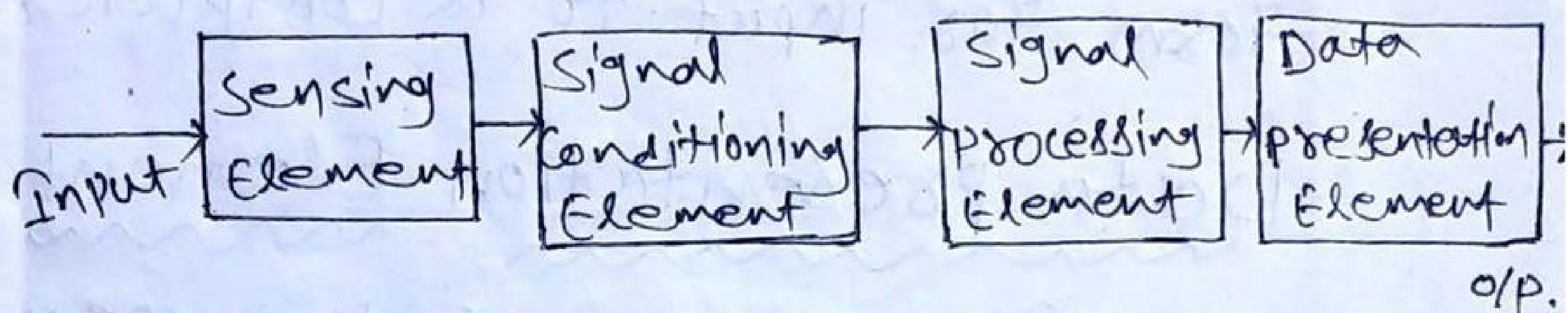


General Measurement System



Sensing Element:-

This is in contact with the process & it gives an output which depends on the variable which is measured.

Ex. - Thermometers

Signal Conditioning Element:-

This takes the output of sensing element which may be in other form than electrical so it needs to be converted into electrical form i.e. - A DC voltage current or frequency signal.

Signal Processing Element:-

This takes the output of conditioning element & converts it a form more suitable for processing.

Ex. - An analog to digital

Converter is used to Convert Continuous signal into ~~analog~~ digital form for input to a Computer.

Data presentation Element :-

It represents the measured value into a form which can be easily recognized by an observer.

Ex. - A Simple pointers can indicator, oscilloscope.

Characteristic of Measurement :-

These are two types :-

(i) Static Characteristics

(ii) Dynamic Characteristics

Static Characteristics

These are used for instruments which are used to measure an unvarying process, all the static performance characteristics one form or another by a process called as Calibration.

→ The starting characteristic can be further into two different categories:-

(i) Systematic characteristic

This can be easily quantified by mathematical or graphical links/means

(a) Range :-→ The i/p. of an element is specified by minimum & maximum value for which the o/p. also has minimum or maximum value.

(b) Span :-→ It is the maximum variation of input or output i.e. - $I_{\max} - I_{\min}$ or output maximum - output minimum.

(c) Linearity :-→ An element is set to be linear if corresponding values of output & input lie on a straight line. It connects the minimum point A ($I/p_{\min}, o/p_{\min}$) to max point B ($I/p_{\max}, o/p_{\max}$)

It has the eqⁿ.

$$\Rightarrow O/P \text{ max} - O/P \text{ min}$$

$$\Rightarrow \left[\frac{O/P \text{ max} - O/P \text{ min}}{I_{\text{max}} - I_{\text{min}}} \right] (I_{\text{max}} - I_{\text{min}})$$

Total straight line eqⁿ.

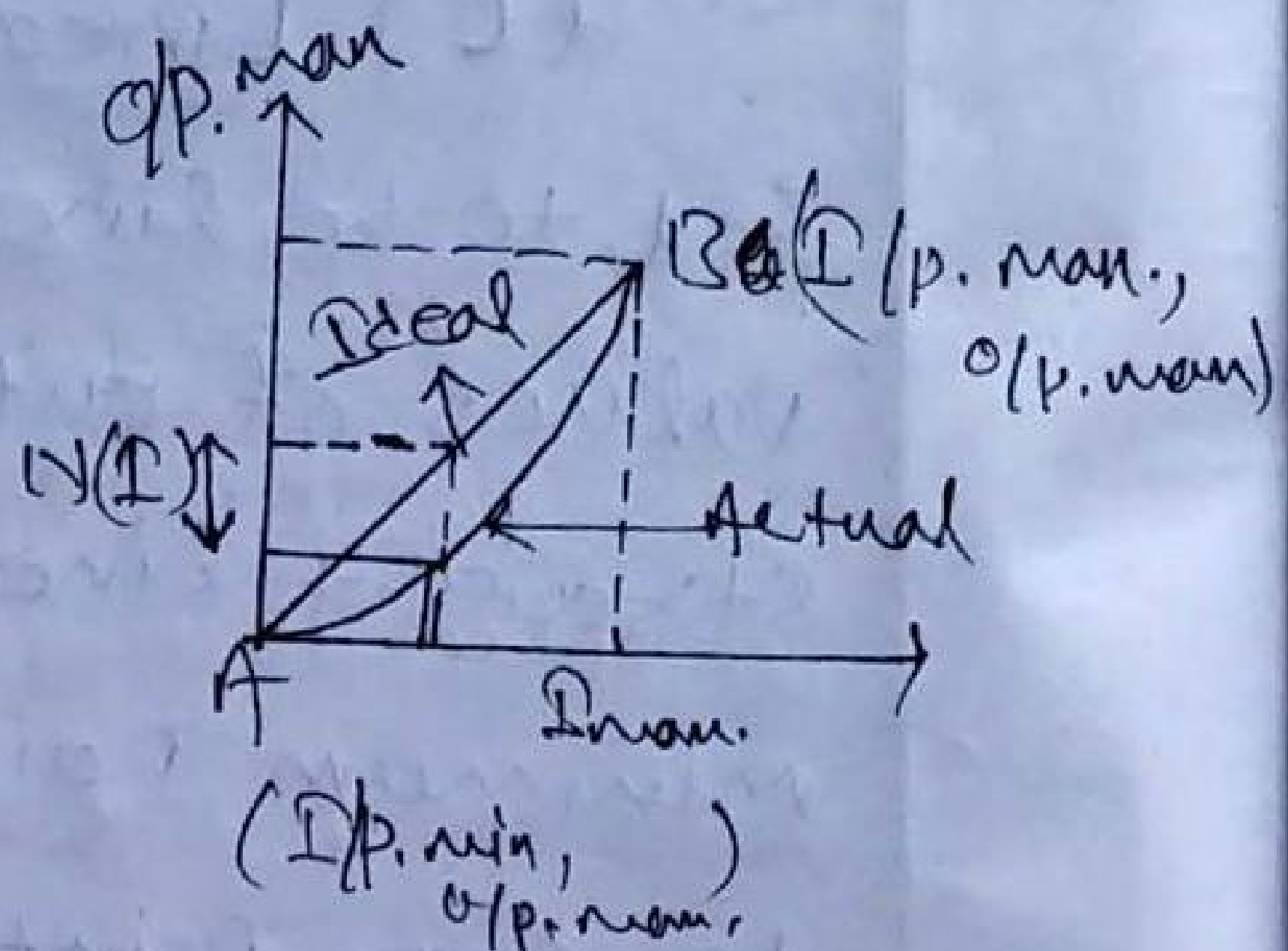
$$\Rightarrow O/P \text{ ideal} = K I/P + A$$

Non-linearity :-

In many cases the straight line relationship is not defined & the element is set to be non-linear which is defined as reference between actual & ideal straight line behaviour.

$$N(I) = O/P(I) - (K I + A)$$

$$\text{maximum Nonlinearity} \Rightarrow \frac{\hat{N}}{O/P \text{ max} - O/P \text{ min}} \times 100$$



Sensitivity :-

It is the rate of change of o/p. w.r.to input. It includes how much sensitive and apparatus is for a measurement.

Environmental effect :-

In general the output depends not only on input signal but also is effected by temperature, atmospheric pressure, relative humidity etc. A modifying input causes the linear behaviour to change for which the linear sensitive factor " K " changes to $K + K_M \times I_M$.

where I_M is the deviation in modifying environmental input.

$$N(I) = d(I) - (K + K_M I_M) + a + K_1 I$$

Hysteresis :-

For a given value of input the output maybe different depending whether the input is increasing or decreasing and hysteresis is the difference betⁿ these two values.

It has the eqⁿ.

$$\Rightarrow \text{o/p max} - \text{o/p min}$$

$$\Rightarrow \left[\frac{\text{o/p max} - \text{o/p min}}{I_{\text{max}} - I_{\text{min}}} \right] (I_{\text{max}} - I_{\text{min}})$$

Total straight line eqⁿ.

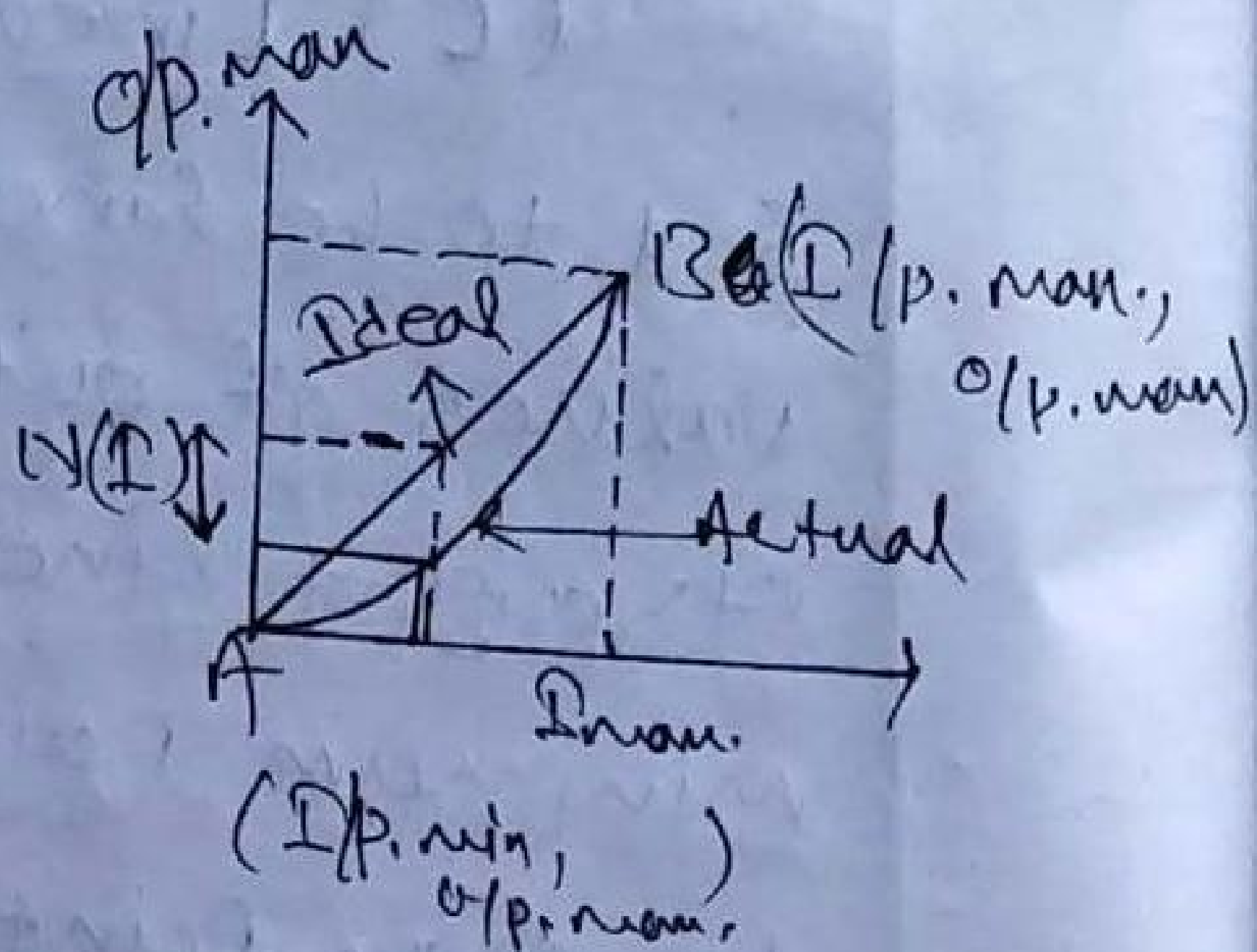
$$\Rightarrow \text{o/p ideal} = K I/P + a$$

Non-linearity:-

In many cases the straight line relationship is not defined & the element is set to be non-linear which is defined as reference between actual & ideal straight line behaviour.

$$N(I) = \text{o/p}(I) - (K I + A)$$

$$\text{maximum Nonlinearity} \Rightarrow \frac{\hat{N}}{\text{o/p.max} - \text{o/p.min}} \times 100$$



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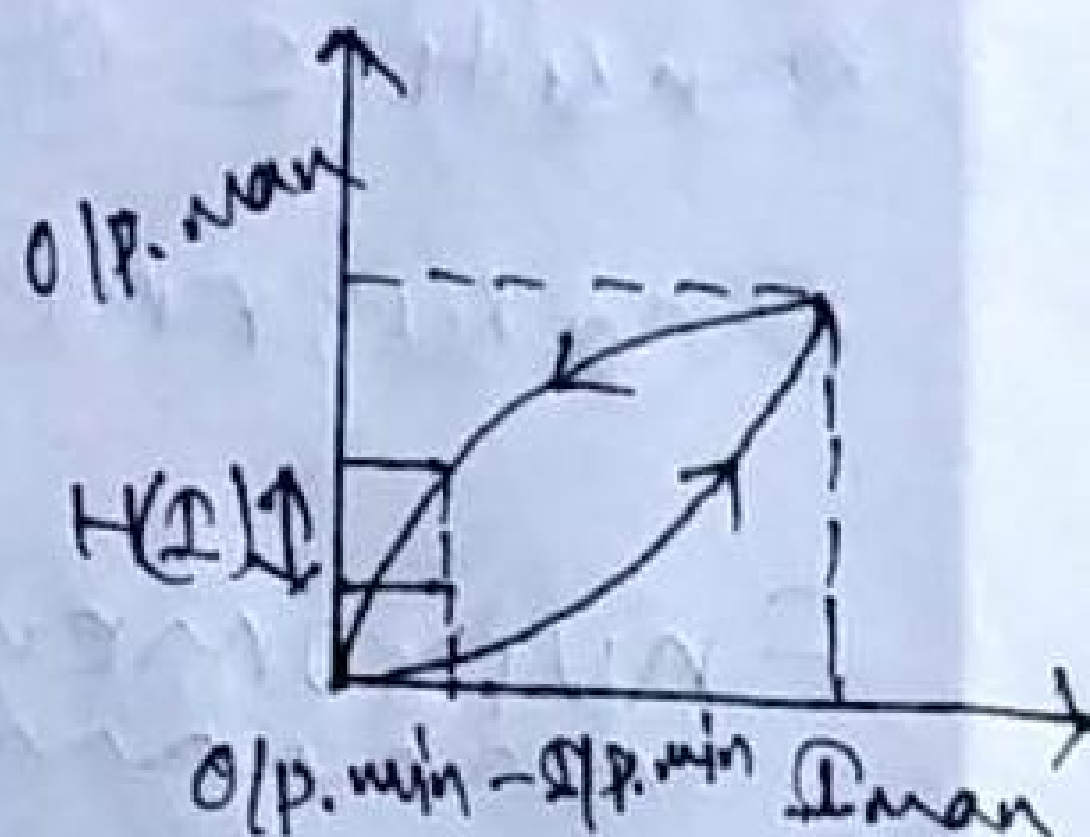
$$N(I) = d(I) - (K + K_M I_M) + a + K_1 I$$

Hysteresis :-

For a given value of input the output maybe different depending whether the input is increasing or decreasing and hysteresis is the difference betⁿ these two values.

$$H(I) = O(I_1) - O(I_2)$$

$$\text{maximum hysteresis} \Rightarrow \frac{\hat{H}}{O/p.\text{max} - O/p.\text{min}} \times 100$$



Resolution :-

Some elements are characterised by output increasing in a series of discrete steps or a large increase in output without any large variation in input.

$$\text{It is equal to } \frac{\Delta I R}{I_{\text{max}} - I_{\text{min}}} \times 100\%$$

Wear & ageing :-

These effects can cause the characteristics of an element to change slowly but systematically throughout its life. One example is stiffness constant of a spring which decreases with time.

Error Band :-

Non-linearity, hysteresis in many sensor or transducers are so small that it is not useful to quantify its effect for this case a manufacturer always provides a statistical statement that its output will remain within $(+)$ or $(-)$ $\pm X$ around the actual behaviour.

In general a probability density function $p(u)$ is defined as $\int_{u_1}^{u_2} p(u) du$

Any instrument that closely obeys the above equation over its intended range of operating condition is defined as zero (0) order instrument.

Transfer function

$$\frac{X_0}{X_1} = \frac{b_0}{a_0} = K$$

$\Rightarrow$ Static Sensitivity

Since $X_0 = K X_1$ is an algebraic equation. It is clear that the

instrument output will follow the instrument input without any time lag, thus a zero order instrument shows a perfect dynamic response

First order instrument :-

If in eq. (i) all a's b's are zero other than a_1, a_0, b_0 then

we get

$$a_1 \frac{dx_0}{dt} + a_0 x_0 = b_0 x_1$$

Dividing by a_0 through out

$$\frac{a_1}{a_0} \frac{dx_0}{dt} + x_0 = \frac{b_0}{a_0} x_1$$

$$(zD+1)x_0 = kx_1$$

$$z = \frac{a_1}{a_0} = \text{time constant}$$

$$k = \frac{b_0}{a_0} = \text{static sensitivity}$$

Transfer function

$$\Rightarrow \frac{x_0}{x_1} = \frac{k}{zD+1}$$

2nd order Instrument!:-

If in eq. (1) all a's b's are zero other than $a_2, a_1, a_0; b_0$ then

$$\frac{a_2 d^2 X_0}{dt^2} + a_1 \frac{dX_0}{dt} + a_0 X_0 = b_0 X_1 \dots (2)$$

taking $\omega_n = \frac{a_0}{a_2} = \text{undamped natural frequency}$

$$\xi = \frac{a_1}{\sqrt{a_0 a_2}} = \text{Damping ratio} \{ \text{has no dimension} \}$$

Dividing eq. (2) by a_0 we get

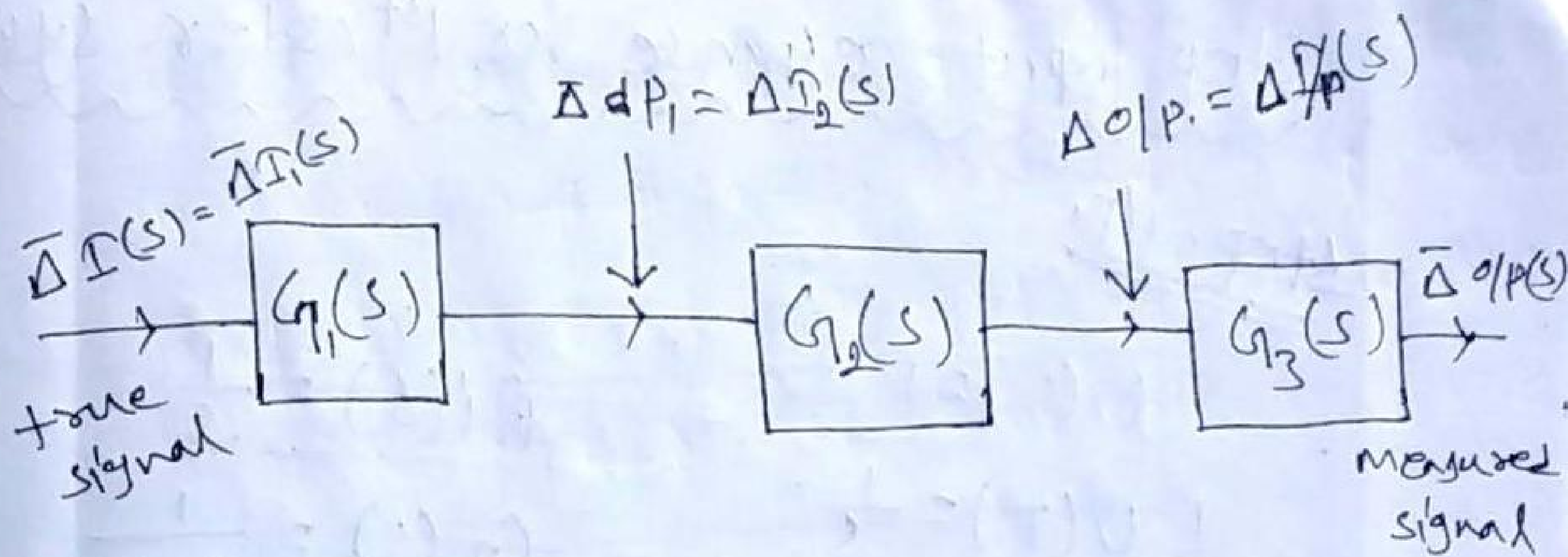
$$\frac{a_2}{a_0} \frac{d^2 X_0}{dt^2} + \frac{a_1}{a_0} \frac{dX_0}{dt} + X_0 = \frac{b_0}{a_0} X_1$$

$$= \left(\frac{D^2}{(\omega_n)^2} + \frac{2\xi D}{\omega_n} + 1 \right) X_0 = K u$$

$$= \frac{X_0}{X_1} = \frac{K}{D^2 \omega_n^2 + \frac{2\xi D}{\omega_n} + 1}$$

Dynamic error!:-

Dynamic error is defined as difference between the true value of output if no static error is present and the experimental value of the o/p.



Each element denoted by G_1, G_2, G_3 etc, under takes the true output (without any static error) can be represented by steady state sensitivity K_I & transfer function $G(s)$. Here all the steady state sensitivity factors $K_1, K_2, \dots, K_n$ equals to 1 & the over all transfer function $G(s)$ is equal to the product of gain of all the element.

$\frac{\Delta o/p.}{\Delta i/p.} = G(s)$, we can find the system output signal, $\Delta o/p(t)$ w.r.t. time varying $\Delta i/p.$ signal.

Thus dynamic error $e(t)$ equals to measured signal - True value which is equal to $\Delta o/p. - \Delta i/p..$

Step input response for 1st order system:

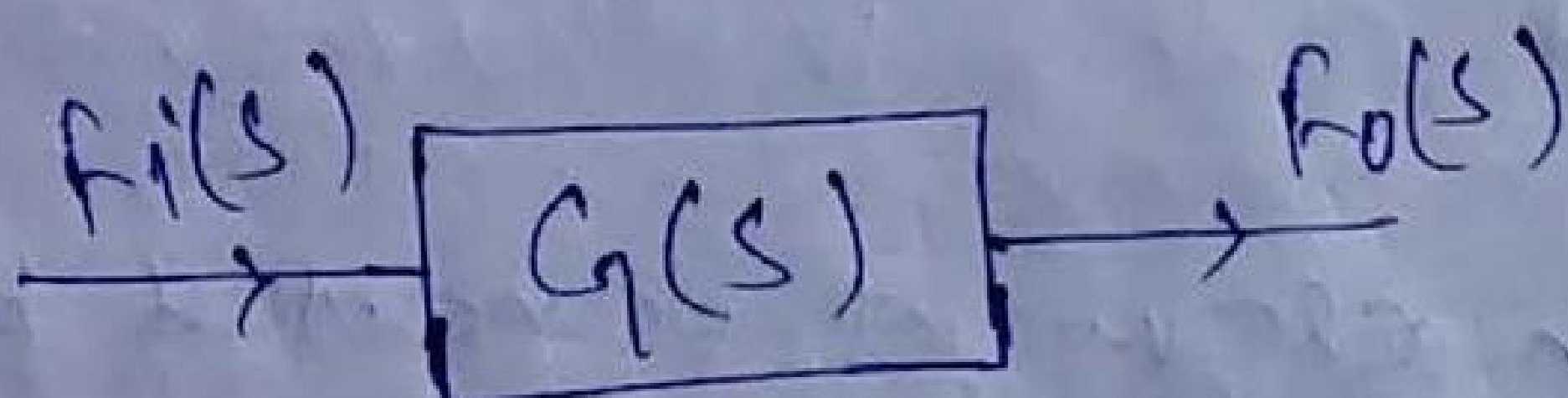
Step - i/p:

$$U(s) = 1$$

$$F_i(s) = \frac{1}{s}$$

$$LU(\tau) = \frac{1}{s}$$

$$G(s) = \frac{1}{s\tau + 1}$$



$$F_o(s) = \frac{1}{s(s\tau + 1)}$$

$$\Rightarrow F_o(s) = F_i(s) G(s)$$

Solving by partial fraction method

$$\frac{1}{s(s\tau + 1)} = \frac{A}{s} + \frac{B}{s\tau + 1}$$

$$\frac{1}{s(s\tau + 1)} = \frac{A(s\tau + 1) + Bs}{s(s\tau + 1)}$$

$$= A + A\tau s + Bs = 1$$

$$= A + s(A\tau + B) = 1$$

$$\text{Equating both side } A = 1 \quad B + A\tau = 0$$

$$B = -\tau$$

$$F_o(s) = \frac{A}{s} + \frac{B}{s\tau + 1}$$

Taking Laplace Inverse

$$f(t) - f_0(t) = U(t) - e^{-t/2}$$

$$\text{for } t > 0 \quad U(t) = 1$$

$$f_0(t) = 1 - e^{-t/2}$$

Second Order system:-

$$\text{Here } G(s) = \frac{1}{\frac{1}{\omega_n^2} s^2 + \frac{2\zeta}{\omega_n} s + 1}$$

$$F_i(s) = 1/s$$

$$F_o(s) = \frac{1}{s \left(\frac{1}{\omega_n^2} s^2 + \frac{2\zeta}{\omega_n} s + 1 \right)}$$

In partial form

$$\frac{A}{s} + \frac{Bs + C}{\frac{s^2}{\omega_n^2} + \frac{2\zeta s}{\omega_n} + 1}$$

$$\Rightarrow \frac{A \left(\frac{s^2}{\omega_n^2} + \frac{2\zeta s}{\omega_n} + 1 \right) + Bs^2 + Cs}{s \left(\frac{s^2}{\omega_n^2} + \frac{2\zeta s}{\omega_n} + 1 \right)}$$

$$1 = A \left(\frac{s^2}{\omega_n^2} + \frac{2\zeta s}{\omega_n} + 1 \right) + Bs^2 + Cs \left(\frac{A}{\omega_n^2} + B \right) s + A$$

$$= \left(\frac{A}{\omega_n^2} + B \right) s^2 + \left(\frac{2A\zeta}{\omega_n} + C \right) s + A = 1$$

on equating both sides

$$A = 1 \quad B = -\frac{1}{\omega_n^2}$$

$$\frac{2\xi}{\omega n} + c = 0$$

$$c = -\frac{2\xi}{\omega n}$$

$$F_0(s) = \frac{1}{s} + \frac{\frac{-s}{\omega n^2} - \frac{2\xi}{\omega n}}{\frac{s^2}{\omega n^2} + \frac{2\xi s}{\omega n} + 1}$$

$$\Rightarrow \frac{1}{s} - \frac{s + 2\xi \omega n}{s^2 + 2\xi \omega n s + \omega n^2}$$

$$\Rightarrow \frac{1}{s} - \frac{s + 2\xi \omega n}{s^2 + 2\xi \omega n s + (\omega n \xi)^2 - (\omega n \xi)^2 + \omega n^2}$$

$$= \frac{1}{s} - \frac{s + 2\xi \omega n}{(s + \omega n \xi)^2 + \omega n^2(1 - \xi^2)}$$

There are 3 cases

(i) $\xi = 1$, It is also known as critical damping case

$$\frac{1}{s} - \frac{s + 2\omega n}{(s + \omega n)^2}$$

$$\Rightarrow \frac{1}{s} - \frac{1}{s + \omega n} - \frac{\omega n}{(s + \omega n)^2}$$

Taking Laplace inverse

$$f_0(t) = u(t) - e^{-\omega n t} - \omega n t \cdot e^{-\omega n t}$$

(ii) $\xi < 1$, also called as underdamping case.

The roots of the characteristic equation

$$s^2 + 2\xi\omega_n s + \omega_n^2$$

$$s = \frac{-2\xi\omega_n \pm \sqrt{4\xi^2\omega_n^2 - 4\omega_n^2}}{2}$$

$$s = -\xi\omega_n \pm \omega_n\sqrt{\xi^2 - 1}$$

Finally the response will be

$$f_0(t) = U(t) \left[1 - e^{-\xi\omega_n t} \cos \omega_n \sqrt{1 - \xi^2} t - \frac{\xi}{\sqrt{1 - \xi^2}} \sin \omega_n \sqrt{1 - \xi^2} t \right]$$

For overdamp case ($\xi > 1$)

$$f_0(t) = U(t) - e^{-\xi\omega_n t} \cosh \omega_n \sqrt{\xi^2 - 1} t - \frac{\xi}{\sqrt{\xi^2 - 1}} \sinh \omega_n \sqrt{\xi^2 - 1} t$$

Q.) Let a step response of a force is applied to a sensor with stiffness constant $K = 10^3 \text{ N/mtr.}$, mass = 0.1 K.g. & damping constant $\lambda = 10 \text{ N/s/mtr.}$ Find out the displacement for a step change in force of two newton. The initial force is 10 newton.

$$\text{Damping Coefficient} = \xi = \frac{\lambda}{2\sqrt{km}}$$

$$\Rightarrow \frac{10 \text{ N sec/m}}{2 \times \sqrt{10^3 \times 10^{-1}}} = 0.5$$

Initial steady state displacement = 10^{-2}

$$\frac{F(0)}{K} = \frac{10}{10^{-3}} = 10^2 \text{ m}$$

$$1 \text{ cm} = 10 \text{ mm}$$

Force is now changed by 2 N.

So $x(t) = K \times \text{step height} \times \text{unit step response}$

$$10^{-3} \times 2 \left[1 - e^{-\xi \omega_n t} \left(\cos \omega_n \sqrt{1 - \xi^2} t + \frac{\xi}{\sqrt{1 - \xi^2}} \sin \omega_n \sqrt{1 - \xi^2} t \right) \right]$$

$$\frac{\xi}{\sqrt{1 - \xi^2}} \sin \omega_n \sqrt{1 - \xi^2} t$$

$$u(t) = 2 \left[1 - e^{-50t} \left(\cos 86.6t + 0.588 \sin 86.6t \right) \right] \text{ mm}$$

Ramp Input :-

For Ramp input

Let the Ramp i/p. be $\mathcal{I}(t)$

$$\mathcal{I}(t) = \mathcal{I}/s^2$$

For 1st order

$$F_o = G(s) F(s)$$

$$= \frac{1}{1+zs} \cdot \frac{\mathcal{I}}{s^2}$$

$$= \frac{A}{1+zs} + \frac{Bs+C}{s^2}$$

$$\frac{As^2+Bs+C+Bzs^2+Czs}{s^2(1+zs)}$$

Solving the above equation

$$As^2+Bs+C+Bzs^2+Czs = \mathcal{I}$$

$$(A+Bz)s^2 + (B+Cz)s + C = \mathcal{I}$$

Comparing LHS & RHS

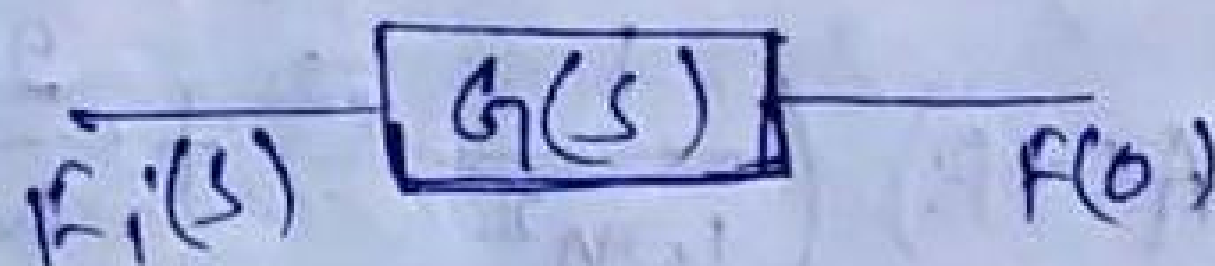
$$C = \mathcal{I} \quad B+Cz = 0$$

$$A+Bz = 0 \quad B = -Cz$$

$$A = -Bz \Rightarrow -\mathcal{I}z$$

$$A = -(-\mathcal{I}z)z$$

$$= \mathcal{I}z^2$$



$$z = ny$$

Putting the values of

A, B (in eq. 1)

$$\frac{Iz^2}{1+z^2} = \frac{Iz}{s} + I/s^2$$

Taking Laplace Inverse

$$F(t) = Iz e^{-t/2} - Iz + It$$

For 2nd order system

$$\text{Gain } G(s) = \frac{1}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1}$$

$$\cancel{F_o(s)} F_o(s) = G(s) \cdot F_i(s)$$

$$\Rightarrow F_i(s) = I/s^2$$

$$F_o(s) = \frac{I}{s^2 \left(\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1 \right)}$$

$$F_o(s) = \frac{As+B}{s^2} + \frac{Cs+D}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1}$$

$$= \frac{(As+B) \left(\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1 \right) + (Cs^3+D)}{s^2 \left(\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1 \right)}$$

$$K_2 \frac{A}{\omega n^2} s^3 + \frac{2\epsilon A}{\omega n} s^2 + As + \frac{B}{\omega n^2} s^2 + \frac{2\epsilon}{\omega n} Bs$$

$$B + Cs^3 + Ds^2 = 1$$

$$\left(\frac{A}{\omega n^2} + C\right)s^3 + \left(\frac{2\epsilon A}{\omega n} + \frac{B}{\omega n^2} + D\right)s^2 + \left(A + \frac{2\epsilon B}{\omega n}\right)s$$

$$s + B = 1$$

on Comparing

$$B = 1 \quad \frac{A}{\omega n^2} + C = 0$$

$$A + \frac{2\epsilon}{\omega n} B = 0 \quad -\frac{2\epsilon}{\omega n^3} + C = 0$$

$$A = -\frac{2\epsilon}{\omega n} \quad C = \frac{2\epsilon}{\omega n^3}$$

$$\frac{2\epsilon}{\omega n} A + \frac{B}{\omega n^2} + D = 0$$

$$\frac{2\epsilon}{\omega n} \left(-\frac{2\epsilon}{\omega n}\right) + \frac{1}{\omega n^2} + D = 0$$

$$D = \frac{4\epsilon}{\omega n^2} - \frac{1}{\omega n^2}$$

Resistive Sensing elements :-

The resistance of a simple metallic Conductor is given by

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

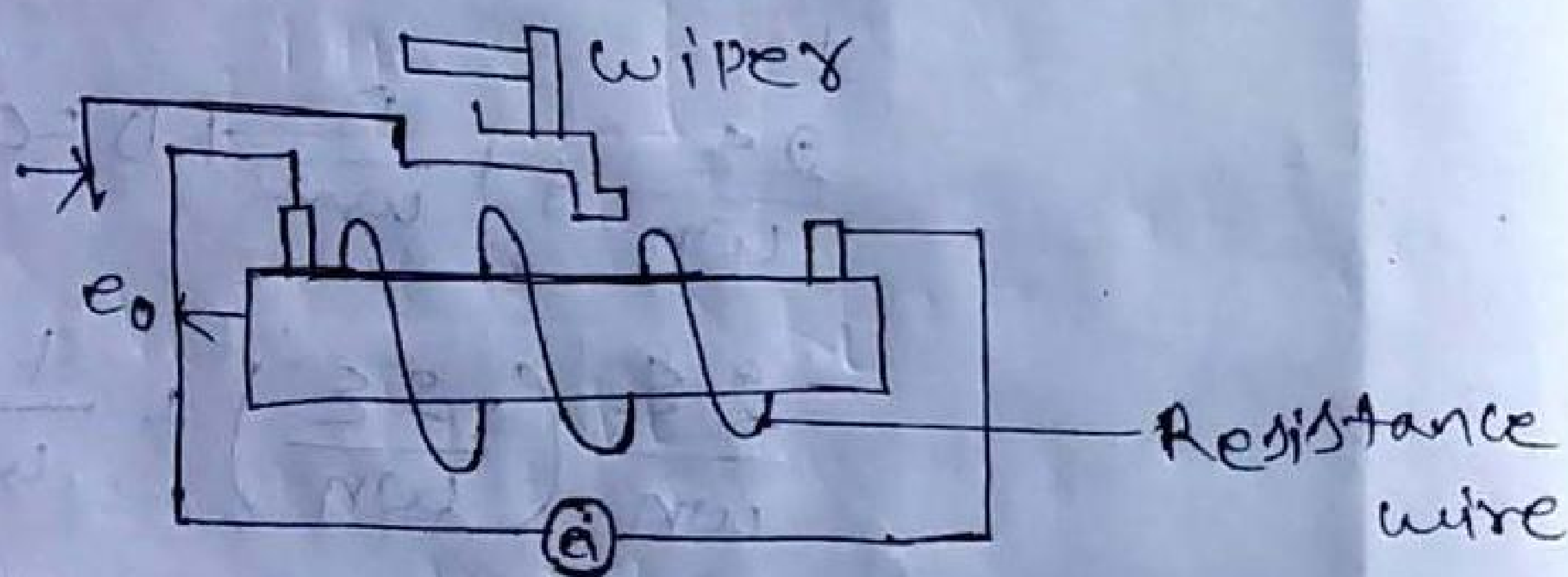
Resistive elements can sense temperature, heat, flux change, flow of viscosity, displacement, Gas composition.

(i) Potentiometer :-

These sensing elements are used for linear displacement measurement. It consists of a resistive element with a sliding contact.

The motion of the contact may be linear or rotational.

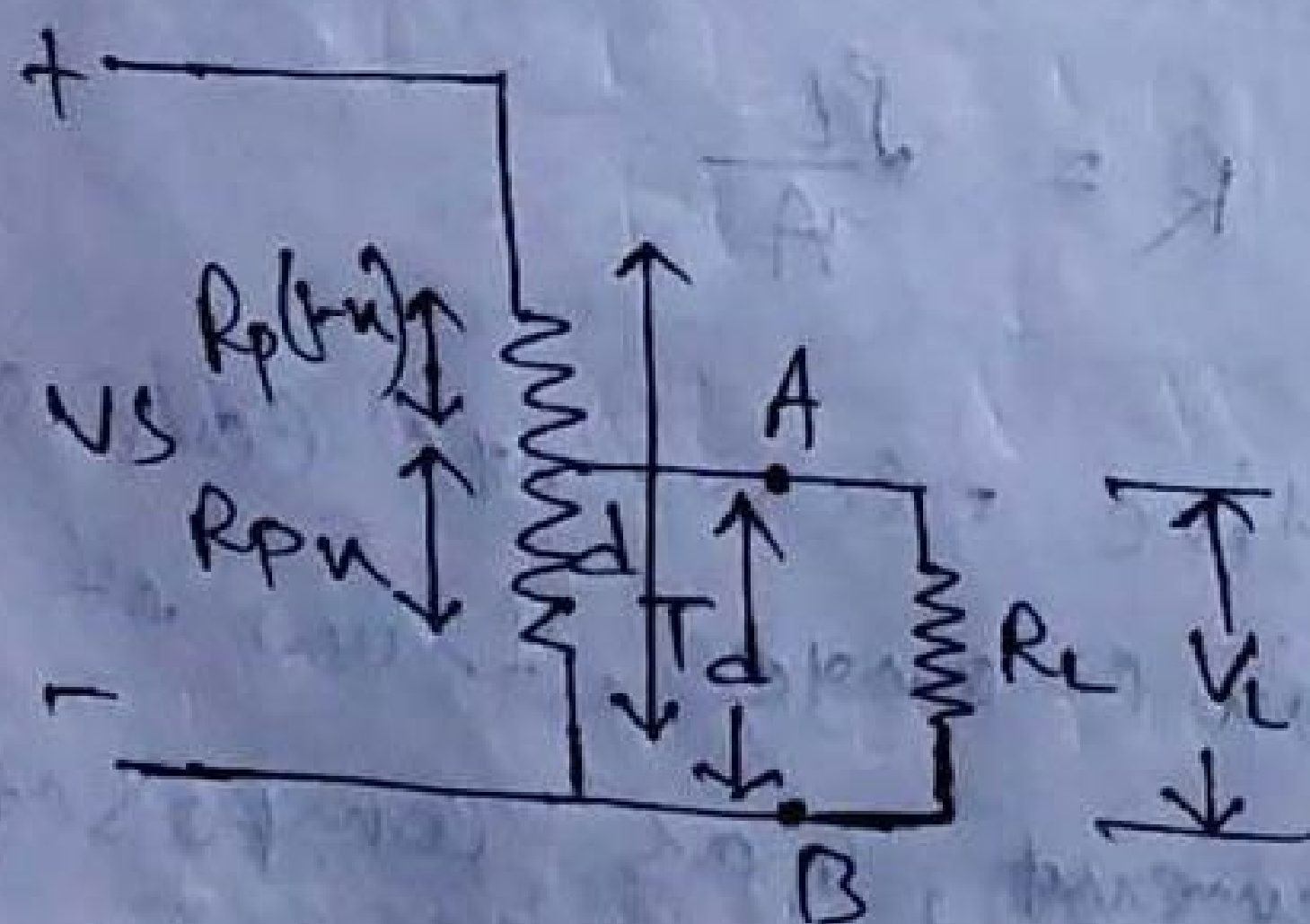
It is a passive transducer, it requires an external source for its operation.



e_o = output voltage

e_i = ~~Res~~ Input voltage

Schematic diagram :-



$R_p = \text{Total resistance}$

$u = d/dt = \text{Fractional displacement}$

$dt = \text{Total length}$

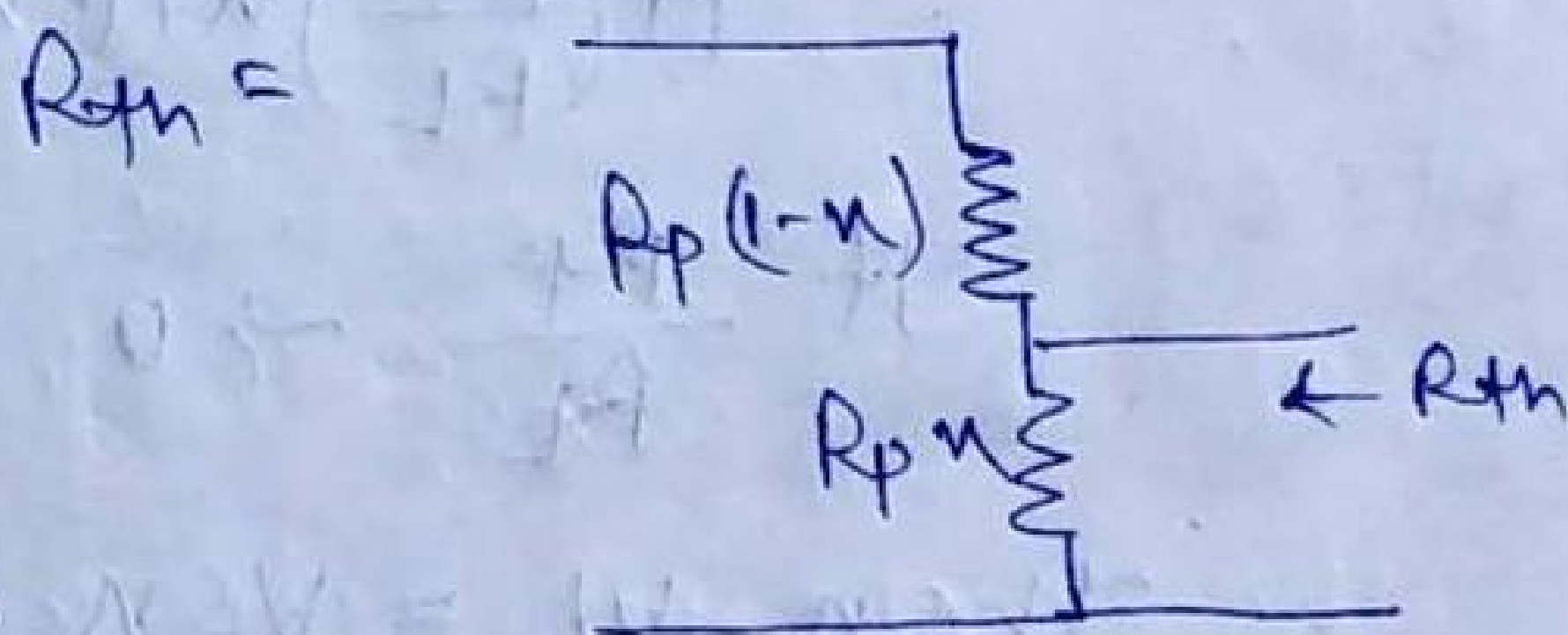
$d = \text{Length Covered by wiper}$
due to application of
measured variable

This device consists of a cylindrical
stator with wire around it or a
layer of conducting film deposited
on it.

$$\text{Resistance Covered by wiper} = \frac{R_p \times d}{dt}$$
$$= R_p \times u$$

The voltage across load is V_L and to
~~find~~ find this thevenin is used.

(i) $E_{th} = U.S.u$



$$R_{th} = R_p(1-u) \parallel R_p u$$

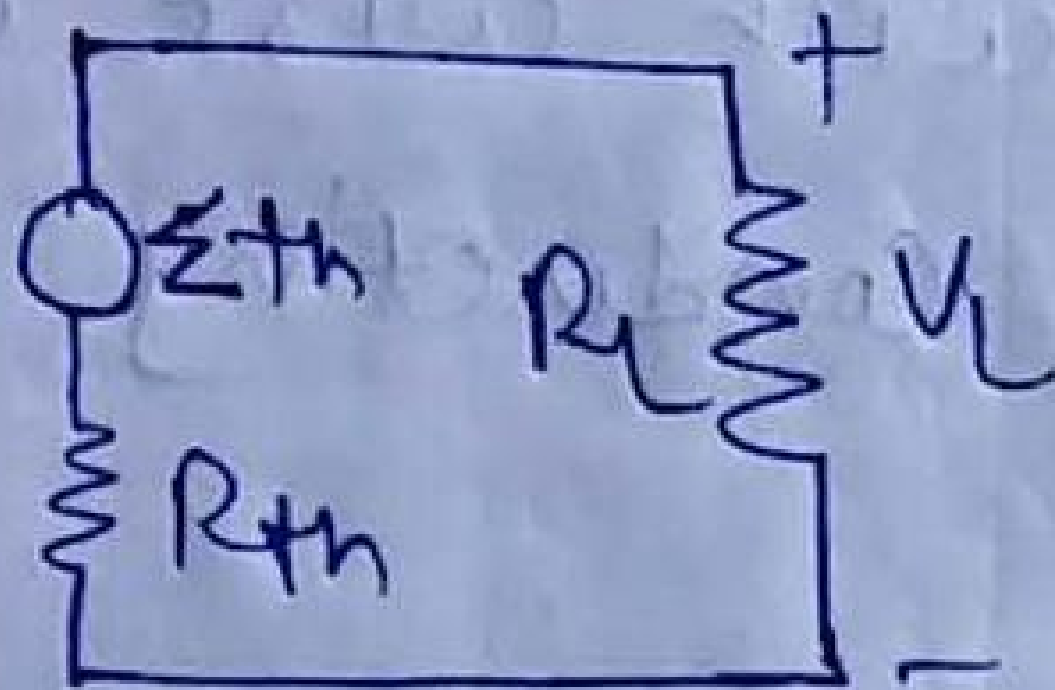
$$= \frac{R_p(1-u) R_p u}{R_p(1-u) + R_p u}$$

$$= \frac{(R_p - R_p n) R_p n}{R_p}$$

$$= \frac{R_p^2 n - R_p^2 n^2}{R_p}$$

$$= \frac{R_p^2 n (1-n)}{R_p}$$

$$R_{th} = R_p n (1-n)$$



$$V_L = \frac{E_{th}}{R_{th} + R_L} \times R_L$$

$$= \frac{V_S n R_L}{R_p n (1-n) + R_L}$$

$$= \frac{V_S n}{1 + \left(\frac{R_p}{R_L}\right) n (1-n)} \quad \dots \quad (i)$$

$$\text{If } \frac{R_p}{R_L} \rightarrow 0$$

$$\text{then } V_L = V_S n \quad \dots \quad (ii)$$

The eqⁿ. (i) shows a non-linear relationship between supply voltage V_S & load

From eq. (ii) under ideal condition when the load resistance is taken to be infinite then the load voltage will be proportional to the supply voltage.

The resistive body of the device is a wire of a platinum of 0.01 millimeter (mm) on a insulated device. The resolution error is equal to $\frac{100}{N} \%$.

where
 $N \rightarrow$ No. of turns

which is determined by diameter of the wire, this device covers displacement span from 0.5 to 100 with a non-linearity of ~~0.001~~ $\pm 0.2 \%$, resolution of 0.008%, & a resistance value of 1k Ω per inch. In case of ~~the~~ conducting plastic element there is no resolution error but where is rapidly with temperature.

Resistance Thermometer / Thermistor
for temperature measurement :-

Generally resistance of most metals increase with temperature in the range -100°C to 800°C .

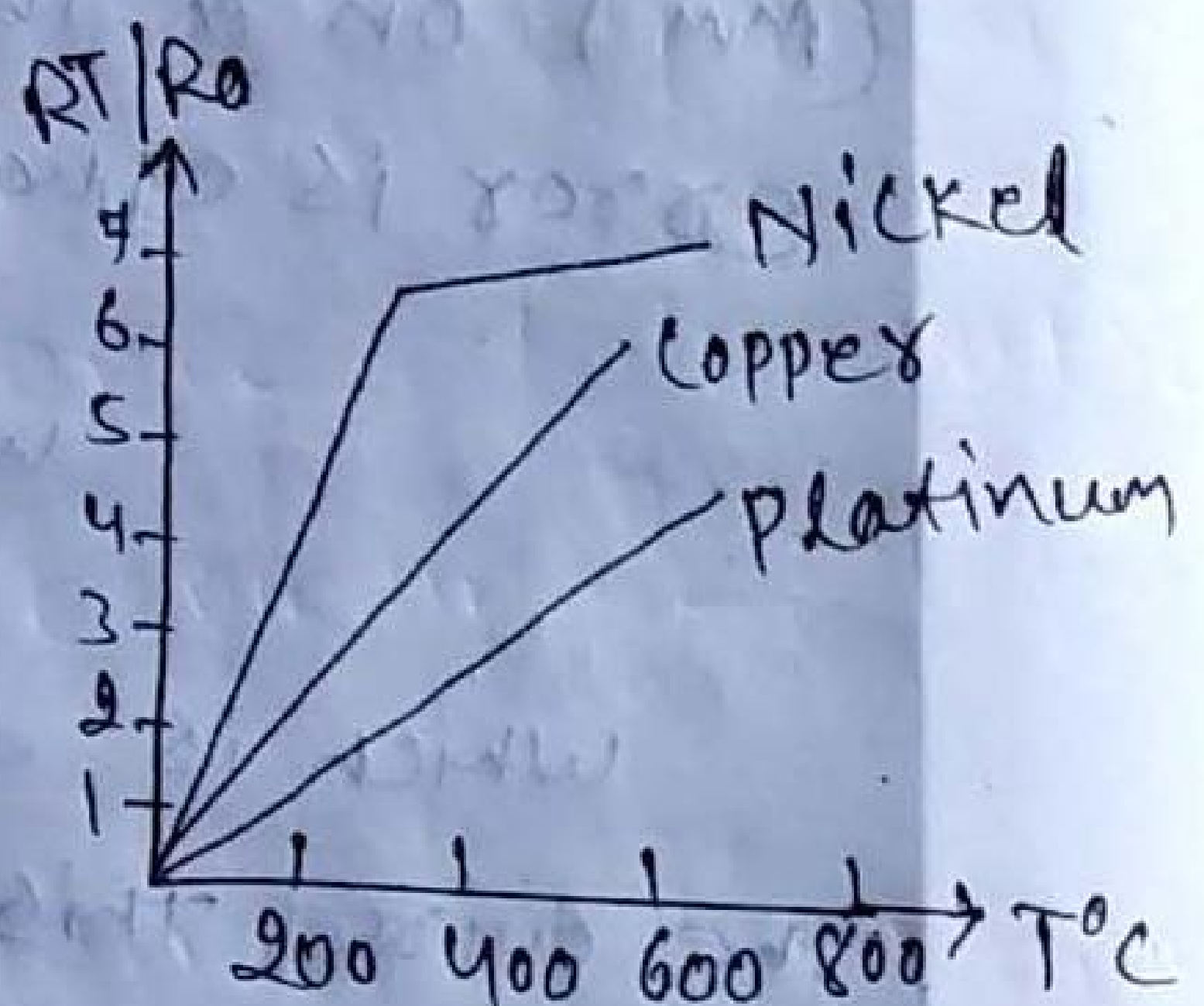
$$R_T = R_0 (1 + \alpha T + \beta T^2 + \gamma T^3 + \dots)$$

R_0 = Resistance of metal at 10°C

α, β, γ = Temperature Coefficient

if magnitude of non-linear terms are small

$$R_T = R_0 (1 + \alpha T)$$



From the above graph though platinum is expensive but is used in industries as it is chemically inert. Its temperature range is $\sim 200^\circ\text{C}$ to 800°C .

The fundamental interval which is the difference between resistance of the material at 100°C & 0°C is equal to 38.5Ω .

For grade mark platinum tolerance

at 200°C , The amount of electrical power dissipated in the element should be limited to avoid self heating.

Thermistor :-

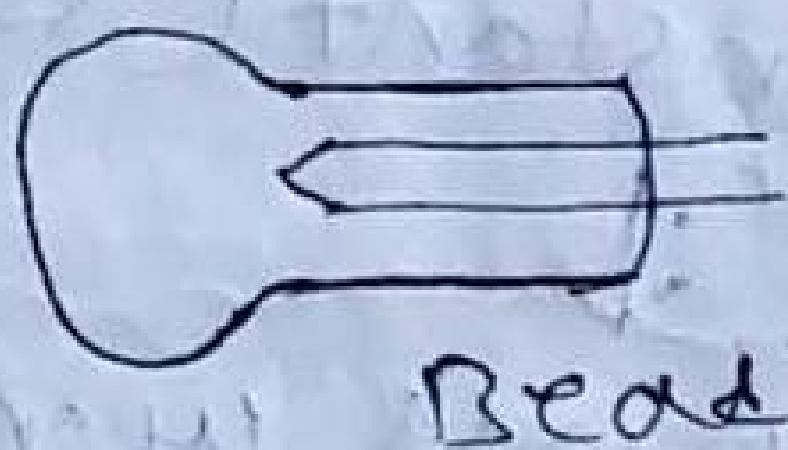
Here the resistive temperature elements are made from ~~semi-conductor~~ semi-conductor i.e. oxide of Chromium (Cr), Mn, Iron, Nickel.

The resistance of these elements decreases with temperature & are highly sensitive to temperature change.

Range $\rightarrow -60^{\circ}\text{C}$ to 15°C

Resistance range $\rightarrow 0.5\ \Omega$ to $0.75\ \text{M}\Omega$

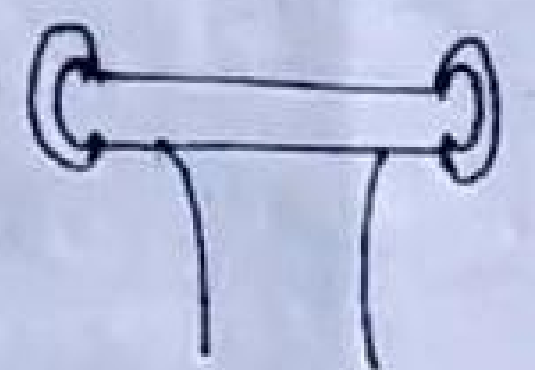
Construction :-



Bead



Disc



Rod

$\hookrightarrow$ These are basically in the form of Bead, Disc, Rod.

$\hookrightarrow$ The Beads are smallest in size, whose diameters ranges from 0.015mm to 1.25mm .

4 The Disc are made under high pressure & are transform cylindrical shape, 2.5mm to 25mm

Resistance temperature characteristics

$$R_{\theta} = R_{\theta_1} \exp \left[B \left(\frac{1}{\theta} - \frac{1}{\theta_1} \right) \right]$$

R_{θ} → Resistance at temperature
 θ in Kelvin in Ω

R_{θ_1} → Resistance at temp θ_1 in
Kelvin in Ω

$\theta_1 \rightarrow 25^{\circ}\text{C}$ (298 K) usually

$B \rightarrow$ Constant (3500 to 4500 K)

↓

Depends upon material

NTC (Negative

temperature coefficient)

Resistance
(Ω)

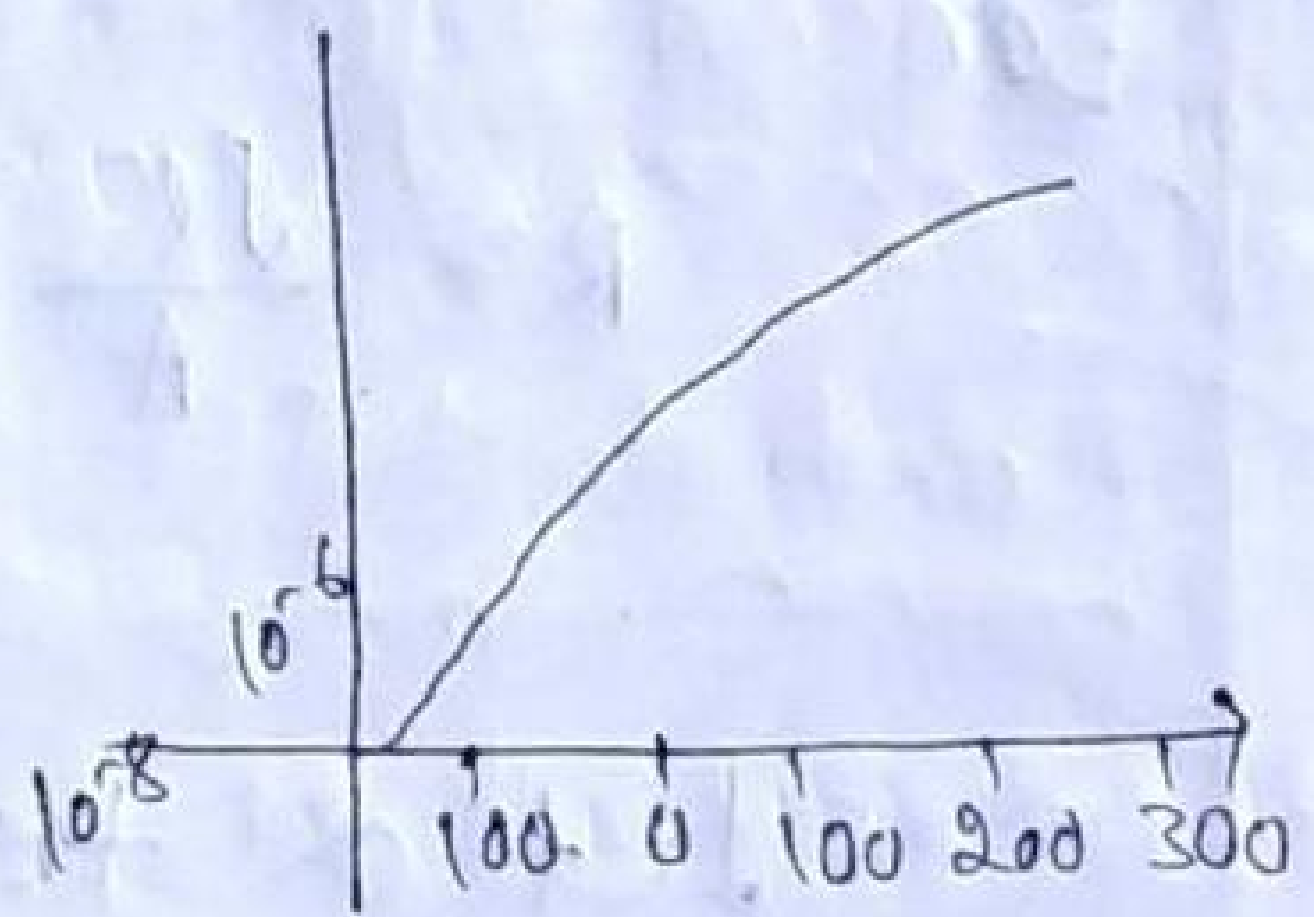
10^4

10^2

$12\text{K}\Omega \pm 7\%$

$0.95\text{K}\Omega \pm 5\%$

PTC (positive temperature coefficient)



(platinum)

100 Ω at -55°C to 10k Ω
at 120°C

Strain Gauge :-

If a metal conductor is elongated or compressed, its resistance changes because the length & diameter changes. Also, there is a change in resistivity of the conductor & this effect is termed as piezoresistivity effect.

↳ These instruments are used for measurement of stress, associated strain in experimental analysis.

Gauge factor derivation :-

Let us consider a strain gauge of circular wire having dimension length $\rightarrow l$, diameter $\rightarrow d$ before

being strain.

$$R = \frac{SL}{A} \dots \textcircled{i} \text{ of unstrained Gauge}$$

Let a tensile stress "S" be applied. This causes length to increase but area decreases i.e. - $\Delta L, \Delta D, \Delta A, \Delta R$ are corresponding

Changed.

Expression of R indifferented form w.r.t S.

$$\frac{dR}{dS} = \frac{S}{A} \frac{\partial L}{\partial S} - \frac{SL}{A^2} \frac{\partial A}{\partial S} + \frac{L}{A} \frac{\partial S}{\partial S} \dots \textcircled{ii}$$

$$\text{Area} \rightarrow \pi/4 D^2$$

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

Dividing eqn. (ii) by $R = SL/A$

$$\frac{1}{R} \frac{dR}{dS} = \frac{1}{L} \frac{\partial L}{\partial S} - \frac{1}{A} \frac{\partial A}{\partial S} + \frac{1}{S} \frac{\partial S}{\partial S} \dots \textcircled{iii}$$

$$\frac{1}{A} \frac{\partial A}{\partial s} = \frac{(2\pi/4)D}{(\pi/4)D^2} \frac{\partial D}{\partial s} = \frac{2}{D} \frac{\partial D}{\partial s}$$

eqn (iii) Can written as

$$\frac{1}{R} \frac{\partial R}{\partial s} = \frac{1}{L} \frac{\partial L}{\partial s} - \frac{2}{D} \frac{\partial D}{\partial s} + \frac{1}{\rho} \frac{\partial \rho}{\partial s}$$

$$\text{Poisson ratio} = \nu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

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

$$\partial D/D = -\nu \times \partial L/L$$

$$\frac{1}{R} \frac{\partial R}{\partial s} = \frac{1}{L} \frac{\partial L}{\partial s} + \nu \frac{2}{L} \frac{\partial L}{\partial s} + \frac{1}{\rho} \frac{\partial \rho}{\partial s}$$

for small variation

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + \nu 2 \frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \dots (iv)$$

Gauge factor is defined as ratio of per unit change in resistance to per unit change in length i.e.

$$G \rightarrow \frac{\Delta R/R}{\Delta L/L}$$

eqn (iv) $\frac{\Delta L}{L}$ the Gauge factor

$$= 1 + 2\nu + \frac{\Delta \rho/\rho}{\epsilon}$$

When piezo resistive effect is taken

~~Bonded Type Strain Gauge~~

V.V. Imp

Bonded type strain gauge:-

- It consists of a metal foil which is cut into grid like structure.
- It is mounted on a resin film base which is attached to the structure on which stress is applied. With an adhesive.
- The gauge should be positioned in such a way that its ~~active~~ active axis is along the direction of measured strain.
- The structure is subjected to a force due to this force the structure will change its dimension. As the strain gauge is bonded to the structure it will also undergo changes in length & dimensions.
- This strain changes the resistance of the gauge which can be measured with the help of Wheatstone's bridge.

Properties:-

→ Gauge factor = 2 to 2.2

Unstrained resistance = $120 \pm 1 \Omega$

Linearity = $\pm 0.3\%$

maximum tensile strain = $+2 \times 10^{-2}$

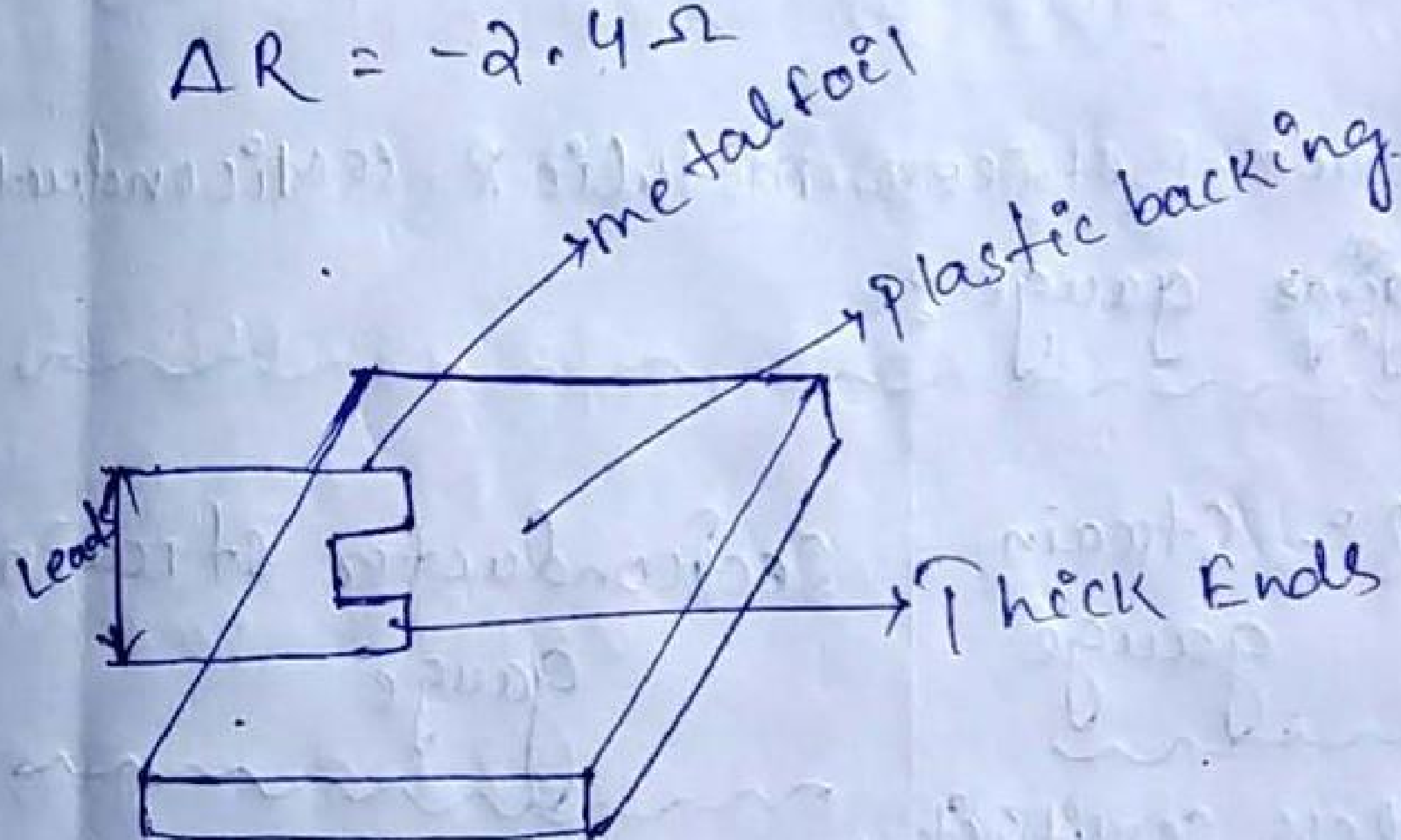
maximum compressive strain = -1×10^{-2}

maximum operating condition = 150°C

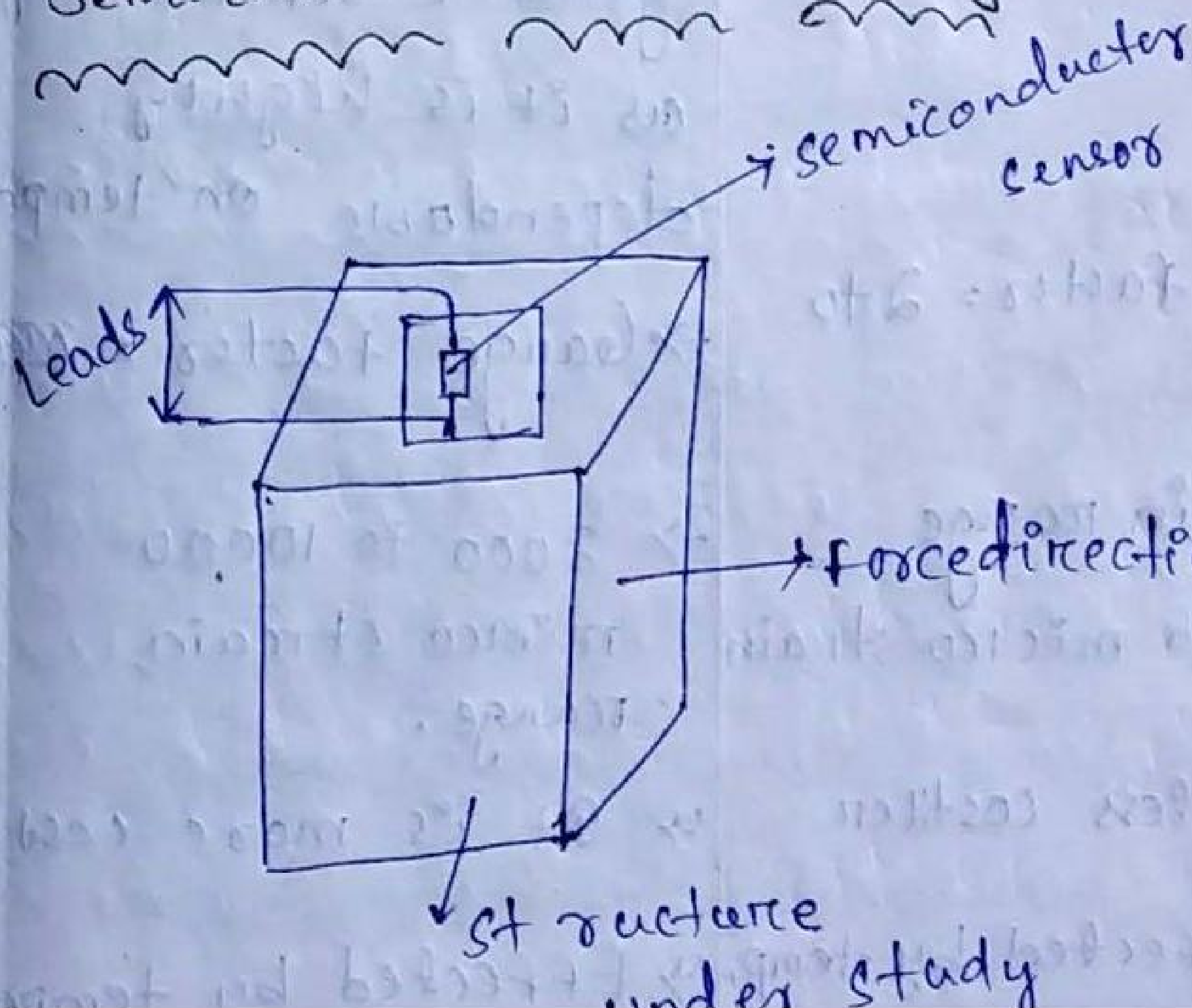
At maximum tensile strain $\Delta R = 4.8 \Omega$

At maximum compressive strain

$$\Delta R = -2.4 \Omega$$



Semiconductor strain Gauge:-



Working:-

- When even a pressure is applied on the test item it will undergo a change which will cause the strain gauge parameters to change.
- It leads to change of parameters of the sensing element which results in change in resistance of the strain gauge which is measured by the help of a Wheatstone bridge.

Difference Between metallic & semiconductor strain gauge :-

Metallic Strain gauge

→ It has less sensitivity

→ Gauge factor = 2 to 3.5

→ strain range = 1 Lakh micro strain

→ It is less costlier

Semiconductor strain gauge

→ It has higher/greater sensitivity as it is highly dependable on temperature.

→ Gauge factor = ~~200~~ 130

→ 3000 to 10,000 micro strain range.

→ It is more costlier

↳ It shows positive temp. coefficient
↳ It shows negative temp. coefficient.



Capacitance can be changed by the following methods:-

(i) variable separation displacement

ⓐ If there is a displacement of x meter x mtr. & the separation

Changes to $d+x$. Then the new capacitance will be given by

$$C = \frac{\epsilon_0 \epsilon_r A}{d+x}$$

(ii) variable area displacement

Sensor :-

In this type the displacement x causes the overlap area to decrease by $\Delta A = wx$

where, w = width of the plate so the

new capacitance will be equal to

$$C = \frac{\epsilon_0 \epsilon_r (A - \Delta A)}{d}$$

(iii) variable dielectric sensor :-

The displacement causes the amount of dielectric material, the total capacitance is now equal to

dielectric constant ϵ_1 & the second
~~width~~ with overlapping area A_2 &
dielectric constant

The new capacitance will be
equal to

$$C = \frac{\epsilon_0 \epsilon_1 A_1}{d} + \frac{\epsilon_0 \epsilon_2 A_2}{d}$$

$$A_1 = \omega n \quad A_2 = \omega(1-n)$$

l = length of plates

ω = width

$$C = \frac{\epsilon_0}{d} [\epsilon_1 \omega n + \epsilon_2 \omega(1-n)]$$

$$\Rightarrow \frac{\epsilon_0 \omega}{d} [\epsilon_2 l - (\epsilon_2 - \epsilon_1)n]$$

Three plate differential or

push-pull displacement sensor:-

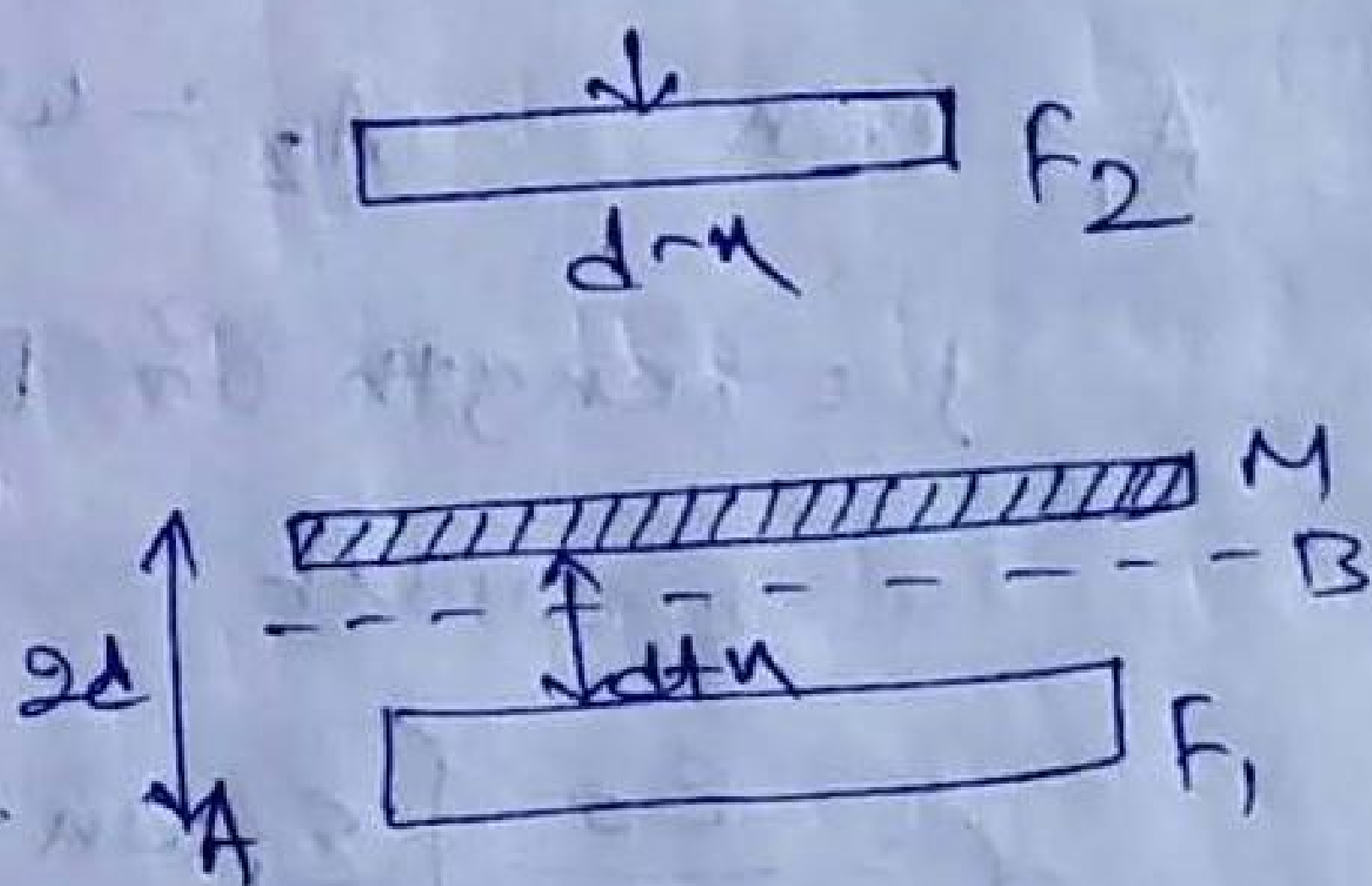
Its principle is same as that
variable separation displacement
sensor, the only difference is that

it avoids the non-linear
characteristics. This sensor consist

of a plate moving between two
fixed plate F_1 & F_2 F_1 & F_2 of "F"

is the displacement of the plate from the center line, then the capacitance C_1 & C_2 formed by MF_1 & MF_2 , respectively are

$$C_1 = \frac{\epsilon_0 \epsilon_r A}{d+u} \quad C_2 = \frac{\epsilon_0 \epsilon_r A}{d-u}$$



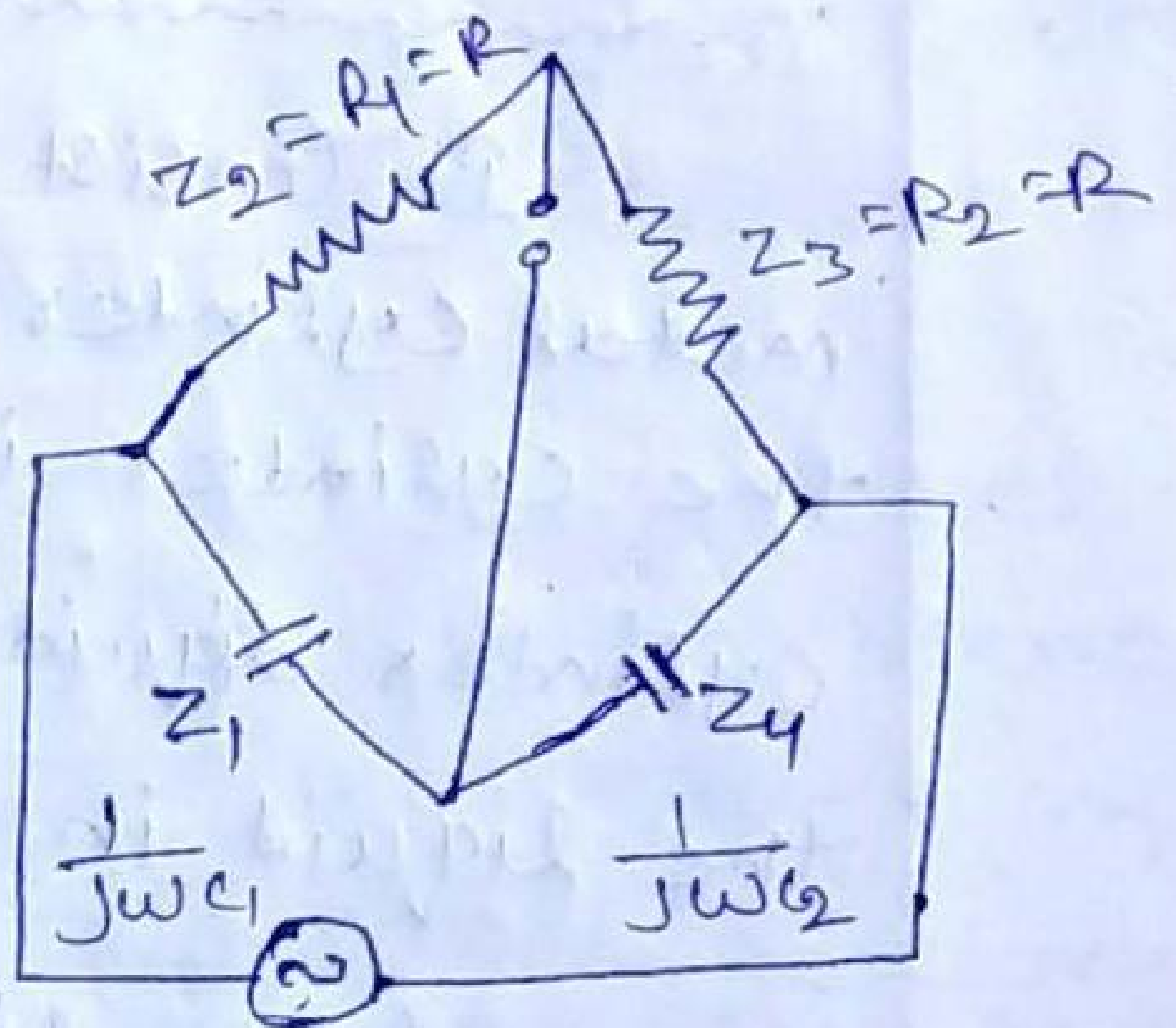
Advantages of differential push-pull
Capacity or inductive type instrument

↳ The non-linear characteristic of a variable separation displacement sensor can be reduced if this arrangement is used in AC deflection bridge.

↳ Hysteresis error of this type are limited to mechanical component only.

↳ They have ~~for~~ Continuous resolution & high output.

Linearity Improvement Using Capacitors



$$E_{th} = V_s \left[\frac{1}{1 + Z_1/Z_4} - \frac{1}{1 + Z_2/Z_3} \right]$$

$$\Rightarrow V_s \left[\frac{1}{1 + C_1/C_2} - \frac{1}{1 + R_1/R} \right]$$

$$\Rightarrow V_s \left[\frac{C_2}{C_2 + C_1} - \frac{1}{2} \right]$$

putting $C_1 = \frac{\epsilon_0 \epsilon_r A}{d+n}$ $C_2 = \frac{\epsilon_0 \epsilon_r A}{d-n}$

$$V_s \left[\frac{d-n}{d-n+d+n} - \frac{1}{2} \right]$$

$$\Rightarrow V_s \left[\frac{d-n}{2d} - \frac{1}{2} \right]$$

$$\Rightarrow V_s \left[\frac{d+n-d}{2d} \right]$$

$$E_{th} = VS \cdot \frac{\mu}{2A}$$

linear & independent
of ω .

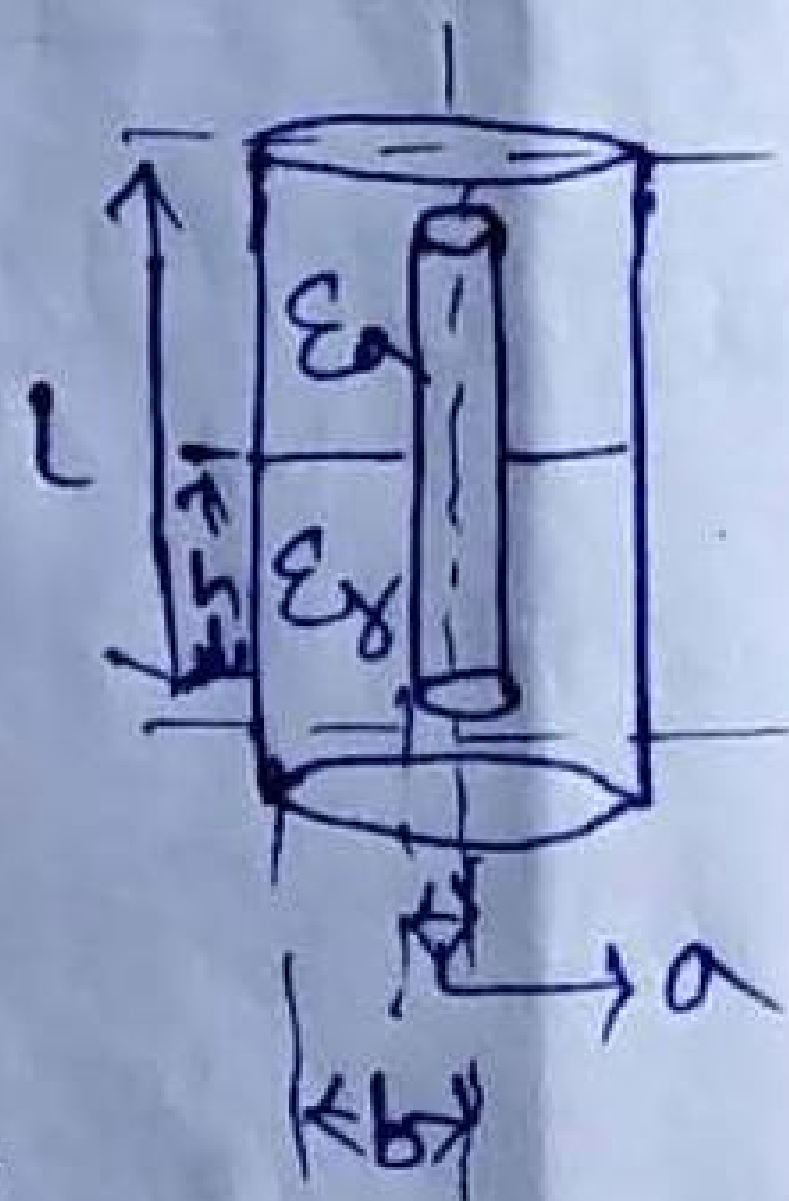
Level Capacitive Sensor:-

It consists of two concentric metal cylinders, the space between the cylinders is filled up by the cylinder liquid to a height (h) of the liquid in the vessel.

If the liquid is non-conducting it will form a suitable dielectric the total capacitance of the sensor will be equal to sum of liquid & air capacitance.

For a Co-axial cylinder

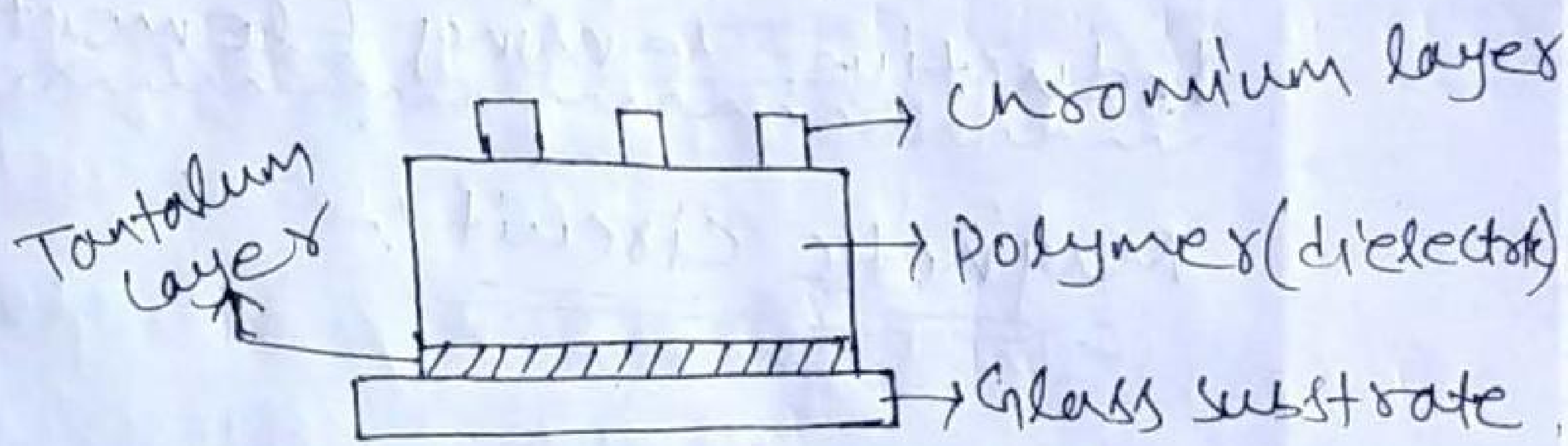
$$C = \frac{2\pi \epsilon_0 \epsilon_r}{\log b/a}$$



For a level sensor

$$C_n = \frac{2\pi \epsilon_0 \epsilon_r h}{\log b/a} + \frac{2\pi \epsilon_0 \epsilon_0 (l-h)}{\log b/a}$$

THIN FILM CAPACITIVE HUMIDITY SENSOR :-



Here the dielectric is a polymer which has the ability to absorb water molecules after absorbing the dielectric constant changes leading to change in capacitance. It consists of a layer of tantalum deposited on a glass over it a layer of polymer dielectric is added and lastly there is a layer of chromium,

which gets damaged under high stress force, thereby allowing water molecules to enter into it.

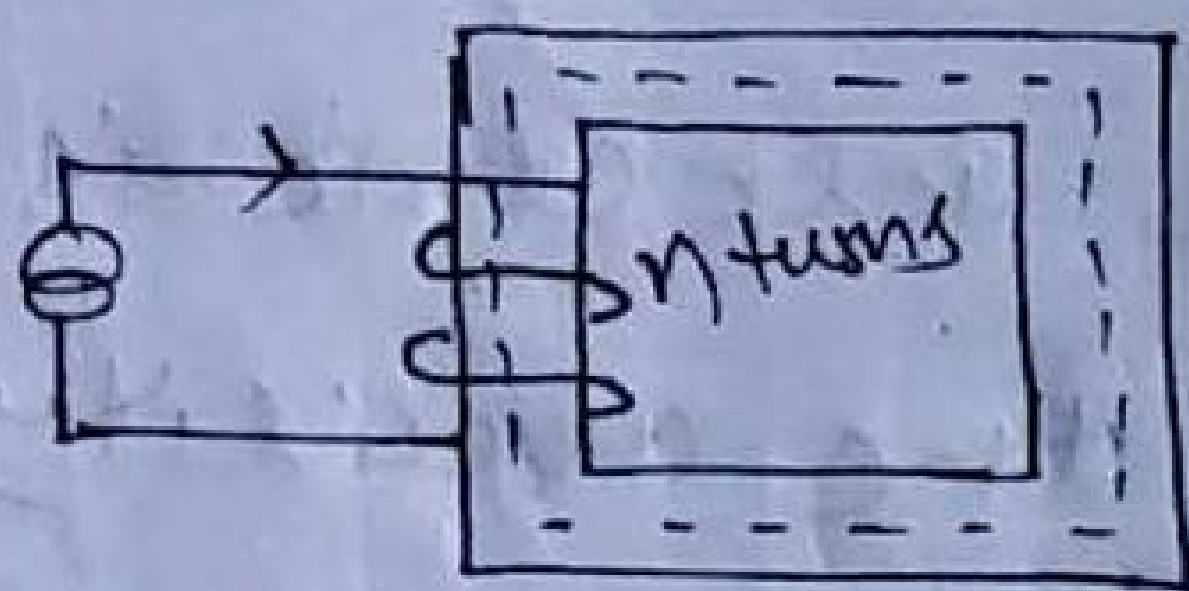
Input range of this type is 0-100% of relative humidity.

Its capacitance value is 375 pico Faraday at 0% relative humidity & the linear sensitivity is 1.7% of relative humidity.

maximum deviation maybe 2% due to non-linearity & 1% due to hysteresis

Inductive sensing Element:-

magnetic circuit:-



The above circuit consists of a core of magnetic material on which a coil of "n" of turns is wound around it & is carrying a current

$$\text{MMF} = \phi \times R, \quad R = \text{Reluctance}$$

$$\text{But } \text{MMF} = ni$$

$$\phi = \frac{\text{MMF}}{R}$$

$$\Rightarrow \frac{ni}{R} \text{ webers in a single turn}$$

Total flux N linked by entire coil of n turns.

$$N = n\phi$$

$$N = \cancel{n\phi} \Rightarrow n^2 i / R$$

Self inductance of a coil is equal to ratio of total flux to total current flowing through the circuit.

$$\text{So } L \rightarrow \frac{\text{Total flux}}{\text{Total current}}$$

$$\Rightarrow \frac{n^2 i}{R} \times \frac{1}{i}$$

$$\Rightarrow \boxed{n^2 / R = L}$$

$$\boxed{\text{Reluctance} = \frac{L}{\mu \mu_0 n^2 A}}$$

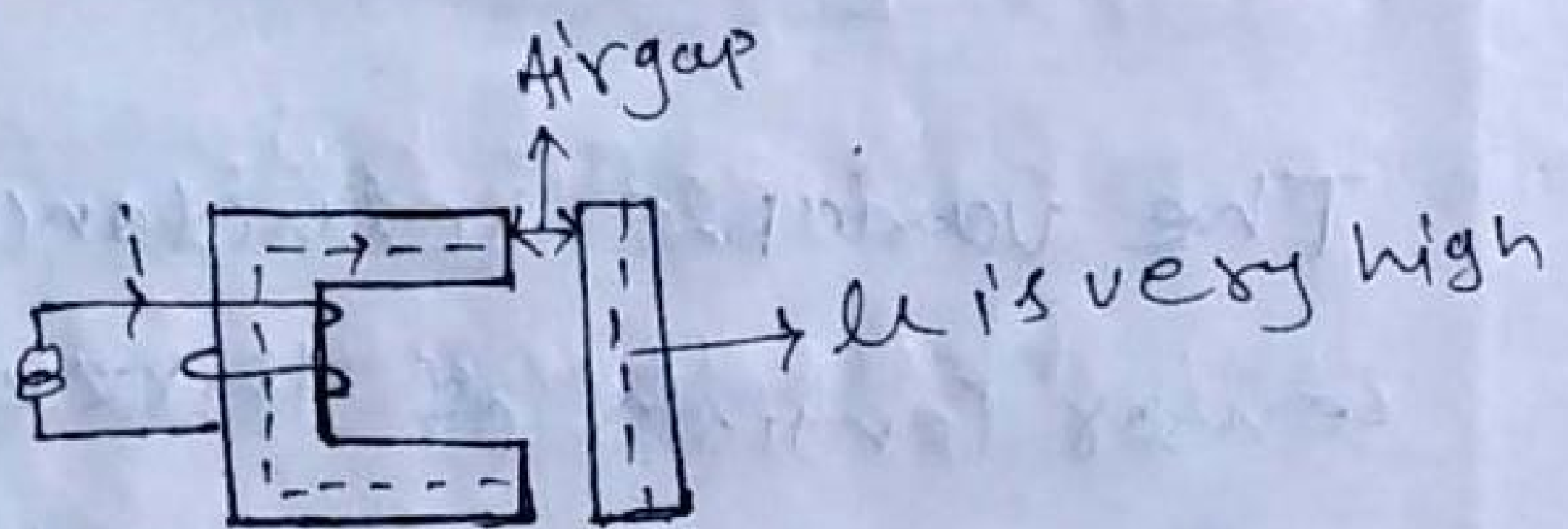
$L \rightarrow$ Total length of flux path,

$\mu \rightarrow$ Relative permeability of the ckt material

$\mu_0 \rightarrow$ Permeability of free space

which is $4\pi \times 10^{-7} \text{ H/m}$

$A \rightarrow$ Area of the plate



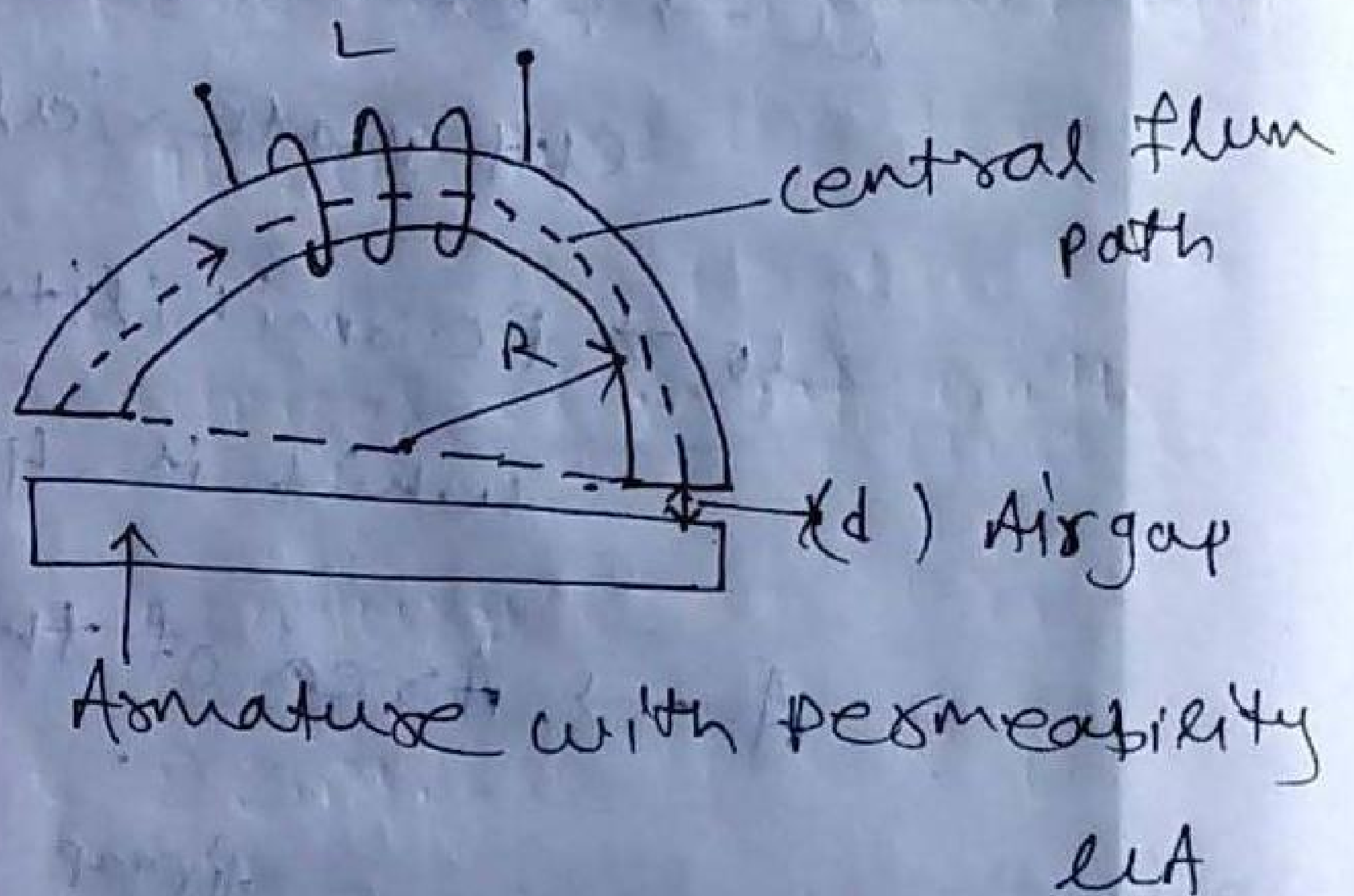
In the above figure the core is separated into two parts by the help of an air gap of variable width. The

Reluctance of the circuit will now be equal to sum of reluctance of the core. Due to the presence of Airgap the permeability decreases which leads to increases in reluctance, finally the flux & inductance value will decrease which leads to change in voltage:

$$\boxed{E = L \frac{di}{dt}}$$

Variable Reluctance Displacement

Sensor



The variable reluctance displacement sensor consists of three elements i.e. A ferromagnetic core in the shape of a semi-circle. A variable Airgap & lastly a ferromagnetic plate or

The total reluctance will be equal to the reluctance of all the three elements (Core, Airgap & Armature) length of the average flux path is $\pi \times R$ through the core, so reluctance of the core will be equal to

$$\Rightarrow R_{\text{core}} = \frac{L}{\mu_0 \mu_r \pi R}$$

$$\Rightarrow \frac{\pi R}{\mu_0 \mu_r \pi R^2}$$

$$\Rightarrow \frac{1}{\mu_0 \mu_r R}$$

Total length of flux path in the airgap is equal to twice the airgap distance,

Assuming $\mu_r = 1$

$$L = 2d$$

$$R_{\text{airgap}} = \frac{L}{\mu_0 \mu_r A}$$

$$\Rightarrow \frac{2d}{\mu_0 \pi r^2}$$

Length of the average flux bar in the armature is equal to twice the radius i.e. $2 \times R$.

We assume that most of the flux is concentrated with an area

$$\pi R^2$$

$$R_{\text{armature}} = \frac{2R}{\mu_0 \mu_r 2\pi t}$$

$$R_{\text{tot}} = R_{\text{core}} + R_{\text{airgap}} + R_{\text{armature}}$$

$$= \frac{R}{\mu_0 \mu_r \pi^2} + \frac{2d}{\mu_0 \pi \pi^2} + \frac{R}{\mu_0 \mu_r \pi^2}$$

$$= \frac{R}{\mu_0 \pi} \left[\frac{1}{\mu_r} + \frac{1}{\mu_r} \right] + \frac{2d}{\mu_0 \pi \pi^2}$$

$$R_{\text{tot}} = R_0 + Kd$$

R_0 = Reluctance at zero Airgap

$$K = 2\pi \mu_0 \times \pi \pi^2$$

For a typical element with

$$n = 500 \text{ turns}$$

$$R = 2 \text{ cm.}$$

$$\pi = 0.5 \text{ cm.}$$

$$\text{thickness} = 0.5 \text{ cm.}$$

permeability of core & armature

equal to μ_0

The value of inductance is given by

$$L = \frac{n^2}{R}$$

$$= \frac{n^2}{R_{TOT}}$$

$$= \frac{n^2}{R_0 + Kd}$$

$$L = \frac{L_0}{1 + \alpha d}$$

$$L_0 = \frac{n^2}{R_0} = \text{Inductance at zero displacement}$$

$$\alpha = K/R$$

Value of L_0 & α depend upon core

geometry permeability etc. For the above element $L = 19$ millihenry at $d = 0$ &

$L = 7.6$ millihenry at $d = 1$ millimeter. The

only disadvantage of this type is its non-linearity.

Push-pull or Differential Displacement

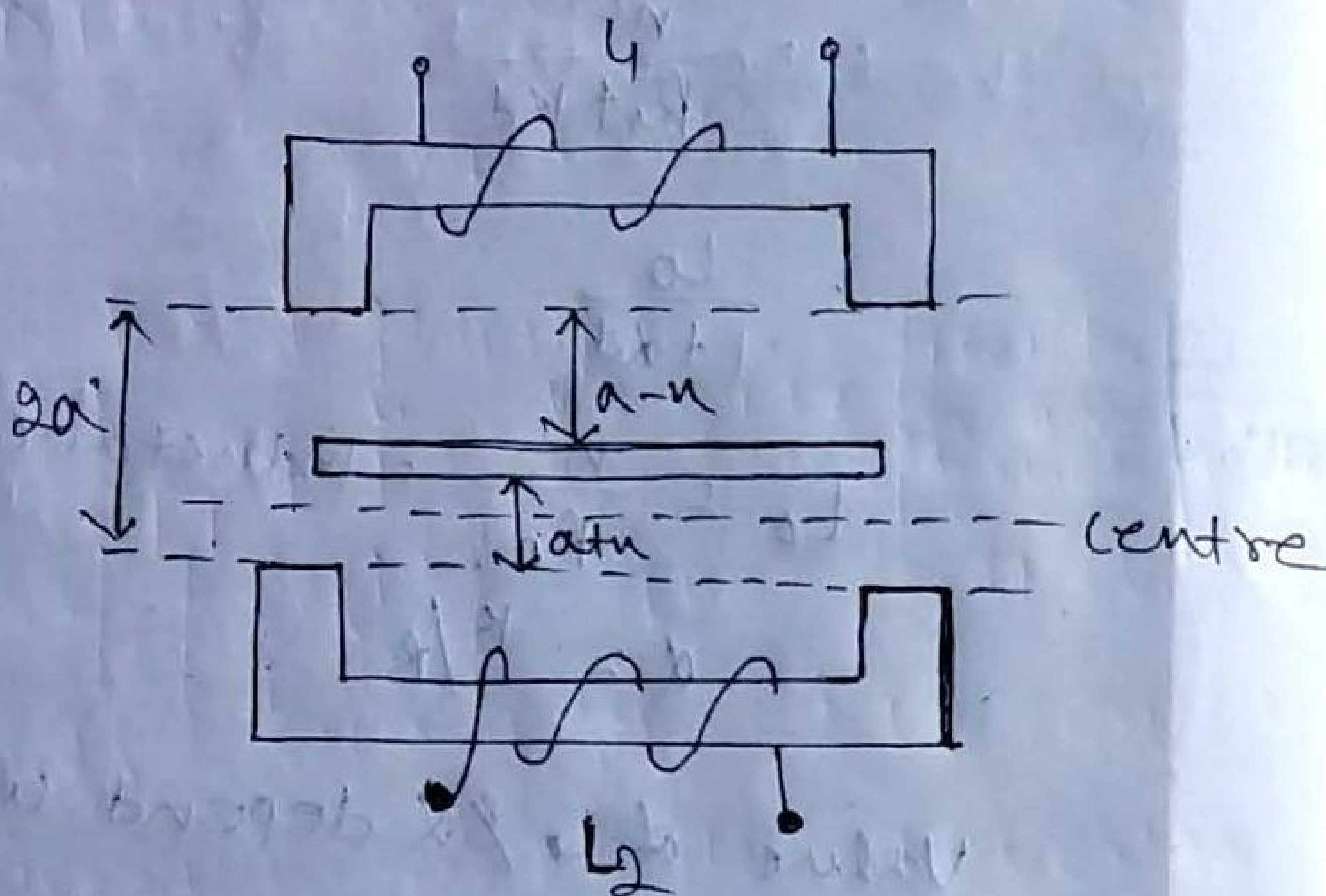
Sensor :-

It consists of a armature moving between two identical cores separated by a fin distance of $2a$ meter. Here

L will be equal to :

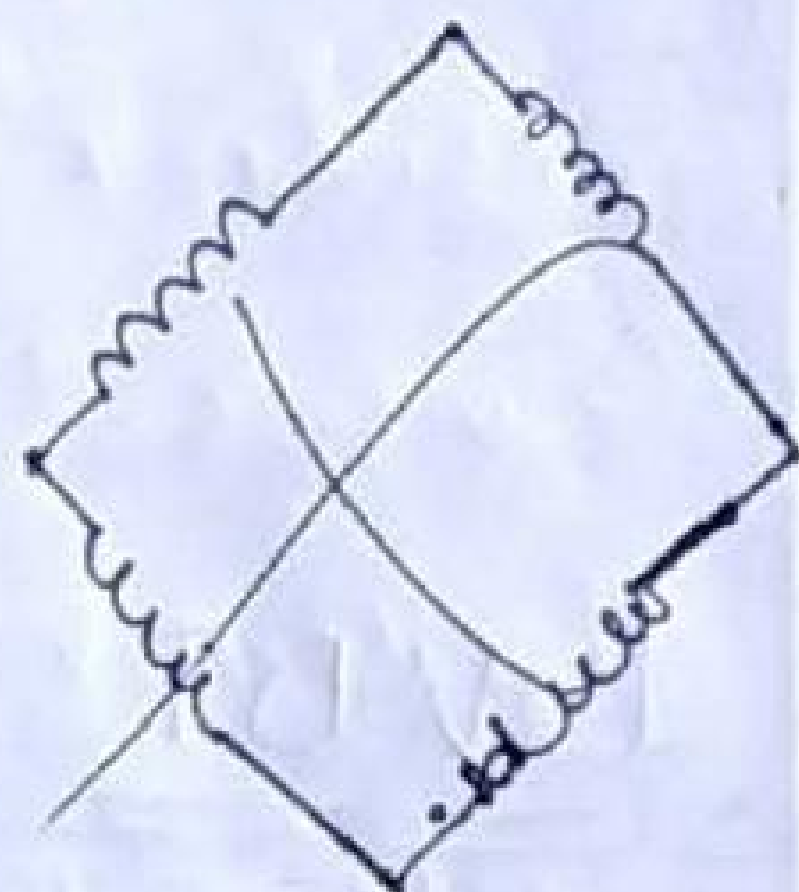
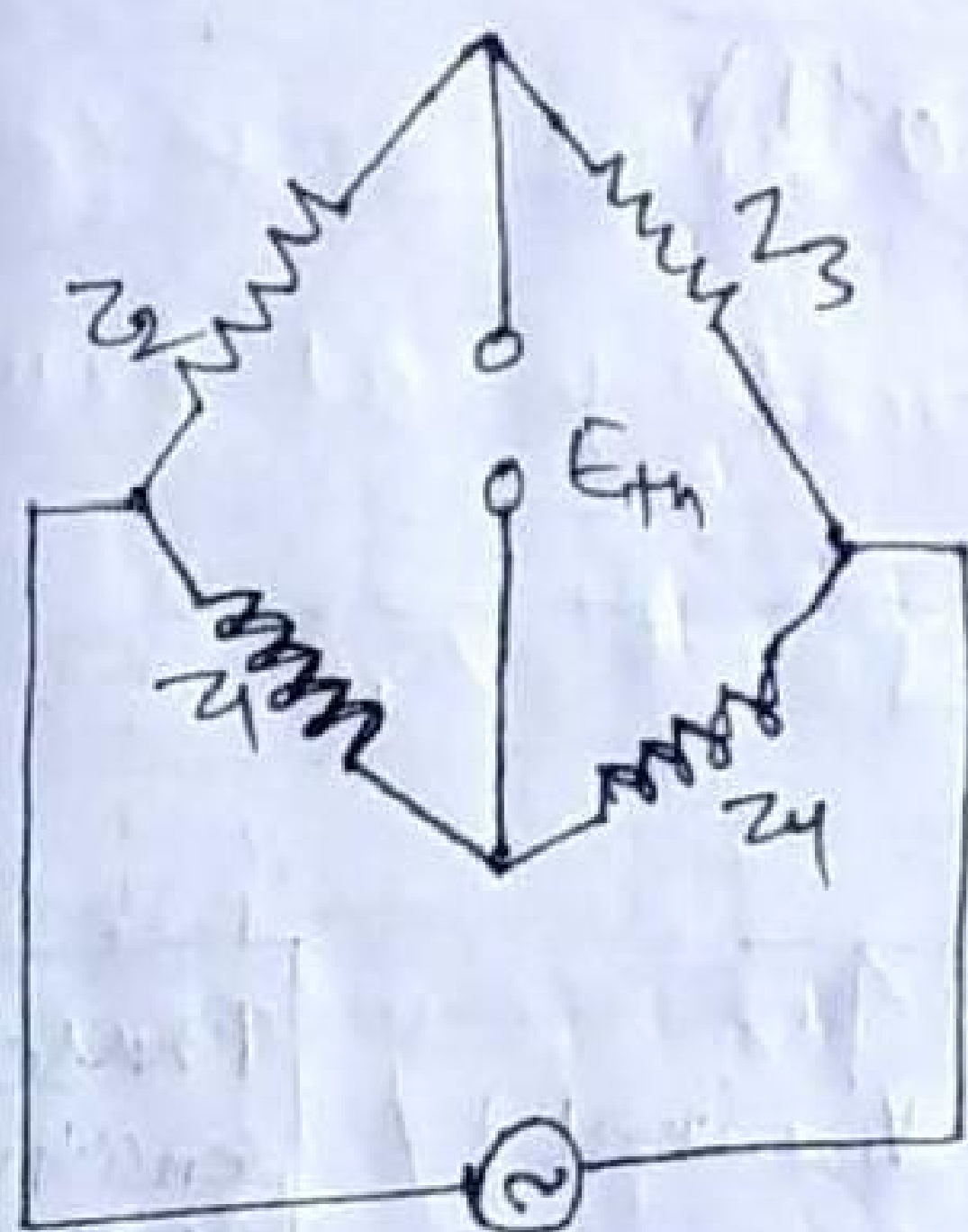
$$L_1 = \frac{L_0}{1 + \alpha(a-x)}$$

$$L_2 = \frac{L_0}{1 + \alpha(a+x)}$$



The relation between L_1 & L_2 & x is still non-linear but if the sensor is used in a AC depletion bridge then the overall relation between output voltage distance x will become linear, its parameters are input span equals to $\frac{1}{2}$ inch, coil of inductance at zero airgap is equal to 25 millihenry, The coil resistance equals to 70- Ω & maximum non-linearity is equal to 0.5%.

Linearity Improvement



$$Z_1 = j\omega L_1 \quad Z_4 = j\omega L_2$$

$$Z_2 = Z_3 = R$$

$$E_{tn} = V_s \left[\frac{1}{1 + \frac{Z_4}{Z_1}} - \frac{1}{1 + \frac{Z_2}{Z_3}} \right]$$

$$\Rightarrow V_s \left[\frac{1}{1 + L_2/L_1} - \frac{1}{2} \right]$$

$$\Rightarrow V_s \left[\frac{L_1}{L_1 + L_2} - \frac{1}{2} \right]$$

$$\Rightarrow \frac{V_s}{2} \left[\frac{L_1 - L_2}{L_1 + L_2} \right]$$

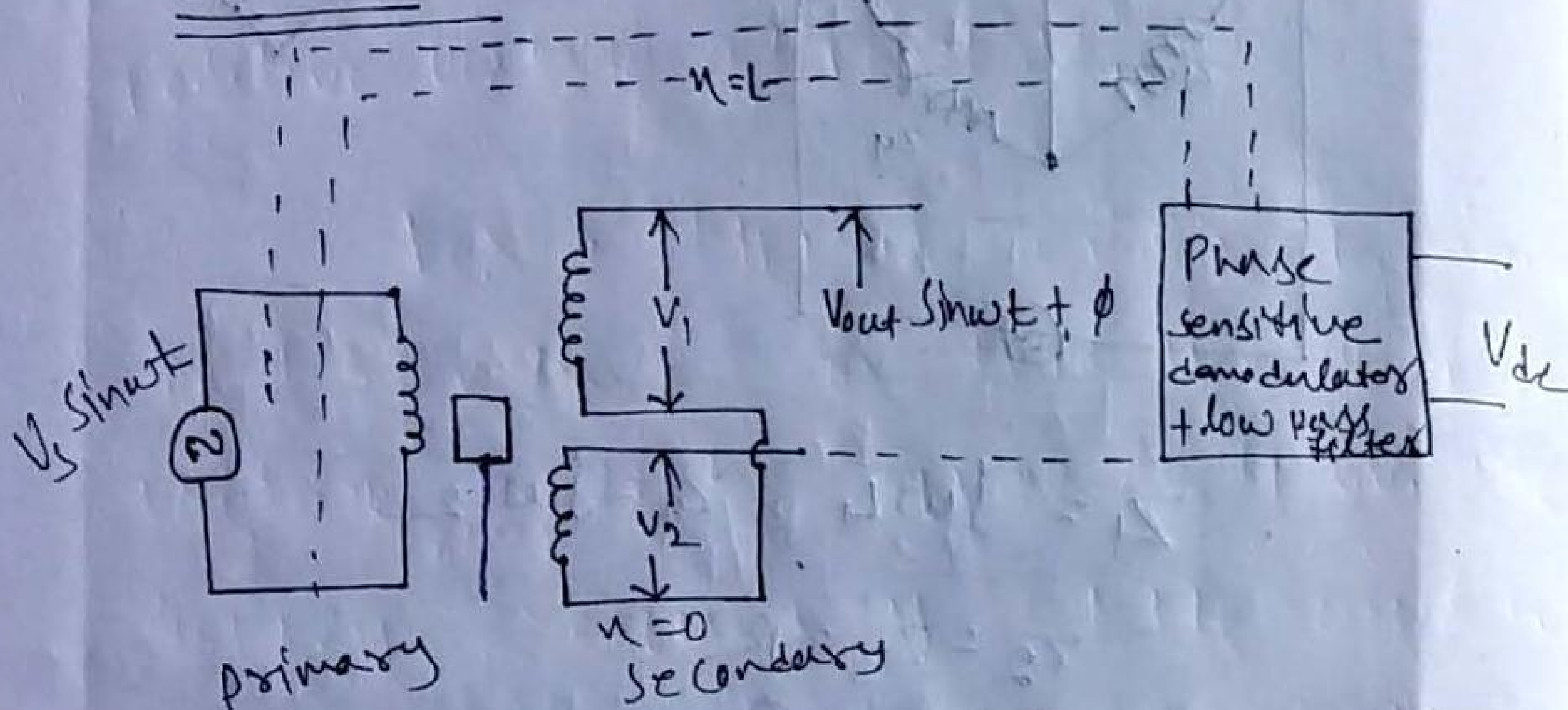
$$\Rightarrow \frac{V_s}{2} \left[\frac{\frac{L_0}{1 + \alpha(a - u)} - \frac{L_0}{1 + \alpha(atu)}}{\frac{L_0}{1 + \alpha(atu)} + \frac{L_0}{1 + \alpha(a - u)}} \right]$$

$$\Rightarrow \frac{V_s}{2} \left[\frac{(1 + \alpha(atu)) - (1 + \alpha(a - u))}{(1 + \alpha(atu)) + (1 + \alpha(a - u))} \right]$$

$$E_{th} = 2 \times n \times \frac{V_s}{2} \cdot \frac{1}{2(\alpha + 1)}$$

$$\Rightarrow \frac{V_s \times n}{2(\alpha + 1)}$$

L.V.D.T

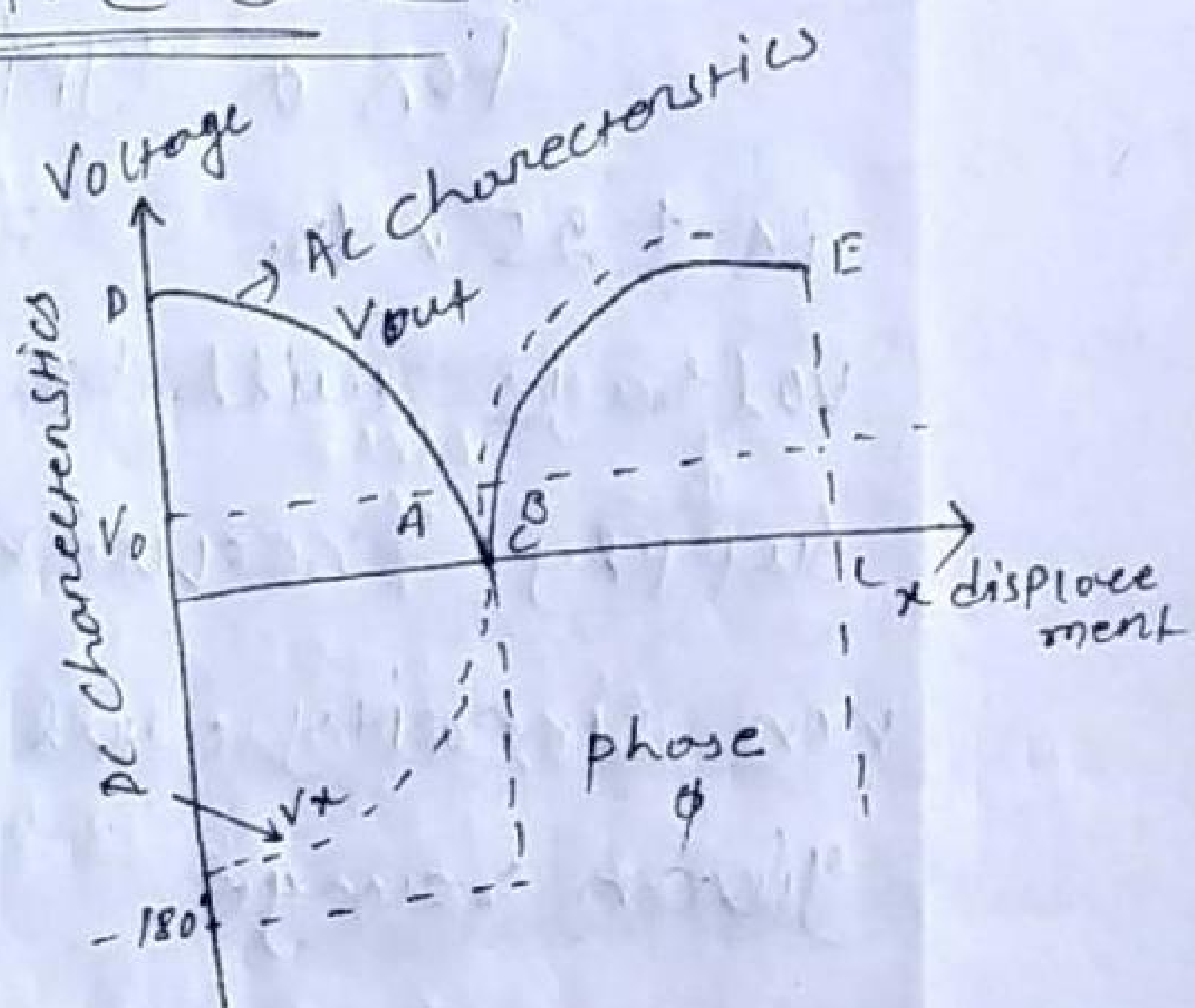


The primary winding is energised by AC voltage of V_s Amplitude. The two secondaries are connected in series opposition, so that the net output voltage is the difference between V_1 & V_2 . (Voltages induced in the secondary)

→ A ferromagnetic core moves inside a former which will alter the mutual inductance between primary & secondary. When the core

the o/p. voltage will be equal to zero
 So the o/p. voltage changes with the
 core position x thereby changing the
 output voltage & its phase angle.

Relation between phase angle & Position of the Core :-



In the above figure "C" is the null
 point at which the output voltage will
 be equal to zero at the points "A" & "B"
 equally spaced around the point "C", we
 get the required output voltage i.e. at
 point "A" the output voltage is 180° out of
 phase with the primary voltage & at "B"
 the o/p. voltage is in phase with the
 primary voltage at points "D" & "E" non-
 linearity occurs.

The AC output voltage signal can be converted into DC by the help of a rectifier or a phase modulator which senses the phase difference and gives a negative voltage at point "A" & positive voltage at point "V".

For a typical sensor the range is ± 25 mts. For this the supply voltage will be equal to 4.6V, The supply frequency 5 kHz will be non-linearity will be 1% above the given range.

Electro Magnetic Sensor :-

$$\mathcal{E} = - \frac{dN}{dt}$$

$$N = \Phi \mu n$$

These elements are used for measurement of linear & angular velocity. This is operated on Faraday's law of electromagnetic induction, which states that if the flux linked by a

back emf is induced in the conductor
the change in flux is due to motion
of the conductor i.e. - the induced emf
is a function of linear angular velocity
of the motion.

Variable Inductance Reluctance

Tacho Generator:-

This structure consist of a wheel
of ferromagnetic material and a
coil wound around a permanent magnet
This will moves in closed proximity
with the pole piece causing the flux
linked by the coil to change with time
by inducing $\mathcal{E}$ emf in it whose magnitude
can be calculated by considering the
magnetic circuit formed by the permanent
magnet airgap & where the m.m.f.
is constant with time & depends upon the
strength of the magnet.

$$\phi = \frac{\text{MMF}}{R}$$

Total flux linked by coil of a "N" no. of turns

$$\Rightarrow N\phi = \frac{N \times \text{MMF}}{R} \dots \dots \textcircled{1}$$

That means $N \propto \frac{1}{R}$

Eqn. $\textcircled{1}$ can be written as $N(\phi) = a + b m \cos \phi$

a = Mean flux

b = Amplitude of flux variation

m = No. of teeth

Hence,

$$E = - \frac{dN}{dt} = - \frac{dN}{d\theta} \times \frac{d\theta}{dt}$$

$$\frac{dN}{d\theta} = -bm \sin m\theta$$

$$\frac{d\theta}{dt} = \omega r \text{ (Angular velocity)}$$

$$\theta = \omega r t \text{ (Assuming } \theta=0 \text{ at } t=0)$$

$$E = -bm \omega r \sin m \omega r t$$

$$E = bm \omega r$$

$$f = \frac{m \omega r}{2\pi}$$

The amplitude & frequency are proportional to angular velocity of the wheel so ωr can be found out from either amplitude or frequency of the signal. practically the amplitude is measured by a distant recorder or indicator but it is effected by electrical interference & loading effect.

therefore a frequency system is preferred where no. of cycles in a given time is counted a digital signal corresponding to angular velocity.

Q.) A variable reluctance tachogenerator consists of a ferromagnetic gear, wheels consist of 22 no. of teeth rotating closed to the magnet & coil assembly, the total flux linked is given by

$$\cancel{N(\theta)} N(\theta) = 4 + 1.5 \cos 22\theta \text{ m/Wb}$$

Calculate the amplitude & frequency when angular velocity is 1000 rpm.

Soln.

$$N(\theta) = a + b \cos m\theta$$

$$N(\theta) = 4 + 1.5 \cos 22\theta$$

$$a = 4 \quad b = 1.5$$

$$m = 22$$

$$E = b m \omega$$

$$= 1.5 \times 22 \times 1000 = 33000 \text{ V}$$

$$f = \frac{m \omega}{2\pi} = \frac{22 \times 1000}{2 \times 3.14} = 3503.18 \text{ Hz}$$

Q.1) A variable reluctance sensor consists of a coil made up of steel of diameter ϕ relative permeability 100 which is bent to form a semi-circular of diameter 4 cm.

Solⁿ

$$\text{Total Reluctance} = \frac{R}{\mu_0 \mu_r l} + \frac{2d}{\mu_0 \pi r^2}$$

$$+ \frac{R}{\mu_0 \mu_r l}$$

$$\text{Given } \mu_r = \mu_A = 100$$

$$\mu_0 = 4\pi \times 10^{-7}$$

$$d = 1 \text{ mm}$$

$$r = 2 \text{ cm}$$

$$l = 0.5 \text{ mm}$$

$$R = 0.5 \text{ cm}$$

$$R = \frac{0.5}{4\pi \times 10^{-7} \times 100 \times 4} + \frac{2 \times 0.1}{4\pi \times 10^{-7} \times \frac{22}{7} \times 4}$$

$$+ \frac{0.5}{4\pi \times 10^{-7} \times 100 \times 2 \times 0.5}$$

$$\Rightarrow 17633.64$$

$$L = \frac{n^2}{R} = \frac{500 \times 500}{17633.64} = 14.17 \text{ Henry}$$

Hall effect sensor

It varies its output voltage in response to a magnetic field, it is used for proximity switching speed detection current sensing etc.

Working principle:-

When a beam of particles is pass through a magnetic field, forces act on this particles & the beam is deflected from its straight path. Similarly, when a conductor is placed in a magnetic field perpendicular to direction of electron, there will be ~~be~~diverted. As a result one plane of the conductor will become negatively charged & the other becomes positively charged.

The voltage between the two surfaces is the hall voltage. This type of sensors either so linear property ($V_H \propto$ magnetic flux density) &

Application of all effect sensor :-

These are basically used for position detection, speed control or detection & current sensing.

Advantages :-

(i) It has less cost, it can be used up to 60 kHz.

(ii) It doesn't suffer from contact resistance.

(iii) It is not effected by environmental condition.

This type of device less accuracy & its how good depends to a new value which requires compensation.

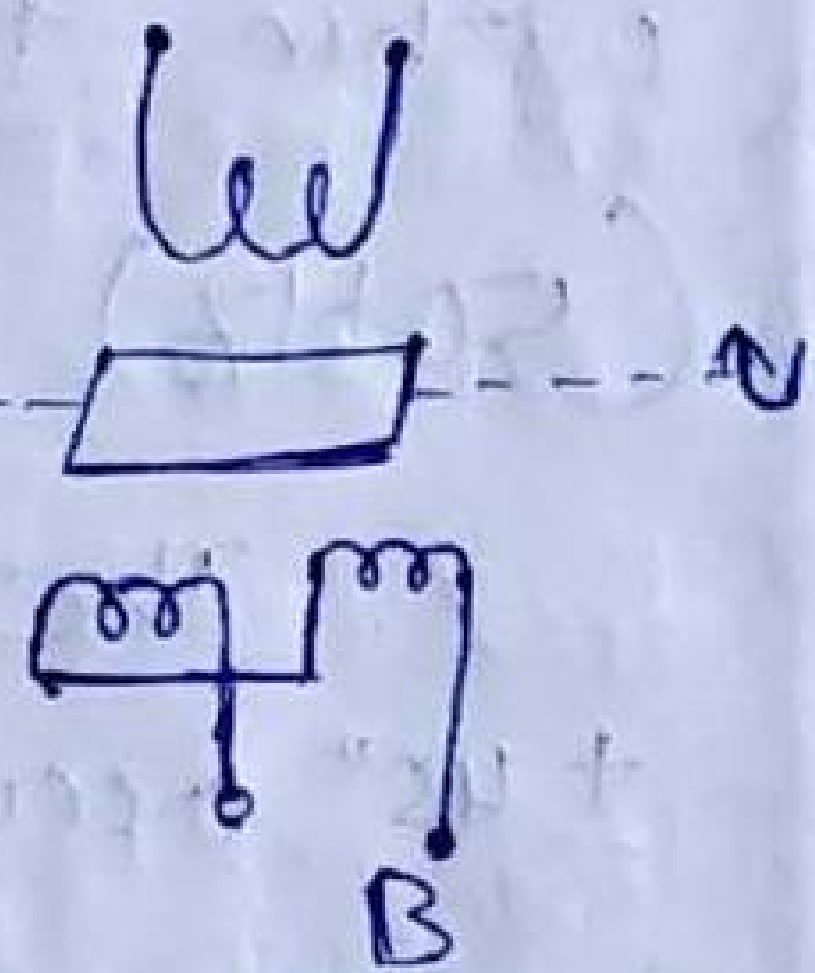
(RVD) Rotary Variable Differential Transformer

It is use for angular

displacement measurement

by producing a variable

ac output voltage.



This is linearly proportional to angular displacement of the shaft.

The stator coil consists of a primary excitation coil & pair of secondary output coil. A fixed alternating current excitation is given to the primary stator i.e. - Electromagnetically coupled with the secondary coil. The output coils are so designed that one coil is in phase with the excitation coil & the other is 180° out of phase.

When the rotor is in a position that directs equal flux into both the output coil the net o/p. voltage will be equal to zero.

When the rotor is displaced from this position o/p. voltage is produced which is proportional to direction of rotation.

Its excitation frequency lies within $\pm 1\%$ of the supply frequency.
(50 Hz)

The RVDT operates between $\pm 45^\circ$ accuracy, but the accuracy

→ Its Advantage is low sensitivity to temperature change, it is not effected by primary voltage or frequency variation.

→ It is less costly.

→ It is smaller in size.

→ It has simple control electronics.

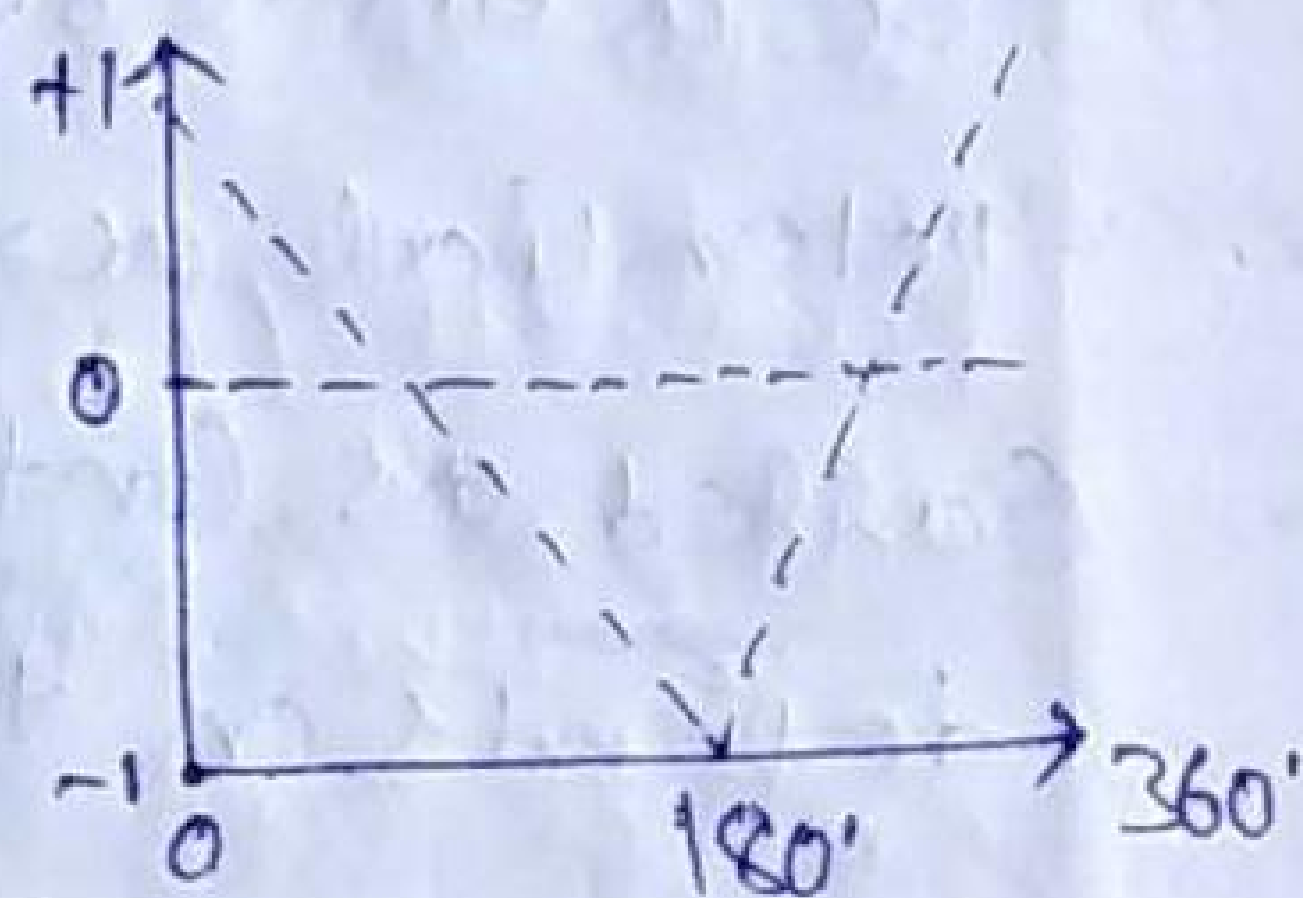
$$\theta = G \left(\frac{V_1 - V_2}{V_1 + V_2} \right)$$

G = sensitivity

$$V_2 = V_1 \pm G \cdot \theta$$

$$\Delta V = 2 \cdot G \cdot \theta$$

$V_1 - V_2$ gives a proportional voltage.



→ Since the o/p. voltage is a function of angle of the shaft & sensitivity so, these types of device is independent of supply voltage & supply frequency.

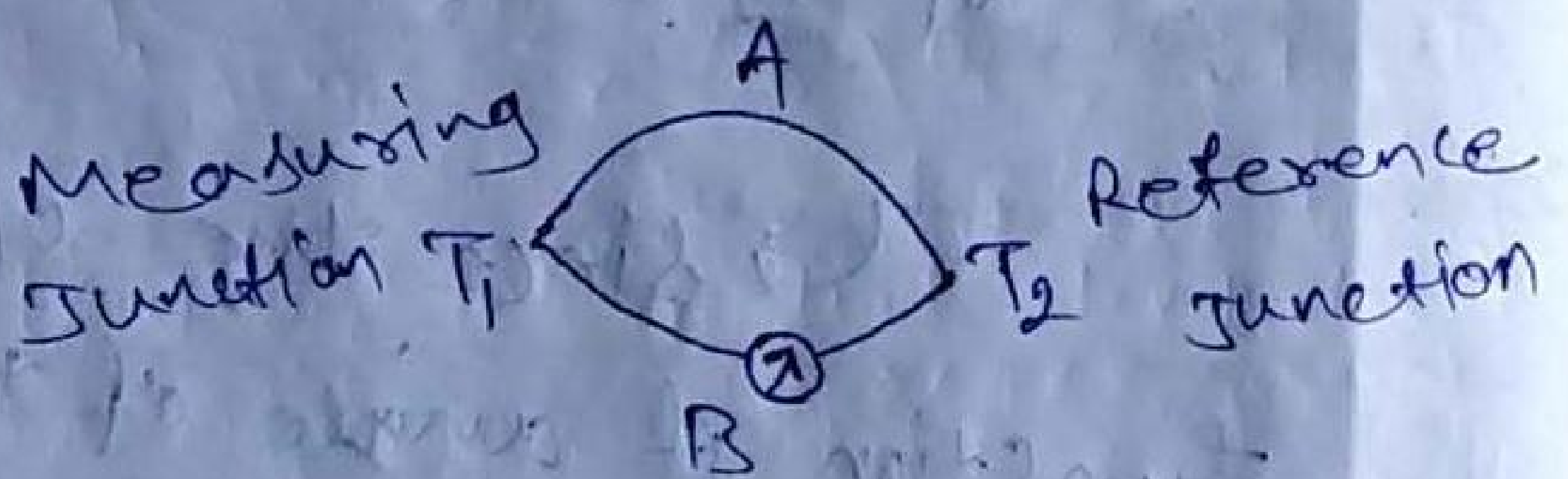
Thermo Electric Sensing Element

These are mostly use for measurement of temperature.

Working principle:-

When two different metals A & B are joint together there will be a difference in the electric potential across the junction which is called as contact potential, which depends on type of metal & ~~there~~ their temperature is given as

$$E_T^{ab} = a_1 T + a_2 T^2 + a_3 T^3 + \dots$$



$E_{T_1 T_2 AB}$

A thermocouple is a close circuit consisting of two junction at temperature T_1 & T_2 respectively. If a high impedance voltmeter is introduced in the

will flow through it & measured emf is shown in the figure.

$$E_{T_1 T_2}^{AB} = E_{T_1}^{AB} - E_{T_2}^{AB}$$

$$= [a_1 T_1 + a_2 T_1^2 + \dots] - [a_1 T_2 + a_2 T_2^2 + \dots]$$

$$= a_1 (T_1 - T_2) + a_2 (T_1^2 - T_2^2) + \dots$$

Measured emf depends upon temperature of both junction.

$T_1 \rightarrow$ Temp. to be measured

$T_2 \rightarrow$ Temp. of reference junction

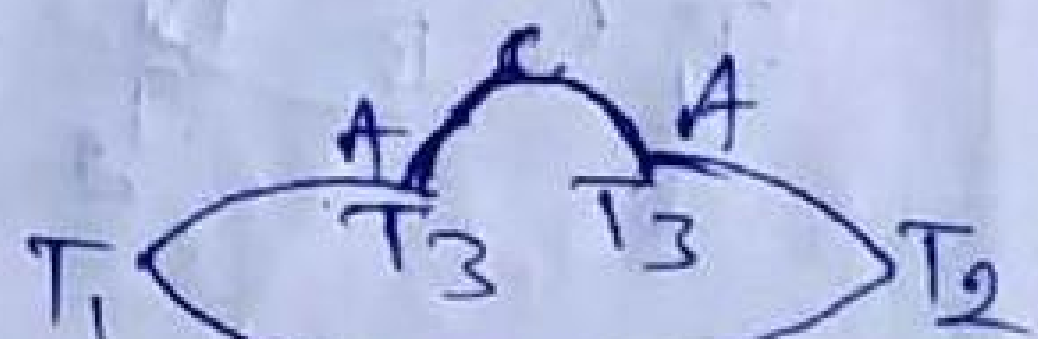
Law's of Thermocouple :-

Point -01

It states that emf of a given thermocouple depends only on temperature of the junctions & is independent of the temperature of wire connecting the junction.

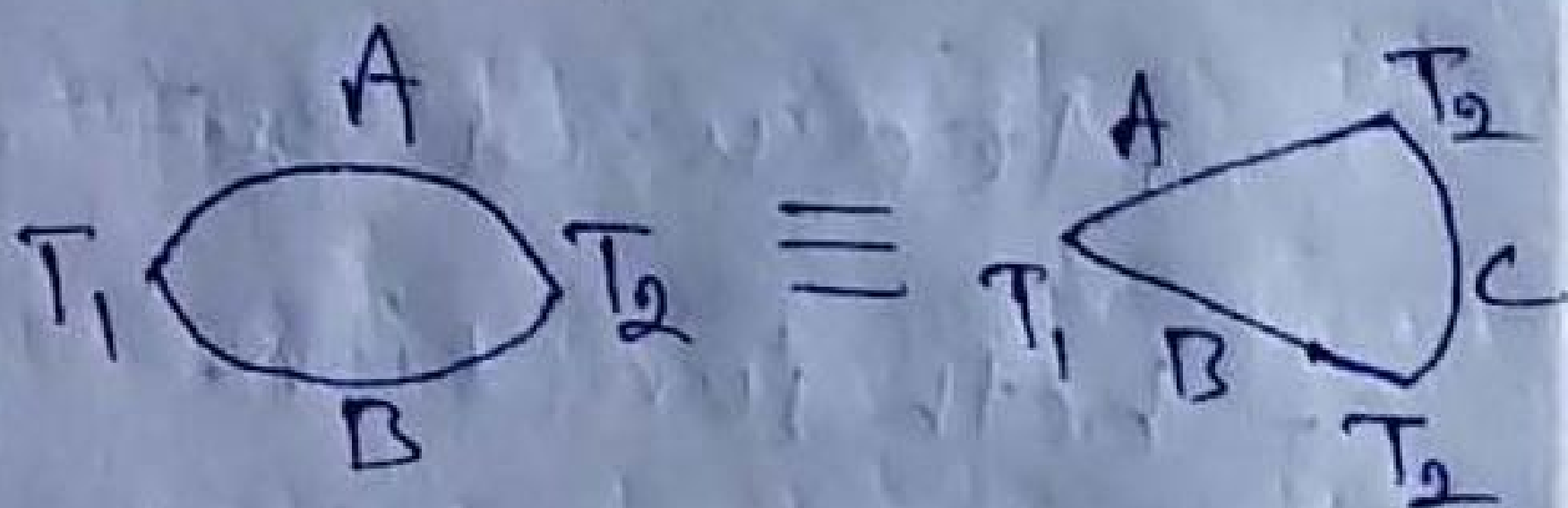
Point -02

It states that if a third metal is introduced into either metal A or B and if the two new junction are at same temperature T_3 , then the emf remains unchanged.



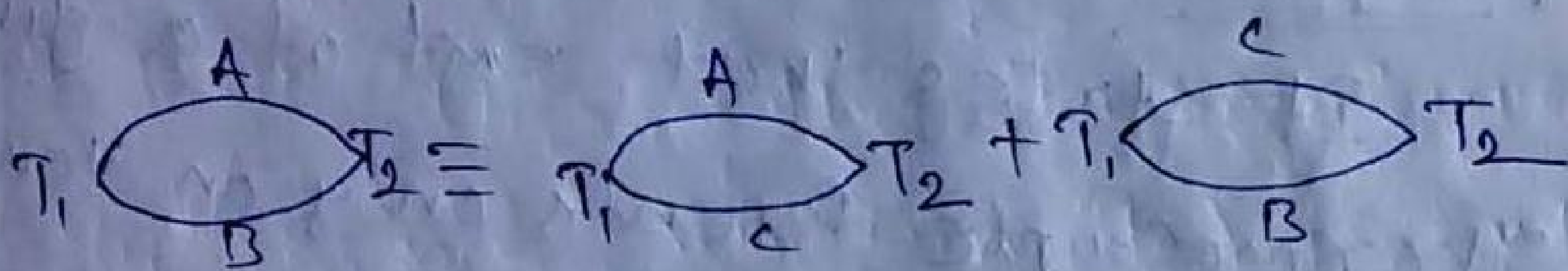
Point-03

It states that if a third metal C is inserted between A & B at either junction and the two new junction A/C or C/B are at same temperature T_1 ~~or~~ T_2 C, then the emf remains unchanged.



Point-04 (Law for Intermediate metal)

This law is used to find out the emf of Copper iron thermocouple, if emf of Copper constant & constant iron thermocouple are given.



Point-05 (Law for Intermediate temperature)

$$E_{T_1 T_2} = E_{T_1 T_3} + E_{T_2 T_3}$$

$T_3 \rightarrow$ Intermediate temperature

$$\text{If } T_2 = 0, \quad E_{T_1 0} = E_{T_1 T_3} + E_{T_3 0}$$



The working principle of thermocouple is based on two principles.

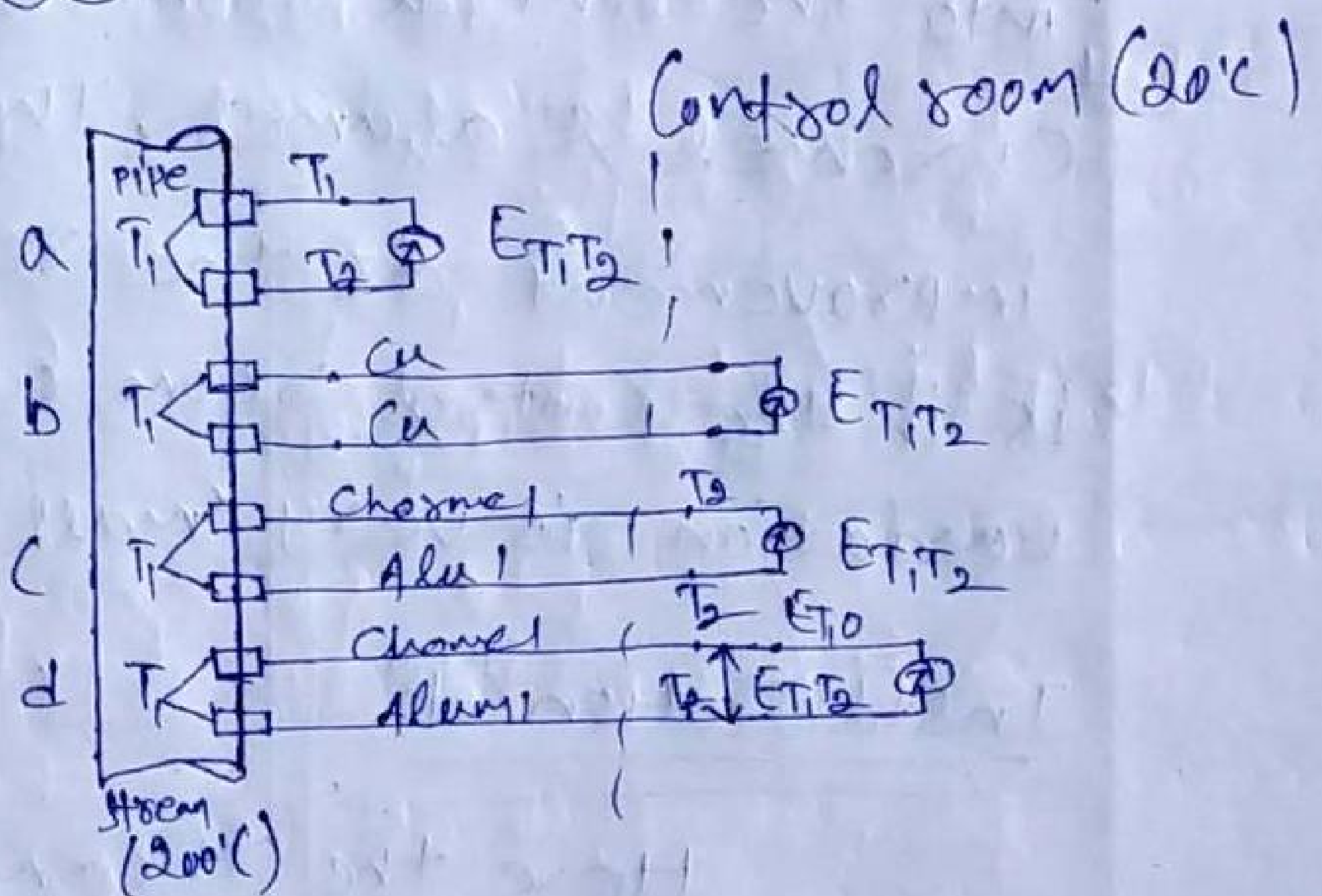
(i) Seebeck effect:-

It states that if a closed circuit is formed of two dissimilar metals at the two junctions are maintained at different temperature an electric current will flow through the circuit.

(ii) Peltier effect:-

It states that when a loop is formed of two dissimilar metals & if an external current is forced to flow then one of the junction gets heated & the other junction stay cool.

Installation:-



Installation "a"

Here the meter is located just outside the pipe, the reference junction temperature T_2 can vary widely from 0°C to $+50^\circ\text{C}$.

Installation "b"

In this type the meter is located inside a control room & is connected to the ~~thermo~~ thermocouple through copper & this is also not used as the reference junction (T_2) is still located in open atmosphere.

Installation "c"

Here the thermocouple reference junction (T_2) is extended into the control room with the help of chromel & alumel. This is an improvement as the reference junction is in the control room where the temp. variation is very small (about 10°C).

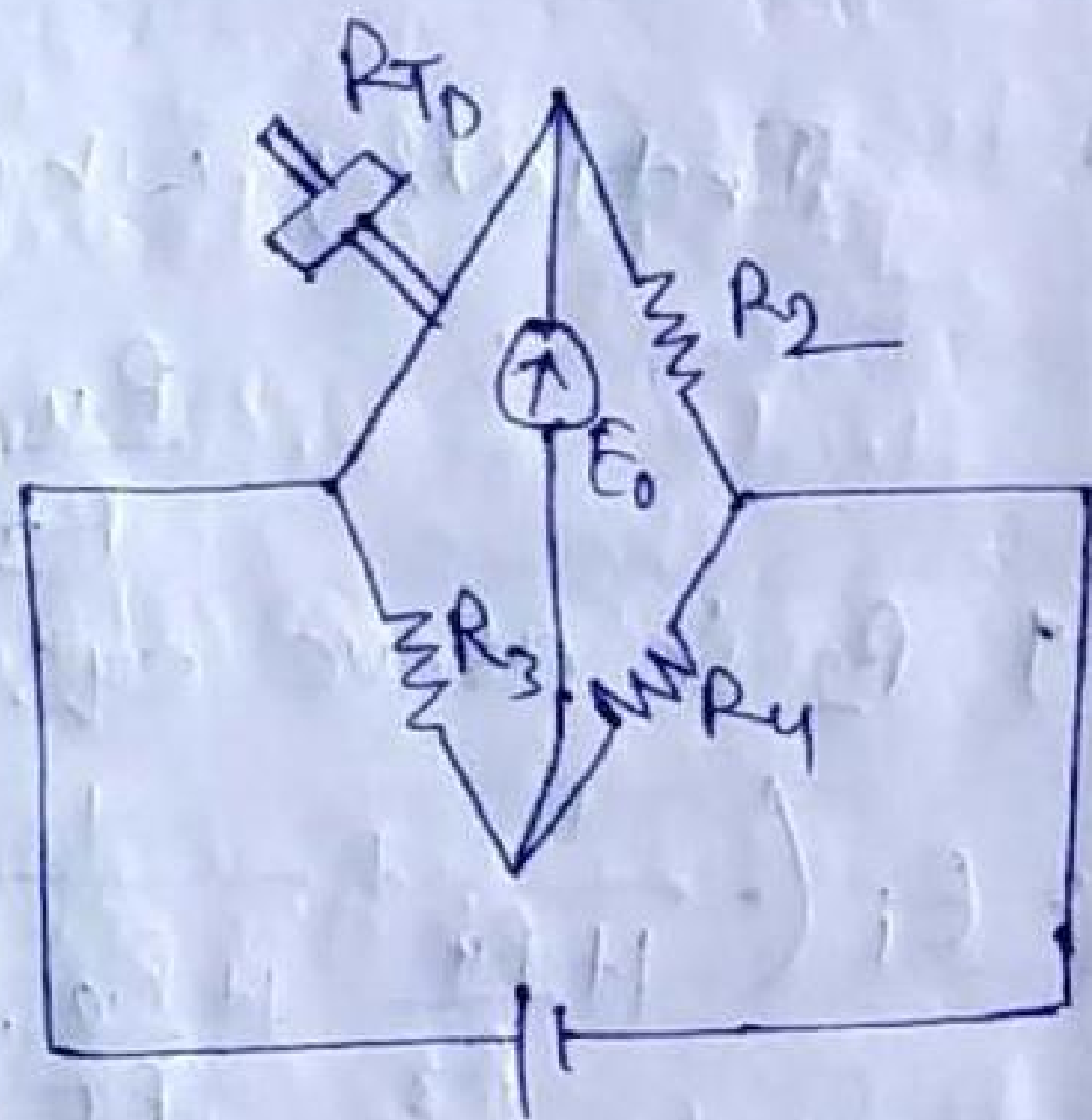
Installation "d"

Here the thermocouple emf

$T_1^{\circ}\text{C}$ & ref. Junction $T_2^{\circ}\text{C}$. If we introduce another source of emf of magnitude $E_{T_2,0}$ then the voltmeter will give a emf (measured temp. T_1 & Ref. temp. 0°C all through the Ref. Junction temp. is 20°C).

Cold Junction Compensation :-

Here a bridge circuit is use to generate a compensating voltage for the cold junction of the thermocouple.



Let the Cold junction temperature be $T^{\circ}\text{C}$ for which compensating voltage is equal to E_0 , let there be a small variation in temperature when E_0 is given as

$$E_0 = KT$$

The variation E_0 can be obtain

by inserting an RTD in one arm of a wheatstone bridge.

For small temperature change the resistance temperature relation of a RTD can be written as

$$R_T = R_0 (1 + \alpha T)$$

As α is very small

$$\frac{R_T}{R_0} \approx 1$$

For a resistive bridge

$$E_{th} = E_i \left(-\frac{1}{1 + \frac{R_4}{R_3}} + \frac{1}{1 + \frac{R_2}{R_T}} \right)$$

Initially when bridge is balanced

$$\frac{R_4}{R_3} = \frac{R_2}{R_0} = R_2 = R_0 \frac{R_4}{R_3}$$

Putting R_2 in above eqn.

$$E_{th} = E_i \left(-\frac{1}{1 + \frac{R_4}{R_3}} + \frac{1}{1 + \frac{R_0 \cdot R_4}{R_T \cdot R_3}} \right)$$

If $\delta \gg \gamma$ then

$$E_{th} = E_i \left(-\frac{1}{\gamma} + \frac{n}{\delta} \right)$$

$$\text{Let } \frac{R_4}{R_3} = \gamma \quad \frac{R_T}{R_0} = n$$

$$= E_i \left(\frac{n-1}{\gamma} \right)$$

$$E_{th} = E_i \left(-\frac{1}{1+\gamma} + \frac{1}{1 + \frac{1}{n} \cdot \gamma} \right)$$

$$E_i \left(\frac{-1 + R_T/R_0}{R_4/R_3} \right)$$

$$\Rightarrow E_i \left(-\frac{1}{1+\gamma} + \frac{n}{n+\gamma} \right)$$

$$\frac{E_i \times R_3}{R_4} \left(-1 + \frac{R_0(1+\alpha T)}{R_0} \right)$$

$$= \frac{E_i R_3}{R_4} (-1 + 1 + \alpha \cdot T)$$

$$= E_i R_0 / R_4 \cdot \alpha T$$

Ic Temperature Sensor :-

→ Each of the above three temperature transducers describe that is RTD, thermocouple & transistor have significant limitations.

→ For Ex. - Thermocouple has a low o/p. signal which varies inversely with temperature increase of ~~RTD~~ RTD though there is a linear change in the resistance but it is very small for a large change in temperature.

→ lastly in case of thermistor there is a large change in resistance with temperature but it is highly non-linear.

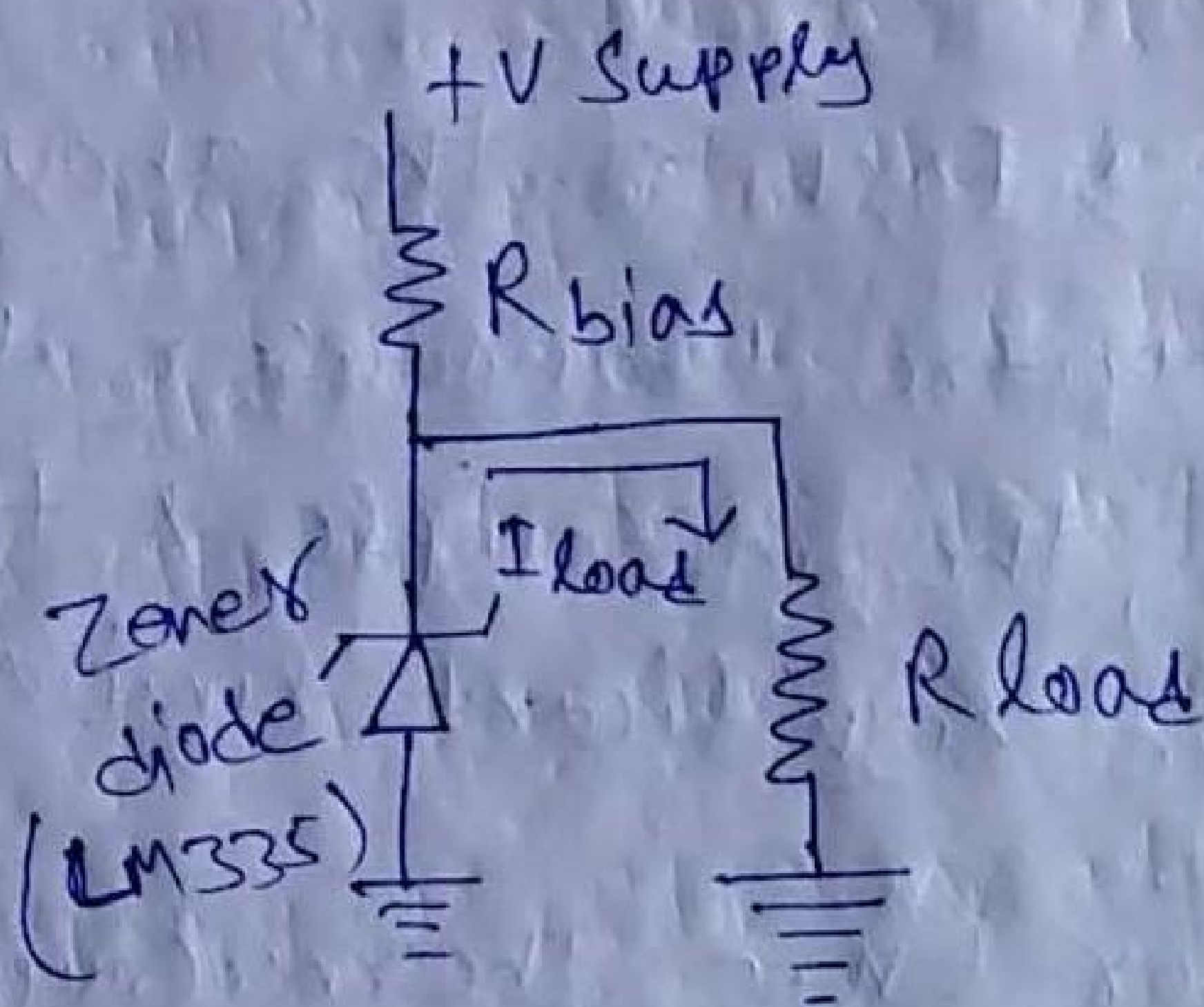
→ For each of these electronic compensation has to be used along with sum additional ckt may be required to increase the o/p. voltage or current.

→ It is therefore required to combine temperature sensing element along with signal conditioning element on a single integrated chip.

→ There are 3-types of Ic sensors

(a) LM335 (b) LM34 series (c) AD592

(a). LM335 :-



$$V_Z = \frac{10}{T} \text{ mV}$$

T = Temperature in $^{\circ}\text{K}$

θ = Temperature in $^{\circ}\text{C}$

It is a temperature sensing general diode which means reverse side gives an o/p.

For which a reverse current has to be maintain with in 400 micro Amp.

(b) LM34 series :-

Here the o/p. voltage is directly proportional to Fahrenheit

leading. It has low cost, low o/p.
impedence linear o/p. & it draws a
very small current of around 70 micro
Amp. from the supply & its heating is
limited to $\pm 0.2^{\circ}\text{F}$.

(c) AD 592 :-

In case the signal is to be
transmitted over large distance, then
this type of IC is a better choice as
its o/p. signal is a current signal
given by :-

$$I_{\text{out}} = 1 \times 10^{-6} T$$

$T \rightarrow \text{temp. in } ^{\circ}\text{K}$

$$I_{\text{out}} = 273 \times 10^{-6} + 1 \times 10^{-6} \theta$$

$\theta = \text{temperature } ^{\circ}\text{C}$

- ↳ It has low cost
- ↳ Its temperature range $-25^{\circ}\text{C} - 105^{\circ}\text{C}$
- ↳ Its linearity is $0.2/^{\circ}\text{C}$
- ↳ Its Accuracy is 0.5 at 25°C

Elastic Sensor:-

It converts an i/p. force into an o/p. displacement. The working principle of this type of device is that if a force is applied to a spring then the amount of extension or compression of the ~~spring~~ spring is approximately proportional to force applied. These are mainly used for measuring torque, pressure & acceleration. Generally this type of instrument are followed by secondary displacement sensor which convert the displacement signal into electric signal.

There are basically 3-types of sensor

(i) Elastic diaphragm:-

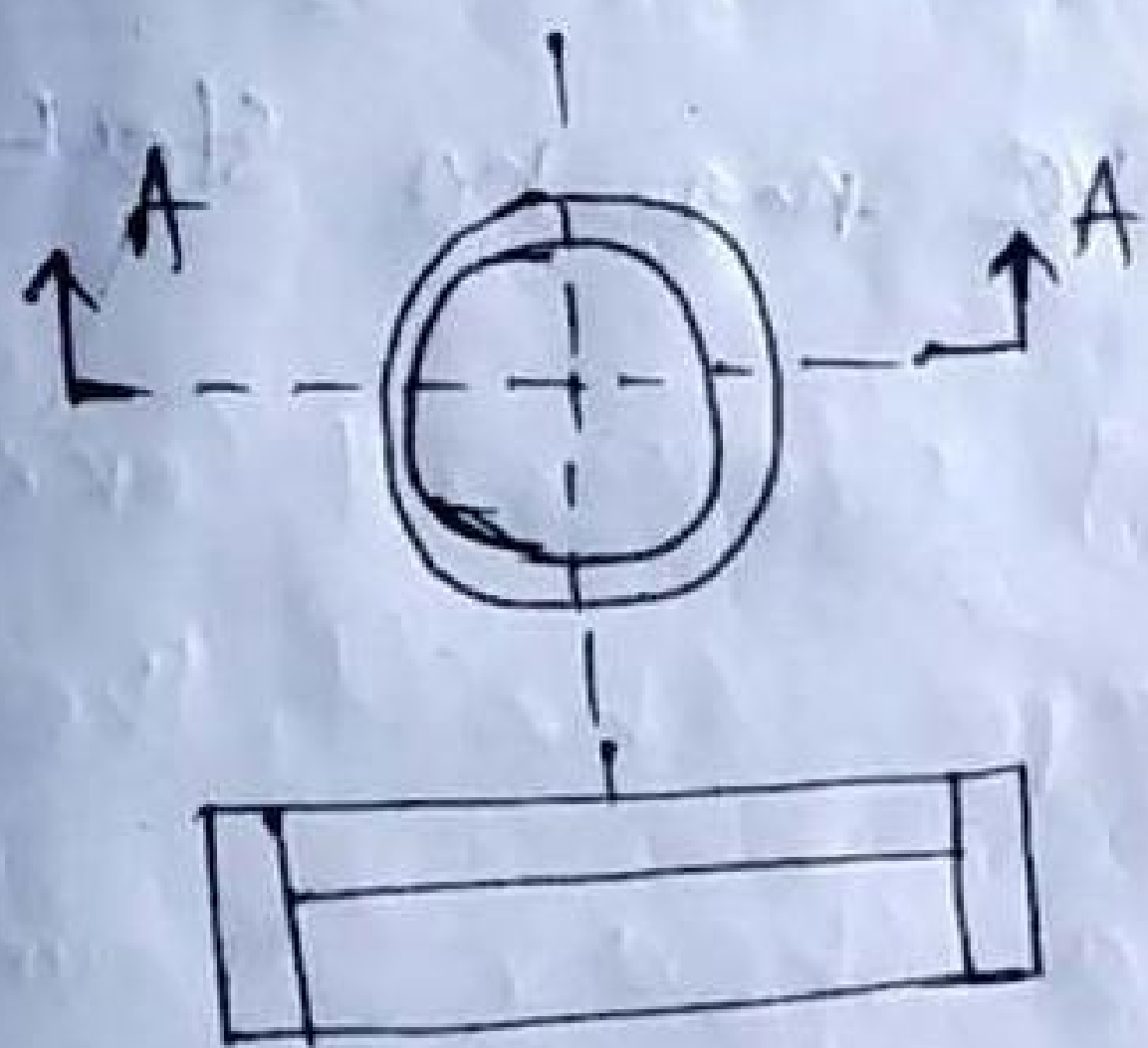
many dynamic pressure measuring apparatus use an elastic diaphragm & ~~the~~ primary pressure transducer, these are basically of flat type, corrugated type.

The flat type transducer generally

larger deflections, this displacement are mechanically provided to a pointer & scale in a flat metal diaphragm. The ~~def~~ deflection is limited either by stress requirement or deviation from linearity. (30% is allowed).

For this case certain type of secondary transducers are connected at the center in addition to auxiliary spring force to control the deflection of the diaphragm.

In Corrugated type which are used for larger deflection use large diameter for which it is only use for static system.



Section A - A
Flat diaphragm



Corrugated diaphragm

(c) Bellows element :-

It is a thin ~~walled~~ ^{walled} cylindrical cup like structure with no. of folds for its cylindrical surface along the axis of cup.

where precision more important, specially metallic alloy are used for providing larger displacement with pressure but where precision is not require rubber & plastic material are used.

The bellows are initially stressed or compressed by pressure difference between inner & outer surface, it has low spring rate, low sensitivity and linear relation between pressure & displacement but this type of device have no hysteresis at zero condition.



(iii) Bourdon Tube Elements :-

most mechanical elements for measurement of pressure & acts as a primary sensor for converting pressure into linear & angular displacement. It consists of a thin walled tube of overall or flat sided area & bends into a circular arc of central angle $(200^\circ - 270^\circ)$ one end of the tube is attached to a rigid base while the other end is free to rotate. Due to pressure difference between inside & outside of the tube, the tube gets deformed into a sea like structure resulting a displacement of the free end, thereby changing the coiling angle to change from

ψ_0 to ψ .

The equation of the, this type of instrument

$$\frac{\Delta \psi}{\psi_0} = \Delta P \left[\frac{1 - \mu^2}{E \times b \times t} R_0^2 \right] \left[1 - \frac{b^2}{a^2} \right] \left[\frac{a}{R \times n} \right]$$

ΔP = Pressure difference

R_0 = Radius of Arc

μ = Poisson ratio

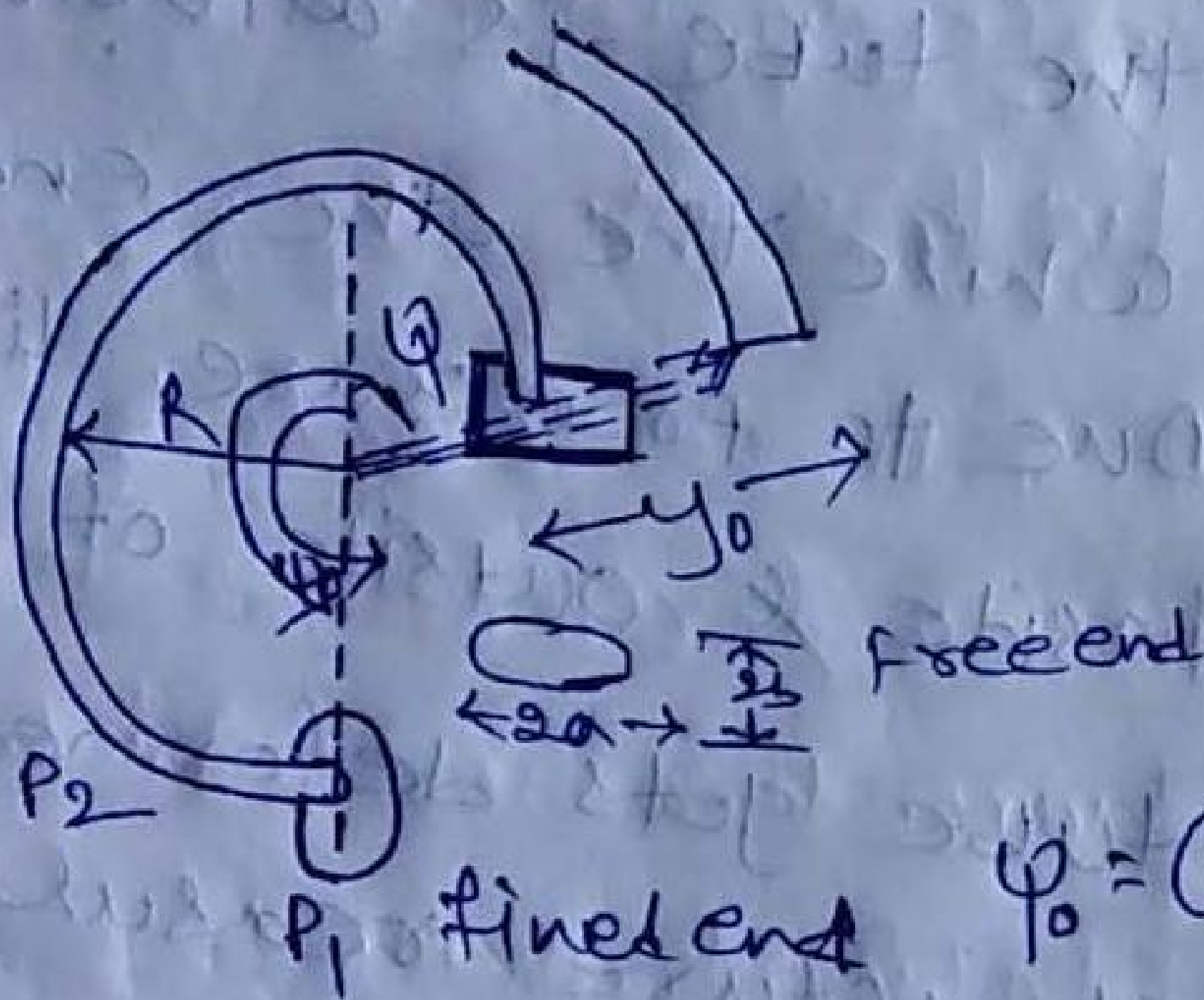
E = Young's modulus

a = Semi major axis

b = Semi minor axis

t = thickness

$\Delta\psi, \psi_0$ = Angle in radian



ψ_0 = Coiling angle

Torque sensor :-

This sensing element consists of a cylindrical shape shaft, the applied torque produces a shear strain (θ) in the shaft & the corresponding linear tensile strain & compressive strain on the surface.

The strain gauge 1 is mounted with its acting axis at 45° to the shaft axis, which suffers a maximum tensile strain ($+E$) whereas the gauge 2 is mounted at an angle of -45° w.r.t the shaft axis.

$$C = \frac{T}{\pi S a^3}$$

S = Shear modulus

a = radius of shaft

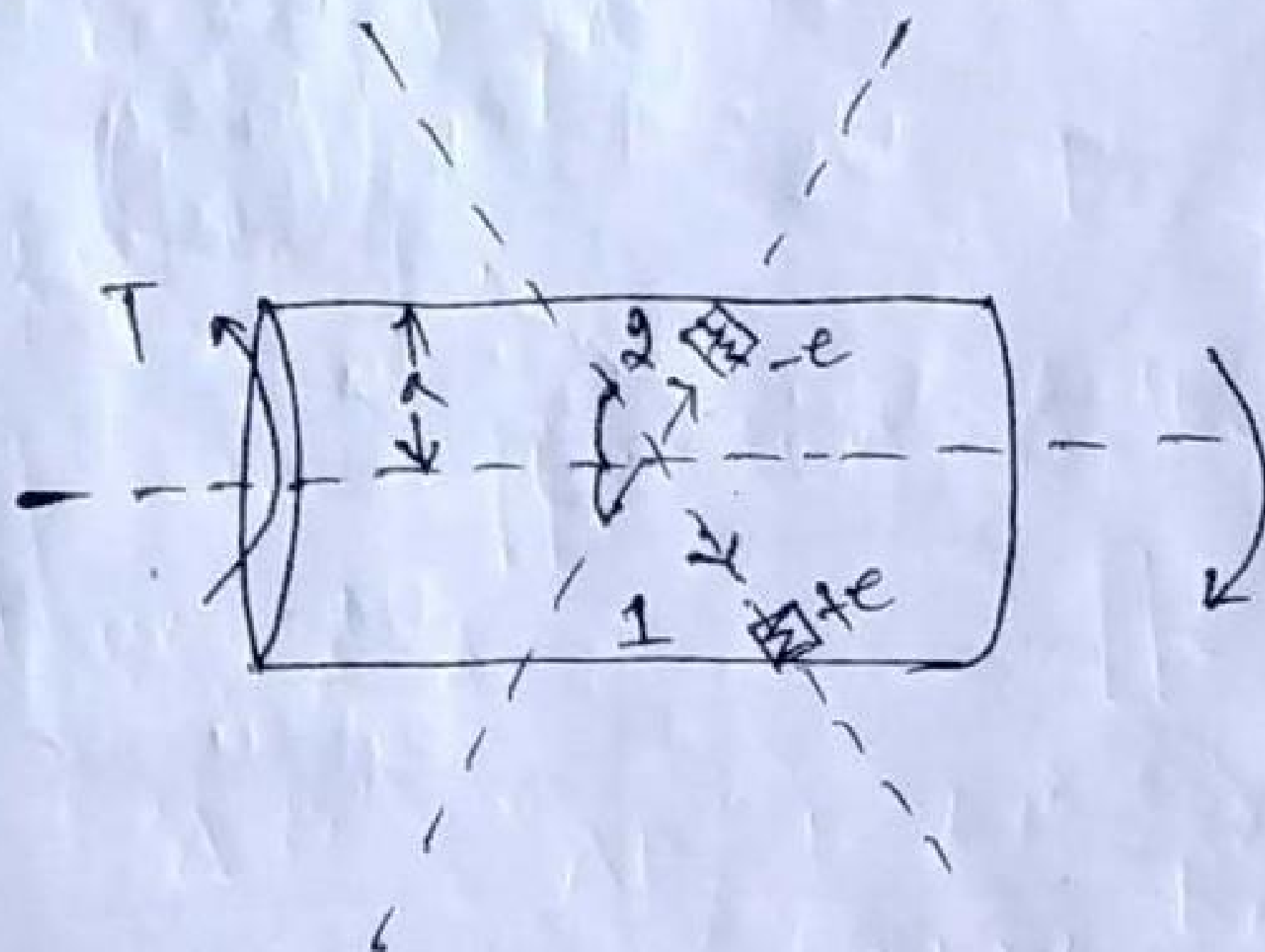
Resistance of gauges

$$R_1 = R_3 = R(1 + GFE)$$

$$R_2 = R_4 = R(1 - GFE)$$

Corresponding o/p. voltage

$$E_{th} = VSGFE, V_s = \text{applied voltage}$$



Signal Conditioning Element

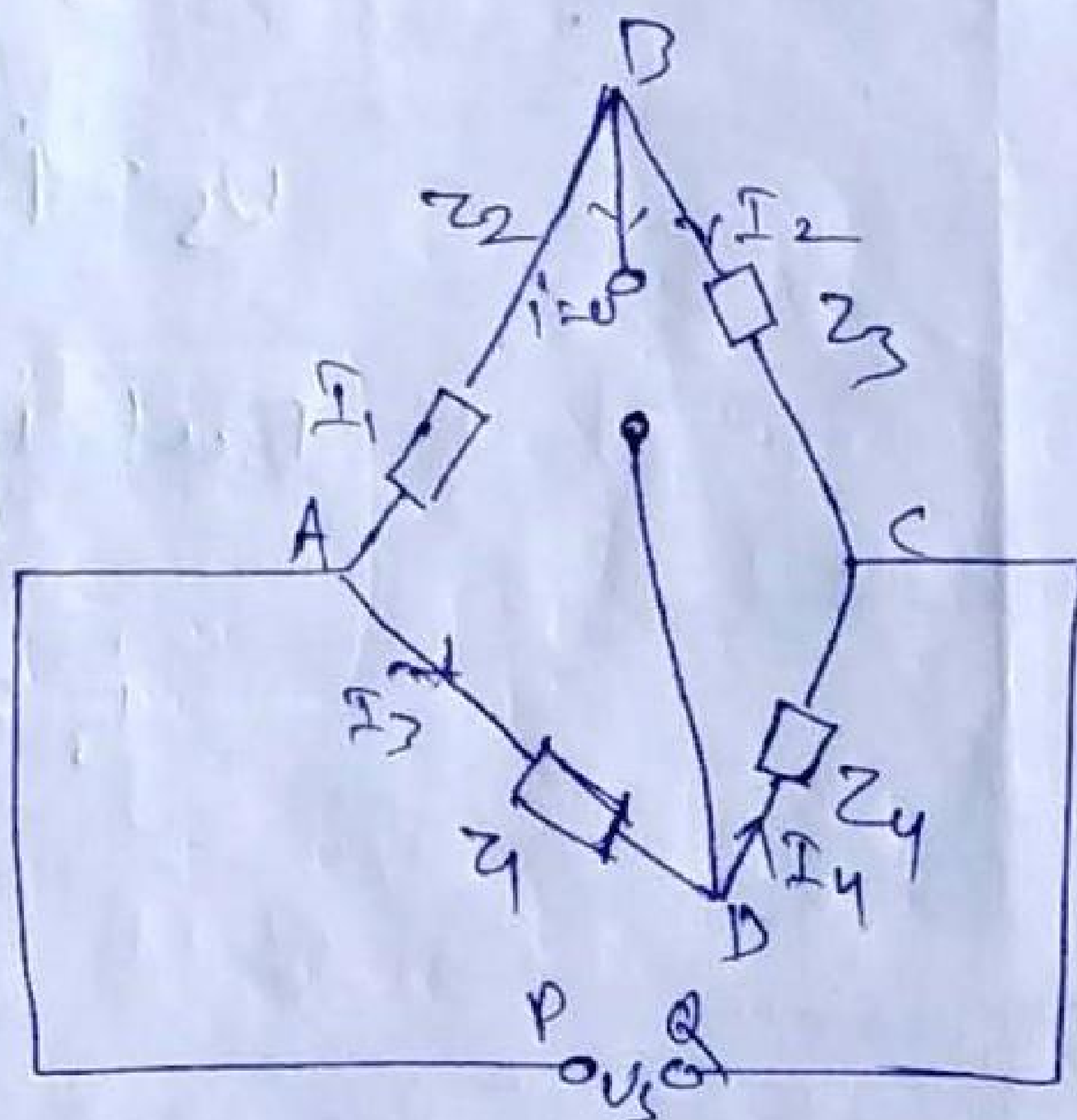
Deflection Bridge :-

→ The signal conditioning elements convert the o/p. of a sensor into a form suitable for further processing.

→ The o/p. is basically DC voltage, DC current & a variable frequency.

The Deflection bridge usually convert the o/p. of a resistive, capacitive & inductive sensor into a suitable voltage signal.

Thevenin equivalent circuit for a deflection bridge :-



Generally A Thevenin Ckt Consists of a voltage source with a series impedance Z_{TH} .

As BD is open Current across it zero.

Applying KVL to loop PABCQ

$$V_s - i_1 z_2 - i_2 z_3 = 0$$

$$V_s = i_1 z_2 + i_2 z_3$$

as $i = 0$ (through BD)

$$i_1 = i_2$$

$$i_1 = \frac{V_s}{z_2 + z_3}$$

Similarly for the loop

~~PBCQ~~ PADCQ

$$V_s - i_3 z_1 - i_4 z_4 = 0$$

$$V_s = i_3 z_1 + i_4 z_4$$

But $i_3 = i_4$

$$i_3 = \frac{V_s}{z_1 + z_4}$$

P 8 A

Potential at B = ~~V_S~~ $V_S - I_1 Z_2$

$$D = V_S - I_3 Z_1$$

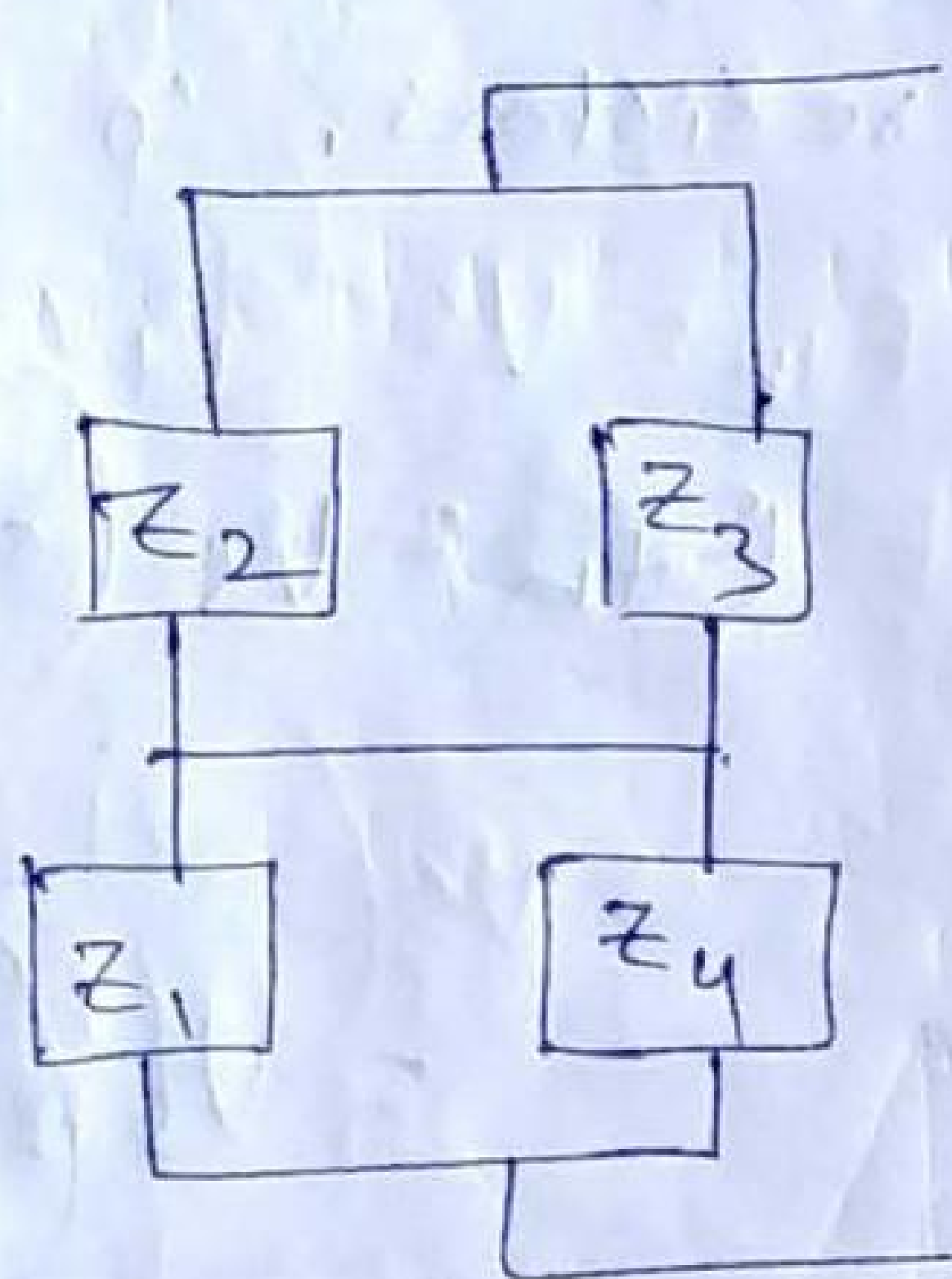
$$E_{th} = V_B - V_D$$

$$= V_S - I_1 Z_2 - (V_S - I_3 Z_1)$$

$$= I_3 Z_1 - I_1 Z_2$$

$$= \frac{V_S}{Z_1 + Z_4} \cdot Z_1 - \frac{V_S}{Z_2 + Z_3} \cdot Z_2$$

$$E_{th} = V_S \left(\frac{Z_1}{Z_1 + Z_4} - \frac{Z_2}{Z_2 + Z_3} \right)$$



Assuming
internal Z
of $V_S \approx 0$

$$Z_{th} = Z_1 \parallel Z_4 + Z_2 \parallel Z_3$$

If we connect a load across B & D

$$I_L = \frac{E_{th}}{Z_{th} + Z_L}$$

If $Z_L \gg Z_{th}$

then $V_L = E_{th}$

$$E_{th} \times Z_L$$

Design of Resistive Deflection Bridge

In this case the V_{in} will be equal to

$$E_{th} = \left[\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3} \right]$$

$$R_{th} = R_1 \parallel R_4 + R_2 \parallel R_3$$

~~Use OpAmp~~

Let us say that the I/P. Sensing element is connected to one of the resistance of the deflection bridge. Let the resistance R_1 depend upon I/P. Such that $R_1 = R_i$ & R_2, R_3, R_4 are fixed resistors. So E the V_{in} will be

$$E_{th} = V_s \left(\frac{R_i}{R_i + R_4} - \frac{R_2}{R_2 + R_3} \right)$$

$$= V_s \left(\frac{1}{1 + (R_4/R_i)} - \frac{1}{1 + \frac{R_3}{R_2}} \right)$$

Condition - 01

For designing this we have to know three parameters V_s , $\frac{R_3}{R_2}$, $\frac{R_4}{R_2}$

For individual value of R_2 & R_3 are not required, thus if current min^m & current max^m are the values of measured variable the corresponding sensor resistance will be equal to R_{min} & R_{max} . So the bridge

op. will also have a range of voltage ($V_{min} - V_{max}$).

Condition - 02

$$\frac{R_3}{R_2} = \frac{R_4}{R_{min}}$$

We have to limit the power $I_3^2 R_3$ in the sensor to a level which enables it to be dissipated as heat flow to the surrounding fluid otherwise the temperature of the sensor will rise.

If, w = maximum power dissipated
 $T^2 \rho T < w$

For keeping the non-linearity between specified limit (E_{th} & I i/p.),

Assuming V_{min} to be equals to zero, the relation between voltage & i/p. current will be a straight line.

We know that

$$\frac{R_3}{R_2} = \frac{R_4}{R_{Imin}}$$

$$R_4 = \left(\frac{R_3}{R_2} \right) R_{Imin}$$

Putting the value of R_4 in E_{th} eqⁿ.

$$E_{th} = V_s \left(\frac{1}{1 + \left(\frac{R_4}{R_I} \right)_{min}} - \frac{1}{1 + \frac{R_3}{R_2}} \right)$$

$$\Rightarrow V_s \left(\frac{1}{1 + \left(\frac{R_3}{R_2} \right) \frac{R_{Imin}}{R_I}} - \frac{1}{1 + \frac{R_3}{R_2}} \right)$$

$$\text{Let } V = \frac{E_{th}}{V_s} \quad \gamma = \frac{R_3}{R_2} \quad n = \frac{R_I}{R_{Imin}}$$

So

$$V = \frac{1}{1 + \gamma} - \frac{1}{1 + \gamma}$$

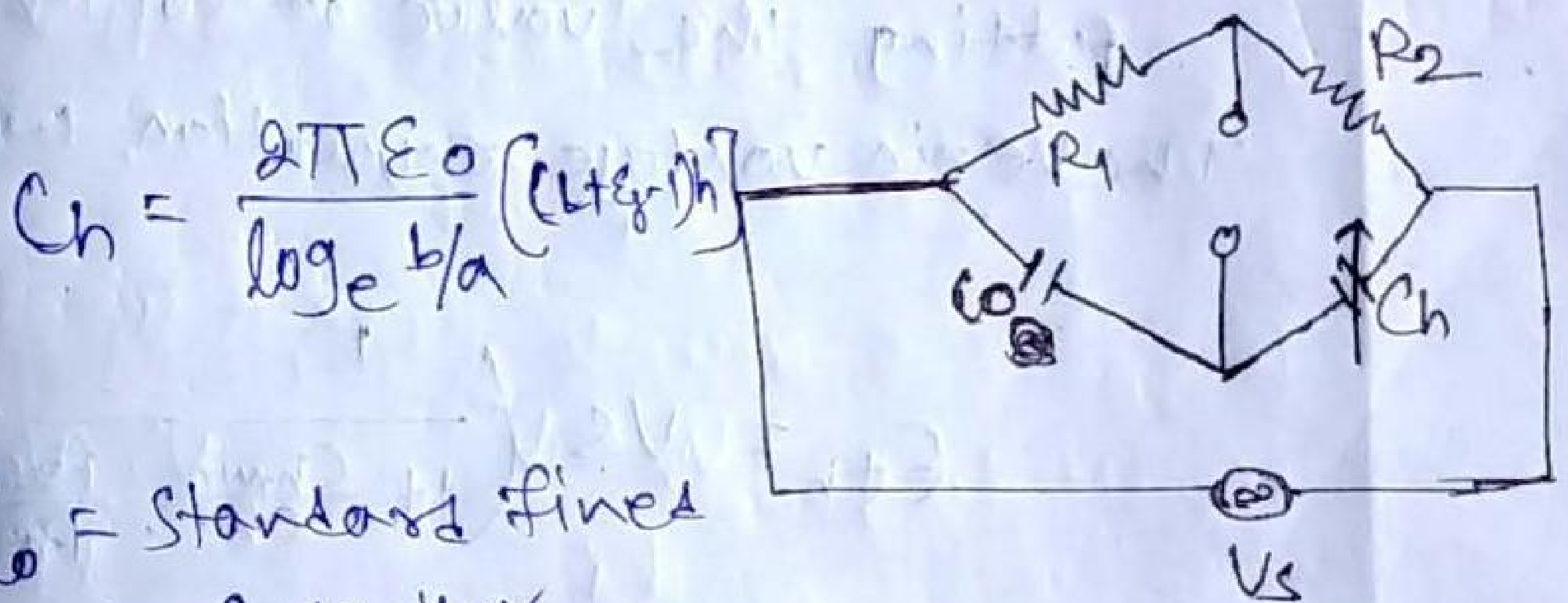
At $n=1$ $V=0$, bridge is balanced.

i.e. $n=1$, $I=I_{min}$, $R_1 = R_{min}$

Design of Reactive Bridge :-

(i) Single element Bridge :-

A reactive bridge has an AC supply voltage, It consists of two reactive impedance & two resistive impedance i.e. -



C_0 = Standard fixed Capacitor

$$Z_2 = R_1$$

$$Z_1 = \frac{1}{j\omega C_0}$$

$$Z_4 = \frac{1}{j\omega C_h}$$

$$Z_3 = R_2$$

So E_{th} will be equal to

$$E_{th} = V_s \left(\frac{1}{1 + \frac{R_4}{R_1}} - \frac{1}{1 + \frac{R_3}{R_2}} \right)$$

To get minimum o/p. voltage i.e. -
 O/p. voltage equals to zero, then the
 condition is E_{th} equals to zero.

$$1 + \frac{C_0}{C_{thmin}} = 1 + \frac{R_2}{R_1}$$

$$\frac{C_0}{C_{thmin}} = \frac{R_2}{R_1}$$

$$C_0 = C_{thmin} \times \frac{R_2}{R_1}$$

putting the value of C_0 in the
 Thevenin voltage equation we get

$$E_{th} = V_S \left(\frac{1}{1 + \frac{C_{thmin}}{C_h} \frac{R_2}{R_1}} - \frac{1}{1 + \frac{R_2}{R_1}} \right) \rightarrow 0$$

If $\frac{R_2}{R_1} \gg 1$ then

$$E_{th} = V_S \left(\frac{C_h R_1}{C_{thmin} R_2} - \frac{R_1}{R_2} \right)$$

$$E_{th} = V_S \frac{R_1}{R_2} \left(\frac{C_h}{C_{thmin}} - 1 \right)$$

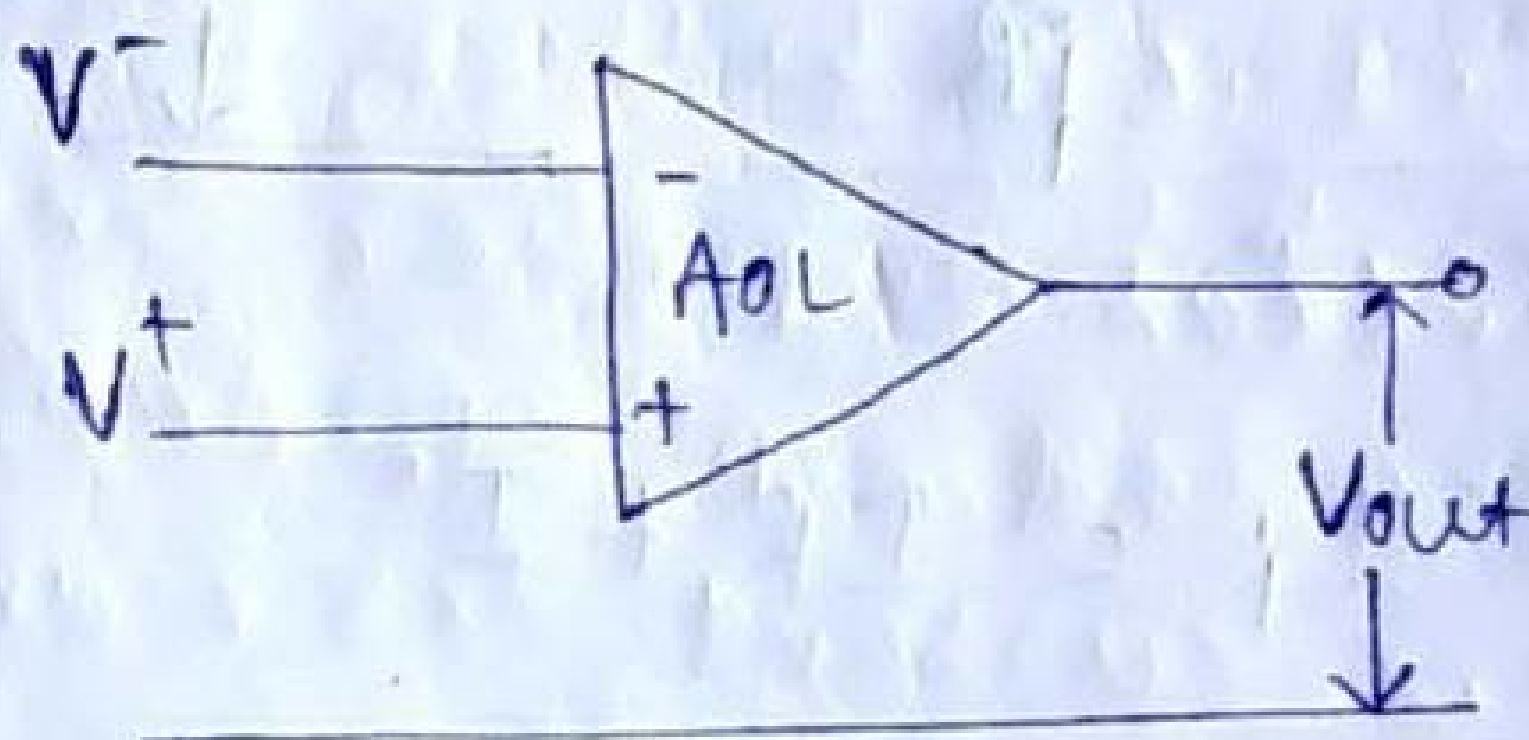
Amplifiers :-

The Operational Amplifier (OPAMP)
 has a high o/p. & is use to amplifies the
 small value into many

While using op-Amp a feedback network is used to produce transfer characteristic precise. usually it has to i/p. & a single o/p. the o/p. voltage is equal to

$$V_{out} = A_{OL} (V_1 - V_2)$$

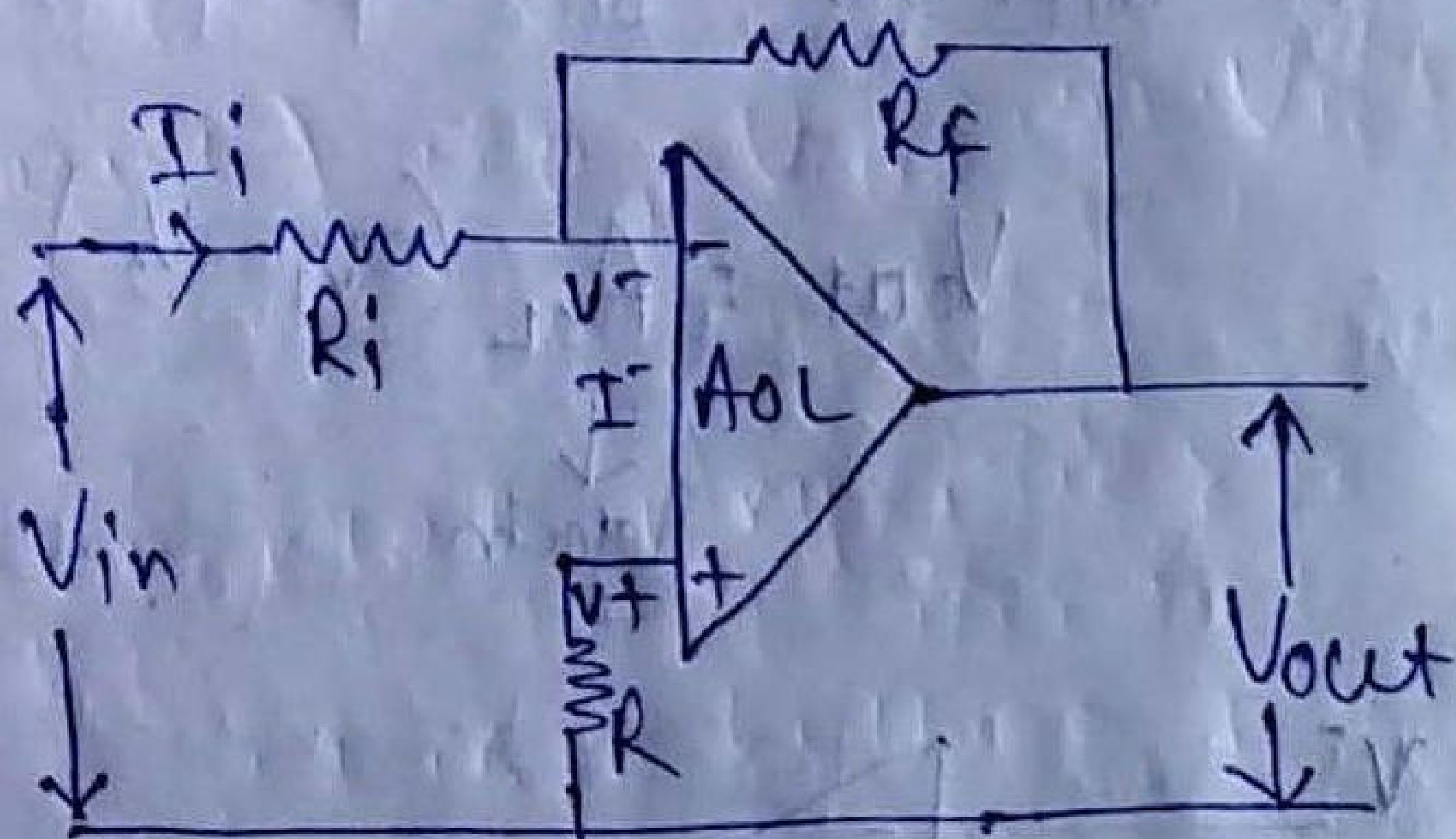
↓
gain



<u>Characteristics</u>	<u>Ideal</u>	<u>Practical</u>
open loop gain	∞	2×10^5
Z_{in}	∞	$2M\Omega$
Z_{out}	0	75Ω
V_{input} offset	0	$1mV$
Input bias current	0	$80nA$
Bandwidth	∞	$5KHz$
CMRR	∞	$90dB$
Slew rate	∞	$1V/\mu s$

Application

i) Inverting Amplifier



$$I_i = I_f + I^-$$

As I^- is very small

$$I_i = I_f$$

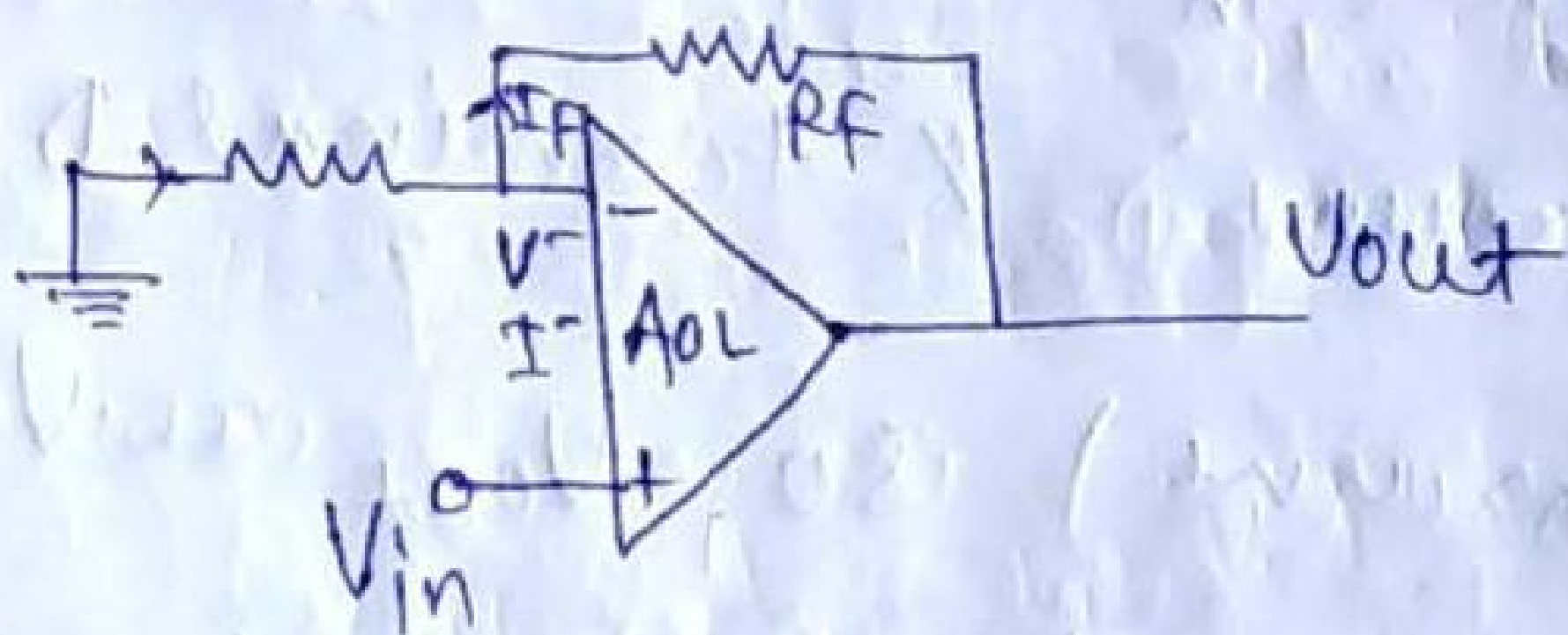
$$\Rightarrow \frac{V_{in} - V^-}{R_i} = \frac{V^- - V_{out}}{R_f}$$

But in this case $V_o = V^+ = 0$

$$\Rightarrow \frac{V_{in}}{R_i} = -\frac{V_{out}}{R_f}$$

$$\boxed{R_f \cdot \frac{V_{in}}{R_i} = -V_{out}}$$

ii) Non Inverting



$$\text{As } V^+ = V^-$$

$$I_i = I_F + I^-$$

$$\Rightarrow I_i = I_F$$

$$\frac{0 - V^-}{R_i} = \frac{V^- - V_{out}}{R_F}$$

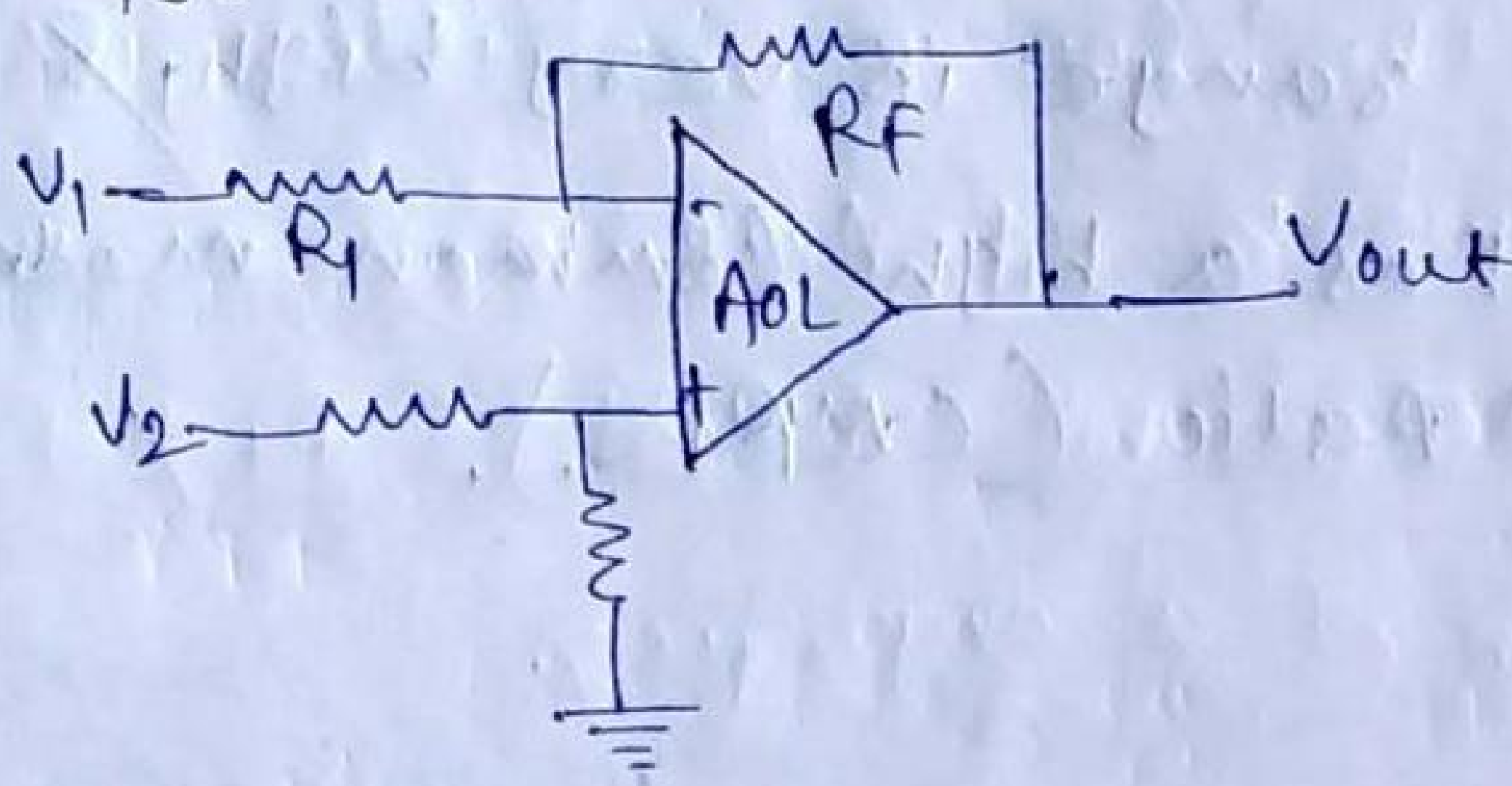
$$-V^- R_F = V^- R_i - V_{out} R_i$$

$$V_{out} R_i = V^- R_i + V^- R_F$$

$$\Rightarrow V^- (R_i + R_F)$$

$$V_{out} = V_{in} \left(1 + \frac{R_F}{R_i} \right)$$

(ii) Differential Amplifier



This amplifier amplifies the bridge o/p. E_{th} at terminal B (V_1 w.r.t. Ground) & terminal D (V_2 w.r.t. Ground) so, $V_{out} = V_B - V_D$

Instrumental Amplifier:-

It is a higher performance differential amplifier consisting of several closed loop op-amp. The o/p. voltage & current for many transducers are very small also noisy is more for low o/p. of the transducer.

To eliminate this type of amplifier is used.

Characteristics:-

→ It has a high i/p. impedance

→ It has infinite open loop Gain

→ It has a common mode, voltage range is very high, & it also

has a high Common mode Rejection Ratio (CMRR).

Filter

An electronic filter is a frequency selective signals of frequency outside that band.

The filters are classified into a no. of ways

(i) Analog Filters: which process analog signals.

(ii) Digital filters: $\rightarrow$ These also can analyze analog signal but it uses digital techniques.

(iii) Passive filters: $\rightarrow$ which use resistor, capacitor & inductor.

(iv) Active filters: $\rightarrow$ Uses op-amp, Transistors in addition to passive elements.

(v) RC filters: $\rightarrow$ Are used for low frequency or audio frequency signals

(vi) LC filters: $\rightarrow$ High frequency or Radio

Crystal Filters Are Used.

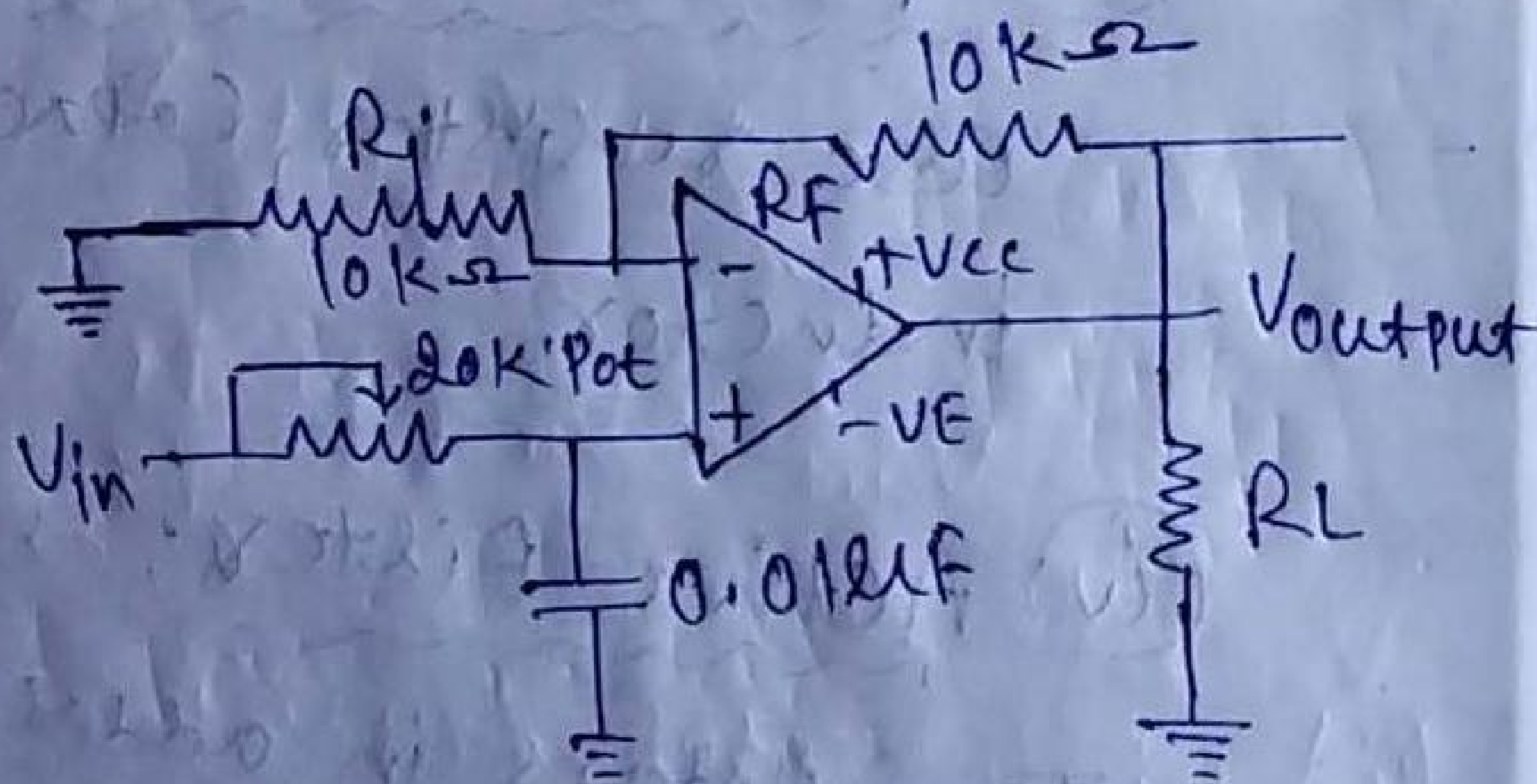
An active filter has the following advantage:-

i) There is a flexibility in gain & frequency adjustment.

ii) Due to high i/p. impedance & low o/p. impedance of op-Amp used in active filter there is no loading problem.

iii) It is economical.

Low Pass Filter:- (First Order)



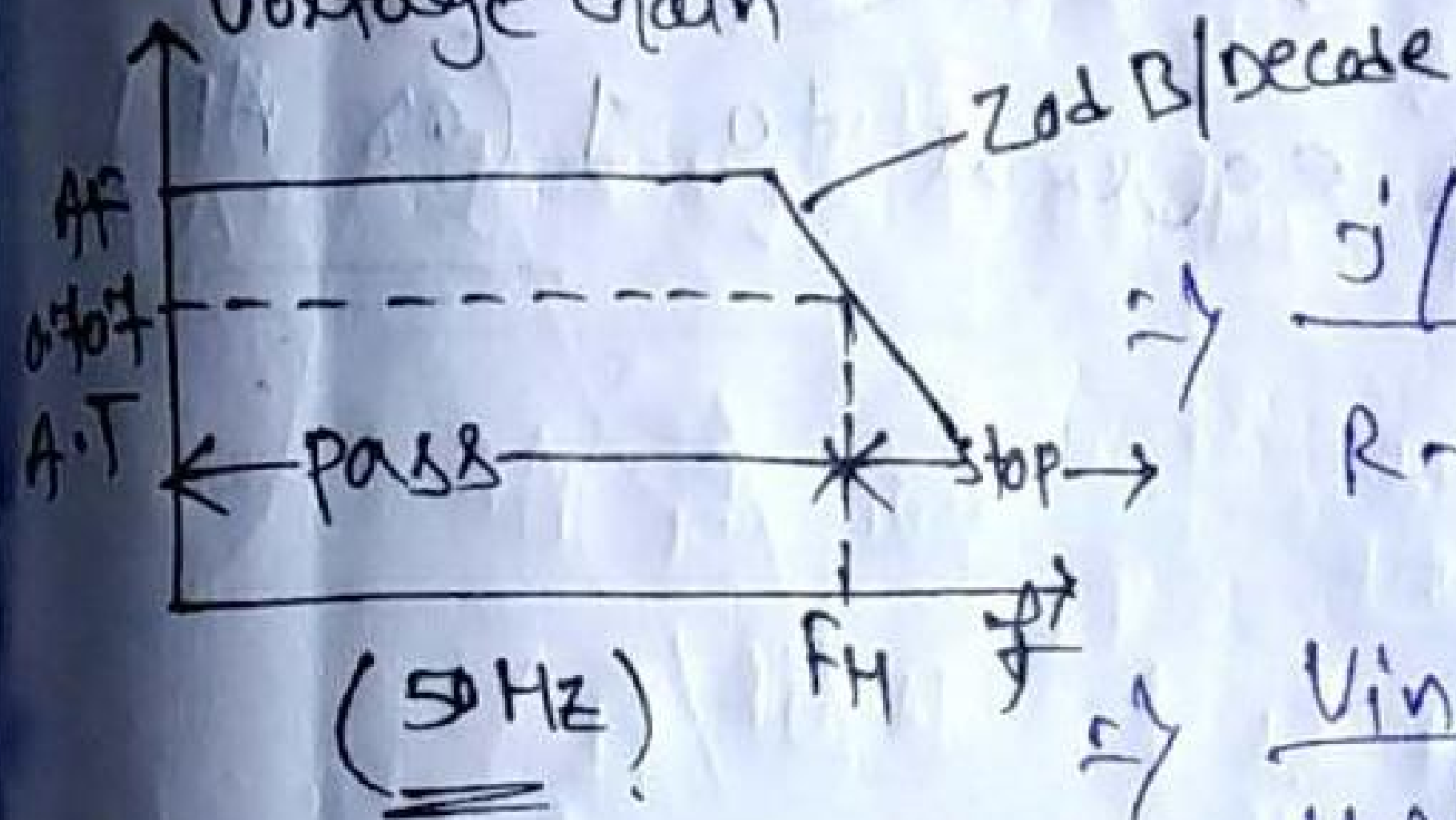
The low pass filter uses a RC network op-Amp in non-inverting mode. The resistors R_i & R_F determine gain of an amplifier.

According to voltage divider rule
voltage at the terminal

$$V_t = \frac{-j\omega C}{R - j\omega C} V_{in}$$

wave form

voltage gain



$$\Rightarrow \frac{j/2\pi f C}{R - j/2\pi f C} V_{in}$$

$$\Rightarrow \frac{V_{in}}{1 + j2\pi f RC}$$

O/p. voltage

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_{in}$$

$$= \left(1 + \frac{R_F}{R_1}\right) \left(\frac{V_{in}}{1 + j2\pi f RC}\right)$$

$$\frac{V_o}{V_{in}} = \frac{AF}{1 + j2\pi f RC} = \frac{AF}{1 + j(f/F_H)}$$

$$\frac{V_o}{V_{in}} = \text{Gain of Amplifier}$$

$$AF = 1 + \frac{R_F}{R_1} = \text{pass band gain of amplifier}$$

f = frequency of i/p.

$$F_H = \frac{1}{2\pi RC} = \text{High Cut off}$$

$$\text{So, Gain} = \left| \frac{V_o}{V_{in}} \right| = \frac{AF}{\sqrt{1 + (f/f_H)^2}}$$

$$\text{Phase angle } \phi = \tan^{-1} f/f_H$$

At low frequency ($f \ll f_H$)
the gain is equal to 1 (or AF)

$$\text{At, } f = f_H$$

$$\text{Gain} = 0.707 AF$$

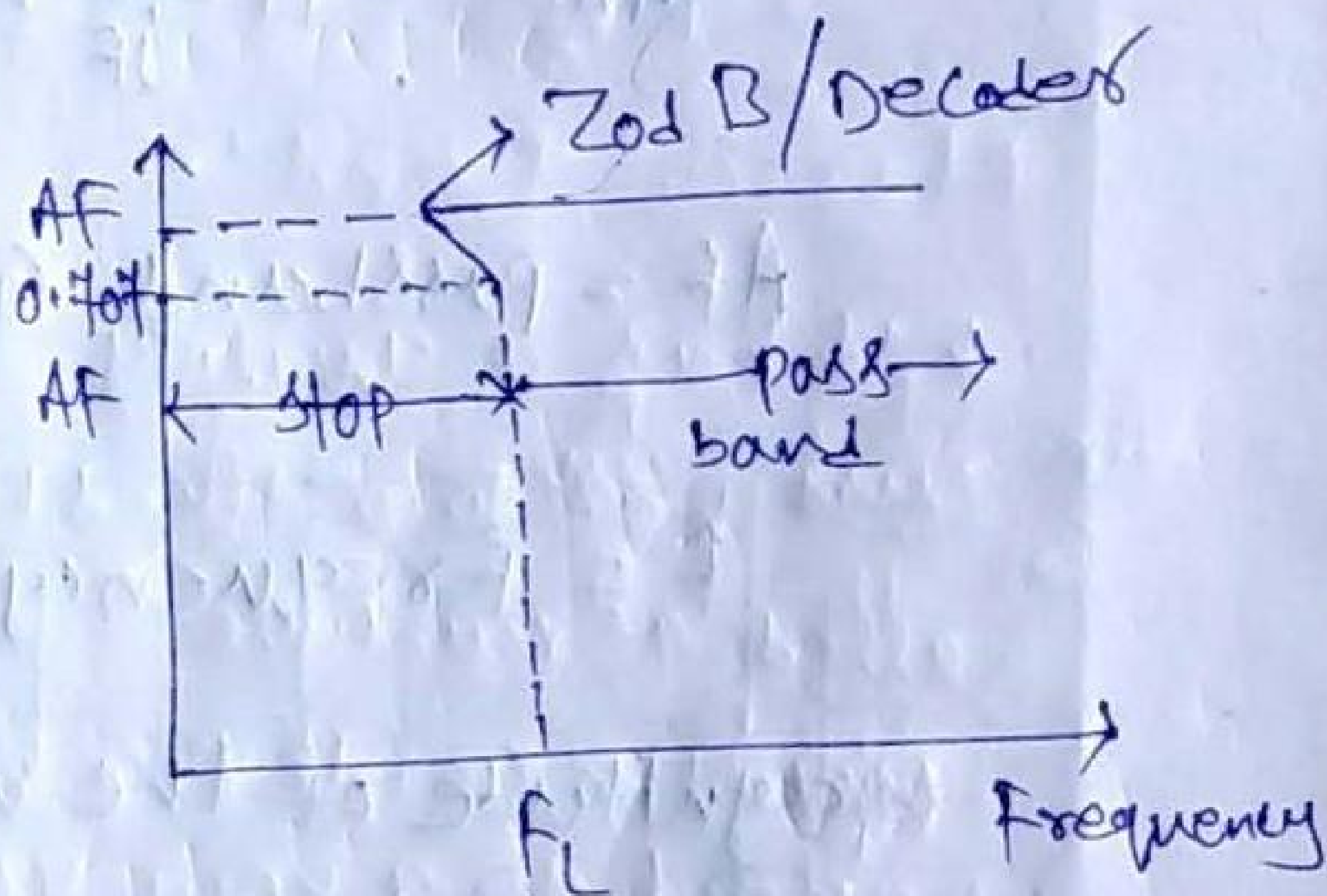
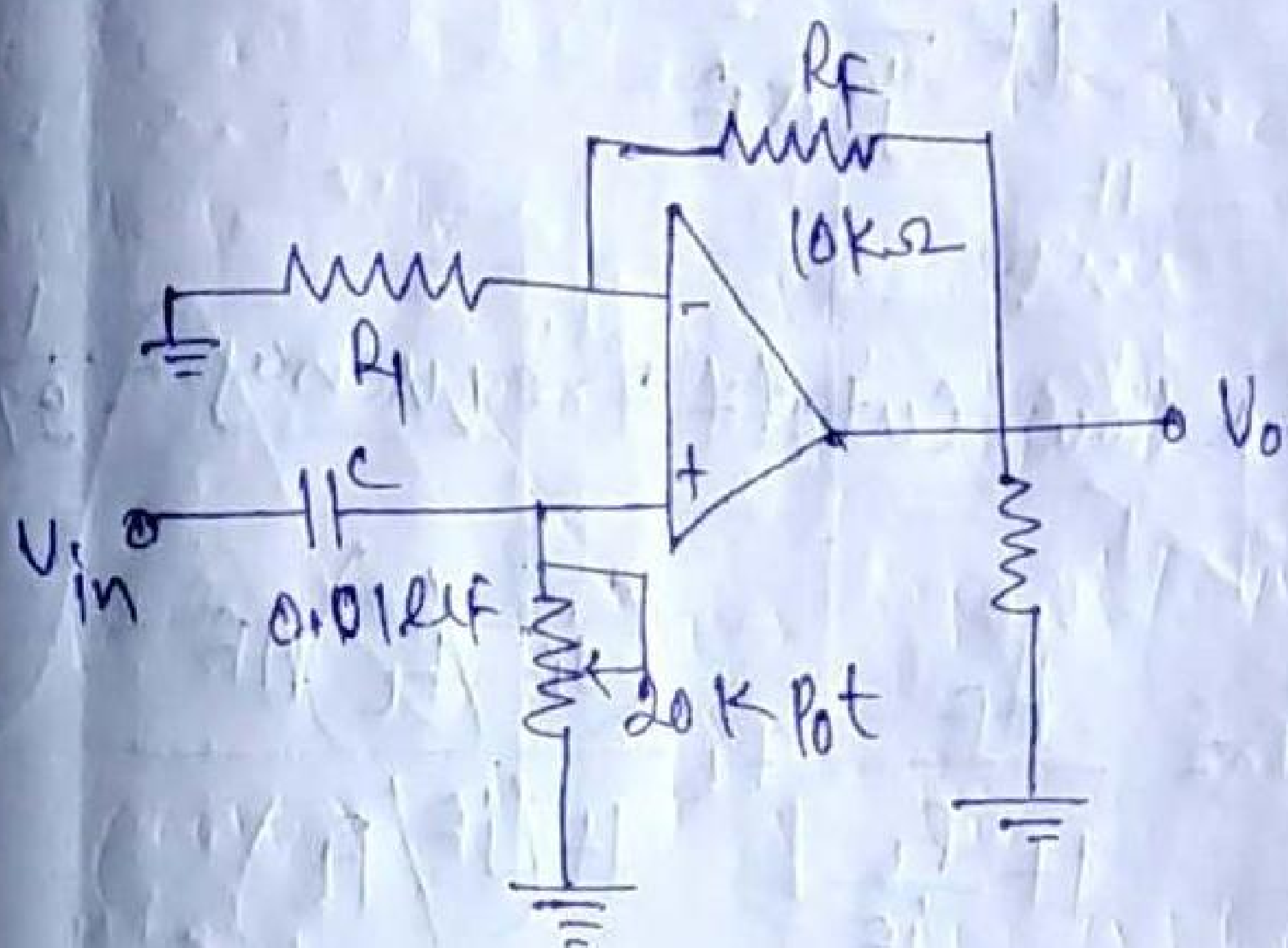
At frequency greater than
frequency with maximum
frequency for example of the
frequency response curves,
the rise time is $1/f_H$ is
also known as corner frequency or cut
frequency or gain cut-off frequency
frequency.

$$\frac{AF}{\sqrt{2}} = 0.707$$

Bandwidth. 20 dB
frequency response. 60 dB

High Pass Filter:-

These are formed by interchanging frequency determining resistor & capacitor.



Applying voltage divided rule to the +ve terminal we get,

$$V_+ = \frac{V_{in}}{R - jX_c} \times R = \frac{RV_{in}}{R - \frac{j}{2\pi f_c C}}$$

$$(\because j \times j = -1)$$

$$\Rightarrow \frac{(2\pi f_c R V_{in}) \times j}{1} = \frac{j 2\pi f_c R V_{in}}{1}$$

$$\Rightarrow \left(1 + \frac{R_F}{R_1}\right) \left(\frac{V_{in} \times j2\pi F R_c}{1 + j2\pi F R_c} \right)$$

$$\frac{V_o}{V_{in}} = \frac{A_F}{1 + \frac{1}{j2\pi F}}$$

Let, $F_L \rightarrow$ low cutoff frequency $= \frac{1}{2\pi R_c}$

$$\frac{V_o}{V_{in}} = \frac{A_F}{1 + \frac{F_L}{jF}} = \frac{(jF/F_L) A_F}{1 + (jF/F_L)}$$

$A_F =$ passband gain of filter $= 1 + \frac{R_F}{R_1}$

$F =$ frequency of i/p. signal

magnitude of the voltage gain is given by

$$\left| \frac{V_o}{V_{in}} \right| = \frac{A_F (F/F_L)}{\sqrt{1 + (F/F_L)^2}}$$

Band Pass Filter

It has a passband betⁿ two cutoff

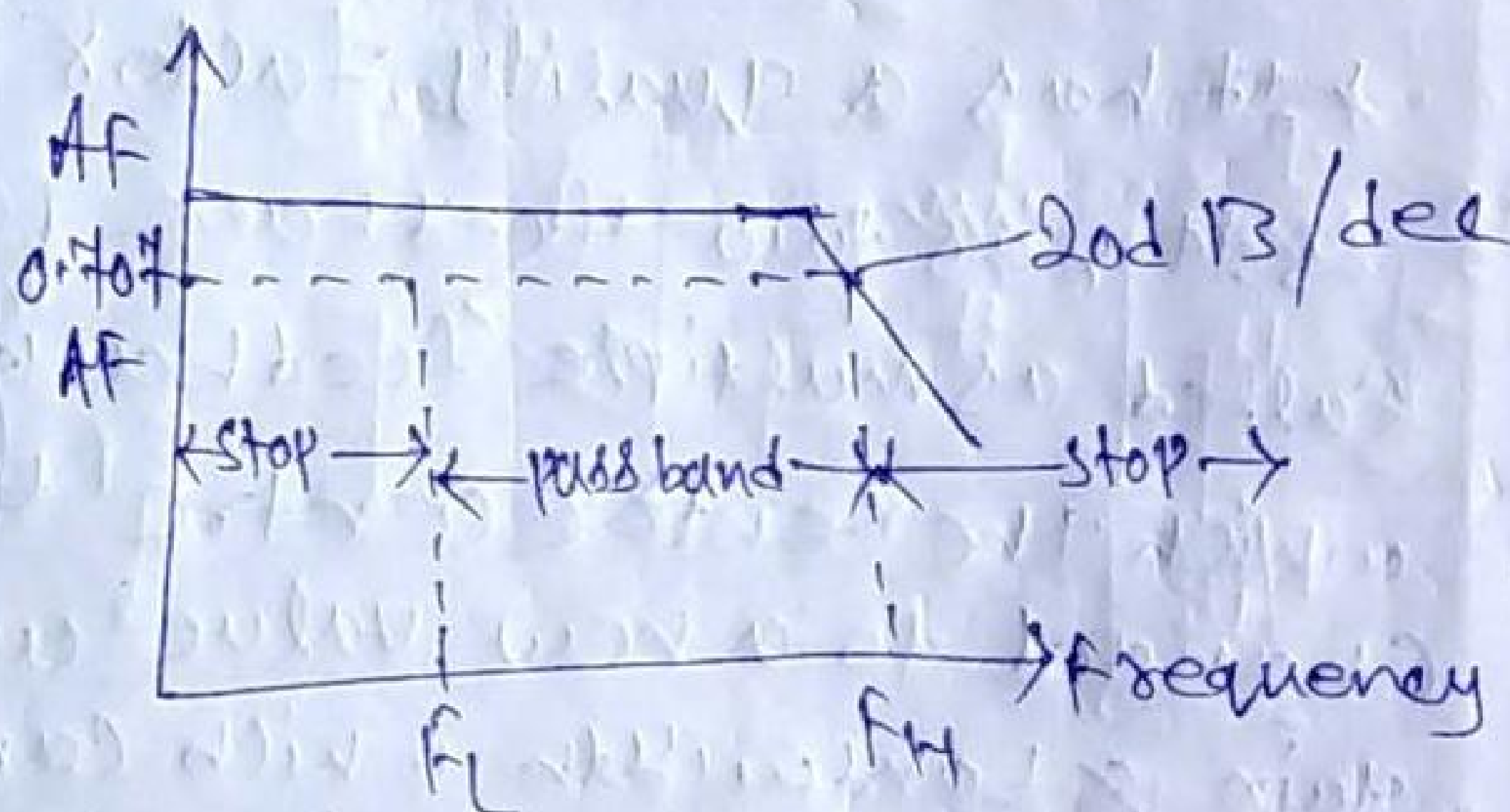
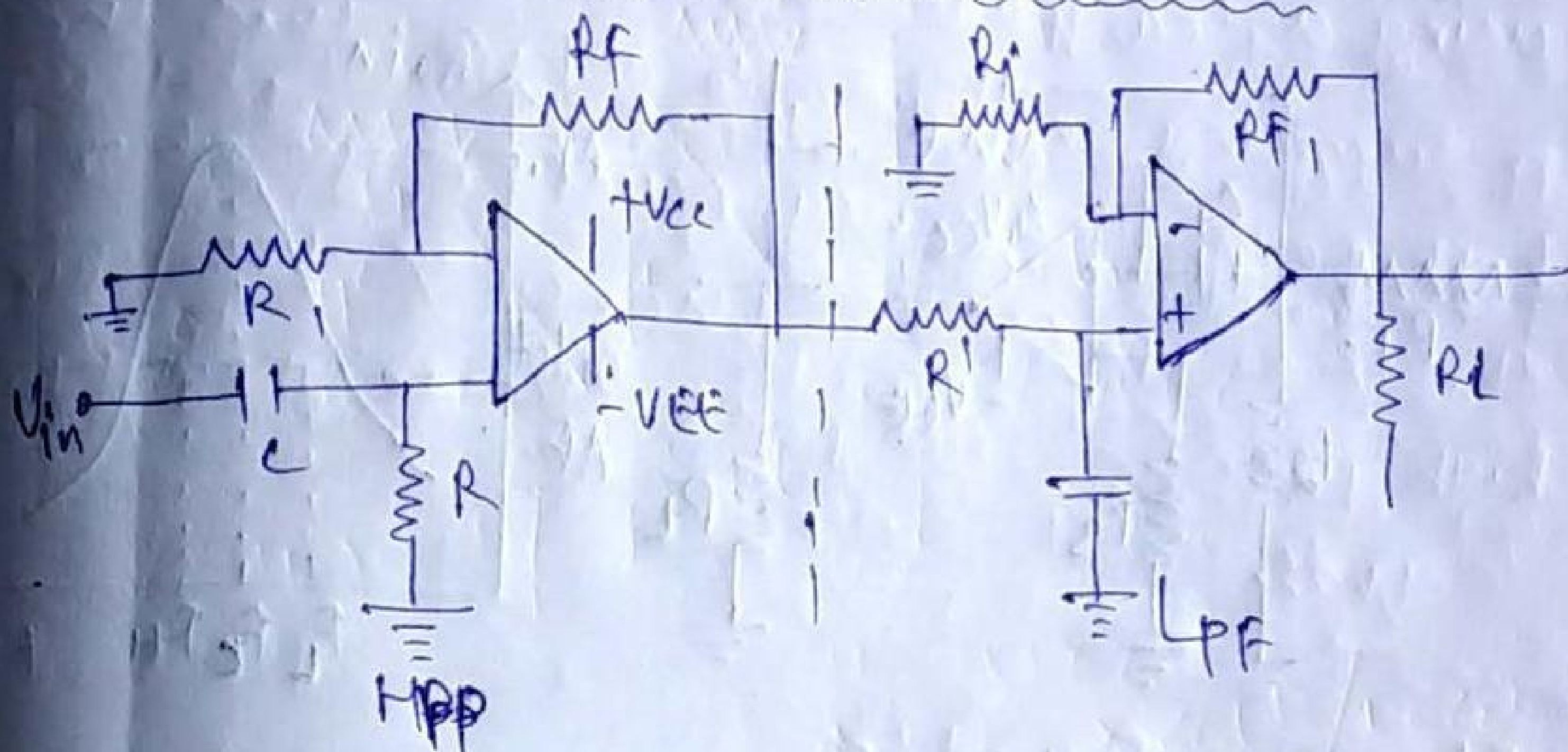
frequency F_H & F_L such that $F_H > F_L$.

$\rightarrow$ Any frequency outside the band is attenuated. Generally these are of two types

i) wide band pass filter

ii) Narrow

c) Wide band pass filter:-



For wide band pass filter the quality factor is less than 10, which is a measure of selectivity i.e., more is the value of "Q" more selective is the filter or narrower is its bandwidth.

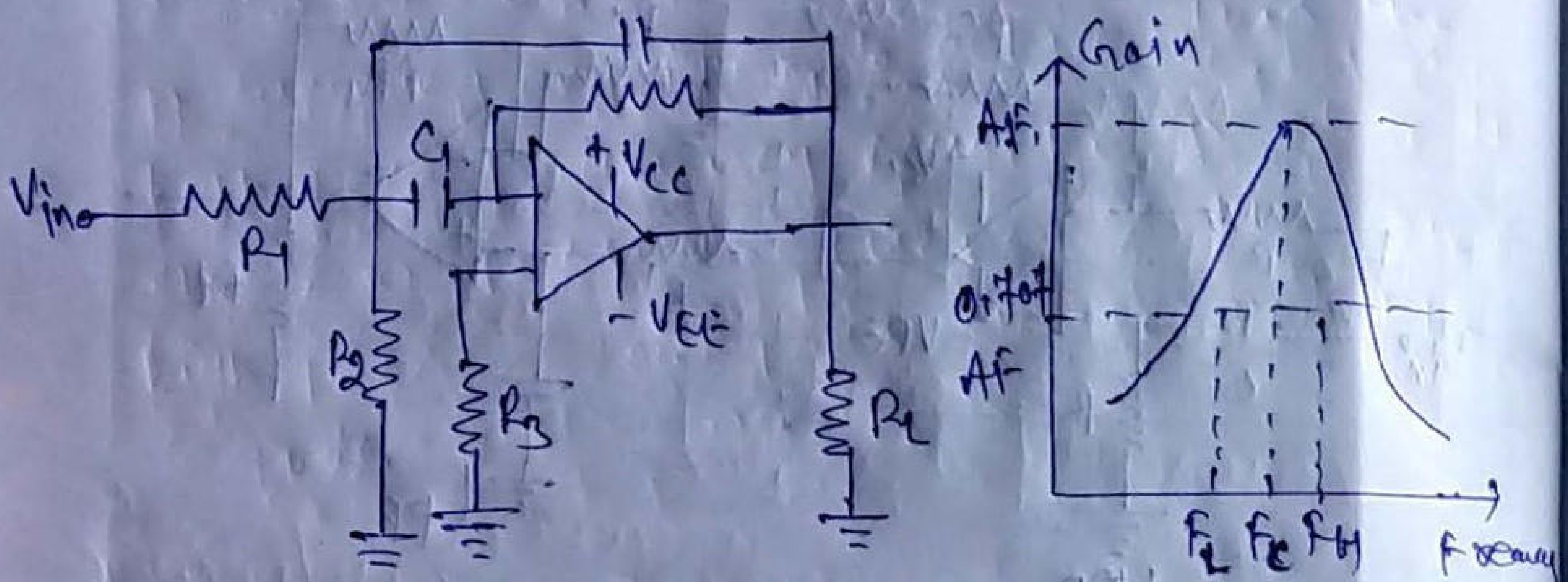
→ Generally "Q" is given by

$$Q = \frac{f_c}{f_H - f_L}$$

For a wide band pass $f_c = \sqrt{f_H f_L}$

for a narrow band pass o/p. voltage peaks at centre frequency " F_c ".

Narrow Band pass Filter :-



→ It has a quality factor greater than 10.
 → It has two feedback path so also called as multiple feedback filter as of which the ~~center~~ centre frequency can be changed to a new value without effecting gain & bandwidth which can be done by change in the resistor R_2 to R_2' , such that

$$R_2' = R_2 = \left(\frac{F_c'}{F_c} \right)^2$$

→ It is designed for a particular value of F_c for simplifying $C_1 = C_2 = C$.

$$R_1 = \frac{Q}{2\pi F_c A_F}$$

$$R_2 = \frac{Q}{2\pi F_c (2Q^2 - A_F)}$$

$$R_3 = \frac{Q}{\pi F_c C}$$

where,

$AF = \text{Gain at } F_c$

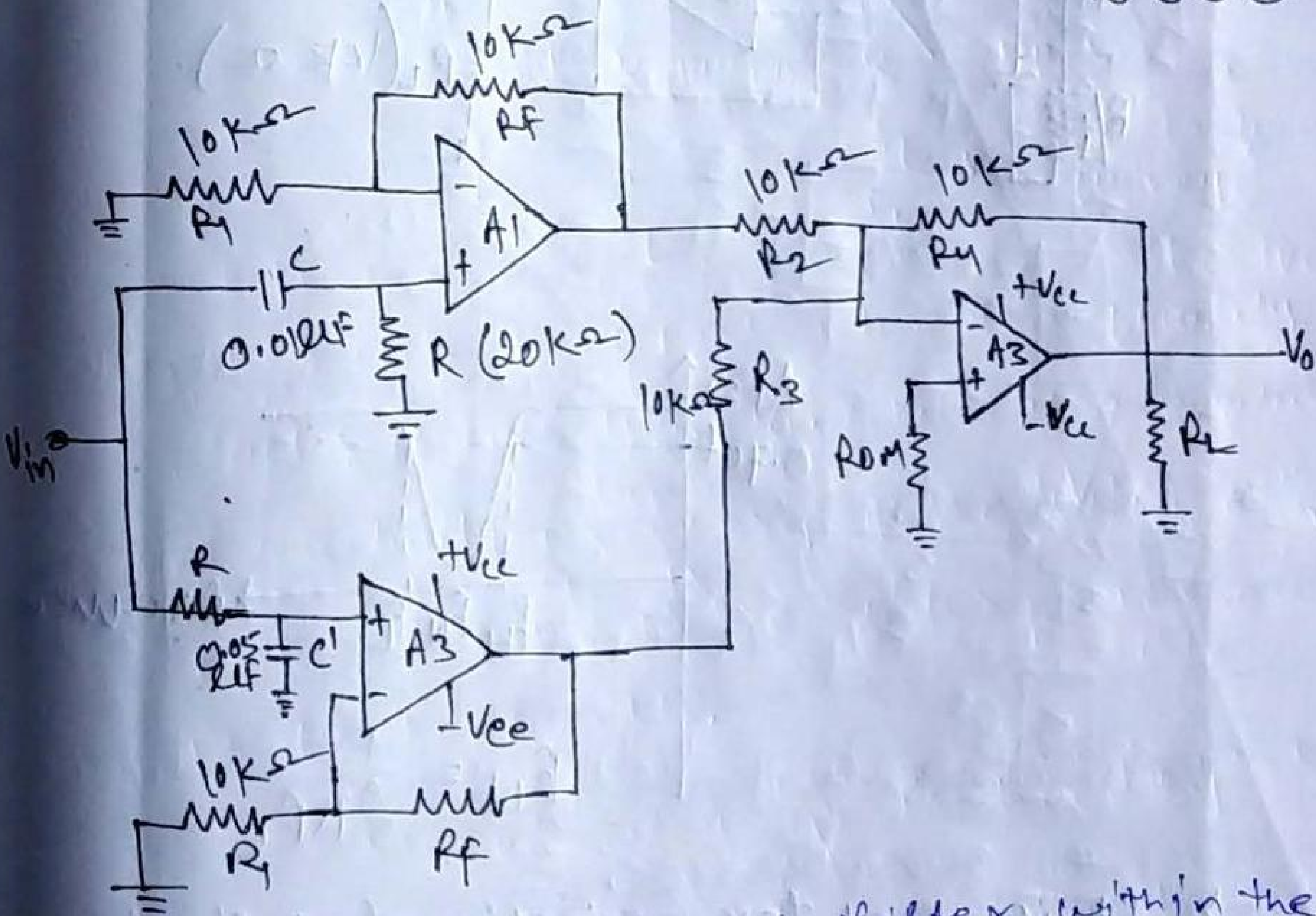
$$AF = \frac{R_3}{2R_1}$$

However, Gain AF must satisfy condition

$$AF < 2Q^2$$

Band Reject / Band Stop / Band Eliminate

Filter:-

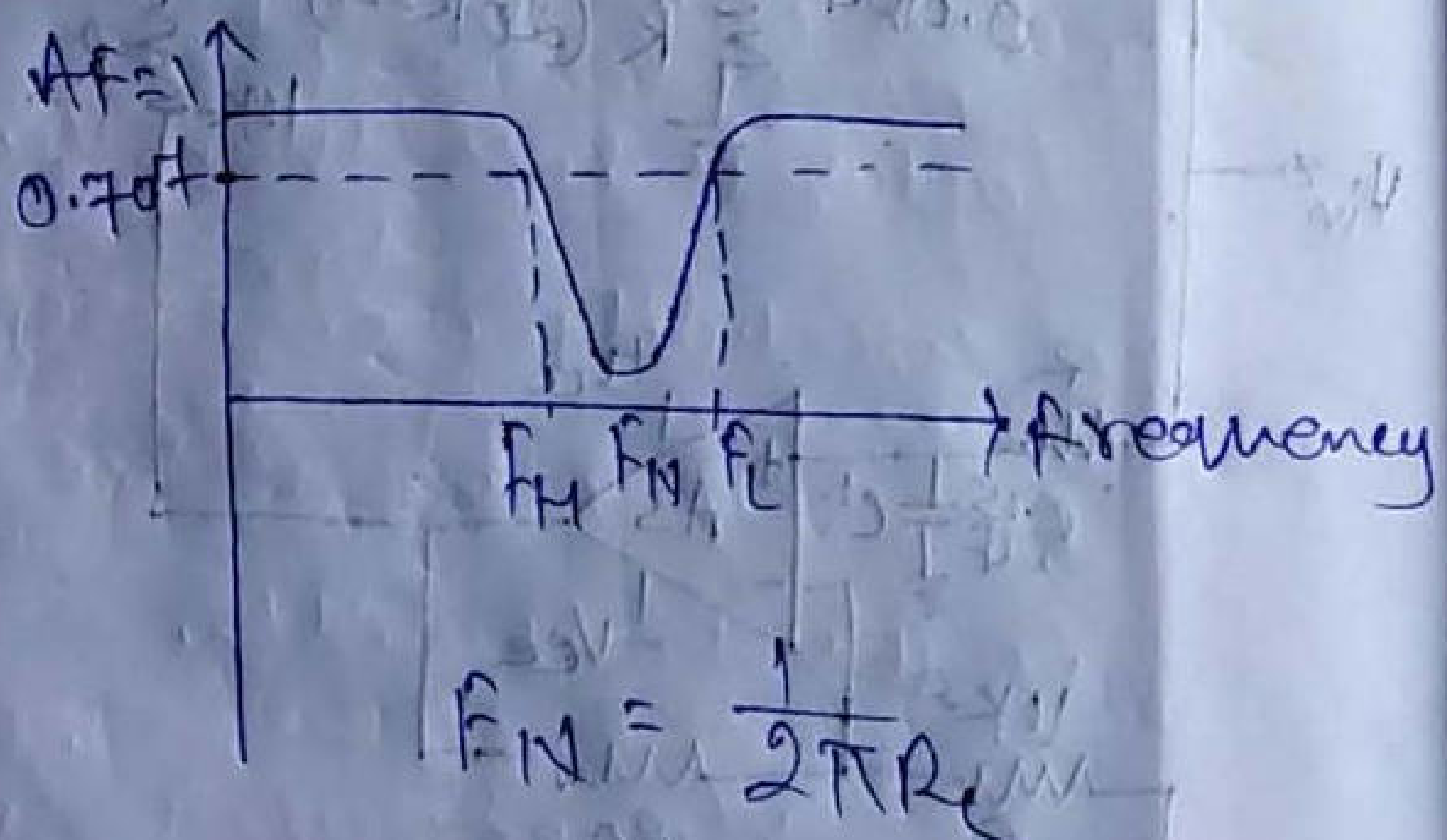
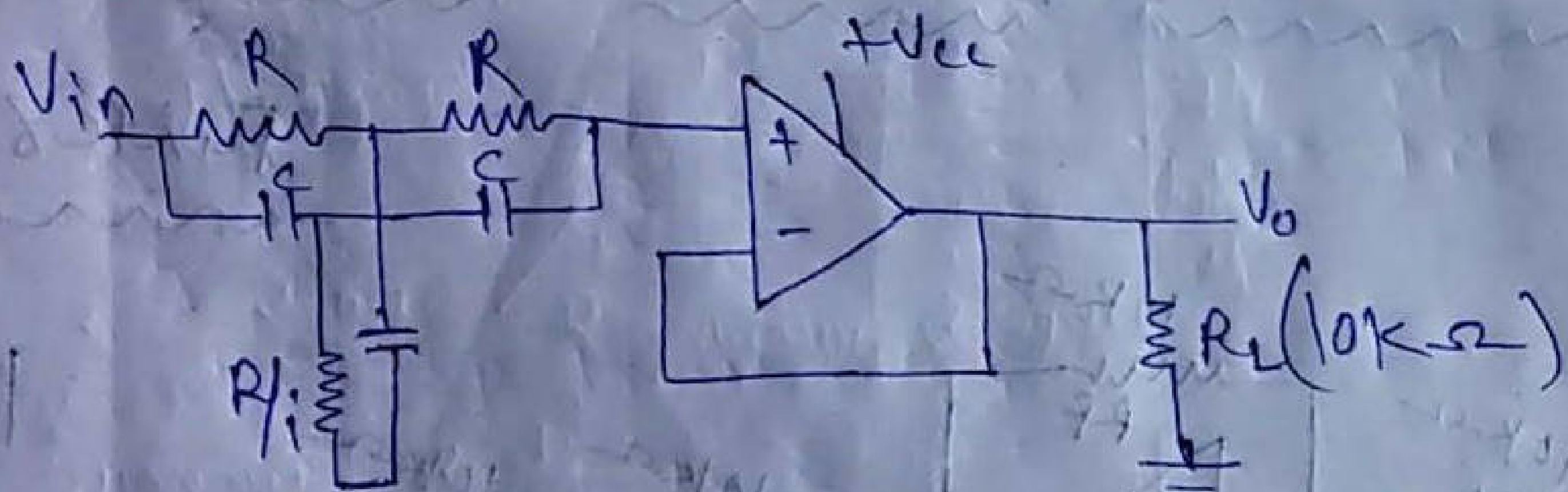


In a band reject filter, within the stop band frequency are eliminated & outside this the frequency are allowed to pass. It can also be divided into

wide band & narrow band, Reject Filter.

→ In a wide band filter the quality factor is less than (< 10) & is constructed using a low pass filter, high pass filter & a summing amplifier, to achieve this the high pass frequency must be greater than the low pass frequency & the gain of high pass & low pass filter must be equal.

Narrow Band:-



→ It is used for rejection of a single frequency such as 60 Hz power line frequency humming sound.

→ It Comprise of Two "T-shape" network, one of which consists of two resistor and a Capacitor or another network consisting of two Capacitors & a single resistors.

→ The notch out frequency is the frequency at which attenuation ~~both~~ occurs.

Both passive network have low quality factor which can be improve using a voltage follower circuit. It is mostly used in Bio-medical & Communication network.

Current Transmitter:-

→ The sensing element can either be represented using a voltage source or a current source but a Tx system more efficiently can reject series interference.

→ In industries the o/p. DC current signal (4 to 20mA) is proportional to the input measured variable. Generally the current transmitters can be of C.L. type having feedback & open loop type where microcomputers are used which improves the overall efficiency flexibility & versatility.

→ In a C.L. transmitter the overall sensitivity depends on feedback path elements where as in an open loop system the sensitivity depends on each element which change due to modifying the i/p. or non-linear effect, by using mechanical components or IC the performance can be improve the closed loop transmitter.

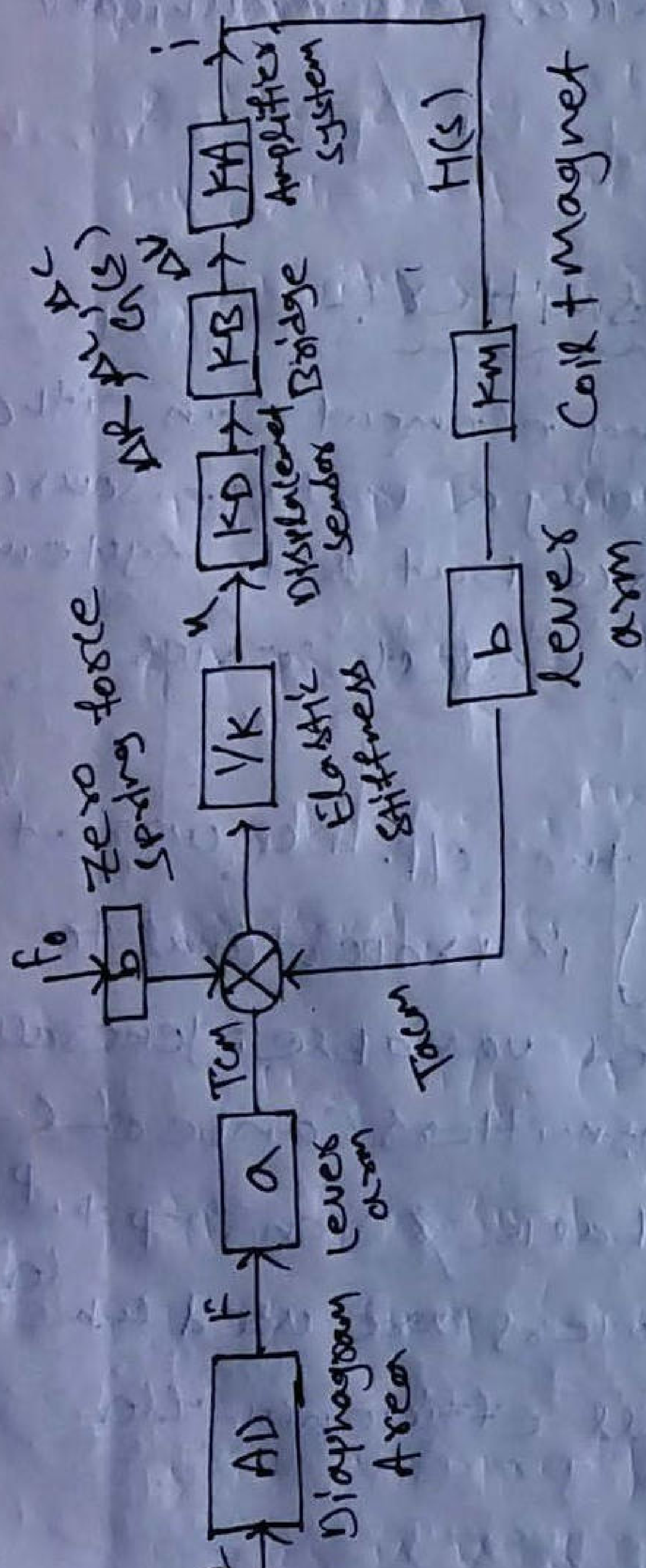
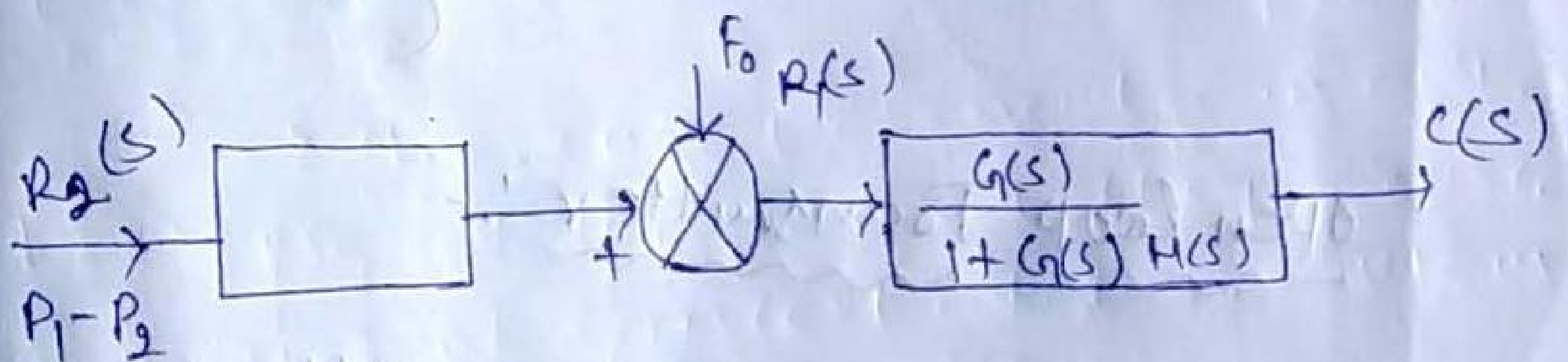


Figure for closed loop Transmitter

The diaphragm force $P_1 - P_2$ into AD produces a clock wise torque given by AD into $P_1 - P_2$ into a on the lever, the o/p. Current is feedback to a coil inside a permanent magnet to produce a force, $k_m \times I$ on the lever corresponding anti-clockwise torque ~~$k_m \times I_b$~~ $k_m \times I_b$.

→ The resulting change in o/p. Current is feedback to the coil & magnet for adjusting anticlockwise torque until approximate torque balance is obtain.



$$G(s) = \frac{1}{K} K D K B K A$$

$$H(s) = G K M$$

$$R_2(s) = A D a$$

$$R_f(s) = b$$

$$i \Rightarrow \left[(P_1 - P_2) R_2(s) + F_0 R_f(s) \right] \left[\frac{G(s)}{1 + G(s)H(s)} \right]$$

$$\Rightarrow \frac{K D K B K A / K}{1 + K D K B K A b K M / K} \left[(P_1 - P_2) A D a + b F_0 \right]$$

If $K A$ is given high then $K D K B K A b K M \gg 1$

It consists of two T-shape networks one of which consists of two resistors and a capacitor or another T-network consisting of two capacitors and a single resistor.

The notchout frequency is the frequency at which attenuation occurs, both passive networks have low quality-factor which can be improved using a voltage follower ckt, it is mostly used in biomedical and communication network.

Current transmitters:

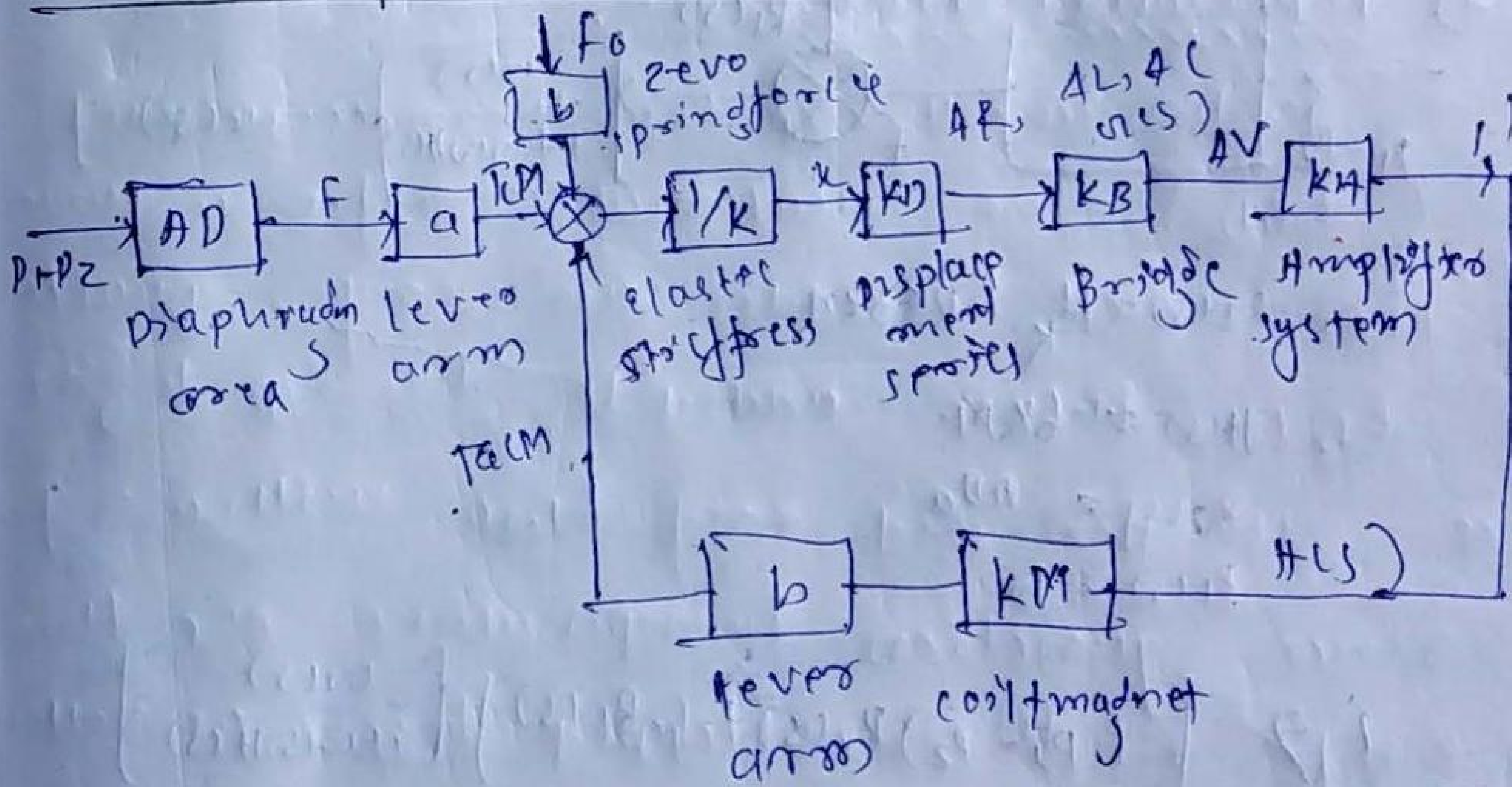
The sensing element can either be represented using a voltage source or a current source, but a current transmission system more efficiently can reject source interference.

→ In industries the o/p DC current signal (ϕ 4 to 20 mA) is proportional to the o/p measured variable, generally the current transmitter can be of closed loop type having feedback

and open loop type where microcomp
eters are used which improves the over
all efficiency flexibility and versata
ility.

→ In a close loop transmitter the overall sensitivity depends on ~~upon~~ feed back path elements. Whereas in an open loop system the sensitivity depends on each element which change due to modification of i/p or non-linear effect. By using mechanical components or I.C the performance can be improve.

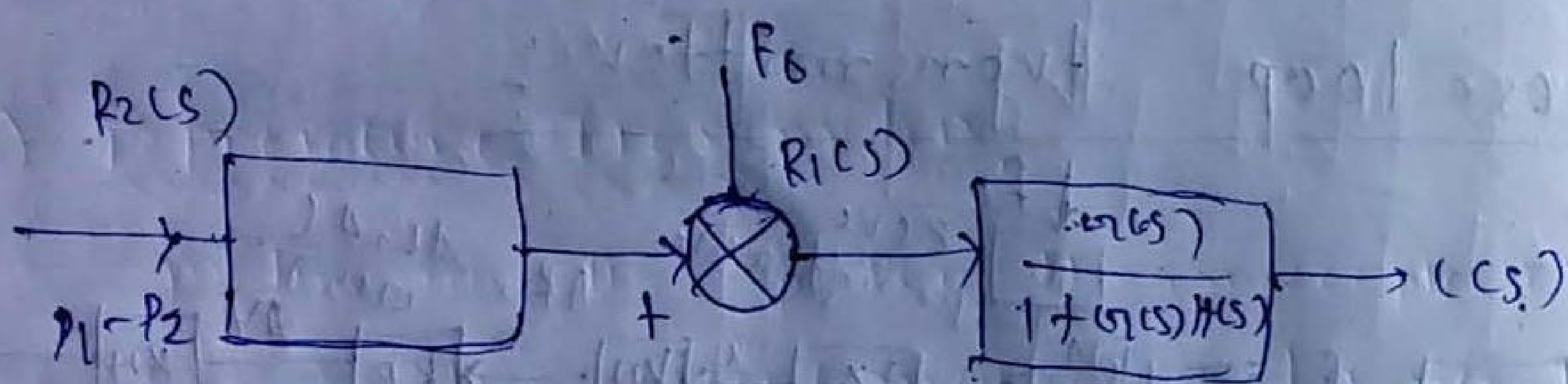
Close loop transmittance!



→ The diaphragm force $P_1 - P_2$ AND produces a clockwise torque $\odot$ given by $AD \times (P_1 - P_2) \times$ on the lever the output current as feedback to a COP, considered permanent magnet to produce a force

$K_M \times I$ on the lever and a corresponding
 anticlockwise torque $K_M \times I_b$ any im-
 balance of the torque causes the
 lever to rotate and the resultant dis-
 placement x is measured by the sensor
 bridge-amplified system.

The resulting change in output current is fed-
 back to the coil and magnet for adjusting
 anticlockwise torque until an approximate
 torque balance



$$G(s) = \frac{1}{K} K_D K_B K_A$$

$$H(s) = b K_M$$

$$R_2(s) = A D a$$

$$R_1(s) = b$$

$$\Rightarrow \left[(p_1 - p_2) R_2(s) + F_0 R_1(s) \right] \left[\frac{G(s)}{1 + G(s)H(s)} \right]$$

$$\Rightarrow \frac{K_D K_B K_A / K}{1 + K_D K_B K_A b K_M / K} \left[(p_1 - p_2) A D a + b F_0 \right]$$

If K_A is high then

$$\frac{K_D K_B K_A b K_M}{K} \gg 1$$

$$\begin{aligned} \text{Then } 1 &\rightarrow (P_1 - P_2) \left(\frac{A_D a}{b K_M} \right) + \frac{b f_0}{b K_M} \\ &\rightarrow \frac{a}{b} \frac{A_D}{K_M} (P_1 - P_2) + \frac{f_0}{K_M} \end{aligned}$$

The overall sensitivity is independent of the diaphragm stiffness, displacement, sensor sensitivity and amplifier gain. The i/p span and zero adjustment has to be done mechanically by altering the ratio a/b and the zero adjustment can be done by altering the force f_0 (Transmitter sensitivity = $\frac{a}{b} \frac{A_D}{K_M}$)

$\frac{f_0}{K_M}$ zero bias

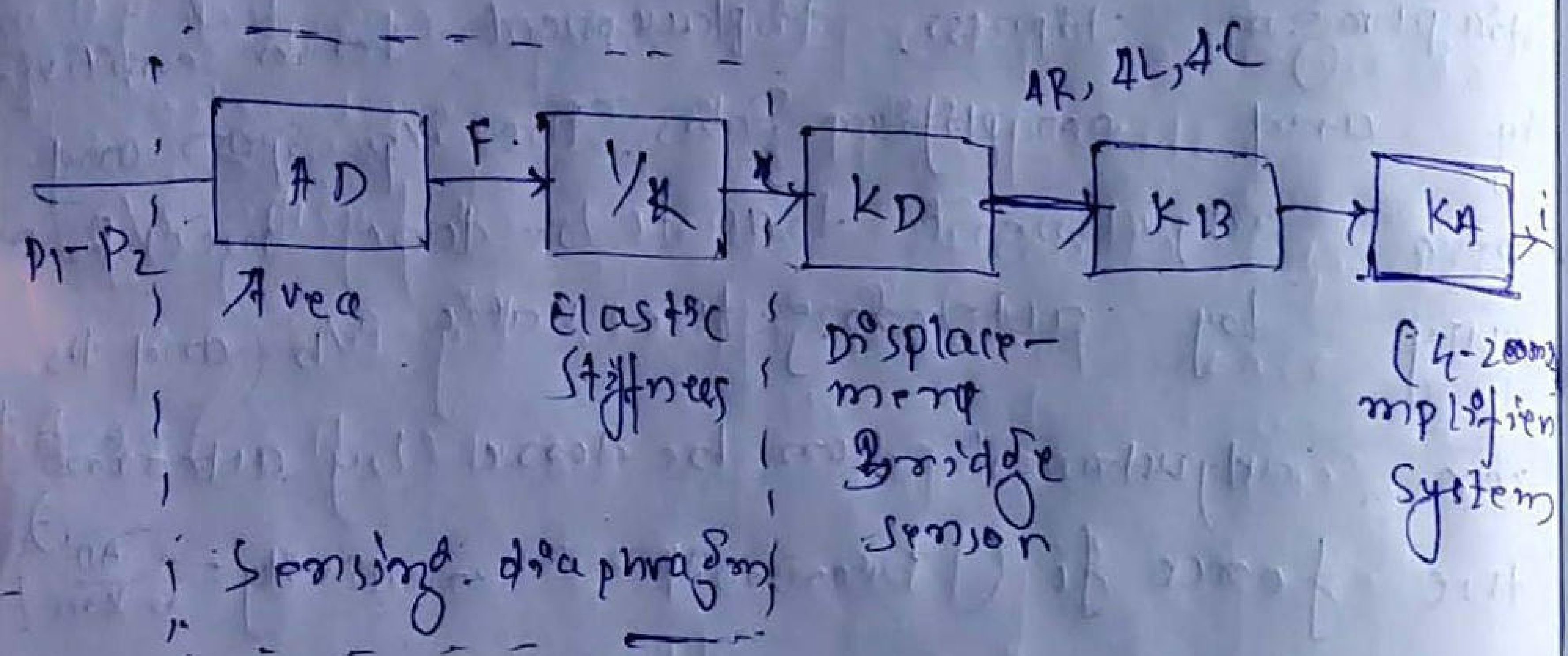
Open loop Transmitter:

→ (i) pressure transmitter:

Here there is no feedback present the i/p $(P_1 - P_2)$ differential acting over a area A_D of sensing diaphragm produces a deflection of force = $A_D \times (P_1 - P_2)$ which is oppose by an elastic spring force (K_x)

→ Displacement can be measured by a variable capacitance, reactance or resistance strain gauge with resistance strain gauge can use

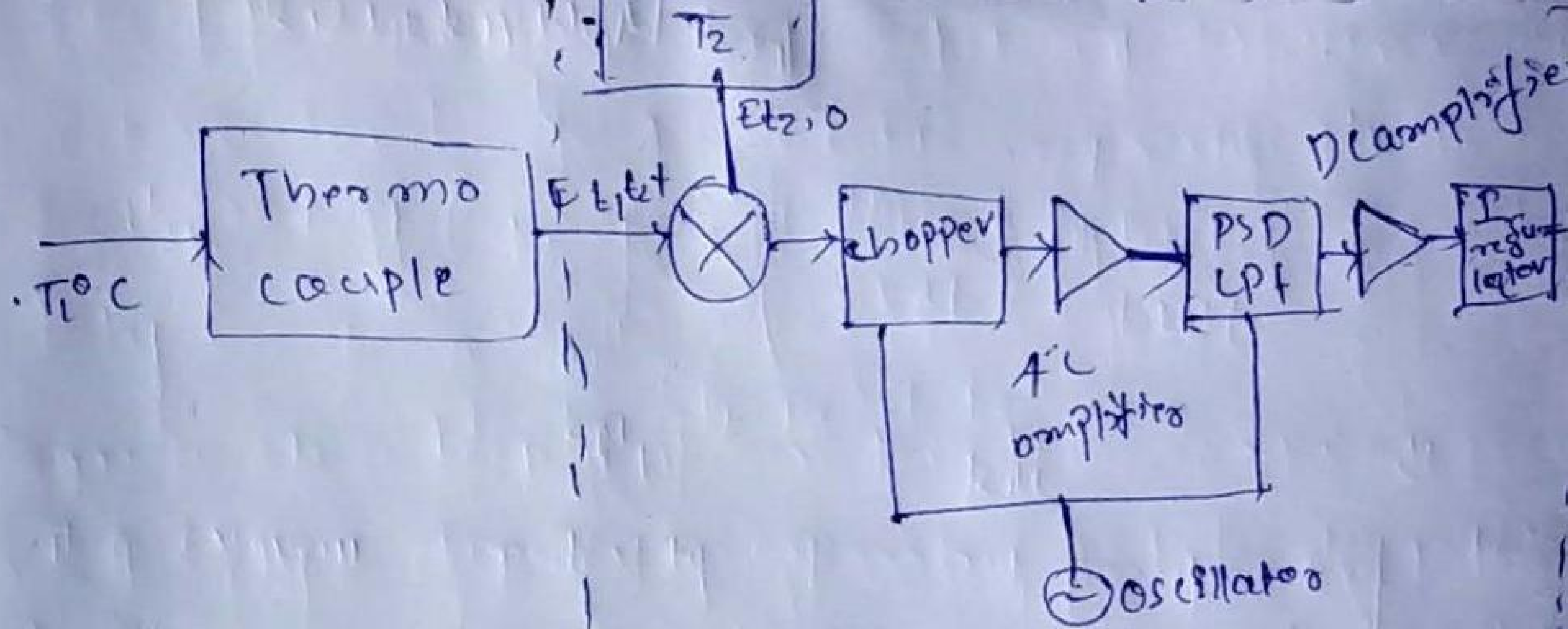
DC deflection bridge with an amplifier system and op current regulation of a capacitive or inductive displacement sensor is used then an AC carrier system is used.



2) Temperature Transmitter

→ In this case the i/p is a thermocouple emf (E_{T_1, T_2}) the automatic reference junction ckt provides an emf equal to $E_{T_2, 0}$ this is added to the i/p to give

a compensated emf $E_{T_1, 0}$ with a reference junction temperature $0^\circ C$. this emf is then chopped to give AC voltage necessary for a carrier system. this transmitter is located close to the process so that the signal can be transmitted to a remote control room.



Open loop transmitter
with mv $^{\circ}\text{C}/\text{p}$