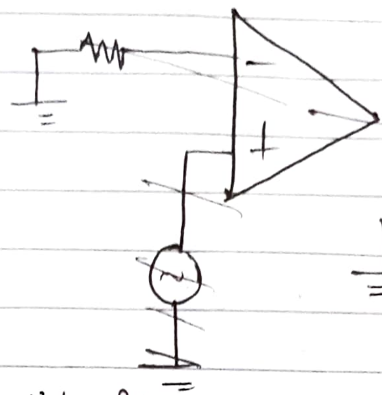
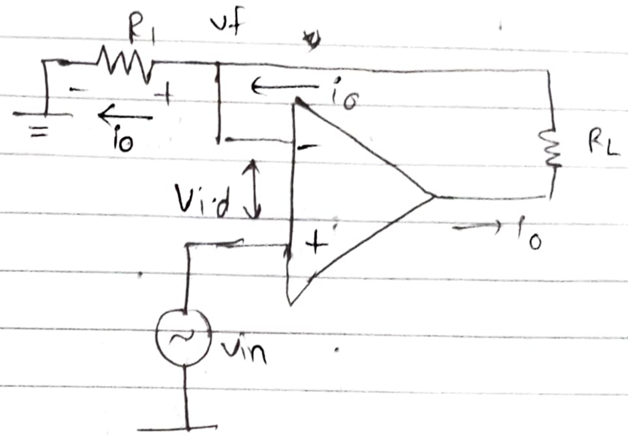
Module 2

Applications of op-amp-

(1) Voltage to current converter with floating load





$V_{in} + V_{id} = R_f$

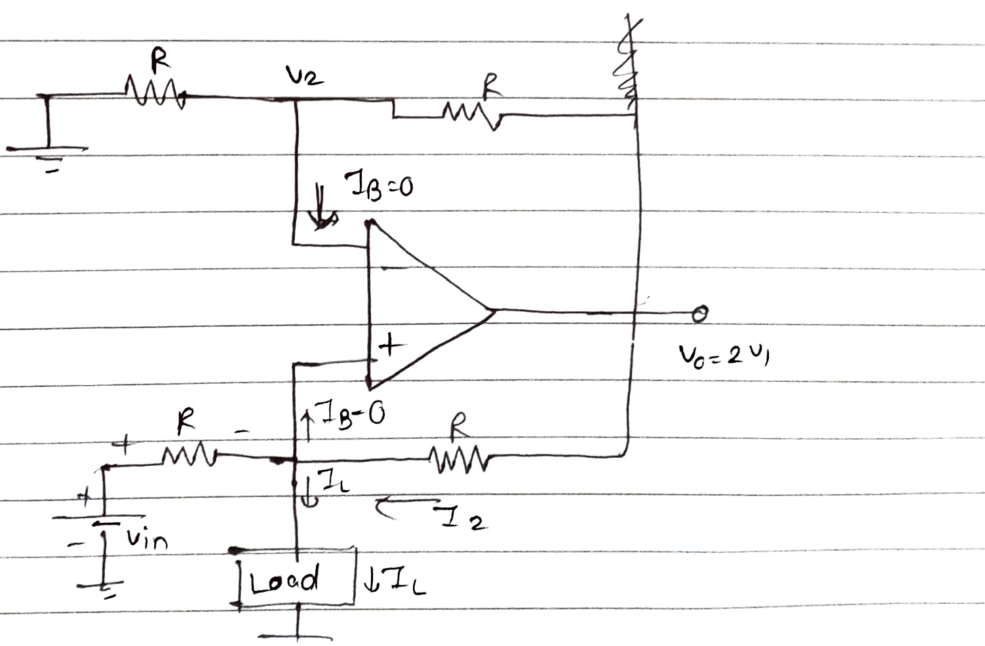
$V_{id} \simeq 0 \quad V_{in} = V_f$

$V_{in} = I_o R_1$

$\boxed{I_o = V_{in} / R_1}$

Used in many applications like diode match finders, LED Tester, Zener diode tester, Low voltage AC and DC voltmeter

* Voltage to current with grounded load:



$I_1 + I_2 = I_B + I_L$

$I_1 + I_2 = I_L$

$$\frac{V_{in} - V_1}{R} + \frac{V_1 - V_0}{R} = I_L$$

$V_{in} - V_1 + V_0 - V_1 = I_L R$

$V_{in} + V_0 - 2V_1 = I_L R$

$I_L R - V_{in} + V_0 = 2V_1$

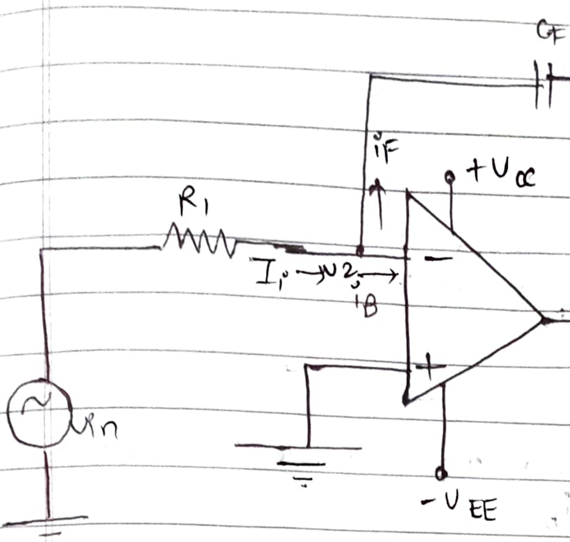
$V_1 = \frac{V_{in} + V_0 - I_L R}{2}$

$$\boxed{V_0 = 2V_1}$$

$$\boxed{I_L = \frac{V_{in}}{R}}$$

i/p	o/p
sin	cos
square	triang
triang	sin

* Op-amp as Integrator:



$$V_o = -\frac{1}{R_1 C_F}\int_0^t V_{in}\,dt$$

instead of $R_F = C_F$

KVL at V_2,

$$I_1 \simeq I_F$$

$$\frac{V_{in} - V_2}{R_1} = C_F \frac{d(V_2 - V_0)}{dt}$$

$V_2 = 0$

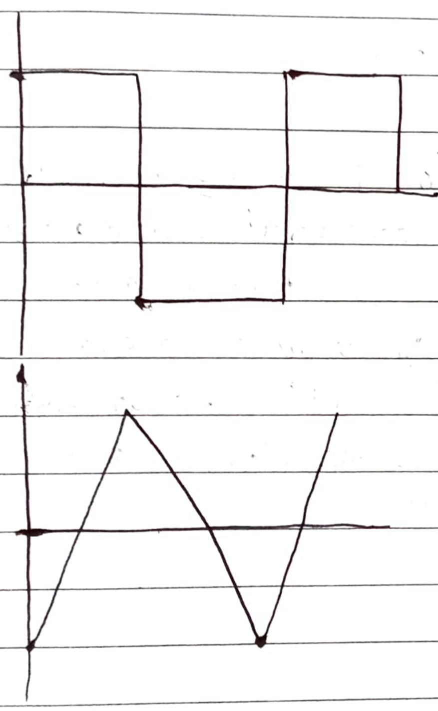
$$\frac{V_{in}}{R_1} = -C_F \frac{dV_o}{dt}$$

$$V_{in} = -R_1 C_F \frac{dV_o}{dt}$$

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

i/p

o/p

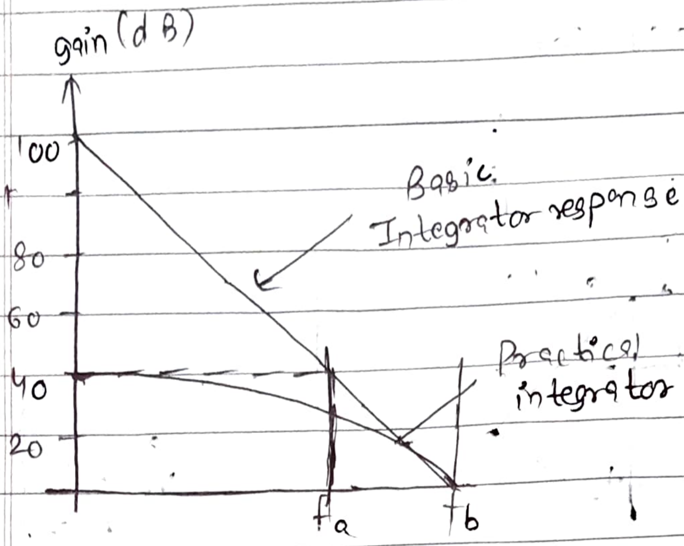


$$A_v = -\frac{X_C}{R_1}$$

$$\boxed{A_v = -\frac{1}{2\pi f_c R_1}}$$

produces error voltage

At low frequency, CF will act as open circuit, If we connect RF in parallel to Open circuit, it will limit the gain, hence called practical integrator



~~for~~ Criteria to design integrator

$F_a = \frac{1}{2\pi R_1 C_F}$

$F_b = \frac{1}{2\pi R_F C_F}$

$f_a < F_b$

$F_a = \frac{f_b}{10}$

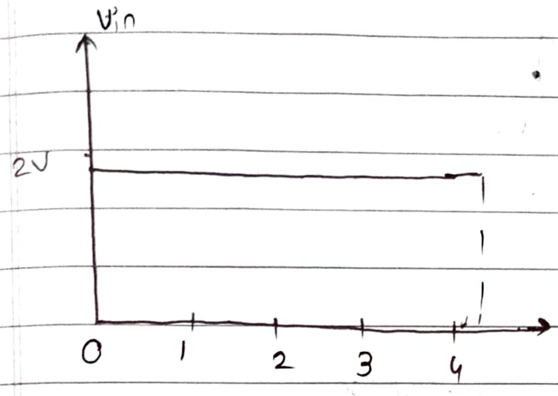
$\boxed{T \geq R_F C_F}$

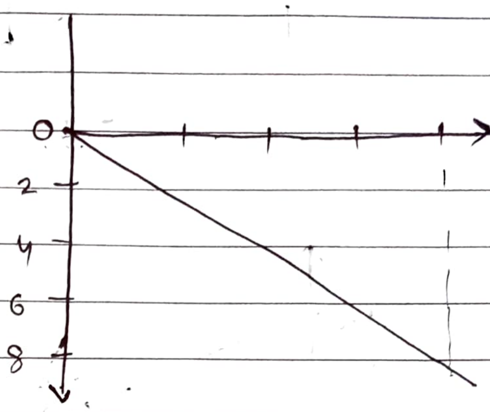
① In ideal integrator at low frequency, capacitor will behave as an open circuit, due to this whole circuit will act as a open loop configuration, so even small amount of input offset voltage produces a error voltage at output, so to avoid this practical integrator is used and R_F is connected across capacitor C_F so that gain will be limited, i.e $-\frac{R_F}{R_1}$

$$V_0 = \frac{-1}{R_1 C_F} \int_0^t V_{in}\, dt$$

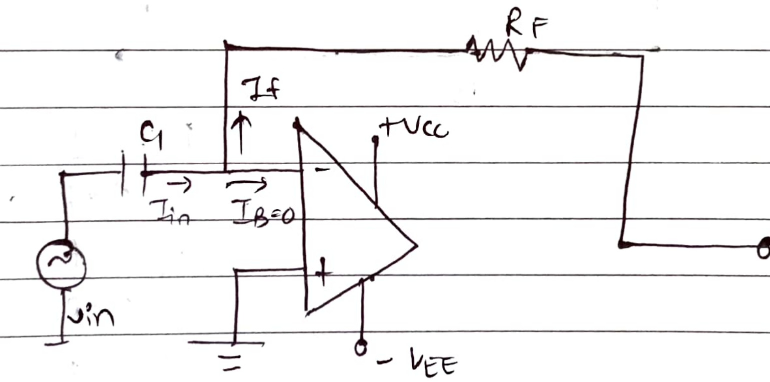
$$= \left[-\int_0^1 2\,dt + \int_1^2 2\,dt + \int_2^3 2\,dt + \int_3^4 2\,dt \right]$$

$$\boxed{V_0 = -8}$$





* Differentiator



$$\boxed{V_0 = -R_F C_1 \frac{d\,V_{in}}{dt}}$$

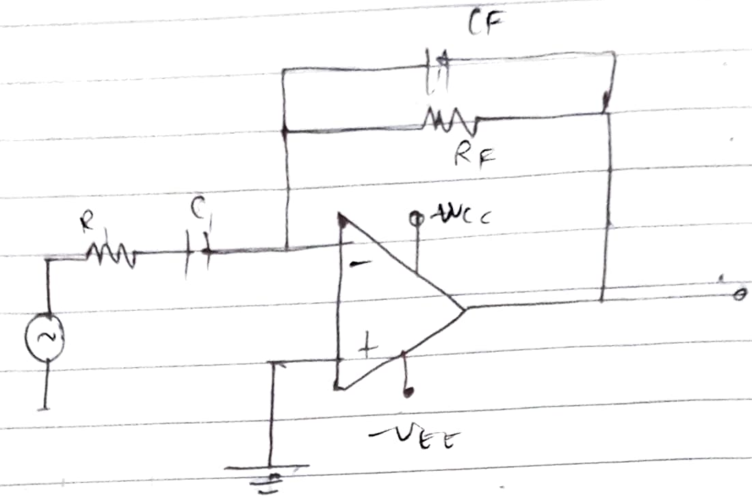
$$C_1 \frac{dV_{in}}{dt} = \frac{-V_0}{R_F}$$

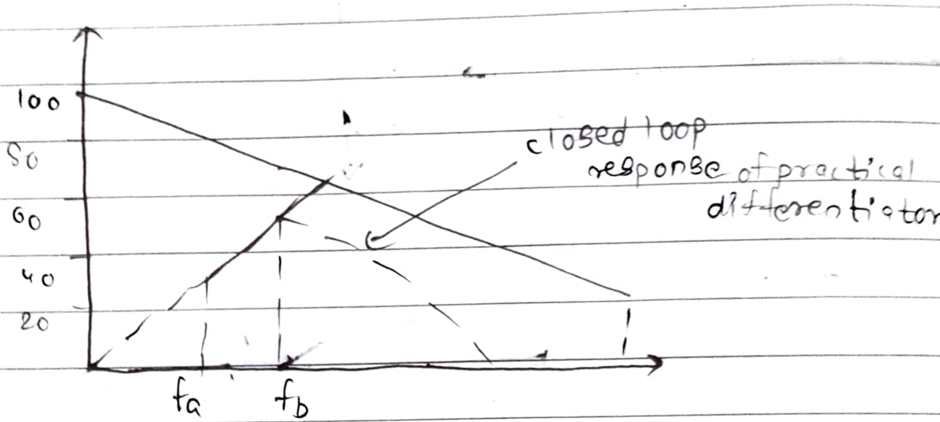
$$A_v = \frac{-R_F}{X_C}$$

$$= -R_F\, 2\pi f c$$

i/p	
sin	
square	sp
triang	squa

For practical differentiator





$$F_a = \frac{1}{2\pi R_F C_1}$$

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

$$F_a < F_b < F_c$$

$$T \geq R_F C_1$$

Design a differentiator to differentiate an input signal that varies from 10 Hz to 1 kHz.
If a sin wave of 1 volt peak at 1 kHz is applied to differentiator, then derive output.

→ $V_o = -R_F C_1 \frac{dv_{in}}{dt}$ $\qquad f_a < f_b < f_c$

$f_a = 1\,kHz$

(max i/p freq) ① $F_a = \frac{1}{2\pi R_F C_1}$

$C =$ less than $1\mu f$

$\boxed{C_1 = 0.1\mu f}$

$\boxed{R_F = 1.59\,k\Omega}$

② $f_b = 20\,kHz$

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

$\boxed{R_1 = 79.5\,\Omega}$

③ $R_1 C_1 = R_F C_F$

$C_F = \frac{79.5 \times 0.1 \times 10^{-6}}{1.59 \times 10^{3}}$

$\boxed{C_F = 5\,nF}$

$V_o = -R_F C_1 \frac{dv_{in}}{dt}$

$= -1.59 \times 10^{3} \times 0.1 \times 10^{-6} \frac{d}{dt}(v_p \sin\omega t)$

$= -0.159 \times 10^{-3} \frac{d}{dt} \sin 2\pi \times 10^{3} t$ $\qquad (v_p = 1)$

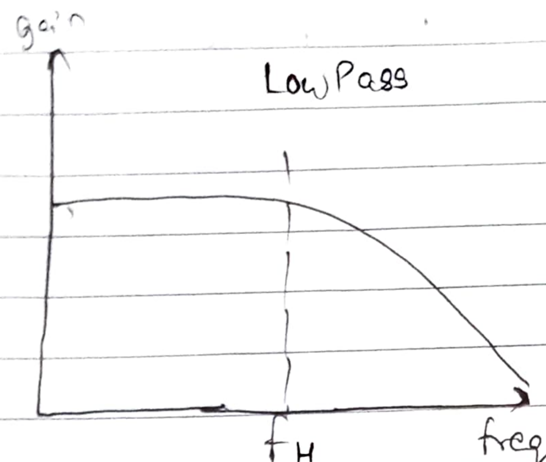
$2\pi \times \cancel{10^{3}} - 0.159 \times \cancel{10^{-3}} \cos 2\pi \times 10^{3} t$

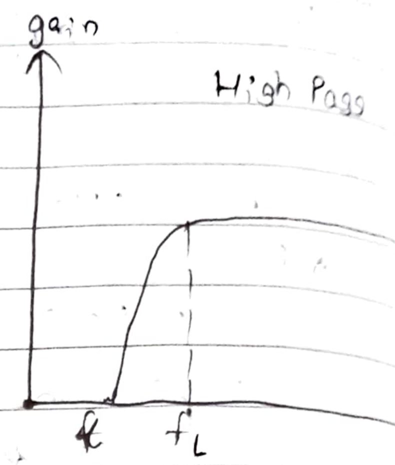
$= -0.99 \cos(2\pi 10^{3} t)$

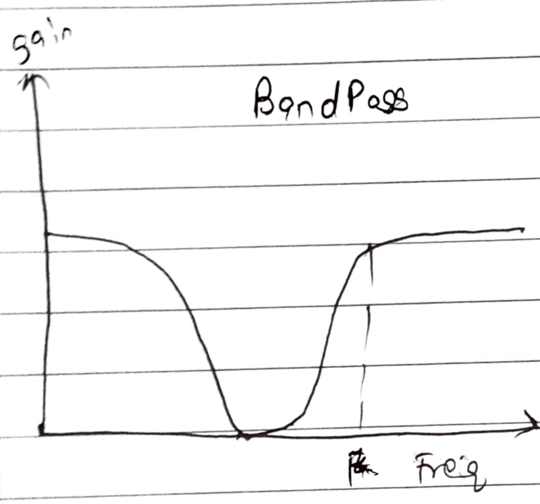
Module

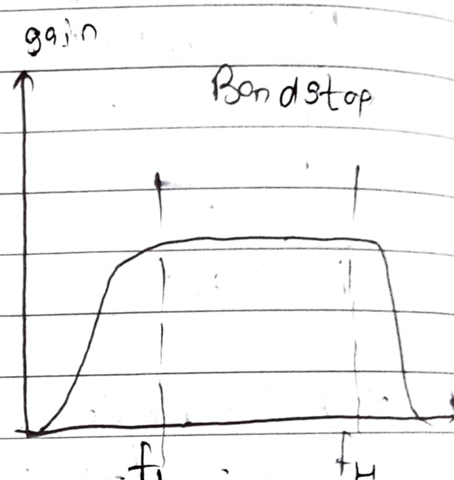
Filters

1) Active ~~or~~ Passive
2) RF$_{(LC)}$ or AF$_{(RC)}$
3) ~~RC or LC~~ Analog or Digital









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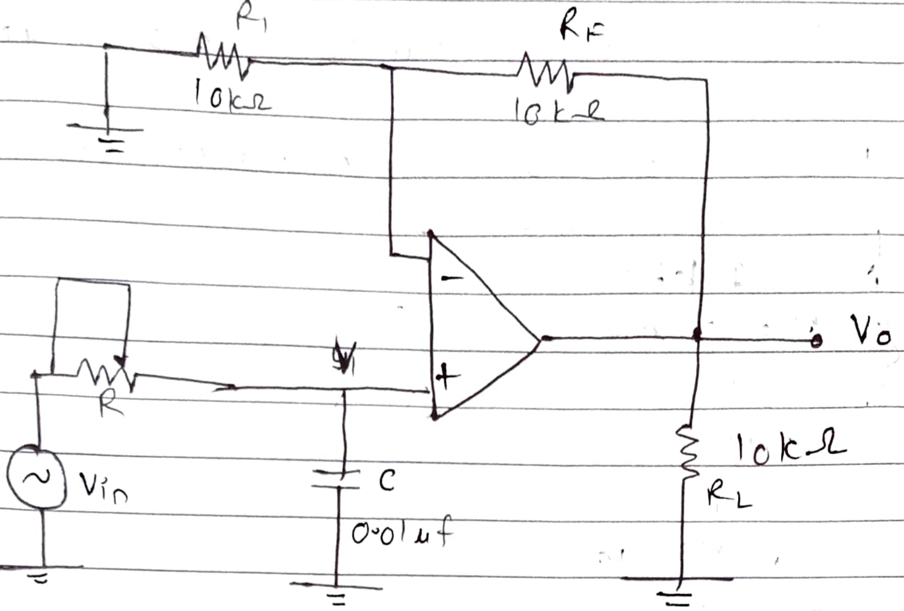
1) 1^{st} order Low Pass Filter



$$V_1 = \frac{-jX_C}{R + jX_C} \cdot V_{in}$$

$$V_o = (1 + R_F/R_1) V_1$$

$$V_1 = \frac{V_{in}}{1 + j2\pi fRC}$$

$$V_o = (1 + R_F/R_1) V_1$$

$$V_1 = \frac{V_{in}}{1 + j2\pi fRC}$$

$$V_o = (1 + R_F/R_1) \frac{V_{in}}{1 + j2\pi fRC}$$

$$\frac{V_o}{V_{in}} = \frac{A_f}{1 + j(f/f_H)}$$

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

(5M)

Design steps

1. Choose a high cutoff frequency f_H.
2. Select the value of capacitor less than or equal to $1 \mu F$
3. Calculate the value of R
4. Select the value of R_1 and R_F for desired gain.

eg:- Design a low pass filter with cutoff frequency 1 kHz pass band gain of 2.

→ 1. $f_H = 1\ kHz$

2. $C = 0.1\ \mu F$

3. $f = \frac{1}{2\pi RC}$

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

$$= \frac{10^4}{2\pi}$$

$$= 1591.5$$

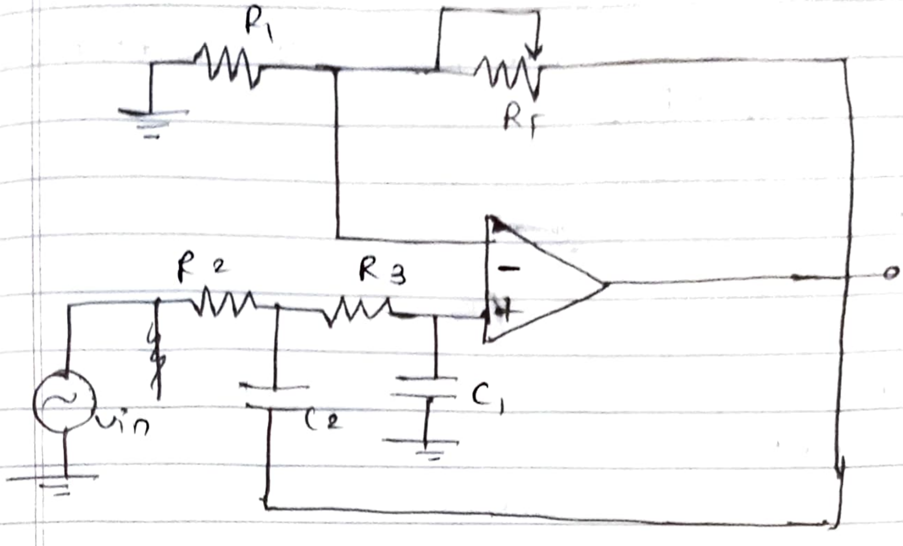
$$= 1.59\ k\Omega$$

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

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

$$R_F = 1 k\Omega, \ R_1 = 1 k\Omega$$

* Second Order Low Pass Filter

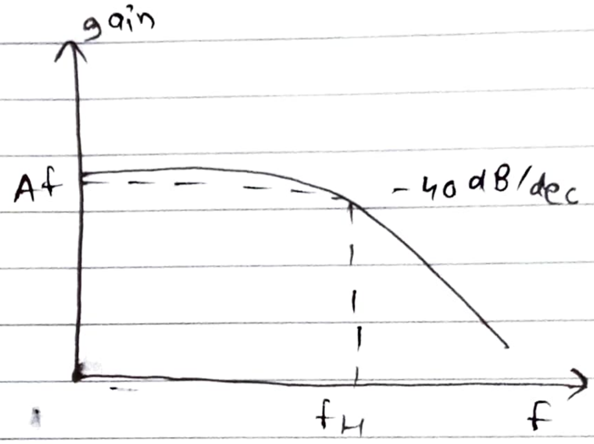


$$f_H = \frac{1}{2\pi\sqrt{R_2 R_3 C_1 C_2}}$$

$$\left|\frac{v_o}{v_{in}}\right| = \frac{A_f}{\sqrt{1+\left(\frac{f}{f_H}\right)^4}}$$

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

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



Design a second order filter
① Choose a value of higher cutoff frequency f_H.
② Assume $R_2, R_3 = R$
$C_1 = C_2 = C$
$C < 1\mu F$
③ $f_H = \frac{1}{2\pi RC}$ Calculate value of R based on formula,

* C^t

(4) Determine the value of R_F and R_1 should be ~~l~~ less than equal to $100 k\Omega$ $(R_1 \le 100 k\Omega)$

eg:- 1) Design a second order low pass filter with higher cutoff frequency 1 kHz.

- (1) $f_H = 1 kHz$
- (2) $C = 0.0047$
- (3) $f_H = \frac{1}{2\pi RC}$

  $R = 33.86 k\Omega$

- (4) $1 + \frac{R_F}{R_1}$

  $R_1 = 30 k\Omega$

  $R_F = 17.58 k\Omega$