SSM I

Date 1/08/19

Chapter 1

Sensor

Physical Domain

- Physical → Temperature, Humidity, Pressure, Force, Flow
- Chemical → CO_2, CO; explosive
- Biological → Diseases; Anatomy

⇓

Sensor → Phy: converts one form of energy to other

Transducer + Circuits → Volts, Amps

Actuator

Opposite of transducer.
Electrical Input & Physical Output.
eg → Motor, Relay

A sensor is always a transducer but vice versa is not always true.

– Table 1.1 in book.

Accelerometer

measures acceleration.
$F = ma$
measures force & as m is constant, we get acc^n.

- capacitive accelerometer.

Parameters in accelerometer:-

1. Dynamic Range :- Maximum accⁿ that is can measure.

Range → $\pm 1g$; $\pm 2g$, $\pm 5g$, $\pm 16g$

2. Resolution/sensitivity → smallest unit of measurement it can measure reliably
eg → thermometer → 0.1°c is resolutⁿ

unit of resolution is same as that of dynamic range.

3. Sensitivity to external parameters (1.10.2)

unit depends on external parameter

4. Accuracy
How close is measured value to actual value.

5. Stability
Over time how stable the data is
Bias Drift → change in bias / eg with change in temp, bias changes
↓
Difference b/w measured & actual value
Constant / Predictable in nature
Bias instability →
Random in nature.

6. Scale Factor

Errors → Additive
→ Multiplicative

$y \rightarrow \quad y = s.f(x) + b$

b → Additive error / Bias

$f(x)$ → Actual thing that should be measure

s → Scale factor ~~(Additive error)~~ Multiplicative

– Actual value → $10 m/s^2$
Measured " → $12 m/s^2$ → It can be bias of 2 or scale factor of 1.2

Reverse the scale accelerometer.

$-10 m/s^2 \longrightarrow -8$ Bias of 2
$-12 m/s^2 \longrightarrow$ scale factor of 1.2

7. Noise Floor ($\sqrt{Hz}$).

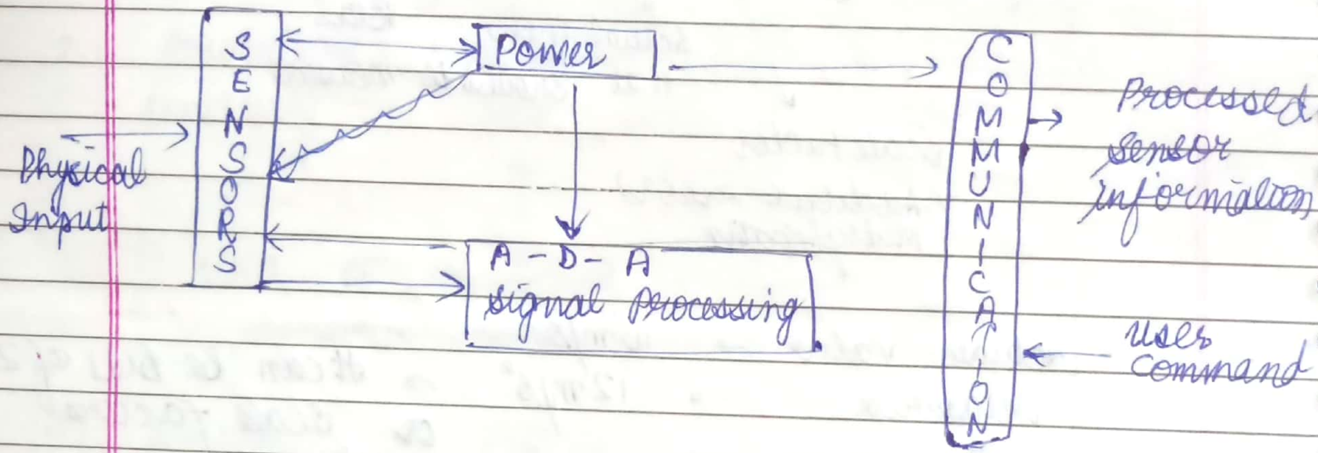
8. Repeatability

$$= \frac{\text{Max} - \text{Min value}}{\text{Full Range}} \times 100.$$

6/08/19

Smart Sensor -

Smart sensor system



Using sensors now we can regenerate power.

1. Low Powered sensing elements.
2. Power Battery / Energy harvesting
3. High speed wireless comm. (5G)

6/08/19

Date 6/08/19

Temperature / Thermal Sensor

- Degree of ~~how~~ hotness or coldness is temperature.

Temperature Scales

1. Kelvin scale.

$\frac{1}{273.16}$ the part or fraction of triple point of water

water can coexist as water liquid & gas at this point.

2. Celcius Scale (centigrade).

took 2 reference pt.s → boiling & freezing pt.
0° C   100° C

after 1 yr → 100° C   0° C.

100° Scale → ∴ centi

3. ~~Far~~ Fahrenheit scale

Ice pt. (Freezing pt.)
32° F

Avg Body temp of human
96° F
↓ Later
93.8° F

4. Re'aumur scale.

Freezing pt
0°

Boiling pt
80°

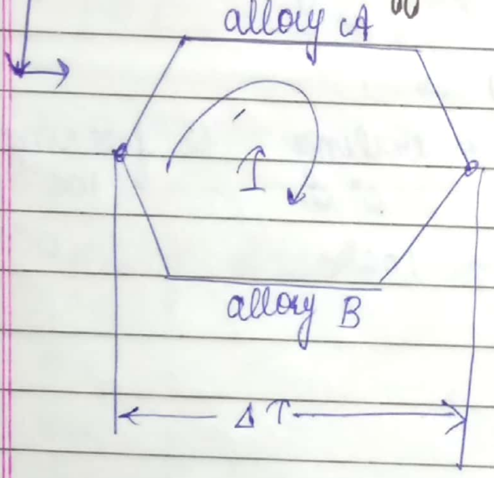
used in beer industry.

5. Rankine Scale

273.16 K ≃ 491.69° Rankine.

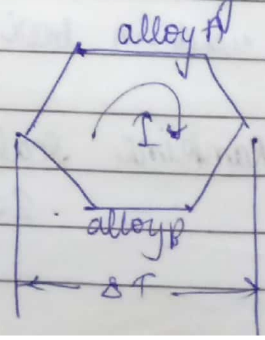
6. International Practical Temp Scale (IPTS)
- multiple reference pts
Ice pt   Steam pt   Tripple pt of N_2

Thermocouples
→ Seebeck effect
→ Peltier effect



- If temp difference is introduced b/w the 2 junction pts, there will be a current flowing from hot ~~junction~~ junction to cold junction
- Both junctions have diff temp.

Peltier effect
- can make Peltier heater, cooler.
- If there is a current flowing b/w 2 junctions then 1 junction is at high temp & other at low temp.



Types of thermocouples →
J, K, T.

RTD (Resistance Temp. Detector)

$$R_t = R_0(1 + at + bt^2 + ct^3 + \dots)$$

calliberation curve
2 curves → 1 expected & other observed curve
then match the 2 curves.
→ To bring real world behaviour to expected behaviour.

a → Temp coefficient
b, c, ... → Higher order temp coeff.

most common RTD →
Platinum RTD
$a_0 = 0.00385\ \Omega/\Omega$ valid for (0–100°C)
$R_0 = 25.5\ \Omega$

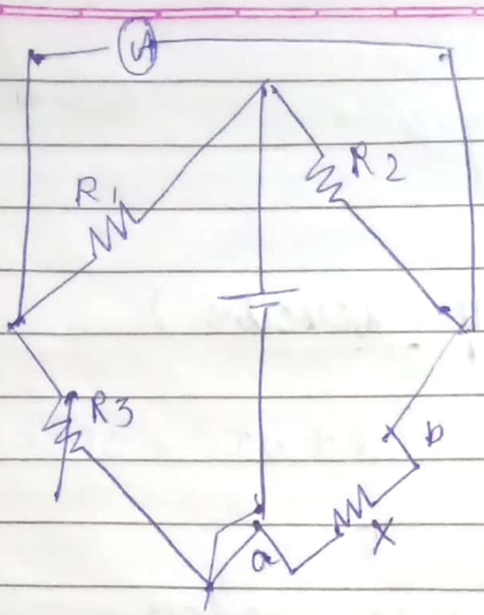
can be used to measure from triple pt of hydrogen (13.81K) to freezing pt of antimony (730.75°C)

For >100°C, callendar's eqⁿ →

$$t = \frac{100(R_t - R_0)}{R_{100} - R_0} + \delta\left(\frac{t}{100} - 1\right)\frac{t}{100}$$

$\delta \approx 1.5$ (callendar's coefficient)

Wheatstone bridge



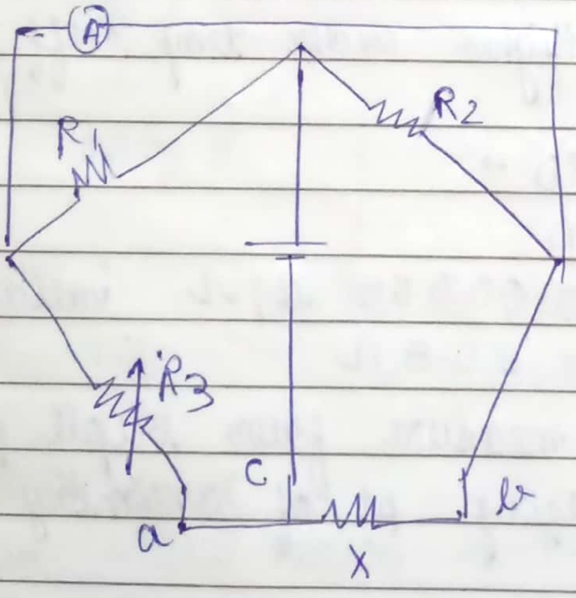
$R_1 + R_3 = R_2 + X + a + b$

If $R_1 = R_2$
$R_3 = X + a + b$

Measures res. of X with error of a & b

To remove this error, we have 3 terminal RTD instead of 2 terminal RTD.

3 terminal RTD →



- length of a & length of b must be same.
- Also material of a & b are need to be same.

$C + R_1 + R_3 + a = R_2 + b + X + C$

$R_1 + R_3 + a = R_2 + b + X.$

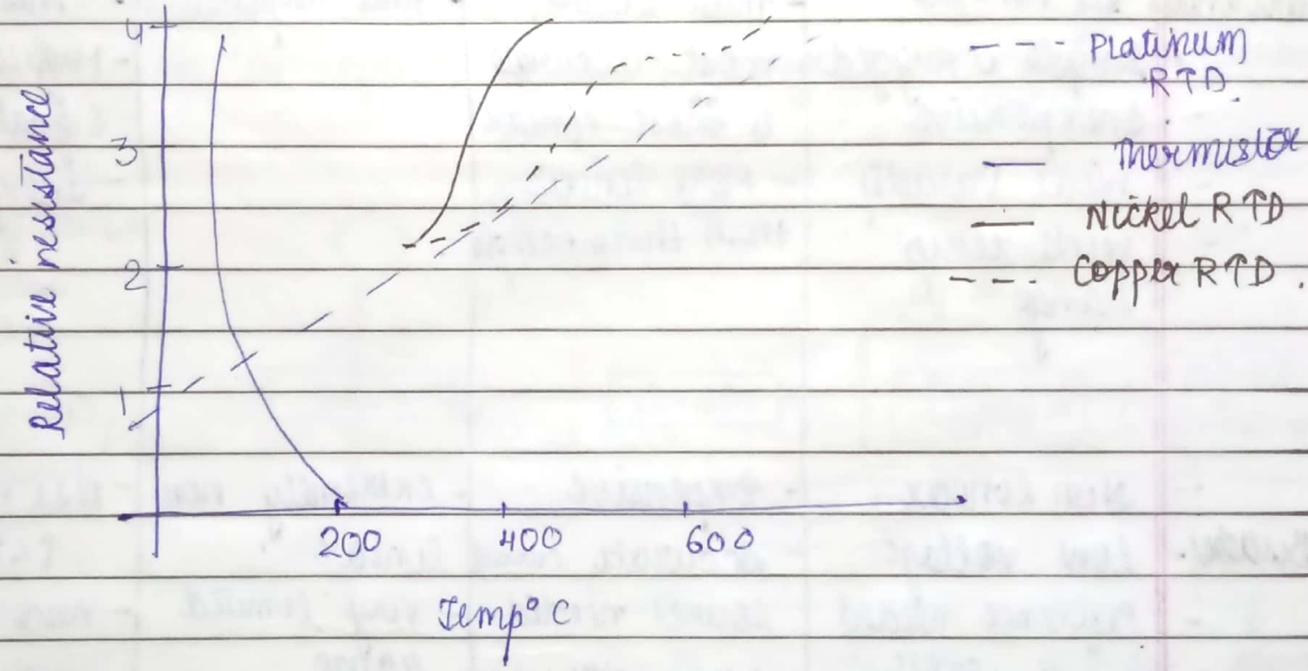
Thermistors

not widely used. — made of semiconductor.
high temp coefficient

$$R_t = R_0 \, e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

$B \rightarrow$ manufacturer defined constant.

$B \propto \frac{E}{K} \rightarrow$ energy level in eV



Platinum RTD $\rightarrow$ linear behaviour $\therefore$ most preferred.

By adding ckt like AtoD, etc $\rightarrow$ convert non linear into linear.

$\frac{2}{3} = \frac{4}{6}$

$R_1 \times R_3 = R_2 \times R_4$

R_2 / R_4

& R_1 / R_3

IC Sensor (Smart)

CKT & sensing element on same substrate

IC

mostly thermistor as it is made of semicond^n.
→ can be RTD / thermocouple

	Thermocouple	RTD	Thermistor	IC Sensor
Advantages	- Self powered. - Simple & rugged. - Inexpensive - wide variety - wide temp range.	- most stable - most accurate & ~~most linear~~ - More linear than thermocouple.	- Fast response.	- most linear - Highest o/p signal - Inexpensive
Disadv.	- Non linear - low voltage - Reference needed - least stable - least sensitive	- expensive - Accurate current source needed - ΔR is very small. - Self heating	- extremely non linear. - Very limited range - very fragile	- Less range $T < 200°C$ - need Power supply - Slow.

Scanned by CamScanner

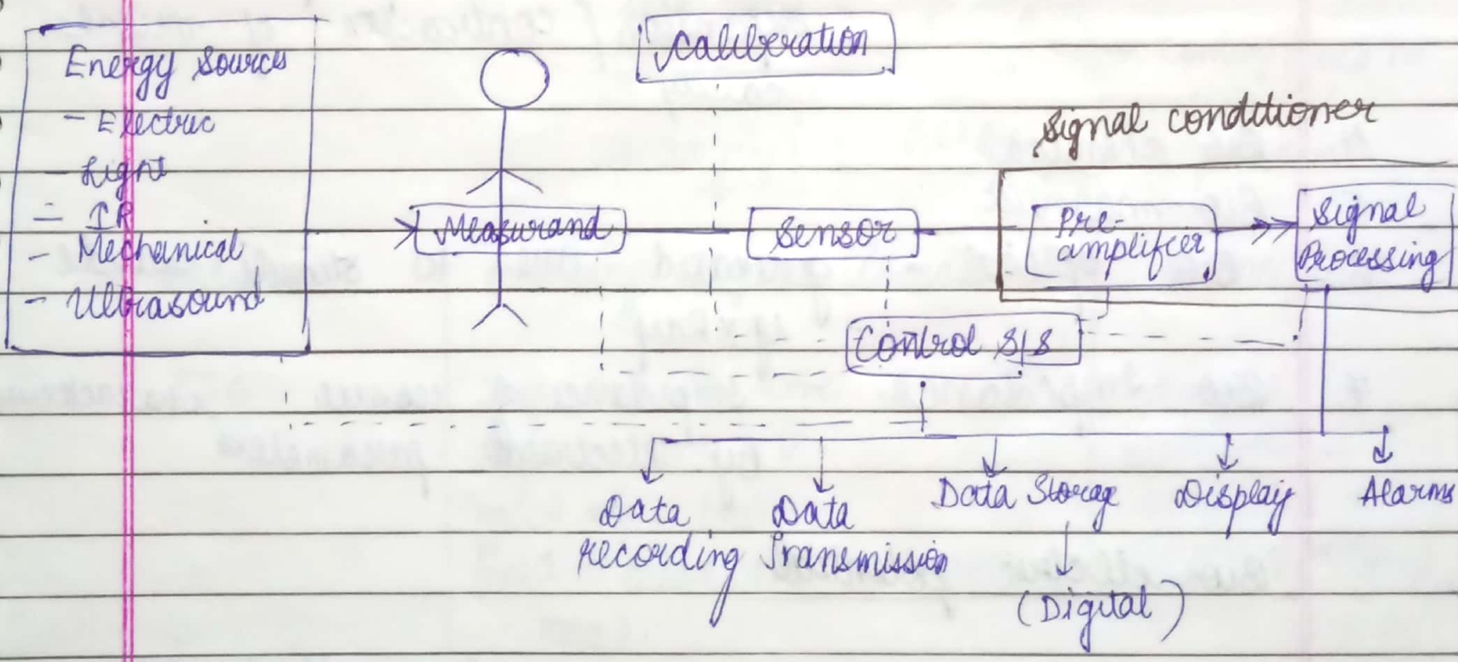
8/8/19

Biomedical Instrumentation

- measures physiological parameter related to body.

- measure / determine presence of some physical quantity
  Electronic →
- EEG, ECG, X Ray, BP Monitor, Glucose monitor

Mechanical Instruments -
BP Monitor, Gas gauge
pressure in eyes → pressure guage (to measure tension in eyes)
(Glaucoma)



- sensor errors → tolerance level is 0. For this active calibration S/S is needed.

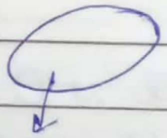
Measurand → Physical qty to measured.
signal cond. → Imp Matching / DAC /
↳ vary from simple resistor to multistage amplifier to ADC

In Vivo	In Vitro
↓	↓
- Inside the body measurement.	- ~~Ott~~ Measurement is outside
- ~~BP~~ eg → BP, thermometer temp.	- eg Glucose measurement, In Vitro fertilisation

Different sources of biomedical signals

1. Bioelectric - eg Measurement of membrane potential
2. Bio acoustic - sound measurement.
3. Bio mechanical - any type of motion / disp done due to expansion / contraction of muscle cavity
4. Bio chemical
5. Bio magnetic
6. Bio optical - generated due to stimuli outside eg X Ray
7. Bio Impedance. - Impedance of tissue characterised by electrical parameters.

Bio electric potential



cell Membrane

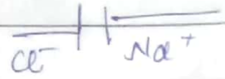
Each cell has lots of ions inside. It has membrane called cell membrane

K^+, Cl^- ✓

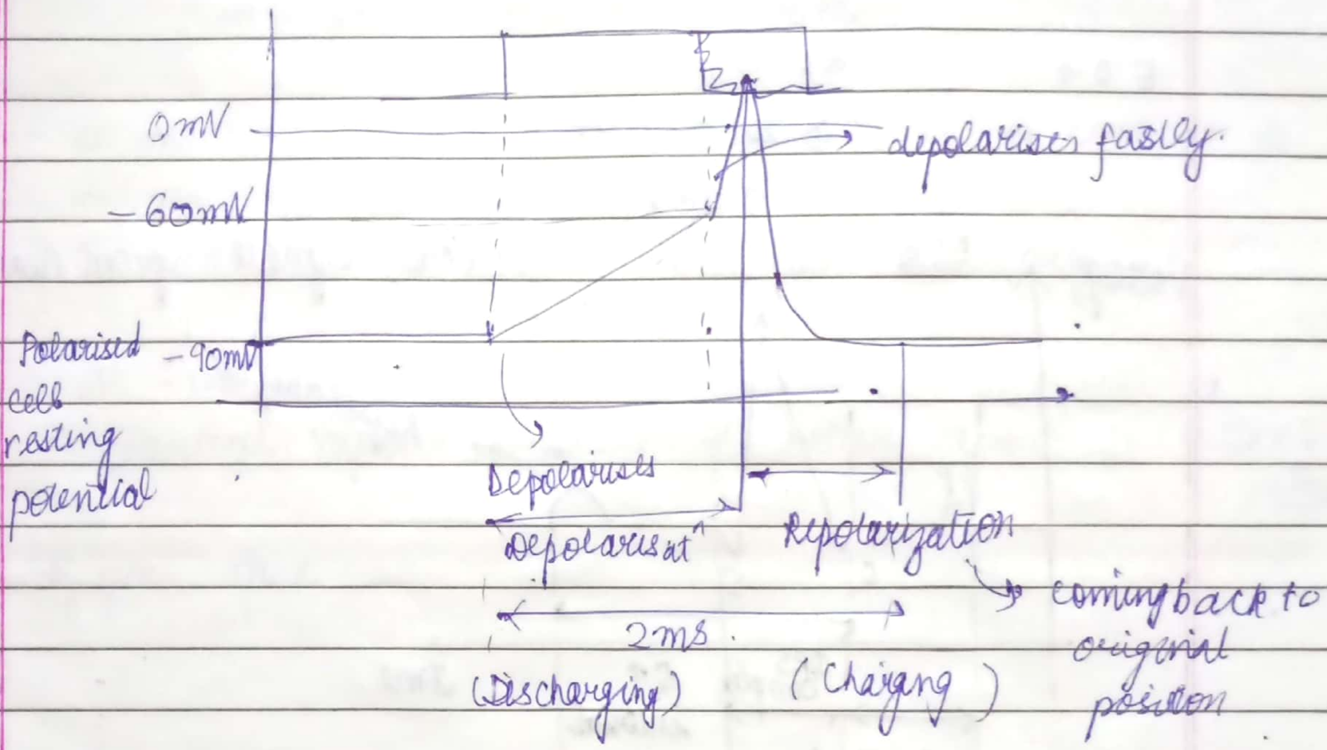
Na^+ ✗

- Responsible for any type of ?

Rest potential



Rest condition → Polarized condition



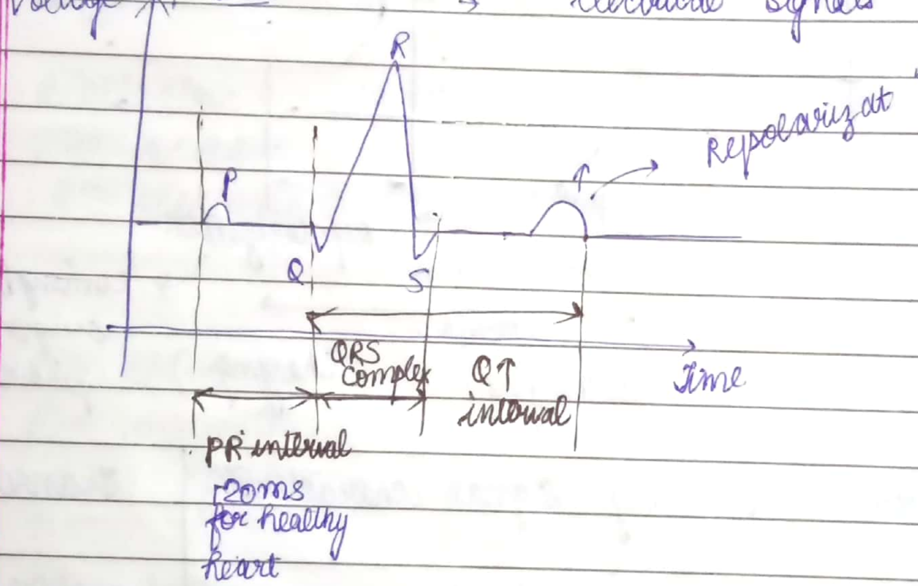
Parameter	Primary signal characteristic	Transducer
EGG	Freq 0.05 to 120Hz Amp 0.1 to 5 mV Typical amp : 1mV. (need to build LPF with gain of 1000)	surface electrode is connected to surface of body)
EEG	0.1 to 50HZ 2 to 200 µV 50µV	Surface
EMG	5 to 2KHZ 0.05 to 5mV 1 mV	needle

13/08

ERG — DC to 20Hz — contact electrodes
0.5 μV to 1mV
0.5mV.

EOG — DC to 100Hz
10 to 3500μV
0.5mV.

ECG → electrical signals from heart.



— 12lead ECG,

EEG — Brain waves

δ	0.5 – 4
θ	4 – 8
α	8 – 13
β	13 – 22
γ	22 – 30

From scalp → signal's amp is 100μV or less
On the cell . cortex → 1mV

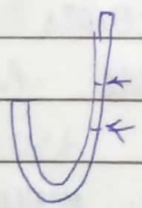
13/08/19

Humidity / Moisture Measurement

Water in liquid form → moisture
in gaseous form → humidity

- To measure humidity, condense it & cool it & see the temperature.
- To quantify moisture, we use humidity
- At $-112^\circ C$
  Partial vapour pressure of water vapour $\approx 0.8 \times 10^{-6}$ mm Hg
- If you mix

- Barometer → ~~mercury~~. Mercury is filled in it



Just for 200°C 10^9 order change in partial vapour pressure.

At $100^\circ C$ -
Partial vapour pressure of water vapour ≈ 760 mm Hg

Applications :-

1. Tobacco & paper industry.
2. Human comfort → air conditioner (HVAC)
3. Semiconductor industry (moisture in clean rooms has to be maintained 10-50% RH)

4. Food & Warehouse. (Refrigerator)
5. Agriculture (soil's moisture content has to be maintained at a specific level)

- metallurgy (- mixing alloys)

- sensor needs to robust to survive a huge dynamic range.

common parameters

1. - Dry bulb temperature
2. - Wet bulb temperature

In humid areas, wet bulb temp is high
Perceived temp > Real temp^n (when humidity is high)
Real temp > Percieved temp^n (when low humidity)

3. - Dew Point Temp^n

Temp^n when sat^n occurs.
Temp at which humidity becomes 100% RH.
→ Dew at night in areas where humidity is very high.

eg From AC room when you move out fogging on specs?
Max temp^n at which fogging will happen.

4. - %RH.

$$\frac{\text{water vapour}}{\text{max water vap at given temp}^n}$$

At 10°C dew pt → the partial vap pressure is 1227.6.76
25° " → " - " 3074.41 Pa

$$\frac{1276.76}{3074.41} = 40\% \text{ RH}$$

Measurement of humidity

- Secondary measurement is required

Primary Measurement - measuring directly the qty

~~For calculating~~ Measure a corelated qty
eg. to find force, you first measure acc^n.

Instruments to measure RH

1. wet bulb / dry bulb.
   ↓
   Primary instrument → two thermometers.

Psychrometric Charts

2. Mechanical expansion.
   Silica gel → humidity absorbant
   in shoes pouches
   How much the size is changing.

3. Dunmore element. (set of 2 wires)
   Bifilar wound wire on insulating substrate, coated with LiCl.
   ↓
   salt for Humidity sensing

4. Pope cell.
   There is a conductive polymer which is humidity sensitive.

5. Bulk effect - Thin film of sulfonated polymer

6. Surface Resistance.

7 Strain Gauge - It's range change to some deformation induced.

8 capacitance - Two plates b/w them we have dielectric & use a dielectric which is sensitive to humidity.

Humidity changes → dielectric const changes.

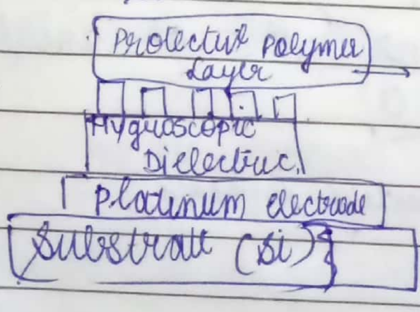
<u>Measurement of dew point</u>

1. condensation type hygrometer → chilled surface. a small mirror is cooled down & check whether it is getting condensed or not. Moment that happens.

2 Heated saturated salt

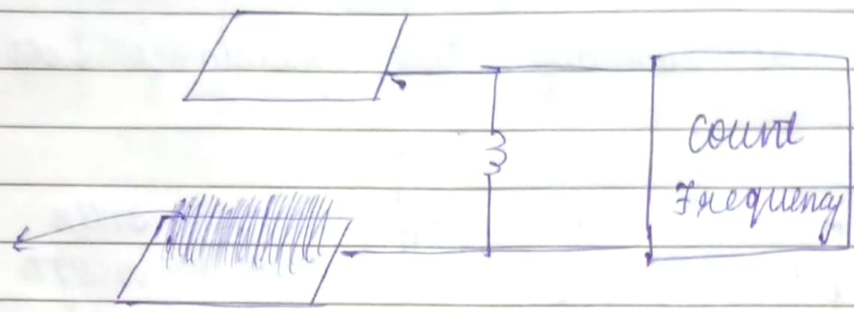
3/4 capacitive → Al_2O_3, SiO_2

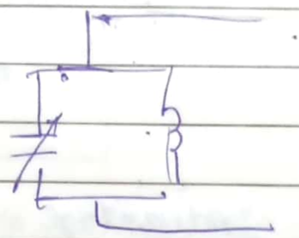
<u>capacitive</u> →



side view

Measuring capacitance





Advantages :

1. O/p voltage is linear
2. stable results for big dynamic range
3. can detect wide range of RH.

Long range sensing is not possible using capacitive.

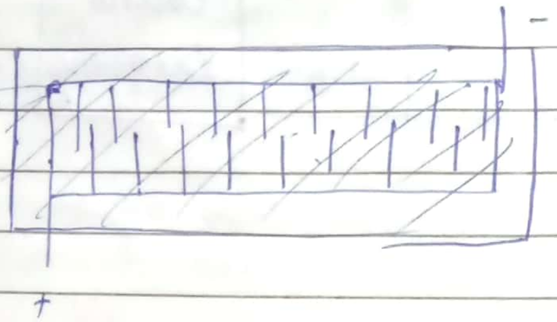
Eg: HVAC, printers, automobiles.

20/08/19

Resistive Humidity Sensors

more often, as humidity ↑ses, resistance ↓ses

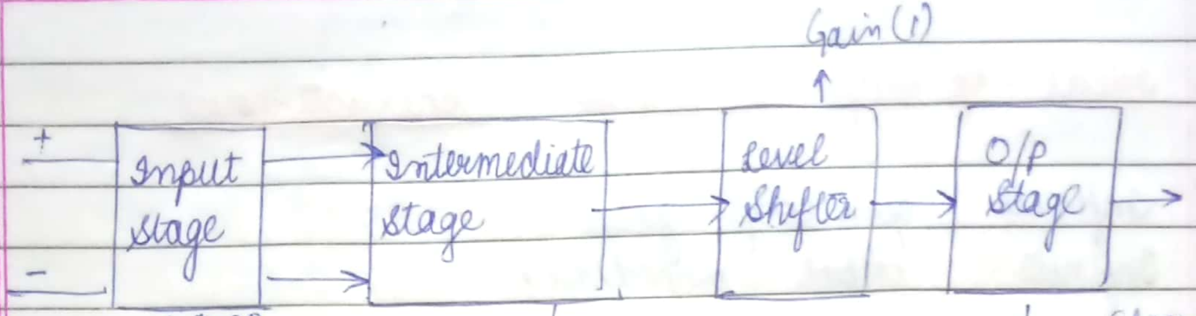
Hydroscopic material



Inter design
Benefit → In same plate space, more surface area

- extremely cost effective] Advantage
- susceptible to environment] Disadvantages
  measuring humidity in already humid region is difficult
- easily interchangable] Advantage
- used for places where we don't need accuracy & can not spend much.

- why is there a need of op amp for making amp^n, why not xsistor ?
  xsistor requires large i/p current which is not practically possible to give so op amp.

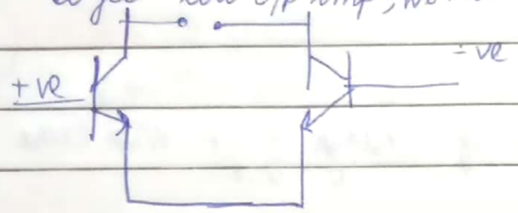


↓ DIBO
- CMRR
- Gain ≈ (50–100)
- High i/p impedance

↓ Dual i/p unbalanced o/p
Gain (10–50)
- This stage is to ↑se gain

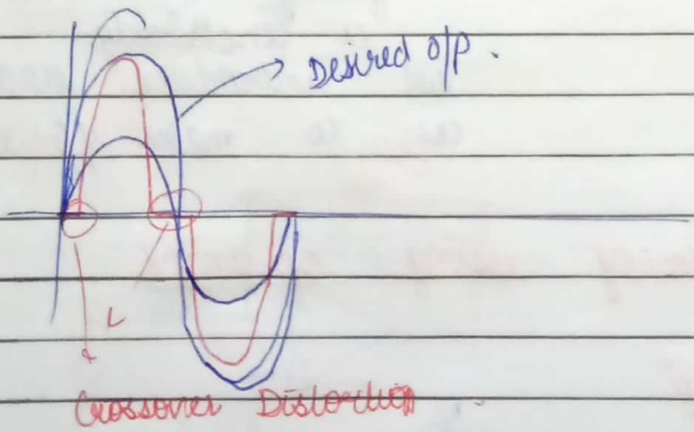
↓ Class AB amp
Push Pull complementary amp
to get low o/p impedance
To remove cross over distortion
Gain (5–10)

To get low o/p imp, we have more stages.



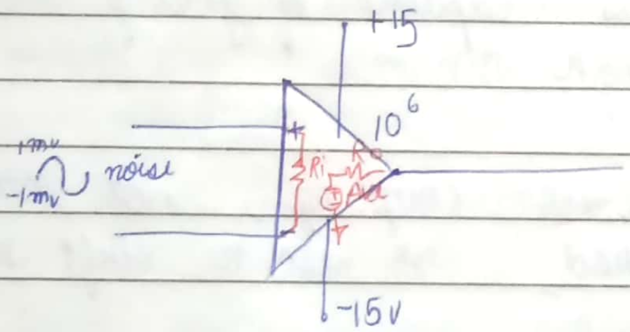
- Dual I/p Balanced o/p
- Only differential i/p is capable of giving CMRR.
- CMRR should be high.

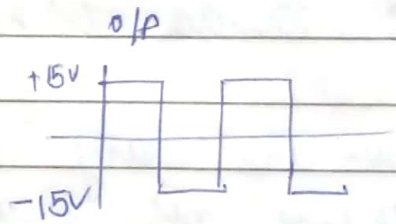
→ Here we are using direct coupling, not cap coupling so DC is not blocked, we need to shift DC. ∴ we use level shifter.



Ideal op amp electrical characteristics

1. Infinite open loop gain
2. Infinite input impedance
3. 0 o/p impedance
4. 0 o/p voltage when input = 0.
5. Infinite Bandwidth
6. Infinite CMRR
7. Infinite slew rate.
   max rate of change of o/p with time

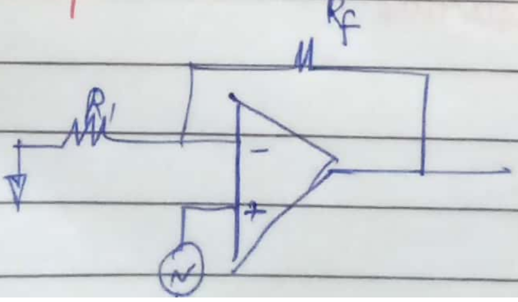




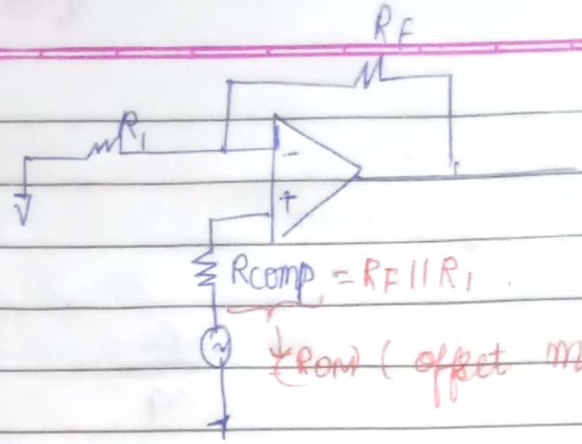
no i/p only noise & we are getting oscillations this is instability
we introduce feedback so as to make s/s stable.

Signal Conditioning using op amps

1. Non Inverting ampr.



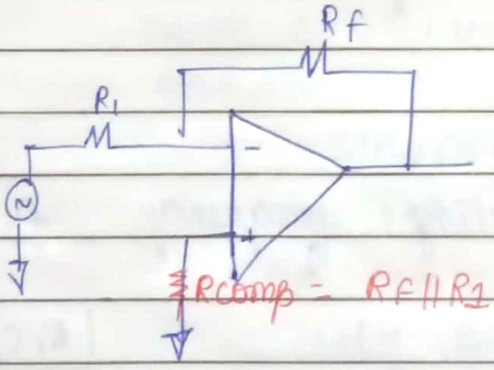
$$A_V = 1 + \frac{R_f}{R_1}.$$



Practical op Amp

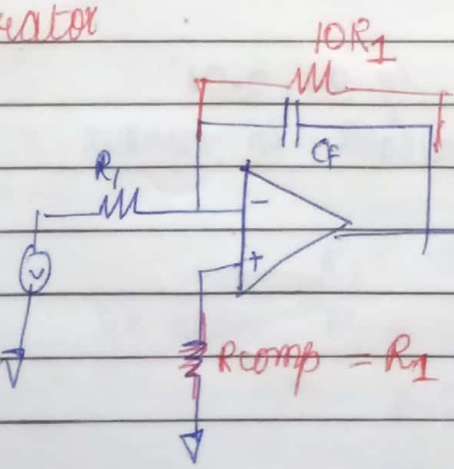
Rcomp → To ensure that small amt of current going in +ve terminal = small amt of current going into -ve terminal

2. Inverting Amplifier



$$A_V = -\frac{R_F}{R_1}$$

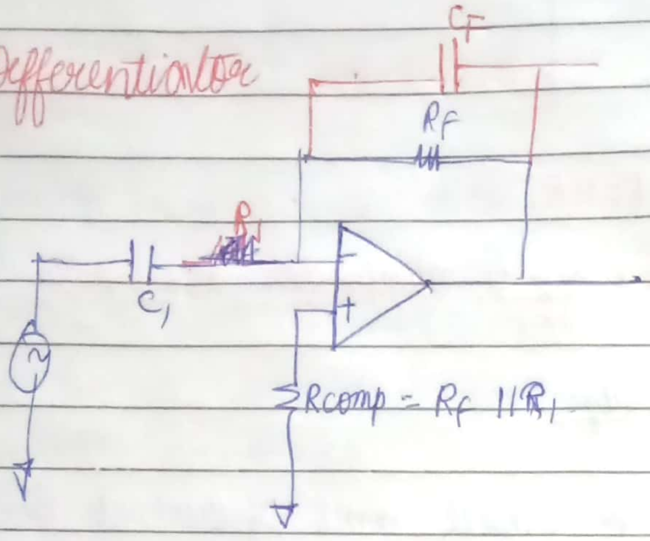
3. Integrator



For low freq cap → OC
so instability
So we put resistor in parallel with capacitor CF.

- Fix R_1 & find R_f .

4 Differentiator



$A_V = \frac{-R_f}{X_{C_1}}$

On ↑ing freq, gain ↑ses 20dB/decade

$R_1 \approx 0.01 R_F - 0.1 R_F$

Steps to design a practical differentiator

1. $f_a \rightarrow$ Highest frequency that needs to be differentiated

$f_a = \frac{1}{2\pi R_f C_1}$

2. $f_b \rightarrow$ Gain limiting frequency $f_b \approx 20 f_a$.

$f_b = \frac{1}{2\pi R_1 C_1}$ $\boxed{R_1 C_1 = R_F C_F}$

Choose cap → μF eg. 0.1, 0.01
choose values available in market .

Typical values

Standard: E-12 scale.

1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2, 10

Any multiples of 10 of these 12 nos is also standard

every no. is 20% more of previous no.

- Any device → 10% tolerance.
  Round off to these resistors' value.

Ques Design a differentiator that frequency is 20 Hz - 800 Hz

$$f_a = 800\ Hz = \frac{1}{2\pi C_1 R_F}$$

choose $C_1 = 0.1\mu F$.

$$800 = \frac{1}{2\pi \times 0.1 \times 10^{-6} R_F}$$

$R_F = 1.98 K\Omega$

We can choose $R_F = 1.8K\Omega$ or $2.2K\Omega$

We choose $R_F = 2.2K\Omega$.

$$f_b = 16KHz = \frac{1}{2\pi R_1 C_1}.$$

~~$R_F \approx 10 R_1$.~~

~~$R_1 =$~~

$R_1 = 99.5 K\Omega$

We choose $R_1 = 100\Omega$.

$R_1 C_1 = R_f C_f$

$C_f = 0.0045\mu F$

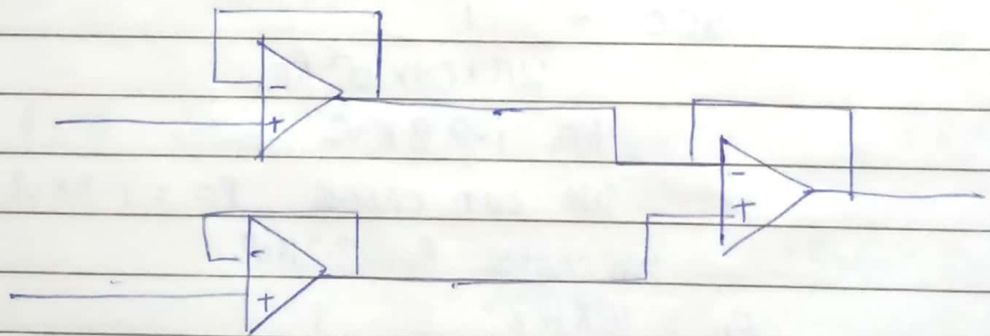
We choose $C_f = 0.0047\mu F$.

Scanned by CamScanner

21/08/19

Instrumentation Amplifier

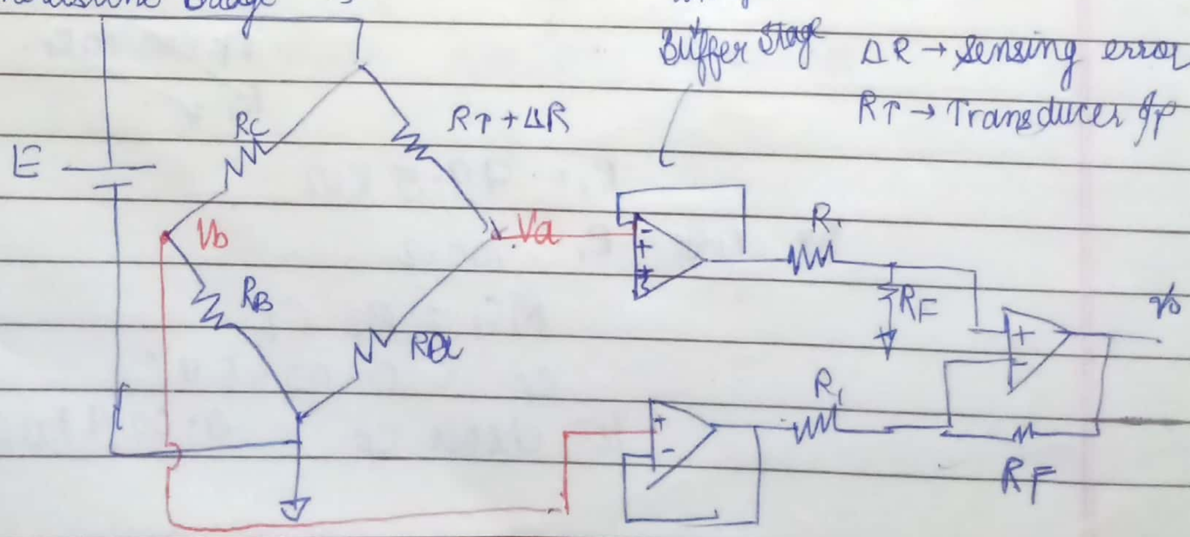
- In instrumentat" amp", gain can be externally set.
- CMRR is very high
- Accuracy is very high
- Stable passive resistive feedback n/w is there.
- Package consisting of multiple op amps, wired with accurate & stable resistive / capacitive feedback.
- Gain can be selected externally
- High gain accuracy, gain stability & CMRR
- All the op amps are on same substrate



Wheatstone Bridge →

unity feedback amp"
Buffer stage

$\Delta R \rightarrow$ Sensing error
$R_T \rightarrow$ Transducer o/p



Buffer stage → Gain of unity.

$$A_v = \frac{R_F}{R_1}$$

At zero condition, bridge is balanced

$$\frac{R_C}{R_B} = \frac{R_T}{R_a}, \quad \Delta R = 0, \quad V_a = V_b$$
$$\therefore V_{ab} = 0$$

Design a bridge in accordance with transducer.

$$V_a = \frac{E\, R_a}{R_a + R_T + \Delta R}$$

$$V_b = \frac{E\, R_b}{R_b + R_c}$$

$$\therefore V_{ab} = E\left(\frac{R_a}{R_a + R_T + \Delta R} - \frac{R_b}{R_b + R_b}\right).$$

If $R_a = R_b = R_c = R_t \rightarrow R$

$$V_{ab} = E\left(\frac{R}{2R + \Delta R} - \frac{R}{2R}\right)$$

$$V_{ab} = E\left(\frac{R}{2R + \Delta R} - \frac{1}{2}\right)$$

$$V_{ab} = \frac{-\Delta R \cdot E}{2(2R + \Delta R)}$$ → input to instrumentation amp^r

$$V_o = \frac{R_F}{R_1} \times V_{ab}$$

Ques Assume a thermistor is connected to a bridge ckt with $R_A = R_B = R_C = 120\,K\Omega$. Excited by $E = +5$. The thermistor has nominal resistance $= 120\,K\Omega$ at reference temp $= 25^\circ C$ & temp coefficient of $-1K\Omega/^\circ C$. Determine o/p voltage at $T = 0^\circ C$ & $T = 100^\circ C$. If $R_F = 10K\Omega$, $R_1 = 2.2K\Omega$.

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

$R_A = R_B = R_C = 120K$.

$E = +5V$

For $0^\circ C \rightarrow$

$\Delta R = \cancel{120(1-} \; 25\,K\Omega$

$$\text{o/p voltage} = \frac{-\Delta R E}{2(2R+\Delta R)} \times \frac{R_F}{R_1}$$

$$= \frac{-25 \times \cancel{10^3} 5}{2(2(120K)+25K)} \times \frac{10 \times 10}{\cancel{2}2}$$

$= -1.07V$.

For $T = 100^\circ C \rightarrow$

$\Delta R = -75\,K\Omega$ as $\Delta T = 75^\circ C$.

$$\text{o/p voltage} = \frac{+75 \times 5}{\cancel{2}(240-75)} \times \frac{\cancel{10}^{5} \times 10}{22}$$

$$\frac{75 \times 5 \times 5 \times 10}{22 \times 165} = 5.17V$$

240
75
165

Filters → device that ↑ses SNR

→ Passband (zero attenuation)

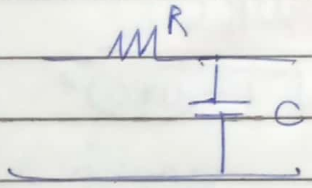
→ stopband (infinite attenuation)

- Response time
- Bandwidth over which measurement is desired.

Filters
- → Passive
- → Active

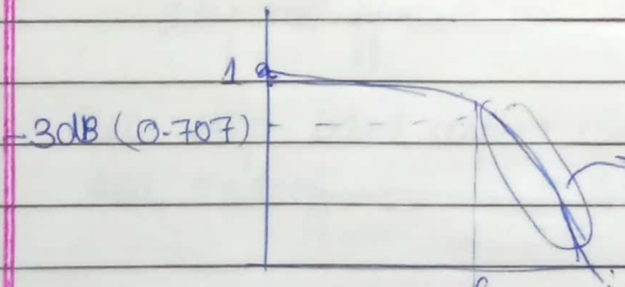
- LPF
- HPF
- BPF
- BRF (Notch)
- All Pass

- Passive Low pass



$$\frac{V_o}{V_{in}} = \frac{1}{1+sRC} \qquad \left|\frac{V_o}{V_{in}}\right| = \frac{1}{\sqrt{1+(\omega RC)^2}}$$

Gain

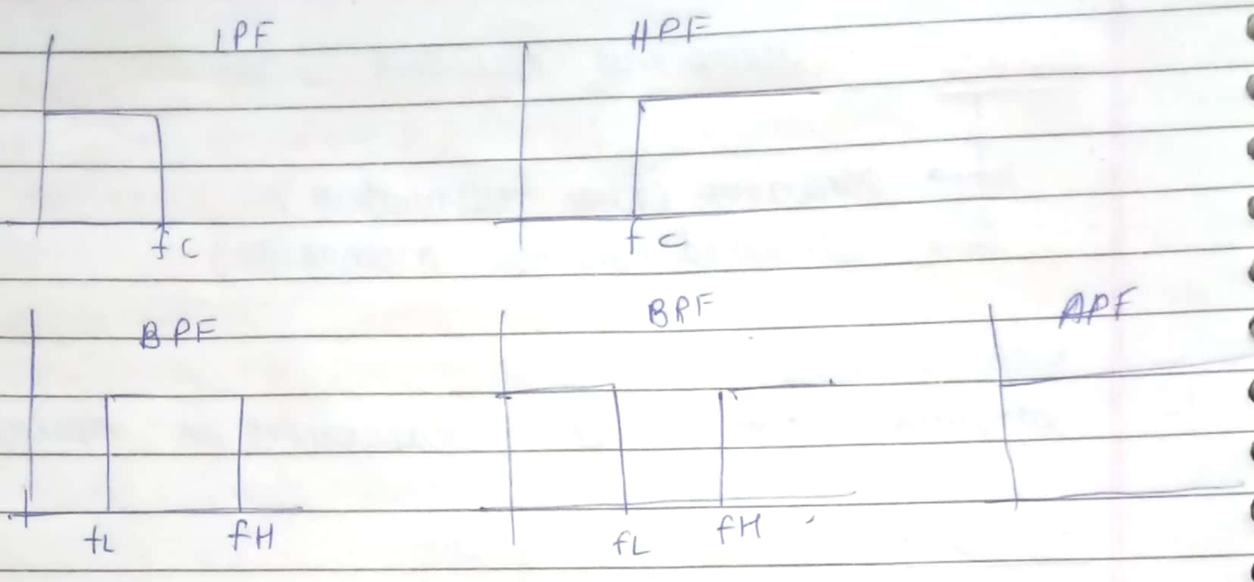


At 3dB → half power freq.

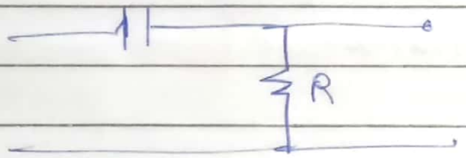
$\boxed{\tau = RC}$.

$$f_c = \frac{1}{2\pi RC}$$

Ideal Responses

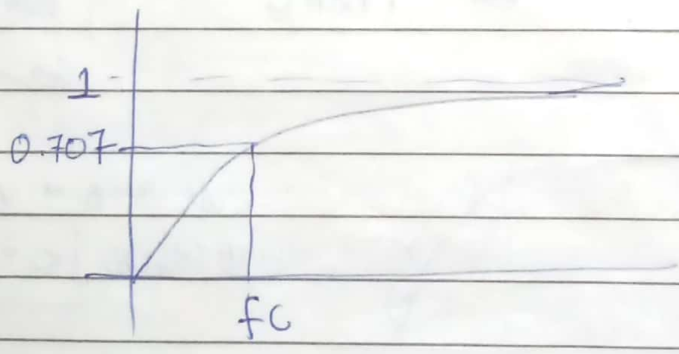


- Practical HPF



$$\frac{SRC}{1+SRC}$$

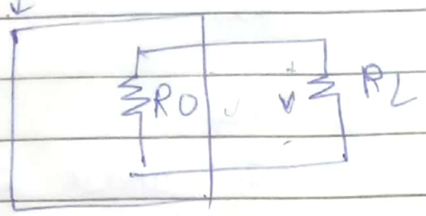
$$\left|\frac{V_0}{V_{in}}\right| = \frac{\omega RC}{\sqrt{1+(\omega RC)^2}}$$



Active Filters

- In passive filters gain is not more than 1 & we can not have gain of our choice. ∴ we need active filters.

- Gain & Frequency control.
- Due to high input impedance & low o/p impedance, loading effect

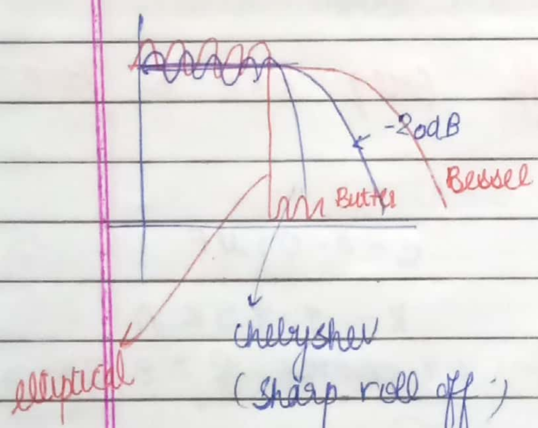


make RO = 0 no loading effect ; v won't reduce for any value of RL

- cheap (cheaper than inductor not cap).

Types :-

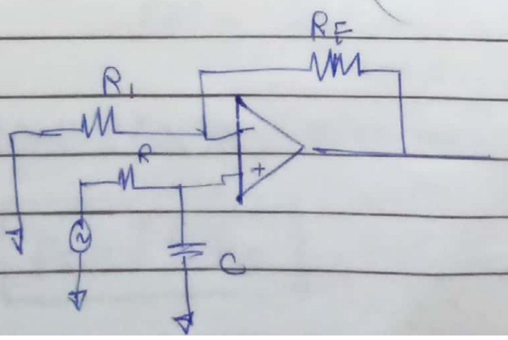
1. Butterworth 2. chebyshev 3. elliptical 4. Bessel.



Best stop band resp → elliptical
Abt tradeoff → Butterworth

First order LP Butterworth

(Maximally flat) (Flat Flat)



$$f_c = \frac{1}{2\pi RC}$$

$$\text{Gain} : 1 + \frac{R_F}{R_1}$$

Scanned by CamScanner

$TF = \frac{A_f}{1 + j\omega RC}$

cap will introduce phase diff
(Phase lag)

- Phase angle compensation in bessel.
- Phase lag in butterworth. If phase lag is not a problem use butterworth.

At $f = f_c$ Gain $= 0.707 A_f$

$f < f_c$, Gain $= A_f$

$f > f_c$. Gain $< A_f$

Ques. Design a LPF with cutoff freq 2KH & gain = 2

$f_c = 2\,KHz$

$f_c = \frac{1}{2\pi RC}$

$C = 0.01\,\mu F$.

$R = 7.95\,K\Omega$

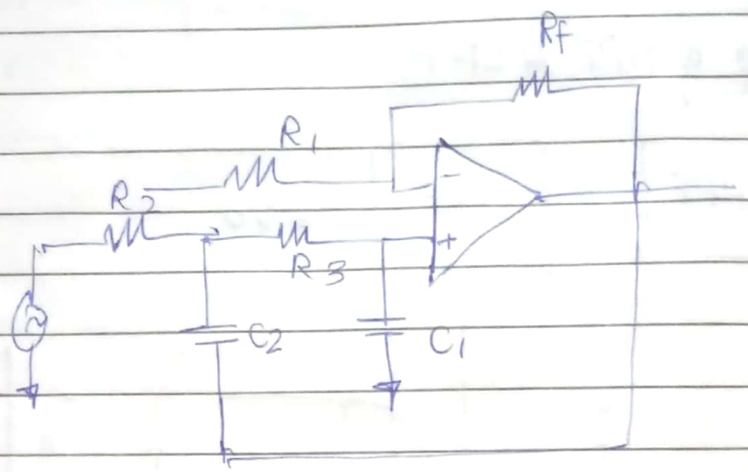
We choose $R = 8.2\,K\Omega$

$1 + \frac{R_F}{R_1} = 2$

$\frac{R_F}{R_1} = 1$

Choose $R_F = R_1 = 10\,K\Omega$.

Second Order LP Butterworth



$A_F = 1 + \frac{R_F}{R_1}$

$f_c = \frac{1}{2\pi\sqrt{R_2 C_2 R_3 C_1}}$

Que Design 2^{nd} order filter with $f_C = 2KHz$

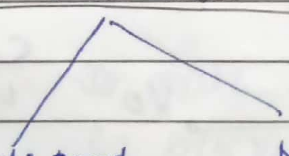
choose $R_2 = R_3 = R$ $C_1 = C_2 = C$

$f_c = \frac{1}{2\pi RC}$

choose $C = 0.0033\mu F$

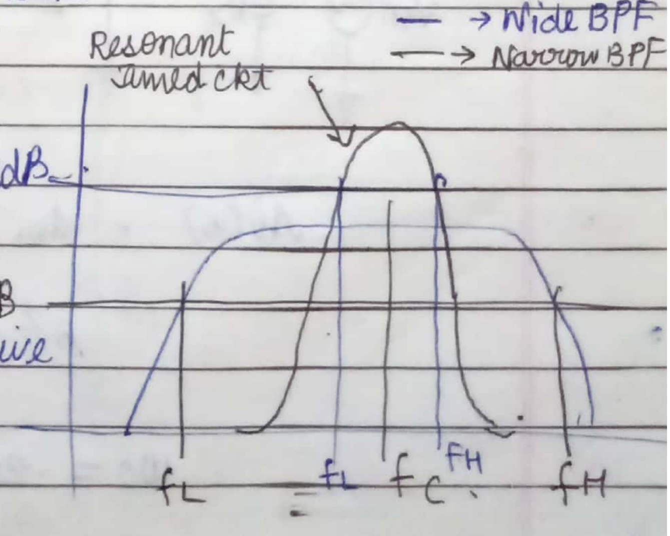
$R = 24K\Omega$ $(22K\Omega)$

3/08/19 **Band Pass Filter**



Wide Band $Q<10$

Narrow Band $Q>10$



Q Factor $= \frac{f_c}{BW}$.

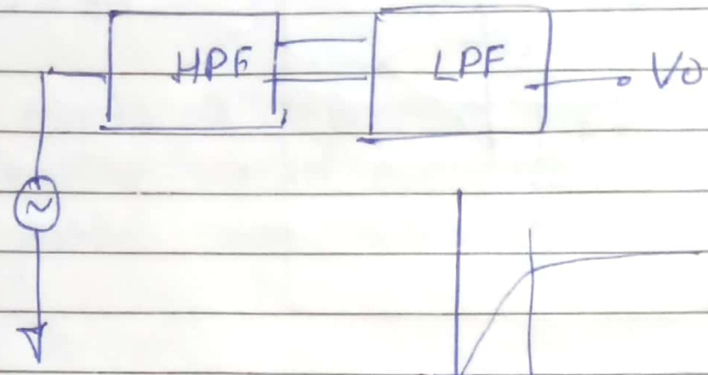
$BW = f_H - f_L$

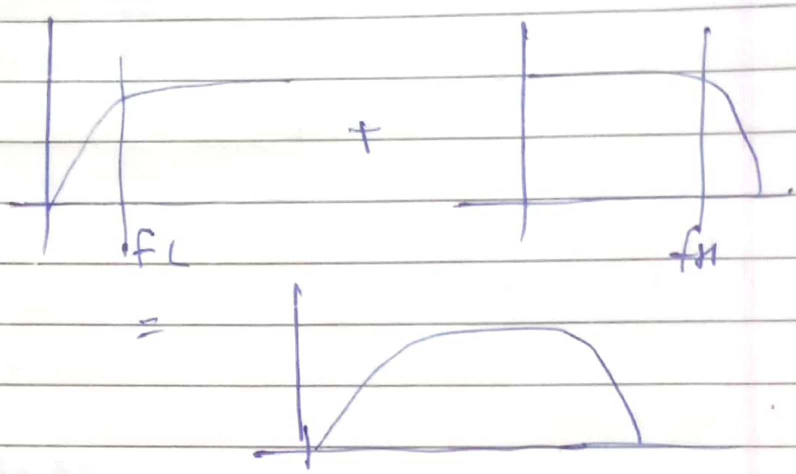
Higher Q factor ⇒ more selective

$\boxed{f_c = \sqrt{f_L f_H}}$

Wide BPF

cascading of HPF & LPF

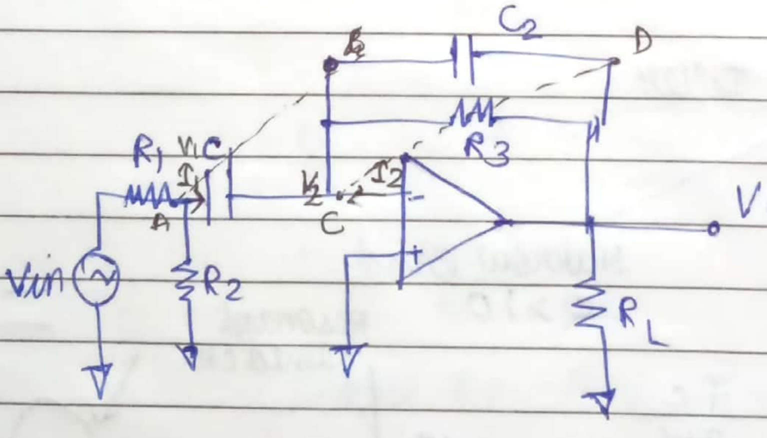




f_L decides HPF
f_H decides LPF

Narrow BPF

$V_1 \rightarrow$ Pot b/w A & D
$V_2 \rightarrow$ Pot b/w C & D.

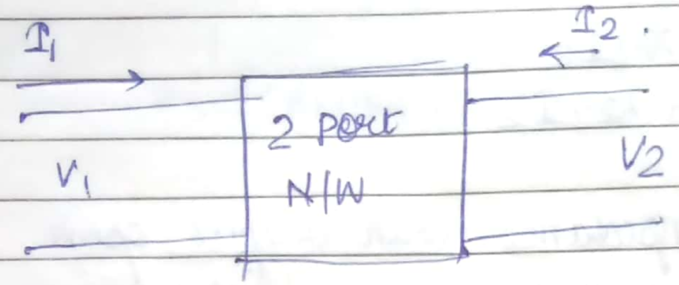


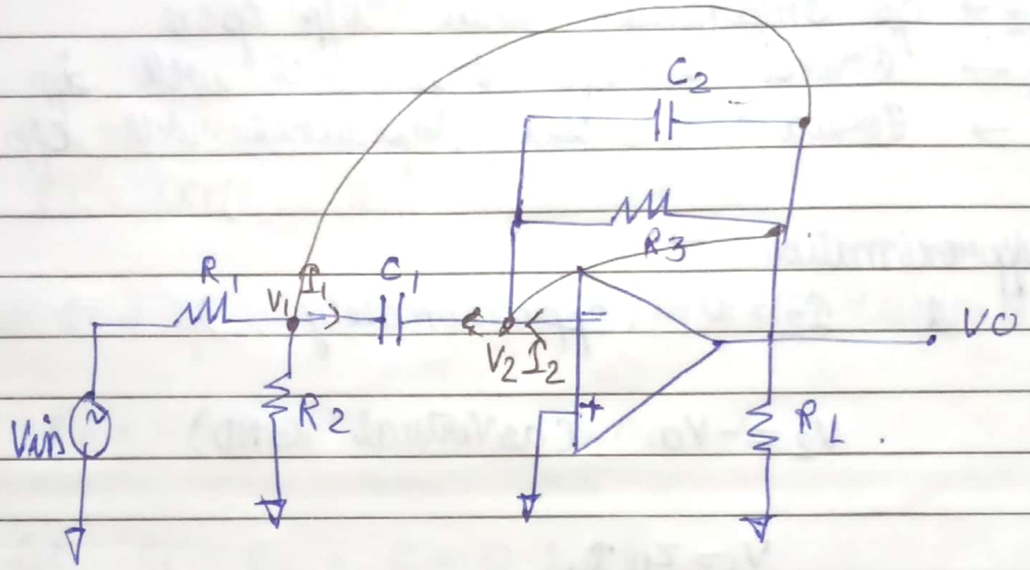
C_1 & R_3 combine to form HPF

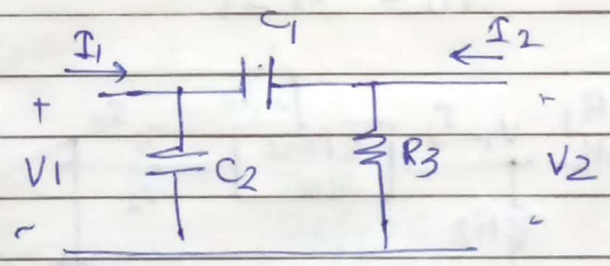
C_2 & R_1, R_2 combine ~~to~~ to form LPF.

$$A_v(s) = \frac{A_{vo}\, s \left(\frac{\omega_o}{Q}\right)}{s^2 + \left(\frac{\omega_o}{Q}\right)s + \omega_o^2}$$

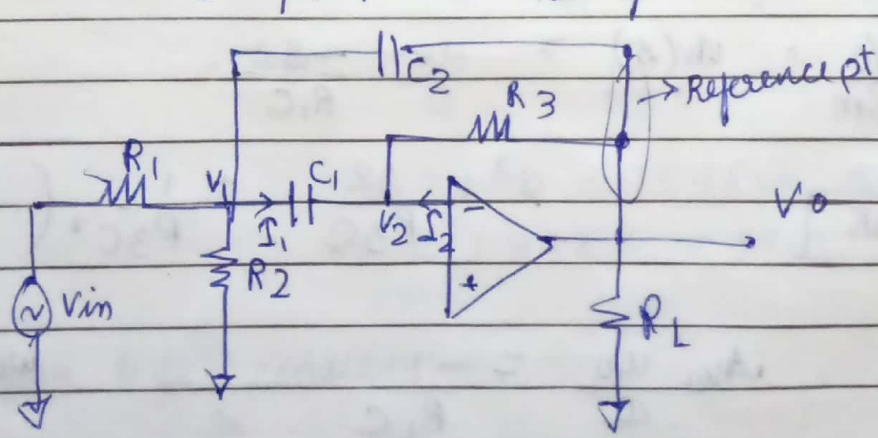
$$\omega_o = 2\pi f_c$$







To make ckt consistent with two port, put C_2 b/w V_1 & common pt .



$V_1 = Z_{11} I_1 + Z_{12} I_2$
$V_2 = Z_{12} I_1 + Z_{22} I_2$

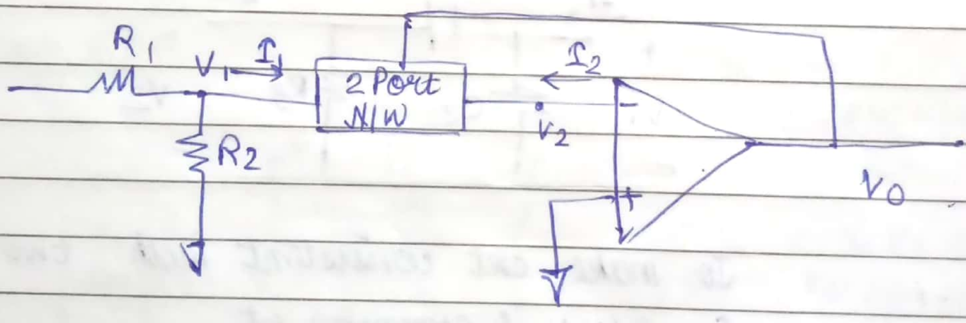
$Z_{11} \rightarrow$ I/p Impedance with output open
$Z_{22} \rightarrow$ O/p Impedance with i/p open
$Z_{12} \rightarrow$ Reverse Transfer Impedance with o/p open.
$Z_{21} \rightarrow$ Forward transfer impedance with O/p open.

Approximation $\rightarrow$

$I_2 = 0$ (approximately)

$V_2 = -V_0$ (as Virtual GND)

$V_1 = Z_{11} I_1$
$-V_0 = Z_{21} I_1$



$$\frac{V_0}{V_{in}} = A_v(s) = \frac{\frac{-s}{R_1 C}}{s^2 + \frac{s2}{R_3 C} + \frac{1}{R_3 C^2}\left(\frac{R_1 + R_2}{R_1 R_2}\right)}$$

Derivation in link

$$A_{v_0} \frac{\omega_0}{Q} = \frac{-1}{R_1 C} \qquad \omega_0 = 2\pi f_c$$

$$\frac{\omega_0}{Q} = \frac{2}{R_3 C}$$

$$\omega_0^2 = \frac{1}{R_3 C (R_1 \| R_2) C}$$

$$A_{V0} = \frac{-R_3}{2R_1}.$$

Ques Design Narrow BPF with

i) $f_C = 1\,KHz$, $Q = 5$, $A_{V0} = 8$

As $Q = 5$ if not mentioned, we will design Wide BPF

ii) $f_C = 1.5\,KHz$ $Q = 5$, $A_{V0} = 8$

i) Let $C_1 = C_2 = C = 0.1\,\mu F$

$$A_{V0} \frac{2\pi f_C}{Q} = -\frac{1}{R_1 C}$$

$$R_1 = \frac{-Q}{2\pi f_C \times C}.$$

$$= \frac{-5}{2\pi \times 10^3 \times 0.1 \times 10^{-6}}$$

$$= 9.9\,K\Omega \approx 10\,K\Omega$$

$$\frac{\omega_0}{Q} = \frac{2}{R_3 C}$$

$$R_3 = 159\,K\Omega \approx 150\,K\Omega$$

$$R_2 = 1.89\,K\Omega \approx 2\,K\Omega$$

ii) Gain & Q constant.

In $\omega_0^2 = \frac{1}{R_3 C (R_1 \| R_2)}$

Substitute same R_1, R_2, $f_C = 1.5\,KHz$ & find R_3

OR

$$(2\pi f_c)^2 = \frac{1}{R_3 C^2 (R_1 || R_2)}$$

$$f_{c_1}^2 = \frac{R_1 + R_{2_1}}{R_3 C^2 (R_1 R_{2_1}) 2\pi^2}$$

$$f_{c_2}^2 = \frac{R_1 + R_{2_2}}{R_3 C^2 (R_1 R_{2_2}) (2\pi)^2}$$

$$\frac{R_{22}}{R_{21}} = \left(\frac{f_{c1}}{f_{c2}}\right)^2 \quad \text{(after manipulation)}$$

$$\frac{R_{2_2}}{2\cancel{0}} = \left(\frac{1}{1.5}\right)^2$$

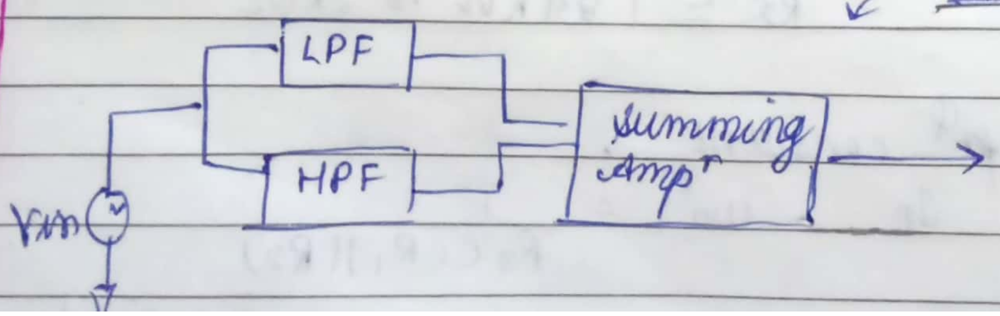
$$R_{22} = \frac{2}{1.5 \times 1.5}$$

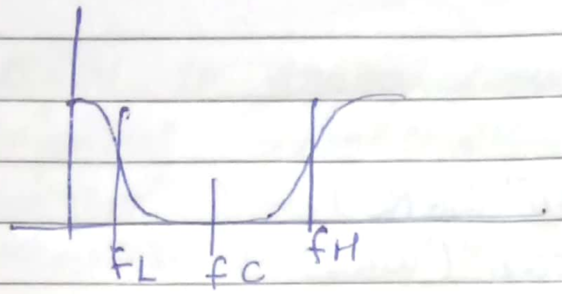
$$R_{22} = \frac{200}{225}$$

$$R_2 = \frac{Q}{2\pi f_c C (2Q^2 - A_V)}$$

Band Reject Filter (~~Hotch~~ Notch Filter)

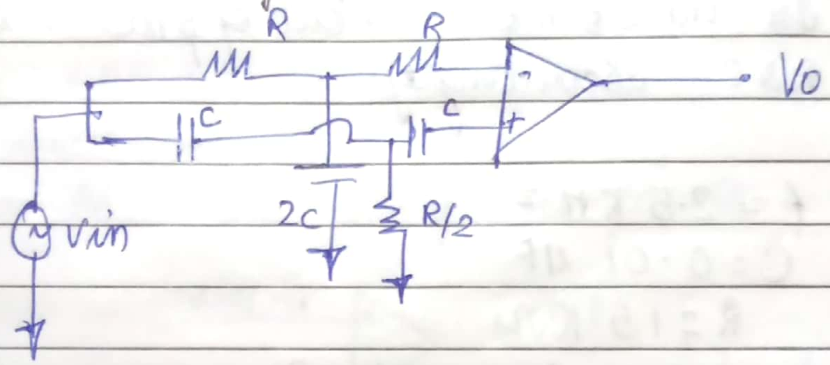
1. LPF in parallel with HPF. Wide Band Reject Filter

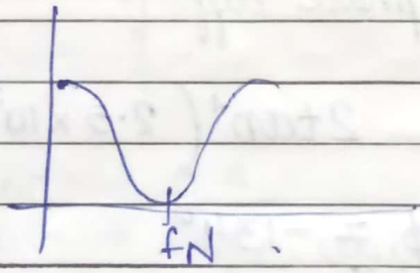




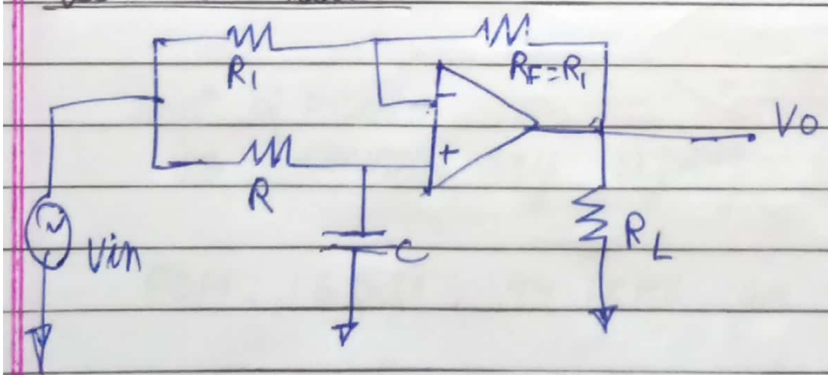
$f_L \rightarrow$ determined by LPF
$f_H \rightarrow$ " " HPF.

Narrow Band Reject Filter (Notch Filter)





All Pass Filter



$$\frac{V_o}{V_{in}} = \frac{1 - 2\pi j f RC}{1 + j\,2\pi f RC} = \frac{1 - j2\pi fRC}{1 + j2\pi fRC}$$

(if $R_1 = R$)

$|A_V| = 1$

Phase $\phi = 2\tan^{-1}(2\pi f RC)$

$\phi = 2\tan^{-1}(\omega RC)$

This filter is used for phase connection.

eg → In transformers → out of phase. So choose R & C accordingly.

Ques If $f = 2.5\ KHz$

$C = 0.01\ \mu F$

$R = 15\ K\Omega$

type of phase diff ?

$\phi = 2\tan^{-1}(2.5 \times 10^{3} \times 0.01 \times 10^{-6} \times 15 \times 10^{3})$

$\phi = -134^{0}$

One lecture missing

Digital to Analog converters

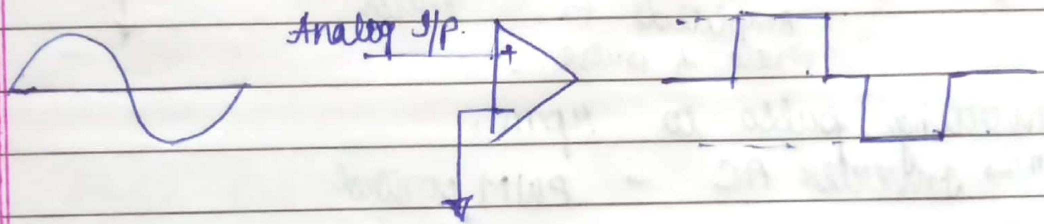
Important characteristics :

1. Resolution
2. Maximum sampling Rate
3. Total harmonic distortion + noise
4. Dynamic range

1 Bit ADC →

2 levels.

- can be made using comparator



1 bit ADC → 0, 1

2 bit ADC → (0,0), (0,1), (1,0), (1,1)

$\downarrow V_1$ $\downarrow V_2$ $\downarrow V_3$ $\downarrow V_4$

Appⁿ of PCM →

to convert any signal to .wav file.

PCM, 16 bits, 44.1KHz for CD audio.

DVD, Blue Ray → 24 bits per sample.

O/p → DAC.

I/p → DA C

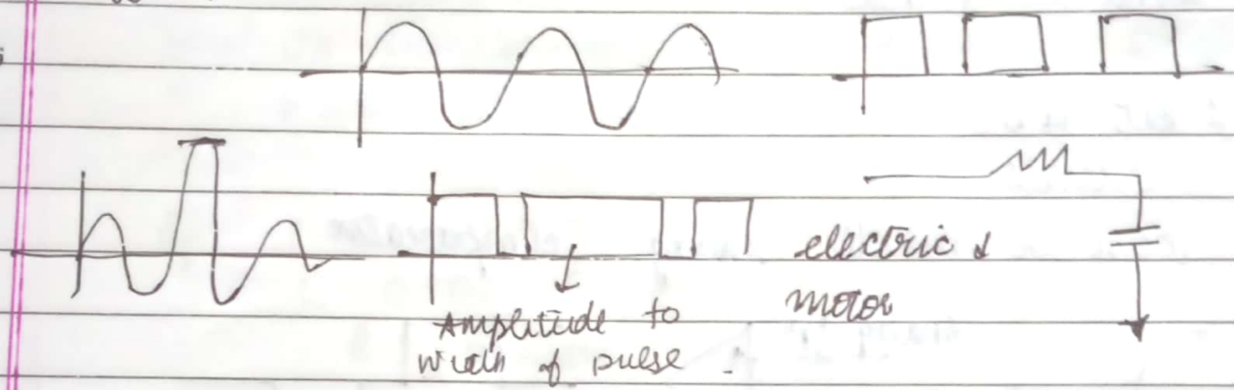
Telephone → 300 Hz to 3 KHz

fs for telephone → 8 KHz.

Different types of DAC

1 L.P.F.

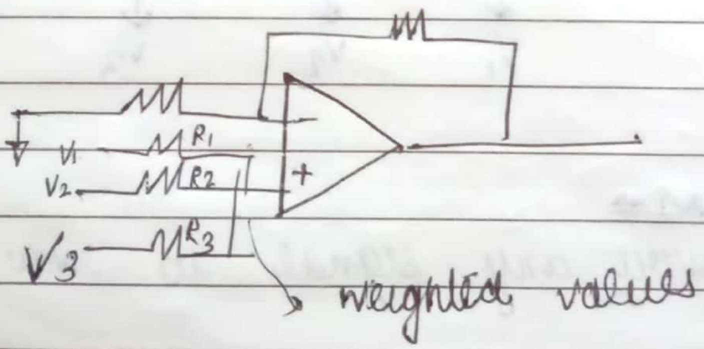
2.

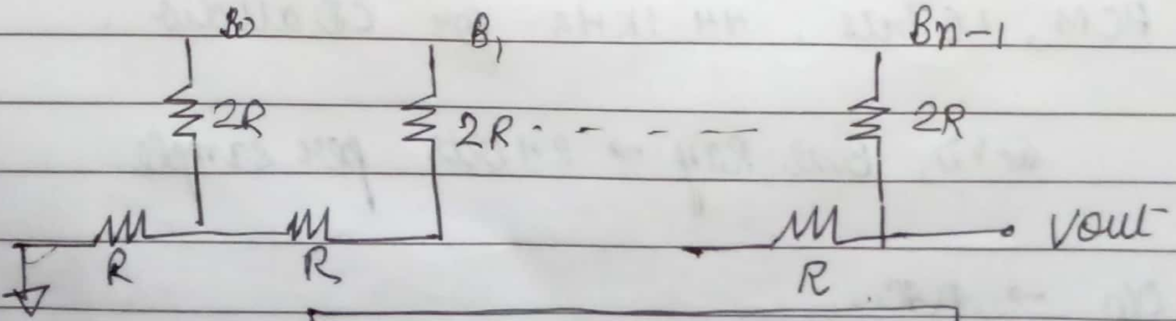


converting pulse to rpm.

Appⁿ → inverter AC → PWM control.

2. Binary weighted DCA motors → R2R ladder





$$\boxed{V_{out} = V_{ref} \times \frac{\text{Bit value}}{2^N}}$$

, N → no. of bits (resolution)

$V_{ref} = 3.3V$, 5 bit DAC.

00000   11111

0   31.

$V_{out} = 0$

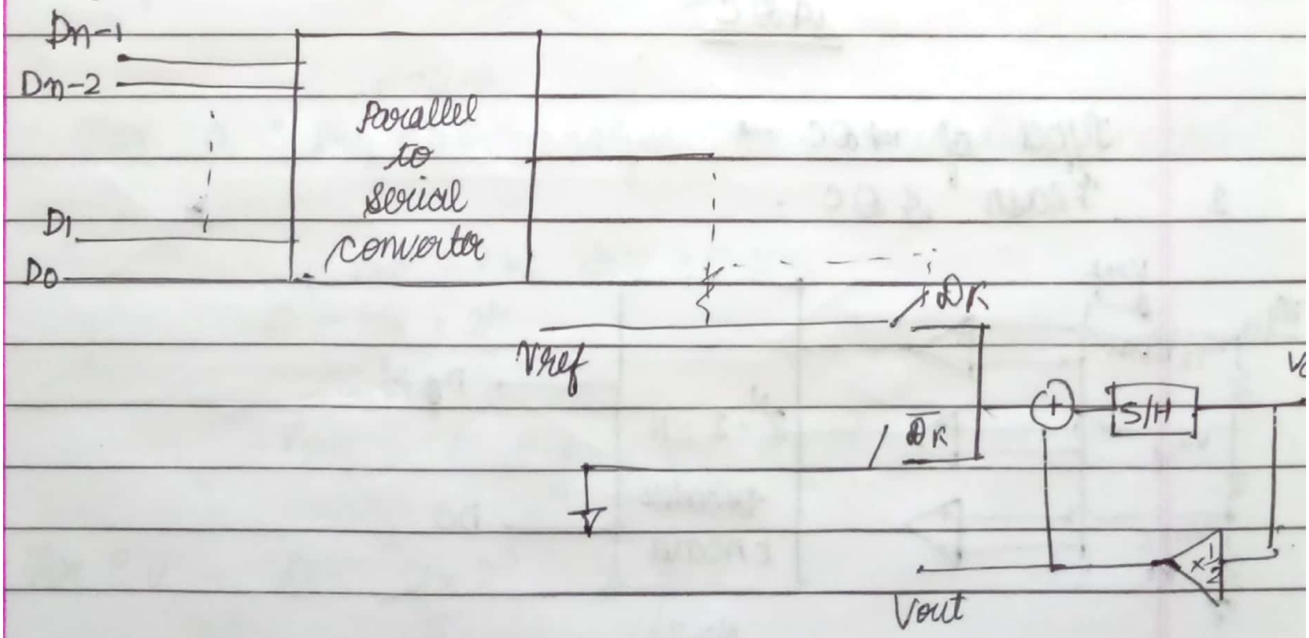
$V_{out} = \frac{3.3 \times 31}{2^5} = 3.1969\ V.$

0 to 3.1969 V → Dynamic Range.

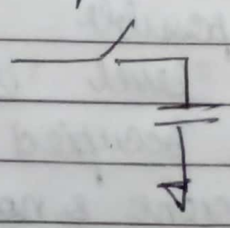
$\text{Resolution} = \frac{3.1969}{2^5} = 0.10\ V.$

$\text{Resolution} \approx \frac{V_{ref}}{2^N} = \frac{3.3}{2^5}$ (Approximate)

Cyclic DAC.



Simple Sample & Hold ckt →



Que Find o/p voltage at end of each cycle for a 4 bit cyclic DAC.

$D = 1101$ $V_{ref} = 5V$

$$V_{out} = V_{ref} \times \frac{\text{Bit word}}{2^N} = \frac{5 \times 13}{2^4}$$

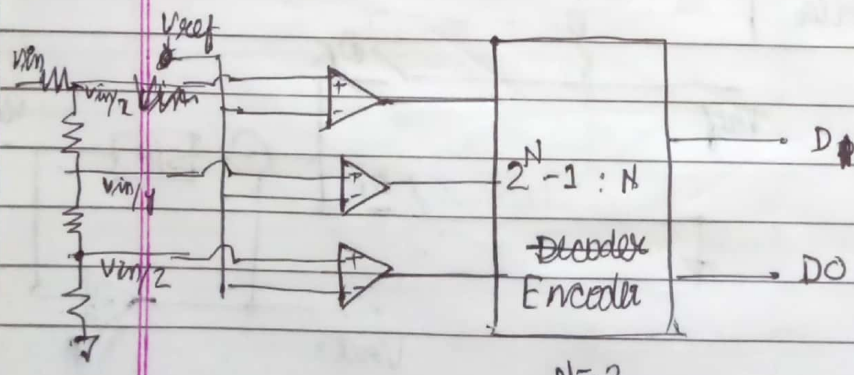
$$= 4.0625\ V$$

clock cycle	D_{K-1}	$V_{out}(K)$	V_{out}
1	1		$\frac{1}{2}[1\times5 + 0] = 2.5V$
2	0		$\frac{1}{2}[0\times5 + 2.5] = 1.25\ V$
3	1		$\frac{1}{2}[1\times5 + 1.25] = 3.125$
4	1		$\frac{1}{2}[1\times5 + 3.125] = 4.06\ V$

ADC

Types of ADC →

1. Flash ADC.



N=2

2 Bit Flash ADC

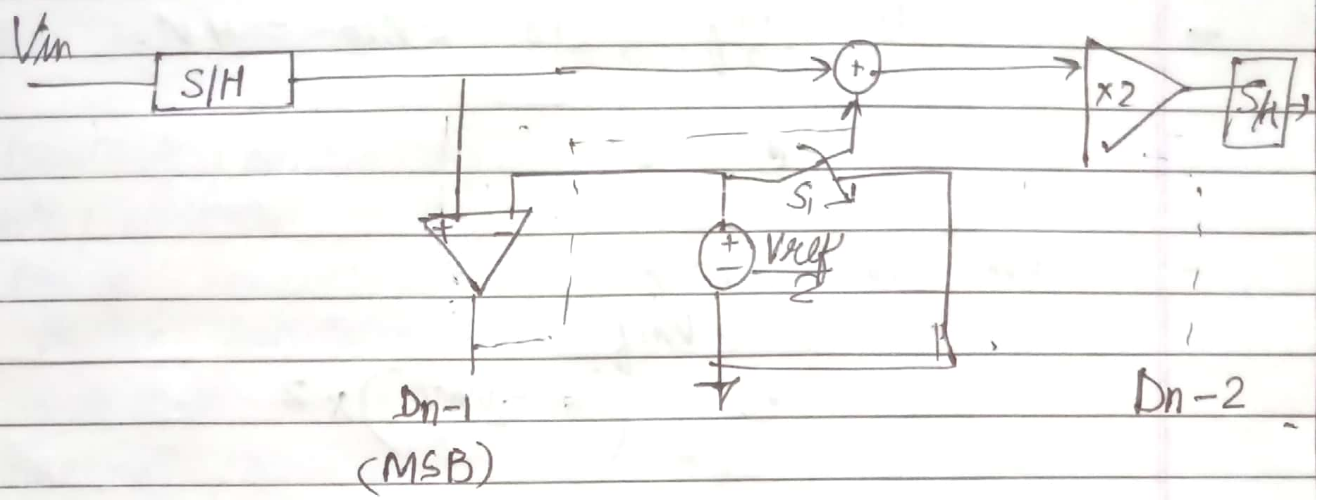
Fastest ADC possible

But for each level 2 resistors are needed

60 to 70% space occupied by Resistor

Not space efficient & not power efficient.

2. Pipeline ADC



If $V_{in} < \frac{V_{ref}}{2}$ S_1 closed. $O/P = 2V_{in}$.

If $V_{in} > \frac{V_{ref}}{2}$ $\left(V - \frac{V_{ref}}{2}\right) \times 2$

Ques For a 3 bit pipeline ADC, analyse the conversion process

$V_{in} = 2V$, $V_{ref} = 5V$.

→ $D = \frac{V_{in} \times 2^N}{V_{ref}}$

$V_{out} = \frac{V_{ref}}{2^N} \times$ bit word

For 2V, $D = \frac{2 \times 2^3}{5} = 3.2$

↓

011

4V → $\frac{4 \times 8}{5}$ 6.4 ↓ 110. 4.5 → 7.2 ↓ 111

5V → 8 111

Quantizat^n error

$V_{in} = 2V \qquad V_{ref} = 5V$

$V_{in} < \frac{V_{ref}}{2}, \quad V_0 = 2V_{in} = 4V.$

$D_2 = 0.$

$V_{in} = 4V \qquad V_{ref}$

$V_{in} > V_{ref}$

$V_0 = \left(V_{in} - \frac{V_{ref}}{2}\right) \times 2$

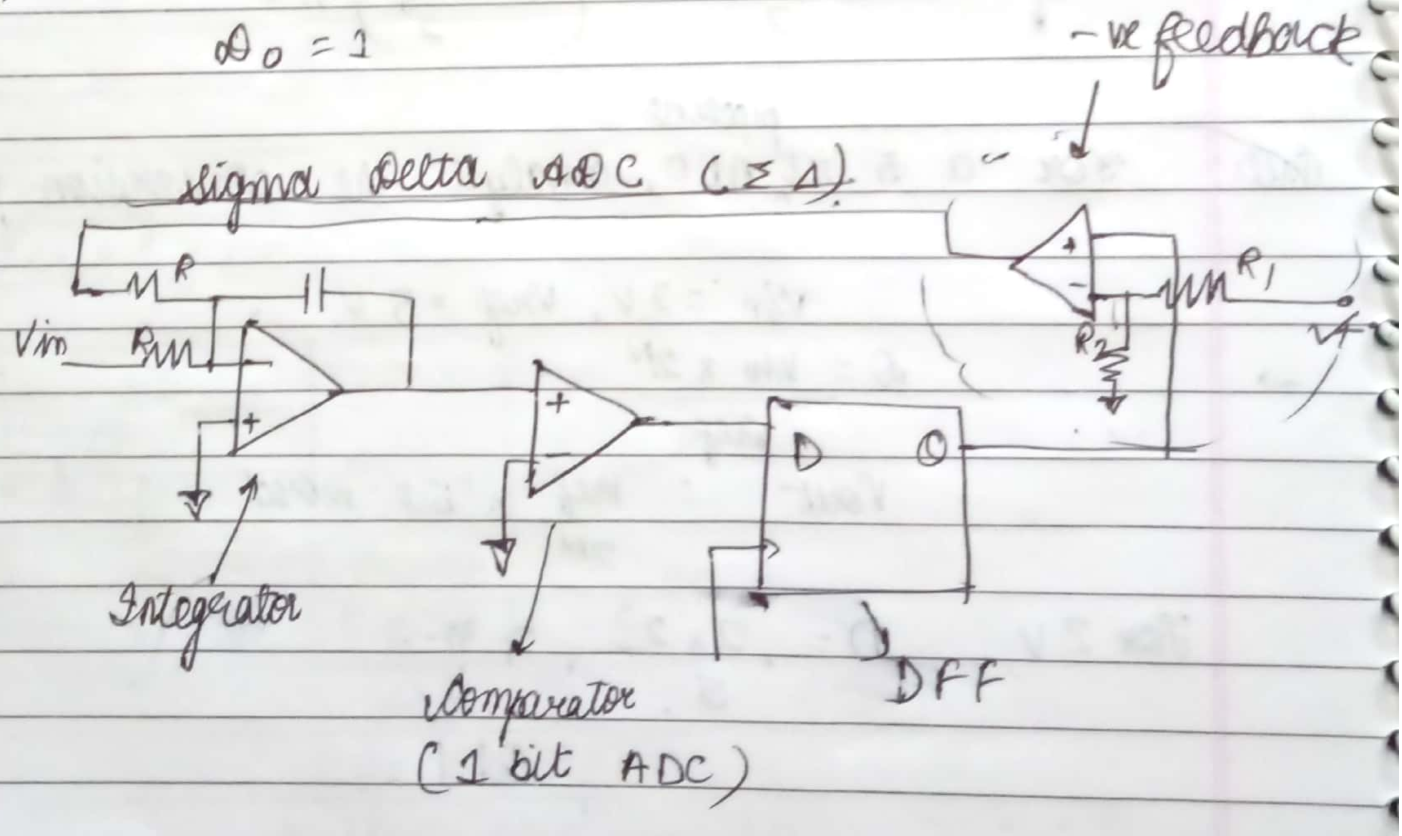
$= (4 - 2.5) \times 2 = 3V$

$D_1 = 1.$

$V_{in}\ 3V.$

$D_0 = 1$

Sigma Delta ADC ($\Sigma\Delta$)



24 bit

5/09/19

Semiconductor Device characterization

Some key parameters

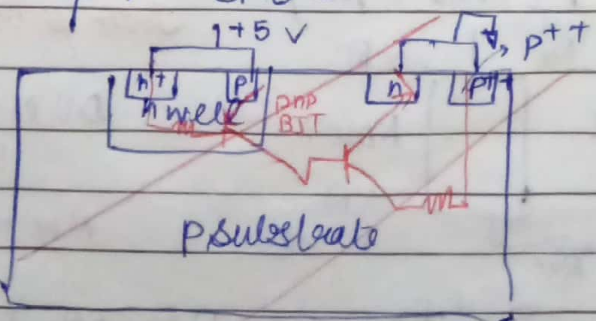
1. Resistivity / conductivity
2. Hole / electron density / mobility
3. Doping concentration / profile
4. Miller Orientation
5. Dielectric quality / thickness
6. Thickness / resistivity / conductivity of thin sheets
   - metal
   - polymer
   - Poly Si

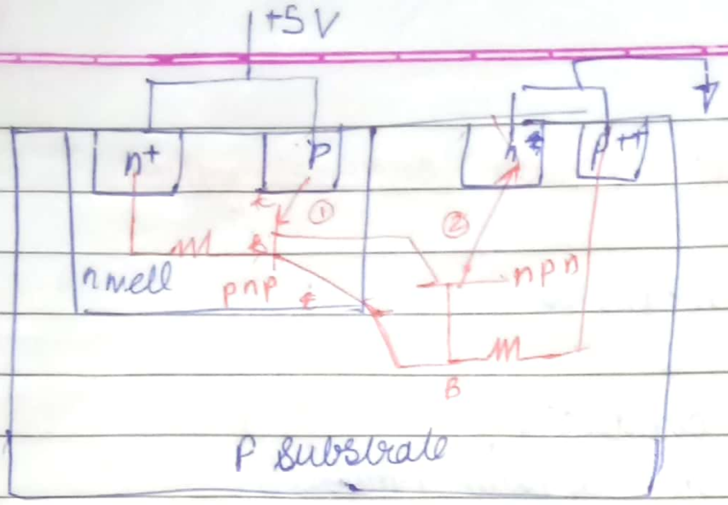
~~Book: Schroder: 3Ed. Ch-1~~

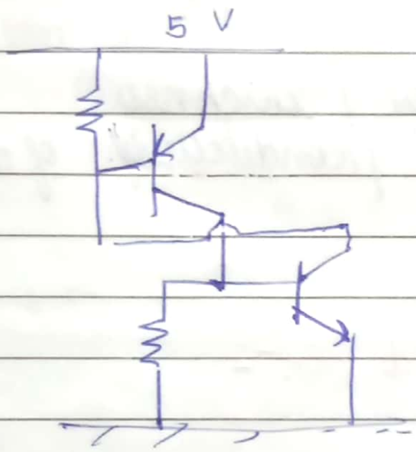
Resistivity

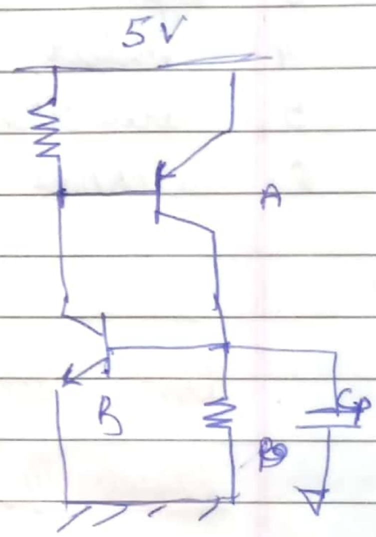
Why?

1. Series resistance
2. Capacitance $\rightarrow C = \frac{\varepsilon A}{d}$. Wet $\Rightarrow$ more permittivity; Dry $\Rightarrow$ less permittivity
3. Threshold voltage
4. Hot carrier degradation
   Carrier carrying
   high kinetic energy
   If resistivity $\uparrow$ $\Rightarrow$ ~~ho~~ KE $\downarrow$ $\Rightarrow$ hot carrier deg. $\downarrow$
5. Latch up in CMOS.









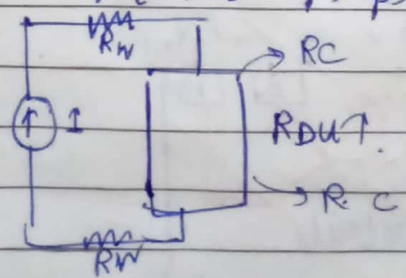
Initially both A & B are off then Cp gets charged ⇒ A is on now. Then B is ON.

If resistivity is high ⇒ gain of that stage is high
⇒ Problem of latch up arises

Reduce resistivity to solve problem of latch up.

$$\rho = \frac{1}{q(n\mu_n + p\mu_p)}$$

Two probe measurement

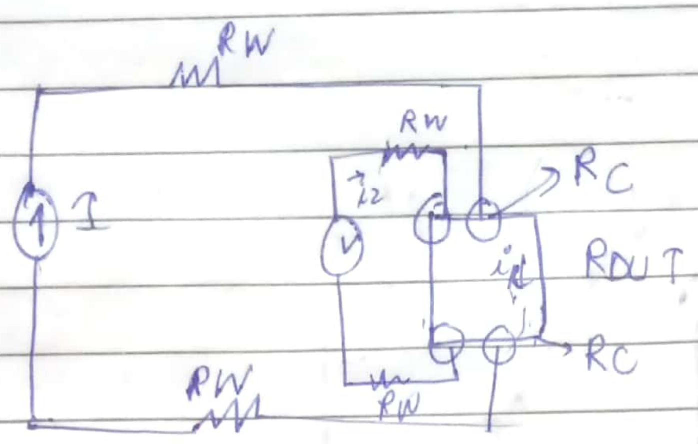


DUT → device under testing

RW → Resistance of wire

$$V = I(R_{DUT} + 2R_W + R_C)$$

4 probe measurement (Kelvin's Probe)

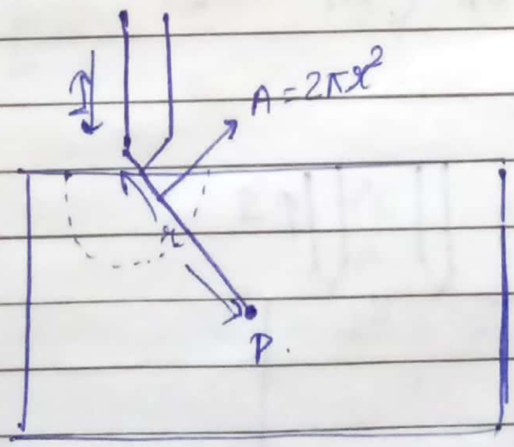


$$\cancel{V = I(R_{DUT} + 2R_W + 2R_C)}$$

$$V_{AB} = i_1 R_{DUT} + i_2 (R_{DUT} + 2R_W + 2R_C)$$

$$V_{AB} \simeq i_1 R_{DUT} \quad \text{as } i_2 \text{ is negligeble}$$

Single probe



Vector Ohm's Law

$$\vec{E} = \rho \vec{J} = -\frac{dV}{dr}$$

$$J = \frac{I}{2\pi r^2} \quad A/cm^2$$

$$V_p = \int_0^V dV$$

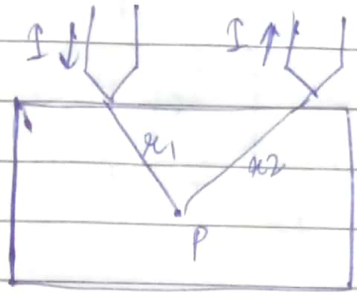
$$= -\int_0^r J\rho\, dr$$

$$\cancel{V_p = -J\rho r}$$

$$-\frac{I\rho}{2\pi}\int_0^r \frac{1}{r^2}\, dr$$

$$\boxed{V_P = \frac{+I\rho}{2\pi r}}$$

Two probe

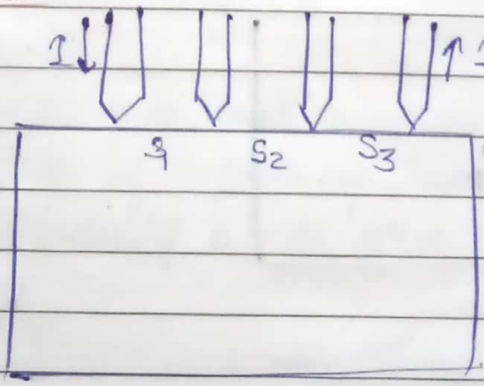


$$V_1 = \frac{I\rho}{2\pi r_1}$$

$$V_2 = \frac{-I\rho}{2\pi r_2}$$

$$V_t = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Four probe



$\cancel{V_{12}}$ $$V_1 = \frac{I\rho}{2\pi}\left(\frac{1}{s_1} - \frac{1}{s_2+s_3}\right)$$

$$V_2 = \frac{I\rho}{2\pi}\left(\frac{1}{s_1+s_2} - \frac{1}{s_3}\right)$$

$$V_{12} = \frac{I\rho}{2\pi}\left(\frac{1}{s_1} - \frac{1}{s_2+s_3} - \frac{1}{s_1+s_2} + \frac{1}{s_3}\right)$$

If $S = S_1 = S_2 = S_3$

$$V_{12} = \frac{I\rho S}{2\pi S^2}$$

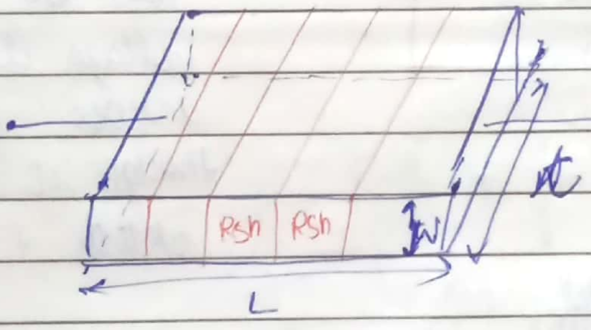
$$\boxed{\rho = \frac{V}{I} \times 2\pi S}$$

$$\boxed{\rho = \frac{FV}{I} 2\pi S}$$

Ideally $F = 1$

$F \rightarrow$ correction parameter

Sheet Resistance



$$R = \frac{\rho L}{A} = \frac{\rho L}{Wt} = \left(\frac{\rho}{t}\right)\left(\frac{L}{W}\right)$$

$\boxed{\frac{\rho}{t}} \rightarrow R_{sh}$ (sheet resistance)

$\Omega/\square$

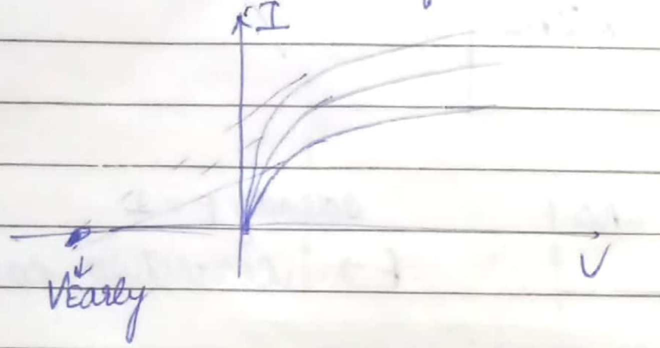
5 blocks $\rightarrow$ $R = 5R_{sh}$

12/09/19

$I = I_0 e^{qV/\eta kT}$

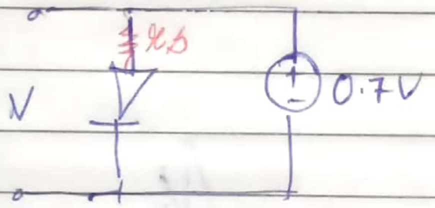
Semiconductor Characterisation (Series Resistance Measurement)

IV characteristics of diode →



$r_s = \Delta I / \Delta V$

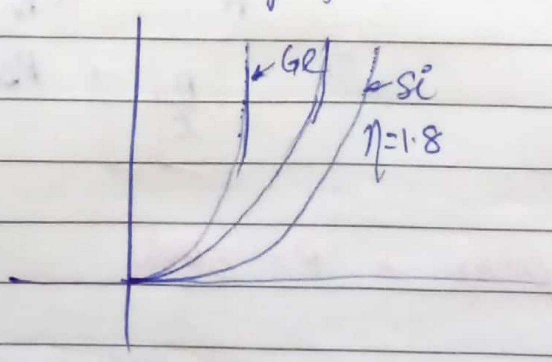
r_s → series Resistance



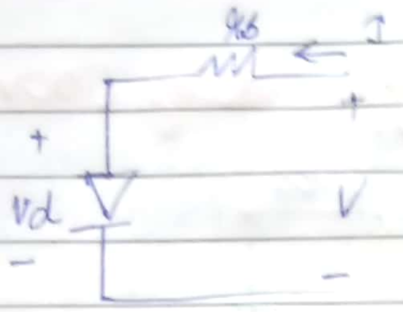
Bcz of r_s, there will be some voltage drop across diode, even though it is short ckted.

$$I = I_0 \left(e^{qV/\eta kT} - 1 \right)$$

η → Ideality factor.



η → to scale IV characteristics of diode.



$V_d \rightarrow$ Barrier Potential

for Si $\rightarrow$ 0.7

$$V = V_d + I r_s$$

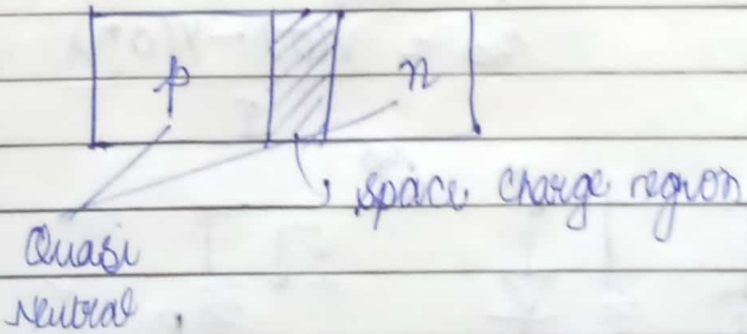
$$V_d = V - I r_s$$

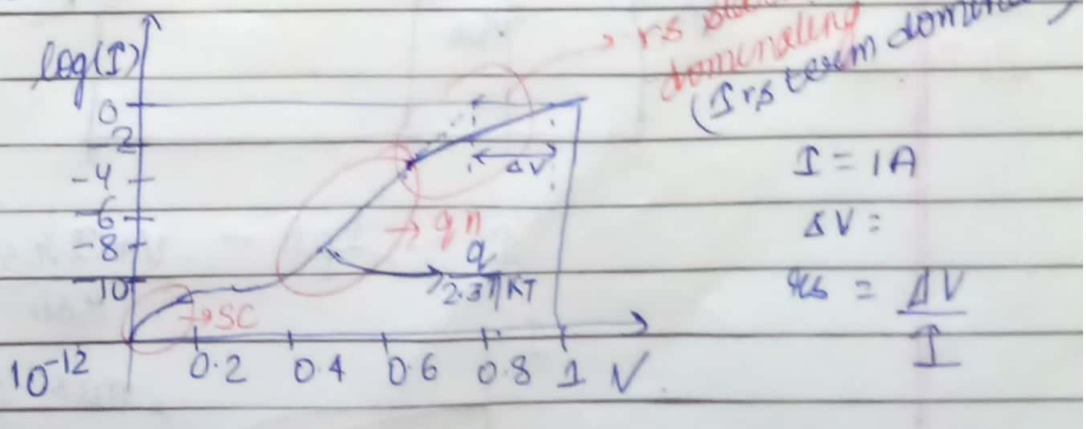
$$\boxed{I = I_0 \left(e^{\frac{q(V - I r_s)}{\eta k T}} - 1 \right)}$$

$$I = I_{sc}(\quad) + I_{qn}(\quad)$$

I_{sc} → space charge Region current

I_{qn} → Quasi Neutral (Neutral but dynamic)





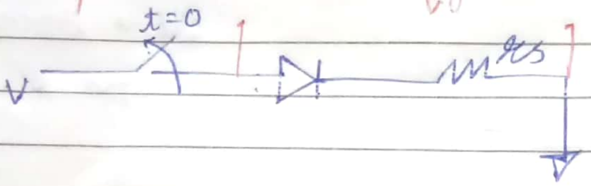
$I = 1A$

$\Delta V :$

$r_s = \dfrac{\Delta V}{I}$

Method 1 : I-V characterisation

Method 2: Open circuit voltage delay (OCVD)

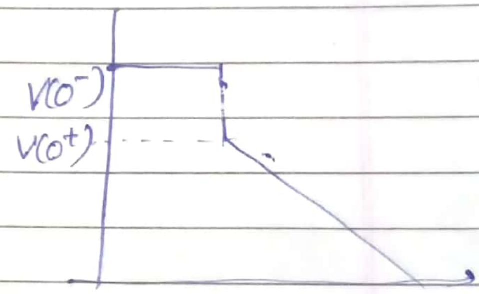


For $t<0$, switch was closed till steady state.

$V(0^-) = V_d + I r_s$

For time $t>0$,

$V(0^+) = V_d$

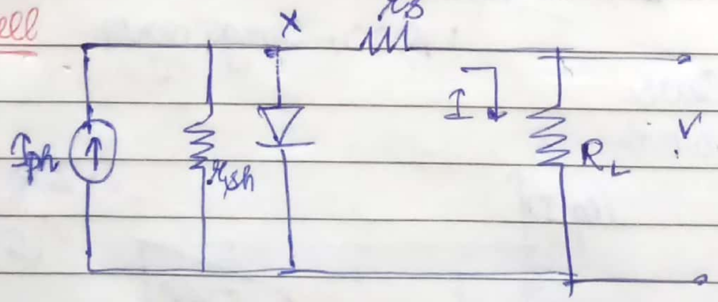


$V(0^-) = V(0^+) + I r_s$

$$r_s = \frac{V(0^-) - V(0^+)}{I}$$

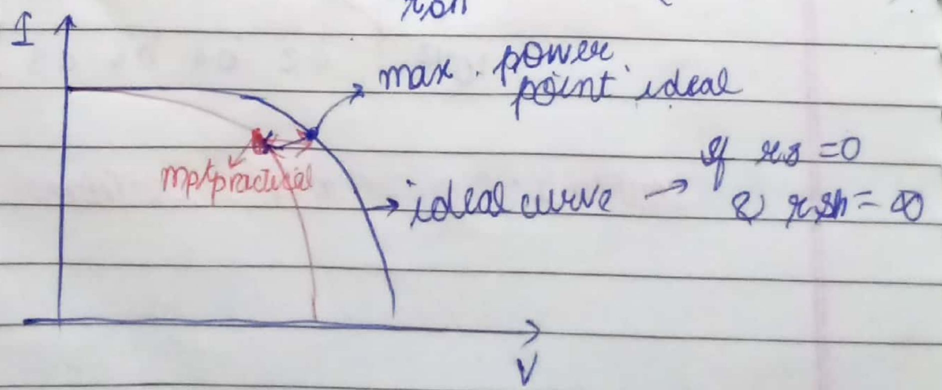
Solar Cell

Equivalent ckt of Solar Cell



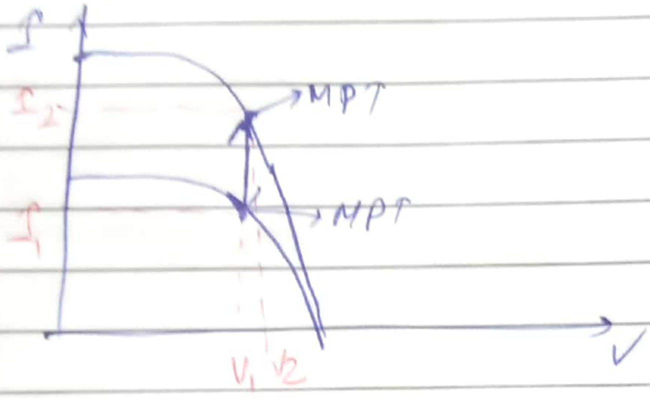
$r_{sh} \rightarrow$ Shunt Resistance

$$I = I_{ph} - \frac{V + I r_s}{r_{sh}} - I_0 \left(e^{q\left(\frac{V + I r_s}{\eta K T}\right)} - 1 \right)$$



To measure r_s for solar cell →

perform experiment twice.
with different light intensities



$$\frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1} = r_s.$$

solar cell is a pn junction.