Module -6

Filters

~~Ty~~ Two types of filters

→ Analog filters [i) Passive filters ii) Active filters]
→ Digital filters

Advantages of Active over Passive

→ Simple circuit
→ Easy to vary gain . .

Active filter

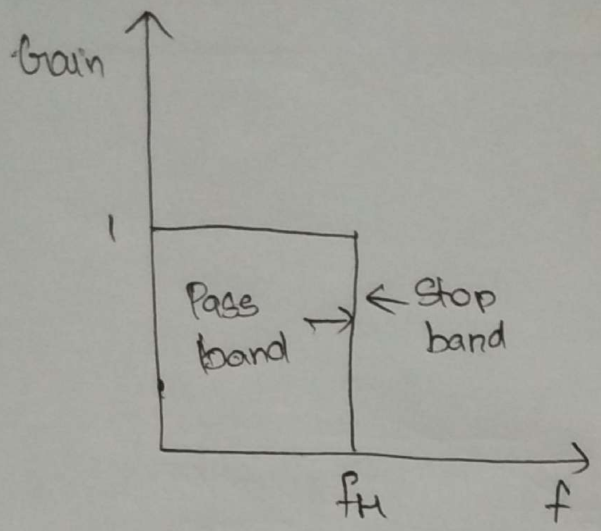
→ Low pass filter
→ High pass filter
→ Band ~~bas~~ pass filter
→ Band Reject Filter.

→ Low pass filter

f_H → higher cut of frequency.

if i/p $f < f_H$ → then it is called pass band.

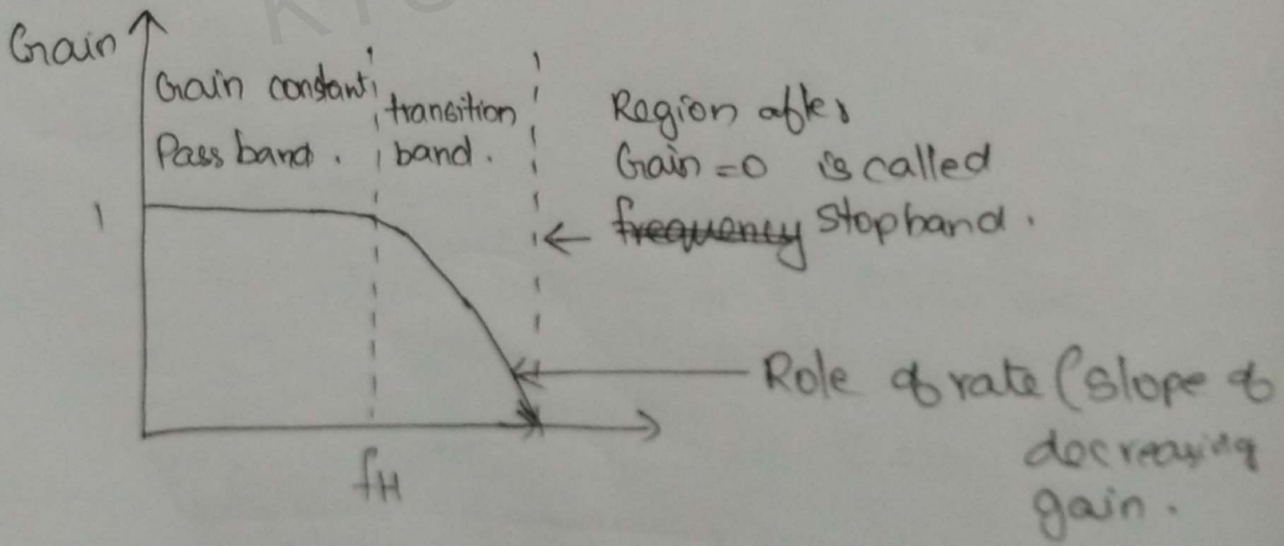
when $f > f_H$ → Gain decreases and called as stop band



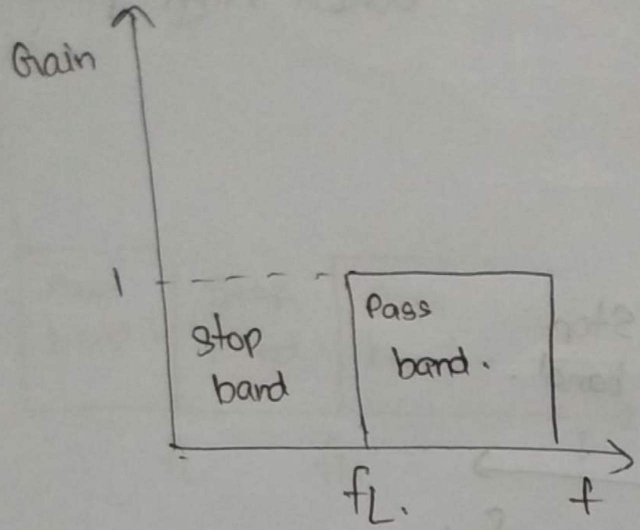
Attenuation ⇒ Reduction or gain in output signal.

At pass band attenuation is 0.

and at stop band attenuation is maximum.



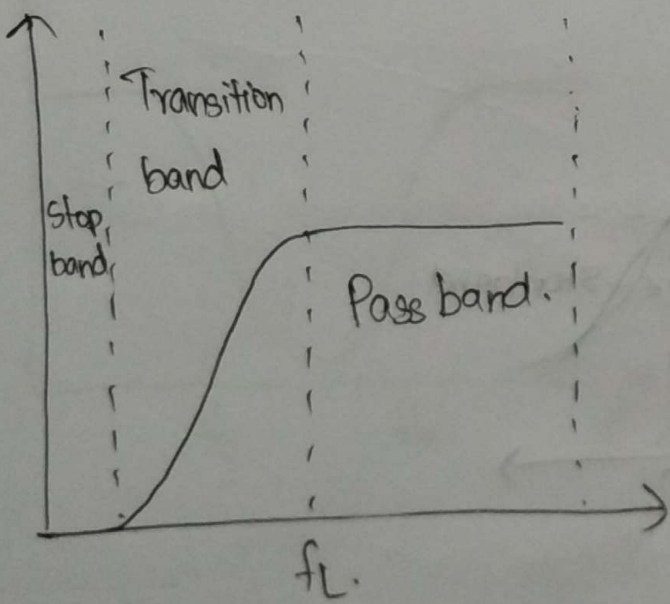
High Pass filter



$f_L \rightarrow$ lower cutoff frequency.

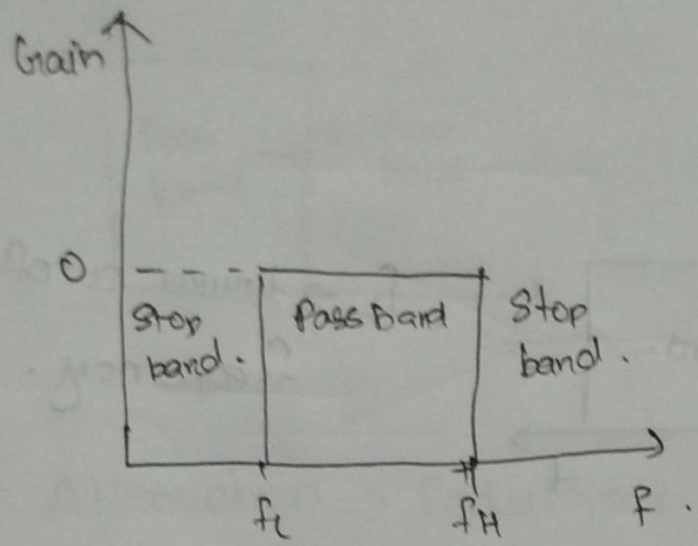
when $f < f_L$ the signal got attenuated and the region is called stop band

when $f > f_L$ the signal has max gain and the region is called pass band.



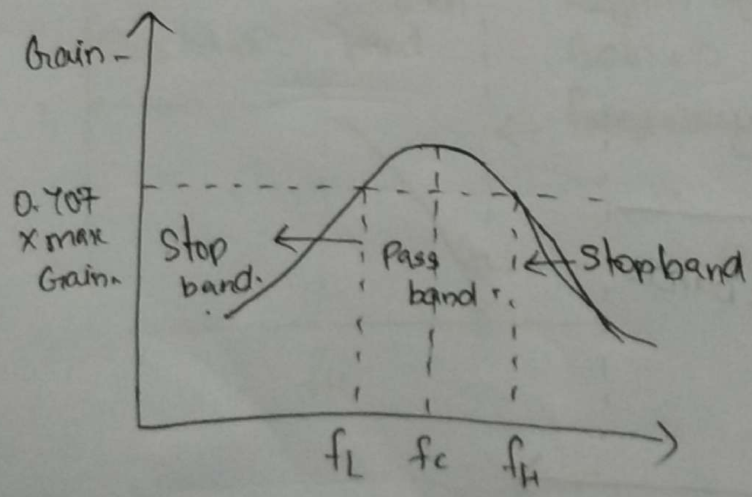
→ Band Pass filter (BPF).

(Combination of low pass and high pass filter)



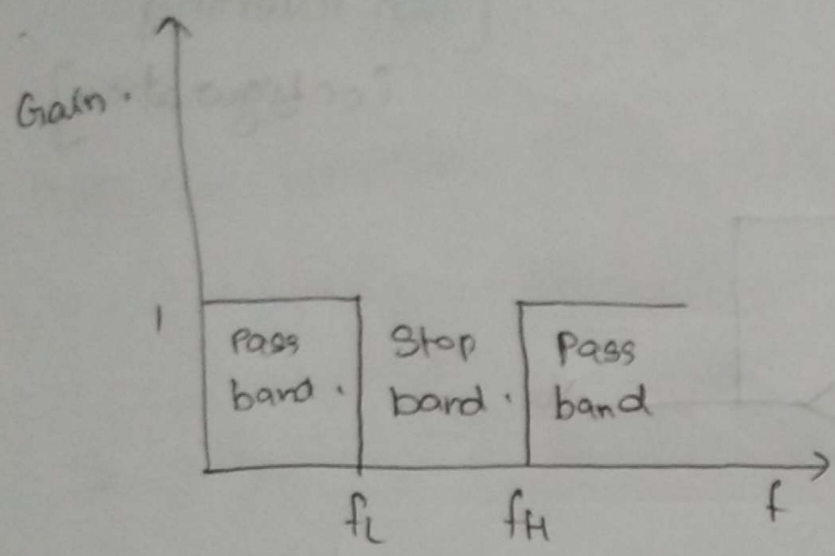
if $f < f_L$ and $f > f_H$ the i/p signal is attentualed . i.e Gain = 0.

The f between f_L and f_L the signal has max gain.



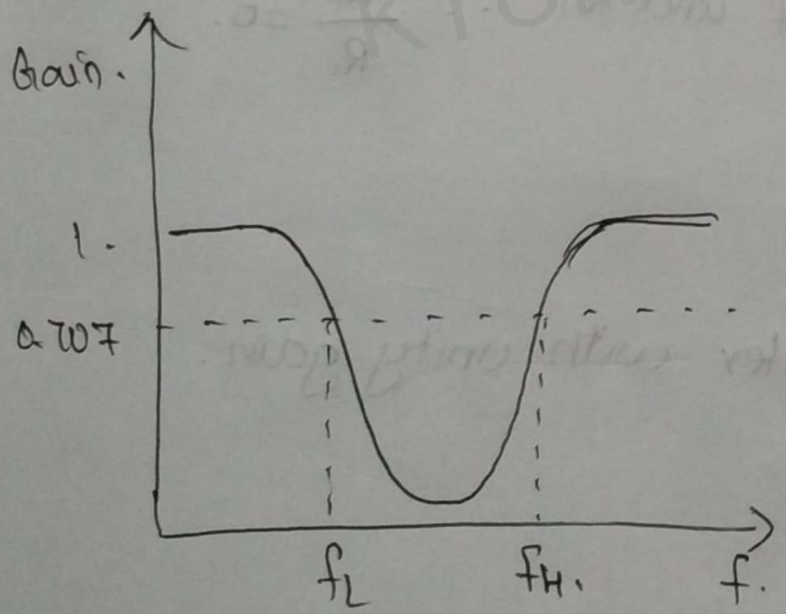
→ Band Reject Filter

(Opposite of band pass)



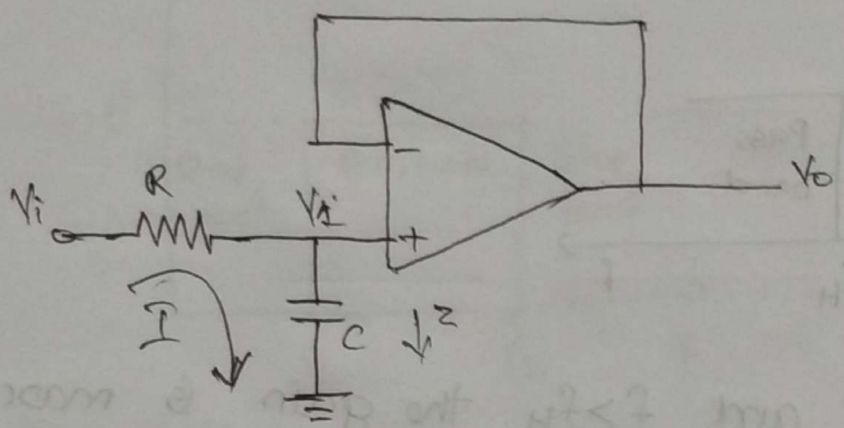
when $f < f_L$ and $f > f_H$ the gain is max.

when f is between f_L and f_H the signal is attenuated and the gain is 0.



First Order LPF

[Non inverting Configuration]

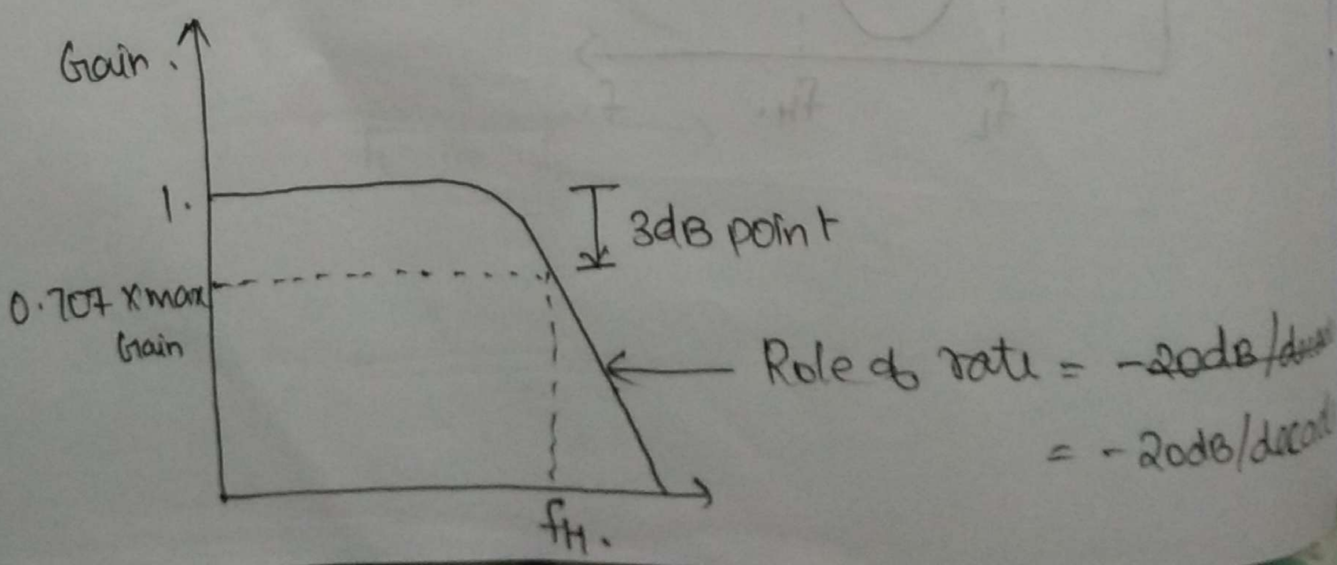


Gain $A = 1 + \frac{R_f}{R_1}$

we dont have R_f and R_1 $\therefore \frac{R_f}{R_1} = 0$.

$\therefore$ Gain $A = 1$

i.e first order filter with unity gain.



dB/decade → For every 10kHz the gain decreases by 20dB.

Transfer function $H(s)$

$$H(s) = \frac{V_o(s)}{V_i(s)}$$

it is the ratio of i/p voltage to o/p voltage.

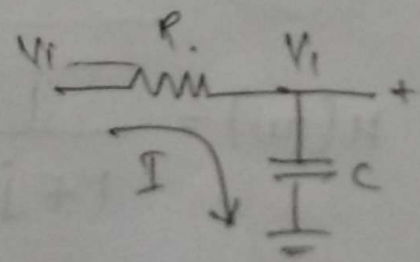
$s = j\omega$

$$V_o(s) = \left(1 + \frac{R_f}{R_1}\right) V_1(s)$$ [Gain × Voltage at non inverting terminal]

$$\frac{R_f}{R_1} = 0$$

$$V_o(s) = V_1(s)$$

Capacitor impedence $Z = \frac{1}{sC}$



Current $I = \frac{V_i(s)}{R+Z} = \frac{V_i(s)}{R + \frac{1}{sC}}$

$$\Rightarrow V_1(s) = I \times Z$$

$$= \left(\frac{V_i(s)}{R + \frac{1}{sC}}\right) \frac{1}{sC}$$

$$= \frac{V_i(s)}{sCR+1}$$

$$V_o(s) = \frac{V_i(s)}{1+sCR}.$$

$$H(s) = \frac{V_o(s)}{V_i}$$

$$= \frac{1}{1+sCR}.$$

Substitute $s = j\omega$.

$$H(j\omega) = \frac{1}{1+j\omega RC}.$$

$$\boxed{\frac{1}{RC} = \omega H}$$

$$H(j\omega) = \frac{1}{1+j\omega \times \frac{1}{\omega H}}$$

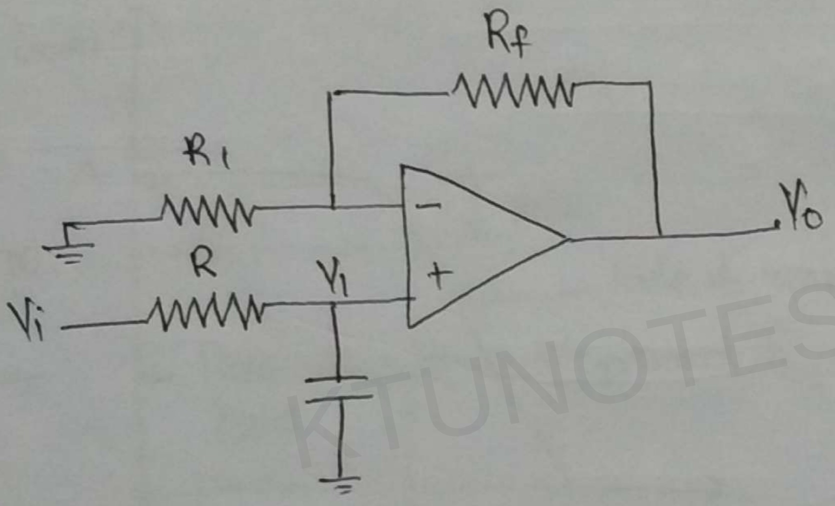
$$= \frac{1}{1+\frac{jf}{f_H}}$$

$$|H(jf)| = \frac{1}{\sqrt{1+(f/f_H)^2}}$$

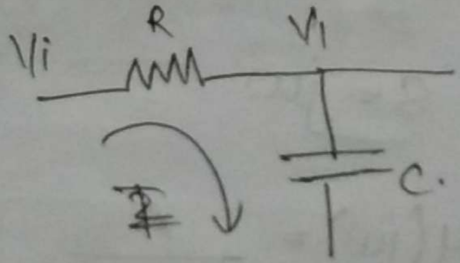
when $f = f_H$

$$|H(j\tfrac{f}{f_H})| = \frac{1}{\sqrt{2}} = \underline{\underline{0.707}}$$

First order LPF with variable gain



$$A = 1 + \frac{R_f}{R_1}$$



$$H(s) = \frac{V_o(s)}{V_1(s)}.$$

$$V_o(s) = \left(1 + \frac{R_f}{R_1}\right) V_1$$

$$I = \frac{V_i(s)}{R + Z}$$

$$V_1(s) = I Z$$

$$= \left[\frac{V_i(s)}{R+Z}\right] Z$$

$$Z = \frac{1}{sC}.$$

$$= \left[\frac{V_i(s)}{R + \frac{1}{sC}}\right] \times \frac{1}{sC}$$

$$V_1 = \frac{V_i(s)}{sCR+1}$$

$$V_0 = A V_1$$

$$= \frac{A V_i(s)}{sCR+1}$$

$$H(s) = \frac{A}{1+sCR}.$$

$$s = j\omega$$

$$H(j\omega) = \frac{A}{1+j\omega CR}.$$

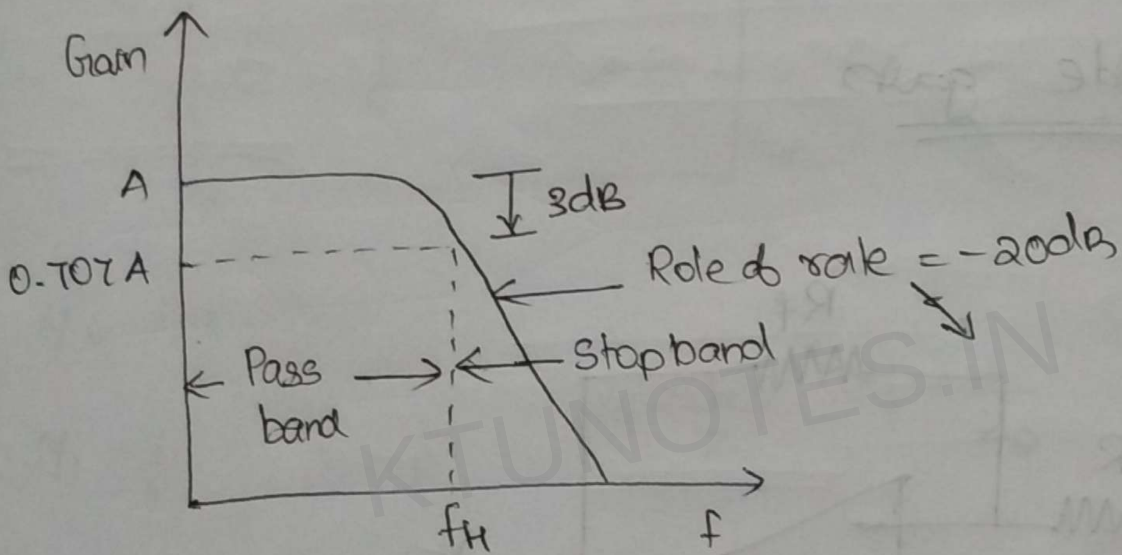
$$\frac{1}{RC} = \omega_H.$$

$$H(j\omega) = \frac{A}{1+j\frac{\omega}{\omega_H}}$$

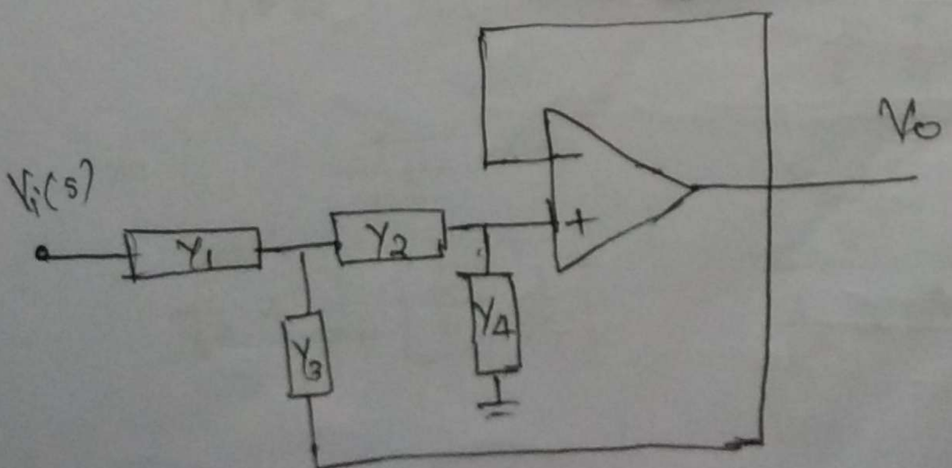
$$|H(j\omega)| = \frac{A}{\sqrt{1+\left(\frac{\omega}{\omega_H}\right)^2}}$$

$$|H(jf)| = \frac{A}{\sqrt{1+\left(f/f_H\right)^2}}$$

$f_H \rightarrow$ cutoff frequency.



General Second Order Active filter with unity gain.



Y → admittance.

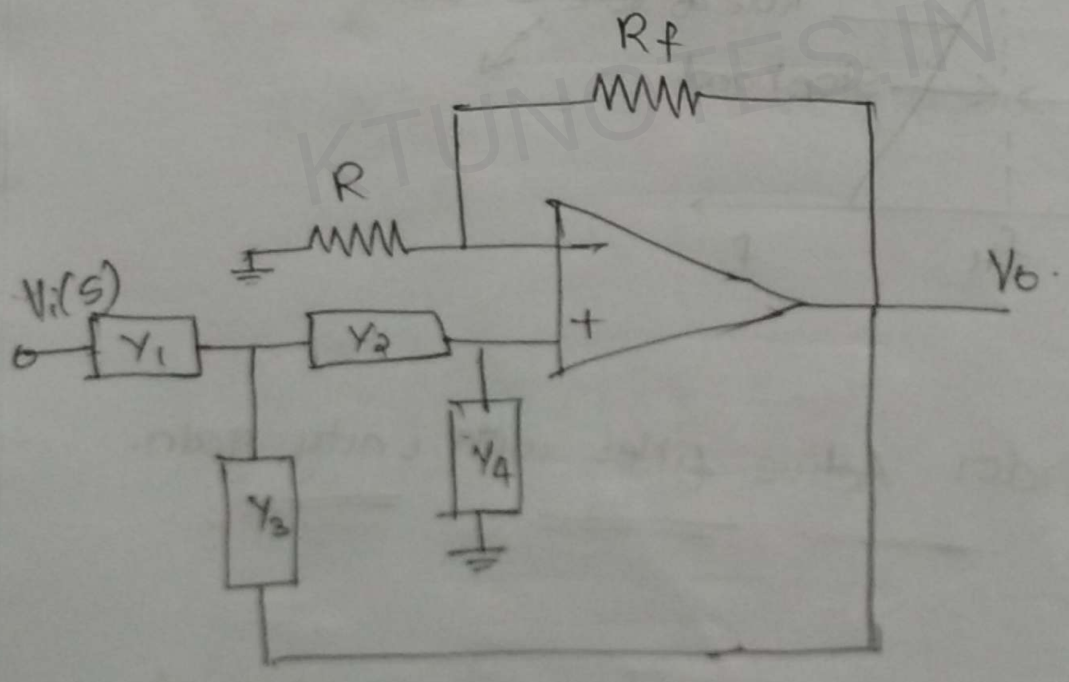
$Y = \frac{1}{R}$

$Y = \frac{1}{Z}$

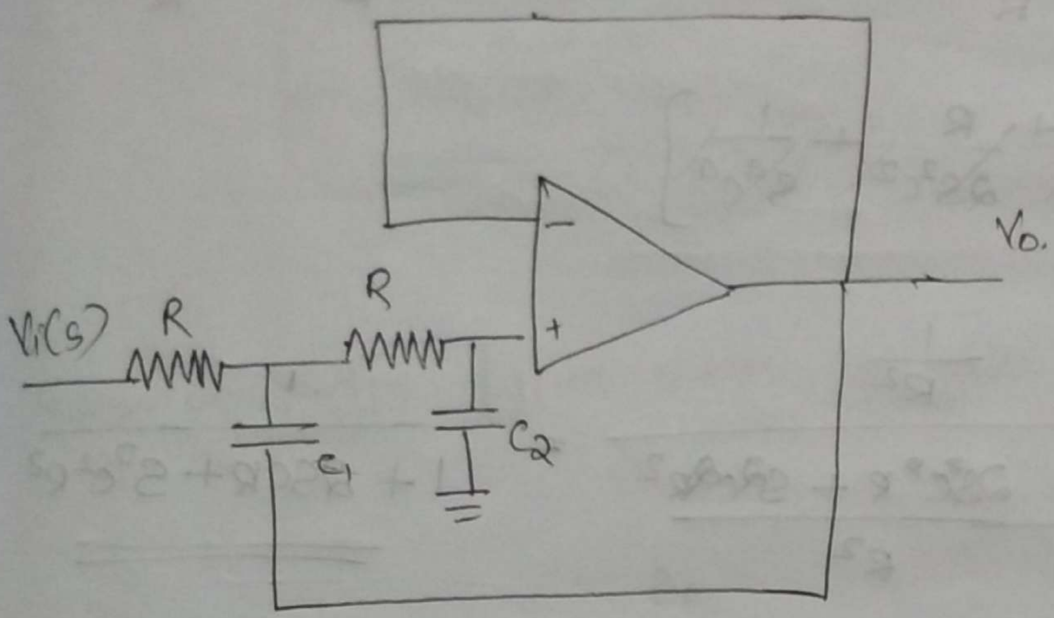
transfer function:

$$H(s) = \frac{Y_1 Y_2}{Y_1 Y_2 + Y_4(Y_1 + Y_2 + Y_3)}$$

General second order Active filter with variable gain



Second Order Low Pass Filter



Y = Admitance.

$Y_1 = \frac{1}{R}$ $\quad Y_2 = \frac{1}{R}$ $\quad Y_3 = \frac{1}{Z_1}$ $\quad Y_4 = \frac{1}{Z_2}$.

$Z_1 = \frac{1}{SC_1}$ $\quad Z_2 = \frac{1}{SC_2}$.

$$H(s) = \frac{Y_1 Y_2}{Y_1 Y_2 + Y_4(Y_1 + Y_2 + Y_3)} = \frac{\frac{1}{R} \cdot \frac{1}{R}}{\frac{1}{R} \cdot \frac{1}{R} + \frac{1}{Z_2}\left[\frac{1}{R} + \frac{1}{R} + \frac{1}{Z_1}\right]}$$

$$= \frac{\frac{1}{R^2}}{\frac{1}{R^2} + \frac{1}{Z_2}\left[\frac{2}{R} + \frac{1}{Z_1}\right]} = \frac{\frac{1}{R^2}}{\frac{1}{R^2} + SC_2\left[\frac{2}{R} + SC_1\right]}$$

Assume $C_1 = C_2 = C$.

$$\Rightarrow \frac{\frac{1}{R^2}}{\frac{1}{R^2} + \frac{2S^2C^2}{R} + S^2C^2} \qquad \frac{\frac{1}{R^2}}{\frac{1}{R^2} + \frac{2S^2C^2R}{R^2} + \frac{S^2C^2R^2}{R^2}}$$

$$\cancel{\frac{1}{R^2}} \times \left[\cancel{R^2} + \cancel{\frac{R}{2S^2C^2}} + \cancel{\frac{1}{S^4C^4}}\right]$$

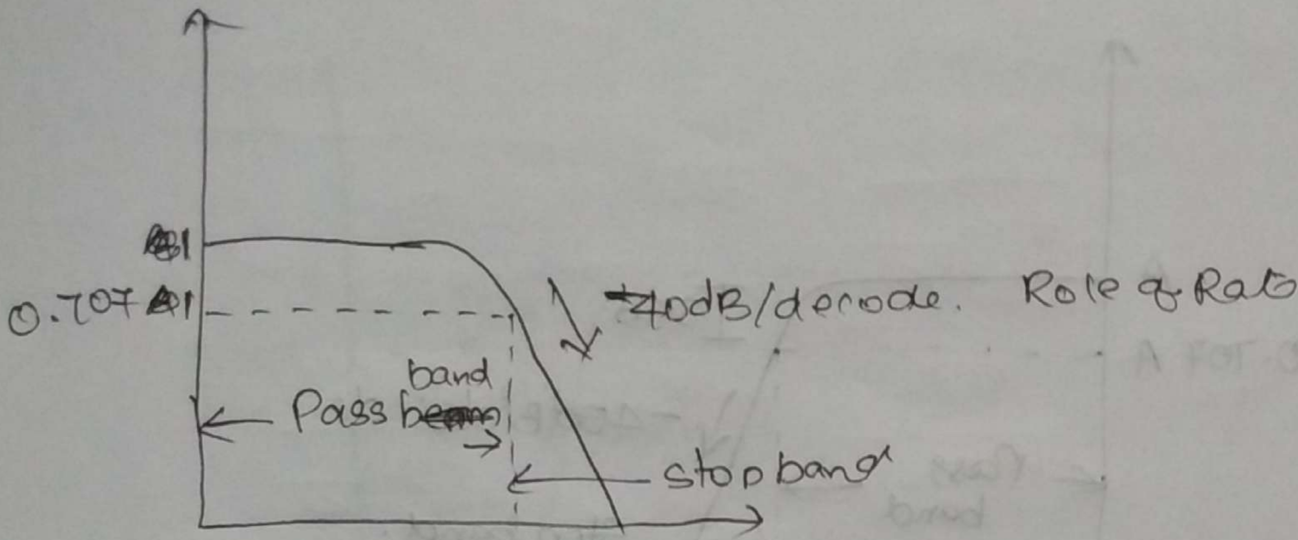
$$\Rightarrow \frac{\frac{1}{R^2}}{\frac{1 + 2S^2C^2R + S^2C^2R^2}{R^2}} = \frac{1}{1 + 2SCR + S^2C^2R^2}$$

$$\Rightarrow \frac{1}{1 + \cancel{2S^2C^2R} + \cancel{S^4C^4R^2}}$$

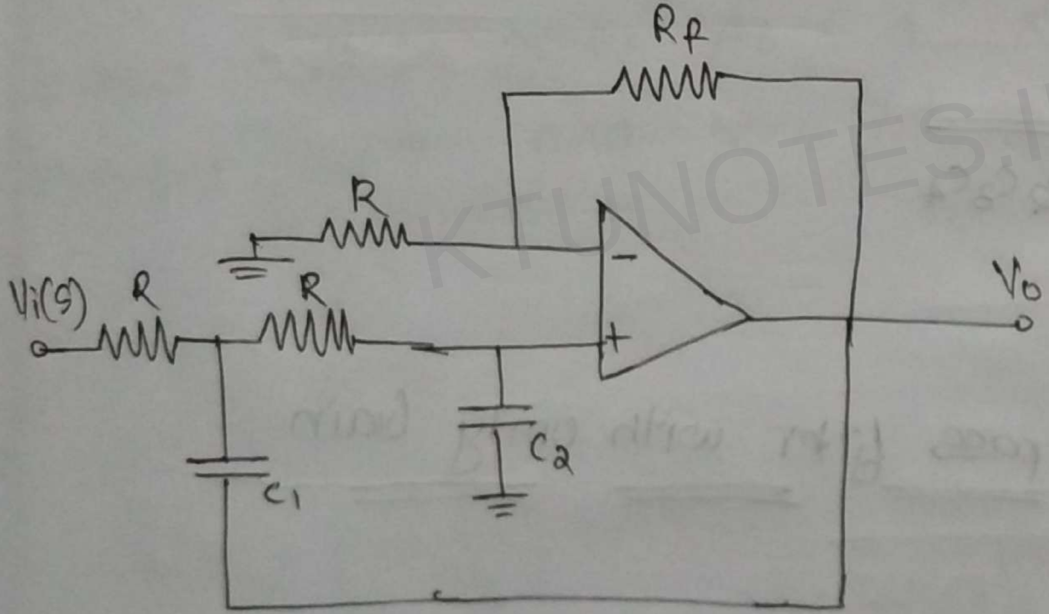
$$\Rightarrow \frac{1}{(\cancel{S^2C^2R} + 1)^2}$$

$$\Rightarrow \frac{1}{(SCR + 1)^2}$$

$$|H(jf)| = \frac{1}{\sqrt{1 + (f/f_H)^4}}$$

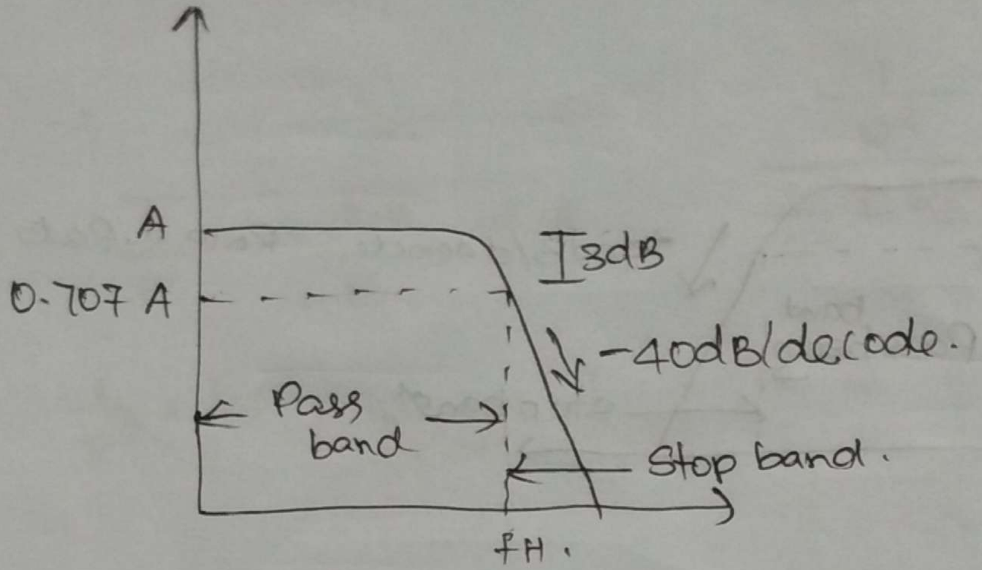


Second order filter with variable gain



~~Gain~~ $A = \left(1 + \frac{R_f}{R_1}\right)$ $\frac{R_f}{R} \neq 0$

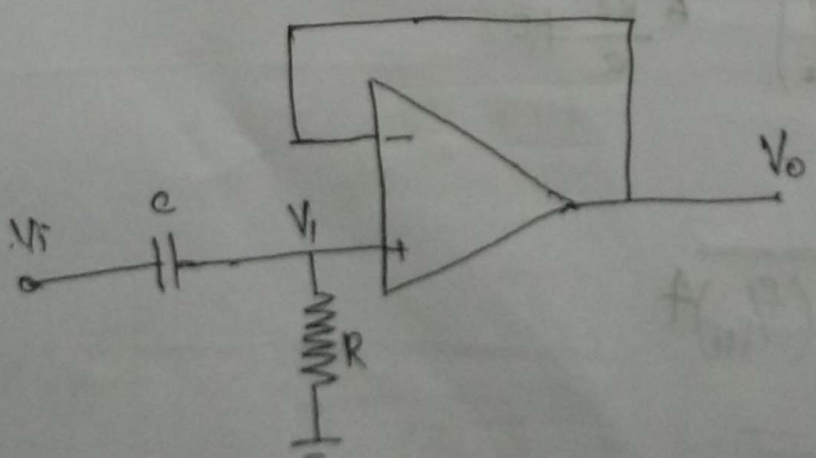
$$\Rightarrow |H(jf)| = \frac{A}{\sqrt{1 + \left(f/f_H\right)^4}}$$

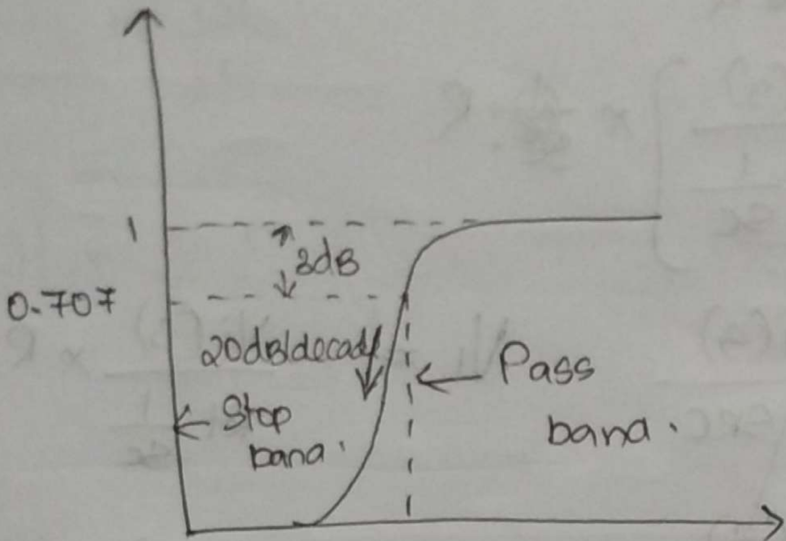


$$f_H = \frac{1}{2\pi RC}$$

$$f_H = \frac{1}{2\pi\sqrt{R_1 R_2 C_3 C_4}}$$

First order high pass filter with unity Gain





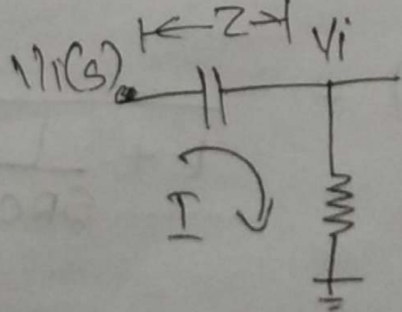
At low f capacitive reactance X_C will be very high ∴ low current. Thus output will be zero. As f ↑ X_C ↓ thus current flow ↑ and ~~Vout~~ o/p V ↑

$$A(s) = \frac{V_o(s)}{V_i(s)}$$

$$V_o(s) = \left(1 + \frac{R_f}{R_1}\right) V_i(s)$$

$$R_f = 0$$

$$\therefore V_o(s) = V_i(s)$$



$$I = \frac{V_i(s)}{R+Z} \qquad Z = \frac{1}{sC}$$

$$I = \frac{V_i(s)}{}$$

$$V_1(s) = I \cdot R$$

$$= \left[\frac{V_i(s)}{R + \frac{1}{sC}}\right] \times R$$

$$\Rightarrow \cancel{V_o = \frac{V_i(s)}{1 + sRC}}$$

$$V_1 = \frac{V_i(s)}{R + \frac{1}{sC}} \times R$$

$$\cancel{H(s) = \frac{V_o(s)}{V_i(s)}}$$

$$= \frac{V_i(s)\,R}{\frac{RsC + 1}{sC}}$$

$$\cancel{H(s) = \frac{1}{1 + sRC}}$$

$$V_o = V_1 = \frac{V_i(s)\,sRC}{1 + sRC}$$

$s = j\omega$

$$H(s) = \frac{sRC}{1 + sRC} \qquad s = j\omega$$

$$H(j\omega) = \cancel{\frac{j\omega RC}{1 + j\omega RC}}$$

$$H(s) = \frac{1}{1 + \frac{1}{sRC}}$$

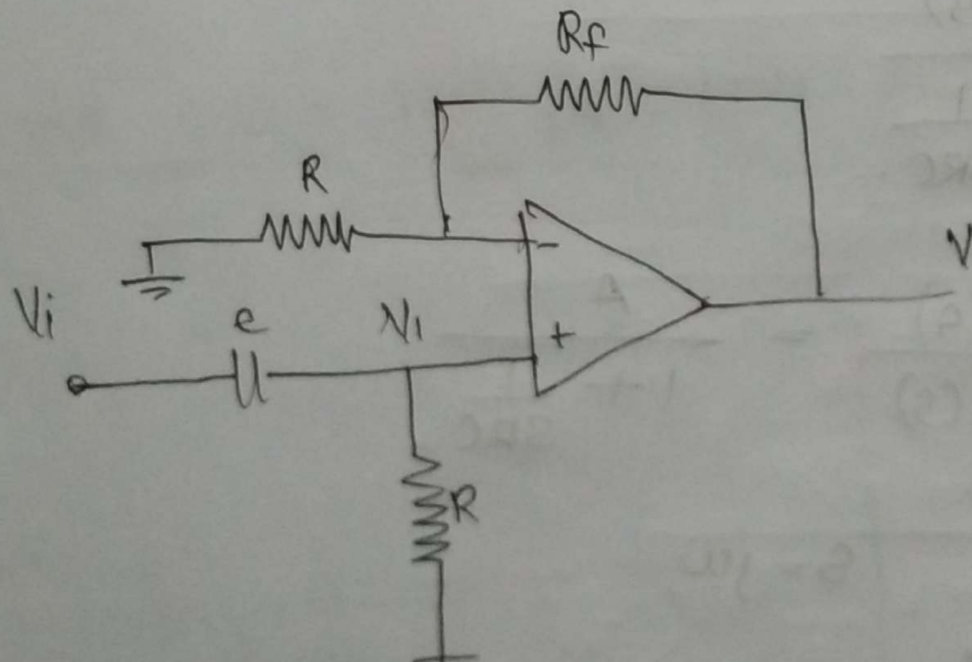
$$H(j\omega) = \frac{1}{1 + \frac{1}{j\omega RC}} \qquad \frac{1}{RC} = \omega_L$$

$$H(j\omega) = \frac{1}{1 + \frac{\omega_L}{j\omega}}$$

$$|H(j\omega)| = \frac{1}{\sqrt{1 + \left(\frac{\omega_L}{\omega}\right)^2}}$$

$$|H(jf)| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

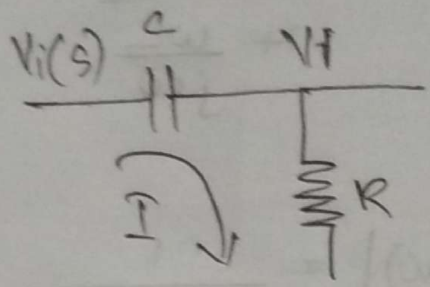
First order high pass filter with variable gain



$$A = 1 + \frac{R_f}{R}$$

$$I = \frac{V_i(s)}{Z+R}$$

$$= \frac{V_i(s)}{R+\frac{1}{sC}}$$



$$V_1 = IR$$

$$= \left[\frac{V_i(s)}{R+\frac{1}{sC}}\right]R$$

$$= \frac{V_i(s)}{1+\frac{1}{sRC}}$$

$$V_o = AV_1$$

$$= \frac{A\,V_i(s)}{1+\frac{1}{sRC}}$$

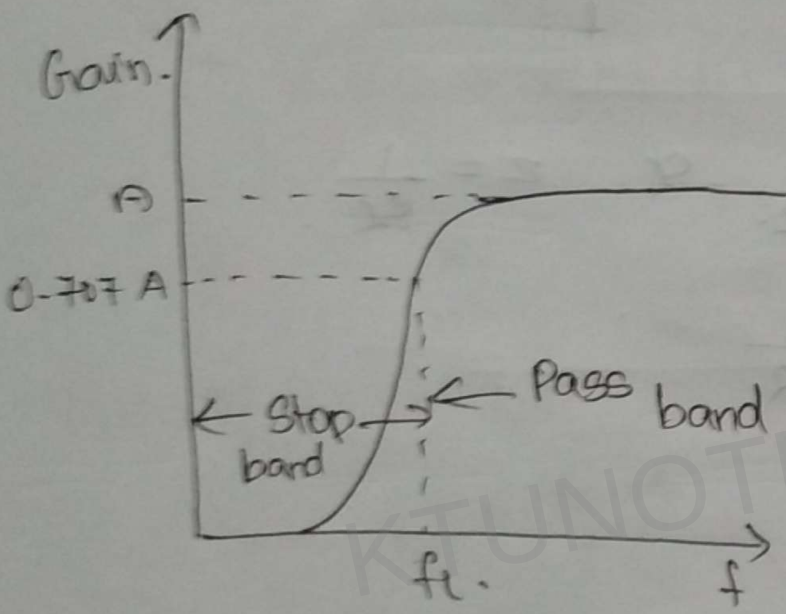
$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{A}{1+\frac{1}{sRC}}$$

$$\frac{1}{RC} = \omega_L, \qquad s = j\omega$$

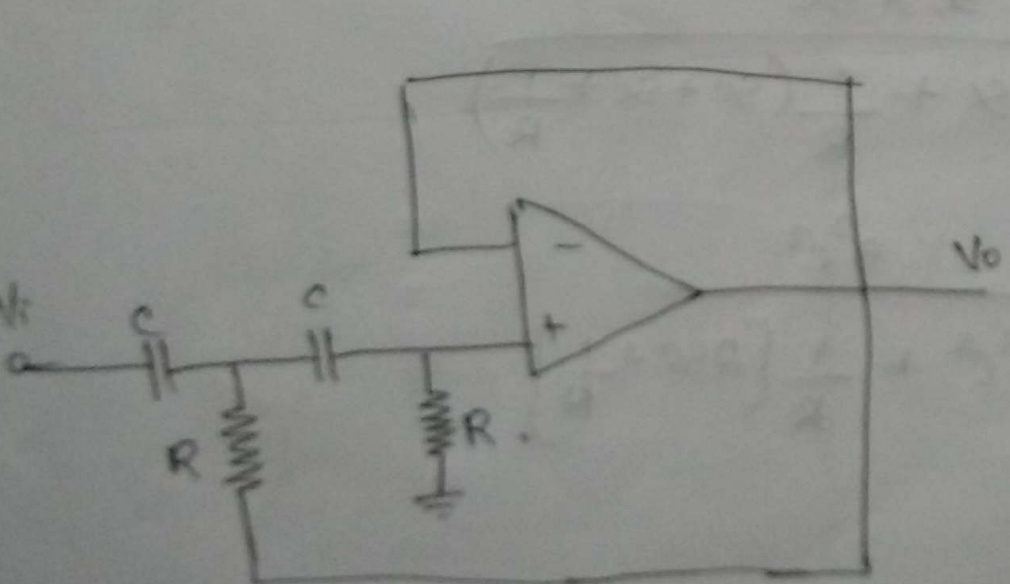
$$H(j\omega) = \frac{A}{1+\frac{\omega_L}{j\omega}}$$

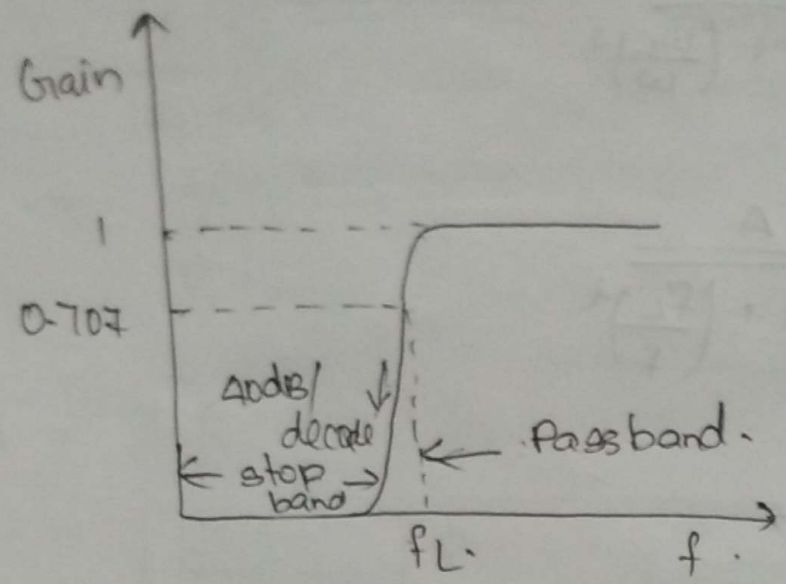
$$|H(j\omega)| = \frac{A}{\sqrt{1+\left(\frac{\omega_L}{\omega}\right)^2}}$$

$$|H(jf)| = \frac{A}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}$$



Second order high pass filter · unity Gain





$Y_1 = \frac{1}{Z} = SC \qquad Y_2 = \frac{1}{Z} = SC. \qquad Z = \frac{1}{SC}.$

$Y_3 = \frac{1}{R} \qquad Y_4 = \frac{1}{R}$

$$H(S) = \frac{Y_1 Y_2}{Y_1 Y_2 + Y_4(Y_1 + Y_2 + Y_3)}$$

$$= \frac{SC \times SC}{SC \times SC + \frac{1}{R}\left(SC + SC + \frac{1}{R}\right)}$$

$$= \frac{S^2C^2}{S^2C^2 + \frac{1}{R}\left[2SC + \frac{1}{R}\right]}$$

Scanned by CamScanner

$$\Rightarrow \frac{s^2c^2}{s^2c^2 + \frac{2s}{R} + \frac{1}{R^2}}$$

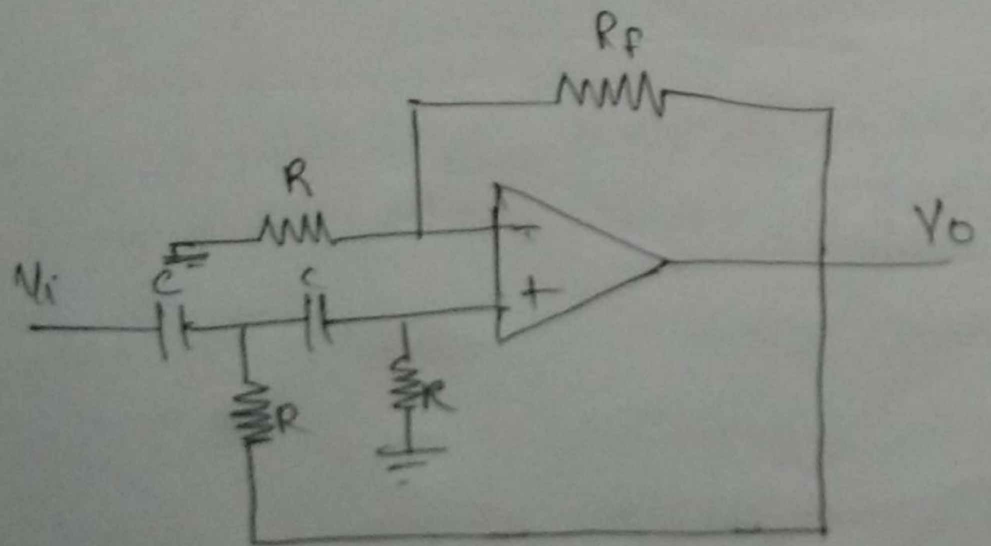
$$\Rightarrow \frac{s^2c^2}{\frac{R^2s^2c^2 + 2sRC + 1}{R^2}}$$

$$\Rightarrow \frac{s^2R^2c^2}{R^2s^2c^2 + 2sRC + 1.}$$

$\Rightarrow$ ~~SR~~

$$|H(jf)| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f}\right)^4}}$$

Second order high pass filter with variable gain

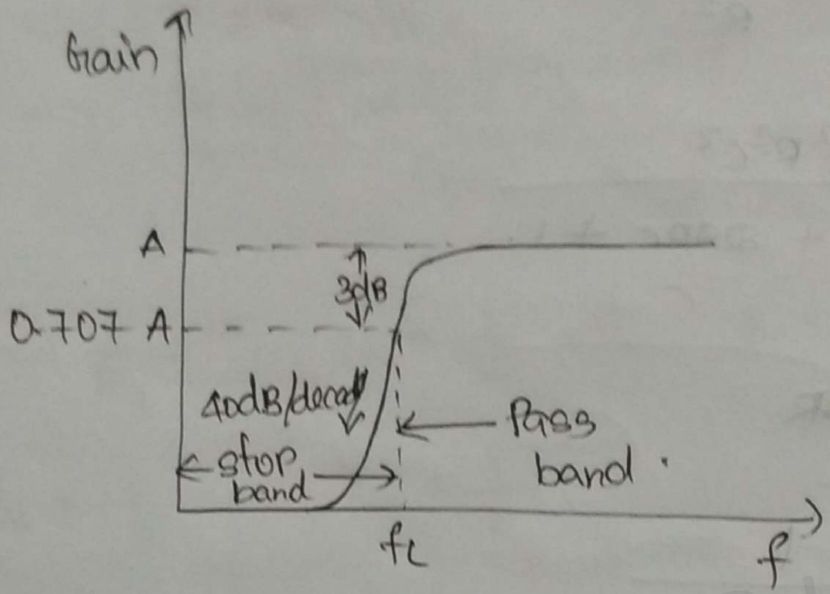


$$|H(jf)| = \frac{A}{\sqrt{1+\left(\frac{f_L}{f}\right)^4}}$$

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

when $R_1 = R_2 = R$

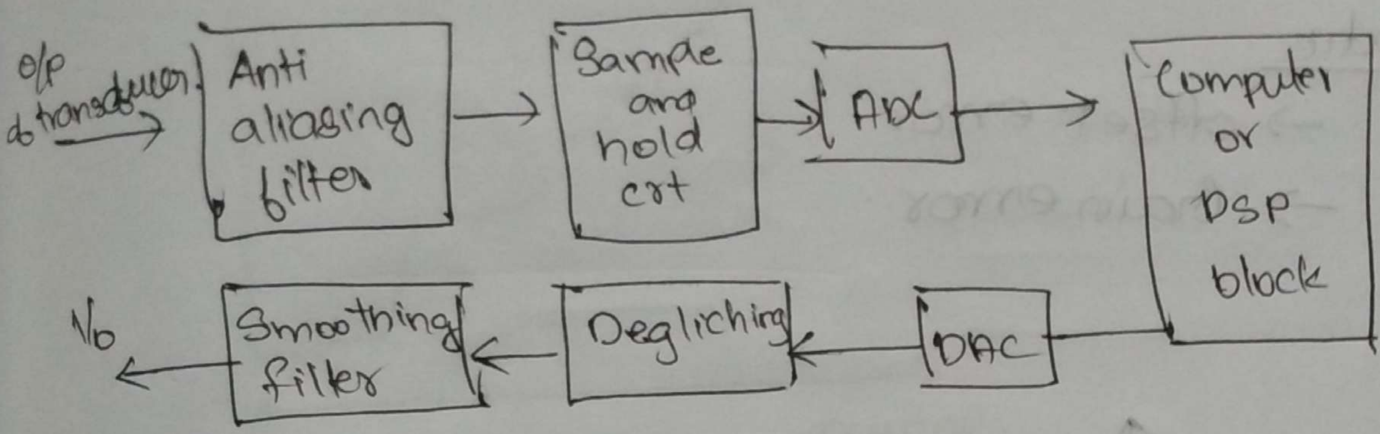
$$f_L = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$



M6

Data Converter

S/m



Digital to Anolog Converters

1) Weighted Resistors DAC.
2) R-2R ladder.

D/A convertor specification

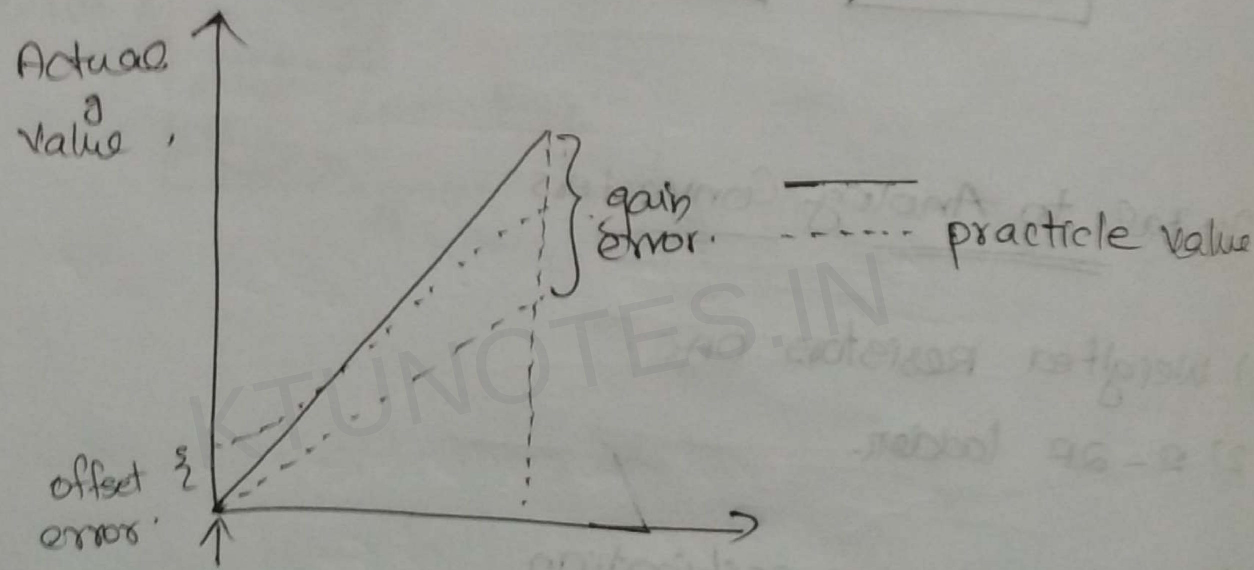
→ Accuracy.
→ Linearity
→ Differential Non-linearity. (DNL)
→ ~~Input~~ Integral Non-linearity (INL)
→ Montoncity
→ Resolution.
→ Temperature sensitivity.

Accuracy – o/p's maximum deviation from ideal value, expressed in terms of 1LSB

2 types of error : → Static
→ dynamic

Static

→ offset error
→ Gain error.



The difference with practicle and ~~paper~~ theoretical values is called offset error

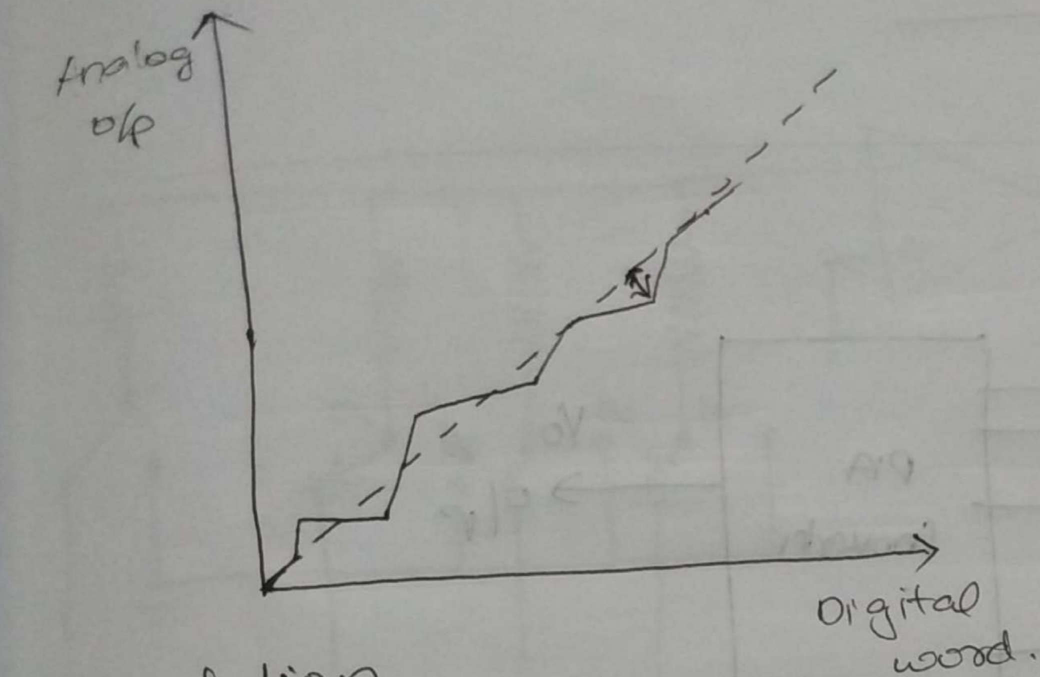
→ Linearity

2 types of error

→ full scale error.

Difference between actual value and ideal value in terms of %

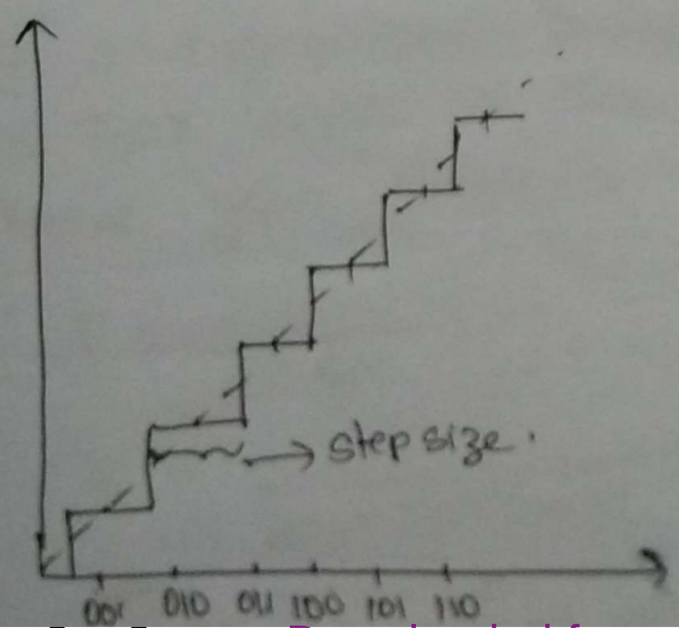
→ Integral Non-linearity (INL)



→ Resolution

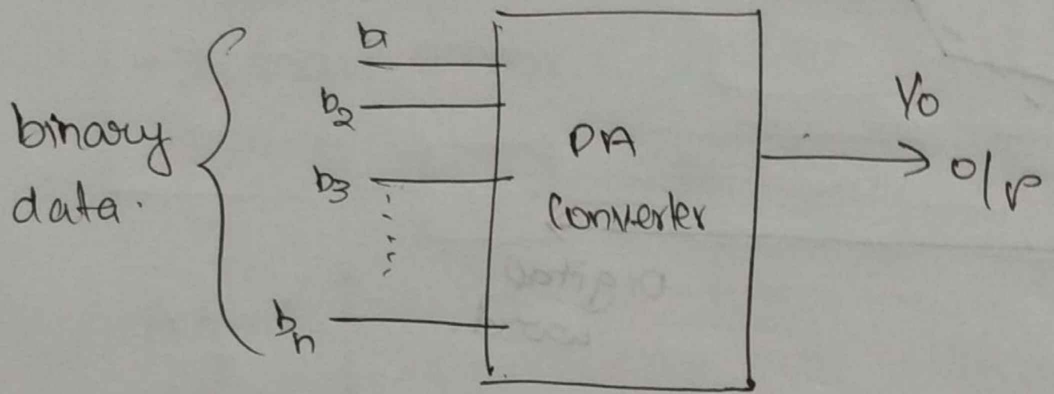
$$\text{Resolution} = \frac{\text{Step size}}{\text{Full scale voltage}} \times 100$$

$$= \frac{1}{\text{Total no. of step}} \times 100$$



Ability to detect a small change in i/p.

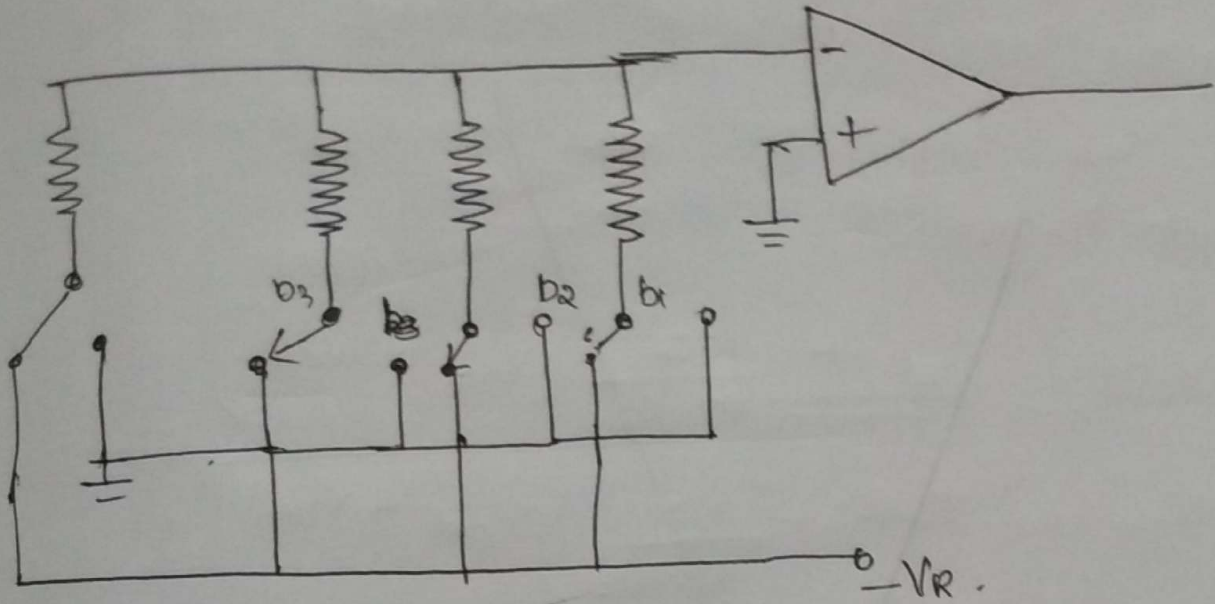
→ Temperature sensitivity:



$$V_0 = K V_{FS} \left(b_1 2^{-1} + b_2 2^{-2} + \cdots b_n 2^{-n} \right)$$

where $K \rightarrow$ scaling factor.

$V_{FS} \rightarrow$ full scale voltage.



$$I_0 = I_1 + I_2 + I_3 + I_n$$

$$V_0 = I_0 R_f$$

$$V_0 = \frac{R_f}{R} V_{FS} \left(b_1 2^{-1} + b_2 2^{-2} + \dots b_n 2^{-n} \right)$$

Q. Design a differentiator to differentiate an input signal that varies in frequency from 10Hz to 1kHz.

Ans:- Assume your capacitor = 1μF

Ans:- $f = \frac{1}{2\pi RC}$

$R = \frac{1}{2\pi \times 1 \times 10^{-6} \times 10}$ = ~~15kΩ~~. 1~~59~~ 16kΩ.

15.9kΩ.

R ~~$= \frac{1}{2\pi \times (1 \times 10^{-6}) \times 10^{3}}$~~ =

Q. Consider the schmitt crct $R_1 = 56\,\cancel{\Omega}\,k\Omega$. $R_2 = 150\Omega$
$V_i = 1V_{pp}$ sin wave of 6 50 Hz, $V_{ref} = 0\,V$.
opamp used ~~to~~ ~~sat~~ with supply voltages $\pm 15V$
and saturation voltages are ~~±30V~~. $\pm 13.5V$.
Determine the upper threshold voltage and V_{lt}
Draw the input and o/p waveform of
schmit trigger.

Ans:- $$V_{ut} = V_{ref} + \frac{R_2}{R_1+R_2}\left[V_{sat} - V_{ref}\right]$$

$$V_{lt} = V_{ref} - \frac{R_2}{R_1+R_2}\left[V_{sat} + V_{ref}\right]$$

$$V_{ut} = 0 + \frac{150}{150 + 56\times10^3}\left[13.5 - 0\right]$$

$$= \underline{\underline{36mV}}$$

$$V_{lt} = 0 + \left(\frac{150}{56\times10^3 + 150}\right)\left[-13.5 - 0\right]$$

$$= \underline{\underline{-36mV}}$$

Q. A 1^{st} order low pass ~~twonder~~ butterworth filter has a cut of frequency of 10 kHz and unity gain at low frequency. Find the ~~r~~ transfer function magnitude in dB at 12 kHz for the filter.

Ans: Transfer function $H(s) = \frac{V_o(s)}{V_i(s)}$.

$$|H(jf)| = \frac{1}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$$

$$= \frac{1}{\sqrt{1+\left(\frac{12}{10}\right)^2}}$$

$$= 0.64$$

$$= -3.87\,dB$$

Q. Design a 1^{st} order low pass filter at a cut of frequency of 2kHz with a pass band gain of 2.

$f_H = 2\,kHz = 2\times10^3\,Hz$

$A = 2$, $C = 1\mu F = 1\times10^{-6}\,F$

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

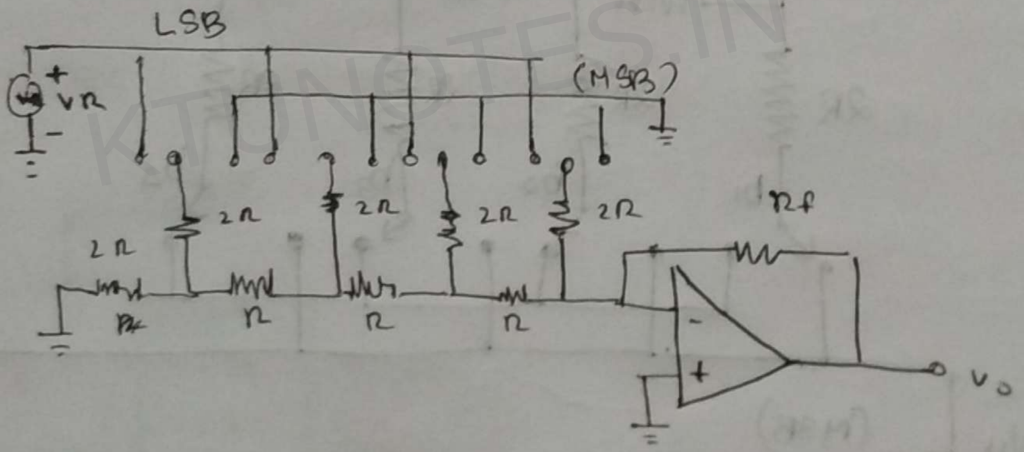
$$\therefore R_f = \frac{1}{2\pi \times f_H \times C} = \frac{1}{2\pi \times 2 \times 10^3 \times 10^{-6}} = \cancel{250\Omega}\ 79.6\Omega$$

$$A = 1 + \frac{R_f}{R_1}$$

$$2 = 1 + \frac{1k\Omega}{R_1}$$

$$R_1 = \underline{\underline{1k\Omega}}$$

R-2R ladder type



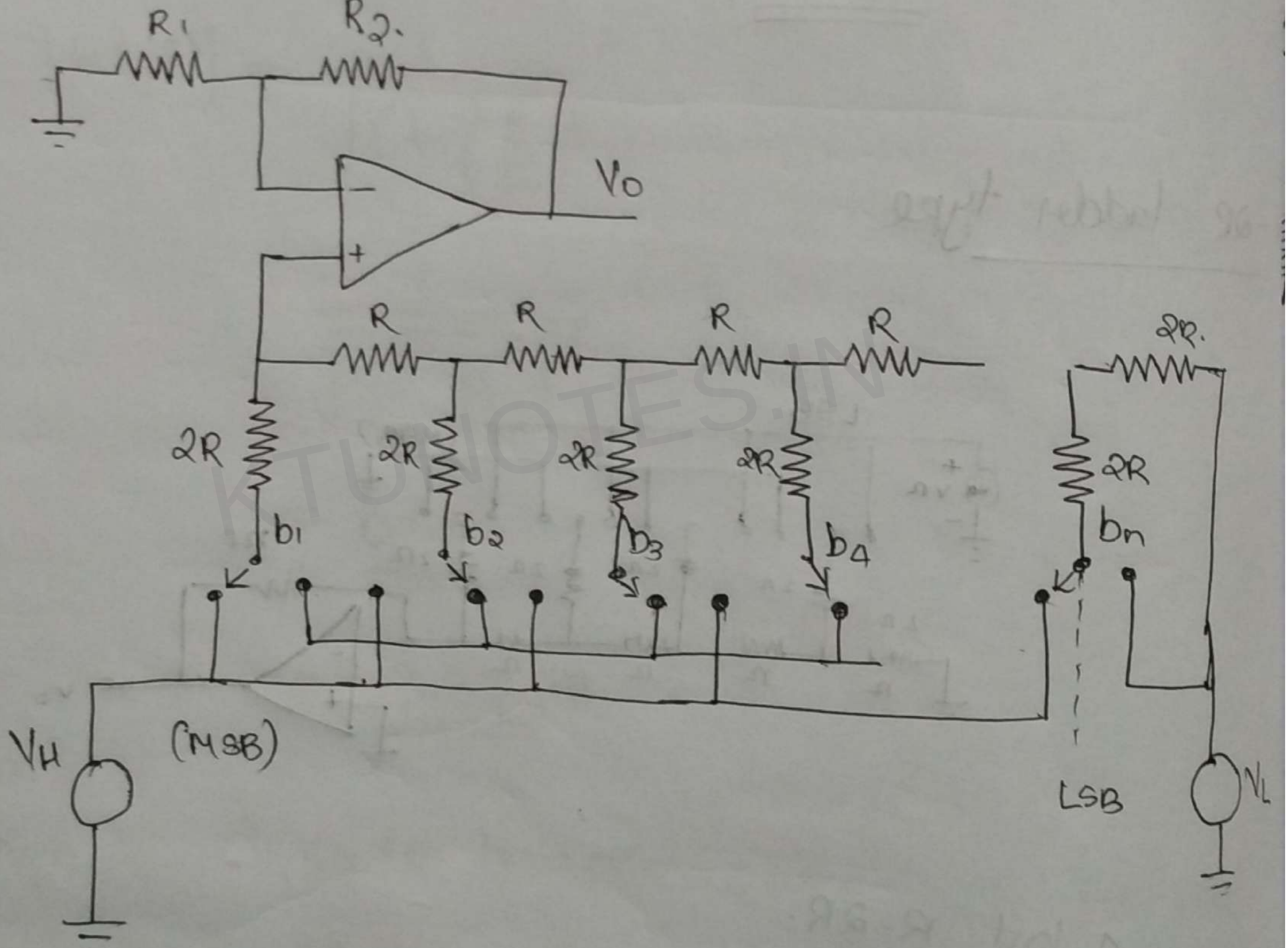
4 bit R-2R.

b_1	b_2	b_3	b_4	
1	0	0	0	$\frac{V_R}{2}$
0	1	0	0	$\frac{V_R}{4}$
0	0	1	0	$V_R/8$

$$V_0 = V_R\left[2^{-1}b_1 + 2^{-2}b_2 + \dots b_n 2^{-n}\right)$$

$$\text{Resolution} = \frac{1}{2^n} \times V_R \cdot \frac{R_f}{R}$$

Voltage mode



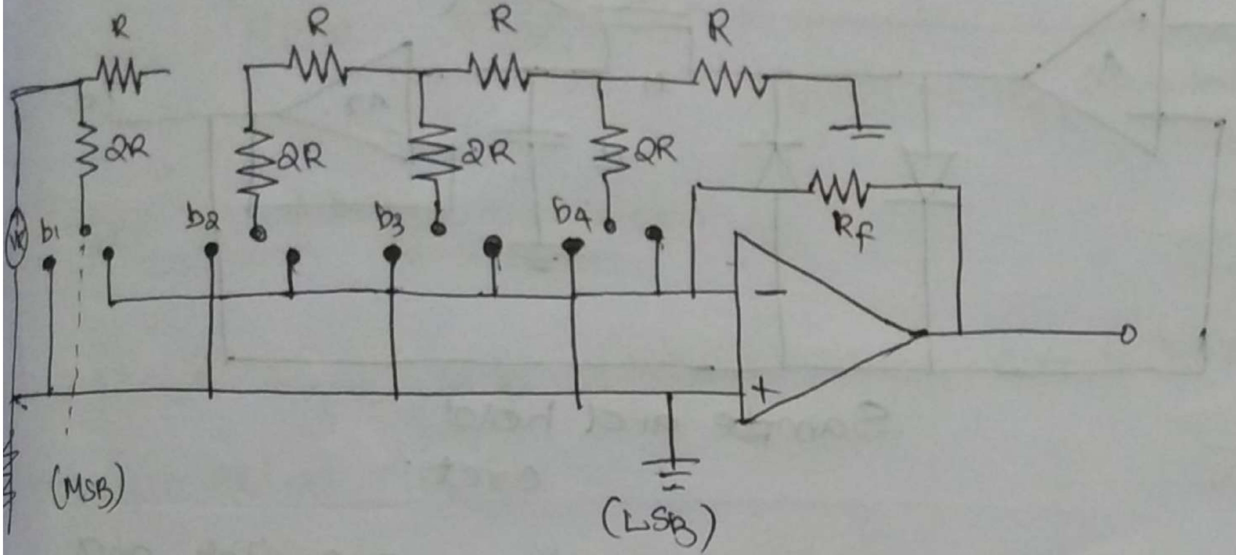
Advantage

→ Accuracy is more

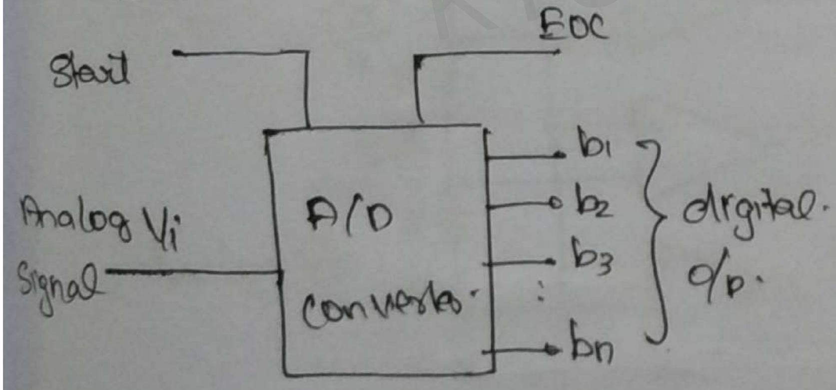
→ Easy to expand the network [by adding extra R–2R ladder]

~~Invalid~~

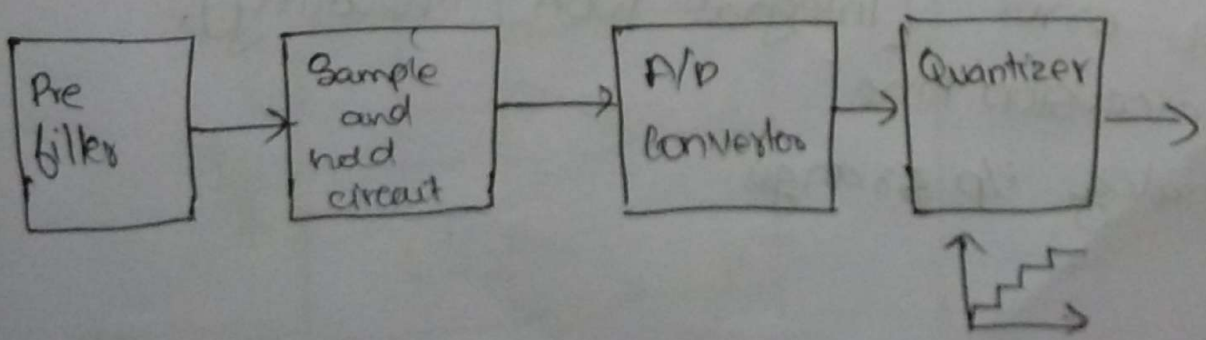
Inverted Mode 2R



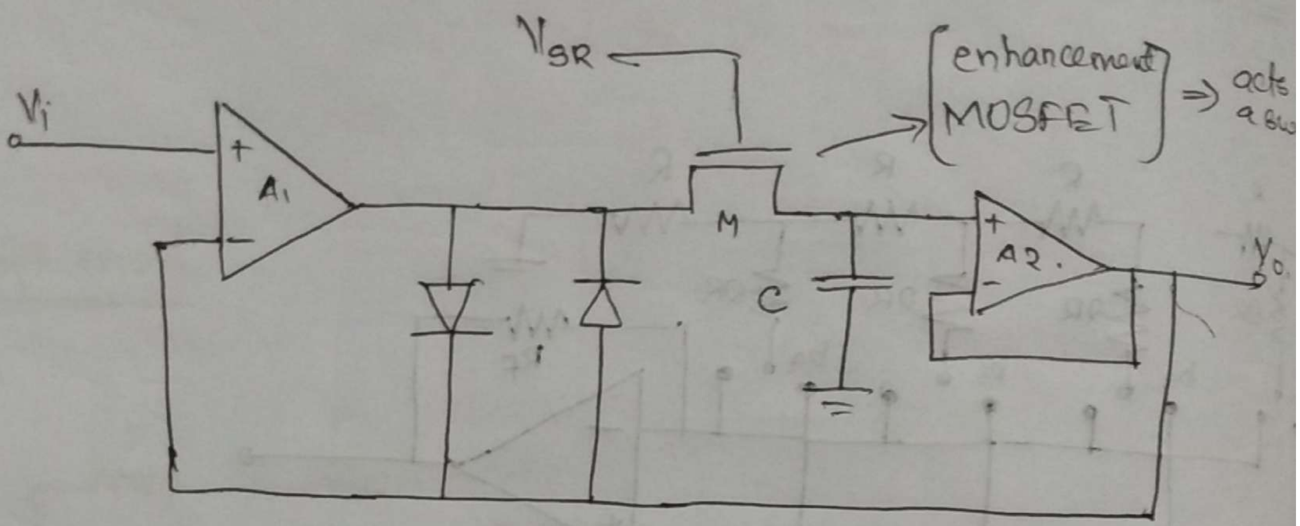
A to D converter   Analog ⇒ Digital



⇓



Sample and hold



Sample and hold crct.

If V_{SR} is high the mosfet act as a switch and turns on. If V_{SR} is low the mosfet act as an open switch (off).

Specification

→ Resolution
→ Quantization error
→ Analog error
→ DNL error [Differential Non linearity].
→ INL error [Integral Non linearity].
→ conversion time
→ Analog i/p range.

→ Resolution :

$$\text{Resolution} = \frac{1}{\text{Total no. of Steps}}$$

$$\text{Here Resolution} = \frac{1}{\text{Total no. of combinations}}$$

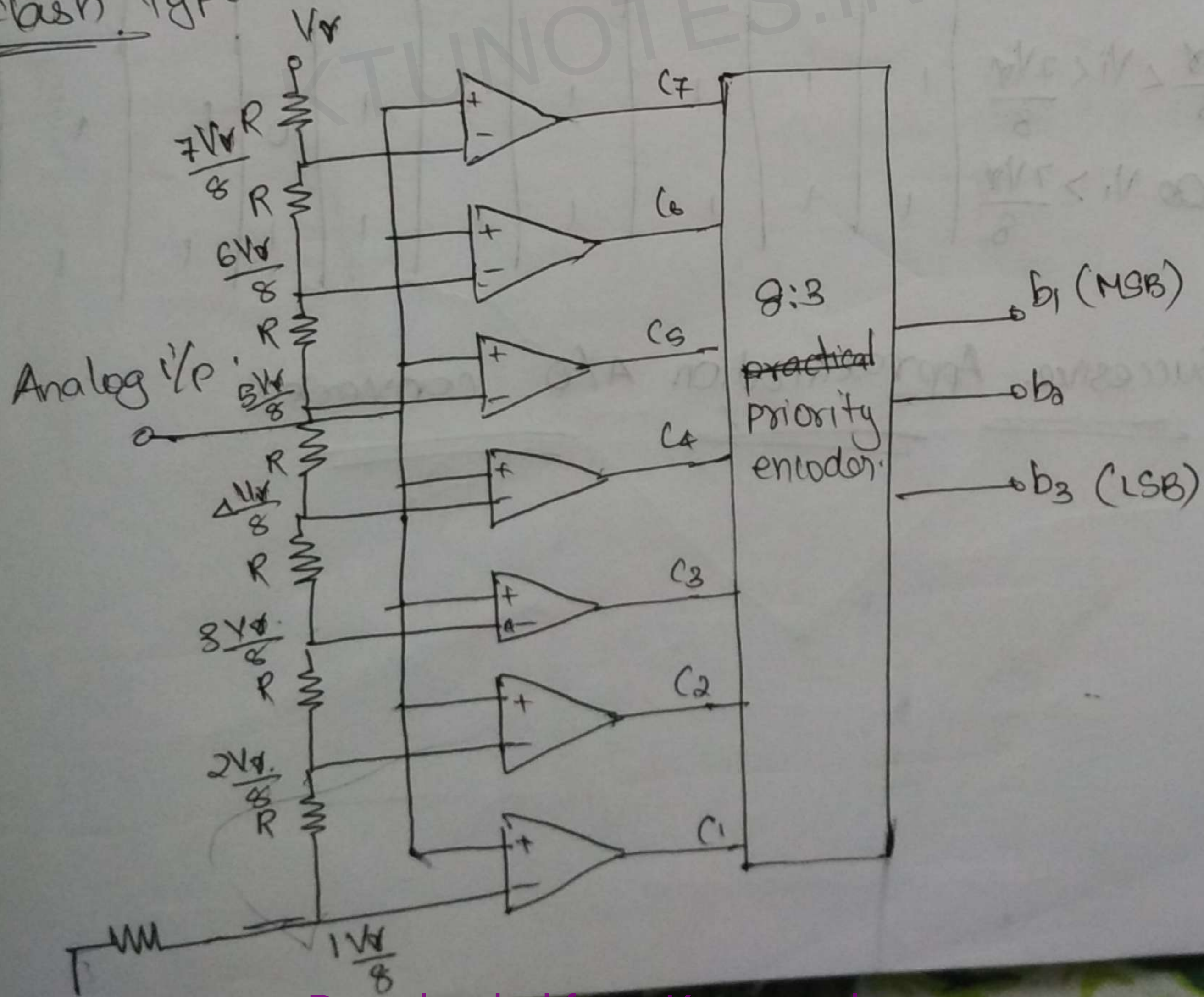
Types of A to D converters

→ Flash type A/D [Fastest, easy, simple to design]

→ Succesive Approx

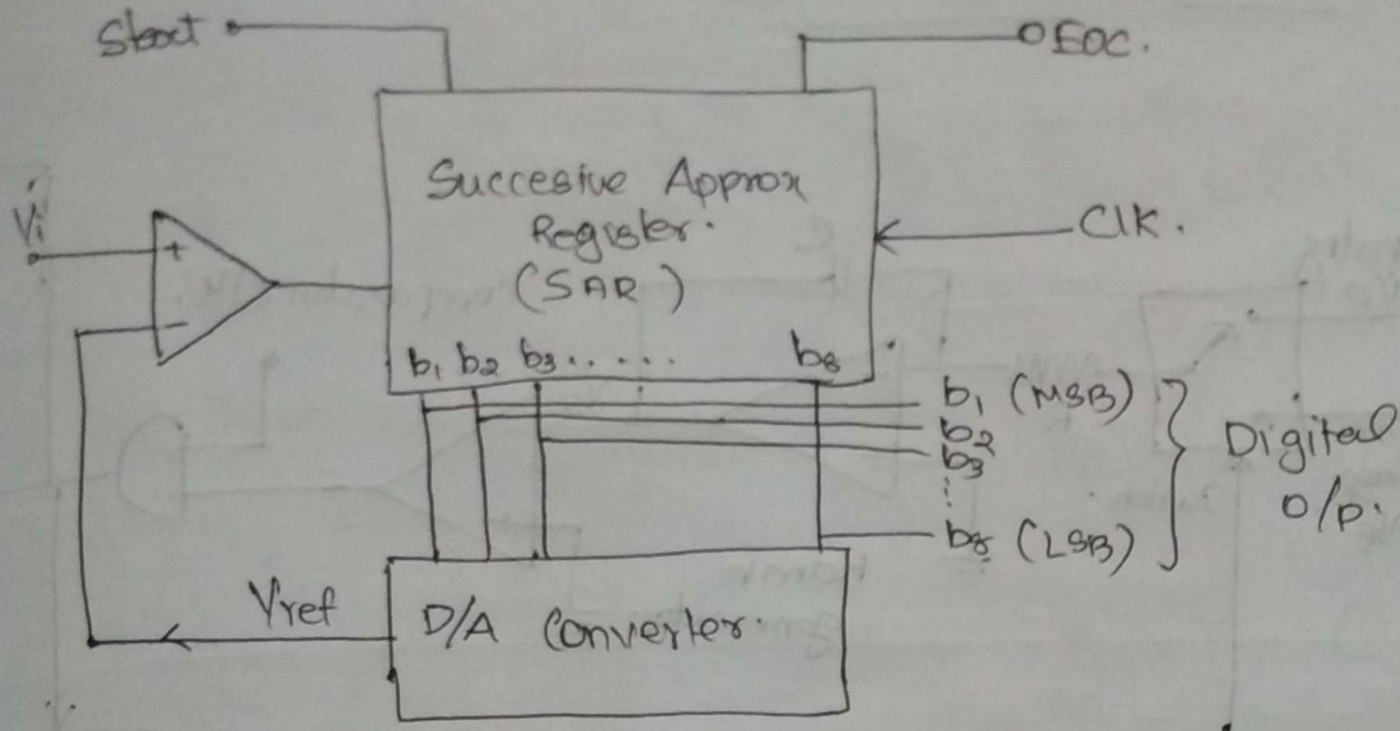
→ Dual slope.

→ Flash type



Analog i/p	C_1	C_2	C_3	C_4	C_5	C_6	C_7	b_1	b_2	b_3
$0 < V_i < \frac{1V_r}{8}$	0	0	0	0	0	0	0	0	0	0
$\frac{1V_r}{8} < V_i < \frac{2V_r}{8}$	1	0	0	0	0	0	0	0	0	1
$\frac{2V_r}{8} < V_i < \frac{3V_r}{8}$	1	1	0	0	0	0	0	0	1	0
$\frac{3V_r}{8} < V_i < \frac{4V_r}{8}$	1	1	1	0	0	0	0	0	1	1
$\frac{4V_r}{8} < V_i < \frac{5V_r}{8}$	1	1	1	1	0	0	0	1	0	0
$\frac{5V_r}{8} < V_i < \frac{6V_r}{8}$	1	1	1	1	1	0	0	1	0	1
$\frac{6V_r}{8} < V_i < \frac{7V_r}{8}$	1	1	1	1	1	1	0	1	1	0
$V_i > \frac{7V_r}{8}$	1	1	1	1	1	1	1	1	1	1

Successive Approximation A/D converter

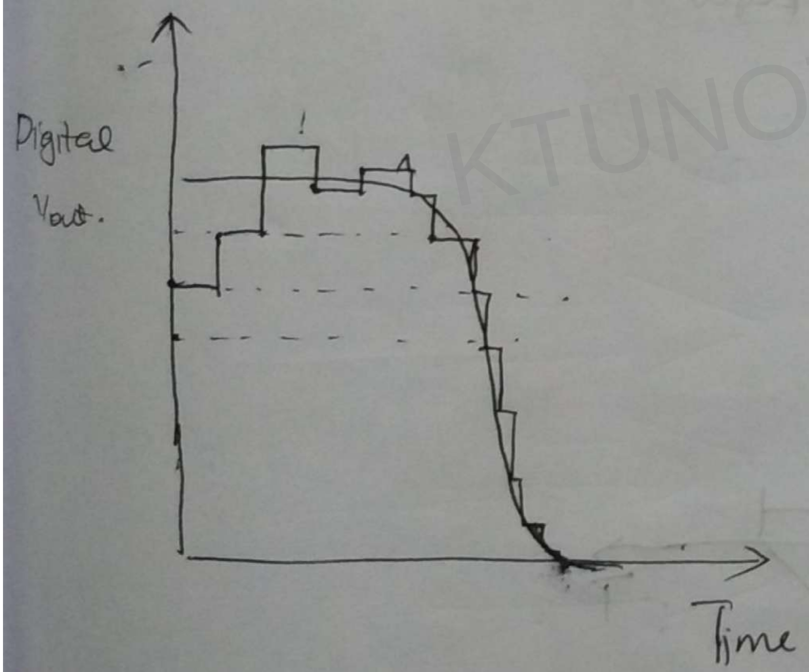


when $V_i < V_{ref}$

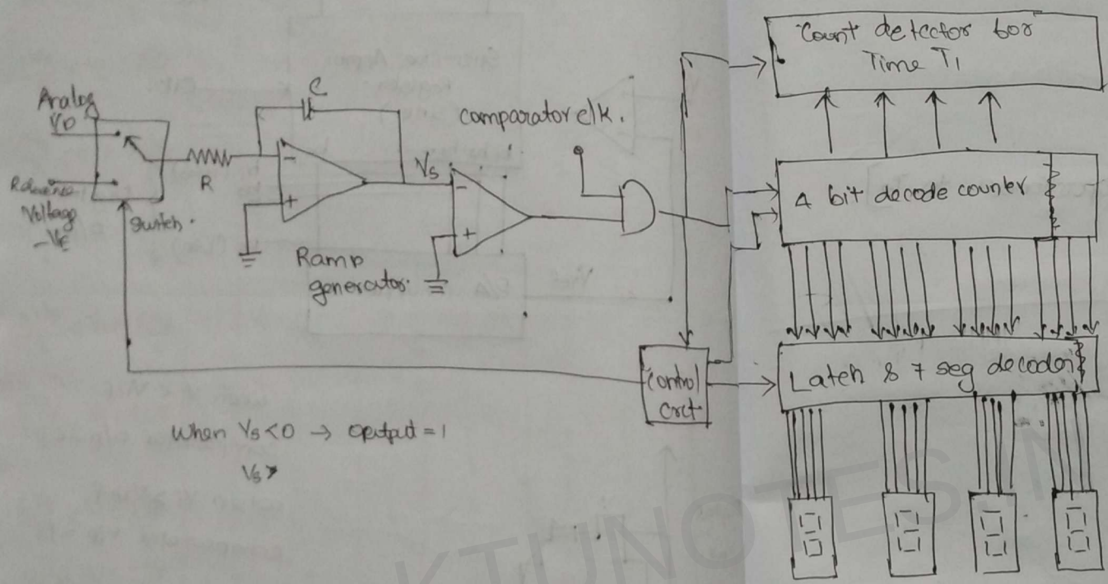
comparator o/p = 0

when $V_i > V_{ref}$

comparator o/p = 1



Dual Slope A/D Converter



When $V_S < 0$ → output = 1

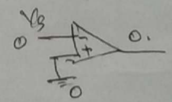
$\rightarrow T_1$ time is fixed.

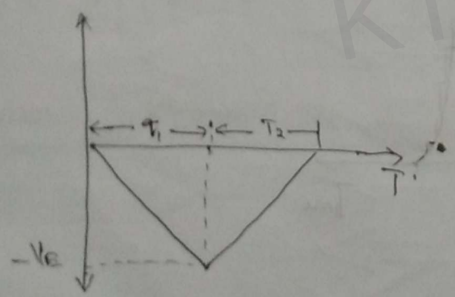
$$-V_S = \frac{V_i}{RC} \times T$$

$$V_S = \frac{-V_i}{RC} \times T \quad \text{—} \; ①$$

After T_1 time the switch connects to V_{ref}. So we get a +ve slop. but lower than 0.

When V_S increases and reaches 0. the comparator input will become equal.





∴ Input of AND gate is 0. So the gate will be off.

$$V_S = \left(\frac{-V_R}{RC} \times T_2\right) \quad \text{—} \; ②$$

where V_R → Reference Voltage.

from ① and ⑤

$$-\frac{V_i}{RC} \times T_1 = \frac{V_R}{RC} \times T_2$$

$$V_i = \frac{-V_R}{T_1} \times T_2$$

$\Rightarrow V_i \propto T_2$ [V_i proportional to T_2].

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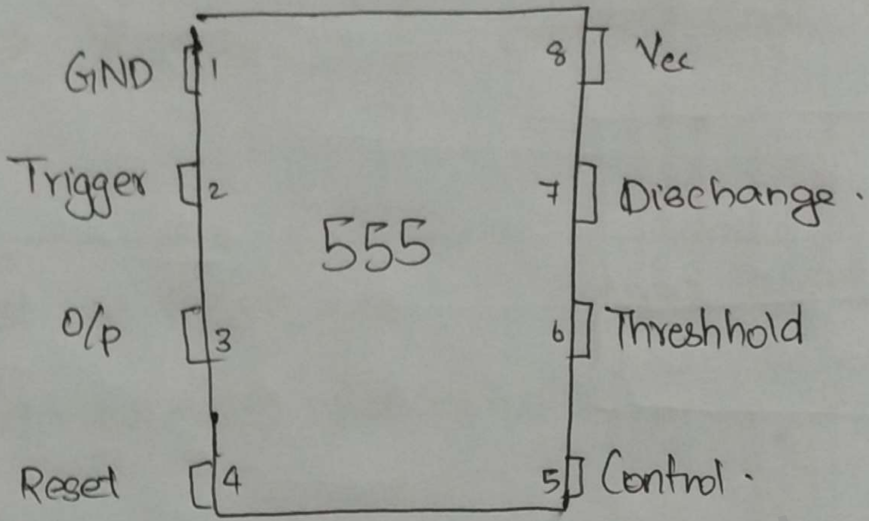
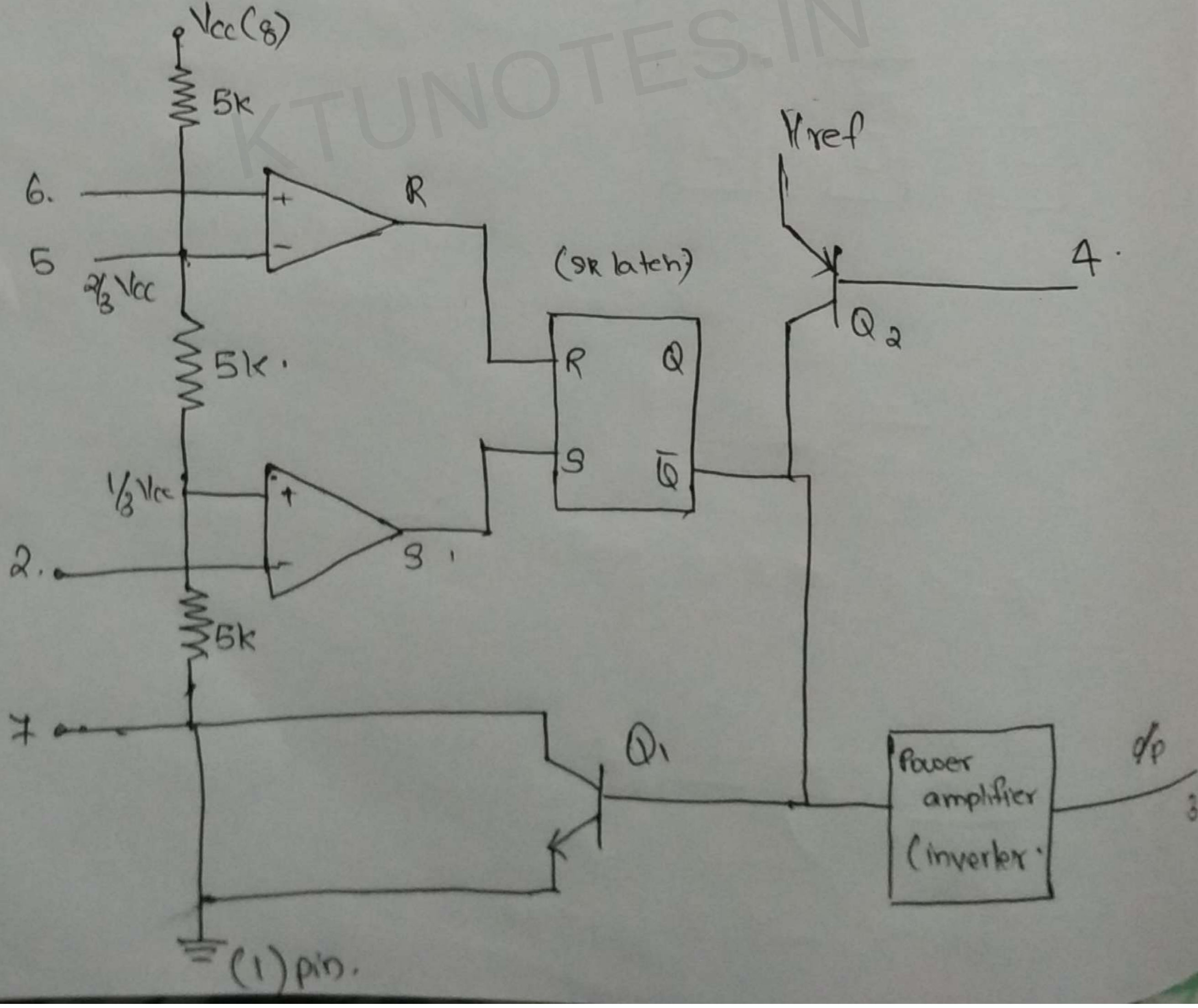
fastest → Flash type

high accuracy → Successive

555 Ic

- → 8 pin IC
- → Manufactured by Signetic coorperation
- → SE 555 / NE 555





→ when pin 4 ~~is~~ ~~low~~ gets low, IC get RESET.

→ 5 ⇒ control pin. $\frac{2}{3}V_{cc}$

→ To remove noise we connect pin 5. with capacitor of 0.01μF to ground.

→ when threshold (6) > $\frac{2}{3}V_{cc}$ then

→ Voltage varies from 5-18V.