CHAPTER - 1

INTRODUCTION TO INSTRUMENTATION SYSTEM

→ An instrumentation system is collection of devices and software that operate together to measure and record physical or electrical parameters such as voltage, current, flow rate, temperature, pressure, humidity and other variables.

→ It consists of sensors or transducers that convert physical or electrical quantities into electrical signals, signal conditioning circuits that amplify, filter or modify the signals, data acquisition system that digitize and store signals, and controls system that use the data to adjust ~~and~~ the process or the system.

→ The main purpose of instrumentation system is to monitor or control a process or system in real time.

Functional block diagram of instrumentation system.

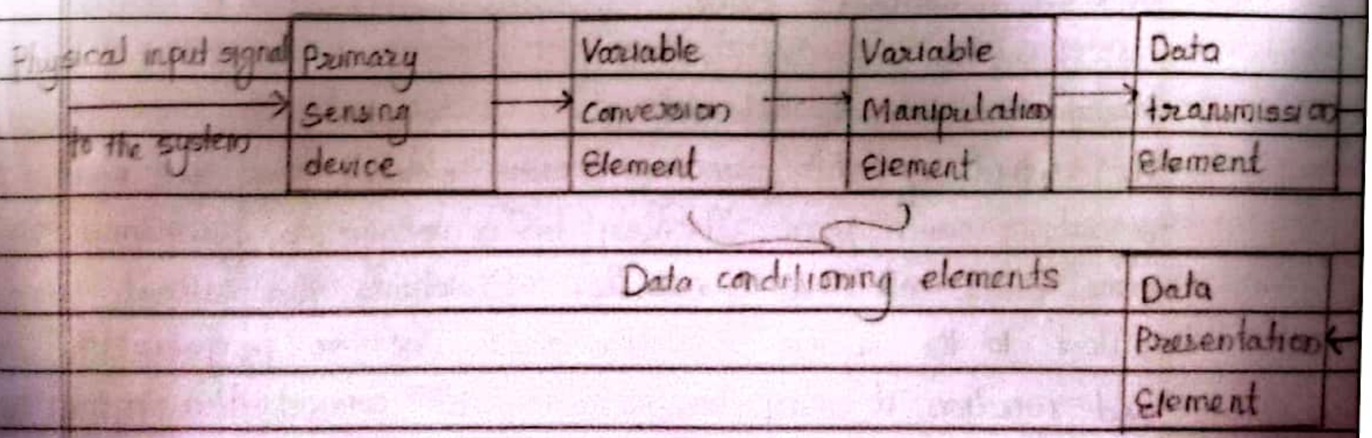

Fig: Block diagram or function block of instrumentation system.

What do you mean by instrumentation? Explain functional diagram of an instrumentation system with suitable example.

Instrumentation can be defined as the design, equipping, and/or use of measuring instruments in order to accomplish some specific objective in terms of measurement, or control, or both.

ary sing ment	→ Variable conversion element	→ Variable manipulation element	→ Data transmission element	→ Data Presentation element

$\underbrace{\text{Variable conversion element} \quad \text{Variable manipulation element}}_{\text{Data conditioning element}}$

Primary sensing device

The quantity to be measured makes its first contact with the primary sensing element. This act is immediately followed by the conversion of measurand into an ~~ala~~ analogous electrical signal with the help of transducers. This stage is also known as detector transducer stage.

Variable conversion Element

The output of the primary sensing element may be electrical signal of any form. It may be a voltage, a frequency or some other electrical parameter. Sometimes this output is not suited to the system. For the instrument to perform the desired function, it may be necessary to convert this output to some other suitable form while preserving the information content of the original signal. This work is performed by the variable conversion element.

3. Variable Manipulation Element

→ The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. Manipulation here means only a change in numeric value of the signal. For example, an electronic amplifier accepts a small voltage signal as input and produces an output signal which is also voltage but of greater magnitude. Thus a voltage amplifier acts as a variable manipulation element.

4. Data transmission element

→ After variable manipulation is done, it becomes necessary to transmit data from one to another. The element that performs this function is called a Data Transmission Element. For example space-crafts are physically seperated from the earth where the control stations guiding their movements are located. Therefore control signals are sent from these stations to space-crafts by a complicated telementary system using radio signals.

5. Data Presentation Element

→ The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control, or analysis purposes. The information conveyed must be in a form intelligible to the ~~system~~ personnel or to the intellegent instrumentation system. This function is done by data presentation element.

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Topics:

Errors and uncertainity in measurement

Static performance parameters:

→ Accuracy → Threshold → Hysteris → Span.
→ Precision → sensitivity → Dead band
→ Resolution → linearity → Drift

Qn. Justify that a device that gives precised result may not be accurate.

→ Suppose that we have an ammeter which posses an high degree of precision by virtue of ~~which~~ its clearly legible, finely divided, distinct scale and a knife edge pointer with mirror arrangements to remove parallax. Let us say that its reading can be taken to 1/100 of an ampere. At the time, its zero, adjustment is wrong. Now every time we take a reading, the ammeter is as precise as ever, we can take readings down to ~~an~~ 1/100 of an ampere, and the reading are consistent and "clearly defined". However, the results taken with this ammeter are not accurate, since they donot conform to truth on account of its faulty zero adjustment.

Let us cite another example. Consider the measurement of a known voltage of 100 V with a voltmeters. Five readings are taken, and the indicated values are 104, 103, 105, 103 and 105 V. From these values it is seen that the instrument cannot be depended on for an accuracy better than 5%. (5V in this case), while a precision of ± 1% is indicated since the maximum deviation from the mean reading of 104 V is only 1.0 volts. Thus, we can find the instrument is precised but not accurate.

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Thus, when it is stated that a set of readings shows precision it means that the results agree among themselves. However, there is no gurantee of accuracy, as there may be some systematic disturbing effect that causes all the measured value to be in error.

Impedence loading

Impedance matching

Statical analysis of errors in measurement:

-) Static tool helps to analyze uncertainity of the final result. It helps to interpret large number of readings into meaningful conclusion.

(i) Arithmetic mean:

$$\bar{X} = \frac{X_1 + X_2 + X_3 - - - + X_n}{n}$$

$$\boxed{\therefore \bar{X} = \frac{\Sigma X}{n}}$$

where,

$\bar{X}$ = Arithmetic mean

ΣX = sum of the given readings

n = total number of readings.

$$\boxed{d_1 = X_1 - \bar{X}}$$

$\downarrow$

deviation from mean

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(ii) Standard deviation:

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots d_n^2}{n-1}}$$

$$\boxed{\sigma = \sqrt{\frac{\Sigma d_i^2}{n-1}}}$$

Standard deviation

(iii) Probability of error:

$$\boxed{r = \pm 0.6745\, \sigma}$$

Probable error

Qn. Ten measurements of the resistance of a resistor gave 101.2Ω, 101.7Ω, 101.3Ω, 101.0Ω, 101.5Ω, 101.3Ω, 101.2Ω, 101.4Ω, 101.3Ω, & 101.1Ω. Assume that only random errors are present. Calculate

(a) Arithmetic mean

(b) Standard deviation of the readings

(c) Probable error

Soln:

Number of readings (n) = 10

$\Sigma X = 101.2\Omega + 101.7 + 101.3 + 101.0 + 101.5 + 101.3 + 101.2 + 101.4 + 101.3 + 101.1$

$= 1013$

Now,

Arithmetic mean $(\bar{X}) = \frac{\Sigma X}{n}$

$= \frac{1013}{10}$

$= 101.3$

$d_1 = \bar{X} - X_1 = 0.1$

$d_2 = -0.4$

$d_3 = 0$

$d_4 = 0.3$

$d_5 = -0.2$

$d_6 = 0$

$d_7 = 0.1$

$d_8 = -0.1$

$d_9 = 0.2$

So, standard deviation $= \sqrt{\dfrac{\Sigma d_i^2}{n-1}}$

$= \sqrt{\dfrac{(0.1)^2 + 0.4^2 + 0.3^2 + 0.2^2 + 0.1^2 + 0.1^2 + 0.2^2}{9}}$

$= 0.2$

Probable error $(r) = \pm\ 0.6745\ \sigma$

$= \pm\ 0.6745 \times 0.2$

$= \pm\ 0.1349$ //

Q) A set of independent current measurement was taken by six observers and recorded as 12.8 mA, 12.2 mA, 12.5 mA, 12.9 mA & 12.4 mA. Calculate

(a) Arithmetic mean

(b) Deviation from mean

(c) Standard deviation and Probable error.

→ Soln:-

no of readings $(n) = 5$

Sum of readings $(\Sigma X) = (12.8 + 12.2 + 12.5 + 12.9 + 12.4)$ mA

$= 62.8$ mA.

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Arithmetic mean $(\bar{X}) = \frac{\Sigma X}{n}$

$= \frac{62.8}{5}$

$= 12.56\,mA$

Now,

$d_1 = X_1 - \bar{X} = 12.8 - 12.56 = 0.24\,mA$

$d_2 = X_2 - \bar{X} = 12.2 - 12.56 = -0.36\,mA$

$d_3 = X_3 - \bar{X} = 12.5 - 12.56 = -0.06\,mA$

$d_4 = X_4 - \bar{X} = 12.9 - 12.56 = 0.34\,mA$

$d_5 = X_5 - \bar{X} = 12.4 - 12.56 = -0.16\,mA$

$\Rightarrow \Sigma d_i^2 = d_1^2 + d_2^2 + d_3^2 + d_4^2 + d_5^2$

$= (0.24)^2 + (-0.36)^2 + (-0.06)^2 + (0.34)^2 + (0.16)^2$

$= 0.332.$

Standard deviation $(\sigma) = \sqrt{\frac{\Sigma d_i^2}{n-1}}$

$= \sqrt{\frac{0.332}{4}}$

$= 0.288\,mA$

Again,

Probable error $= \pm\, 0.6745\,\sigma$

$= \pm\, 0.6745 \times 0.288$

$= \pm\, 0.194\,mA.$

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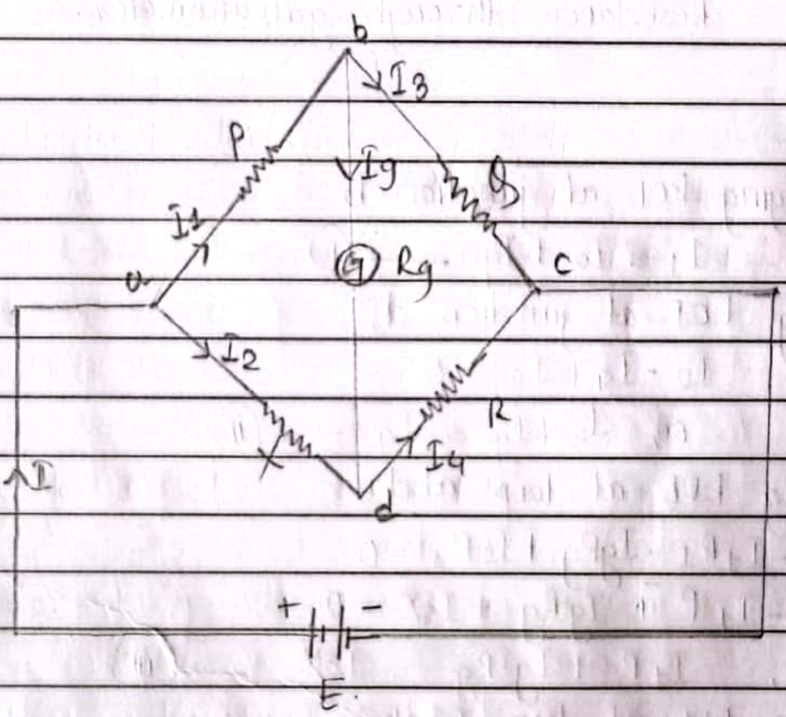
Wheatstone bridge

→ Wheatstone bridge is an electric device which is used for accurate measurement of resistance of the conductor.
In other words, it can be defined as the arrangement of four resistors connected in the form of bridge in which three resistors are known and one unknown resistor is measured in terms of other 3 resistors.



Principle:- when the cell is connected in the circuit and value of resistor are adjusted in such a way that galvanometer shows null deflection and bridge is said to be balanced.
At balanced condition, the current flowing through the galvanometer is 0 (i.e potential at b = potential at d) and product of resistance in opposite arm is equal. i.e

$$PR = XQ$$

$$\Rightarrow \frac{P}{Q} = \frac{X}{R}$$

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Proof:

Suppose initially the bridge is not balanced. then

let I_1 = current flowing through resistor P

I_2 = current flowing through resistor X

I_3 = current flowing through resistor Q

I_4 = current flowing through galvanometer R

I_g = current flowing through galvanometer

R_g = Resistance through galvanometer.

Now,

Applying KCL at junction b

$$I_1 = I_3 + I_g \quad \text{—— (i)}$$

Applying KCL at junction d,

$$I_2 - I_4 + I_g = 0$$

$$\text{or, } I_2 + I_g = I_4 \quad \text{—— (ii)}$$

Applying KVL at loop abda

$$-I_1 R_1 - I_g R_g + I_2 R_3 = 0$$

$$\text{or, } -I_1 P - I_g R_g + I_2 X = 0$$

$$\text{or, } I_1 P + I_g R_g = I_2 X \quad \text{—— (iii)}$$

Applying KVL at loop bcdb

$$-I_3 Q + I_4 R + I_g R_g = 0$$

$$\text{or, } I_4 R + I_g R_g = I_3 Q \quad \text{—— (iv)}$$

Now, the value of resistors are adjusted in such a way that the current flowing through the galvanometer is 0 so using $I_g = 0$ in above 4 eqns.

$$I_1 = I_3 \quad \text{—— (v)}$$

$$I_2 = I_4 \quad \text{—— (vi)}$$

$$I_2 X = I_1 P \quad \text{—— (vii)}$$

$$I_4 R = I_3 Q \quad \text{—— (viii)}$$

Dividing eqn (vii) by (viii), we get.

$$\frac{I_2 X}{I_4 R} = \frac{I_3 P}{I_3 Q}$$

$$\Rightarrow \frac{P}{Q} = \frac{X}{R} \quad \#$$

Numerical only:

Note:- Limiting error:

Qn. A 0-150V voltmeter has guranteed accuracy of 1% full scale reading. The voltage measured by this device is 83V. Calculate limiting error and also calculate percentage limiting error at the indication of 83 volts.

⇒ Soln:-

Magnitude of limiting error :-

$= 1\% \times 150$

$= 1.5$

Percentage limiting error $= \frac{1.5}{83} \times 100\ \%$

$= 1.80\%$

AC bridges

Kelvin bridge → unknown resistance

Maxwell bridge } unknown inductance

Hay's bridge }

Schering Bridge → unknown capacitance

Wein bridge → frequency

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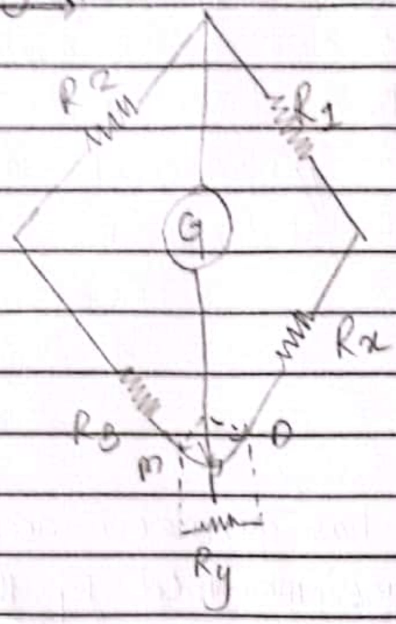
kelvin bridge :-



when point P is at

when galvanometer's point is connect to point n, R_y is added to R_3.

when galvanometer is connected to point m, R_y is added to unknown resistor 'R_x'.

If galvanometer is connected to point P in betn two points m and n in such a way that ratio of resistance from n to p and from m to p equals the ratio of resistors R_1 and R_2.

$$\text{i.e } \frac{R_{np}}{R_{mp}} = \frac{R_1}{R_2} \quad \text{—} \text{ (a)}$$

The balanced eqn for bridge.

$$R_x + R_{np} = \frac{R_1}{R_2}(R_3 + R_{mp}) \quad \text{—} \text{ (b)}.$$

Putting eqn (a) in (b).

$$R_x + \left[\frac{R_1}{R_1+R_2}\right] \cdot R_y = \frac{R}{R_2}\left(R_3 + \frac{R_2}{R_1+R_2}\right) \cdot R_y$$

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Alternatively,

$$R_{np} = \frac{R_1}{R_2} \cdot R_{mp}.$$

Put,

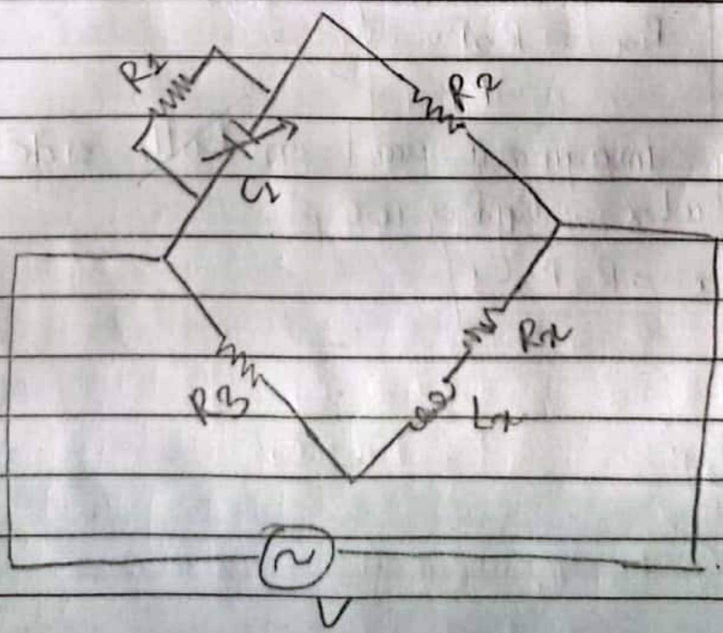
$$R_x + \frac{R}{R_2}(R_{mp}) = \frac{R_1}{R_2}(R_3 + R_{mp})$$

$$\boxed{R_x = \frac{R_1 \cdot R_3}{R_2}}$$

Hence unknown resistance can be find by above eq^n. It provides more accurate result for low value of resistance.

Maxwell's Bridge:-

Maxwell's bridge is used for the measurement of inductance. This bridge is used to measure the inductance of coil having moderate or medium quality factor.



$$Y_1 = \frac{1}{Z_1} = \frac{1}{R_1} + j\omega C_1$$

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_x = R_x + j\omega L_x.$$

$$Z_4 = R_4$$

For balanced case,

$$Z_1 Z_x = Z_2 Z_3$$

$$Z_x = \frac{Z_2 Z_3}{Z_1}$$

or, $Z_x = Z_2 Z_3 \times Y_1$.

or, $R_x + j\omega L_x = \frac{R_2 R_3}{\cancel{R_1}} \left(\cancel{+ j R_2 R_3} \frac{1}{R_1} + j\omega C_1 \right)$

$$R_x + j\omega L_x = \frac{R_2 R_3}{R_1} + j R_2 R_3 \omega C_1$$

Equating real part of both sides

$$\boxed{R_x = \frac{R_2 R_3}{R_1}}$$

Equating imaginary part on both side,

$$\omega L_x = R_2 R_3 \omega C_1.$$

$$\boxed{L_x = R_2 R_3 C_1}$$

Hay's bridge :

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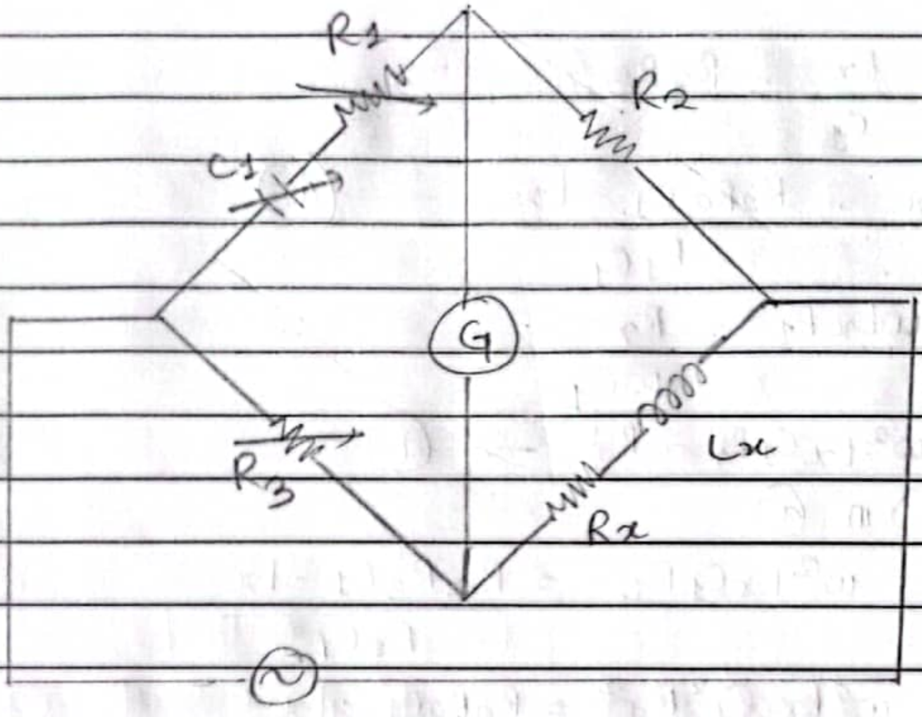

$Y_1 = \frac{1}{R_1} + j\omega C_1$

$Z_2 = R_2$

$Z_x = R_x - \frac{j}{\omega C_x}$

$Z_3 = \frac{-j}{\omega C_3}$

$Z_1 = R_1 - jX_C = R_1 - \frac{j}{\omega C_1}$

$Z_2 = R_2$

$Z_3 = R_3$

$Z_x = R_x + jX_{Lx} = R_x + j\omega L_x$

For balanced case,

$$Z_1 Z_x = Z_2 Z_3$$

$$\left(R_1 - \frac{j}{\omega C_1}\right)\left(R_x + j\omega L_x\right) = R_2 R_3$$

or, $R_1 R_x + jR_1\omega L_x - \frac{R_x}{\omega C_1} j + \frac{L_x}{C_1} = R_2 R_1$

or, $\left(R_1 R_x + \frac{L_x}{C_1}\right) + \left(\omega L_x R_1 - \frac{R_1}{\omega C_1}\right) j = R_2 R_3$

Equating.

$$R_1 R_x + \frac{L_x}{C_1} = R_2 R_3$$

$$\text{or,} \quad R_x = \frac{R_2 R_3 C_1 - L_x}{R_1 C_1} \quad \text{—— (a)}$$

$$\text{Also,} \quad \omega L_x R_1 = \frac{R_x}{\omega C_1}$$

$$\text{or,} \quad \omega^2 L_x C_1 R_1 = R_x \quad \text{—— (b).}$$

using (b) in (a)

$$\omega^2 L_x C_1 R_1 = \frac{R_2 R_3 C_1 - L_x}{R_1 C_1}.$$

$$\text{or,} \quad \omega^2 L_x C_1^2 R_1^2 = R_2 R_3 C_1 - L_x$$

$$\text{or,} \quad L_x (\omega^2 C_1^2 R_1^2 + 1) = R_2 R_3 C_1$$

$$\therefore \boxed{L_x = \frac{R_2 R_3 C_1}{\omega^2 C_1^2 R_1^2 + 1}}$$

Now,

$$R_x = \frac{\omega^2 R_2 R_3 C_1 \times C_1 R_1}{\omega^2 C_1^2 R_1^2 + 1}$$

$$\text{or,} \quad \boxed{R_x = \frac{\omega^2 C_1^2 R_1 R_2 R_3}{\omega^2 C_1^2 R_1^2 + 1}}.$$

Measurement of Capacitance:-

Schering's bridge:-

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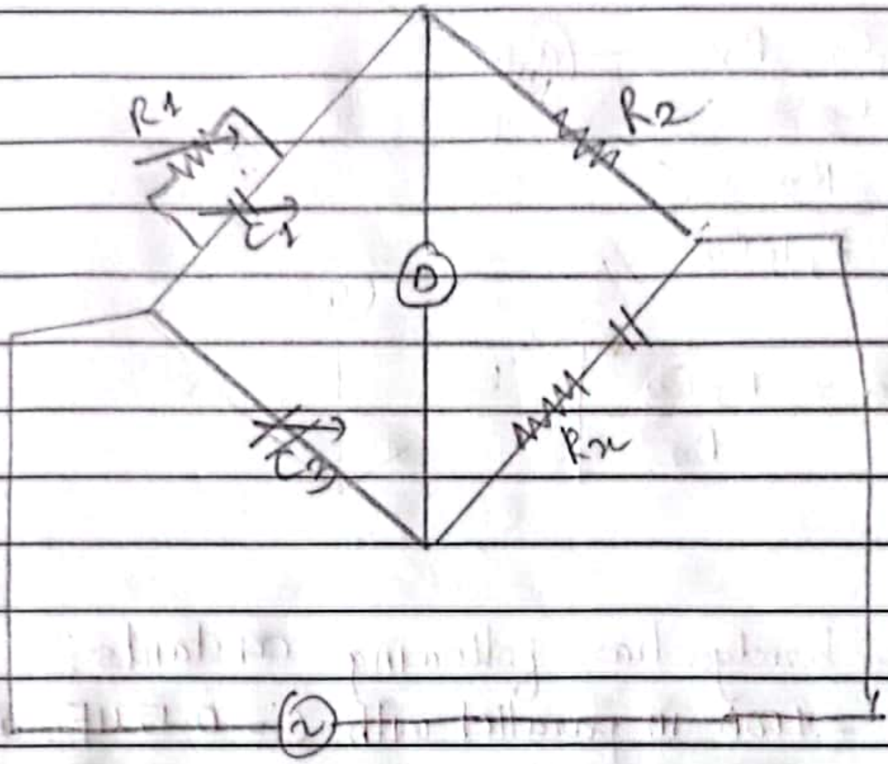


$$Y_1 = \frac{1}{R_1} + j\omega C_1$$

$$Z_2 = R_2$$

$$Z_x = R_x - \frac{j}{\omega C_x}$$

$$Z_3 = \frac{-j}{\omega C_3}$$

for balanced condition

$$Z_1 . Z_x = Z_2 . Z_3$$

$$Z_x = \frac{Z_2 . Z_3}{Z_1} = Z_1 Z_2 Y_1$$

$$= \left(\frac{1}{R_1} + j\omega C_1\right) R_2 . \left[\frac{-j}{\omega C_3}\right].$$

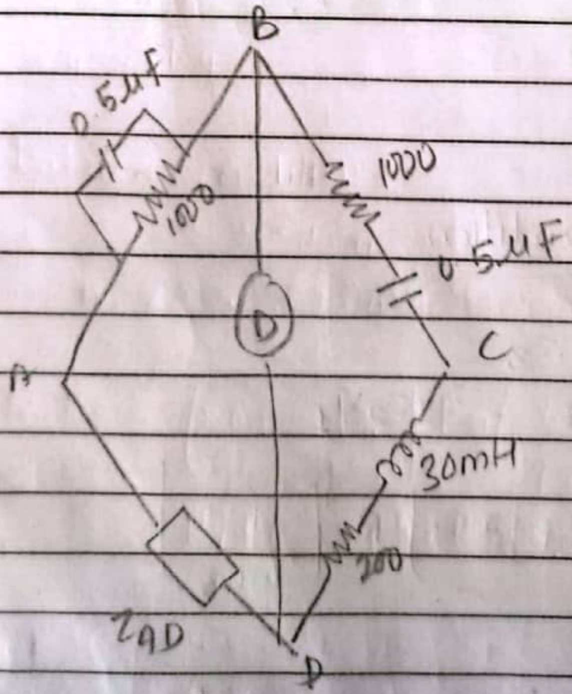
$$R_x - \frac{j}{\omega C_x} = -\frac{R_2}{R_1 \omega C_3} j + \frac{C_1}{C_3} R_2 .$$

$$R_x = \frac{C_1}{C_3} R_2 \quad \text{—— (a)}$$

$$\frac{1}{\omega C_x} = \frac{R_2}{R_1 \omega C_3}$$

$$\therefore \boxed{C_x = \frac{R_1 C_3}{R_2}}$$

A 1000 Hz bridge has following constants:-
Arm AB, R = 1000 in parallel with C = 0.5 μF; arm BC, R = 1000 Ω in series with C = 0.5 μF; arm CD, R = 200 Ω in series with L = 30 mH. Find the constants of DA to make the balance bridge also mention given result is inductor or capacitor. Also find the value of capacitance.



Here,

$$Y_1 = \frac{1}{1000} + j\{0.5\times10^{-6}\times2\pi\times1000\}$$

$$= \frac{1}{1000} + j\times3.1416\times10^{-3}$$

$$Z_2 = 1000 - \frac{j}{2\times\pi\times1000\times0.5\times10^{-6}}$$

$$= 1000 - 318.3098$$

$$Z_3 = 200 + 2\times\pi\times1000\times30\times10^{-3}\,j$$

$$= 200 + 188.49j$$

for balanced case,

$$Z_1 \cdot Z_3 = Z_2 \cdot Z_x$$

$$\text{or, } Z_x = \frac{Z_1 \cdot Z_3}{Z_2}$$

$$= \frac{Z_3}{Y_1 \cdot Z_2}$$

$$= \frac{200 + 188.49j}{\left(\frac{1}{1000} + j\times3.1416\times10^{-3}\right)(100 - 318.3098)}$$

$$= 79.431 - j15.67 \quad \{\text{capacitor}\}.$$

$$X_c = 15.67$$

$$\frac{1}{2\pi f c} = 15.67$$

$$\Rightarrow c =$$

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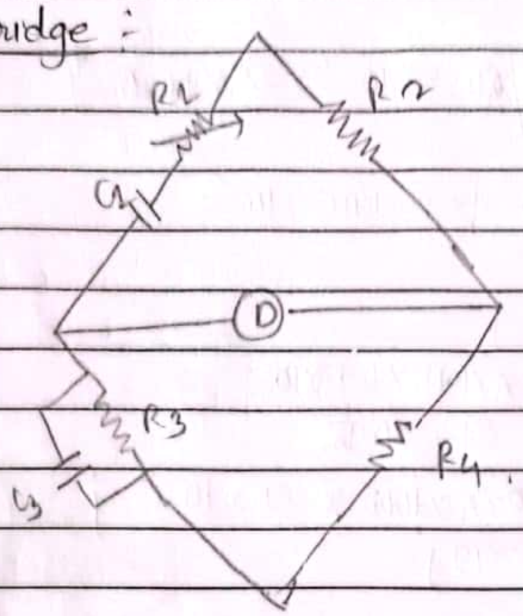
Wein Bridge :



$$Z_1 = R_1 - \frac{j}{2\pi f C_1}$$

$$Z_2 = R_2$$

$$Y_3 = \frac{1}{R_3} + j \times 2\pi f \times C_3$$

$$Z_4 = R_4$$

for balance condition,

$$Z_2 Z_3 = Z_1 Z_4$$

$$\text{or, } Z_2 = Z_1 Z_4 Y_3$$

$$\text{or, } R_2 = \left(R_1 - \frac{j}{\omega C_1}\right) R_4 \left(\frac{1}{R_3} + j\omega C_3\right).$$

$$= \frac{R_1 R_4}{R_3} + j\left(R_1 R_4 \omega C_3 - \frac{R_4}{R_3 \omega C_1}\right) + \frac{\omega C_3 R_4}{\omega C_1}$$

Realpart,

$$R_2 = \frac{R_1 R_4}{R_3} + \frac{C_3}{C_1} . R_4$$

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$$\boxed{\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1}}$$

imaginary part,

$$R_1 R_4 \omega C_3 - \frac{R_4}{R_3 \omega C_1} = 0$$

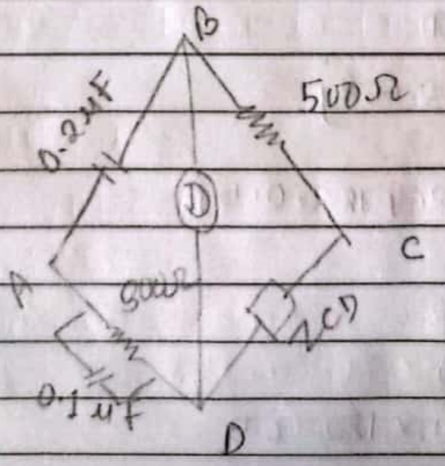
or, $R_1 R_4 R_3 \omega^2 C_1 C_3 = R_4$

or, $\omega^2 = \frac{1}{R_1 R_3 C_1 C_3}$.

$$\omega = \sqrt{\frac{1}{R_1 R_3 C_1 C_3}}$$

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{1}{R_1 R_3 C_1 C_3}}}$$

Qn. An AC Bridge circuit is working at 1000 Hz. Arm AB have 0.2 μF pure capacitor, arm BC has 500Ω pure resistor, arm CD has unknown impedence and arm DA 300Ω resistance in parallel with 0.1 μF capacitor. Find the constants of arm CD considering it as series circuit.



$\omega = 2\pi f$

$\therefore \omega = 2\pi \times 1000$

$= 6283.185$

$$Z_1 = \frac{-j}{\cancel{\omega C_1}\,\omega C_1}$$

$$Z_2 = 500\,\Omega$$

$$Z_3 = ?$$

$$Y_4\ \cancel{Z_4} = \frac{1}{R_4} + j\omega C_4$$

$$= \frac{1}{300} + j\omega \times C_4$$

Here, $Z_1 \cdot Z_3 = Z_2 \cdot Z_4$.

or, $$Z_3 = \frac{Z_2}{Z_1 \cdot Y_4}$$

$$= \frac{500}{\left(\frac{-1}{\omega C_1}\right)\left(\frac{1}{300} + j\omega \times 0.1 \times 10^{-6}\right)}$$

$$= \frac{500}{\frac{-1}{300\,\omega C_1} + \frac{\cancel{\omega} \times 0.1 \times 10^{-6}}{\cancel{\omega}\, C_1}}$$

$$= \frac{500}{\frac{-1}{300 \times 6283.185 \times 0.2 \times 10^{-6}} \cdot j + \frac{0.1}{0.2}}$$

$$= \frac{500}{0.5 - 2.652j}$$

$$= 34.326 + 182.065i$$

$\therefore$ $R_3 = 34.326\,\Omega$.

$$L_3 = \cancel{\omega} X_L / \omega$$

$$= \cancel{6283.185 \times 182.065}$$

$$= 0.0289 \cancel{\times 10} = 28.9\,mH$$

Transducer

→ Device that converts non-electrical energy into electrical energy. It converts one form of energy into another for the purpose of measurement or transfer of information.

Classification of transducers

Transducers

- Based on physical phenomenon
  - (a) Primary transducers
  - (b) Secondary transducers
- Based on the power type
  - (a) Active transducer
  - (b) Passive transducer
- Based on the type of o/p
  - (a) Analog &
  - (b) digital transducer
- Based on the electrical phenomenon
  - → Resistive transducer
  - → Inductive
  - → Capacitive
  - → Photovoltaic
  - → Photoelectric.
- Based on non-electrical phenomenon
  - → linear displacement
  - → Rotatory "
- Based on transduction phenomenon
  - → Transducer
  - → Inverse transducer

Characteristics of transducers:

The main characteristics of transducers are:

1. Sensitivity 2. Range 3. Precision 4. Accuracy
5. Resolution 6. Threshold 7. Hysteresis 8. Linearity & so on

Selection of transducer:-

followings are the factors which need to be considered while selecting a transducer.

(i) High input impedance and low output impedance.
(ii) Good resolution
(iii) Sensitive
(iv) Small size
(v) High degree of accuracy and repeatability.
(vi) free from errors.

Strain Gauge:-

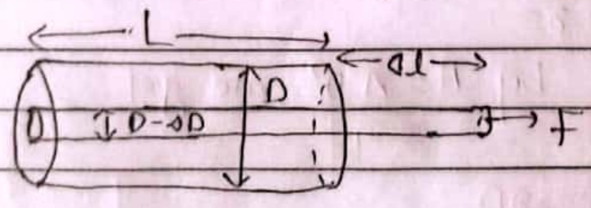
Principle of operation:-

The strain gauge is a device that is used to convert a mechanical displacement into change in resistance. It is a device that is used to measure strain of an object.

Mathematically,

$$\text{strain}, e = \frac{\Delta l}{L} = \frac{\text{change in length}}{\text{original length}}$$

Mathematical Derivation:-



let us consider a strip of elastic material, when the tension is applied, longitudinal dimension increases and lateral dimension reduces and lets consider this as positive strain.

Unstrained gauge

The resistance of unstrained gauge is give by

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$$R = \frac{\rho L}{A}$$

Strained gauge,

when the tension/tensile stress is applied to the wire, then length increases and cross-sectional area decreases.

Differentiating R with respect to 'S' (stress) stress

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\partial L}{\partial s} - \frac{\rho L}{A^2}\frac{\partial A}{\partial s} + \frac{L}{A}\frac{\partial \rho}{\partial s}$$

Dividing above eqn by $R = \frac{\rho L}{A}$, we get,

$$\frac{1}{R}\frac{\partial R}{\partial s} = \frac{1}{L}\frac{\partial A}{\partial s} - \frac{1}{A}\frac{\partial A}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{— (i)}$$

Eqn (i) shows that, the per unit change in resistance is due to the per unit change in length, per unit change in area and per unit change in resistivity.

Now, cross-sectional area is given by

$$A = \frac{\pi D^2}{4}$$

diff. A wr to S,

$$\frac{\partial A}{\partial s} = \frac{2\pi}{4} D \frac{\partial D}{\partial s}$$

Dividing above eqn by $A = \frac{\pi D^2}{4}$, we get

$$\frac{1}{A}\frac{\partial A}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s}$$

Putting above value in eqn (i), we get

$$\frac{1}{R}\frac{\partial R}{\partial s} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\partial \rho}\frac{\partial \rho}{\partial s} \quad \text{— (ii)}.$$

From Poison's ratio (ν).

$$\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{-\partial D/D}{\partial L/L}$$

$$\frac{\partial D}{D} = -\nu\frac{\partial L}{L}$$

Put value of $\frac{\partial D}{D}$ in eqn (ii)

$$\boxed{\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}}$$

Gauge factor G_F :-

The Gauge factor of material is defined as the ratio of per unit change in resistance to per unit change in length.

$$G_F = \frac{\Delta R/R}{\Delta L/L} \Rightarrow \frac{\Delta R}{R} = G_F \cdot \frac{\Delta L}{L} = G_F \times E.$$

$$\boxed{\frac{\Delta R}{R} = \varepsilon G_F}$$

put the value of $\frac{\Delta R}{R}$ in eqn (iii)

$$\frac{G_F\varepsilon}{\varepsilon} = \frac{\varepsilon}{\varepsilon} + \frac{2\nu\varepsilon}{\varepsilon} + \frac{\Delta\rho}{\rho/\varepsilon} \leftarrow \text{neglegible.}$$

$$\boxed{G_F = 1 + 2\nu}$$

This give the relation betn gauge factor and poissons ratio.

Resistive transducers,

Inductive transducers :-

(i) LVDT → Linear Variable Displacement Transducer

(ii) RVDT → Rotary Variable Displacement Transducer

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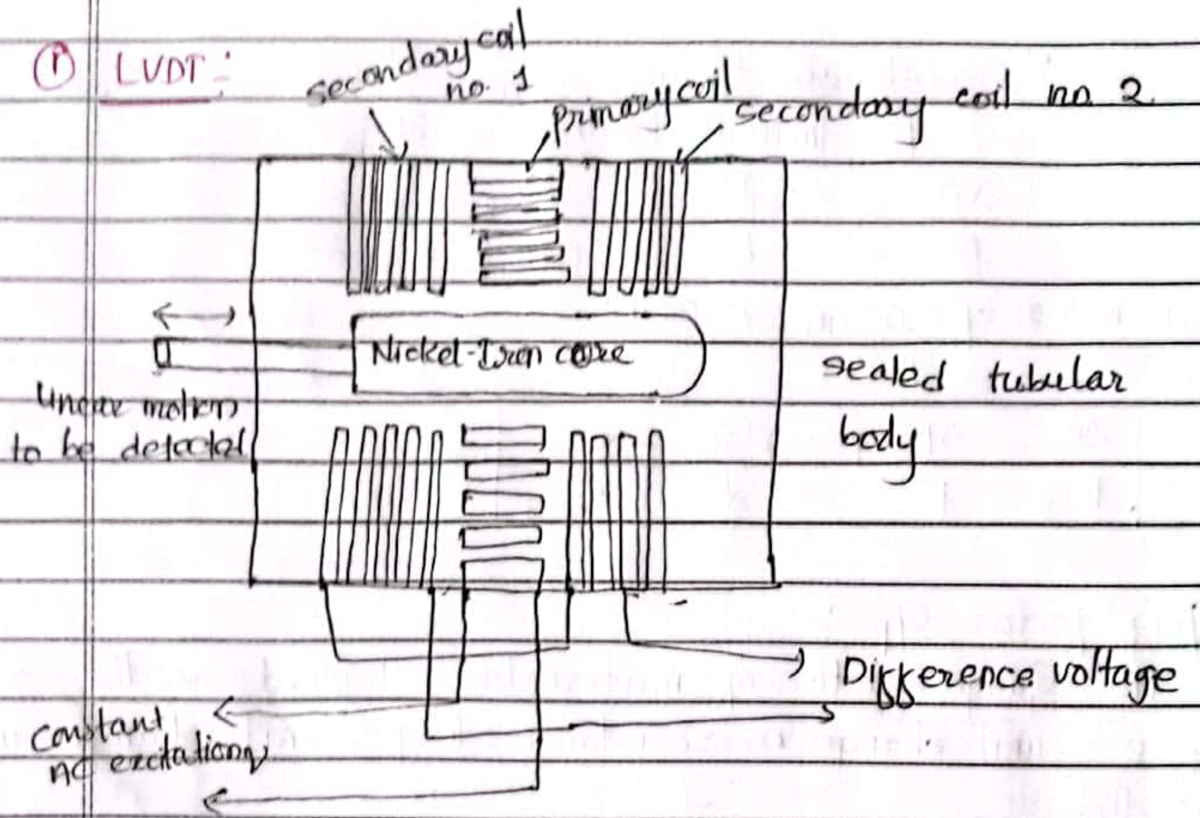
1 LVDT :



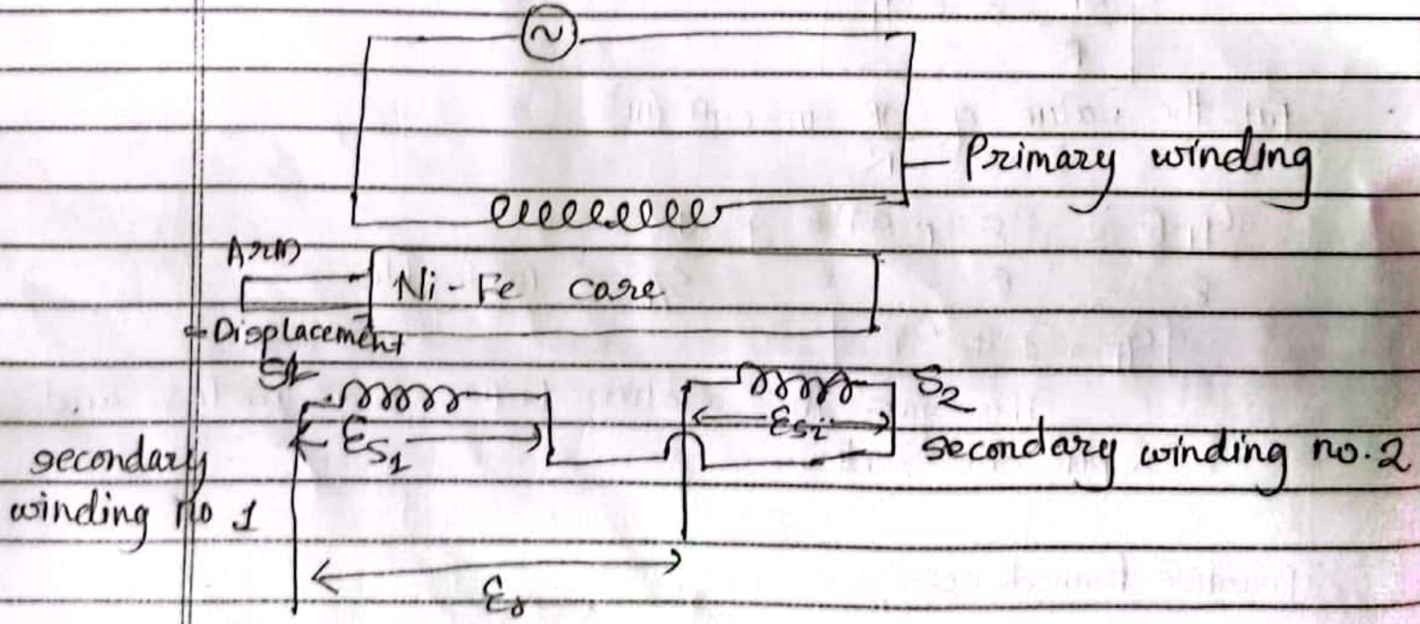


fig: Equivalent circuit of LVDT.

$\boxed{E_0 = E_{S_1} - E_{S_2}}$ $\xrightarrow{0}$ when core is at centre

↓ when core is at left

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Capacitive transducers :

Capacitive trandúcer is the capacitor with variable capacitance. The capacitive transducer is composed of two parallel metal plates that are separated by dielectric medium such as air. In parallel plate capacitor, the distance between the 2 plates is fixed but in variable capacitive transducer, the distance between two plates is variable.

conductive plates

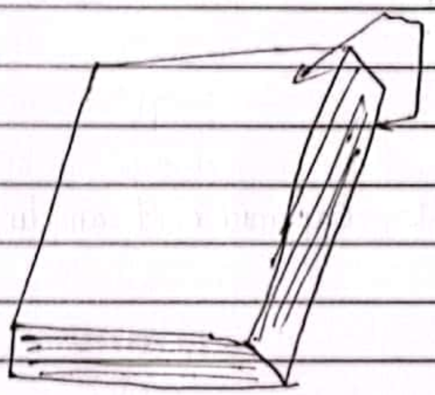

Fig: Capacitive transducers

$$C = \frac{\epsilon A}{d}$$ where,

A = Overlapping area of the plates
ϵ = Permitivity of medium
d = distance betn the plates.

The capacitance of the variable capacitive transducer can change with the change of dielectric material, change in the area of the plates, and distance betn the plates.

There are three types of capacitive transducers

(a) Changing area of the plate of capacitive transducers.
(b) Changing distance betn the plates capacitive transducers.
(c) Changing dielectric constant type of capacitive transducers.

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Changing area of plate type of capacitive transducer:-

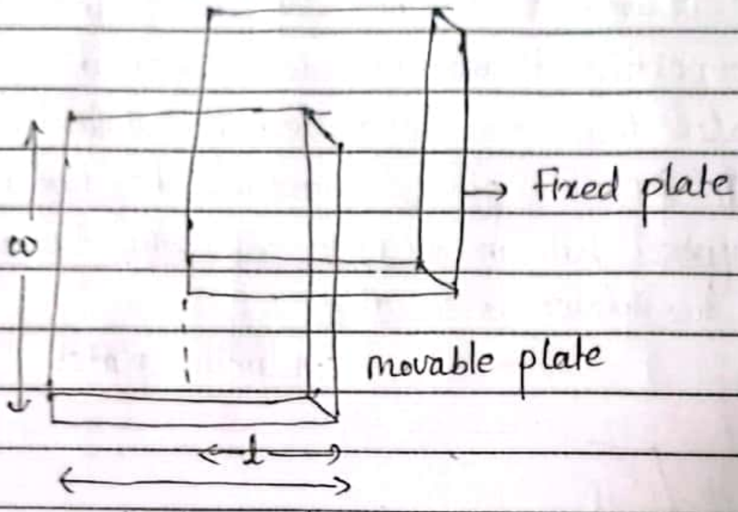


fig:- linear displaceable Capacitive transducer

$$C = \frac{\epsilon A}{d}$$

$$C = \frac{\epsilon_0 \epsilon_r w l}{d} \quad , w = \text{width}$$

$\boxed{C \propto l}$ for linear case,

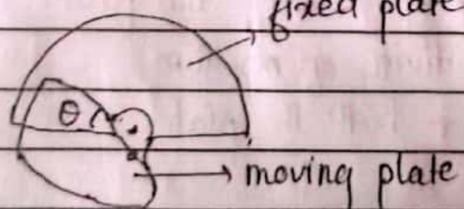
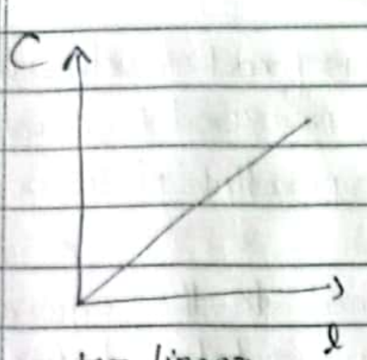


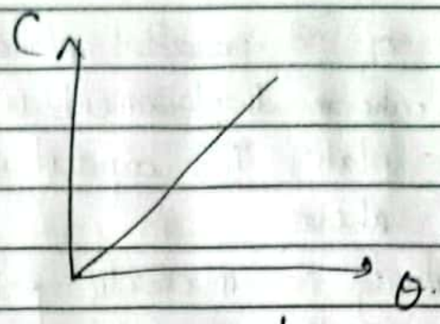
fig:- Rotary type of capacitive transducer.

$$C = \frac{\epsilon A_\theta}{d} = \frac{\epsilon \theta r^2}{2d}$$

$\boxed{C \propto \theta}$



for linear



for rotary

Principle of change in separation distance :-

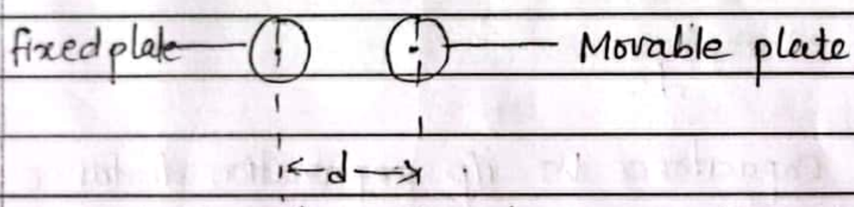


fig: Capacitive transducer working in the principle of change in distance

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon_0 \varepsilon_r A}{d} \quad \text{---} (1)$$

$$S = \frac{\text{change in O/p}}{\text{change in I/p}} = \frac{\partial C}{\partial d}$$

or $S = \frac{\partial}{\partial d}\left[\frac{\varepsilon_0 \varepsilon_r A}{d}\right]$

$$= -\frac{\varepsilon_0 \varepsilon_r A}{d^2}$$

or, $S = \frac{-C}{d}$

S = sensitivity

It consists of 2 parallel plates, one is fixed & other is mov... The object whose displacement is to be measured is coupled wi... the movable plate. The capacitance of parallel plate is given by eqn (1) above.

Thus sensitivity is inversely proportional to the square of separation so there exist a non-linear relation between o/p and input as shown in the fig below.

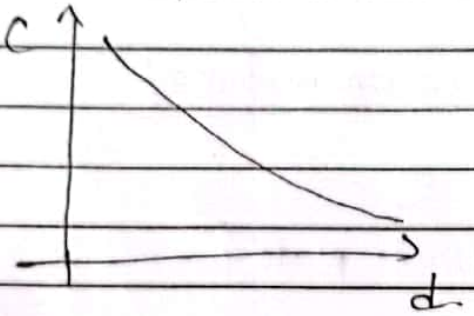


fig: Plot of Capacitance Vs i/p separation distance.

Capacitive liquid level transducer

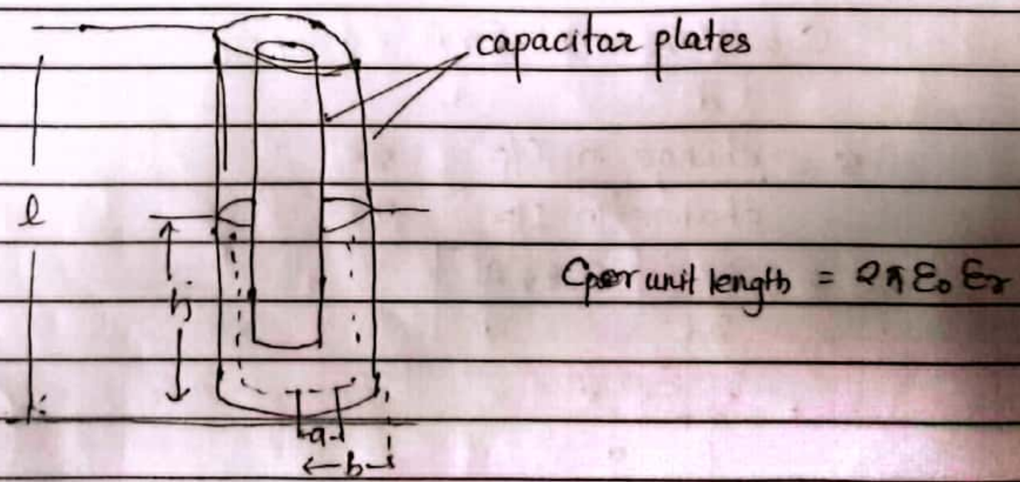


Fig (a) Capacitive transducer for measurement of liquid level

It consists of two concentric cylinders having radii a and b. The capacitance per unit length of concentric cylinders is given by

$$C_{\text{per unit length}} = \frac{2\pi \varepsilon_0 \varepsilon_r}{\ln(b/a)} \quad \text{—— (1)}$$

It is placed inside the liquid whose height is to be measured. So there is formation of two capacitors, one having the liquid as dielectric between the plates being the length 'h', other having air as dielectric being the length of 'l-h'. These two capacitors are supposed to be connected in parallel. The total capacitance is given by

$$C = C_1 + C_2$$

$$= \frac{2\pi \varepsilon_0 \varepsilon_r h}{\ln(b/a)} + \frac{2\pi \varepsilon_0 \varepsilon_r (l-h)}{\ln(b/a)} \quad \{\because \varepsilon_r \text{ in air} = 1\}$$

$$= \frac{2\pi \varepsilon_0 \cancel{\varepsilon_r}}{\ln(b/a)} (\varepsilon_r h + l - h)$$

$$= \frac{2\pi \varepsilon_0 \cancel{\varepsilon_r}}{\ln(b/a)} [\varepsilon_r h + (l-h)]$$

$$\therefore C = \frac{2\pi \varepsilon_0}{\ln(b/a)} [(\varepsilon_r - 1)h + l]$$

Thus whenever height of liquid changes, the capacitance also ~~so~~ changes so the capacitance will be a measure of height of liquid. i.e by measuring the capacitance we can ~~b~~ measure the height of liquid.

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Potentiometer (POT)

It is one of the examples of resistive transducer and is used for measurement of displacement. The displacement may be linear or rotary. Hence there are 2 types of potentiometer:

(i) Linear Potentiometer
(ii) Rotary Potentiometer

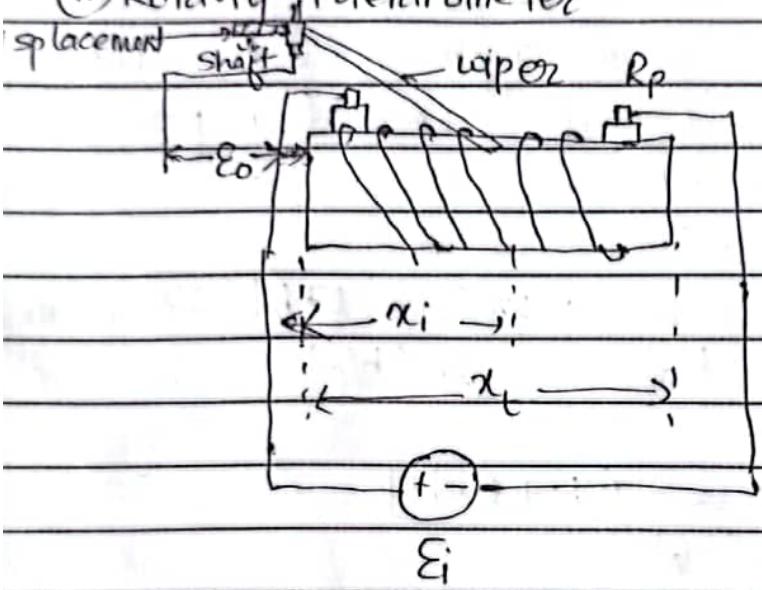

fig: linear POT

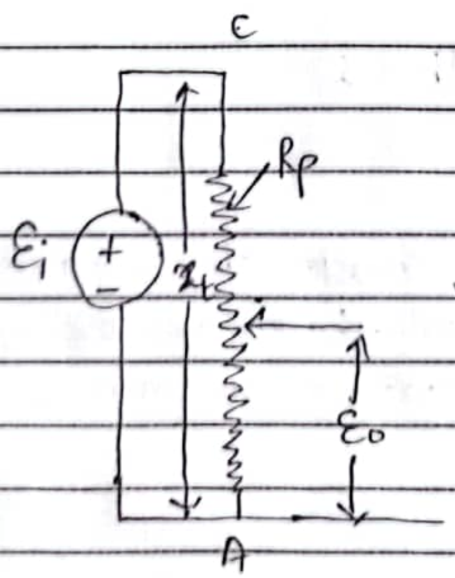

fig: Equivalent circuit of POT

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Consider linear potentiometer as shown in the fig (a) and (b).
let input applied voltage = ε_i.
total resistance of potentiometer = R_p
total length of potentiometer = x_t
resistance per unit length = $\frac{R_p}{x_t}$

Displacement = x_i
resistance of displacement = $\frac{R_p}{x_t} \times x_i$

$$= \frac{x_i}{x_t} \times R_p.$$

$$= K \times R_p$$

where $K = \frac{x_i}{x_t}$

The ideal output voltage across displacement is given by

$$\varepsilon_o = \frac{R_{AB}}{R_{AB}+R_{BC}} \times \varepsilon_i$$

$$= \frac{KR_p}{R_p} \times \varepsilon_i$$

$$\Rightarrow \boxed{\varepsilon_o = K\,\varepsilon_i}$$

$$\Rightarrow \boxed{\frac{\varepsilon_o}{\varepsilon_i} = \frac{x_i}{x_t}} \quad \text{——— (1).}$$

from eqn (1) we can conclude that there exist a linear relationship between output voltage and input voltage.

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Q. The wire in a strain gauge is 0.1 m long and has an initial resistance of 120Ω. On application of force, the wire length increases by 0.1mm and resistance increases by 0.21 Ω. Determine gauge factor of the device.

Soln:-

$$\text{initial resistance} = 120\Omega$$

$$\Delta R = 0.21\,\Omega$$

$$l = 0.1$$

$$\Delta L = 0.1 \times 10^{-3}$$

$$\therefore GF = \frac{\Delta R}{R} \times \frac{L}{\Delta L}$$

$$= \frac{0.21}{120} \times \frac{0.1}{0.1 \times 10^{-3}}$$

$$= 1.75 \; //$$

Q. Find the strain that results from a tensile force of 1000 N applied to a 10 m long aluminium bar having cross sectional area of $4 \times 10^{-4}\ m^2$ cross-sectional area. Modulus of elasticity of given bar is $69\ GN/m^2$.

$$Y = \frac{\text{stress/area}}{\text{strain}}$$

$$\therefore \text{strain} = \frac{\text{stress}}{Y}$$

$$= \frac{1000 / 4 \times 10^{-4}}{\cancel{4 \times 10^{-4}}\ 69 \times 10^{9}}$$

$$= \cancel{1.45 \times 10^{-9}}$$

$$= 3.623 \times 10^{-5}$$

A strain gauge having a resistance of 800 Ω and gauge factor 5 is bonded onto a member of a structure under tensile stress. Determine the % strain suffered by the member if the change in resistance of the gauge is measured as 2.4 Ω.

Solⁿ:-

$GF = 5$

$R = 800\Omega$

$\Delta R = 2.4\Omega$

$$GF = \frac{\Delta R/R}{strain}$$

$$w.\quad strain = \frac{\Delta R/R}{GF}$$

$$= \frac{2.4/800}{5}$$

$$=$$

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$$E_0 = \frac{\theta_i}{\theta_t} \times E_i$$

A voltage dividing potentiometer is used to measure an angular displacement. The angle of displacement is 60° and total angle of the travel of potentiometer is 355°. Calculate voltage output on open circuit if the potentiometer is excited by 60V source.

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Velocity transducer:

The velocity transducer is essentially consists of a moving coil suspended in magnetic field of permanent magnet as shown in the fig below.

A velocity generated by motion of the coil in the field is used to generate output. The output is proportional to the velocity of the coil and this type of transducer are used for the measurement of velocities developed in linear, sinusoidal or random manner. In order to gain higher stability damping is done.

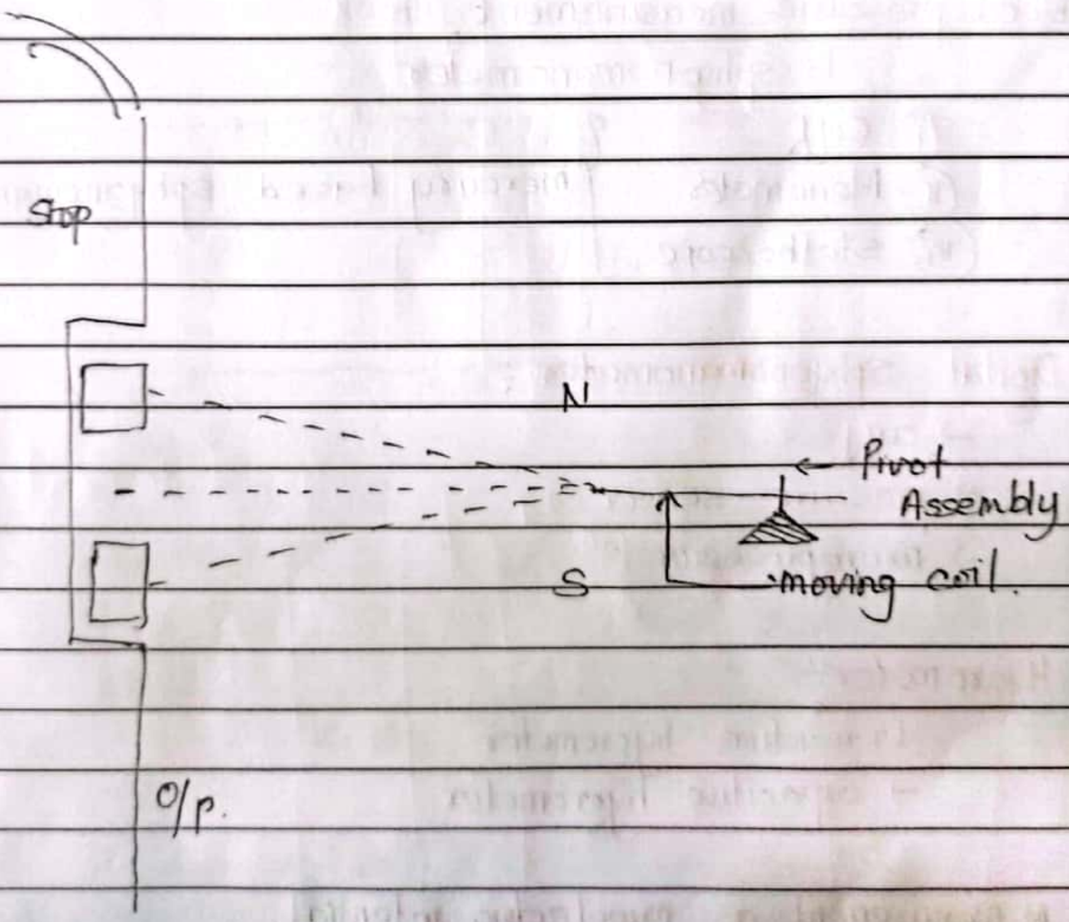

fig :- Velocity transducer

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Piezoelectric transducer,

The piezoelectric transducer are used for the measurement of force, pressure or acceleration. In certain crystals, an electric field appears across certain surface of the crystal if the dimension of the crystal is changed by application of mechanical force. Thus, potential is produced as these materials generate an electric charge within them when deformed. This effect is reversible and is known as piezoelectric effect.

Blood pressure measurement

↳ sphygnomanometer

(i) Cuff
(ii) Manometer
(iii) Stethoscope

} mercury based sphygnomanometer.

Digital Sphygnomanometer :

→ cuff
→ pressure sensor
→ microprocessor

Hygrometer :

↳ resistive hygrometer
→ capacitive hygrometer

M Measurement of myoelectric potential.

↓

EMG (Electro MyoGraphy)

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Calibration & errors in transducer
↓ is an essential process in transducer measument to ensure accuracy and reliability.

Measurement of resistance :
Classification of resistance :
low resistance :- below 1Ω (kelvin double bridge).
Medium resistance: $1\Omega - 100k\Omega$
↳ Ammeter - voltmeter method
High resistance : above $100k\Omega$.

Ammeter-voltmeter method :-

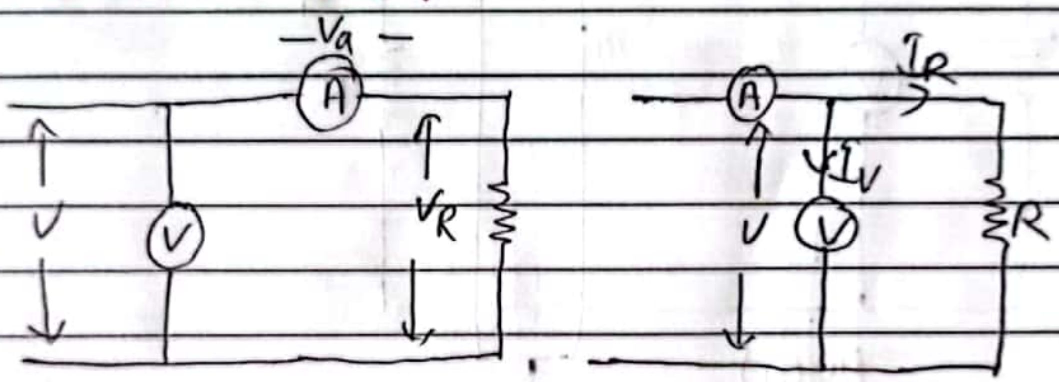

fig (a) fig (b)

fig (a)

$V = V_a + V_R$

$V_a = IR_a$

$V_R = IR$

$R_{m_1} = \frac{V}{I} = \frac{V_a + V_R}{I}$

$\boxed{R_{m_1} = R_a + R}$

$\boxed{R = R_{m_1} - R_a}$

$R = R_{m_1}\left(1 - \frac{R_a}{R_{m_1}}\right)$

$I = I_v + I_R$

$R_{m_2} = V/I$

$= \frac{V}{I_v + I_R}$

$= \frac{V}{\frac{V}{R_v} + \frac{V}{R}}$

$= \boxed{R_{m_2} = \frac{R_v R}{R_v + R}}$

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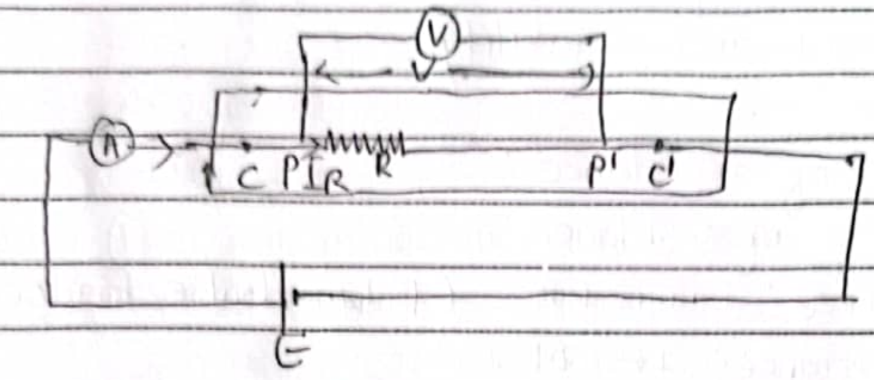
Low Resistance Measurement



Measurement of high resistance.

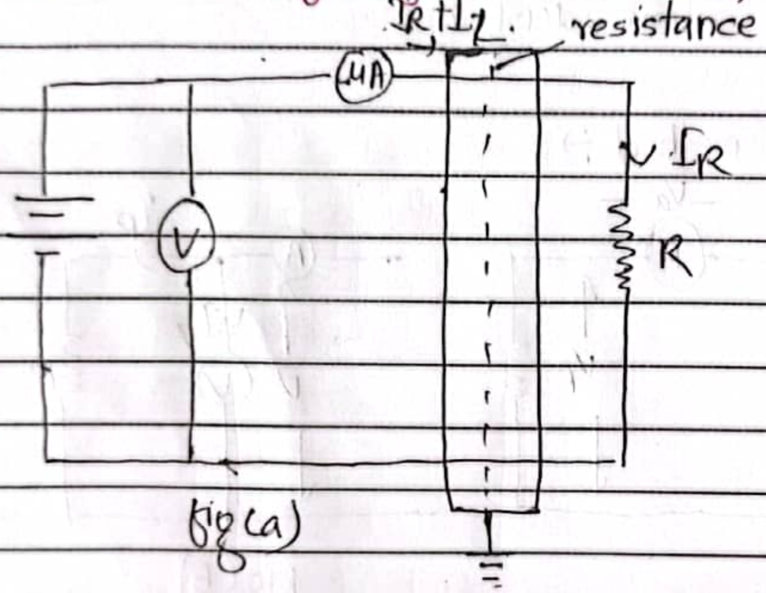


fig (a)

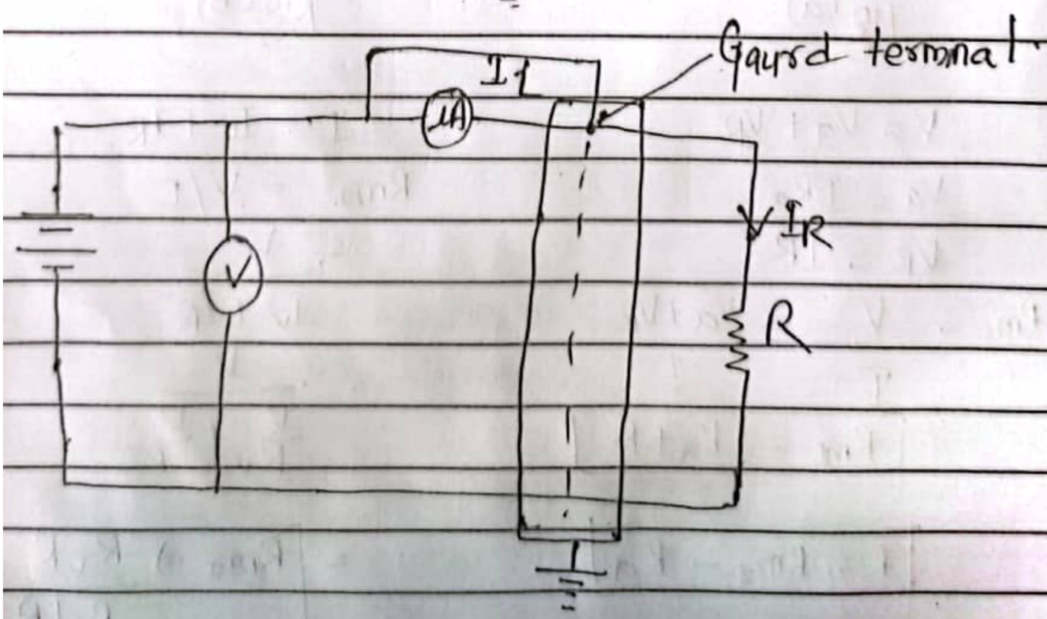


fig (b)

Ohm meter

→ It is a device that is used to measure resistance of a quantity

Resistance of healthy human body → 1000Ω.

→ series ohmmeter
→ shunt ohmmeter
→ Multirange ohmmeter.

Series ohmmeter:

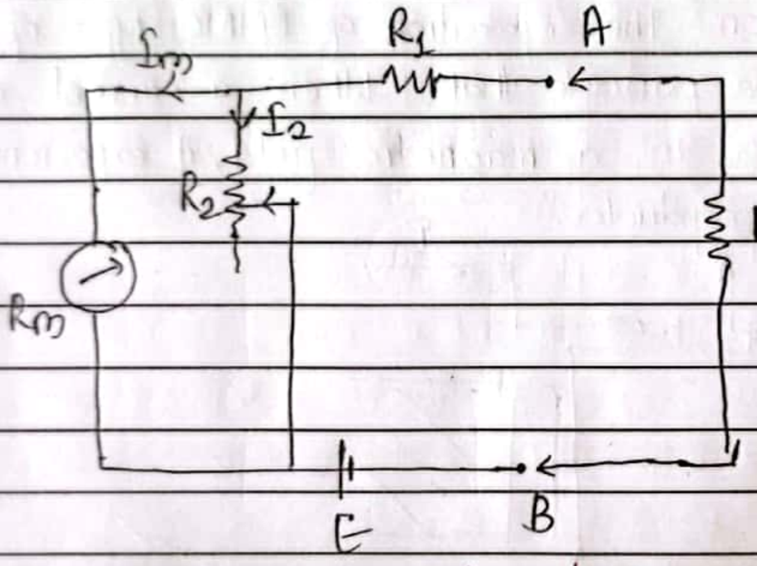


fig: series ohmmeter.

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Moving coil and moving iron instruments:
↳ given by D Arsonal.

There are two types of instrument that work on the pr-
ple of D Arsonal.

(i) Permanent Magnet Moving coil
(ii) Electromagnetic or Dynamometer type.

Permanent Magnet Moving coil (PMMC) as a ammeter

Principle of operation: The operation of PMMC type of instrum-
is based upon the principle that; "When a current carrying
conductor is placed in a magnetic field, it experiences a torq-
which moves the conductor."

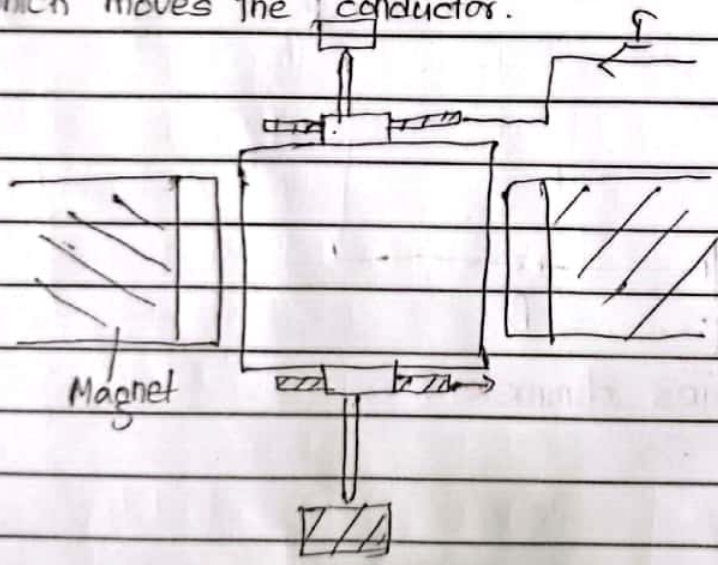

fig (a)

Construction:

Deflecting torque :

when a current is passed through a coil, force acted upon its both side which produces a deflecting torque.

let B = flux density wb/m²

l = length or depth of coil.

b = breadth of coil

N = no of turns

If 'I' amphere of currents is passed through the coil, the force on coil = NBI. Principle of operation

∴ Deflecting torque T_d = force x $\perp^r$ distance.

$= NBI(l \times b)$

$\boxed{T_d = NBIA}$ (Nm²) where A is area of rectangular coil.

when $BNA = k$

$T_d = kI$

$\boxed{T_d \propto I}$

for spring controlled instruments, controlling torque ($\boxed{T_c \propto \theta}$)

angle of deflection

for equilibrium condition,

$\boxed{T_d = T_c}$

Hence, deflection is directly proportional to current through the meter.

$\boxed{\theta \propto I}$

Extension of ammeter

when PMMC is used as ammeter, it can be extended with the help of low shunt resistance, where shunt provides a path for extra-current.

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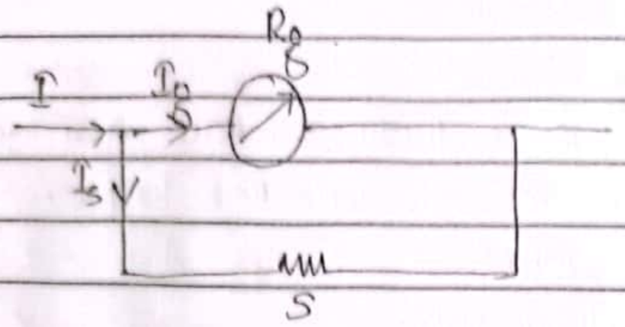

fig: Extending range of ammeter.

This shunted instrument can be made to measure current many times greater than their normal full scale deflection. The ratio of maximum current (with shunt) to full scale deflection current (without shunt) is known as multiplying factor of the shunt.

let R_g = Resistance of instrument

S = shunt Resistance

I_g = full scale deflection current

I = line current to be measured

we know that, voltage across shunt and instrument are equal as they are connected in parallel.

$$V_g = V_s$$

$$I_g R_g = I_s S$$

or, $I_g R_g = (I - I_g) S$

or, $\boxed{\dfrac{I}{I_g} = 1 + \dfrac{R_g}{S}}$

It can be seen that lower the value of shunt greater is multiplying factor.

How will you use a PMMC instrument which gives full scale deflection at 50 mV and 10mA current has

1. ammeter 0 to 10 A range
2. Voltmeter 0 to 250V range.

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Soln:-

$I_g = 10mA$

$V_g = 50mV$

$R_g = \frac{50}{10} = 5\Omega$

$\frac{I}{I_g} = 1 + \frac{R_g}{S}$

or, $\frac{10}{10\times10^{-3}} \cancel{= \frac{S+R_g}{S}} - 1 = \frac{5}{S}$

or, $\frac{10 - 10\times10^{-3}}{10\times10^{-3}} = \frac{5}{S}$

$\Rightarrow S = \frac{5\times10\times10^{-3}}{9.99}$

$= 5\times10^{-3}\,\Omega.$

$\frac{V}{V_g} = 1 + \frac{R}{R_g}$

$\left(\frac{250}{50\times10^{-3}} - 1\right)\times R_g = R.$

$\Rightarrow R = 25\,k\Omega.$

R is connected in series to increase range.

I will use a shunt resistance of $5\times10^{-3}\,\Omega$ in order to increase the range of ammeter from 10mA to 0 to 10A.

Extending the range of voltmeter.

The range of instrument when used as a voltmeter can be increased by using a high resistance in series with it.

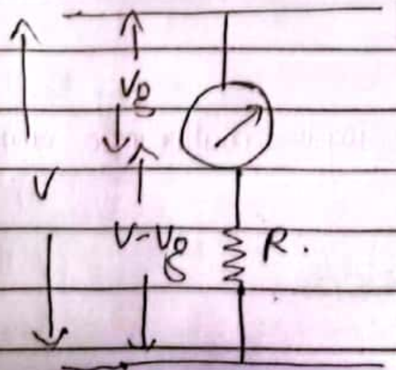


Fig:- Extending range of voltmeter

let I_g be the full scale deflection current,

R_g = resistance of instrument

$V_g = I_g \times R_g$ = full scale P.d

V = voltage to be measured

R = series resistance to be added

we know,

$$I_g = \frac{V}{R+R_g}$$

Also,

$$V_g = I_g . R_g .$$

$$V_g = \frac{V}{R+R_g} R_g \qquad \left[\because I_g = V/R+R_g\right]$$

or, $\frac{R+R_g}{R_g} = \frac{V}{V_g}$

$$\therefore \boxed{\frac{V}{V_g} = 1 + \frac{R}{R_g}} \longrightarrow (*)$$

Above eqn (*) shows that multiplication factor increases by increasing value of 'R'.

Multirange ammeter:

The current range of DC ammeter may be further extended by a number of shunts, selected by a range switch such ammeter is called multirange ammeter.

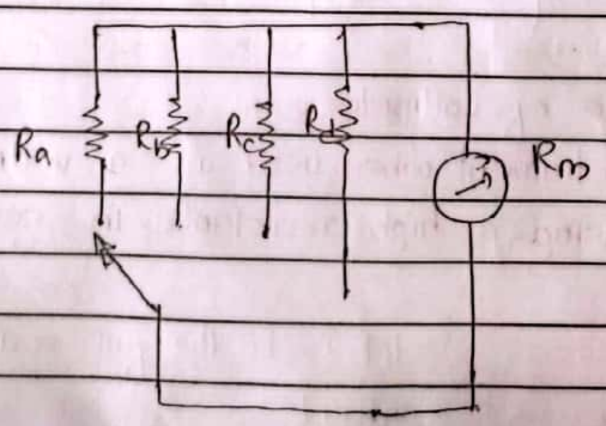


Fig: schematic diagram of simple multirange ammeter.

Multirange Voltmeter :-

The addition of a number of multipliers, together with range switch is known as multirange voltmeter. This voltmeter provides the facility to work with number of voltage range. fig below shows schematic diagram of multirange voltmeter having 4 multipliers R_1, R_2, R_3 and R_4.

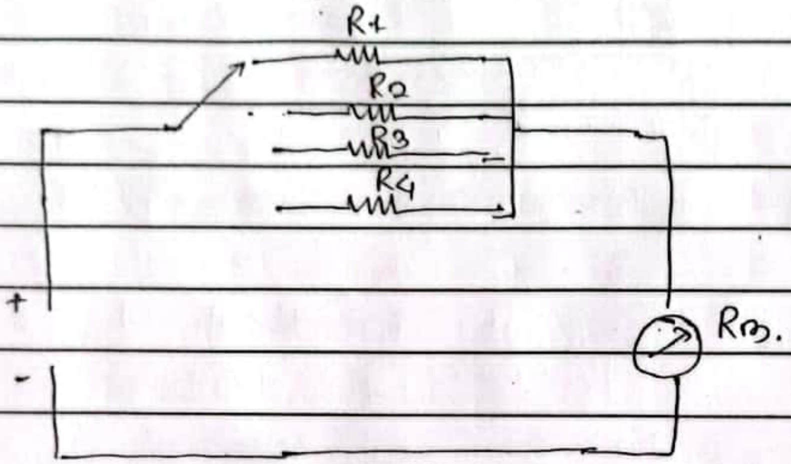
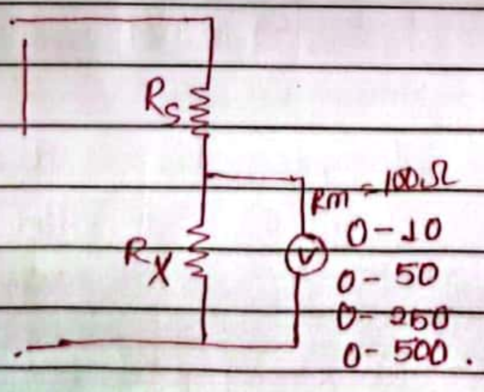


fig:- schematic diagram of a simple multirange voltmeter

Qn. A basic movement with internal resistance, $R_m = 100\Omega$ and full scale current $I_{fsd} = 1\,mA$ is to be converted into a multirange DC voltmeter with voltage ranges to i) 0-10 ii) 0-50V iii) 0-250V iv) 0-500V.

* Soln The circuit arrangement is shown in the fig below.



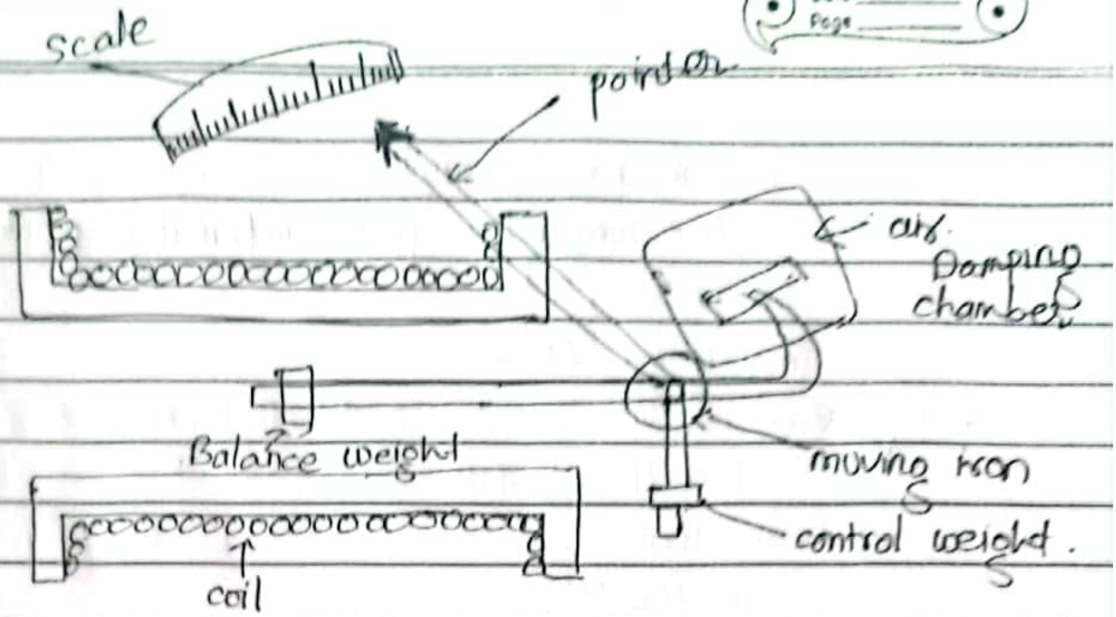


fig: Moving iron instrument of Attraction types.

Moving iron instrument :

Two types

(i) Attraction type instrument
(ii) Repulsion type instrument

Attraction type ~~inst~~ moving iron instrument :

Working principle:

when a soft iron piece is placed in a magnetic field of current carrying coils, it is attracted towards the centre of coil.

when instrument is connected to the circuit, the operating current flows to the stationary, a magnetic field is setup and soft iron piece is magnetised which is attracted to the centre of coil. Thus, the pointer attached to spindle is deflected over the calibrated area.

let T_d be the deflecting torque produced which depends on the force acting on the iron piece in magnetic field.

force acting on iron piece is given by

$$F \propto mH$$

where,

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m = pole strength.

H = magnetic field intensity produced by coil.

Also

$m \propto H$ —— (ii)

from (i) & (ii)

$F \propto H^2$ —— (iii)

we know that,

$$H = \frac{NI}{l}$$

$$\boxed{H \propto I}$$

$$\boxed{F \propto I^2} \text{ —— (iv)}$$

since $T_d \propto F$

so,

$$\boxed{T_d \propto I^2} \text{ —— (v)}$$

For controlling torque T_c,

$T_c \propto \theta$ —— (vi).

For steady state

$$T_d = T_c$$

$$\boxed{\theta = I^2} \text{ —— (vii)}$$

Eqn (vii) shows that angle of deflection is directly proportional to square of current.

(ii) Repulsive type of moving iron instrument

Principle:

Repulsive type force acts when two similarly magnetised iron piece are placed together. A pointer is attached to moving iron

Working:

when the instrument is ~~attached~~ connected to the circuit, the

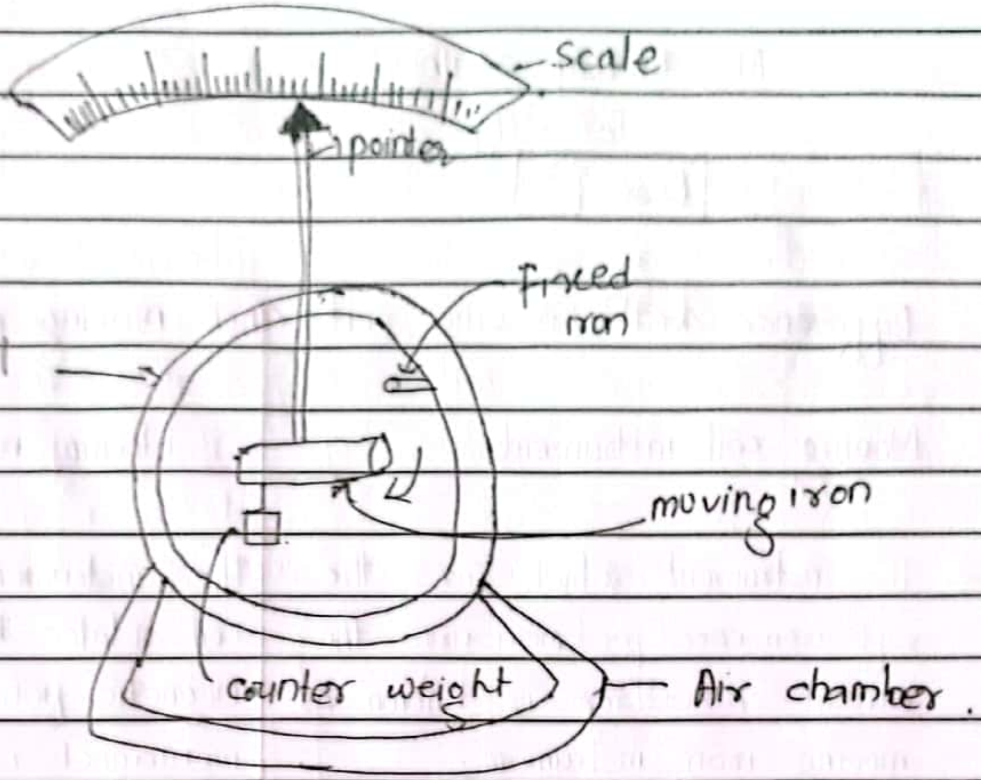

fig: Repulsive type MI instrument

operating current flows through the coil, A magnetic field is setup along the axis of coil. The magnetic field magnetizes both the iron pieces ~~simi~~ in a similar manner (same polarity) A force of repulsion acts between the two iron pieces and the moving iron moves away (repels) fixed iron. Thus the pointer attached to the spindle deflects over the callibrated area.

The deflecting torque produced by two similarly magnetised iron bars is proportional to the pole strength of both bars.

$T_d \propto m_1 m_2$ —— (i)

$m_1 \propto H$ —— (ii)

$m_2 \propto H$ —— (iii).

$T_d \propto H^2$ —— (iv)

we know that,

$$\boxed{T_d \propto I^2}$$

Also, $T_c \propto \theta$

At steady state,

$$T_c = T_d$$

$$\boxed{\theta \propto I^2}$$

Difference betn moving coil and moving iron instrument.

Moving coil instrument	Moving iron instrument
The instrument which uses the soft iron core for measuring the current or voltage is known as moving iron instrument.	The instrument in which the coil rotates both betn the magnetic field of the permanent ~~m~~ magnet is known as the moving coil instrument.
It works on the principle that the iron attracts towards the magnet, the magnetic field induces because of the electromagnet ~~of~~ the iron piece piece is placed betn this field.	It works on the principle that the force acting on the coil placed betn the magnetic field of the permanent magnet and because of this magnetic field, the coil rotates.
It uses soft iron piece as a rotating element.	→ uses the coil as a rotating element.
The working principle of the MI instrument depends on magnetism.	The working principle of MC instrument is similar to the working principle of dc motor.
MI is less accurate.	MC is more accurate.

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→ It uses the air friction damping.	It uses the eddy current damping system.
→ consumes more power.	consumes less power.
→ used for measuring both DC and AC.	used for DC measurement.
→ gravity or spring provides the controlling torque to the instrument.	the spring provides the controlling torque to the MC instrument.
→ The deflection of MI is proportional to the square of current.	The deflection of MC is proportional to the current.
→ can be used as an - ammeter - voltmeter - wattmeter.	can be used as an : - ammeter - Voltmeter - galvanometer. - ohmmeter.

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Qn. Mention application PMMC and MI instruments.

Wattmeter

A wattmeter is essentially an inherient combination of ammeter and voltmeter. and therefore consists of two coils known as current coil and pressure coil (voltage coil).

The general connection of wattmeter for single phase wattage (power measurement) is shown is fig below.

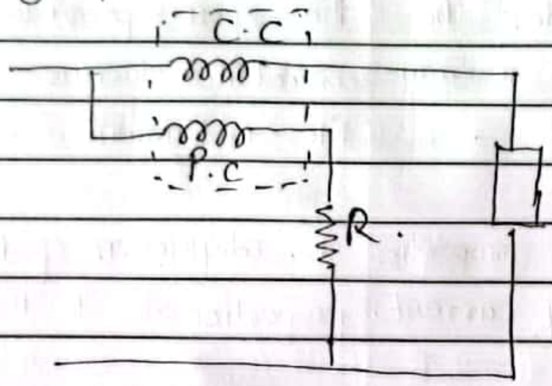
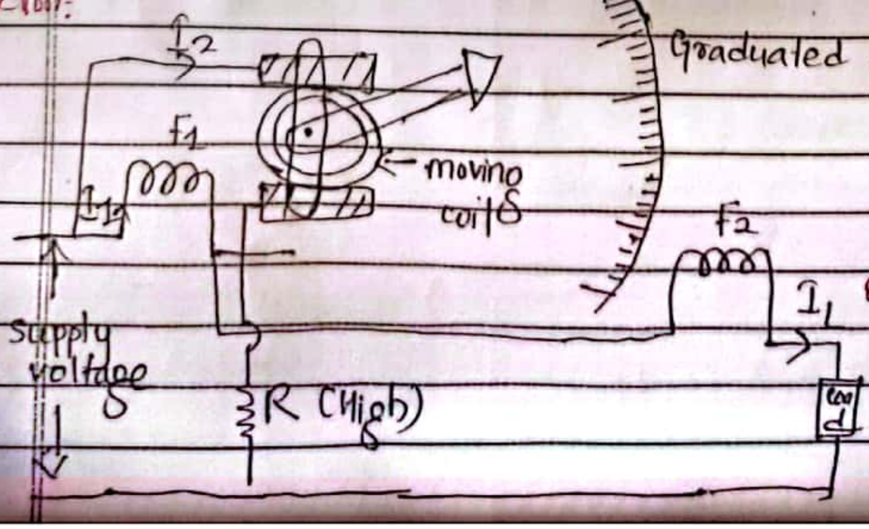


fig: 1-ϕ wattmeter connection

Type of wattmeter
(i) Electrodynamometer type wattmeter.
(ii) Induction type wattmeter.

(i) Electrodynamometer Type wattmeter

Construction:



fig(a) Construction of Electrodynamometer type wattmeter.

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It consists of two coils : fixed coil and moving coil. The fixed coil is divided into two halfs : F_1 and F_2, which are connected in series with load whose power is to be measured. The moving coil is connected to the suplly voltage in parallel.
A high resistance 'R' is connected in series with moving coil as moving coil is connected across the supply voltage.

Mathematical derivation :-

In case of dynamometer type wattmeter, there is no iron core so field strength and hence the flux density is directly proportional to current 'I_1' and is given by

$$B = KI_1 \quad \text{——— (1)}$$

So the fixed coils 'F_1' and 'F_2' are responsible for producing required magnetic field. Now, when the current flows through the moving coil, it experiences deflecting torque and moves to show deflection. The deflecting torque produced is given by

$$T_d \propto BI_2 \quad \text{——— (2)}$$

since $I_2 \propto KV$ and $B \propto KI$,

$$T_d \propto KVI,$$

$$\boxed{T_d = k.\text{ power}} \rightarrow \text{for dc}$$

for a.c $\quad T_d = vi \qquad v \rightarrow rms,\ i \rightarrow rms.$

$$\boxed{P = vi\cos\phi}$$

(ii) Induction type wattmeter :-

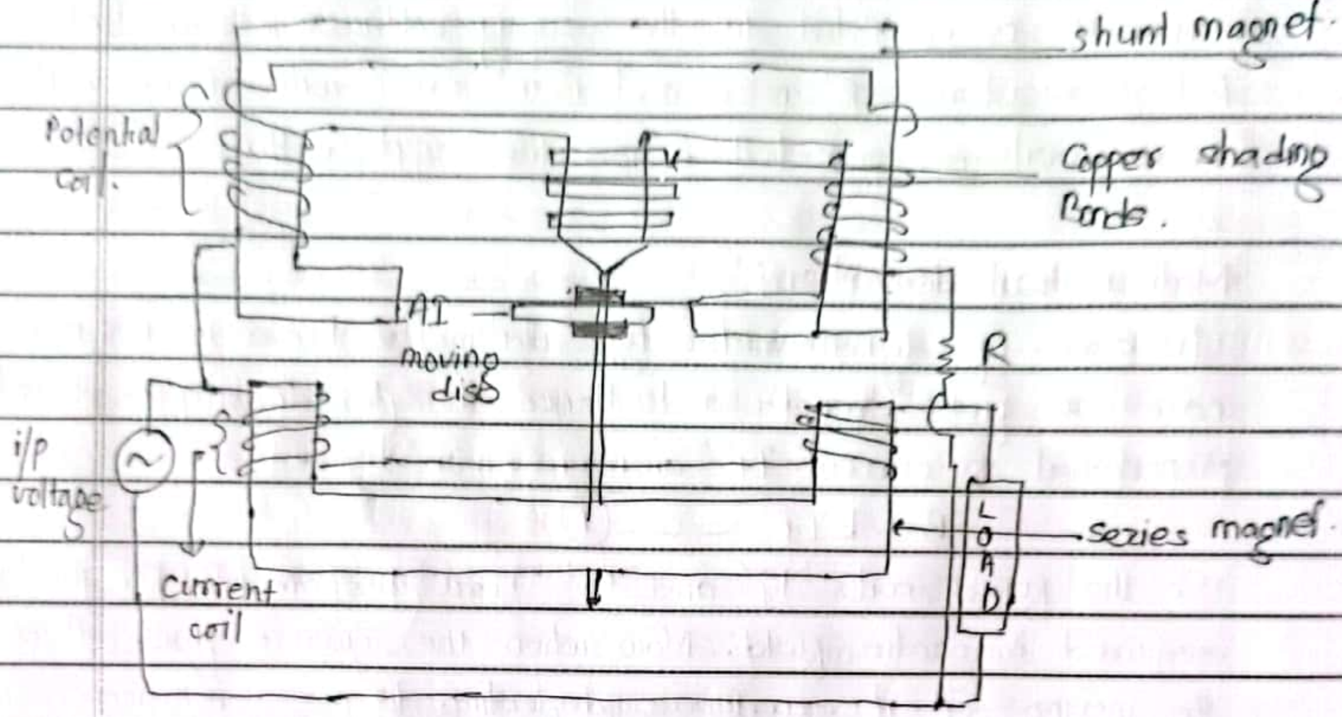
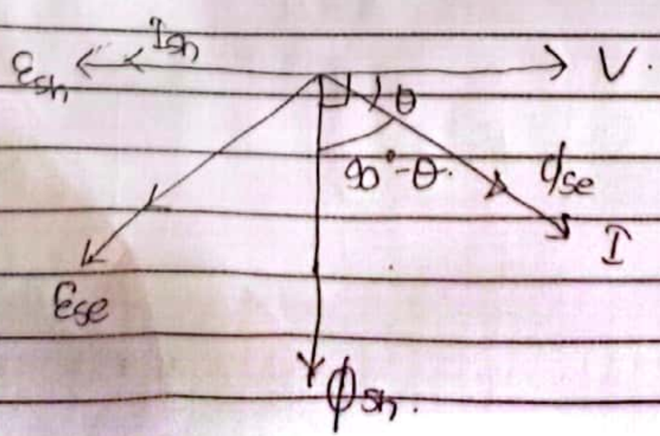


fig:- Induction type wattmeter

Qn. Explain working principle and construction of energy meter and power factor meter.

Working principle of induction type wattmeter.



let V = circuit voltage

I = circuit current

θ = angle betⁿ V & I

ϕ_{se} = flux created by the series electromagnet this will be in phase with I

ϕ_{sh} = flux created by shunt electromagnet. this will be inphase with 'V'

The flux ϕ_{se} of series electromagnet induces emf as E_{se} in the disc. This emf causes the eddy current I_{SE} in the disc. ~~This emf causes~~ let us assume that the disc is fully resistive. Hence eddy current I_{SE} caused by induced emf E_{se} will be inphase with that emf. So, I_{se} also lags the current I by $90°$.

$\therefore$ angle betⁿ ϕ_{se} and $I_{se} = 90°$.

The flux ϕ_{sh} of shunt electromagnet induces emf E_{sh} in the disc. This emf causes the eddy current I_{sh} in the disc. Let us assume that the disc is fully resistive. Hence eddy current I_{sh} caused by induced emf. E_{sh} will be in phase with that emf. So, E_{sh} also lags by $90°$.

Mathematical derivation:

The torque produced by interaction of ϕ_{se} I_{SE} and ϕ_{sh}:

$$T_1 = k I_{se} \phi_{sh} \cos\theta \quad \text{--- (a)}$$

torque produced by interaction of I_{sh} and ϕ_{se} is

$$T_2 = k I_{sh} \phi_{se} (\cos(180° - \theta)) \quad \text{--- (b)}.$$

The resultant deflecting torque is

$$T_d = T_1 - T_2$$

$$= k I_{se} \phi_{sh} \cos\theta - k I_{sh} \phi_{se} \cos(180° - \theta)$$

$$= k\,[I_{se}\phi_{sh}\cos\theta + I_{sh}\cdot\phi_{se}\cos\theta].$$
$$= k\,[k_1 VI\cos\theta + k_2 VI\cos\theta].$$
$$= kVI\cos\theta\,[k_1+k_2].$$
$$\boxed{T_d \; \alpha \; VI\cos\theta.}$$

Energy meter :

Energymeter are integrating instruments used to measure quantity of electrical energy supplied to a load for a particular period of time. There are three types of energymeter.

i) Electrolytic energymeter
ii) Clock - Energymeter
iii) Motor energymeters;

Single phase induction type energymeter :

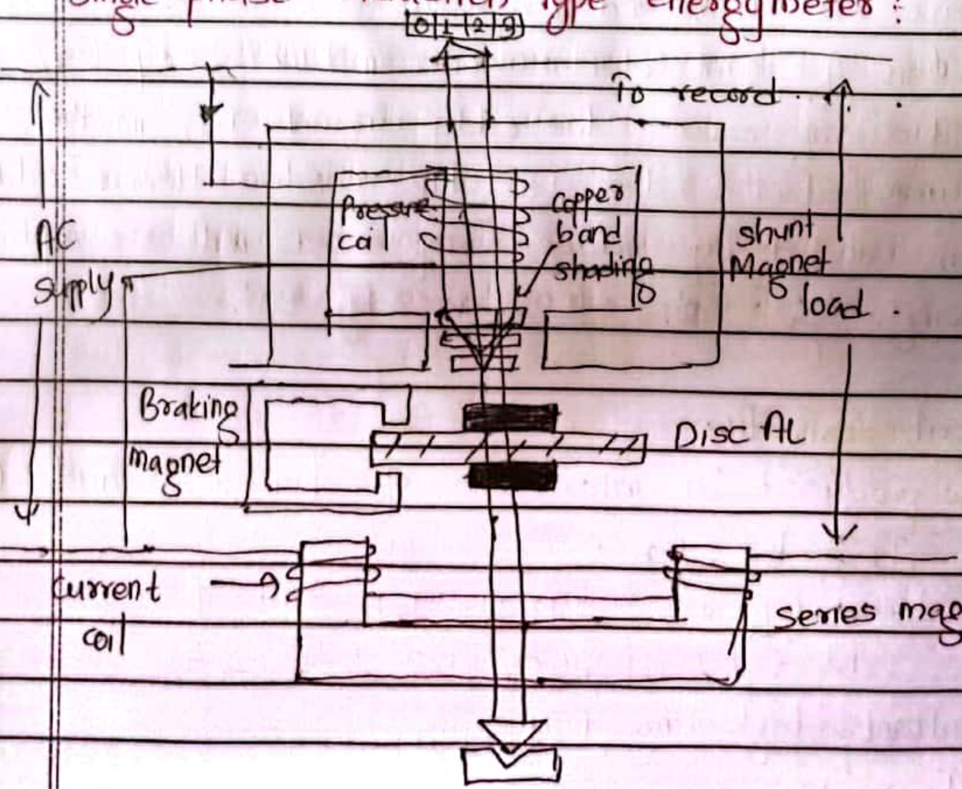


fig:- Induction type energymeter.

This energymeter consists of 4 parts:-

1) driving system
2) Moving system
3) Braking system
4) Registering system

Power factor meter:-

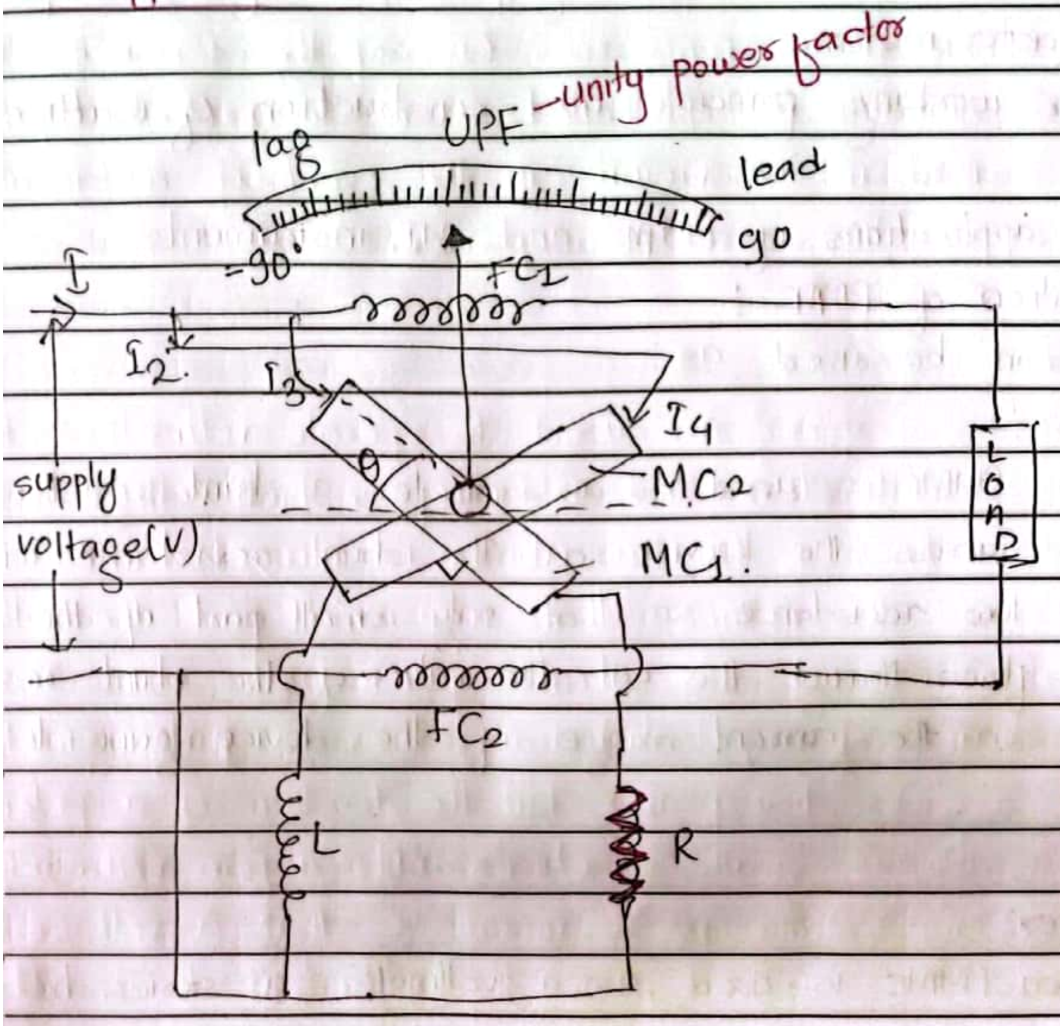


fig: single phase Electrodynamometer type of power factor meter.

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Instrument transformer:
→ Current transformer
→ Potential transformer

Write short notes on
(a) CT and PT
(b)

Qn. Explain construction & working principle of single phase powerfactor meter.

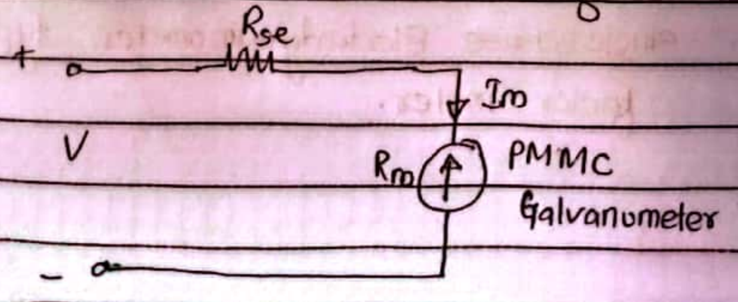
Qn. Explain working principle and construction of wattmeter.

Mention applications of PMMC and MI instruments

Soln:- Application of PMMC:
It can be used as:

(i) Ammeter:
when PMMC is used as an ammeter, a shunt resistor is connected across the moving coil. The shunt resistance will have suitable low resistance so that only small part of the main current flows through the coil. The value of the shunt resistor depends on the current range of the device going to be measured.

(ii) Voltmeter:
when PMMC is used as a voltmeter, a series high resistance is connected in series with the moving coil.



Galvanometer

The galvanometer is used to measure a small value of current along with its direction and strength.

Ohmmeter

The ohmmeter is used to measure the resistance of the electric circuit by applying a voltage to a resistance with the help of battery.

Application of MI instruments

Ammeter

Instrument always connected in series with the circuit and carries the current to be measured.

The current flowing through the coil produces the desired deflecting torque.

It should have low resistance as it is connected in series.

Voltmeter

Instrument always connected in parallel with the circuit.

The current flowing through the operating coil of the meter produces deflecting torque.

It should have high resistance.

Short notes on :

CT and PT

Current Transformer's

The current transformer is used with the its primary winding connected in series with line carrying the current to be measured and, therefore, the primary current is dependant upon the load connected to the system and is not determined by the

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load (burden) connected on the secondary winding of the current transformer. The primary winding consists of very few turns, and therefore, therefore is no appreciable voltage drop across it. The secondary winding of the current transformer has larger no of turns, the exact number being determined by the turns ratio. The ammeter, or wattmeter current coil, are connected directly across the secondary winding terminals. Thus a current transformer operates it secondary winding nearly under short circuit conditions. One of the terminals of the secondary winding is earthened so as to protect equipment and personnel in the vicinity in the event of an insulation breakdown in the current transformer.

Potential transformers:

Potential transformers are used to operate voltmeters, the potential coils of wattmeters and relays from high voltage lines. The primary winding of the transformer is connected across the line carrying the voltage to be measured and the voltage circuit is connected across the secondary winding.

The design of a potential transformer is quite similar to that of a power transformer but the loading of a potential transformer is always small, sometimes only a few volt-amphere. The secondary winding is designed so that a voltage of 100 to 120 V is delivered to the instrument load. The normal secondary voltage rating is 110 V.

UNIT- 3

OPERATIONAL AMPLIFIER :-

Operational amplifier is an example of signal conditioning element. Operational amplifier is a versatile device that can be used to amplify dc as well as Ac input signal.
These amplifier were used to as adder, substractor, differentiator, integrator and buffer.
Opamp is simply a triangular shaped device having two inputs and single output.
One input terminal is designated by -ve sign and known as inverting mode and another terminal is designated by +ve sign and known as non-inverting mode.
A typical Op-amp is made up of 3 types of amplifier circuits such as

a) Differential amplifier
b) Voltage amplifier and
c) push-pull amplifier

as shown in the fig below.

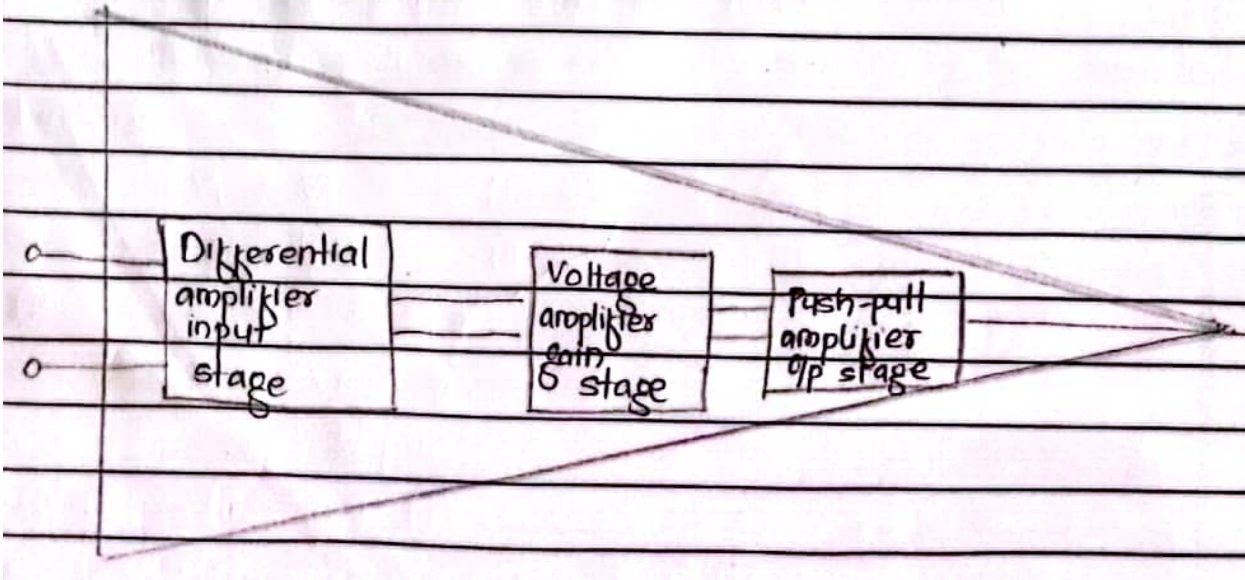

fig: Internal block diagram of an op-amp

The symbol of op-amp is shown below:

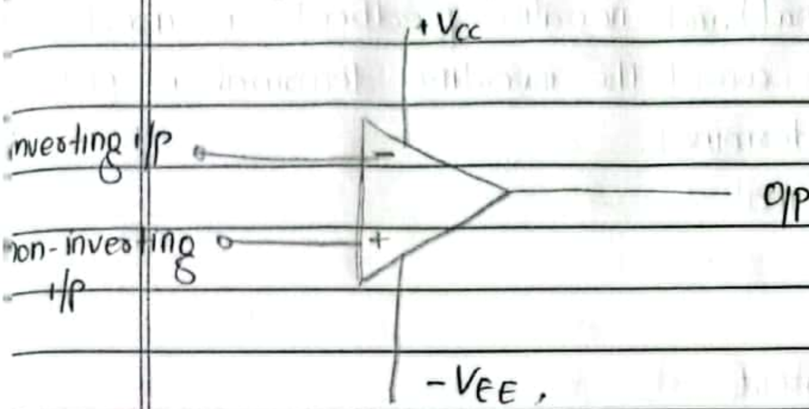

fig: Symbol of OP-amp circuit

Characteristics of Ideal Op-amp:

i) Infinite Voltage gain A_0.

ii) Infinite input resistance R_i so that any signal source can drive it and there is no loading of the preceeding stage.

iii) Zero output resistance R_0, so that the output can drive an infinite no of devices.

iv) Zero output voltage when i/p voltage is zero.

v) Infinite bandwidth so that any frequency signal from 0 to ∞ can be amplified without attenuation.

vi) Infinite common-mode rejection ratio so that the o/p common-mode noise voltage is zero.

vii) Infinite slew rate so that o/p voltage changes occur simultaneously with i/p voltage changes.

There are two modes of operation of Op-amp

i) Non-inverting mode

ii) Inverting mode

i) Non-inverting mode

let us consider an ideal operational amplifier operating in

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non-inverting mode (i.e input is provided to the non-inverting terminal or positive terminal) and negative feedback is used as shown in fig. let us consi The inverting terminal is grounded.

let, V_+ = non-inverting terminal

V_- = inverting terminal

V_i = input voltage

V_0 = output voltage

I_f = feedback current

R_f = feedback resistance

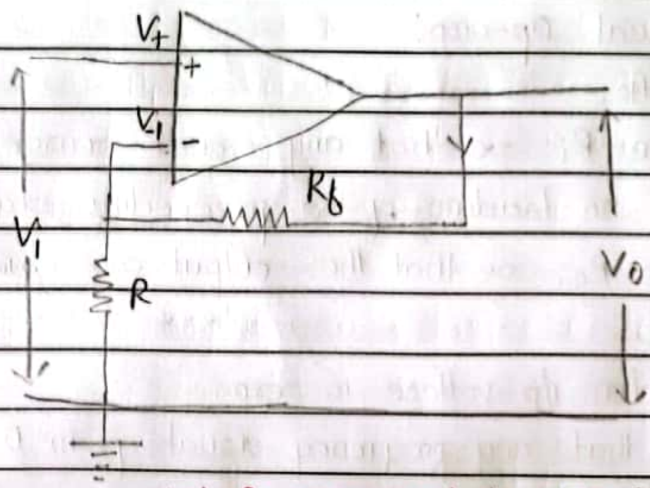

fig: Op-amp used in non inverting mode

From fig

$$V_+ = V_i \quad \text{—— (i)}$$

$$V_- = I_f \cdot R \quad \text{—— (ii)}$$

Also, $V_0 = I_f (R + R_f)$

$$I_f = \frac{V_0}{R + R_f} \cdot R \quad \text{—— (iii)}$$

from (ii) and (iii).

$$V_- = \frac{V_0}{R_f + R} \cdot R \quad \text{—— (iv)}$$

As, we know that

$$A_0 = \frac{V_0}{(V_+ - V_-)}$$

or, $V_0 = A_0(V_+ - V_-)$

or, $V_0 = A_0\left(V_i - \frac{V_0}{R+R_f}\cdot R\right)$

or, $\frac{V_0}{A_0} = V_i - \frac{V_0}{R+R_f}\cdot R$ —— (v)

since we know that $A_0 = \infty$ for ideal op-amp,
we can say,

$\frac{V_0}{A_0} = 0$ —— (vi)

$0 = V_i - \frac{V_0}{R+R_f}\cdot R$.

or, $\frac{V_0}{V_i} = \frac{R_f + R}{R}$

or, $\boxed{A_i = \frac{V_0}{V_i} = 1 + \frac{R_f}{R}}$ —— (vii) where, A_i = closed loop gain & eqn (7) shows that +ve terminal is non-inverting

ii. Inverting mode

let us consider an ideal operational amplifier operating in inverting mode (i.e input is provided to the inverting terminal or negative terminal) and negative feedback (stability) is used as shown in fig. And the non-inverting terminal is grounded.

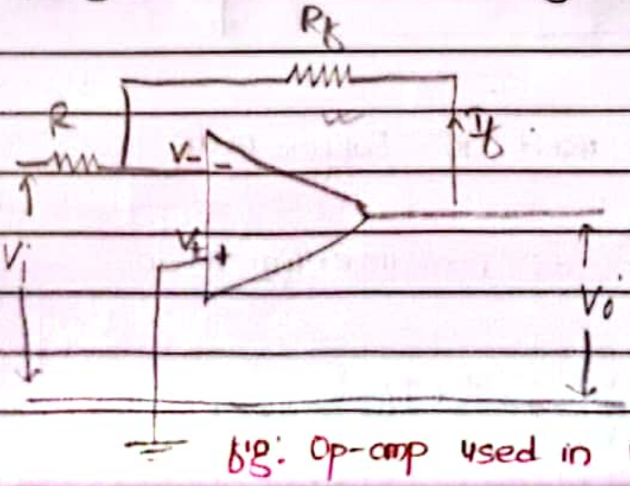

fig: Op-amp used in inverting mode

From fig

$V_+ = 0$ —— (1)

As we know,

$V_+ - V_- = 0$

$\therefore V_- = V_+ = 0$

Using KCl at terminal V_- gives.

$I + I_f = 0$

or. $\frac{V_i - V_-}{R} + \frac{V_0 + V_-}{R_f} = 0$

$\frac{V_0}{R_f} = \frac{-V_i}{R}$

$\therefore \boxed{A_i = \frac{V_0}{V_i} = -\frac{R_f}{R}}$ where, A_i = closed loop gain & eqn shows V_- is inverting terminal.

Operation amplifier on a buffer mode (Isolation mode) :-

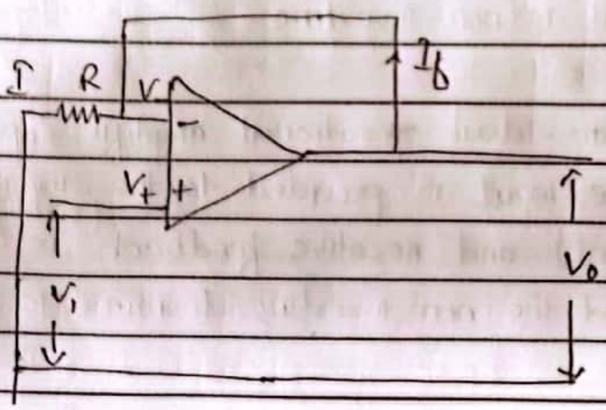

fig:- Op-amp used in Buffer mode

Derivation same as non-inverting mode then we have,

$A_i = \frac{V_0}{V_i} = 1 + \frac{R_f}{R}$

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$$\Rightarrow \frac{V_o}{V_i} = 1 + \frac{0}{R}$$

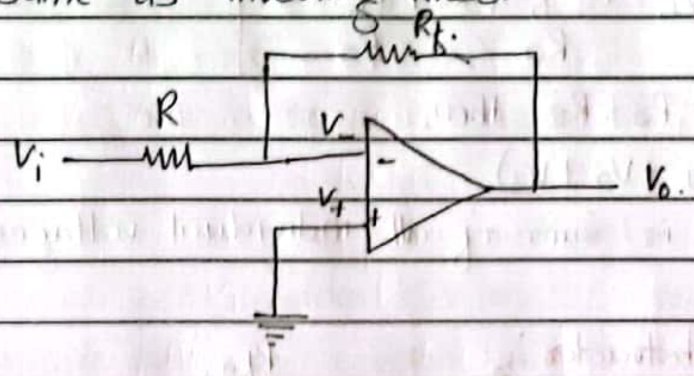
$$\Rightarrow \boxed{V_o = V_i}$$

Application of Op-amp.

→ Amplifiers can be used as inverter, adder, subtractor, integrator, differentiator, buffer in instrumentation.

(a) Op-amp as inverter

→ Same as inverting mode.

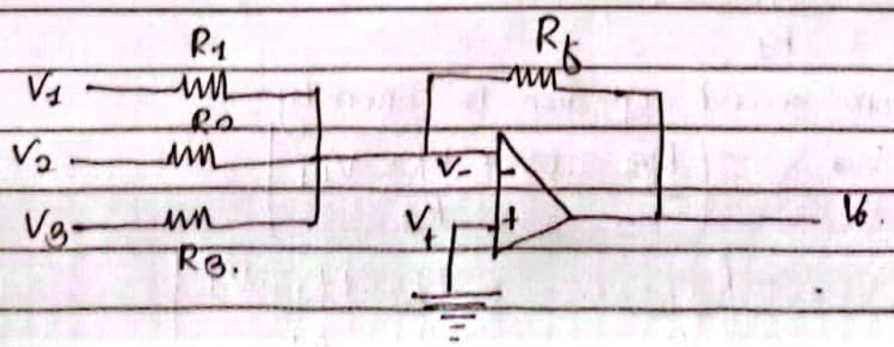


The closed gain of op-amp as inverter can be gained as

$$A = \frac{V_o}{V_i} = \frac{-R_f}{R}$$

if $R_f = R$, then $\boxed{V_o = -V_i}$

(b) Op-amp as adder



Op-amp as adder

If only V_1 is applied then o/p is given by
$$V_{o1} = \frac{-R_f}{R_1} V_1$$
similarly for $V_{o2} = \frac{-R_f}{R_2} V_2$

$$V_{o3} = \frac{-R_f}{R_3} V_3$$
If all signals are applied together
$$V_o = V_{o1} + V_{o2} + V_{o3}$$
$$= -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]$$
If $R_f = R_1 = R_2 = R_3$ then,
$$V_o = -(V_1 + V_2 + V_3).$$
Thus o/p voltage is sum of all individual voltages.

(c) Op-amp as a substractor:

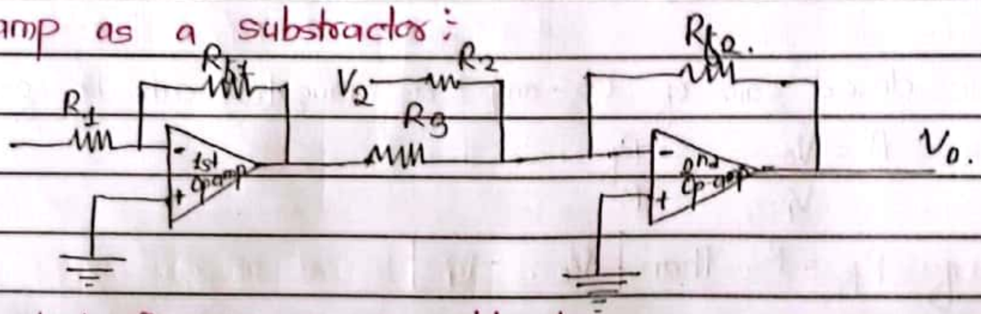


fig:- Op-amp as a subtractor

The o/p from the first operational amplifier is given by:
$$V_{o1} = \frac{-R_{f1}}{R_1} V_1 \quad \text{—— (1)}$$
The o/p from second op-amp is given by:
$$V_{o} = -\left(\frac{R_{f2}}{R_2} \cdot V_2 + \frac{R_{f2}}{R_3} V_{o1}\right)$$
$$= -\left(\frac{R_{f2}}{R_2} \cdot V_2 - \frac{R_{f2}}{R_3} \cdot \frac{R_{f1}}{R_1} \cdot V_1\right)$$

If $R_{f2} = R_{f1} = R_1 = R_2 = R_3$ then,

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

which shows o/p signal is difference of two i/p.

(d) Op-amp as an integrator:

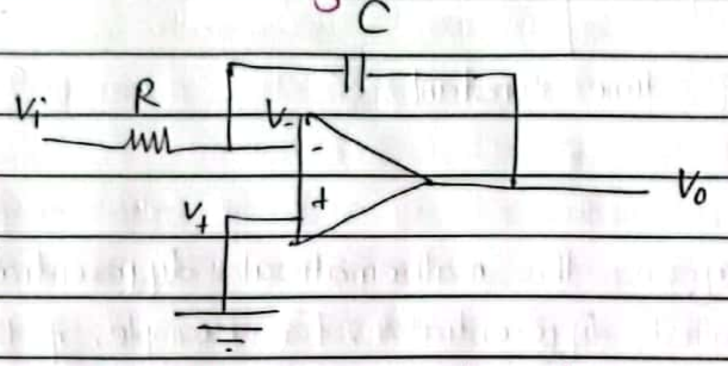


fig: Op-amp as integrator

A circuit that performs mathmetical integration of input signal is known as integrator. For e.g., if input to the integrator is square wave, the o/p will be a triangular wave.

From fig:

$V_+ = 0$

As we know,

$V_+ = V_- = 0$

$\therefore V_+ = V_- = 0$

Applying KCl at terminal V. gives,

$$I + I_c = 0.$$

$$\text{or, } \frac{V_i - V_-}{R} + C\frac{d(V_0 - V_-)}{dt} = 0.$$

$$\text{or, } \frac{C\,dV_0}{dt} = \frac{-V_i}{R}$$

$$\text{or. } dV_0 = \frac{-1}{RC} V_i\,dt$$

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$$\text{or, } \int dV_0 = \frac{-1}{RC}\int V_i\,dt$$

$$V_0 = \frac{-1}{RC}\int V_i\,dt.$$

$$\therefore \boxed{V_0 = -\frac{1}{\tau}\int V_i\,dt}$$

where, $RC = \tau$ time constant.

Differentiator:-

A circuit that performs the mathematical differentiation of input signal is called differentiator. For example, if the input to the differentiator is a triangular waveform then the output will be square wave.

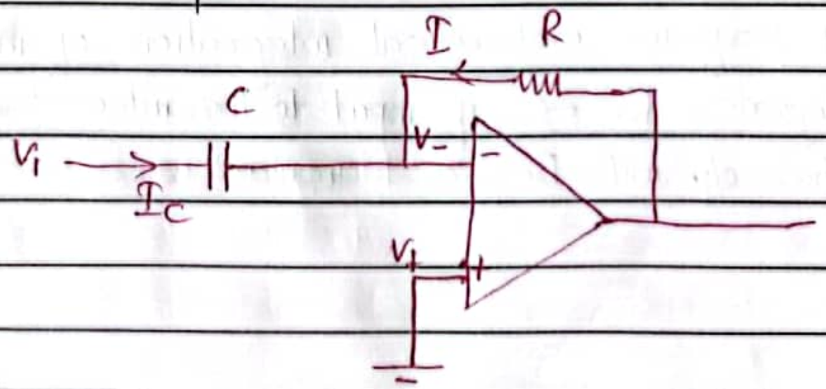


fig:- Op-Amp as a differentiator

$$V_+ = 0$$

$$V_+ - V_- = 0$$

$$\text{or, } V_+ = V_- = 0$$

On applying KCl at V_-

$$I_c + I = 0$$

$$\text{or, } \frac{C\,d(V_i - V_-)}{dt} + \frac{V_0 - V_-}{R} = 0$$

$$\therefore V_0 = -RC\frac{dV}{dt} = -\tau\frac{dV}{dt}$$

Instrumentation Amplifiers :-

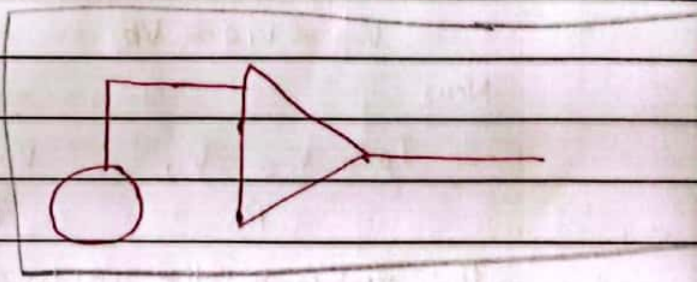
→ Instrumentation amplifier is a dedicated differential amplifier with extremely high input impedance. Its gain can be precisely set by a single internal or external resistor.

→ The high Common-Mode Rejection ratio makes this amplifier very useful in recovering small signals burried in large common-mode offsets and noise.

→ Instrumentation amplifier is a closed loop device with precisely set gain. This amplifier allows to optimize signals, noise. The Op-amp in constrast can be used to build a wide variety of circuits but doesn't make as good as a difference amplifier as does an instrumentation amplifier.

→ Instrumentation amplifier is superior than other amplifier because of following reasons :-

(i) Selectable gain with high gain accuracy and gain linearity.
(ii) Differential i/p capability with high common-Mode Rejection Ratio.
(iii) High stability of gain with low temperature coefficient.
(iv) Low drift errors
(v) low output impedances.



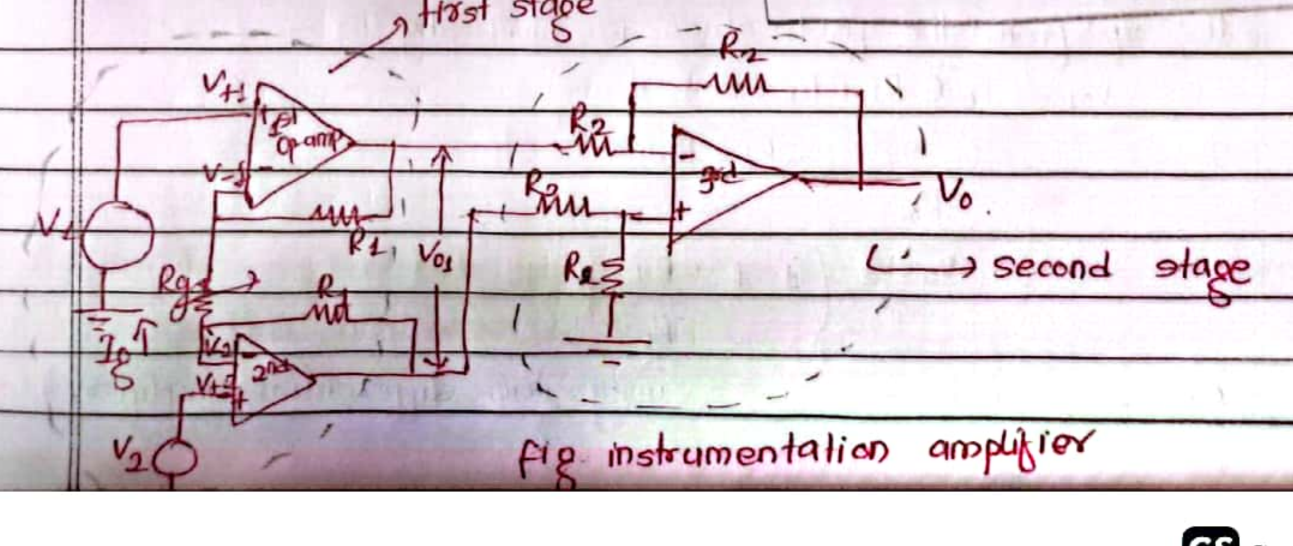


Fig. instrumentation amplifier

Instrumentation amplifier consists of two stages. The first stage consists of two carefully matched op-amps.
The two inputs V_1 and V_2 are applied to non-Inverting terminal of Op-amp 1 & Op-amp 2 respectively.
The o/p from first stage, V_{01} is taken through string of resistors (R_1, R_g & R_1)
The two resistors each R_1 are connected internal to the integrated circuit whereas R_g is connected externally.
By changing value of R_g, the gain of instrumentation amplifier can be changed. So, R_g is known as gain setting resistance.
Secondary stage of the instrumentation amplifier is unity gain differential amplifier.

from fig:

$$V_{+1} = V_1$$

As we know,

$$V_{+1} - V_{-1} = 0$$

$$\therefore V_{-1} = V_{+1} = V_1$$

similarly

$$V_{-2} = V_{+2} = V_2$$

Now,

$$I_g = \frac{V_{-2} - V_{-1}}{R_g} = \frac{V_2 - V_1}{R_g}$$

The o/p from the first stage is given by:

$$V_{01} = I_g (R_1 + R_1 + R_g)$$

$$= \frac{V_2 - V_1}{R_g} (2R_1 + R_g)$$

$$= V_2 - V_1 \left(1 + \frac{2R_1}{R_g}\right)$$

As, the second stage is a unity gain differential amplifier, the o/p from the second stage is given by:-

$$V_0 = -V_{01}$$

$$V_0 = -(V_2 - V_1)\left(1 + \frac{2R_1}{R_g}\right)$$

$$\text{or,} \quad \frac{V_0}{V_2 - V_1} = -\left(1 + \frac{2R_1}{R_g}\right)$$

$$\therefore A = \frac{V_0}{V_2 - V_1} = -\left(1 + \frac{2R_1}{R_g}\right)$$

Thus, by changing the value of R_g, the gain of instrumentation amplifiers can be changed. For high value of R_g will gain will be low & vice-versa.

Data Acquisition System:-

DAS

Digital data acquisition system:-

{sensing, conditioning, processing &

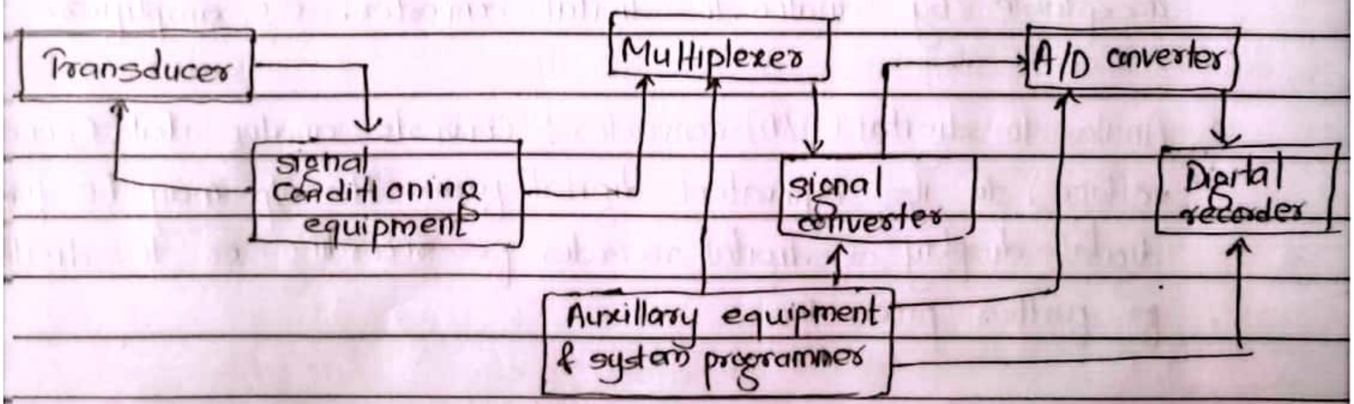


Fig:- Digital DAS

Digital DAS may include some or all the equipment shown above.

Essential functional operations are:-

Handling of analog signals

Making the measurement

Converting data to digital form & handling it.

(iv) Internal programming controls

Components

a. Transducer: Conversion of physical quantity into electrical signal which is acceptable by DAS.

b. Signal conditioning equipment: Transforms the transducer o/p to desired magnitude and form as required by next stage of DAS. Also provides proper working condition for transducer.

c. Multiplexer: Shares the single channel with more than one o/p ie accepts multiple analog i/ps and connect them sequentially to measuring output terminal. This device is usually used for long distance

d. Signal converter: Converts or translates analog signal to a form acceptable by analog to digital converter. e.g amplifier.

e. Analog to digital (A/D) converter: Converts analog data (generally voltage) to its equivalent digital form. Its o/p may be feed to digital display or digital recorder for recording or to digital computer for further processing.

f. Auxillary equipments: Contains devices for system programming functions & digital data process. Typical functions of these equipment can be comparision and linearisation.
These equipments may be digital computers.

g. Digital recorders: After completion of all test and generation of final data, recording is done. e.g punch cards, CD, magnetic tapes.

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b. Digital Printers: After recording the no of data, printing is done if required.

DAS

→ It is a system that accumulates, stores & distributes the data.

→ Since system is able to store and distribute data sometimes this system is also known as Data logger.

→ These are used in different industries where no of datas are recorded and accumulated.

→ There are diff tools & technologies in DAS based on no of channel.

DAS are of two types:

1) Single chanelled DAS

2) Multiple chanelled DAS.

1) Single chanell DAS:

→ A channel in a data acquisition system fundamentally represents an input source which is required to measure, digitize and further process.

→ In this type of DAS, only one channel is provided for processing.

→ The block diagram of single channel DAS is given by,

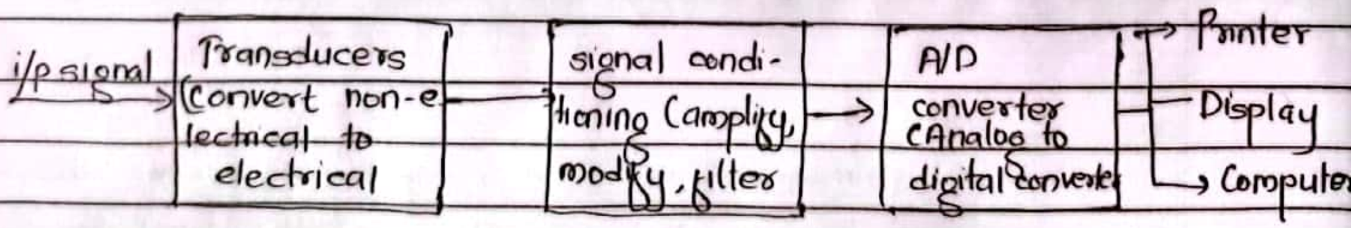

fig: single channel DAS

→ Sometimes buffer can be used as per requirement.

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Multichannel DAS :-

unlike, single channel DAS, there's multiplexer to accumulate multiple inputs.

The block diagram of multi-channel DAS is shown in fig below:

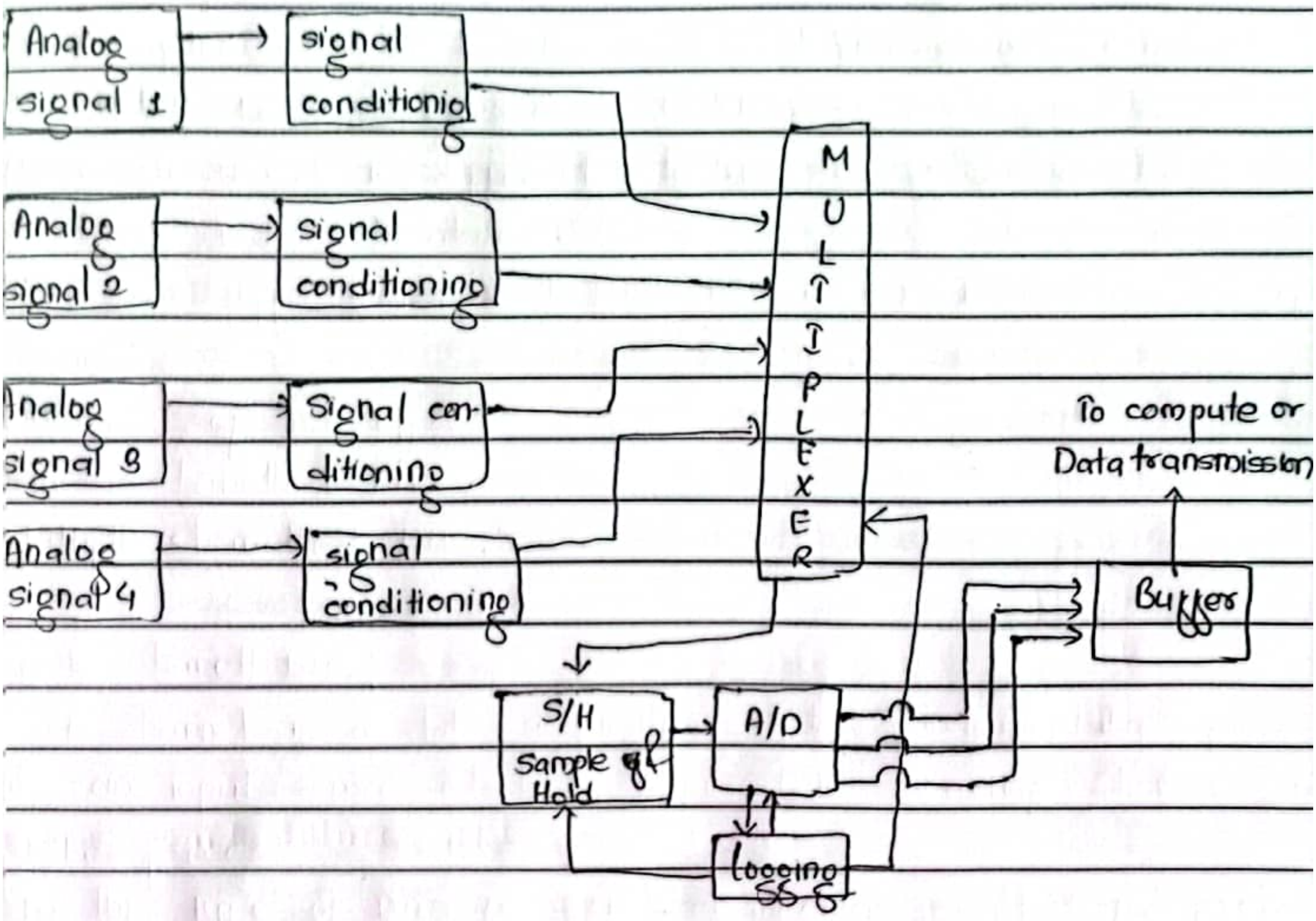


fig: Multiple channel DAS

Individual analog signals are applied directly or after amplification to the multiplexer.

Converted to digital signals by the A/D converter.

Digital output is either stored or transmitted.

Sample and hold circuit is used to sample analog signal.

Multiplexer accept analog signal which is converted in suitable form.

Once all of above operation is accomplished, then the o/p is transferred to different peripherals.

(explain each blocks)

→ Buffer is used when isolation is required or for long distance.

PC based DAS :-

→ Nowadays, PC based DAS are used widely as they are cheaper and common in every field.

→ In this type of DAS, PC-ADD-ON card is used after the transducer. By using this card, analog signal can be directly interfaced with PC.

→ PC being more powerful communication and having ability to analyze multiple measured data, these are used in DAS.

Features of PC based DAS :-

→ It can display parameters of the system continuosly.

→ System parameters are displayed with some display attributes such as blinking, underline so that operator can operate immediately.

→ Several parameters can be plotted simultaneously or individually as per requirement.

→ Block diagram of this DAS is

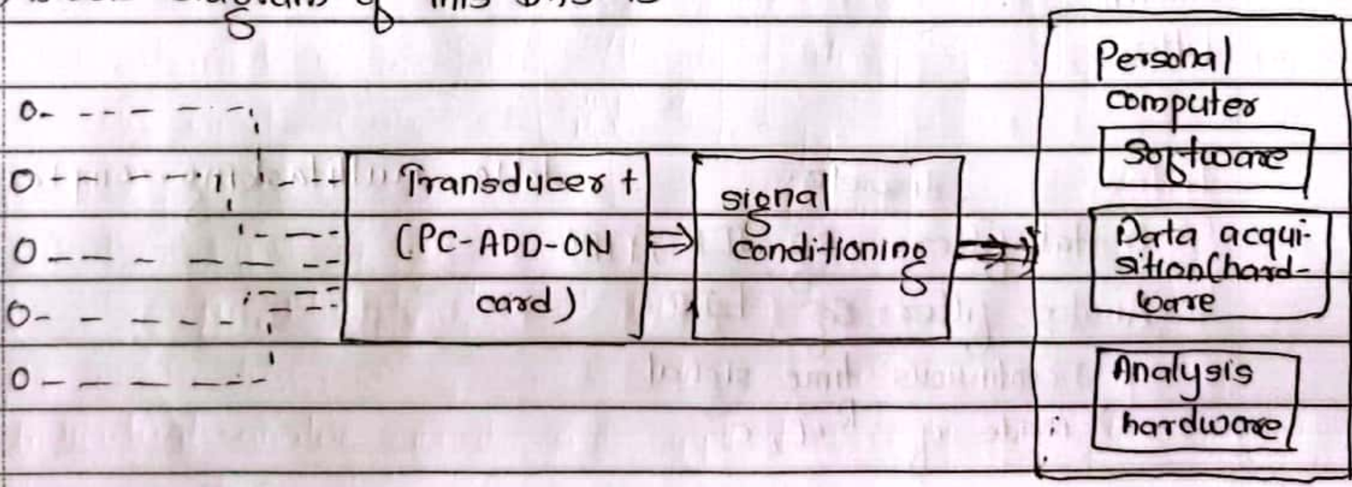


fig: Block diagram of PC based DAS.

{Communication System}

Effects of Noise in Instrumentation :

→ ~~Me~~ Measurement errors
→ Reduced signal to noise ratio (SNR)
→ Drift and instability.
→ Interference & cross talk.
→ Uncertainity
→ Error increase.

Waveshaping circuits :-
→ Clipper
→ Rectifier
→ Chopper
→ Inverter
→ Altenutor
→ Filter

Filter
↳ Digital filter → discrete - e.g IIR, FIR → stable, multitasking, complex processing
↳ Analog filter - e.g ~~FIR~~
↳ continuous time signal
↳ made of R, L, C

Types of analog filters
(i) High pass filter :

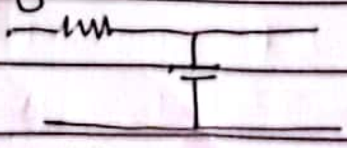
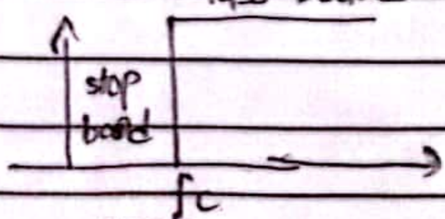
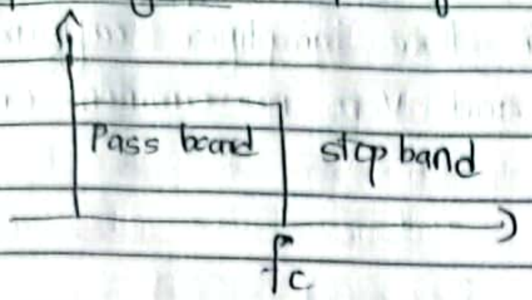


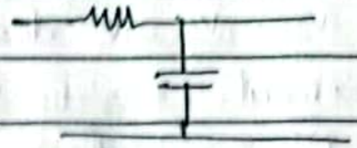
fig.



graph.

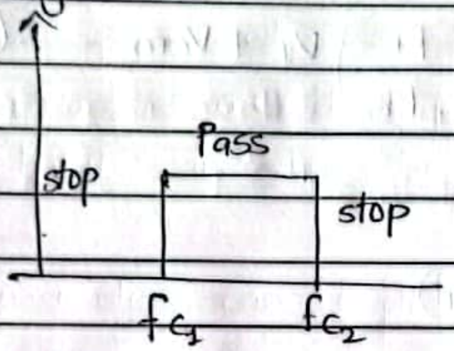
ii) low pass filter: pass f below cutoff frequency



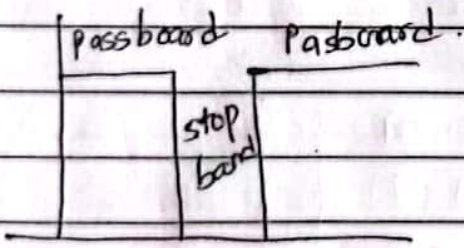


graph

ii) Band pass filter



iv) Band stop filter



Instrumentation amplifier:

Three amplifier configuration:

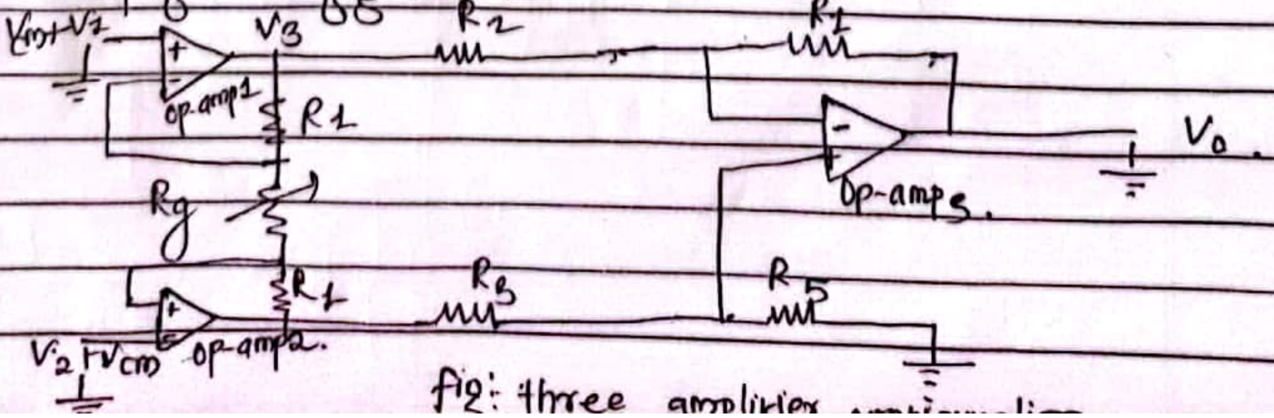


fig: three amplifier configuration

→ The circuit above shows instrumentation amplifier having three OP amps. This is also known as three amplifier configuration.

→ V_1 & V_2 are desired signal and V_{cm} is common on mode signal.

for simplicity

let $R_2 = R_3 = R_5$

from fig:

$$V_3 = \left(1 + \frac{R_1}{R_0}\right)V_1 - \left(\frac{R_1}{R_0}\right)V_2 + V_{cm} \quad \text{--- (i)}$$

$$V_4 = \left(1 + \frac{R_1}{R_0}\right)V_2 - \left(\frac{R_1}{R_0}\right)V_1 + V_{cm} \quad \text{--- (ii)}$$

Now,

$$V_0 = V_3 - V_4$$

Putting value from (i) & (ii)

$$\boxed{V_0 = \left(1 + \frac{2R_1}{R_0}\right)(V_2 - V_1)}$$

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CHAPTER - 4

DATA CONVERTER AND CONNECTORS

Mostly signals occuring in nature are analog type. Analog quantities are continuous function of time and most of transducers give an analog output. In order that the computer process this analog signal, they are required to be converted into digital which can be done by analog to digital converter. Digital to analog conversion also has large importance. Digital to analog converters used in computer driven CRT displays, digital generation of analog waveform & digital control of automatic process control systems.

General consideration for A/D or D/A converter.

For an n-bit system, a number can be represented by

$$d_{n-1} 2^{(n-1)} + d_{(n-2)} 2^{n-2} + --- + d_1 2^1 + d_0 2^0$$

Consider a 4-bit system having full range E_R. Then, for different combination of digital i/p, analog voltage is given by.

Digital i/p	Analog voltage
1000 →	$E_R/2$
0100 →	$E_R/2^2$
0010 →	$E_R/2^3$
0001 →	$E_R/2^4$

Thus, for an n-bit system having full range E_R weight or range of $MSB = \frac{E_R}{2}$.

$$LSB = \frac{E_R}{2^n}$$

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Consider the 4-bit system explained above then the analog o/p for a digital i/p having all bits high i.e i/p = 1111 can be obtained superimposing all the values given in above table.,

$$E_0 = \frac{E_R}{2} + \frac{E_R}{2^2} + \frac{E_R}{2^3} + \frac{E_R}{2^4}$$

$$= E_R\left[1\times 2^{-1} + 1\times 2^{-2} + 1\times 2^{-3} + 1\times 2^{-4}\right]$$

$$= E_R\left[d_3 2^{-1} + d_2 2^{-2} + d_1 2^{-3} + d_0 2^{-4}\right]$$

$$= \frac{E_R}{2^4}\left[d_3 2^3 + d_2 2^2 + d_1 2^1 + d_0 2^0\right].$$

Thus, for n-bit system, the analog voltage is given by

$$E_0 = \frac{E_R}{2^n}\left[d_{n-1} 2^{n-1} + d_{n-2} 2^{n-2} + \cdots d_1 2^1 + d_0 2^0\right].$$

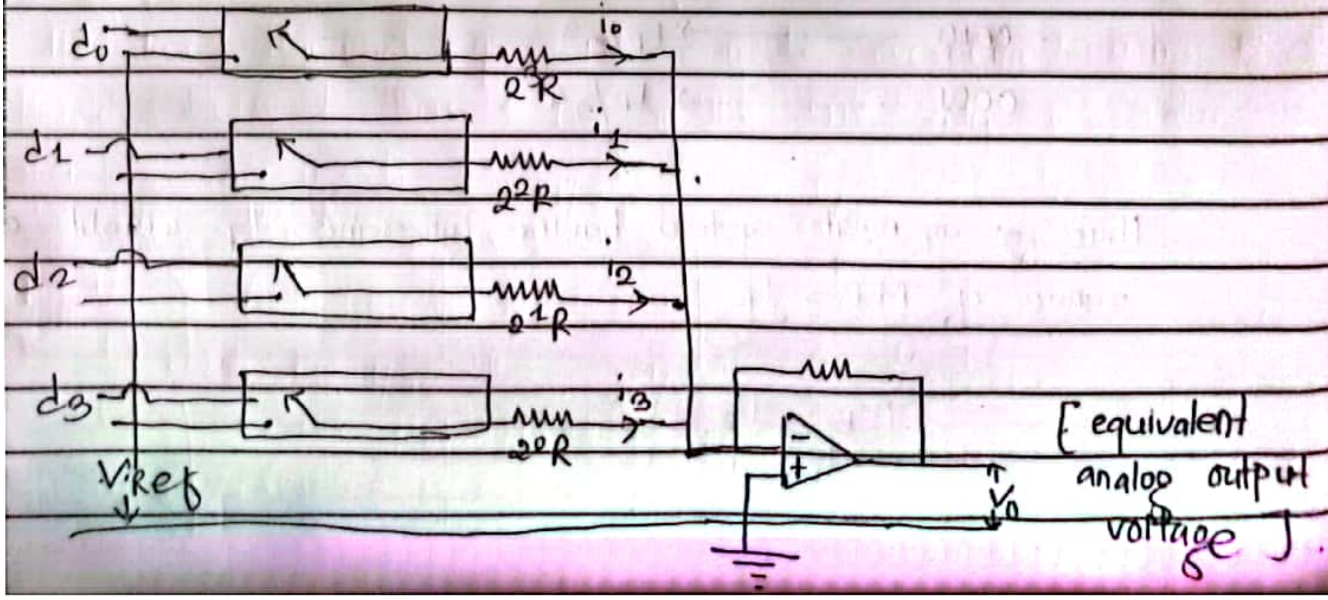
DAC (Digital to Analog converter)

(i) R-2R DAC

(ii) WRN DAC

(iii) ~~Delta signal DAC~~

WRN DAC (Weighted Resistor Network DAC)



In WRN DAC, the resistor is weighted reverse of binary system i.e resistance associated with most significant bit has the least value and as we move from MSB to LSB, the resistance value increases with a factor R as shown in table below.

For 4-bit

Bit	d_3	d_2	d_1	d_0
Binary weight	2^3	2^2	2^1	2^0
Resistance weight or value	2^0R	2^1R	2^2R	2^3R

Thus, for n-bit system,

weight or value of the resistance in MSB = 2^0R.

weight or value of the resistance in LSB = $2^{n-1}R$

A reference voltage V_{Ref} is applied to all the resistors through the switches. This switch responds only to binary digit 1 i.e an input of 1001 which close switch associated with MSB & LSB. For different combination of digital i/p, analog value of current is given below.

Digital i/p	Analog o/p
1000	$i_3 = \frac{V_{Ref}}{2^0R}$
0100	$i_2 = \frac{V_{Ref}}{2^1R}$
0010	$i_1 = \frac{V_{Ref}}{2^2R}$.
0001	$i_0 = \frac{V_{Ref}}{2^3R}$

If all the bits are high i.e 1111, then resultant current is given by:-

$$i = i_3 + i_2 + i_1 + i_0$$

$$= \frac{V_{Ref}}{2^0 R} + \frac{V_{Ref}}{2^1 R} + \frac{V_{Ref}}{2^2 R} + \frac{V_{Ref}}{2^3 R}.$$

$$= \frac{V_{Ref}}{R}\left[1\times2^0 + 1\times2^{-1} + 1\times2^{-2} + 1\times2^{-3}\right].$$

$$= \frac{V_{Ref}}{R}\left[d_3 2^0 + d_2 2^{-1} + d_1 2^{-2} + d_0 2^{-3}\right].$$

$$= \frac{V_{Ref}}{2^3 R}\left[d_3 2^3 + d_2 2^2 + d_1 2^1 + d_0 2^0\right]$$

formula Thus, for n-bit.

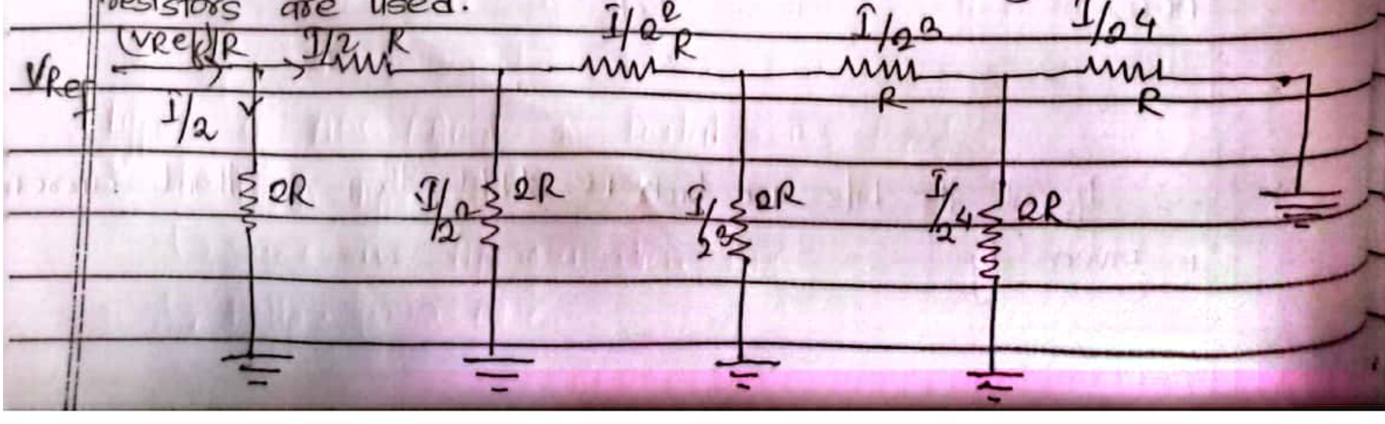
$$i_n = I = \frac{V_{Ref}}{2^{n-1} R}\left[d_{n-1} 2^{n-1} + d_{n-2} 2^{n-2} + d_{n-3} 2^{n-3} + \dots d_0 2^0\right]$$

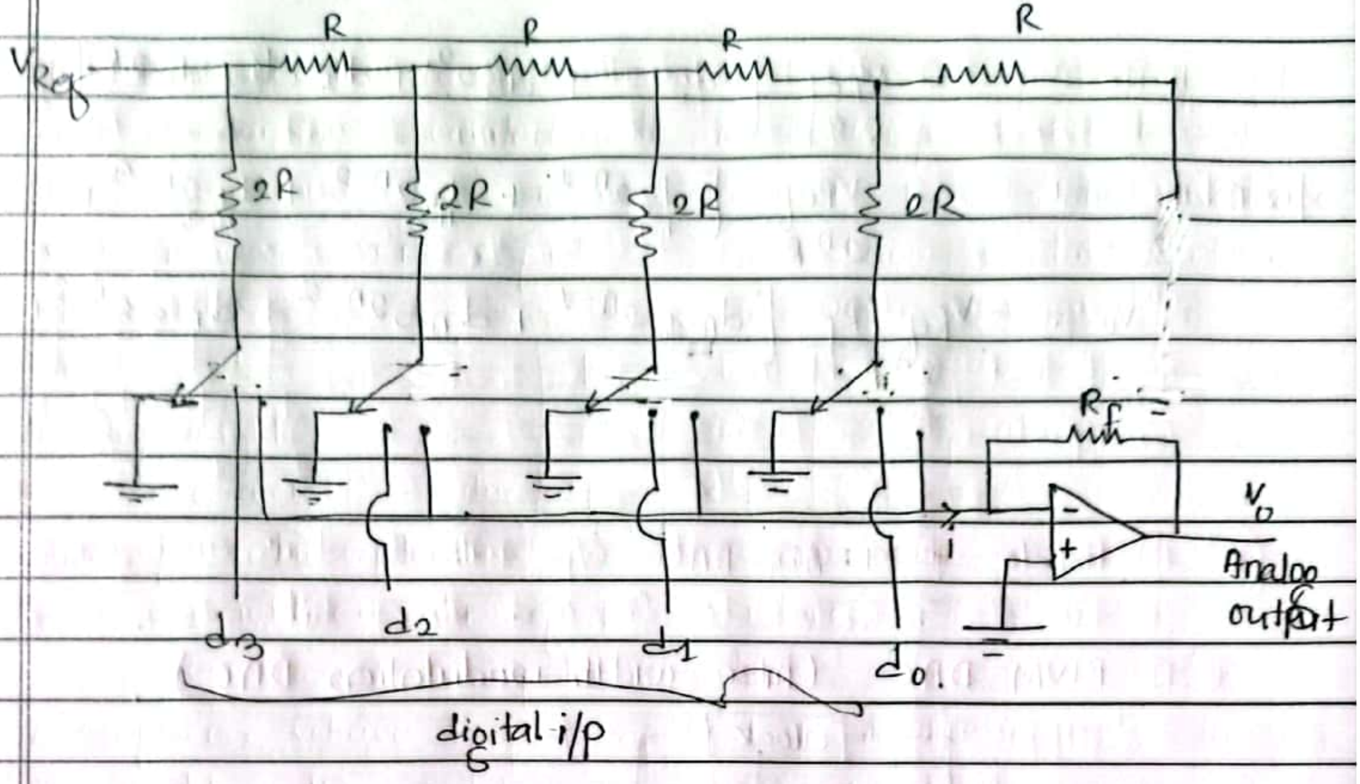
Drawback of WRN DAC

1. As the no of bit increases, the resistance value also increases. Thus, for higher bit converter the range of resistance becomes very high and it becomes difficult to fabricate all resistors in the same IC.
2. For higher bit converter, the tolerance value of resistance in LSB becomes much greater than the value of MSB.

R:2R Ladder Network DAC:

→ The two drawbacks of WRN can be overcomed using R:2R ladder Network DAC. As in this DAC only two value of resistors are used.





Right hand side of each node of figure above has two equal resistors each having resistance 2R connected in parallel so the current reaching to any node will be divided into equal parts. The current will be divided according to the expression. $I/2^n$.

i.e $\frac{I}{2^1}, \frac{I}{2^2}, \frac{I}{2^3}, \frac{I}{2^4}, \ldots$

Thus, the resistive ladder n/w of figure above generates a primary sequence of the current, I_k all the bits of digital i/p are high i.e input equals 1111 then resultant current is given by:

$$i = \frac{I}{2^1} + \frac{I}{2^2} + \frac{I}{2^3} + \frac{I}{2^4}.$$

$$i = I\left[1\times 2^{-1} + 1\times 2^{-2} + 1\times 2^{-3} + 1\times 2^{-4}\right]$$

$$= \frac{V_{Ref}}{R}\left[d_3 2^{-1} + d_2 2^{-2} + d_1\times 2^{-3} + d_0\times 2^{-4}\right]$$

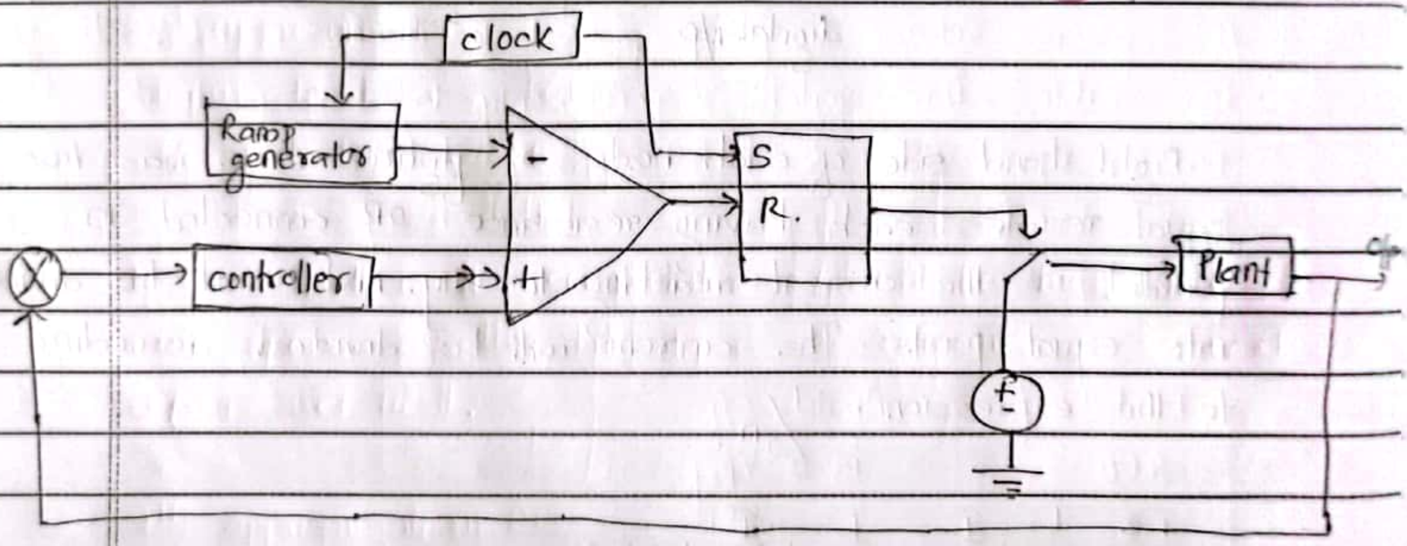
$$= \frac{V_{Ref}}{2^4 R}\left[d_3 2^3 + d_2 2^2 + d_1 2^1 + d_0 2^0 \right].$$

for n-bit, $i = \frac{V_{Ref}}{2^n R}\left[d_{n-1} 2^{n-1} + d_{n-2} 2^{n-2} + d_{n-3} 2^{n-3} + \dots d_0 2^0 \right]$

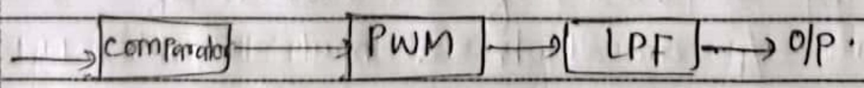
$$V_0 = \frac{-V_{Ref} \cdot R_f}{2^n R}\left[d_{n-1} 2^{n-1} + d_{n-2} 2^{n-2} + d_{n-3} 2^{n-3} + \dots d_0 2^0 \right]$$

(iii) ~~Delta to sigma ADC DAC~~

A PWM DAC (Pulse width modulation DAC)



OR



Types of ADC (Analog to Digital converter)

- ↳ Flash Type ADC
- ↳ Sucessive Approximation ADC
- ↳ Delta-sigma ADC

↳ Dual slope ADC
↳ Counter type ADC

Successive Approximation (SA) ADC

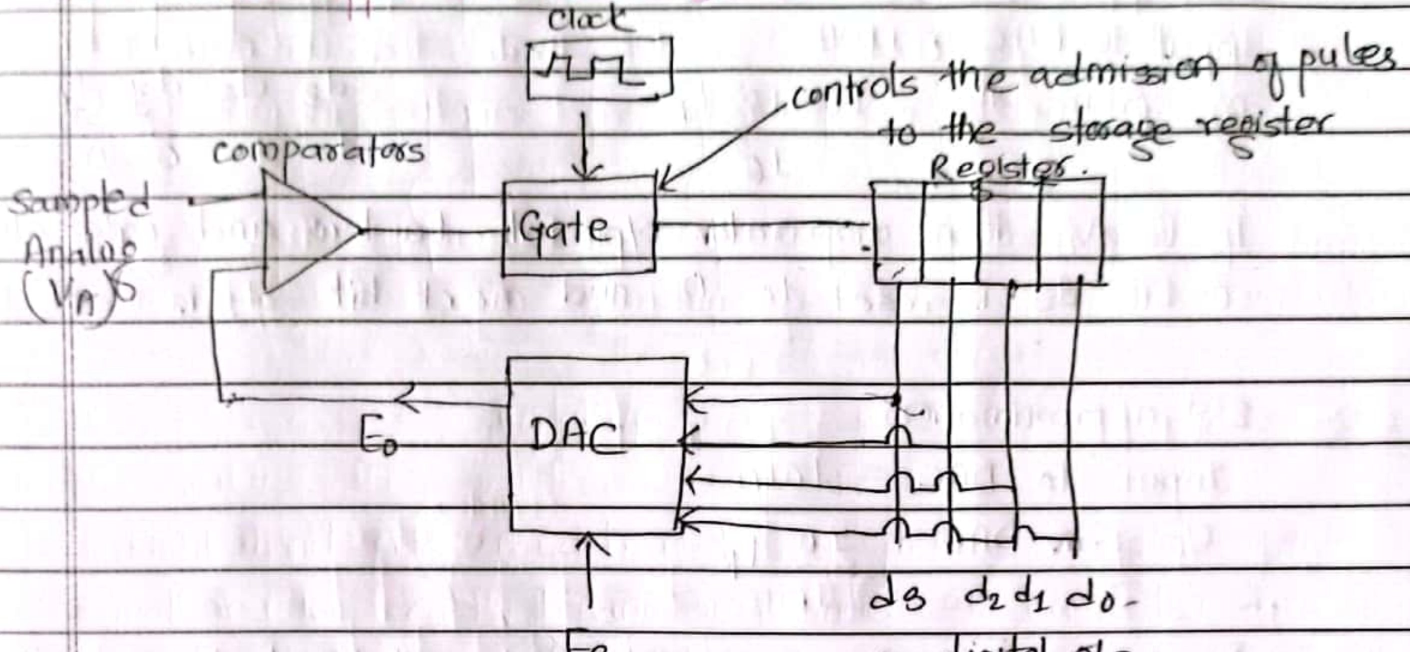
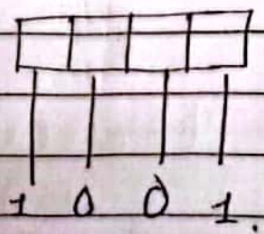


fig: 4-bit SA ADC.

- Successive approximation ADC is probably the most commonly used analog to digital converter.
- This method is based on comparing the i/p and o/p voltage with another analog voltage until the two are equal or as close as it is possible to set them.
- figure above shows substali systems involved in this ADC.

$$E_0 = \frac{E_R}{2^n}\left[d_{n-1}\, 2^{n-1} + \cdots + d_0\, 2^0\right].$$



1st approximation

Input to DAC = 1000

o/p from DAC = $E_0 = \frac{8}{16} E_R$

If $E_0 < V_A$, then the comparator o/p will be high and the gate opens. So, the bit d_3 remain 1 and next bit d_2 is set to 1.

2nd approximation

input to DAC = 1100

o/p from DAC = $E_0 = \frac{12}{16} E_R$

If $E_0 > V_A$ then comparator o/p will be low and gate closes so bit d_2 is reset to 0 and next bit d_1 is set to 1.

3rd approximation

Input to DAC = 1010

o/p from DAC = $\frac{10}{16} E_R$

If $E_0 < V_A$ then the comparator o/p will be high and the gate opens. So the bit d_1 is se remains 1 & next bit d_0 is set to 1.

4th approximation

i/p to DAC = 1011

o/p from DAC = $E_0 = \frac{11}{16} E_R$

If $E_0 > V_A$ then the comparator o/p will be low and gate closes so the bit d_0 is reset to 0. Then neared digital o/p for analog input will be 1010.

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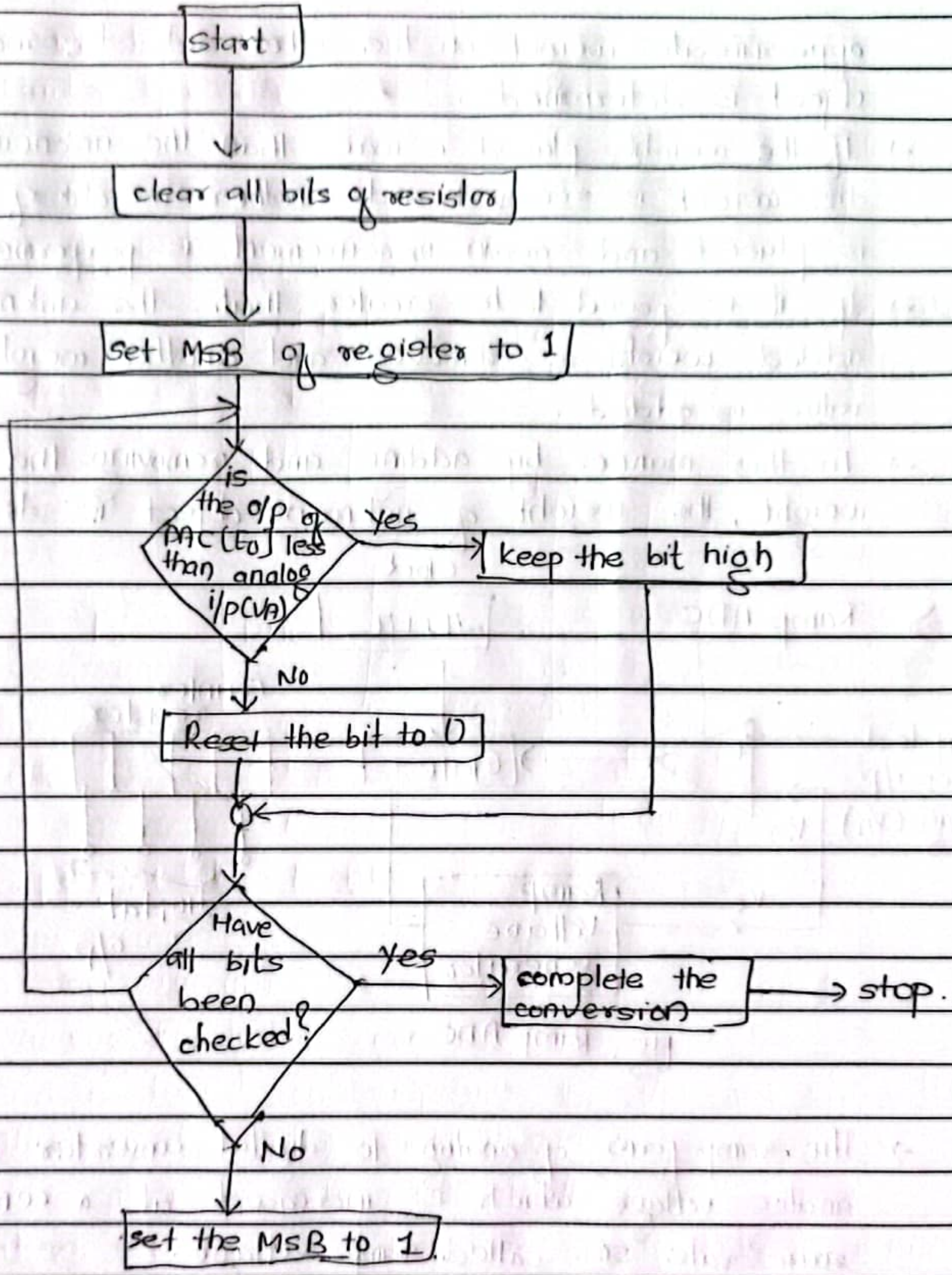

Successive Approximation principle can be easily understood using a simple example, the determination of the weight of an object.
By using a balance and placing the object on one side and

approximate weight on the other side the weight of the object is determined.

→ If the weight placed is more than the unknown weight, the weight is removed and another weight of smaller value is placed and again measurement is performed.

→ If it is found to be greater than the unknown weight, the added weight is removed and another weight of smaller value is added.

→ In this manner by adding and removing the appropriate weight, the weight of unknown object is determined.

⇒ Ramp ADC

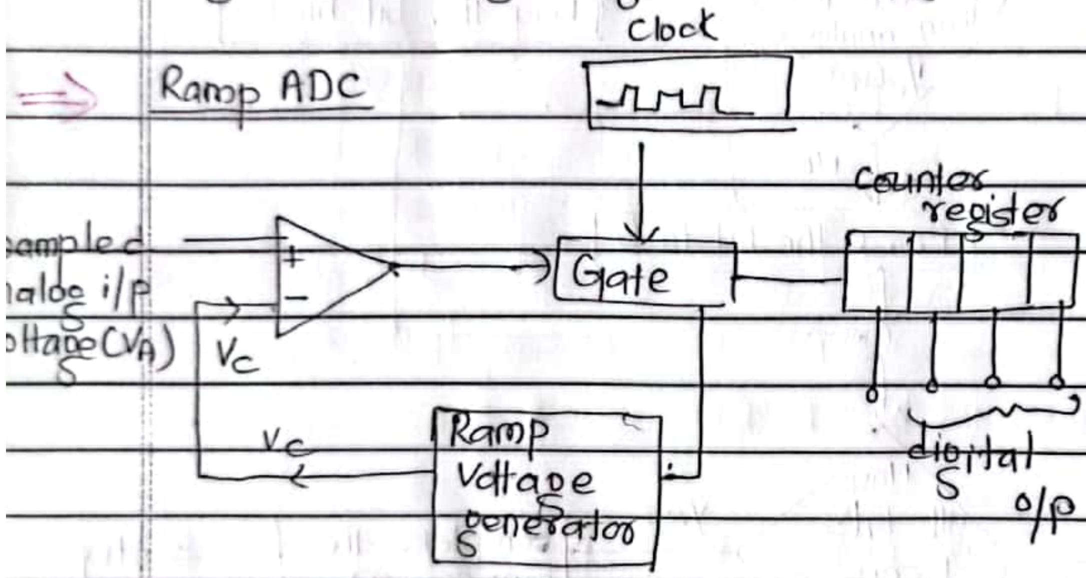

fig: Ramp ADC.

→ The ramp form of analog to digital converter involves an analog voltage which is increased at a constant ~~current source~~ rate so called ramp voltage.

→ The ramp voltage is generated by a capacitor being charged from a constant current source.

→ The time taken for the ramp voltage to increase to the value of the i/p analog voltage will depend on the size of the sampled analog voltage.

→ Figure above shows subsystem involved in the ramp form of analog to digital converter.

→ Ramp converters are cheaper but relatively slow.

Ramp generator

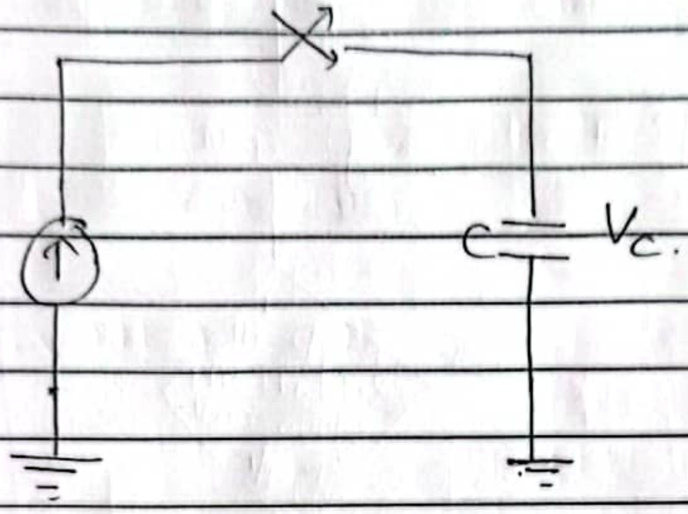

fig: ramp generator.

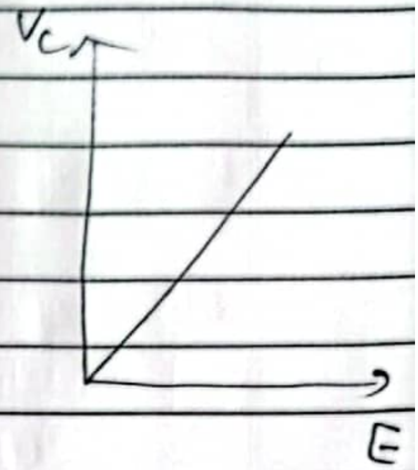

fig: ramp voltage

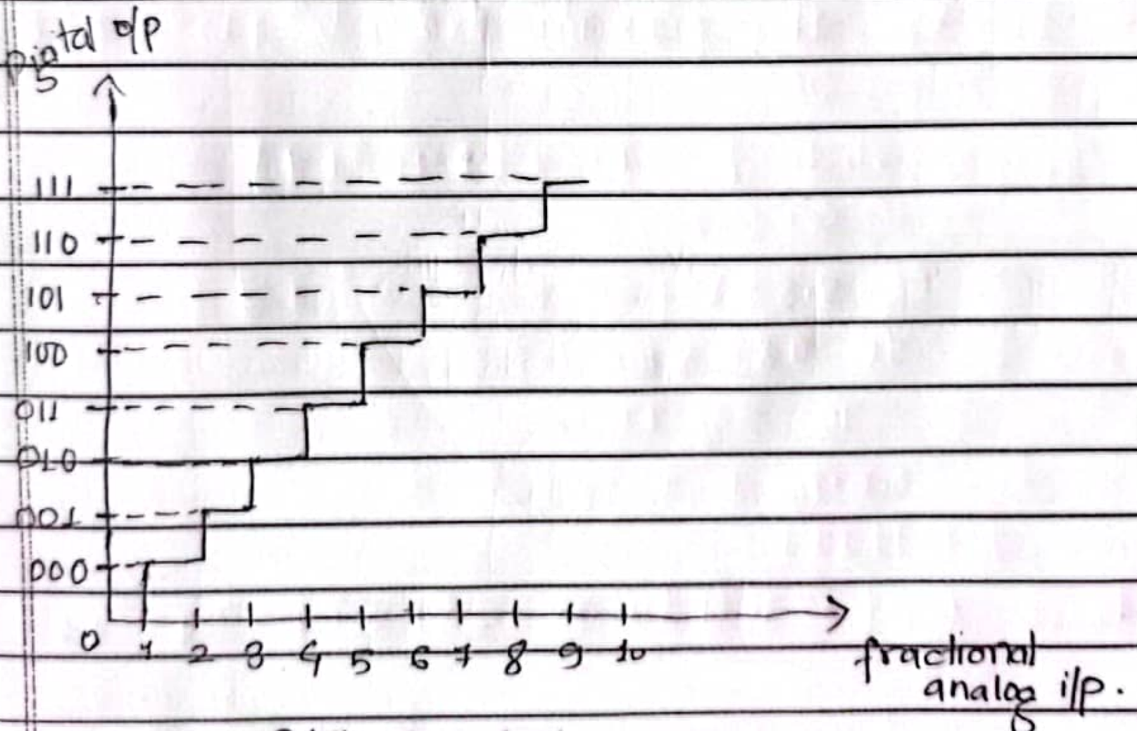

fig: 3-bit digital o/p

① A 6-bit converter is used for a dc voltage range of 0-10V. Find weight of MSB & LSB. Also find exact range of converter and the error. Find the error if a 9-bit converter is used. Mention which converter is suitable for conversion based upon acquired result.

Solⁿ:

$n = 6$

Weight of MSB $= \frac{E_R}{2} = \frac{10}{2} = 5V$

Weight of LSB $= \frac{E_R}{2^n} = \frac{10}{2^6} = 0.156V.$

Input $= 111111$

Normally yei formula:

$E_0 = \frac{E_R}{2^n}\left[d_{n-1}2^{n-1} + d_{n-2}2^{n-2} + \dots + d_0 2^0\right]$

$= \frac{10}{2^6}\left[1\times2^5 + 1\times2^4 + 2^3 + 2^2 + 2^1 + 2^0\right]$

$= \frac{10}{64}\left[32+16+8+4+2+1\right]$

$= 9.84V$

Error $= \frac{10-9.84}{10} \times 100\%$

$= 1.6\%.$

Case-II Input $= 111111111$

$E_0 = \frac{10}{2^9}\left[2^8+2^7+2^6+2^5+2^4+2^3+2^2+2^1+2^0\right]$

$= \frac{10}{2^9}\left[256+128+64+32+16+8+4+2+1\right]$

$= 9.98V$

Error $= \frac{10-9.98}{10} \times 100\% = 0.2\%.$

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∴ Hence, the 8-bit converter is suitable for conversion.

Q) What will be the 6-bit successive approximation digital output for an analog input 3.3V & $E_R = 5V$.

Soln:

$n = 6$

$E_R = 5$

$V_A = 3.3 \text{Volt}$

1st approximation

input to DAC = 100000

$$\text{o/p from DAC} = \frac{E_R}{2^n}\left[d_5 2^5 + d_4 2^4 + \dots d_0 2^0\right]$$

$$= \frac{E_R}{2^6}\left[1 \times 2^5\right]$$

$$= 2.5V.$$

$E_0 < V_A$; remain d_5 at 1 & set d_4 to 1.

so

2nd approximation

i/p to DAC = 110000

$$\text{o/p from DAC} = \frac{5}{2^6}\left[1 \times 2^5 + 1 \times 2^4\right]$$

$$= 3.75V$$

$E_0 > V_A$; d_3 is reset to 0 & d_2 is set to 1.

3rd approximation

i/p = 101000

$$\text{o/p} = \frac{5}{2^6}\left[1 \times 2^5 + 1 \times 2^3\right]$$

$$= 3.125V.$$

since, $E_0 < V_A$, d_3 remains 1 & d_2 is ~~reset~~ set to 1

4^{th} approximation

i/p = 101100

$$o/p = \frac{5}{2^6}\left[2^5 + 2^3 + 2^2\right]$$

$$= 3.4375V$$

Since, $E_0 > V_A$, d_2 is reset to 0 & d_1 is set to 1.

5^{th} approximation

i/p = 101010

$$o/p = \frac{5}{2^6}\left[2^5 + 2^3 + 2^1\right]$$

$$= 3.28\ V.$$

since, $E_0 < V_A$, d_1 remains 1 & d_0 is set to 1.

6^{th} approximation

i/p = 101011

$$o/p = \frac{5}{2^6}\left[2^5 + 2^3 + 2^1 + 2^0\right]$$

$$= \cancel{3.4375}\ 3.35V$$

since, $E_0 > V_A$, d_0 is reset to 0.

Hence, digital o/p = 101010.

Qn) An analog transducer with a 0-10 V i/p is able to distinguish a change of 10mV in its i/p signal.

(a) Calculate its resolution

(b) Calculate the no of bits of an A/D converter so that the digital o/p has almost the same resolution.

(c) Calculate the number of decision level.

(d) the quantisation error.

Soln:

change $(\Delta) = 10mV$.

Now,

$$\boxed{\text{Resolution} = \frac{\Delta}{i/p}}$$

$$= \frac{10\times10^{-3}}{10}$$

$$= 10^{-3} \qquad \frac{1}{1000}$$

Also, $\boxed{\text{resolution} = \frac{1}{2^n}}$ $\qquad \frac{1}{1000} = \frac{1}{2^n}$

or, $10^{-3} \times 2^n = 1$

$\Rightarrow 2^n = 10^3$

$2^n = 2^{10}$

$\therefore n = 10$

$$\boxed{\text{Quantization interval, } Q = \frac{10}{2^n}}$$

$$= \frac{10}{1024}$$

$$= 9.765\times10^{-3}$$

$$\boxed{\text{Quantization error } (E_q) = \frac{Q}{2\sqrt{3}}}$$

$$= 2.819\times10^{-3}$$

no of decision level $= 2^n - 1$

$= 1024 - 1 = 1023$ //

Delta-sigma ADC

oversampling

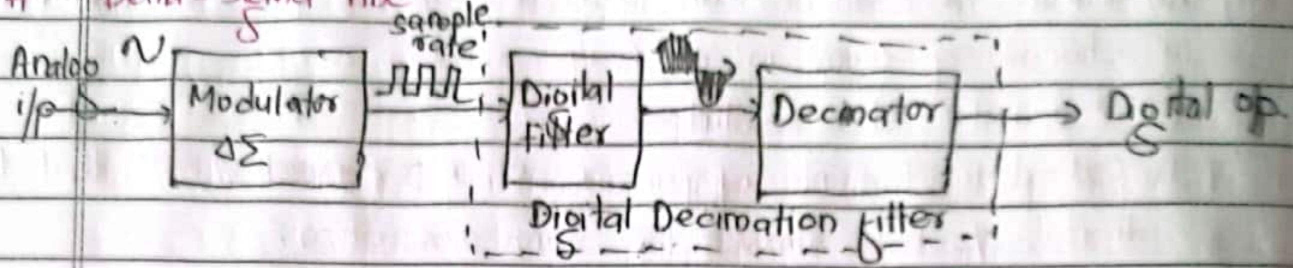

fig: Delta-Sigma ADC

Props & connecters

CHAPTER - 5

WAVE ANALYZER

A wave analyzer is an instrument designed to measure the relative amplitudes of frequency component in a complex or distorted waveform. Usually, the instrument acts as a frequency selective voltmeter, which is tuned to the frequency of one signal while rejecting all other signal components. There are two types of wave analyser depending upon the frequency ranges used.

(i) Frequency selective wave analyzer

(ii) Heterodyne wave analyzer.

(i) Frequency selective wave analyzer

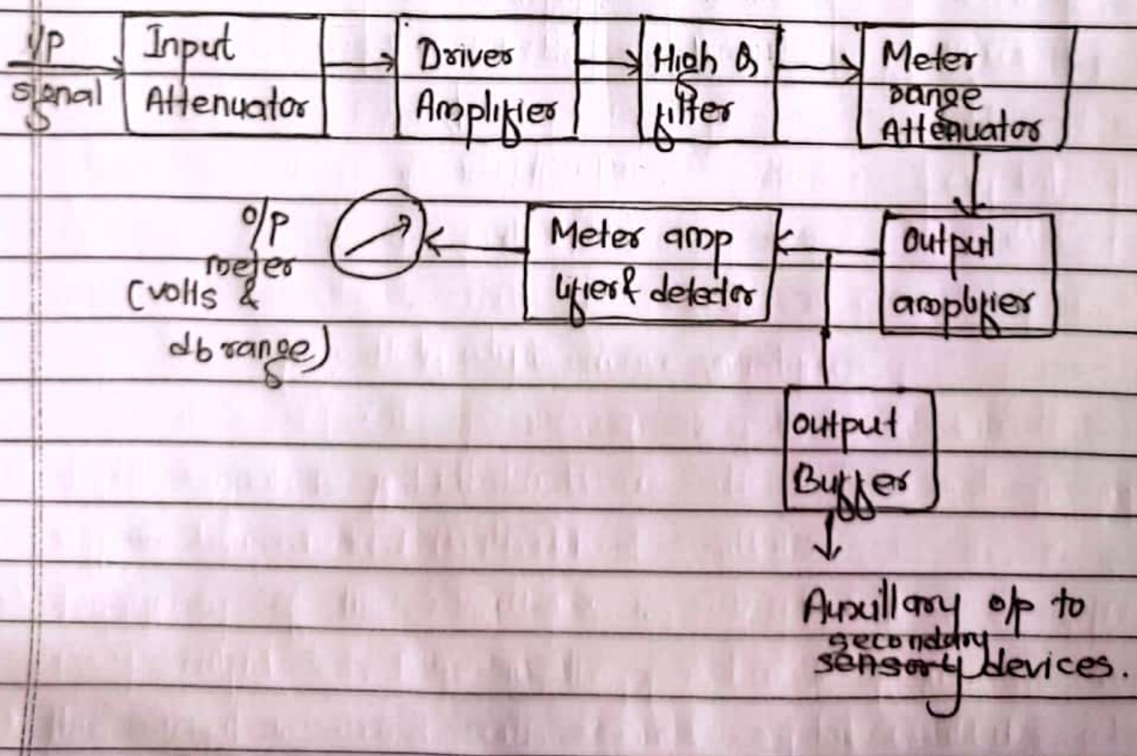

fig:- Block diagram of selective frequency wave

The frequency selective wave analyzer is a type of wave analyzer that operates on the principle of frequency selective voltmeter. It is operated to measure the frequency in the audio range of 20 Hz - 20 kHz. It uses a narrow pass band filter & it is tuned to the desired frequency components to measure the block diagram of this analyser is shown above.

Working:

The input signal that is to be analyzed is provided to an i/p attenuator. Since the signal contains max^m amplitude and it is attenuated by this attenuator. It works as a range multiplier because a high range of amplitude of the signal is measured. The o/p of the i/p attenuator is amplified by the driver amplifier & its o/p is fed to high-Q-filter section. The High Q-filter section selects the particular frequency components and rejects the remaining unwanted frequencies of the signal. It contains two RC section, two amplifier filters connected in cascade. By varying the value of the capacitor the frequency range can be changed. By varying the value of resistor, the desired frequency can be changed within the desired range.

The output of the High Q-factor filter is fed to the meter range attenuator to select the audio frequency input signal. The AF input signal is attenuated by a meter range attenuator. The o/p of the meter range attenuator is amplified by the o/p amplifier. The o/p buffer drives the AF signal to the output devices such as counters, recorders etc. The meter circuit display the reading o/p of the AF signal in the range of volts and decibels.

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Heterodyne Wave analyzer:

This type of wave analyzer is used to measure frequency megahertz range. It's working principle is heterodyne (mix) of high IF (Intermediate frequency) with i/p signal, which is to be analysed. The block diagram of this analyzer is as shown below:

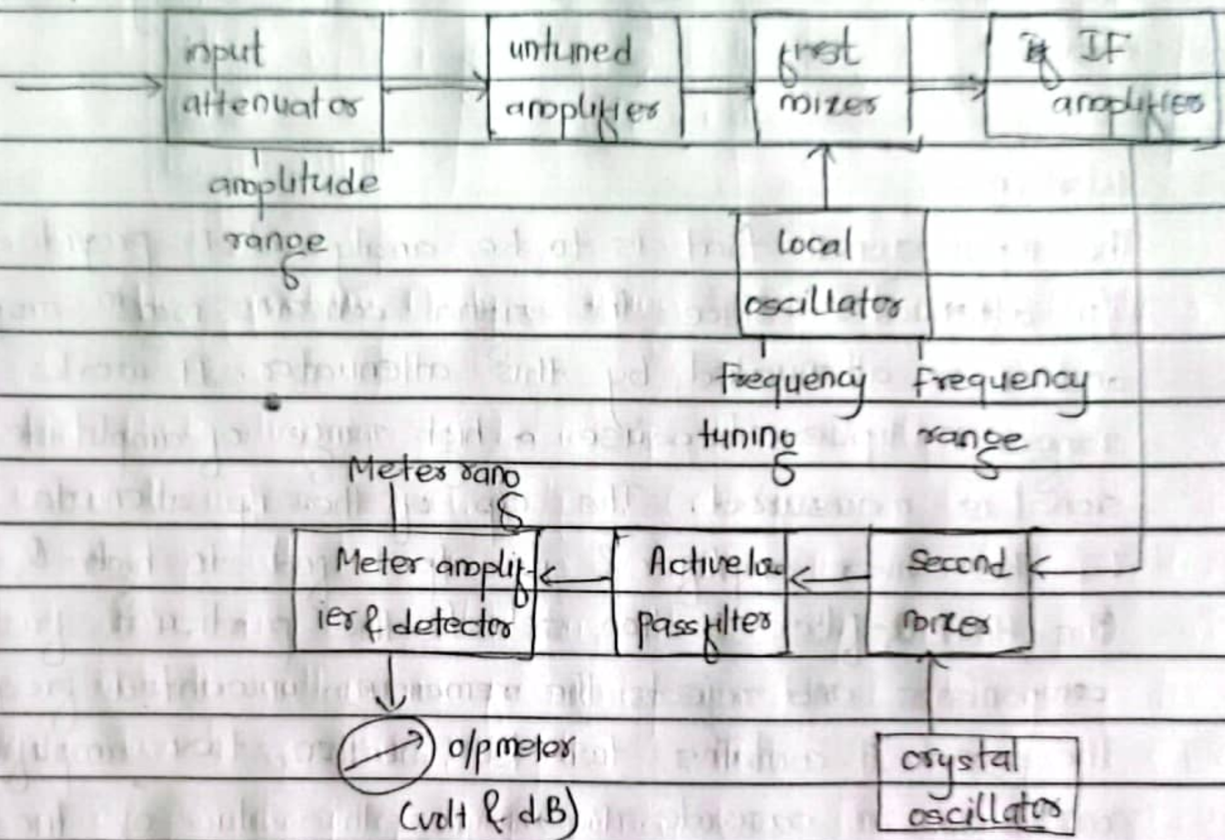


fig: Heterodyne wave analyzer

Input signal is fed through an attenuator and an amplifier before being mixed with local oscillator.

Frequency of this oscillator is adjusted to give a fixed frequency output which is in the passband of the IF amplifier. This signal is mixed with second crystal oscillator, whose frequency is such that the o/p from mixer is centered on zero frequency.

The subsequent active filter has controllable bandwidth, & possess

Page

the selected component of the frequency on the indicating meter.

→ In order to gain good frequency, stability, frequency synthesizer can be used.

Application of wave analyzer

1. Measures the harmonic distortion of the signal.
2. desired frequency component of the signal can be selected from this analyzer.
3. Used as an automatic frequency controller.
4. Used in electrical measurements.
5. Used for reduce sound and vibration produced by the electrical machines in industries.
6. used to measure the amplitude of the signal along with noise and interfering signals.
7. used as a harmonic distortion analyzer.

Spectrum analyzer

→ A spectrum analyzer is an electronic instrument used to measure and analyze the frequency spectrum of a signal. It provides a graphical representation of the amplitude or power level of the signal across different frequencies. Spectrum analyzers are widely used in various fields, including telecommunication, audio engineering research and development.

Types of spectrum analyzer:

A) Basic spectrum analyzer using swept reciever design.
B) IRF spectrum Analyzer.
C)

Basic Spectrum Analyzer using Swept Reciever design :-

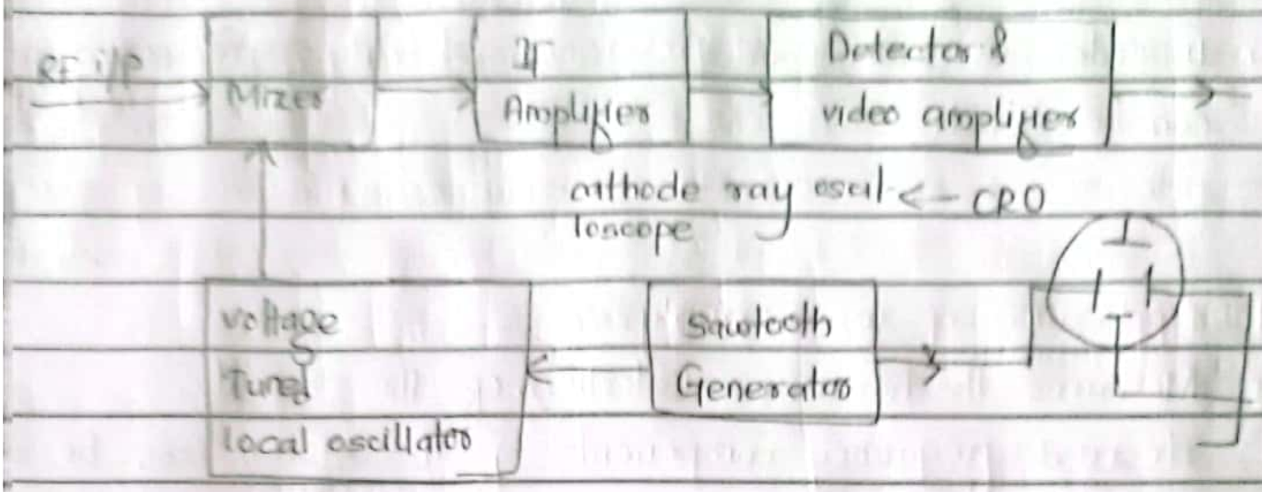


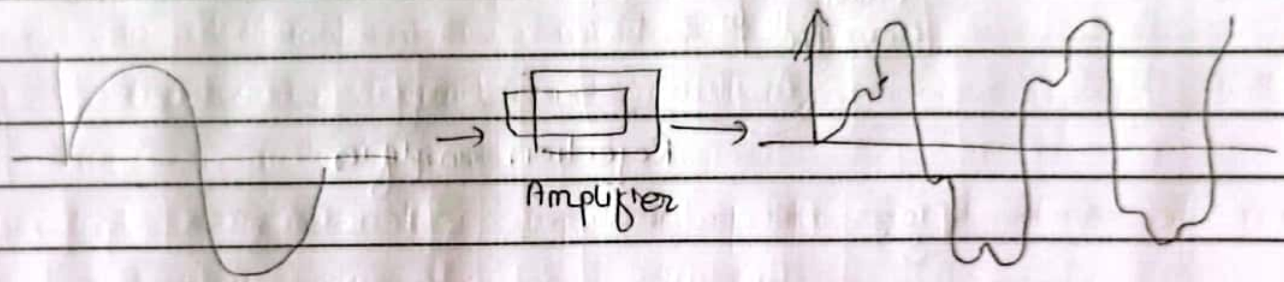
Fig: spectrum Analyzer using Swept reciever Analyzer

The block diagram of basic spectrum analyzer using swept reciever design is shown in fig. On referring block diagram, the ~~saw~~ sawtooth generator provides the sawtooth voltage which drives the horizontal axis element of CRO (scope) and this sawtooth voltage is frequency controlled element of the voltage tunned oscillater. As the oscillator sweeps from minimum to max^{m} frequency of its frequency band at a linear reccuring rate, ~~rate~~ it beats with frequency component of the i/p signal & produce ~~M~~ an IF, whenever a frequency component ~~is~~ meet it sweeps. The frequency component and voltage tuned oscillator frequency beats together to produce a frequency difference i.e IF. The IF corresponding to the component is amplified and detected if necessary, and then applied to the vertical plates of CRO, producing a display of amplitude v/s frequency.

Q1) Write short notes on
i) RF spectrum analyzer.

ii) Distortion analyzer

A sinusoidal waveform applied to an electronic device i.e an amplifier may not generate exact replication of input waveform due to different distortions. Distortions may be the result of the inherent non-linear characteristic of different instrument. This non linear behaviour of circuit elements introduces harmonic distortions.



There are different types of distortions:

(i) Frequency distortions.
→ This occurs because the amplification factor of the amplifier is different for diff. frequencies.

(ii) Phase distortions
→ This occurs on account of energy storing element in system as they displace in phase with i/p signals.

(iii) Amplitude distortions
(iv) Intermodulation distortion
(v) Crossover distortion

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THD = $\left(\frac{[(\sum \text{harmonics})^2]^{1/2}}{\text{fundamental component}} \right) \%$

Fundamental Suppression Analyzer :

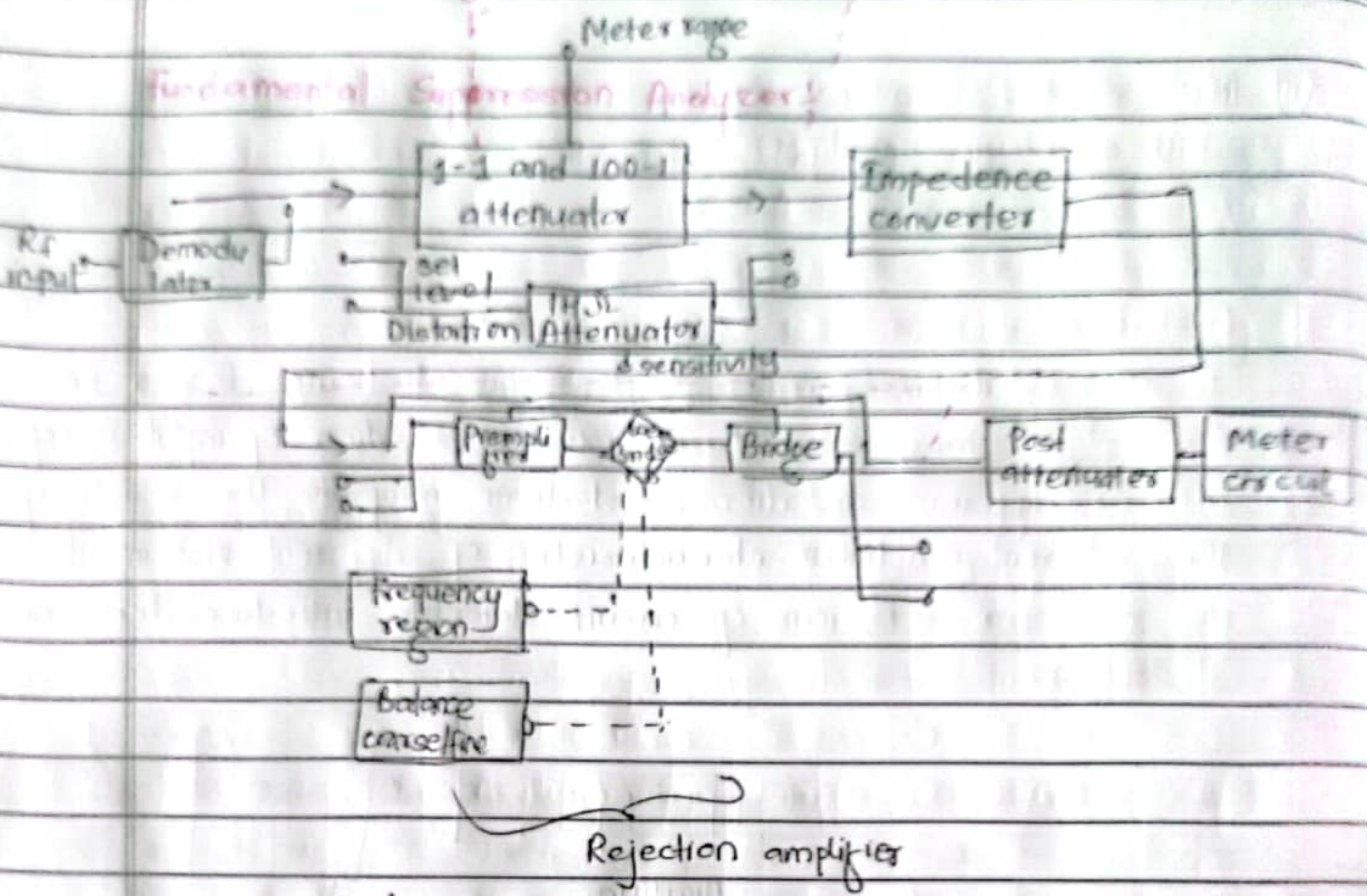

fig :

Measurement of frequency

Frequency can be measured by counting the number of cycles of an unknown signal for a precisely controlled time interval. The block digram for a counter in the frequency mode of operation is shown below.

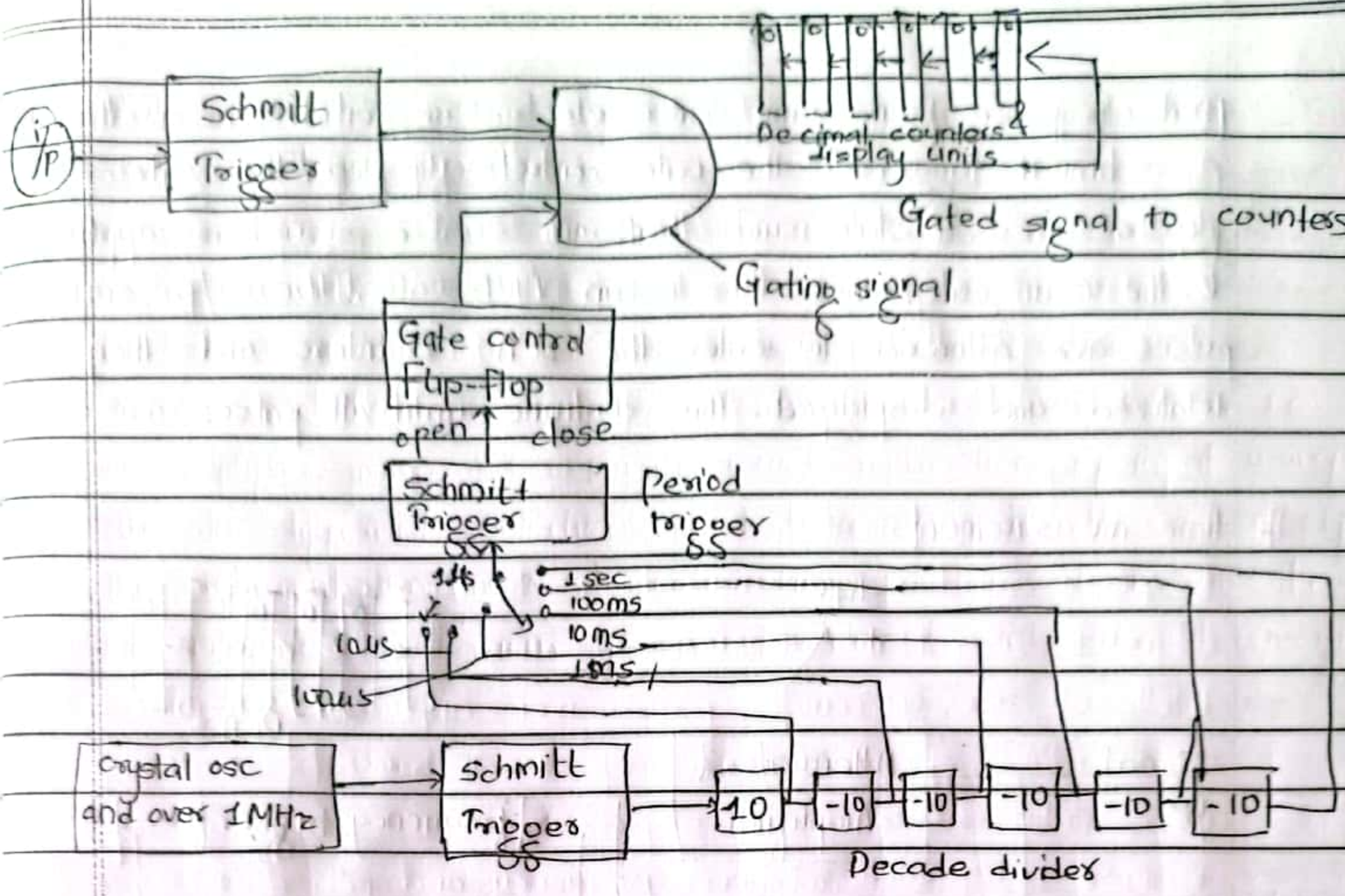

fig: counter in frequency mode of operation.

There are two signals that need to be traced i.e i/p signal (o measured frequency) & the gating signal, which determines the length of time during which DCAs are allowed to accumulate pulses. The i/p signal is amplified and passed to schmitt trigger. Here, it is converted into a square wave with very fast rise and fall time, then differentiated & clipped. As a result, the signal which arrives at the input to the main gate consists of a series of pulses separated by the period of original input signal.

In the block diagram, the oscillator frequency of 1 MHz is used. The timebase o/p is saved by Schmitt trigger so that positive spikes, are applied to a no of decade divider whose o/p are connected to timebase selector. This allows the time interval to be selected from one μs to 1s. The

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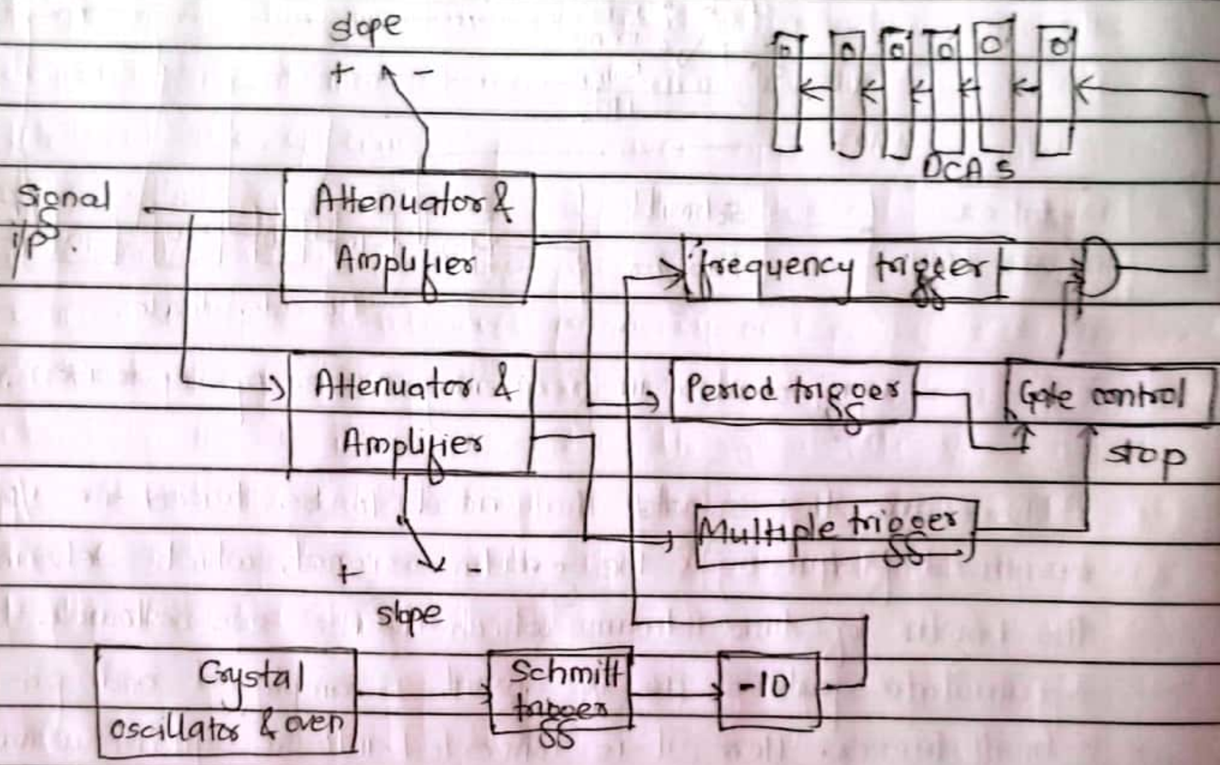
first o/p pulse from timebase selector is switch passes through a schmmit trigger to the gate control flip flop. The gate flip-flop assumes a state such that an enable signal is applied to the main gate, since this is an AND gate, the i/p signal pulses are allowed to enter the DCAs counters and they are totalized and displayed. This continue until all pulses are counted

Time measurement



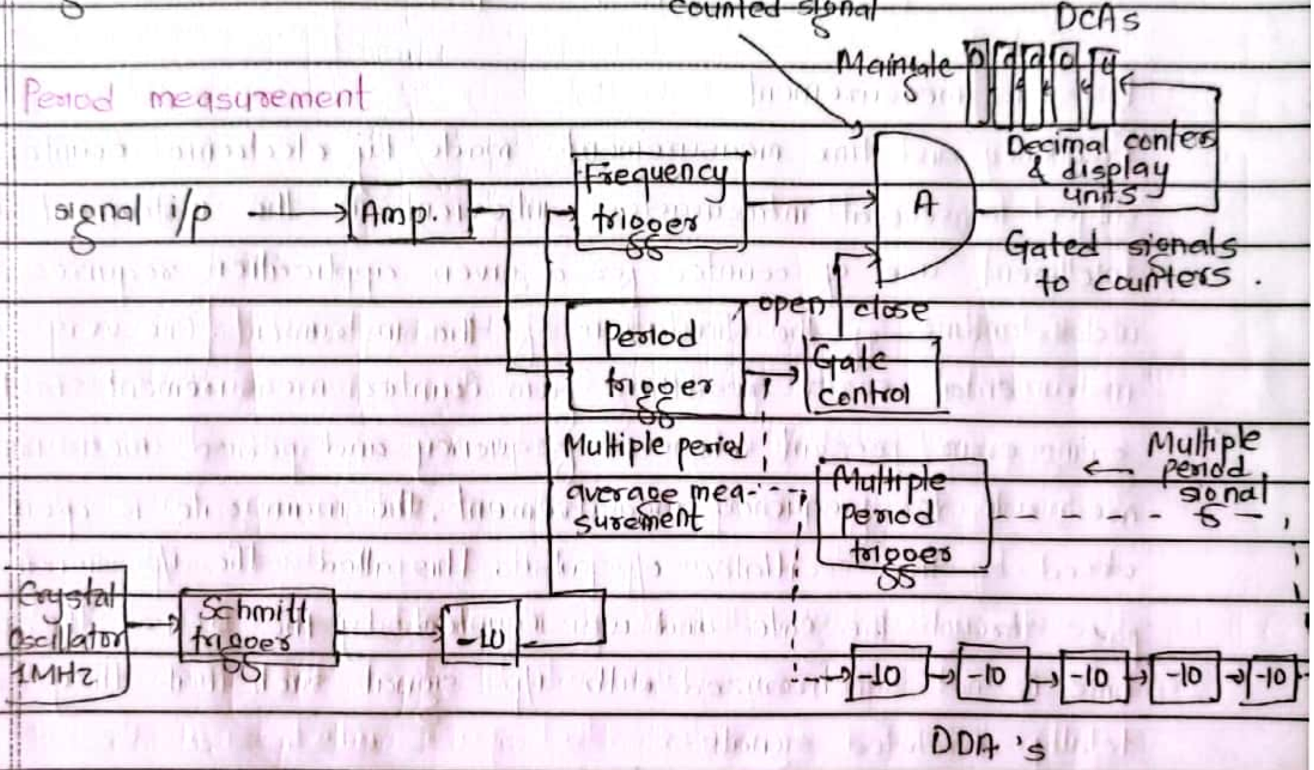
↳ Time-interval measurement can be made with the same basis blocks as ratio measurements

↳ In this measurements time interval is measured and it is used in determining the pulse width of a certain waveform.

↳ The block diagram of for this is shown above

→ This configuration shows two parallel input signal channels, where one channel supplies the enabling pulse for the main gate and other channel supplies the disabling pulse for the same gate. The main gate is enabled at a point on the leading edge of the i/p signal waveform & closed on the trailing edge of same waveform. The counter must then have slope-selection feature as indicated in block diagram. The trigger level control permits selection of the point on the incoming signal waveform at which measurement begins and ends.

Period measurement



Block Diagram of single & multiple period measurement.

→ Inorder to measure period, same circuit is used which was used for frequency measurement

→ The blocks are rearranged so that the counted signal & gating signal are reversed.

→ fig above shows the block diagram of period measurement using the same counter components. The i/p signal whose period is to be measured, is amplified, ~~saved~~ shaped by the period trigger and fed to DDAs in cascade counting the i/p frequency. This divided signal is now shaped multiple period trigger and applied to the gate control flip-flop. The gate control provides the enable pulse and stop pulse for the main gate. The main gate will remain open for a greatly increased time period. The DCA will count the interval which occur during that period. The redoubt logic is so designed that the decimal point will display the proper unit.

Errors in measurement

Frequency and time measurements made by electronic counter are subject to several inaccuracies inherient in the instrument itself. Intelligent use of counter for a given application requires an understanding of the limitation of the instrument. One very common instrumental error resulting from counter measurement is the gating error, present whenever frequency and period measurements are made. for frequency measurement, the main gate is opened and closed by the oscillator o/p pulse. This allows the i/p signal to pass through the gate and we counted by the DCAs. The gating time is not synchronized with i/p signal such that they are totally unrelated signals

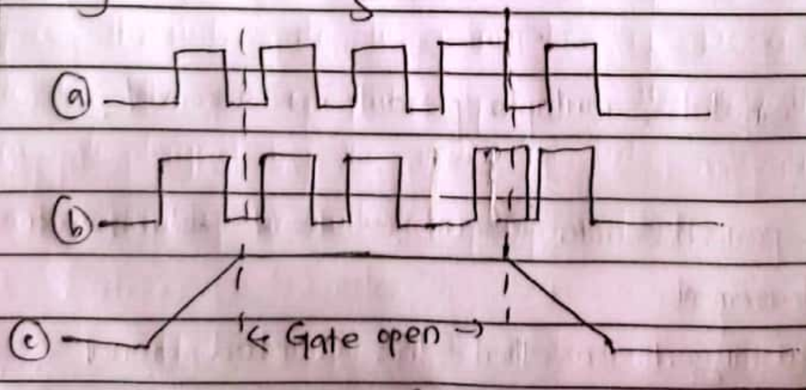


fig: frequency & time measurement.

In fig above, waveform (a) and (b) represent input signal in different phase relationship with respect to gating signal. Clearly, in one case 86 pulse will be counted in other case only 2 pulse are allowed to pass through gate.

→ Along with gating error, there is another type of error that is caused by momentary frequency variation due to voltage transients. Such condition is known as short-term stability error.

→ Ageing and deterioration of devices can lead to long term stability error.

Digital voltmeter

Types of digital voltmeter

→ Ramp type of DVM
→ Integrating type of DVM
→ Potentiometer DVM
→ Successive approximation DVM
→ Continuous balance DVM

in syllabus

Ramp type of DVM

→ The operating principle of ramp type DVM is measurement of the time it takes for a linear ramp voltage to change from 0V to the level of i/p voltage or vice-versa. This interval is then measured with an electronic time interval counter and count is displayed as number of digit on electronic indicating tubes

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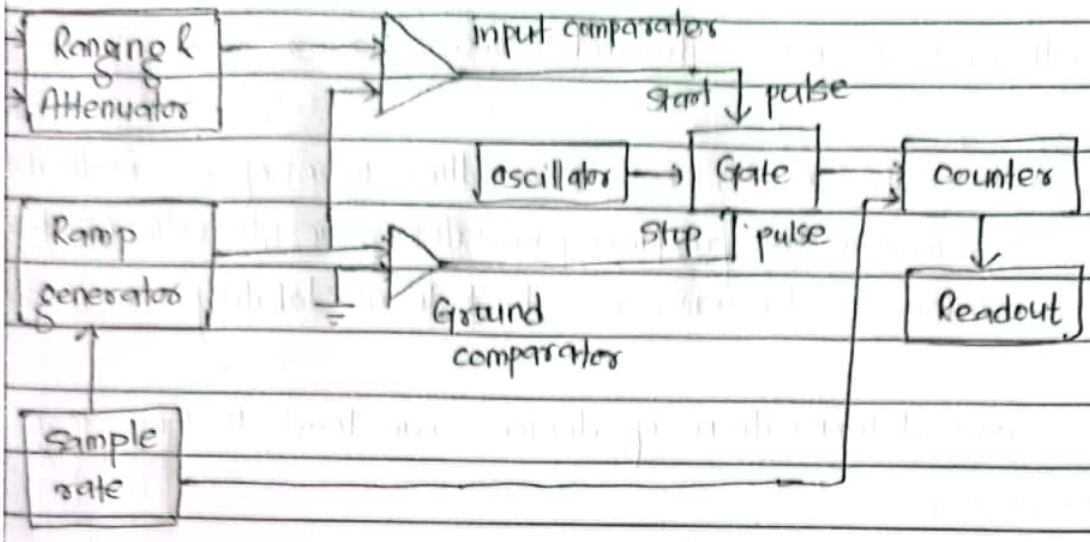

fig: Block diagram

At the start of measurement cycle, a ramp voltage is initiated, this voltage can be positive or negative going. The -ve going ramp is compared continuously with unknown i/p voltage. At the instant that ramp voltage equals the unknown voltage, a comparator generates a pulse which opens gate. The ramp voltage continues to decrease with time. When it finally reaches zero, a second comparator generates an o/p pulse which closes the gate.

An oscillator generates clock pulse which are allowed to pass through gate to a number of Decade Counting units which totalize the no of pulses passed through the gates. The decimal no, displayed by the indicator tube associated with counter, is a measure of magnitude of i/p voltage.

The sample rate determines the rate at which the measurement cycles are initiated. The oscillations of this multivibrator can be adjusted and it provides an initiating pulse for ramp generator to start its next ramp voltage.

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Integrating type of DVM.