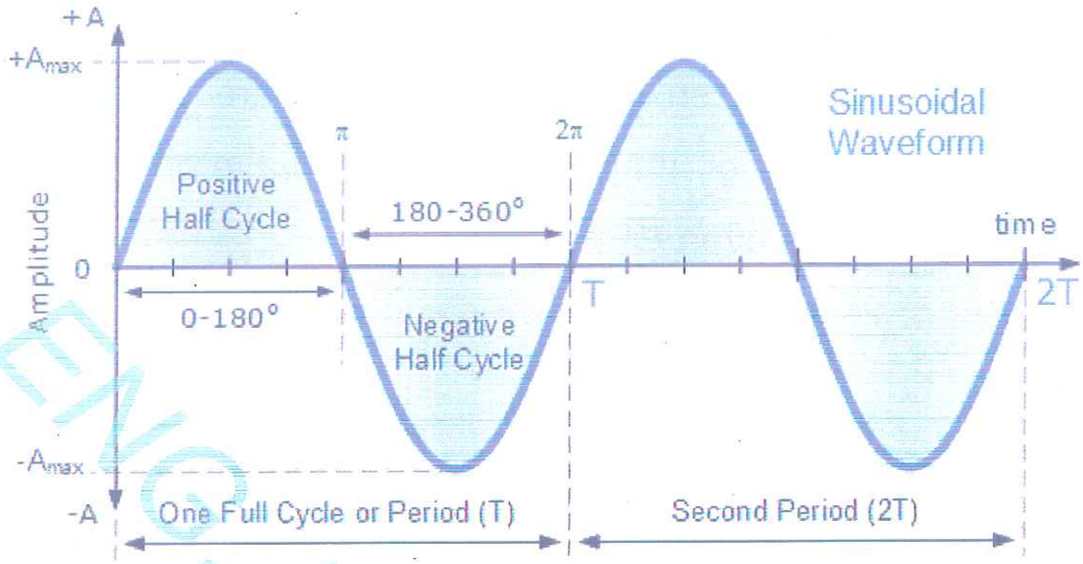
A Sine Wave Waveform (analogue waveform):



Waveform period (T): the time it takes for electrical waveforms to repeat themselves .Units of periodic time, (T) include: **Seconds** (s), milliseconds (ms) and microseconds (μs).

Waveform frequency (F): If we take the reciprocal of the period, (1/T) we will get the number of times that an electrical waveform repeats it self in one second or cycles per second, and this is commonly known as **Frequency** with units of **Hertz, (Hz)**. 1Hz is exactly equal to 1 cycle per second.

$$\text{Frequency} = \frac{1}{\text{Periodic time}} \quad \text{or} \quad f = \frac{1}{T}\ \text{Hz}$$

$$\text{Periodic time} = \frac{1}{\text{Frequency}} \quad \text{or} \quad T = \frac{1}{f}\ \text{sec}$$

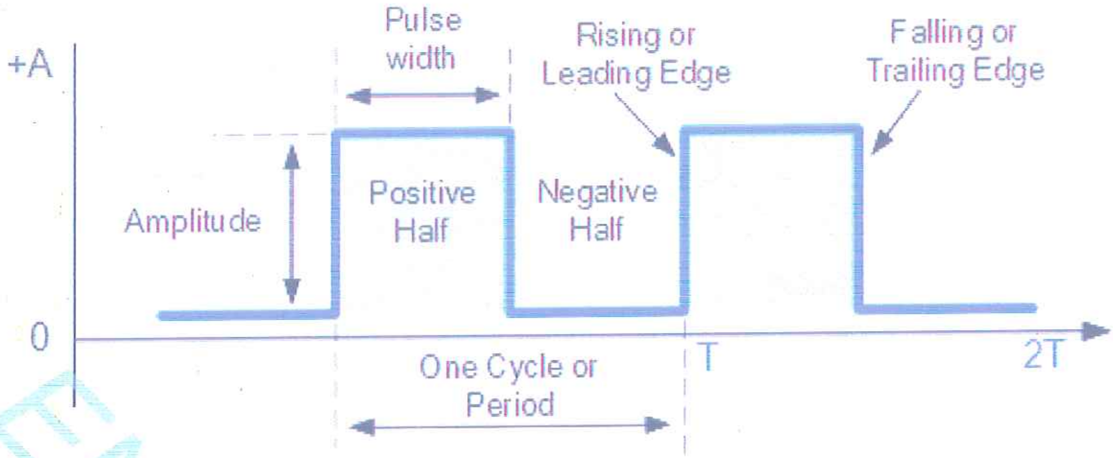
Where: f is in Hertz and T is in Seconds.

One **Hertz** is exactly equal to one cycle per second, but one hertz is a very small unit so prefixes are used that denote the order of magnitude of the waveform such as **kHz**, **MHz** and even **GHz**.

Prefix	Definition	Written as	Time Period
Kilo	Thousand	kHz	1ms
Mega	Million	MHz	1us
Giga	Billion	GHz	1ns
Tera	Trillion	THz	1ps

Digital Electrical Waveforms :**digital waveforms** are used in digital logic and microprocessor electronic circuits for clock and timing control signals.

A special case of digital waveform is a Square Wave Waveform is shown below :



in square waveform , the positive pulse width (time) must be equal to the negative(or zero) pulse width (time).

Digital Wave " Duty cycle " : the time of the positive pulse width is known as the "Duty Cycle" of the period.

Example : for a digital wave waveform with positive or "ON" time is equal to (0.5 m sec) ,and the negative or "OFF" time is equal to (0.5 m sec) .Find :

1) duty cycle .

2) wave form frequency .

solution : 1) the duty cycle can be calculated using the following formula:

$$\text{duty cycle} = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

t_{ON} = ON time

t_{OFF} = OFF time

$t_{ON} + t_{OFF}$ = Time period

duty cycle = (0.5) / (0.5+0.5) = 50% .

2)as frequency is equal to the reciprocal of the period, (1/T) we can define the frequency of a digital wave waveform as:

$$\text{Frequency} = \frac{1}{\text{"ON" time} + \text{"OFF" time}}$$

Frequency = 1 / (0.5 exp -3 + 0.5 exp -3) = 1000 Hz .

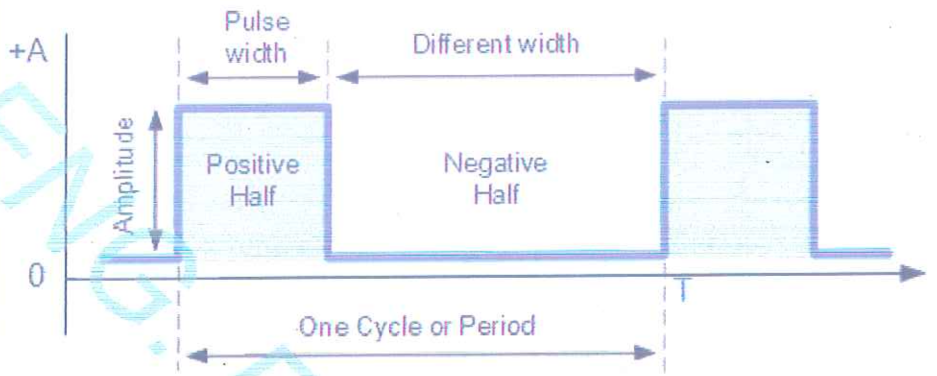
Example :a Square Wave electrical waveform has a pulse width of 10ms, calculate its frequency, (f).

solution :for a square wave shaped waveform, the duty cycle is given as 50%, therefore :

period of the waveform = T = 10ms + 10ms = 20ms

$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{10mS + 10mS} = 50Hz$$

If the duty cycle of the digital waveform is any other value than 50%, (half-ON half-OFF) the resulting waveform would then be called a **Rectangular Waveform** or if the "ON" time is really small a **Pulse**.



Example : a Rectangular waveform has a positive pulse width (Mark time) of 10ms and a duty cycle of 25%, calculate its frequency.

solution :the duty cycle is given as 25% or 1/4 and this is equal to the mark time which is 10ms, then :

period of the waveform = T = 10ms + (75% T) = (100% T)

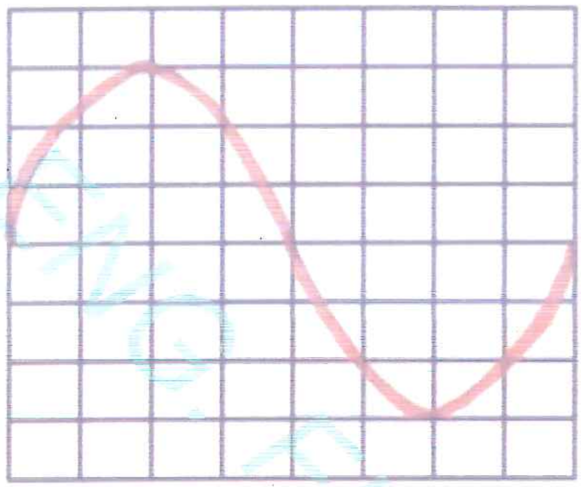
T = 10ms (25% T) + 30ms (75% T) = 40ms .

$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{10\text{mS} + 30\text{mS}} = 25\text{Hz}$$

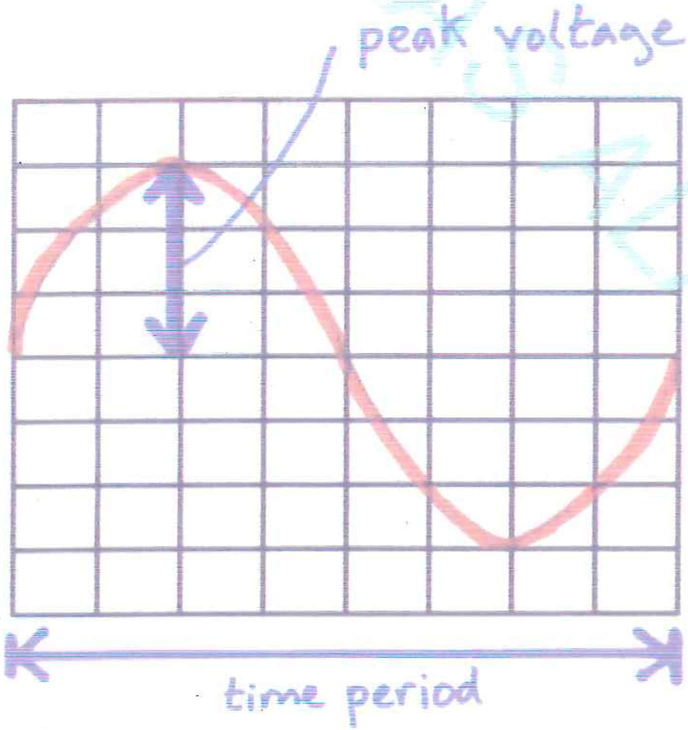
Example :you have an oscilloscope with :

- **Y-gain** (volts/division) = 1 v/div.
- **Time base** (time/division) = 0.002 s/div.

Calculate the peak voltage ,period and time of the following waveform :



solution :



The **peak voltage** (amplitude) = 3 squares x 1 = 3V .

The **time period** (T) = 8 squares x 0.002 = 0.016 s.

We can **calculate the frequency** (f) in hertz (Hz) using the equation below;

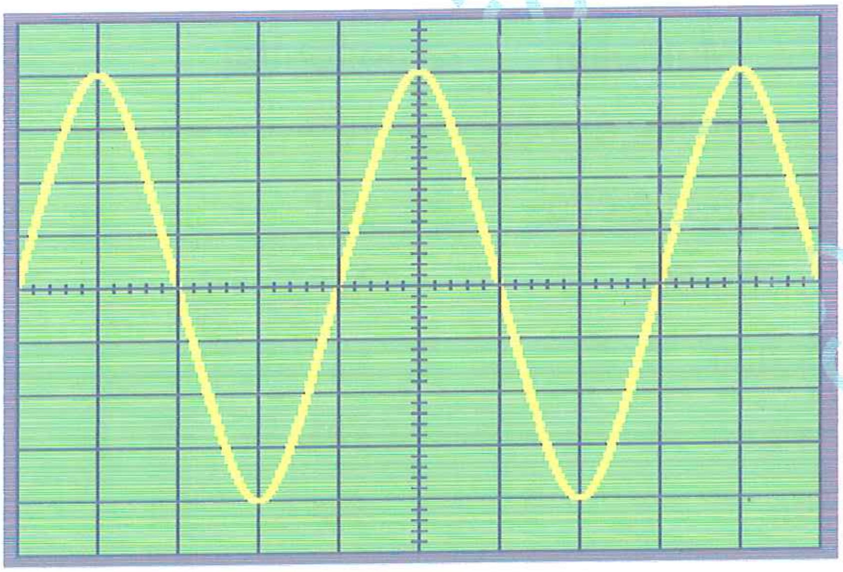
$$f = \frac{1}{T}$$

f = 1 divided by 0.016 = 62.5 Hz

Example :you have an oscilloscope with :

- **Y-gain** (volts/division) = 0.5 v/div.
- **Time base** (time/division) = 5 ms/div.

Calculate the peak voltage ,period and time of the following waveform :



solution :

The **peak voltage** (amplitude) = 4 squares x 0.5 = 2V .

The **time period** (T) = 4 squares x 5 ms = 20 ms .

We can calculate the frequency (f) in hertz (Hz) using the equation below :

$$f = \frac{1}{T}$$

..thus f = 1 divided by (20 exp-3) = 50 Hz

Units of Measurement :

The units by which we now measure physical quantities is called the S.I. (System International) system **established in 1960 The following are some of units that we will need in our study :**

Metric Prefix Table :

Prefix	Symbol	Multiplier	Exponential
tera	T	1,000,000,000,000	10^{12}
giga	G	1,000,000,000	10^{9}
mega	M	1,000,000	10^{6}
kilo	k	1,000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
		1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}

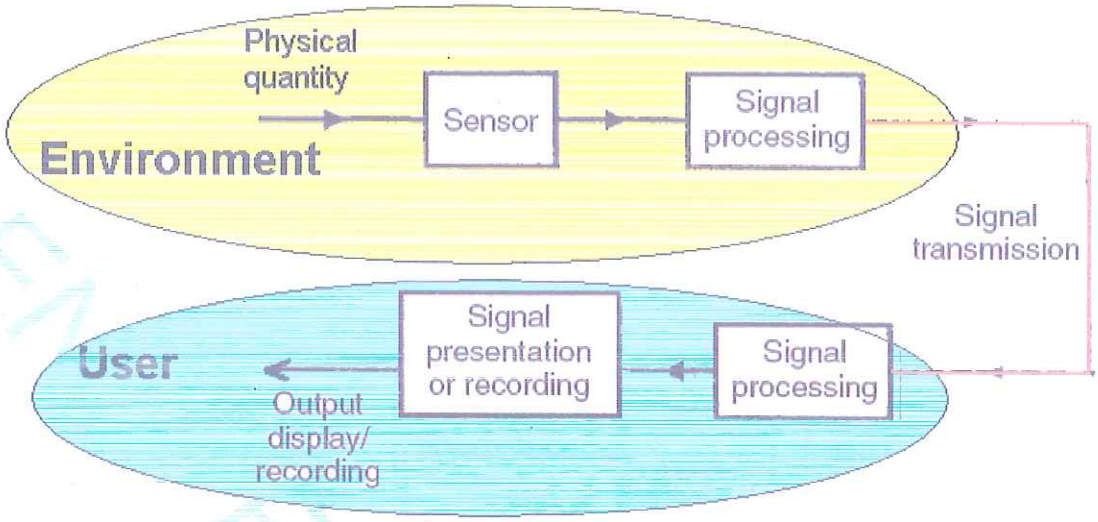
micro	μ	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}
pico	p	0.000000000001	10^{-12}

Basic Electrical Formulas and Standard Electrical Units :

Parameter	Measuring Unit	Symbol
Voltage	Volt	V or E
Current	Ampere	I or i
Resistance	Ohm	R or Ω
Conductance	Siemen	G or 1/Ω
Capacitance	Farad	C
Charge	Coulomb	Q
Inductance	Henry	L or H
Power	Watts	W
Impedance	Ohm	Z
Frequency	Hertz	Hz

Measurement Systems

Block diagram of measurement system :-



Elements of Measurement System

A measuring system exists to provide information about the physical value of some variable being measured.

Elements of a measurement system:-

measuring system consists of several separate elements as shown **in the previous figure** :-

1. **Sensor :-**that converts physical quantity level to be measured to an electrical signal .
2. **Signal processing elements** :-

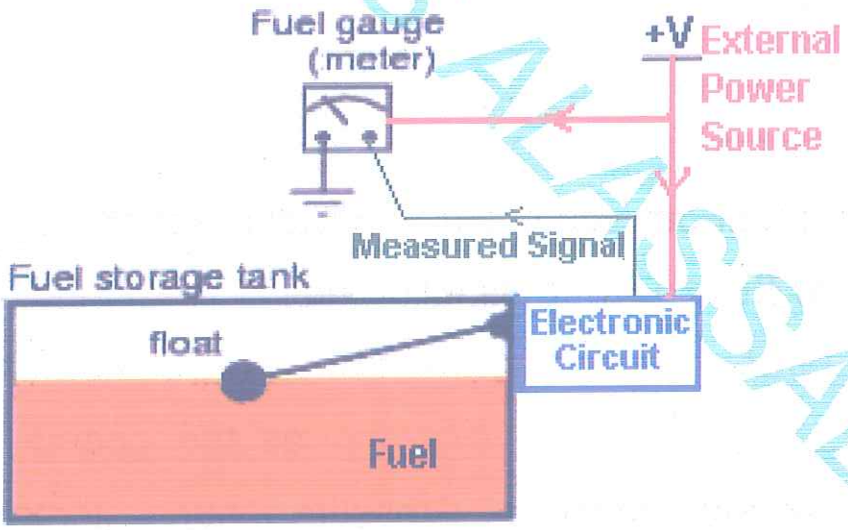
   exist to improve the quality of its input signal .**This element is needed in both environment and user sides**.

3. **Signal transmission** :-is needed when the observation point away from the site of the sensor ,**otherwise it will not be needed .**
4. **Signal presentation** :-It is the final stage in which the user will make use of the measured data in any way that is suitable to him .

Active and passive instruments :-

Instruments are divided according to **whether the instrument contains or not a power supply** as :

1- Active: contains a power supply .Example ,our home **Voltmeter** and **Clamp on meter** ,both of them needs a battery to be operated .



The energy in the output signal comes from the external power source .

Has higher reading quality and cost .

2- Passive : does not contains a power supply . Example

,our home **Car tires Pressure meter** and **Temperature meter** ,both of them doesn't need a battery to be operated .

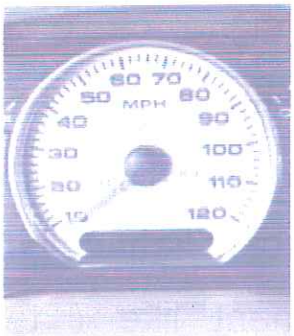
Gas Pressure Meter

The energy needed in moving the pointer is derived from the quantity being measured .There is no external power supply used .Has lower reading quality and cost .

Analogue and digital instruments :-

Measurement devices could be divided **according to the nature of their output** ,as following :

1. **Analogue instrument :-** gives an output that varies **continuously** (not discrete) as the quantity being measured changes .Pressure gauge ,temperature meter are good examples (**pointer moves in front of continuous scale**) .

ANALOG 

2. **Digital instrument** :-has an output that varies in discrete steps or values .The digital voltmeter and digital blood pressure meter are examples (give reading as discrete numbers ,they are not contain pointer in front of continuous scale) .

DIGITAL 

Important Sources of instrument reading error :-

1. originally found in the manufacture of the instrument because of tolerances in the components of the instrument.
2. wear in instrument components over a period of time.
3. effect of environmental disturbances like humidity ,dust .
4. Connecting leads :In connecting together the components.
5. routing of cables :this also needs careful planning

such that signal cable rout must be kept away by suitable distance from the following noise sources :

a) mains-powered equipment and cables.
b) fluorescent lighting circuits.
c) equipment like (telephone , loudspeakers , wireless mobiles radios).
d) switching of nearby d.c. and a.c. circuits, and corona discharge .

Measurement error

Random error : In some experiments, the results shows variation from one to another, because of errors found in each reading .

The cases of these errors : are not recognized, therefore the elimination or reduction of these errors are not possible ,but their effect on measurement reading accuracy could be minimized by taking the reading many times ,as number of reading increased the effect of random error on measurement accuracy will be decreased.

Error of Measurement : can be define difference between the actual value of a quantity and the value obtained by a measurement.

Solving the problem of these errors :Repeating the measurement will improve (reduce) the random error .

Absolute error : can be defined as the difference between the expected value of the variable and the measured value of the variable.

Where:

1) e = absolute error
2) Yn = expected value
3) Xn = measured value

e = Yn – Xn

Relative error (Percent of Error) : to express the error as a percentage .

$$Percent\ error = \frac{absolute\ error}{expected\ value}\ x\ 100\%$$

$$Percent\ error = \frac{e}{Y_n}\ x\ 100\%$$

$$Percent\ error = \frac{Y_n - X_n}{Y_n}\ x\ 100\%$$

Example 1 the expected value of the voltage across a resistor is 50V; however, measurement yields a value of 49V. Calculate

a) The absolute error

b) The percent of error

c) The percent of accuracy

Solution :

a) e = Yn – Xn = 50V – 49V = 1V

b) $$Percent\ error = \frac{50-49}{50}\ x\ 100\%$$

$$= 0.02\ x\ 100\%$$

$$= 2\%$$

c)

$$\textbf{percent of accuracy} = 100\% - percent\ of\ error$$

$$= 100\% - 2\%$$

$$= 98\%$$

Example 2 The following set of ten measurements was recorded in the laboratory. Calculate the precision of the fourth measurement.

Measurement Number	Measurement Value X_n (volts)
1	98
2	102
3	101
4	97
5	100
6	103
7	98
8	106
9	107
10	99

Solution: The average value for the set of measurements is equal to the sum of the measurements divided by 10 :

$\bar{x} = \frac{1}{N}\sum x_i$ where N=10 .

Then : $\overline{X}$ = 101.1 volts .

The precision of the fourth measurement is :

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

$$= 1 - \left|\frac{97 - 101.1}{101.1}\right|$$

$$= 1 - 0.04$$

$$= \mathbf{0.96}$$

Example 3 after measuring the time needed for a certain process with a stopwatch for five times ,

You obtain the following table:

Trial number, i	1	2	3	4	5
Measured Value, x_i (seconds)	3.9	3.5	3.7	3.4	3.5
Deviation, $d_i = x_i - \bar{x}$ (seconds)	0.3	-0.1	0.1	-0.2	-0.1

Find best estimated time ,and the average of deviations .

Solution :

$$\bar{x} = \frac{1}{N}\sum x_i = \frac{3.9+3.5+3.7+3.4+3.5}{5}\,s = 3.6\ s$$

$$\bar{d} = \frac{1}{N}\sum d_i = \frac{(0.3)+(-0.1)+(0.1)+(-0.2)+(-0.1)}{5}\text{s} = 0\text{ s}$$

Example 4 A set of independent current measurements was taken by six observers and recorded as 12.8 mA ,12.2 mA ,12.5 mA , 13.1 mA ,12.9 mA , and 12.4 mA .Now Calculate readings arithmetic mean (estimated value) and error range .

1. estimated value = average value of measured quantity (current)

$$I_{av} = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6}{N}$$

$$= \frac{12.8\text{ mA} + 12.2\text{ mA} + 12.5\text{ mA} + 13.1\text{ mA} + 12.9\text{ mA} + 12.4\text{ mA}}{6}$$

Iav = 12.65 amperes

2.

Imax − Iav = 13.1 − 12.65 = 0.45 A

Iav − Imin = 12.65 − 12.2 = 0.45 A

The average range of error therefore equals to :

(0.45 + 0.45) /2 = ±0. 45 A

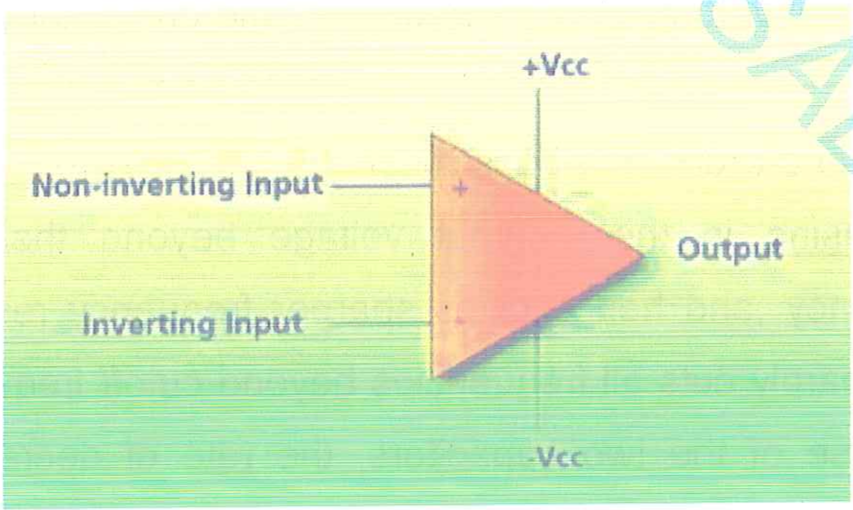
Introduction to signal processing

Signal processing is concerned with improving the quality of the reading or signal at the output of a measurement system.

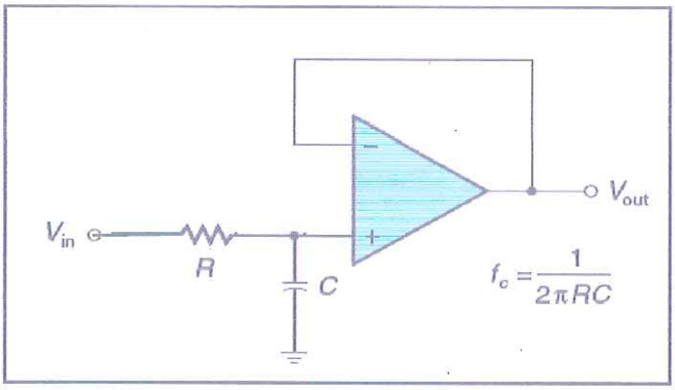
Signal filtering in the measurement system :-

Why we need Low pass filter (LPF) in measurement system ? :- at most ,we need a LPF since measurement signals frequency (which we want to pass) is normally of low value ,while harmful noise signals frequency (which we want to eliminate) is of high frequency value .

First order active Low pass filters :- By using op amps and reactive elements, we built active filters .To build an active filter ,we need (**capacitors** ,**resistors** ,**operational amplifier**) .

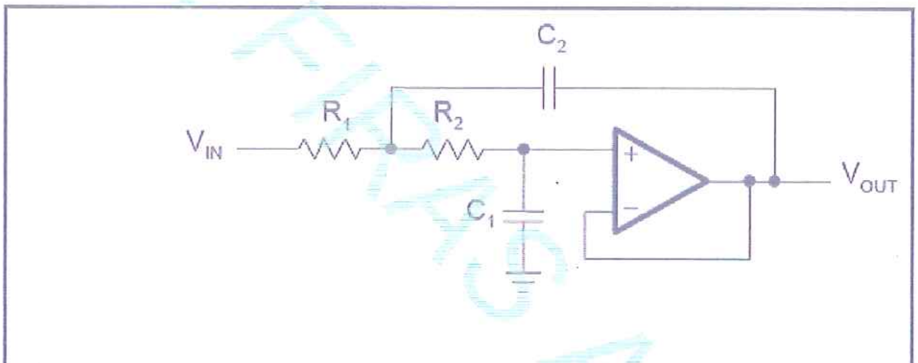


the following figure shows the first order active LPF :



Second-Order Low-Pass Filter :-

The following figure ,shows the *second-order* LPF :



Unity-Gain Low-Pass Filter

The operational amplifier is an electronic device that has two high impedance inputs known as the inverting input and non-inverting input respectively ,and one output .

A *second-order* low-pass filter is one that give more decreasing in the output voltage beyond the cutoff frequency ,and hence gives sharper frequency response that sharply cuts all frequencies beyond cutoff frequency . Because of the two capacitors, the rate of decrease in gain is twice as fast as before as in first order LPF .

The cutoff frequency equation :

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

Example :- If you know that your measurement system sensor provide voltage that having frequency of (500) hertz and the noise voltage effect on the system at the (signal transmission) part , design a unity gain 2nd order LPF that can remove high frequency noise components .Then draw the LPF circuit diagram ,the block diagram of the measurement system showing the position of the LPF. Use capacitor value of 500 PF.

Solution :-

$$Wo = \frac{1}{\sqrt{R1.R2.C1.C2}}$$

If we choose $R1 = R2, C1 = C2$ then

$$2.\pi.500 = \frac{1}{\sqrt{R^2 \cdot C^2}}$$

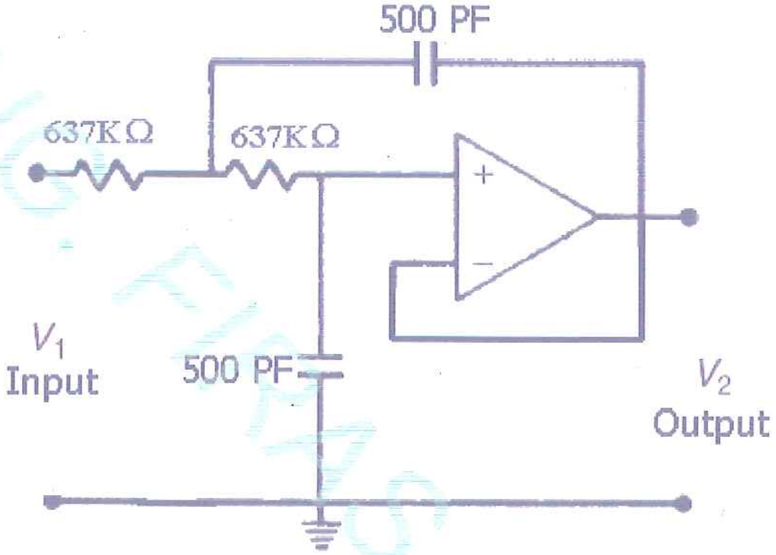
$$1000\pi = \frac{1}{R.C} \quad \text{then} \quad RC = \frac{1}{1000\pi}$$

If we put C = 500 Pico farad then

$$R = \frac{1}{500000 * 10^{-12} * \pi}$$

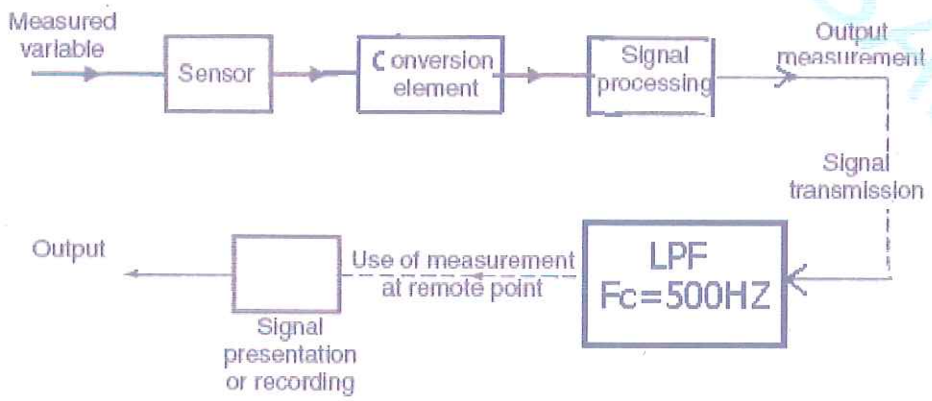
Then $R1 = R2 = R = 637 KiloOhm$

The filter circuit diagram is as following :-



second order
Low pass filter circuit diagram

The position of our filter inside the measurement system is after signal transmission part at the receiver end :



Question :If you know that your measurement system sensor provide voltage that having a frequency of (20) Hz

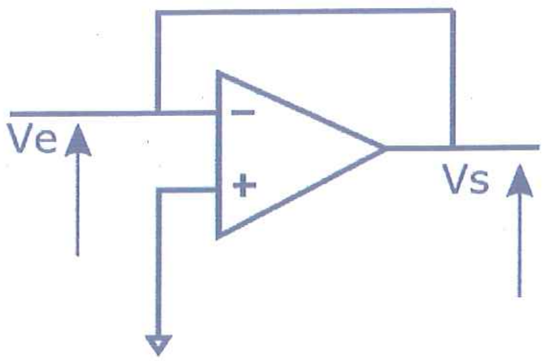
, and the noise voltage effect on the system at the signal transmission part .Design a unity gain 2^{nd} order LPF that can remove high frequency noise components. Then draw the LPF circuit diagram ,the block diagram of the measurement system showing the position of the LPF . Use resistor value of 3.3 KΩ .

Top 8 Fundamental Op Amp Circuits :

As well as **resistors** and **capacitors** that are passive components, **operational amplifiers** are one of the basic building blocks of analogue electronic circuits.

1. Voltage Follower :

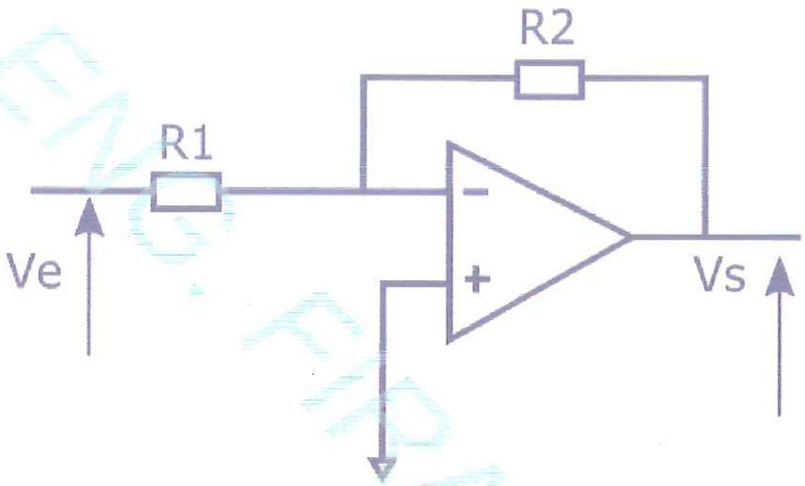
The most basic circuit is the voltage buffer .



$$V_S = V_e$$

2. Inverting Op Amp :

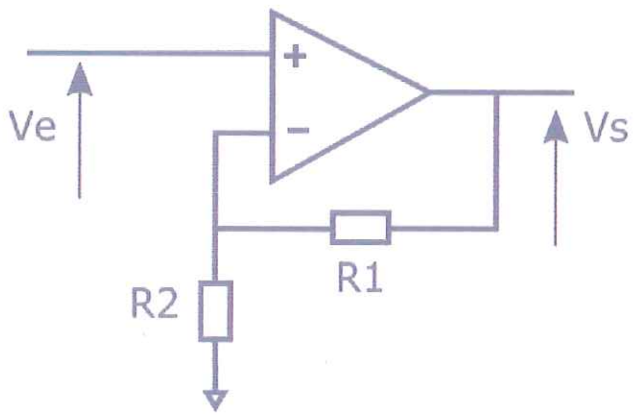
In this configuration, the output is fed back to the negative or inverting input through a resistor (R2). The input signal is applied to this inverting pin through a resistor (R1) .The positive pin is connected to ground.



$$V_S = -V_e \frac{R_2}{R_1}$$

3. Non-inverting Op Amp :

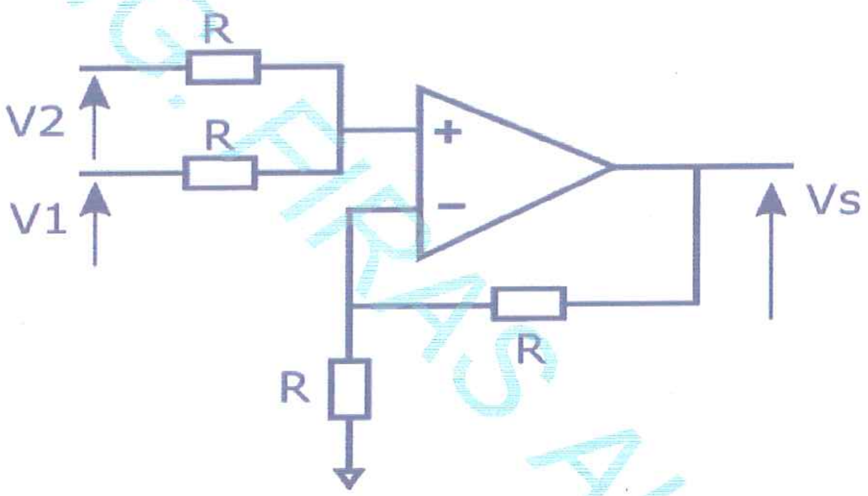
This configuration is very similar to the inverting operation amplifier. For the non-inverting one, the input voltage is directly to the applied to the non-inverting pin.



$$V_S = Ve\,(1 + \frac{R_1}{R_2})$$

4. Non-inverting Summing Amplifier :

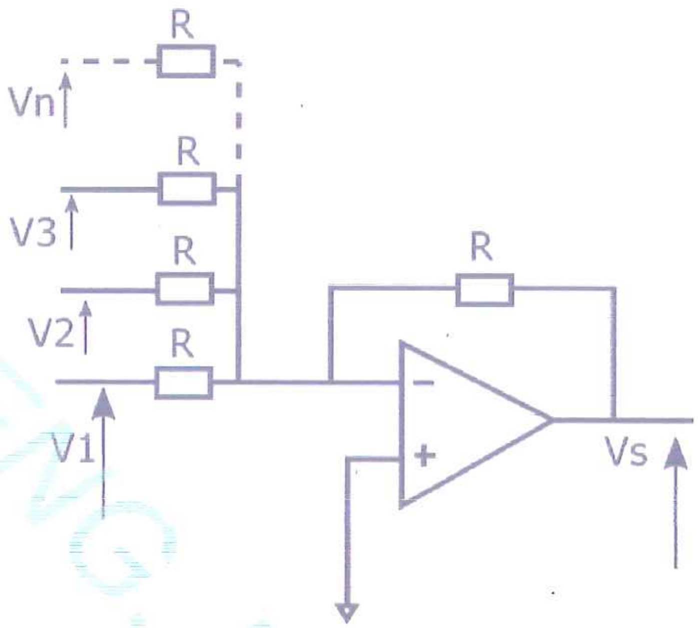
To add 2 voltages, only 2 resistors can be added on the positive pin to the non-inverting operational amplifier circuit.



$$V_S = V_1 + V_2$$

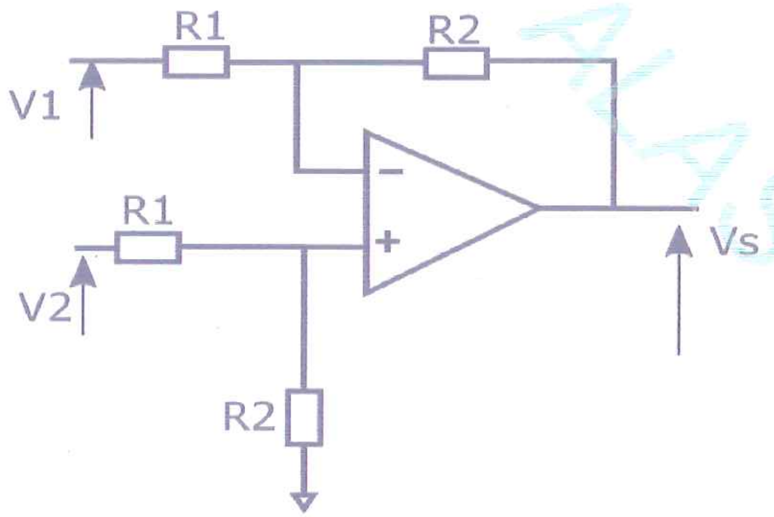
5. Inverting Summing Amplifier :

By adding resistors in parallel on the inverting input pin of the inverting operation amplifier circuit, all the voltages are summed.



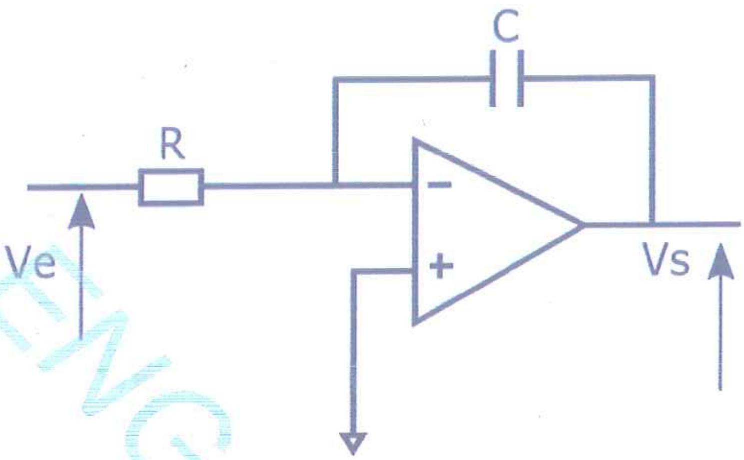
$$V_S = -(V_1 + V_2 + V_3 + \cdots + V_n)$$

6. Difference Amplifier :



$$V_S = \frac{R_2}{R_1}(V_2 - V_1)$$

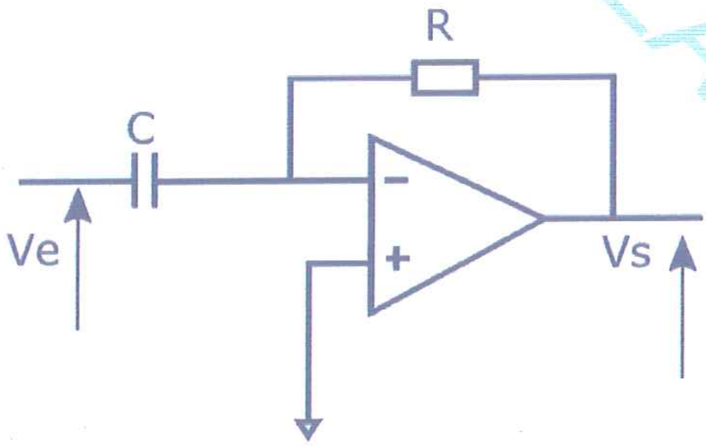
7. Integrator :



$$V_S = -\frac{1}{RC}\int V_e\,dt$$

8. Op Amp Differentiator :

The differentiator works similarly to the integrator by swapping the capacitor and the resistor.

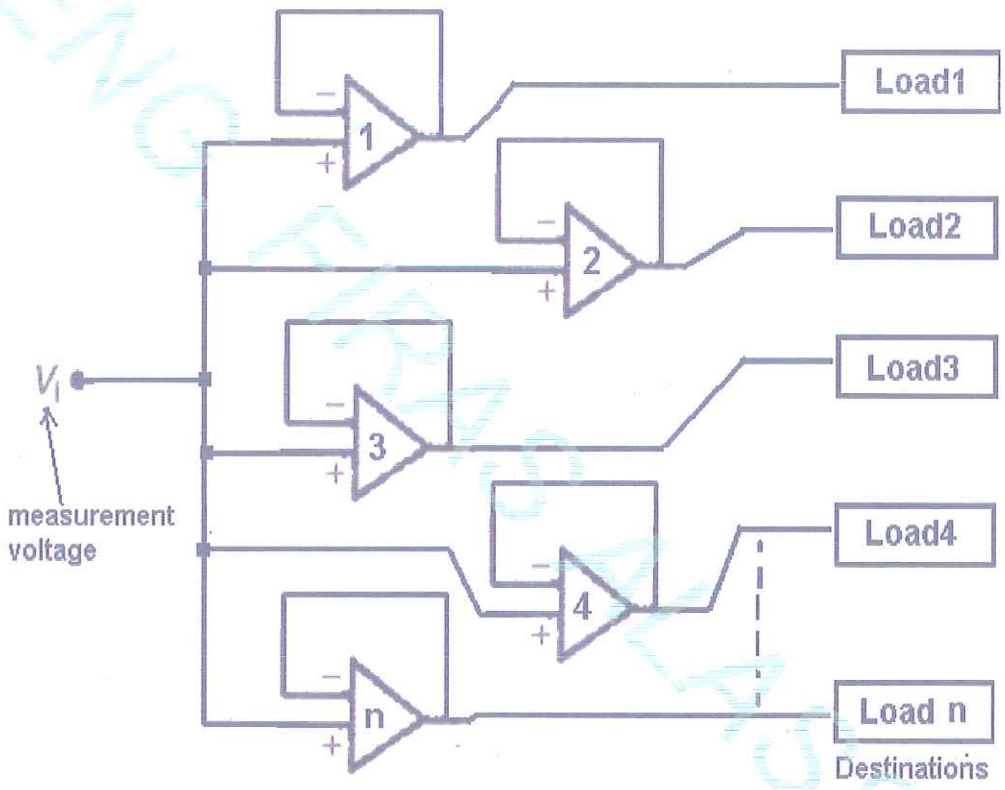


$$V_s = -RC\frac{dV_e}{dt}$$

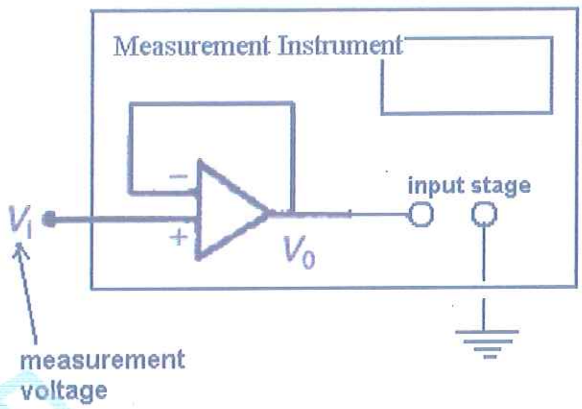
Q) Determine voltage follower main applications .

Answ :

1.reduce the load on the measured signal source that happened when measurement signal is supplied to many loads .



2.used in the input stage of expensive measurement instruments as protection wall .Any fault in measurement voltage like (short circuiting ,sudden high voltage change ,over voltage ,... etc) will be prevented from propagating to the next stages .

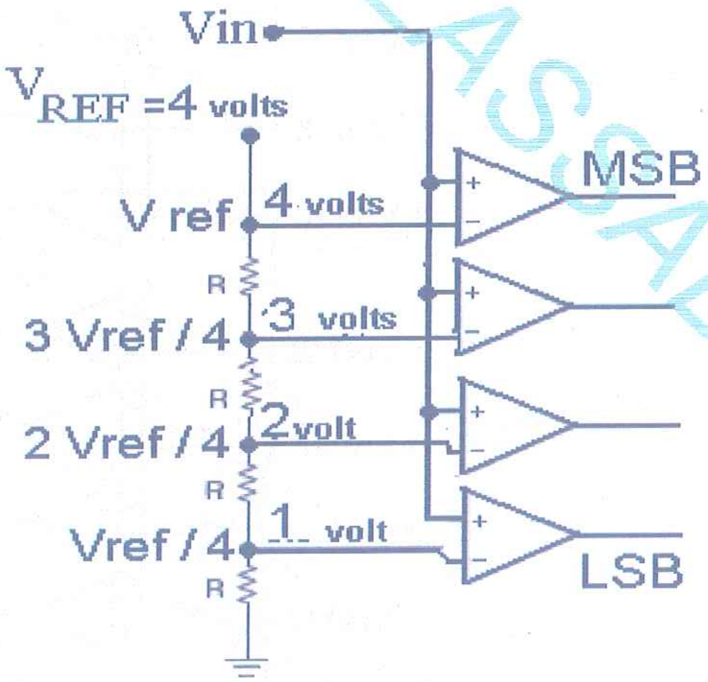


Q)for "4 bits instrumentation flash ADC" with reference voltage of 4 volts :

- design and then draw the schematic diagram of flash ADC .
- determine the maximum allowed input signal with reason .
- the output ,when input voltage = 2.8 volts .

answ :

-the design :

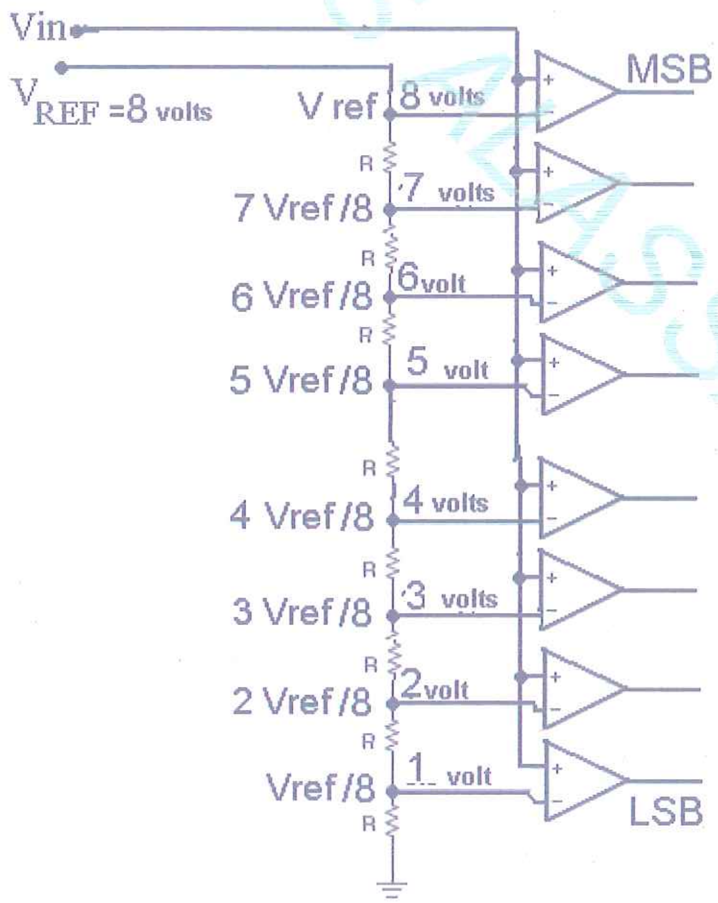


- the maximum allowed value for input voltage is 4 volts = Vref ,otherwise the output of all comparators will be all 1's always regardless the value of Vin (i.e. no distinguishing between samples values) .
- output (MSB … LSB) = 0011 .

Q)for "8 bits instrumentation flash ADC" with reference voltage of 8 volts :

- design and then draw the schematic diagram of flash ADC .
- determine the maximum allowed input signal with reason .
- the output ,when input voltage = 6.9 volts .

answ :the design :



- the maximum allowed value for input voltage is 8 volts = Vref ,otherwise the output of all comparators will be all 1's always regardless the value of Vin (i.e. no distinguishing between samples values) .
- output (MSB … LSB) = 00111111 .

Q)determine goals that could be achieved from computerized measurement system .

answ :they are :

1- digital measurement data storage .

2- digital measurement data editing .

3- digital measurement data analysis .

4- digital measurements data transmission to faraway point .

Measuring devices :-

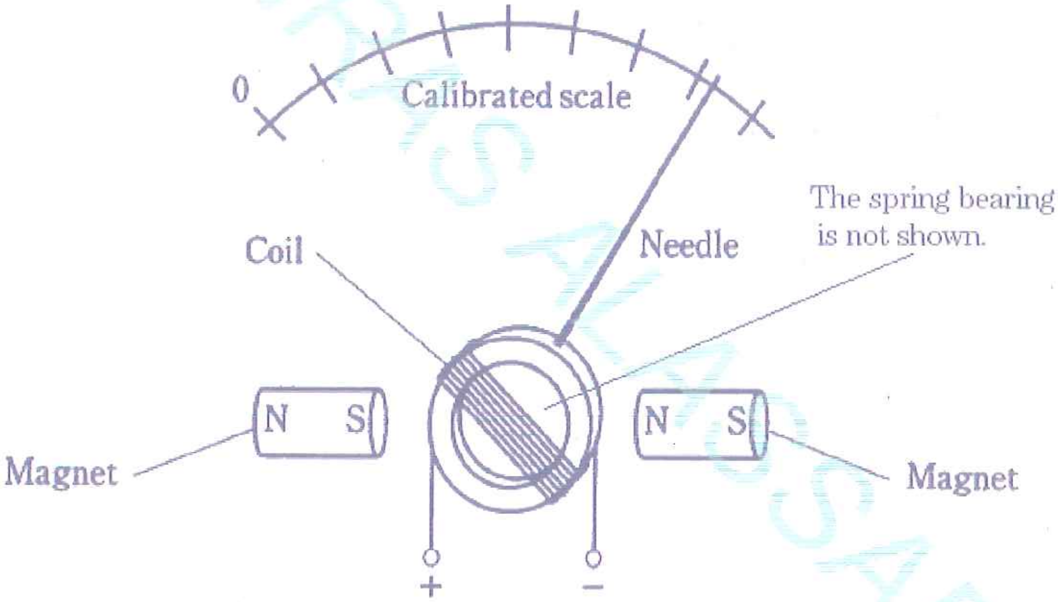
Here ,we will deal with measuring devices and instruments that are used to measure the electricity quantities .

Moving coil meter :-

Basic features :-

Device principle of operation : a magnetic field device . The magnetic field is produced by two stationary permanent magnets .

Device diagram :



Input voltage application point :applied to the positive and negative terminals of moving coil .

Is device active or passive (with reason) ? :passive ,because the energy needed for moving pointer (needle) is resulted from the opposite magnetic force between stationary field and the magnetic field of moving coil when current passes through it .

Is device digital or analogue (with reason) ? :analogue ,because reading is given by a pointer moved in front of continuous scale .

Does device measure DC or AC voltages and currents ? : DC only .

Advantages :

1) Simple construction . 2) good sensitivity .

3)accuracy . 4) linear scale .

Disadvantage :responds only to D.C. signals ,but not A.C. signals

Q: what are the factors that will effect on sensitivity of moving coil ammeter ? how they will affect the device sensitivity ?

Answ:the **ammeter sensitivity** is **directly** proportional to :

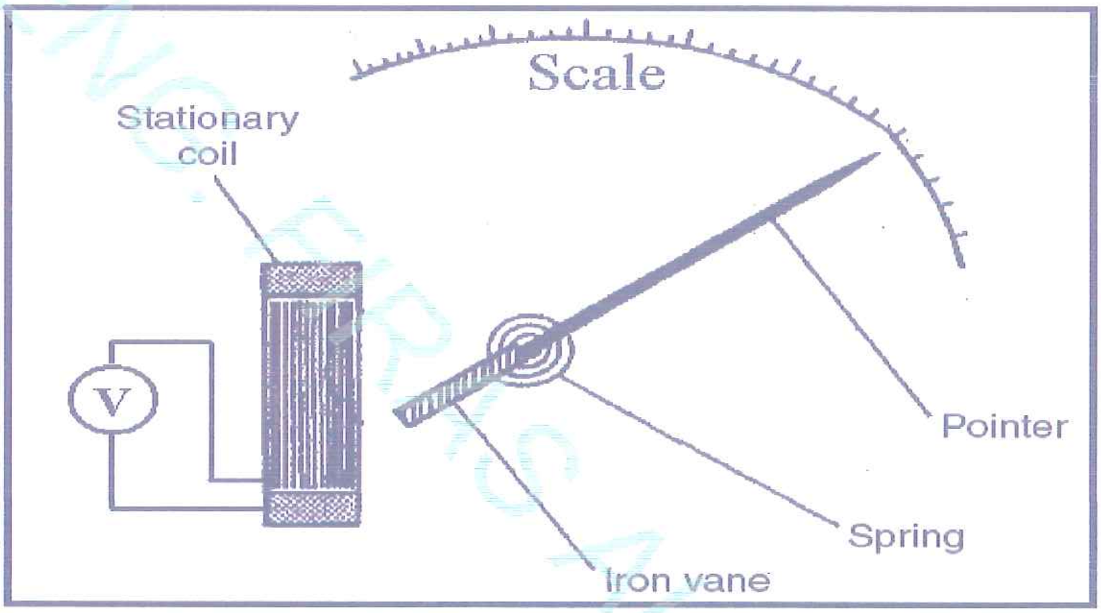
1. the strength of the permanent magnet .
2. the number of turns in the coil.

Moving Iron meter :-

Basic features :-

Device principle of operation : a magnetic field device .The magnetic field is produced when measured current passes through stationary coil .

Device diagram :



Input voltage application point :applied to the terminals of stationary coil .

Is device active or passive (with reason) ? :passive ,because the energy needed for moving pointer (needle) is resulted from the attraction magnetic force between stationary coil when current passes through it and the iron van .

Is device digital or analogue (with reason) ? :analogue ,because reading is given by a pointer moved in front of continuous scale .

Does device measure DC or AC voltages and currents ? : both .

Advantages :

1. As well as measuring D.C. signals, the moving-iron meter can also measure A.C. signals.
2. It is the cheapest form of meter available .

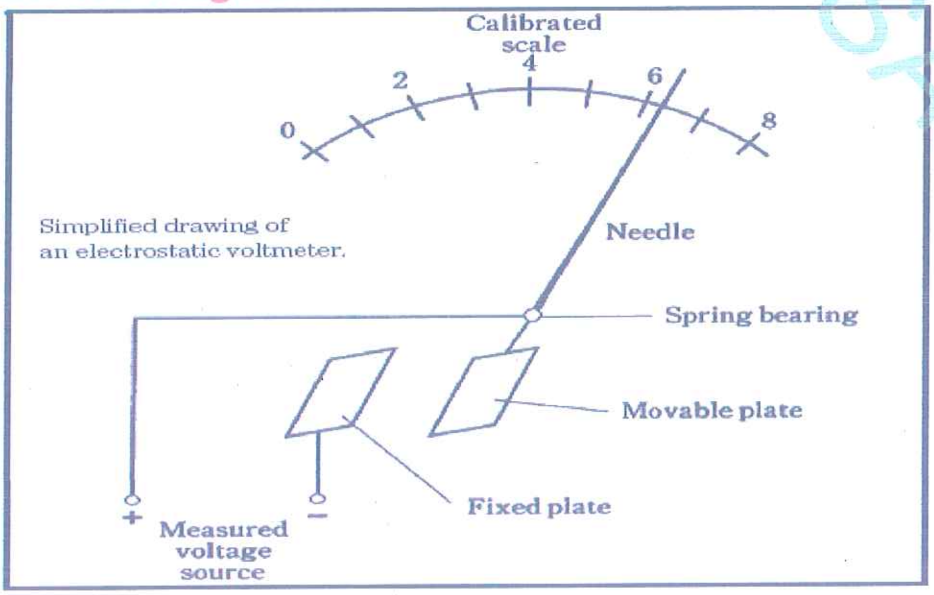
Disadvantage :low frequency range .

Electrostatic meter :

Basic features :

Device principle of operation : an electrical field device . The electrostatic field is generated between fixed and movable plates .

Device diagram :



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