XY plotter is a tool used to graphically display the relationship between two variables measured simultaneously. This can be incredibly useful for visualizing how two parameters (such as voltage, current, pressure, temperature, etc.) change in relation to each other. XY plotters are commonly used in conjunction with data acquisition systems, oscilloscopes, or other types of measurement devices to help engineers and researchers analyze data trends and correlations.

Advantages of Using XY Plotters:

Immediate Visual Feedback: The ability to visualize the relationship between two variables in real-time helps engineers understand system behavior without needing to look at tables of raw data.

Detection of Patterns and Trends: By plotting two related variables together, XY plotters make it easier to identify trends, non-linearities, correlations, or anomalies that might otherwise be hard to discern.

Convenient Comparison: The plot provides an intuitive comparison between two quantities, making it easier to analyze complex relationships (e.g., resistance vs.

temperature).

Curve tracer :The **curve tracer** is an important concept in electronic measuring instruments because it allows engineers and technicians to visually analyze and evaluate the behavior of various electronic components, particularly semiconductors like diodes, transistors, and thyristors

Galvanometric recorders in electronic measuring instruments revolves around the use of a **galvanometer**, which is an electromechanical device that detects and measures small electric currents. A galvanometric recorder is essentially an instrument that uses a galvanometer to create a continuous, graphical record of the current over time, often in the form of a trace or curve on paper or a digital display

Servo transducer:

A **servo transducer** is an electromechanical device that converts a physical quantity, such as position, speed, or force, into an electrical signal. It is commonly used in electronic measuring instruments to accurately detect and measure mechanical movements or changes in parameters, and then translate them into an electrical output that can be processed or displayed.

Magnetic recording

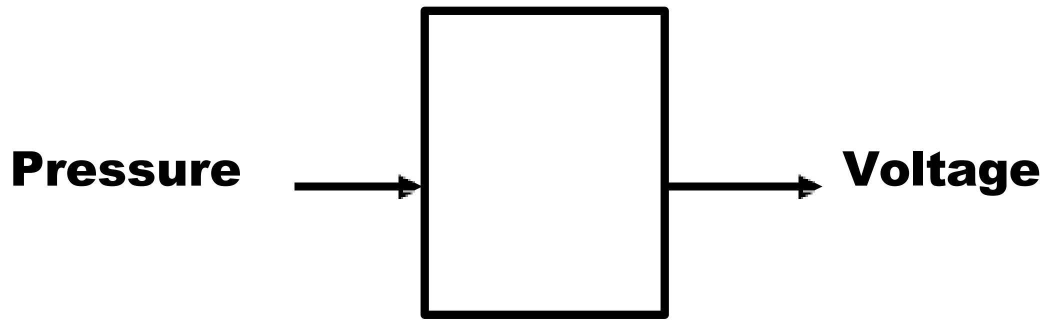
Magnetic recording is a method of storing data by magnetizing a material (usually a tape, disk, or another magnetic medium) in a way that represents information, typically in the form of digital or analog signals. In the context of **electronic measuring instruments**, magnetic recording is used for the purpose of **storing, logging, and analyzing data** that has been measured by various sensors or instruments, often over time or under varying conditions. This can include measurements like voltage, current, temperature, pressure, etc.

UNIT-5

TRANSDUCERS

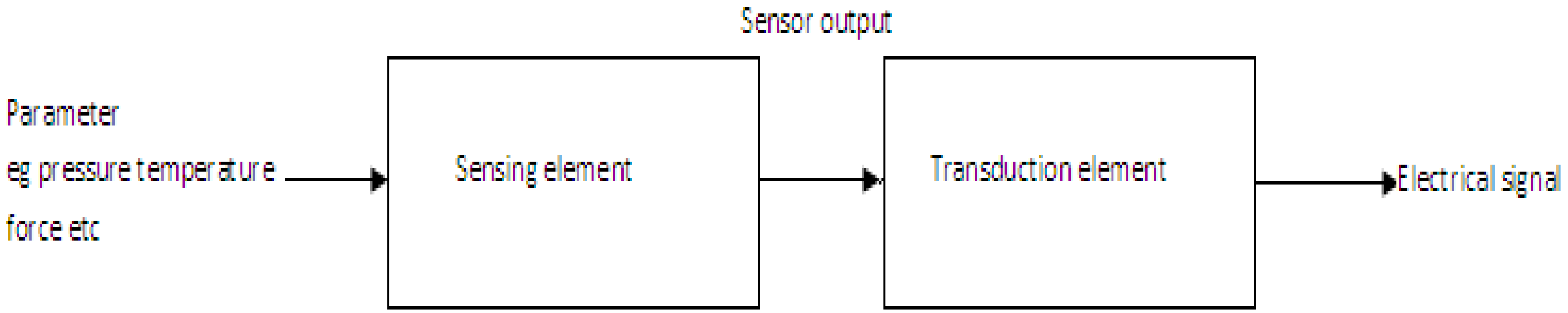
INTRODUCTION OF TRANSDUCERS

- A transducer is a device that convert one form of energy to other form. It converts the measurand to a usable electrical signal.
- In other word it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.



BLOCK DIAGRAM OF TRANSDUCERS

- Transducer contains two parts that are closely related to each other i.e. the sensing element and transduction element.
- The sensing element is called as the sensor. It is device producing measurable response to change in physical conditions.
- The transduction element convert the sensor output to suitable electrical form.



CHARACTERISTICS OF TRANSDUCERS

1. Ruggedness
2. Linearity
3. Repeatability
4. Accuracy
5. High stability and reliability
6. Speed of response
7. Sensitivity
8. Small size

TRANSDUCERS SELECTION FACTORS

1. **Operating Principle:** The transducer are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive , optoelectronic, piezo electric etc.
2. **Sensitivity:** The transducer must be sensitive enough to produce detectable output.
3. **Operating Range:** The transducer should maintain the range requirement and have a good resolution over the entire range.
4. **Accuracy:** High accuracy is assured.
5. **Cross sensitivity:** It has to be taken into account when measuring mechanical quantities. There are situation where the actual quantity is being measured is in one plane and the transducer is subjected to variation in another plan.
6. **Errors:** The transducer should maintain the expected input-output relationship as described by the transfer function so as to avoid errors.

Contd.

7. **Transient and frequency response :** The transducer should meet the desired time domain specification like peak overshoot, rise time, setting time and small dynamic error.

8. **Loading Effects:** The transducer should have a high input impedance and low output impedance to avoid loading effects.

9. **Environmental Compatibility:** It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.

10. **Insensitivity to unwanted signals:** The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.

CLASSIFICATION OF TRANSDUCERS

The transducers can be classified as:

I. Active and passive transducers.

II. Analog and digital transducers.

III. On the basis of transduction principle used.

IV. Primary and secondary transducer

V. Transducers and inverse transducers.

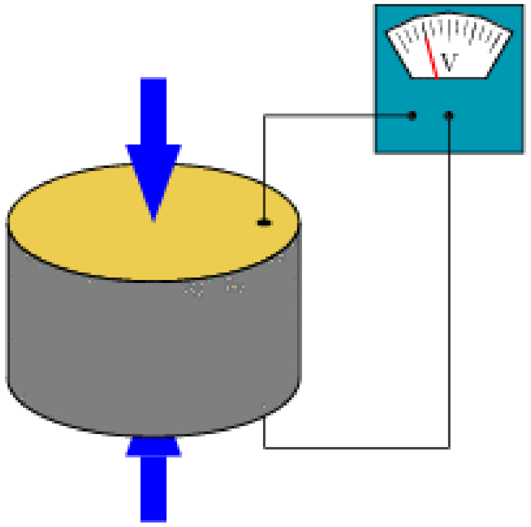
ACTIVE AND PASSIVE TRANSDUCERS

- **Active transducers :**
- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

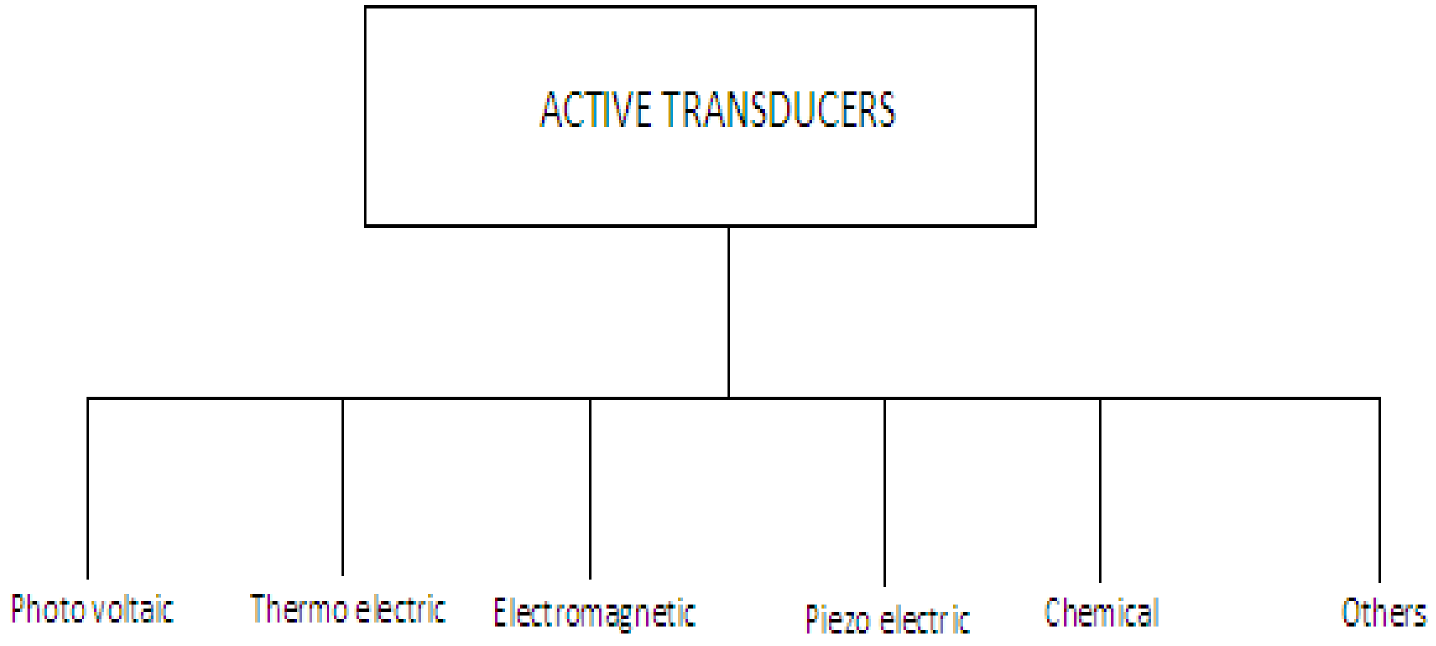
I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used.

Piezoelectric Transducer



CLASSIFICATION OF ACTIVE TRANSDUCERS



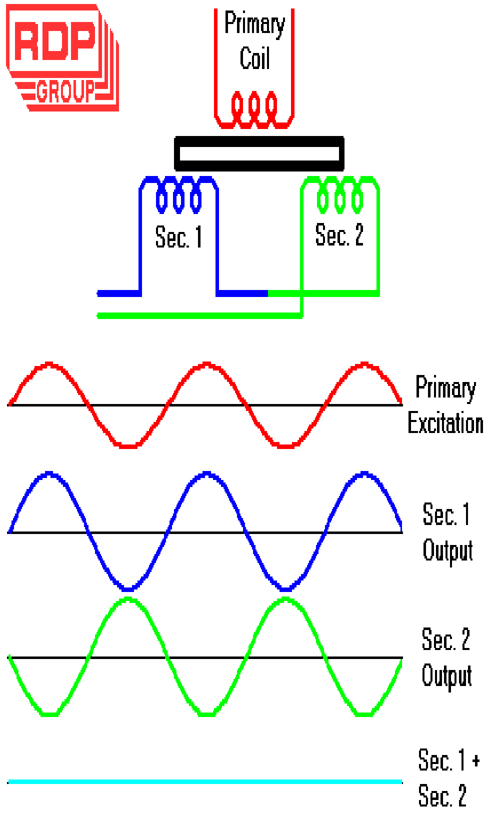
ACTIVE AND PASSIVE TRANSDUCERS

- **Passive Transducers :**

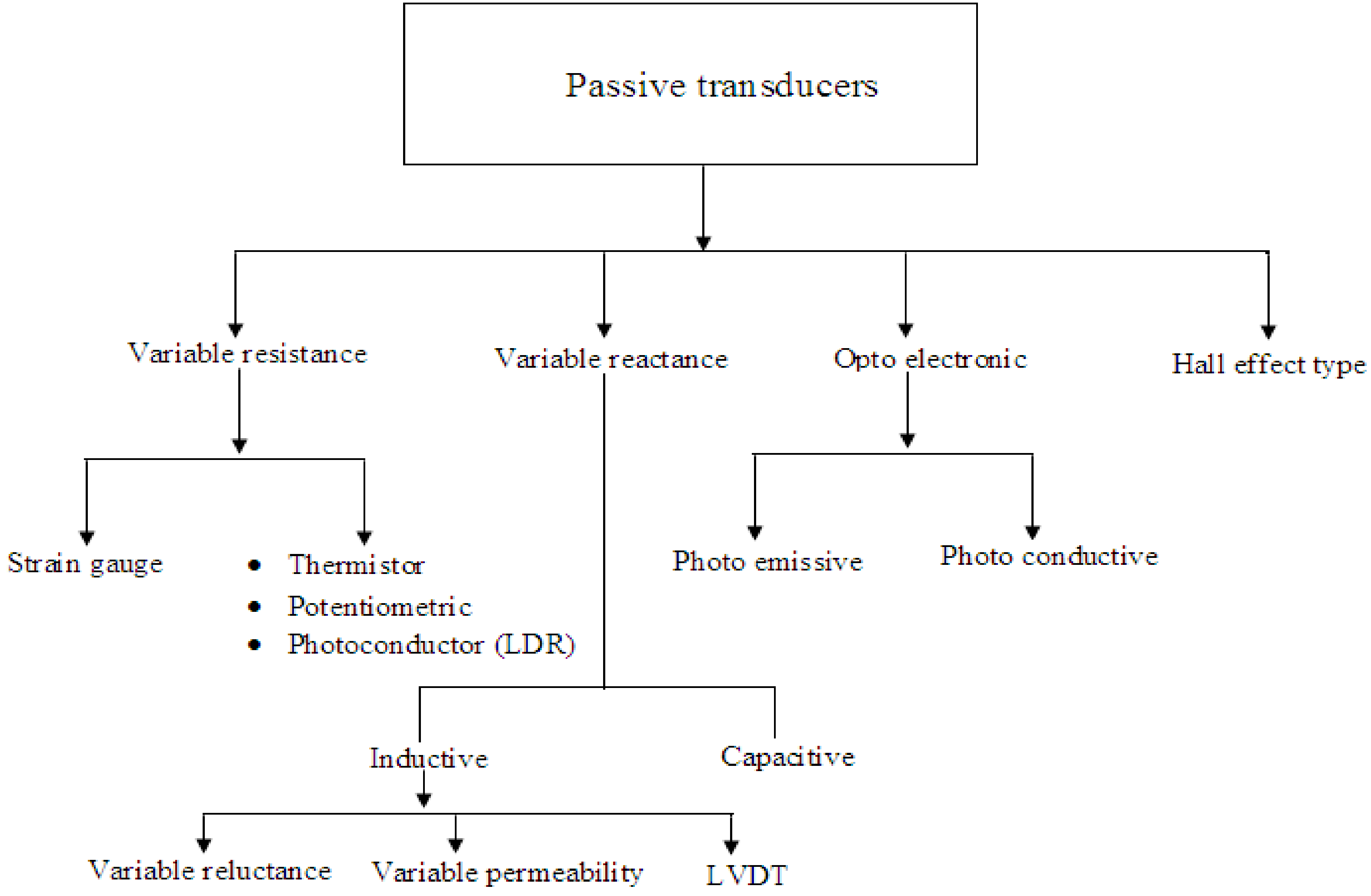
I. These transducers need external source of power for their operation. So they are not self generating type transducers.

II. A DC power supply or an audio frequency generator is used as an external power source.

III. These transducers produce the output signal in the form of variation in resistance, capacitance, inductance or some other electrical parameter in response to the quantity to be measured.



CLASSIFICATION OF PASSIVE TRANSDUCERS



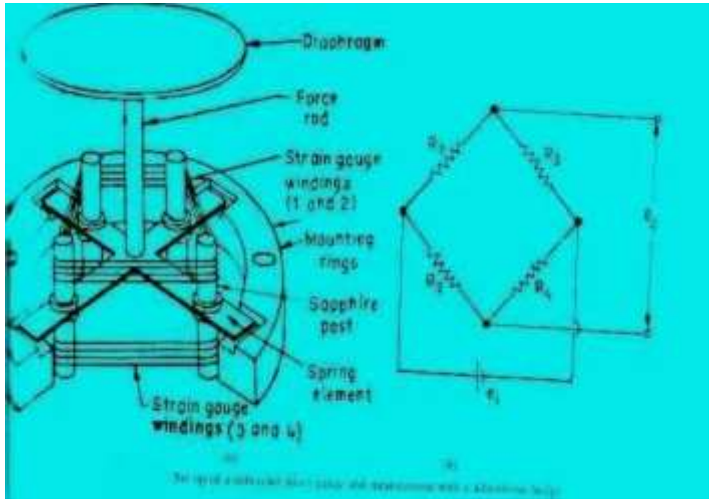
PRIMARY AND SECONDARY TRANSDUCERS

- Some transducers contain the mechanical as well as electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical device are called as the primary transducers, because they deal with the physical quantity to be measured.

- The electrical device then convert this mechanical signal into a corresponding electrical signal. Such electrical device are known as secondary transducers.

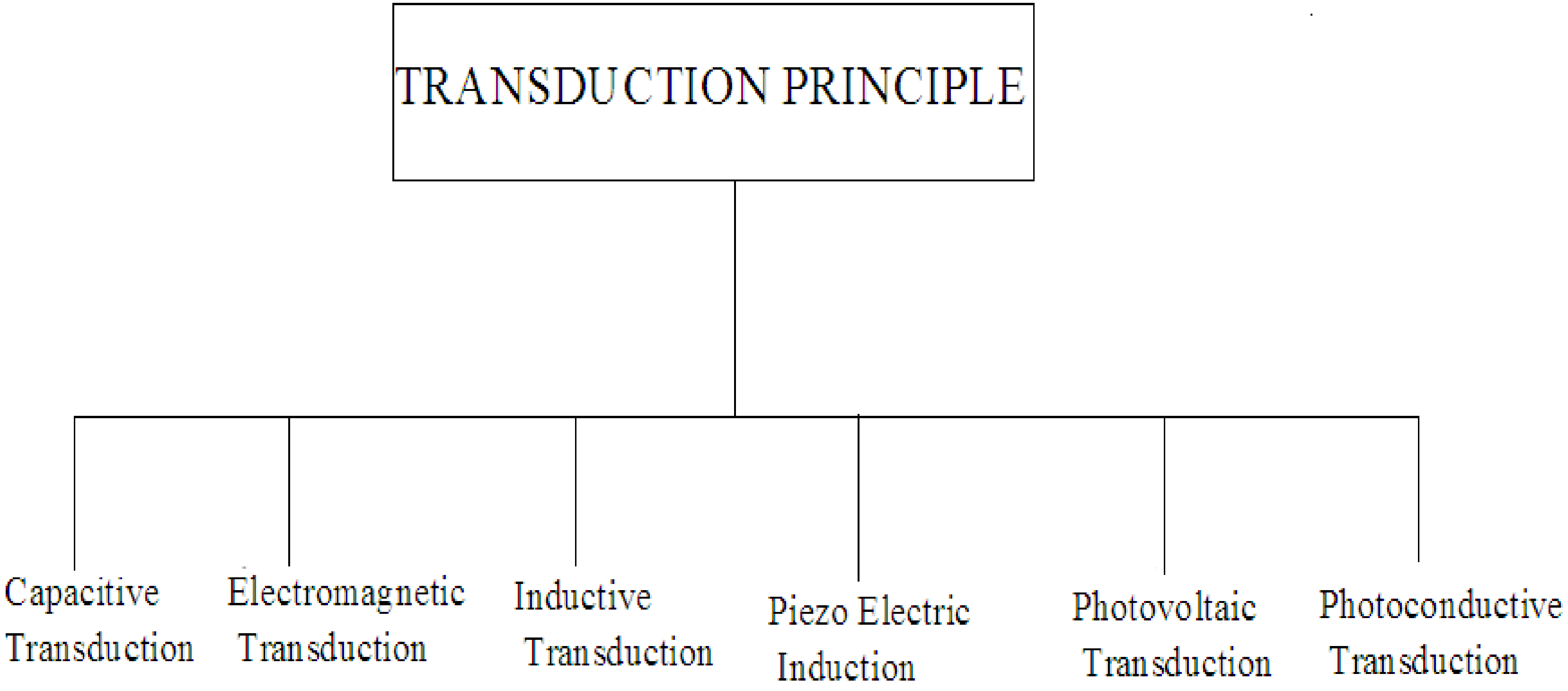
CONTD

- Ref fig in which the diaphragm act as primary transducer. It convert pressure (the quantity to be measured) into displacement(the mechanical signal).
- The displacement is then converted into change in resistance using strain gauge. Hence strain gauge acts as the secondary transducer.



CLASSIFICATION OF TRANSDUCERS

According to Transduction Principle



CLASSIFICATION OF TRANSDUCERS According to Transduction Principle

CAPACITIVE TRANSDUCER:

- In capacitive transduction transducers the measurand is converted to a change in the capacitance.
- A typical capacitor is comprised of two parallel plates of conducting material separated by an electrical insulating material called a dielectric. The plates and the dielectric may be either flattened or rolled.
- The purpose of the dielectric is to help the two parallel plates maintain their stored electrical charges.
- The relationship between the capacitance and the size of capacitor plate, amount of plate separation, and the dielectric is given by

$C = \varepsilon_0 \varepsilon_r A / d$

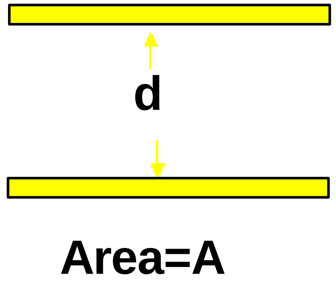
d is the separation distance of plates (m)

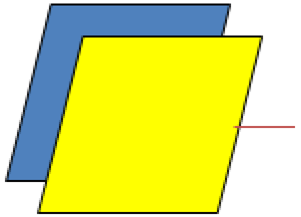
C is the capacitance (F, Farad)

ε_0 : absolute permittivity of vacuum

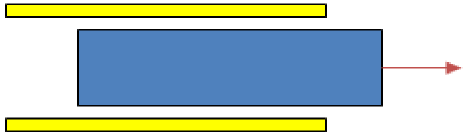
ε_r : relative permittivity

A is the effective (overlapping) area of capacitor plates(m2)





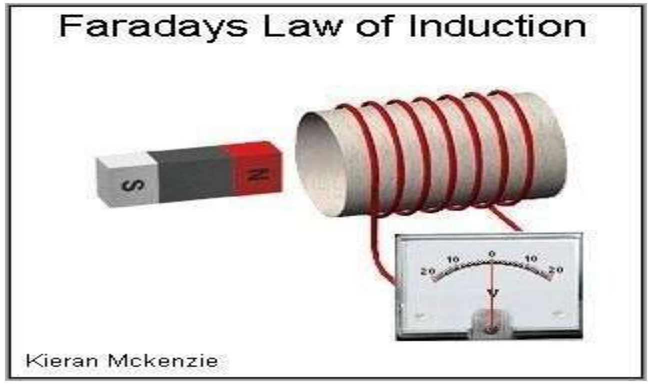
Either A, d or ε can be varied.

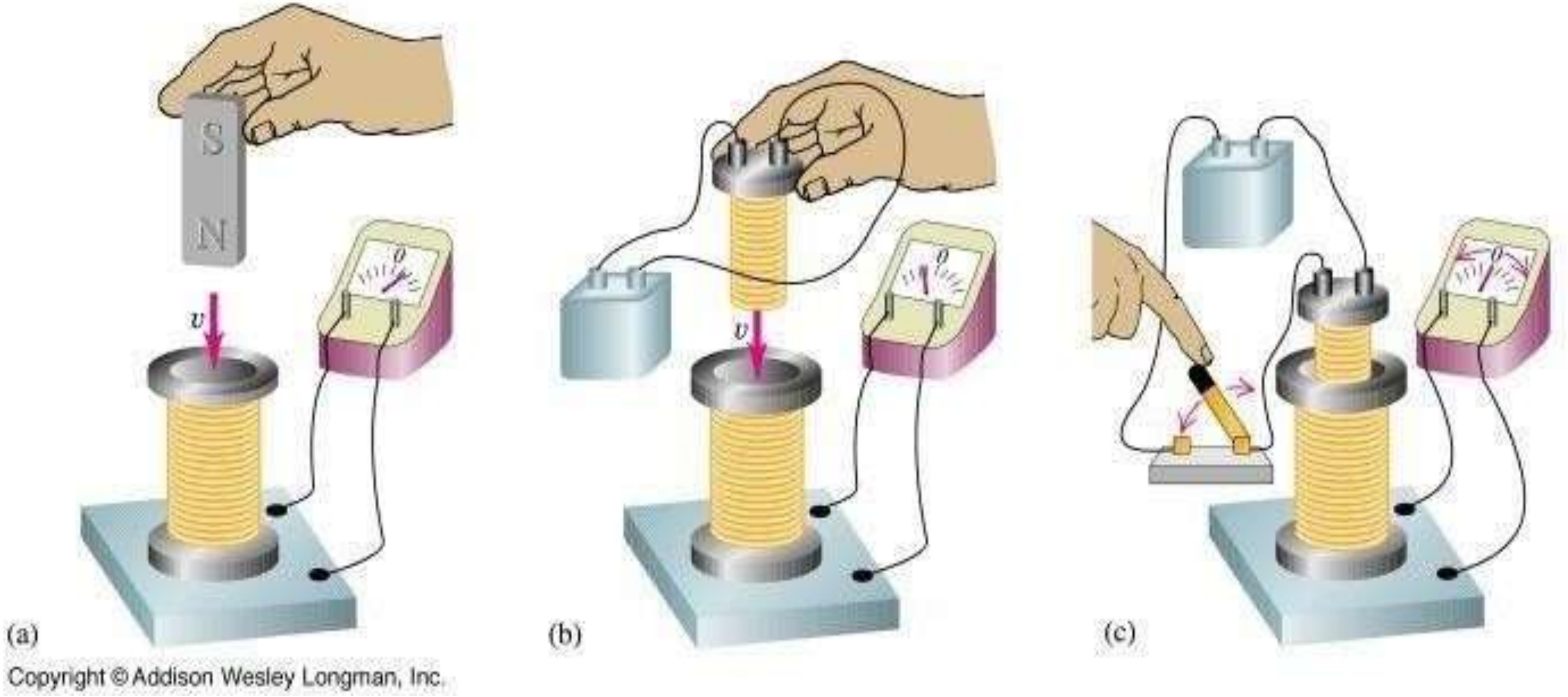


CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

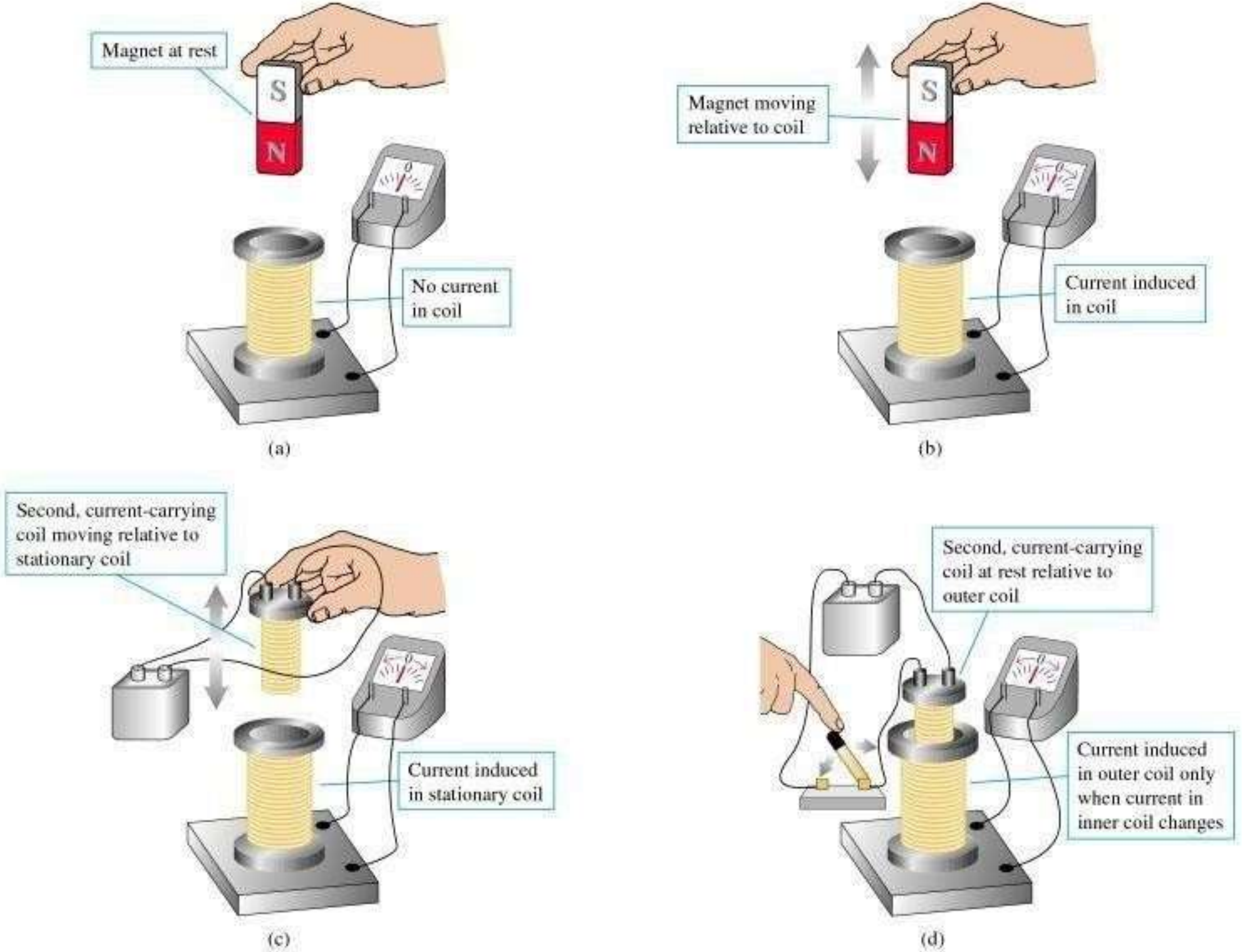
ELECTROMAGNETIC TRANSDUCTION:

- In electromagnetic transduction, the measurand is converted to voltage induced in conductor by change in the magnetic flux, in absence of excitation.
- The electromagnetic transducer are self generating active transducers
- The motion between a piece of magnet and an electromagnet is responsible for the change in flux





Current induced in a coil.


Magnet at rest
S
N
No current
in coil
(a)
Magnet moving
relative to coil
S
N
Current induced
in coil
(b)
Second, current-carrying
coil moving relative to
stationary coil
Current induced
in stationary coil
(c)
Second, current-carrying
coil at rest relative to
outer coil
Current induced
in outer coil only
when current in
inner coil changes
(d)

CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

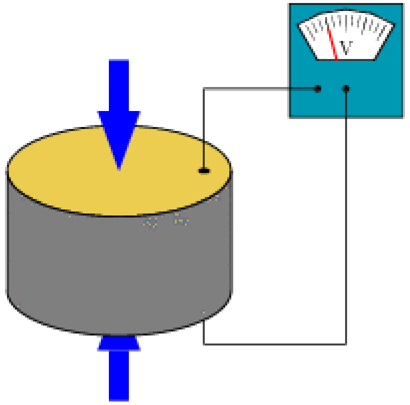
INDUCTIVE TRANSDUCER:

- In inductive transduction, the measurand is converted into a change in the self inductance of a single coil. It is achieved by displacing the core of the coil that is attached to a mechanical sensing element

CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

PIEZO ELECTRIC INDUCTION :

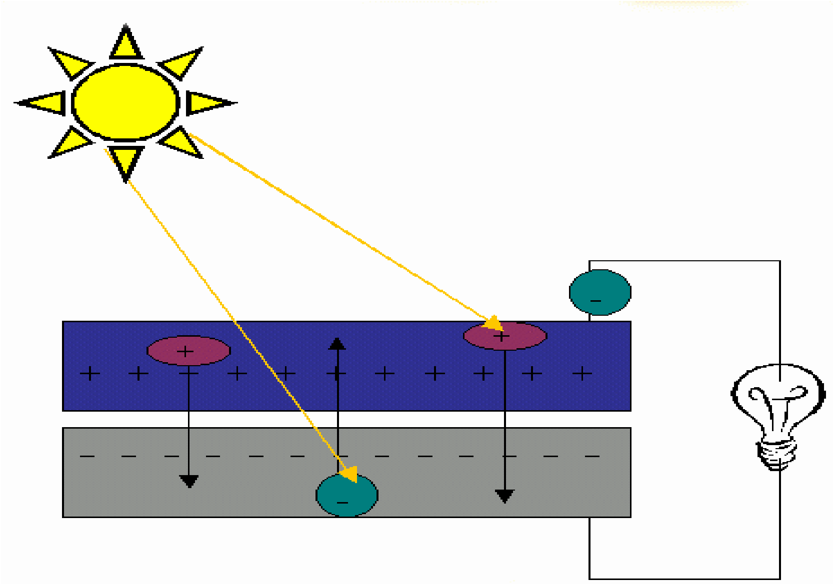
- In piezoelectric induction the measurand is converted into a change in electrostatic charge q or voltage V generated by crystals when mechanically it is stressed as shown in fig.

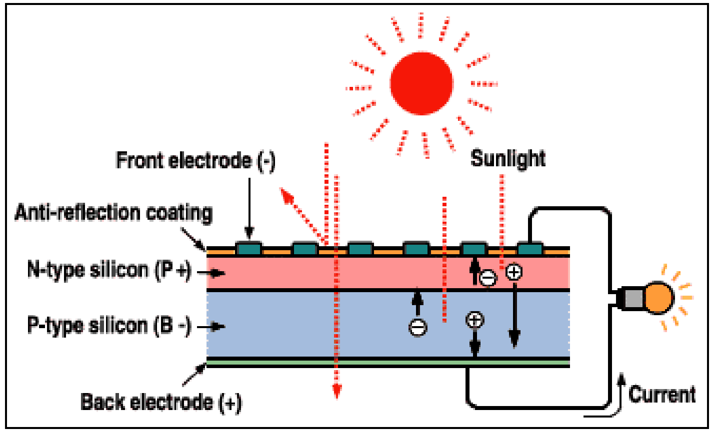


CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

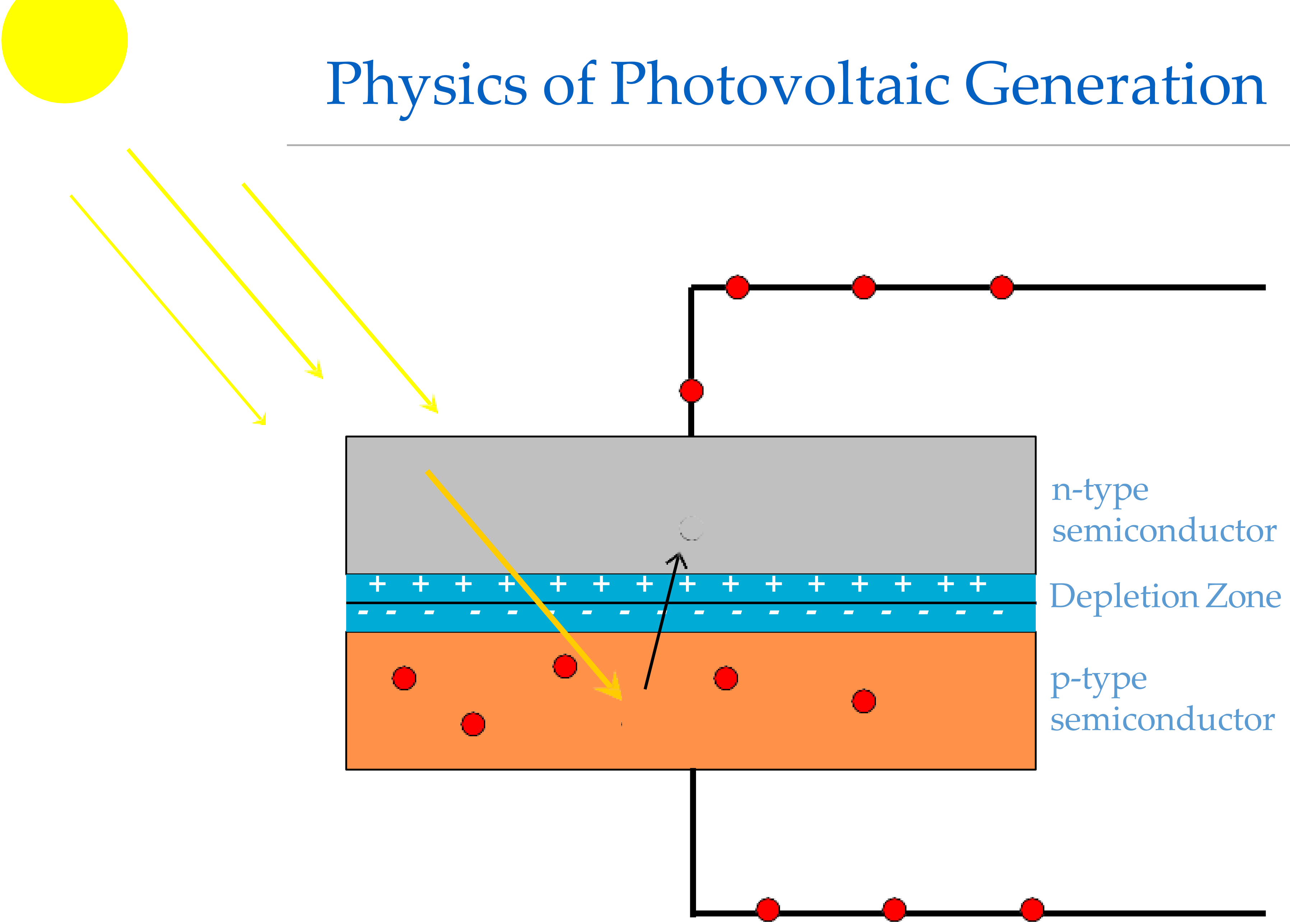
PHOTOVOLTAIC TRANSDUCTION :

- In photovoltaic transduction the measurand is converted to voltage generated when the junction between dissimilar material is illuminated as shown in fig.





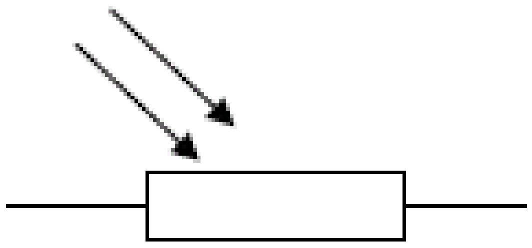
Physics of Photovoltaic Generation



CLASSIFICATION OF TRANSDUCERS
According to Transduction Principle

PHOTO CONDUCTIVE TRANSDUCTION :

- In photoconductive transduction the measurand is converted to change in resistance of semiconductor material by the change in light incident on the material.



CLASSIFICATION OF TRANSDUCERS
Transducer and Inverse Transducer

TRANSDUCER:

- Transducers convert non electrical quantity to electrical quantity.

INVERSE TRANSDUCER:

- Inverse transducers convert electrical quantity to a non electrical quantity

PASSIVE TRANSDUCERS

- **Resistive transducers** :
  - Resistive transducers are those transducers in which the resistance change due to the change in some physical phenomenon.
  - The resistance of a metal conductor is expressed by a simple equation.
  - $R = \rho L/A$
  - Where R = resistance of conductor in Ω L = length of conductor in m

    A = cross sectional area of conductor in m^2

    ρ = resistivity of conductor material in Ω-m.

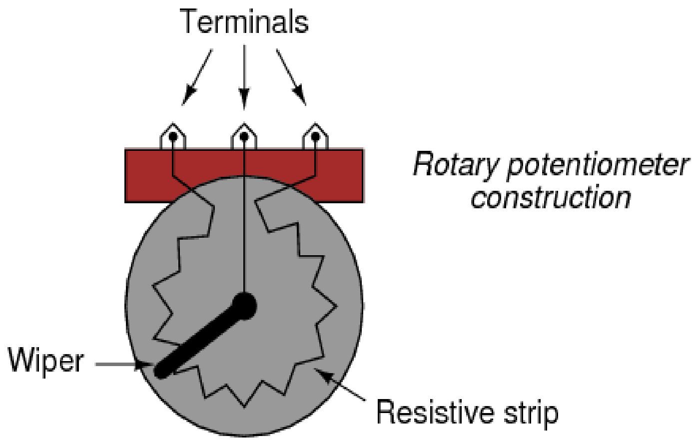
RESISTIVE TRANSDUCER

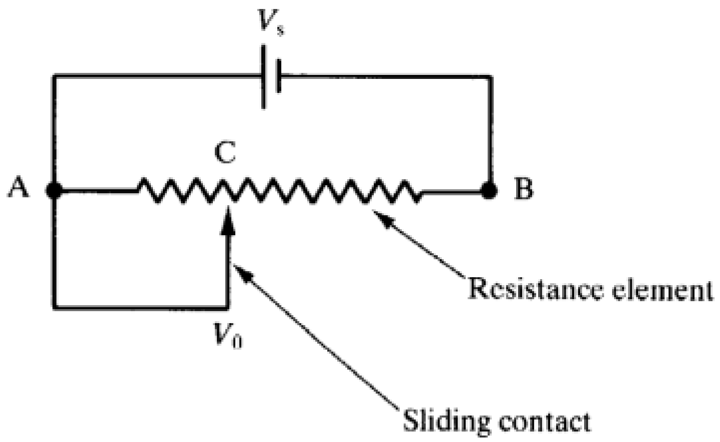
There are 4 type of resistive transducers.

1. Potentiometers (POT)
2. Strain gauge
3. Thermistors
4. Resistance thermometer

POTENTIOMETER

- The potentiometer are used for voltage division. They consist of a resistive element provided with a sliding contact. The sliding contact is called as wiper.
- The contact motion may be linear or rotational or combination of the two. The combinational potentiometer have their resistive element in helix form and are called helipots.
- Fig shows a linear pot and a rotary pot.





STRAIN GAUGE

- The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change.
- This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.

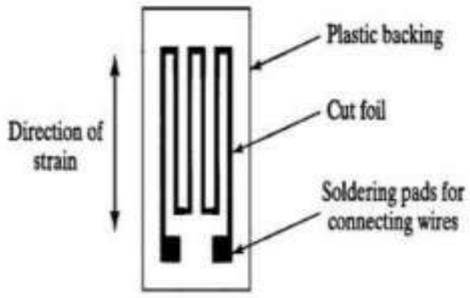
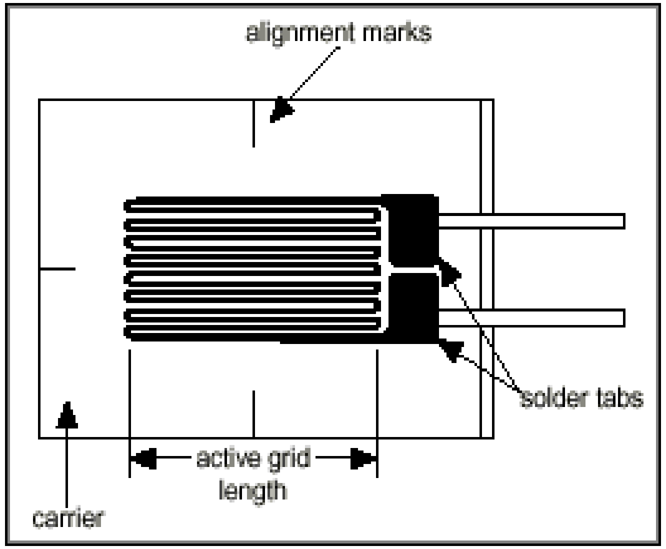


FIGURE 8.2
Foil strain gage.



TYPES OF STRAIN GAUGE

- The type of strain gauge are as

1. Wire gauge

a) Unbonded

b) Bonded

c) Foil type

2. Semiconductor gauge

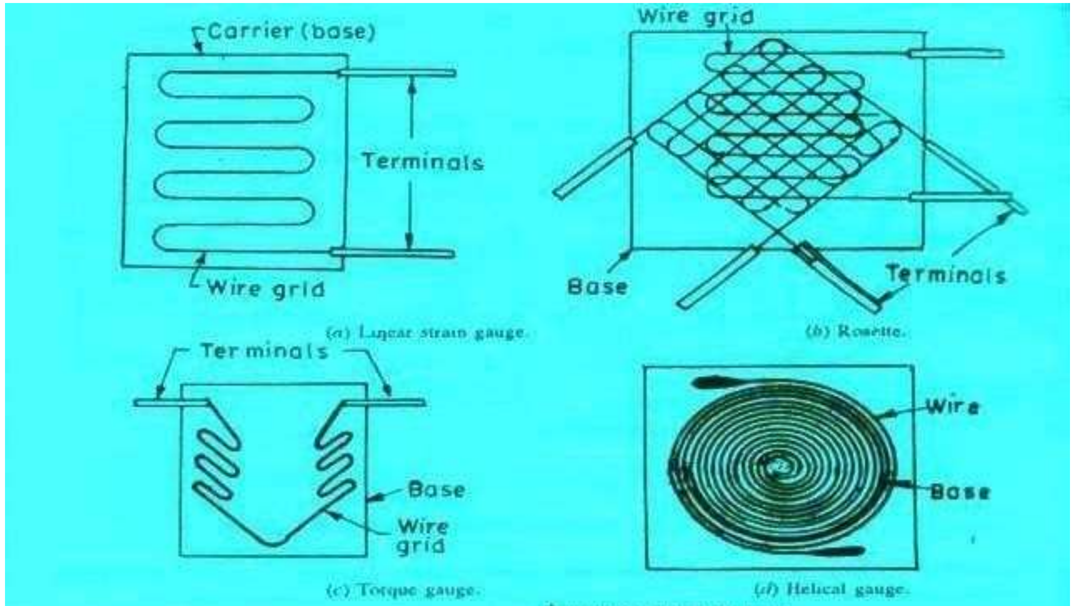
UNBONDED STRAIN GAUGE

- An unbonded meter strain gauge is shown in fig
- This gauge consist of a wire stretched between two point in an insulating medium such as air. The wires may be made of various copper, nickel, crome nickle or nickle iron alloys.
- In fig the element is connected via a rod to diaphragm which is used for sensing the pressure. The wire are tensioned to avoid buckling when they experience the compressive force.

- The unbounded meter wire gauges used almost exclusively in transducer application employ preloaded resistance wire connected in Wheatstone bridge as shown in fig.
- At initial preload the strain and resistance of the four arms are nominally equal with the result the output voltage of the bridge is equal to zero.
- Application of pressure produces a small displacement , the displacement increases a tension in two wire and decreases it in the other two thereby increase the resistance of two wire which are in tension and decreasing the resistance of the remaining two wire .
- This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure .

BONDED STRAIN GAUGE

- The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer.
- A resistance wire strain gauge consist of a grid of fine resistance wire. The grid is cemented to carrier which may be a thin sheet of paper Bakelite or Teflon.
- The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical damage.
- The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires.



Resistance wire strain gauge.

BONDED METAL FOIL STRAIN GAUGE

- It consist of following parts:

1. **Base (carrier) Materials:** several types of base material are used to support the wires. Impregnated paper is used for room temp. applications.
2. **Adhesive:** The adhesive acts as bonding materials. Like other bonding operation, successful strain gauge bonding depends upon careful surface preparation and use of the correct bonding agent.

   In order that the strain be faithfully transferred on to the strain gauge, the bond has to be formed between the surface to be strained and the plastic backing material on which the gauge is mounted .

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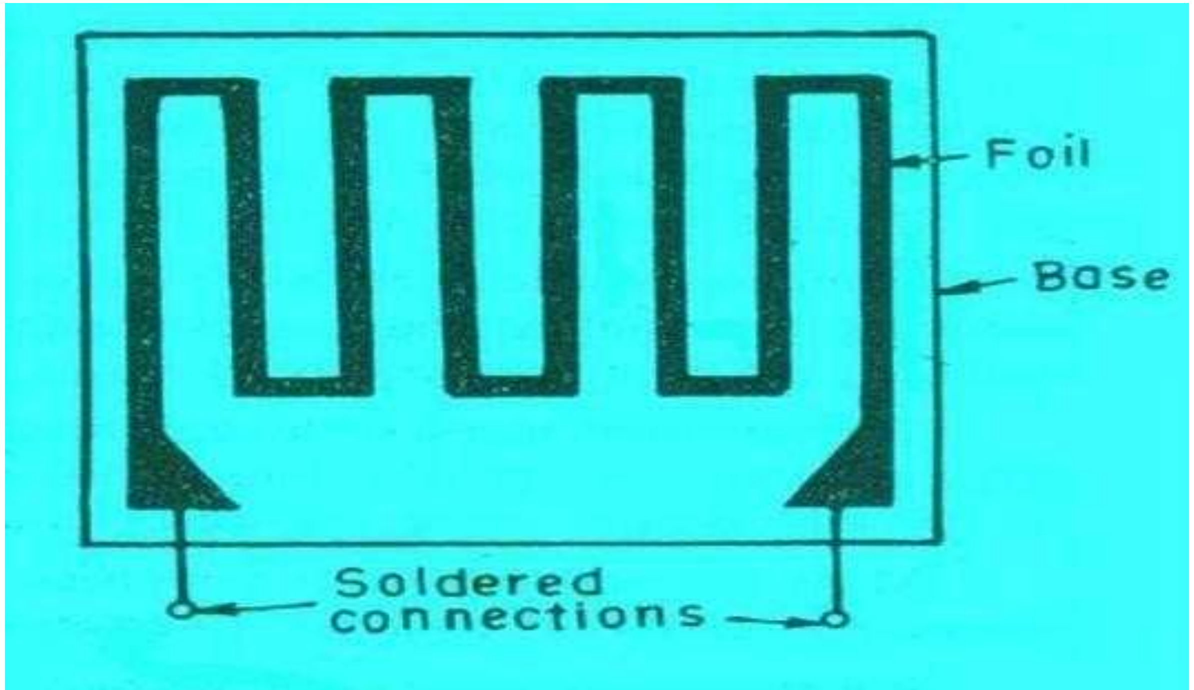


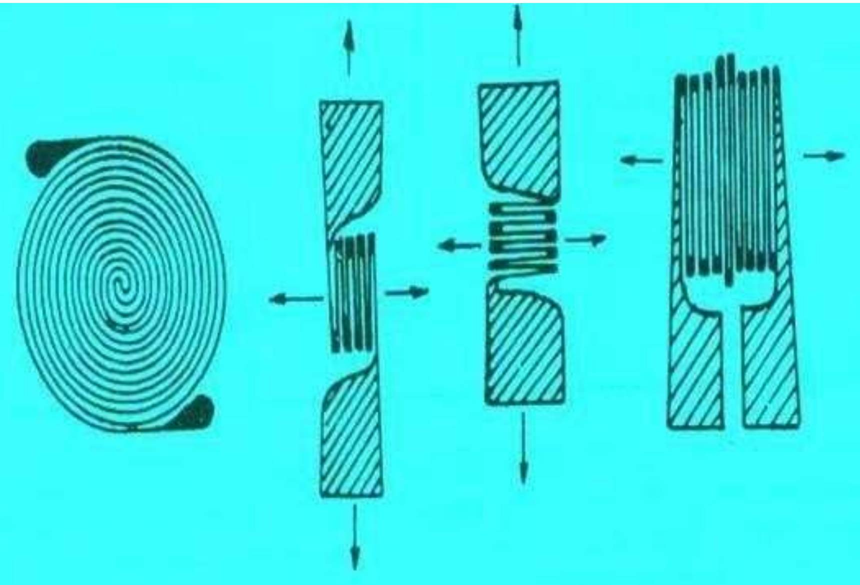
Bonded metal foil gauge.

It is important that the adhesive should be suited to this backing and adhesive material should be quick drying type and also insensitive to moisture.

3. **Leads:** The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficient.

Contd.

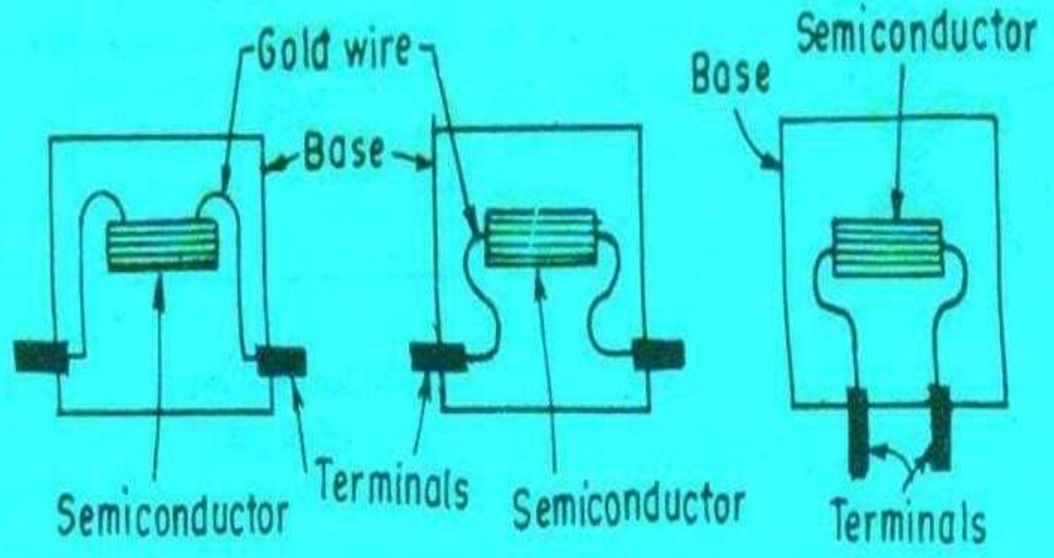
- This class of strain gauge is only an extension of the bonded metal wire strain gauges.
- The bonded metal wire strain gauge have been completely superseded by bonded metal foil strain gauges.
- Metal foil strain gauge use identical material to wire strain gauge and are used for most general purpose stress analysis application and for many transducers.



Metal foil strain gauges.

SEMICONDUCTOR GAUGE

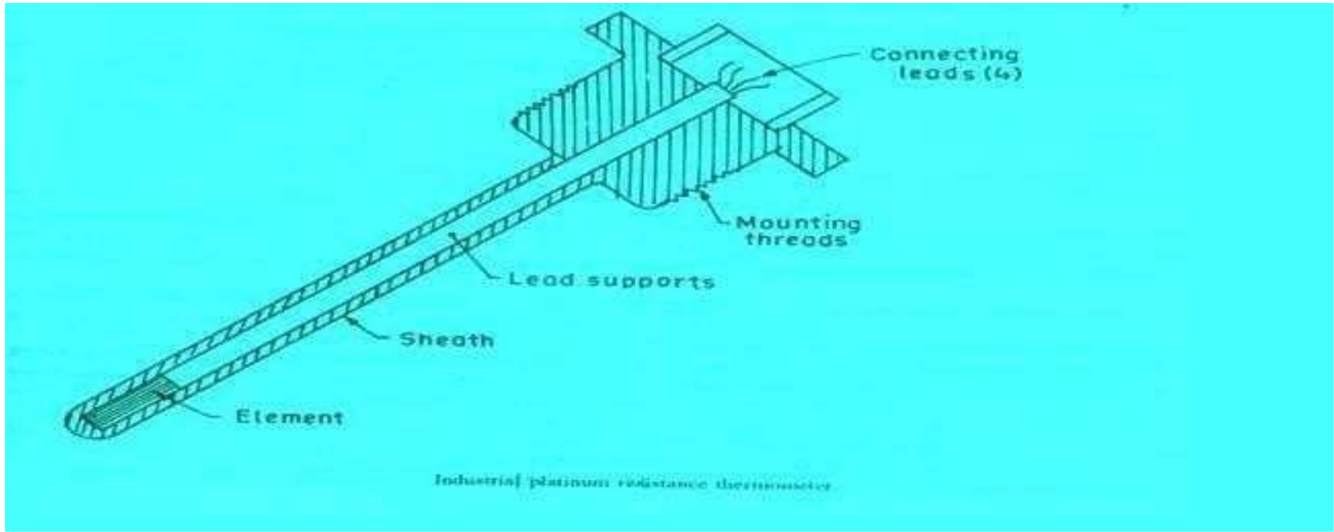
- Semiconductor gauge are used in application where a high gauge factor is desired. A high gauge factor means relatively higher change in resistance that can be measured with good accuracy.
- The resistance of the semiconductor gauge change as strain is applied to it. The semiconductor gauge depends for their action upon the piezo-resistive effect i.e. change in value of resistance due to change in resistivity.
- Silicon and germanium are used as resistive material for semiconductor gauges.



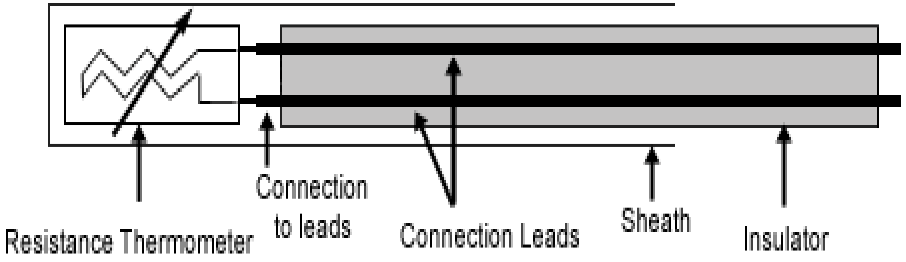
Semi-conductor strain gauge.

RESISTANCE THERMOMETER

- Resistance of metal increase with increases in temperature. Therefore metals are said to have a positive temperature coefficient of resistivity.
- Fig shows the simplest type of open wire construction of platinum résistance thermometer. The platinum wire is wound in the form of spirals on an insulating material such as mica or ceramic.
- This assembly is then placed at the tip of probe
- This wire is in direct contact with the gas or liquid whose temperature is to be measured.



Industrial platinum resistance thermometer

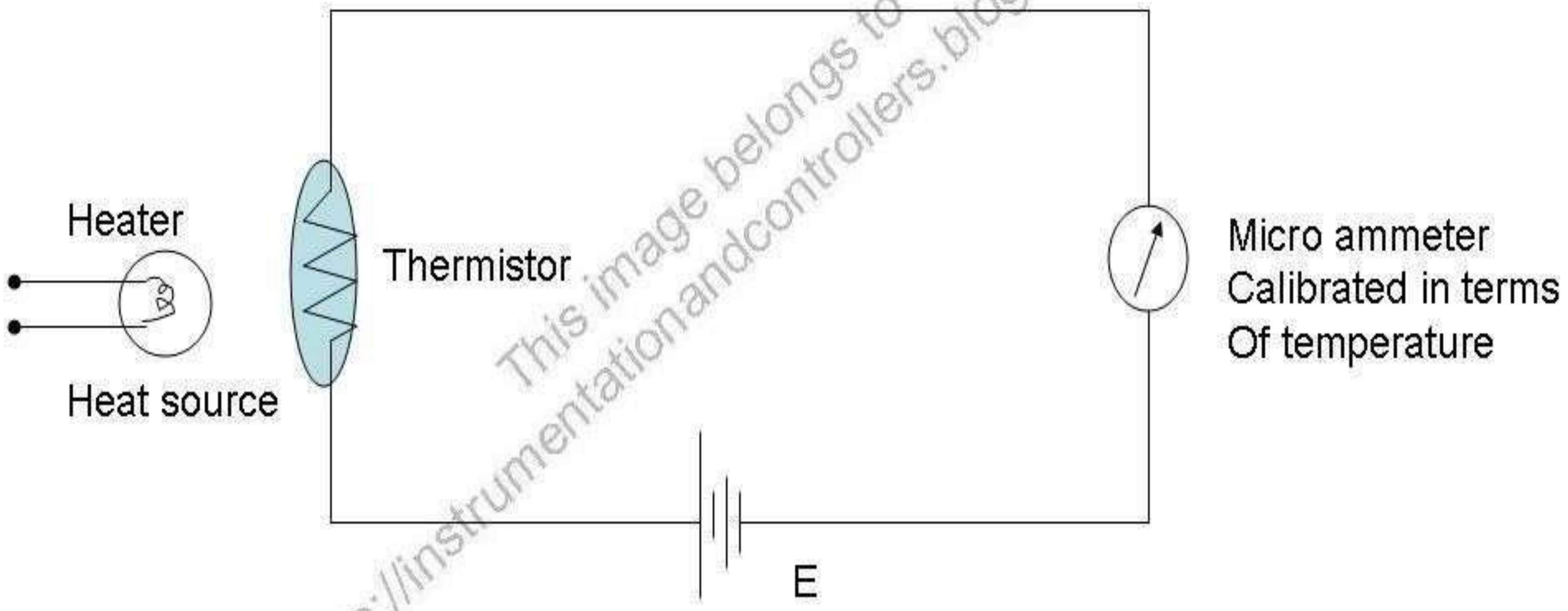


- The resistance of the platinum wire changes with the change in temperature of the gas or liquid
- This type of sensor have a positive temperature coefficient of resistivity as they are made from metals they are also known as resistance temperature detector
- Resistance thermometer are generally of probe type for immersion in medium whose temperature is to be measured or controlled.

THERMISTOR

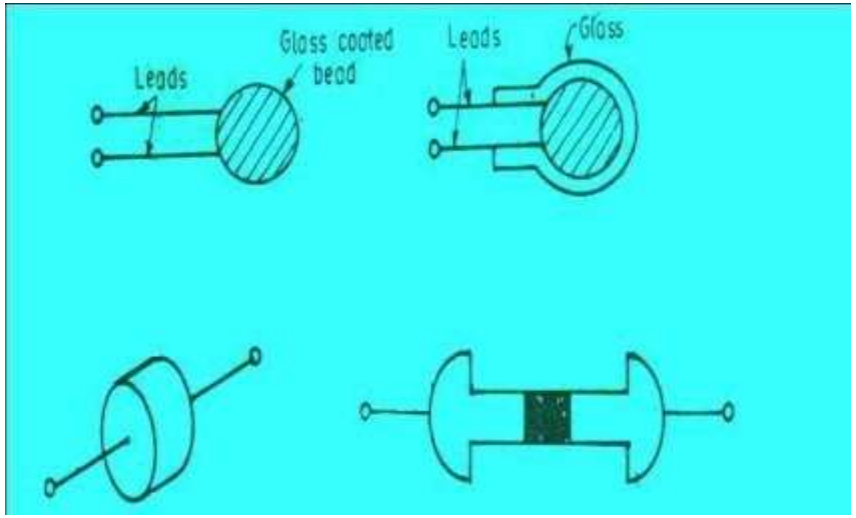
- Thermistor is a contraction of a term ―thermal resistor‖.
- Thermistor are temperature dependent resistors. They are made of semiconductor material which have negative temperature coefficient of resistivity i.e. their resistance decreases with increase of temperature.
- Thermistor are widely used in application which involve measurement in the range of 0-60º Thermistor are composed of sintered mixture of metallic oxides such as manganese, Nickle, cobalt, copper, iron and uranium.

Temperature measurement using thermistor



Contd.

- The thermistor may be in the form of beads, rods and discs.
- The thermistor provide a large change in resistance for small change in temperature. In some cases the resistance of thermistor at room temperature may decreases as much as 6% for each 1ºC rise in temperature.

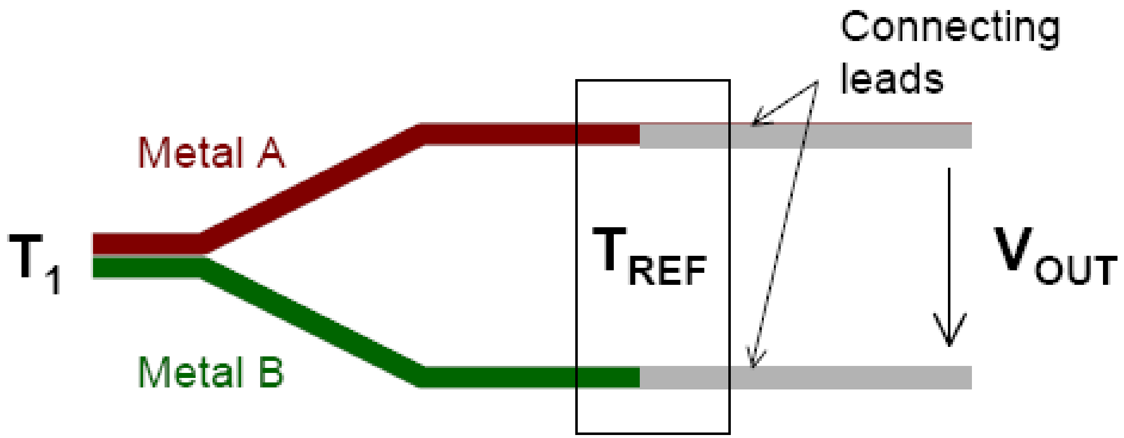


Thermocouples

See beck Effect

When a pair of dissimilar metals are joined at one end, and there is a temperature difference between the joined ends and the open ends, thermal emf is generated, which can be measured in the open ends.

This forms the basis of thermocouples.



VARIABLE-INDUCTANCE TRANSDUCERS

- An inductive electromechanical transducer is a transducer which converts the physical motion into the change in inductance.
- Inductive transducers are mainly used for displacement measurement.

- The inductive transducers are of the self generating or the passive type. The self generating inductive transducers use the basic generator principle i.e. the motion between a conductor and magnetic field induces a voltage in the conductor.

- The variable inductance transducers work on the following principles.

- Variation in self inductance

- Variation in mutual inductance

PRINCIPLE OF VARIATION OF SELF INDUCTANCE

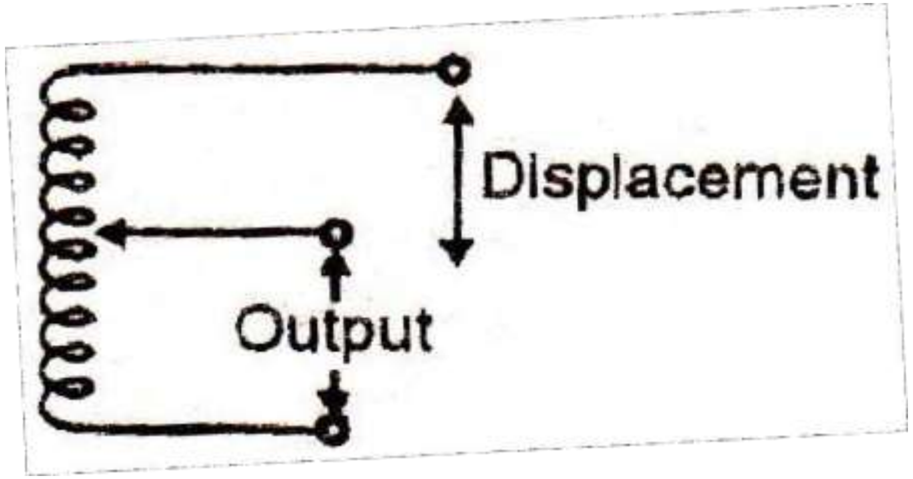
- Let us consider an inductive transducer having N turns and reluctance R. when current I is passed through the transducer, the flux produced is
- $\Phi = Ni / R$
- Differentiating w.r.t. to t,
- $d\Phi/dt = N/R * di/dt$
- The e.m.f. induced in a coil is given by
- $e = N * d\Phi/dt$

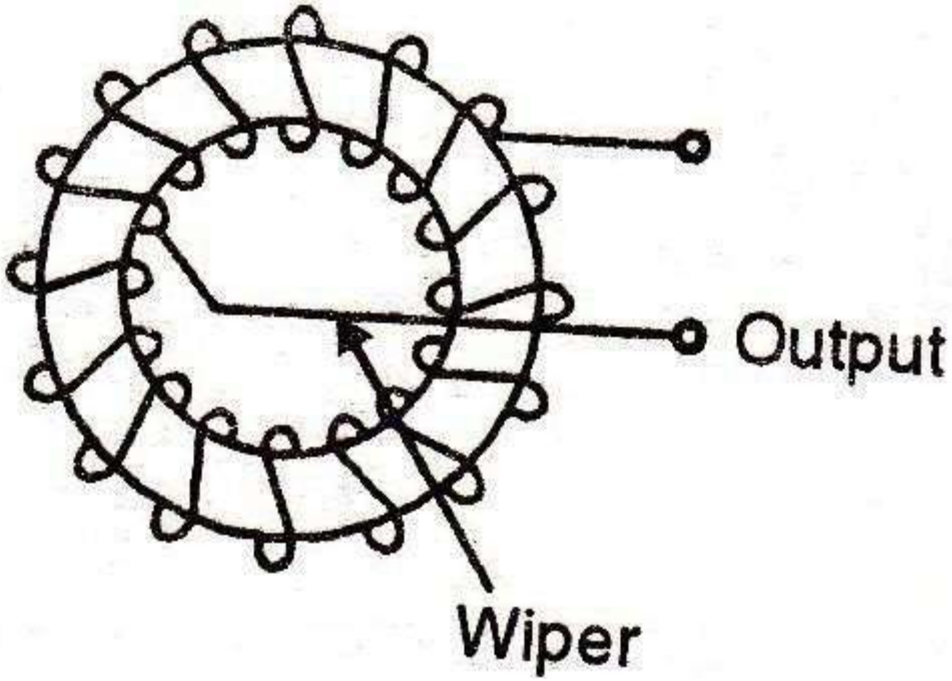
- $e = N * N/R * di/dt$
- $e = N^2 / R * di/dt$
- Self inductance is given by
- $L = e/di/dt = N^2 / R$
- The reluctance of the magnetic circuit is $R = l/\mu A$
- Therefore $L = N^2 / l/\mu A = N^2 \mu A / l$
- From eqn we can see that the self inductance may vary due to

i. Change in number of turns N
ii. Change in geometric configuration
iii. Change in permeability of magnetic circuit

CHANGE IN SELF INDUCTANCE WITH CHANGE IN NUMBER OF TURNS N

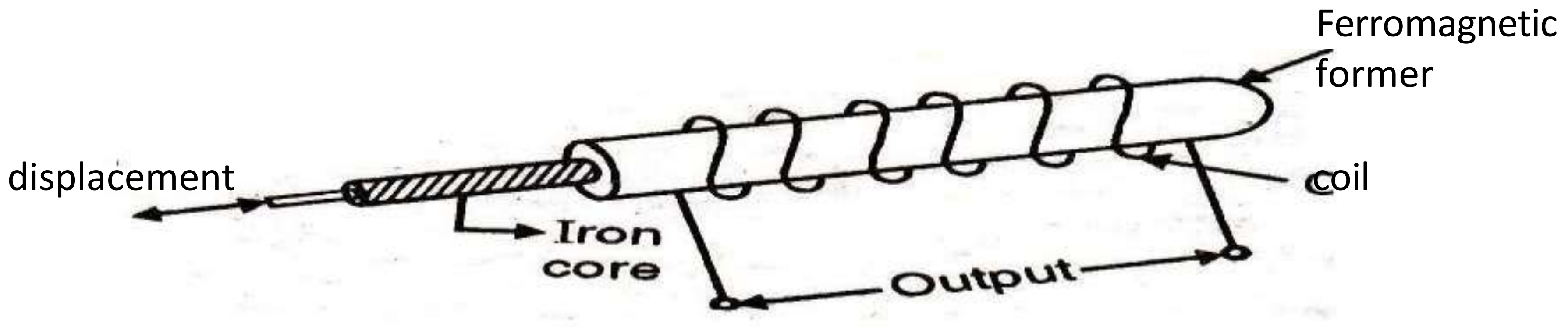
- From eqn we can see the output may vary with the variation in the number of turns. As inductive transducers are mainly used for displacement measurement, with change in number of turns the self inductance of the coil changes in-turn changing the displacement
- Fig shows transducers used for linear and angular displacement fig a shows an air cored transducer for the measurement of linear displacement and fig b shows an iron cored transducer used for angular displacement measurement.


Displacement
Output


Output
Wiper

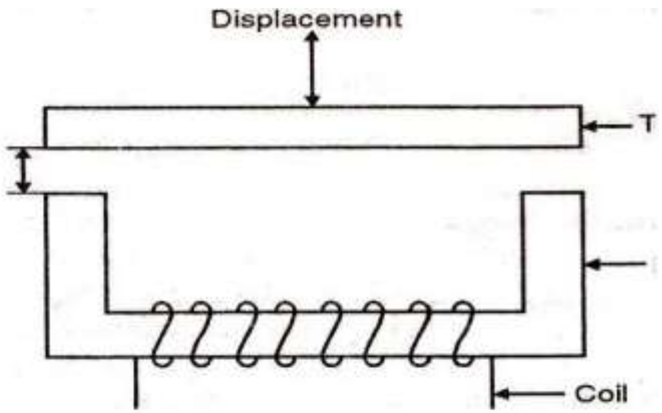
CHANGE IN SELF INDUCTANCE WITH CHANGE IN PERMEABILITY

- An inductive transducer that works on the principle of change in self inductance of coil due to change in the permeability is shown in fig
- As shown in fig the iron core is surrounded by a winding. If the iron core is inside the winding then the permeability increases otherwise permeability decreases. This cause the self inductance of the coil to increase or decrease depending on the permeability.
- The displacement can be measured using this transducer



VARIABLE RELUCTANCE INDUCTIVE TRANSDUCER

- Fig shows a variable reluctance inductive transducer.
- As shown in fig the coil is wound on the ferromagnetic iron. The target and core are not in direct contact with each other. They are separated by an air gap.
- The displacement has to be measured is applied to the ferromagnetic core
- The reluctance of the magnetic path is found by the size of the air gap.
- The self inductance of coil is given by
- $L = N^2 / R = N^2 / Ri + Ra$
- N : number of turns
- R : reluctance of coil
- Ri : reluctance of iron path
- Ra : reluctance of air gap

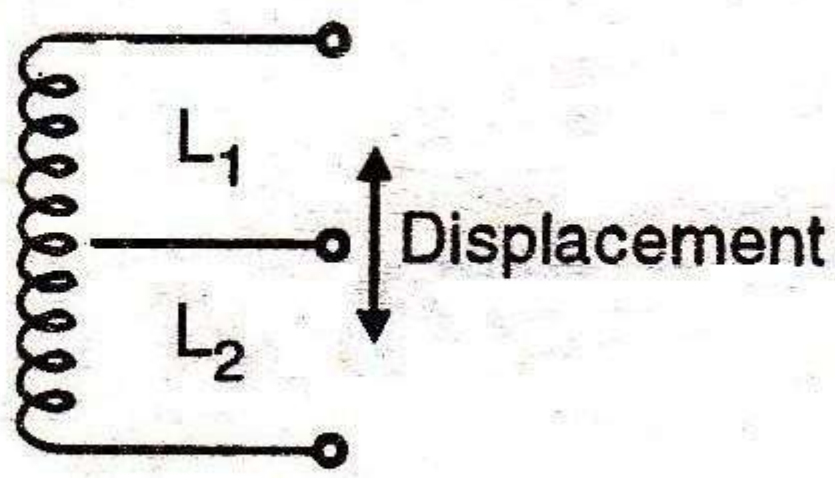


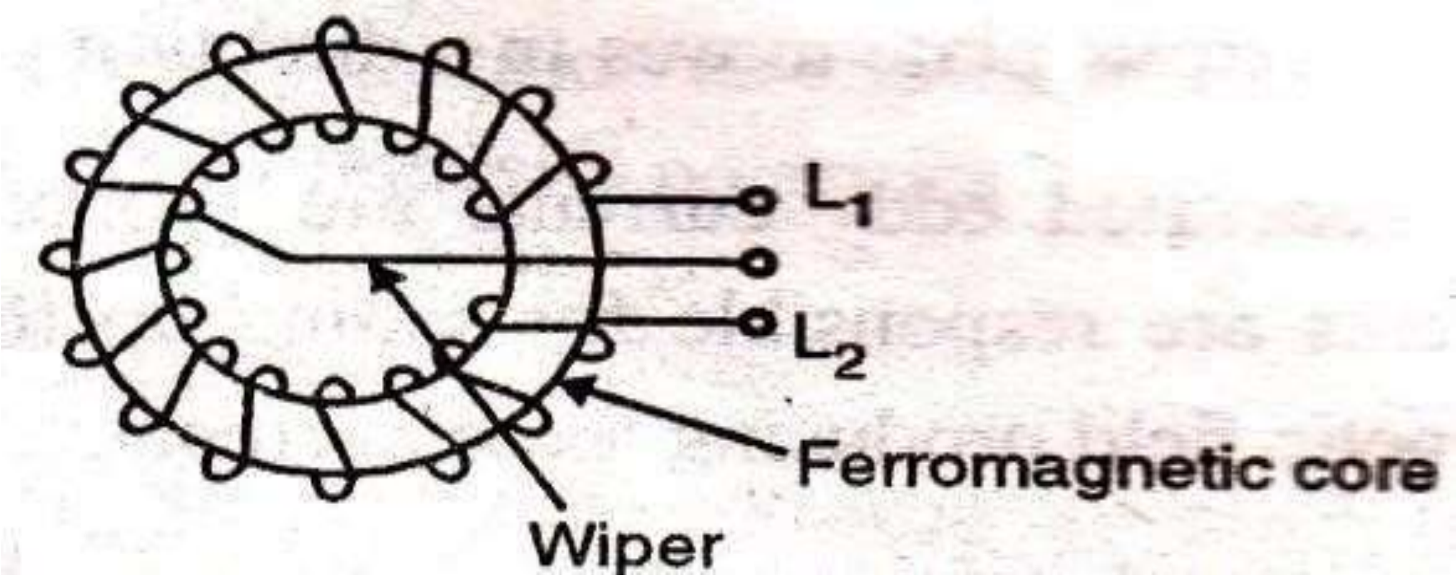
CONTD.

- The reluctance of iron path is negligible
- $L = N^2 / Ra$
- $Ra = la / \mu_o A$
- Therefore L œ 1 / la i.e. self inductance of the coil is inversely proportional to the air gap la.
- When the target is near the core, the length is small. Hence the self inductance is large. But when the target is away from the core, the length is large. So reluctance is also large. This result in decrease in self inductance i.e. small self inductance.
- Thus inductance is function of the distance of the target from the core. Displacement changes with the length of the air gap, the self inductance is a function of the displacement.

PRINCIPLE OF CHANGE IN MUTUAL INDUCTANCE

- Multiple coils are required for inductive transducers that operate on the principle of change in mutual inductance.
- The mutual inductance between two coils is given by
- M = KsqrtL1L2
- Where M : mutual inductance
- K : coefficient of coupling
- L1:self inductance of coil 1
- L2 : self inductance of coil 2
- By varying the self inductance or the coefficient of coupling the mutual inductance can be varied

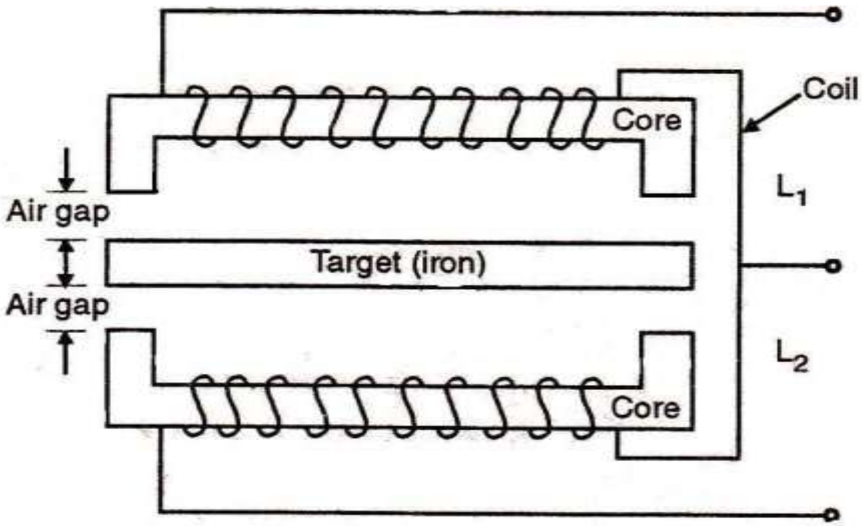

L1
Displacement
L2


L1
L2
Ferromagnetic core
Wiper

DIFFERENTIAL OUTPUT TRANSDUCERS

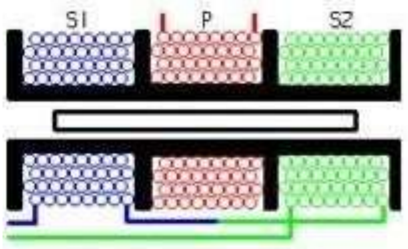
- Usually the change in self inductance ΔL for inductive transducers is insufficient for the detection of stages of an instrumentation system.
- The differential arrangement comprises of a coil that is divided in two parts as shown in fig a and b.
- In response to displacement, the inductance of one part increases from L to L+ΔL while the inductance of the other part decreases from L to L- ΔL. The difference of two is measured so to get output 2 ΔL. This will increase the sensitivity and minimize error.
- .

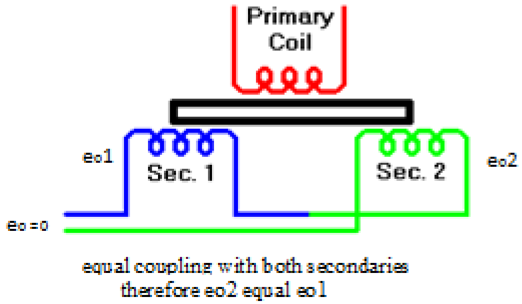
- Fig c shows an inductive transducer that provides differential output. Due to variation in the reluctance, the self inductance of the coil changes. This is the principle of operation of differential output inductive transducer


Coil
Core
L1
Air gap
Target (iron)
Air gap
L2
Core

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER(LVDT)

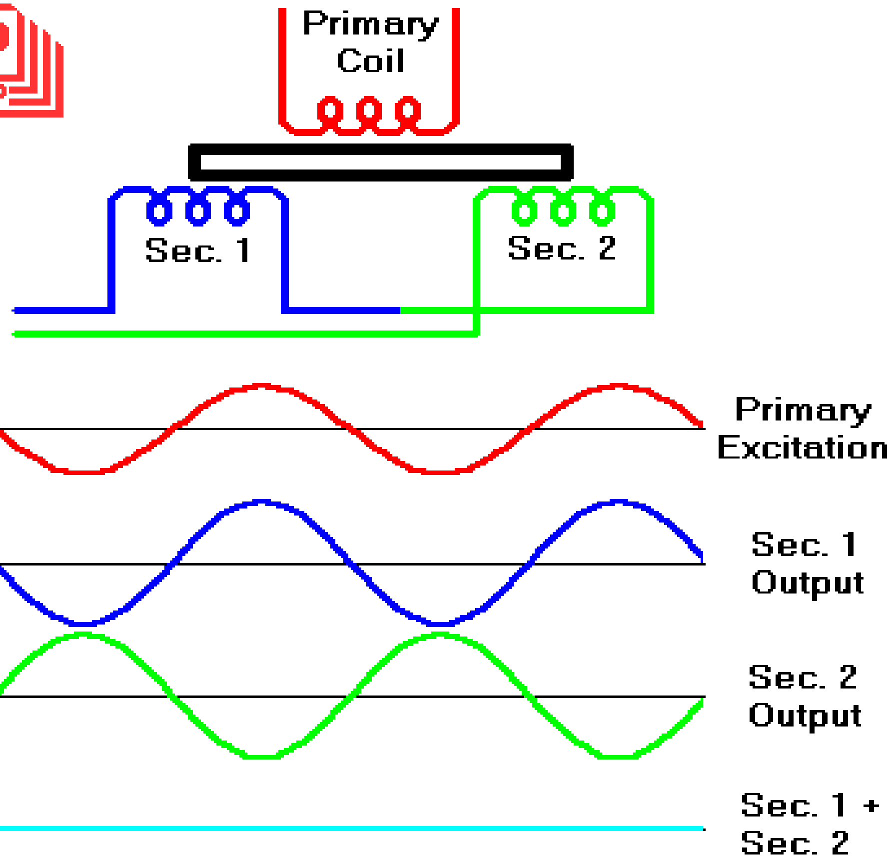
- AN LVDT transducer comprises a coil former on to which three coils are wound.
- The primary coil is excited with an AC current, the secondary coils are wound such that when a ferrite core is in the central linear position, an equal voltage is induced in to each coil.
- The secondary are connected in opposite so that in the central position the outputs of the secondary cancels each other out.





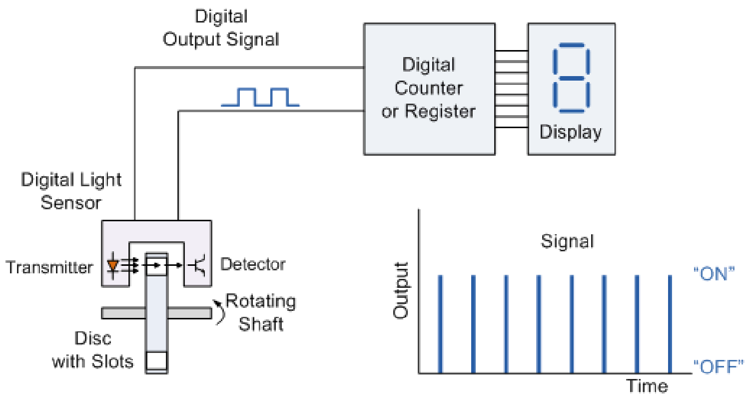
LVDT contd…

- The excitation is applied to the primary winding and the armature assists the induction of current in to secondary coils.
- When the core is exactly at the center of the coil then the flux linked to both the secondary winding will be equal. Due to equal flux linkage the secondary induced voltages (eo1 & eo2) are equal but they have opposite polarities. Output voltage eo is therefore zero. This position is called ―null position‖



Primary Coil
Sec. 1
Sec. 2
Primary Excitation
Sec. 1 Output
Sec. 2 Output
Sec. 1 + Sec. 2

- Now if the core is displaced from its null position toward sec1 then flux linked to sec1 increases and flux linked to sec2 decreases. Therefore eo1 > eo2 and the output voltage of LVDT eo will be positive
- Similarly if the core is displaced toward sec2 then the eo2 > eo1 and the output voltage of LVDT eo will be negative.



Transducers

Terminology

- Transducer that convert one form of energy into another
- Sensors/Actuators are input/output transducers
- Sensors can be *passive* (e.g. change in resistance) or *active* (output is a voltage or current level)
- Sensors can be *analog* (e.g. thermocouples) or *digital* (e.g. digital tachometer)

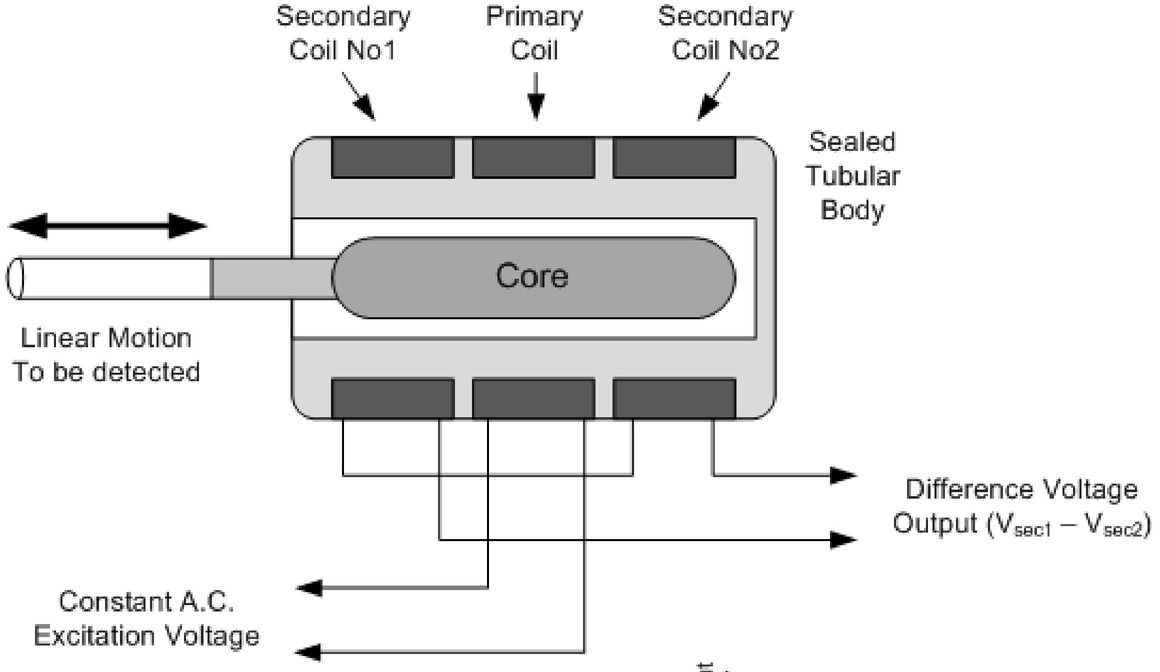
Transducer Types

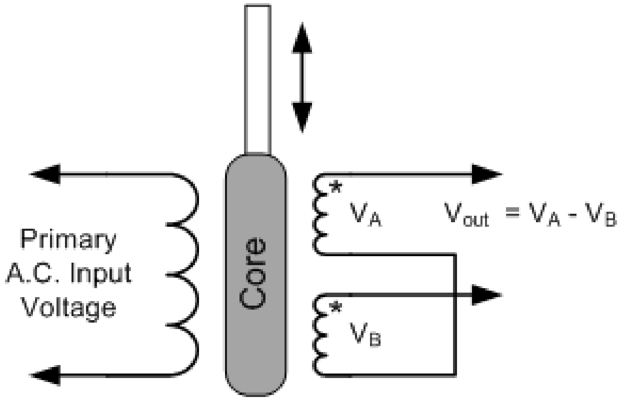
e

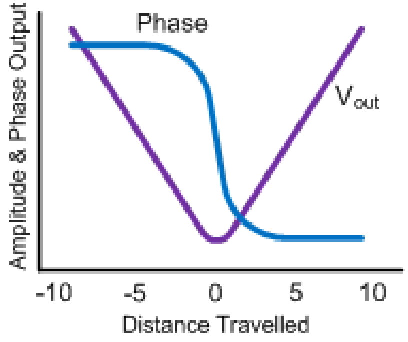
Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR), Photodiode, Phototransistor, Solar Cell	Lights & Lamps, LED's & Displays, Fiber Optics
Temperature	Thermocouple, Thermistor, Thermostat, Resistive temperature detectors (RTD)	Heater, Fan, Peltier Elements
Force/Pressur e	Strain Gauge, Pressure Switch, Load Cells	Lifts & Jacks, Electromagnetic, Vibration
Position	Potentiometer, Encoders, Reflective/Slotted Opto-switch, LVDT	Motor, Solenoid, Panel Meters
Speed	Tacho-generator, Reflective/Slotted Opto-coupler, Doppler Effect Sensors	AC and DC Motors, Stepper Motor, Brake
Sound	Carbon Microphone, Piezo-electric Crystal	Bell, Buzzer, Loudspeaker

Positional Sensors: LVDT

Linear Variable Differential Transformer



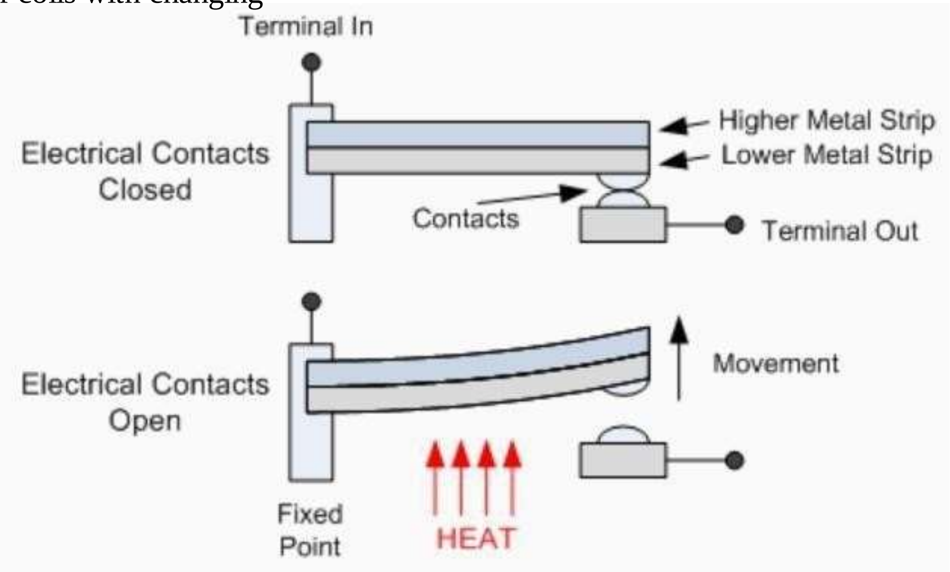




Temperature

switch (electro-mechanical) – used in thermostats. Can be ―creep‖ or ―snap‖ action.

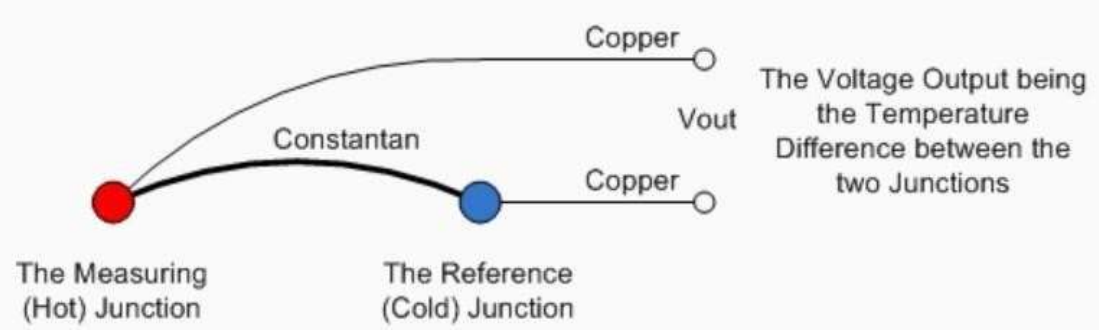
Creep-action: coil or spiral that unwinds or coils with changing temperature



- Thermistors (thermally sensitive resistors); Platinum Resistance Thermometer (PRT), very high accuracy.

Thermocouples

Two dissimilar metals induce voltage difference (few mV per 10K) – electro-thermal or Seebeck effect

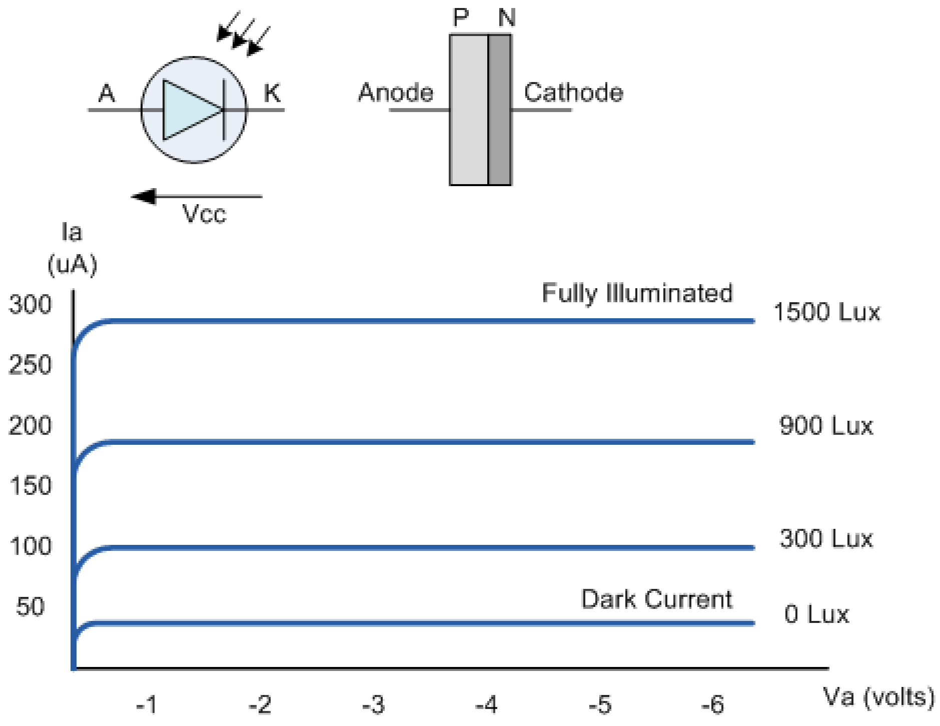


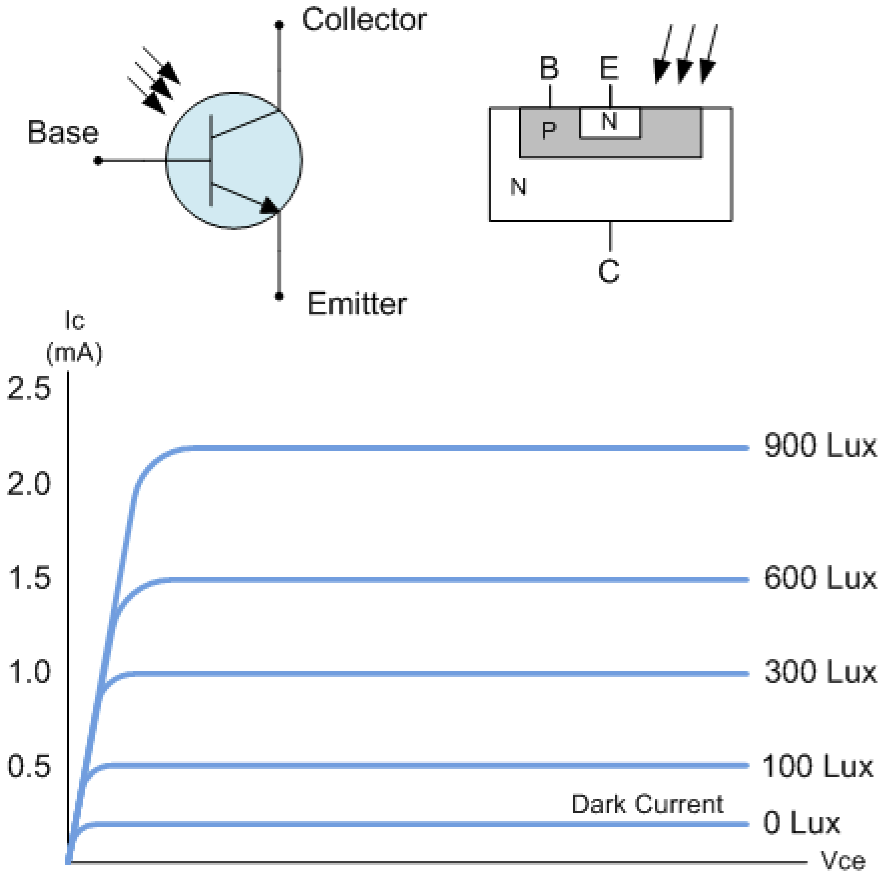
- Use op-amp to process/amplify the voltage
- Absolute accuracy of 1K is difficult

Photojunction devices

phototransistor

photodiode





Classification of transducers

1. Based on principle of transduction
2. Active & passive
3. Analog & digital
4. Inverse transducer

Passive transducer

Device which need external power for transduction from auxiliary power source

Eg : resistive, inductive, capacitive

Without power they will not work

Active transducer

- No extra power required.
- Self generating
- Draw power from input applied
- Eg. Piezo electric x’tal used for acceleration measurement

Resistive Transducer

- In this transducer, the resistance of the output terminal of the transducer gets varied according to the measurand.

- Some resistive transducers are:-

Potentiometer

Strain gauge

Resistance Thermometer

RESISTIVITE POTENTIOMETERS

A resistance element provided with a movable contact. This is very simple and cheap form of transducer and is widely used. It convert linear or rotational displacement into a voltage.

The contact motion can be

- Linear
- rotation
- combination of the two such as helical

Strain Gauges

- It is a device which is used for measuring mechanical surface strain and one of the most extensively used electrical transducer. It can detect and convert force or small mechanical displacement into electrical signal. Many other quantities such as torque, pressure, weight and tension etc, which involve the effect of force or displacement can be measured with string gauge.

- Gauge Factor (G) = Change in resistance per unit strain.

Strain Gauge can be of four types:-

1. Wire strain gauge
2. Foil strain gauge
3. Thin film strain gauge
4. Semiconductor strain gauge

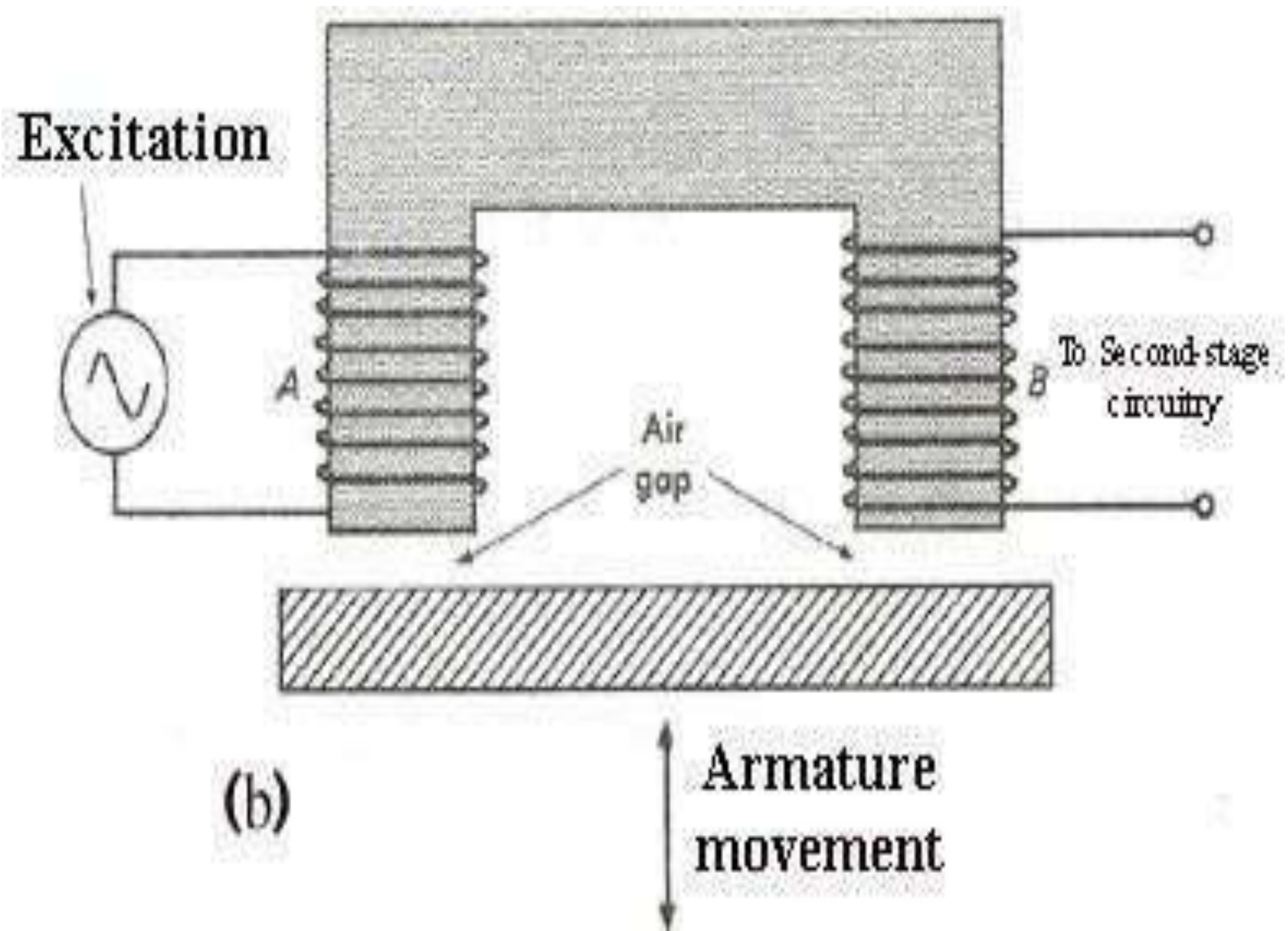
INDUCTIVE TRANSDUCERS

- Inductive transducers are those in which SELF INDUCTANCE of a coil or the MUTUAL INDUCTANCE of a pair of coil is altered due to variation in the measurand.

- Change in inductance ΔL is measured.

- The **self inductance** of a coil refers to the flux linkage within the coil due to current in the same coil.

- **Mutual inductance** refers to the flux linkages in a coil due to current in adjacent coil.


Excitation
A
Air
gap
B
To Second-stage
circuitry
Armature
movement

(b)

CAPACITIVE TRANSDUCERS

A capacitor is an electrical component which essentially consists of two plates separated by an insulator.

The property of a capacitor to store an electric charge when its plates are at different potential is referred to as capacitance.

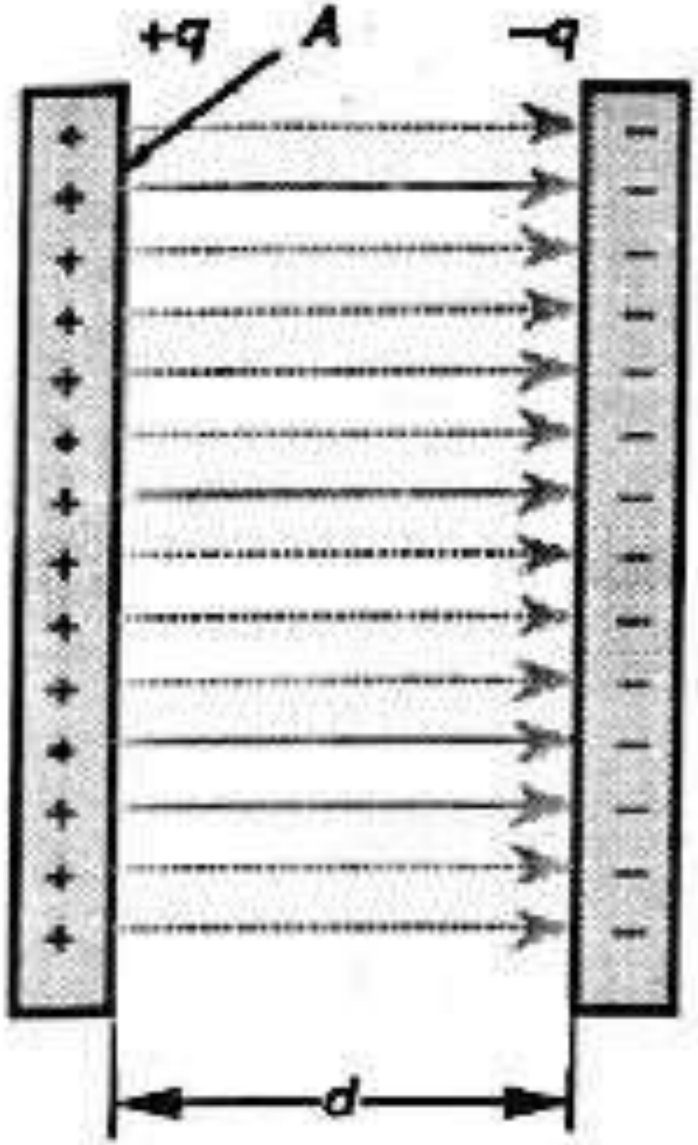
Capacitance C = $\frac{Q}{V}$

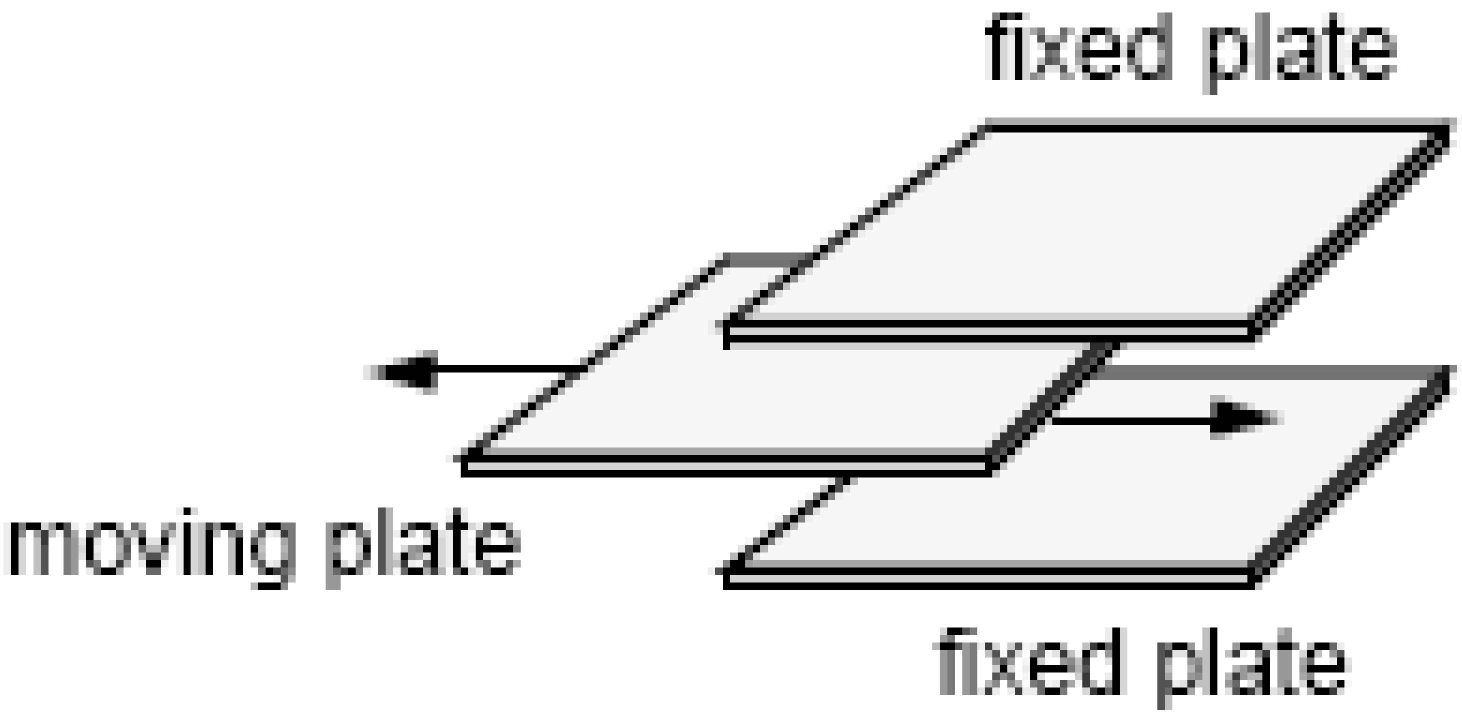
If the capacitance is large, more charge is needed

to establish a given voltage difference.

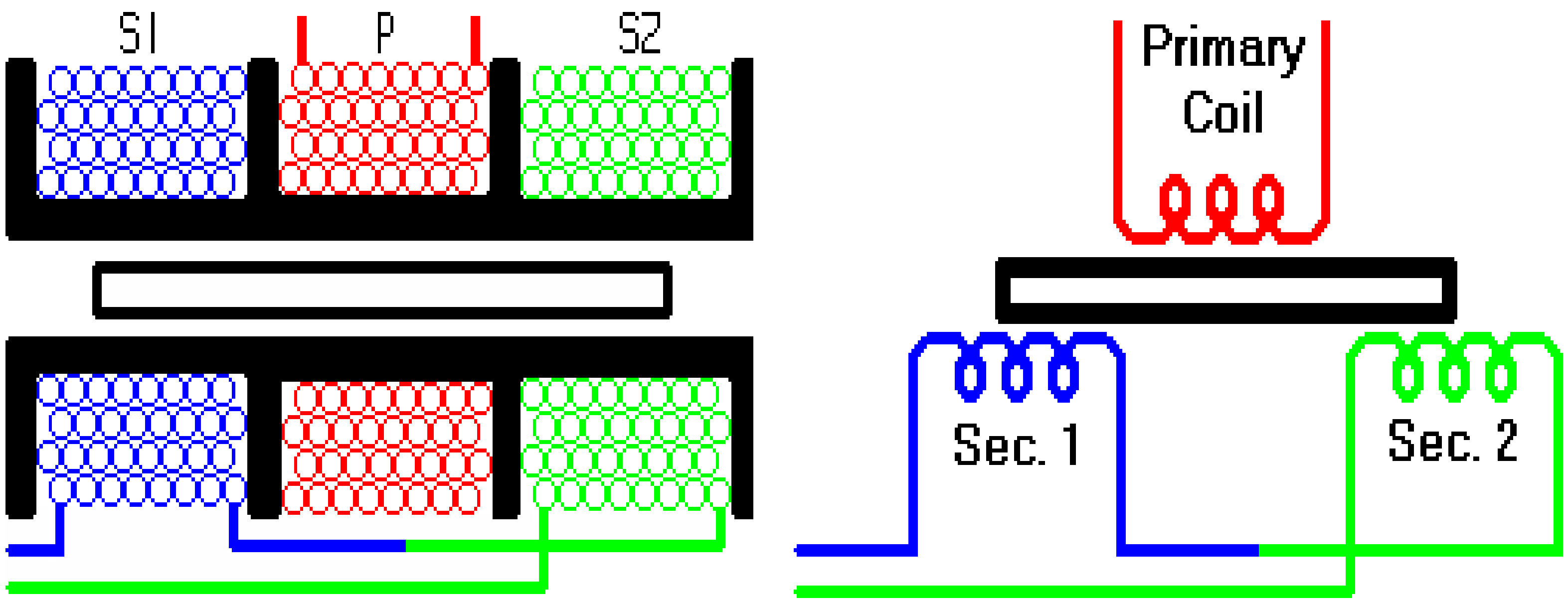
The capacitance between two parallel metallic plates of area

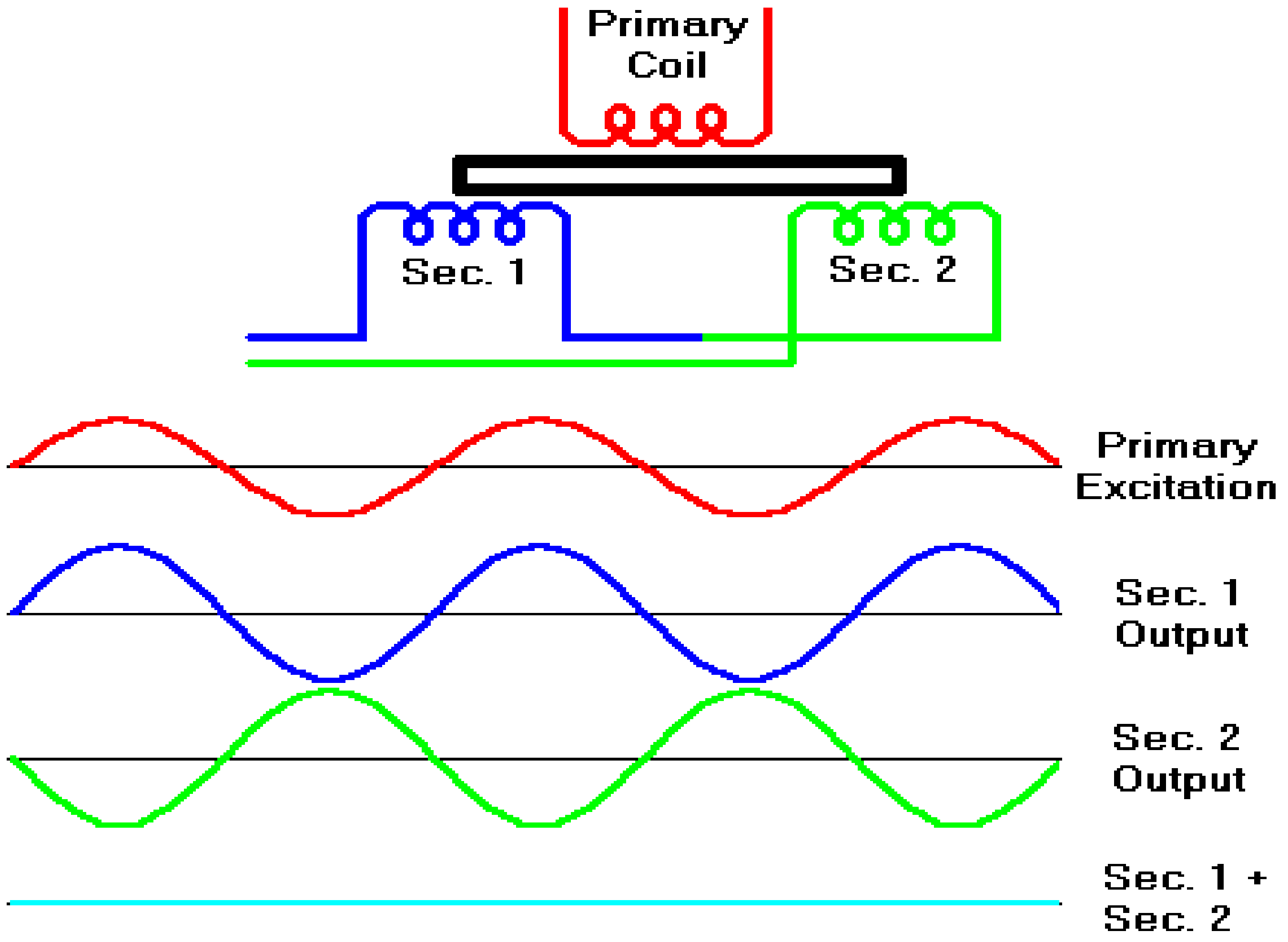
$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \qquad \left(\varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{m} \right)$$


+q
A
−q
d


fixed plate
moving plate
fixed plate

Linear Variable Differential Transformer (LVDT)




Primary
Coil
Sec. 1
Sec. 2
Primary
Excitation
Sec. 1
Output
Sec. 2
Output
Sec. 1 +
Sec. 2

➢Geometric centre of coil arrangement is called the NULL position. The output voltage at the null position is ideally zero.

➢However it is small but nonzero (null voltage). Why?

1. Harmonics in the excitation voltage and stray capacitance coupling between the primary and the secondary
2. Manufacturing defects.

Advantages

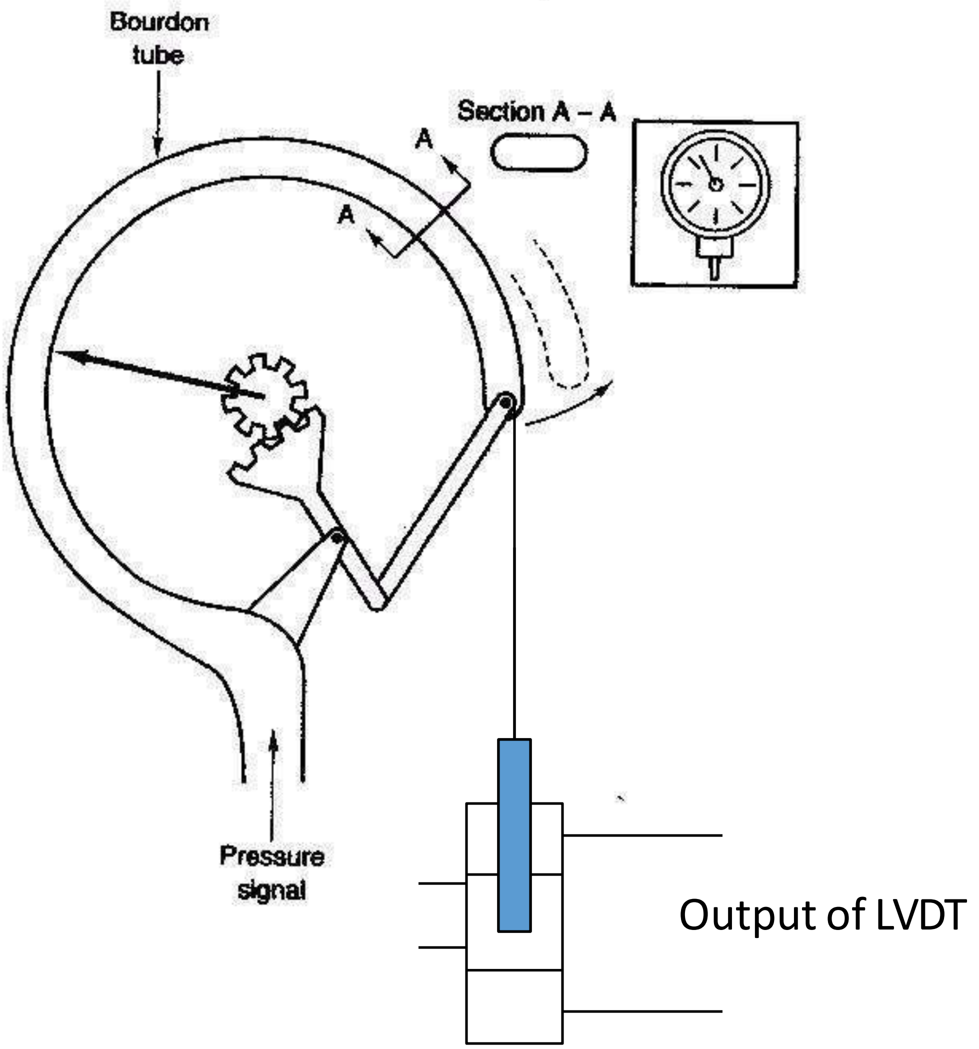
1. Wide range of displacement from μm to cm.
2. Frictionless and electrical isolation.
3. High output.
4. High sensitivity [sensitivity is expressed in mV (output voltage)/ mm (input core displacement)].

Disadvantages

1. Sensitive to stray magnetic fields.
2. Affected by vibrations.
3. Dynamic response is limited mechanically by the mass of core and electrically by frequency of excitation voltage.

Pressure Measurement

- The measurement of force or pressure can be done by converting the applied force or pressure into displacement by elastic element (such as diaphragam, capsule, bellows or bourdon tube) which act as primary transducer.
- This displacement, which is function of pressure is measured by transducer which act as secondary transducer (these may be potentiometer, strain gauge, LVDT, piezoelectric, etc.).


Bourdon tube
Section A – A
A
A
Pressure signal
Output of LVDT

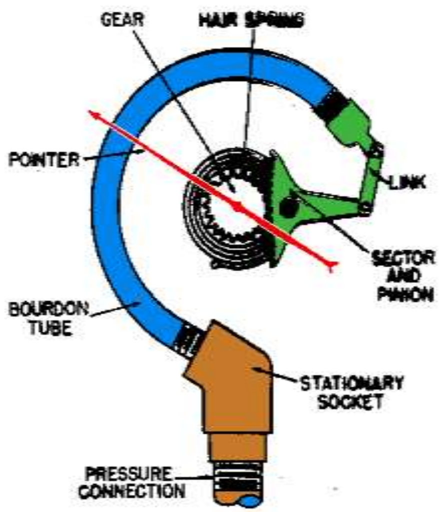
Bourdon Tube Pressure Gauge

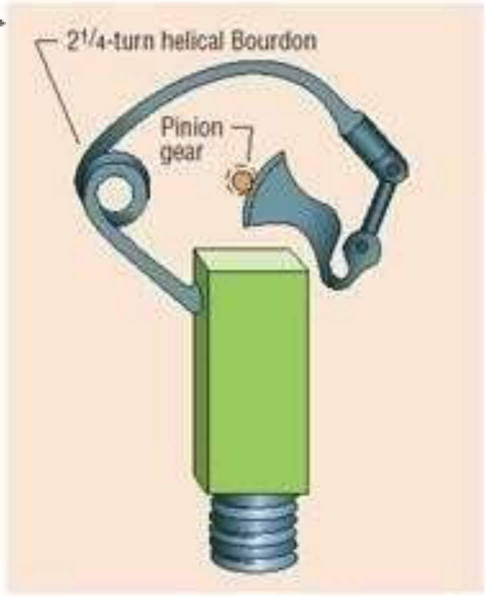
- Perhaps the most common device around today is the pressure gauge which utilizes a bourdon tube as its sensing elements.
- ***Bourdon :*** A bourdon tube is a curved, hollow tube with the process pressure applied to the fluid in the tube. The pressure in the tube causes the tube to deform or uncoil. The pressure can be determined from the mechanical displacement of the pointer connected to the Bourdon tube. Typical shapes for the tube are ―C‖(normally for local display), spiral and helical.

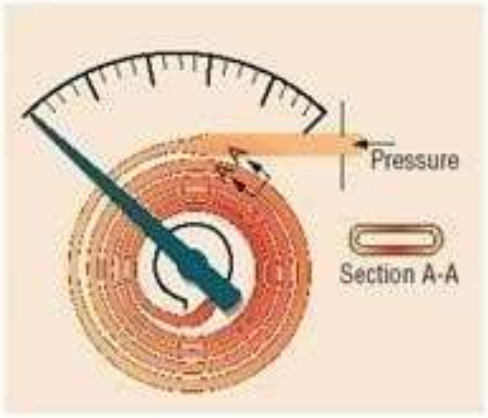
Bourdon Tube Pressure Gauge

Bourdon tubes are generally are of three types;

1. C-type
2. Helical type
3. Spiral type







Thermo- couple

The thermocouple is one of the most commonly used method for measuring the process temperature. The operation is based on seebeck effect.

Thermo-couple consists of two dissimilar metals joined together as shown. It forms two junctions 1 and 2 in which one junction is hot and other is cold. Due to this difference in temperature, an e.m.f. is generated and electric current flow in circuit.