EC21101
Basic Electronics
Sudip Nag

Book: Electronic Circuits: Analysis & Design
Author: D. A. Neamen

Syllabus (brief):
1. RC circuit theory
2. Diodes
3. Transistors: BJTs & FETs
4. Op-amps
5. Digital circuits

Assessments:
1. Attendance : 5 (De-registration by IITKGP)
2. Class Tests 1 & 2 : 10
3. Assignments 1 & 2 : 10
4. Mid-sem : 25
5. End-sem : 50

RC Circuit Theory : Filters

R → Resistors ; C → Capacitors ; L → Inductors

Component's resistance to an AC.

Reactance by 'R' = R = X_R

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

" " 'L' = $\omega L = 2\pi f L = X_L$

Electronic filters

Filters: 1) Passive & Active (types)

2) Low pass, high pass, band pass, band stop & all pass (types)

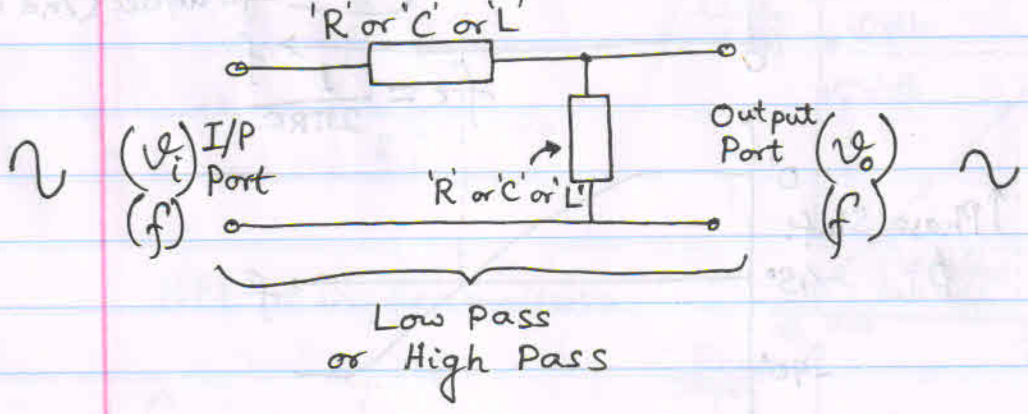
3) First order, second order, ... (types)

4) Butterworth, Chebychev, Bessel, etc. (types)

→ Filters are primarily freq. selective circuits.

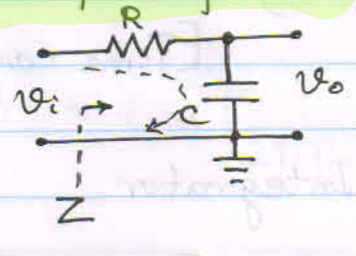
→ Passive filters utilize a combination of R, C & L.

→ Structure/circuit of a passive filter:



$|v_o| \leq |v_i|$

1. Low pass filter



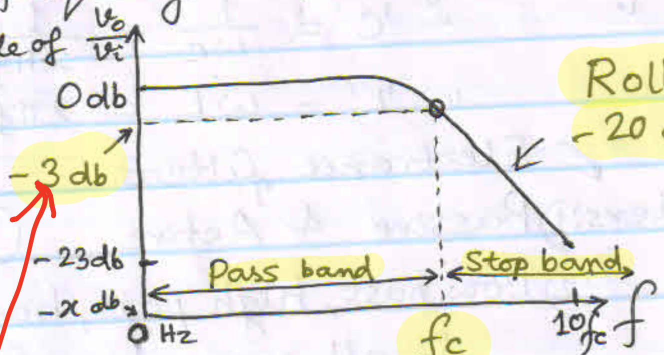
$$v_o = v_i \times \left(\frac{Z_2}{Z_1 + Z_2}\right)$$

$Z_1 = R$; $Z = \sqrt{R^2 + X_c^2}$

$Z_2 = X_c$

$$\Rightarrow v_o = v_i \cdot \frac{X_c}{Z}$$

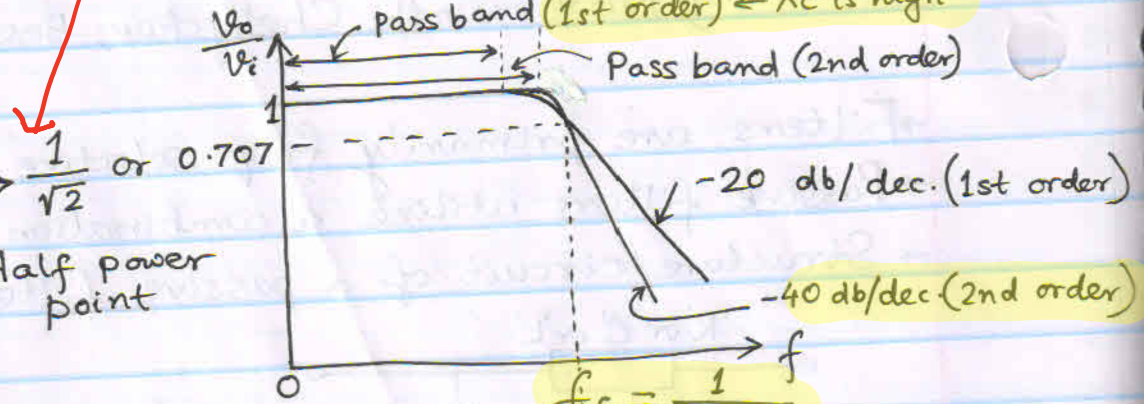
Low-pass frequency response:



$\underbrace{\left[20 \log_{10} \frac{v_o}{v_i}\right]}_{\text{Gain}}$

Roll-off rate -20 db/dec.

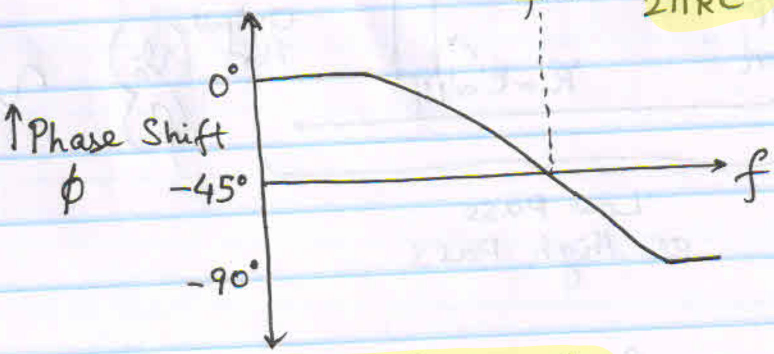
f_c Critical/Cut-off freq



Half power point

Bode plots

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

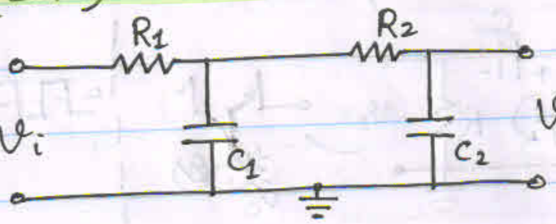


$$\phi = -\tan^{-1}(2\pi f RC)$$

$\tau = R.C$ [Time constant]

Low Pass Filter → Integrator

Second (2nd) order LPF (−40 db/dec. roll-off)

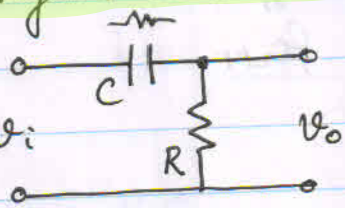


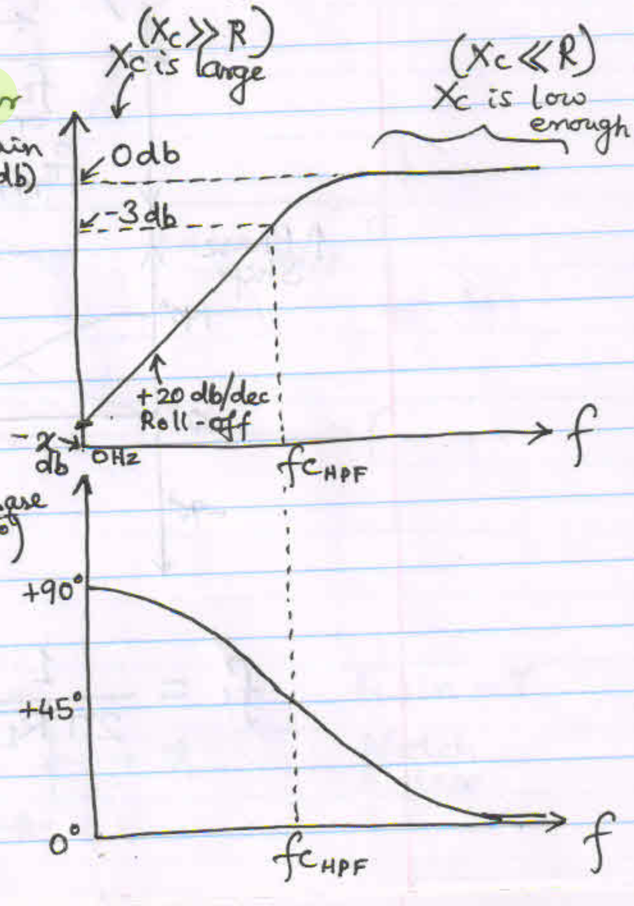
$$f_c = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

$$f_{(-3db)} \approx f_c \sqrt{2^{\left(\frac{1}{n}\right)} - 1} \qquad [n = \text{Order}]$$

Cascading of passive RC stages introduces attenuation. Max. O/P cannot be 0 db. It is less than 0 db in the passband (undesired). Therefore, active filters are used for larger/higher order filters.

2. High Pass Filter: 1st order (HPF)





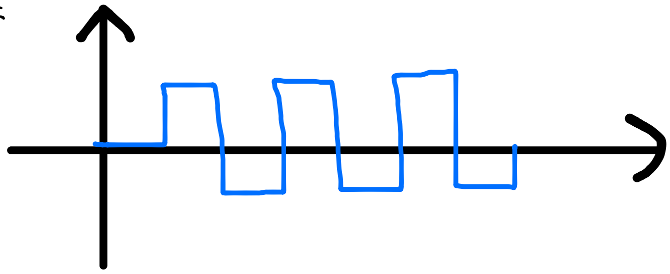
HPF → Differentiator

$$f_{c_{HPF}} = \frac{1}{2\pi RC}$$

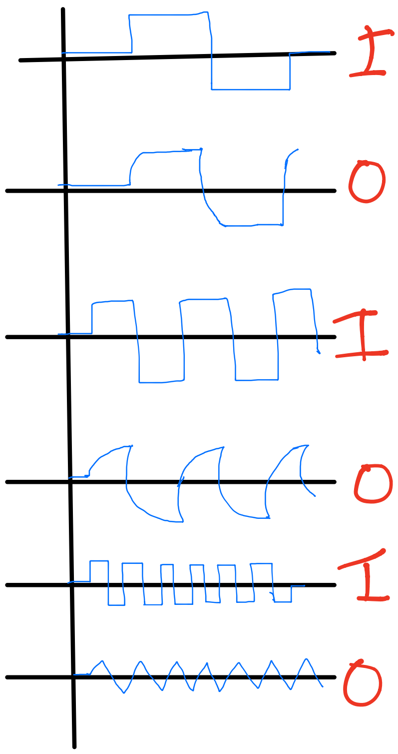
$$\phi = \tan^{-1}\left(\frac{1}{2\pi f RC}\right)$$

Sq. Wave Output

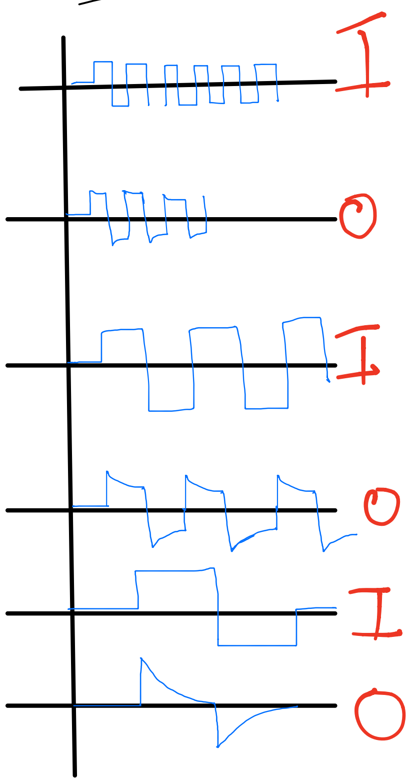
Input Wave



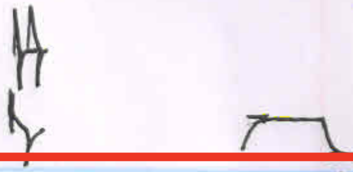
LPF



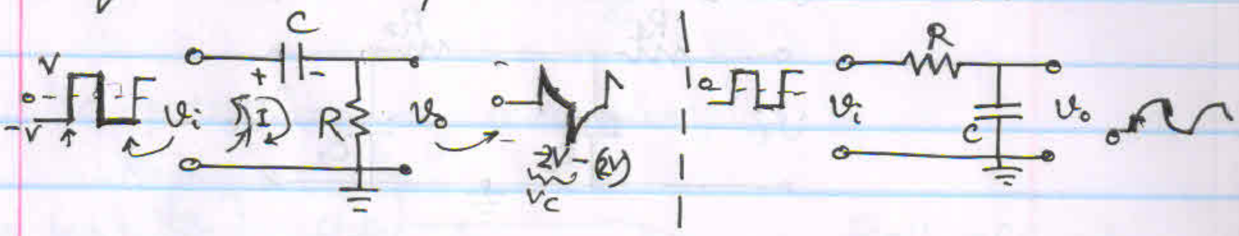
HPF



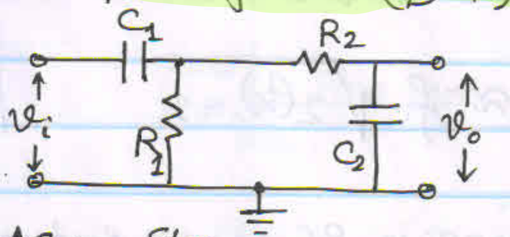
$V_m\left(1 - e^{\frac{-t}{RC}}\right)$



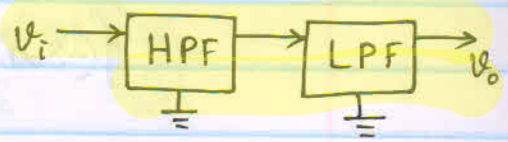
Square wave input: HPF LPF

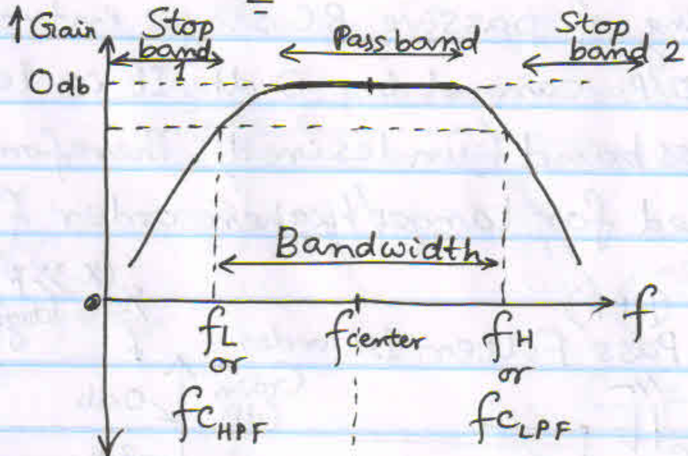


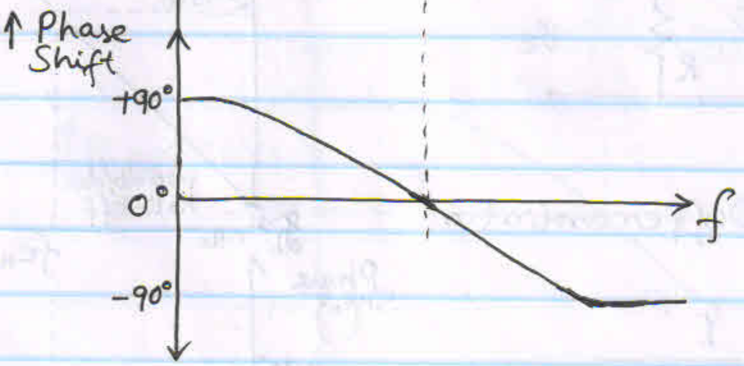
3. Band-pass filter (BPF):



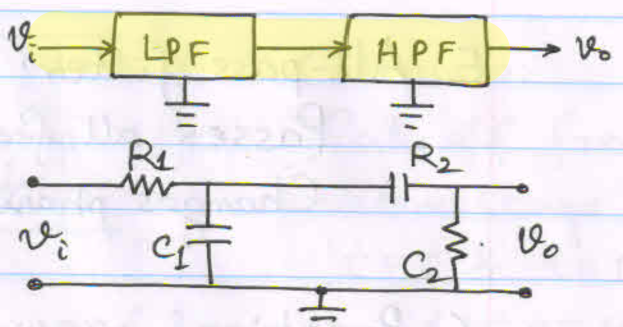
$\Rightarrow$



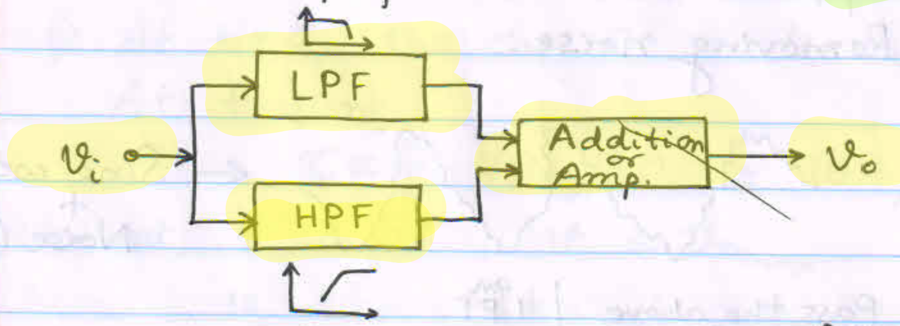


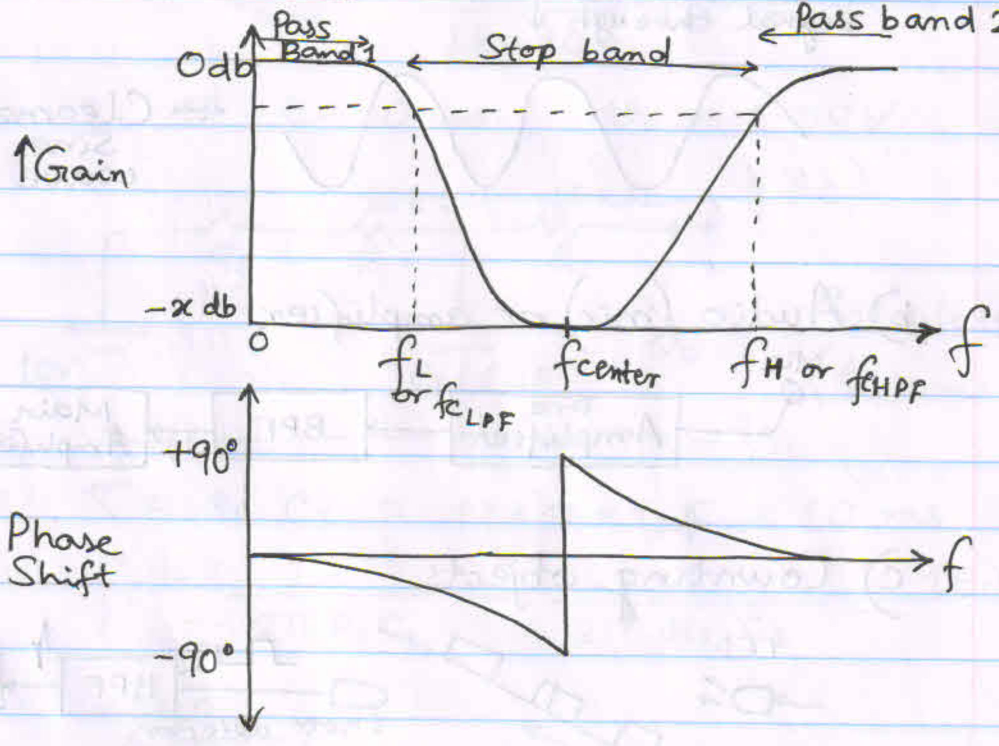


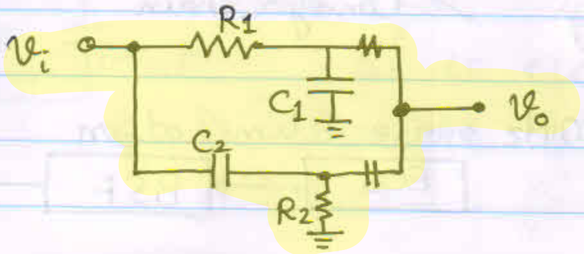
$$f_L = \frac{1}{2\pi R_1 C_1} \quad ; \quad f_H = \frac{1}{2\pi R_2 C_2}$$

BPF could also be: 

4. Band-stop filter: BSF or notch filter





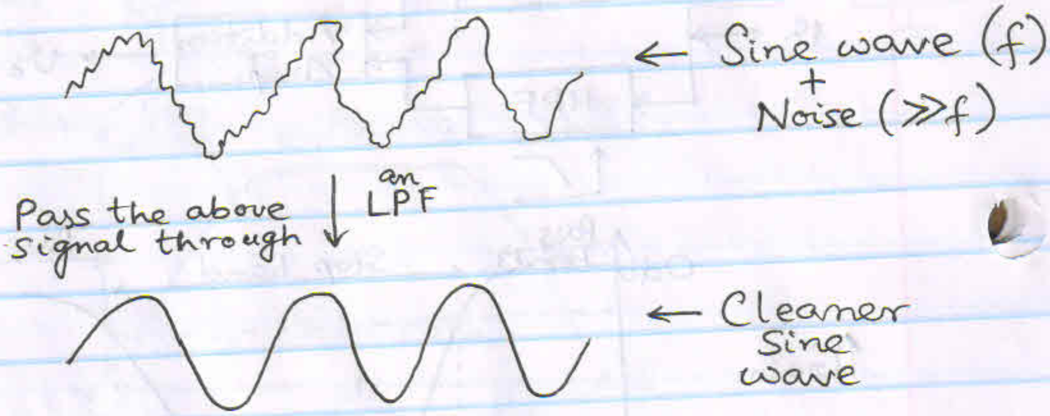
Ckt: 

Twin-T Notch Filter

5. All-pass filter: Usually active type.
Passes all freq. at a constant gain.
Changes phase shift w.r.t. freq.

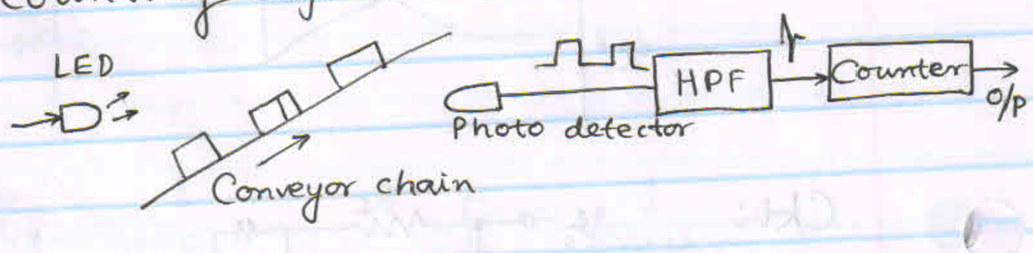
6. Practical view-points on filters:
Applications:

a) Removing noise:

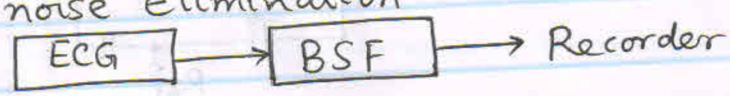


b) Audio (mic) or amplifier:

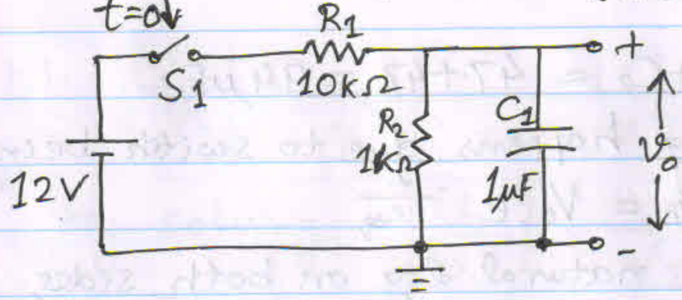
c) Counting objects:



d) 50 Hz noise elimination



Tutorial (RC Circuits)

1. 

Calculate:
i) Cut-off freq.
ii) O/P voltage at $t = 0$ & $t = 10\,ms$

Solⁿ i) $f_c = \dfrac{1}{2\pi (R_1 // R_2) C} = \dfrac{1}{2\pi \times (10k // 1k) \times 1\mu F} = 175.07\ Hz$ (Ans)

ii) At $t = 0$, the cap. C_1 is discharged; $v_o = 0V$ (Ans)

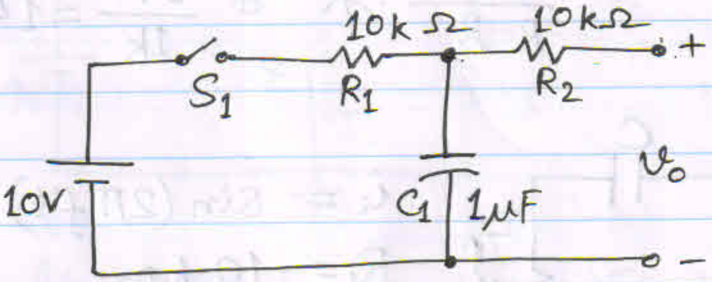
At $t = 10ms$:

$$\tau = (R_1 // R_2) . C_1 = 909\ \mu s$$

at, $t \geqslant 5\tau$, $v_o \approx v_{o_{max}}$

$$v_{o_{max}} = \frac{1k}{1k + 10k} . 12 = 1.09\ V$$

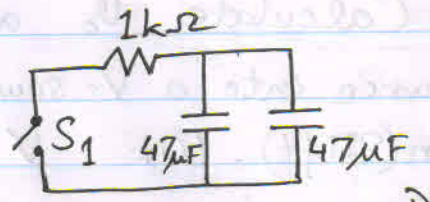
$\therefore$ at $t = 10\ ms$, $v_o = 1.09V$ (Ans)

2. 

Calculate τ & f_c
(Assume $R_L = \infty$)

Solⁿ. $\tau = R_1 . C_1 = 10k\Omega \times 1\mu F = 10\ ms$ (Ans)

$$f_c = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi\ R_1\ C_1} = 15.91\ Hz \text{ (Ans)}$$

3. 

At $t = 0$, $v_c = 12V$ & S_1 is closed

i) Calculate time when $V_c = 6V$
ii) Calc. P_{max} for the resistor.

Sol^n. i) $C_{eq} = C_1 + C_2 = 47 + 47 = 94\,\mu F$

Discharging happens due to switch being closed.

$$\therefore v_c = V_0 . e^{-\frac{t}{RC_{eq}}}$$

Taking natural log on both sides,

$$\ln\left(\frac{v_c}{V_0}\right) = -\frac{t}{R.C_{eq}}$$

$$\Rightarrow t = -R.C_{eq}.\ln\left(\frac{v_c}{V_0}\right)$$

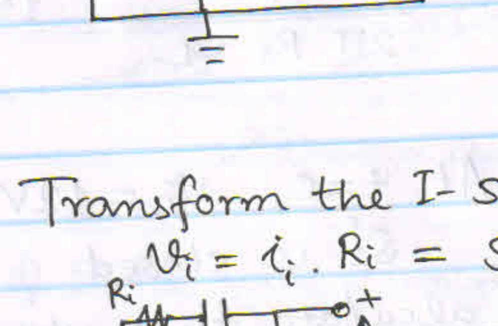
$$= -1k.94\mu.\ln\left(\frac{6}{12}\right) = 65.15\ ms \quad \text{(Ans)}$$

ii) Power rating of a resistor:

$$P_{max} = I_{peak}^2 . R$$

$$= \frac{V_{peak}^2}{R.\cancel{R}}.\cancel{R} = \frac{144}{1k} = 144\ mW \quad \text{(Ans)}$$

4.



$i_i = \sin(2\pi f t)\ mA$

$R_i = 10\ k\Omega$

$f = 10\ kHz\ \&\ 100\ kHz$

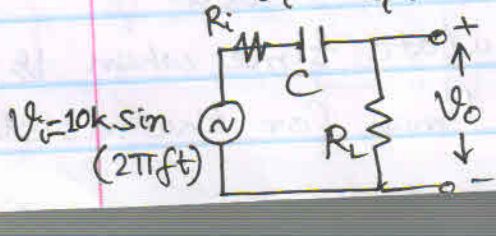
$C = 2.2\ nF$

$R_L = 10\ k\Omega$

Calculate v_o at f.

Sol^n. Transform the I-source into a V-source.

$$v_i = i_i . R_i = \sin(2\pi f t) . 10k \quad V$$



$$\left|\frac{v_o}{v_i}\right| = \frac{R_L}{\sqrt{R_L^2 + (X_C + R_i)^2}}$$

by solving, $\left|\frac{v_o}{v_i}\right| = \frac{\omega R_L C}{\sqrt{1 + \omega^2 C^2 (R_i + R_L)^2}}$

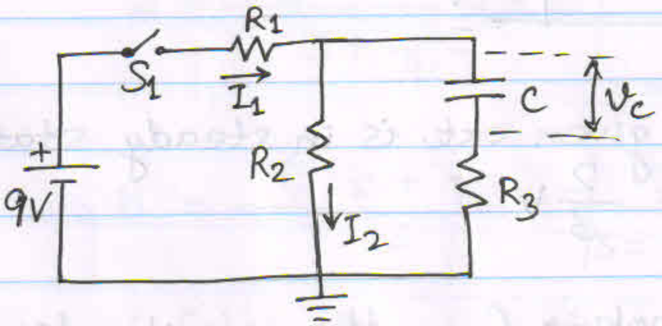
At 10 kHz, $\left|\frac{v_o}{v_i}\right| = 0.47$

$\therefore v_o\Big|_{10kHz} = 4.7 \sin(20 \times 10^3 \pi t)$ V (Ans)

At 100 kHz, $\left|\frac{v_o}{v_i}\right| = 0.499$

$\therefore v_o\Big|_{100kHz} = 5 \sin(20 \times 10^4 \pi t)$ V (Ans)

5.



$v_c = 0$ at $t<0$

$R_1 = 10\,k\Omega$

$R_2 = 10\,k\Omega$

$R_3 = 1\,k\Omega$

$C = 10\,\mu F$

At $t=0$, S_1 is closed i) Find I_1 & I_2 at $t = 0, 1s$.

At $t = 2s$, S_1 is opened ii) " " " " " $t = 2s$.

Sol^n i) At $t=0$, C is like a short.

$$I_1\Big|_{0s} = \frac{9}{R_1 + (R_2 // R_3)} = \frac{9}{10k + (10k//1k)} = 0.825\,mA$$

$$I_2\Big|_{0s} = \frac{R_3 \cdot I_{1(0s)}}{R_2 + R_3} = \frac{1k \times 0.825m}{10k + 1k} = 75\,\mu A$$

$$\tau = R_{eq} \cdot C = [(R_1 // R_2) + R_3] \cdot C = 6k \cdot 10\mu = 60\,ms$$

$\because$ $1s \gg \tau$

At 1s, C is fully charged at 4.5V → No 'I' through C.

$\therefore I_{1(1s)} = I_{2(1s)} = \frac{9}{R_1+R_2} = \frac{9}{20k} = 0.45 mA$ (Ans)

ii) At t=2s, battery is disconnected.

$I_{1(2s)} = 0$

$I_{2(2s)} = \frac{4.5}{R_2+R_3} = \frac{4.5}{10k+1k} = 409 \mu A$