PH3104
PS10

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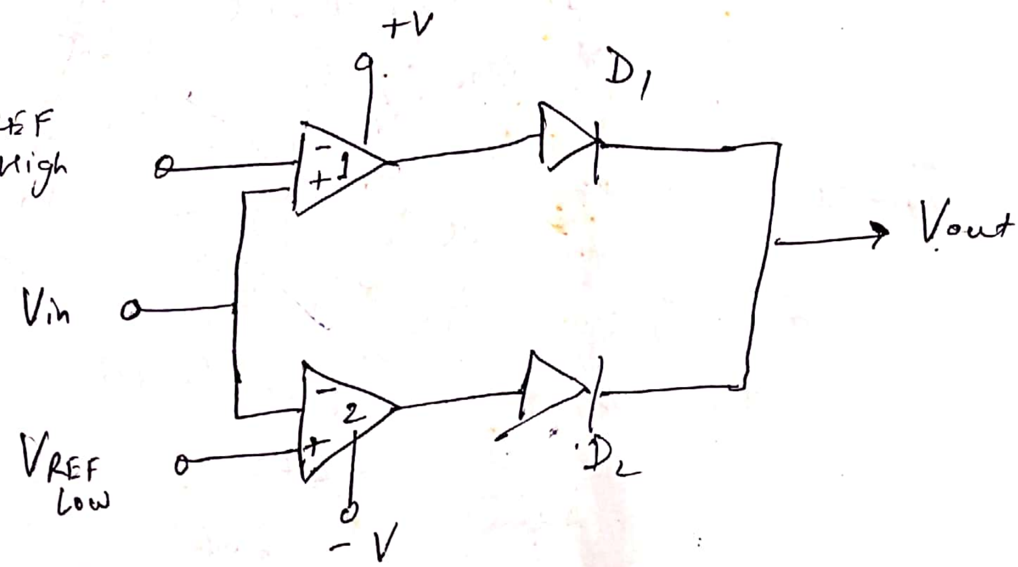
19MS151

Q1



Case I :- $V_{IN} < V_{REF}$ (High) , $V_{in} < V_{REF}$(Low)

Output of op amp(1) is negative ($-V_{sat}$) which makes D_1 reverse biased.
Op amp (2) output is positive $\Rightarrow D_2$ is forward biased.

$V_{out} = V_{sat}$

Case II :- $V_{IN} > V_{REF}$(high) , $V_{in} > V_{REF}$ (low)

Op amp (1) output is positive $\Rightarrow D_1$ is forward biased.
Op amp (2) is negative $\Rightarrow D_2$ is reverse biased.

$V_{out} = V_{sat}$

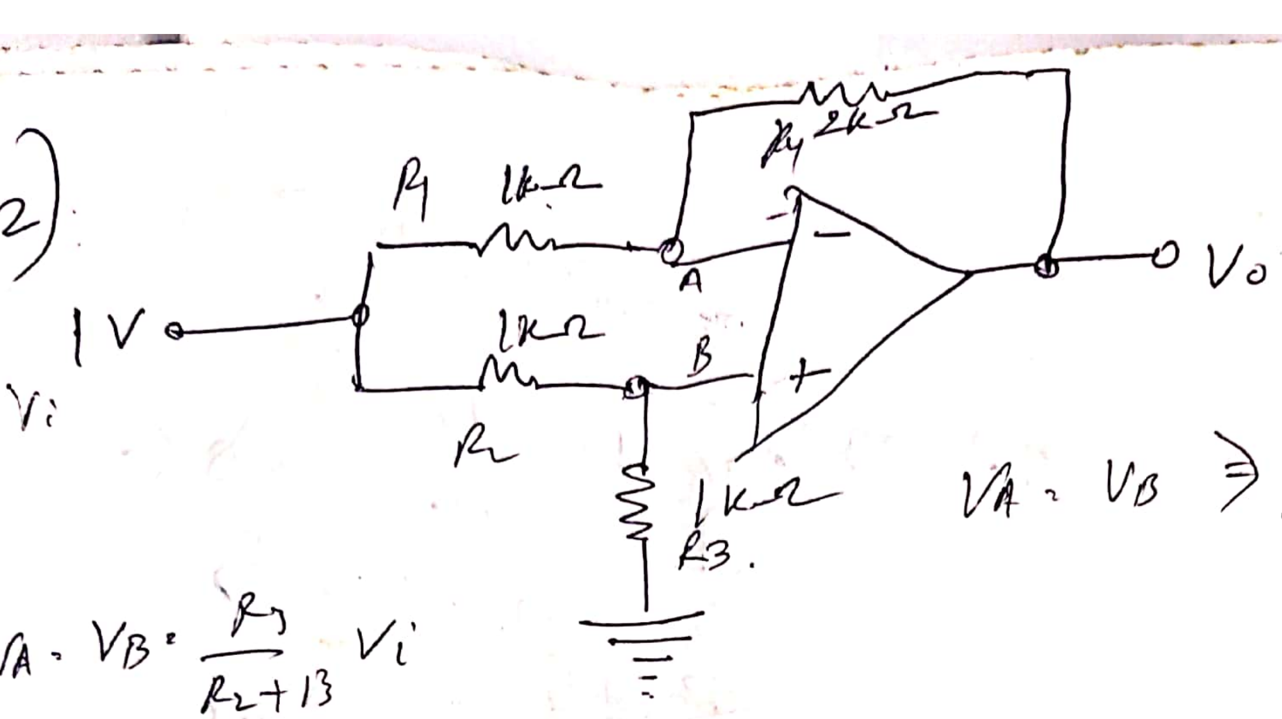
Case III :- V_{REF} (low) < V_{in} < V_{REF} high.

Op amp (1) & (2) is negatively saturated,
D_1 & D_2 are reverse biased.

$V_{out} = 0$

The device works within a specific range.

2)



$V_A = V_B \Rightarrow$ vir ground.

$$V_A = V_B = \frac{R_3}{R_2+R_3} V_i$$

$$\frac{V_A - V_i}{R_1} + \frac{V_A - V_o}{R_4} = 0.$$

$$V_o = R_4\left(\frac{V_A}{R_1} + \frac{V_A}{R_4} - \frac{V_i}{R_1}\right)$$

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

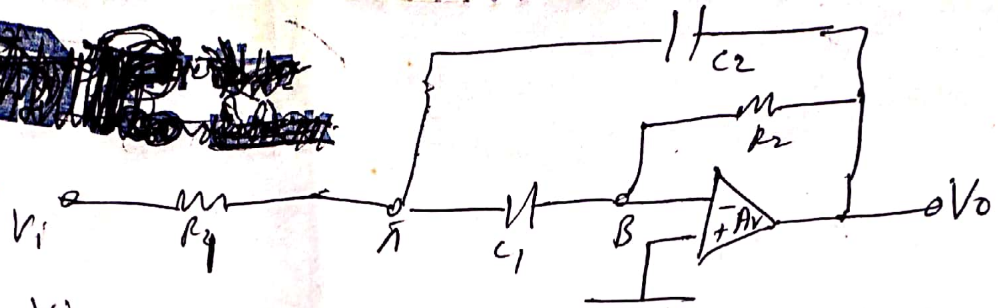
$$\Rightarrow \frac{V_o}{V_i} = \left(\frac{R_1R_3 - R_2R_4}{R_1(R_2+R_3)}\right)$$

$V_i = 1V$, $R_1 = R_2 = R_3 = 1k\Omega$, $R_4 = 2k\Omega$.

$$V_o = -0.5\, V_i = -0.5\ V$$

[redacted]

Q 7



$$\frac{V_A - V_i}{R_1} + \frac{V_A - V_o}{\frac{1}{j\omega C_2}} + \frac{V_A - V_B}{\frac{1}{j\omega C_1}} = 0$$

$$\frac{V_B - V_A}{\frac{1}{j\omega C_1}} + \frac{V_B - V_o}{R_2} = 0$$

$V_B = 0$ set virtual ground

$$-\frac{V_A}{\frac{1}{j\omega C_1}} = \frac{V_o}{R_2}$$

$$V_A = -\frac{V_o}{j\omega C_1 R_2}$$

$$\Rightarrow -\frac{V_i}{R_1} = \frac{V_o}{j\omega C_1 R_1 R_2} + \frac{V_o j\omega C_2}{j\omega C_1 R_2} + j\omega C_2 V_o + \frac{V_o}{R_2}$$

$$\frac{V_o}{V_i} = -\frac{j\omega C_1 R_2}{1 + j\omega R_1 (C_1 + C_2) + (j\omega)^2 C_1 C_2 R_1 R_2}$$

$$\Rightarrow \frac{V_o}{V_i} = \frac{\frac{-j\omega C_1 R_2}{R_1 R_2 C_1 C_2}}{\frac{1}{R_1 R_2 C_1 C_2} + \frac{j\omega R_1 (C_1 + C_2)}{R_1 R_2 C_1 C_2} + (j\omega)^2}$$

$$f_B = \frac{C_1 + C_2}{R_2 C_1 C_2}$$

Bandwidth

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

$$Q = \frac{f_c}{f_B} = \frac{\frac{1}{\sqrt{R_1 R_2 C_1 C_2}}}{\frac{R_2 C_1 C_2}{C_1 + C_2}} = \frac{(C_1 + C_2)}{\sqrt{R_1}} \cdot \frac{1}{(R_2 C_1 C_2)}$$

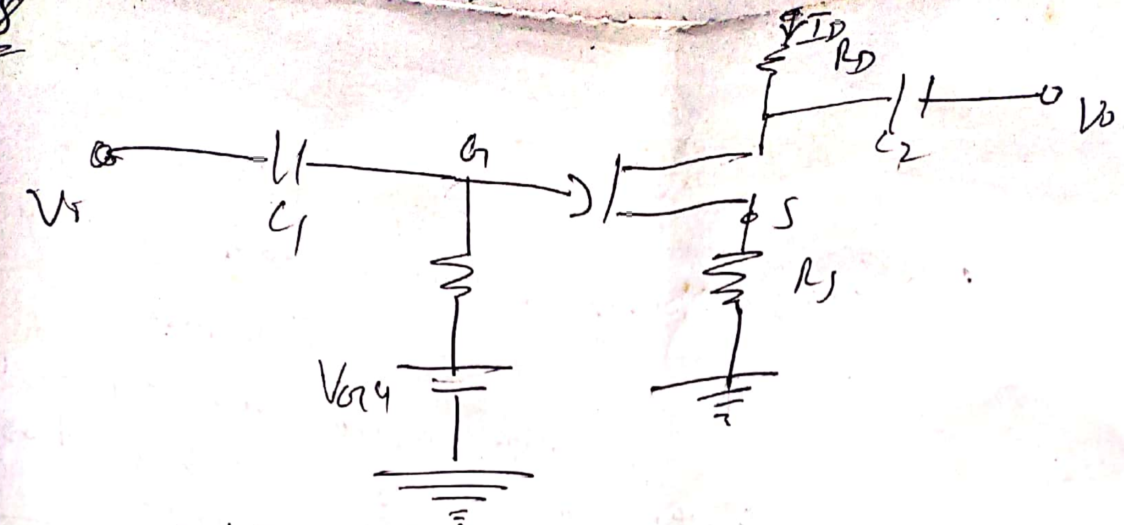
$C_1 = C_2 = C$.

$$\Rightarrow Q = \frac{2C}{\sqrt{R_1}} \frac{1}{(R_2)^{3/2} C^3}$$

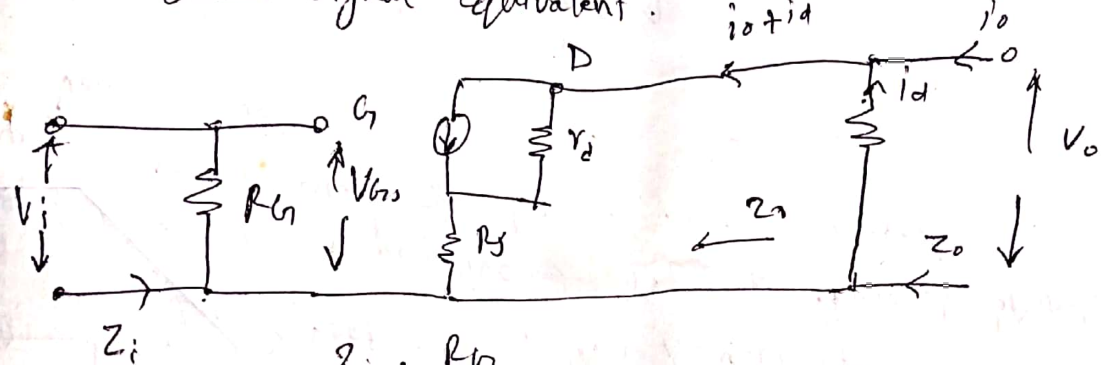
$$= \frac{2}{\sqrt{R_1}(R_2)^{3/2} C^2}$$

narrow band

Q8



Small signal equivalent.



$Z_i = R_G$.

$Z_o = Z_o' \,||\, R_D$ — output impedance

$Z_o' = (r_d + R_S(1 + g_m r_d)) \,||\, R_D$.

$$Z_o = \frac{R_D}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}$$

KCL at D.

$$I_o + i_d = i' + g_m V_{gs}.$$

$$i_o = g_m V_{gs} + \frac{V_o + V_{gs}}{r_d} - I_D$$

$$V_o = - i_d R_D.$$

$$I_o = g_m V_{gs} + \frac{V_{gs}}{r_d} - \frac{I_D R_D}{r_d} - I_D$$

$$I_o = \left(g_m + \frac{1}{r_d}\right) V_{gs} - \frac{I_D R_D}{r_d} - I_D$$

$$V_{gs} = -(I_o + I_D) R_S.$$

$$\Rightarrow I_o \left(1 + g_m R_S + \frac{R_S}{r_d}\right) = -I_D\left(1 + g_m R_S + \frac{R_S}{r_d} + \frac{R_D}{r_d}\right)$$

$$Z_o = \frac{V_o}{I_o} = -\frac{R_D \cancel{\left(1 + g_m R_S + \frac{R_S}{r_d}\right)}}{1 + g_m R_S + \frac{R_S}{r_d} + \frac{R_D}{r_d}}$$

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$$Z_o = \frac{(r_d(1+g_mR_S)+R_S)R_D}{r_d(1+g_mR_S)+R_S+R_D}$$

KVL at input

$$V_i - V_{gs} - V_{RS} = 0$$

$$\Rightarrow V_{gs} = V_i - I_D R_S$$

KVL at output

$$V_{rd} = V_o - V_{RS}$$

$$\Rightarrow I' = \frac{V_o - V_{RS}}{r_d}$$

KCL at D

$$I_d = I' + g_m V_{gs}$$

$$= g_m(V_i - I_D R_S) - \frac{I_D R_D + I_D R_S}{r_d}$$

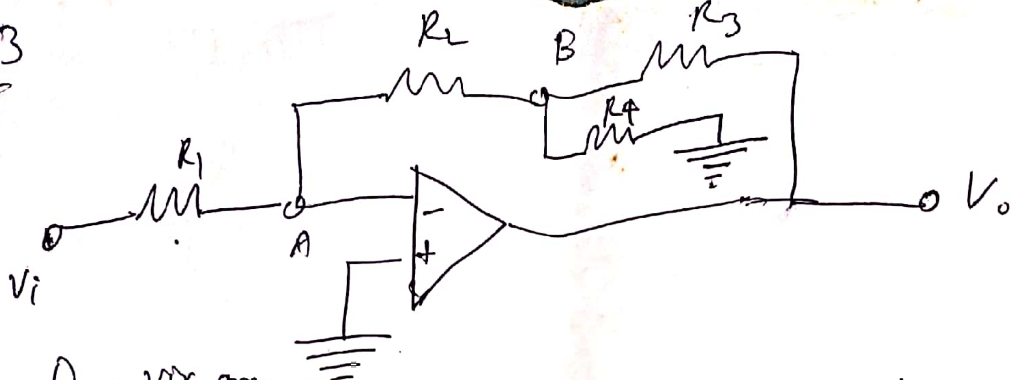
$$\Rightarrow I_D = \frac{g_m V_i}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}$$

$$V_o = \frac{-g_m R_D V_i}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}$$

$$\Rightarrow A_v = \frac{V_o}{V_i} = \frac{-g_m R_D}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}$$

Amp

Q3



$V_A = 0$ -- vir groun

$$\frac{V_B - V_o}{R_3} + \frac{V_B}{R_4} + \frac{V_B}{R_2} = 0 \Rightarrow V_B = \frac{V_o}{R_3\left(\frac{1}{R_4}+\frac{1}{R_2}+\frac{1}{R_3}\right)}$$

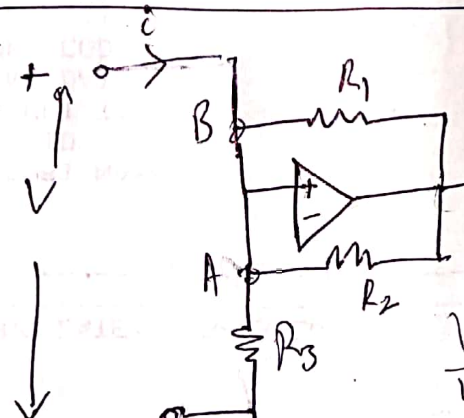
&

$$\frac{V_A - V_i}{R_1} + \frac{V_A - V_B}{R_2} = 0 \Rightarrow V_B = -\frac{R_2}{R_1} V_i$$

$$\Rightarrow \frac{V_o}{V_i} = \frac{-R_2 R_3}{R_1}\left(\frac{1}{R_4}+\frac{1}{R_2}+\frac{1}{R_3}\right)$$

This is an improvement over standard Inverting op-amp as its a better approximation for current to not flow into the op-amp.

Q4



$$i = \frac{V_o - V_i}{R_1}$$

$$V_i + \frac{V_i}{R_3} R_2 = V_o$$

$$\frac{V_o}{V_i} = 1 + \frac{R_2}{R_3} = A_0$$

Hus

$$\Rightarrow V_o = \begin{cases} V_{sat}, & V_i > \frac{V_{sat}}{1+R_2/R_3} \\ \left(1+\frac{R_2}{R_3}\right)V_i, & \frac{-V_{sat}}{1+R_2/R_3} \leq V_i \leq \frac{V_{sat}}{1+R_2/R_3} \\ -V_{sat}, & V_i < \frac{V_{sat}}{1+R_2/R_3} \end{cases}$$

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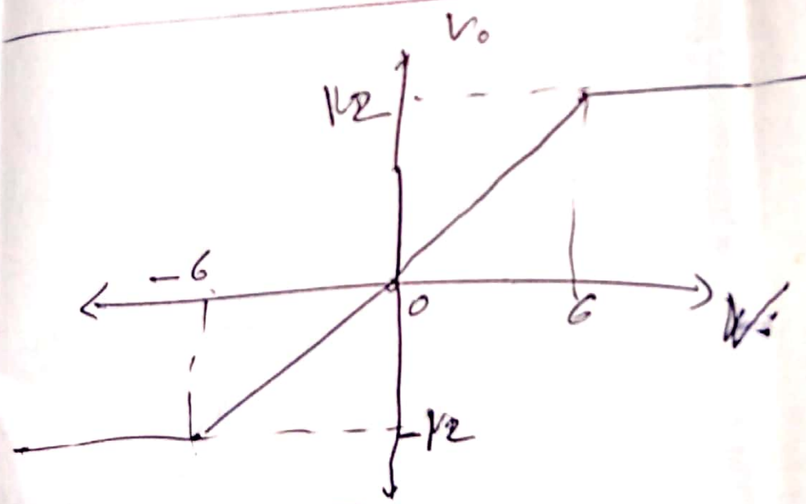
$$i = \begin{cases} \dfrac{V_{sat} - V_i}{R_3}, & V_i > \dfrac{V_{sat}}{1 + R_2/R_3} \\ \dfrac{-V_{sat} \pm V_i}{R_3}, & V_i < V_{sat}/1 + R_2/R_3 \\ \dfrac{R_2}{R_1 + R_3} V_i, & -\dfrac{V_{sat}}{1 + \frac{R_2}{R_3}} < V_i < \dfrac{V_{sat}}{1 + \frac{R_2}{R_3}} \end{cases}$$

$R_1 = R_2 = R_3 = 1k$, $V_{sat} = 12V$.

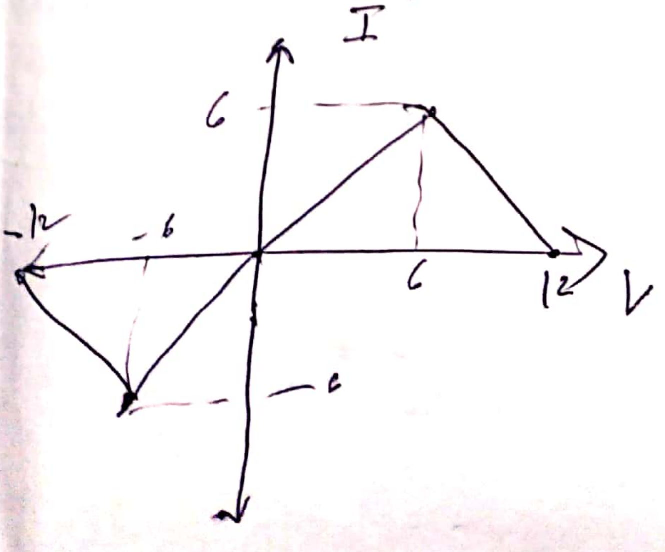
$A_v = 1 + 1 = 2$.

$$V_0 = \begin{cases} 12, & V_i > 6\ V \\ 2V_i, & -6V < V_i < 6V \\ -12, & V_i \le -6V. \end{cases}$$

$$i = \begin{cases} (12 - V_i)\ mA, & V_i \ge 6V \\ V_i\ mA, & -6V \le V_i \le 6V \\ -(12 + V_i)\ mA, & V_i \le -6V \end{cases}$$

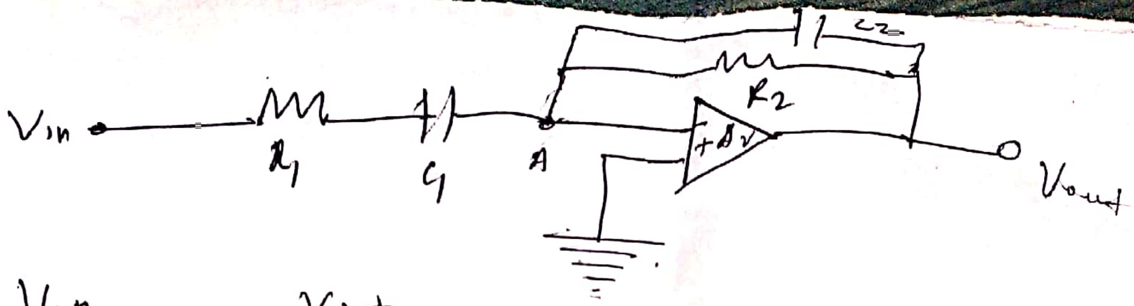


V_0 vs V_i



i vs V.

Q6



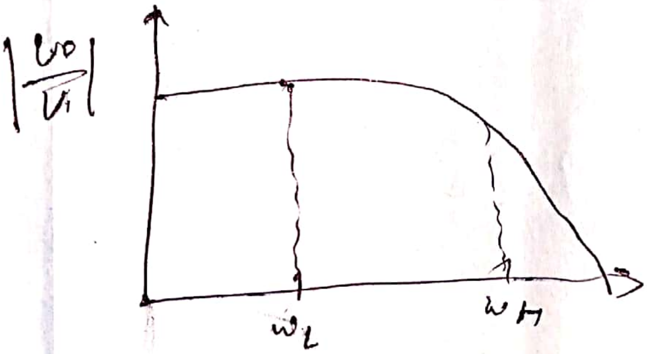
$$\frac{V_{in}}{R_1 + \frac{1}{j\omega C_1}} = -\frac{V_{out}}{R_2 \parallel \frac{1}{j\omega C_2}}$$

$$\frac{V_{out}}{V_{in}} = -\frac{R_2 \parallel \frac{1}{j\omega C_2}}{R_1 + \frac{1}{j\omega C_1}} = -\frac{\frac{R_2 / j\omega C_2}{R_2 + \frac{1}{j\omega C_2}}}{R_1 + \frac{1}{j\omega C_1}}$$

$$= -\left(\frac{1}{1+j\omega R_2 C_2}\right)\left(\frac{j\omega R_2 C_2}{1+j\omega R_1 C_1}\right)$$

$$\omega_L = \frac{1}{R_1 C_1}, \quad \omega_H = \frac{1}{R_2 C_2}$$

Low cutoff   High cutoff



Sorry for late, loadshedding !!

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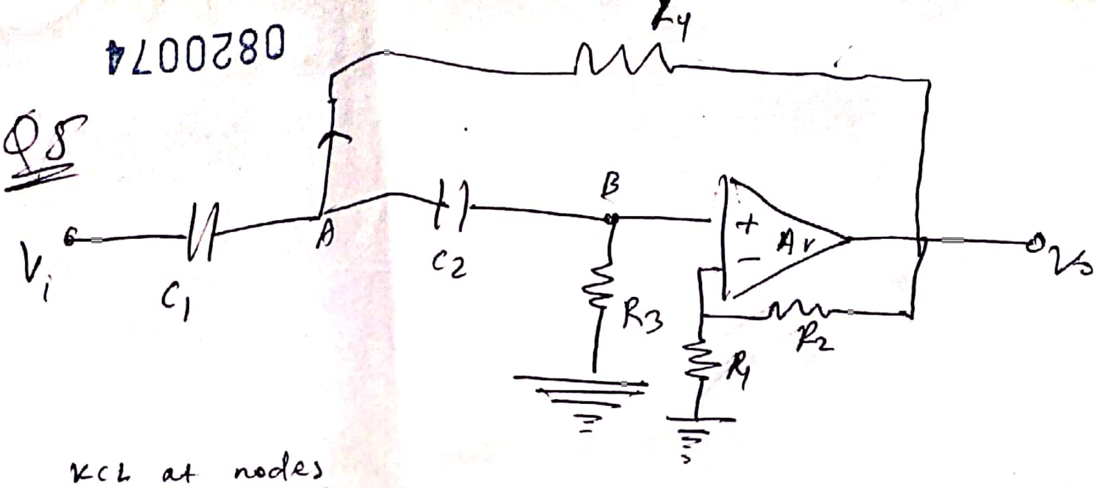
Q8



KCL at nodes

$$\frac{V_A - V_i}{\frac{1}{j\omega C_1}} + \frac{V_A - V_o}{R_4} + \frac{V_A - V_B}{\frac{1}{j\omega C_2}} = 0.$$

$$\frac{V_B - V_A}{\frac{1}{j\omega C_2}} + \frac{V_B}{R_3} = 0. \qquad \Rightarrow V_B = \frac{R_1}{R_1+R_2} V_o.$$

$$\left(\frac{R_1}{R_1+R_2} V_o - V_A\right) j\omega C_2 + \frac{R_1 V_o}{R_3(R_1+R_2)} = 0$$

$$\Rightarrow V_A = \frac{V_o R_1}{R_1+R_2}\left(1 + \frac{1}{C_2 j\omega R_3}\right)$$

$$\Rightarrow V_o\left(\frac{j\omega C_1}{R_1+R_2}\left(1+\frac{1}{j\omega C_2 R_3}\right) + \frac{V_o R_1}{R_4(R_1+R_2)}\left(1+\frac{1}{j\omega C_2 R_3}\right) - \frac{V_o}{R_4} + \frac{V_o R_1}{R_3(R_1+R_2)}\right) = j\omega C_1 V_i$$

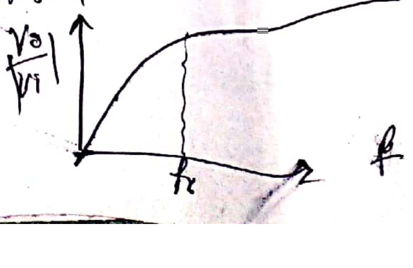
$$\frac{V_o}{V_i} = \frac{\left(1+\frac{R_2}{R_3}\right)(j\omega)^2 C_1 C_2 R_3 R_4}{R_3 R_4 C_1 C_2 (j\omega)^2 + \left(R_4 C_1 + R_4 C_2 - \frac{R_2}{R_1} R_3 C_2\right) j\omega + 1}$$

$$\frac{V_o}{V_i} = \frac{A j\omega}{j\omega + \omega_0}$$

$$\frac{V_o}{V_i} = \frac{\frac{R_1+R_2}{R_1}}{1 + \frac{1}{(j\omega)^2 C_1 C_2 R_3 R_4} + \frac{\left(R_4(C_1+C_2) - \frac{R_2 R_3}{R_1}\right)}{(j\omega) C_1 C_2 R_3 R_4}}$$

$\frac{V_o}{V_i} \to 0,\ \omega \to 0$ $\qquad \omega \to \infty \Rightarrow \frac{V_o}{V_i} \to$ max.

$\omega_0^2 = \frac{1}{C_1 C_2 R_3 R_4}$ ..- cut-off $\qquad \Rightarrow f_c = \frac{1}{2\pi\sqrt{C_1 C_2 R_3 R_4}}$



active high band