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Diploma in Electrical and Electronics Engineering

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M – Scheme

e-TEXTBOOK
on
Transducers and Signal Conditioners

for
IV Semester DEEE

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TEXT BOOK

S.No	Title	Author	Publishers
1.	Transducers and Instrumentation	DVS Murty	PHI 2009

REFERENCE BOOK

S.No	Title	Author	Publishers
1.	Sensor and Transducers	D. Patranabis	PHI 2011
2.	A Course in Electrical and Electronics Measurements and Instrumentation.	1.A.K. Sawhney 2.Puneet Sawhney	Dhanpat Rai & Co (P) Ltd., New Delhi 1993
3.	Measurement and Instrumentation	Arun. K	PHI 2010
4.	Operational Amplifiers and Linear Integrated Circuits	1.Robert F. Coughlin 2.Frederick F. Driscoll	PHI 1992
5.	Op. amp & Linear Integrated Circuits	Ramakant. A. Gayakwad	PHI 1992

UNIT I

Classification and Sensing Elements

1.1 Transducers

Introduction

- Instrumentation is a kind of control system adopted in industries by which physical quantity involved in the industrial process are measured and controlled to achieve the maximum production.
- An instrumentation system generally consists of three major elements, namely, the input device, a signal conditioning or processing device, and an output device.
- The input device receives the quantity under measurement and delivers a proportional electrical signal to the signal conditioning device.
- In signal conditioning device the signal is amplified, filtered or otherwise modified to a form, acceptable to the output device.
- The output device may be a simple indicating meter, an oscilloscope or a chart recorder for visual display.

Transducer -Definition

A transducer is a device which converts energy from one form to another form. This energy may be electrical, mechanical, chemical, optical or thermal. The transducer that gives electrical energy as output is known as electrical transducer. The output of electrical signal may be voltage, current or frequency. The production of these signals is based upon resistive, capacitive, inductive effects etc.

Transducer is a ddevice, which converts a physical quantity into the proportional electrical quantity is called a transducer.The transducer is the device used in the input stage of an instrumentation system to sense the physical quantity to be measured or controlled is called as transducer.

Need for Transducers

The quantities involved in most of the instrumentation systems such as pressure, temperature, flow, movement are non-electrical nature. These non-electrical quantities cannot be easily measured and controlled. Hence they are to be converted into an electrical signal because an electrical signal can easily be amplified, attenuated, filtered, detected, analysed, modulated, transmitted, recorded and so on.

Two Parts of Transducer

Sensor: Sensor is a device that produces a measurable response to a change in physical condition or physical quantity.

Transduction: It transforms the output of the sensor to an electrical output.The energy conversion that takes place is called as transduction.

1.2 Classification based on principle of operation

Types of Transducer

The transducers can be classified into the following types.

- Resistive, inductive and capacitive transducers.
- Primary and secondary transducers.
- Active and passive transducers.
- Analog and digital transducers.
- Input and output transducers.
- Direct and inverse transducers.

Table 1 give an idea of various types of transducers available for different applications.

	Transducer	**Transduction(conversion)**
1	Thermocouple	Temperature to voltage
2	Piezo-electric crystal	Pressure to voltage
3	Tachometer	Angular velocity to voltage
4	Thermister	Temperature to resistance
5	Photo-cell	Light to current
6	Strain gauge	Displacement to resistance
7	Potentiometer	Displacement to resistance
8	Moving plate capacitor	Displacement to capacitance
9	Moving core inductor	Displacement to inductance
10	LVDT	Displacement to reluctance

11	Photo conductor	Light to resistance
12	Half effect device	Magnetism to voltage
13	Resistance hygrometer	Humidity to resistance

Classification of Electrical Transducers

According to the principle of operation, the transducers can be classified as resistive, inductive, capacitive etc.., depending upon how they convert the input quantity of resistance, inductance or capacitance respectively. They can be further classified as piezoelectric,thermoelectric, optical, magnetorestrictive etc...Further it can be classified as

- active and passive transducers
- On the basis of transduction principle used
- analog and digital transducers
- primary and Secondary transducers
- transducer and inverse transducer

Active Transducer:

- Self generating transducers.
- It develops an electrical parameter which is proportional to the physical quantity under measurement.
- It does not require any external source or power for their operation.

Examples:

Tachogenerators , Thermocouples, Piezoelectric etc..,

Passive Transducer

- Passive Transducers are known as externally powered transducers.
- these transducers derive the power required from an external power source for the conversion process.
- they may also absorb some energy from the physical phenomenon which is being measured.

Examples:

Strain gauges, Thermistors etc..,

Basis of Transduction

- Capacitive
- Electromagnetic
- Inductive
- Piezoelectric
- Photovoltaic
- Photoconductive

Analog and digital Transducer

- Analog : These transducer convert the input quantity into an analog output.[Example : Strain gauge , LVDT thermistor and Thermocouple]
- Digital : These transducers produces an electrical output.

  [Example : Optical encoder]

Primary or Secondary

- Some transducers consist of mechanical device along with the electrical device
- Mechanical device acts as a primary and converts physical quantity into mechanical signal.
- The electrical device then converts mechanical signal produced by primary transducer into an electrical signal. It acts as a secondary transducer.

Example:

Pressure Measurement

Bourdon's Tube: Primary

LVDT: Secondary

Transducer and Inverse Transducer

- Transducer converts non-electrical quantity into electrical quantity

[Example : Microphone Converts sound signal into an electrical signal]

- Inverse Transducer converts electrical quantity into non-electrical quantity

[Example : Loudspeaker converts electrical signal into sound signal]

Advantages of Electrical Transducer

- Electrical signals can be easily attenuated or amplified
- The power requirement of transducer is very less
- The output of the transducer can be easily used, transmitted and processed for the purpose of measurement
- The reduced effect of friction and other mechanical nonlinearities
- Less weight and portable
- Less Expensive

1.3 Primary Sensing Elements:

1.3.1 Bourdon tube Pressure Gauge:

- The concept behind the working of bourdon tube is that, a cross sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure. Bourdon tube is a primary transducer which converts change in pressure into change in linear or angular displacement.

- The bourdon pressure gauges used today have a slight elliptical cross section and the tube is generally bent into a C shape or arc length of about 270 degrees. The detailed diagram of the bourdon tube is shown in Fig1. below:
- The pressure input is given to a socket which is soldered to the tube at the base. The other end or free end of the device is sealed by a tip.
- This tip is connected to a segmental lever through an adjustable length link. The lever length may also be adjustable.
- The segmental lever is suitably pivoted and the spindle holds the pointer as shown in the figure.
- A hair spring is sometimes used to fasten the spindle of the frame of the instrument to provide necessary control torque for proper meshing of the gear teeth
- The mechanical construction has to be highly accurate in the case of a Bourdon Tube Gauge.

Fig.1.1

Working

As the fluid pressure enters the bourdon tube, it tries to be reformed (change shape) and because of a free tip available, this action causes the tip to travel in free space and the tube unwinds.

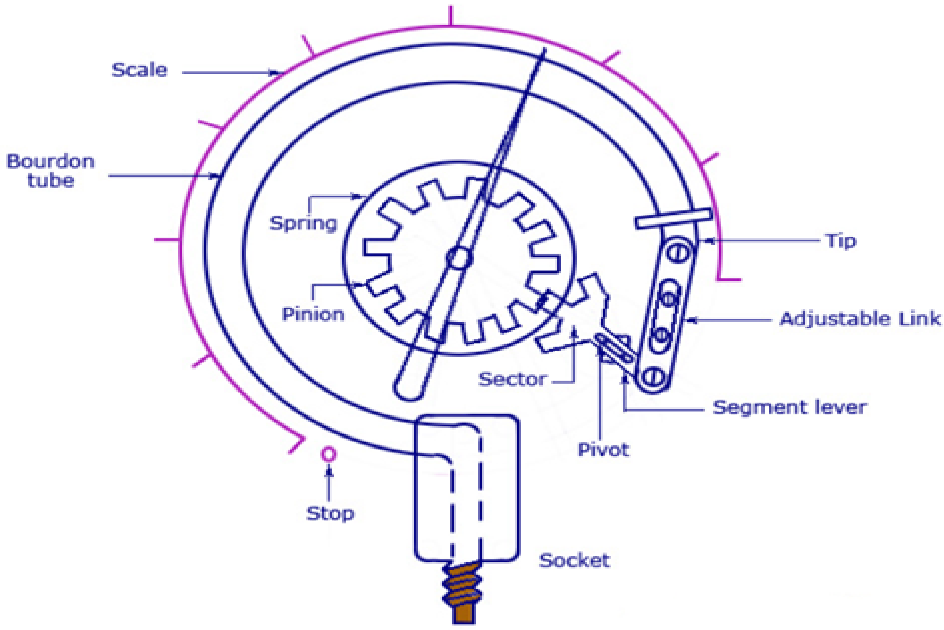


Fig 1.1 Bourden Tube

- The simultaneous actions of bending and tension due to the internal pressure make a nonlinear movement of the free tip. This travel is suitable guided and amplified for the measurement of the internal pressure.
- But the main requirement of the device is that whenever the same pressure is applied, the movement of the tip should be the same and on withdrawal of the pressure the tip should return to the initial point.
- A lot of compound stresses originate in the tube as soon as the pressure is applied. This makes the travel of the tip to be nonlinear in nature.
- If the tip travel is considerably small, the stresses can be considered to produce a linear motion that is parallel to the axis of the link. The small linear tip movement is matched with a rotational pointer movement.
- This is known as multiplication, which can be adjusted by adjusting the length of the lever. For the same amount of tip travel, a shorter lever gives larger rotation.

- The approximately linear motion of the tip when converted to a circular motion with the link lever and pinion attachment, a one-to-one Correspondence between them may not occur and distortion results. This is known as angularity which can be minimized by adjusting the length of the link.
- Other than C type, bourdon gauges can also be constructed in the form of a helix or a spiral. The types are varied for specific uses and space accommodations, for better linearity and larger sensitivity.
- For thorough repeatability, the bourdon tubes materials must have good elastic or spring characteristics.
- The surrounding in which the process is carried out is also important as corrosive atmosphere or fluid would require a material which is corrosion proof.
- The commonly used materials are phosphor bronze, silicon bronze, beryllium copper, and other C-Cr-Ni-Mo alloys, and so on.
- In the case of forming processes, empirical relations are known to choose the tube size, shape and thickness and the radius of the C tube.
- Because of the internal pressure, the near elliptic or rather the flattened section of the tube tries to expand as shown by the dotted line in the figure below (a).

The same expansion lengthwise is shown in figure (b). The arrangement of the tube, however forces an expansion on the outer surface and a compression on the inner surface, thus allowing the tube to unwind. This is shown in figure (c).

Expansion of Bourdon Tube Due to Internal Pressure

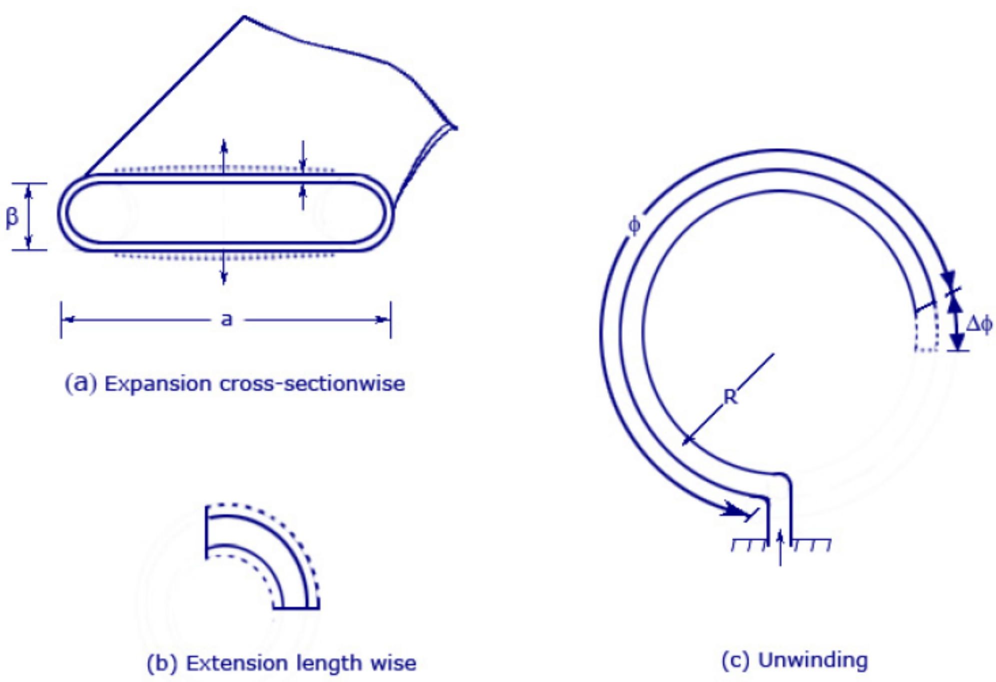


Fig 1.2 Expansion of Bourdon tube due to internal pressure

Bellows

It is also a transducer used for pressure measurement

The bellows element, basically, is a one piece expandable, collapsible and axially flexible member. It has many convolutions or fold. The basic way of manufacturing bellows is by fastening together many individual diaphragms. It can be manufactured form a single piece of thin metal. For industrial purposes, the commonly used bellow elements are:

- By turning from a solid stock of metal
- By soldering or welding stamped annular rings
- Rolling a tube
- By hydraulically forming a drawn tubing

Working

- The action of bending and tension operates the elastic members. For proper working, the tension should be the least.
- The manufacturer describes the bellows with two characters – maximum stroke and maximum allowable pressure.
- The force obtained can be increased by increasing the diameter. The stroke length can be increased by increasing the folds or convolutions.
- For selecting a specific material for an elastic member like bellows, the parameters to be checked are:
    - Range of pressure
    - Hysteresis
    - Fatigue on dynamic operation
    - Corrosion
    - Fabrication ease
    - Sensitivity to fluctuating pressures

- For strong bellows, the carbon steel is selected as the main element. But the material gets easily corroded and is difficult to machine.
- For better hysteresis properties trumpet bass, phosphor bronze, or silicon bronze are used. Better dynamic performance with good sensitivity can be achieved by using beryllium copper. Stainless steel is corrosion resistive, but does not have good elastic properties.
- All bellow elements are used with separate calibrating springs. The springs can be aligned in two ways – in compression or in expansion when in use. Both these types, with internal compression springs or external tension springs, are commercially known as receiver elements and are used universally in pneumatic control loops.
- The figures 1. shows the compressed and expanded type. Spring opposed bellows are also shown below. The open side of a bellows element is usually rigidly held to the instrument casing and because of the rigid fixing, the effective or active length of the bellows element is smaller than its actual length. This device is used in cases where the control pressure range is between 0.2 to 1 kg/cm2.

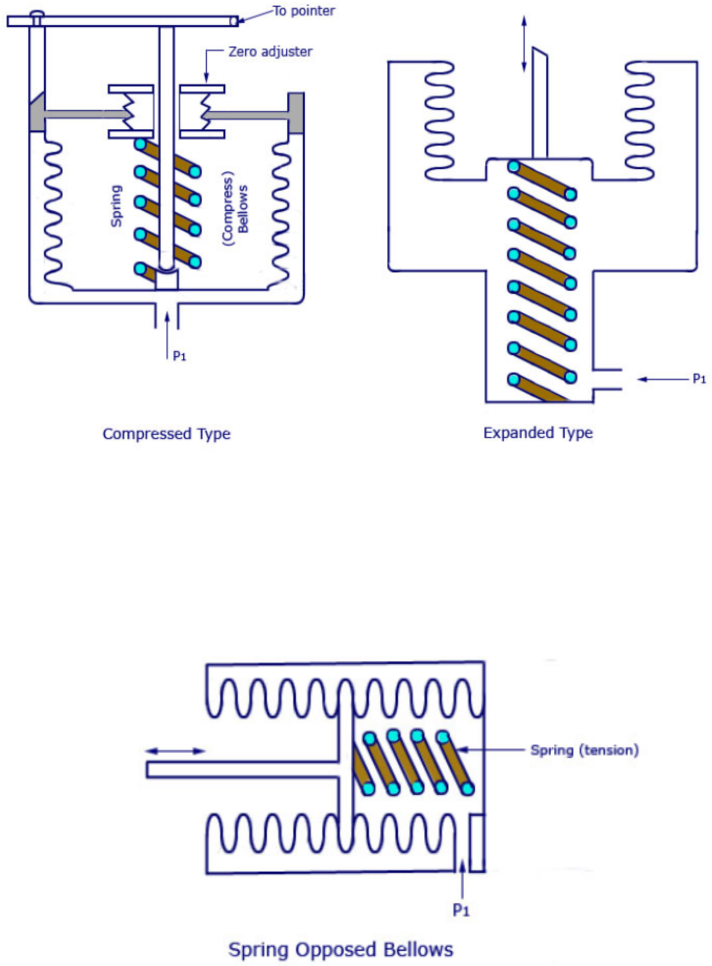


Fig 1.3 Bellow Pressure Gauge

Because of the device's dynamic operation, the life of a bellow is an important consideration. In terms of choice of elastic material for the sensors, the corrosive medium requires special precaution. Besides this, there are other factors showing that the medium should not come in direct contact with the measuring element. They are shown below:

- The direct impact of static head on the measuring element may cause error in response.
- Direct touch of the medium may cause corrosion, high viscosity fluids may cause response error and entailed materials in the medium may clog in the element.
- In some critical processes in food processing and pharmaceutical industries, cleaning of the measuring system is necessitated.
- Removal of the measuring element for servicing should be convenient.
- All these factors suggest that a type of seal should be placed between the process fluid and the measuring element. The best example is the diaphragm seal. It consists of a flexible diaphragm made of corrosion resistance material and sealed within a chamber that can connect the process on one side and the measuring element on the other.

- The effective area of an elastic element like diaphragm or bellows element is generally less than the geometrical area. For finding out the effective area, a known load change is made externally to the centre of the element and the corresponding deflection noted. The differential pressure is then found out for the same deflection.

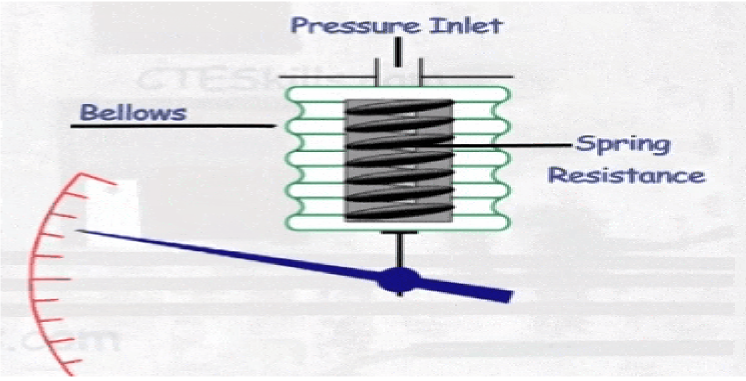


Fig 1.4

Applications of Pressure Gauges:

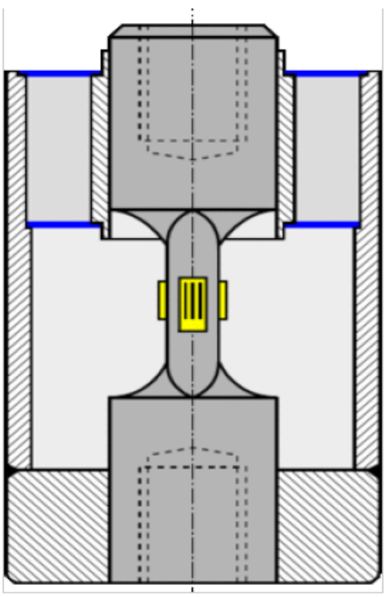
- To maintain pressure in oil and gas, alternative fuels, chemical manufacturing, petrochemical and mobile hydraulics industries to protect against extreme environments, like in oil, gas and petrochemical industries, which face system vibration, pulsation, pressure spikes and corrosion for processing, oil and gas and chemical applications
- general Purpose applications in HVAC, refrigeration, ventilation and food and beverage industries
- to eliminate potential leak path for sanitary, chemical, petrochemical, pharmaceutical and process industries
- highly accurate test gauges for calibration and testing in laboratories and suitable for corrosive and industrial applications and are intended for pressure monitoring panels, gaseous or liquid media that will not obstruct the pressure system or attack copper alloy parts and process industry applications.
- For monitoring condensation pressures and vapour pressures of liquids are suitable industries and applications with corrosive environments and gaseous and liquid media.

Load Cells

A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured. The various types of load cells include hydraulic load cells, pneumatic load cells and strain gauge load cells.

Strain gauge load cell

- Through a mechanical construction, the force being sensed deforms a strain gauge. The strain gauge measures the deformation (strain) as a change in electrical resistance, which is a measure of the strain and hence the applied forces.
- A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. Load cells of one strain gauge (quarter bridge) or two strain gauges (half bridge) are also available. The electrical signal output is typically in the order of a few mill volts and requires amplification by an instrumentation amplifier before it can be used.
- The output of the transducer can be scaled to calculate the force applied to the transducer. Sometimes a high resolution ADC, typically 24bit, can be used directly.
- Strain gauge load cells are the most common in industry. These load cells are particularly stiff, have very good resonance values and tend to have long life cycles in application.
- Strain gauge load cells work on the principle that the strain gauge (a planar resistor) deforms/stretches/contracts when the material of the load cells deforms appropriately. These values are extremely small and are relational to the stress and/or strain that the material of load cell is undergoing at the time.
- The change in resistance of the strain gauge provides an electrical value change that is calibrated to the load placed on the load cell.
- Strain gauge load cells convert the load acting on them into electrical signals. The gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. In most cases, four strain gauges are used to obtain maximum sensitivity and temperature compensation.



Push-pull rod load cell spring element

Fig 1.5

- Two of the gauges are usually in tension can be represented as T1 and T2 and two in compression can be represented as C1 and C2, and are wired with compensation adjustments.

- The strain gauge load cell is fundamentally a spring optimized for strain measurement. Gauges are mounted in areas that exhibit strain in compression or tension. When weight is applied to the load cell, gauges C1 and C2 compress decreasing their resistances. Simultaneously, gauges T1 and T2 are stretched increasing their resistances.
- The change in resistances causes more current to flow through C1 and C2 and less current to flow through T1 and T2. Thus a potential difference is felt between the output or signal leads of the load cell.
- The gauges are mounted in a differential bridge to enhance measurement accuracy. When weight is applied, the strain changes the electrical resistance of the gauges in proportion to the load. Other load cells are fading into obscurity, as strain gauge load cells continue to increase their accuracy and lower their unit costs.

Common shapes:

There are several common shapes of load cells:

- Shear beam, a straight block of material fixed on one end and loaded on the other
- Double ended shear beam, a straight block of material fixed at both ends and loaded in the center
- Compression load cell, a block of material designed to be loaded at one point or area in compression
- S type load cell, a S shaped block of material that can be used in both compression and tension (load links and tension load cells are designed for tension only)
- Rope clamp, an assembly attached to a rope and measures its tension. Rope clamps are popular in hoist, crane and elevator applications due to the ease of their installation; they have to be designed for a large range of loads, including dynamic peak loads, so their output for the rated load tends to be lower than of the other types
- Load pin, used for sensing loads on e.g. axles

Common issues:

Mechanical mounting: the cells have to be properly mounted. All the load force has to go through the part of the load cell where its deformation is sensed. Friction may induce offset or hysteresis. Wrong mounting may result in the cell reporting forces along undesired axis, which still may somewhat correlate to the sensed load, confusing the technician.

Overload: Within its rating, the load cell deforms elastically and returns back to its shape after being unloaded. If subjected to loads above its maximum rating, the material of the load cell may plastically deform; this may result in a signal offset, loss of linearity, difficulty with or impossibility of calibration, or even mechanical damage to the sensing element (e.g. de-lamination, rupture).

Wiring issues: the wires to the cell may develop high resistance, e.g. due to corrosion. Alternatively, parallel current paths can be formed by ingress of moisture. In both cases the signal develops offset (unless all wires are affected equally) and accuracy is lost.

Electrical damage: the load cells can be damaged by induced or conducted current. Lightning's hitting the construction, or arc welding performed near the cells, can overstress the fine resistors of the strain gauges and cause their damage or destruction. For welding nearby, it is suggested to disconnect the load cell and short all its pins to the ground, nearby the cell itself. High voltages can break through the insulation between the substrate and the strain gauges.

Nonlinearity: At the low end of their scale, the load cells tend to be nonlinear. This becomes important for cells sensing very large ranges, or with large surplus of load capability to withstand temporary overloads or shocks (e.g. the rope clamps). More points may be needed for the calibration curve.

Excitation and rated output

The bridge is excited with stabilized voltage (usually 10V, but can be 20V, 5V, or less for battery powered instrumentation). The difference voltage proportional to the load then appears on the signal outputs. The cell output is rated in mill volts per volt (mV/V) of the difference voltage at full rated mechanical load. So a 2.96 mV/V load cell will provide 29.6 mill volt signal at full load when excited with 10 volts. Typical sensitivity values are 1 to 3 mV/V. Typical maximum excitation voltage is around 15 volts.

Wiring

- The full bridge cells come typically in four wire configuration. The wires to the top and bottom end of the bridge are the excitation (often labelled E+ and E−, or Ex+ and Ex−), the wires to its sides are the signal (labelled S+ and S−). Ideally, the voltage difference between S+ and S− is zero under zero load, and grows proportionally to the load cell's mechanical load.
- Sometimes a six wire configuration is used. The two additional wires are "sense" (Sen+ and Sen−), and are connected to the bridge with the Ex+ and Ex wires, in a fashion similar to four

terminal sensing. With these additional signals, the controller can compensate for the change in wire resistance due to e.g. temperature fluctuations.

- The individual resistors on the bridge usually have resistance of 350 Ω. Sometimes other values (typically 120 Ω, 1,000 Ω) can be encountered. The bridge is typically electrically insulated from the substrate. The sensing elements are in close proximity and in good mutual thermal contact, to avoid differential signals caused by temperature differences.

Using multiple cells

One or more load cells can be used for sensing a single load.

- If the force can be concentrated to a single point (small scale sensing, ropes, tensile loads, point loads), a single cell can be used. For long beams, two cells at the end are used. Vertical cylinders can be measured at three points, rectangular objects usually require four sensors. More sensors are used for large containers or platforms, or very high loads.
- If the loads are guaranteed to be symmetrical, some of the load cells can be substituted with pivots. This saves the cost of the load cell but can significantly decrease accuracy.
- Load cells can be connected in parallel; in that case, all the corresponding signals are connected together (Ex+ to Ex+, S+ to S+, ...), and the resulting signal is the average of the signals from all the sensing elements. This is often used in e.g. personal scales, or other multipoint weight sensors.

Piezoelectric load cells work on the same principle of deformation as the strain gauge load cells, but a voltage output is generated by the basic piezoelectric material proportional to the deformation of load cell and Useful for the dynamic/frequent measurements of forces. Most applications for piezoelectric based

Load cells are in the dynamic loading conditions, where strain gauge load cells can fail with high dynamic loading cycles. It must be remembered that the piezoelectric effect is dynamic, that is, the electrical output of a gauge is an impulse function and is not static. The voltage output is only useful when the strain is changing and does not measure static values.

Hydraulic load cell

The cell uses conventional piston and cylinder arrangement. The piston is placed in a thin elastic diaphragm. The piston doesn't actually come in contact with the load cell. Mechanical stops are placed to prevent over strain of the diaphragm when the loads exceed certain limit. The load cell is completely filled with oil. When the load is applied on the piston, the movement of the piston and the diaphragm results in an increase of oil pressure which in turn produces a change in the pressure on a Bourdon tube connected with the load cells.

Because this sensor has no electrical components, it is ideal for use in hazardous areas.[6] Typical hydraulic load cell applications include tank, bin, and hopper weighing.[7] By example, a hydraulic load cell is immune to transient voltages (lightning) so these type of load cells might be a more effective device in outdoor environments. This technology is more expensive than other types of load cells. It is a more costly technology and thus cannot effectively compete on a cost of purchase basis.

Pneumatic load cell:

The Load cell is designed to automatically regulate the balancing pressure. Air pressure is applied to one end of the diaphragm and it escapes through the nozzle placed at the bottom of the load cell. A pressure gauge is attached with the load cell to measure the pressure inside the cell. The deflection of the diaphragm affects the airflow through the nozzle as well as the pressure inside the chamber.

Other types:

Other types include vibrating wire load cells, which are useful in geomechanical applications due to low amounts of drift, and capacitive load cells where the capacitance of a capacitor changes as the load presses the two plates of a capacitor closer together.

Ringing:

Every load cell is subject to "ringing" when subjected to abrupt load changes. This stems from the spring like behavior of load cells. In order to measure the loads, they have to deform. As such, a load cell of finite stiffness must have spring like behavior, exhibiting vibrations at its natural frequency. An oscillating data pattern can be the result of ringing. Ringing can be suppressed in a limited fashion by passive means. Alternatively, a control system can use an actuator to actively damp out the ringing of a load cell. This method offers better performance at a cost of significant increase in complexity.

Uses:

Load cells are used in several types of measuring instruments such as laboratory balances, industrial scales, platform scales[and universal testing machines.[10] From 1993 the British Antarctic Survey installed load cells in glass fibre nests to weigh albatross chicks.[11] Load cells are used in a wide variety of items such as the seven post] which is often used to set up race cars.

Thermistors:

A thermistor is a type of resistor whose resistance is dependent on temperature, more so than in standard resistors. The word is a portmanteau of thermal and resistor. Thermistors are widely used as inrush current limiter, temperature sensors (Negative Temperature Coefficient or NTC type typically), self resetting over current protectors, and self-regulating heating elements (Positive Temperature Coefficient or PTC type typically).

Thermistors are of two opposite fundamental types:

- With NTC, resistance decreases as temperature rises to protect against inrush overvoltage conditions. Commonly installed parallel in a circuit as current sink.
- With PTC, resistance increases as temperature rises to protect against over current conditions. Commonly installed series in a circuit as resettable fuse.
- Thermistors differ from resistance temperature detectors (RTDs) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different;
- RTDs are useful over larger temperature ranges, while thermistors typically achieve a greater precision within a limited temperature range, typically −90 °C to 130 °C.

Assuming, as a first order approximation, that the relationship between resistance and temperature is linear, then:

$$\Delta R = k \Delta T$$

where , ΔR change in resistance , ΔT change in temperature , k first order temperature coefficient of resistance

Thermistors can be classified into two types, depending on the classification of k . If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor, or posistor. If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor.

Resistors that are not thermistors are designed to have a k as close to 0 as possible, so that their resistance remains nearly constant over a wide temperature range.

Instead of the temperature coefficient k, sometimes the temperature coefficient of resistance α_T (alpha sub T) is used. It is defined as

$$\alpha_T =$$

Conduction model

- NTC

  Many NTC thermistors are made from a pressed disc, rod, plate, bead or cast chip of semiconducting material such as sintered metal oxides. They work because raising the temperature of a semiconductor increases the number of active charge carriers it promotes them into the *conduction band*. The more charge carriers that are available, the more current a material can conduct. In certain materials like ferric oxide ($Fe2O3$) with titanium (Ti) doping an *ntype* semiconductor is formed and the charge carriers are electrons. In materials such as nickel oxide (NiO) with lithium (Li) doping a *ptype* semiconductor is created where holes are the charge carriers. This is described in the formula:

$$\mathbf{I = n.A.v.e}$$

I = electric current (amperes)

n = density of charge carriers (count/m^3)

A = cross-sectional area of the material (m^2)

v = drift velocity of electrons (m/s)

e = charge of an electron (coulomb)

- Over large changes in temperature, calibration is necessary. Over small changes in temperature, if the right semiconductor is used, the resistance of the material is linearly proportional to the temperature. There are many different semiconducting thermistors with a range from about 0.01 kelvin to 2,000 kelvins (−273.14 °C to 1,700 °C).

- PTC

  Most PTC thermistors are made from doped polycrystalline ceramic (containing barium titanate ($BaTiO3$) and other compounds) which have the property that their resistance rises suddenly at a certain critical temperature.

  Barium titanate is ferroelectric and its dielectric constant varies with temperature. Below the Curie point temperature, the high dielectric constant prevents the formation of potential barriers between the crystal grains, leading to a low resistance. In this region the device has a small negative temperature coefficient.

  At the Curie point temperature, the dielectric constant drops sufficiently to allow the formation of potential barriers at the grain boundaries, and the resistance increases sharply with temperature. At even higher temperatures, the material reverts to NTC behaviour.

- Another type of thermistor is a silistor, a thermally sensitive silicon resistor. Silistors employ silicon as the semi conductive component material. Unlike ceramic PTC thermistors, silistors have an almost linear resistance temperature characteristic. Barium titanate thermistors can be used as self-controlled heaters; for a given voltage, the ceramic will heat to a certain temperature, but the power used will depend on the heat loss from the ceramic.
- The dynamics of PTC thermistors being powered also is extremely useful. When first connected to a voltage source, a large current corresponding to the low, cold, resistance flows, but as the thermistor self heats, the current is reduced until a limiting current (and corresponding peak device temperature) is reached. The current limiting effect can replace fuses. They are also used in the degaussing circuits of many CRT monitors and televisions where the degaussing coil only has to be connected in series with an appropriately chosen thermistor; a particular advantage is that the current decrease is smooth, producing optimum degausing effect.
- Another type of PTC thermistor is the polymer PTC, which is sold under brand names such as "Polyswitch" "Semifuse", and "Multifuse". This consists of plastic with carbon grains embedded in it. When the plastic is cool, the carbon grains are all in contact with each other, forming a conductive path through the device. When the plastic heats up, it expands, forcing the carbon grains apart, and causing the resistance of the device to rise, which then causes increased heating and rapid resistance increase. Like the BaTiO3 thermistor, this device has a highly nonlinear resistance/temperature response useful for thermal or circuit control, not for temperature measurement. Besides circuit elements used to limit current, self-limiting heaters can be made in the form of wires or strips, useful for heat tracing. PTC thermistors 'latch' into a hot / low resistance state: once hot, they stay in that low resistance state, until cooled. In fact, Neil A Down ie showed how you can use the effect as a simple latch/memory circuit, the effect being enhanced by using two PTC thermistors in series, with thermistor
- A cool, thermistor B hot, or vice versa. Selfheating effects when a current flows through a thermistor, it will generate heat which will raise the temperature of the thermistor above that of its environment. If the thermistor is being used to measure the temperature of the environment, this electrical heating may introduce a significant error if a correction is not made. Alternatively, this effect itself can be exploited. It can, for example, make a sensitive airflow device employed in a sailplane rate of climb instrument, the electronic variometer, or serve as a timer for a relay as was formerly done in telephone exchanges.
- The electrical power input to the thermistor is just:

$$P_E = I \cdot V$$

where I is current and V is the voltage drop across the thermistor. This power is converted to heat, and this heat energy is transferred to the surrounding environment. The rate of transfer is well described by Newton's law of cooling:

$$P_T = K\,(T_R - T_O)$$

where T_R is the temperature of the thermistor as a function of its resistance R, is the temperature of the surroundings, and K is the dissipation constant, usually expressed in units of milliwatts per degree Celsius. At equilibrium, the two rates must be equal.

$$P_E = P_T$$

Applications

PTC

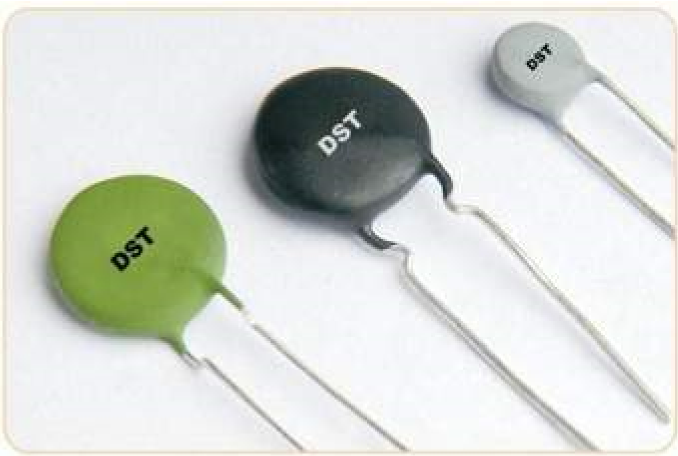
- As current limiting devices for circuit protection, as replacements for fuses. Current through the device causes a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings, the device heats up, causing its resistance to increase. This creates a self reinforcing effect that drives the resistance upwards, therefore limiting the current.
- As timers in the degaussing coil circuit of most CRT displays. When the display unit is initially switched on, current flows through the thermistor and degaussing coil. The coil and thermistor are intentionally sized so that the current flow will heat the thermistor to the point that the degaussing coil shuts off in under a second. For effective degaussing, it is necessary that the magnitude of the alternating magnetic field produced by the degaussing coil decreases smoothly and continuously, rather than sharply switching off or decreasing in steps; the PTC thermistor accomplishes this naturally as it heats up. A degaussing circuit using a PTC thermistor is simple, reliable (for its simplicity), and inexpensive.
- As heater in automotive industry to provide additional heat inside cabin with diesel engine or to heat diesel in cold climatic conditions before engine injection.
- In temperature compensated synthesizer voltage controlled oscillators.
- In lithium battery protection circuits.
- In an electrically actuated Wax motor to provide the heat necessary to expand the wax.

NTC

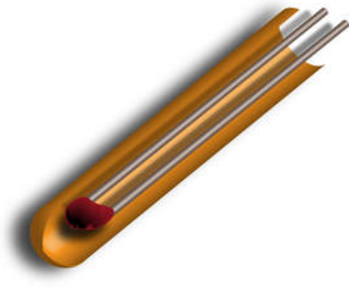
- As a resistance thermometer for low temperature measurements of the order of 10 K.
- As an inrush current limiter device in power supply circuits, they present a higher resistance initially, which prevents large currents from flowing at turn ON, and then heat up and become much lower resistance to allow higher current flow during normal operation. These

thermistors are usually much larger than measuring type thermistors, and are purposely designed for this application.

- As sensors in automotive applications to monitor things like coolant or oil temperature inside the engine, and provide data to the ECU and to the dashboard, To monitor the temperature of an incubator.
- Thermistors are also commonly used in modern digital thermostats and to monitor the temperature of battery packs while charging.
- Thermistors are often used in the hot ends of 3D printers; they monitor the heat produced and allow the printer's control circuitry to keep a constant temperature for melting the plastic filament.
- In the food handling and processing industry, especially for food storage systems and food preparation.
- Maintaining the correct temperature is critical to prevent food borne illness.
- Throughout the consumer appliance industry for measuring temperature. Toasters, coffee makers, refrigerators, freezers, hair dryers, etc. all rely on thermistors for proper temperature control.
- NTC thermistors come in bare and lugged forms; the former is for point sensing to achieve high accuracy for specific points, such as laser diode die, etc.



Disc type Thermistor



Bead type

Fig 1.6

Metal Resistance Thermometer

This thermometer is an instrument used to measure the temperature variation in control room.

Working principle

In each metallic conductor, their resistance changes when its temperature is changed. By calculating the variation in resistance, the temperature variations may be calculated. The thermometer which utilizes this phenomenon is called “resistance thermometer”.

Construction

The construction of resistance thermometer detector is shown in figure. RTD uses platinum, nickel or copper as a resistance element. Generally, platinum wire is wound on either ceramic bobbin to form a resistance element. This resistance element is placed inside the hollow structure called protection tube. It is made up of stainless steel or carbon steel.

Internally lead wire is used to connect resistance element with external lead terminals. Lead wire covered by insulated tube for short circuit prevention. Fiber glass is used for low and medium temperature and a ceramic insulation for high temperature.

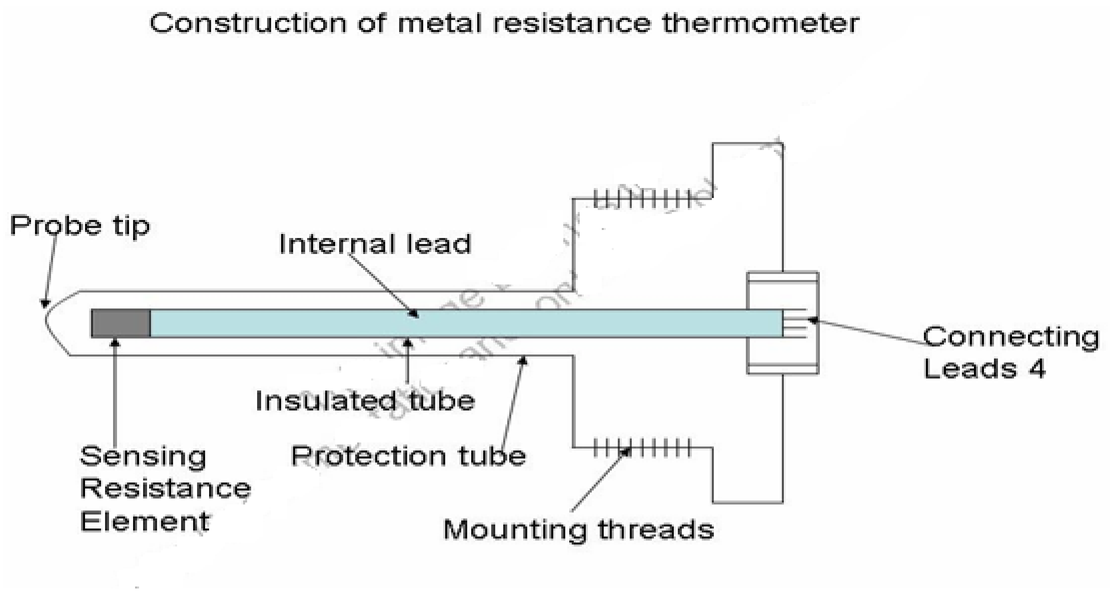


Fig 1.7

Operation

Initial resistance is measured by using Wheatstone bridge. Probe tip of the RTD is placed near the heat source. Outer cover uniformly distributes heat to sensing resistance element. As the temperature varies, the resistance of the material also varies. Now, final resistance is again measured. From the above measurement, variation in temperature can be calculated as follows,

Rt = R0 (1+Dt)
Dt = ((Rt/R0)-1)/x

Where,
Rt = resistance at t degree centigrade.
R0 = Resistance at room temperature.
Dt = Difference in temperature.
X = Temperature coefficient of RTD material.

Thus from the above formula by knowing Rt, R0 and x, the difference in temperature can be calculated.

Advantages

- Accuracy is more.
- More linear than thermocouple.
- No necessary for temperature compensation.
- Performance is stable for long period.

Disadvantages:

Expensive.
Their change in temperature is very small even for large change in input temperature.
External current source is required.
Low sensitivity.

1.13. DIGITAL ENCODING TRANSDUCER

Advancements in ‘Digital Processing (DSP) Technology has made signals being processed by Computers, whether it is process control in industries or entertainment audio or video. All the real time changes in the physical quantities are converted into electrical quantities by transducers. If processed by computers these electrical quantities are to be converted into digital signals by ADC. Sometimes the transducers give pulse information about the Quantity to be measured (for example speed) which could be directly processed by computers . Such a Transducer is a digital encoding Transducer which give digital outputs. They are convenient to use since they can be directly interfaced with a digital computer.

Digital transducers are often called encoders. They are used to measure linear displacements and rotational speed. Digital encoding transducers or digitizers enable a linear or rotary displacement to be directly converted into digital form without an intermediate analog forms and analog to digital (A/D) conversion is not required.

Digital transducers use either optical methods or electrical methods.

1.13.1 OPTICAL ENCODER

- The optical transducers have a set of coded tracks consisting of transparent and opaque patterns in a binary fashion & associated lamps (light sources) and photocells (light sensors) to detect the corresponding switching sequence as shown in the fig.1.

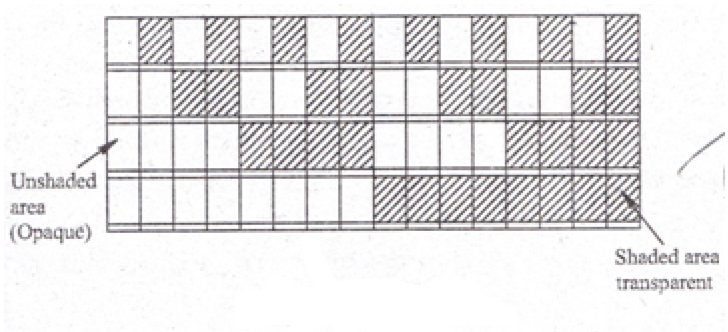


Fig 1.8 Optical Encoder

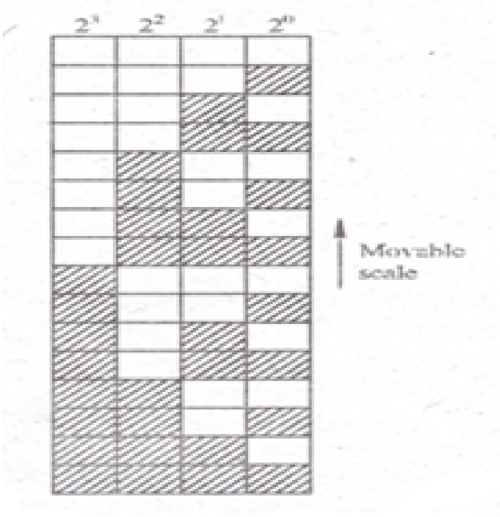
- A photo sensor and a light source are on the two sides of the pattern sector. The displacement is applied to the sector and changes the amount of light falling on the photo electric sensor depending on the sequence of patterns. The photo sensors generate proportional pulse sequences which could be directly converted into binary.
- In figure the pattern start from 4 bit binary '0000' (all opaque) on the left hand side to the 4 bit binary '1111' (all transparent) on the right hand side
- The displacement or speed can be calculated from the difference binary patterns and the time taken.
- The number of levels in the encoder determines the accuracy of the displacement or speed

Advantages

i) Digital read out available directly

ii) Since there is no mechanical contact, problems of wear and tear and alignment do not occur.

RESISTIVE DIGITAL ENCODERS



- The figure 1.9 shows the schematic diagram of a resistive digital encoder. The patterns are similar to optical encoders but the shaded portions are made of conducting material and unshaded portions are made of non-conducting materials.
- Brushes are placed on the transducer which acts as sliding contacts. The circuits of contacts which touch with the conducting areas are completed and the circuits of others which make contacts with insulated areas are not completed. Thus the encoder gives out a digital readout which is an indication of position and hence the encoder determines the displacement and subsequently calculates the speed.

1. . SHAFT ENCODER OR SPATIAL ENCODER

- A shaft encoder is a mechanical converter which translates the angular position of the shaft into digital binary values.

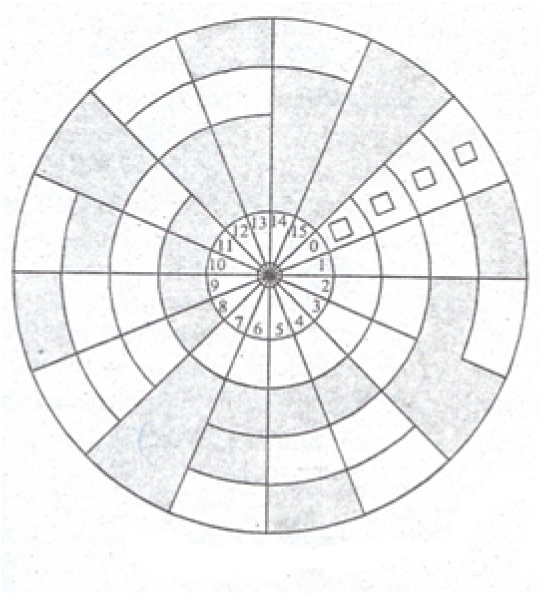


Fig.1. 10

- The schematic diagram of shaft encoder is shown in the fig.1. This encoder has four tracks which are divided into conduction and insulation portions.
- As the encoder moves under the brushes, the lamp circuits are closed or opened so that a digital number is shown on the readout lamps
- Here the disc is divided into concentric circular tracks. Then it is divided into number of segments in a manner depending upon code being used.
- For pure binary code, the inner most track is halved, the next quartered, the next divided into eight parts and so on.
- Each track has twice as many segments as the adjacent one near the centre.
- Here the detection method determines the treatment of the disc. Alternate segments on each track are made transparent and opaque, if transmitted light and photo cells are used.
- If the segments are made reflecting and nonreflecting, reflected lights and photo cells are commonly used.
- Electrical methods are used for detecting in case, the segments are made alternatively conduction and non-conducting.
- The binary 0 or 1 is obtained from each track depending upon the angular position of the disc. The accuracy of the shaft encoder depends upon the number of tracks used.
- Shaft encoders are used in tachometers

Review question

PART A

1. Define transducers and mention its uses
2. Mention the various types of transducers
3. Specify the necessity of transducers.
4. Define active transducer and give examples.
5. Define passive transducers and give examples.
6. Define secondary transducers and give transducers.
7. Define bourdon tubes and mention its uses.
8. Define bellows and mention its uses.
9. Define load cell and mention its types.
10. Define thermistor and mention its types.

    PART B

11. Explain the basic requirement of transducer.
12. Explain the active and passive transducers
13. Explain primary and secondary transducers.
14. What do you mean digital encoding transducer.
15. Explain the types of thermistor.

    PART C

16. a) Explain the primary sensing elements.

    b) Explain the shaft encoder with diagram.

17. 17. a) explain the resistive digital encoder with diagram.

    b) With the diagram explain bellows.

18. 18. a) with the diagram explain bourdon tubes

    b) Explain optical encoder.

19. 19 a) with diagram explain load cells.

    b) Explain metal resistance themistor.

UNIT II

PASSIVE TRANSDUCERS

Introduction

Three types of transducers: light bulb, microphone, and electric motors

A **transducer** is a device that converts one form of energy to another. Usually a transducer converts a signal in one form of energy to a signal in another. Transducers are often employed at the boundaries of automation, measurement, and control systems, where electrical signals are converted to and from other physical quantities (energy, force, torque, light, motion, position, etc.). The process of converting one form of energy to another is known as transduction.

Examples of common transducers include the following:

- A microphone converts sound into electrical impulses and a loudspeaker converts electrical impulses into sound (i.e., sound energy to electrical energy and vice versa).
- A solar cell converts light into electricity and a thermocouple converts thermal energy into electrical energy.
- An incandescent light bulb produces light by passing a current through a filament. Thus, a light bulb is a transducer for converting electrical energy into optical energy.
- An electric motor is a transducer for conversion of electricity into mechanical energy or motion.

An actuator is a device that actuates or moves something. An actuator uses energy to provide motion. Therefore, an actuator is a specific type of a transducer. Which of the previously mentioned examples is an actuator?

SENSOR:

A sensor is a device that receives and responds to a signal. This signal must be produced by some type of energy, such as heat, light, motion, or chemical reaction. Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal.

Based on this explanation of a sensor, you should see that sensors are used in all aspects of life to detect and/or measure many different conditions. What are some sensors that you are familiar with or use daily?

Human beings are equipped with 5 different types of sensors.Fig2.1

Eyes detect light energy, ears detect acoustic energy, a tongue and a nose detect certain chemicals, and skin detects pressures and temperatures. The eyes, ears, tongue, nose, and skin receive these signals then send messages to the brain which outputs a response. For example, when you touch a hot plate, it is your brain that tells you it is hot, not your skin.

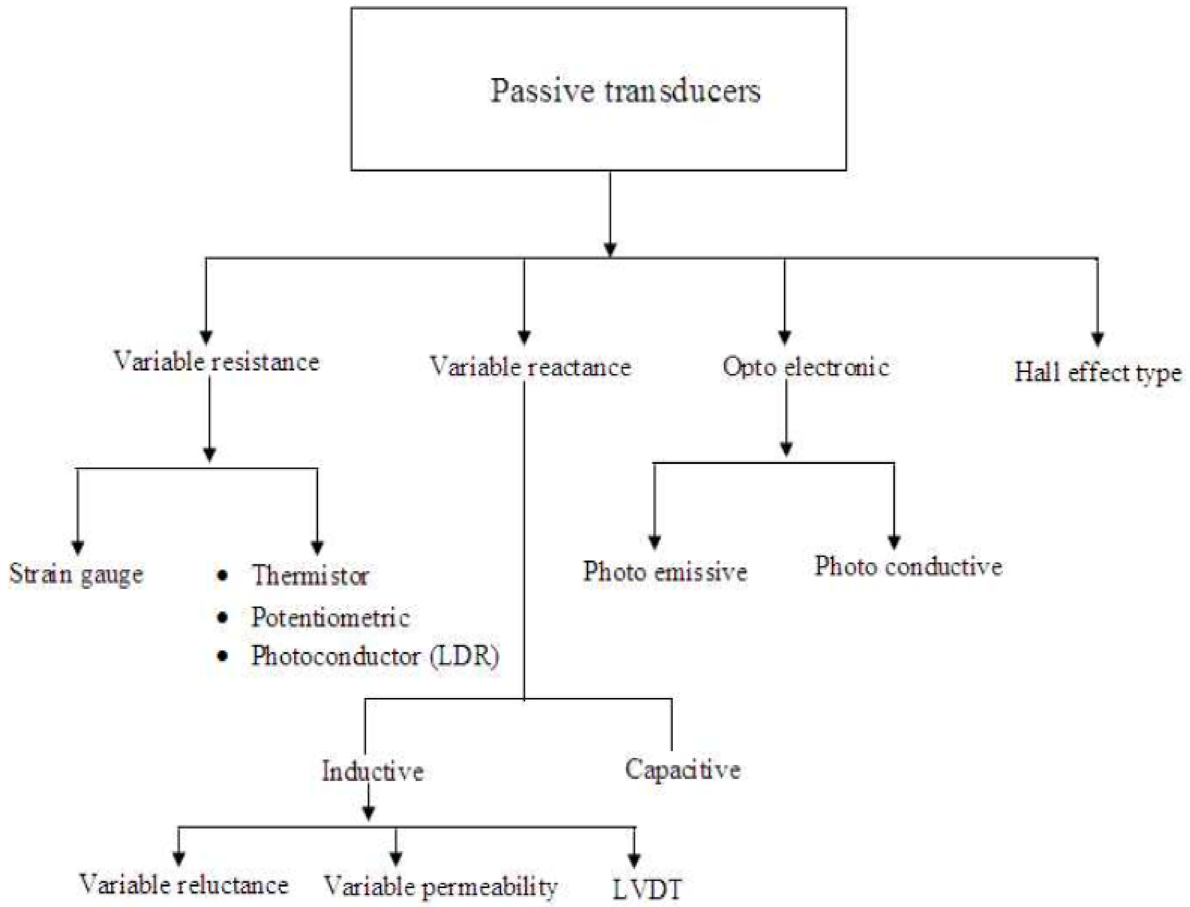
Passive Transducers:

These transducers need external source.

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

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



2.1. RESISTIVE TRANSDUCER

Resistive transducer is a transducer in which a variation in a quantity or signal produces a variation in resistance, which in turn produces a proportional conversion to a quantity or signal in another form., Resistance transducer are very much useful in instrumentation system like level measurement strain measurement etc.

Variable Resistance Transducer

The variable resistance transducers are one of the most commonly used types of transducers. The variable resistance transducers are also called as resistive transducers or resistive sensors. They can be used for measuring various physical quantities like temperature, pressure, displacement, force, vibrations etc. These transducers are usually used as the secondary transducers, where the output from the primary mechanical transducer acts as the input for the variable resistance transducer. The output obtained from it is calibrated against the input quantity and it directly gives the value of the input.

Principle of Working of Variable Resistance Transducer

The variable resistance transducer elements work on the principle that the resistance of the conductor is directly proportional to the length of the conductor and inversely proportional to the area of the conductor. Thus if L is the length of the conductor (in m) and A is its area (in m square), its resistance (in ohms) is given by:

$$R = \rho L/A$$

Where ρ is called as resistivity of the material and it is constant for the materials and is measured in ohm-m

The resistance of some materials also changes with the change in their temperature. This principle is primarily used for the measurement of temperature.

Types of Resistive Transducer:

1. Strain Gauge
    a. Wire Strain Gauge
    b. Foil Strain Gauge
    c. Semiconductor Strain Gauge
2. Potentiometer
3. Thermistor
4. Resistance Thermometers

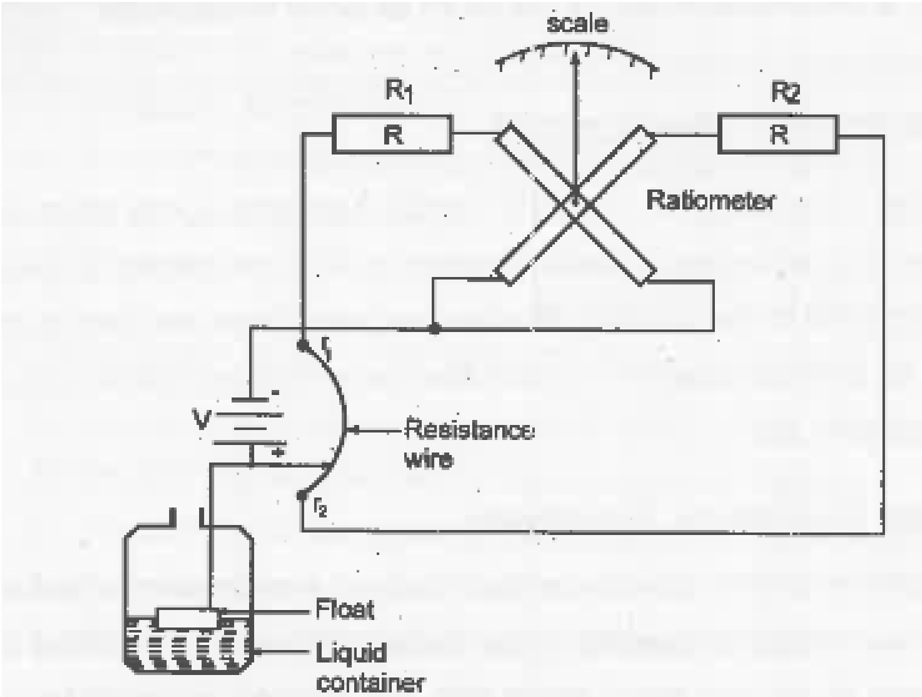


Fig2.2

2.2. STRAIN GAUGE

Strain Gauge is a passive **transducer** that converts a mechanical elongation or displacement produced due to a force into its corresponding change in resistance R, inductance L, or capacitance C. A strain gauge is basically used to measure the strain in a work piece. If a metal piece is subjected to a tensile stress, the metal length will increase and thus will increase the electrical resistance of the material. Similarly, if the metal is subjected to compressive stress, the length will decrease, but the breadth will increase. This will also change the electrical resistance of the conductor. If both these stresses are limited within its elastic limit (the maximum limit beyond which the body fails to regain its elasticity), the metal conductor can be used to measure the amount of force given to produce the stress, through its change in resistance.

Definition

Strain gauge is a passive resistive transducer which converts the strain experienced by a mechanical member or structure into a change in resistance of wire elements provided inside the gauge. A Strain gauge is an example of a passive transducer which converts a mechanical displacement into change of resistance of the strain wire.

1. Principle of strain gauge

The basic principle of a strain gauge is that a resistance wire stretches within its elastic limits, shows an increase in resistance when elongated. When attached to the surface of a structure by means of an elastic cement, the variation in the resistance of the wire will follow the changes in surface dimensions of the structure due to stress formation.

2. Importance of Strain gauge

1. A strain gauge finds its application as a measurement transducer in many areas.

It is extensively used for the measurement of strain and the associated stress in experimental stress analysis.

2. Strain gauges are fixed on the surface of materials to sense

Strain of the material or strictures under applied load or force and to provide an electrical output signal proportional to the strain.

3. Strain gauges are also being used to investigate strain in many structural materials over a wide range of environmental conditions.
4. Measurement of stress occurring in vibrating jet engine turbine blades operation at high temperature or in rocked engine fuel vessels containing liquid oxygen having negative temperature can be done using strain gauges transducers.
5. In aircraft, the electrical signals generated by the strain gauge can be telemetered by radio to ground instrument so that the structural strains can be measured under actual flight conditions.
6. In the medical field investigation of strain in bone structure has been some by bonding gauges to human skulls and animal leg bones.

Thus application of strain gauges in the field of instrumentation and measurement is practically very vast.

3. Construction of Strain Gauges

There are three types of strain gauges according to their type of construction

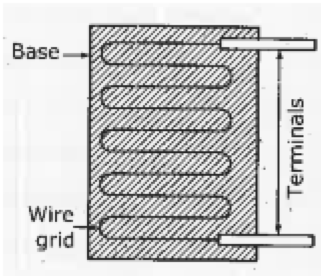
1. Wire wound strain gauges.
2. Foil type strain gauges.
3. Semiconductor strain gauges.

We shall confine our discussion to wire wound strain gauges only which can further be divided into two types namely.

a) Bonded strain gauge
b) Un bonded strain gauge

a) Bonded strain gauge

A Strain gauge Transducer is made of a thin wire of diameter varying from 0.02 to 0.04 mm cemented in a zig-zag pattern on a thin flat paper. The zig-zag winding has a very low inductance and capacitance and trie connecting leads are twisted to minimise the added inductance. The sensitivity of a strain gauge is indicated Base in terms of a factor called the gauge factor which is defined as the charge in resistance per unit change in length of Wire the strain wire. A high gauge factor mean grid a relatively large resistance change bonded wire strain gauge making the strain gauge more sensitive.



Bonded wire strain gauge

Fig2.3

b) Un Bonded strain gauge

In this type of strain gauge, the wire elements are used for sensing the strain which are not bonded directly to the member under strain. Hence it is called **Un bonded strain gauge**.

4. Strain gauge in measurement of displacement

Fig2.4 given below shows the one type of unbounded strain gauge for the measurement of displacement. In this type a frame-like moving structure called armature is supported in the centre of a stationary frame the armature can move only in one direction.

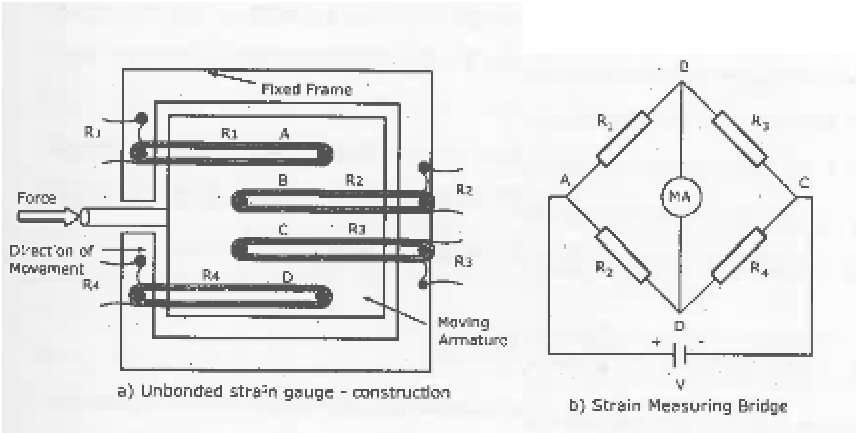


Fig2.4

The movement in that direction is limited by four filaments of strain - sensitive wire. The filaments are of equal dimensions having equal resistances and are arranged as shown in fig2.4 when a body is displaced an external force is applied to the strain gauge, which moves the armature in the direction indicated.

The movement of the armature due to the strain of the structure causes a change in the dimensions of the sensing elements. Hence the elements A and D increase in length, whereas the elements B and C decrease in length. As a result, the resistance R1 and R4 increase and R2 and R3 decrease. These four resistances are formed as the four arms of a Wheatstone bridge, for the purpose of strain measurement.

Since the resistance of all the four resistors R1 to R4 change due to application of stress (force), the strain gauge gives increased sensitivity.

Initially the bridge is balanced when stress is not applied. When stress is applied, the resistance elements experience strain and change their resistance values and upset the balance of the bridge. The unbalanced current indicated by the sensitive centre -zero mill ammeter which is calibrated to read the magnitude of displacement of the armature.

The displacement of the body is calculated from the readings obtained from the mill ammeter. Thus the displacement of the structuralmember, is measured in terms of electrical quantity.

5. Applications of Strain Gauges

- Strain gauges are used extensively for analysing the dynamic strains in complex structures such as the stress and the strain in bridges, automobiles, roads etc.
- Resistance strain gauges are very useful for measurement of tension, torque, force, stresses in structures.
- Strain gauges are used in load cells and proving rings to measure force by the strain produced.

2.3. CAPACITIVE TRANSDUCER

It is known that the capacitance of a parallel plate capacitor is inversely proportional to the distance‘d’ between the two plates. Any variation of ‘ d ’ causes a corresponding variation of the capacitance.

This principle is applied in a capacitive transducer for Measurement of displacement, Figure 2.5 shows the use of a variable position capacitive transducer employed for the measurement of displacement.

The capacitor is made up of two plates, one fixed and the other free to move under the application of the displacement force.

The cantilever plate 'A' is spring controlled. As the displacement force is applied, the movable plate mounted on 'C' moves towards the fixed plate reducing the distance between the two plates 'A' and 'B'. Due to the decrement in the distance between the two plates, the capacitance of capacitor increases. Normally, the air between the two plate work as a dielectric medium. Since the capacitance of air capacitor is basically non-linear, to bring in linearity in measurement, a material of high dielectric constant is placed in between the two plates as shown in figure 2.5.

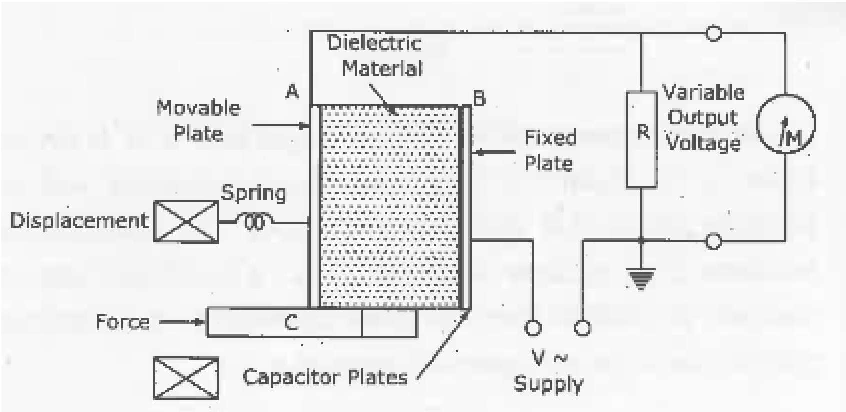


Fig2.5

The advantages of capacitive transducers are that, the torce required for their operation is very small and can be used in small systems, and they are externally sensitive.

The disadvantages are that their 3erformance is severely affected by dirt and other contaminants, that they are sensitive to temperature variations and as a result may give erratic or distorted response. For measurement of pressure, one of the capacitor plates may be made in the form of a diaphragm. Application of pressure on the diaphragm would reduce the effective distance between the two plates and thereby increase the value of capacitance as shown in figure 2.6.

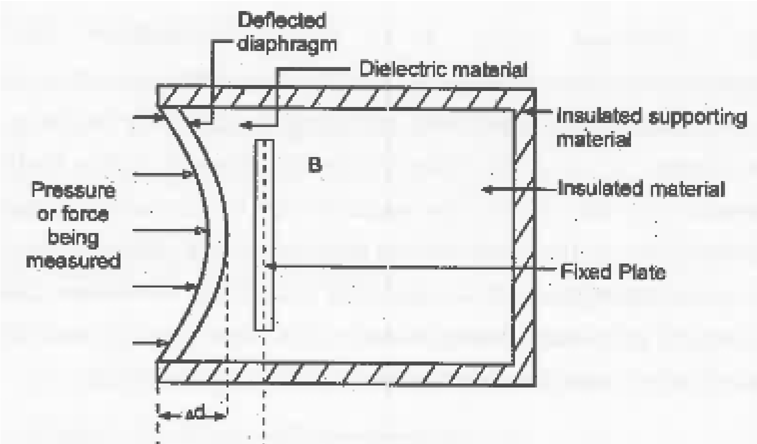


Fig 2.6

The distance between the two plebs changes form'd' to (d-Dd) as shown in the figure 2.6. This capacitance is attached with an oscillator .circuit (not shown in the figure). The frequency of oscillation of the oscillator would change as the diaphragm plate, 'A' changes its position from the initial condition to the deflected position due to the application of force on it.

Advantages of Capacitive Transducers

- Operating forces are extremely small.
- Highly Sensitive.
- Very good frequency response.
- Requires very small power.
- High resolution.
- Not affected by star by magnetic fields.
- High input impedance, hence no loading effects.

Disadvantages

- Metallic parts of the transducer must be insulated and the frame must be earthed.
- Due to edge effects the capacitance values do not vary lin¬early with liquid level raising.

- Cables connecting the capacitance transducer to the measuring circuit contribute sizable error in readings.

Applications of capacitance Transducers

- Capacitance transducers can be used for measuring linear and angular displacements.
- Can be used for measuring force and pressure.
- Can be used directly as pressure transducers where the dielectric constant of the medium changes with pressure.
- Used to measure humidity in gases.
- In association with mechanical converters, capacitive transducers can be used for measurement of volume, density, liquid level, weight etc.
- Used in logic controllers as proximity sensors/switches.

2.4. LIQUID LEVEL MEASUREMENT OF. CAPACITIVE TRANSDUCERS

1. Capacitive Transducer method

A capacitor can be, used as a liquid level transducer in any one of the following three methods.

1. Variable area method.
2. Capacitive Voltage Divider Method.
3. Variable Dielectric Constant Method.

2. Variable Dielectric Constant Method

Among the above three methods variable dielectric constant methods is very widely used for the level detection of liquids. If the liquid is non-conducting it can be used as a dielectric in the capacitor, which is used as transducer.

The arrangements for measurement of liquid level for non-conducting liquids are explained below:

3. Arrangement of capacitive transducers

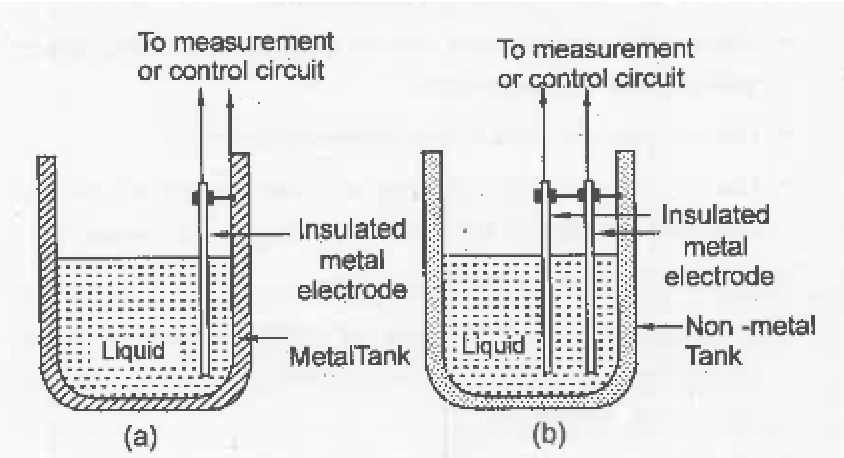


Fig2.7

Fig 2.7 (a) shows an insulated metal electrode firmly fixed near and parallel to the metal wall of the tank. If the liquid is non-conductive, the electrode and the tank wall form the plates of a parallel plate capacitor with the liquid in between them acting as the dielectric. If the liquid' is conductive the rod and the liquid form the plates of the capacitor, and the insulation between them is the dielectric.

The capacitance of this capacitor depends, among other' factors, upon the height of the dielectric between the plates. The greater the height, the greater the capacitance. The lesser the height, the smaller is the capacitance. Thus the capacitance is proportional to the height of the liquid in the tank.

Where the tank is not of metal, two parallel insulated rods (electrodes), kept at a fixed distance apart are used as shown in fig. 2.7 (b) The two rods act as two plates of a parallel plate capacitor. The higher the liquid level, the greater is the capacitance. The capacitance in the above cases may be measured and this measured capacitance is an indication of liquid levels. The value of capacitance can be converted into an a.c. voltage which can be measured by a liquid level indicator.

4. Liquid Level Indicator Arrangement

The capacitor arrangement in the tank is connected to an op. amplifier circuit as shown in the fig 2.8. An a.c. voltage VI at V2 is connected to the input to the corresponding output is over view at the output which can be measured by a meter. The arrangement of a Liquid level indicator using an operational amplifier is shown fig 2.8.

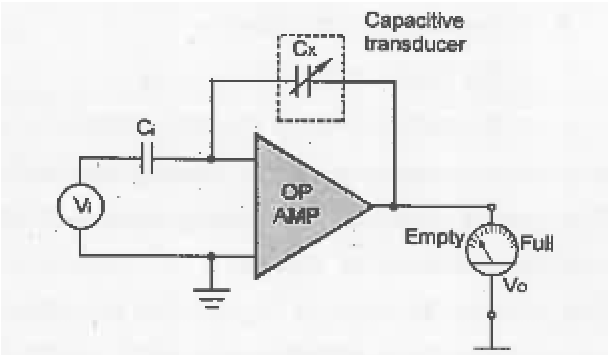


Fig 2.8

2.5. INCUCTIVE TRANSDUCER

In an inductive transducer measurement of a force or a displacement is done by utilising the change in the inductance ratio of a pair of coils or by the change of inductance in a single coil. Inductance of a coil may be expressed as:

$L = N\ d\ \phi/di$

Assuming liner relationship between 0 and I,

$L = N\ \phi\ /1$

or $L = N\ BA/I \quad (\backslash\phi = BA)$

$= N$ mHALImH)

$= N$ m NINII[H = NI/1]

or $L = m\ N^2A/I$

Where N = the number of turns of the inductor

A = the area of a the core

I= the length of the coil

m = the permeability cf the core material

Inductance of the coil may be varied by varying the parameters as given in. The various methods of obtaining change in inductance value of a coil are explained as follows:

One method, commonly used, is to vary the reluctance of the magnetic circuit by having a movable core which would change in inductance of the coil as a result of application of a force can be used to measure the magnitude of the applied force.

The coil whose inductance would vary on application of the force to be measured may be used as one of the components of an L-C oscillator whose frequency, f would vary with the variation of inductance as; f =1/2 LC

Thus through proper calibration of the oscillator scale measurement of the force can be made.

Figure 2.9.shows two types inductive transducers.

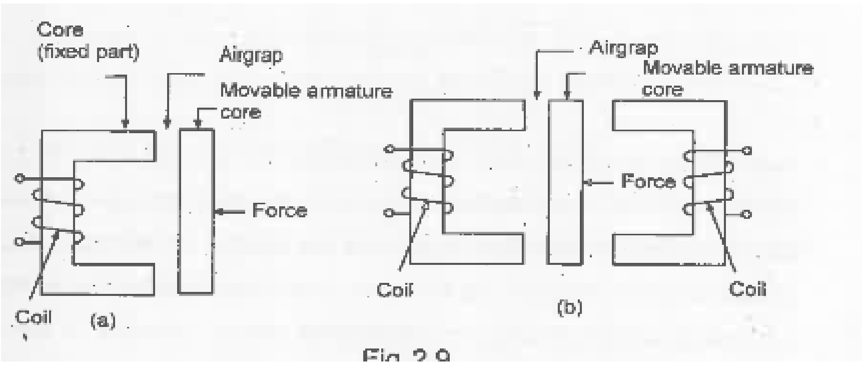


Fig2.9

As shown in fig. 2.9 (a), the magnetic flux path is completed through a ferromagnetic armature core/diaphragm which on application of a force moves relative to the fixed part of the core. Change in air-gap in the magnetic circuit produces a change in the inductance of the coil.

In the differentia! form as shown in fig. 2.9(b), inductance of the two coils will change oppositely. Due to movement of the armature induction of one coil will increase while that of the other will decrease. These two oils may be used as adjacent arm of the measuring bridge.

Figure.2.10 (b) shows another type of inductive transducer with a movable core. This type of transducer is suitable for

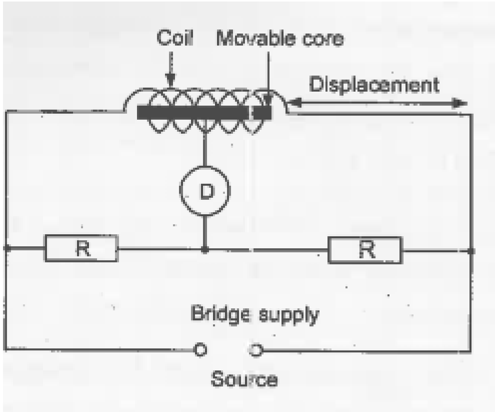


Fig2.10

Two halves of the inductor are connected as two adjacent arms of the bridge. If the core is centrally place, the two halves of the coil will have equal inductance value and the bridge will be balanced. A deviation in the position of the core due to any displacement force will unbalance the bridge. the deflection of the detector D can be calibrated as proportional to the magnitude of displacement of the movable core.

2.6. CAPACITIVE TRANSDUCERS AS PROXIMITY SENSORS

The principle of operation of capacitance transducers is based on
the simple relation for a parallel plate capacitor

Parallel plate capacitance $\mathbf{C = A\varepsilon_r\varepsilon_o/d}$

Where

A = Area of plates in m

e_r = Relative permilivity or dielectric constant

e_o= permittivity of tree space

d = distance between the plate

The capacitance value can be changed by carrying any one of the above.
These variations may be caused by physical variables like force, pressure and displacements. To cite one example, capacitance value changes due to variation in dielectric constant in liquid level measurements. Depending on how the capacitance is varied, the capacitance transducers can be classified into three types. They use change in a) plate area b) distance between plates c) Dielectric material. These are primarily used for measuring displacement. In one way they also act as proximity sensors.

a) Transducers using change in Plate Area

Parallel plate capacitance is directly proportional to area common to parallel plates. Based on this principle linear displacement and circular movement can be measured.

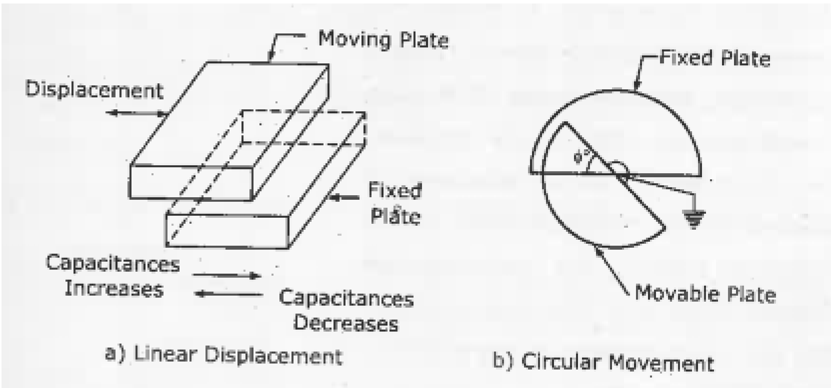


Fig 2.11

In linear displacement type, two plates are there; one plate is fixed and the other plate is movable. The displacement to be measured is connected to the movable plate. When movable plate is moved away from the fixed plate, the plate common area is reduced, and hence capacitance value is lowered. This variable capacitance is made a part of the measuring bridge which in turn delivers on electrical output. The capacitance varies linearly with displacement. This type is suitable for linear displacements ranging from 1 to 10cm.
In the circular movement type, they two plates are sector shaped. One plate is fixed and the other one is movable in a circular fashion about a common centre. The movable plate centre axis is attached to the displacement to be measured. When there is angular displacement, the

movable plate moves over the fixed plate. Since plate common area changes, the capacitance varies linearly with angular shift. This type is used for measuring angular displacement or movement uplo a maximum of 180°

b) Transducers using change in Distance between Plate

Fig 2.12 shows the basic form of a capacitive transducer. It utilise the change in apacitance due to change in distance between plates. One plate is fixed and the other one is movable. The displacement to be measured is attached to the movable plate. When distance varies, the capacitance changes inversely. This type is used only for measurement of extremely small displacements.

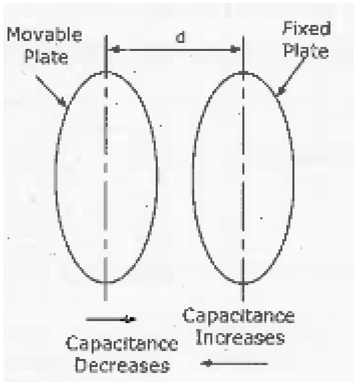


Fig2.12

C) Transducers using variation of dielectric constant

This type employs variation of capacitance due to change in dielectric constant of the medium between the plates or electrodes. Imagine .an insulating medium be placed between parallel plates.

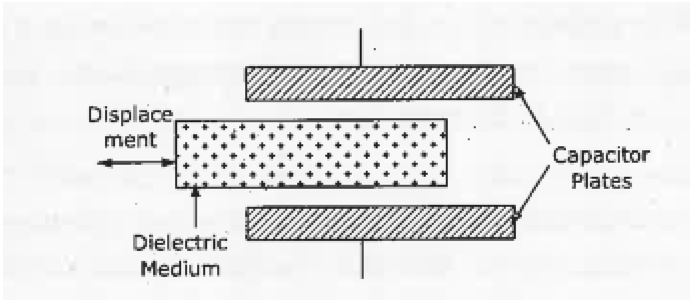
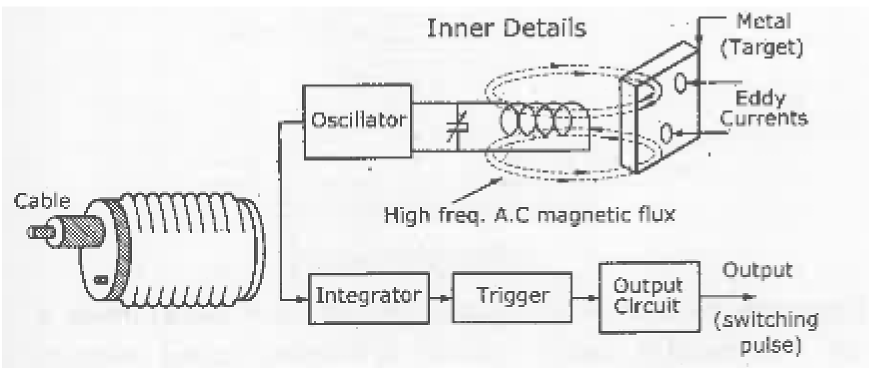


Fig2.13

Let e r be the relative permittivity of that medium. When the plates fully cover the dielectric medium, we get maximum capacitance. When the displacement to be measured is attached to the dielectric piece the capacitance changes for any movement of the dielectric. Inductive Proximity Sensor It, is a solid state switch based on the principle of high frequency electro-magnetic induction. There are no moving parts inside the device. It has high speed operation the device offers switching action without any spark it is best suitable for PLC control circuits .

Inductive Proximity Sensor

It is a solid state switch based on the principle of high frequency electromagnetic induction there are no moving parts inside the device. It has high speed operation the device offers switching action without any spark it is best suitable for PLC control circuits .



The fig 2.14 shows the arrangement of a Inductive proximity switch with its internal parts. A high frequency AC magnetic field is produced and propagated outside the sensing face of the device if any metallic part enters into the magnetic field produced by the device energy is absorbed by the metal face. Hence there is a reduction in the amplitude of the oscillation. This reduction in amplitude of the magnetic wave is sensed and there by reducing in the oscillations. Reduction in amplitude inside the proximity switch with suitably process and the unit is made ON or OFF which is suitable for PLC.

2.7. MEASUREMENT OF PRESSURE USING INDUCTIVE TRANSDUCER

A simple arrangement can be built, in which a change in the inductance of a sensing element (coil) is caused by a pressure change. Such an apparatus is given in fig 2.15.

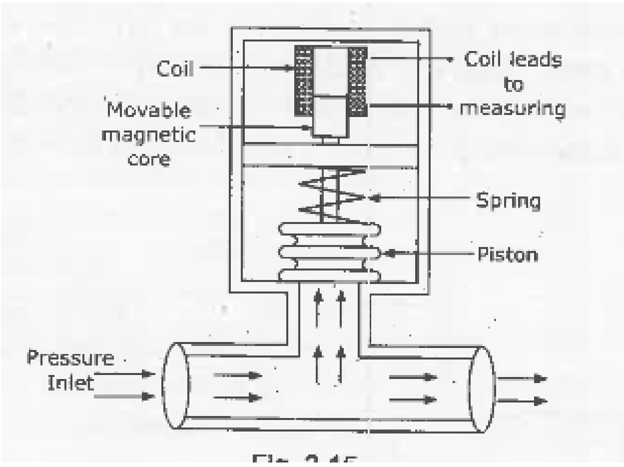


Fig2.15

It basically consists of a movable magnetic core placed inside a coil. The movable core is attached to a spring loaded pressure arm. When high pressure air or fluid is supplied at the inlet, the pressure arm carrying the movable magnetic core is moves. The metal bellows help in containing the high pressure substance. The pressure acting on the movable core causes an increase in the inductance of the coil.

The change in inductance is directly proportional to the pressure applied. The coil leads are connected to one arm of a Wheatstone bridge. The bridge circuit gives the direct reading of the pressure. It should be noted that the bridge is adjusted to null position when no pressure is applied.

One advantage of the inductive type pressure transducer is that, no moving contacts are present. This provides continuous resolutions of the change in pressure with no extra frictional load imposed on the measuring system.

2.8. LINEAR VARIABLE DIFFERENTIALTRANSFORMER -LVDT

LVDT is an induction type transducer. It is widely used to translate the linear displacement or motion into an electrical signal. The construction detail of a LVDT is shown in fig. 2.16. LVDT consists of a single primary winding P and two secondary windings S1 and S2 all wound on a commonly cylindrical former

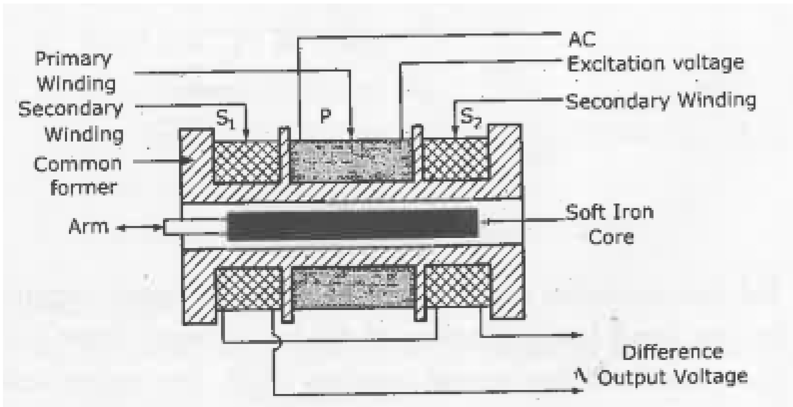


Fig2.16

The secondary windings have equal number of turns and are identically placed on either side of the primary winding. The primary winding is connected to an AC source. A movable soft iron core is placed inside the former.

The displacement to be measured is applied to an arm attached to the soft iron core. The core is usually made of nickel-iron alloy with length wise slots to reduce eddy current losses. When the soft iron core is in normal mid position (Null position), equal voltages are induced in the two secondary windings.

A.0 Inputs

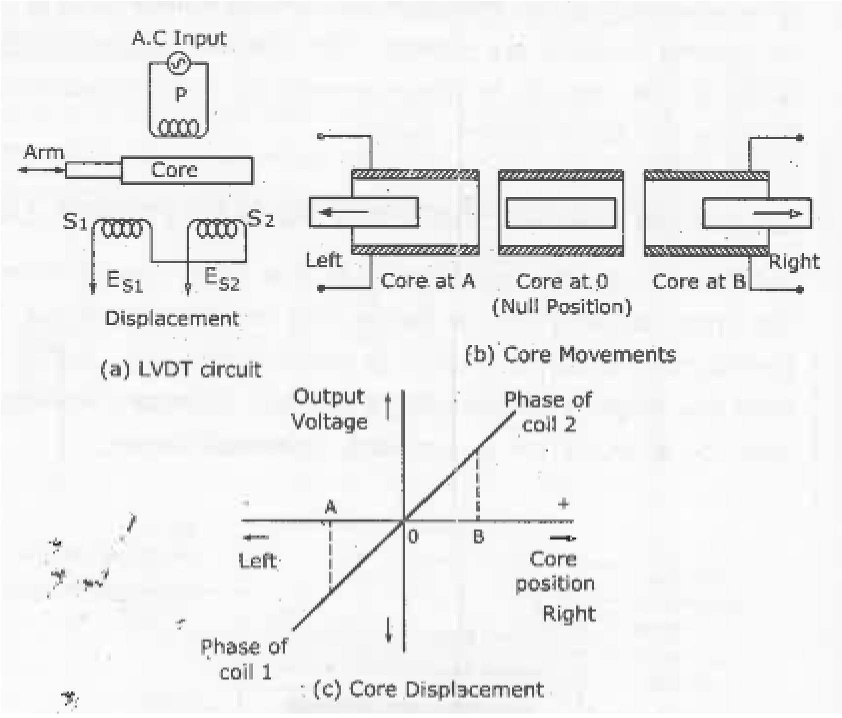


Fig2.17

The two secondary windings are connected in series opposition. So, the output is the difference of the two voltages. When the soft iron core is in the normal position (Null), the output voltage $E_0 = Es_1 - Es_2 = 0$; because the two induced voltages Es_1 and Es_2 are equal.

Now, if the core is moved to the left, beyond the null position more flux lines will link with secondary S1. Accordingly Es_1 will be greater than Es_2. We get a net output voltage, with a polarity indicated in the fig. 2.17.Similarly when the core is moved to right side beyond the Null position, induced voltage Es_2 will be greater than Es_1

Once again we get a net output voltage in the opposite polarity of voltage obtain during the moving of the core in. the left direction. The magnitude of the signal voltage output depends on the physical displacement of the core. The output voltage is taken for further processing and control.

Advantages

- Output voltage is linear for displacement upto 5mm.
- Infinite resolution, even a displacement of 10-3 mm can be recorded.
- High output and hence amplification may not be required.
- High sensitivity; it is highly sensitive to even slight movements.
- Ruggedness. They take up shock and vibrations easily.
- Small and light in weight
- Less friction and less noise.
- Low hysteresis and hence gives reliable readings when used repeatedly.
- Low power consumption; it is around 1 watt

Disadvantages

- Relatively large displacement is required for appreciable differential voltage output.
- Sensitive to stray (outside) magnetic fields, hence shielding is essential
- Sometimes readings are affected due to vibration
- Performance is affected due to temperature rise Dynamic response is affected by the mass of the apparatus and the frequency of supply.

Application

- The LVDT can be used in all applications where displacements ranging from fraction of a mm to a few cm have to be measured.
- Acting as a transducer it can be used as a device to measure force, weight and pressure.

2.9.ROTARY VARIABLE DIFFERENTIAL TRANSFORMER (RVDT)

A linear variable differential transformer (LVDT) may be used to sense angular displacement. Then the arrangement is known as rotary variable differential transformer (RVDT).

It is very similar to a LVDT except that the core is cam shaped and rotated between two windings with the help of a shaft. The RVDT
arrangement shown in fig.2.18.

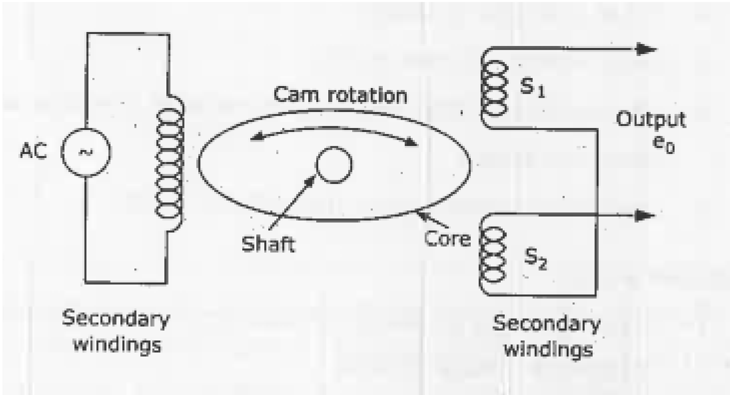


Fig2.18

The working principle of an RVDT is similar to that of a LVDT. At null position of the cam shaped core, the induced voltages in the two secondary windings S1 and S2 are equal and opposite. Therefore nett output voltage across the secondary iszero.

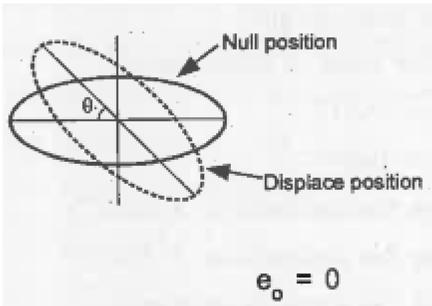


Fig2.19

Any angular displacement of core (0°) as shown in fig 2.19 from the null position will give a differential output voltage across the secondary windings. Greater the angular displacement, greater will be the differential output. The response of the transducer is therefore linear.

Clockwise rotation gives an increasing voltage of secondary of one phase and anticlockwise rotation produces an increasing voltage in the other phase. Hence, the amount of angular displacement and its direction may be checked from the magnitude and phase of the output voltage of the

REVIEW QUESTIONS

2 Mark Questions

1. What is an resistance transducer?
2. What is a strain gauge?
3. Mention the types of strain gauge?
4. What is a LVDT?
5. What is a RVDT?
6. What are the applications of LVDT?
7. What are the applications of RVDT?
8. What are the proximity sensors?
9. Mention the types of transducer?
10. What are the importance of strain gauge?
11. What is a resistive transducer?
12. What is a capacitive transducer?
13. What are the application of transducer?
14. What is a liquid level measurement transducer?
15. What is an inductive proximity sensor?
16. What is a capacitive proximity sensor?
17. What is a bonded strain gauge?

3 Marks Questions

1. State two applications of LVDT
2. List the importance of Strain gauge
3. Explain the bonded strain gauge
4. Explain the un bonded strain gauge
5. Write the application of strain gauge
6. Write the short notes on capacitive transducer
7. Write short notes on inductive transducer
8. Write short notes on Inductive proximity sensor?
9. List the advantages of capacitive transducer
10. List the disadvantages of capacitive transducer

11. What are the applications of capacitive transducer?
12. What are the advantages of LVDT?
13. What are the disadvantages of LVDT?
14. Give an example of transducer
15. What are the applications of strain gauge?
16. List the advantages and disadvantages of capacitive transducers
17. Write short note on liquid level measurement
18. What is the principle of RVDT?
19. What is the principle of LVDT?

10 Marks Questions

1. Explain the working with a neat diagram of a RVDT?
2. Explain the working with a neat diagram of a LVDT
3. Explain the working of resistance transducer?
4. Explain the difference between active and passive transducers. Give examples?
5. List out the advantage of electrical transducers over mechanical transducers?
6. With a neat circuit explain of strain gauge? Explain any one type?
7. Explain with a neat diagram and working principle of strain cage?
8. Explain with a neat diagram and working of capacitive transducers
9. Explain with a neat diagram and working of inductive proximity sensor and its working
10. Explain with a neat diagram and working of capacitance proximity sensor transducer
11. Explain the method of measuring strain using a strain gauge with a bridge circuit?
12. Explain with a neat sketch how pressure is measured using an inductive transducer?
13. Explain with a neat sketch of variable resistance transducer
14. Explain the working principle of a capacitive transducer as proximity sensor?
15. Explain the working principle of a measurement of pressure using inductive transducer
16. Explain the construction and working of a variable resistance transducer
17. Briefly explain the construction and importance of strain gauge
18. Explain with a neat diagram and working of resistive transducer

19. Explain the construction and working of liquid level measurement of capacitive transducer with neat sketches
20. Explain the difference between active and passive transducers. Give examples

UNIT-III

ACTIVE TRANSDUCERS

20.6. THERMOCOUPLE

A thermocouple is a kind of temperature transducer. It is an active transducer which generates thermal emf by the conversion of heat energy. It is very useful element for measuring temperature of extreme ranges.

1. Principle of Thermocouple

A thermocouple consists of a pair of dissimilar metal wires joined together at one end (sensing, or hot junction) and terminated at the other end (reference, or cold junction) which is maintained at a known constant, temperature (reference temperature). When a temperature difference exists between the sensing junction and the reference junction, an emf is produced that causes a current in the circuit.

Consider two dissimilar materials joined together in the form of a loop so that there are two junctions. Such .a system is illustrated in fig 3.1. If a temperature difference is maintained between these two junctions an electric current will flow round the loop.

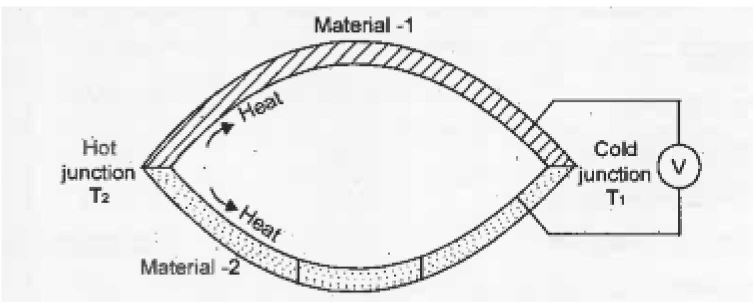


Fig3.1

The magnitude of the current will depend on both the materials used and the temperature difference of the junction (AT = T2 - T1). If the circuit is broken an open circuit voltage 'V appears across the terminals of the break as shown in fig 3.1.

When the reference junction is terminated by a meter or recording instrument, as shown in fig 3.1 the meter indication will be proportional to the temperature difference between the hot junction and the reference junction. This thermoelectric effect, caused by contact potentials at the junctions, is known as the Seebeck effect, named after the German physicist Thomas Seebeck. The sensing is based on the principle that a current flows in a closed circuit made up of two dissimilar metals. The magnitude of the thermal emf depends on the material of the wires used and on the temperature difference of the junctions.

Combination of material like iron-constantan, copper - constantan, chrome! (nickel-chromium), alimel (nickel- aluminium), chrome! -constantan, platinum rhodium-platinum, etc, are used as thermo, couple pair of materials for different range of temperature measurement

Thermocouple Material	Sensitivity (emf in m V per °K)	Temperature range (9(°K)
Copper-constantan	0.05	3-673
Iron-constantan	0.05	63-1473.
Chromel-alumel	0.04	3-1643
Chromel-constantan	0.08	3-1273
Platinum—platinum rhodium	0.01	223-2033

Figure 3.2 shows the use of a thermocouple for the measurement of unknown temperature.

It may be noted that extension wires are to be used when the measuring device is to be placed at a considerable distance from the same material as the thermocouple element. Thermocouple junctions are made by welding or soldering without using any flux. Industrial thermocouples generally have the hot junction in the process and the cold or the reference junction in the meter.

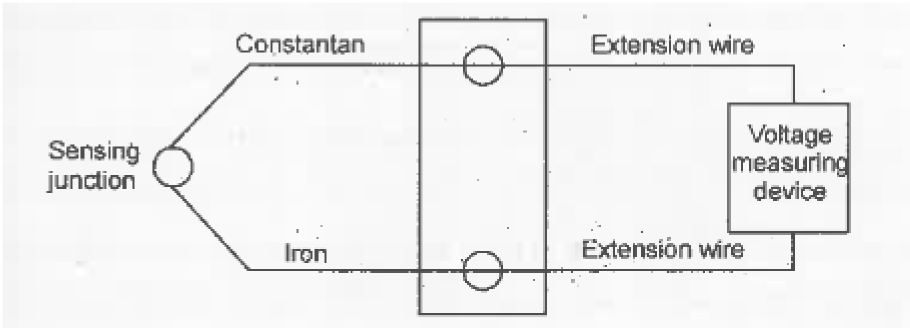


Fig3.2

This requires compensation by different techniques for ambient temperature variation. The thermo junctions are protected against contamination by enclosing them in protective sheaths.

Advantages

- Thermocouples are cheaper than the resistance thermometers.
- Thermocouples follow the temperature changes with a small time lag and as such are suitable for recording comparatively rapid changes in temperature.
- Thermocouples are very convenient for measuring the temperature at one particular point in a piece of apparatus.

Disadvantages

- They have a lower accuracy and hence they cannot be used for precision work.

2. Measurement of pressure using Thermocouples

A thermocouple vacuum gauge consists of a heater element (heated a temperature of 50° to 400°C by a known constant 'current) having a thermocouple in contact with its centre is shown in fig 3.3. This gauge operates on the principle that at low pressures, the thermal conductivity of a gas is the function of pressure.

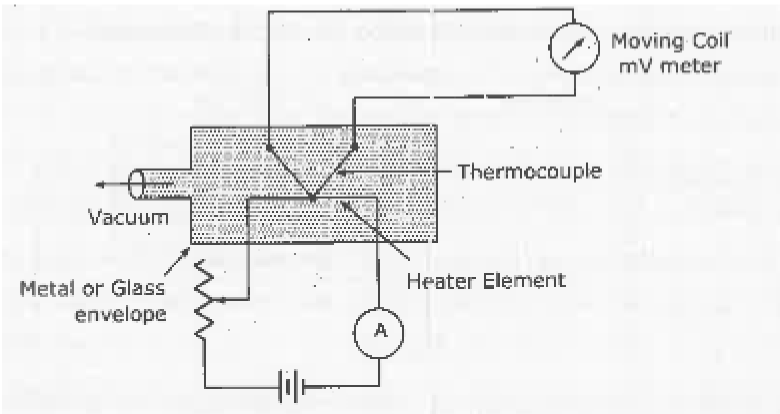


Fig3.4

The heater element and thermocouple are enclosed in a glass or metal envelope which is valued into the vacuum system. The heater element is heated by a constant current and its temperature depends upon the amount of heat which is lost to the surroundings by conduction and convection.

At pressure below 10-3 mm Hg, the temperature of the heater wire ¬is, a function of the pressure of surrounding gas. Thus the thermocouple provides an output voltage which is a function of temperature of heater element and consequently of the pressure of the surrounding gas. The moving coil instrument may be directly calibrated to read the pressure.

2.7. TACHO GENERATORS

A transducer that converts speed of rotation directly into electrical signal is called a tachogenerator. the purpose of tachogenerator is to convert angular speed into a directly dependent voltage signal. Such tachogenerators are commonly used for instrumentation in a control process, in providing feedback for constant speed servomechanism, For providing damping to stabilise unstable control systems. A tachogenerator is normally an integral part of the motor geared to its shaft.

It is basically a d. c. generator. the output voltage is collected from the armature through a brush and commutator arrangement and connected across a voltmeter which is calibrated in terms of rpm. For creation of magnetic field permanent magnets or separately excited field magnets are used. However, 'use of a permanent magnet system is more common. Figure 3.4 shows a d.c tachogenetator in diagrammatic form

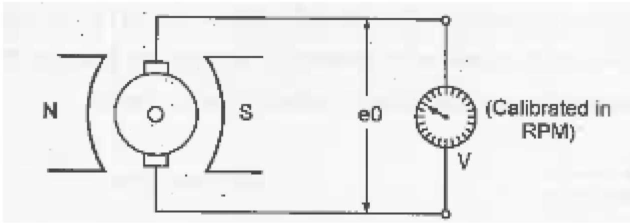
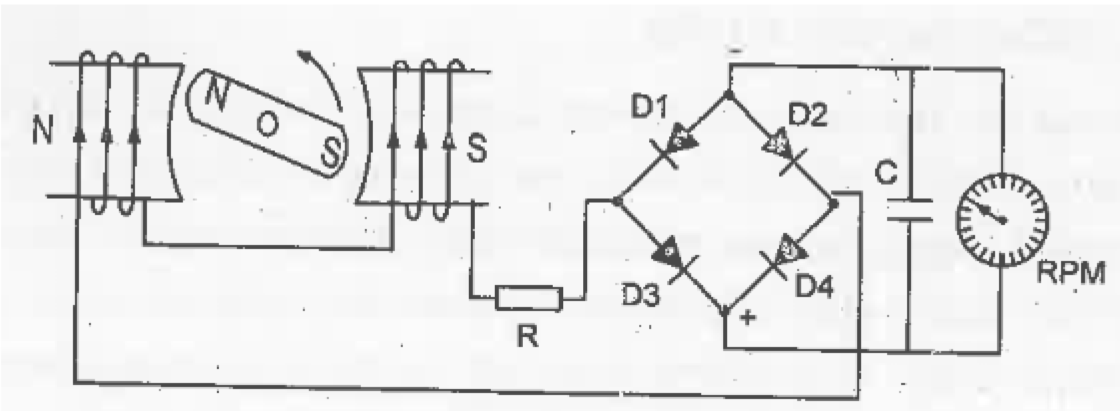


Fig3.4

The disadvantage with permanent magnet d.c tachogenerators is that of ageing and sensitivity to vibrations and mechanical shocks. However, use of superior magnetic material like alnico shoes better resistance to ageing.

As shown in figure 3.5. in an a. c. tachogenerator, rotation of a magnet induces alternation emf in the stator windings. The A.C. tachogenerators are used where control of speed is required a .c. winding has been shown as the stator. However, most often, three-phase windings are provided on the stator slots.



The output is connected to a bridge rectifier. This eliminates the use of the commutator and brush & in a conventional d. c. generator, which in turn reduces maintains problems. The reason for the use of three-phase windings in place of a single phase winding is that, the per unit weight of the tacho generators is reduced.

3.3. MEASUREMENT OF SPEED OR ANGULAR VELOCITY

The speed of any revolving member or a shaft can be measured using tacho generator. The fig 3.6 shows the arrangement of the measurement of speed of a rotating machine by means of a tacho generator which is sometimes called a tachometer.

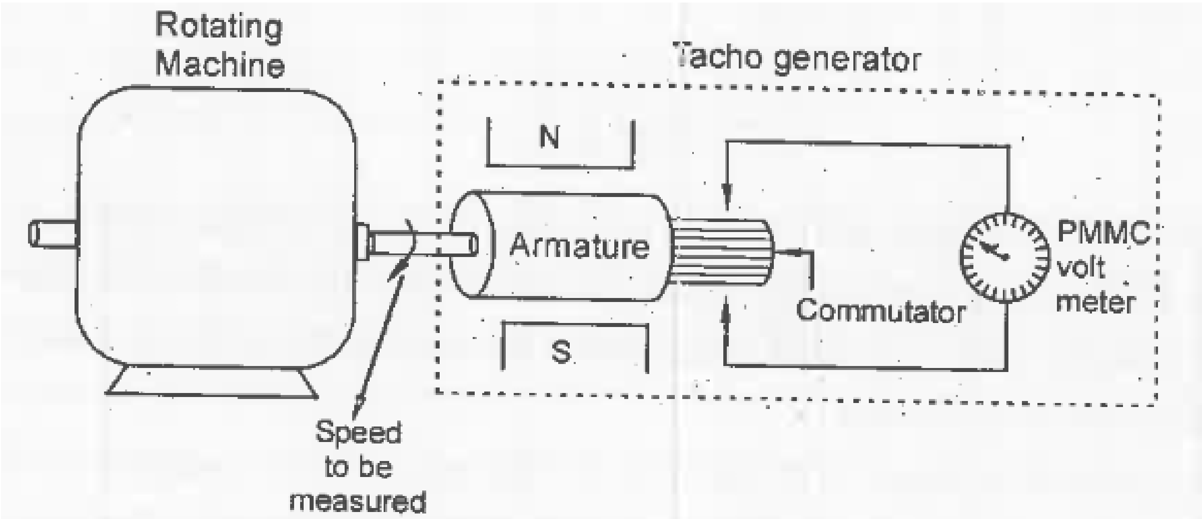


Fig3.5

The tachogenerator, is coupled to the shaft of the rotating machine. The rotation of the rotating machine is transmitted to the armature of the tacho generator. The armature revolves in the magnetic field provided by two permanent magnetic poles N and S. As such the voltage generated in the armature will be proportional to speed only. The polarity of voltage gives the direction of rotation. The voltage is fed to a voltmeter with uniform scale graduated directly in speed RPM.

The angular velocity of the rotating machine can also be measured in this method.

Let N be the speed of the machine indicated .by the tacho generator.

Then angular velocity $\omega = \quad 2\Pi N/60$ rad/sec

Advantages

- Direction of rotation is indicated by polarity of output voltage.
- The output voltage is generally about 10m V/RPM and can be measured with an ordinary voltmeter.

Disadvantages

- Due to variation in brush pressures errors are introduced in the speed measured.
- Maintenance of armature and brushes is difficult.
- Voltmeter input impedance should be high to minimize armature current drawn. Otherwise the armature reaction flux will be high and that will distort the main flux which will ultimately produce non-linear relation between speed and voltage. The readings obtained will be erroneous.

3.4 PIEZO-ELECTRIC TRANSDUCER

In piezoelectric crystalline material such as quartz, barium, titanite, etc. a potential difference appears across the opposite faces of them as a result of dimensional change due to the application of a mechanical force. This piezoelectric effect is reversible, i.e., if a potential difference is applied cross the opposite faces of the material, change in physical dimensions takes place.

The piezoelectric effect occurs only in crystals with asymmetrical charge distribution so that the lattice deformation is a relative displacement of the positive and negative charges within the lattice. The displacement of the internal charges produces equal amount of external charges of opposite polarity on the opposite sides of the crystal,. These charges can be measured by connecting two electrodes to the two opposite surfaces and measuring the potential difference between them.

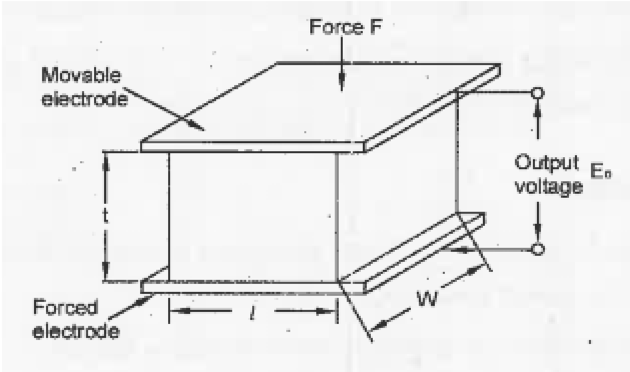


Fig3.7

Due to this inherent characteristic of piezoelectric materials, they can be used in various measurement application such as in measurement of force, pressure and acceleration (by properly calibrating the voltage scale in terms of force, pressure or acceleration). When force F is applied on the piezoelectric crystal along one 'axis, as shown in fig 3.7 mechanical deformations take place which generates a charge and the charge appears as voltage across the electrodes.

Charge $Q = dF$

Where d = charge sensitivity

F = applied force

Young 's modulus $E = \text{stress/strain} = F/A \div \Delta t/t$

$F = AE\ \Delta t/t$

where A = area of cross - section

Also, $Q = E_oC$

Where C = Capacitance between electrodes

$E_o = Q/C = dF/C$

But $C = \varepsilon_o \varepsilon_r A/t$

$E_o = dtF/\varepsilon_o \varepsilon_r A$, $E_o = dt/\varepsilon_o \varepsilon_r \times F/A = gtP$

Where, $g = d/\varepsilon_0\varepsilon_r$ and P=F/A , g is called the voltage sensitivity of the crystal and P is the pressure.

3.5. MEASUREMENT OF PRESSURE

Fig 3.8 shows a pressure transducer which 'utilities the property of piezoelectric crystals.

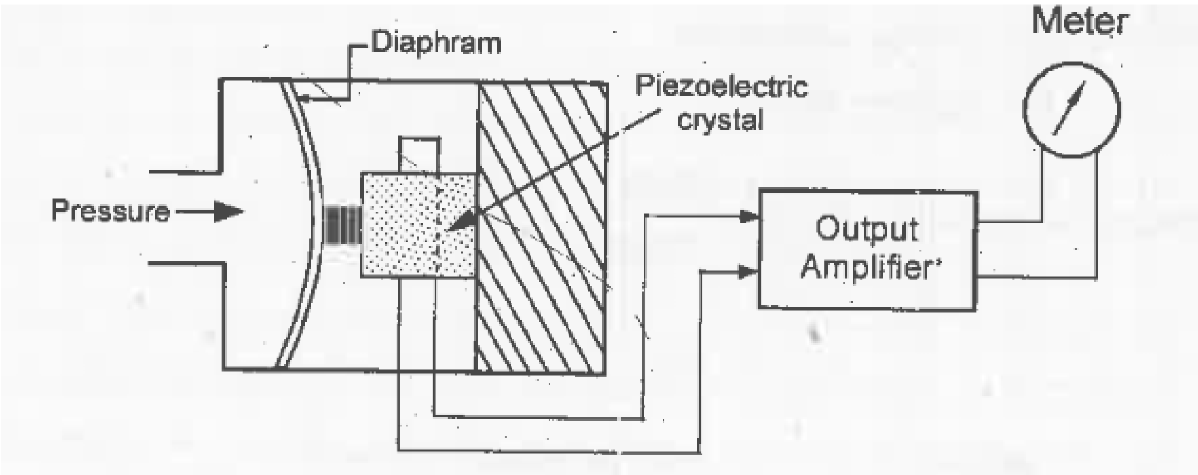


Fig3.8

The transducer consists of a diaphragm by which pressure is transmitted to the piezoelectric crystals This crystal generates an emf across its two surface proportional to the magnitude of the applied pressure. The device needs no external source of power and is therefore self-generating. The generated emf can be amplified to drive a meter so as to indicate the pressure. The main disadvantages of this kind of transducer are they cannot measure static condition, and the output voltage is affected by the temperature variations of the crystal.
Piezoelectric pressure transducers are used in measuring high pressure that changes rapidly like the inside pressure of the cylinder of a gasoline engine, compressors, etc.

3.6. MEASUREMENT OF VIBRATIONS

Fig 3.9 shows the vibrating transducer which utilities the property of piezoelectric crystal.

The transducer consists of a member by which vibrations are transmitted to the piezoelectric crystal. When the crystal is subjected to vibrations, the crystal generates an a.c emf across its opposite two surfaces proportional to the magnitude of the vibrations.

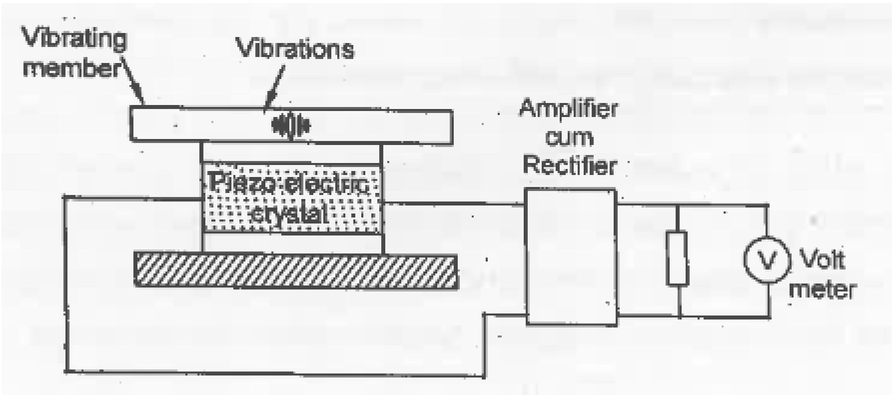


Fig3.8

The device needs no external source of power and is therefore self-generating. The generated emf can be amplified to drive a meter so as to indicate the vibrations:

The main advantage of this kind of transducer is that it can measure the vibrations accurately.

Uses of Piezo electric transducers

(i) The use of piezo electric transducer element is confined primarily to dynamic measurement. Hence the elements are primarily used in the measurement of quantities as surface roughness and in accelerometers and vibration pickups.

Ultrasonic generator elements also use barium titanate, a piezo electric material. Such elements are used in industrial cleansing apparatus and also in under water detection system known as sonar.

3.7. HALL EFFECT TRANSDUCERS

The transducer which uses the Hall Effect of strip of a semi conductor material when it is exposed to the unknown magnetic field is called as Hall Effect transducer.

If a strip of conducting material carries current in the presence of a transverse magnetic field, an emf is produced between the opposite edges of the conductor. The effect that products an emf by the transverse magnetic field its called as Hall effect.

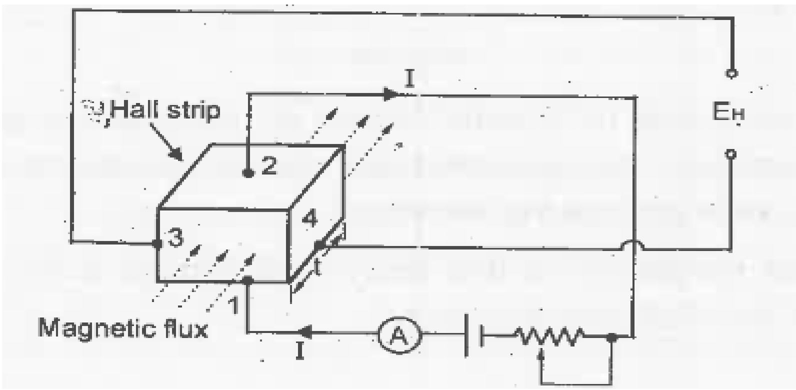


Fig 3.10

Let us consider an arrangement of a strip through which current

I is passed through leads 1 and 2 of the strip as shown in fig.3.10. The output leads connected to edges 3 and 4.

Output leads are at the same potential when there is no transverse magnetic field passing through the strip. NYE, = 0

When a transverse magnetic field passes through the strip output voltage EH appears across the output leads. This voltage is proportional to the current and the field strength

The magnitude of the voltage depends upon the current, flux density and property of conductor called "Hall effect Co-efficient". The emf can be measured after sufficient amplification, because it will be very weak signal at the time of production.

The Hall Effect is present in most of the metals and semi conductors in varying amounts, depending upon the densities and motilities of carries.

A number of materials exhibit the Hall Effect, but in many cases it is so small that it has no practical value. Germanium can be manufactured with a very high Hall coefficient, and germanium probes to measure magnetic flux are used for small flux densities. Hall Effect elements are extensively used in magnetic measurement. They can also be used for sensing of current.

Applications of Hall effect transducers

- Magnetic to Electric Transducer.
- Measurement of Displacement

- Measurement of Current
- Measurement of Power

1. Magnetic to electric transducers

The Hall Effect transducer can be used as a magnetic to electric transducer. A semiconductor plate is inserted in to the magnetic field to be measured. The magnetic lines of force are perpendicular to the semi conducting plate. The transducer gives an output voltage which is proportional to B, the magnetic field density. The system has the advantage of requiring a very small space in the direction of the magnetic field and therefore, the Hall element can be inserted in narrow gaps for magnetic measurement in air spaces. Also the element gives out a continuous electric signal in direct response to the magnetic field strength.

2. Measurement of displacement

The Hall Effect element can be used for the measurement of the location or displacement of a structural element. i.e. it can serve as an indirect acting position displacement or proximity cases where a change of geometry of a magnetic structure causes a change of magnetic field strength. An example is shown in fig 3.11 which shows a Ferro magnetic structure having a permanent magnet.

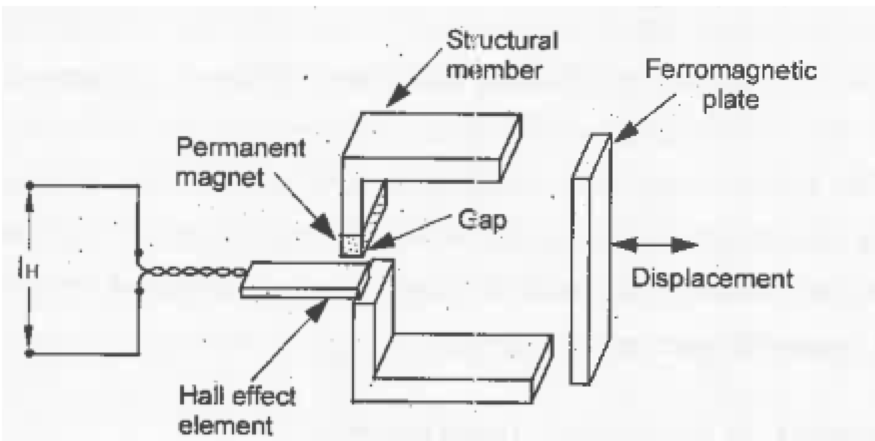


Fig3.11

The Hall Effect transducer is located in the gap adjacent to the permanent magnet. The field strength is produced by the permanent magnet plate. The voltage output of the Hall Effect transducer is proportional to the field strength in the gap which is a function of the position of the ferromagnetic plate from the structure i.e. the displacement. The method permits measurement of displacement down to 0.025mm.

3. Measurement of current

An interesting application of Hall Effect transducer is shown in fig 3.12 the device serves to measure current in a conductor without the need for interrupting the circuit and without making electrical connection between the conductor circuit and the meter. (This is similar in action to the clamp on ammeter described) A current (d.c. or a.c.) passes through the conductor and set up a magnetic field surrounding the conductor.

This magnetic field is proportional to the current. A Hall Effect transducer is placed in a slotted Ferromagnetic tube which acts as a magnetic concentrator.

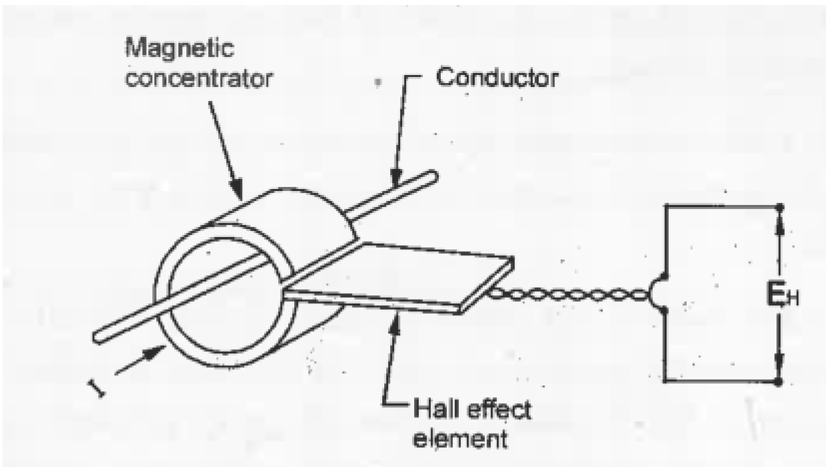


Fig3.12

The voltage produced at the output terminals is proportional to the magnetic filed strength and hence is proportional to the current flowing in the conductor. The system can be used for measurement of currents from less than a mA to thousands ampere. At high current levels, the magnetic concentrator can be omitted since field is fairly strong in the vicinity of the Hall Effect element and thus can cause appreciable output voltages which can be easily detected.

4. Measurement of power

The measurement of power can be achieved using a Hall Effect transducer.

3.8. PHOTOVOLTAIC CELLS (SOLAR BATTERY)

There are devices generate electrical energy when light impulse is applied on them. These are also known as photovoltaic cells. They are also made of semiconductor materials such as silicon, selenium, etc. they convert light energy into electric energy and in doing so they do not require any external power. That is why they are also classified as active electric transducers.

A solar cell is the most popular example of this class of device. The P-N junction of silicon material is generally used to produce a photovoltaic cell. A limitation of this device is its Vow efficiency. Usually

Large banks of solar cells (connected in series)a re required to generate sufficient voltage.

Generally photo voltaic cells are illuminated by the sun solar energy for the generation of electrical energy. Hence they are called solar cells.

Photovoltaic cells are also called a solar energy converter. The current flow from a Photovoltaic cell may be used to power electronics devices. Such energy converts using sunlight as the primary energy are called solar batteries. A solar battery consists of a number of solar cells.

Working of Solar cell

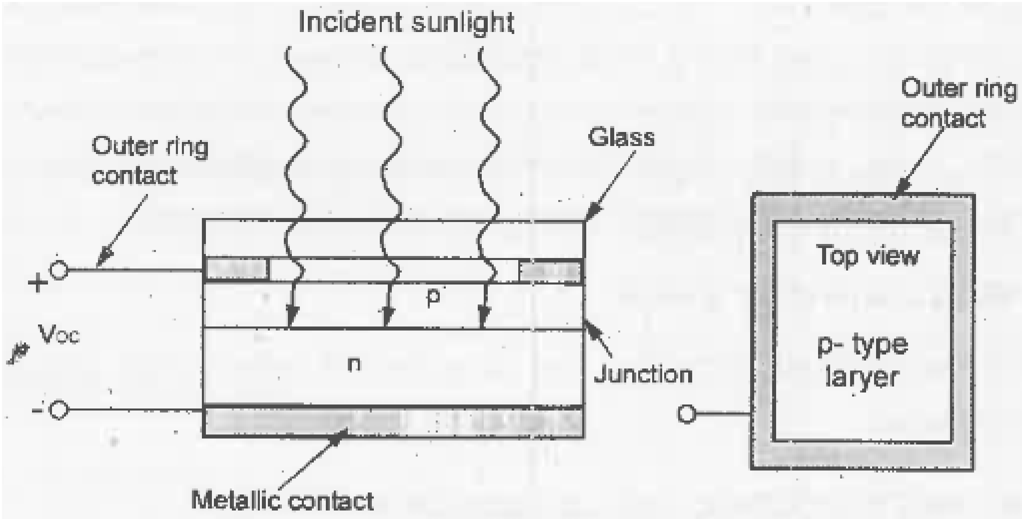


Fig 3.13

Fig 3.13 shows the construction of a solar cell where a thin piece of silicon is mounted on a light weight backing system. The silicon wafer is made with an N-P junction near ifs surface. This may be either N on P or P on N. The N layer contains as excess of electrons the P layer an excess of holes; at the junction thermal diffusion causes t he electrons to migrate to the P layer and the holes to migrate to the N layer, leaving a thin layer of hole and electron-free silicon.

A photon with the requisite energy will be absorbed by one of the silicon atoms in the equilibrium area, creating an electron hole pair. The field at the junction will carry the electron into the N layer hole pair.

1. Solar Photo Voltaic Module

The individual solar cell is small ,usually 2 x 2 cm to 8 x 8 cm, and thus cannot supply much power. It is necessary to join the thousands to individual cells in a series-parallel array or combination to obtain the voltage and current necessary to supply the load (in direct noon-day sunlight a solar cell generates an open circuit voltage of about 0.6V only).

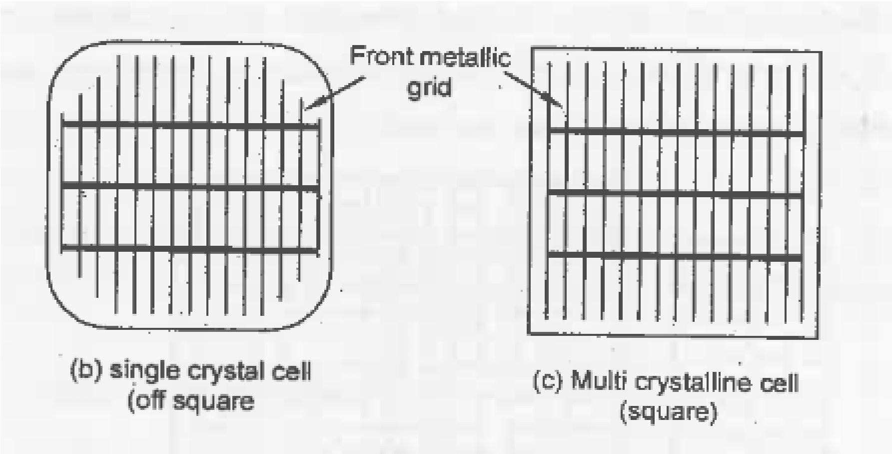


Fig3.14

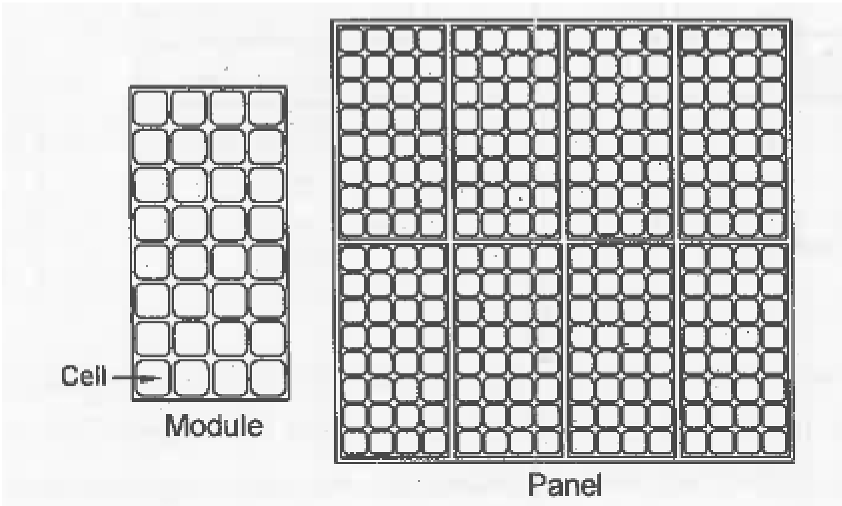
A bare single cell cannot be used for outdoor energy generation by itself. It is because (i) the output of a single cell is very small, and (ii) it requires protection (capsulation) against dust, moisture, mechanical shacks and outdoor harsh conditions. Workable voltage and reasonable power is obtained by inter connecting an appropriate number of cells. The unit is fixed on a durable back cover of several square feet, with a transparent cover on the top and hermetically sealed to make it suitable for outdoor applications. This assembly is known as ,solar module-a basic building block of PV system.

The most common commercial modules have a series connection of 32 or 36 silicon cells to make it capable of charging a 12-V storage battery. However, larger and smaller capacity modules are also available in the international market.

2. Solar PV Panel

Large number of cells solar can be arranged for supplying power to loads under 10 KW. Overall cell efficiency approaches 12 percent with a practical limit of 16 percent. The cell is readily damaged by space radiation, and therefore very thin covers are used for protection against such damage.

Several solar modules are connected in series / parallel to increase the voltage/current ratings. When modules are connected in se-tries, it is desirable to have each module's maximum power production occur at the same current.



When modules are connected in parallel, it is desirable to have each module's maximum power the installer should have this information available for each module. Solar panel is a group of several modules connected in a series-parallel combination in a frame that can be mounted on a structure. Fig 3.15 shows the construction of module and, panel.

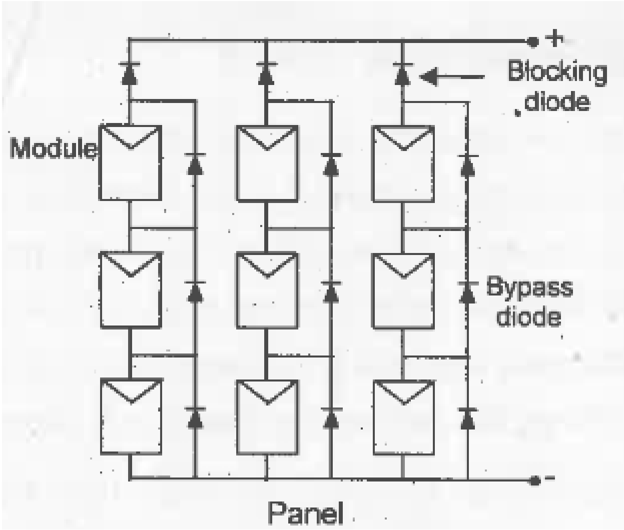


Figure 3.16 shows a series-parallel connection of modules in a panel. In a parallel connection, blocking diodes are connected in series with each series string of modules, so that if any string should fail, the power output of the remaining series strings will not be absorbed by the failed string. Also, bypass diodes are installed across each module, so that is one module should fail; the output of the remaining modules in a string will bypass the failed module. Some modern PV modules come with such internally embedded bypass diodes.

Applications of Solar Cells

- Pumping water for the purpose of drinking or for minor irrigation during sunshine hours is a very successful application of a stand alone PV system without storage
- In dark situations lighting is required when the sun is not available, but battery storage is essential.
- Solar PV power can be used to meet low energy demands of many remote, small, isolated and generally unapproachable villages in most developing countries.
- On highways, SPV power is being used for lighted road signs and highway telephone booths even in many industrialized nations.
- Power source for satellite system.

3.9. PHOTOCONDUCTIVE CELLS

Photo resistors are generally prepared either by coating a layer of powdered photosensitive material or by depositing a semiconductor film on an insulating base. Silicon is usually preferred for this purpose. The semiconductor film deposited on an insulating substance constitutes a unit which is placed in either a metallic or a plastic case whose top surface is covered with glass.

The glass cover of the compact unit allows light rays to reach the semiconductor coated surface and accordingly the resistance changes. They are usually made in the form of cadmium sulphide discs provided with two tinned copper connecting leads. Rating and performance of the device shown in fig 3.17, are characterized by the value of current flowing through the device at a given voltage and the amount of light flux.

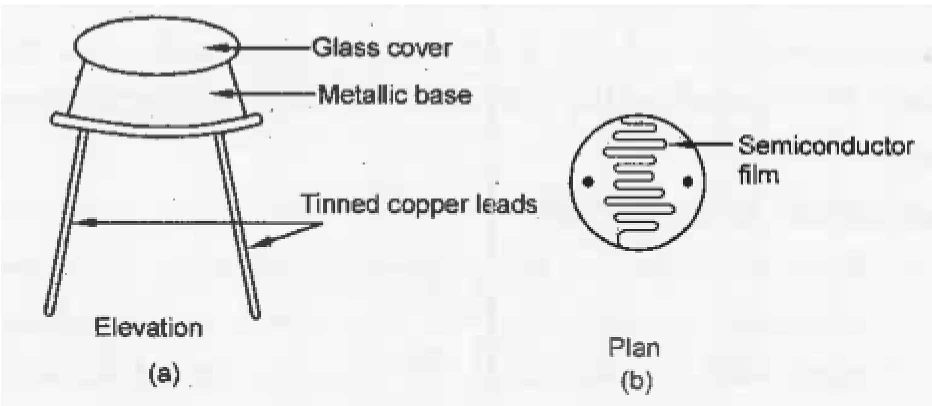


Fig3.17

A photoconductive cell is basically a light dependent resistor (LDR) made of some semiconductor material. The device when kept in darkness poses very high resistance of the order of several hundred mega ohms. When the device is kept in darkness and supplied with some external potential, owing to the very high resistance, almost a negligible amount of current flow in the circuit. This is called the dark current. On illuminating the device, its resistance decreases to a low value and hence immediately a large amount of current starts flowing.

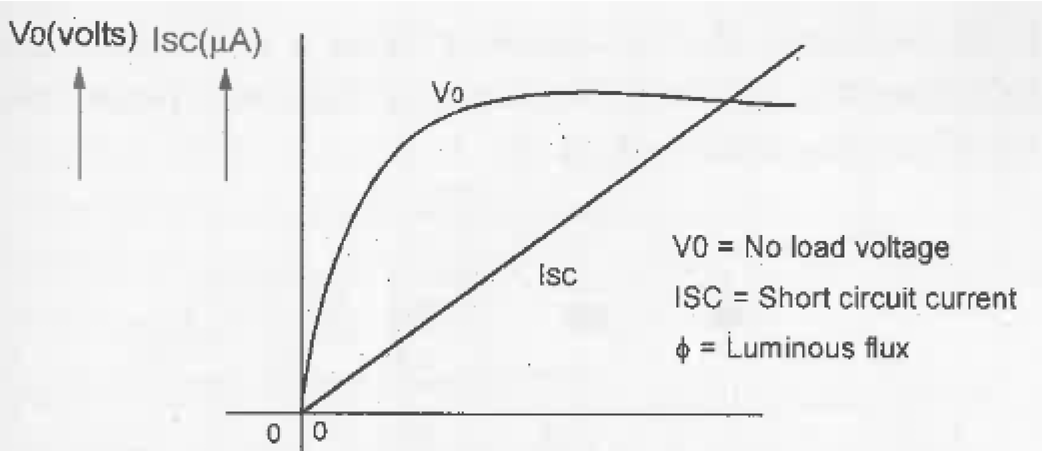


Fig 3.18

The i--r drop of the device appears as the voltage drop across it. Sensitivity of this device is found to be of the value of a few mill amperes per unit lux (mA/lm). This is greater than the sensitivity of gas filled and vacuum photo cells. The heat dissipation of the devices is of the order of 100mw to 1w.

Photoconductive cells are used for the following purposes:

3. Recording situations where fast changes take place.
4. Measuring light quantity (light metre)
5. As a light operated ON-OFF relay
6. Recording a modulating light intensity
7. Light sensitive trips and alarms.

Cadmium sulphide cell is the photoconductive cell most widely used. The surface of this cell has a coating of cadmium sulphide. This coating also contains some impurities like antimony, indium nitrate etc. which increases the efficiency of the device. The cadmium sulphide cells have a very high dissipation capability and sensitivity. A lead sulphide cell is another photoconductive cell which is used for infrared spectrums, viz. infrared detection of infrared absorption measurements

Automatic street lighting circuit using LDR

The device is basically a switch which automatically provides supply to the lamp when kept in darkness. Change of resistance of the light dependent resistor (LDR) aces as an automatic switch. The circuit has been shown in fig 3.19.

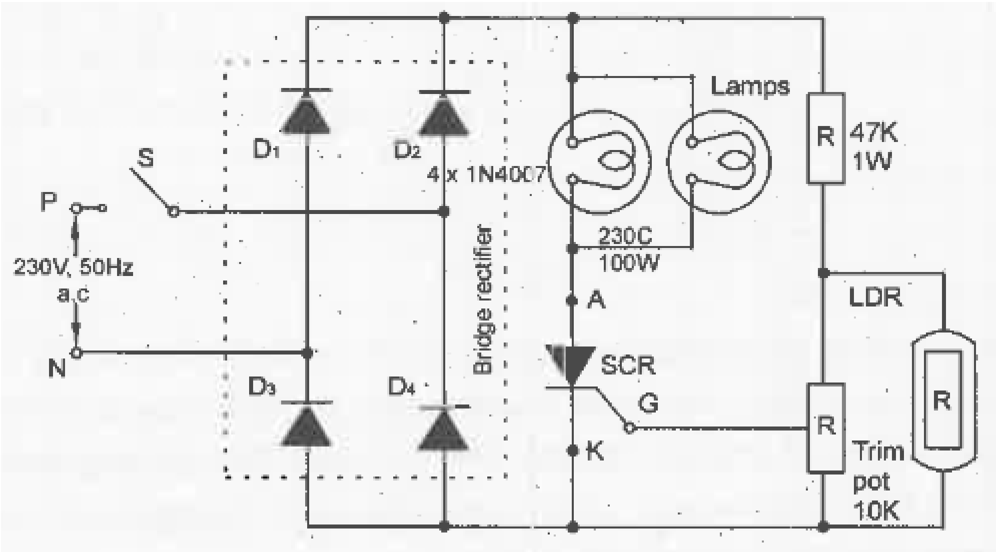


Fig3.19

The working of this circuit is as follows

The mains a.c. supply is rectified by means of a full wave bridge rectifier formed with the help of four diodes D1, D2, D3 and D4. A part of this rectified d.c. voltage is fed to the gate of the SCR. This is done by means of a potential divider arrangement made with the help of a 47K resistor and a 10K pot. To limit the gate current, a 10 K pot has been used.

During the day when the LDR receives enough light, its resistance becomes very low may be a few ohms only. In this condition the current flows through the 47K resistor and the LDR by passing the 10K pot. Under such conditions no signal will be available at the gate of the SCR and the SCR will remain in the OFF state.

The lamps connected in the circuit will not be energized. On the other hand, towards evening, when the quantity of light falling on the LDR surface reduces, its resistance will increase gradually of light falling on the LDR surface reduces, its resistance will increase gradually and in total darkness its resistance will become very high. With the LDR posing a very high resistance in the circuit, current will flows through the 47 KΩ resistors and through the 10 KΩ pot instead of flowing through the LDR.

As soon as the current starts flowing through the 10KΩ pot, the signal will be available at the gate of the SCR. This would enable the SCR to trigger immediately. The moment, the SCR would start conducting the lamps will get energized and start glowing.

The 10 K pot can be adjusted to switch ON the SCR at a predetermine illumination level. In this circuit it is observed that the LDR works as a triggering agent for the SCR which in turn acts as an automatic switch for the lamp. While installing this device, care should be taken to mount the LDR in such a position that no shadow is cast on its surface during the day time.. A proper heat sink should be used for mounting the SCR.

3.10. NUCLEAR INSTRUMENTATION

A lot of instrumentation is needed to measure the amount of radioactivity encountered in nuclear research work and for tracking of radiated alpha, beta and gamma particles.

The energy of these particles is absorbed by other molecules, producing chemical changes, ionization, or other reactions that produce visual evidence of the presence of other particles. These processes are used to detect, count and trace the movement of such particles.

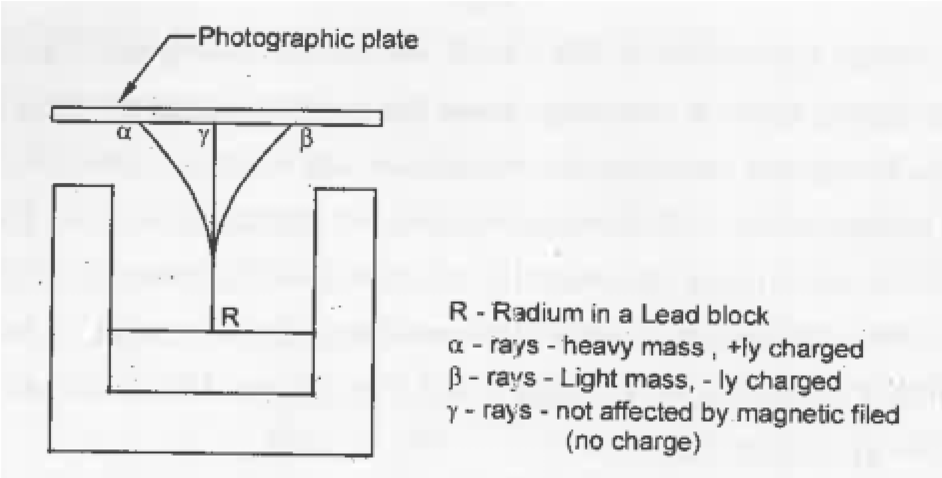


Fig3.20

Types of Radiations

Radioactive materials emit nuclear radiations which mainly consist of four parts.

1. **Alpha particles**

The alpha particle is a helium nucleus consisting of two protons and one neutron. It has a mass of 62x10'27kg and carries a positive charge of 3.2 x 10-9C. The alpha particle is the heaviest and the slowest, travelling at speeds of from 1/10 to 1/100 of the velocity of light. Since it has the greatest mass and slowest speed, it is least penetrating. It penetrates about 0.02 mm of Aluminium foil.

2. **Beta Particles**

The beta particle is an electron with a mass of 9.03 x 10-31kg and a charge of 1.6x10-19C. Since beta particle is much lighter than alpha particle and has a speed approximately equal to that of light, it can penetrate much farther than alpha particle- about 100 times the penetration of alpha particle.

3. **Gamma Particles**

Gamma particles or gamma rays, are an electromagnetic radiation with a wavelength of approximately 0,03 to 3 angstrom. Gamma particles travel at the speed of light, and because of their shorter wavelength, has great penetrating power. Gamma rays can penetrate about 20 cm through a mass of lead.

4. **Neutrons**

The Mass of the neutron is intermediate between that of alpha and beta particles, having the same mass as a proton. The speeds of neutrons may be high or low depending upon the source from which they are emitted. Because neutron has no charge it is very difficult to detect. However, its penetrating power is small.

The above mentioned properties and other properties of these particles must be considered in the methods and processes for their detection and measurement. In the following pages, a few methods of detection and measurement of the above mentioned particles are described.

3.11. MEASUREMENT OF RADIATION USING GEIGER MULLER TUBE

The Geiger Muller tube or simply Geiger tube are frequently used for detection and measurement of alpha, beta and gamma rays. This tube is a diode, consisting of a cathode which is a long metal cylinder and an anode which is a fine wire running through the centre of the cylinder.

Both of them are mounted in a thin walled, air tight, glass envelope, sealed by an extremely thin window through which radiations may pass at one end. The air is evacuated from the envelope and a small amount of an inert gas, such as Argon, is added.

The voltage of the battery is kept below the ionization potential of the gas. Now if radiation penetrates through the window and enters the envelope it would ionize some of the gas atoms. The resulting negative ions go towards the anode and positive ions towards the cathode.

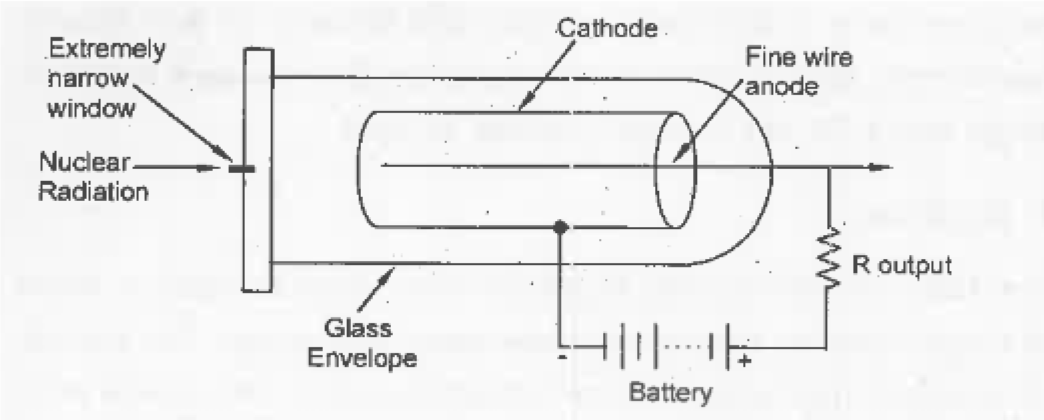


Fig3.21

In their passage, the ions collide with some of the gas atoms, causing them to be ionized in turn. This process continues till whole of the gas atoms are ionised. In fact complete ionization takes place in no time. A pulse of current: thus flows through the tube. This current is flow through the resistance R, which is connected in the anode circuit.

The resulting voltage drop across R is the output the tube, the ionization starts and a current again flows through resistance R giving an output voltage. This way a series of alpha or beta particles or bursts of gamma rays, Cause a series of current pulses to pass through the anode circuit 01 the tube and hence through resistance R.

The output pulses from resistance R .may be amplified and registered by a counting device. By counting the number of pulses, we can know the number of particles entering the Geiger Muller tube in a particular interval of time. The number counted gives the intensity of radiation. The pulses may be stored in some cases and the total count may be calibrated directly in terms of radio-activity.

The counting rate of this tube is seldom greater than 103 counts are second.

REVIEW QUESTIONS

2 Mark Questions

1. What is a Thermocouple?
2. What is a tacho generator?
3. What is a DC tacho generator?
4. What is a pressure transducer?
5. What is a vibrations sensor?
6. Define Hall Effect transducers
7. What are the applications of Hall Effect transducer?
8. What is photo voltaic cell?
9. What is a solar photo voltaic module?
10. What is a photo conductive cell?
11. Explain the working of measurement of vibrations by piezoelectric crystal
12. Explain the working of working of solar cell?
13. State the working principle of thermocouple?
14. Mention the speed angular velocity
15. What is a Hall Effect transducer?
16. What is a nuclear instrumentation?
17. What is a Geiger Muller tube?
18. State the principle of thermocouple
19. Mention the material of thermocouple
20. What is a AC tacho generator?
21. State the application of Hall Effect
22. What is the material used for Hall Effect

3 Mark Questions

1. List the advantages and disadvantage of thermocouples
2. Write short notes on thermocouple?
3. Write short notes on tacho generators
4. Write the advantages of tacho generators
5. Write the disadvantages of tacho generators 6: Write short notes on Hall Effect transducer?

6. Explain the short notes sole: - photo voltaic module
7. List the applications of Hall Effect transducers?
8. Explain measurement of displacement
9. Mention the types of application of solar cell
10. List the advantage of thermocouple
11. List the disadvantage of thermocouple
12. Write a short notes on measurement of gas pressure thermocouples
13. Explain the procedure of measuring speed
14. Explain the procedure of 'measuring angular velocity
15. Explain the working of Giger muller tube
16. Write the applications of solar cell
17. List the types of nuclear instrumentation

10 Mark Questions

1. Explain with a neat diagram and working of thermocouple?
2. Explain the construction and working of a Giger Muller counter to measure radiation at a site.
3. Explain with a neat diagram and principle of piezoelectric transducers?
4. Explain the construction and working of A.C. Tacho generator?
5. Explain the construction and working of D.C. Tacho generator?
6. Explain the construction and working principles of a thermocouple?
7. Explain with a neat diagram construction and working of measurement of pressure?
8. Explain with a neat diagram construction and working of measurement of vibrations?
9. Draw and explain the working of a D.C. tacho generator. List the advantages and disadvantages
10. Explain with a neat diagram and working principle of measurement of pressure using thermocouple
11. Explain with a neat diagram and working principle of measurement of speed or angularvelocity
12. Briefly explain with a neat diagram of Piezoelectric transducer
13. Explain the construction and working of a magnetic to electric transducers
14. Explain the neat diagram and working of Hall Effect transducers

15. Explain the construction and working principles of photovoltaic cells
16. Explain with a neat diagram and working of photo conductive cells.
17. Explain the working of solar photo voltaic module and solar PV panel
18. Explain the principle of automatic street lighting circuit using LDR
19. Explain the working of Hall Effect transducer applications
20. Draw and explain the automatic street lighting circuit using LDR
21. Briefly explain the working of nuclear instrumentation
22. List the advantages and disadvantages of thermocouples
23. Explain the working of a D.C. tachogenerator. List the advantages and disadvantages.
24. Explain the working principle of a Piezoelectric transducer for pressure measurement

UNIT-4 OPERATIONAL AMPLIFIERS

Operational Amplifier is basically an excellent high gain d.c. amplifier. In the analog computers, it is used to perform a variety of mathematical operations such as addition, subtraction, multiplication etc. Due to its use in performing mathematical operations it has been given a name operational amplifier. Because of their low cost, small size, versatility, flexibility and dependability, op-amps are used in the fields of process control, communications, computers, power and signal sources, displays and measuring systems.

Op-amp symbol & terminals

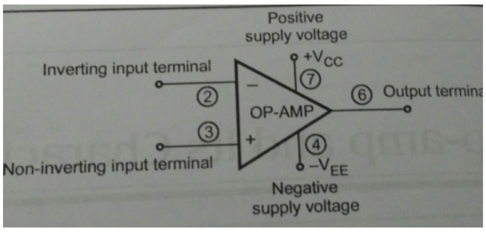


Fig.4.1. Op-amp symbol with terminals

The symbol for an op-amp along with its various terminals, is shown in fig .4.1

The op-amp is indicated basically by a triangle which points in the direction of the signal flow.

All the op-amps have the following five terminals:

1. The positive supply voltage terminal v_{cc} or + v .
2. The negative supply voltage terminal $-v_{ee}$ or –v .
3. The output terminal.
4. The inverting input terminal, marked as negative.
5. The non inverting input terminal, marked as positive.

4.1. Block Diagram of Operational amplifier

op-amps are available in an integrated circuit from. Commercial integrated circuit op-amps usually consists of four cascaded block. The block diagram of IC op-amp is shown in the Fig 4.2.

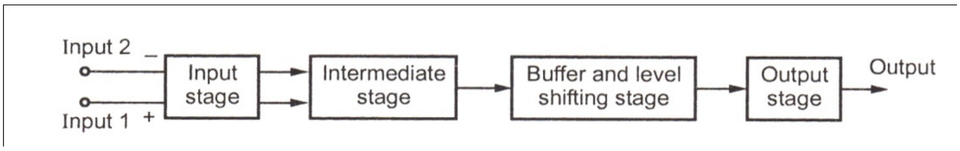


Fig.4.2. Block Diagram of op-amp

Input Stage

The input stage requires high input impedance to avoid loading on the sources. It requires two input terminals. It also requires low output impedance. All such requirements are achieved by using the **dual input, balanced output differential amplifiers** as the input stage. The function of differential amplifier is to amplify the difference between the two input signals. The differential amplifier has high input impedance. This stage provides most of the voltage gain of the amplifier.

Intermediate Stage

The output of the input stage drives the next stage which is an intermediate stage. This is another differential with dual input, unbalanced i.e. single ended output. The overall gain requirement of the op-amp is very high. The input stage alone cannot provide such a high gain. The main function of the intermediate stage is to provide an additional voltage gain required. Practically, the intermediate stage is not a single amplifier but the chain of cascaded amplifiers called multistage amplifiers.

Level Shifting Stage

All the stages are directly coupled to each other. As the op-amp amplifies d.c. signals also, the coupling capacitors are not used to cascade the stages. Hence the d.c. quiescent voltage level of previous stage gets applied as the input to the next stage. Hence stage by stage d.c. level increases well above ground potential. Such a high d.c voltage level may drive the transistors into saturation. This further may cause distortion in the output due to clipping. This may limit the maximum a.c. output voltage swing without any distortion. Hence before the output stage, it is necessary to bring such a high d.c. voltage level to zero volts with respect to ground.

The **level shifter** stage bring the d.c. level down to ground potential, when no signal is applied at the input terminals. Then the signal is given to the last stage which is the output stage.

The buffer is usually an **emitter follower** whose input impedance is very high. This prevents loading of the high gain stage.

Output Stage

The basic requirements of an output stage are low output impedance, large a.c. output voltage swing and high current souring and sinking capability.

The **push-pull complementary amplifier meets** all these requirements and hence used as an output stage. This stage increases the output voltage swing and keeps the voltage swing symmetrical with respect to ground the stage raises the current supplying capability of the op-amp.

In short, the overall block diagram can be shown as in the Fig.4.3.

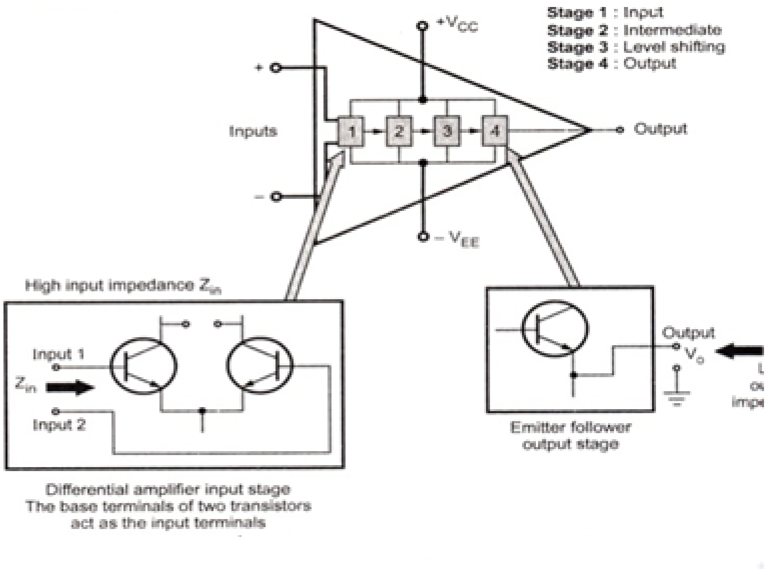


Fig.4.3. Block Diagram of an operational amplifier

4.2 Signal conditioning

Introduction

The primary objective of industrial process control is to control physical parameters such as temperature, pressure, flow rate, level, force, light intensity, and so on. The process control system is designed to maintain these parameters near some desired specific value. These parameters can change either spontaneously or because of external influences. So, we must constantly provide corrective action to keep these parameters constant or within the specified range.

To control the process parameter, we must know the value of that parameter and hence it is necessary to measure that parameter. **In** general, a measurement refers to the transduction of the process parameter into some corresponding analog of the parameter, such as a pneumatic pressure, an electric voltage, or current.

A **transducer** is a device that performs the initial measurement and energy conversion of a process parameter into analogous electrical or pneumatic information. Many times further transformation or signal enhancement may be required to complete the measurement function. Such processing is known as **signal conditioning**.

4.2.1 Electronic aided measurement system:

For any measurement system, the first stage detects the physical quantity to be measured, and this is done with the help of suitable transducer. The next stage converts this signal into an electrical form. The second stage is used to amplify the converted signal such that it becomes usable and suitable for the last stage which is signal conditioning stage. The last stage includes various elements used for different purposes such as indicating, recording, displaying, data processing and control elements. A typical electronic aided measurement system is as shown in the Fig 4.4.

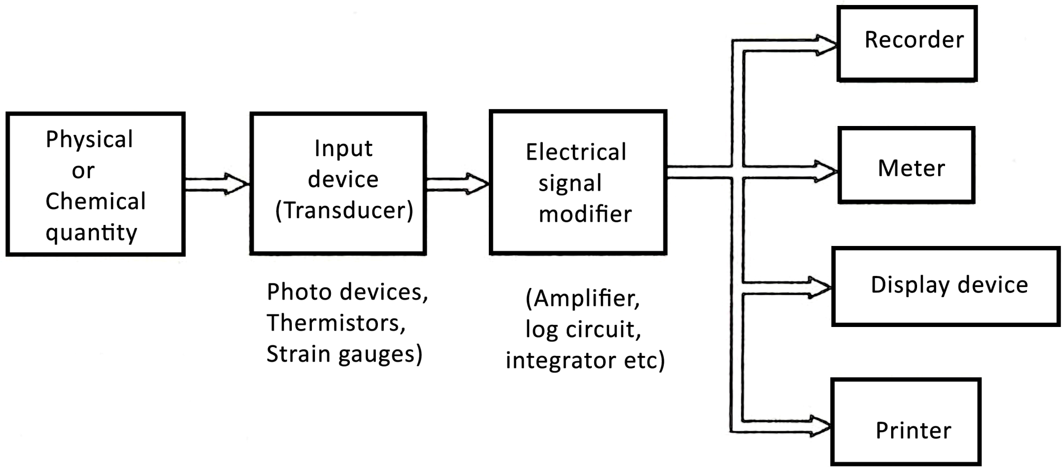


Fig 4.4: Block diagram of Electronic aided measurement system.

The first stage is the input device which is a transducer, it converts physical quantity into an usable form i.e. electrical signal. In other words, the quantity measured is encoded as an electrical signal. The next stage modifies the electrical signal in the form suitable for the output or read-out devices. Generally the most frequently used electronic circuits are amplifiers, with parameter adjustments and automatic compensation circuits specially used for temperature variation of the input device and non-linearity's of the input device. The output is obtained from read-out devices such as meter, recorder, printer, display units etc. In general, the quantity which is measured by using transducer can be encoded in different ways.

The electronic aided measurement system represents the measurement of physical quantity faithfully in the analog or digital form of it, obtained from the signal conditioning circuits. For passive transducers, the signal conditioning circuit mainly includes excitation and amplification circuitry, while for active transducers, only amplification circuitry is needed and the excitation is not needed.

Depending on the type of the excitation either a.c. or d.c. source, we have a.c. signal conditioning system and d.c. signal conditioning system.

4.2.2 D.C. Signal Conditioning System:

The block diagram of d.c. signal conditioning system is shown in the Fig 4.5

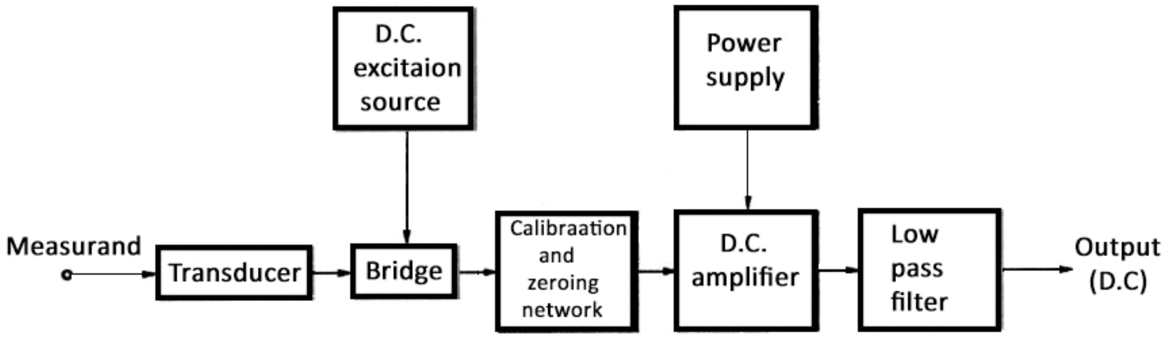


Fig 4.5: DC signal Conditioning System.

The resistance transducers are commonly used for the d.c. systems. The resistance transducers like strain gauge form one or more arms of a Wheatstone bridge circuit. A separate d.c. supply is required for the bridge. The bridge is balanced using potentiometer and can be calibrated for unbalanced conditions. This is the function of Calibration and zeroing network. Then there is d.c. amplifier which also requires a separate d.c. supply.

The d.c. amplifier must have following characteristics:

- Balanced differential inputs.
- High common mode rejection ratio. (CMRR)
- High input impedance.
- Good thermal and long term stability.

The d.c. system has following advantages:

- It is easy to calibrate at low frequencies.
- It is able to recover from an overload condition.

But the main disadvantage of d.c. system is that it suffers from the problems of drift. The low frequency spurious unwanted signals are available along with the required data signal. For overcoming this, low drift d.c. amplifiers are required. The output of d.c. amplifier is given to a low pass filter. The function of low pass filter is to eliminate unwanted high frequency components or noise from the required data signal. Thus the output of low pass filter is the required data signal. Thus the output of low pass filter is the required d.c. output from the d.c. signal conditioning system.

The applications of such system are in use with common resistance transducers are Potentiometers and resistance strain gauges.

4.2.3 A.C. Signal Conditioning System:

The limitation of d.c. signal conditioning system can be overcome up to certain extent, using a.c. signal conditioning system. The block diagram of a.c. signal conditioning system is shown in the Fig 4.6.

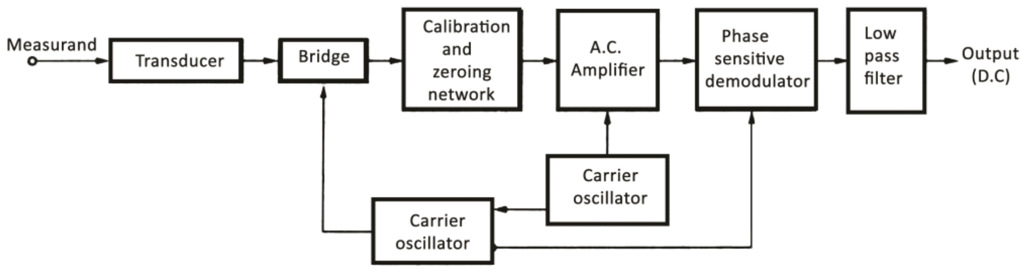


Fig 4.6: AC signal Conditioning System.

This is carrier type a.c. signal conditioning system. The transducer used is variable resistance or variable inductance transducer. The carrier oscillator generates a carrier signal of the frequency of about 50 Hz to 200 kHz. The carrier frequencies are higher and are at least 5 to 10 times the signal frequencies.

The bridge output is amplitude modulated carrier frequency signal. The a.c. amplifier is used to amplify this signal. A separate power supply is required for the a.c. amplifier. The amplified signal is demodulated using phase sensitive demodulator. The advantage of using phase sensitive demodulator is that the polarity of d.c. output indicates the direction of the parameter change in the bridge output.

Unless and until spurious and noise signals modulate the carrier, they will not affect the data signal quality and till then are not important. Active filters are used to reject main frequency pick up. This prevents the overloading of a.c. amplifier. Filtering out of carrier frequency components of the data signal is done by phase sensitive demodulator.

The applications of such system are in use with variable reactance transducers and for the systems where signals are required to be transmitted through long cables, to connect the transducers to the signal conditioning system. This type of signal conditioning includes the circuits like sample and hold, multiplexers, analog to digital converters etc.

4.3. Operational Amplifier IC 741 Pin Diagram

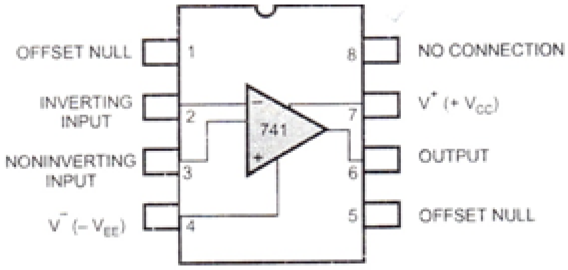


Fig.4.7 Pin diagram of IC 741 op-amp

- The IC 741 is 8 pin IC available in dual in line package (DIP). The pin Diagram of IC 741 op-amp is shown in the Fig.4.7.
- The pins 1 and 5 are offset null pins. These are used to nullify offset voltages and provide offset voltage compensation.
- The pin 2 is non-inverting input terminal. The output is to be taken from pin 6. The op-amp requires dual supply i.e. positive supply and negative supply.
- The positive supply is to be given to pin 7 while negative supply is to be given to pin 4.
- The pin 4 is for - V_{EE} supply while pin 7 is for + Vcc supply.
- The pin 8 is the dummy pin and no connection is to be made to this pin externally.

4.4 . Operational Amplifiers –Important Terms

1. Common-Mode Input Resistance (R_{INCM})

For op amps operating in the linear region, this term defines the input common-mode voltage range divided by the change in input bias current across that range.

R_{INCM} =

2. DC Common-Mode Rejection (CMR_{DC})

This is a measure of the op amp's ability to reject DC signals present in equal measure at both

inputs. CMR_{DC} can be calculated using the common-mode voltage range (CMVR) and the change in
peak-to-peak input offset voltage across that range.

$$CME_{DC} = 20*log$$

3. AC Common-Mode Rejection (CMR_{AC})

CMR_{AC} is a measure of the amplifier's ability to reject AC signals present in equal measure at both inputs. It is a function of differential open-loop gain divided by common-mode open-loop gain. CMR_{AC} is usually specified at a given frequency and over a DC common-mode range.

$$\boldsymbol{CMR_{AC} = 20* log}$$

Where $\boldsymbol{A_{OL(DIFF)}} =$ and $\boldsymbol{A_{OL(CM)}} =$

4. Gain-Bandwidth Product (GBW)

This is the constant product *AOL * f* in the region of the -20dB/decade roll off on the open-loop Gain verses frequency characteristic curve.

5. Input Bias Current (I_B)

For op amps operating in the linear region, this term indicates the average current that flows into the inputs.

6. Input Bias-Current Drift (TCIB)

This is the change in input bias current due to the change in temperature. TC_{IB} is usually expressed in pA/°C.

7. Input Offset Current (I_{OS})

This is the difference between the currents flowing into the two inputs.

8. Input Offset-Current Drift (TC_{IOS})

This is the change in input offset current due to the change in temperature. TC_{IOS} is usually Expressed in pA/°C.

9. Differential-Mode Input Resistance (R_{IN})

This is the change in input offset voltage divided by the change in input current. This change results from that changing voltage. For either input with the other input connected to a fixed common-mode voltage:

$R_{IN(DIFF)}=$

10. Output Impedance (Z_O)

For op amps operating in the linear region, this term indicates the small-signal internal impedance of the output terminal.

11. Output Voltage Swing (V_O)

This term indicates the maximum peak-to-peak voltage swing that the output can achieve without clipping the signal. V_O is usually specified into a given load resistance and relative to the supply range.

12. Power Dissipation (Pd)

This is the quiescent power dissipated by the device under the given supply voltages. P_d is usually specified with no load attached to the output.

13. Power-Supply Rejection Ratio (PSRR)

This measures the ability of an amplifier to maintain its output voltage unchanged as the supply voltage varies. PSRR is often determined by measuring the change in input offset voltage as a result of the change in power-supply voltage.

$PSRR_{dB}$ =20*log

14. Slew Rate (SR)

This is the maximum large-signal rate of change of the output voltage divided by the amount of time that the change takes to occur. SR is usually expressed in V/µs, and sometimes listed separately for positive-moving and negative-moving signals.

15. Supply Current (I_{CC}, I_{DD})

This indicates the quiescent current required by the device at the given supply voltage.
These terms are usually specified with no load attached to the output.

16. Unity Gain Bandwidth (BW)

This is the maximum frequency for which the open-loop gain is greater than one.

17. Input Offset Voltage (V_{OS})

This indicates the voltage difference that, when applied differentially to the inputs, causes the output to equal zero.

18. Input Offset-Voltage Drift (TC_{VOS})

This indicates the change in input offset voltage over temperature, usually expressed in μV/°C.

19. Input Capacitance (C_{IN})

For op amps operating in the linear region, $\mathbf{C_{IN}}$ is the capacitance of either input terminal with the other input terminal connected directly to ground.

20. Input Voltage Range (V_{IN})

This is the voltage range at the inputs over which the amplifier operates with predictable results. $\mathbf{V_{IN}}$ is usually expressed relative to the supply range.

21. Input-Voltage Noise Density (e_N)

For op amps, input voltage noise can be modelled as a series noise-voltage source connected to either input. $\mathbf{e_N}$ is usually expressed in nV /(nanovolts per root Hertz) and usually specified at a single frequency.

22. Input-Current Noise Density (i_N)

For op-amps, input current noise can be modelled as two noise current sources, one connected from each input to a common point. $\mathbf{i_N}$ is usually expressed in pA /(pico amps per root Hertz) and usually specified at a single frequency.

4.5 Characteristics of Ideal Op-amp

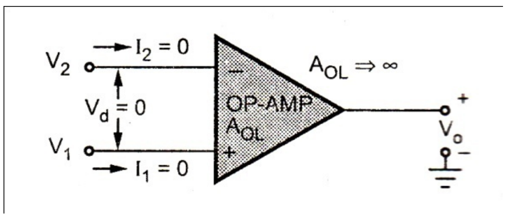


Fig.4.8. Ideal Op-amp

Fig.4.8. shows an ideal op-amp. It has two input signals V_1 and V_2 applied to non-inverting and inverting terminals, respectively.

The following points can be observed for the ideal op-amp shown in the Fig.4.8.

1) An ideal op-amp draws no current at both the input terminals $I_1 = I_2 = 0$. Thus its input impedance is infinite. Any source can drive it and there is no loading on the driver stage.

2) The gain of an ideal op-amp is infinite (∞), hence the differential input $V_d = V_1 - V_2$ is essentially zero for the finite output voltage V_0.

3) The output voltage V_0 is independent of the current drawn from the output terminals. Thus its output impedance is zero and hence output can drive an infinite number of other circuits.

These properties are expressed generally as the characteristics of an ideal op-amp. The various characteristics of an ideal op-amp are:

a)**Infinite voltage gain: ($A_{oL} = \infty$)**

It is denoted as A_{oL}. It is the differential open loop gain and is infinite for an ideal op-amp.

b) Infinite input impedance : ($R_{in} = \infty$)

The input impedance is denoted as R_{in} and infinite for an ideal op-amp. This ensures that no current can flow into an ideal op-amp.

c) Zero output impedance: ($R_o = 0$)

The output impedance is denoted as R_o and is zero for an ideal op-amp. This ensures that the output voltage of the op-amp remains same, irrespective of the value of the load resistance connected

d) Zero offset voltage : ($V_{ios} = 0$)

The presence of the small output voltage though $V_1 = V_2 = 0$ is called an offset voltage. It is zero for an ideal op-amp. The ensures zero output for zero input signal voltage.

e) Infinite bandwidth:

The range of frequency over which the amplifier performance is satisfactory is called its bandwidth. The bandwidth of an ideal op-amp is infinite. This means the operating frequency range is from 0 to ∞. This ensures that the gain of the op-amp will be constant over the frequency range from d.c. (zero frequency) to infinite frequency. So op-amp can amplify d.c. as well as a.c. signals.

f) Infinite CMMR: ($\rho = \infty$)

The ratio of differential gain and common mode gain is defined as CMRR. Thus infinite CMRR of an ideal op-amp ensures zero common mode gain. Due to this common mode, noise output voltage is zero for an ideal op-amp.

g) Infinite slew rate : ($S = \infty$)

This ensures that the changes in the output voltage occur simultaneously with the changes in the input voltage.

The slew rate is important parameter of op-amp. When the input voltage applied is step type which changes instantaneously then the output also must change rapidly as input changes. If output does not change with the same rate as input then there occurs distortion in the output. Such a distortion is not desirable. Infinite slew rate indicates that output changes simultaneously with the changes in the input voltage.

The parameter slew rate is actually defined as the maximum rate of change of output voltage with time and expressed in V/µs.

Slew rate = S = $\Big|$ maximum

Its ideal value is infinite for the op-amp.

h) No effect of temperature:

The characteristic of op-amp do note change with temperature.

i)Power Supply Rejection Ratio : (PSRR = 0)

The power supply rejection ratio defined as the ratio of the change in input offset voltage due to the change in supply voltage producing it, keeping other power supply voltage constant. It is also called power supply sensitivity.

So if V_{EE} is constant and due to change in V_{CC}, there is change in input offset voltage then PSRR is expressed as,

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{CC}}\bigg|_{V_{EE}\ \text{Constant}}$$

For a fixed V_{CC}, if there is change in V_{EE} causing change in input offset voltage then,

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{EE}}\bigg|_{V_{EE}\ \text{Constant}}$$

It is expressed in mV/V or µV/V and its ideal value is zero.

These ideal characteristics of op-amp are summarized in the Table 3.1.

Characteristics	**Symbol**	**Values**
Open loop voltage gain	A_{OL}	∞
Input impedance	R_{in}	∞
Output impedance	R_o	0
Offset voltage	V_{∞}	0
Bandwidth	B.W.	∞
C.M.R.R	ρ	∞
Slew rate	S	∞
Power supply rejection ratio	PSRR	0

Table 3.1.Ideal Op-amp characteristics

4.6. Ideal Inverting Amplifier

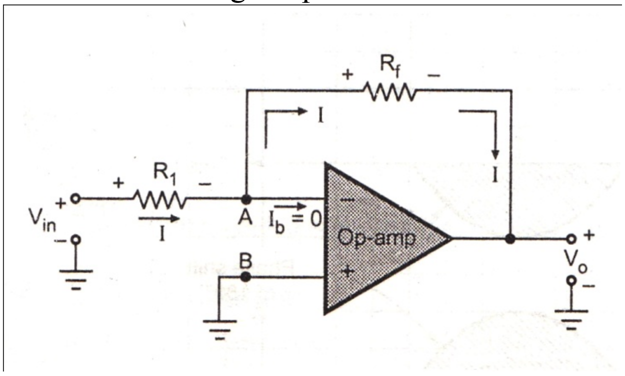


Fig.4.9 Inverting Amplifier

As the name suggests the output of such amplifier is inverted as compared to the input signal. The inverted output signal means having a phase shift of 180^0 as compared to the input signal. So, an amplifier which provides a phase shift of 108^0 between input and output is called inverting amplifier.

The basic circuit diagram of an inverting amplifier using op-amp is shown in the Fig.4.9.

Derivation of closed loop gain:

As node B is grounded, node A is also at ground potential from the concept of virtual ground, so the voltage at A,V_A = 0.

..............(1)

Now from the output side, considering the direction of current I we can write,

..............(2)

Entire current I passes through R_f as op-amp input current is zero.

Equating equations (1) and (2) we get,

A_{VF} = (Gain with feedback)

..............(3)

Theis the gain of the amplifier while negative sign indicates that the polarity of output is opposite to that of input. Hence it is called inverting amplifier.

The input and output waveforms are shown in the Fig.4.10.

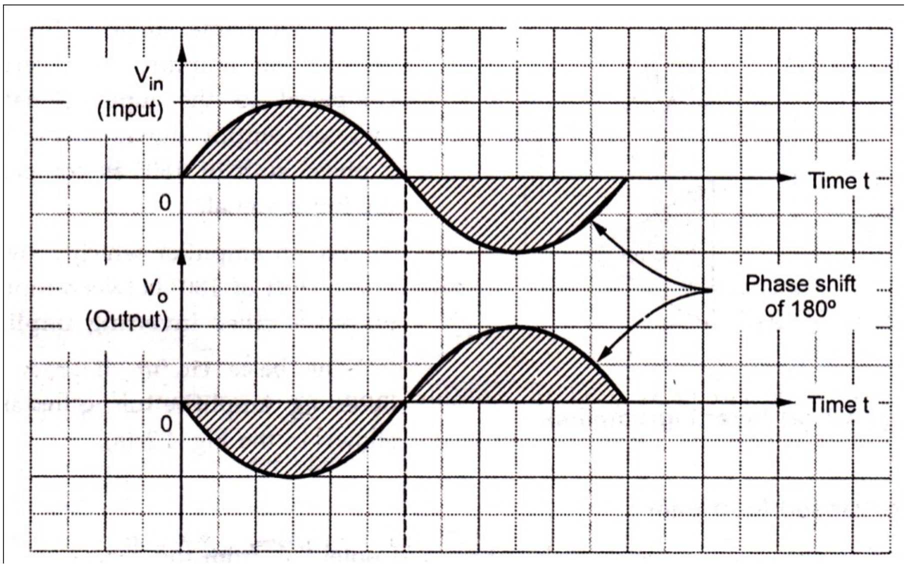


Fig.4.10. waveforms of inverting amplifier

4.7. Sign Changer

In the ideal inverting amplifier if $R_f = R_1$ then the gain is $A_{CL} = -1$. Thus the magnitude of output is same as that of the input but its sign is opposite to that of the input.

$$V_0 = -V_{in} \quad \text{for} \quad R_f = R_1$$

This circuit is called sign change or phase inverter

4.8 Scale Changer

In the ideal inverting amplifier, if R_f is not equal to R_1, then the gain is $A_{CL} = -K$ where $K = R_f / R_1$. Thus the circuit is used to multiply input by a constant K called scaling factor.

$$V_0 = -K \; V_{in}$$

The resistances must be precision resistors to adjust the scaling factor K precisely.

This circuit is called scale changer.

4.9) Ideal Non-inverting Amplifier

An amplifier which amplifies the input without producing any phase shift between input and output is called non-inverting amplifier. The basic circuit diagram of a non-inverting amplifier using op-amp is shown in the Fig. 4.11. The input is applied to the non-inverting input terminal of the op-amp.

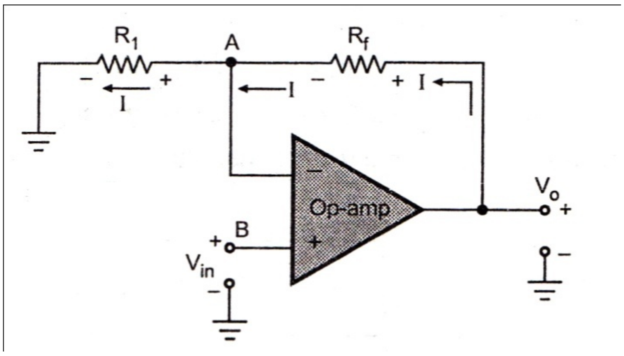


Fig.4.11.Non-Inverting amplifier

Derivation of closed loop gain :

The node B is at potential V_{in}, hence the potential of point A is same as B which is V_{in}, from the concept of virtual ground.

$V_A = V_B = V_{in}$ ....(1)

From the output side we can write,

.............(2)

At the inverting terminal

.............(3)

Entire current passes through R_1 as input current of op-amp is zero.

Equating equations (2) and (3),

=

=

$A_{VF} =$

.............(4)

The positive sign indicates that there is no phase shift between input and output.

The input and output waveforms are shown in the Fig. 4.12.

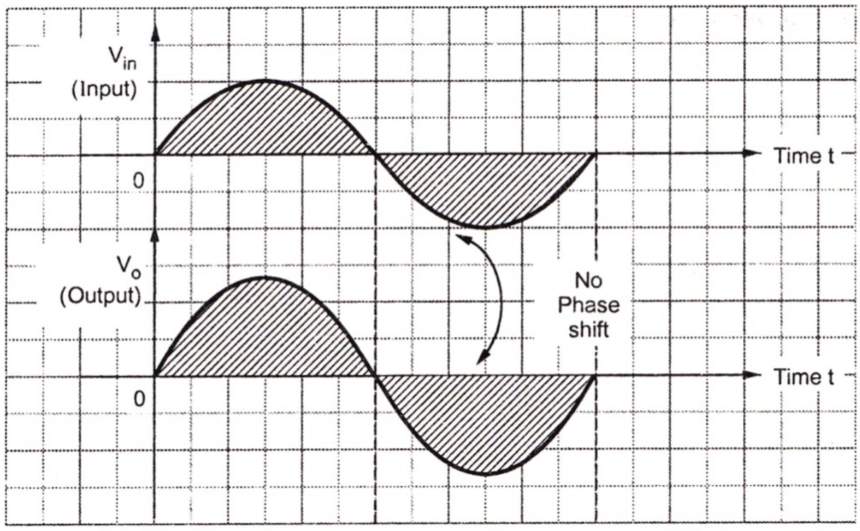


Fig.4.12.Waveforms of non-inverting amplifier

The table 4.1 provides the comparison of the ideal inverting and non-inverting amplifier op-amp circuits.

Sr.No.	**Ideal inverting amplifier**	**Ideal non-inverting amplifier**
1.	Voltage gain = $-R_f / R_1$	Voltage gain = $1+(R_f /R_1)$
2.	The output is inverted with respect to input	No phase shift between input and output.
3.	The voltage gain can be adjusted as greater than, equal to or less than one.	The voltage gain is always greater than one.
4.	The input impedance is R_1.	The input impedance is extremely large.

4.10 summer or Adder Circuit

As the input impedance of an op-amp is extremely large, more than one input signal can be applied to the inverting amplifier. Such circuit gives the addition of the applied signals at the output. Hence it is called **summer** or **adder** circuit. Depending upon the sign of the output, the summer circuits are classified as inverting summer and non-inverting summer.

4.10.1. Inverting Summer

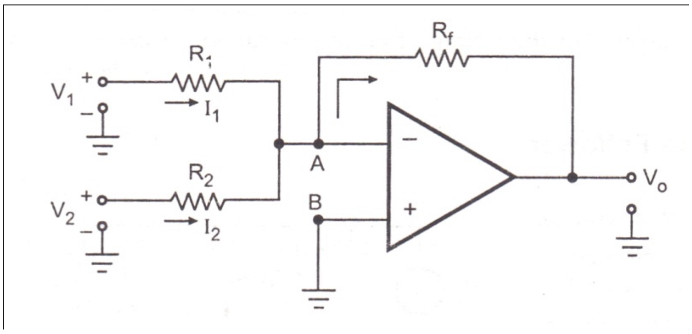


Fig.4.13. Inverting Summer

In the circuit, all the input signals to be added are applied to the inverting input circuit with two input signals is shown in the Fig.4.13

As point B is grounded, due to virtual ground concept, the node A is also at virtual ground potential.

$V_A = 0$ ....(1)

Now from input side,

= ....(2)

= ....(3)

Applying KCL at node A and as input op-amp current is zero,

I= + ...(4)

From the output side

I= = ...(5)

Substituting equations (5),(2) and (3) in equation(4)

..............(6)

If the three resistances are equal, $R_1 = R_2 = R_f$

$$\boxed{V_o = -(V_1 + V_2)}$$ ....(7)

By properly selecting R_f, R_1 and R_2, we can have weighted addition of the input signals like $aV_1 + bV_2$, as indicated by the equation(6).

Infact in such a way, n input voltage can be added.

Thus the magnitude of the output voltage is the sum of the input voltages and hence circuit is called summer or adder circuit.

4.10.2 **Non-Inverting Summing Amplifier**

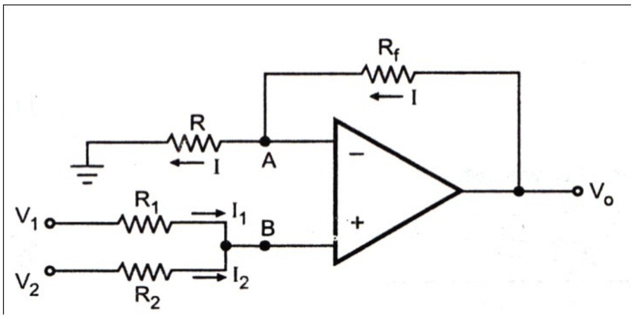


Fig.4.14. Non Inverting Summing Amplifier

The circuit discussed above is inverting summing amplifier, which can be noticed from the negative sign in the equation (6). But a summer that gives non-inverted sum of the input signals is called **non-inverting summing amplifier**. The circuit is shown in the Fig. 4.14.

Let the voltage of node B is V_B. Now the node A is at the same potential as that of B, due to virtual ground.

$V_A = V_B$ ....(8)

From the input side,

= ....(9)

But as the input current of op-amp is zero,

0 ....(10)

=0

..................(11)

Now at node A,

I= $V_B = V_A$ ....(12)

I= ....(13)

Equating the two equations (12) and (13)

=

= ....(14)

Substituting equation (11) in equation (14) we get,

................(15)

The equation (15) shows that the output is weighted sum of the inputs.
If $R_1 = R_2 = R = R_f$, we get

$$\boxed{V_o = V_1 + V_2}$$

...................(16)

As there is no phase difference between input and output, it is called non-inverting summer amplifier

4.11 Subtractor or Difference Amplifier

Similar to the summer circuit, the subtraction of two input voltages is possible with the help of op-amp circuit, called subtractor or difference amplifier circuit.

The circuit diagram is shown in the Fig.4.15.

To find the relation between the inputs and output let use Superposition principle.

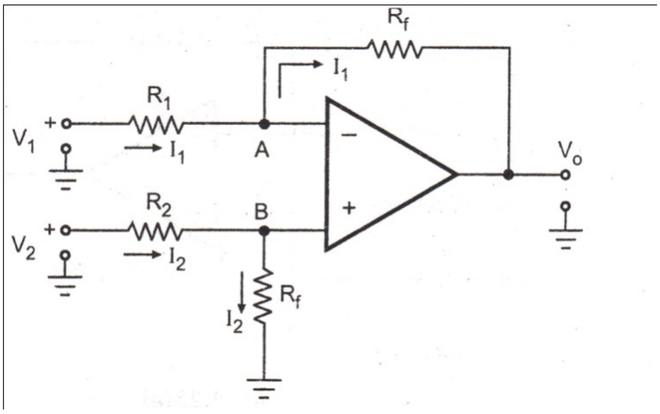


Fig.4.15. Subtractor circuit

Let V_{01} be the output, with input V_1 acting, assuming V_2 to be zero. And V_{02} be the output, with input V_2 acting, assuming V_1 to be zero.

Case 1: With V_2 zero, the circuit acts as an inverting amplifier, as shown in the Fig.4.15. Hence we can write,

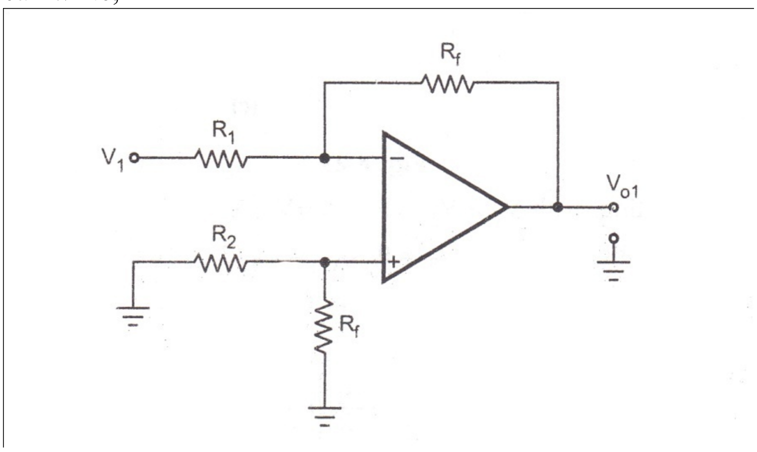
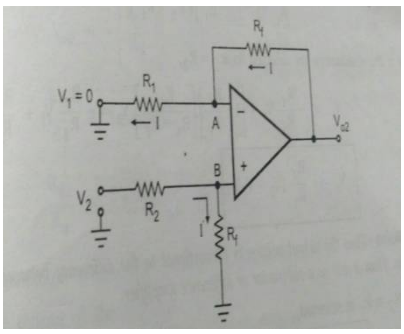


Fig.4.16 Subtractor circuit acting as inverting amplifier with V_2 zero(case 1)

..................(1)

Case 2 : While with V_1 as zero, the circuit reduces to as shown in the Fig.4.17.



Let potential of node B is V_B. The potential of node A is same as B i.e. $V_A = V_B$.

Applying voltage divider rule to the input V_2 loop,

.................(2)

...................(3)

I = ...(4)

Equating the equations (3) and (4),

.................(5)

Substituting V_B from equation (2) in equation (5) we get,

. ...(6)

Hence using superposition principle,

$V_0 = V_{01} + V_{02}$

...................(7)

Now if the resistances are selected as $R_1 = R_2$,

$\boxed{V_0=(V_2-V_1)}$

.......................(8)

thus the output voltage is proportional to the difference between the two input voltage. Thus it acts as a subtract or difference amplifier.

If $R_1 = R_2 = R_f$ is selected,

$\boxed{V_o = V_2 - V_1}$

4.12 **Voltage to Current Converter**

In a voltage to current converter, the output load current is proportional to the input voltage. According to the connection of load, there are two types of V to I converters: Floating type and Grounder type. In floating type V to I converter R_L is not connected to the ground whereas in grounded type, one end of R_L is connected to the ground.

4.12.1 Voltage to Current Converter with Floating Load

The Fig 4.18 show a voltage to current converter in with load resistor R_L is floating.

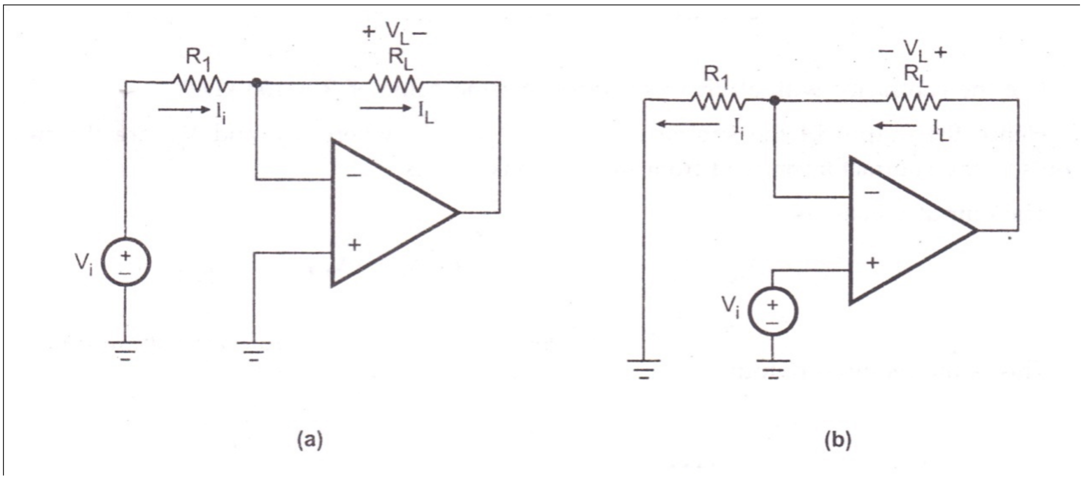


Fig: 4.18 **Voltage to Current Converter With Floating Load**

As input current of op-amp is zero.

= = ...(1)

V_i

.............(2)

Thus the load current is always proportional to the input voltage and circuit works as voltage to current converter

If the load is a capacitor, it will charge or discharge at a constant rate. Hence such converter circuits are used to generate the saw tooth or triangular waveforms. The proportionality constant is generally $1/R_1$ hence this circuit is also called **transconductance amplifier.** It is also called a **voltage controlled current source** (VCCS).

The expression $I_L = V_i / R_1$ holds regardless of the type of the load. It can be linear (e.g., a resistive) or non-linear (e.g., a light emitting diode), or it can have time-dependent characteristics (e.g. , a capacitor). No matter what the load is, the op-amp will draw the current I_i whose magnitude depends only on V_i and R.

4.12.2 Voltage to Current Converter with Grounded Load

When one of end of the load is grounded, it is no longer possible to place the load within feedback loop of the op-amp. Fig. 4.19 shows a voltage to current converter in which one end of load resistor R_L is grounded. It is also known as **'Howland Current Converter'** from the name of its inventor.

The analysis of the circuit is accomplished by first determining the voltage V_1 at the non-inverting input terminal and then establishing the relationship between V_1 and the load current.

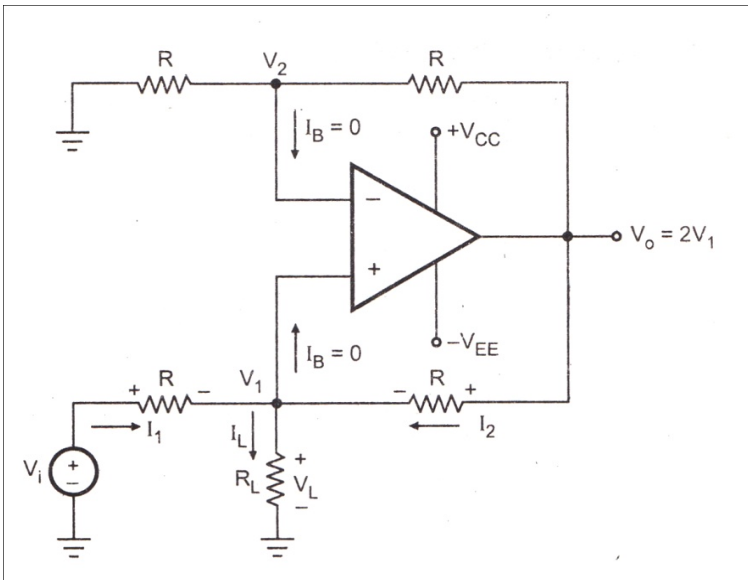


Fig: 4.19 Voltage to Current Converter with Grounded Load

Applying KCL at node V_1 we get,

=

=

$V_i + V_0 - 2V_1 =$

$V_i =$ ....(3)

The gain of op-amp in non-inverting mode is given as $A = 1 + R_f/R_1$. For this circuit it is 1+ R/R = 2. Hence, output voltage can be written as,

$V_0 = 2v_1 = V_i + V_0$ -R ....(4)

0= V_i - R

V_i = R

.......................(5)

From the above equation we can say that the load current depends on the input voltage V_i and resistor R.

4.13 Current to Voltage Converter

In such a converter, the output voltage is proportional to the input current. It accepts an input current I_i and yields an output voltage V_0 such that $V_0 = A I_i$, measured in ohms, it is more appropriate to denote gain by the symbol R. Because of this I-Converters are also called transresistance amplifiers. Fig. 4.20 shows the current to voltage converter.

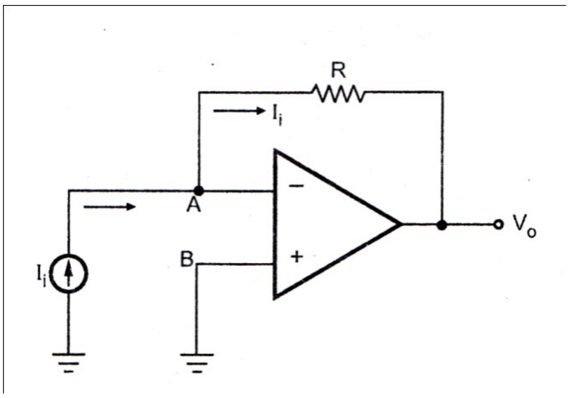


Fig. 4.20. the current to voltage converter

The node A is a virtual ground as node B is grounded. Hence $V_A = 0$.

..............(1)

$V_o \infty$ ....(2)

4.14 Op-amp as a Comparator

The op-amp in open loop configuration can be used as a basic comparator. When two inputs are applied to the open loop op-amp then it compares the two inputs. Depending upon the comparison, it produces output voltage which is either positive saturation voltage ($+V_{sat}$) or negative saturation voltage ($-V_{sat}$).

A comparator is a circuit which compares a signal voltage applied at one input of an op-amp with a known reference voltage at the other input and produce either a high or a low output voltage, Depending on which input is higher. As comparator output has two voltage levels, either high or low, it is not linearly proportional to input voltage.

There are two types of comparator circuits which are,

1. Non –inverting comparator 2.Inverting comparator

4.14.1 Basic Non-inverting Comparator

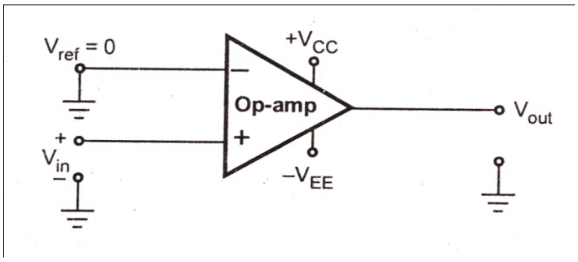


Fig:4.21 Non-inverting Comparator

In this comparator, the input voltage is applied to the non-inverting terminal and no reference voltage is applied to other terminal. So inverting terminal is grounded. The input voltage is denoted to other terminal with which V_{in} while the voltage applied to other terminal with which V_{in} is compared is denoted as V_{ref}. In the basic comparator, $V_{ref} = 0$ v. The **basic non-inverting comparator** is shown in the Fig.4.20.

In the non-inverting comparator, if V_{in} is greater than V_{ref} then output is $+V_{sat}$ i.e. almost equal to $+V_{CC}$. While if V_{in} is less then V_{ref} then output is $-V_{sat}$ i.e. almost equal to $-V_{EE}$.

Thus for Fig.4.20, as $V_{ref} = 0$ V when V_{in} is positive then $V_o = +V_{cc}$. while when V_{in} is negative then $V_0 = -V_{sat} = -V_{EE}$. This is because, as open loop gain op-amp (A_{0L}) is very very high even for very small V_{in} the op-amp output saturates.

Thus the two possible output levels of the comparator are + v_{sat} and – V_{sat}' indicating whether the input voltage is greater than or less then the reference voltage. Such type of the comparator, in which the two possible output levels of the saturating type comparator are + V_{sat} and – V_{sat}.

Note that no feedback is applied to the op-amp and it is operated in open loop conditions, because of which the op-amp is operating in saturating conditions.

The input and out waveform for a basic non- inverting comparator, for sinusoidal input are show in the Fig 4.21

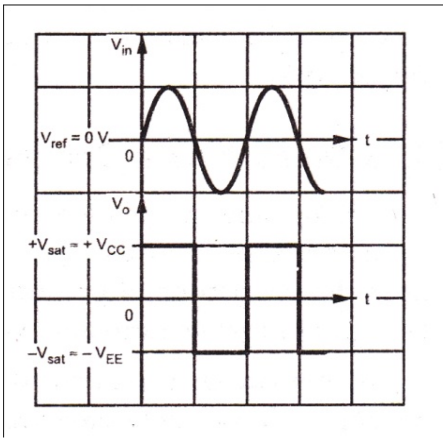


Fig:4.22 Wave forms of a basic non inverting comparator

The op-amp differential voltage gain A_{OL} is very large. So when inverting input is grounded, very small input voltage V_{in} in the range of microvolt is enough to saturate the op-amp. Hence knowing V_{sat} and differential voltage gain A, we can determine the minimum input voltage level required to saturate op-amp as,

$V_{in(min)} =$ for saturation

Now the transfer characteristic is the graph of V_{in} and V_{out}. As A_{OL} is very large hence for very very small positive or negative V_{in}, negative V_{in}, the output saturates. Hence at $V_{in} = 0$, the transfer characteristics is almost a straight line as shown in the Fig. 4.22(a). For example, for 741 C op-amp, $A_{OL}$is 100,000 while $\pm$ V_{sat} levels are $\pm$13.5V for supply of $\pm$ 15 V.

$V_{in(min)} =$

Thus for + 135 μV of V_{in}, output saturates to + V_{sat} while – 135 μV of V_{in} is enough to saturate output at $-V_{sat}$. Hence region -135 μV to + 135 μV of V_{in} the graph of V_{in} and V_{out} is linear. But this range is so small that near $V_{in} = 0$ practically we get a straight line transfer characteristics.

The Fig. 4.23 (a) and (b) shoes the ideal and practical transfer characteristics of a basic non-inverting comparator.

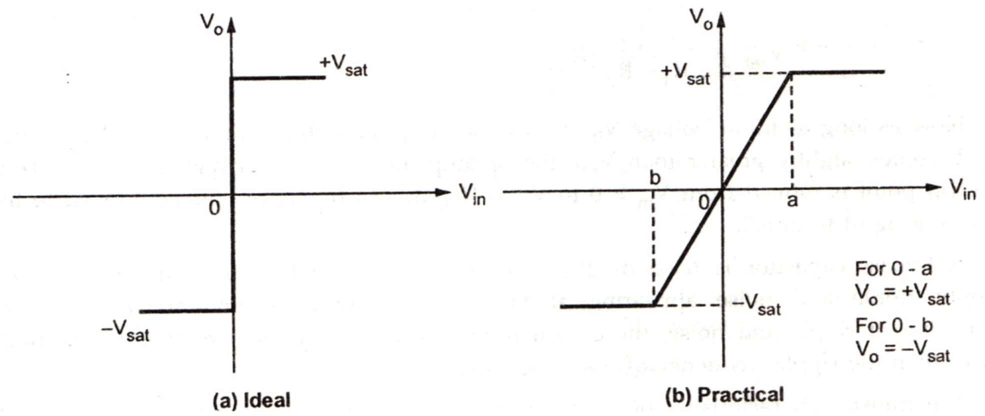


Fig: 4.23 Transfer characteristics of basic non inverting comparator

The point at which the transfer characteristic is straight line is called a **trip point.** The trip point is the input voltage at which the outputs change its states from low to high or high to low. In the basic comparator this trip point is zero as at $V_{in} = 0$, the output change its states.

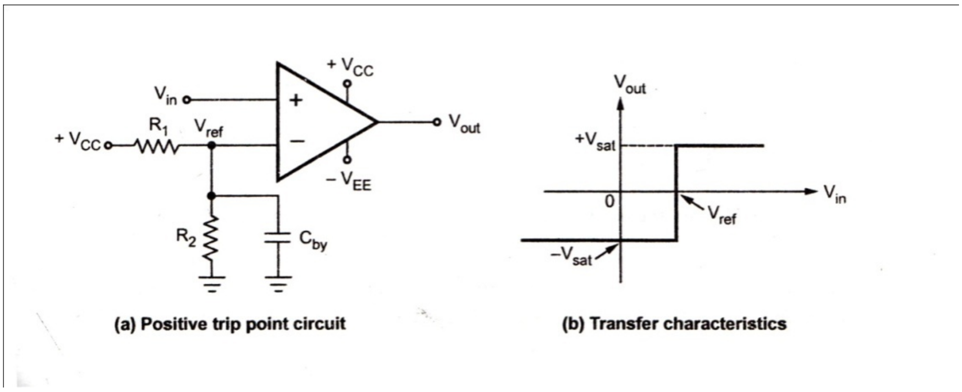
so we can that when V_{in} is greater than trip point, the output is high while if V_{in} is less than the trip point the output is low.

As this change over occurs at $V_{in} = 0$, the basic comparator can be used to detect occurrence os zero in the input voltage. Hence this circuit is called zero crossing detectors. But in practice it is possible to changes the trip point from zero to other voltage. This is achieved by some medications in the basic comparator circuit.

Moving a Trip Point

By application of a reference voltage to the inverting input rather than grounding it, the trip point can be moved.

The Fig. 4.24 shows the application of reference voltage to the inverting input of a basic comparator using a potential divider consisting of resistors R_1 and R_2.



(a) Positive trip point circuit (b) Transfer characteristics

The reference voltage V_{ref} is derived using supply + V_{CC} and potential divider R_1 and R_2. Mathematically V_{ref} is expressed as,

$$V_{ref} =$$

Now as long as input voltage V_{in} is less than V_{ref} the output is low i.e. – V_{sat}. When V_{in} becomes slightly greater than V_{ref}, the op-amp output becomes high i.e. + V_{sat}. Thus the trip point is moved from V_{in} = 0 V_{in} = due to reference voltage applied to the inverting input terminal.

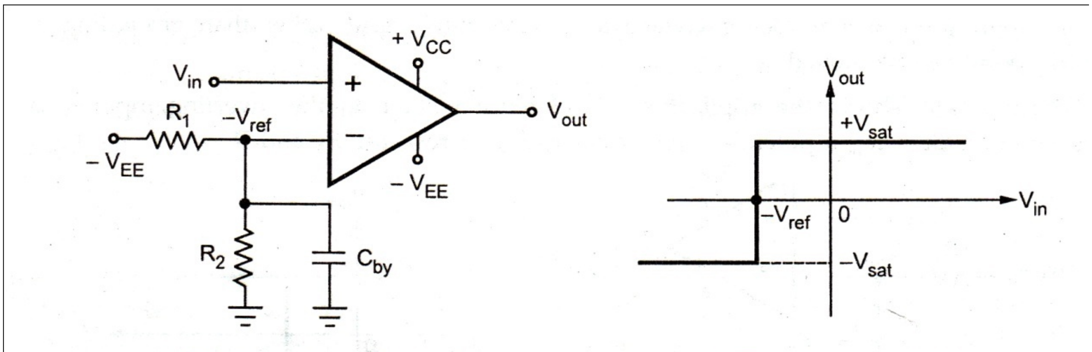
A bypass capacitor is used on the inverting input to reduce the amount of power supply ripple and noise appearing at the inverting input of op-amp. For effective bypassing of ripple and noise, the critical frequency of the bypass circuit must be much lower than the ripple frequency of power supply.

The transfer characteristic of such a comparator is shown in the Fig. 4.24 (b) which indicates positive trip point. Such a comparator is also called a **limit detector** as it detects the particular positive level of input beyond which output goes high. The resistances R_1 and R_2 can be used to set the trip point anywhere between 0 and + V_{CC}.

It is possible to obtain a negative trip point by providing a negative reference voltage to the inverting input. This is achieved by using a supply $-V_{EE}$ to the potential divider of R_1 and R_2.

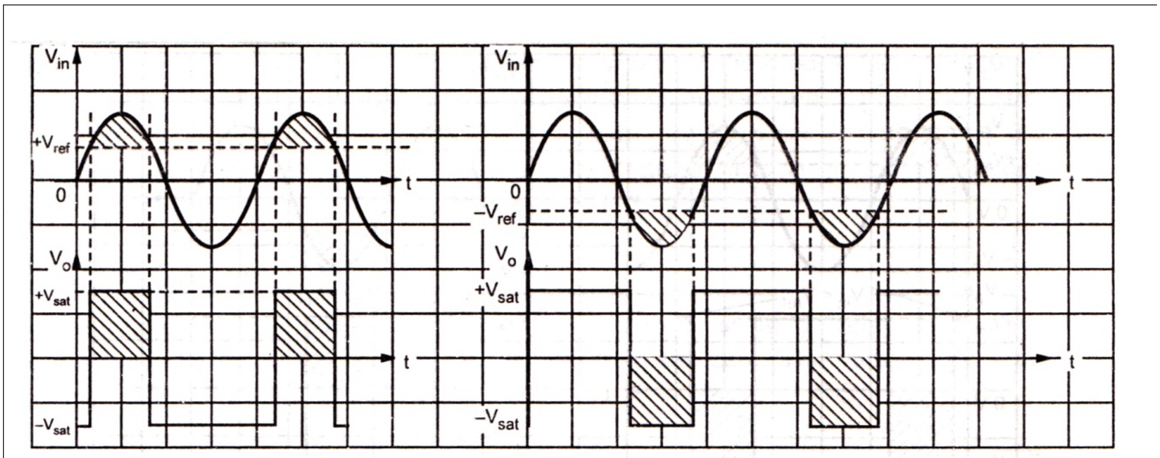
$V_{ref} =$

This is shown in the Fig.4.25 (a). When V_{in} is positive than $-V_{ref}$, error voltage is positive which drives op-amp into positive saturation. When V_{in} is more negative than $-V_{ref}$, error voltage is negative which drives op-amp into negative saturation producing low output. The transfer characteristics are shown in the Fig. 4.25 (b).



(a) Negative trip point circuit (b) Transfer characteristics

The Fig. 4.26 (a) shows input and output waveforms with positive reference voltage while the Fig. 4.26 (b) shows input and output waveforms with negative reference voltage.



(a) Positive V_{ref} (b) Negative V_{ref}

4.1

4.2. Inverting Comparator

The Fig. 4.27 shows inverting comparator in which the reference voltage V_{ref} is applied to the non-inverting (+) input and signal voltage (V_{in}) is a the inverting (-) input of the op-amp. The V_{ref} can be set using a battery and potential divider as discussed earlier for non-inverting comparator.

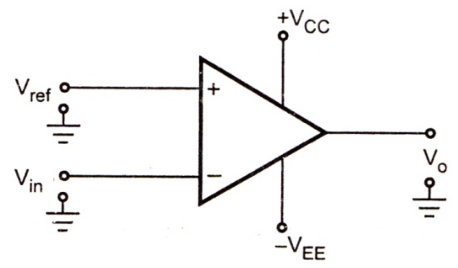


Fig :4.27 Basic inverting comparator with V_{ref}=0V

When V_{in} is less than V_{ref} the output voltage V_0 is at $+V_{sat}$ (= $+V_{CC}$) because the voltage at the inverting input (-) is less than that at the non-inverting (+) input becomes negative with respect to the inverting (-) input and V_0 goes to $–V_{set}$ (= - V_{EE}). The Fig. 4.28 shows the input and output and output waveforms for inverting comparator.

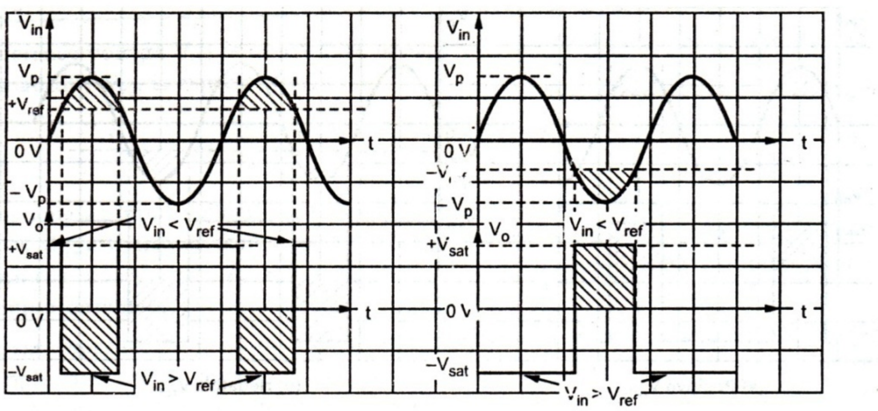
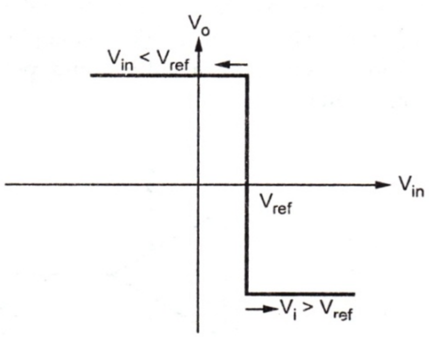


Fig: 4.28 Input and output waveforms for inverting comparator

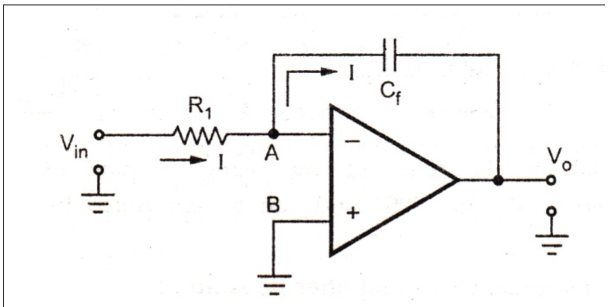
Transfer characteristics for inverting comparator with $+V_{ref}$ are shown in the Fig.4.29.



4.15 integrator

In an integrator circuit, the output voltage is the integration of the input voltage. The integrator circuit can be obtained without using active devices like op-amp, transistors etc. In such a case an integrator is called **passive integrator.** While an integrator using an active device like op-amp is called **active integrator.** In this section, we will discuss the operation of active op-amp integrator circuit.

4.15.1 Ideal active Op-amp Integrator



Consider the op-amp integrator circuit as shown in the Fig.4.30.

The node B is grounded. The node A is also at the ground potential from the concept of virtual ground.

$V_A = 0 = V_B$

As input current of op-amp is zero, the entire current I flowing through R_1, also flows through C_f, as shown in the Fig.4.29.

From input side we can write,

.........................(1)

From output side we can write,

......................(2)

Equating the two equations (1) and (2),

.......................(3)

Integrating both sides,

$- C_f V_0$ ....(4)

$V_0 =$

.....................(5)

Where V_0 (0) is the constant of integration, indicating the initial output voltage.

The equation (5) shows that the output is $- 1 / R_1 C_f$ times the integral of input and $R_1 C_f$ is called time constant of the integrator.

The negative sign indicates that there is a phase shift of 180^0 between input and output. The main advantage of such an active integrator is the large time constant. By miller's theorem the effective capacitance between input terminal A and the ground becomes $C_f(1-A_V)$ where A_V is the gain of the

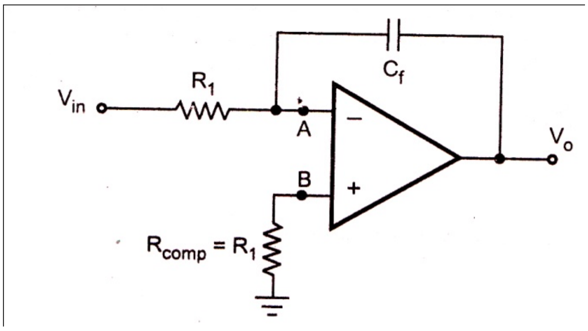


Fig: 4.31 Inverting zero crossing detector

Op-amp which is very large. Due to such large effective capacitance, time constant is very large and thus a perfect integration results due to such circuit.

Sometimes a resistance $R_{comp} = R_1$ is connected to the non-inverting terminal to provide the bias compensation. This is shown in the bias compensation. This is shown in the Fig.4.31.

As the input current of op-amp is zero, the node B is still can be treated at ground potential in this circuit.

4.16 Differentiator

The circuit which produces the differentiation of the input voltage at is output is called **differentiator.** The differentiator circuit which does not use any active device is called **passive differentiator.** While the differentiator using an active device like op-amp is called an **active differentiator.** Let us discuss first the operation of ideal active op-amp differentiator circuit.

4.16.1 **Ideal Active Op-amp Differentiator**

The active differentiator circuit can be obtained by exchanging the positions of R and C in the basic active integrator circuit. The op-amp differentiator circuit is shown in the Fig.4.32.

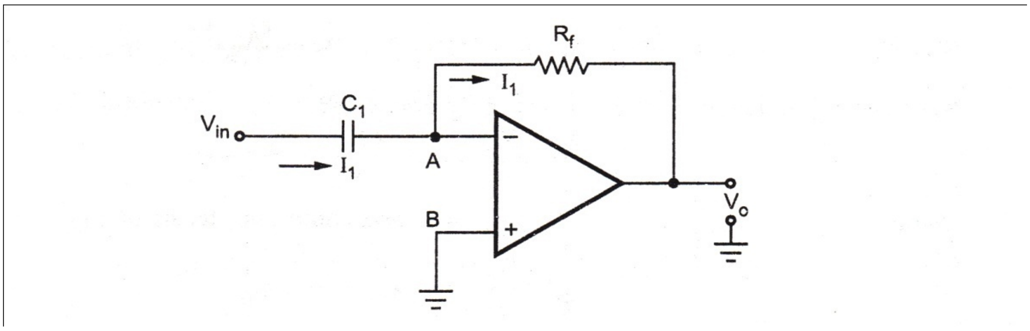


Fig 4.32: op-amp differentiator

The node B is grounded. The node A is also at the ground potential hence $V_A = 0$.
As input current of op-amp is zero, entire current I_1 flows through the resistance R_f.

From the input side we can write,

...................(1)

From the input side we can write,

.....................(2)

Equating the two equations,

........................(3)

........................(4)

The equation shows that the output is C_1 R_f times the differentiation of the input and product C_1 R_f is called **time constant**of the differentiator.

The negative sign indicates that there is a phase shift of 180^0 between input and output. The main advantage of such an active differentiator is the small time constant required for differentiation.

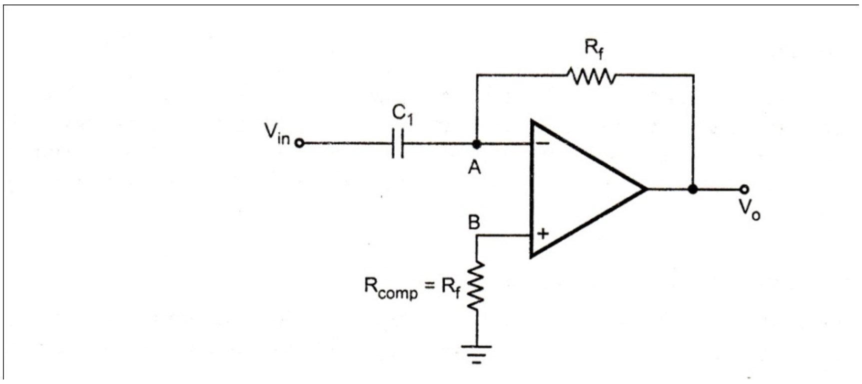


Fig: 4.33 Differentiator with bias compensation

By Miller's theorem, the effective resistance between input node A and ground becomes where A_V is the op-amp which is very large for all the frequencies.

In practice a resistance $R_{comp} = R_f$ is connected to the non-inverting terminal to provide the bias compensation. This is shown in the Fig.4.33.

Review question

PART A

1. Define operation amplifier and state its applications
2. Define signal conditioning.
3. Draw the symbol of OP amp.
4. Define CMRR and slew rate.
5. Draw the circuit diagram of integrator using OP-amp.
6. Define comparator and mention its uses.

PART B

7. Draw and explain the pin details of op-amp 741.
8. Mention the characteristics of an ideal op-amp.
9. Draw and explain the block diagram op-amp.
10. Draw the block diagram of AC signal conditioning system.
11. Explain sign changer using op-amp

PART c

12. a) With the block diagram explain DC signal conditioning system.

    b) With the diagram explain differential amplifier.

13. With the diagrams explain inverting comparator and non inverting comparator.
14. a) with the block diagram explain AC signal conditioning system

    b) Explain current to voltage converter using op-amp with diagram.
15. a) Draw and explain voltage to current converter using op-amp.

    b) With the diagram explain inverting amplifier using op-amp
16. a) with the diagram explain adder using op-amp

    b) With the diagram explain integrator using op-amp.
17. 17. a) with the diagram explain differentiator using op-amp.

    b) with the diagram explain subtractor using op-amp.

UNIT V

Signal Conditioners and Industrial Instrumentation:

5.1 Operational amplifier with capacitive transducer:

Capacitive Transducer converts any change in a physical quantity as an equivalent change in the Capacitance Value and subsequently as a change in the electrical quantity. Operational Amplifiers are used to improve the Sensitivity of the Transducer

Tthe capacitance value of capacitive transducer is converted into measurable electrical quantity by using operational amplifiers in any one of the following parameter , as a

1.RC time delay 2.Oscillator frequency 3.Balancing of a Wheatstone bridge

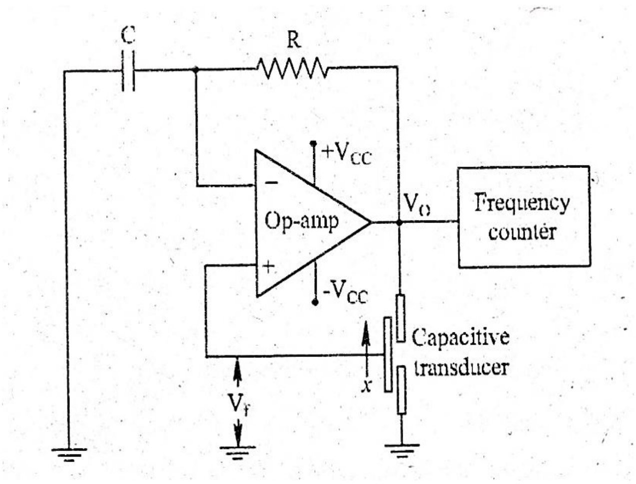


Fig. 5.1 Op amp with capacitive transducer

- The circuit diagram of op-amp with capacitive transducer is shown in the fig.5.1.
- The capacitive transducer is connected at the output side of op-amp.
- A tapping from the capacitive transducer is connected to the non-inverting input of op-amp directly.
- The op-amp output $V_O$is multiplied by a constant Xwhich varies linearly between 0 and 1 depending on the transducer (sensor) plate position and fed to the positive feedback input , so that V_f=V_{ref}= X V_o.
  - With the positive feedback, the op-amp output will be either switched to the positive saturation (+V_{sat}) or negative saturation (-V_{sat}).
  - The capacitive transducer placed at the output side, changes the DC reference voltage applied to the non-inverting input of op-amp. The negative input of op-amp then oscillates from +X $V_{sat}$to –X $V_{sat}$with the time constant RC as shown in Fig.5.2.

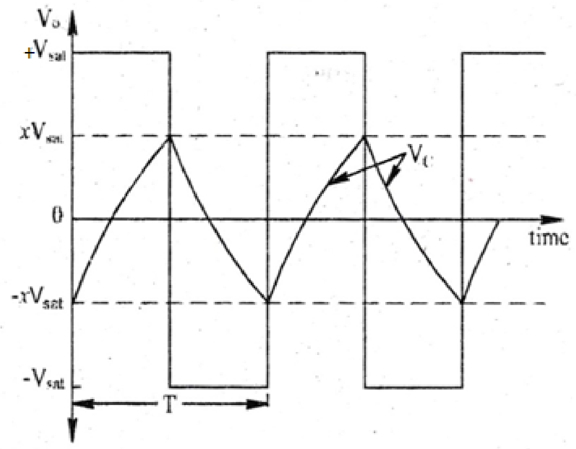


Fig.5.2 Waveform

- When the output is $+V_{sat}$,the capacitor C starts charging towards $+V_{sat}$through resistance R. The voltage at the (+) terminal is held at $+XV_{sat}$ by capacitive transducer. The capacitor is allowed to charge until the voltage across it equals the reference voltage
- When the voltage across the Capacitor C at the inverting input terminal becomes just greater than this reference voltage, the output of Op.Amp is driven to $-V_{sat.}$
- At this instant, the voltage on the capacitor is $+xV_{sat.}$ andIt begin to discharge through R, towards $-V_{sat}$..
- Again When the the capacitor voltage just exceed–$xV_{sat.}$, the outputof OP.Amp. switches back to $+V_{sat.}$ The cycle repeats itself as shown in the fig.5.2.

The oscillation period, T=2RCln

- The circuit is reasonably linear for x << 1 and can be further linearized by replacing the resistor with a current source of ‘I’ amperes. The frequency counter placed at the output counts the frequency which is proportional to change in the capacitive sensor

Applications:

1) Capacitive humidity sensor
2) Capacitive touch sensor

3) Capacitive level sensor

5.2 Operational Amplifier as Instrumentation Amplifier

In instrumentation, the transducers are required to measure physical quantities as electrical quantities. The output of transducers is then amplified, so that they are capable of driving the processing circuit to store and display the measured quantity. For this, an instrumentation amplifier may be used as a form of DC Differential Amplifiers as the signals from transducers are slow varying. The circuit diagram of instrumentation amplifier is shown in the fig.5.3.

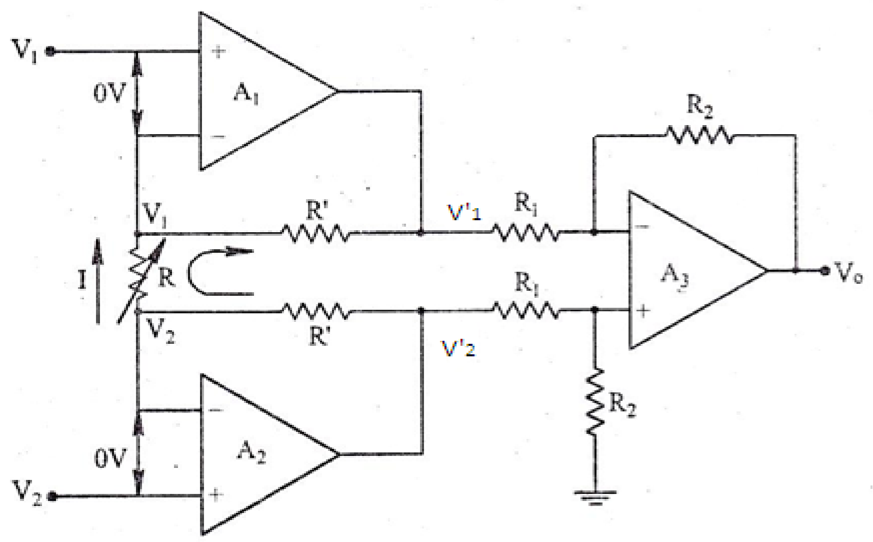


Fig. 5.3 Instrumentation Amplifier

Circuit Operation of instrumentation amplifier:

- The op-amps A_1 and A_2 have differential input voltages as zero

- For $V_1 = V_2$, the voltage drop across R will be zero. As no current flow through R and R', the non inverting amplifier A_1 acts as voltage follower. So its output voltage, $V'_1 = V_1$
- Similarly op-amp A_2 acts as voltage follower having output $V'_2 = V_2$.
- However, when $V_1 \neq V_2$, current flows in R and R' and $(V'_2 - V'_1) > (V_2 - V_1)$.
- Therefore this circuit has more differential gain and CMRR as compared with a single op-amp.
- The gain of op-amp A_3 with respect to V'_2 and V'_1:

$$\mathbf{V_o = R_2 / R_1 (V'_2 - V'_1) \quad \ldots\ldots\ldots\ldots(1)}$$

Since no current flows into the op-amp, the current I flowing in resistor,

$$I = \frac{V_2 - V_1}{R}$$

It passes through the resistor R'

Hence $V_1 = IR' + V_1'$

$$V_1' = V_1 - IR'$$

$$V_1' = V_1 - \frac{R'}{R}(V_2 - V_1) \quad \text{- - - (2)} \quad \left(\because I = \frac{V_2 - V_1}{R}\right)$$

Similarly, $V_2' = IR' + V_2$

$$V_2' = \frac{R'}{R}(V_2 - V_1) + V_2 \quad \text{- - - (3)}$$

Putting the values of V_1' and V_2' in equation (1)

We obtain,

$$V_o = \frac{R_2}{R_1}\left[\frac{R'}{R}(V_2 - V_1) + V_2 - V_1 + \frac{R'}{R}(V_2 - V_1)\right]$$

$$V_o = \frac{R_2}{R_1}\left[\frac{R'}{R}(V_2 - V_1) + (V_2 - V_1) + \frac{R'}{R}(V_2 - V_1)\right]$$

$$= \left(\frac{R_2}{R_1}\right)(V_2 - V_1)\left(\frac{R'}{R} + 1 + \frac{R'}{R}\right)$$

$$V_o = \frac{R_2}{R_1}\left(1 + \frac{2R'}{R}\right)(V_2 - V_1)$$

Features of Instrumentation amplifier as compared with a single Operational Amplifier are

- High gain
- High CMRR
- High gain stability

- Low DC offset
- Low output impedance

5.3 Bridge Amplifier:

While measuring the values of passive components, an unknown value will be calculated from the known values of other components in a bridge, under balanced condition. In order to improves the sensitivity of the bridge Amplifier system.

A Bridge amplifier is a signal conditioning circuit for a transducer as a sensor. An op-amp, four resistors and a transducer form the basic bridge amplifier as shown in the fig.5.4.

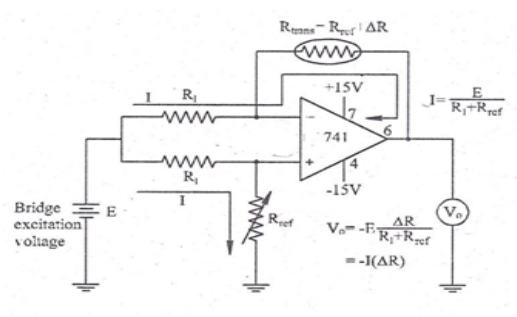


Fig. 5.4 Bridge Amplifier

- The transducer here may any device that converts quantities like temperature , pressure , strain and similar quantities into a change in resistance.

- Here it is referred as $R_{ref.}$(Transducer) which undergoes a change in resistance ΔR.

- R_{ref} is the resistance value of the Transducer Resistance at some reference condition and $R_{trans} = R_{ref} + \Delta R$, where ΔRis the amount of change in the resistance R_{trans} , in proportion to the quantity to be measured.

- Either AC or DC voltages can be used to drive the Bridge ,with negligible internal resistance. The voltage E can be adjusted between +V and -V.

- The resistors R_1arehigh quality metal-film resistance with tolerance less than 1% and low Temperature coefficient of Resistance.

- Current I is constant and is set by R_1, R_{ref} and E. That is , $I = E/(R_1+R_{ref})$. It is noted that the transducer current is constant and equal to I because the voltage drop across both R_1 resistors are equal and E_d=0V.

- The resistor from non inverting input to ground is always chosen to be equal to reference resistance of the transducer so that V_0= 0 volts when $R_{trans} = R_{ref}$. This will allow us to calibrate or check operation of the bridge.

- Hence V_0willbe in proportion with ΔR .

The input-output relation is given by

$V_o = - E = - I \Delta R$

Where I =

$\Delta R \quad = R_{trans} - R_{ref}$

Procedure for balancing the Bridge:

- The transducer is placed in the vicinity of the quantity to be measured with reference value, for example,25^{0}C.

- R_{ref} is adjusted , until V_0 =0V. This can be done by replacing the transducer R_{trans}, with a resistor equal to R_{ref}, and ΔR is made equal zero, and V_0 equals to zero. If done so , the calibration will be easier

5.4 Active Filters using Operational Amplifiers:

Filters are circuits which allow only certain range of frequencies through them and attenuate all the other frequencies. They are also named as frequency selective networks. To achieve this they mainly use the passive components L & C (inductor and Capacitor) along with resistors. This is because the impedance offered by both L & C are frequency dependant.

X_C = &X_L = 2πL

- By using the inductor and capacitor in the shunt arm and in the series arm of the circuit network, the required frequencies could be allowed or attenuated by the filter circuit, by adjusting the net impedance offered by the network.

- To improve the performance of the passive filters, active filters are used. They use operational amplifiers or transistors along with passive filters.

5.4.1. Low pass Filter (LPF)

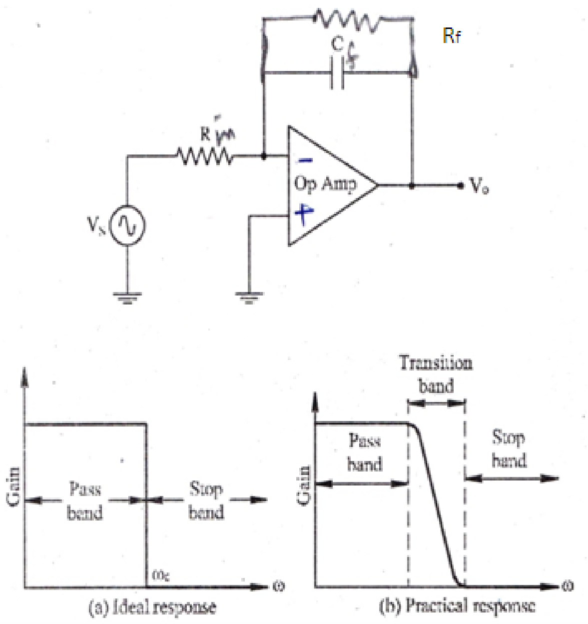


Fig. 5.5 Low Pass Filter

The ideal and practical frequency response characteristics of low pass filter are show in the fig.5.5

- Low pass filter passes low frequency signals and rejects high frequency signals
- A low pass filter has a constant gain from 0 Hz to high (upper) cut off frequencies f_C.
- At f_C, the gain is $1/\sqrt{2}$ time the max. gain or down by 3decibels.
- For $f > f_C$, the gain decreases with increase in input frequency.
- Referring to the circuit

Gain = &$\omega = 2\pi f$

- Gain is high at lower frequency up to cut off frequency 'f_C' as X_{Cf} offered by the Capacitor is high and gain in high.

- Gain goes on decreasing at higher frequencies beyond cut off frequency 'f_C' as X_{Cf} offered by the capacitor is low and hence gain is low.

5.4.2. High pass filter (HPF)

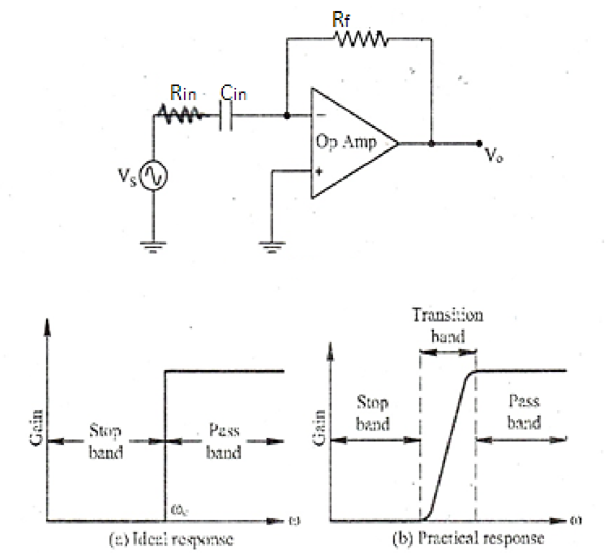


Fig.5.6 High Pass Filter

- High pass filter passes high frequency signals and rejects low frequency signals
- A high pass filter has a constant gain from the cut off frequency 'f_c' to the infinite frequency $f\infty$
- At f_c , the gain of the circuit is $1/\sqrt{2}$ times the maximum gain or down by 3decibels.
- For $f< f_c$, the gain decreases with decrease in input frequency.

Referring to the circuit,

Gain =

- Gain is high at higher frequencies from the cut off frequencies 'f_c' as X_{cf} offered by the capacitors low and hence the gain is high .

- Gain goes on increasing from 0 Hz to the off frequency 'f_c' as the X_{cf} offered by the capacitor is very high and he a gain is low

5.4.3. Low Pass Filter as integrator

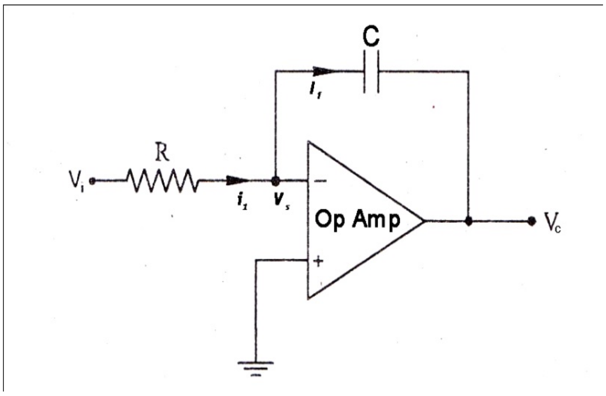


Fig.5.7 LPF as Integrator

When the time constant of the RC low pass filter circuit is very high (ω_τ>>1), the circuit can be operated as an integrator.

- For example if we integrate a constant, the answer is x. If we integrate a square wave the output will be a triangular wave.
- Practically an LPF acts as perfect integrator when τ> 15T, where T is the time period of the input pulse wave form.

Proof:

- When the supply voltage Vis given, the capacitor is charged.
- The charge across the capacitor Q =CV
- The current through the capacitor isi_C

i_C

The feedback current if = i_f= i_C = ...1

The current through the resistor i_1= 2

- In both the equations 1& 2 $V_S = 0$ as it establishes the virtual short and grounded through Non-inverting input.
- Applying kirchoff's law law, i_1 = i_f
- Therefore

- Integrating both the sides

$$\boxed{V_{out} = -\int V_{in}dt + V_k(o)}$$

Where $V_k(0)$ is the initial value across the capacitor

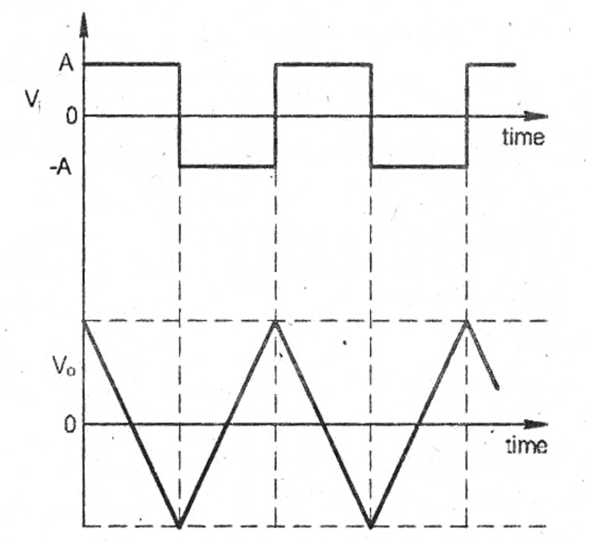


Fig.5.8 Integrator Waveforms

Applications:

- Analog computers
- Analog to Digital converters.

5.4.4. High Pass Filter as Differentiator

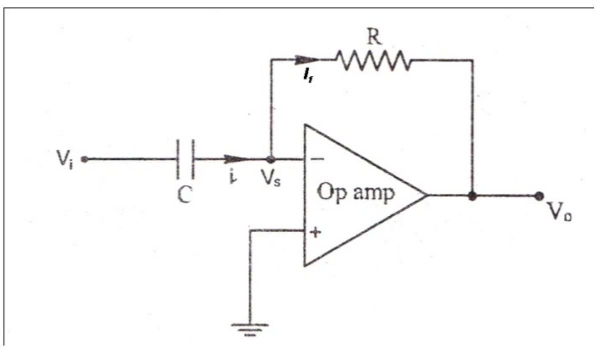


Fig.5.9 HPF as Differentiator

When the time constant of the RC high pass filter circuit is very low (ω_{τ}<<1), the circuit can be operated as an differentiator.

- For example ,if we integrate a triangular wave output will be a square wave and if we integrate a square wave output will be a positive and negative spikes
- Practically an HPF acts as perfect differentiator when the timeconstant τ10% of the period of the input signal wave form.

Proof:

The charge in the capacitor is Q = CV

i_C

The input current

=

The feedback current

= as &

By applying kirchoff'slaw =

V_0 = - RC

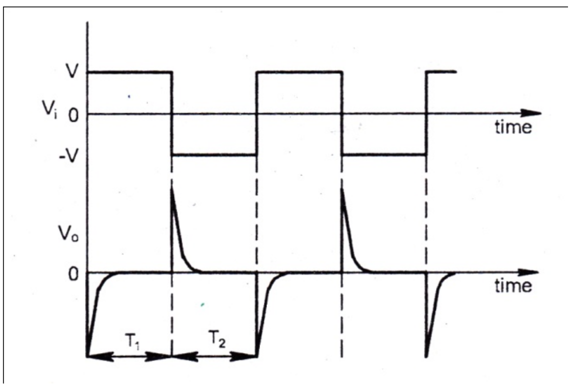


Fig.5.10 Differentiator Waveforms

5.5 Clipper Circuit using Op.Amp.

Clipper is a circuit used to remove or clip off portions of input signal above or below certain reference level. There are Positive and Negative Clippers

5.5.1Positive Clipper:

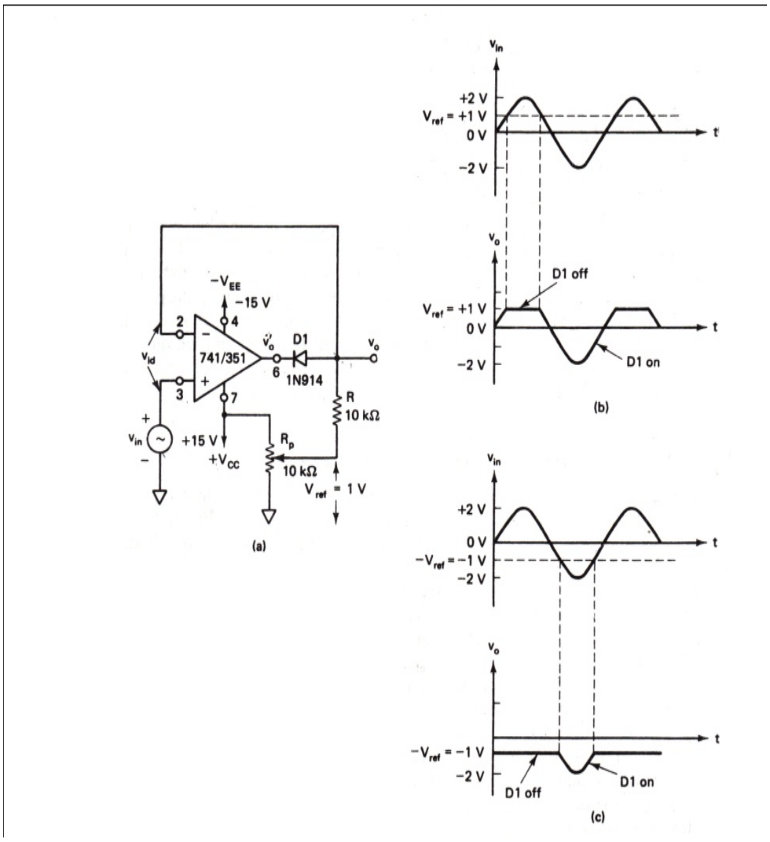


Fig.5.11 Positive Clipper – Circuit & Waveforms

It is a circuit that removes positive portions of input signal and is built of op- amp. With a rectifiers diode as shown in Fig.5.11

- Here the op-amp is basically used as a voltage follower with a diode in the feedback path.

- The clipping level is determined by the reference voltage V_{ref} and should be less than the voltage range of the input signal.
- The reference voltage V_{ref} is derived from the positive or negative supply voltage.

Circuit Operation:

- V_{in} is given to Non- inverting input of the op-amp.
- Feed back is given to the inverting input of the op-amp.
- V_{fef} is derived from $+V_{cc}$

When $V_{in}<V_{ref}$:

- Since the voltage level (V_{fef}) at the inverting input is higher than V_{in}at the Non inverting input , the output at V_o is negative the diode to forward conduction.
- When diode conducts , it shorts (closes) the feedback loop and op amp act as a voltage follower.
- That is V_{out} follows $V_{in}$when $V_{in} \leq V_{ref}$.

When $V_{in}>V_{ref}$:

- When V_{in} is slightly greater than V_{ref}, since the voltage at Non inverting input is greater than inverting input, the output of op-amp is driven positive & diode is reverse biased.
- Now the o/p voltage equals V_{ref}
- Hence $V_{out} = V_{ref}$ when $V_{in}>V_{ref}$.

When V_{ref} is derived from $-V_{EE}$:

- The o/p follows I/p when $V_{in}<(-V_{ref})$ and is clipper at $-V_{ref}$ when $V_{in} \geq (-V_{ref})$ as shown in fig.

5.5.2 Negative clipper :

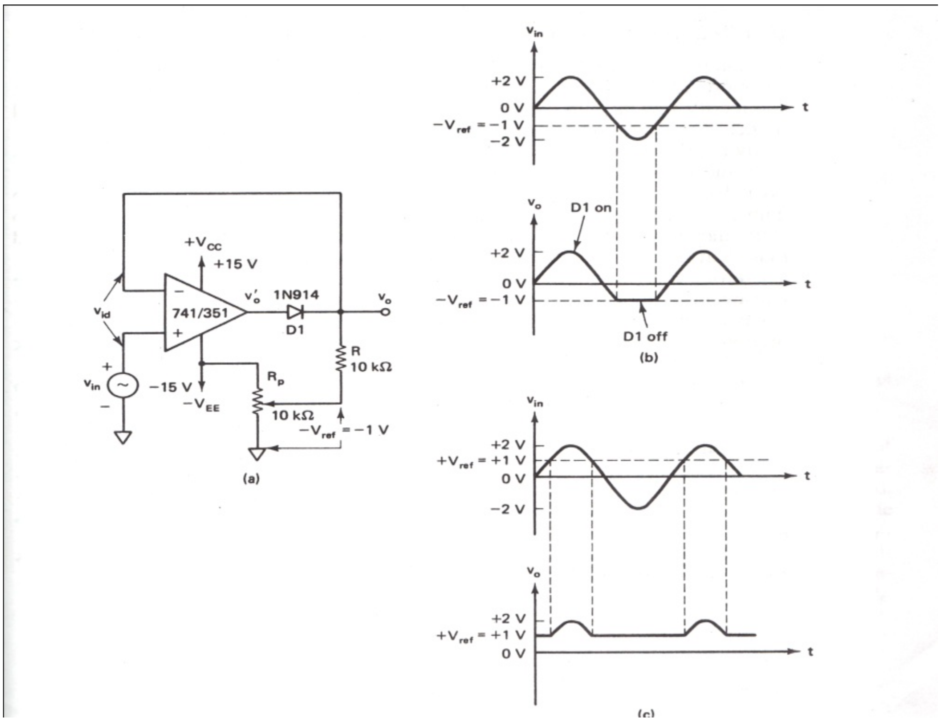


Fig.5.12 Negative Clipper – Circuit & Waveforms

It is a circuit that removes or clip off negative portions of the input signal. Similar to positive clipper it is built of op-amp & rectifier diode but in the opposite direction an shown in Fig .5.12

- The clipping level is determined by the reference voltage V_{ref} and should be less than the voltage range of the input signal.
- The reference voltage V_{ref} is derived from the positive or negative supply voltage.

Circuit operation:

- V_{in} is given to Non inverting input
- feed back from V_{out} is given to inverting of the op-amp.
- V_{fef} is derived from $-V_{EE}$

When V_{in}>(-V_{ref}):

- Since the voltage level (V_{fef}) at the inverting input is less than V_{in}at the Non inverting input, the V_{out} is positive and drives the diode to forward conduction.
- When diode conducts , it shorts (closes) the feedback loop and op amp act as a voltage follower.
- That is V_{out} follows V_{in} when $V_{in} \geq V_{ref}$.

When $V_{in} \leq (-V_{ref})$

- Since the voltage level at the inverting input is greater than V_{in} the V_{out} is negative and diode is reverse biased.
- Now the O/P voltage equals $(-V_{ref})$
- Hence $V_{out} = (-V_{ref})$ when $V_{in} \leq (-V_{ref})$

<u>When V_{ref} is derived from $+V_{cc}$</u>

The output follows V_{in} ,when $V_{in} > (+V_{ref})$ and is clipped at $+V_{ref}$ when $V_{in} \leq (+V_{ref})$ an shown in fig5.12

5.6 Clamper Circuit using Op.Amp

It is a circuit which is used to shift or clamp the input signal to a desired dc level. A desired value of dc voltage is added in series with the input signal.

There are Positive clampers and Negative clamper.

5.6.1.Positive clamper:

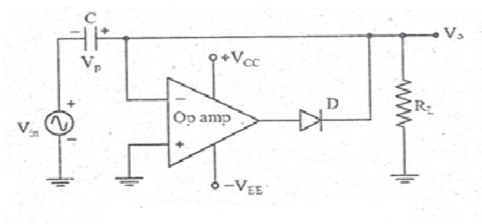


Fig. 5.13 Positive Clamper

If the applied input signal is shifted (or clamped) to positive side it is called positive clamper.

circuit diagram of positive clamper is shown in the fig.5.13

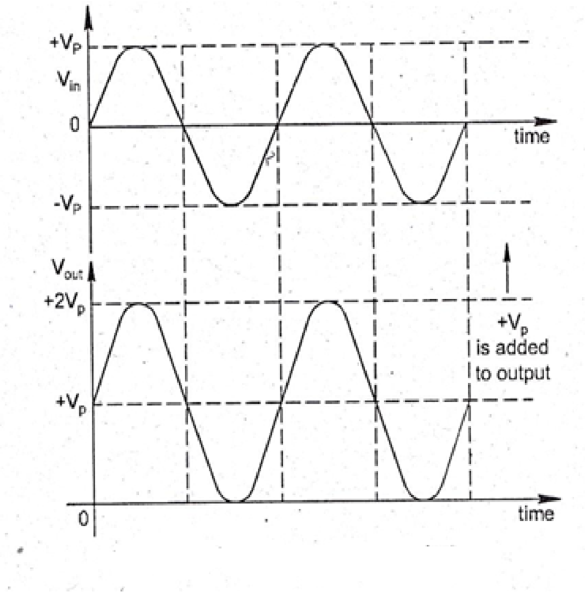


Fig. 5.14 Positive Clamper Waveforms

- When the input voltage is first time negative half cycle as soon as the supply is on , due to the inverting mode of op-amp, the output of op-amp is positive. Now the diode D is forward biased and the capacitor charges to the peak value of the negative cycle of the input voltage V_p, with the polarity as shown in the figure 5.13.

- For all the subsequent cycles of the input voltage , the diode is reverse biased by the fully charged capacitor and will not be conducting at all.

- Now the output voltage is the sum of the input voltage and capacitor voltage.

$$V_O = V_{in} + V_c$$

- Since $V_c = Vp$
  - When Vin = + V_p V , $V_O = V_p + V_c = 2$ Vp
  - When Vin = 0 V , $V_O = V_c =$ Vp
  - When Vin = -V_p V , $V_O = -V_p + V_c = 0$ V

Thus the dc level equal to Vp gets added in the AC output signal. The final output waveform is sinusoidal but shifted positively through Vp. Hence this circuit is called positive clamper. The waveforms are shown in the fig.5.14. The resistance R_L is used to protect the op-amp against excessive discharge currents from the capacitor C, when DC supply voltages are switched off.

5.6.2. Negative clamper

If the applied input signal is shifted (or clamped) to negative side, it is called negative clamper. The circuit diagram of negative clamper is shown in the fig.5.15.

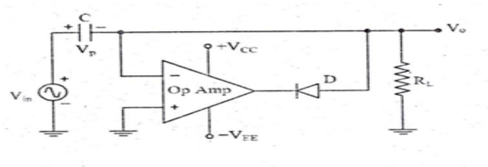


Fig. 5.15 Negative Clamper

- When the input voltage is first time positive half cycle as soon as the supply is on , due to the inverting mode of op-amp, the output of op-amp is negative. Now the diode D is forward biased and the capacitor charges to the peak value of the positive cycle of the input voltage V_p, with the polarity as shown in the figure 5.13.

- For all the subsequent cycles of the input voltage , the diode is reverse biased by the fully charged capacitor and will not be conducting at all.

- Now the output voltage is the sum of the input voltage and capacitor voltage.

$$V_O = V_{in} - V_c$$

- Since $V_c = -Vp$
  - When $Vin = +V_p$ V , $V_O = V_p - V_c = 0$ V
  - When $Vin = 0$ V , $V_O = -V_c = -Vp$
  - When $Vin = -V_p$ V , $V_O = -V_p - V_c = -2V_p$

Thus the dc level equal to -Vp gets added in the AC output signal. The final output waveform is sinusoidal but shifted negatively through -Vp. Hence this circuit is called negative clamper. The waveforms are shown in the fig.5.16. The resistance R_L is used to protect the op-amp against excessive discharge currents from the capacitor C, when DC supply voltages are switched off.

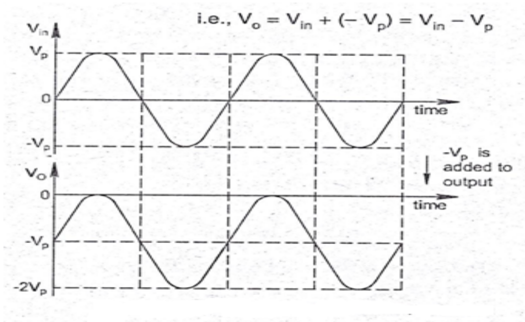


Fig. 5.16 Negative Clamper Waveforms

5.7Successive Approximation ADC:

- The Fig.5.15 shows the block diagram of a 4 bit successive approximation Analog to digital convertor.
- It contains a successive approximation register (SAR), a D/A converter, a clock generator, a comparator and a control logic unit.
- The digital output is taken from the SAR. The output of the D/A converter is called reference voltage, which is applied to the non-inverting input (V+) of the comparator.
-

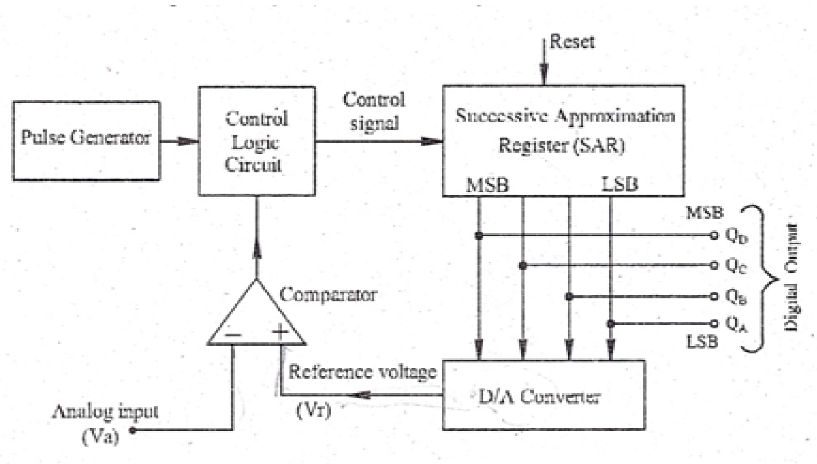


Fig.5.17 Successive Approximation ADC

- The analog voltage to be converted into digital signal is applied into the inverting input (V-) of the comparator.
- If V- is greater than or equal to V+ (V- ≥ V+), the output of the comparator is low level , else if V- is lesser than or equal to V+ (V- ≤ V+) the output goes to high level.
- The SAR register is first reset to make the output as all Zeros .
- The analog input voltage to $V_a$is applied to the inverting input. The SAR register first sets only the MSB bit (1000). This value is then converted into its equivalent analog voltage and applied as reference voltage to the non-inverting input of the comparator.
- The comparator compares the input voltage (V_a) and the reference voltage (V_r).
- The comparator output is low (o) when $V_a \geq V_r$, otherwise the comparator output goes to high (1) level when ($V_a < V_r$).
- If the comparator output is low, the control logic unit permits a control high signal to the SAR.
- The SAR sets the bit of next MSB (1100)
- Otherwise, if the comparator output is high, the control unit permits a control low signal to the SAR
- Now the SAR unit makes the previous set bit as 0 and sets the bit next to the MSB (0100).
- This value is again converted into its equivalent analog signal, and also compared with the input voltage.

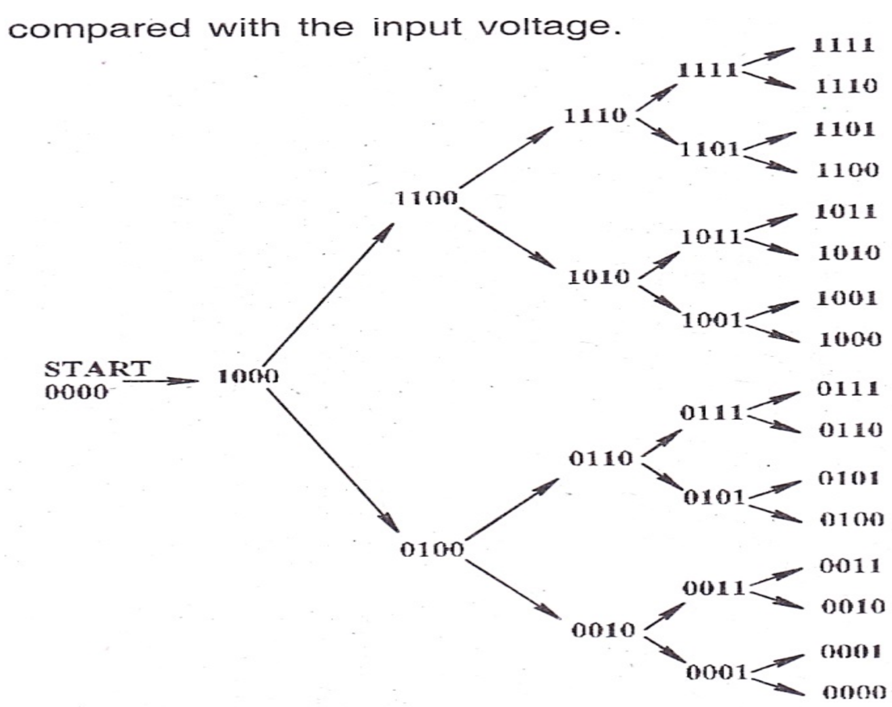


Fig.5.18 Conversion Table

- This process is repeated down to the LSB, and at this time the desired digital value corresponding to the analog input is stored in the counter. The counting sequence begins with MSB and ends with LSB.
- This method is a process of approximating the analog voltage by trying '1' bit at a time, beginning with the MSB as shown in the table.
- The conversion time depends on the number of bits of the digital output
- A display unit may be connected at the output to indicate the output digital value

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5.8. R-2RLadder Network DAC

- Fig.5.17 shows a 3 bit R-2R ladder network Digital to Analog Converter .
- It uses the resistors of only two values, R and 2R.
- The inputs to the resistor network are applied either high level (+5 V) or low level (0V) voltages , through switches depending on whether the digital input is Zero or one

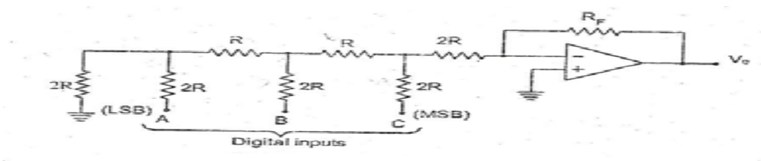


Fig.5.19 R-2R Digital to Analog Converter

- To analyse this circuit, we have assumed the digital input as 001, as shown in the fig.5.18.

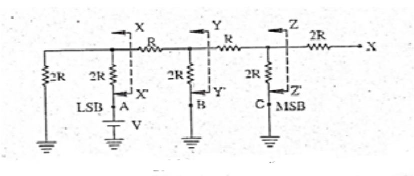


Fig.5.20 Equivalent circuit of R-2R Digital to Analog Converter

- The circuit could be simplified using Thevenin's theorem.

- Applying, Thevenin's theorem at XX', we obtain the circuit of fig.5.19 (a).
- Similarly, applying Thevenin's theorem at YY' and ZZ', we obtain the circuits of fig.5.19(b) and (c) respectively.
- Here LSB has been assumed as 1 and the equivalent voltage obtained is $V/2^3$.
- Similarly, for the digital input of 010 and 100, the equivalent voltages are $V/2^2$ and $V/2^1$ respectively.

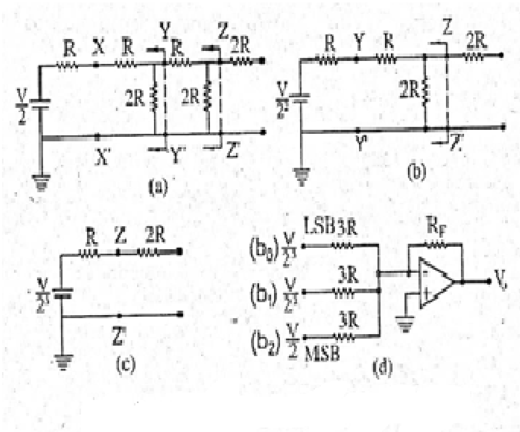


Fig.5.21 Simplified circuits of R-2R Digital to Analog Converter

- The equivalent resistance is 3R in each case. Therefore, we obtain an equivalent circuit of fig 5.17 which is given in fig.5.19(d).
- For the circuit if fig.5.17 , the output analog voltage V_O is given by,

$$
\begin{aligned}
V_O &= -\left[\frac{R_F}{3R}\cdot\frac{V}{2^3}\,b_0 + \frac{R_F}{3R}\cdot\frac{V}{2^2}\cdot b_1 + \frac{R_F}{3R}\cdot\frac{V}{2^1}\,b_2\right] \\
&= -\frac{R_F . V}{3R}\left(\frac{b_0}{2^3} + \frac{b_1}{2^2} + \frac{b_2}{2^1}\right) \\
&= -\frac{R_F . V}{3R}\left(\frac{1b_0 + 2b_1 + 4b_2}{2^3}\right) \\
&= -\left[\frac{R_F}{3R}\right]\left[\frac{V}{2^3}\right][4b_2 + 2b_1 + 1b_0]
\end{aligned}
$$

- The output voltage is proportional to the digital input.

  If $R_F = 3R$ and $V=-2^3$volts(=-8volts)

$V_O=+[4b_2+ 2b_1+1b_o]=(2^2b_2+2^1b_1+2^ob_o)$

- In general, for an N-bit D/A converter, the output voltage can be similarly determined and is given by

$V_O=(2^{N-1} b_{N-1} + b^{N-2}b_{N-2} + \ldots\ldots + 2^2b_2 + 2^1b_1 +2^0b_0$

Where R_F =3R and V= - 2^NVolts

- The number of resistors required for an N-bit D/A converter is 2N in the case of R-2R ladder D/A converter.

Wien Bridge Oscillator:

The Wien Bridge RC oscillator is an audio oscillator and produce sine wave signal, whose amplitude and frequency can be varied.

- Typical maximum amplitude is in the order of 25 V and frequency range from 20 Hz to 100 kHz .
- This oscillator provides pure sine wave with a stable frequency.
- This is feedback amplifier with a Wien bridge as the feedback network.
- It is an ac bridge and it balances only at a particular frequency.
- For the Bridge to Balance the condition is

$$Z_1 Z_4 = Z_2Z_3$$

If $R_1 =R_2=R$ & $C_1=C_2=C$, equitation 1 & 2 are simplified to

- Both the conditions for getting sustained oscillations are obtained when the bridge is balanced at the resonant frequency fo and A_V = = 3

Condition 1:

The net phase shift of the signal through the op.amp& Wien Bridge must be zero

Condition 2:

|AB|≥1, where A is the open loop gain of the amplifier and β is the transfer function of feedback bridge.

- The resistors R3 & R4 are adjusted to balance the bridge at fo, decided by R & C.

  $A_V = 1 +$

  $R_3 = 2R_4$

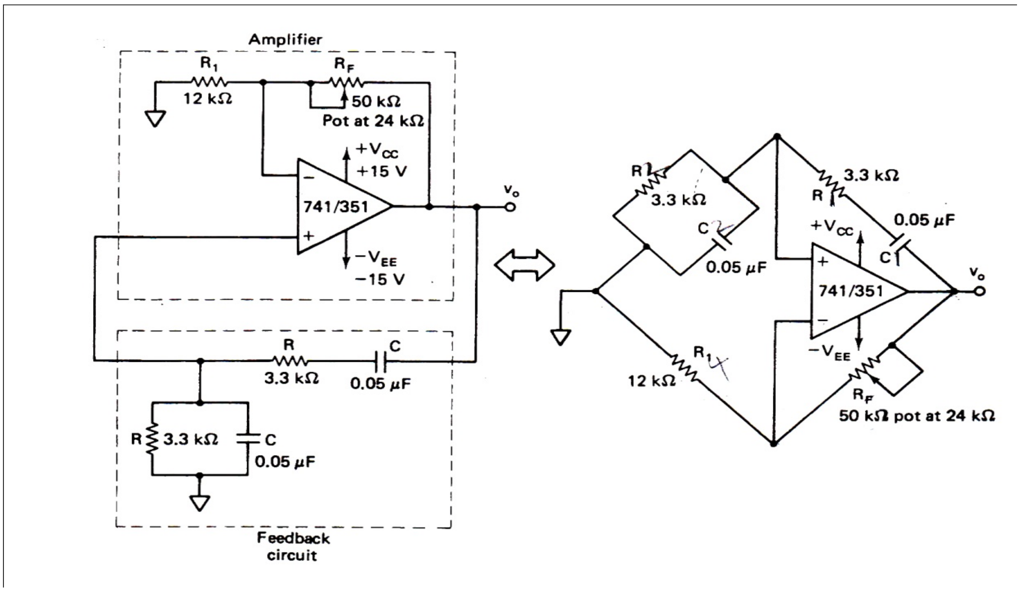


Fig.5.22 Wien Bridge Oscillator

Advantages:

- Provides stable low distortion sinusoidal O/P Voltage upto 100 kHz
- O/P frequency is decided by R & C values

  fo =

Application:

– Measurement of frequency in the audio range

– Used as frequency determines device in harmonic distortion analyzer

5.9 Op. Amp. as Zero Crossing Detector:

Before studying about Zero Crossing Detector , it is prerequisite to understand the operation of op amp as a basic comparator.

5.9.1 Op. Amp as Basic comparator

Introduction:

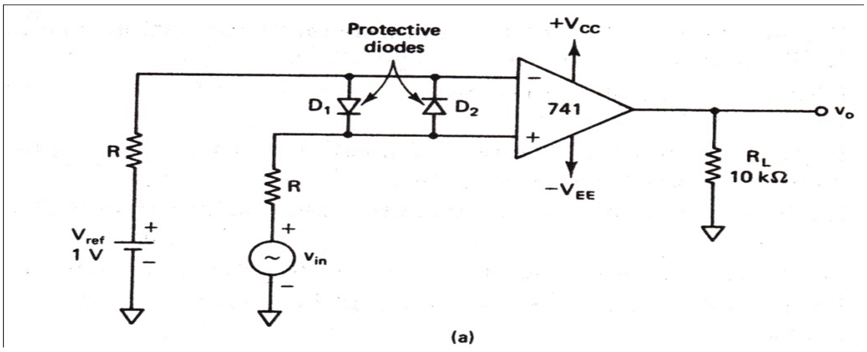
A comparator, as its name implies, compares a signal voltage on one input of an op-amp with a known voltage called the reference voltage on the other input. In its simplest form, it is nothing more than an open-loop op-amp, with two analog inputs and a digital output. The output may be positive or negative saturation voltage, depending on which of the input is the larger.

Comparators are used in circuits such as digital interfacing, Schmitt triggers, discriminators, voltage-level detectors and oscillators.

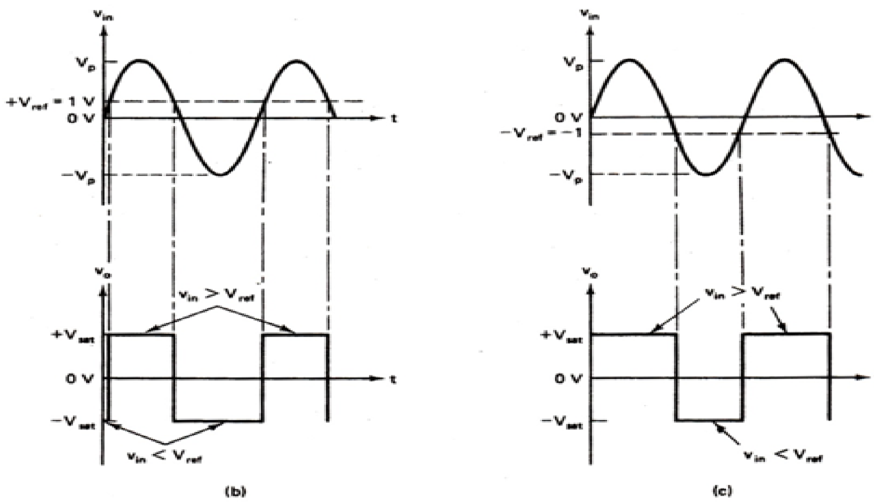
Non Inverting Comparator:

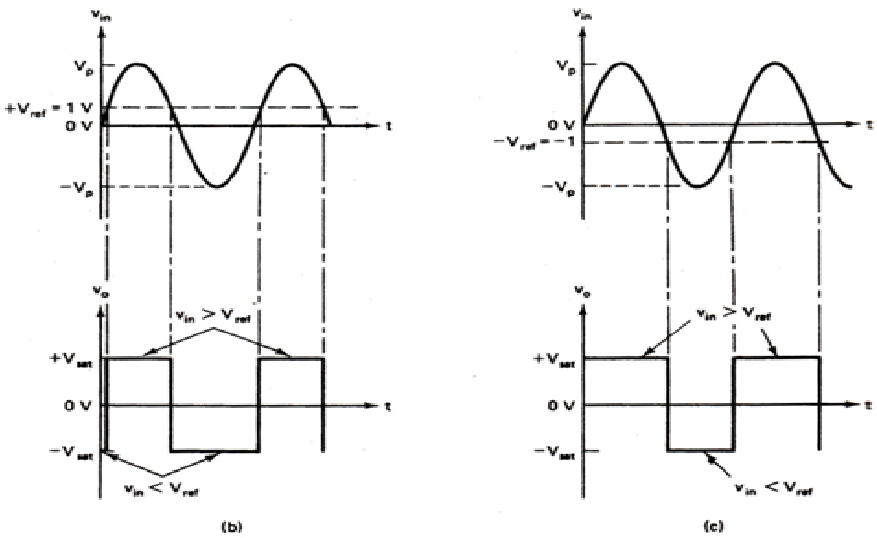
- Figure 5.21 shows an op-amp as a comparator . A fixed reference voltage $V_{ref}$of 1V is applied to the Inverting input or (-) input of op.amp and the other time-varying signal voltage V_{in} is applied to the Non-inverting input or (+) input of op.amp . Because of this arrangement, the circuit is called the Non-inverting comparator.
- When $V_{in}<V_{ref}$, the output voltage $V_0 = -V_{sat}(-V_{EE})$ because voltage at inverting input is greater than Non inverting input $V_{inv.} > V_{noninv.}$
- Similarly, When $V_{in}>V_{ref}$, the output voltage $V_0 = +V_{sat}(+V_{CC})$ because voltage at inverting input is less than Non inverting input $V_{noninv.} > V_{inv.}$
- In short, the comparator is a type of analog-to-digital converter. At any given time the V_0 waveform shows whether V_{in} is greater or less than V_{ref}. The comparator is sometimes also called a voltage-level detector because, for a desired value of V_{ref}, the voltage level of the input V_{in}, the voltage level of the input V_{in} can be detected.
- Referring to the figure 5.9.1 (a), the diodes D1 and D2 protect the op-amp from damage due to excessive input voltage V_{in}. Because of these diodes, the difference input voltage V_{id} of the op=amp is clamped to either 0.7 or -0.7 V. Hence the diodes are called clamp diodes.
- If the reference voltage V_{ref} is positive with respect to ground, with a sinusoidal signal applied to the (+) input, the output waveform will be as shown in figure 5.9.1(b).
- If the reference voltage V_{ref} is negative with respect to ground, with a sinusoidal signal applied to the (+) input, the output waveform will be as shown in figure 5.9.1(c).

- In both the cases , When $V_{in}>V_{ref}$,V_0 is at $+V_{sat}$; when $V_{in}<V_{ref}$ is at $-V_{sat}$.



5.23 Op amp as Non Inverting Comparator





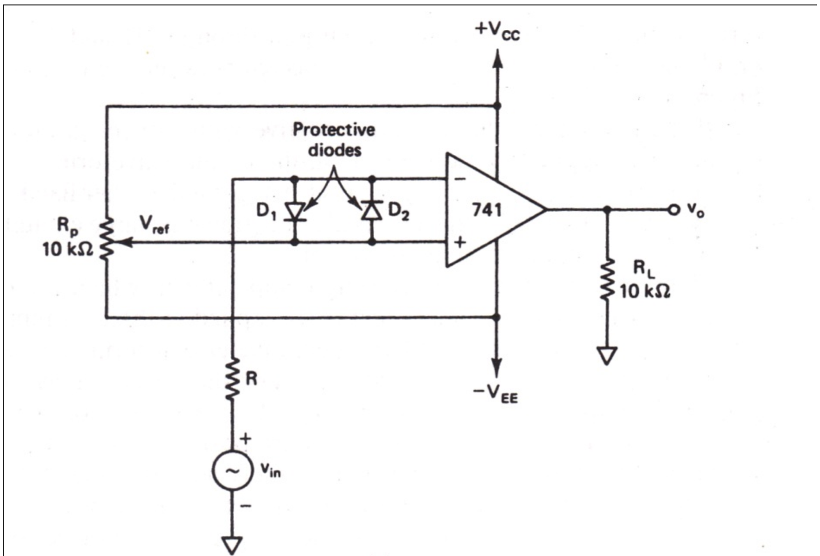
v

5.24 Input and Output waveforms - Op amp as Non Inverting Comparator

Inverting Comparator

- The figure 5.9.2 shows the inverting comparator in which the reference voltage V_{ref} is applied to Non- inverting input and V_{in} is applied to inverting input.

- The 10K potential divider is used to get the required reference voltage from $+V_{cc}$& $-V_{EE}$, either positive or negative.
- With a sinusoidal input voltage, the output voltage has the waveform as shown in figure 5.9.2(b) or (c) depending on whether V_{ref} is positive or negative.



(a)

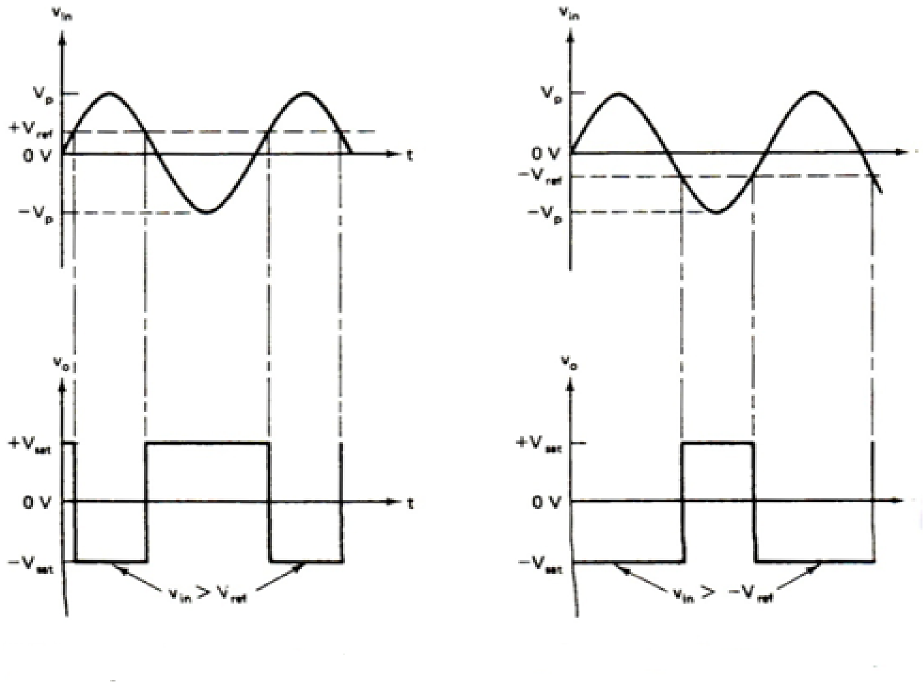
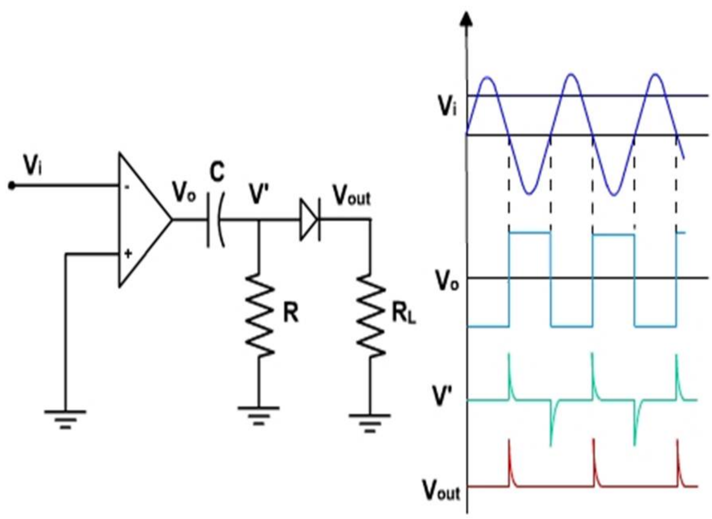


Figure 5.22 (a) Inver ting Comparator (b) Input and output waveforms when V_{ref} is Positive (c)Input and output waveforms when V_{ref} is Negative

Zero Crossing Detector:

In op.amp zero crossing detectors, the output responds every time the input passes through zero. It consists of a comparator circuit followed by differentiator and diode arrangement.



5.25 Zero Crossing Detector ZCD with input and output waveforms

Circuit operation

In the figure shown above a sinusoidal signal Vin is applied to the inverting input of opamp. Since the opamp is in open loop configuration, the output of opamp Vo will be at Negative saturation voltage –Vcc when ever Vin > 0 V and is at positive saturation voltage +Vcc when Vin < 0 V.

The differentiator circuit(combination of capacitor and resistor)
provides an output V' = R*C*dV /dt consisting of peaks at times where the square wave crosses zero voltage.
Vin >0 V, Vo = - Vcc , Capacitor C charges towards –Vcc from +Vcc through R and V' is a negative spike if the time constant RC is less.

Vin < 0 V, Vo = + Vcc , C charges towards + Vcc from –Vcc through R and V' is a positive spike , if the time constant RC is less.
The diode is kept to filter off the negative spikes and positive spikes to indicate the zero crossings where input voltage crosses zero voltage in rising fashion.

Application:

- To count the number of pulses / frequency of ac signals

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Review question

PART A

1. Specify the various basic ways for converting the capacitance value of capacitive transducer into measurable electrical quantity by using op-amp.
2. State the features of instrumentation amplifier.
3. State the advantages of active filter.
4. How can convert HPF into differentiator.
5. Define clipper and clamper.

6. Define ADC and DAC.

PART B

7. Draw the circuit diagram of instrumentation amplifier using op-amp and nite its output voltage.

8. What do you mean active filters and state its advantages.

9. With the diagram explain LPF.

10. Explain Zero crossing detector using op-amp with diagram.

11. Draw the block diagram of successive approximation ADC.

PART C

12. a) With the diagram explain capacitive transducer.

    b) Draw the circuit diagram of Wien bridge oscillator and explain its operation.

13. a) With the diagram explain R-2R ladder network DAC.

    b) Explain Active filters with diagrams.

14. a) With the diagram explain the operation of instrumentation amplifier.

    b) With the diagram explain positive clamper using op-amp.

15. a) With the diagram explain successive approximation ADC.

    b) With the diagram explain positive clipper using op-amp.

16. a) with the diagram explain bridge amplifier using op-amp.

    b) Explain LPF and HPF using op-amp