Linear IC Ramakant Gaikwad

ADIC

Unit -1

*) Ordering information: Generally in ordering IC following info must be specified.

µA741	T	C
↓	↓	↓
Device type (op-amp)	Package type (mini DIP)	Commercial temp. Range (0° to +70°C).

Temp. Ranges:

1. Military: -55°C to +125°
2. Industrial: -20°c to +85°
3. Commercial: 0°c to +70°C.

*) Manufactor's Designation for Linear ICs:

Manufac.	Prefix
Fairchild	µA, µAF
National Semiconductor	LM, LH, LF, TBA
Motorola	MC, MFC
RCA	CA, CD
Texas Instruments	SN
Signetics	N/S, NE, SE, SU
Burr-Brown	BB.

741 - Military grade op-amp
741C - Commercial " "
741A - Improved version of 741
741E - Improved " of 741C
741S - Military grade op-amp with higher slew rate
741SC - Commercial grade op-amp with higher slew rate.

*) Power Supply Connections:

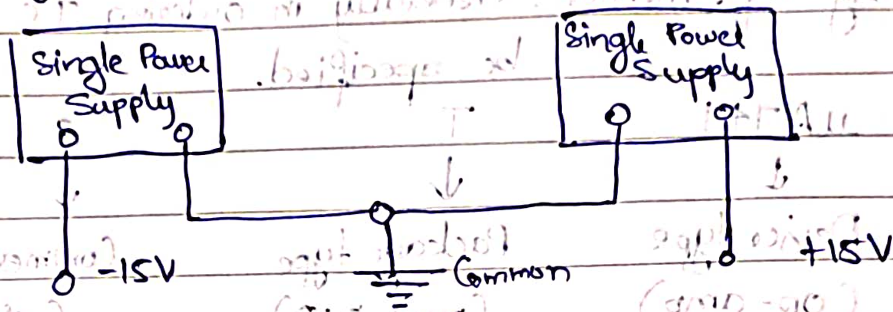
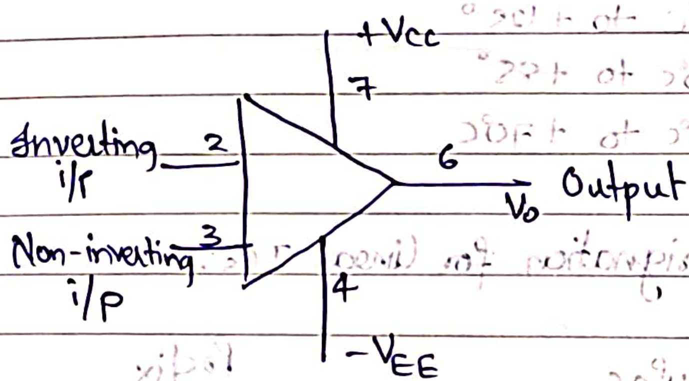


Fig: Dual Power Supply

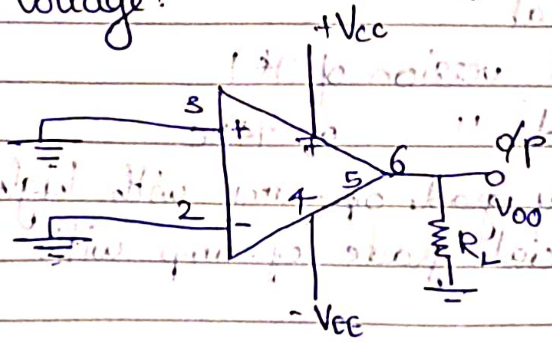


Op-Amp's schematic symbol.
8-pin mini DIP IC op-amp.

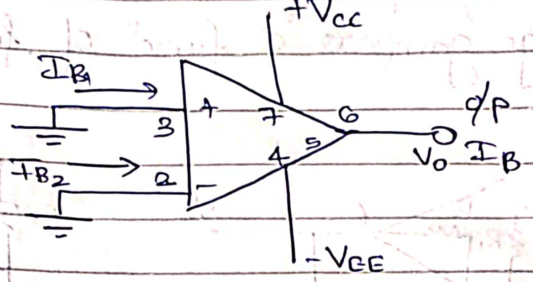
$$I_E = I_C = \frac{V_{EE} - V_{BE}}{2R_E + R_S/\beta_{dc}}$$

$$I_E = I_C = \frac{V_{EE} - V_{BE}}{2R_E}$$

*) Output offset voltage:



*) Input Bias Current

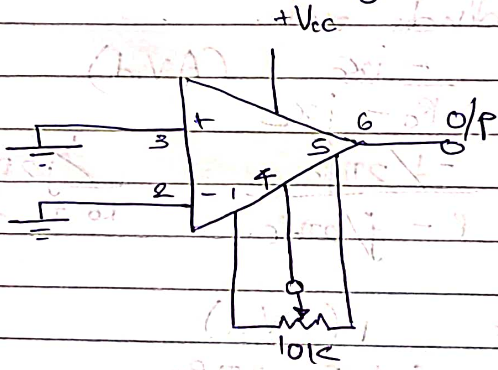


$$I_B = \frac{I_{B1} + I_{B2}}{2}$$
(nA, μA)

I/P offset current
$$I_{io} = |I_{B1} - I_{B2}|$$

$$I_{B1} = \frac{V_{o1}}{R_{b1}} \qquad I_{B2} = \frac{V_{o2}}{R_{b2}}$$

*) offset voltage Adjustment Range



Q. For certain opamp, CMRR is 100dB, and differential gain is 10^5, Find common mode gain.

Soln:
$$CMRR = \frac{\text{Diff. gain}}{\text{Common mode gain}}$$

$$CMRR = 20\log_{10}\left[\frac{A_d}{A_{cm}}\right]$$

$$100\,dB = \frac{10^5}{\text{Common mode gain}}$$

$A_d = 10^5$, $A_{cm} = ?$

$\frac{100\,dB}{20}$ (10^5)

$10^5 = \frac{10^5}{A_{cm}}$

Common mode gain = $A_{cm} = 1$

$A_{cm} = 1$

Q. An opamp has $I_{B1} = 400\,nA$, $I_{B2} = 300\,nA$. Determine bias current I_B and offset current I_{os}.

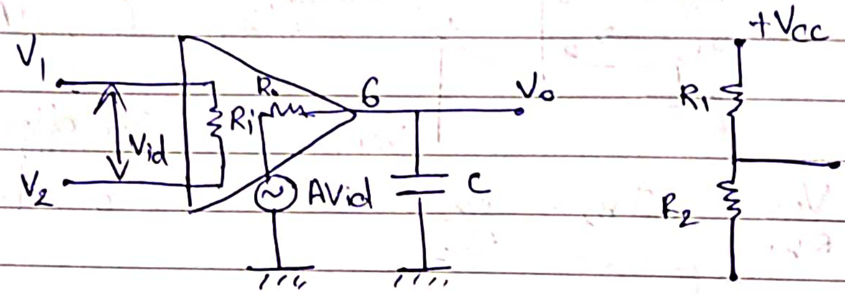
Soln:
~~Bias cur~~ $I_B = \frac{400 + 300}{2}$

$= 350\,nA$

$I_{os} = 100\,nA$.

*) Frequency response of op-Amp.

Open loop voltage gain as a func^n of frequency



a) High freq^n model of an op-Amp with single break frequency.

Apply voltage divider rule.

$$V_o = \frac{-jx_C}{R_o - jx_C}(AV_{id})$$

$$V_o = \frac{-j/2\pi fc}{R - j/2\pi fc} = \frac{1/j2\pi fc}{R_o + 1/j2\pi fc}(AV_{id})$$

$$V_o = \frac{1(AV_{id})}{1 + R_o j2\pi fc}$$

$$V_o = \frac{A(V_{id})}{1 + j2\pi fcR_o}$$

$$\boxed{\frac{V_o}{V_{id}} = \frac{A}{1 + j2\pi fcR_o}}$$

$$A_{OL}(f) = \frac{A}{1 + j2\pi fcR_o}$$

A → gain

f = 0Hz

$$f_o = \frac{1}{2\pi R_o C}$$

$$A_{OL}(f) = \frac{A}{1 + j(f/f_o)}$$

$$\phi(f) = -\tan^{-1}\left(\frac{f}{f_o}\right)$$

$$A_{OL}(f) = \frac{A}{\sqrt{1+(f/f_o)^2}}$$ (open loop gain magnitude)

The same eqn in dB

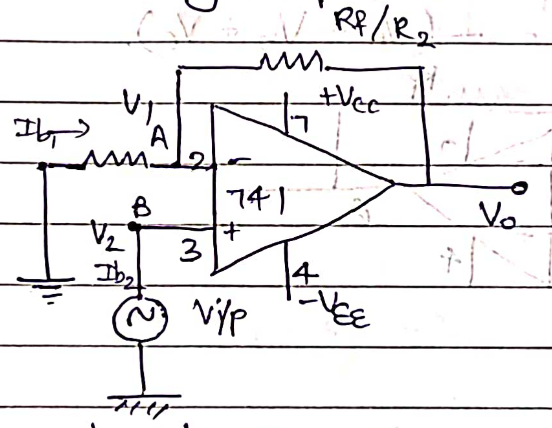
$$A_{OL}(f) = 20\log A - 20\log\sqrt{1+\left(\frac{f}{f_o}\right)^2}$$

$f_o = 5\,Hz$ $A = 200{,}000$ for 741C ($f = 0\,Hz$).

$\therefore$ DC gain = 106 dB.

$$BW = \frac{0.35}{R_f}$$

*) Gain of non-inverting amplifier.

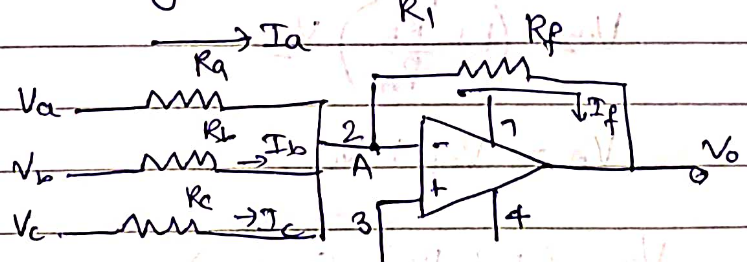


$V_1 \approx V_2$

Applying KCL at node A $\frac{0 - V_1}{R_1} = \frac{V_1 - V_o}{R_f}$

$$\frac{V_o}{V_{i/p}} = 1 + \frac{R_f}{R_1}$$

Non-Inv gain $= 1 + \frac{R_f}{R_1}$



(Inverting) Fig(a) Summing amplifier.

Ramkant Gaikwad.

classmate

Date

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KCL at node A.

$$I_a + I_b + I_c = I_f$$

$$\frac{V_a - V_A}{R_A} = I_a$$

$$I_a = \frac{V_a}{R_a} \quad I_b = \frac{V_b}{R_b} \quad I_c = \frac{V_c}{R_c}$$

$$I_f = \frac{0 - V_o}{R_f}$$

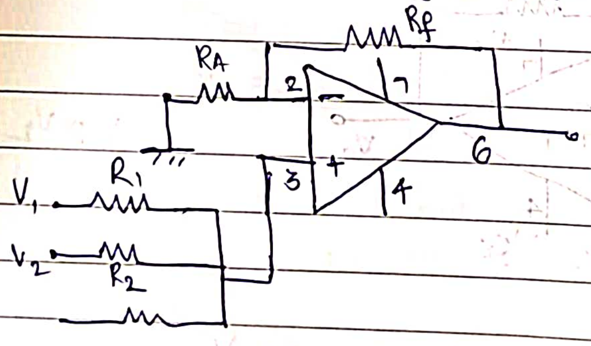
$$I_a + I_b + I_c = I_f$$

$$\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} = \frac{-V_o}{R_f}$$

$$\therefore \quad V_o = -\left[\frac{R_f}{R_a}V_a + \frac{R_f}{R_b}V_b + \frac{R_f}{R_c}V_c\right]$$

If $R_f = R_a = R_b = R_c = R$,

$$V_o = -(V_a + V_b + V_c).$$



Non-Inverting Summing amplifier.

Assume V_1 acting alone

$$V_{o1} = \left(1 + \frac{R_f}{R_A}\right)V_1 \quad \text{— ①}$$

Only V_2 source is present

$$V_{o2} = \left(1 + \frac{R_f}{R_A}\right)V_2$$

$$V_o = V_{o1} + V_{o2}$$

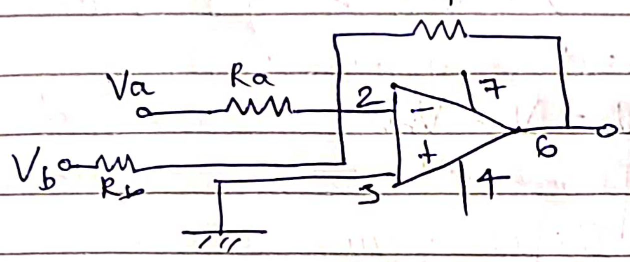
$$V_o = \left(1 + \frac{R_f}{R_A}\right)(V_1 + V_2).$$

11/09

Integrator

gain dB = $20 \log\left(\frac{V_o}{V_i}\right)$

Inverting summing / averaging / scaling amplifier.

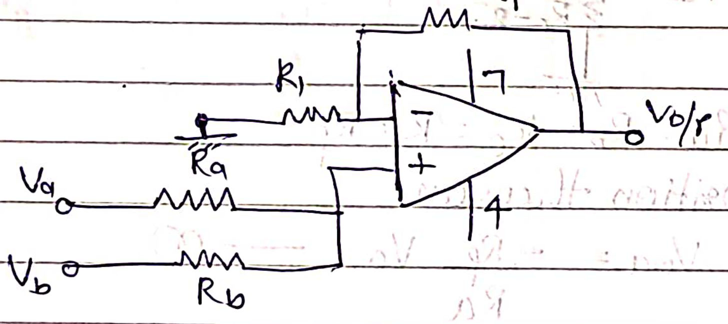


$$V_o = -\left[\frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b\right]$$

$R_f = R_a = R_b = R$.

$$v_o = -(V_a + V_b).$$

Non-Inverting Summing



$$V_{oa} = \left(1 + \frac{R_f}{R_1}\right) V_{i/p}.$$

Voltage divider rule $V_1 = \left(\frac{R_b}{R_a + R_b}\right) V_a$.

$$V_{oa} = \left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_b}{R_a + R_b}\right) V_a \quad \text{— (1)}.$$

$$V_{ob} = \left(1 + \frac{R_f}{R_1}\right) V_1'$$

$$V_1' = \left(\frac{R_a}{R_a + R_b}\right) V_b$$

$$V_{ob} = \left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_a}{R_a + R_b}\right) V_b. \quad \text{— (3)}.$$

$$V_o = V_{oa} + V_{ob}.$$

$$\rightarrow \left[1+\frac{R_f}{R_a}\right]\left\{\left(\frac{R_b}{R_a+R_b}\right)V_a+\left(\frac{R_a}{R_a+R_b}\right)V_b\right\}.$$

$$R_a = R_b = R.$$

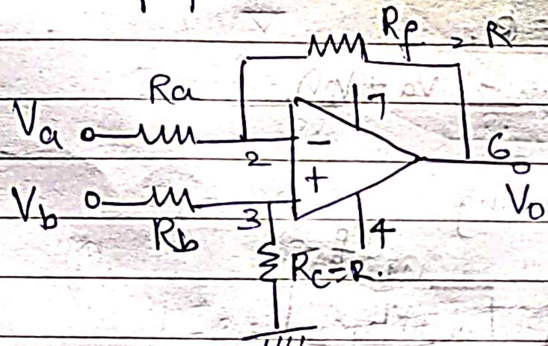
$$V_{ob} = \left(1+\frac{R_f}{R_a}\right)\left(\frac{V_a+V_b}{2}\right).$$

If gain = 1

$$V_o = V_a + V_b.$$

$\cancel{V_{os}}$

Difference amplifier



$$R_a = R_b = R_c = R = R_f$$

Apply superposition theorem

$$V_{oa} = -\frac{R_f}{R_a}V_a \quad \text{——} \quad (1).$$

$$V_{ob} = \left(1+\frac{R_f}{R_1}\right)V_1$$

$$V_1 = \left(\frac{R_b}{R_a+R_b}\right)V_b.$$

$$V_{ob} = \left(1+\frac{R_f}{R_1}\right)\left(\frac{R_b}{R_a+R_b}\right)V_b.$$

$$V_o = V_{oa} + V_{ob}$$

$$V_o = -\frac{R_f}{R_a}V_a + \left(1+\frac{R_f}{R_1}\right)\left(\frac{R_b}{R_a+R_b}\right)V_b$$

$$R_f = R_a = R_b = R$$

$$V_o = -V_a + V_b.$$

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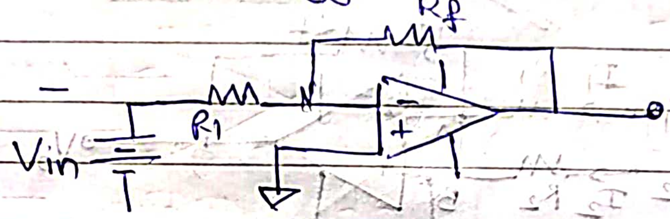
*) Wherever we apply the input → topology.

*) 98% applications of op-amp → -ve feedback
2% → +ve feedback
oscillator, mid trigger.

-ve feedback –

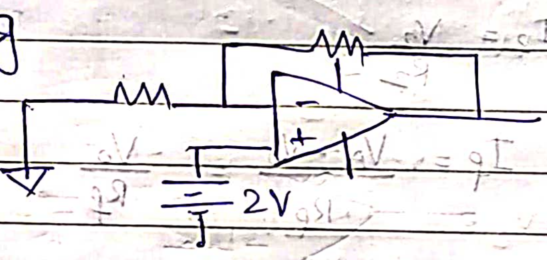


Inverting

$$\boxed{V_o = -\frac{R_f}{R_1} V_{in}}$$

gain ↑
BW ↑
R_i ↑
R_o ↓

Non-Inverting



$$\text{gain} = 1 + \frac{R_f}{R_1}$$

$V_o =$

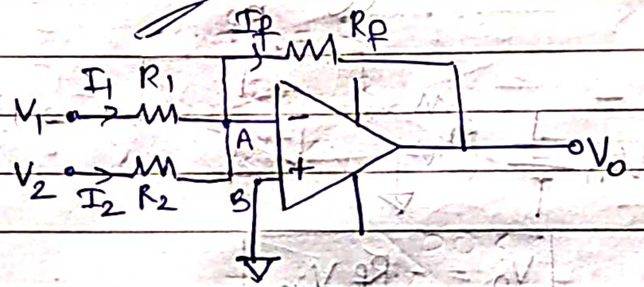
Inv	Non-Inv
180°	360° or 0°
$-\frac{R_f}{R_1}$	$1+\frac{R_f}{R_1}$
Input impedance = R_{in} (R_i)	Input Impedance = R_{in} ↓ very high avoides ckt loading.

- ±15 to ±18V
  80 to 90% of ±Vcc.

* Summing / Adder:

→ more than one input.

Adders: Inv. / Non. Inv.



$V_B \rightarrow$ grnd

$V_A \rightarrow 0 \rightarrow$ virtual grnd.

$$I_1 = \frac{V_1 - V_A}{R_1} = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2}{R_2}$$

$$I_f = \frac{V_A - V_o}{R_f} = \frac{-V_o}{R_f}$$

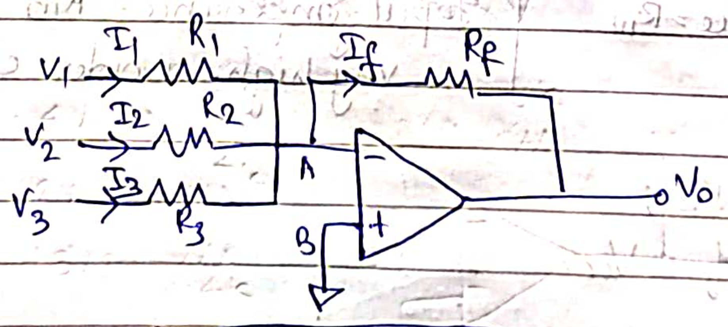
$$I_1 + I_2 = I_f.$$

$$\frac{-V_o}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$

$$R_f = R_1 = R_2 = R.$$

$$\boxed{V_o = -(V_1 + V_2)}$$

* Scalar / Average:



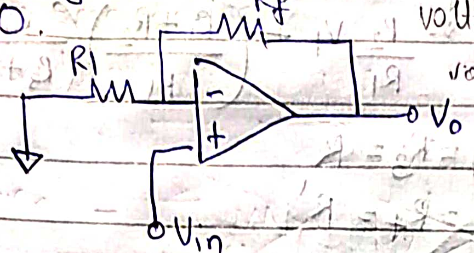
$$\boxed{V_o = -\left(\frac{V_1 + V_2 + V_3}{3}\right)}$$

*) Voltage ~~flower~~: follower:

$\boxed{V_0 = V_{in}}$

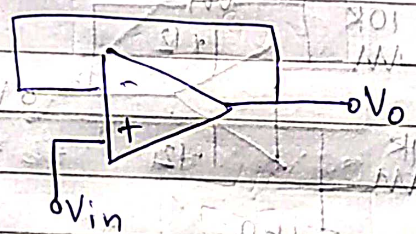
→ Non-Inverting

$R_f = 0$.



When the non-inverting amplifier is configured for unity gain, it is called voltage follower because the o/p voltage is equal and in phase with the i/p.

$$V_0 = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

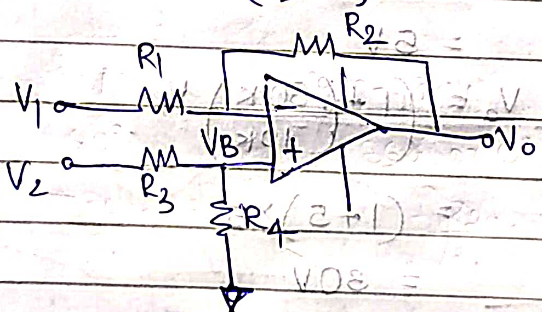


$R_f = 0$. or $R_1 = \infty$.

$A = 1$

*) Differential amplifier/ subtractor:

$$V_0 = A(V_2 - V_1).$$



V_1 acting V_2 grnd → V_{o1}

V_2 acting V_1 grnd → V_{o2}

$V_0 = V_{o1} + V_{o2}$

① $V_{o1} = -\frac{R_2}{R_1} V_1$

② $V_B = \frac{R_4}{R_3 + R_4} V_2$

$$V_{o2} = \left(1 + \frac{R_2}{R_1}\right) V_B$$

$$V_o = V_{o1} + V_{o2}$$

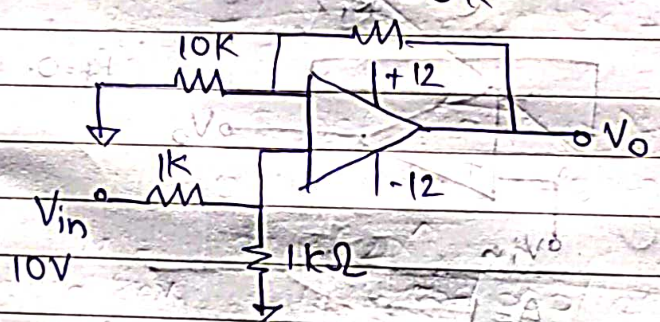
$$= -\frac{R_2}{R_1} V_1 + \left(\frac{R_1+R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right) V_2$$

$$R_1 = R_3 = R$$

$$R_2 = R_4 = R'$$

$$V_o = \frac{R'}{R}(V_2 - V_1)$$

Q



$$V_B = \frac{1k}{1k+1k} V_{in}$$

$$= 0.5 \times 10$$

$$= 5V$$

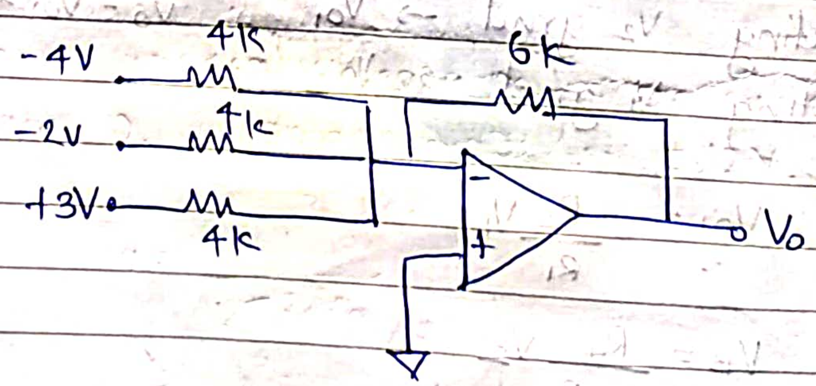
$$V_o = \left(1 + \frac{50k}{10k}\right) V_B$$

$$= (1+5) \times 5$$

$$= 30V$$

But $V_o = 10.8V$

Q.



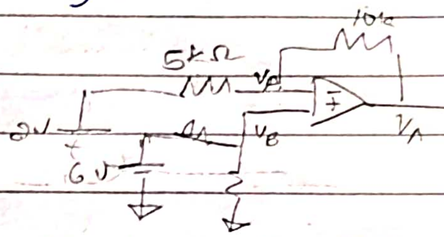
Sol^n:

$$V_o = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right)$$

$$V_o = -\left(\frac{6}{4}\times(-4) + \frac{6\times(-2)}{4} + \frac{6\times 3}{4}\right)$$

$$= -\left(-6 - 3 + 4.5\right)$$

$$V_o = 4.5\,V$$

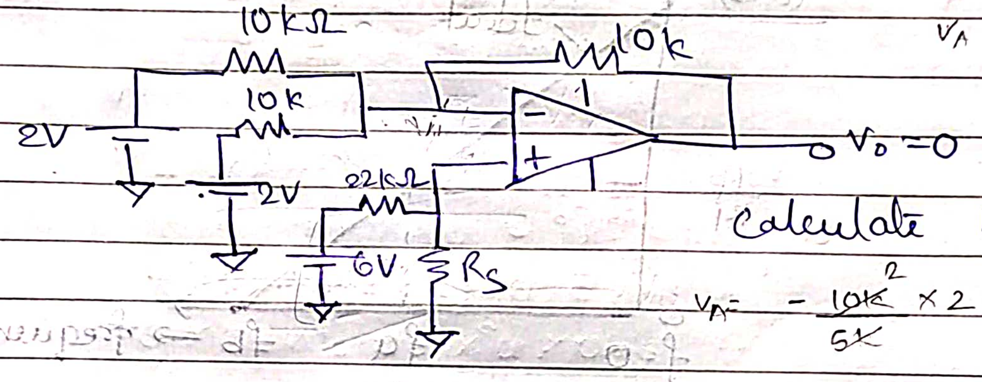


$V_o = V_B - V_A$

$V_A =$

Q. $V_o = -\left(2V_1 + 3V_2 + 5V_3\right)$

Q.



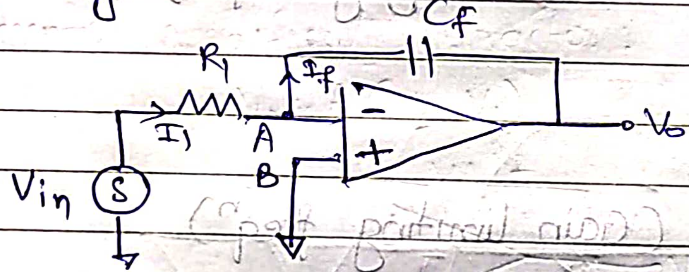
Calculate R_S.

$$V_A = -\frac{10k}{5k}\times 2$$

$$V_A = -4V$$

$$V_2 = \left(1 + \frac{10k}{5k}\right)$$

*) Integrator;
Inverting.



$I_1 = I_f$.

$$I_1 = \frac{V_{in}}{R_1}$$

$q = CV$

$$\frac{dq}{dt} = C_f \frac{d}{dt} V_C$$

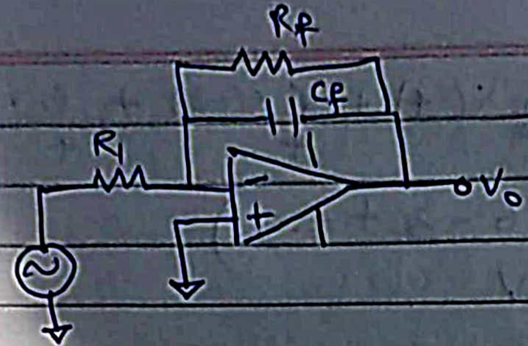
$$\frac{V_{in}}{R_1} = -C_f \frac{d}{dt} V_o \qquad I_f = C_f \frac{d}{dt}(V_A - V_o)$$

$$= -C_f \frac{d}{dt}(V_o)$$

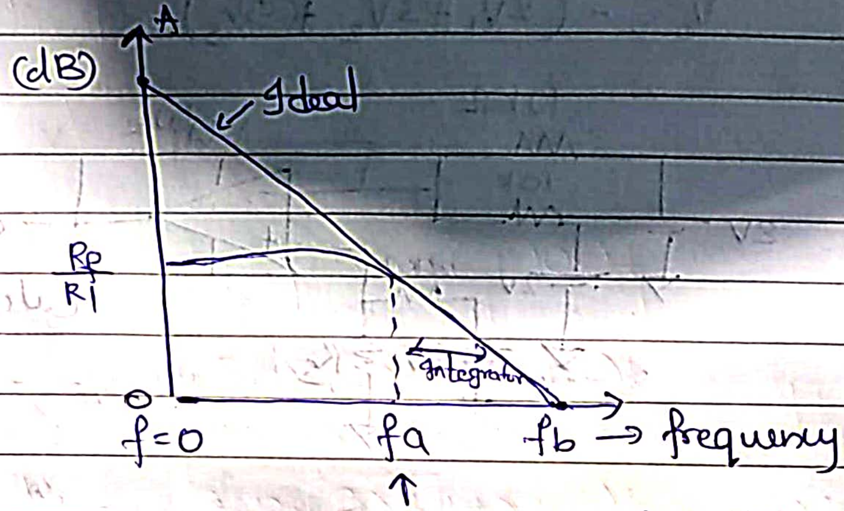
$$-\frac{V_{in}}{R C_f} = \frac{d}{dt} V_o$$

$$\boxed{V_o = -\frac{1}{R_1 C_f}\int V_{in}\,dt + c}$$

Practical



$\frac{R_f}{R_1}$ = dc gain.



0- fa → plain Inv. amplifier

Cut-off / 3dB / corner freq^n.

fb = Unity gain freq^n.

*) Formulas :

$f_a = \frac{1}{2\pi R_f C_f}$ (Gain limiting freq^n).

$f_b = \frac{1}{2\pi R_1 C_f}$

Q Design a practical integrator where cut off freq^n is 1.5kHz DC gain 10. Op-amp operates at ±12V. Assume $C_f = 0.01$ uF.

Sol^n:

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

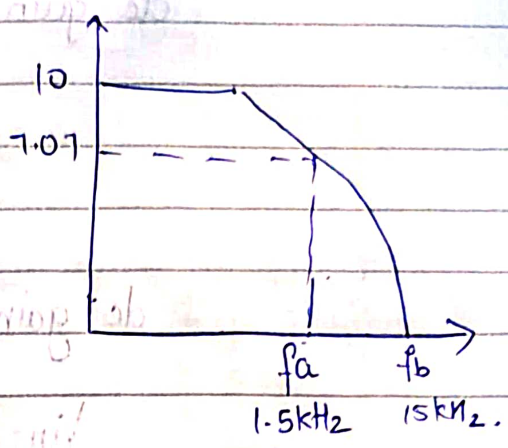
$1.5 \times 10^3 = \frac{1}{2\pi \times R_f \times 0.01 \times 10^{-6}}$

$R_f = 10.6\,\Omega$

$\frac{R_f}{R_1} = 10$

$R_1 = \frac{R_f}{10} = 1.06\,\Omega$

$\frac{10}{\sqrt{2}} = 7.07$

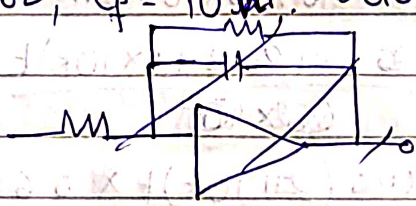


$f_b = \frac{1}{2 \times \pi \times 1.06 \times 0.01 \times 10^{-6}}$

$f_b = 15\text{ kHz}.$

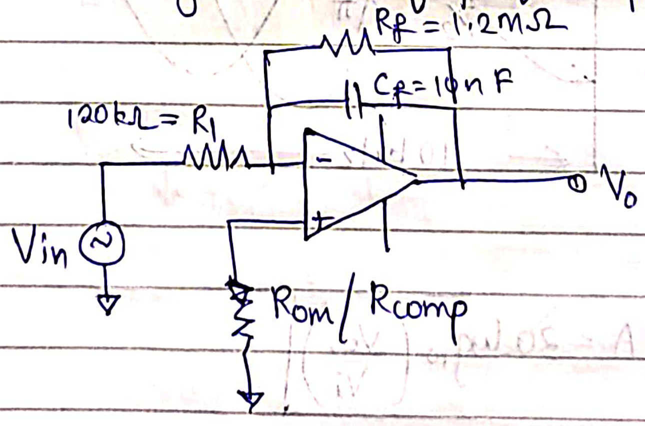
Q. Design a practical integrator component values $R_1 = 120\,k\Omega$, $R_f = 1.2\,M\Omega$, $C_f = 10\,nF$. Determine the safe frequency above which self integration will take place.

Sol^n:



Determine dc gain.
Find the peak value for output voltage with sine wave input of 5 V and freq. 10 kHz.
Draw the rough sketch of freq^n response.

Sol^n:



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

$= \frac{1}{2\pi \times 1.2 \times 10^{6} \times 10 \times 10^{-9}}$

$f_a = 13.28\text{ Hz}$

$\cos a$

$\sin ax$

$\frac{-\cos ax}{a}$

$$dc\ gain = \frac{R_f}{R_1}$$

$$= \frac{1.2 \times 10^6}{120 \times 10^3}$$

$$= 10^6 \times 10^{-3} \times 10^{-2}$$

$$dc\ gain = 10$$

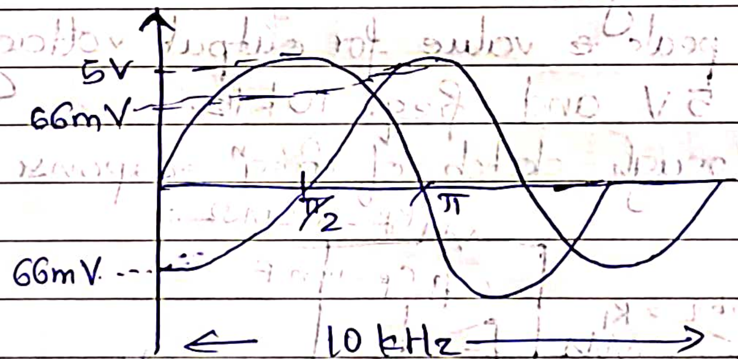
$$V_{in} = V_m \sin \omega t$$

$$V_o = \frac{-1}{R_1 C_f} \int 5 \sin (2\pi\, 10k) t$$

$$= \frac{5 \cos (2 \times 3.14 \times 10k) t}{120 \times 10^3 \times 10 \times 10^{-9} \times 2\pi \times 10^4}$$

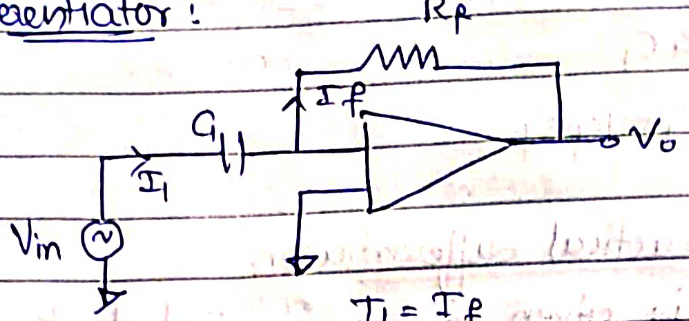
$$V_o = \frac{\cancel{5} \cos (\cancel{2} \times 3.14 \times 10k) t \times 6.6 \times 10^{-2}}{\cancel{6.6 \times 10^{-2}}}$$

$$V_o = \cos (2\pi\, 10k) t \times 6.6 \times 10^{-2}$$



$$\boxed{A = 20 \log_{10} \left(\frac{V_o}{V_i} \right)}$$

*) Differentiator:



$$I_1 = I_f \qquad , \qquad \frac{dQ}{dt} = C_1 \frac{dv_{in}}{dt}$$

$$I_f = \frac{-V_o}{R_f}$$

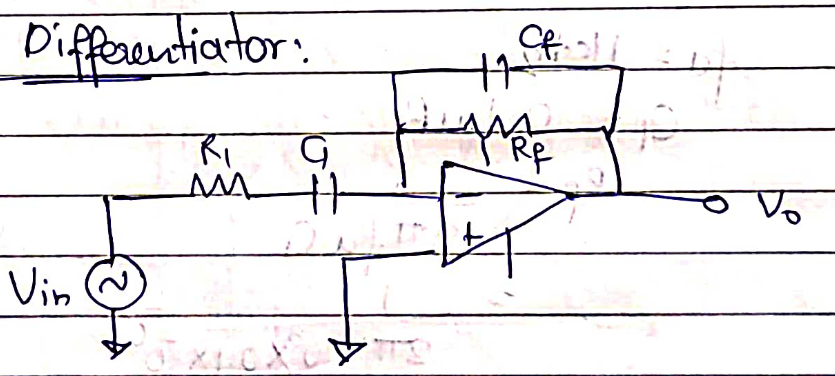
$$I_1 = C_1 \frac{d}{dt} V_{in}$$

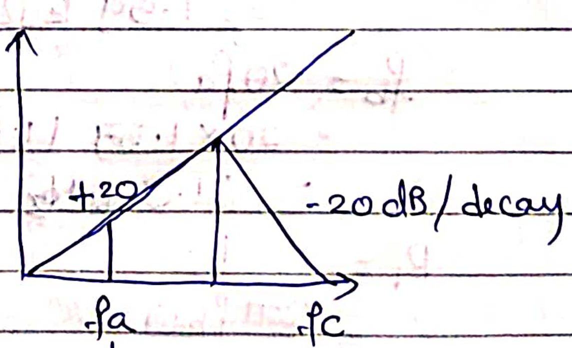
$$C_1 \frac{d}{dt} V_{in} = \frac{-V_o}{R_f}$$

$$V_o = -R_f C_1 \frac{d}{dt} V_{in}$$

1) When $f\uparrow$, circuit becomes unstable
2) Input impedance goes low, ~~so~~ ckt becomes susceptible.
→ noise ~~over~~ overright.

Practical Differentiator:





f_a
↓
unity gain

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

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

$$R_1 C_1 = R_f C_f$$

*) Steps to design practical differentiator.

→ If input signal is given in range, select f_a as the max.

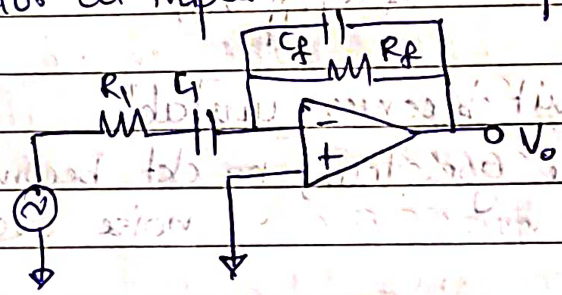
→ Select ~~f~~ Assume appro. value of $C_1 \le$ ~~1~~ 0.1 µF.

→ Select f_b which is 10 or 20 times of f_a.

→ Use $R_1 C_1 = R_f C_f$

Q. Design a differentiator where input signal varies from 10 Hz to 1 kHz. If a sine wave of 1V, 1kHz is applied to the differentiator at input. Plot its output waveform.

Soln:



$f_a = 1\text{kHz}$

$C_1 = 0.1\,\mu F$

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

$$= \frac{1}{2\pi \times 10^3 \times 0.1 \times 10^{-6}}$$

$$= 1.59\,k\Omega$$

$f_b = 20 f_a$

$= 20 \times \cancel{1.59}\ 1\,\text{kHz}$

$= \cancel{31.8\,\text{kHz}}\ 20\,\text{kHz}$

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

$$= \frac{1}{2 \times 3.14 \times 20 \times 10^3 \times 0.1 \times 10^{-6}}$$

$= 10^{4} \times 0.0079$

$= 79\,\Omega$

$R_1 C_1 = R_f C_f$

$\frac{79 \times 10^{-7}}{1.59 \times 10^{3}} = C_f$

$49.6 \times 10^{-10} = C_f$

$C_f = 4.96\ nF.$

$R_{om} = R_f \parallel R_1$

$R_{om} = 79\,\Omega$ (approx.)

$V_o = -R_f C_1 \frac{d}{dt} V_{in}$ $\qquad V_{in} = V_m \sin\omega t$

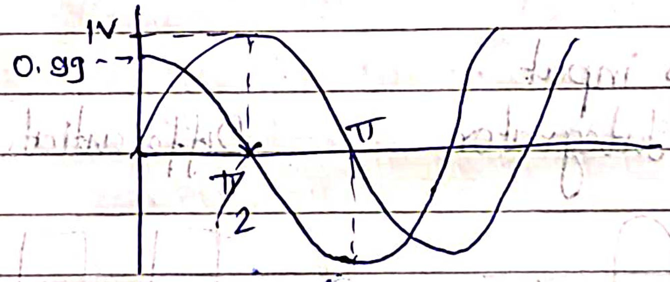
$= 1 \sin 2\pi\, 10^3 t$

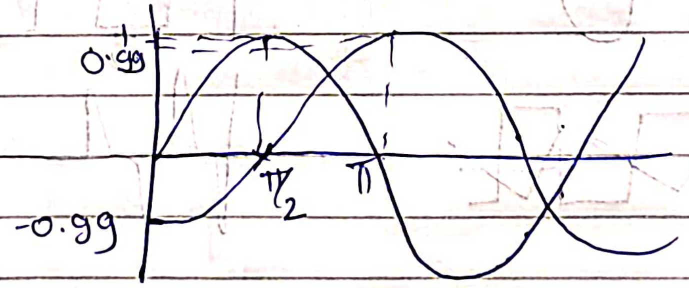
$= -1.59 \times 10^{3} \times 10^{-7} \frac{d}{dt} \sin\omega t$

$= -1.59 \times 10^{-4} \times \omega \times \cos\omega t$

$= -1.59 \times 10^{-4} \times 2 \times 3.14 \times 10^{3} \cos\omega t$

$= -0.99 \cos\omega t.$





Q. Design a practical differentiator that would differentiate an input signal f_{max} 150 Hz. Assume C_1 to be $1\,\mu F$ and $f_b = 10 f_a$

Sol^n:

$f_a = 150\,Hz$

$C_1 = 1\,\mu F$

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

$$= \frac{1}{2 \times 3.14 \times 150 \times 10^{-6}}$$

$$= 1.08\,k\cancel{Hz}\,\Omega$$

$f_b = 10 f_a$

$= 10 \times 150$

$f_b = 1500\,Hz$

$$R_1 = \frac{1}{2 \times \pi \times 1500 \times 10^{-6}}$$

$$= 106.1\,\Omega.$$

$R_1 C_1 = R_f C_f$

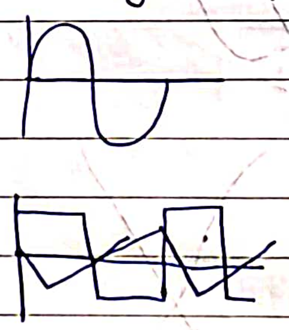
$$C_f = \frac{106.1 \times 10^{-6}}{1.08 \times 10^{3}}$$

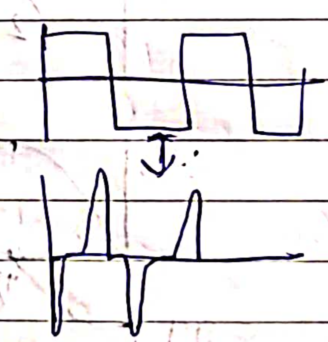
$C_f = \cancel{0.098\,\mu F}\ 0.1\,\mu F.$

*) For a step input

Integrator   Differentiator

sin → cos

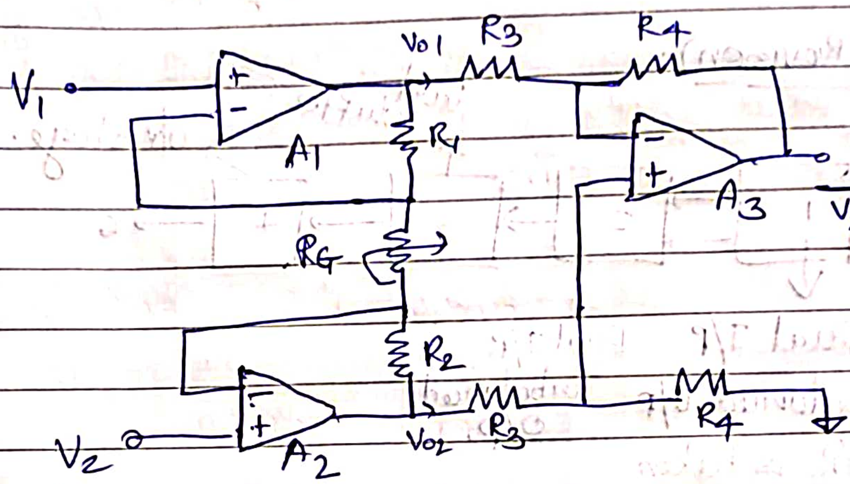




Q. Design a differentiator which differentiates an input signal which varies from 10 Hz to 500 Hz. If a sine wave of 2V peak at 500 Hz is applied to the differentiator input. Write exp. for its output and plot the waveform.
$C_1 = 0.1\,\mu F$ $f_b = 10 f_a$.

Instrumentation Amplifier:

- → High gain
- → $R_i \uparrow$
- → $R_o \downarrow$
- → High CMRR



$$\frac{V_o}{V_2 - V_1} = \left(1 + \frac{2R}{R_G}\right)\left(\frac{R_4}{R_3}\right)$$

Practical
$R_G + R_{Gmin}$.

$R_1 = R_2 = R$.

Q. Calculate the gain offered by 3 Op-Amp based IA for given $R_1 = R_2 = 100\,k\Omega$. $R_G = 5\,k\Omega$, $R_4 = R_3 = 1\,k\Omega$.

Sol^n:

$$\frac{V_o}{V_2 - V_1} = \left(1 + \frac{2 \times 100 \times 10^3}{5 \times 10^3}\right)(1)$$

gain = 41

Q. Design an IA using 3 Op-Amps where gain can be varied from 1 to 500. Assume $R_1 = R_2 = 100\,k\Omega$ $\left(\frac{R_4}{R_3}\right) = 0.5$

Sol^n:

$$A = \left(1 + \frac{2R}{R_{Gmax}}\right)(0.5)$$

$$1 = \left(1 + \frac{2 \times 100 \times 10^3}{R_{Gmax}}\right) 0.5$$

$$2 = 1 + \frac{200 \times 10^3}{R_{Gmax}}$$

$$1 = \frac{200 \times 10^3}{R_G}$$

$R_G = 200\,k\Omega$

$$800 = \left(1 + \frac{200k}{R_{Gmin}}\right) 0.5$$

$$1000 = 1 + \frac{200k}{R_{Gmin}}$$

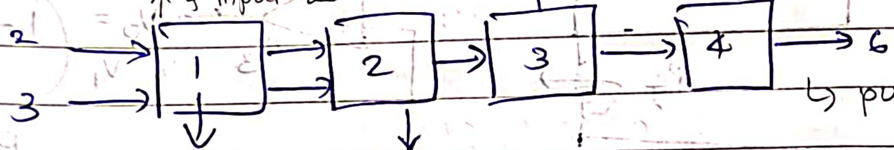
R_{Gmin} = ~~4.99k~~ 0.2kΩ.

*) Unit 1 (Revision):

Most of the voltage gain & input resistance

level shifter (translator) → shifts the o/p of inter. stage to zero w.r.t ground.

o/p stage. → max o/p swing with lower impedance



↳ push-pull complementary.

Dual I/P Balanced O/P ↳ O/P is taken betn 2 collectors

Dual I/P unbalanced O/P. ↓ output is well above ground potential due to direct coupling.

(Intermediate stage).

$$A_d = \frac{R_c}{r_e} \Big\} \text{Balanced.}$$

$$A_d = \frac{R_c}{2r_e} \Big\} \text{unbalanced}$$

	Ideal	
A	∞	
Ri	∞	- any signal source can drive it
Ro	0	- can drive ∞ no. of other devices
CMRR	∞	- $V_{ocm} = 0$
PSRR	0	-
Slew Rate	∞	- output voltage changes simultaneously with i/p voltage
offset voltage	0	- O/P V is zero when i/p is zero
offset current	0	
Bias current	0	

CMRR - ability reject common mode signal.

$$CMRR = \frac{A_d}{A_c}$$

A_d → Differential gain

A_c → Common mode gain.

$= 20 \log_{10}(61356)$. ← to convert to dB.

$= 96\ dB$.

$$A_c = \frac{V_{ocm}}{V_{cm}}$$

Q. CMRR (ρ) = 100 dB, $A_c = 0.1$. Calculate Ad.

Solⁿ:
$$100 = 20\log_{10}(A)$$
$$5 = \log_{10}(A)$$
$$10^5 = A$$
$$10^5 = \frac{A_d}{A_c}$$
$$10^5 = \frac{A_d}{0.1}$$
$$A_d = 10{,}000.$$

*) PSRR (SVRR). → change in i/p offset voltage caused by variation in supply voltages

Power Supply Rejection Ratio: offset V should not change with input voltage.

*) Slew Rate: Rate of change of output w.r.t time.
↳ associated with AC

*) Practical values of IC 741C

- A – 2×10^5
- R_i – $2M\Omega$ → equi r measured at either inv. or non-inv. inp. terminal with other terminal connected to gnd.
- R_o – 75Ω
- CMRR – 90 dB
- S.R – $0.5V/\mu s$
- Inp. offset V – 6 mV – without applying I/P, still get some finite amount of o/p voltage.
- offset I – 200 nA ↙ $|I_{B1} - I_{B2}|$
- Bias current – 500 nA → $\frac{I_{B1} + I_{B2}}{2}$ (average).
- PSRR – 96 dB. = $\frac{\Delta V_{io}}{\Delta V}$

$$SR = \frac{V_o}{t}$$

$V_{in} = V_m \sin\omega t$

$V_o = V_{in}$

$V_o = V_m \sin\omega t$

$$\frac{dV_o}{dt} = V_m \omega \cos\omega t$$

$$SR = \omega V_m$$

$$SR = 2\pi f V_m$$

$$f = \frac{SR}{2\pi V_m}$$

↑

full power B.W.

Q. Calculate full power B.W. for 741 IC which operates at ±12V.
(max operating freq)

Sol^n: $S.R = 0.5\ V/\mu s$

$$f = \frac{0.5}{2 \times 3.14 \times 10.8 \times 10^{-6}}$$

$$= 7.3\ kHz.$$

Q. LM356 IC, SR = 10V/μs. Calculate full power B.W. $V_m = 2V$.

~~Sol^n~~

Q. Assume S.R. = 0.5V/μs, justify whether it is possible to amplify a square wave of peak to peak 500mV. Rise time - 4 μs. Peak to Peak output 5V.

Sol^n: $V_0 = (0.9 - 0.1) \times 5$

$V_0 = 4V$

$$\frac{dV_0}{dt} = \frac{4V}{4\mu s}$$

$$= 1\ V/\mu s.$$

Q. Calculate o/p Voltage for Op Amp whose open loop gain is 2×10^5 of Non-Inv. $V_2 = 7\mu V$ $V_1 = 5\mu V$.

Sol^n: $V_0 = A(V_2 - V_1)$

$= 2 \times 10^5 (2 \times 10^{-6})$

$= 0.4$

BJT / FET / CMOS,

$R_i \uparrow$

$$r_e = \frac{26\,mV}{I_E} \Rightarrow \frac{25.8}{I_C}$$

Inp. off. set Vol. – V that must be applied to null the output.

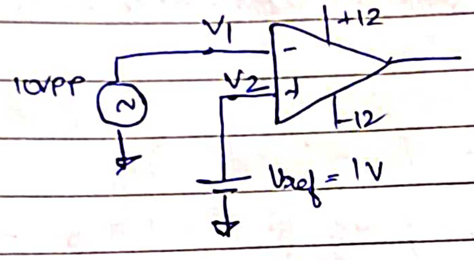
o/p voltage swing – indicates the values of +ve and -ve saturation voltages of the op-Amp. Never exceeds $+V_{CC}$ and $-V_{EE}$.

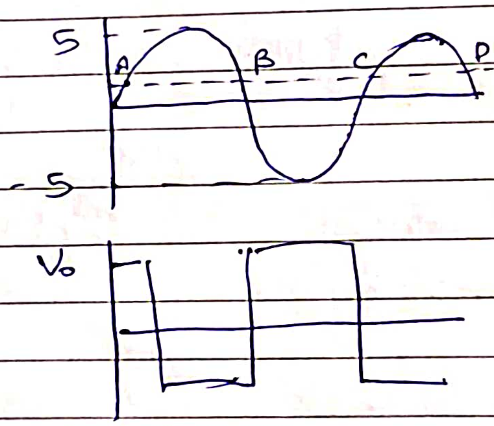
3/11/22

Unit - 3

*) ~~Smith~~ Trigger:

*) Comparator:

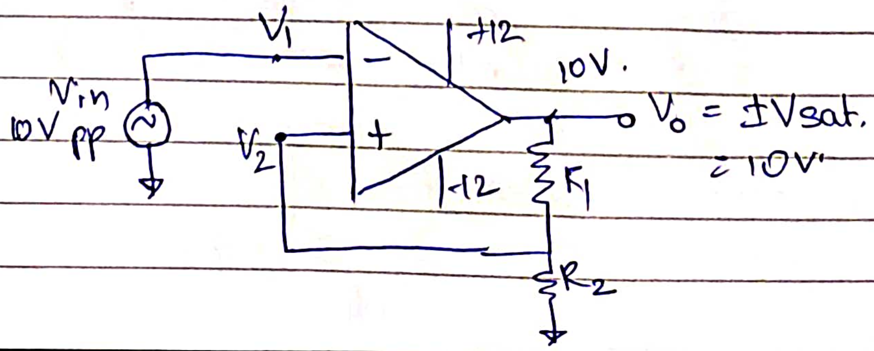




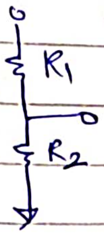
Schmitt
*) ~~Smith~~ Trigger / Regenerative Comparator
Schmitt Trigger is the only circuit which employs +ve feedback.

(Noise Immunity)

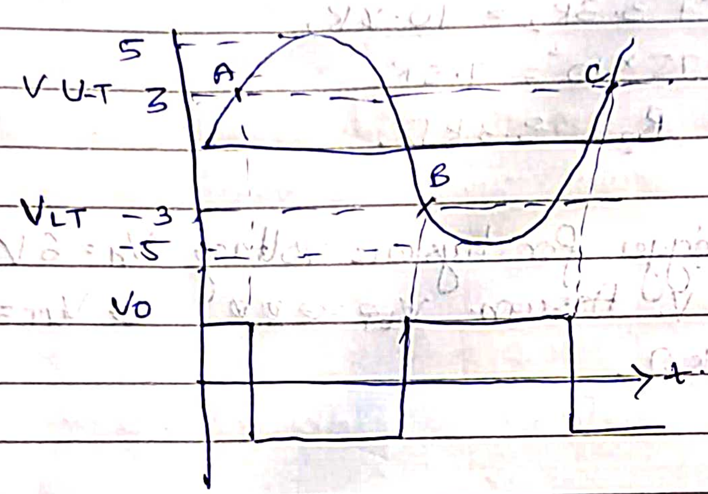
- Inv.
  - Sym.
  - Asym.
- Non-Inv
  - Sym
  - Asym.



V_{UT} upto V_{LT}.
upper trigger, lower trigger.



$$V_x = \frac{R_2 \times 10}{R_1+R_2}$$



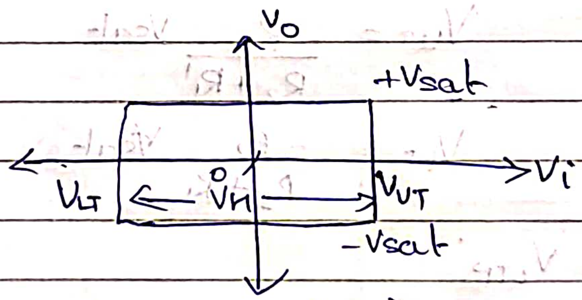
V_1	V_2
0	3V
1	3
3.1	3

V_1	V_2
4	-3V
3	-3V.
0	-3V
-1	-3V

$$V_{UT} = \frac{R_2}{R_1+R_2} V_{sat}.$$

$$V_{LT} = -\frac{R_2}{R_1+R_2} V_{sat}.$$

Transfer characteristics:



$$V_H = V_{UT} - (-V_{LT}).$$

Q. Design an inverting type schmitt trigger to get trigger levels as ± 3.3 V. Assume Op-Amp operates at ± 12 V. Assume R_1 to be 7.5 kΩ. Input signal applied is 10V p to p sine wave.

Sdn: Assume Op-Amp 90% of saturation

$V_0 =$

$$V_{UT} = \frac{R_2}{R_1+R_2} V_{sat}$$

$$3.3 = \frac{R_2}{7.5\times10^3+R_2} \times 10.8$$

$$24.75\times10^3 + 3.3R_2 = 10.8R_2$$

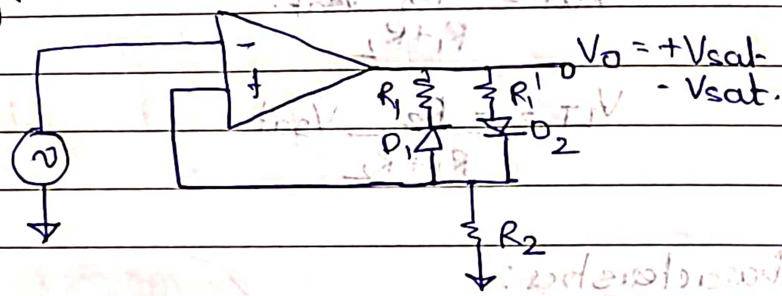
$$24.75\times10^3 = 7.5R_2$$

$$R_2 = 3.3\,k\Omega.$$

Q. Design a schmitt trigger for hystrais voltage $V_H = 6V$. Op-Amp saturates at $\pm10.8V$. Assume ~~$V_{LT} = -2V$~~. $V_{UT} = 4V$.

Sol^n. Assume $R_2 = 10k\Omega$.

*) Asymmetry:



$$V_{UT} = \frac{R_2}{R_2+R_1'} V_{sat}$$

$$V_{LT} = \frac{-R_2}{R_2+R_1} V_{sat}$$

Sol^n:

$$V_H = V_{UTP} - V_{LTP}$$

$$6 = 4 - V_{LTP}$$

$$V_{LTP} = -2V.$$

$$V_{UTP} = \frac{R_2}{R_2+R_1'} \times 10.8$$

$$4 = \frac{10^4}{10^4+R_1'} \times 10.8$$

$$4\times10^4 + 4R_1' = 10.8\times10^4$$

$R_1' \approx 0.667$

$4R_1' = 6.8 \times 10^4$

$R_1' = 1.7 \times 10^4$

$R_1' = 17\,k\Omega.$

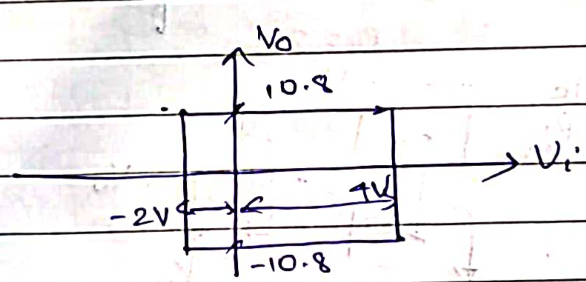
$$V_{LT} = \frac{-R_2}{R_2+R_1} V_{sat}.$$

$$-2 = \frac{-10^4}{10^4+R_1} \times 10.8$$

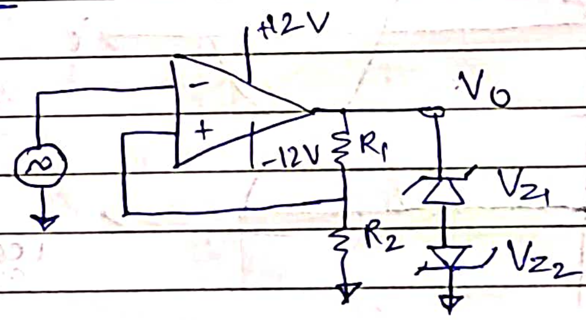
$2\times10^4 + 2R_1 = 10.8\times10^4$

$2R_1 = 8.8\times10^4$

$R_1 = 44\,k\Omega.$



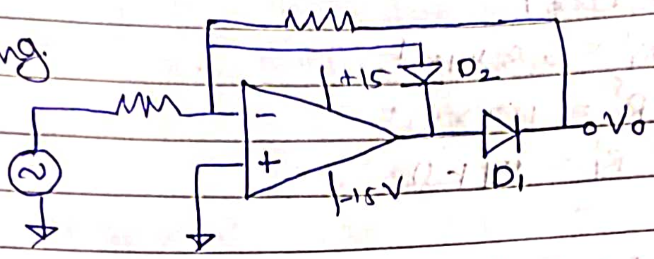
4.) Voltage limiter



Rectifier
- HWR
  - Inv
    - Sat
    - Non sat.
  - Non Inv
- FWR

Rectifier:

Inv. HWR
Non-saturating



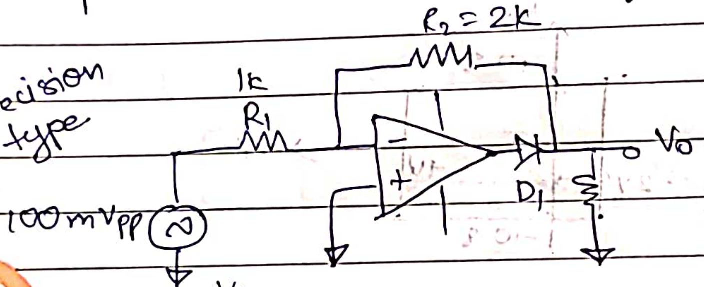
D_2 - avoiding Op-Amp from going into saturation.

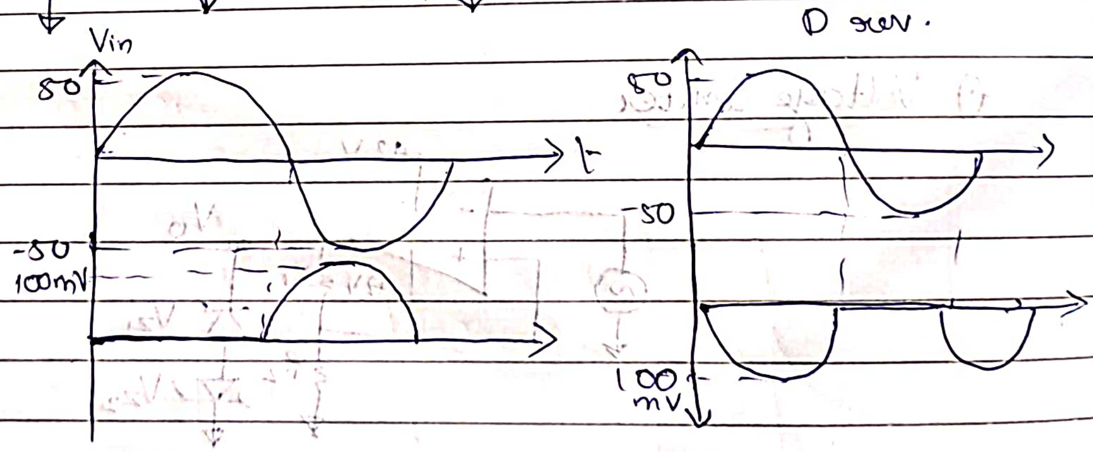
If the input signal is less than the barrier potential of the diode, then that signal cannot be rectified by conventional rectifier.

∴ We need precision rectifier.

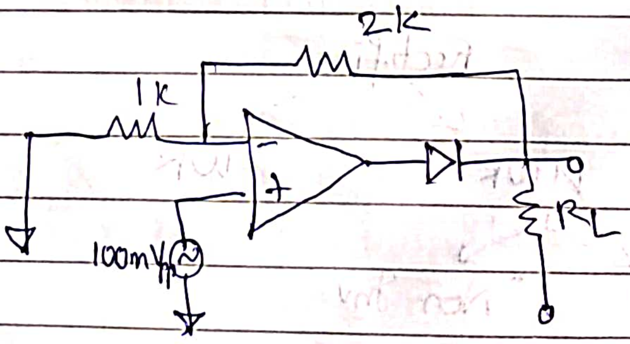
Op-Amp ~~to~~ with the diode in the feedback loop → Super diode

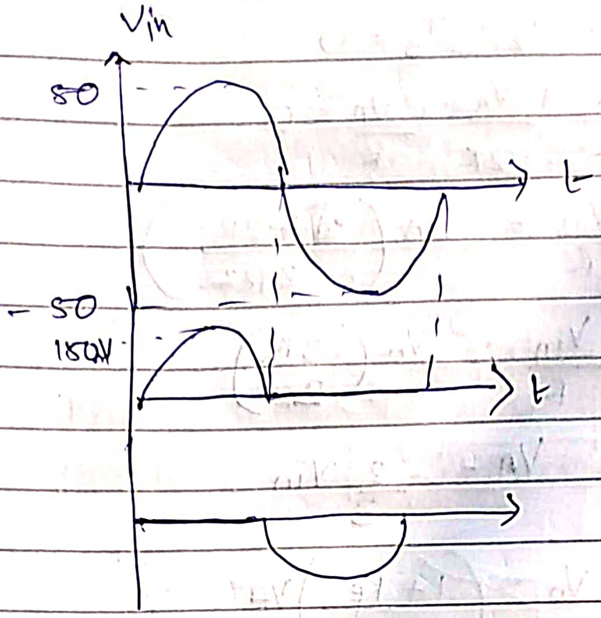
Inv. HWR
Half wave precision saturating type



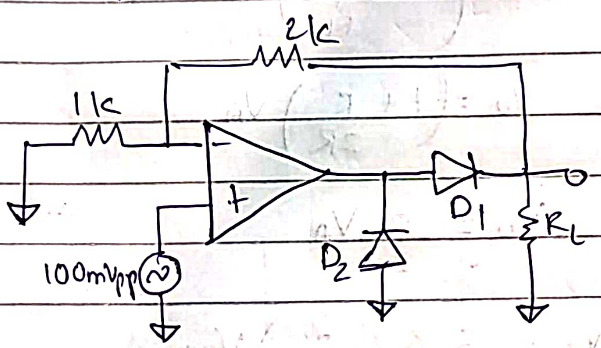


Non-Inv HWR
Saturating type

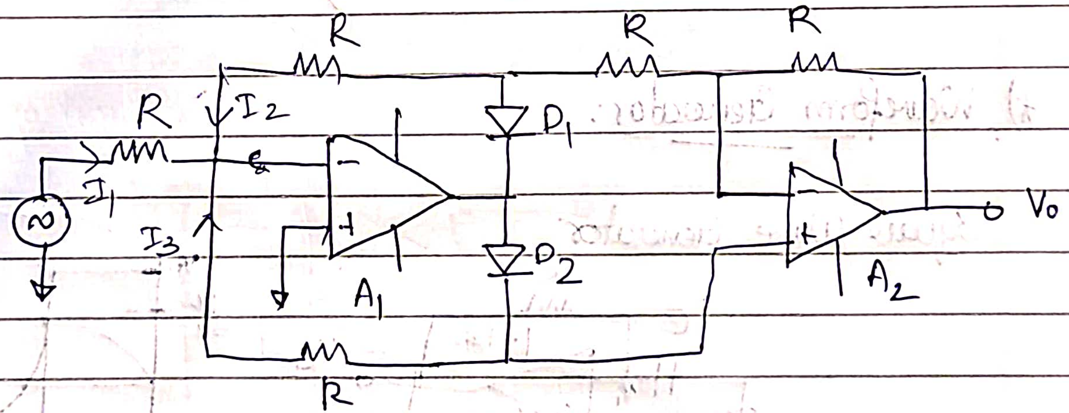




Non-Inv.
HWR
Non-saturing



FWR



For -ve cycle:

$$I_1 = \frac{V_{in}}{R}$$

$$I_2 = \frac{V_A}{2R}$$

$$I_3 = \frac{V_A}{R}$$

$$I_1 + I_2 + I_3 = 0$$

$$\frac{V_{in}}{R} + \frac{V_A}{2R} + \frac{V_A}{R} = 0$$

$$\frac{V_{in}}{R} = -V_A\left(\frac{\cancel{2}R + 2R}{2R^2}\right)$$

$$\frac{V_{in}}{R} = -V_A\left(\frac{3R}{2R^2}\right)$$

$$V_A = -\frac{2}{3}V_{in}$$

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

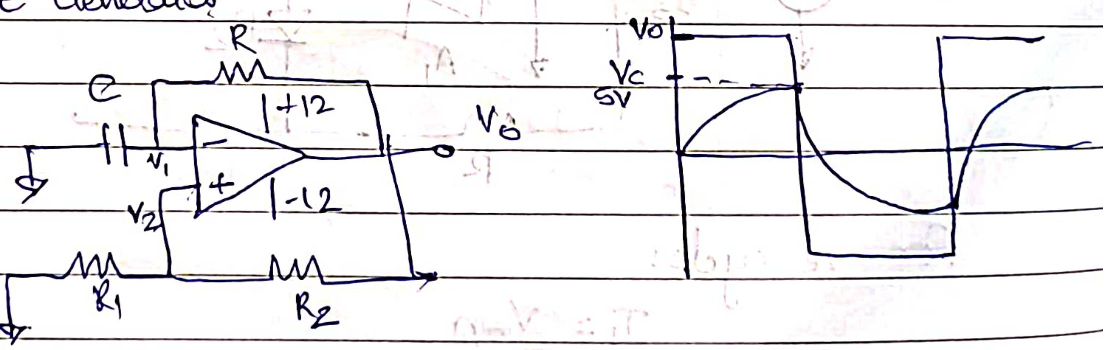
$$V_o = \left(1 + \frac{R}{2R}\right)V_A$$

$$V_o = \frac{3}{2}V_A$$

$$V_o = \frac{3}{2} \times \left(-\frac{2}{3}\right)V_{in}.$$

*) Waveform Generator:

Square Wave Generator



$$V_2 = \frac{R_1}{R_1 + R_2} V_{sat}.$$ $$\beta = \frac{R_1}{R_1 + R_2}$$

Astable multivibrator.

$$f_o = \frac{1}{2RC\ln\left(\frac{2R_1+R_2}{R_2}\right)}$$

$$= \frac{1}{2RC\ln\left(\frac{1+\beta}{1-\beta}\right)}$$

Q. Design a square wave generator for f_o as 1 kHz. Assume $\beta = 0.5$. Assume $C = 0.1\,\mu F$. Assume Op-Amp operates at $\pm 15V$.

Sol^n:

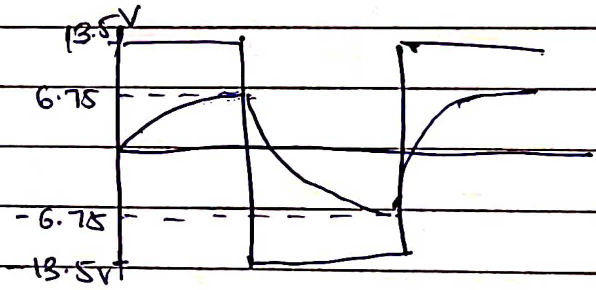
$$f_o = \frac{1}{2RC\ln\left(\frac{1+\beta}{1-\beta}\right)}$$

$$10^3 = \frac{1}{2\times R\times 0.1\times 10^{-6}\ln\left(\frac{1+0.5}{1-0.5}\right)}$$

$$R = \frac{1}{10^{-4}\times 2\times 1.09}$$

$$= 0.45\times 10^{4}$$

$$= 4.5\ k\Omega.$$



Q. Design a wave-form generator for $f_o = 10$ kHz. Duty cycle $= 30\%$. Assume $\beta = 0.5$, $C = 0.1\,\mu F$.

Sol^n:

$$T = \frac{1}{f} = \frac{1}{10}\times 10^{-3}$$

$$0.1\times 10^{-3} = 0.1\,ms$$

$$0.3 = \frac{T_{on}}{T_{total}}$$

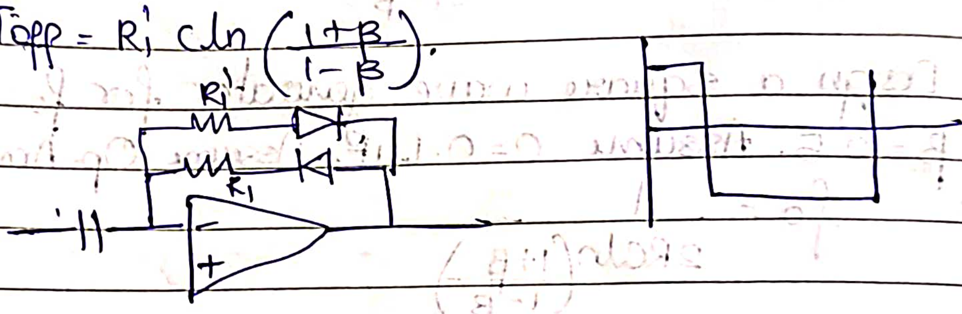
$T_{on} = 0.03 ms$

$T_{off} = 0.1 - 0.03$

$= 0.07 ms.$

$T_{on} = R_1 C \ln\left(\frac{1+\beta}{1-\beta}\right)$

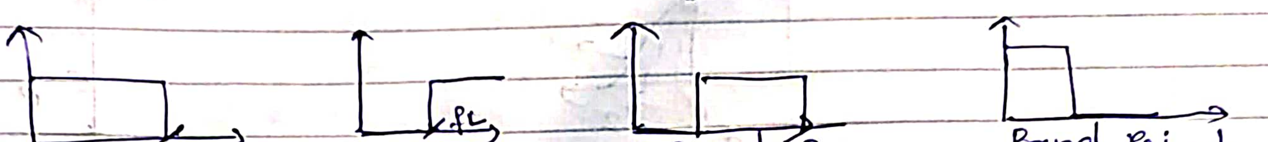
$T_{off} = R_1' C \ln\left(\frac{1+\beta}{1-\beta}\right).$



14/11/22

Unit-4

Active filters & Convertors
ADC · DAC.



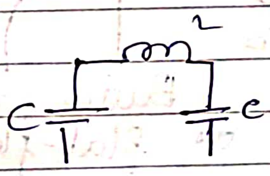
LPF fn   HPF   Band Pass   Band Reject.

Filters
- Passive
- Active

Filters (Type of f)
- All pass.
- LPF
- HPF
- Band Pass
- Band Reject

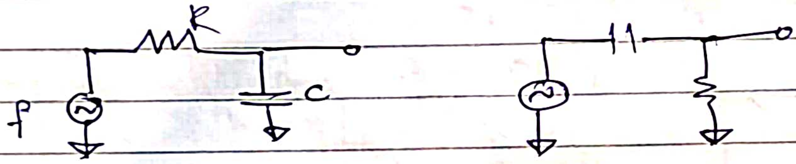
$X_L = 2\pi f L$

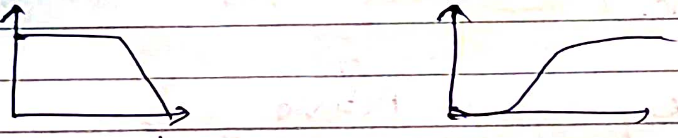
$X_C = \frac{1}{2\pi f C}$



Pi filter

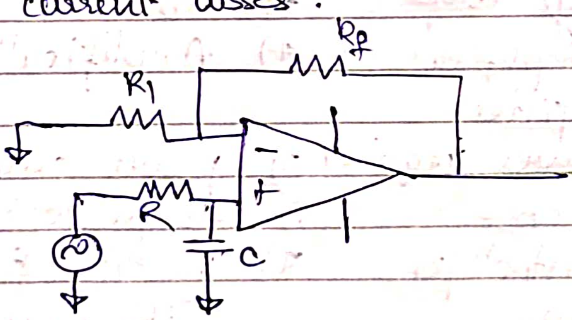
Passive   Active





→ Voltage drop
→ Circuit would get loaded
→ L → eddy current losses.

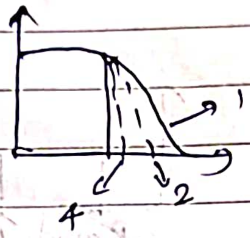
Active:

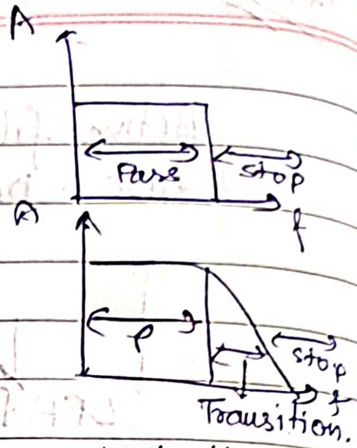


1) I/p impedance ↑
2) No loading effect.
3) Amlification along with filtering.
4) No 'L'. No eddy current losses.

*) On the basis of order.

→ Higher the order, better is the performance.

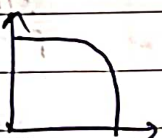




Roll off Rate
-20dB / decade.
-6dB / octave

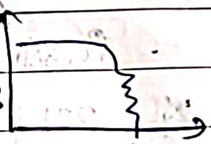
*) Alignment curve :

Flat P.B
Flat S.B



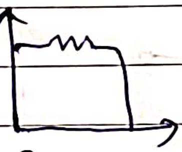
Butter-worth
or flat-flat

Flat P.B.
Rippled S.B



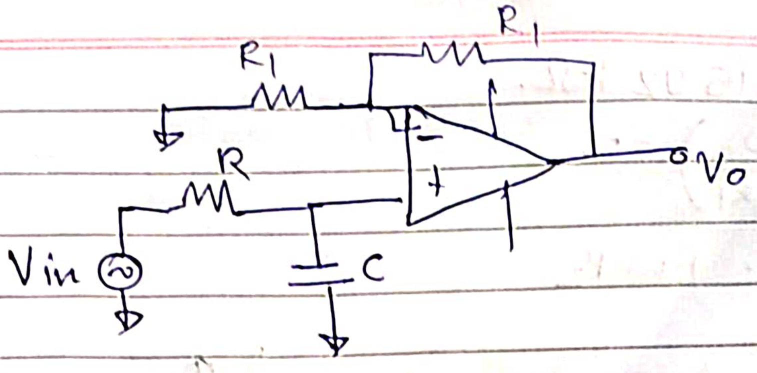
Chebyshev

Rippled P.B.
Flat S.B



Cauer
or Elliptic

Passive	Active
1) R, C, L	1) R, C
2) loading	2) No load
3) Voltage drop	3) No " "
4) No amplifican with filter	4) Amplifican with filter
5) No power required	5) power req.
6) low cost	6) High cost.
7) No restricn for f usage	7) Restricn for f usage. (S.R. is a criteria).
8) Diag.	8) Diag.
9) Eddy current losses	9) No Eddy current losses.



1st order Active LPF.

Low Pass filter

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

$$v' = \frac{-X_c \, V_{in}}{R - X_c}$$

$$v' = \frac{\frac{-1}{j2\pi fC} V_{in}}{R + \frac{1}{j2\pi fC}}$$

$$v' = \frac{V_{in}}{Rj2\pi fC + 1}$$

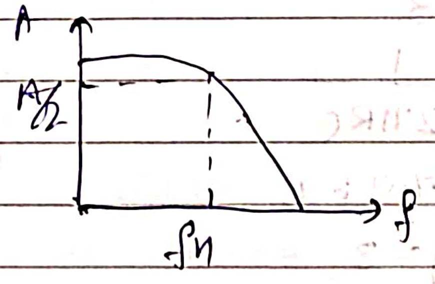
Assume $f = f_H$.

$$\boxed{A_f = \frac{A}{(1 + j f/f_H)}}$$

$$A_f = \frac{A}{\sqrt{1 + f/f_H}}$$

$A_f \rightarrow$ gain with f

$A \rightarrow$ gain without f.



Q Design a 1st order L.P.F for cutoff freq^n 1kHz. Assume C = 0.01uF Pass band gain = 2. Draw freq^n response

Sol^n: ~~fH = 1kHz~~

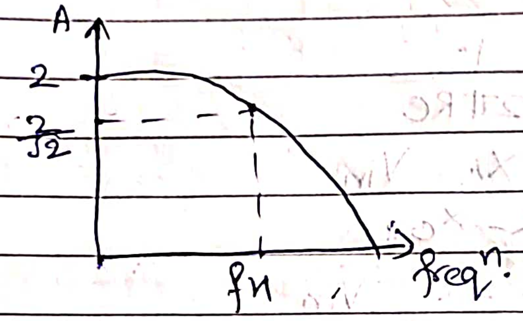
$$f_H = \frac{1}{2\pi RC}$$

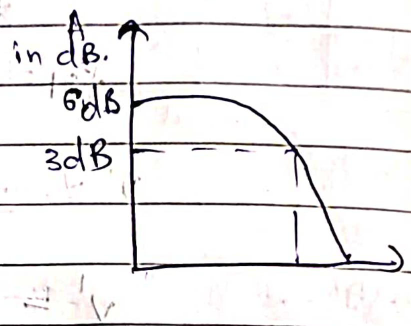
$$R = \frac{1}{2\pi \, 10^3 \times 0.01 \times 10^{-6}}$$

$$R = 15.92\ k\Omega.$$

$$\left(1 + \frac{R_2}{R_1}\right) = 2$$

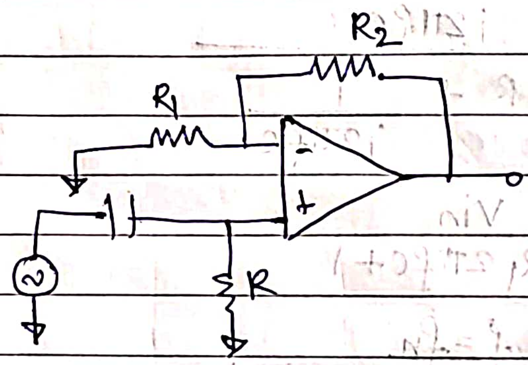
$$\therefore R_1 = R_2$$

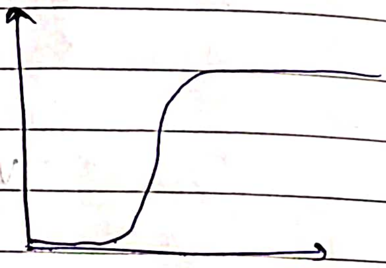




HPF

1st order.





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

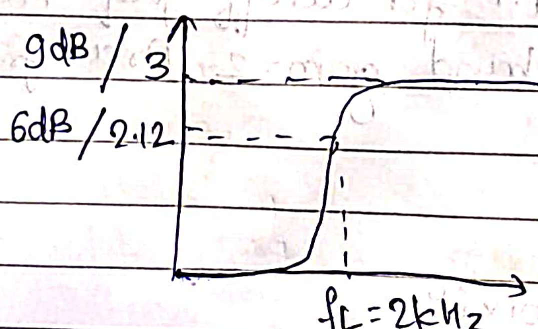
Q. Design 1st HPF for cutoff freq^n = 2kHz. Assume $C = 0.01\mu F$ Pass band gain = 3

Soln:

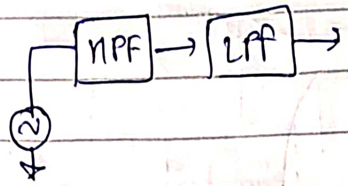
$$f_L = \frac{1}{2\pi RC}$$

$$R = 7.9\ k\Omega$$

$$\left(1 + \frac{R_2}{R_1}\right) = 3$$

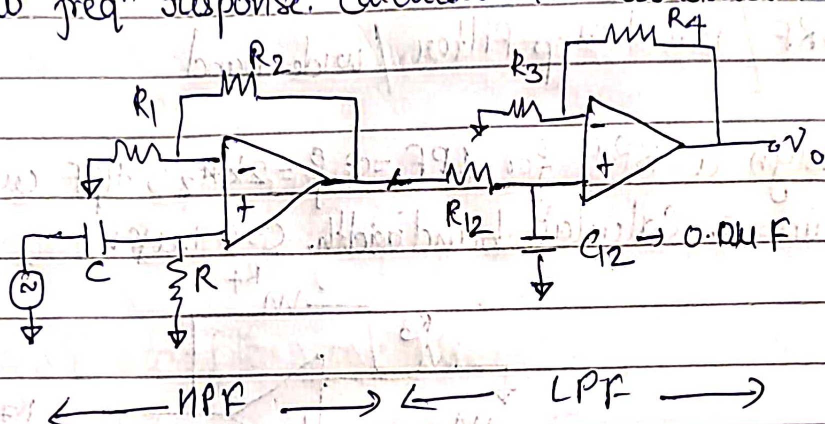


*) BPF



Q. Design a BPF for $f_L = 400Hz$ and $f_H = 4kHz$. Pass band gain = 5. Draw freq^n response. Calculate the bandwidth. Assume $C = 0.01\mu F$

Sol^n:



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

$$400 = \frac{1}{2\pi R \times 10^{-8}}$$

$$R = \frac{1}{2512} \times 10^{8}$$

$$R = 39.8\ k\Omega$$

$$f_H = 4kHz$$

$$f_H = \frac{1}{2\pi R_{12} C_{12}}$$

$$R_{12} = \frac{1}{2 \times \pi \times 4 \times 10^{3} \times 10^{-8}}$$

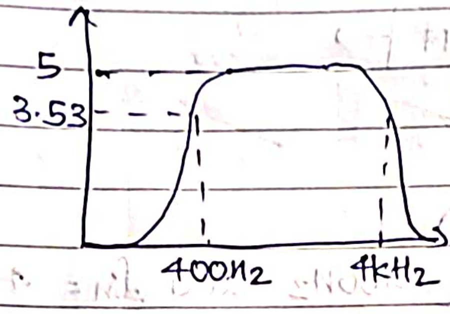
$$= \frac{1}{25.12 \times 10^{-5}}$$

$$= 3.98\ k\Omega$$

$$1 + \frac{R_2}{R_1} = 2.23$$

$\frac{R_2}{R_1} = 1.23$ $R_1 = 1k\Omega$ $R_3 = 1k\Omega$

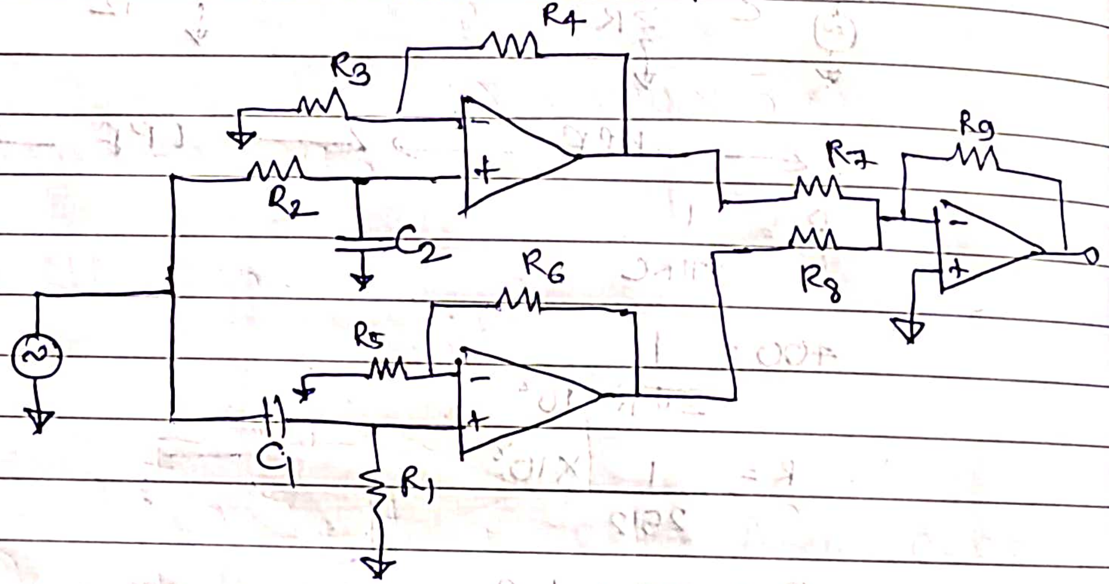
$R_2 = 1.23\ k\Omega$ $R_4 = 1.23\ k\Omega$.



*) BRF / Band stop filter / wide band

Q. Design a BRF for LPF $f = 2kHz$ HPF cutoff $= 4kHz$. Gain = 2. Calculate bandwidth. $C = 0.1\mu F$.

Soln:



$R_3 = R_4 = R_5 = R_6 = 1k\Omega$.

$$R_1 = \frac{1}{2 \times \pi \times 10^{-7} \times 4 \times 10^3}$$

$$= \frac{1}{25.12} \times 10^4$$

$$= 398\ \Omega.$$

$R_2 =$

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

$= 89.44\ Hz.$

*) $Q = \frac{f_c}{BW} = \frac{f_c}{f_H - f_L}$

$f_c = \sqrt{f_H \cdot f_L}$.

$Q < 10 \rightarrow$ wide band.

$Q > 10 \rightarrow$ narrow

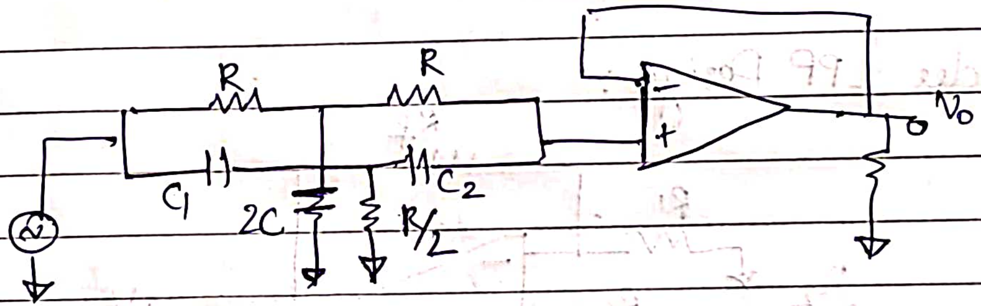
BPF → wide, Narrow

BRF → wide, Narrow

*) Narrow BRF / Notch Filter.

Q. Design a Noth filter for 50 Hz.

Sol^n: Twin 'T' N/w.

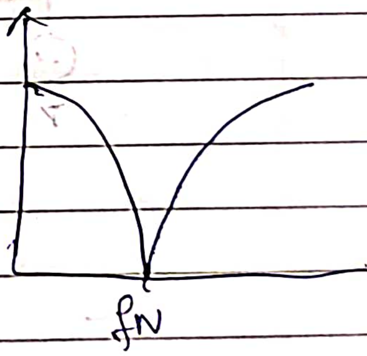


$$50 = \frac{1}{2\pi RC}$$

$$R = \frac{1}{2 \times \pi \times 50 \times 0.068 \times 10^{-6}}$$

$$= \frac{1}{21.352} \times 10^6$$

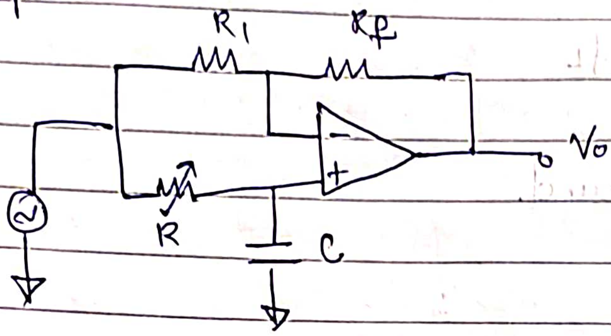
$$= 46.8\,k\Omega.$$

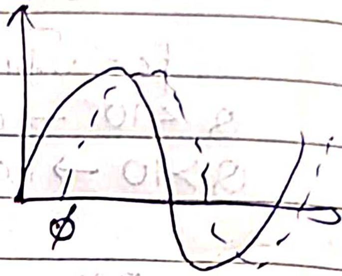


$$\frac{R}{2} = 23.4$$

$$2C = 0.12\,\mu F.$$

*) All pass





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

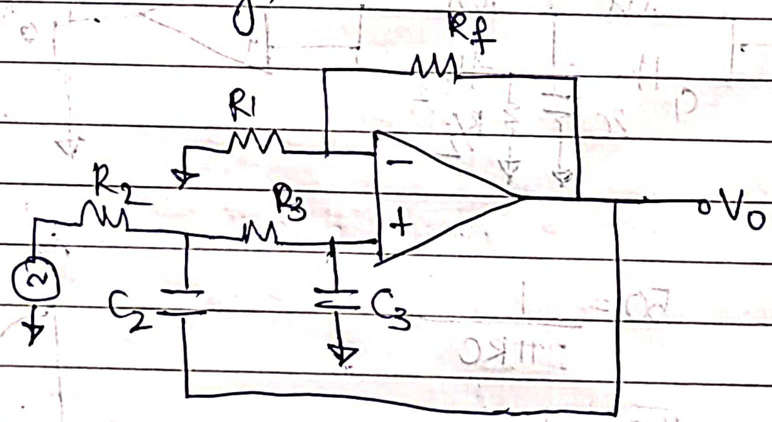
Q. ~~Design All pass filter~~ Calculate phase angle for a all pass filter whose freq. of input is 1KHz. R = 15.9kΩ, C = 0.01uF

Sol^n:

$$\theta = -2\tan^{-1}(2\times\pi\times 15.9\times10^3\times10^{-8}\times10^3)$$

$= -89.6$

*) 2nd order LPF Design:



$R_2 = R_3 = R$
$C_2 = C_3 = C$ } equal component version.

$$f_o = \frac{1}{2\pi\sqrt{R_2R_3C_2C_3}}$$

damping factor $\alpha = \sqrt{2}$ $Q = \frac{1}{\alpha}$

$A = 3 - \alpha$

Q. Design a 2nd order LPF for cutoff freq^n 1 kHz. Assume C = 0.01 μF. Pass band gain = 2.

Sol^n:

$R_2 = R_3 = R$

$C_2 = C_3 = C$

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

$$R = \frac{1}{2\pi \times 10^3 \times 10^{-8}}$$

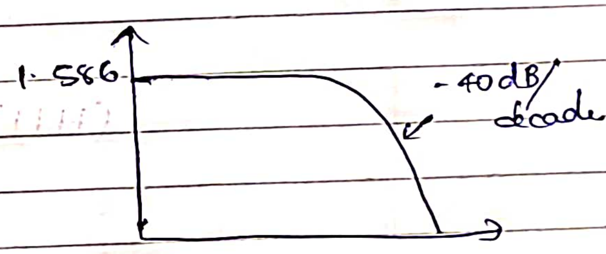
$$= 15.9\,k\Omega.$$

$A = 3 - \alpha$

$= 3 - 1.414$

$= 1.586$

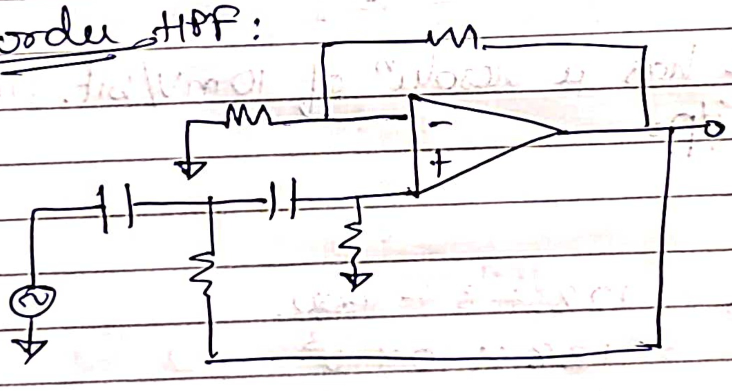
$$1 + \frac{R_f}{R_1} = 1.586$$



$$\frac{R_f}{R_1} = 0.586$$

$R_f = 0.586\ \Omega.$

*) 2nd order HPF:



*) DAC

Digital to Analog converter.

→ Binary weighted

→ R to 2R.

Binary - wide range of resistors is required.

Q. A 4 bit DAC uses a reference of 5V. Calculate corresponding Analog voltage. Digit i/p = $(1011)_2$

Sol^n:

$$Res = \frac{V_{ref}}{2^n - 1}$$

$$= \frac{5}{2^4 - 1}$$

$$= \frac{5}{15} = \frac{1}{3} = 0.33 \text{ mV/bit.}$$

$$(1011)_2 = (11)_{10}$$

$$= 11 \times 0.33$$

$$= 3.3$$

$$(1111)_2 = (15)_{10}$$

$$= 15 \times 0.33$$

$$= 4.95 V$$

$$(0001) = (1)_{10}$$

$$= 0.33 V.$$

Q. An 8-bit DAC has a resolu^n of 10 mV/bit. Find Analog o/p voltage for i/ps

a) 10001010

b) 00010000

Sol^n: a) $(10001010)_2 = 128 + 8 + \cancel{10}2$

$$= 138 \times 10 \times 10^{-3}$$

$$= 138 \times 10^{-2}$$

$$= 1.38 V$$

b) $\cancel{2^5 = 32 \times 10^{-2}}$ $\quad 2^4 = 16 \times 10^{-2}$

$\cancel{= 0.32V.}$ $\quad = 0.16 V.$

c) $(11110000)_2 = 240 \times 10^{-2}$

$$= 2.4 V.$$

d) $(00001111)_2 = 8+4+2+1$

$= 15 \times 10^{-2}$

$= 0.15V.$

e) $(10101010)_2 = 128+32+8+2$

$= 1.7V$

Q. 8 bit DAC has a voltage range 0 to 2.55 V. Find resoluⁿ.

Solⁿ: $Res = \frac{V_{ref}}{2^8 - 1}$

$= \frac{2.55}{255}$

$= 0.01$ V/bit

$= 10$mV/bit.

$Res = \frac{5}{255}$

$= 19$mV/bit.

Q. A 4 bit R-2R ladder n/w uses resistors $R = 10k\Omega$ $2R = 20k\Omega$. Uses $V_R = 10V$. a) Find the resolⁿ of the converter.

Solⁿ: $Res = \frac{10}{2^4 - 1}$

$= \frac{10}{15}$

$= 0.66$ V/bit.

b) Find I_o for Digital i/p 1101.

Solⁿ: $(1101) = 13$

$= 13 \times 0.66$

$= 8.58$ V.

$I_o = 8.58$

*) ADC :

Analog to Digital converter.

→ Flash ADC – hardware becomes complex as no. of bits ↑es.

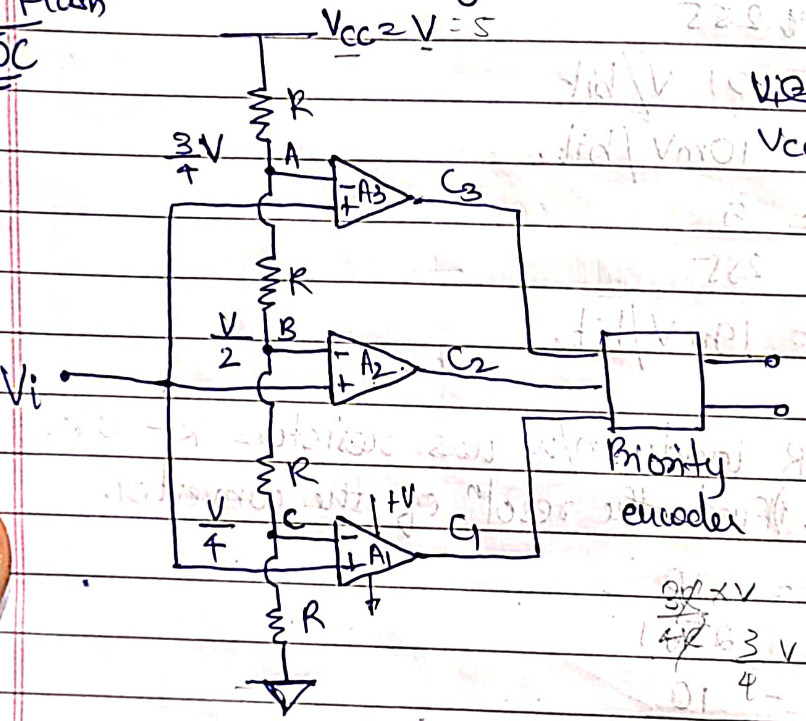
→ Successive approximation converter (SAR). → register.

Comparators – $2^n - 1$

Resistors – 2^n.

Black Box – Priority encoder.

2-Bit Flash ADC

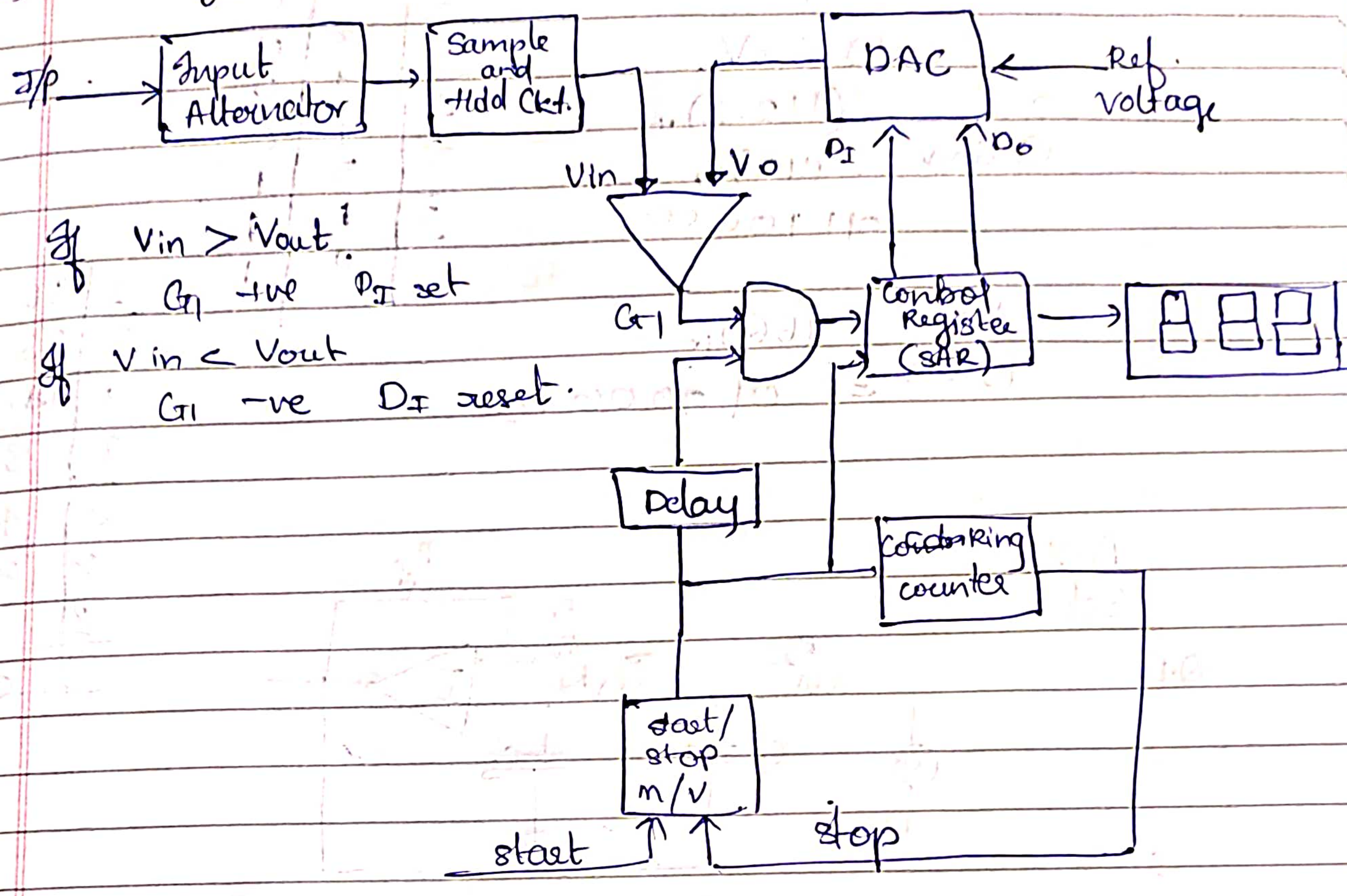


Vcc = 5V

$\frac{3R}{4R} \times V = \frac{3}{4}V$ $\frac{R}{4R} \times V$ $\frac{2R}{4R} \times V = \frac{V}{2}$

Vi	C3	C2	C1
$0 \le V_i \le 1.25$	0	0	0
$1.25 \le V_i \le 2.5$	0	0	1
$2.5 \le V_i \le 3.75$	0	1	1
$3.75 \le V_i \le 5$	1	1	1

7.) SAR type ADC :



If Vin > Vout
G1 +ve D_I set

If Vin < Vout
G1 -ve D_I reset.

1000
1100 or 0100

Q. An 8-bit ADC accepts i/p voltage in range of 0 to 10V.
a) Minimum voltage req. to cause 1 LSB change. (Ans 39.1mV)
b) What i/p range would cause ADC to become all 1
(Ans : 10 - 39.1mV).
c) What is the digital o/p for i/p 4.8 V.

Soln : c) $\frac{4.8}{Resolu^n} = \frac{4.8}{39.2mV} = (122.44)_{10}$

$= (122)_{10}$

$= 10111010$

2	122	0
2	61	0
2	30	1
2	15	0
2	7	1
2	3	1
2	1	1
2	1	0
	0	1

$\frac{3.6}{39.2mV} = (92.3)_{10}$

$= (92)_{10}$

Q. $\text{Resol}^n = \dfrac{5}{2^8 - 1}$

$= 19.6\,mV$

$\dfrac{2.2}{19.6\,mV} = (112.2)_{10}$

$= (112)_{10}$

$= 01110000$

2	112	0
2	56	0
2	28	0
2	14	0
2	7	0
2	3	1
2	1	1
	0	1

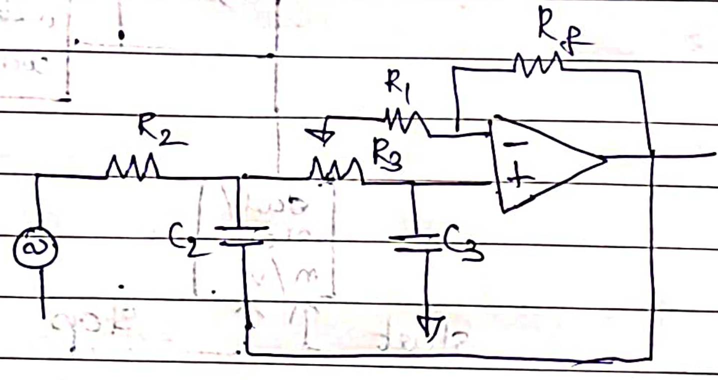
$\dfrac{1.3}{19.6\,mV} = (66)_{10}$

$= 01000010$

2	66	
2	33	0
2	16	1
2	8	0
2	4	0
2	2	0
2	1	0
	0	1

A-2
Set 1

Q.1



$f_H = \dfrac{1}{2\pi RC}$ $\quad R_2 = R_3 = R$, $C_2 = C_3 = C$

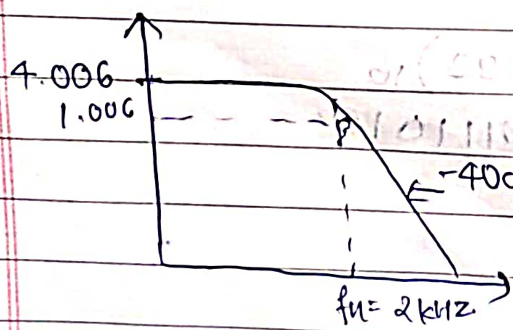
$R = \dfrac{1}{2\pi f_H C}$

$R_1 = \dfrac{1}{2 \times \pi \times 2\times10^3 \times 5\times10^{-8}} = 1.59\,k\Omega$ $\quad \dfrac{1}{6.28\times10^{-5}}$

$A = 3 - \alpha = 1 + \dfrac{R_f}{R_1}$ Assume $R_1 = 1\,k\Omega$.

$A = 1.586$ $\quad 1.586 = 1 + \dfrac{R_f}{10^3}$

$0.586 = \dfrac{R_f}{10^3}$

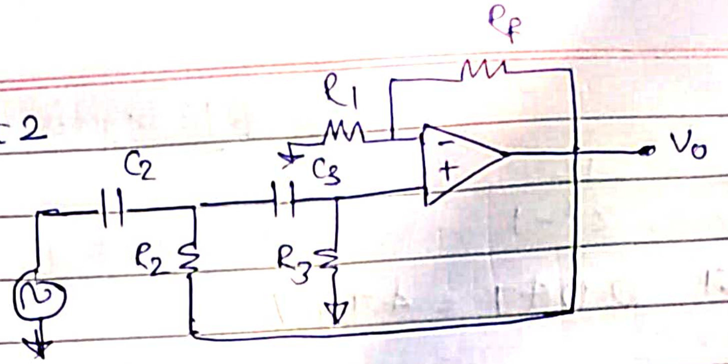


$R_f = 0.586\,k\Omega$.

$R_f = 586\,\Omega$.

Set 2

Q.1



$\alpha = \sqrt{2}$
(B.W.)

$C_2 = C_3 = 0.047 \times 10^{-6} F.$

$R_2 = R_3 = 3.3 \times 10^3 \Omega.$

$R_1 = 27 \times 10^3 \Omega \quad R_f = 15.8 \times 10^3 \Omega.$

$1 + \frac{15.8 \times 10^3}{27 \times 10^3}$

$1.58.$

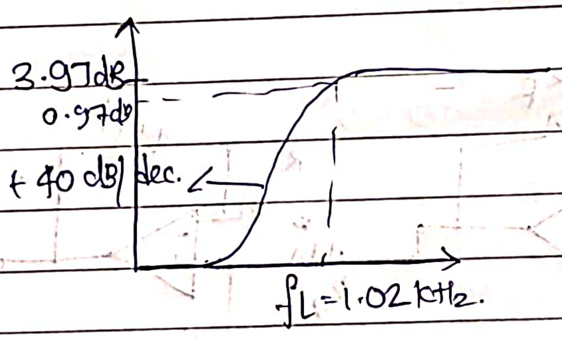
$20 \log_{10}(1.58)$

$f_L = \frac{1}{2\pi\sqrt{R_2 R_3 C_2 C_3}}$

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

$= \frac{1}{2 \times \pi \times 3.3 \times 10^3 \times 0.047 \times 10^{-6}}$

$= 1.02 \text{ kHz}$



Q.2 $Res = \frac{V_{ref}}{2^n - 1}$

$= \frac{10}{2^4 - 1}$

$= \frac{10}{15}$

$= 0.66$

$(1011)_2 = 8 + 2 + 1$

$= 11 \times 0.66$

$= 7.26 V$

$(0110)_2 = 4 + 2$

$= 6 \times 0.66$

$= 3.99$

classmate

Date

Page

Set 3

Q.2 a) $\text{Resol}^n = \frac{12}{2^d}$ $\frac{12}{2^8-1}$

$= 0.047$ $0.047 = 47mV$

b) $12 - 0.047$

$= 11.953\,V$

c) $\frac{6}{0.047} = (127.65)_{10}$

$= (128)_{10}$

$= (10000000)_2$

2	128	
2	64	0
2	32	0
2	16	0
2	8	0
2	4	0
2	2	0
2	1	0
	0	1

Set 1.4

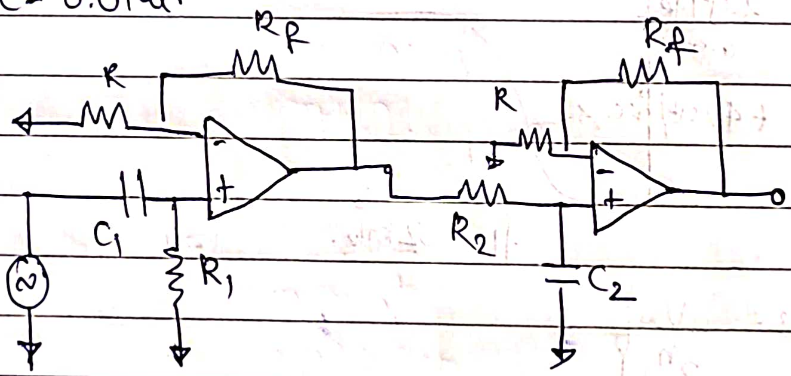
Q.1

$f_L = 400Hz$

$f_H = 2kHz$

$A = 2$

$C = 0.01\mu F$



$f_L = \frac{1}{2\pi R_1 C_1}$

$R_1 = \frac{1}{2\pi \times 400 \times 10^{-8}}$

$= 39.8\,k\Omega.$

$1 + \frac{R_f}{R_1} = \sqrt{2}$

$1 + \frac{R_f}{R_1} = 1.414$

Assume $= 1 + \frac{R_f}{1k\Omega}$ $R = 1k\Omega$.

$$1.414 = 1 + \frac{R_f}{10^3}$$

$$0.414 = \frac{R_f}{10^3}$$

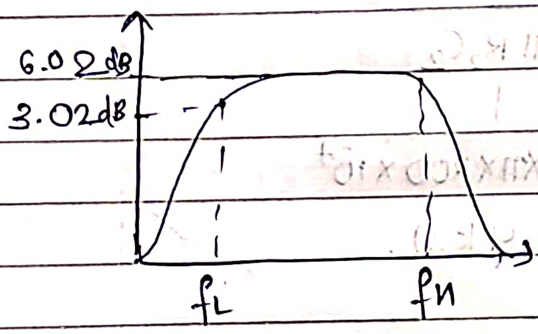
$$R_f = 414\Omega.$$

$$f_H = \frac{1}{2\pi R_2 C_2}$$

$$R_2 = \frac{1}{2 \times 3.14 \times 2 \times 10^3 \times 10^{-8}}$$

$$= \frac{1}{4 \times 3.14 \times 10^{-5}}$$

$$R_2 = 7.9k\Omega$$



$BW = 2kHz - 400Hz = 1600 Hz$

$$f_C = \sqrt{f_L \times f_H}$$

$$= 894.42 Hz.$$

$$Q = \frac{894.42}{1600}$$

$$Q = 0.559$$

Q.2. $Res = \frac{10}{2^4 - 1}$

$= 0.66\ V/bit$

$(1001) = 8+1$

$= 9 \times 0.66$

$= 5.94\ V$

$(1110) = 8+4+2$

$= 14 \times 0.66$

$= 9.24\ V$

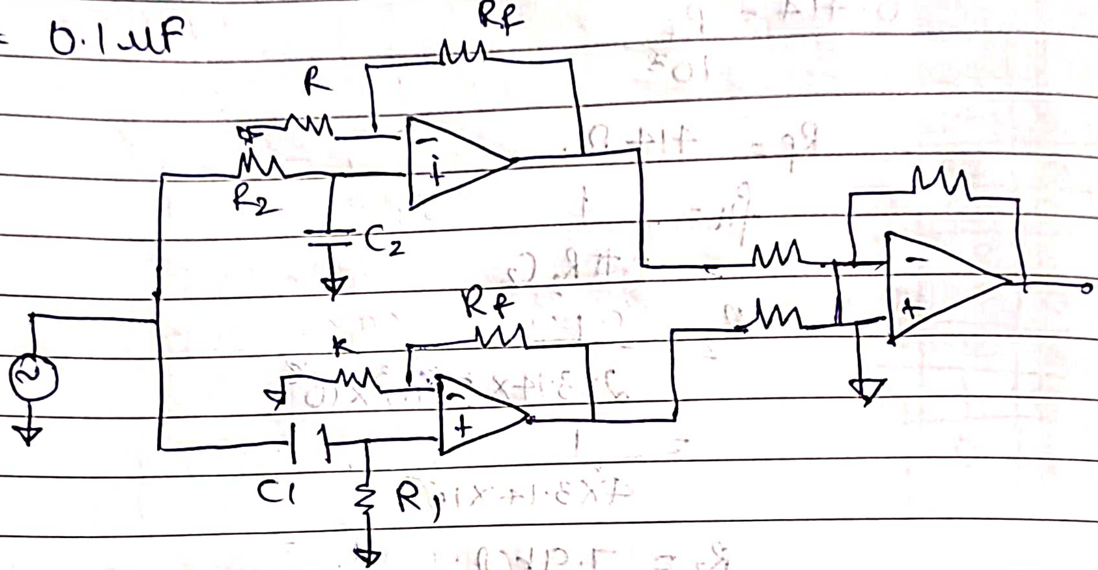
Set 5

Q.1 $f_H = 200Hz$

$f_L = 2kHz$

$A = 1$

$C = 0.1\mu F$



$$200 = \frac{1}{2\pi R_2 C_2}$$

$$R_2 = \frac{1}{2\times\pi\times 200\times 10^{-7}}$$

$$= 7.9k\Omega.$$

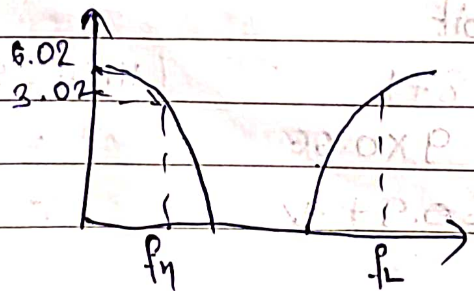
$$R_1 = \frac{1}{2\times\pi\times 2\times 10^{-4}}$$

$$= 0.79\ k\Omega.$$

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

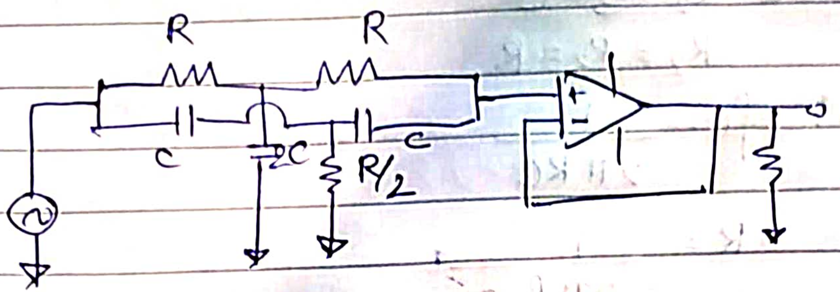
$$= 632.45$$

$$1 + \frac{R_f}{1k\Omega} = 1 \quad R_f = 1k\Omega.$$



Q.2 $f_N = 60\,Hz$

$C = 0.068\,\mu F$



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

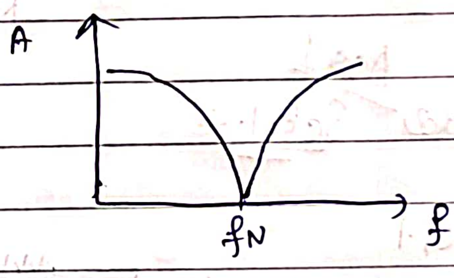
$$R = \frac{1}{2\pi f_N \times C}$$

$$= \frac{1}{2\pi \times 60 \times 68 \times 10^{-9}}$$

$$= 39\,k\Omega$$

$$\frac{R}{2} = 19.5\,k\Omega.$$

$$2C = 0.136\,\mu F.$$



Set 1.6

Q.1 $f_L = 1.5\,kHz$

$C = 0.01\,\mu F$

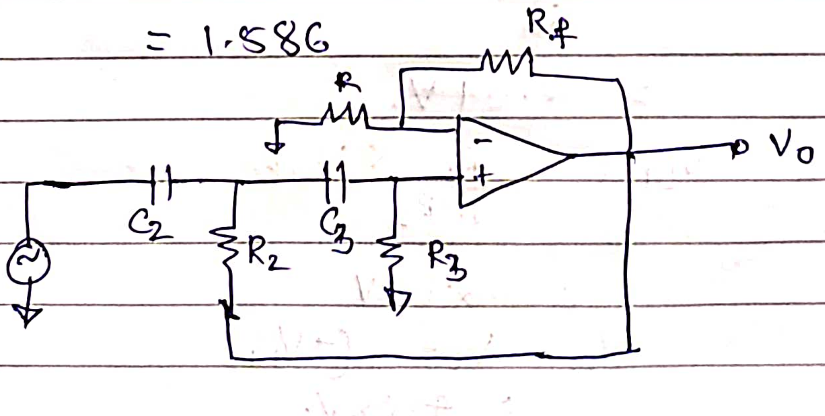
Assume it to be butterworth filter.

$\therefore\ \alpha = \sqrt{2}$

$\therefore\ A = 3 - \alpha$

$= 3 - 1.414$

$= 1.586$



$$f_L = \frac{1}{2\pi\sqrt{R_2 R_3 C_2 C_3}}$$

Assume $C_2 = C_3 = C$

$R_2 = R_3 = R$

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

$$R = \frac{1}{2\pi f_L C}$$

$$= \frac{1}{2\times\pi\times 1.5\times 10^3 \times 10^{-8}}$$

$R = 10.6\,k\Omega$

$$1 + \frac{R_f}{R} = 1.586$$

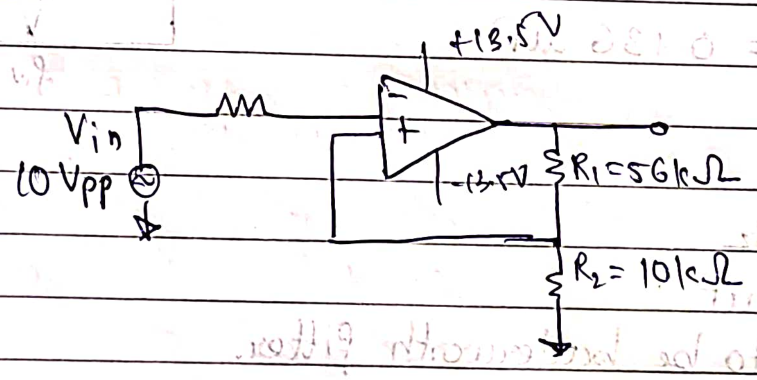
Assume $R = 1\,k\Omega$

$R_f = 586\,\Omega$

Ass 1

Q2 Set 1.4

Q.1



$$V_{UT} = \frac{R_2}{R_1+R_2} \times V_{sat}$$

$$= \frac{10}{66} + 13.5$$

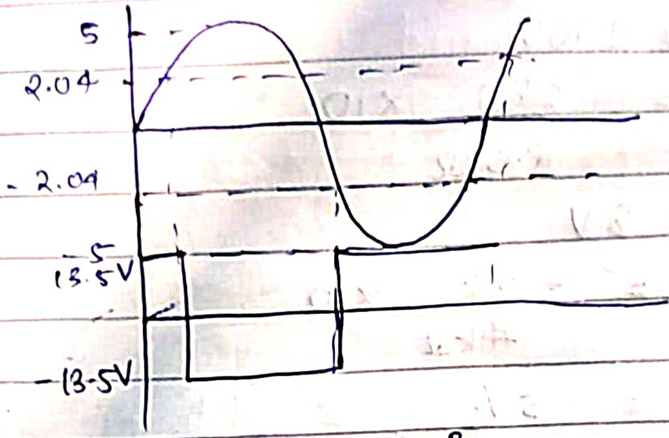
$= 2.04\,V.$

$$V_{LT} = \frac{-R_2}{R_1+R_2} \times V_{sat}$$

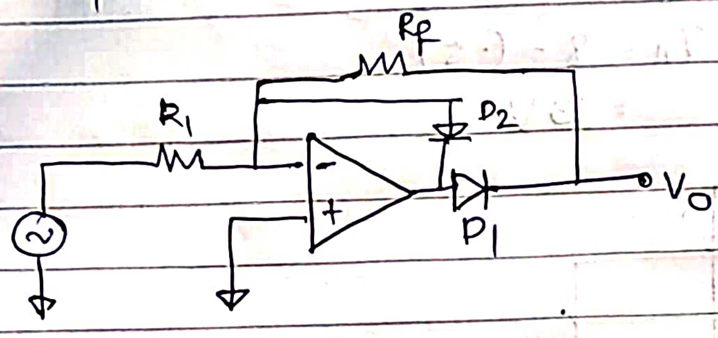
$= -2.04\,V$

$V_H = V_{UT} - (-V_{LT})$

$= 4.08\,V.$

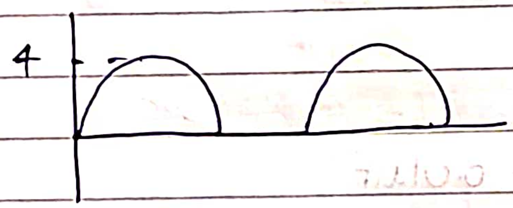


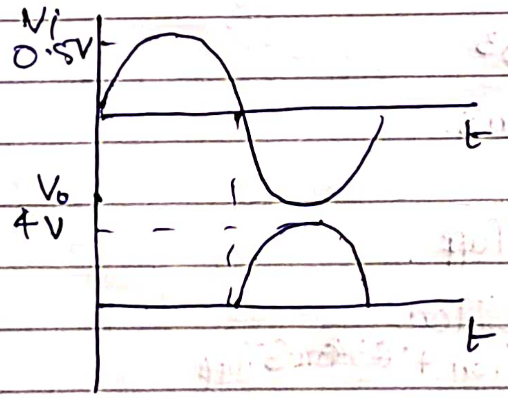
Q.2



$$A = \frac{4}{0.5} = 8$$

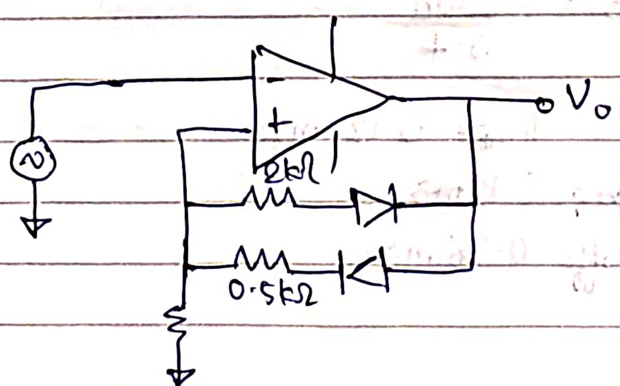
$\therefore R_f = 8k\Omega \quad R = 1k\Omega.$





Set 1.5

Q.1



$V_{sat} = \pm 10V$

$V_{UT} = \frac{2k\Omega}{2.5k\Omega} \times 10$

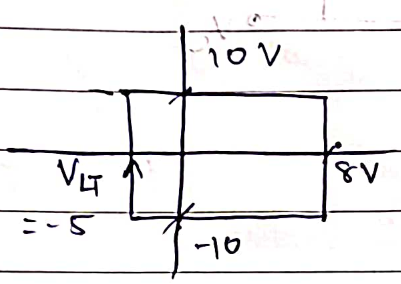
$= 8V$

$V_{LT} = -\frac{2k\Omega}{4k\Omega} \times 10$

$= -5V.$

$V_H = 8 - (-5)$

$= 13V$



Q.2 $f_o = 2.5 kHz$

D.C = 30%

$\beta = 0.5$

$R_1 = 10 k\Omega$

$C = 0.1 \mu F$ $\quad C_f = 0.01 \mu F$

$T = \frac{1}{2.5 \times 10^3}$

$= 0.4 ms.$

$D.C = \frac{T_{on}}{T_{on} + T_{off}}$

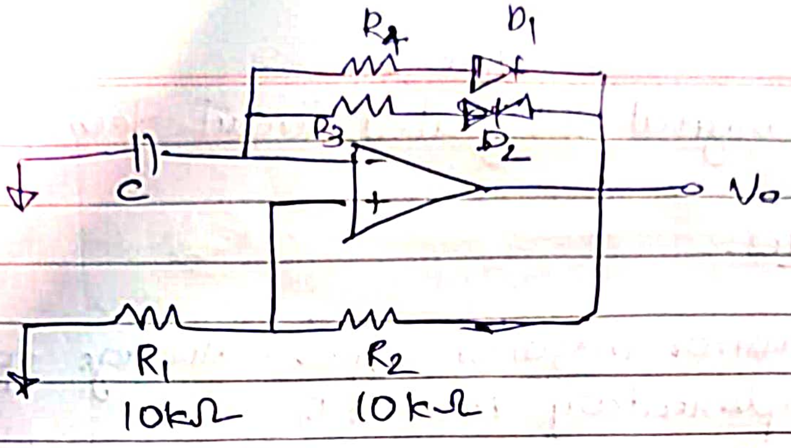
$0.3 = \frac{T_{on}}{T_{on} + T_{off}}$

$0.3 = \frac{T_{on}}{0.4}$

$T_{on} = 0.12 ms$

$T_{on} = 0.12 ms$

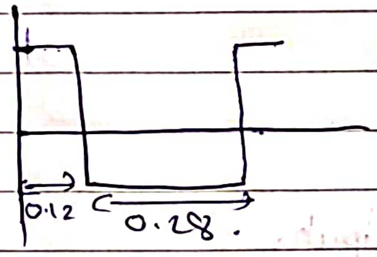
$T_{off} = 0.28 ms.$



$$T_{on} = R_3 C \ln\left(\frac{1+\beta}{1-\beta}\right) \quad (+V_{sat})$$

$R_3 = ?$

$$T_{off} = R_4 C \ln\left(\frac{1+\beta}{1-\beta}\right) \quad (-V_{sat}).$$



28/11/22

Unit-5
Digital Integrated Circuit Technology & Convertors.

*) Logic families:

1) TTL - transistor transistor logic. - Average speed & power consum.
2) CMOS - Complementary MOSFET.
3) ECL - Emitter coupled logic - speed.

CMOS is the best when Power consumption has to be less.

*) Types of TTL
→ Standard
→ High speed
→ Low Power
→ Schhottky.

3-configuration at the output,
→ Totem - Pole
→ Open Collector
→ Tristate

*) Finite State Machine:
→ Mealy
→ Moore machines representation.

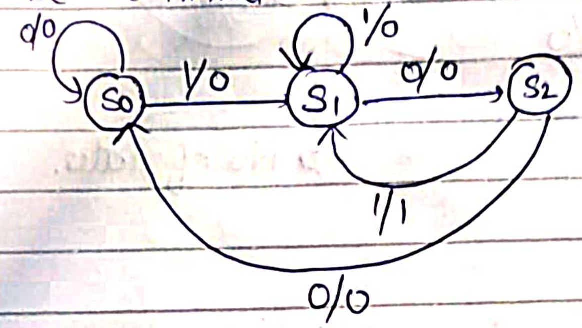
Mealy	Moore
3) Less no. of states required	3) More states are required.
4) Complex difficult to design	4) Easy to design.
5) More hardware.	5) Less hard hardware.

*) To solve
1) Draw the state diagram.
2) Draw state table.
3) Solve o/p eq^n using karnel map.

4) Draw the ckt.

Q. Determine the sequence for 101 using Mealy FSM.

Soln: Let S_0 be the initial state.



State Table

$S_0 \rightarrow 00$

$S_1 \rightarrow 01$

$S_2 \rightarrow 10$

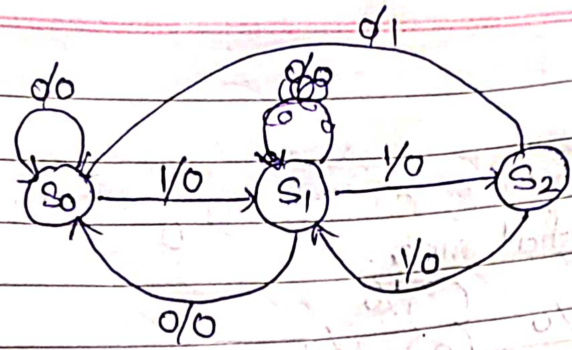
PS		I/P	N.S		O/P.
Q_1	Q_0	x	Q_1^+	Q_0^+	y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	1	0	0
0	1	1	0	1	0
1	0	0	0	0	0
1	0	1	0	1	1

Eqs $y = Q_1 \bar{Q}_0 x$

$\underbrace{2^N = 3}_{\text{no. of states}} \rightarrow$ N – no. of flip flop.

Q 1001. Design the ckt diag. to determine the seq. using mealy FSM.

Q. 110



State Table

$2^N \geq 3$ No. of states.

$S_0 \rightarrow 00$

$S_1 \rightarrow 01$

$S_2 \rightarrow 10$

PS		x	NS		y	F.F.	
Q_B	Q_A	x	Q_B^+	Q_A^+	y	D_B	D_A
0	0	0	0	0	0	0	0
0	0	1	0	1	0	0	1
0	1	0	0	0	0	0	0
0	1	1	1	0	0	1	0
1	0	0	0	0	1	0	0
1	0	1	0	1	0	0	1

D_B

$x \backslash Q_BQ_A$	00	01	11	10

D_B

$x \backslash Q_BQ_A$	00	01	11	10
0	0	0	X	0
1	0	1	X	0

$D_B = xQ_A$.

D_A

$x \backslash Q_BQ_A$	00	01	11	10
0	0	0	X	0
1	1	0	X	1

$D_A = x\overline{Q}_A$.

$D_B = x \cdot Q_A$

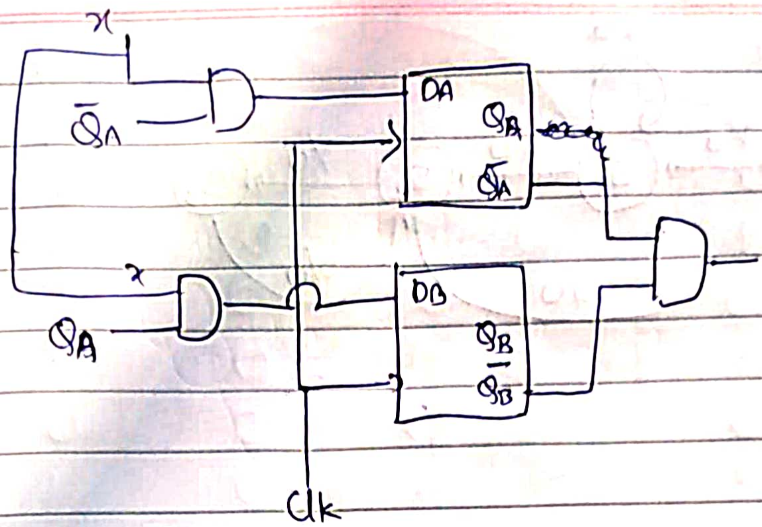
$D_A = x\overline{Q_A}$

$y = \overline{Q_B}\ \overline{Q_A}$

10 → 1
↘ 0

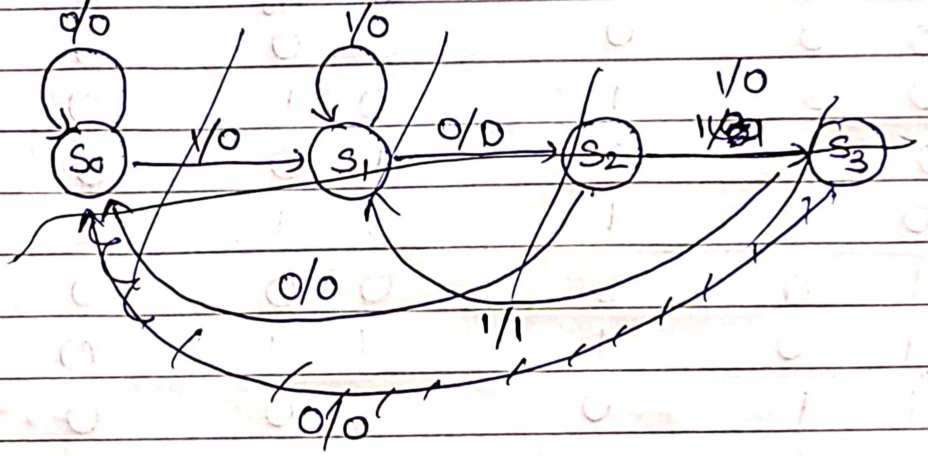
100 10X1

1011
1010



Q. Design a mealy type FSM to detect a seq. 1011.

Soln:



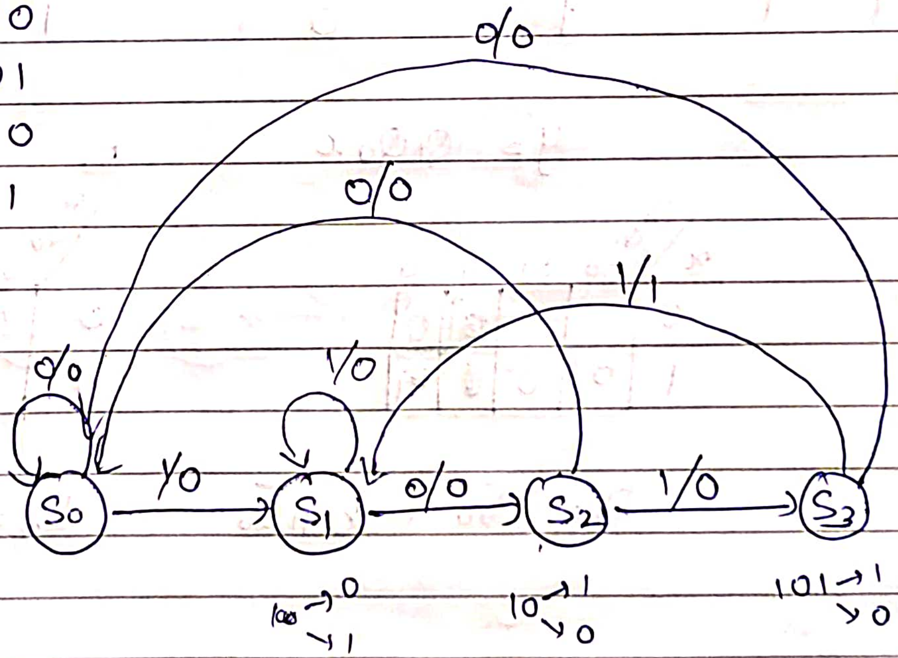
$S_0 \rightarrow 00$

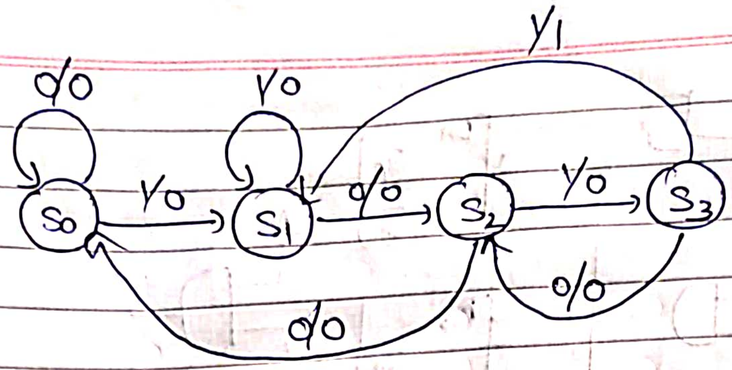
$S_1 \rightarrow 01$

$S_2 \rightarrow 10$

$S_3 \rightarrow 11$

PS





$S_0 \rightarrow 00$

$S_1 \rightarrow 01$

$S_2 \rightarrow 10$

$S_3 \rightarrow 11$

PS		x	NS		y	D F.F.	
Q_1	Q_0	x	Q_1^+	Q_0^+	y	D_1	D_0
0	0	0	0	0	0	0	0
0	0	1	0	1	0	0	1
0	1	0	1	0	0	1	0
0	1	1	0	1	0	0	1
1	0	0	0	0	0	0	0
1	0	1	1	1	0	1	1
1	1	0	1	0	0	1	0
1	1	1	0	1	1	0	1

$y = Q_1 Q_0 x$

D_1

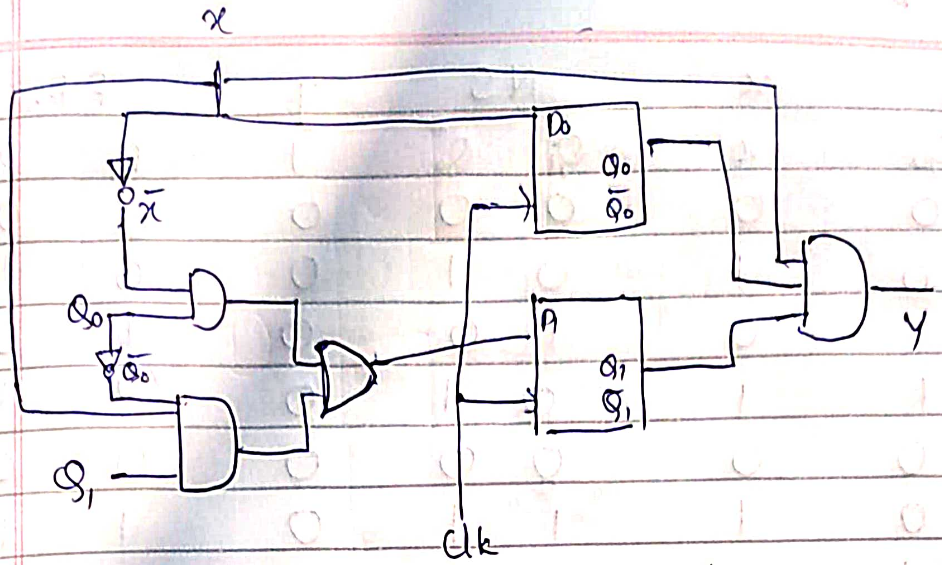
$x \backslash Q_1Q_0$	00	01	11	10
0	0	1	1	0
1	0	0	0	1

D_0

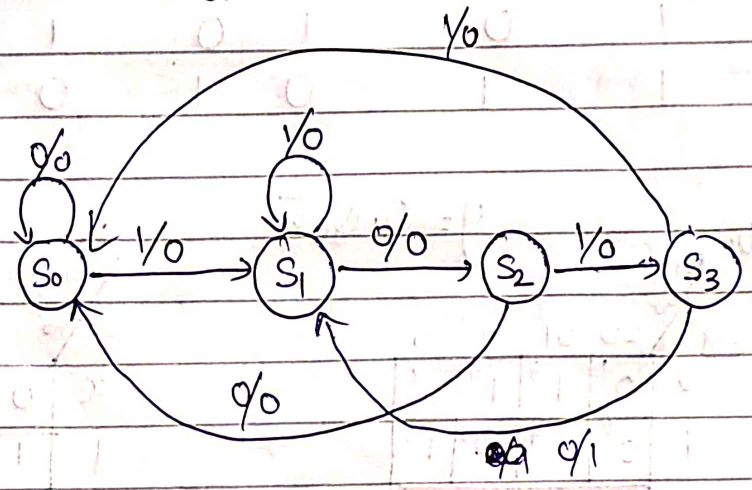
$x \backslash Q_1Q_0$	00	01	11	10
0	0	0	0	0
1	1	1	1	1

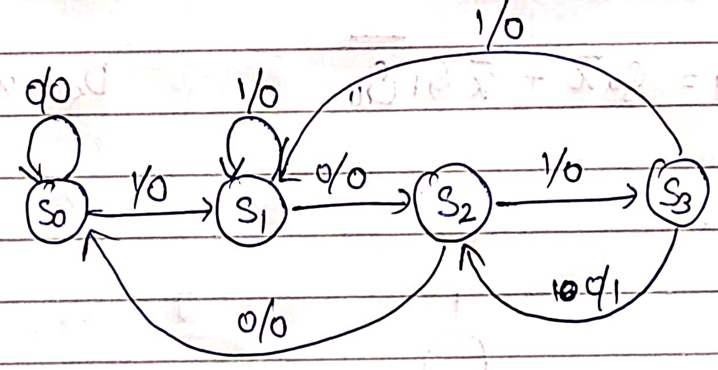
$D_1 = \bar{x} Q_0 + x Q_1 \bar{Q}_0$

$D_0 = x$



Q. 1010





$S_0 \rightarrow 00$

$S_1 \rightarrow 01$

$S_2 \rightarrow 10$

$S_3 \rightarrow 11$

$S_0 \rightarrow 0$

$1 \rightarrow 0$, $\rightarrow 1$

11

$\boxed{S_1 \rightarrow 10}$

$10 \rightarrow 1$, $\rightarrow 0$

100

$\boxed{S_2 \rightarrow 101}$

$101 \rightarrow 0$, $\rightarrow 1$

1010

1011

$1 \rightarrow 0$, $\rightarrow 1$

$S_1 \rightarrow 10$

$10 \rightarrow 1$, $\rightarrow 0$

100

$S_2 \rightarrow 101$

$101 \rightarrow 0$, $\rightarrow 01$

1010

1001. 1100

PS		x	NS		y	F.F.	
Q_1	Q_0	x	Q_1^+	Q_0^+	y	D_1	D_0
0	0	0	0	0	0	0	0
0	0	1	0	1	0	0	1
0	1	0	1	0	0	1	0
0	1	1	0	1	0	0	1
1	0	0	0	0	0	0	0
1	0	1	1	1	0	1	1
1	1	0	1	0	1	1	0
1	1	1	0	1	0	0	1

$$y = Q_1 Q_0 \bar{x}$$

D_1

x \ $Q_1 Q_0$	00	01	11	10
0	0 [1]	1 [3]	1 [7]	0 [5]
1	0 [2]	0 [4]	0 [8]	1 [6]

$$D_1 = Q_0 \bar{x} + x Q_1 \overline{Q_0}$$

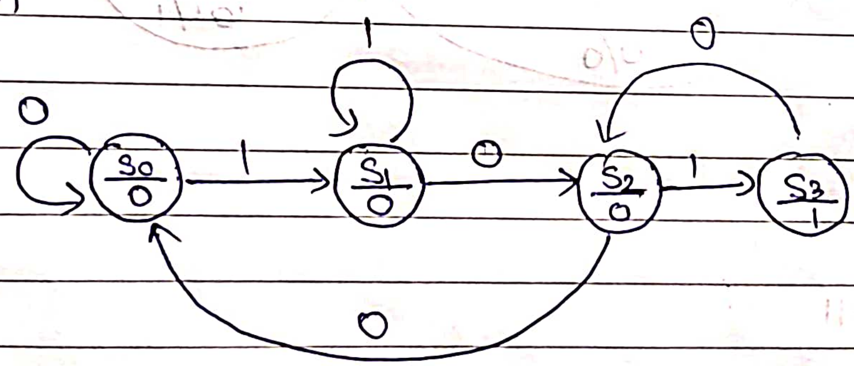
D_0

x \ $Q_1 Q_0$				
0	0	0	0	0
1	1	1	1	1

$$D_0 = x$$

*) Moore :

101

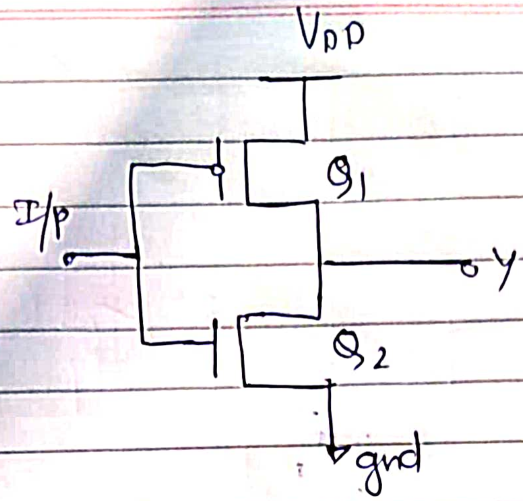


*) Logic Gate using CMOS:

↓

combinaⁿ of P & N.

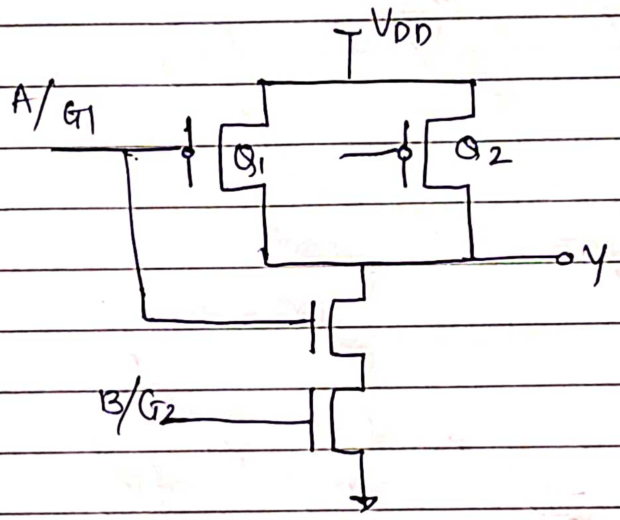
NOT gate



I/p	Y
0	1
1	0

NAND — P - parallel
— N - series

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0



NOR — P - series
— N - parallel.

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0