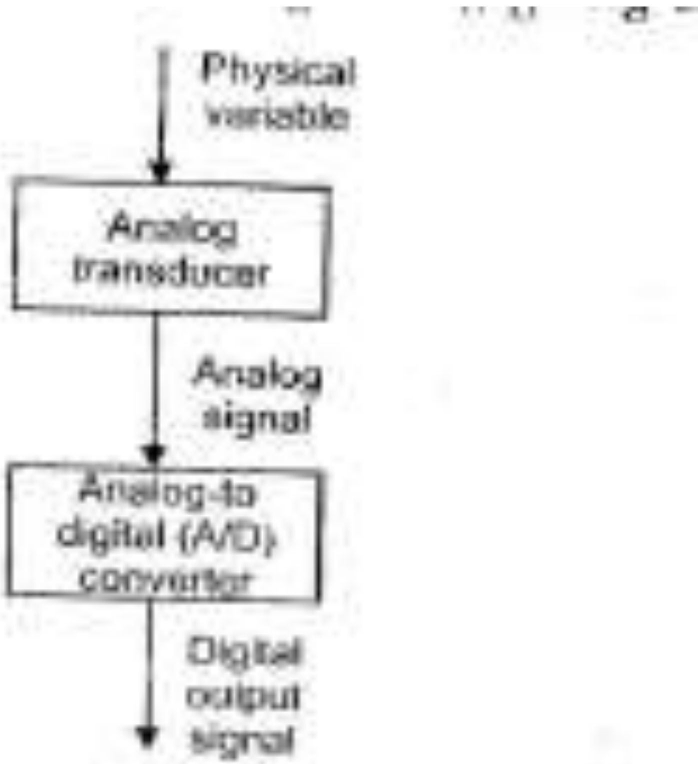
# MODULE 2

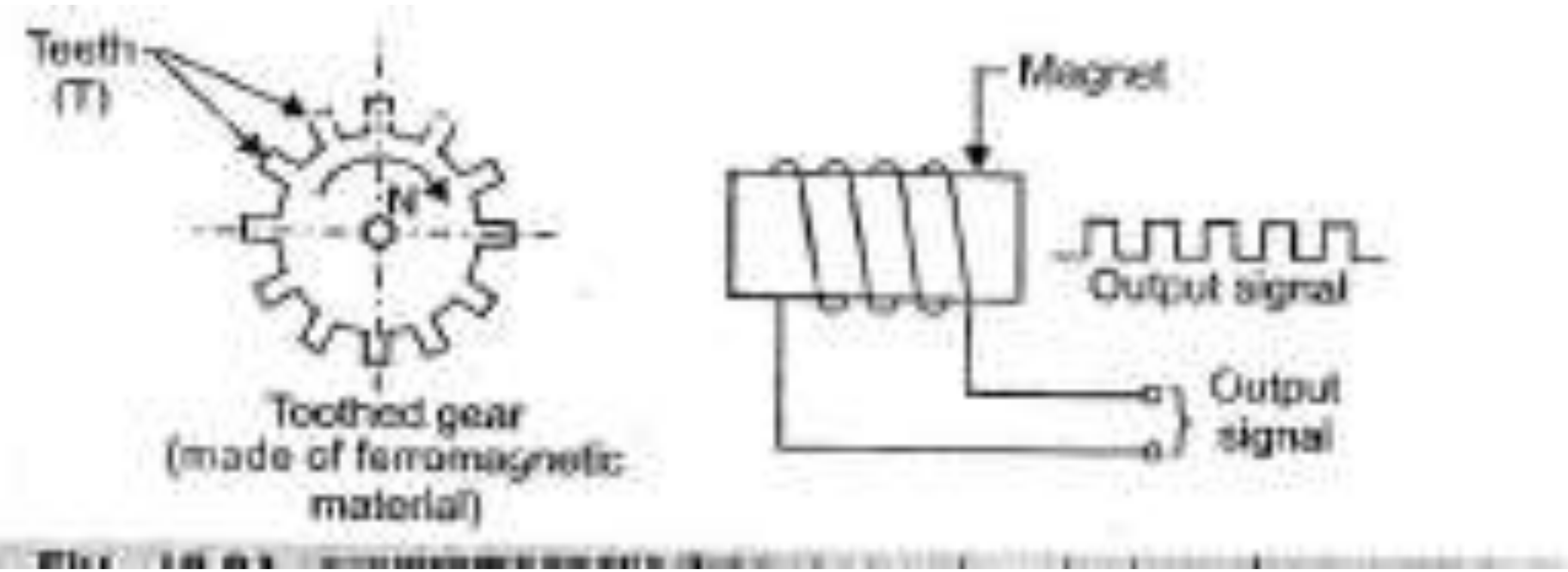
# Digital Transducers

- Introduction

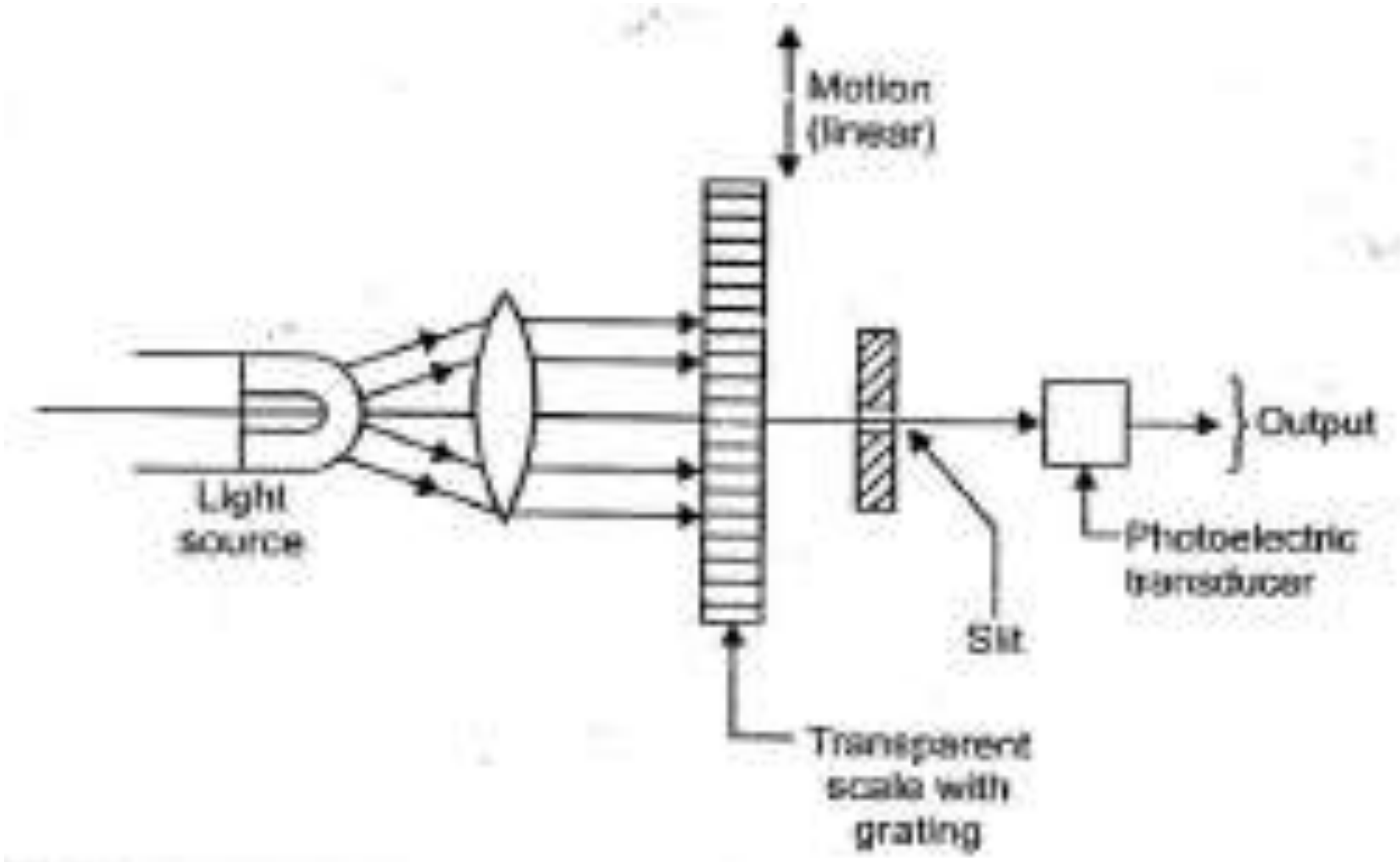


# Frequency domain Transducers

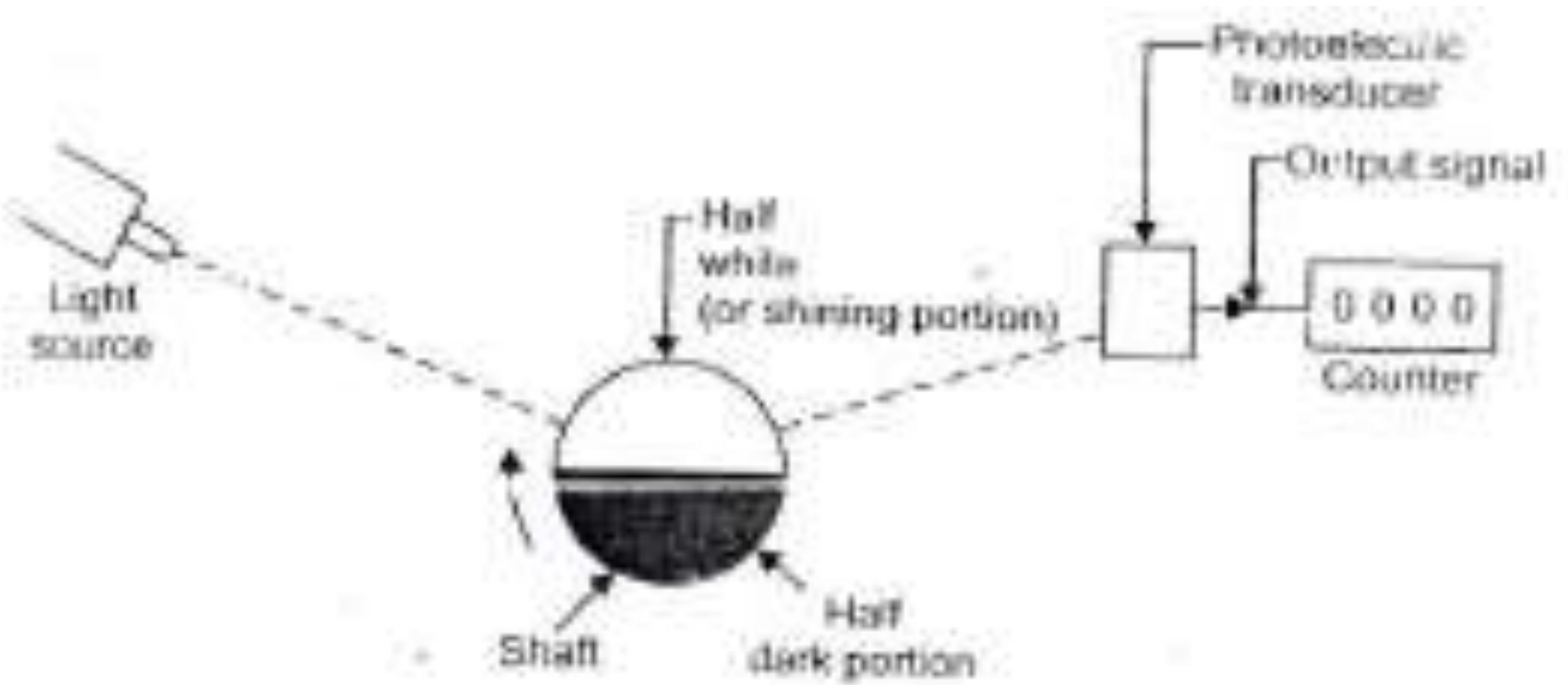
1) Electromagnetic Frequency domain Transducer



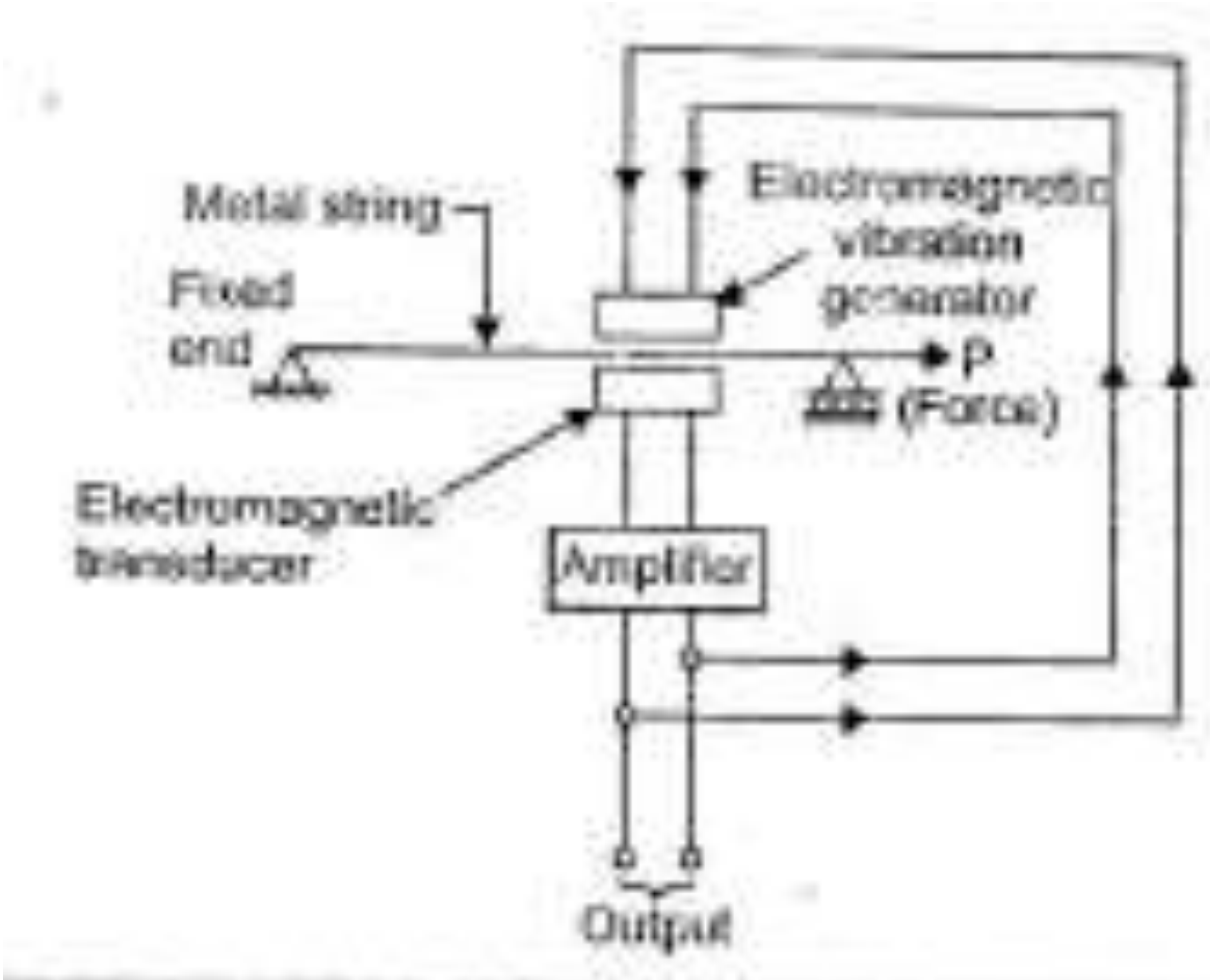
# 2) Opto-electrical frequency domain Transducer



- Opto-electrical frequency domain transducer for rotary motion



# 3) Vibrating string transducer



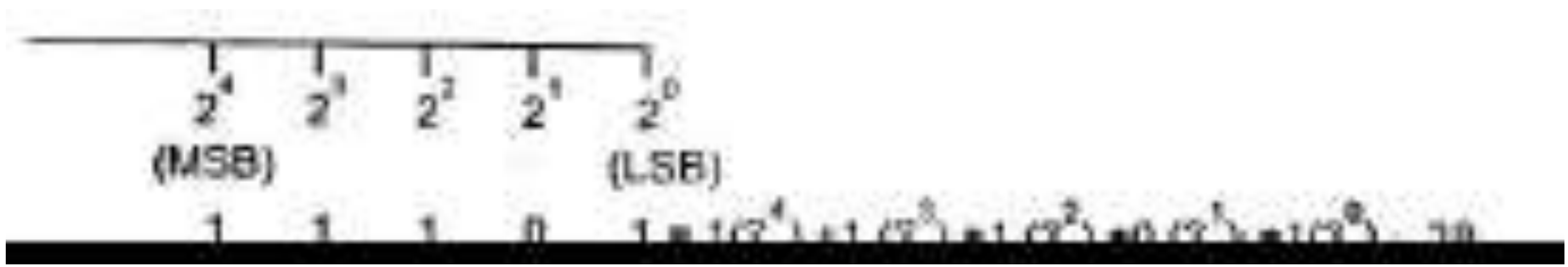
- Natural frequency of vibrating string

$$f = \frac{1}{2l}\sqrt{\frac{P}{a\rho}}$$

$f$ = Natural frequency of the string,
$l$ = Length of the string,
$P$ = Force applied,
$a$ = Area of cross-section of the string, and
$\rho$ = Mass density of the wire material.

# Digital Encoders

- Introduction to digital coding
  - Digital code
  - Straight binary coding



- Types of codes

1) BCD code

2) Excess-3 code

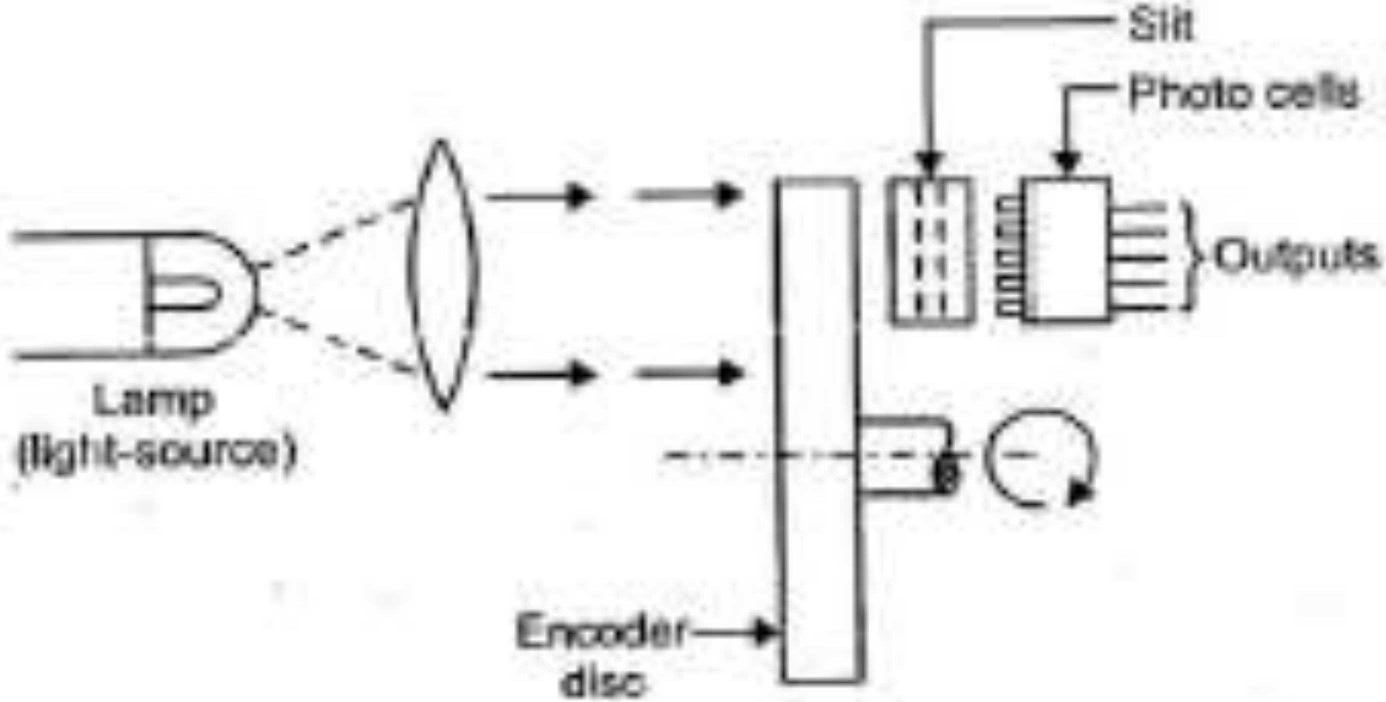
3) Gray code

4) Octal code

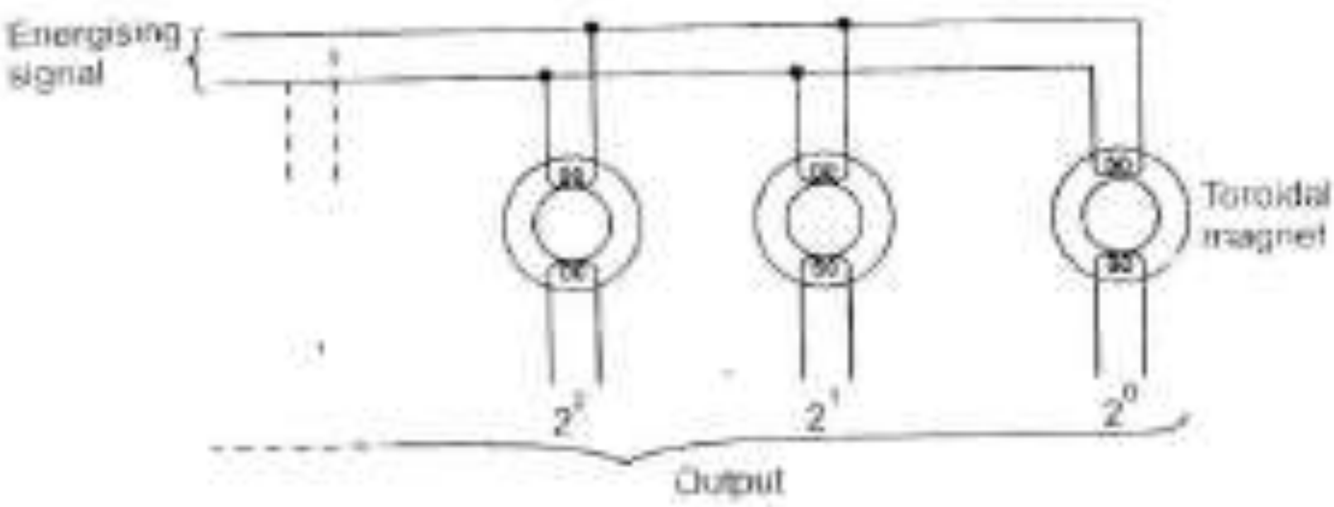
5) Hexadecimal code

# Description of digital encoders

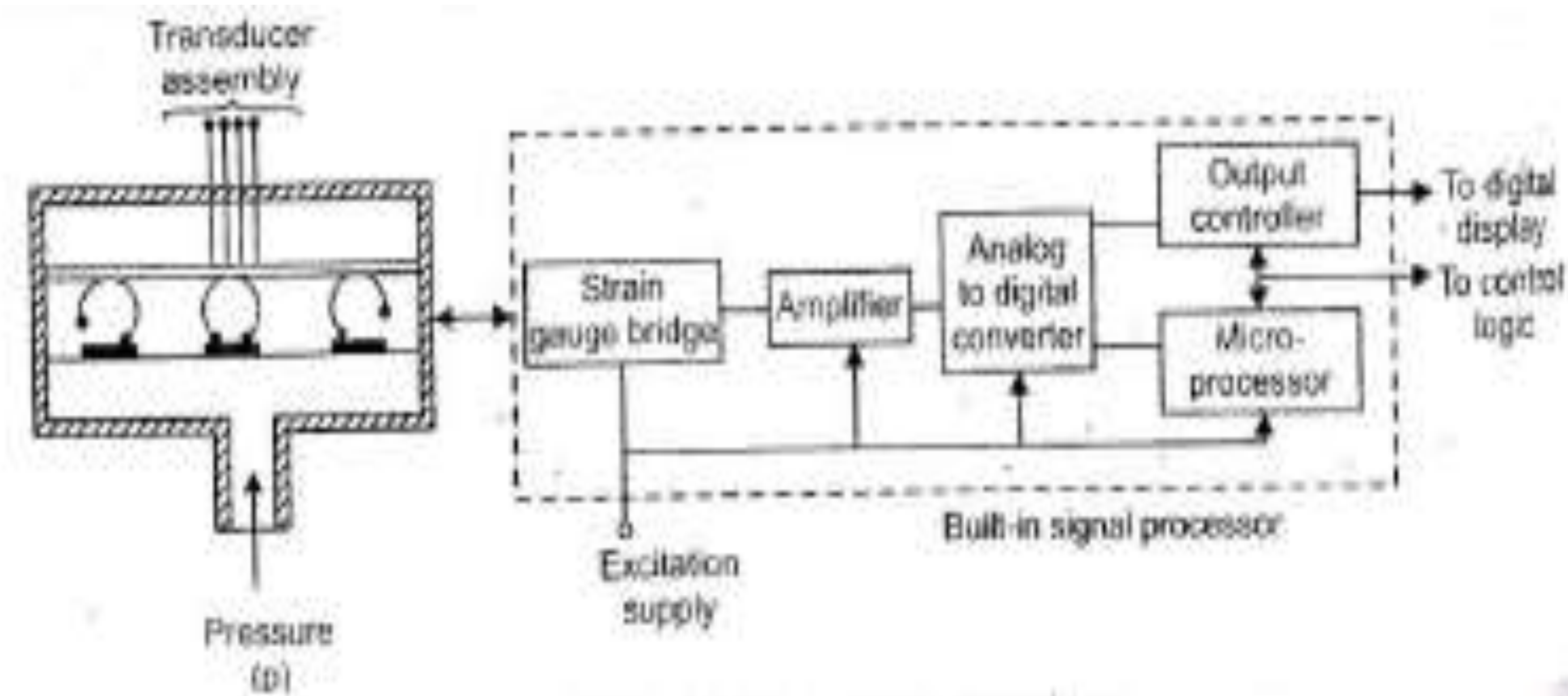
1) Optical type encoder



# 2) Magnetic type encoder



# Digital Pressure Transducer



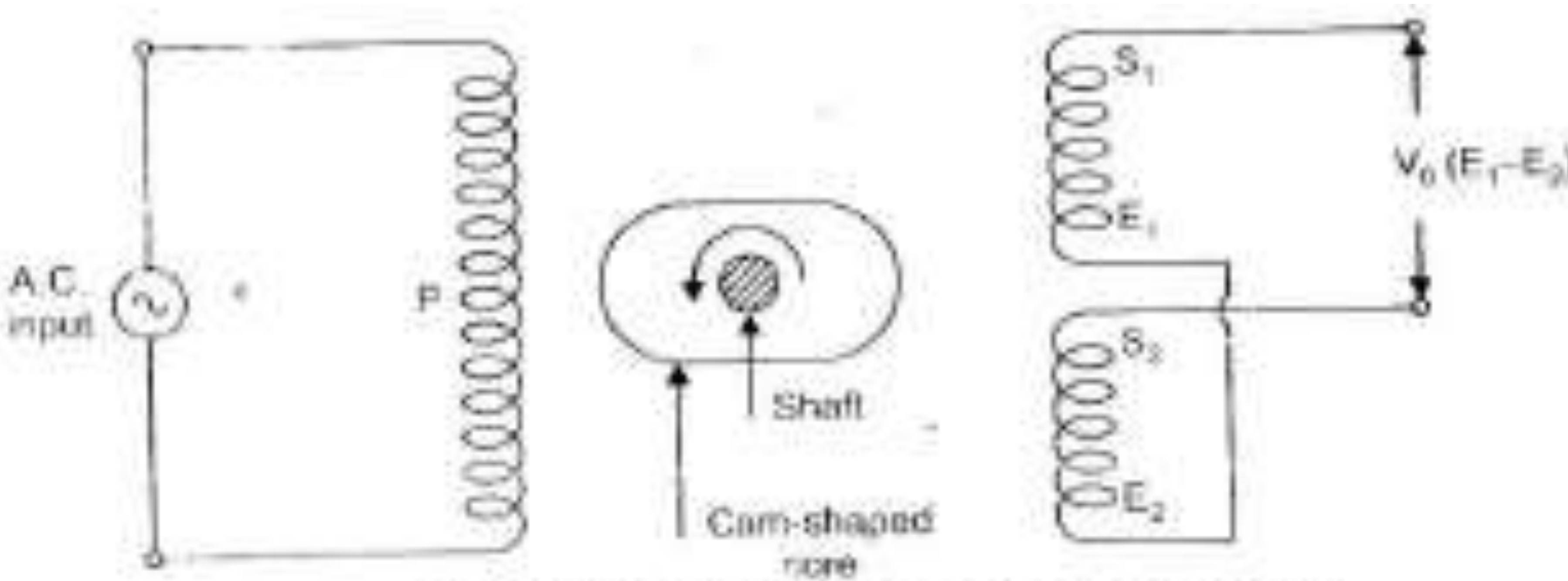
# Recent Trends- Smart Pressure Transmitters

- Advantages
  - Increased range
  - Higher accuracy
  - Reduced cabling cost
  - Better noise immunity
  - Economical

# Selection of Sensors

1. The nature of the measurement required *e.g.*,
   - The variable to be measured, its nomial value, the range of values;
   - The accuracy required;
   - The required speed of measurement;
   - The reliability required;
   - The environmental conditions under which the measurement is to be made.
2. The nature of the output required from the sensor, thus determining the signal conditioning requirements in order to give suitable output signals from the measurement.

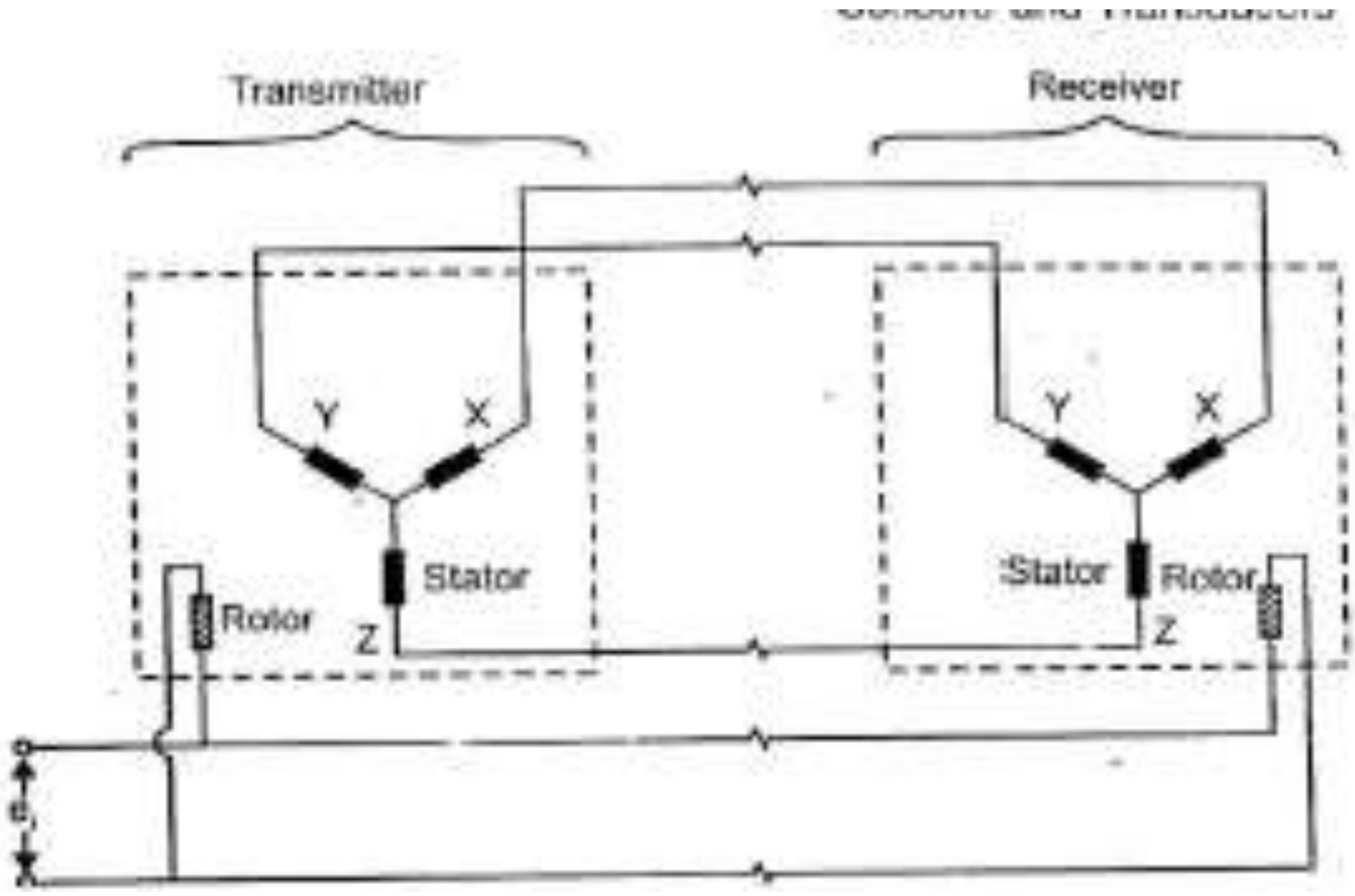
# Rotary Variable Differential Transformer(RVDT)



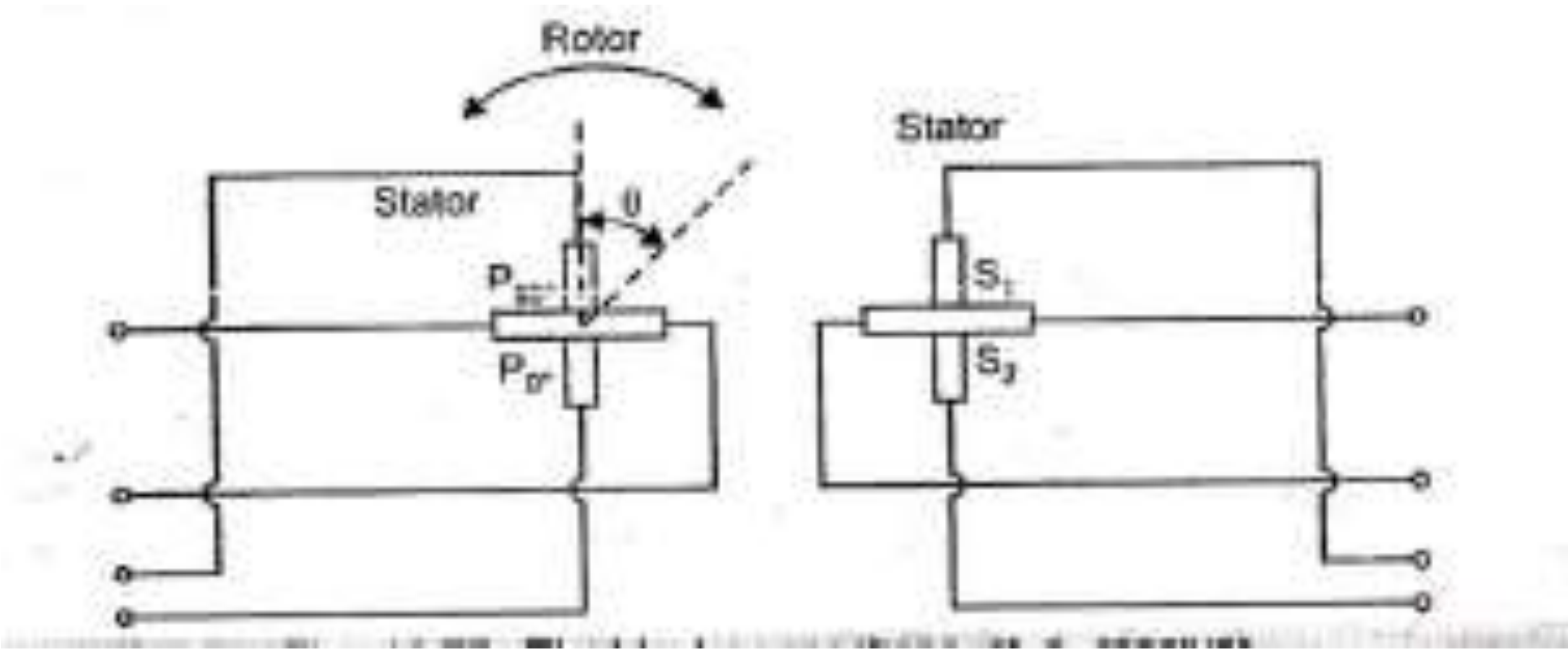

P = Primary winding ; $S_1$, $S_2$ = Secondary windings;
$E_1$, $E_2$ = Induced e.m.fs ; $V_0$ = Output voltage

# Synchros and Resolvers

- Synchro



- Resolver



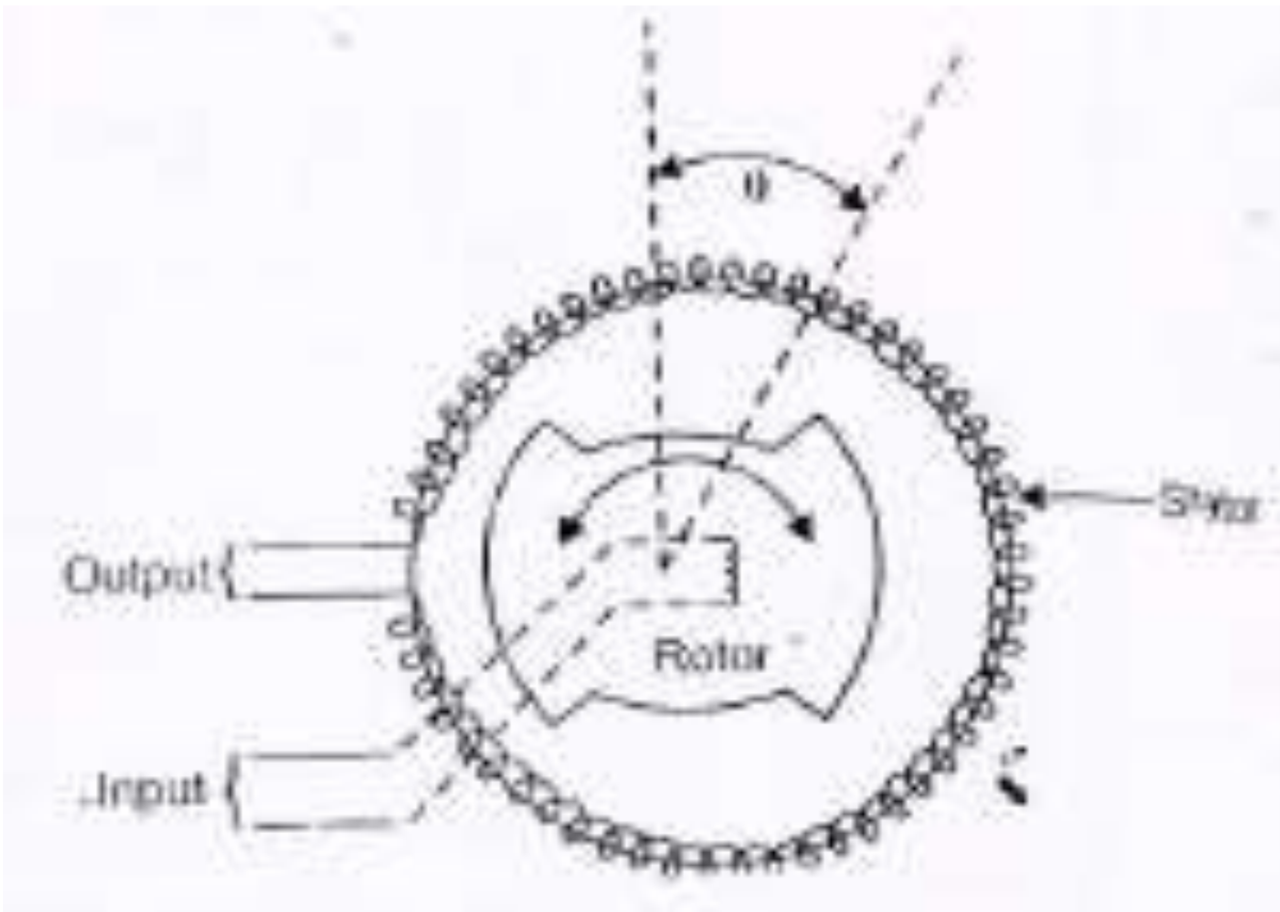
- Advantages of synchros and resolvers

The main advantages of synchros and resolvers are :

1. High reliability.
2. High accuracy (0.01 percent feasible).
3. Infinite resolution.
4. Useful operating angle of 360° and capable of continuous rotations.
5. No rotational wear, except at slip rings.
6. Relatively insensitive characteristics to stray cable capacitances.

# Induction Potentiometers

- These are linear synchro devices used for the measurement of angular displacement



# Micro Electro Mechanical Systems(MEMS)

- Introduction

  - MEMS are small integrated devices which combine electrical and mechanical components like microsensors, microactuators and signal transduction elements.

  - MEMS are used to sense, control and activate mechanical processes.

- Advantages of MEMS

MEMS claim the following advantages over conventional electromechanical systems:

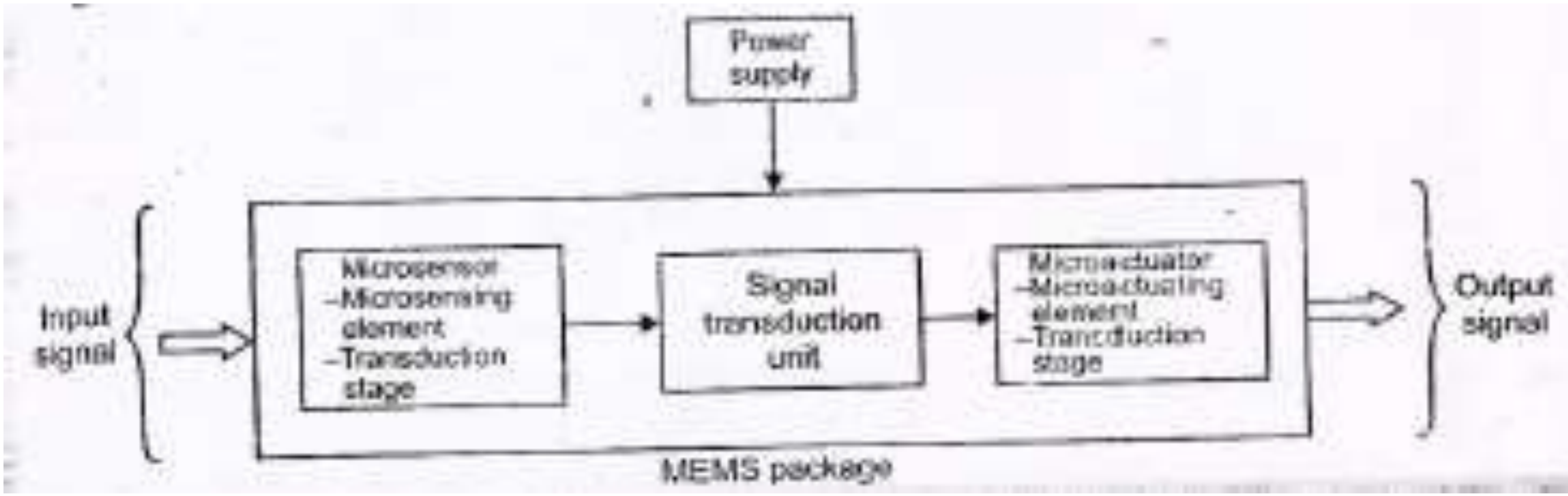
1. Better stability and higher accuracy in the performance.
2. Can be produced on mass scale (once the fabrication design and process is finalised).
3. As these devices are available in very small sizes, they can be easily inserted with other applications (*Miniaturization*).

- Applications of MEMS

The various fields of application of MEMS are :

1. Consumer products.
2. Process and manufacturing industries.
3. Aerospace industry.
4. Automobile engineering.
5. Telecommunication engineering.
6. Medical field.

- Description of MEMS



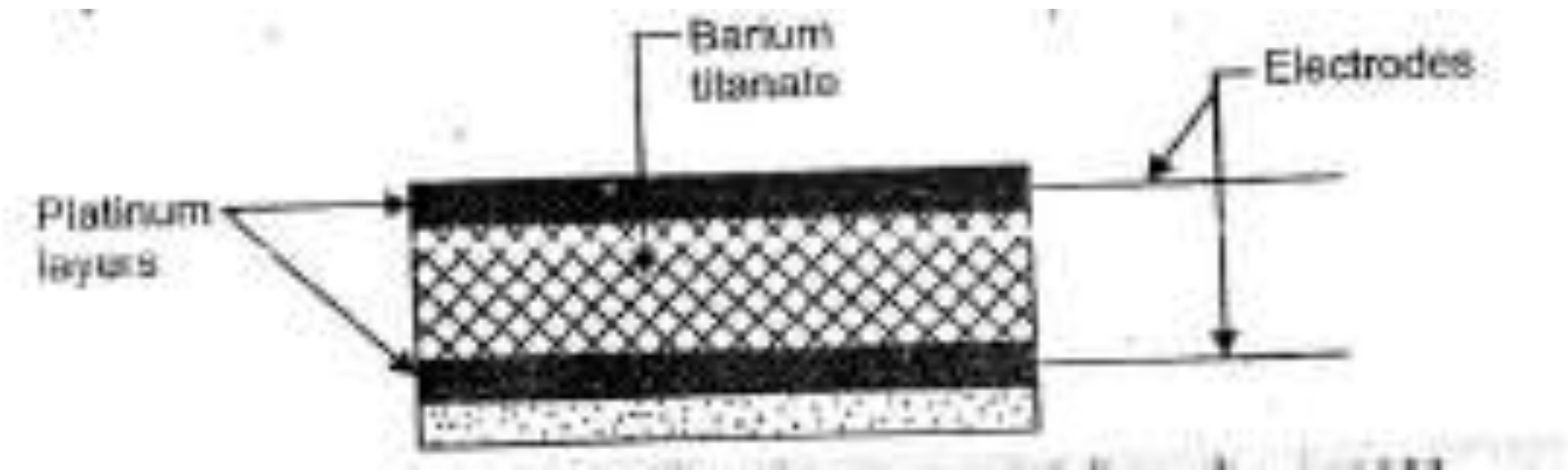

- Input signal
- MEMS package: Microsensors & Microactuators
- Output signals

- Manufacturing of MEMS

1) Bulk Micromachining
2) Surface Micromachining
3) LIGA process

- MEMS Accelometer-Vibration microsensor
  - Piezoelectric type accelerometer

- MEMS humidity microsensor



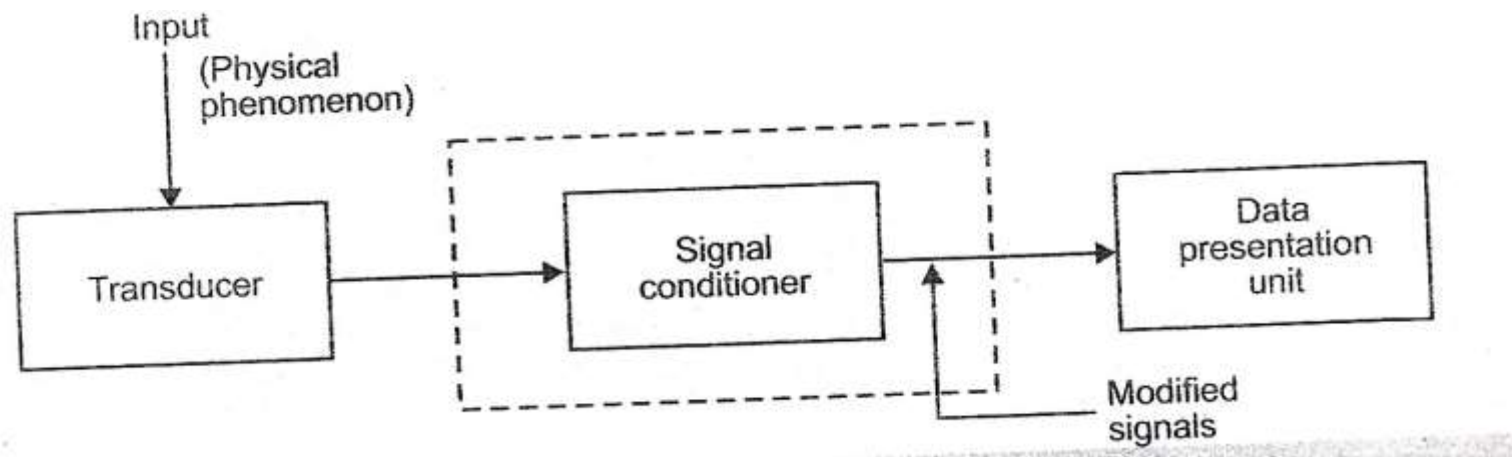

- C=KεA/d

# MODULE 3

Signal Conditioning

# Signal Conditioning

- Introduction



# Signal Conditioning and Its Necessity

The necessity of signal conditioning may be due to following *reasons* :

1. Signals may be too noisy due to electromagnetic interference.
2. Signals may be too small, usually is mV range.
3. Signals may be non-linear and require to be converted into digital form.
4. Signals may be analog one and require to be converted into digital form.
5. Signals may be digital one and need to be converted into analog signals.
6. It may be required to improve the quality of digital signals.

## Processes adopted in Signal Conditioning

1. Protection
2. Getting right type of signals
3. Getting correct level of signals
4. Elimination of interferences
5. Manipulation of signals

# Mechanical Amplification and Electrical Signal Conditioning

- Limitations of mechanical amplification
- Advantages of electrical signal conditioning

# Functions of signal conditioning equipment

1) Amplification
2) Modification or Modulation
3) Impedance Matching
4) Data processing
5) Data Transmission

# Two types of transducers

- In case of "*passive transducers*" (*e.g.*, strain gauges, potentiometer resistance thermometers, inductive and capacitive transducers) excitation is needed because these transducers do not generate their own voltage or current; the excitation is provided from external sources.
- The "*active transducers*" (*e.g.*, technogenerators, thermocouples, inductive pick-ups and piezoelectric crystals) do not require excitation from an external source since they produce their own electrical output. However, these signals have a low voltage level and as such they need to be amplified.

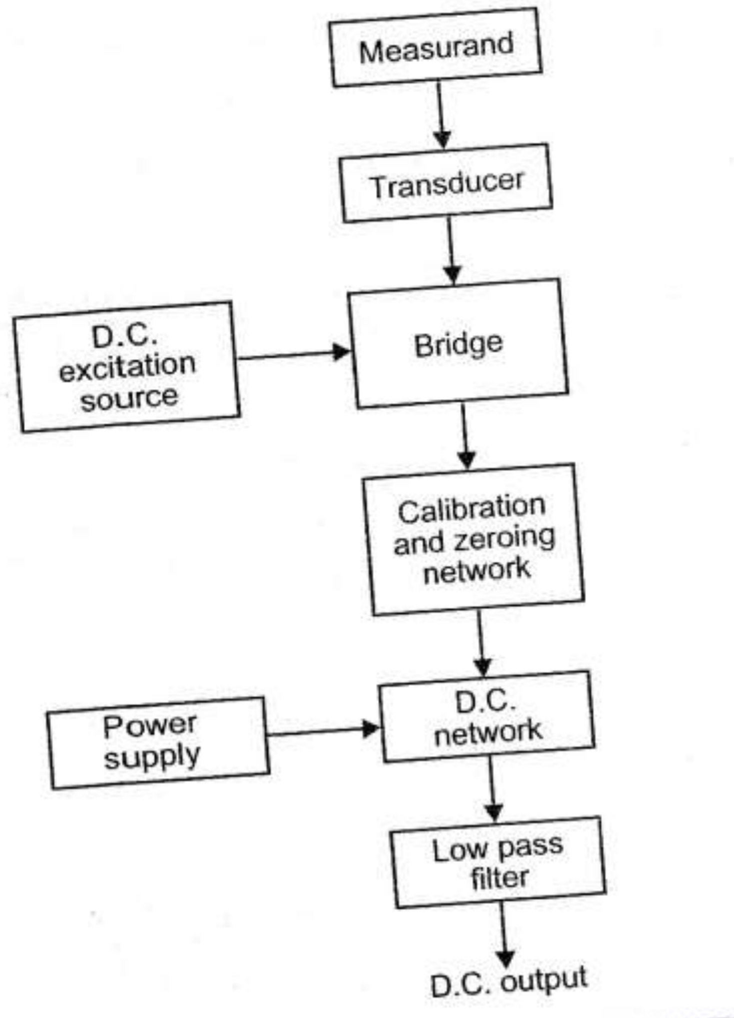
The excitation sources may be

- DC voltage source
- AC voltage source

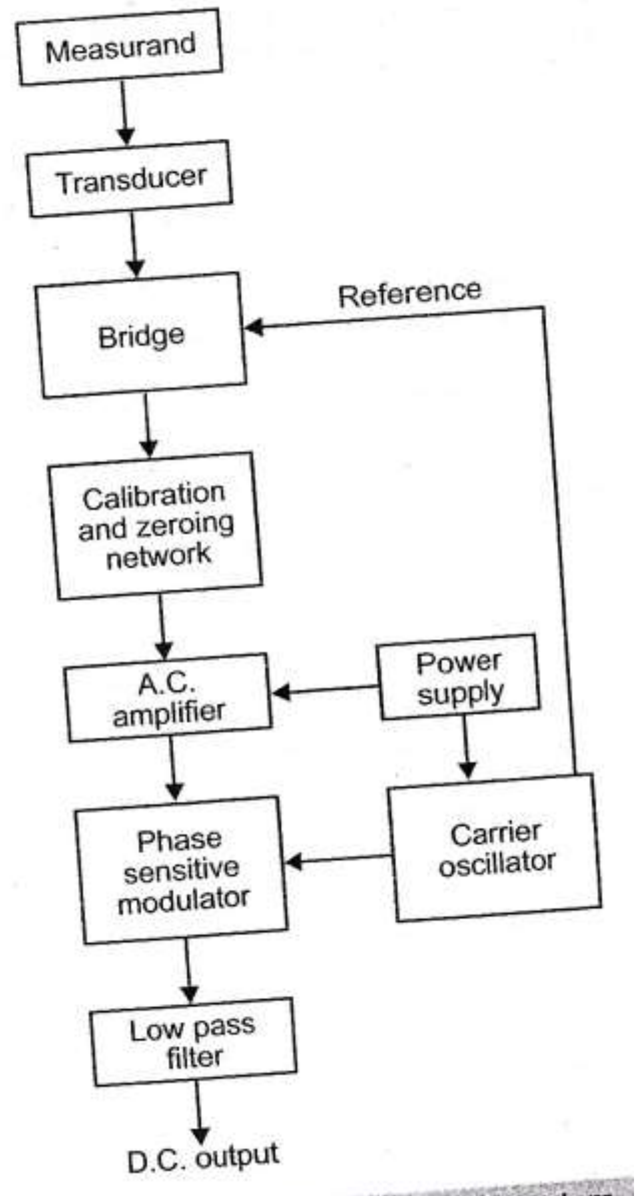
Depending on this, there are two types of signal conditioning systems

- DC signal conditioning systems
- AC signal conditioning systems

# DC signal conditioning systems



# AC signal conditioning systems



# Amplification

An **amplifier** *is a device which is used to increase or augment the weak signal. It may operate on mechanical (levers, gears etc.) optical, pneumatic and hydraulic, or electrical and electronic principles.*

The *ratio of output signal* ($I_o$) *to input signal* ($I_i$) *for an amplifier is termed as* **gain, amplification** *or* **magnification**. The gain of amplification (G) is expressed as:

$$G = \frac{I_o}{I_i} \quad \text{...(17.1)}$$

Since $\frac{I_o}{I_i}$ are in the same units, the gain $G$ is a *dimensionless quantity.*

Invariably, in order to get greater magnification, two or more amplifiers are arranged in series/cascades. The overall gain of the arrangement (assuming that no loading occurs) is given by the product of individual gains of the amplifying units,

*i.e.*,

$$\frac{I_o}{I_i} = G_1 \cdot G_2 \cdot G_3 \,.....$$

Types of amplifiers

1) Mechanical amplifiers
2) Fluid amplifiers
3) Optical amplifiers
4) Electrical and electronic amplifiers

# Mechanical amplifiers

The mechanical amplifiers may be further *classified* as follows:

(*i*) ***Simple and compound levers :*** The compound lever has two or more levers linked together so that output from one lever provides the input to the other.

**Example.** The *Huggenberger extensometer* is one of the most popular and *accurate mechanical amplifier*. It uses a system of compound levers to give *very high magnification* to the order of *2000 or even more*.

(*ii*) ***Simple and compound gears :*** The simple and compound gear trains are used quite frequently *to provide mechanical amplification of either angular displacement or rotary speed*.

A "*compound gear train*" gives *greater modification with the additional advantage of no change in the direction of input signal*.

# Limitations of mechanical amplification

(*i*) Internal loading;

(*ii*) Friction at the mating parts;

(*iii*) Elastic deformation;

# Fluid amplifiers

Fluid amplifiers may be *classified* as follows:

(i) *Hydraulic amplifier* : When a small displacement is applied to a piston operating inside a cylinder containing some liquid, there occurs a large displacement of the liquid in the output tube which has a small diameter.

**Example.** This principle is employed in the *mercury-in-glass thermometer* and the *single-column manometers.*

(ii) *Pneumatic amplifier* : Pneumatic methods are extensively used and can be applied to any type of measurement.

# Optical amplifiers

In optical amplification, a ray of light strikes a mirror with an angle of incidence $i$ and gets reflected with angle of reflection equal to the angle of incidence. When the mirror rotates through an angle $\theta$, the angle of incidence change to $(i + \theta)$. Before rotation of the mirror, the angle between the incident ray and reflected ray is $2i$ and after rotation it is $2(i + \theta)$. Obviously there is angular magnification of $2\theta$ between the incident and reflected rays. In order to get a greater magnification, more number of mirrors surfaces may be used.

**Examples.** This principle to amplify the input signals is used in the following cases.

— Optical levers;

— U.V. galvanometers;

— Mechanical-pointer galvanometers.

# Electrical and Electronic Amplifiers

The electrical amplifiers are used to *increase the magnitude of weak voltage or current signals resulting from electromechanical transducers.*

### 17.8.1. Desirable Characteristics of Electronic Amplifiers

The following are the desirable characteristics of electronic amplifiers:

(*i*) *High input impedance* so that its loading effect on the transducer in minimum.

(*ii*) *Low output impedance* so that the amplifier is *nōt unduly loaded by the display or recording device.*

(*iii*) *Frequency response* should be as *good as that of the transducer.*

# Electronic amplification of gain

- The following are the several *generalities* that can be listed for the ideal (but non-existent) electronic amplifier:

(*i*) Infinite gain (lower gain can be obtained by adding attenuation circuits).

(*ii*) Infinite input impedance; no input current, hence no load on the previous stage or device.

(*iii*) Zero output impedance (low noise).

(*iv*) Instant response (wide frequency bandwidth).

(*v*) Zero output for zero input.

(*vi*) Ability to ignore or reject, extraneous inputs.

• In an electronic amplifier, separate power is provided so that the output power may exceed the input if that is required.

Here, if $v_i$ = Input voltage,

$i_i$ = Input current,

$v_o$ = Output voltage, and

$i_o$ = Output current,

Then :

$$\text{Gain} = \frac{\text{Power output}}{\text{Power input}} = \frac{v_o i_o}{v_i i_i} \quad \text{...(17.3)}$$

$$\text{Voltage amplification} = \frac{\text{Voltage output}}{\text{Voltage input}} = \frac{v_o}{v_i} \quad \text{...(17.4)}$$

$$\text{Current amplification} = \frac{\text{Current output}}{\text{Current input}} = \frac{i_o}{i_i} \quad \text{...(17.5)}$$

- Another way of expressing *power gain* is through the use of *decibel*.

The common logarithm (log to the base 10) of power gain is known as *bel power gain*.

$$\text{Power gain} = \log_{10}\left(\frac{P_o}{P_i}\right)\text{bel}$$

$$1 \text{ bel} = 10\ dB$$

$$\therefore \quad \text{Power gain} = 10\log_{10}\left(\frac{P_o}{P_i}\right)\text{dB} \qquad ...(17.6)$$

If the two powers are developed in the same resistance or equal resistance, then

$$P_i = \frac{V_i^2}{R} = I_i^2 R$$

$$P_o = \frac{V_0^2}{R} = I_o^2 R$$

$$\therefore \quad \textit{Voltage gain} = 10\log_{10}\frac{V_0^2/R}{V_i^2/R} = 20\log_{10}\frac{V_o}{V_i}\text{dB} \qquad ...(17.7)$$

$$Current\ gain = 10\log_{10}\frac{I_o^2 R}{I_i^2 R} = 20\log_{10}\frac{I_o}{I_i}\,dB$$

Examples

# Types of Amplifiers

- AC amplifiers
- DC amplifiers

# Modulated and Unmodulated Signals

The measurand affects the *carrier* by varying either its *amplitude* or its *frequency:*

— In the *former* case the *carrier frequency is held constant and its amplitude is varied by the measurand. This process is known as* **Amplitude modulation** (or **AM**).

— In the *latter* case the *carrier amplitude is held constant and its frequency is varied by the measurand.* This is known as **Frequency modulation** (or **FM**).

The most familiar use of AM and FM transfer of signals is in AM and FM *radio broadcasting.*

When "*modulation*" is used in instrumentation "*amplitude modulation*" (AM) is the *more common form.*

# Integrated Circuits

ICs from the building blocks are used to construct more complex circuits such as :

— Differential amplifiers;
— Mixers (for combining signals);
— Timers;
— Filters;
— Audio preamps;
— Auto-power amplifiers;
— Voltage references;
— Regulators and comparators;
— Several digital devices.

# Operational Amplifiers(Op-amp)

- Definition

- Operational amplifiers are linear integrated circuits that work on *relatively low supply voltage.*
- They are *reliable and inexpensive.*
- An *deal operational amplifier* is device of infinite voltage gain, infinite bandwidth, infinite input impedance (open) and zero output impedance.
- An Op-amp may contain two dozen transistors, a dozen resistors and one or two capacitors.

  **Examples :** μA 709, LM 108-LM 208, CA 741 CT and CA741T.

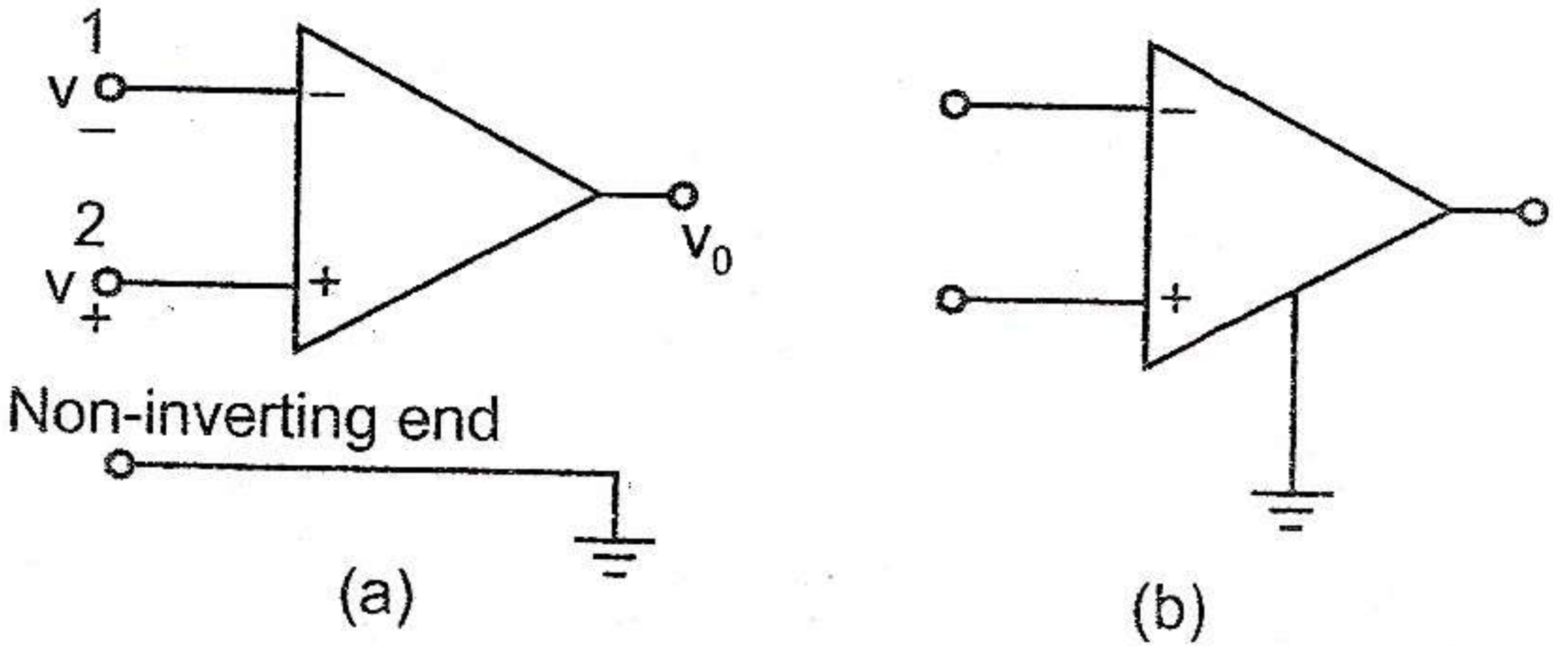
# Specification/Characteristics of an Op-amp

While selecting an Op-amp, the following characteristics need to be considered:

1. *Input offset voltage.* It is the voltage that must be applied at the input terminals to make the output voltage zero (This is about 2 mV for a 741 amplifier). The offset voltage changes with temperature.
2. *Input offset current.* It is defined as the net difference in current that must be applied at the input terminals to make the output voltage zero (This is 20 nA for a 741 amplifier).
3. *Input check current.* It is the mean of the two input currents to make the voltage zero.
4. *Slew rate.* It is the maximum rate at which the output can change. It is expressed as volts/microseconds.
5. *Unity gain frequency.* This is the frequency at which the open loop gain of the amplifier becomes unity.
6. *Common mode rejection ratio (CMRR).* It is the ratio of desirable signals to undesirable signals.

- An Op-amp is the *basic building block* for:
  - Amplifiers
  - Integrators
  - Summers
  - Differentiators
  - Comparators
  - A/D and D/A converters
  - Active filters
  - Sample and hold amplifiers.

# Op-amp Description




V0=G(V+-V-)

## Limitations of Op-amp

- Op-amps have non-ideal characteristics(With both the inputs grounded residual output voltage remains)
- Op-amp output reaches zero at some nonzero input voltage
- Low CMRR
- Thermal drift(Both internal and external circuit elements may be temperature sensitive)

# Applications of Op-amp

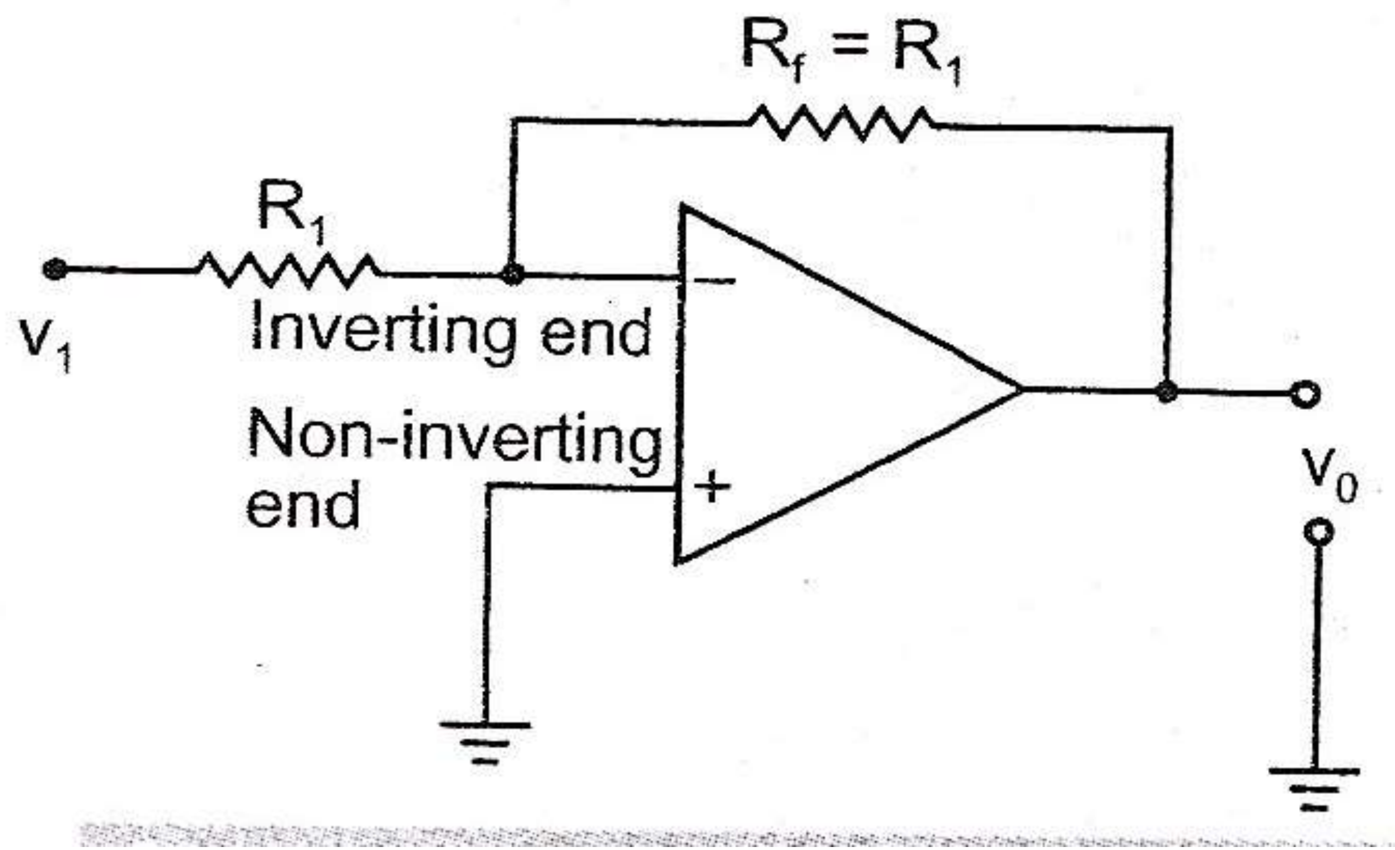
Operational amplifiers may be used as the *basic components of* :

- Linear voltage amplifiers;
- Integrators and differentiators;
- Function generators;
- Impedance transformers;
- Differential amplifiers;
- Voltage comparators;
- Filters;
- Many other devices.

# Op-amp circuits used in instrumentation

1. Inverter;
2. Adder;
3. Subtracter;
4. Multiplier and divider;
5. Integrator;
6. Differentiator;
7. Buffer amplifier;
8. Differential amplifier.

# 1) Inverter



# 2) Adder

**2. Adder.** Fig. 17.6 shows an Op-amp circuit that performs the signals with amplification (if desired); using superposition theorem, we get

Output voltage,

$$v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right) \quad ...(17.13)$$

If $R_1 = R_2 = R_3 = R_f$, then

$$v_o = -(v_1 + v_2 + v_3) \quad ...(17.14)$$

*i.e.*, sum of the individual input voltages. The inversion that occurs cannot be avoided.

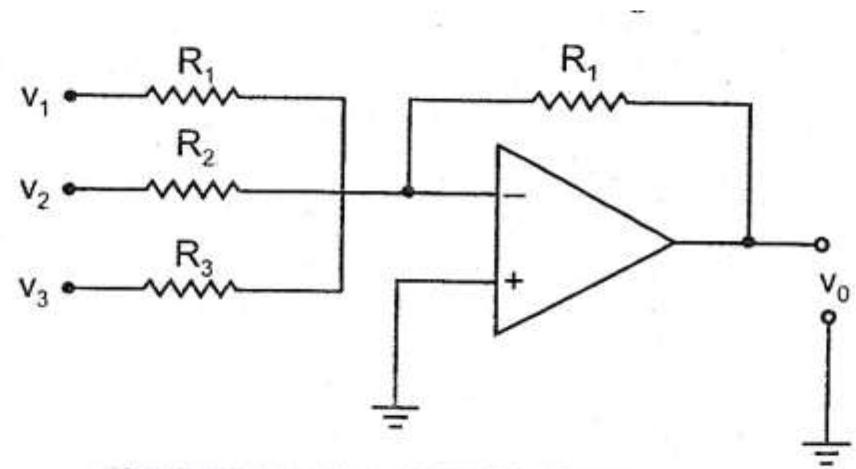


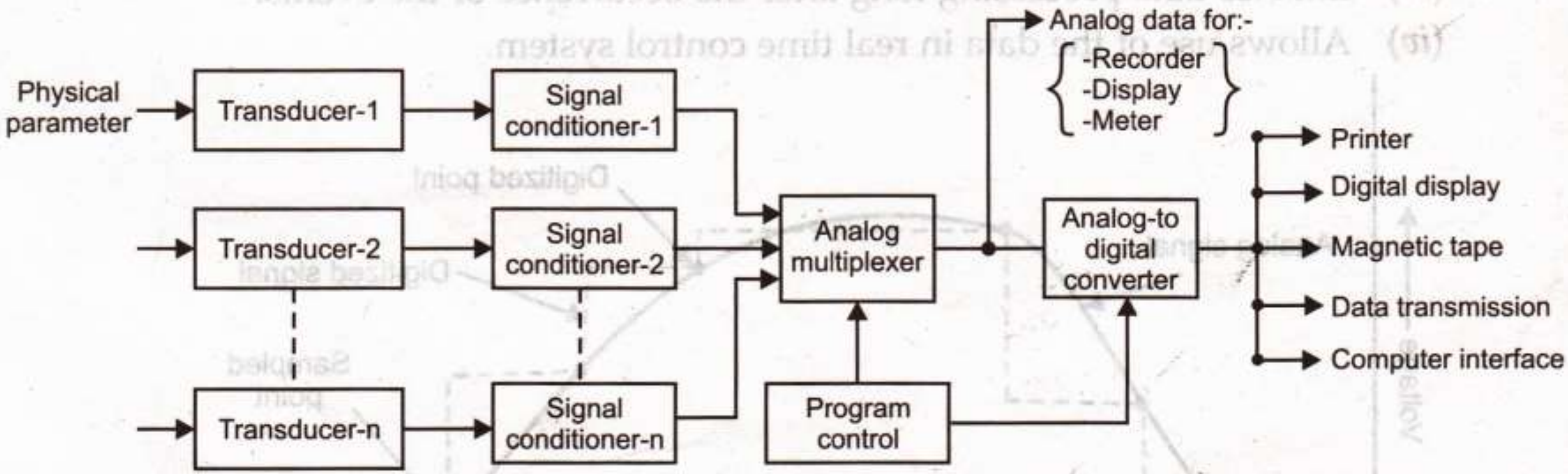

Fig. 17.6. Op-amp as an adder.

# Data Acquisition Systems and Conversion

Data acquisition system

- Introduction

**Data acquisition system** (DAS) *may be defined as a system used for data processing, data conversion, data transmission and data storage.*


Physical parameter
Transducer-1
Transducer-2
Transducer-n
Signal conditioner-1
Signal conditioner-2
Signal conditioner-n
Analog multiplexer
Program control
Analog data for:-
-Recorder
-Display
-Meter
Analog-to digital converter
Printer
Digital display
Magnetic tape
Data transmission
Computer interface

In telecommunications and computer networks, **multiplexing** (sometimes contracted to muxing) is a method by which multiple analog or digital **signals** are combined into one **signal** over a shared medium.

In electronics, a **sample and hold** (S/H, also "follow-and-**hold**") circuit is an analog device that **samples** (captures, takes) the voltage of a continuously varying analog signal and holds (locks, freezes) its value at a constant level for a specified minimum period of time.

Consider a signal from a sensor as illustrated by the analog signal in Fig. 18.2. In this case there are *two options* :

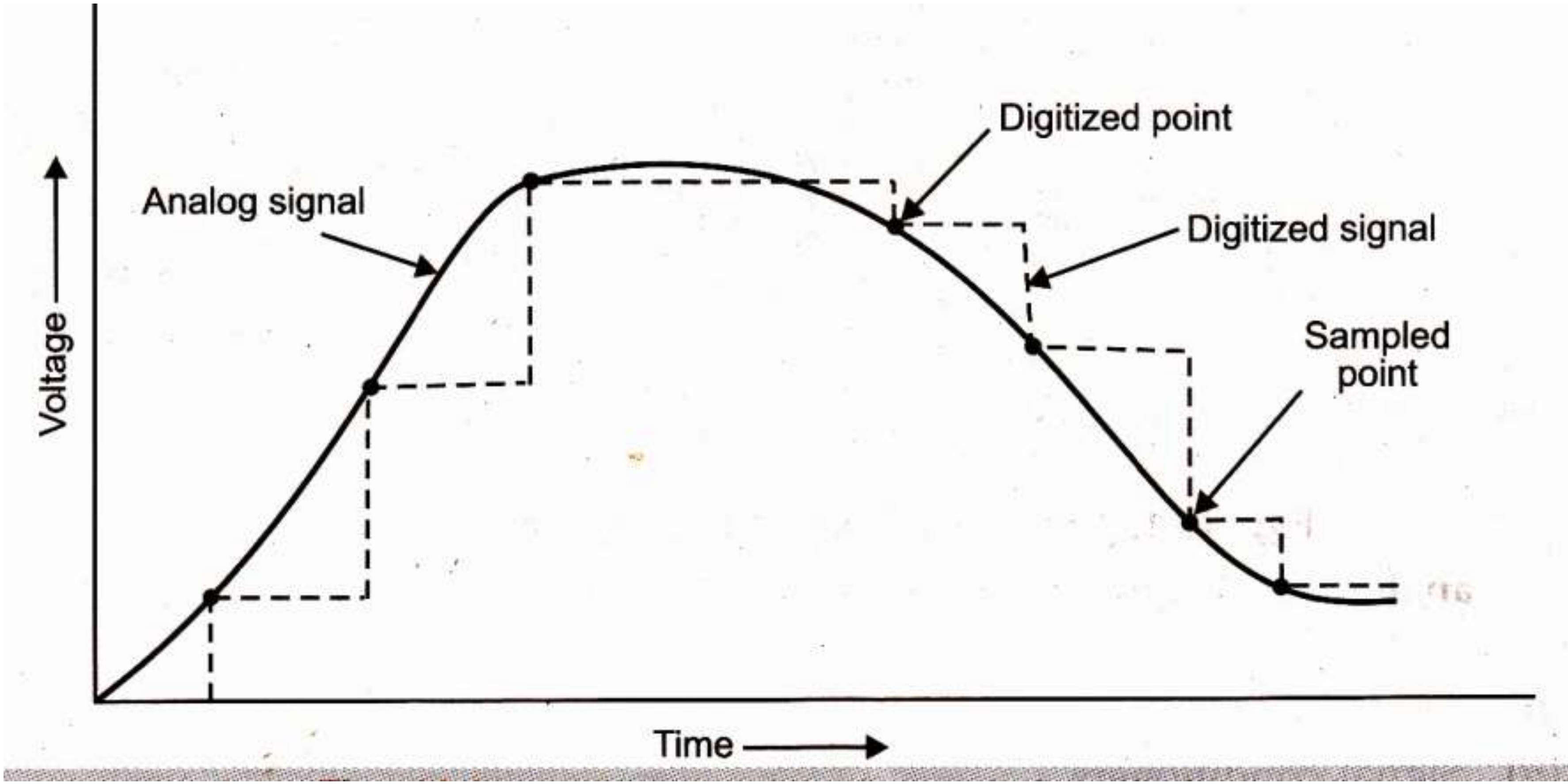
- Firstly, one could record the signal with an analog device such as chart recorder (which physically plots the signal on the paper) or display *it with an oscilloscope.*
- Secondly, *the data may be stored by using a microprocessor or computer. This process is called computer* ***"data acquisition"*** and entails the following *merits*:

  (*i*) Can result in greater data accuracy.

  (*ii*) Provides more compact storage of the data.

  (*iii*) Enables data processing long after the occurrence of the events.

  (*iv*) Allows use of the data in real time control system.



Digitized point
Analog signal
Digitized signal
Sampled point
Voltage
Time

# Objectives and configuration of data acquisition system(DAS)

- Objectives of DAS

1. To be reliable, flexible and capable of being expanded for future requirements.
2. To acquire the necesary data, at correct speed and at correct time.
3. Down time not be more than 0.1 percent.
4. To be able to compute unit performance indices using on-line, real-time data.
5. To maintain on-line optimum and safe operations, it must monitor the complete plant operation.
6. To make use of all data efficiently to inform the operator about the state of the plant.
7. To be able to collect, summarise and store data for diagnosis of operation and record purpose.
8. To provide an effective human communication system and be able to identify problem areas, thereby minimising unit availability and maximising unit through point at minimum cost.

- Configuration of DAS

The important factors that decide the configuration and the sub-systems of a data acquisition system are as follows :

(*i*) The number of channels to the monitored.

(*ii*) Sampling rate per channel.

(*iii*) Signal conditioning requirement of each channel.

(*iv*) Resolution and accuracy.

(*v*) Cost.

The various general configurations include :

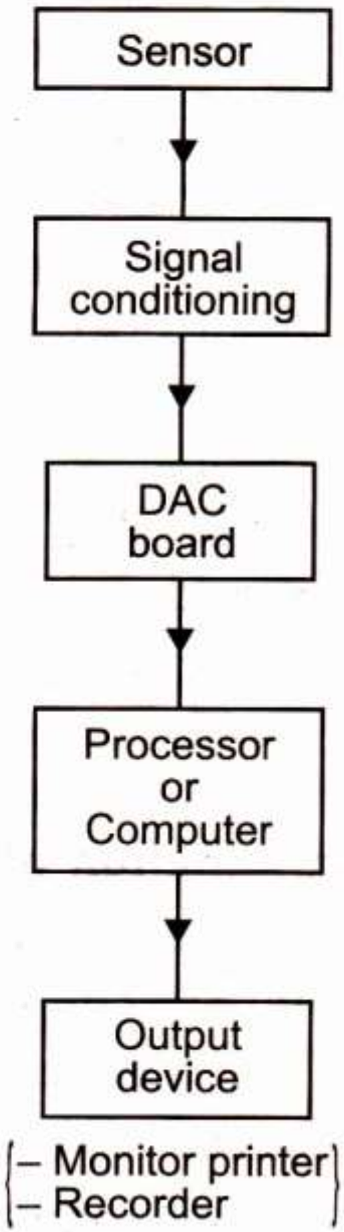
1. *Signal channel possibilities :*
   (*i*) Direct conversion.
   (*ii*) Pre-amplification and direct conversion.
   (*iii*) Sample and hold, and conversion.
   (*iv*) Pre-amplification, sample and hold, and conversion.
   (*v*) Pre-amplification, signal conditioning, and any of the above.
2. *Multi-channel possibilities :*
   (*i*) Multiplexing the outputs of single channel converters.
   (*ii*) Multiplexing the outputs of sample-hold circuits.
   (*iii*) Multiplexing the inputs of the sample-hold circuits.
   (*iv*) Multiplexing low level data.
3. *Noise-reduction options :*
   (*i*) Filtering.
   (*ii*) Integrating converters and digital processing.

# Data acquisition system

**Data acquisition** *is the process of using output signals and inputting that into a computer*. The output signal may be one that originates from direct measurement of electrical quantities such as voltage, frequency, resistance etc. or that originates from sensors.

The description of various types of data acquisition systems is given in the following articles.

# 1) Analog and Automated DAS

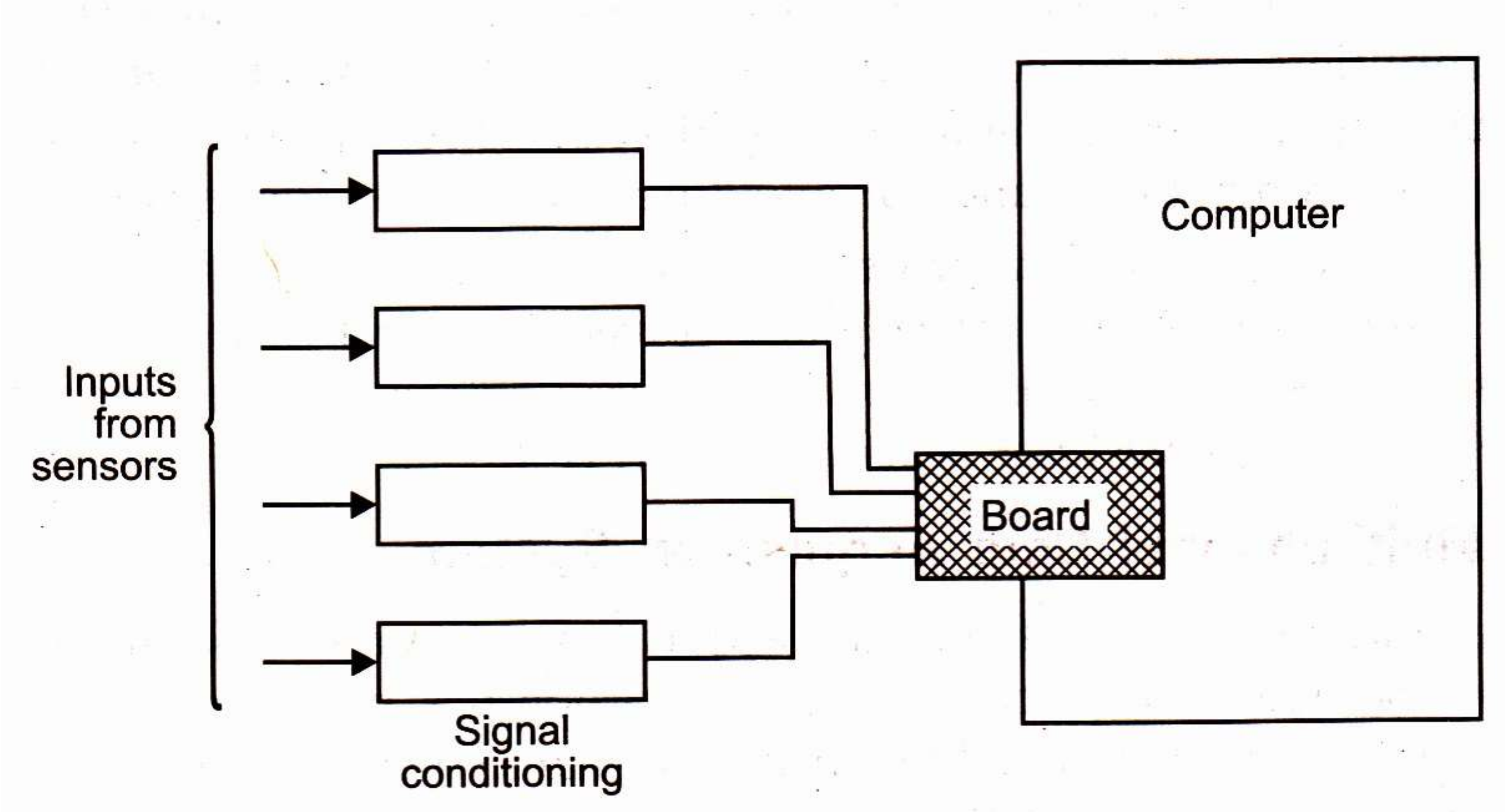


- Automated data acquisition systems
  1) Data loggers
  2) Computer with plug in boards

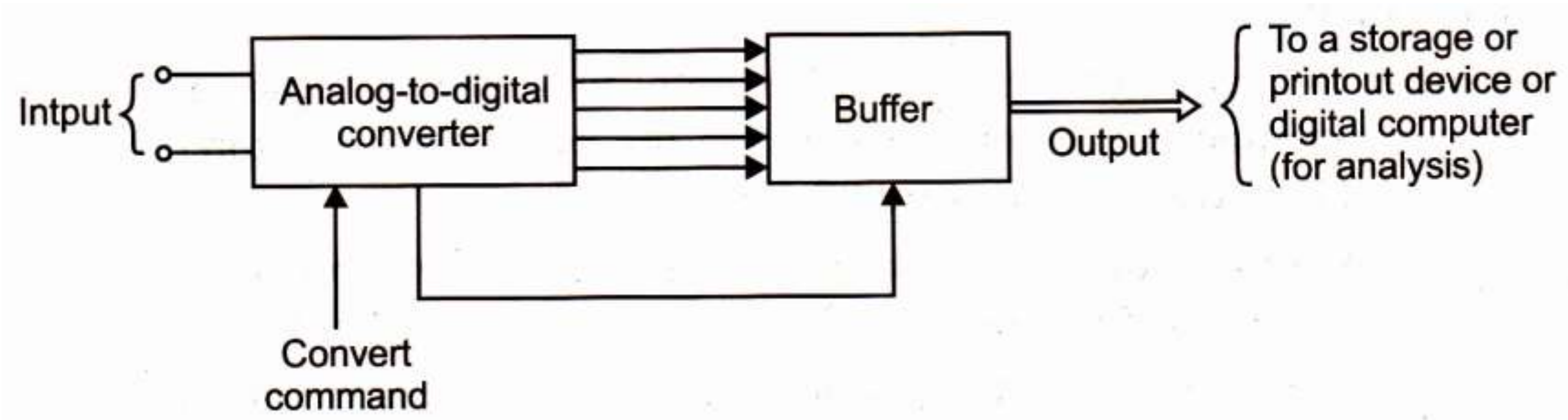
- Data loggers

A **data logger** (also datalogger or **data** recorder) is an electronic device that records **data** over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Increasingly, but not entirely, they are based on a digital processor (or computer).

- Computer with plug-in boards

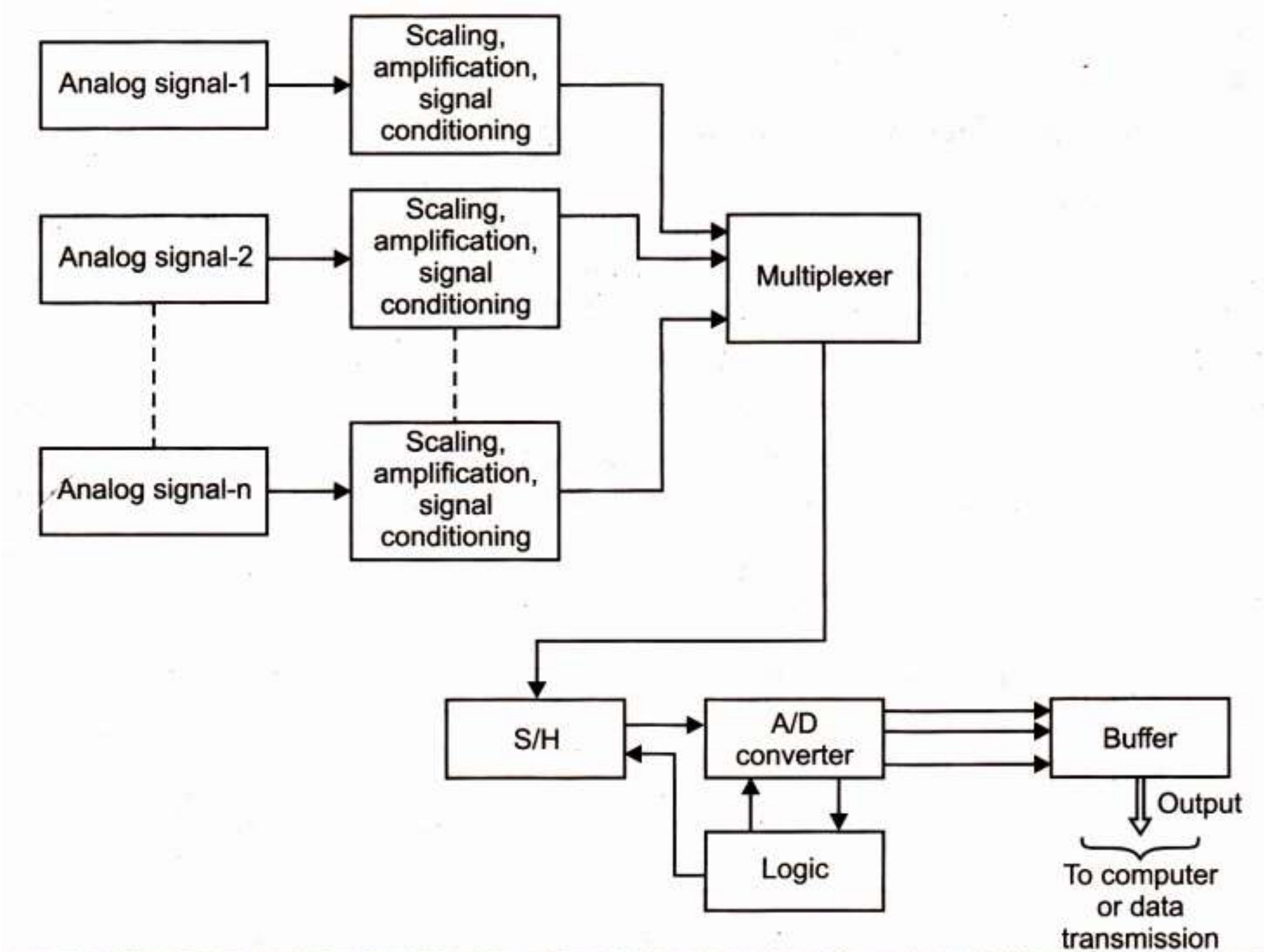


# 2) Single channel data acquisition system

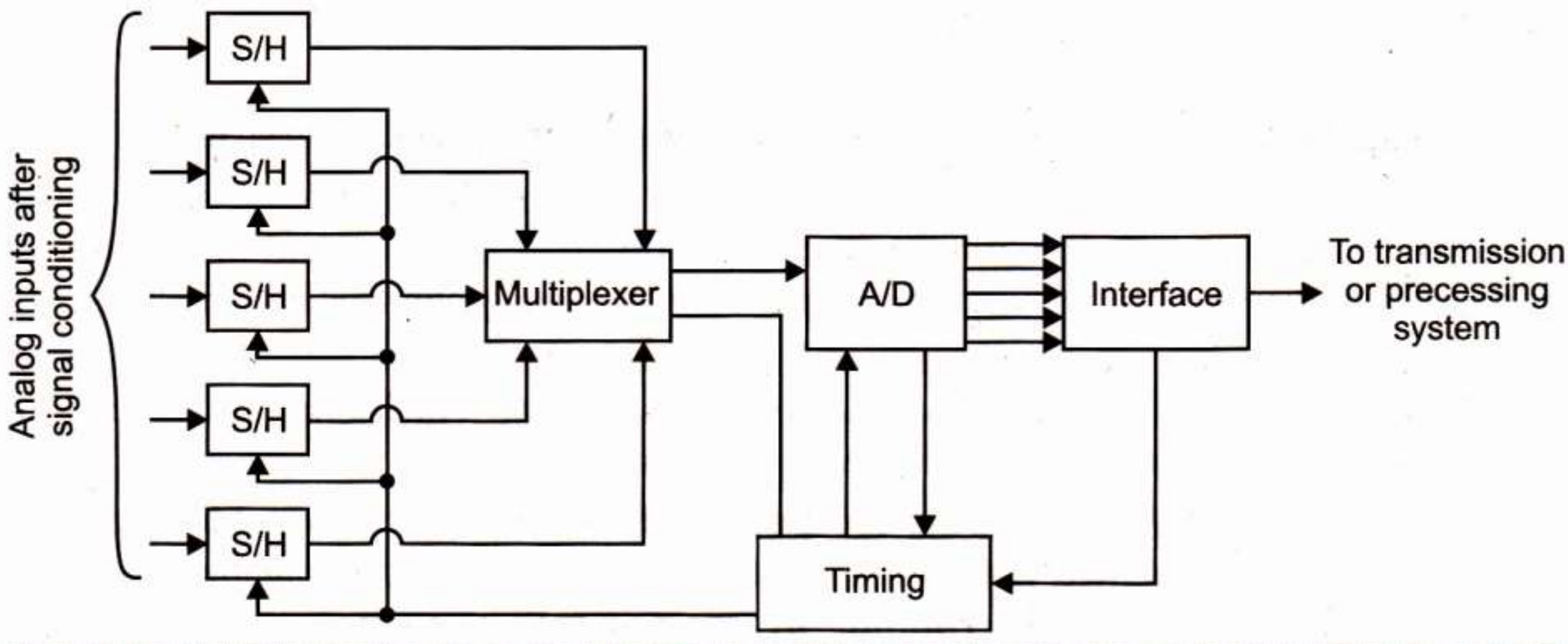


# 3) Multichannel data acquisition system

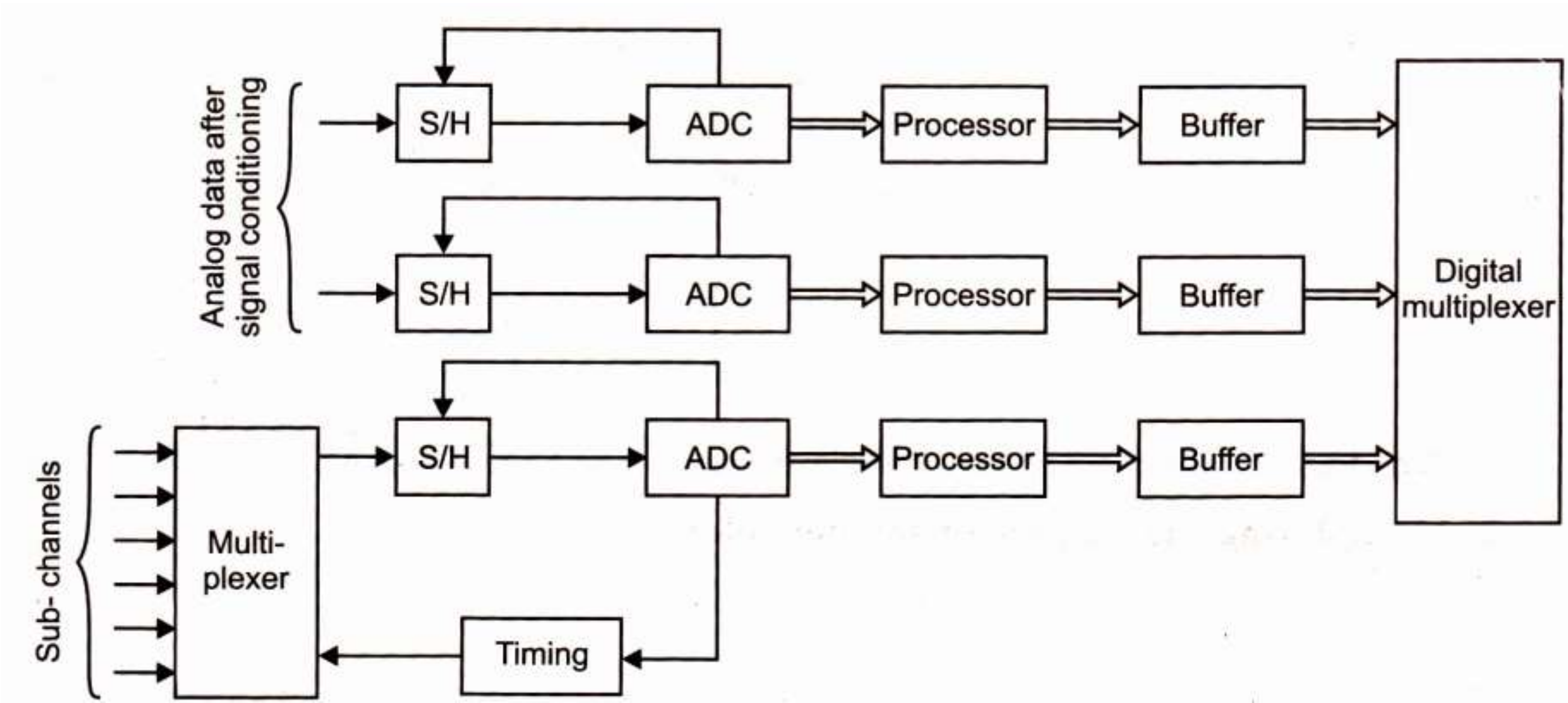
## i) Multi-channel analog multiplexed system



# 2) Multiplexing the outputs of sample-holds



# 3) Multiplexing after A/D conversion



4) Multiplexing low level data

- Applications of DAS

-Aerospace

-Biomedical

-Telemetry

# Data Conversion

- Analog to Digital Conversion(A/D)
  - Digital signals

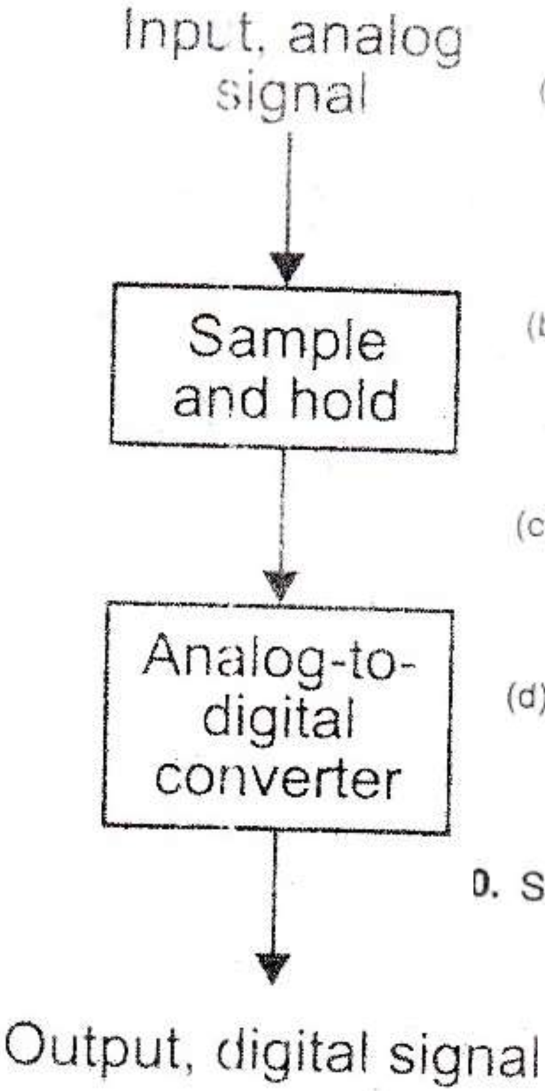
**18.4.1.2. ADC process**

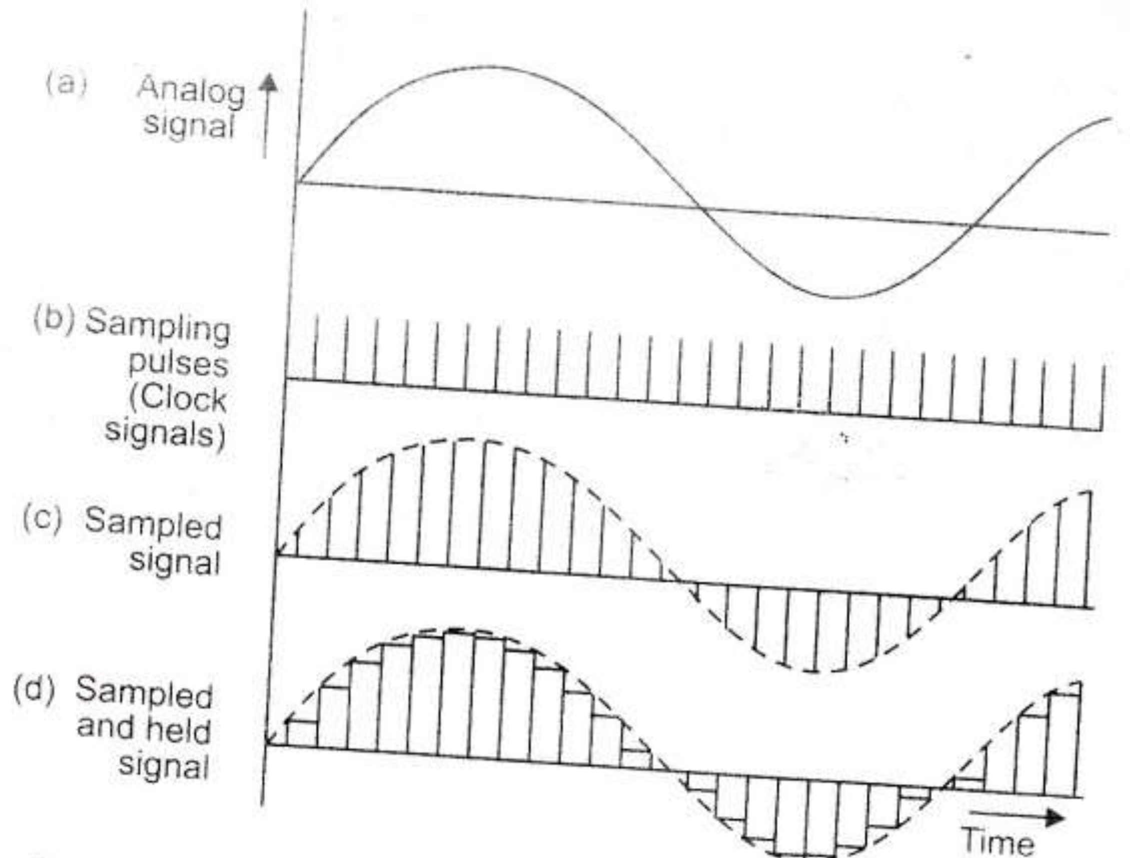
The *"analog-to-digital conversion" process* changes a sampled analog voltage into digital form. This process, conceptually involves the following *two steps:*

(i) ***Quantizing.*** It is defined as the *transformation of a continuous analog input into a set of discrete output states.*

(ii) ***Coding.*** It is *assignment of a digital code word or number to each output state.*

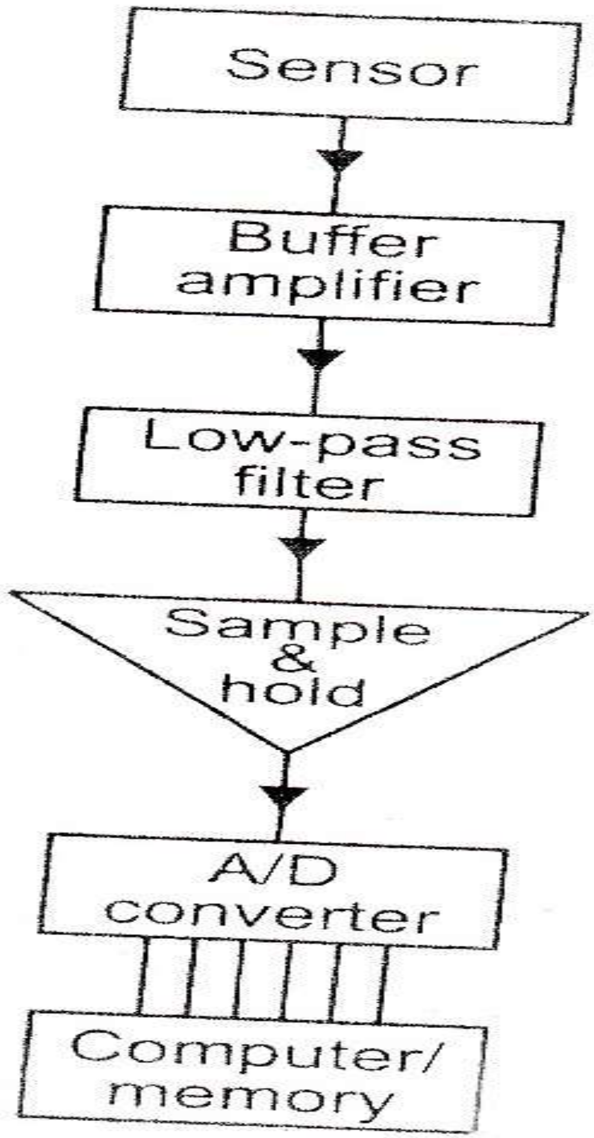
- Procedure of conversion




0. Signals : (a) Analog: (b)

- Components used in A/D conversion



- Analog to Digital converter

  -Definition

- Design principles

***Analog-to-Digital (A/D) converters*** *are designed based on a number of different principles; these are:*

(*i*) Successive approximations.

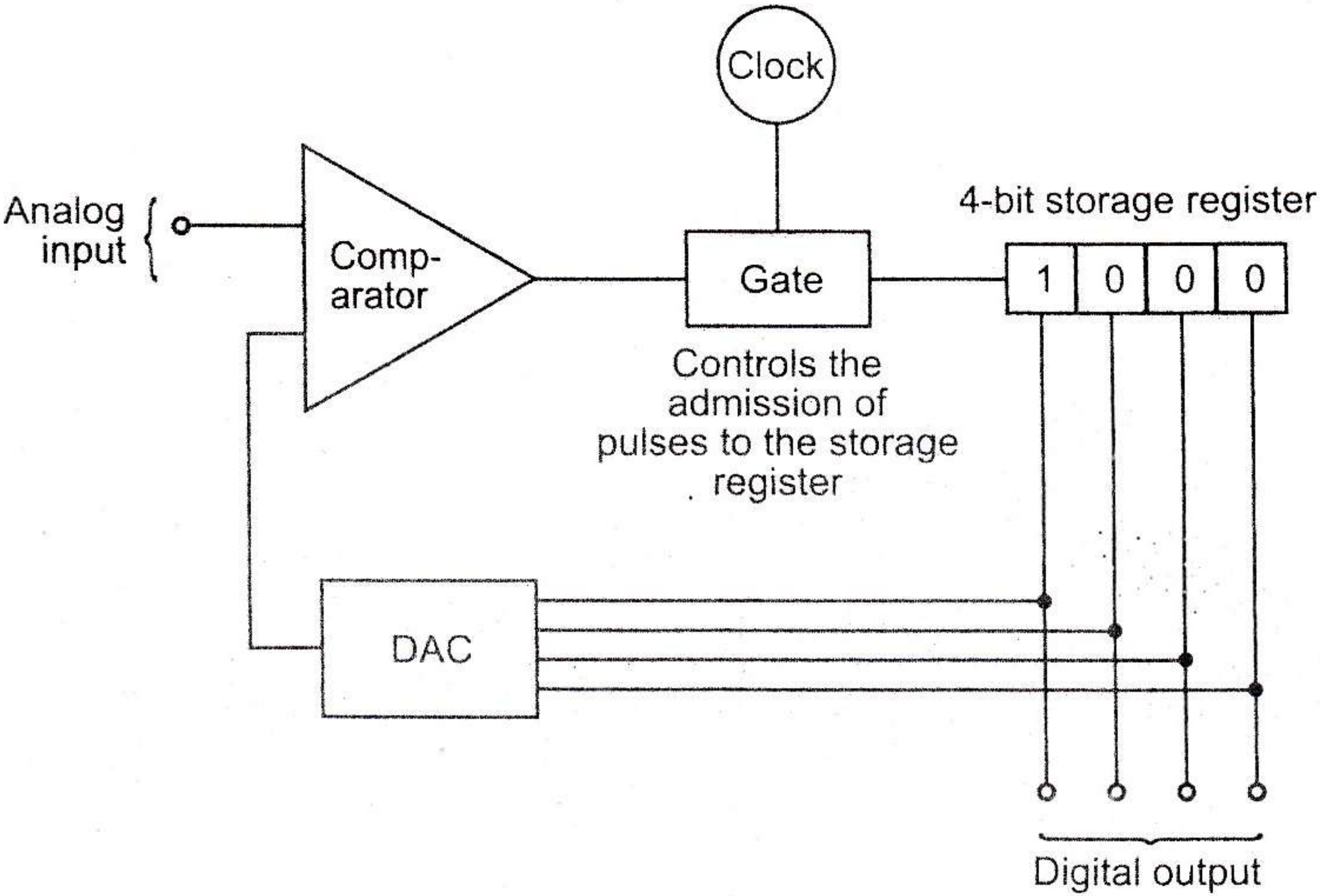
(*ii*) Flash or parallel encoding.

(*iii*) Single-slope and dual-slope integration.

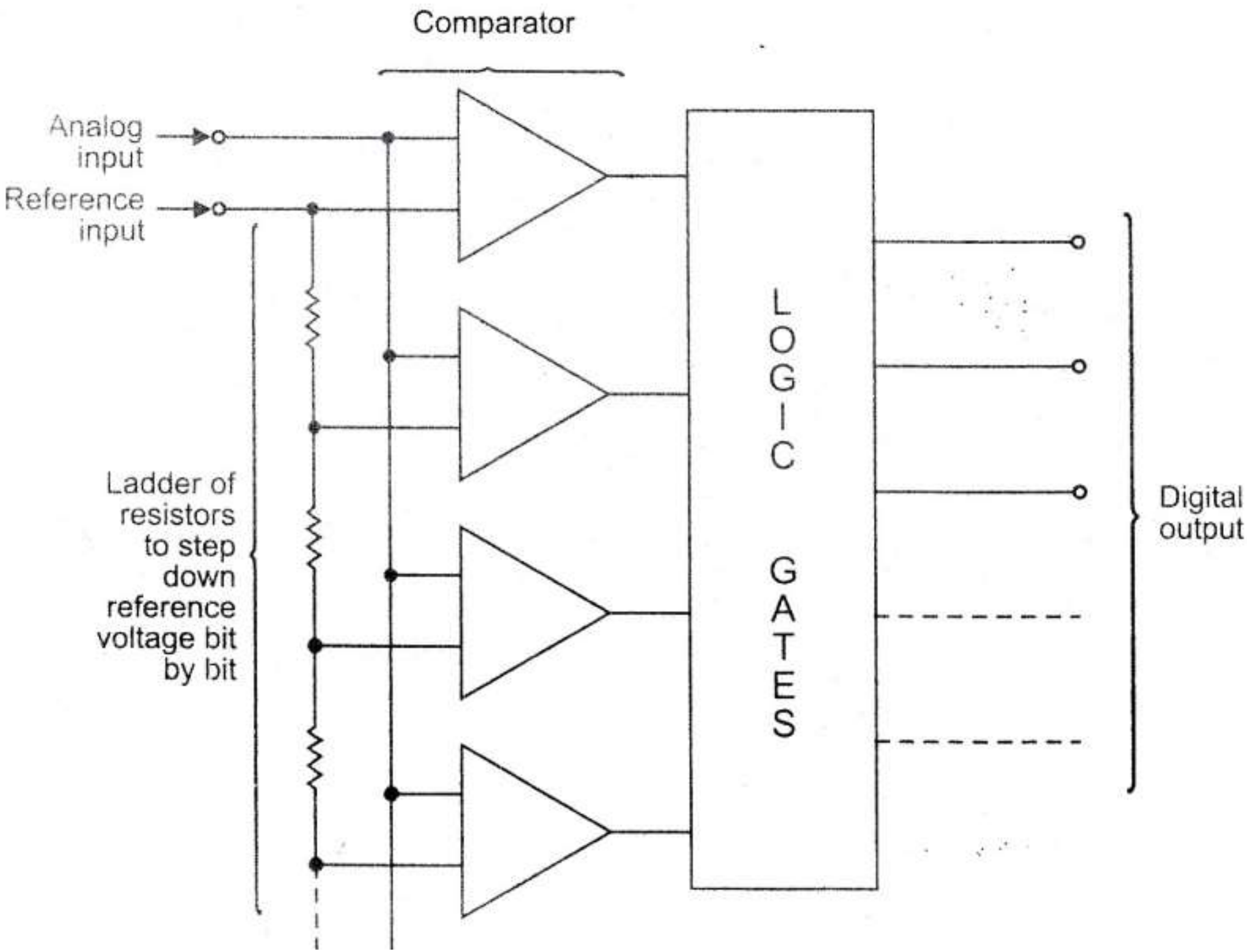
(*iv*) Switched capacitor.

(*v*) Delta sigma.

# 1) Successive approximation A/D converter

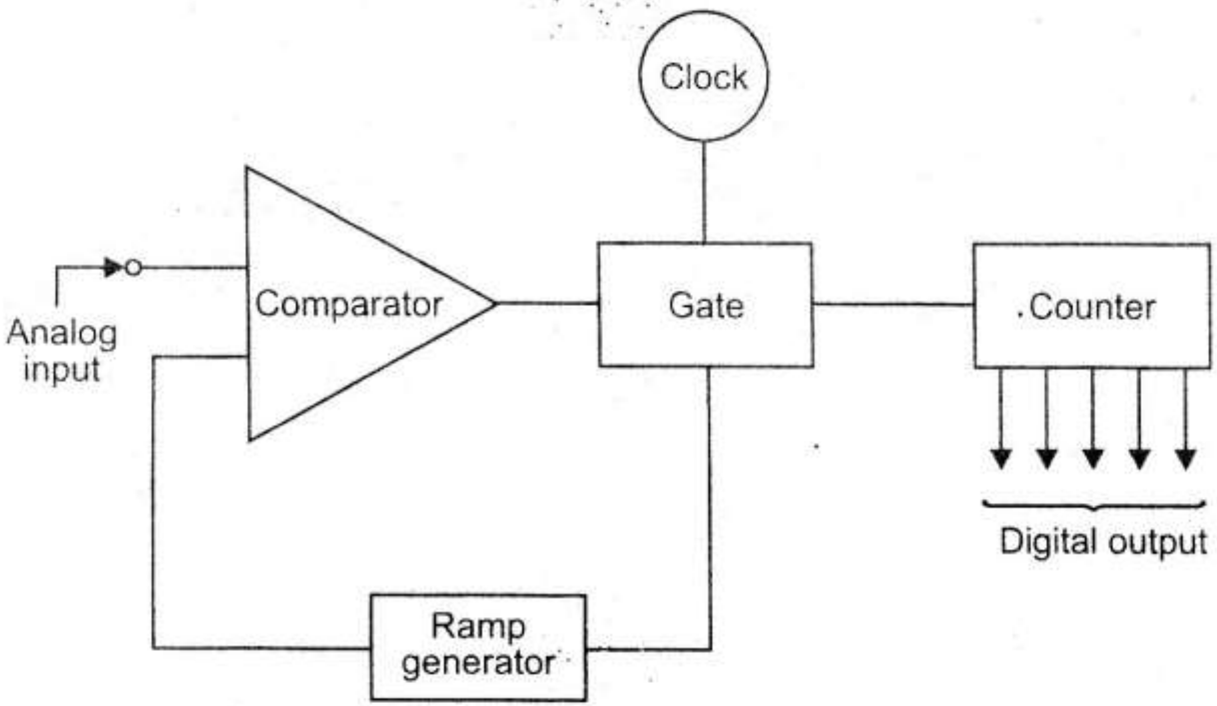


# 2) Flash A/D converter

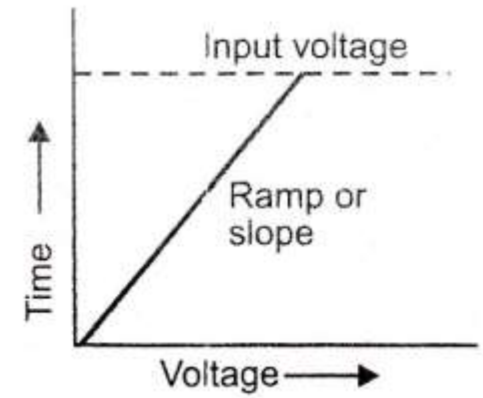


# 3) Single slope and dual slope integration

## a) Single slope or ramp or voltage to time A/D converter

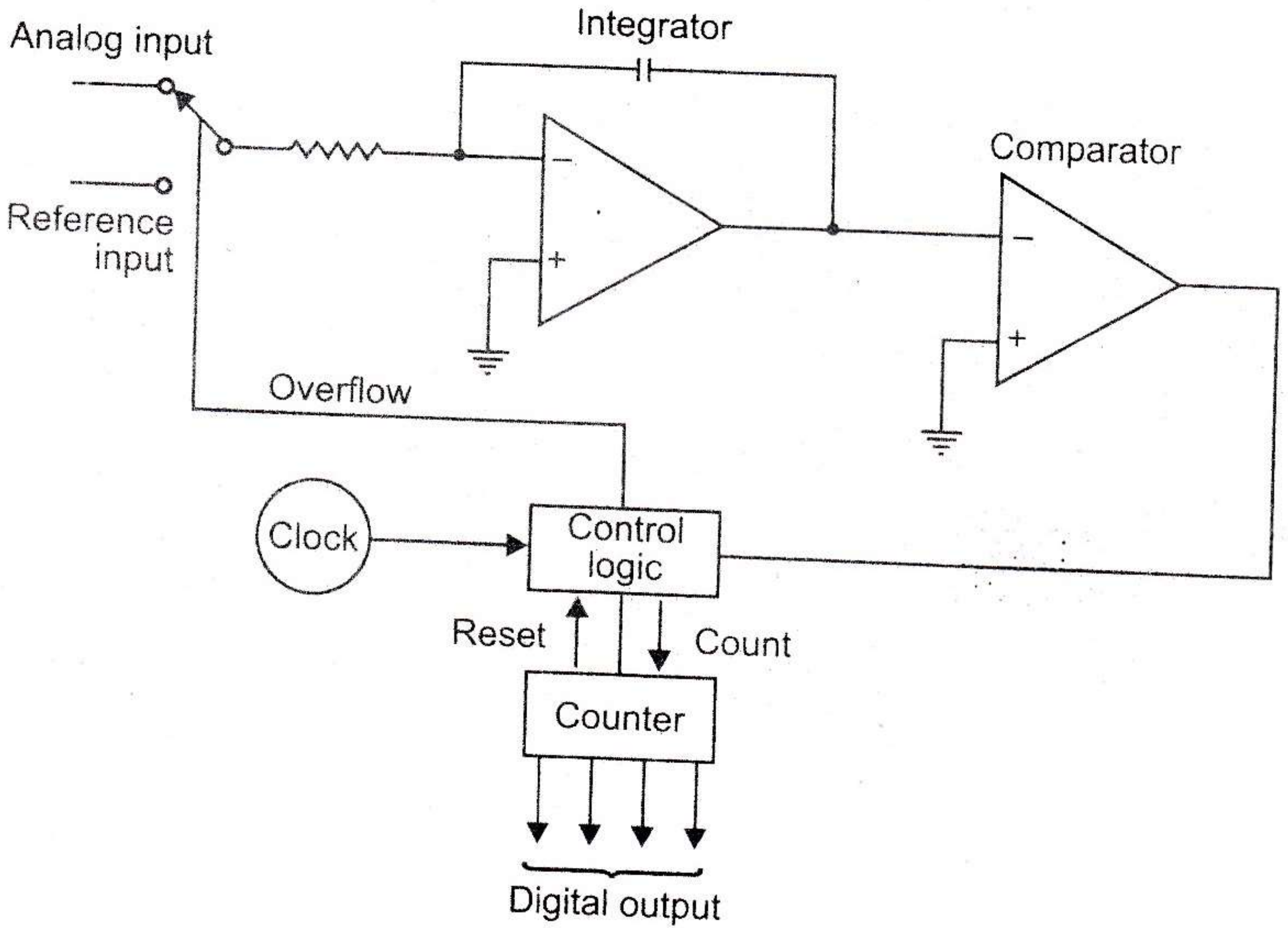



(a) Ramp ADC circuit

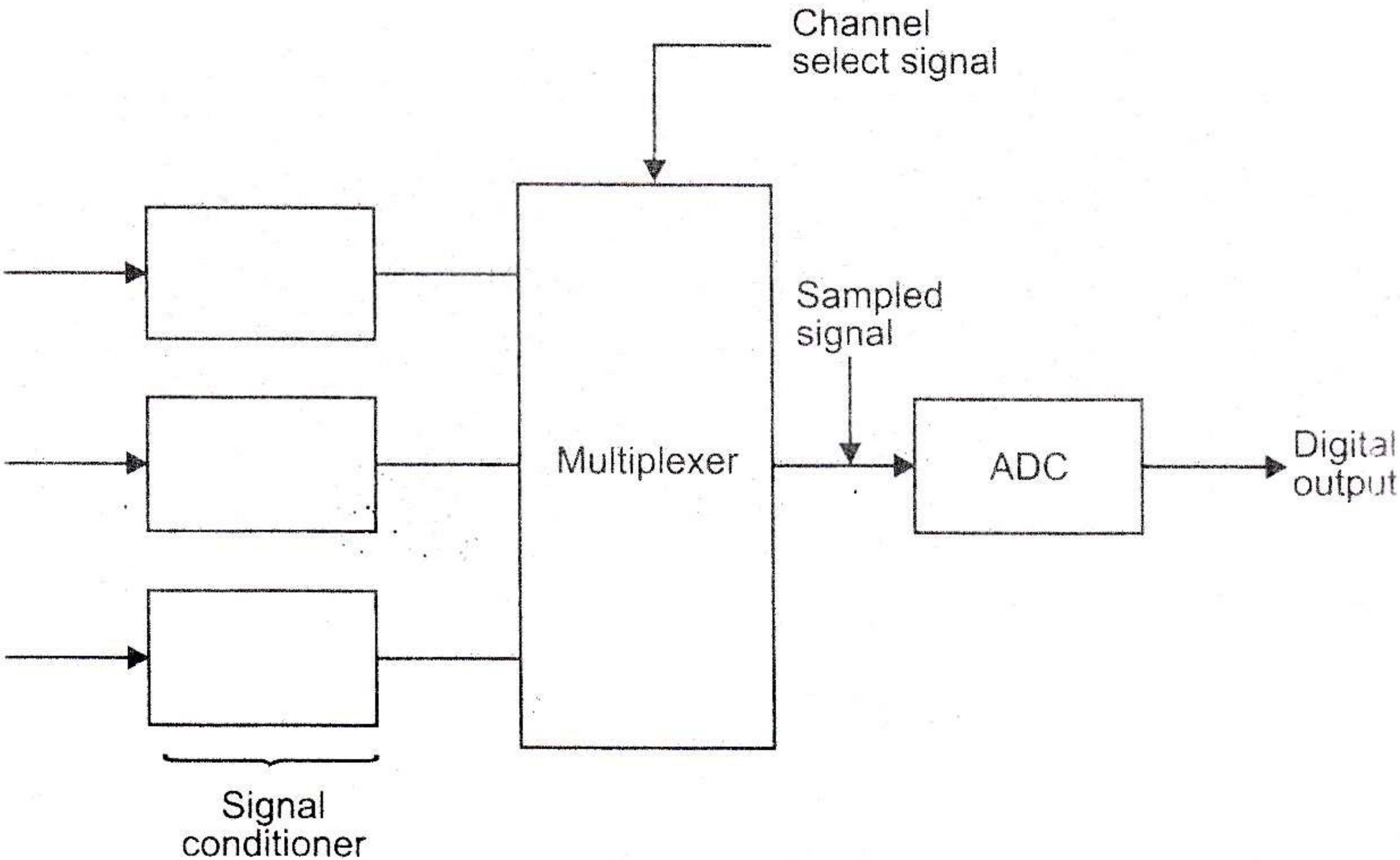



(b) Graphical representation

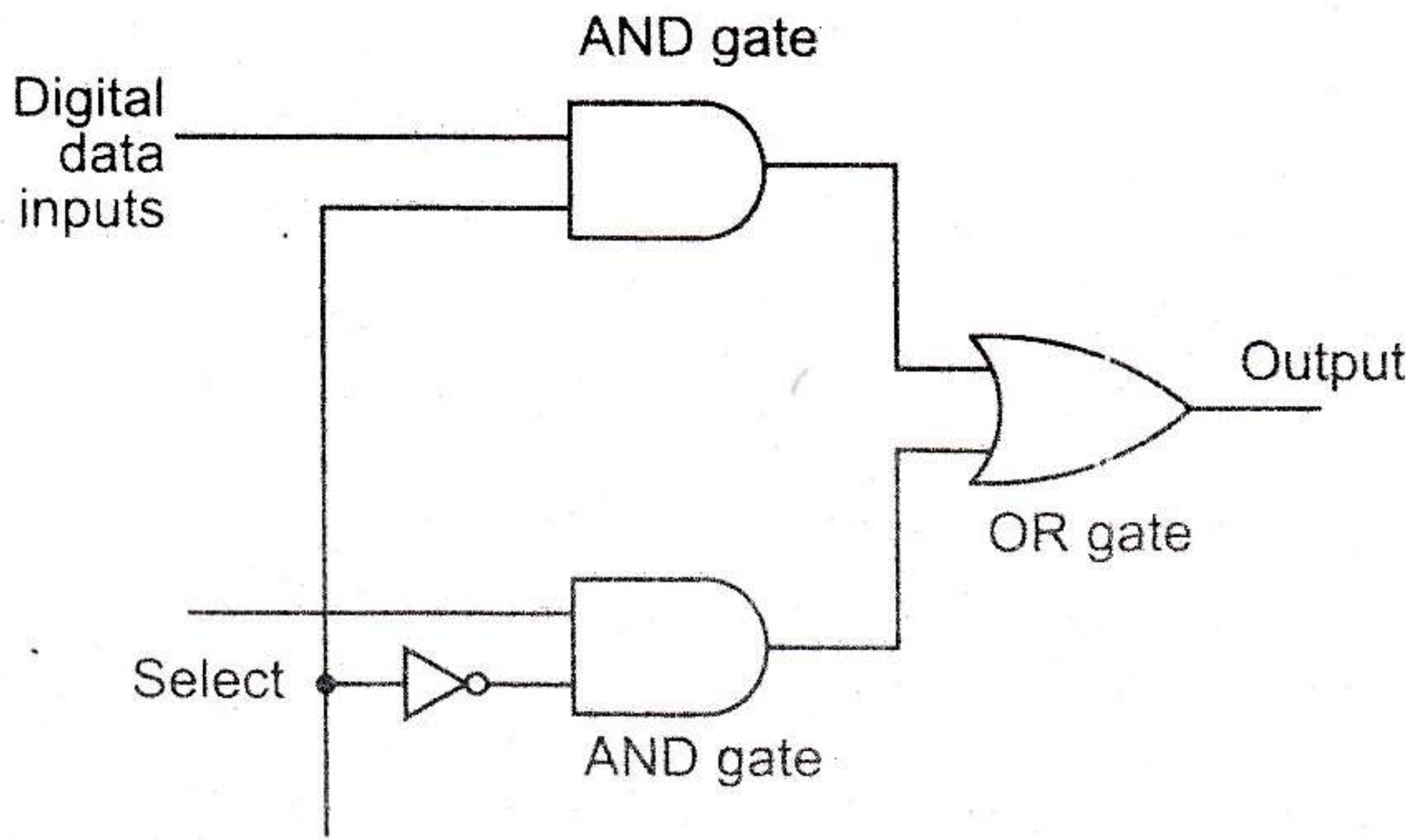
## b) Dual slope integration A/D converter or dual ramp converter



- Multiplexer



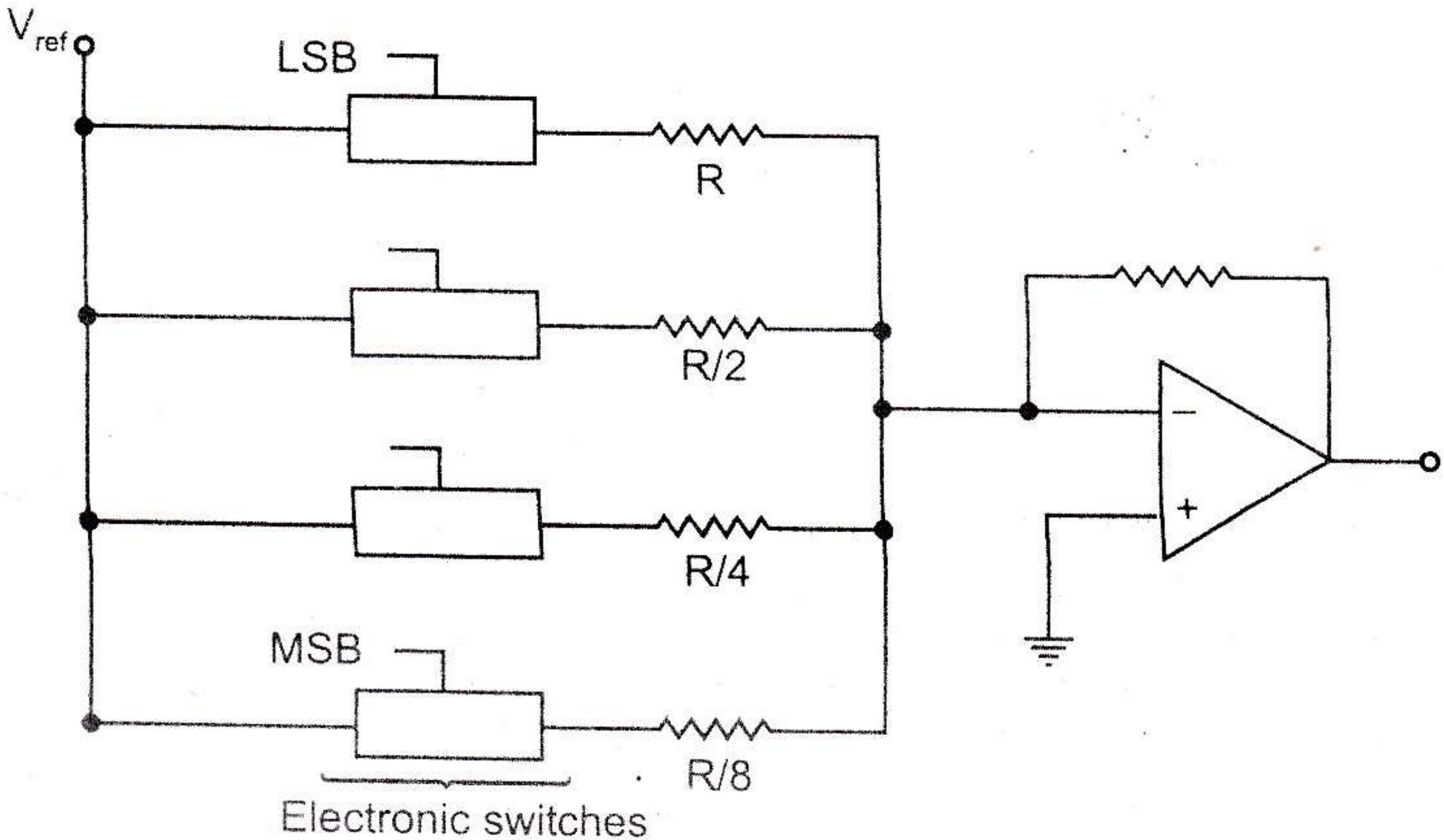
- Digital multiplexer



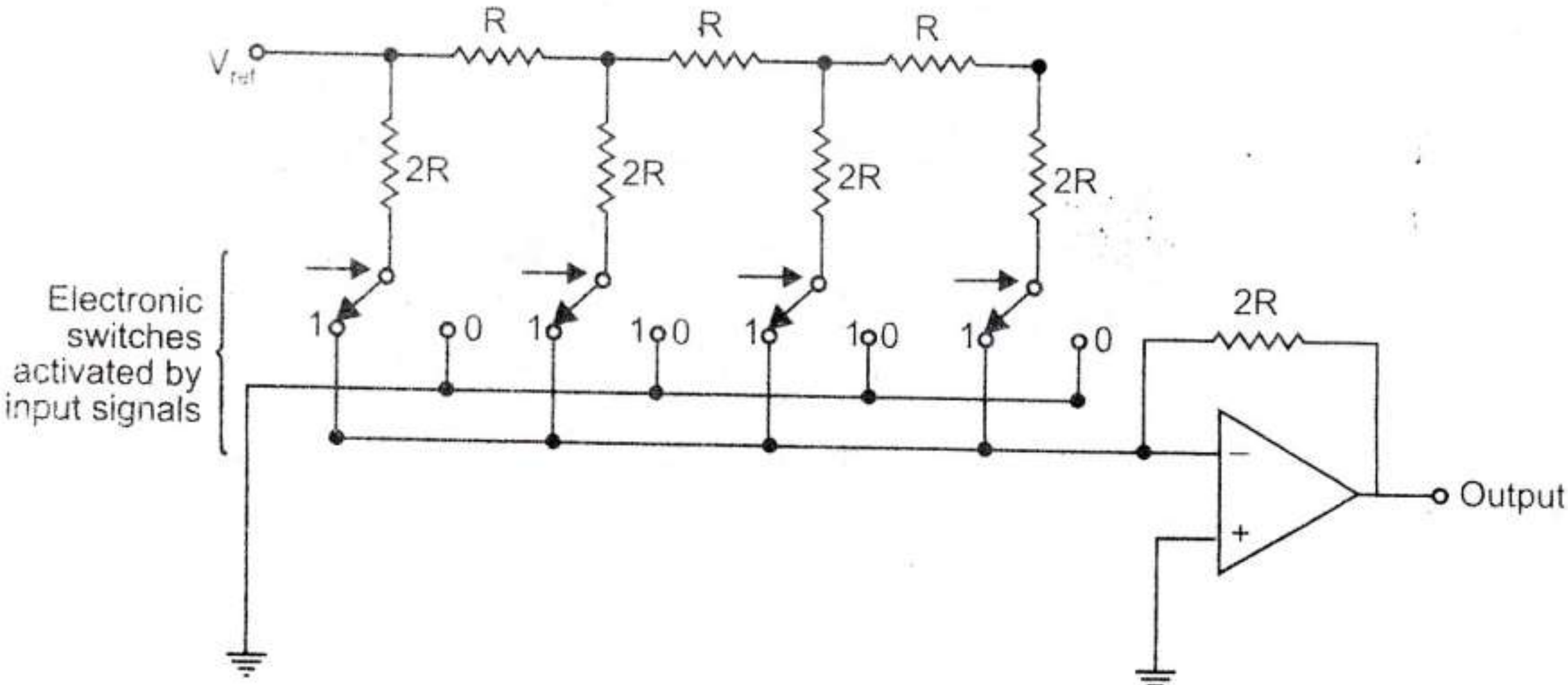
# Digital to Analog (D/A) Conversion

- Definition

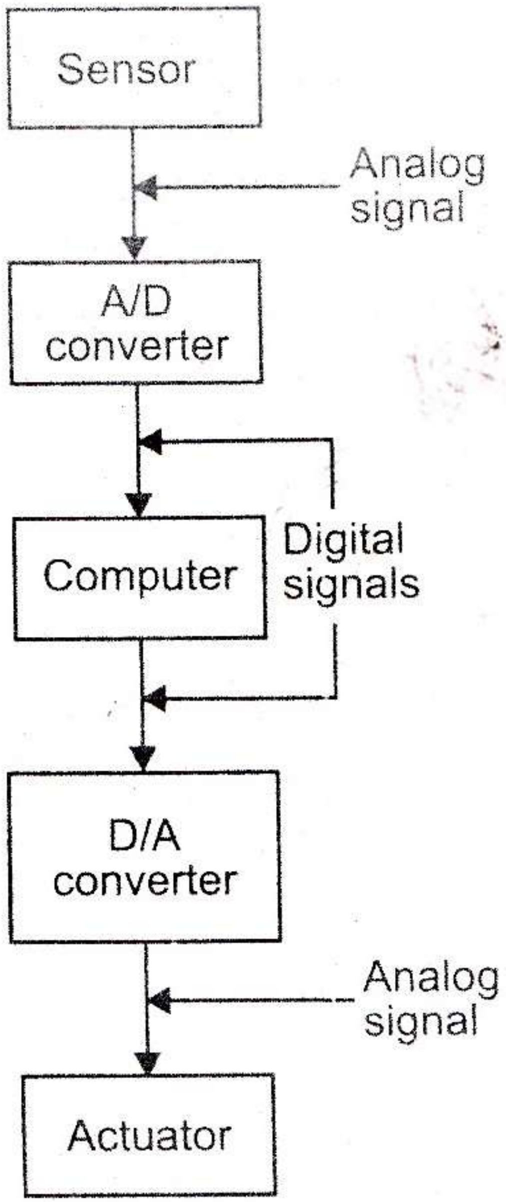
- Weighted resistor D/A converter



- R-2R ladder D/A converter



- Computer control hardware

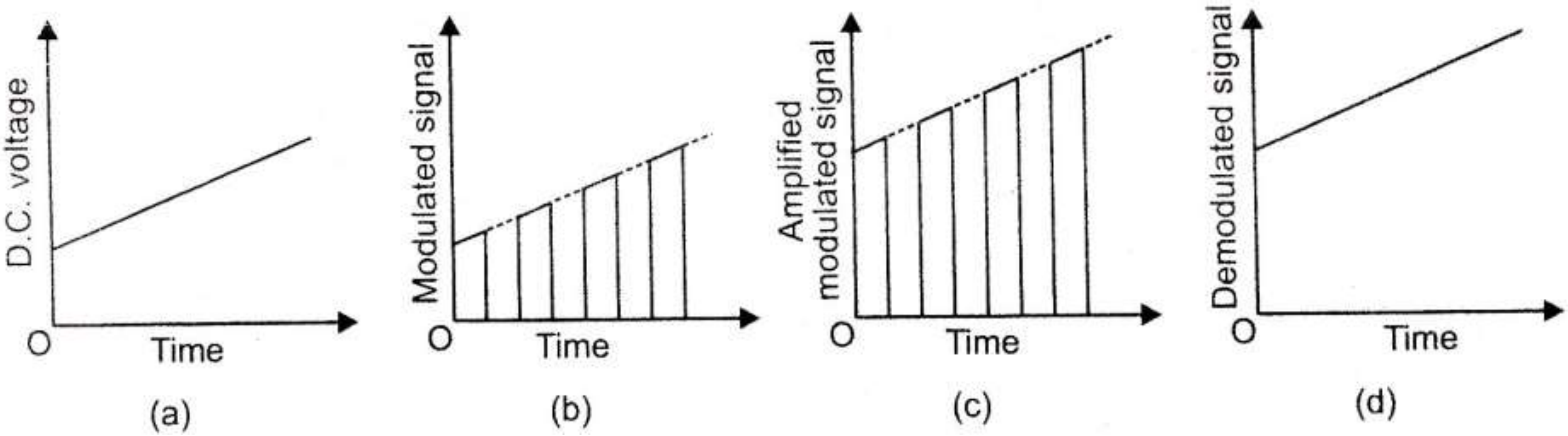


- Pulse Modulation

1) Pulse amplitude modulation (PAM)

2) Pulse width modulation (PWM)

# 1) Pulse amplitude modulation (PAM)



# 2) Pulse width modulation (PWM)

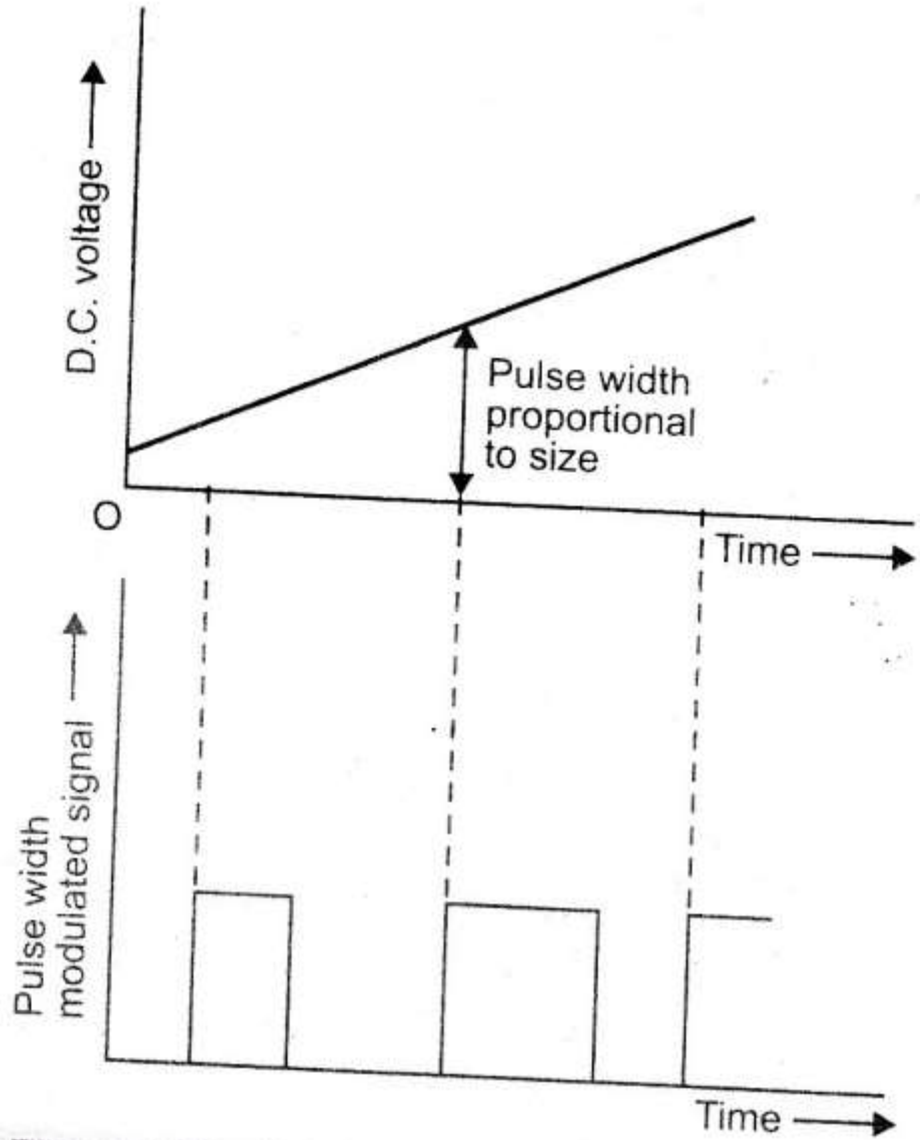



**Fig. 18.22** Pulse width

# Module 4

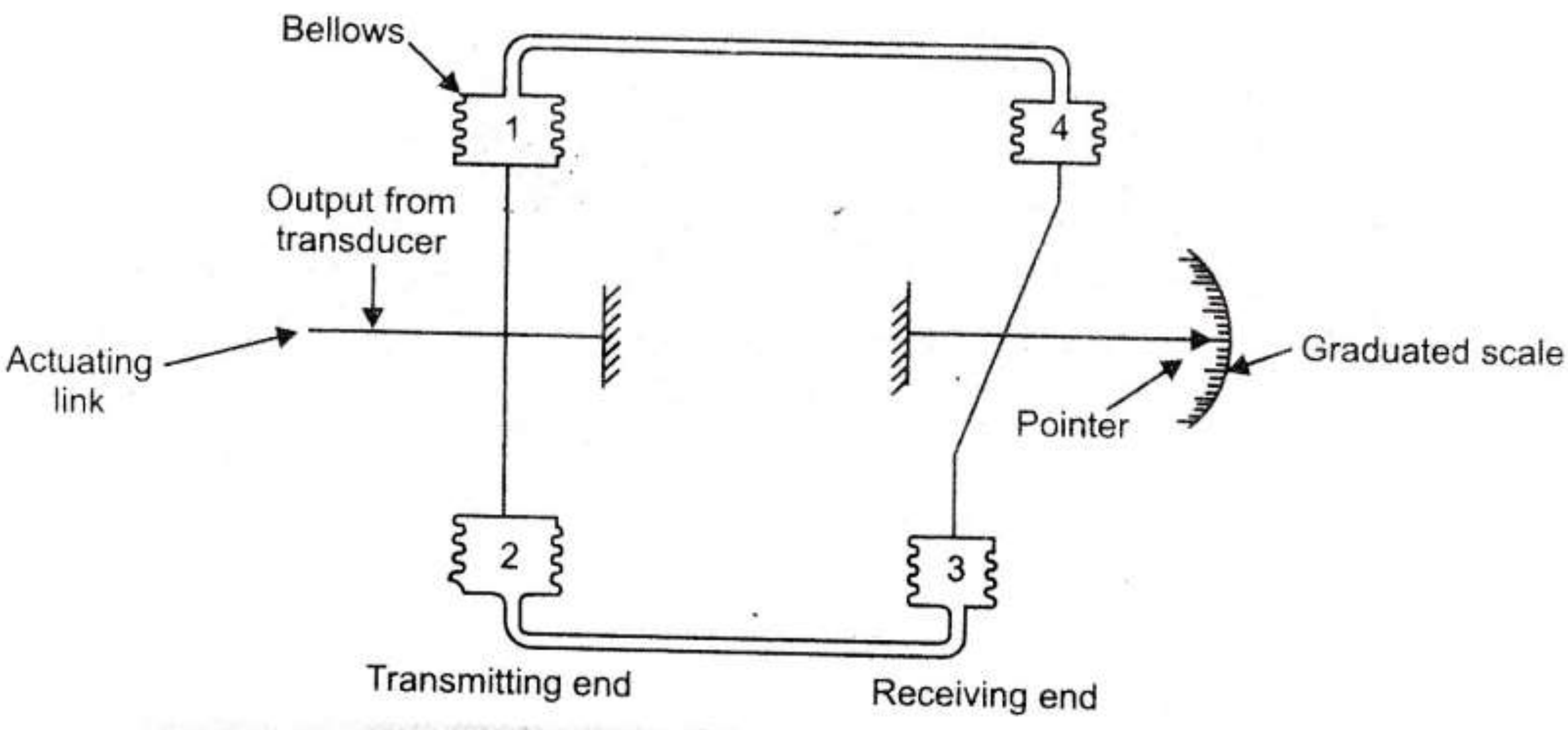
DATA TRANSMISSION AND TELEMETRY

# Data/Signal Transmission

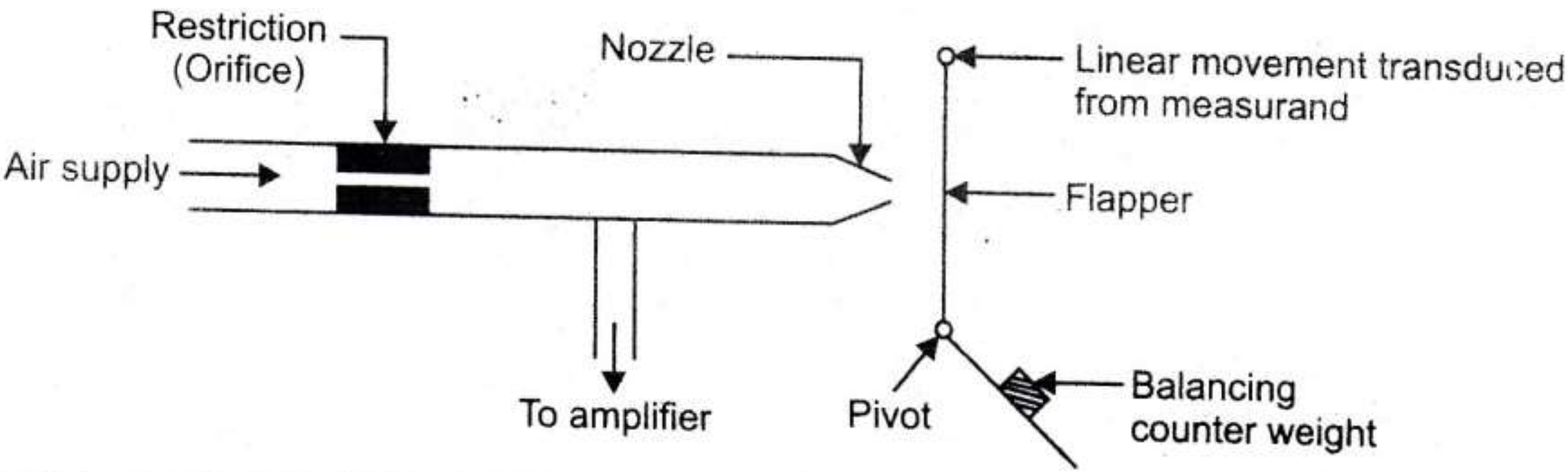
- Definition
- Data transmission
- Telemetry
- Factors affecting the choice of data transmission

# Types of data transmission

1) Mechanical transmission
2) Hydraulic transmission



# 3) Pneumatic transmission



# 4) Magnetic transmission

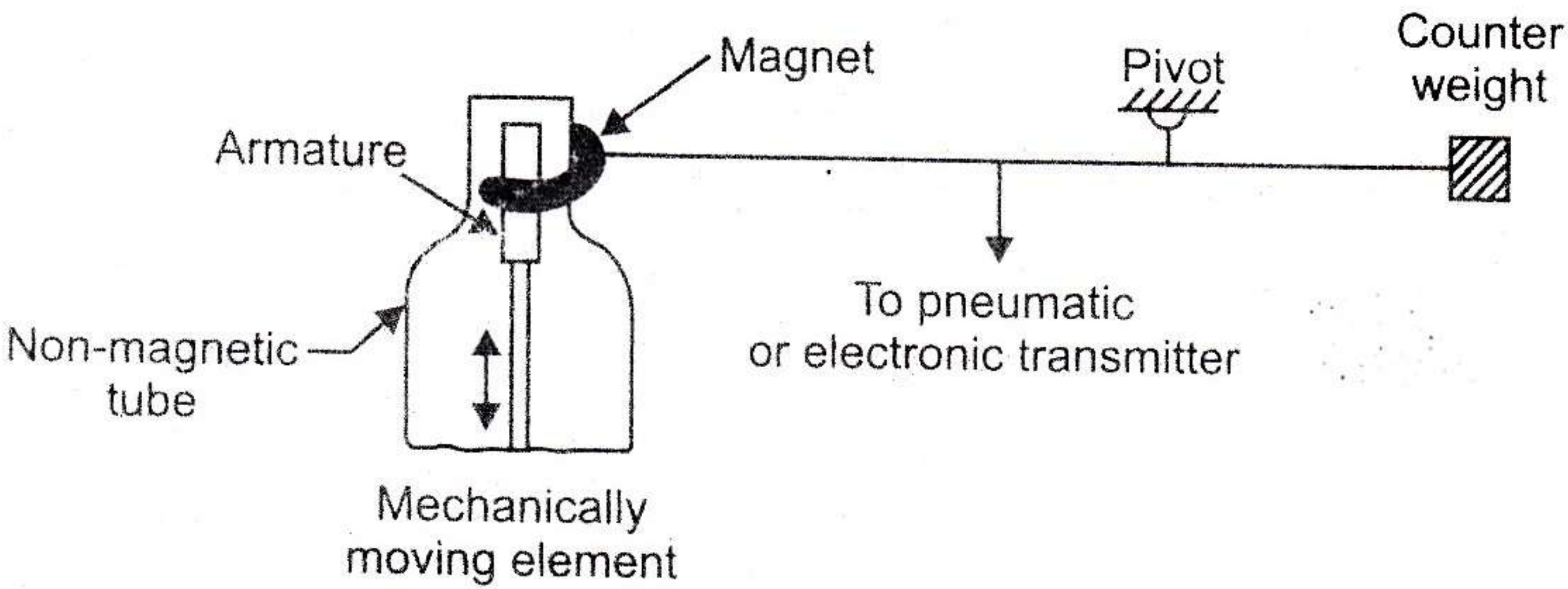



**Fig. 19.3.** Schematic transmission.

# 5) Electric type of transmitters

1. Wheatstone bridge transmitter.
2. Inductance bridge.
3. Impedance bridge.
4. Differential transformer.
5. Self synchronous motor (Selsyn)
6. Resistance manometers.

- Converters

1. Current-to-pneumatic converters.
2. Pneumatic-to-current converters.
3. Voltage-to-current converters.
4. Voltage-to pneumatic converters

# Telemetry

- Definition

**Telemetry** *is defined as a technology which allows users to collect information from inaccessible and inconvenient locations and to transmit it to the accessible places to process, record and display the information in presentable form.*

Or

**Telemetry** *(as the name implies) means measuring at a distance.*

- General telemetring system

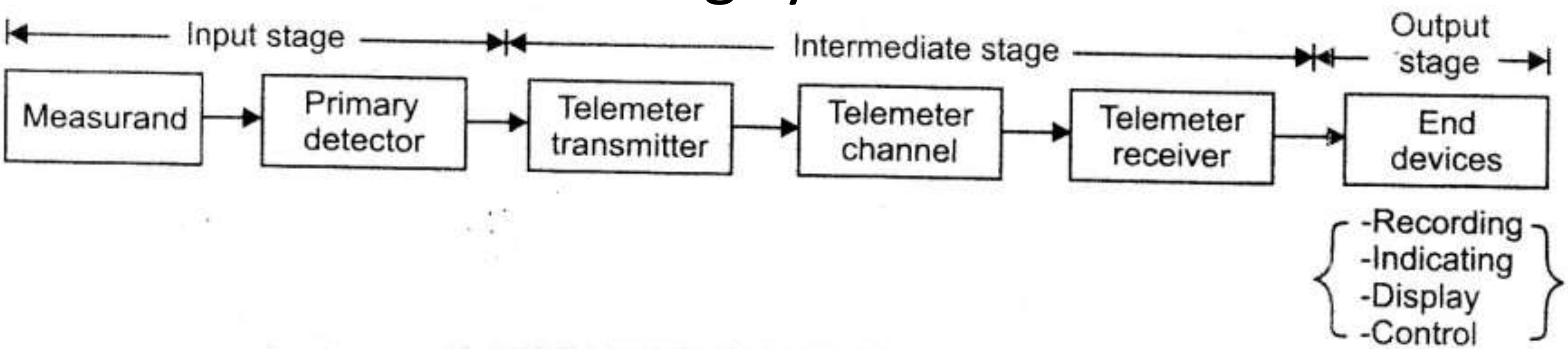



**Fig. 19.4.** Block diagram of general telemetring system.

# Types of telemetry systems

**I. According to the link between the telemeter transmitter and the telemeter receiver :**

1. *Land line* (**D.C.**) *telemetry system :*
   - (*i*) Voltage telemetering system.
   - (*ii*) Current telemetering system.
   - (*iii*) Position (or ratio) telemetering system.
2. *Ratio frequency (RF) telemetry system :*
   - — Frequency telemetering system
   - — Pulse telemetering system.

**II. According to the form in which the information is transmitted :**

1. *Analog telemetry system.* Here information is transmitted in the form of current, voltage, position and frequency.
2. *Digital telemetry system.* In this system the information is transmitted in the form of "pulses".

- Advantages and disadvantages of landline telemetry system

*Advantages :*

(*i*) Very effective system for short-distance transmission (as the telemeter or communication channel can be established with the help of a simple cable or transmission line).

(*ii*) Very simple circuitry is required for the measurement set-up.

(*iii*) The information can be transmitted (in the form of voltage, current and position) easily by the use of modern electronic circuitry available now-a-days.

(*iv*) A wide variety of detectors (or the primary sensing elements) are available which produce electrical signal (voltage or current) in relation with the variable being measured at the system's input stage.

*Disadvantages :*

(*i*) Limited frequency response.

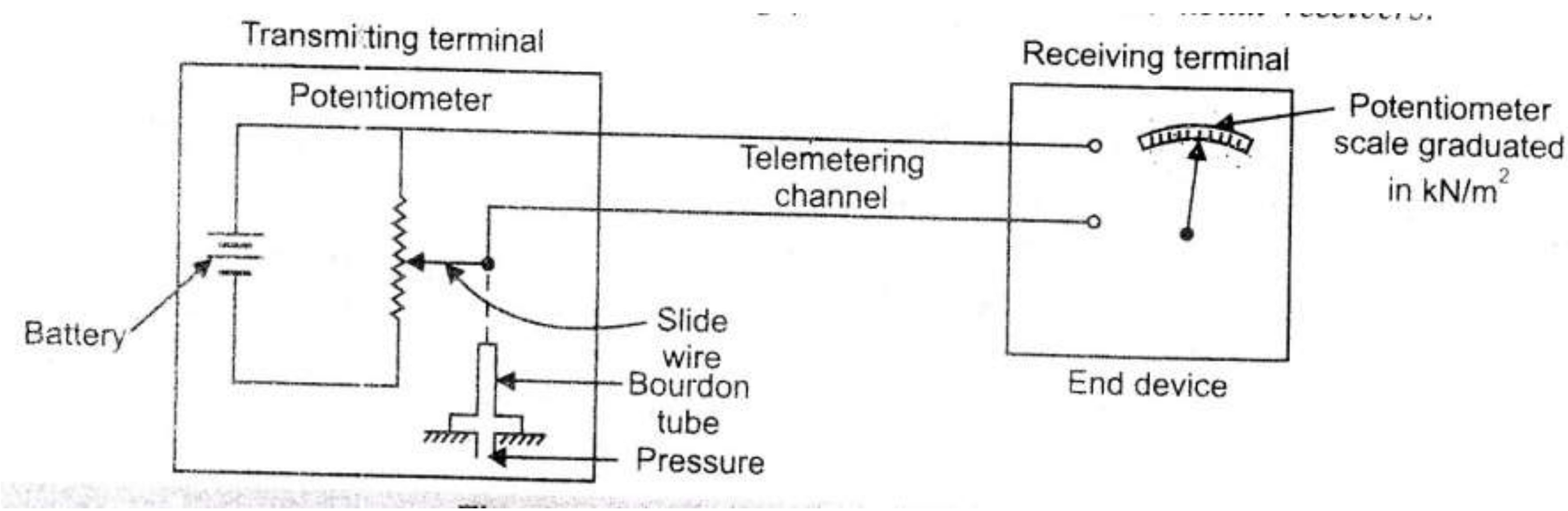
(*ii*) Signal multiplexing is very difficult.

(*iii*) The distortions in the transmission links are directly incorporated in the main system.

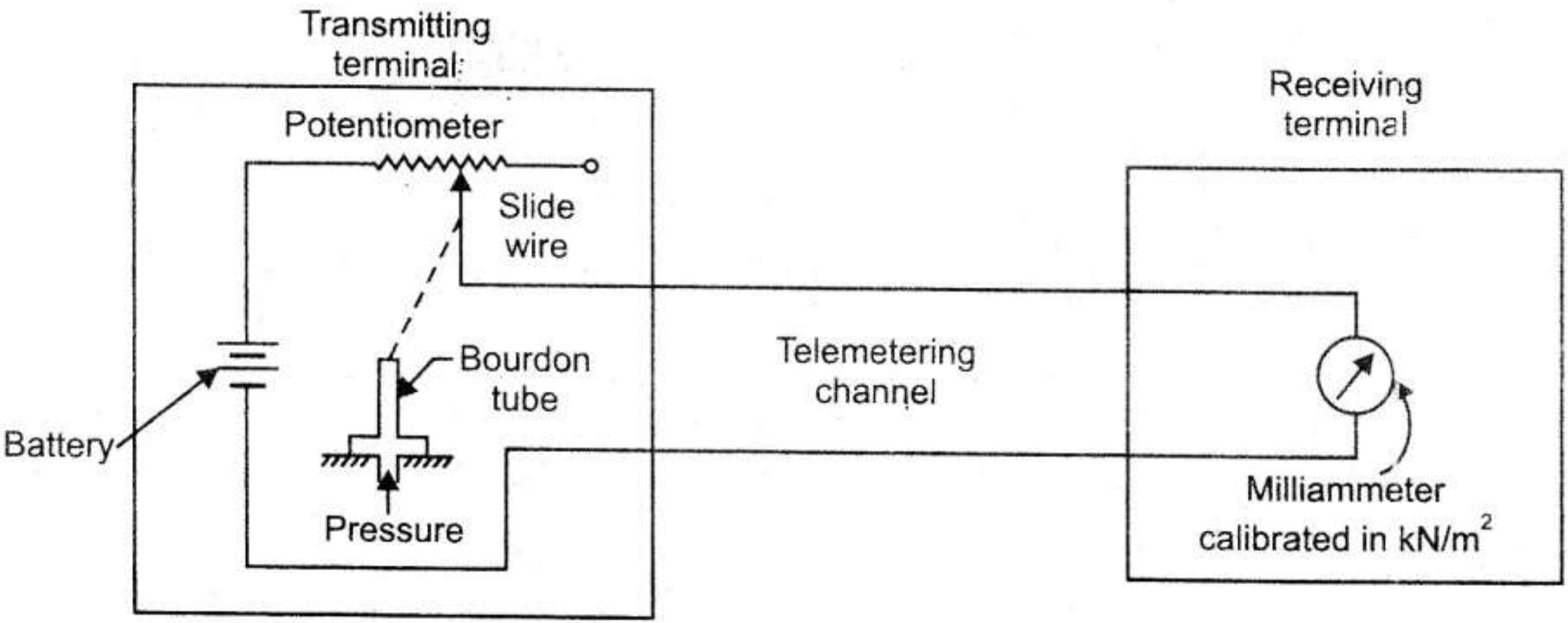
(*iv*) The information transmitted through the link is affected by the EMI effects of main frequency from nearby cable.

(*v*) The effects of thermoelectric emfs are significant in case of telemetry systems transmitting D.C. signals.

# 1) Voltage telemetering system



# 2) Current telemetering system



# i) Motion balance current telemetering system

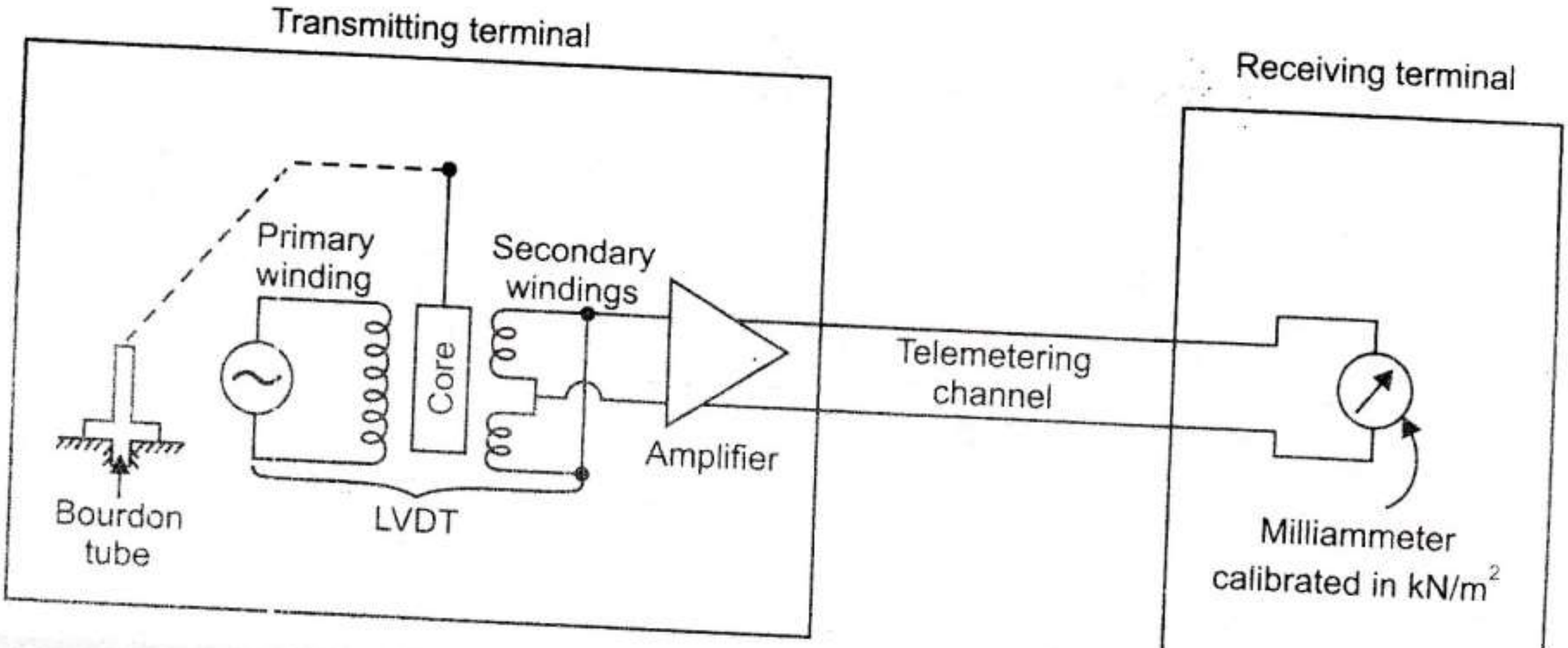
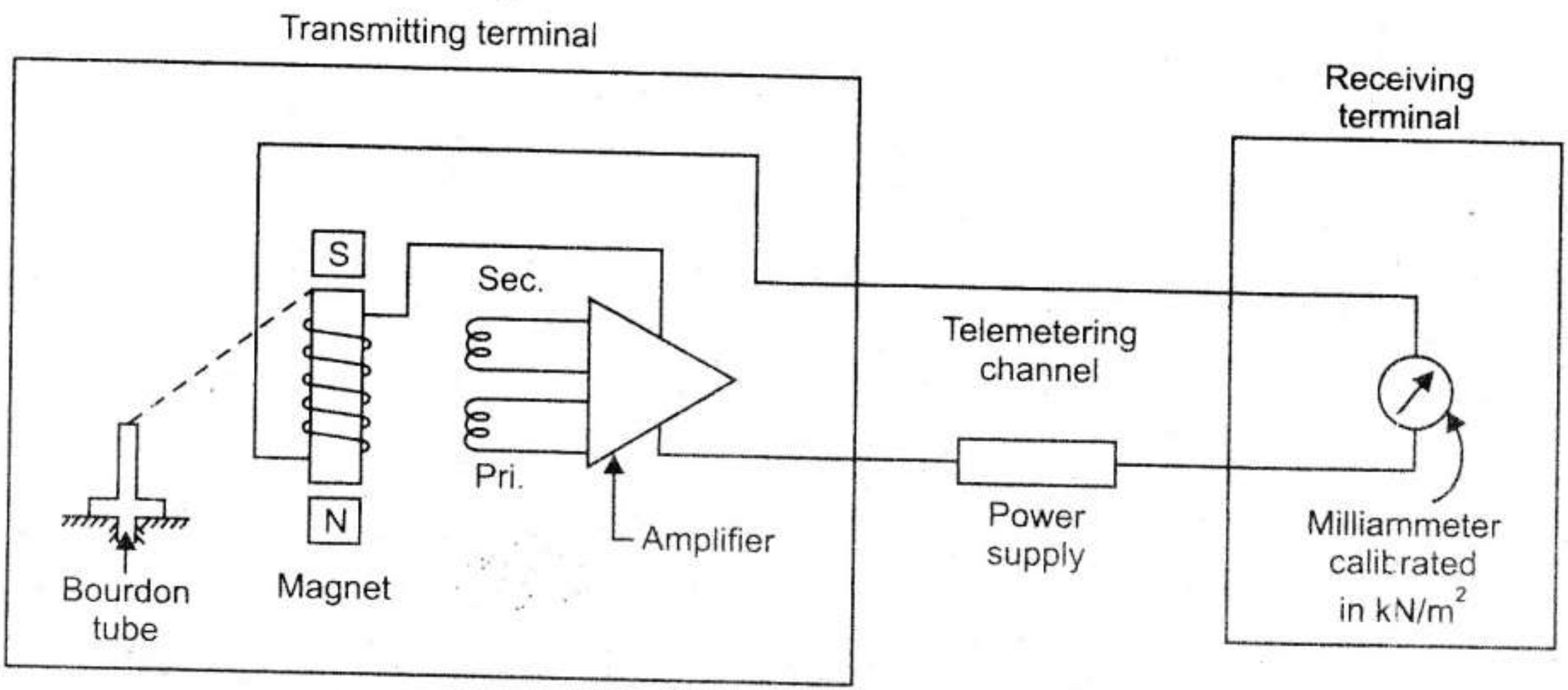



Fig. 19.7. Motion balance

# ii) Force balance current telemetering system



- Advantages of current telemetering system

(i) The current systems can develop higher voltages than most voltage systems and, consequently, it can be made more immune to the effect of thermal and inductance voltages in the interconnecting leads as well as line resistance.

(ii) Simple D.C. milliammeters can be used with special calibration for line resistance.

(iii) Several receivers can be operated simultaneously.

(iv) The received signals can be added or subtracted directly.

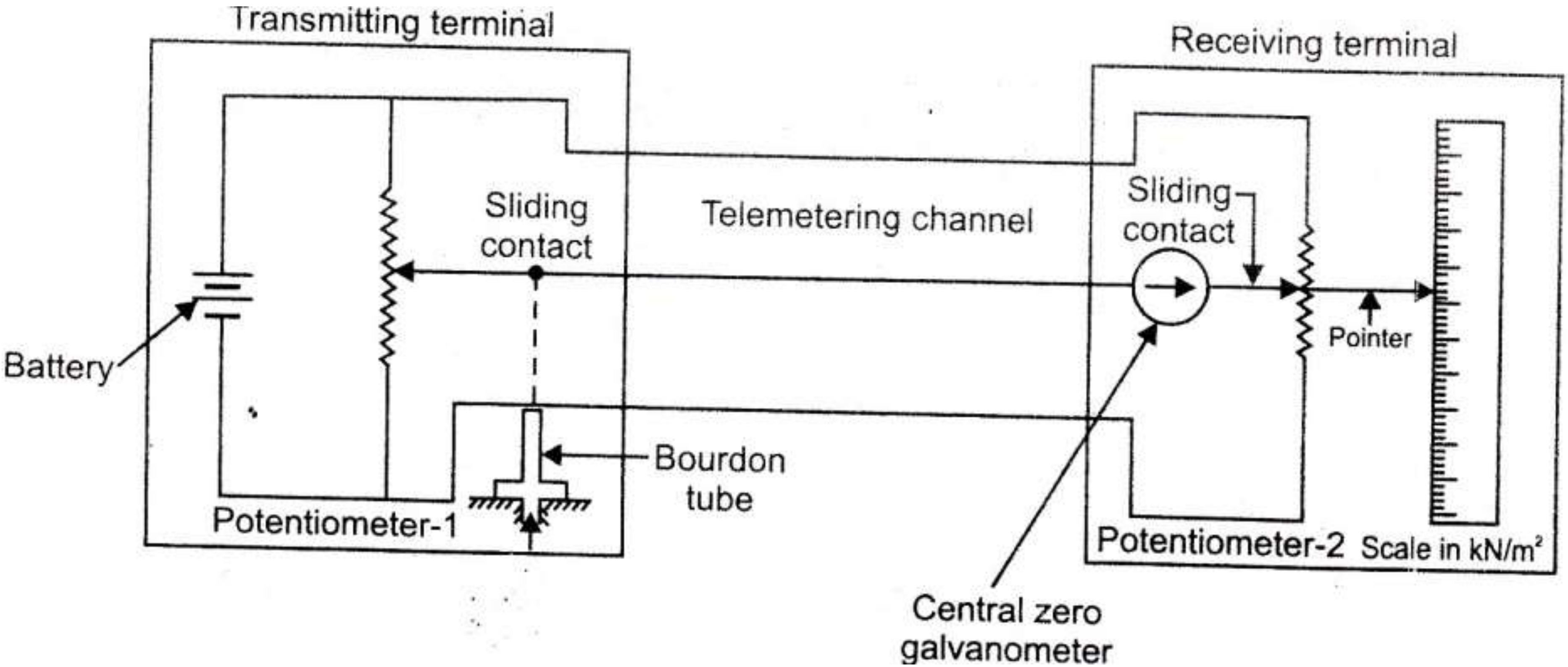
(v) Changes in line resistance are compensated by basic feedback method.

(vi) The response of the system to an input change is almost instantaneous.

(vii) The energy level is adequately high to minimise the effects of extraneous voltages.

- This system is *also not suitable for long distance* since the current output is varied by means of an adjustable resistance in the line.

# 3) Position or Ratio telemetering system



# II) Radio frequency(RF) telemetry system

In this telemetry system the *link between the transmitting end and the receiving end is established through the "radio links"* (there being no physical link).

*Example :* The controlling of aircraft on test flights, rockets and spacecrafts.

- The RF telemetry systems are *more suitable for transmission of data over distances more than 1 km.*
- In this system, along with certain band of the radio frequency spectrum, a microwave link above 4 MHz is also allocated. This is because the radio waves at these frequencies travel in straight lines with some repeaters, located every 30 km to 60 km, on high buildings or towers.

# Introduction to types of signals and transmission paths

Types of signals

1) Analog signals: Ex. Telephone, radio broadcast or TV signals

2) Digital signals: Ex. Telegraph and teleprinter signals

# Transmission paths

1) Line communications: Through transmission lines (Overhead or underground cable)
2) Radio communications: propagation of signals through atmosphere. Antennas are used.

**Major Radio Frequency Bands**

| | *Name* | *Frequencies* | | |
|---|---|---|---|---|
| 1. | Very low frequency (VLF) | Below 30 kHz | ... | Radio location equipment |
| 2. | Low frequency (LF) | 30 kHz to 300 kHz | ... | Wartime radio navigation |
| 3. | Medium frequency (MF) | 300 kHz to 3 MHz | ... | Includes AM radio broadcast band |
| 4. | High frequency (HF) | 3 MHz to 30 MHz | ... | Radio |
| 5. | Very high frequency (VHF) | 30 MHz to 300 MHz | ... | Includes FM broadcast band and television VHF channels |

| | | | |
|---|---|---|---|
| 6. | Ultra high frequency (UHF) | 300 MHz to 3 GHz | ... Includes television UHF channels |
| 7. | Super high frequency (SHF) | 3 GHz to 30 GHz | ... Satellite communications |
| 8. | Extremely high frequency (EHF) | 30 GHz to 300 GHz | ... Satellite communications |

# Modulation and Demodulation

## 1) Modulation

- ***Modulation*** *is the process of combining the low-frequency signal with a very high-frequency radio wave called 'carrier wave (CW)'.* The resultant wave is called *modulated carrier wave.* This job is done at the transmitting station.

*Or*

***Modulation*** *is a process in electronic circuits by which the characteristics of one wave form (carrier) is modified by the variations in another wave (audio signal).*

*Or*

***Modulation*** *is the process of combining an audio-frequency (AF) signal with a radio frequency (RF) carrier wave (Fig. 19.10).* AF signal is called a *modulating wave* and the resulting wave produced is called *modulated wave.* During modulation, some characteristic of the carrier wave is varied in time with the modulating signal and is accomplished by combining the two.

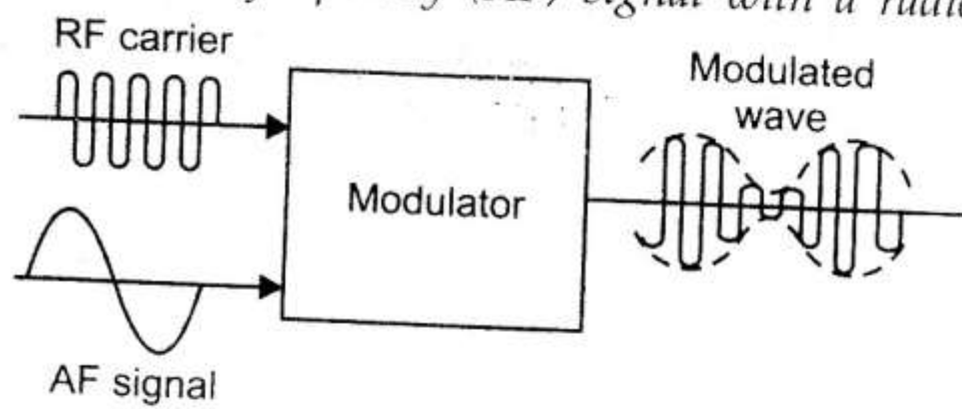



**Fig. 19.10**

- Need of Modulation

Modulation increases operating range.

It reduces the size of transmitting and receiving antennas.

It permits transmission without wire.

It is extremely difficult to radiate low frequency signals through earth's atmosphere in the form of electromagnetic energy.

# Methods of modulation

For a sinusoidal carrier wave, the mathematical expression is given as

$$e = E_c \sin(\omega_c t + \phi) = E_c \sin(2\pi f_c t + \phi) \quad ...(1)$$

Thus, the waveform can be varied by any of its following three factors or parameters :

(*i*) $E_c$ – The *amplitude* ;

(*ii*) $f_c$ – The *frequency* ;

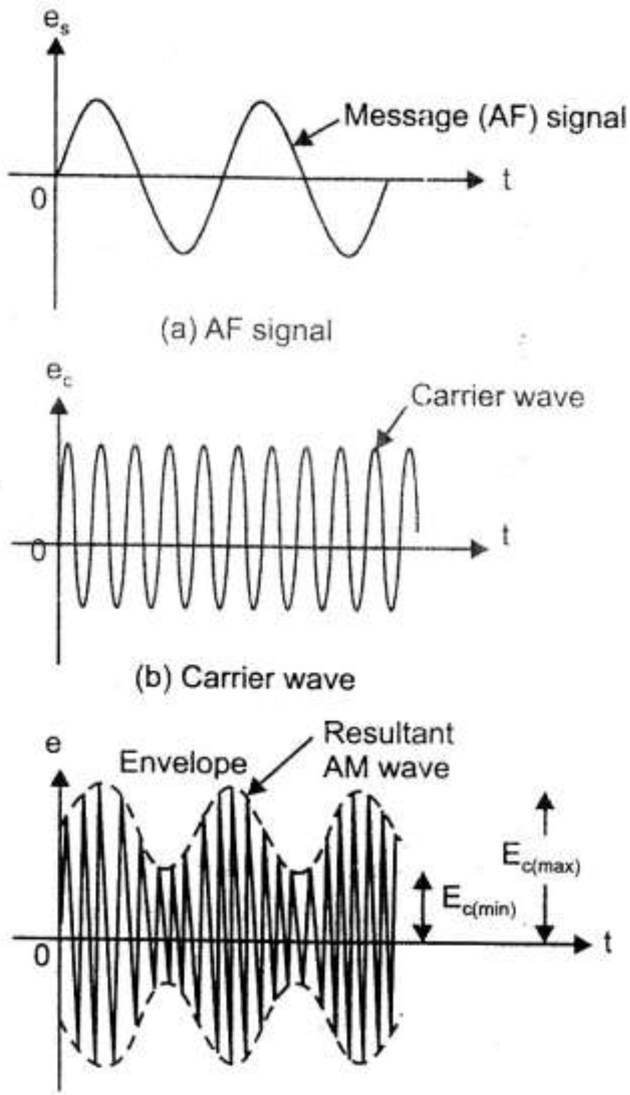
(*iii*) $\phi$ – The *phase*.

Accordingly, there are three types of sine-wave modulations known as :

1. Amplitude Modulation (AM)
2. Frequency Modulation (FM)
3. Phase Modulation (FM).

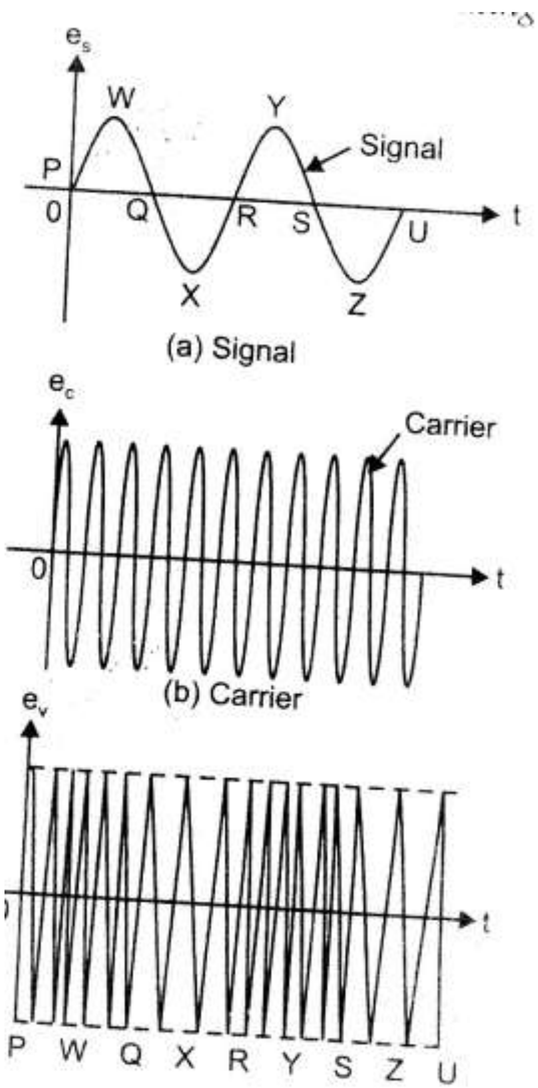
# 1) Amplitude Modulation(AM)

The process by which the amplitude of a carrier wave is varied in accordance with the modulating signal.



# 2) Frequency Modulation(FM)

The process by which frequency of a carrier wave is varied in accordance with the modulating signal.



# 3) Pulse Modulation

**Pulse modulation** is *a technique of modulating the analog signal and converting it into corresponding values. In this process the instantaneous voltage of the analog signal is sampled at regular intervals and transmitted during these sampling periods only.*

Fig.

— **In analog modulation**, the amplitude or freq...

- **Sampling theorem** : This theorem was developed by *Nyquist*.

  It states : *"If sampling rate is any pulse modulating system exceeds twice the maximum signal frequency, the original signal can be constructed at the receiver with minimum distortion."*

  — If $f_m$ is the maximum signal frequency then sampling rate is greater than $2f_m$.

  — The minimum samplings rate is called the *Nyquist rate*.

- Classification of Pulse Modulation

A. *Analog* :

(*i*) PAM

(*ii*) PTM → PDM, PWM
→ PPM

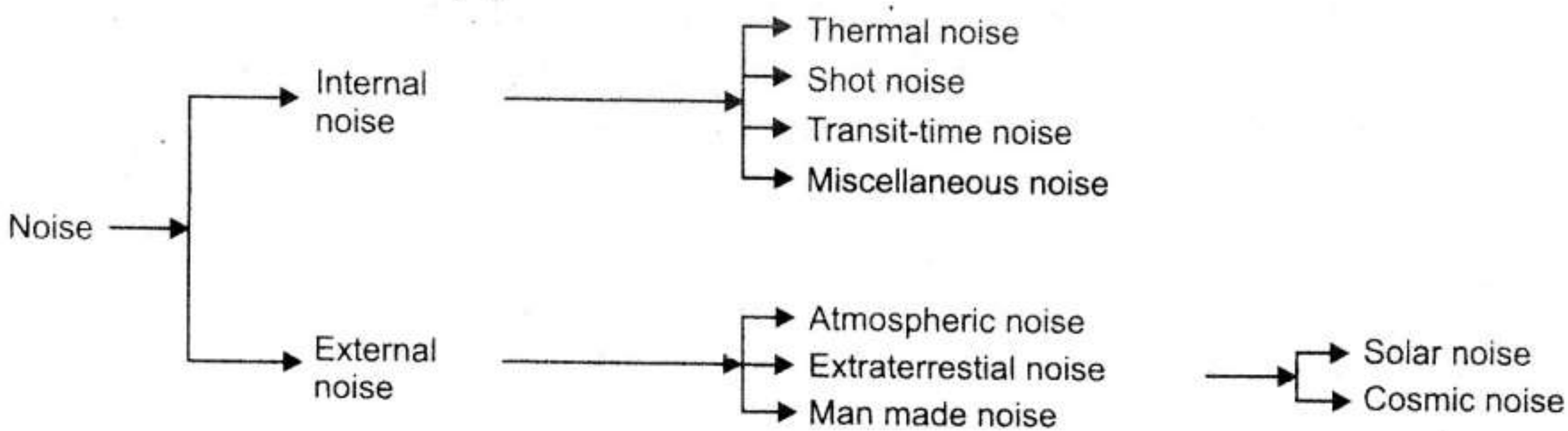
B. *Digital* :

(*i*) PCM, (*ii*) Delta-modulation.

# • Noise

- **Noise** may be defined, in an electrical sense, *as any extraneous form of energy tending to interfere with the proper and easy reception and reproduction of those signals which it is desirable to receive.*

- **Classification of noise :**



# • Modems

- Modem is an *acronym for MODulator DEModulator.*
- *A* **modem** *is a device that converts data from digital computer signals to analog signals that can be sent over a phone line.* This is called *"modulation"*. The *analog signals are then converted back into digital data by the receiving modem.* This is called *"demodulation"*.
- Fig. 19.13 shows a modem interfacing block diagram :

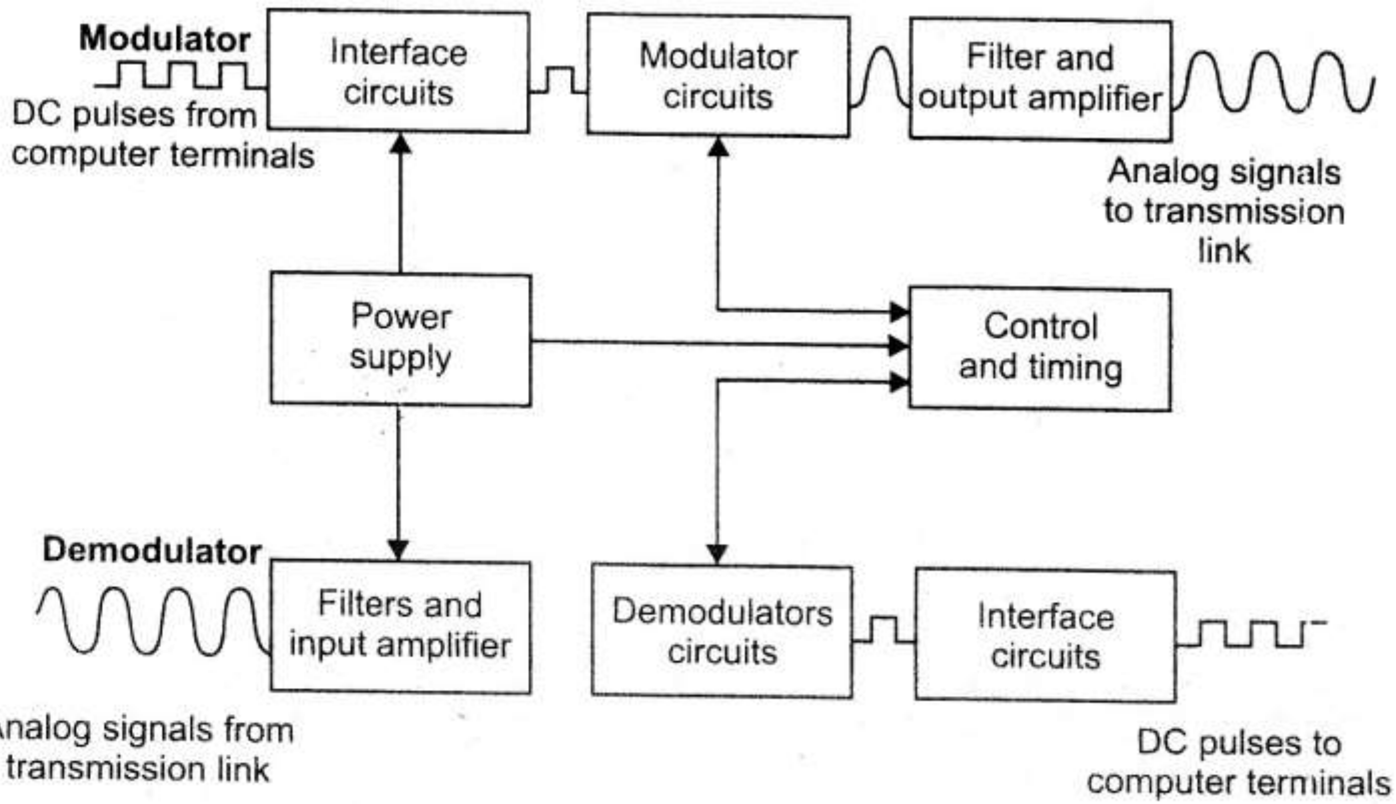
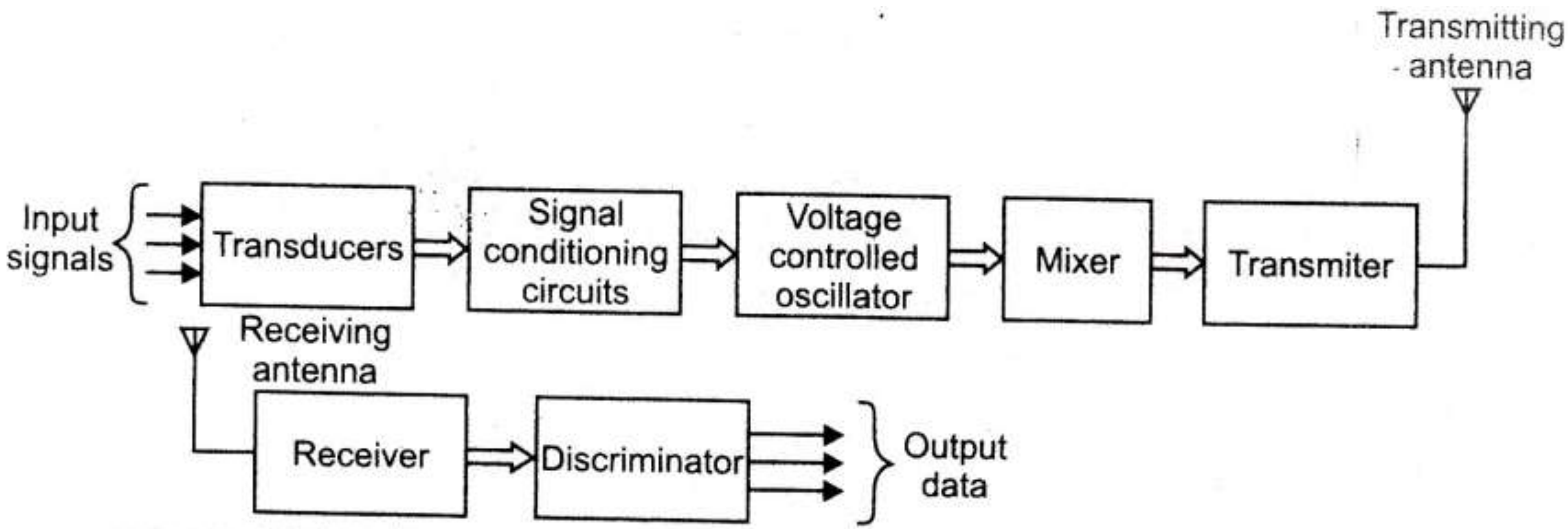
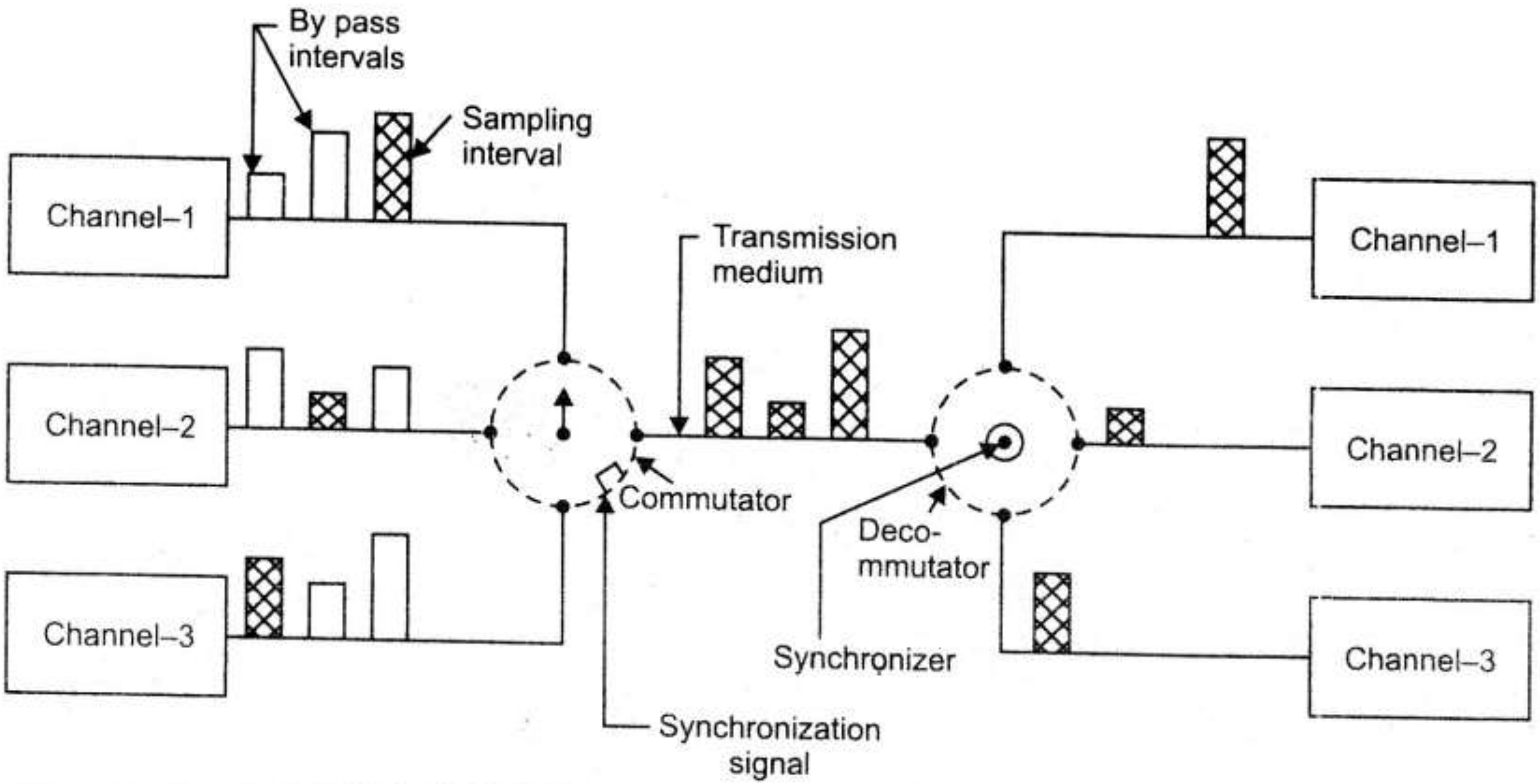



**Fig. 19.13.** Modem interfacing block diagram.

- Frequency Modulation (FM) Telemetry System



- Pulse Amplitude Modulation (PAM) Telemetry System



- Pulse Code Modulation (PCM) Telemetry System

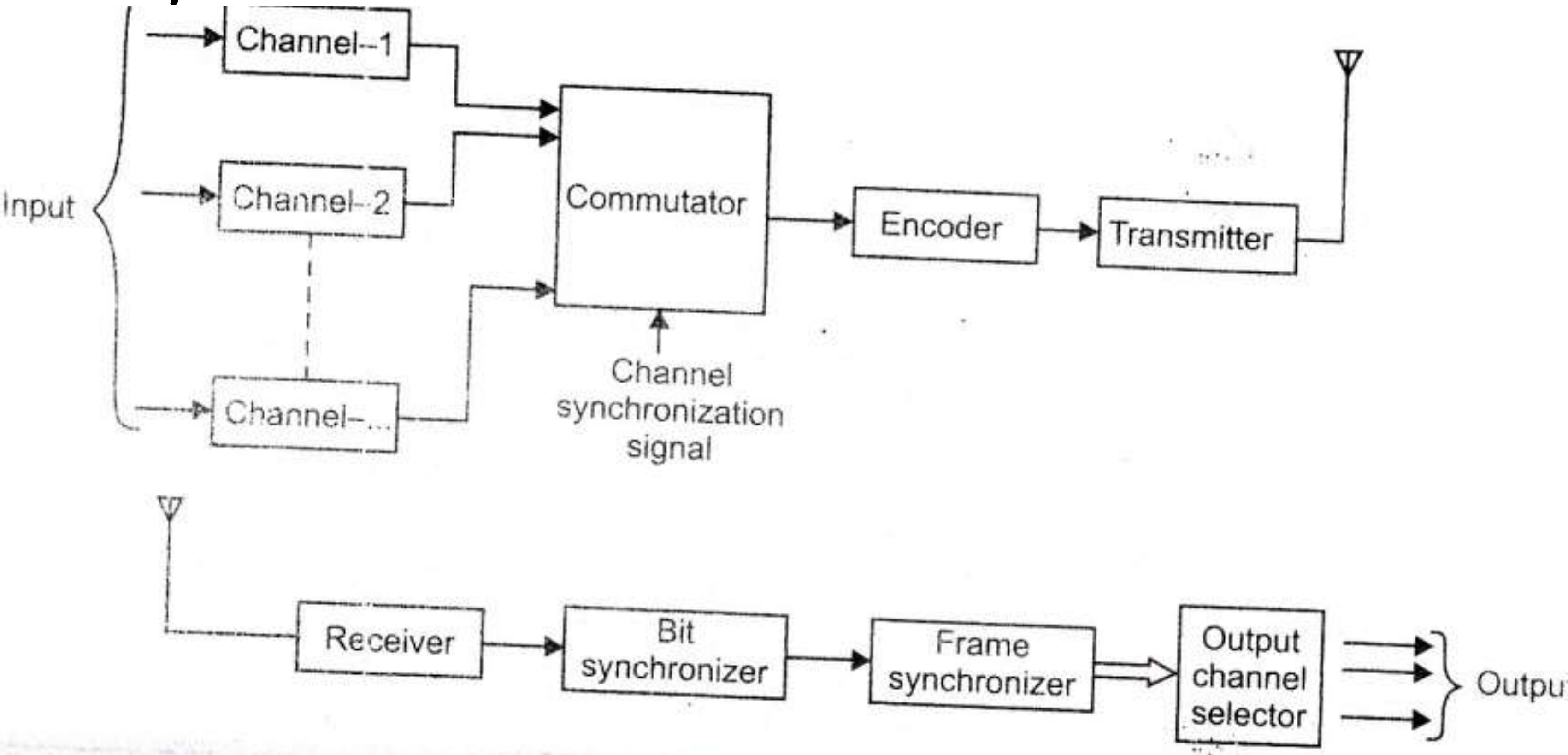



Fig. 19.16 PCM telemet

# Module 5

Measurement of Non-Electrical Quantities

# Pressure Measurement

- Definition: Force per unit area.

**Atmospheric pressure :**

*The atmospheric air exerts a normal pressure upon all surfaces with which it is in contact, and it is known as* **atmospheric pressure.** The atmospheric pressure is also known as *Barometric pressure.*

The atmospheric pressure at sea level (above absolute zero) is called *standard atmospheric pressure.*

*Note:* The local atmospheric pressure may be a little lower than these values, if the place under question is higher than sea level, and higher values if the place is lower than sea level, due to the corresponding decrease of the column of air standing, respectively.

**Gauge pressure :**

*It is the pressure, measured with the help of pressure measuring instrument, in which atmospheric pressure is taken as datum.*

The *atmospheric pressure* on the scale is marked as *zero.*

***Gauges*** record the pressure above or below the local atmospheric pressure, since they measure the difference in pressure of the liquid to which they are connected and that of surrounding air.

If the pressure of the liquid is below the local atmospheric pressure, then the gauge is designated as *'vacuum gauge'* and the recorded value indicates the amount by which the pressure of the liquid is *below* local atmospheric pressure, *i.e., negative pressure.*

(*Vacuum pressure* is defined as the pressure *below the atmospheric pressure*).

**Absolute pressure :**

It is necessary to establish an absolute pressure scale which is independent of the changes in atmospheric pressure. *A pressure of absolute zero can exist only in complete vacuum.*

*Any pressure measured above the absolute zero of pressure is termed as an* **'absolute pressure'.**

A schematic diagram showing the gauge pressure, vacuum pressure and the absolute

- Units for pressure and pressure measuring instruments

The fundamental S.I. units of pressure is pressure is newton per square meter ($N/m^2$). This is also known as *Pascal* ($P_a$).

*"Low pressures"* are often expressed in terms of *mm of water* or *mm of mercury*. This is an abbreviated way of saying that the pressure is such that will support a liquid column of stated height.

- *Standard atmospheric pressure has the following equivalent values :*

  101.3 $kN/m^2$ or 101.3 kPa; 10.3 m of water; 760 mm of mercury; 1013 mb (millibar); $\simeq$ 1 bar = 100 kPa = $10^5$ $N/m^2$.

- Pressure measuring instruments

The pressure measurement instruments can be *categorized* as follows :

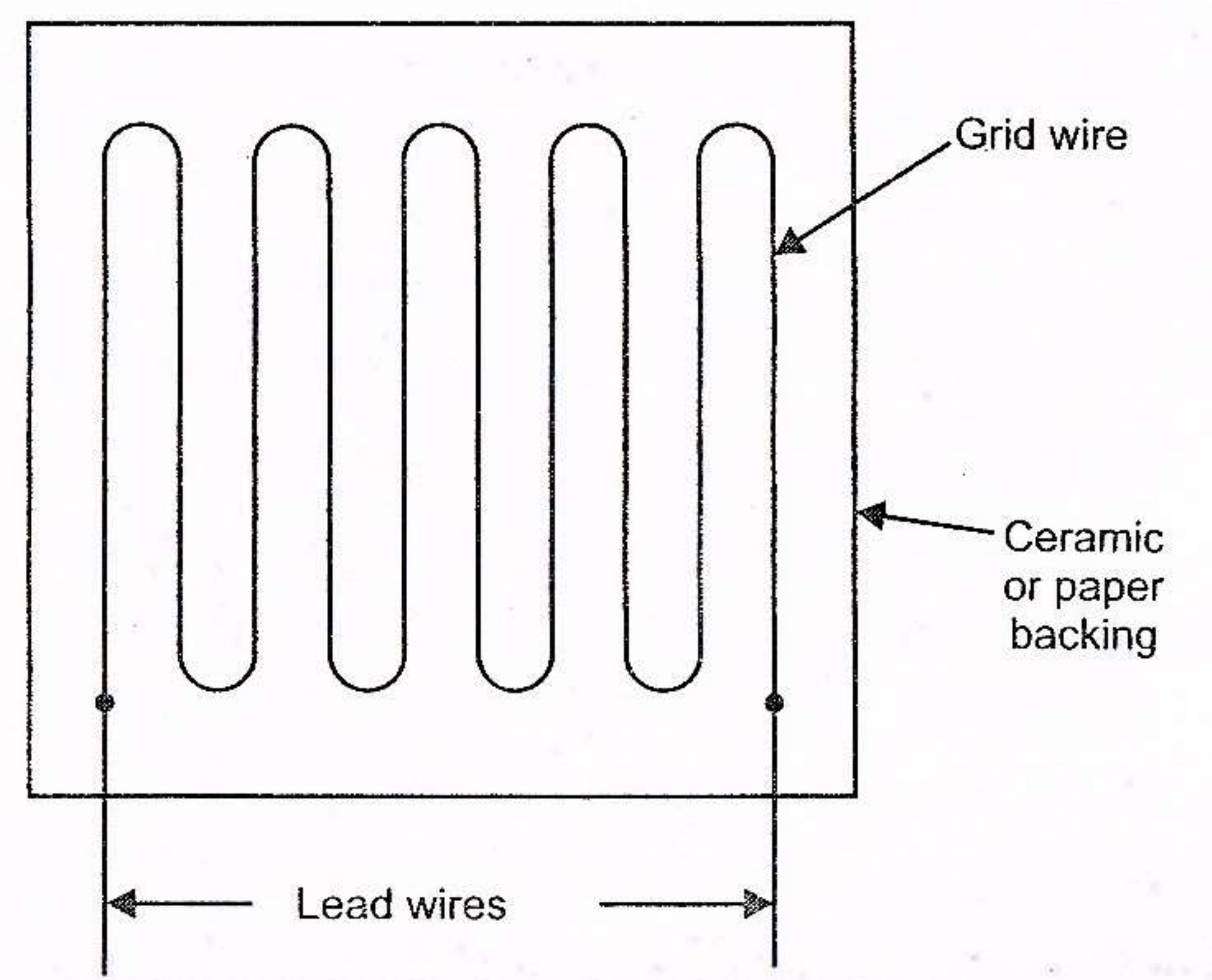
1. *Instruments for measuring low pressures (below 1 mm of Hg) :*
   - Manometers.
   - Low pressure gauges.
2. *Instrument for medium and high pressures (between 1 mm of Hg to 1000 atmospheres) :*
   - Bourdon tube.
   - Diaphragm gauges.
   - Bellow pressure gauge.
   - Dead-weight pressure gauge.
3. *Instrument for measuring low vacuum and ultra high vacuum (760 torr to $10^{-9}$ torr and beyond; 1 torr = 1 mm of Hg) :*
   - Mcleod.
   - Thermal conductivity.
   - Ionization gauges.
4. *Instruments for measuring very high pressures (1000 atmospheres and above) :*
   - Bourdon tube.
   - Diaphragm gauges.
   - Electrical resistance pressure gauges.
5. *Instruments for measuring varying pressure :*
   - Engine indicator.
   - Cathode ray oscilloscope (CRO).

- Electrical pressure transducer

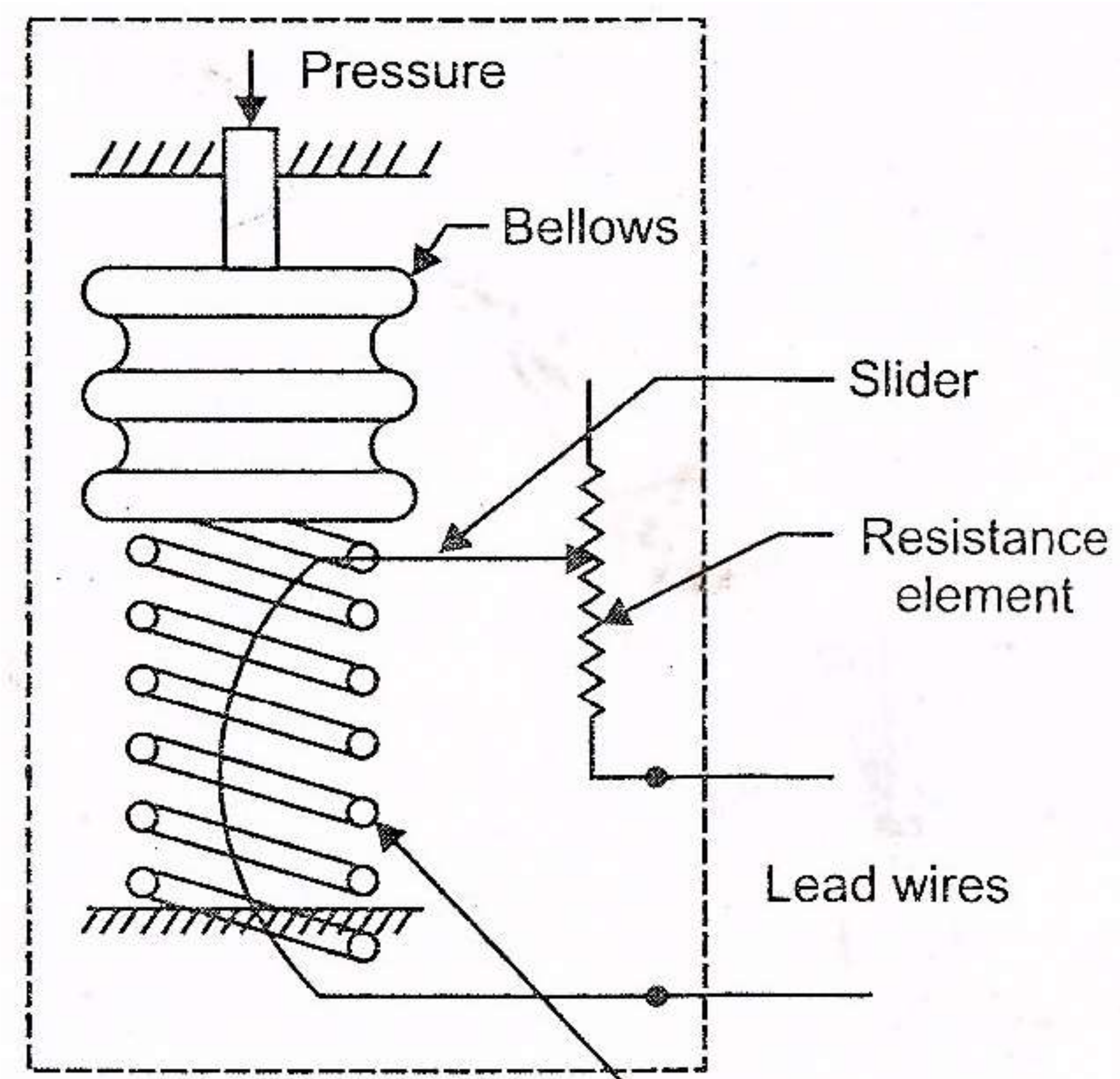
1. Resistance type pressure transducers.
2. Pressure voltage type.
3. Inductive type.
4. Capacitive type.
5. Carbon pile type.
6. Piezoelectric type.
7. Photoelectric type.
8. Electromagnetic type.

# 1) Resistance type pressure transducers

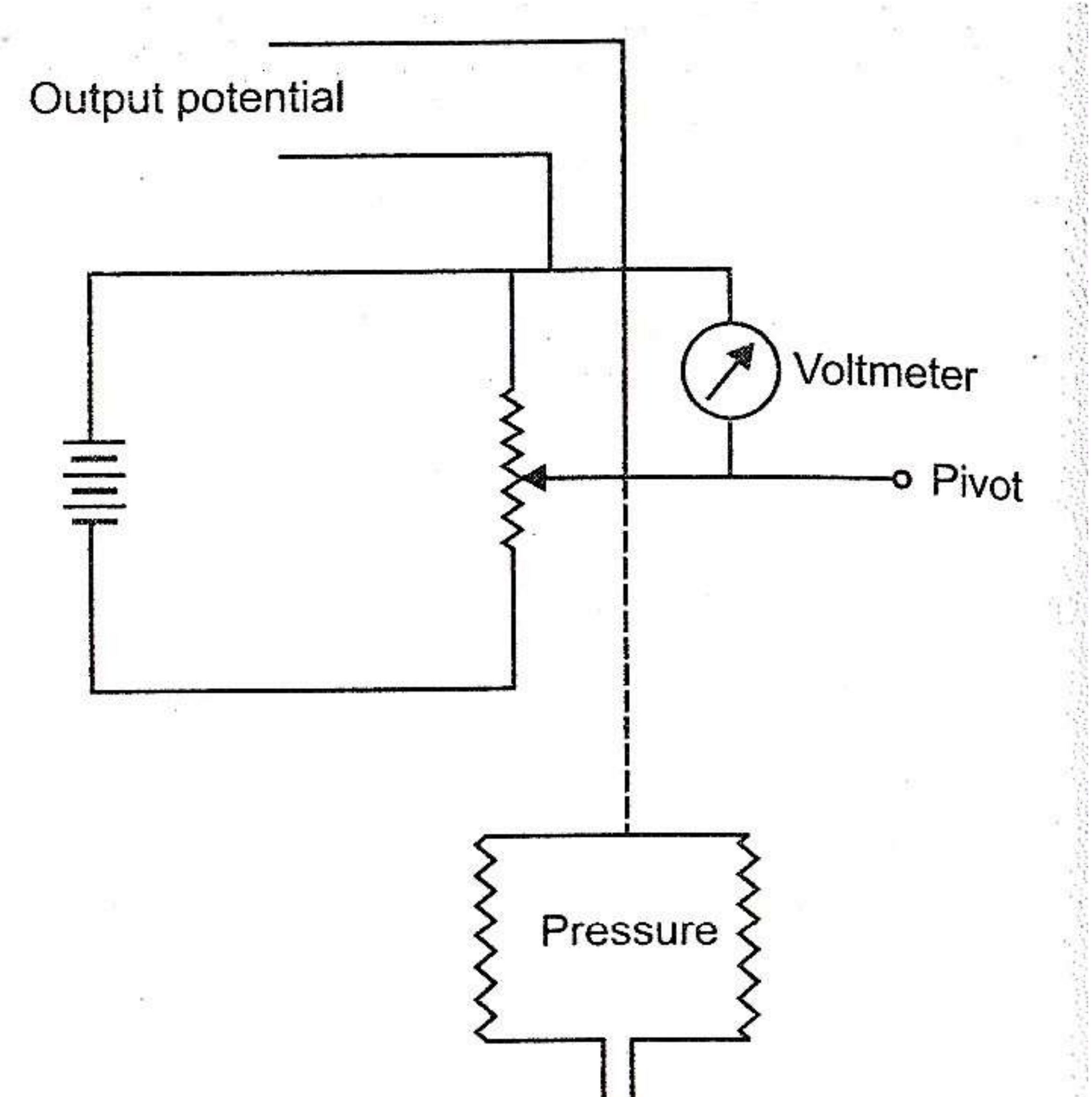
## i) Strain gauges



# ii) Moving contacts

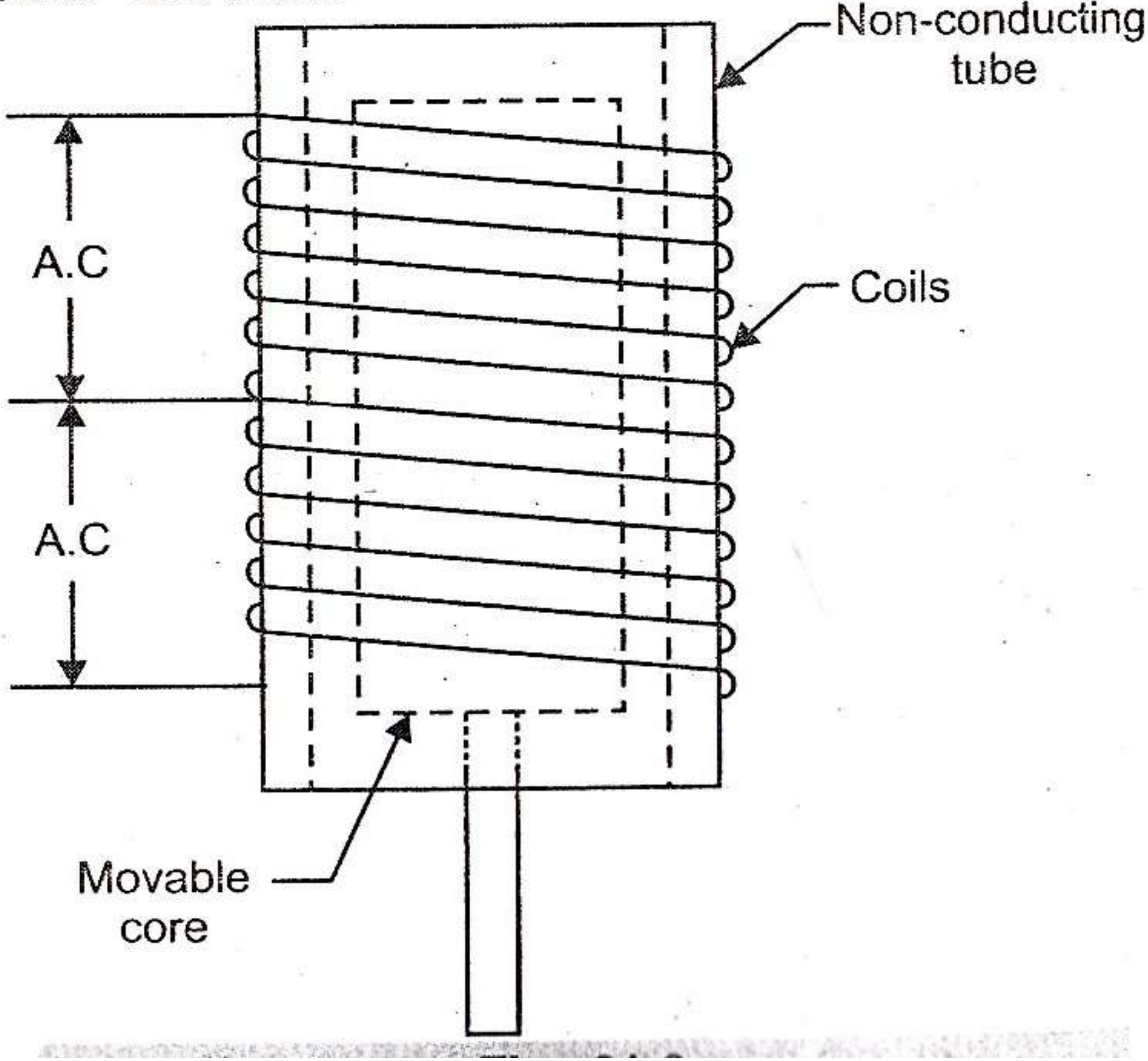


# 2) Pressure voltage transducer

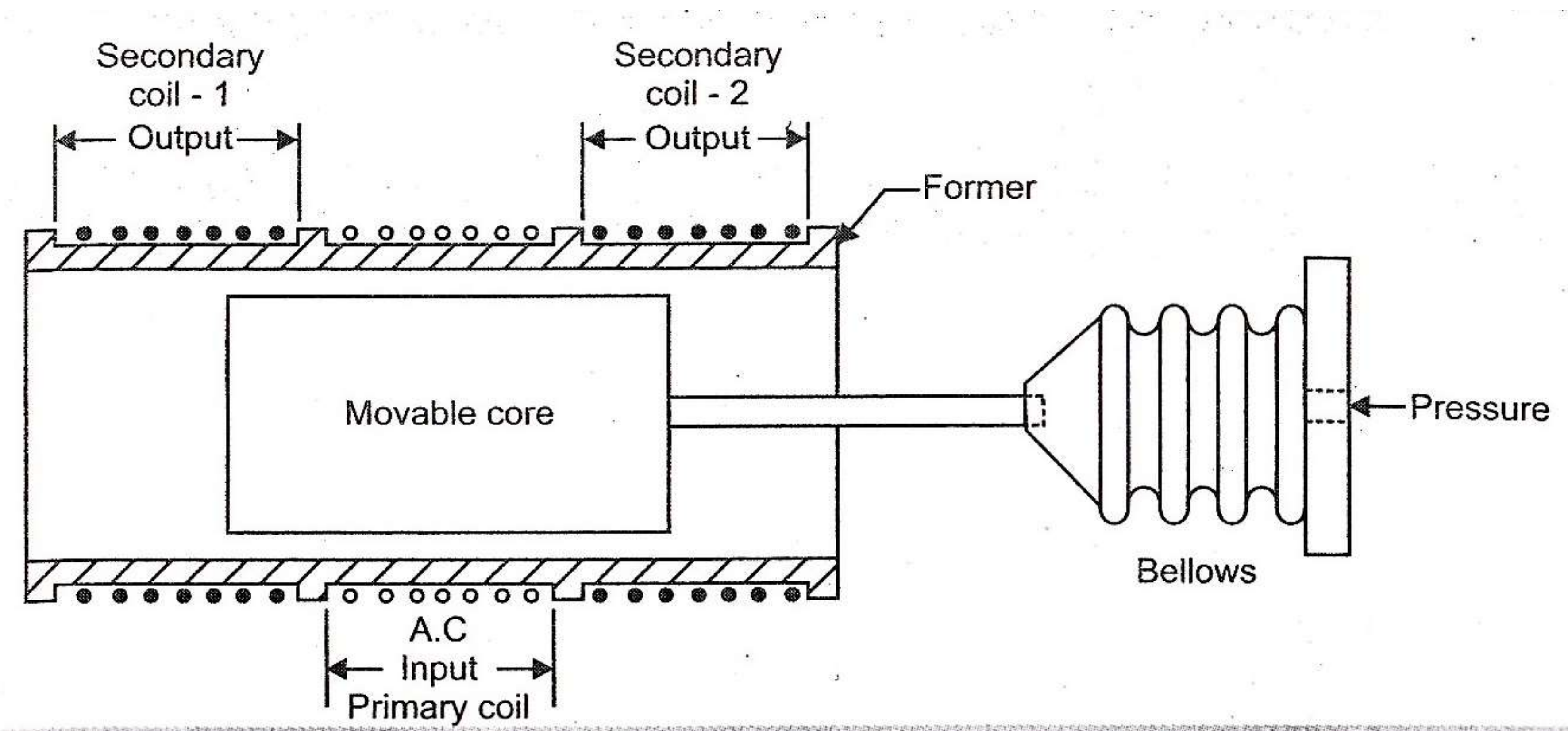


# 3) Inductance type pressure transducer

## Current sensitive coil type

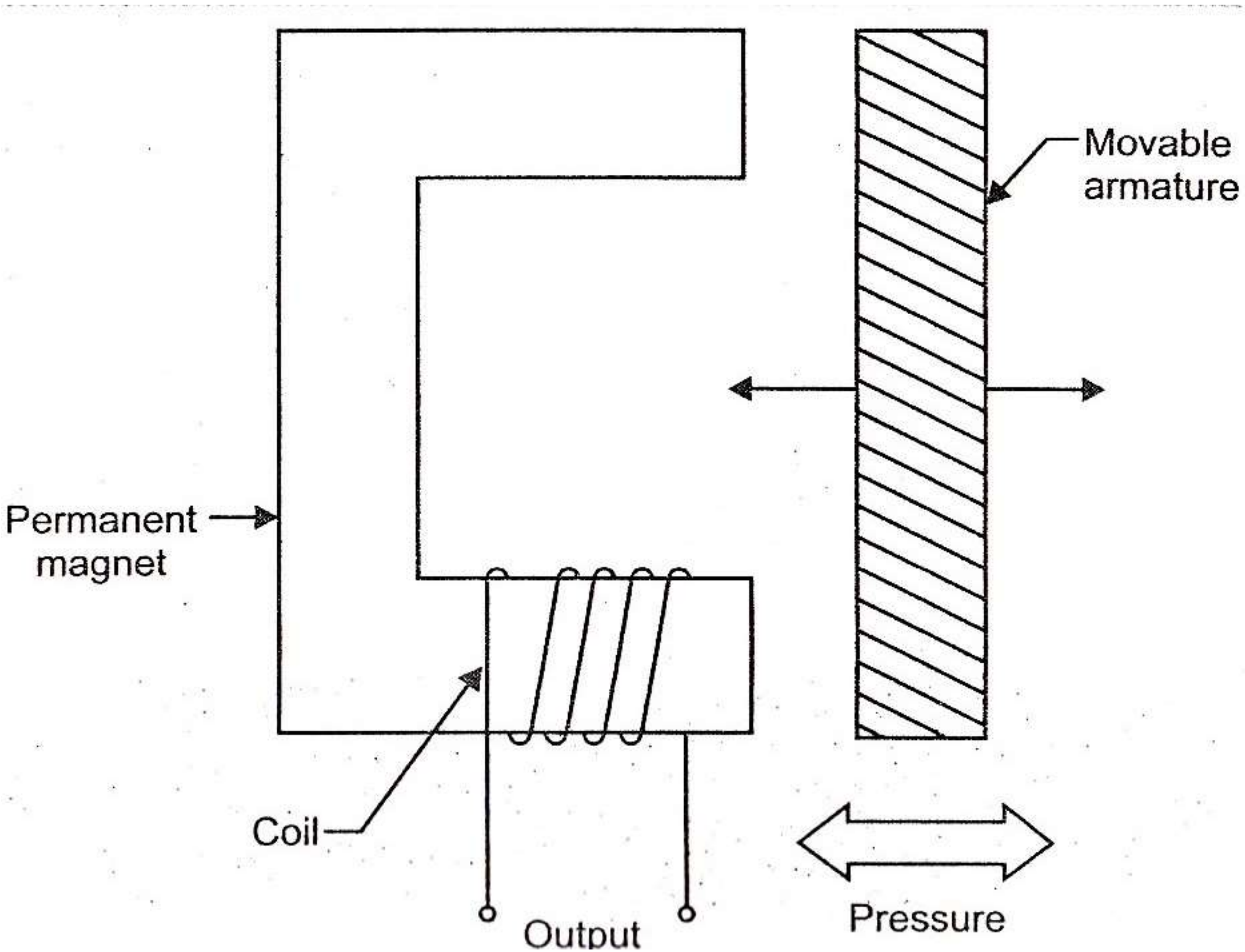


# LVDT type

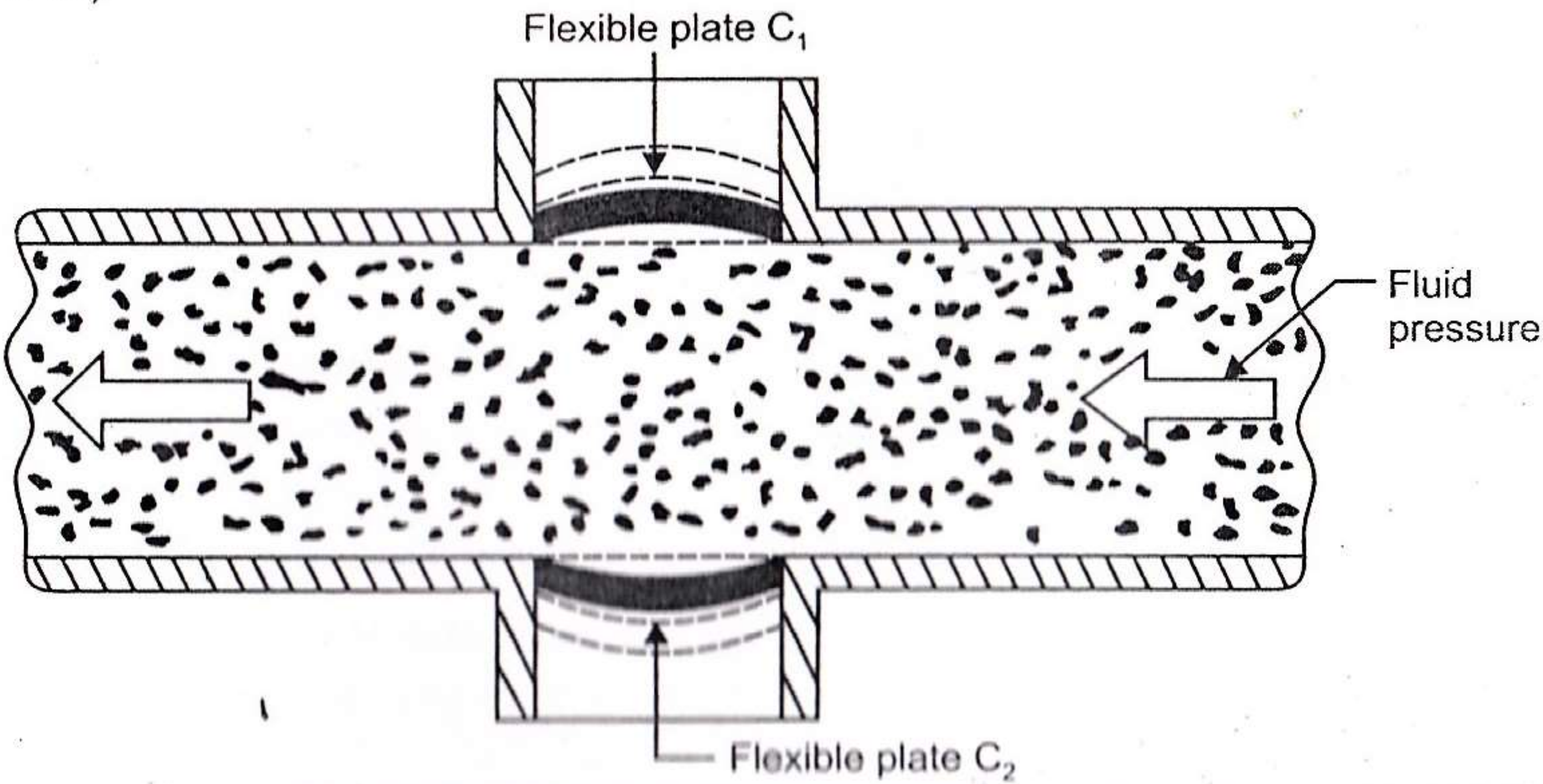


Secondary
coil - 1
Output
Secondary
coil - 2
Output
Former
Movable core
Pressure
Bellows
A.C
Input
Primary coil

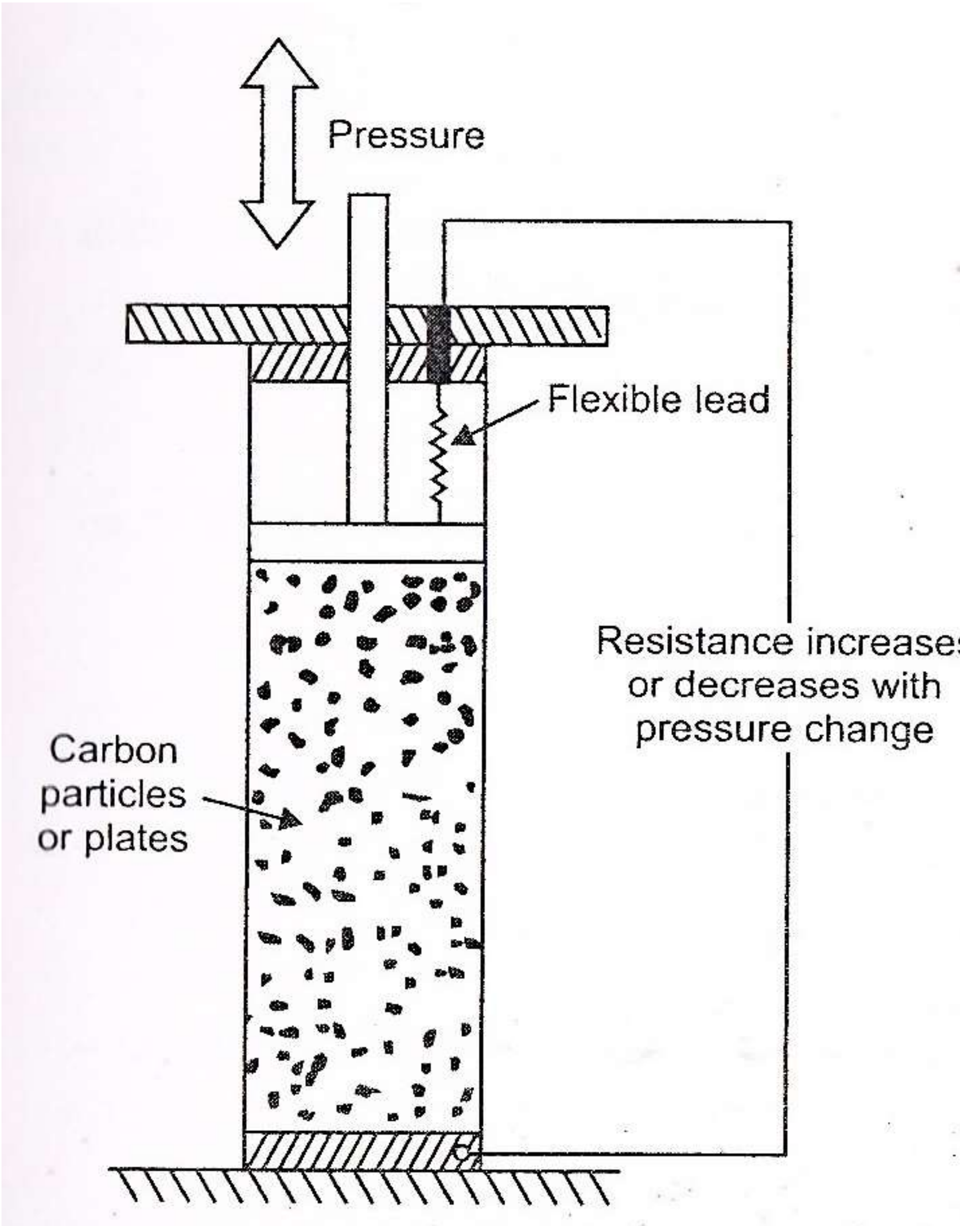
# Reluctance type



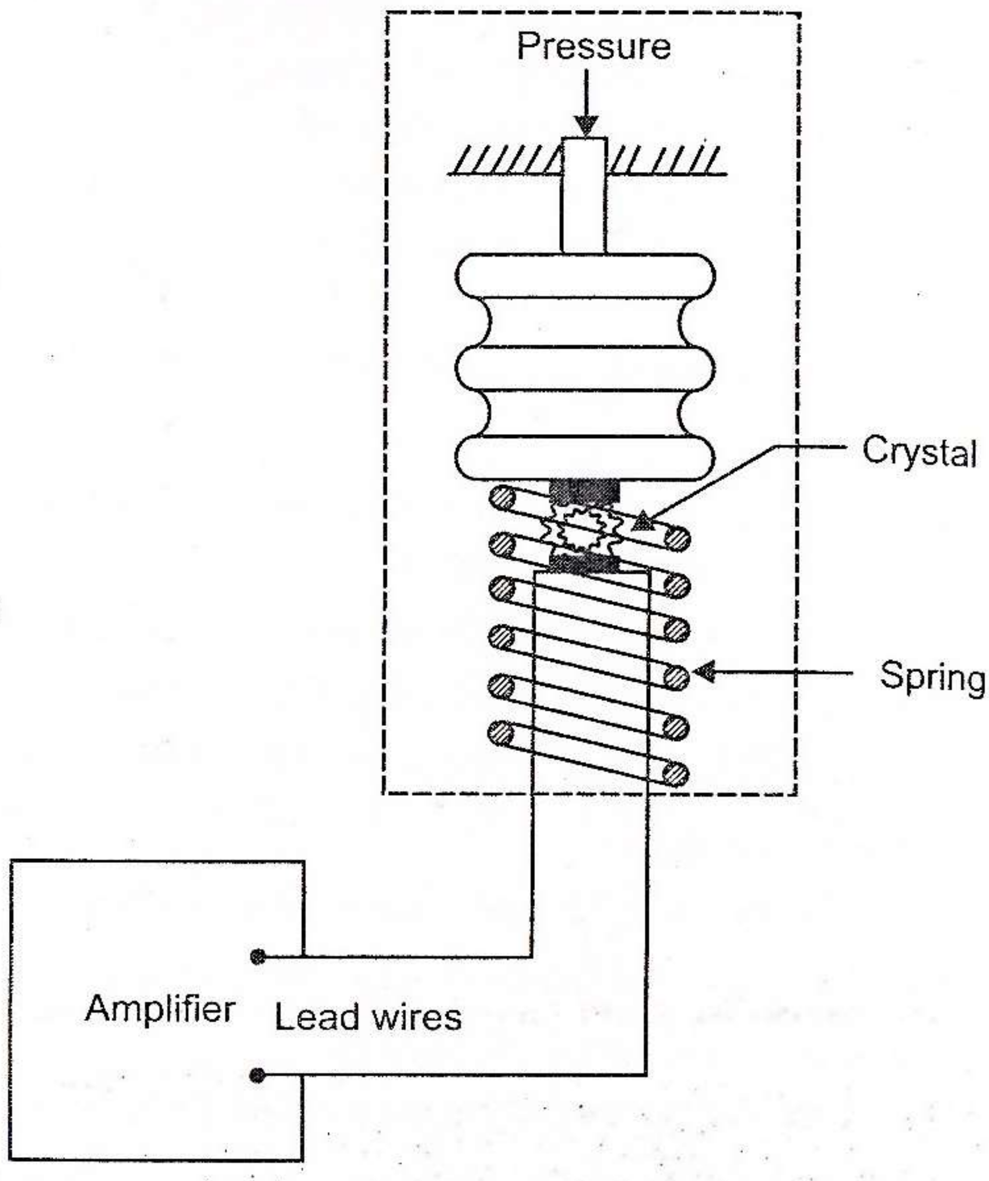
# 4) Capacitive type pressure transducer



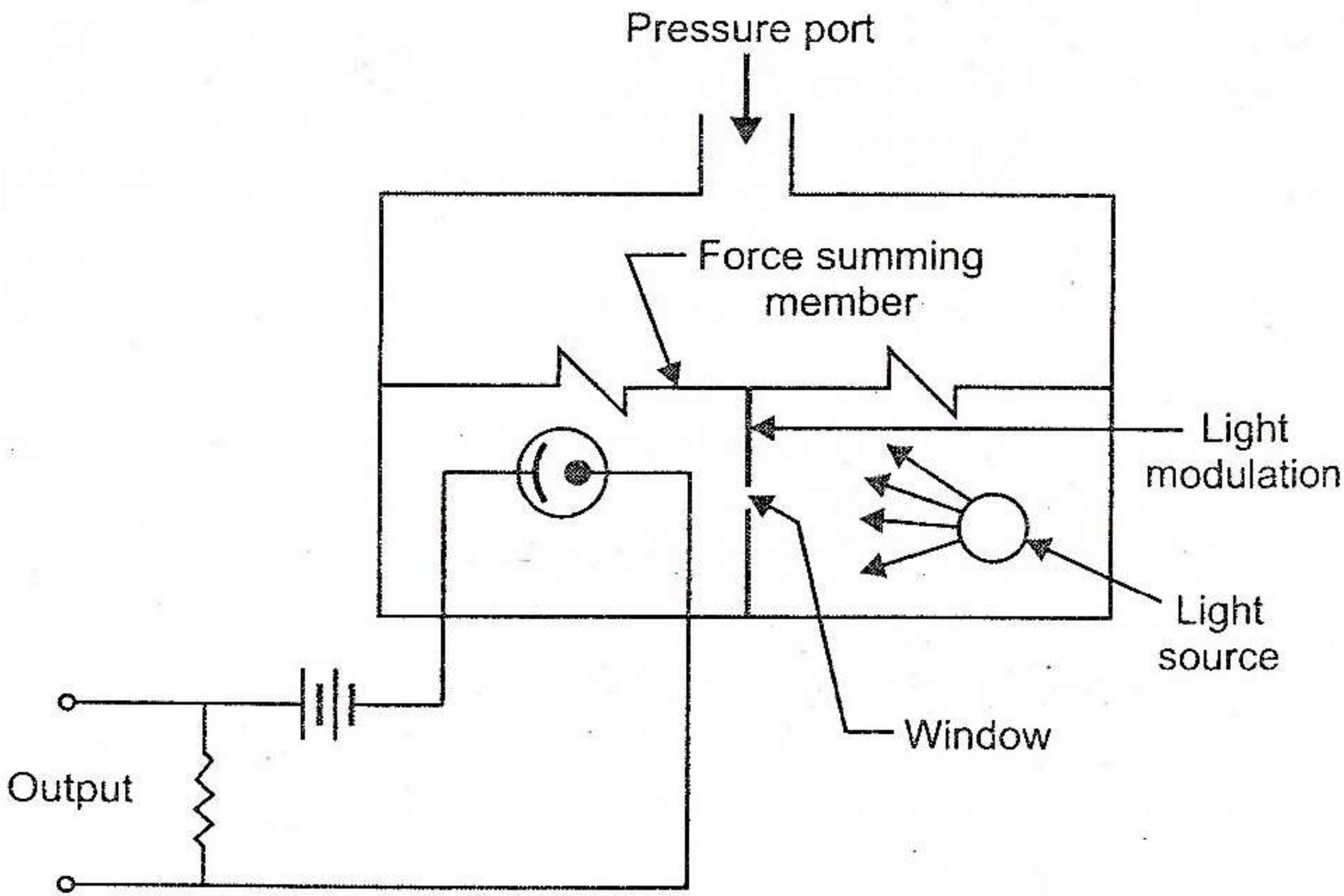
# 5) Carbon pile pressure transducer



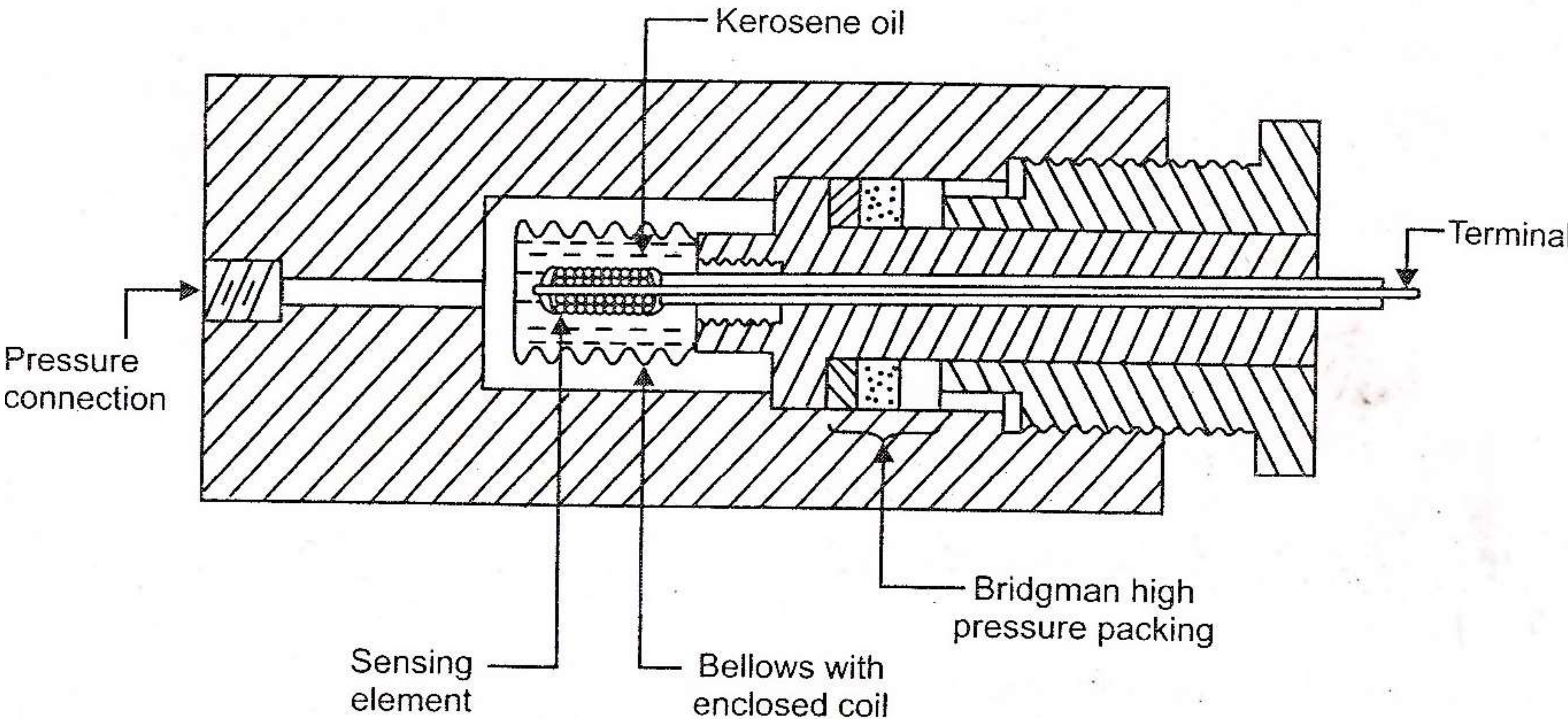
# 6) Piezoelectric pressure transducers



# 7) Photoelectric pressure transducers



# Measurement of high pressure
# Bridgman gauge



# Measurement of low pressure

In general, pressures below atmospheric may be called **low pressures** or **vacuums.**

It is impossible to reach an absolute pressure of zero, since a *positive* magnitude of absolute pressure exists at all times, even in a vacuum.

The *micrometer, which is one-millionth of a meter (0.001 mm) of mercury column, is a common unit of "low pressure".*

***Very low pressure*** ...... any pressure *below* 1 mm of mercury (or torr).

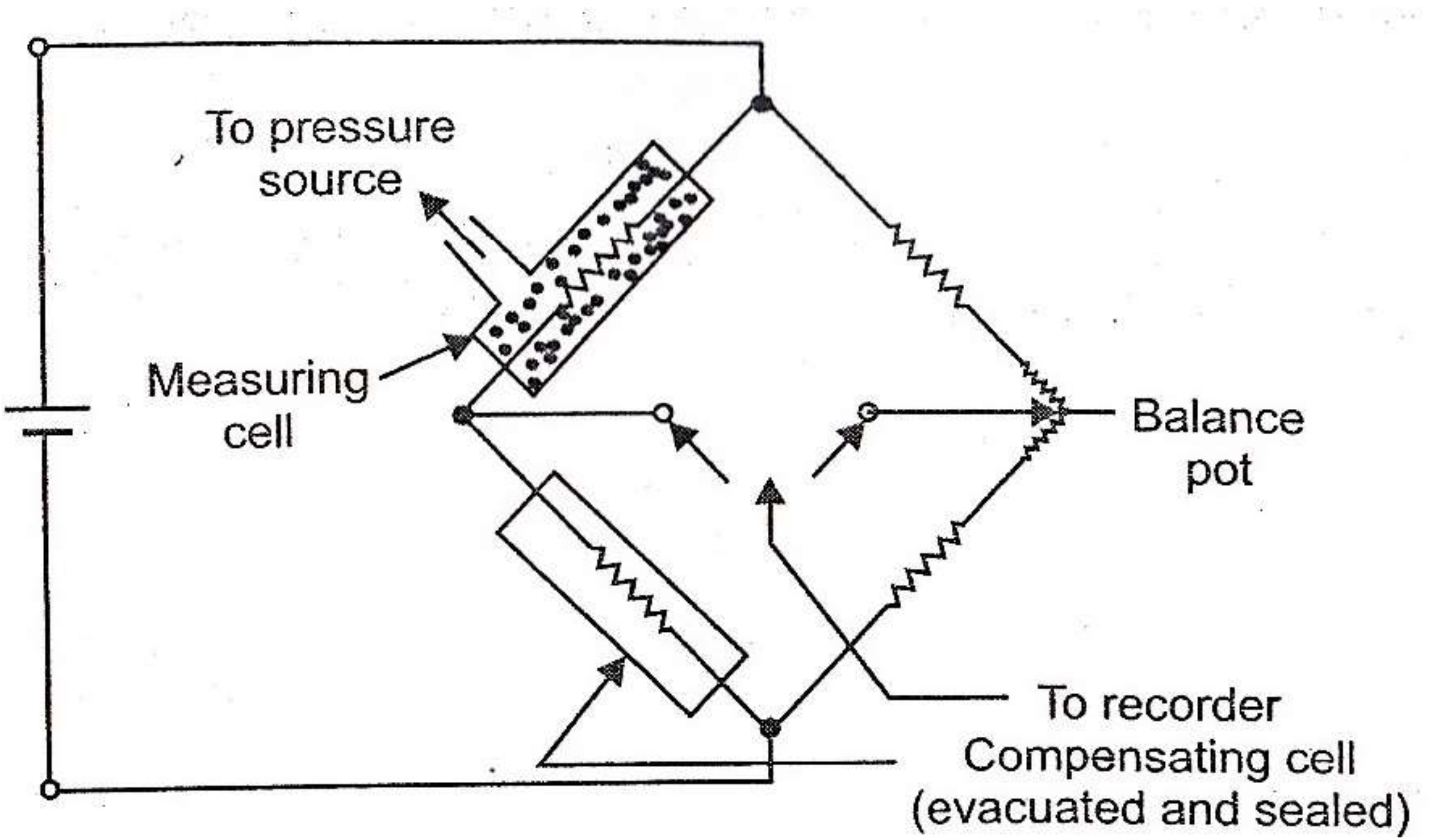
***Ultra low pressure*** ...... *less than* a nanometer ($10^{-3}$ μm).

The two basic methods of measurement of low pressure are :

1. **Direct methods.** Here, the displacement deflection caused by the pressure is measured and is correlated to the pressure. The following devices are included in this *category* :
   - *Spiral Bourdon tubes.*
   - *Flat and corrugated diaphragms.*
   - *Capsules.*
   - *Manometers.*
2. **Indirect or inferential methods.** In these methods, pressure is determined through the measurement of certain other pressure-controlled properties, including volume and thermal conductivity.

   Devices included in this category are :
   - *Mcleod gauge.*
   - *Thermal conductivity gauges.*
   - *Ionization gauges.*
   - *Radioactive vacuum meters.*

# 1) Pirani vacuum gauge



# 2) Ionization gauges