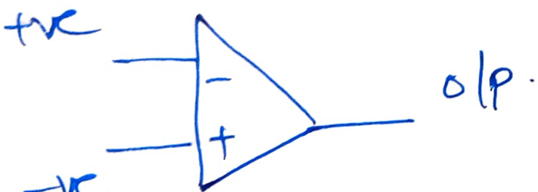
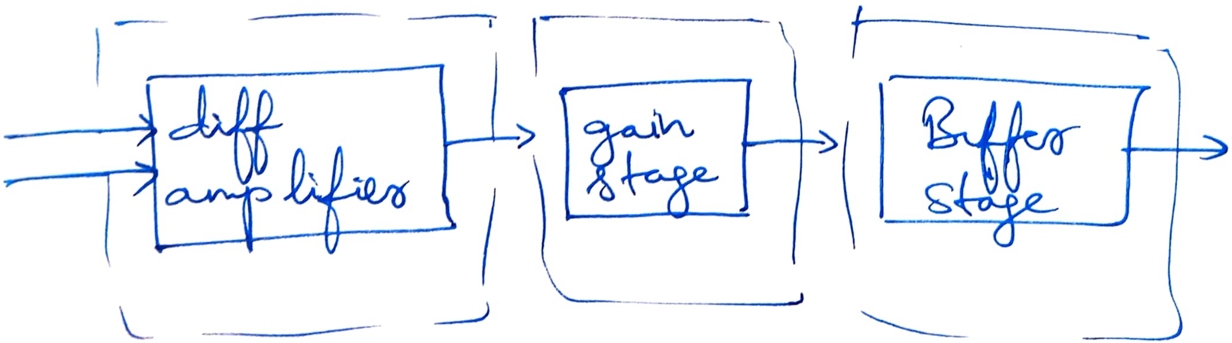
Design of 2 staged OPAMP



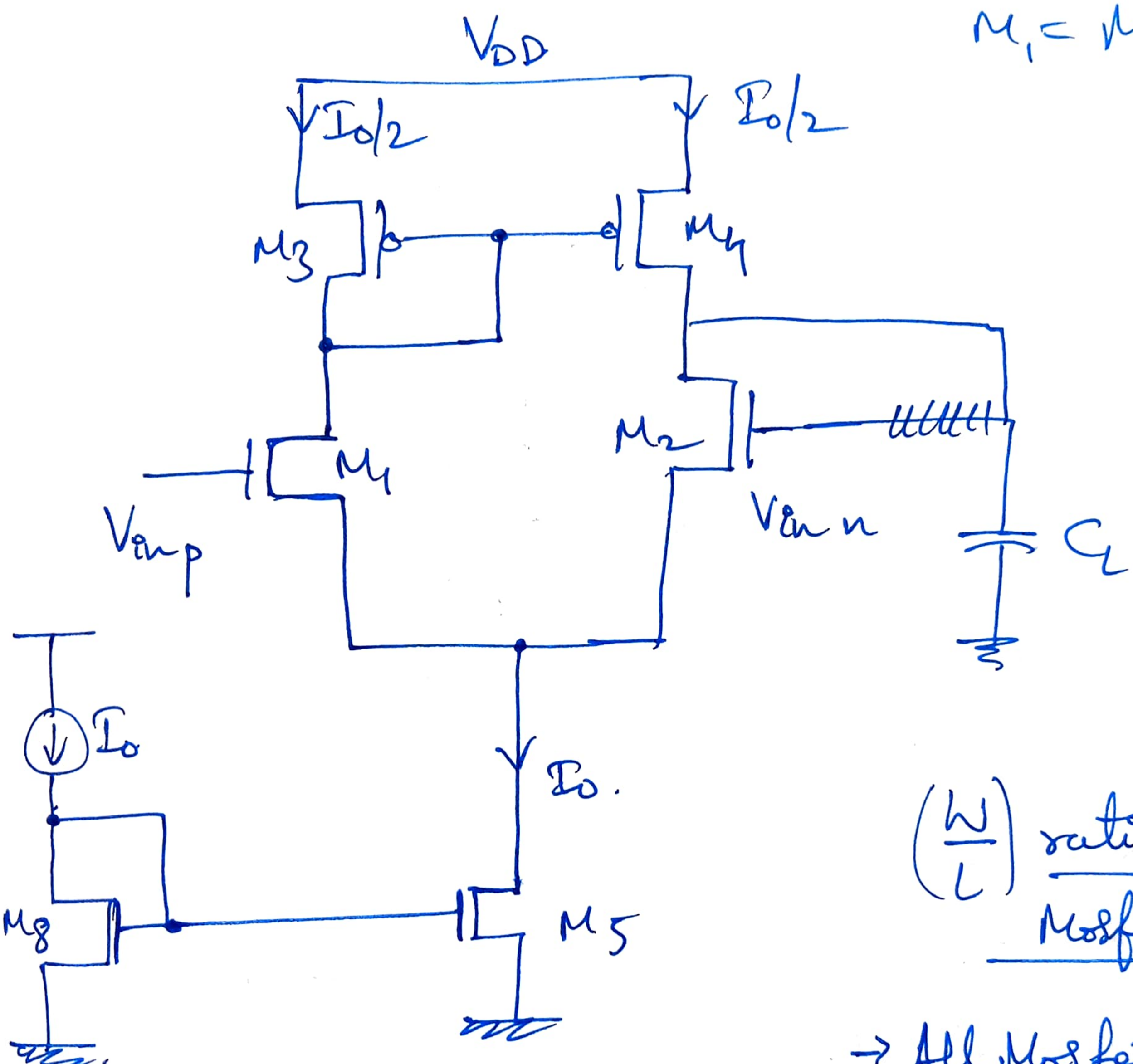
differential i/p

differential amp.



differential Amplifier :-

$M_3 = M_4$ } symmetric
$M_1 = M_2$ }



$\left(\frac{W}{L}\right)$ ratio of all Mosfets

→ All Mosfets in saturation

→ I_0 → slew rate

→ M_3, M_4 → ICMR +

→ M_1, M_2 → Gain Bandwidth Product

→ M_5 → ICMR −

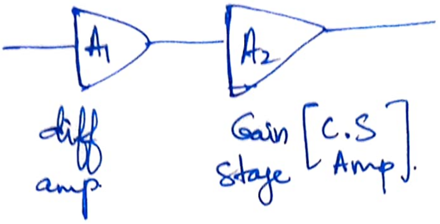
→ M_8 → I_0 & M_5

$\frac{dV}{dt}$; $\cancel{C = q}$ $Q = CV$

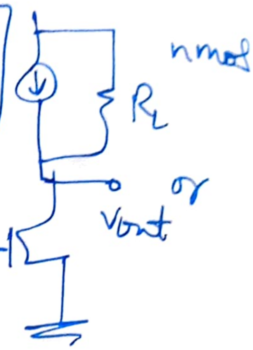
$I = C\frac{dV}{dt}$

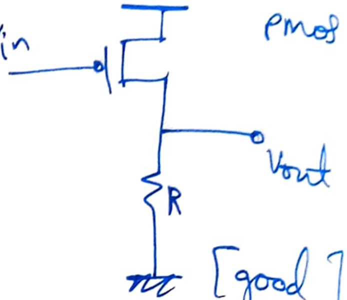
$$\boxed{\frac{dV}{dt} = \frac{I_0}{C_L} = \text{slew rate}}$$

Design a 2 Staged OPAMP

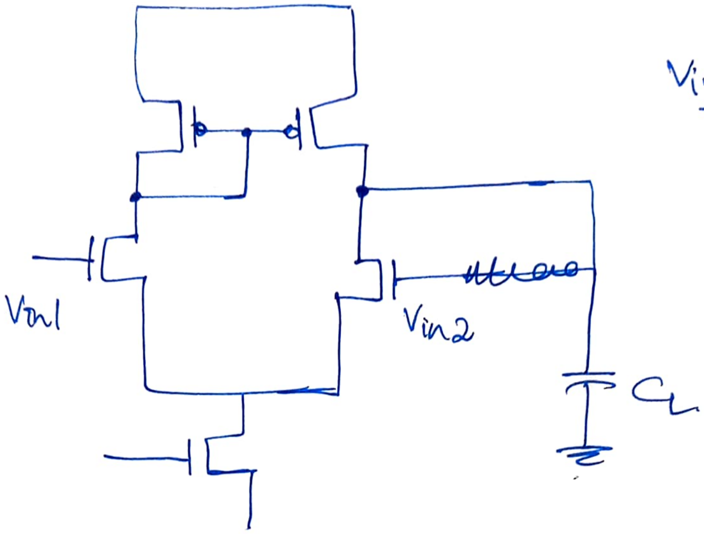


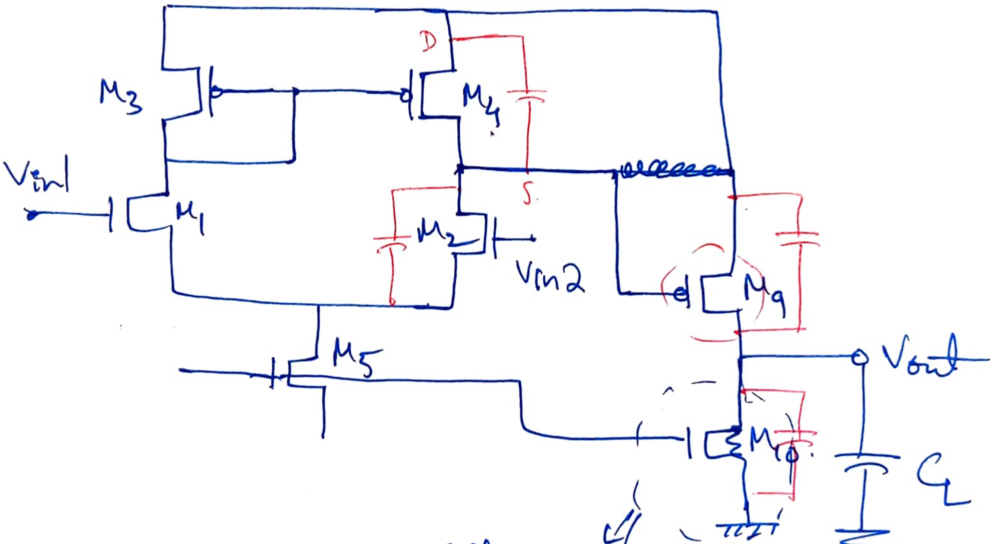
[Swing will be limited]





[good swing]

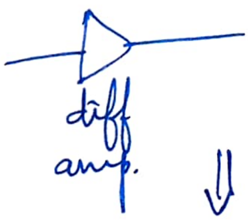




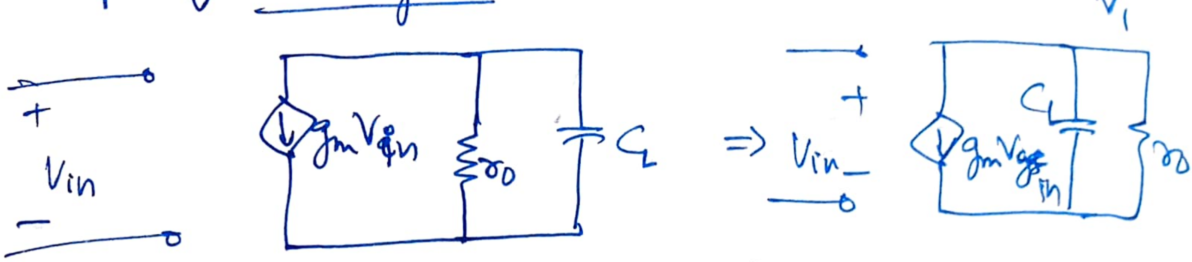
This MOSfet has been used inst-ead of Resistors we implemented a current source using MOSFET

generally each cap of mosfet (D-S) will be present but at 2nd stage ~~it will be~~ the load cap will be very large compared to mosfet ones so neglect

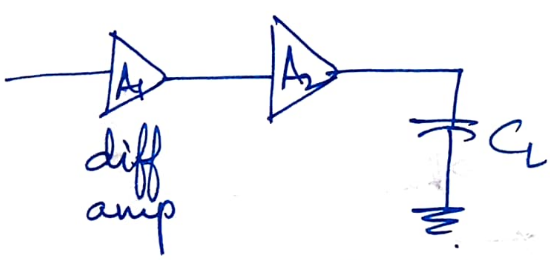
Problem 2

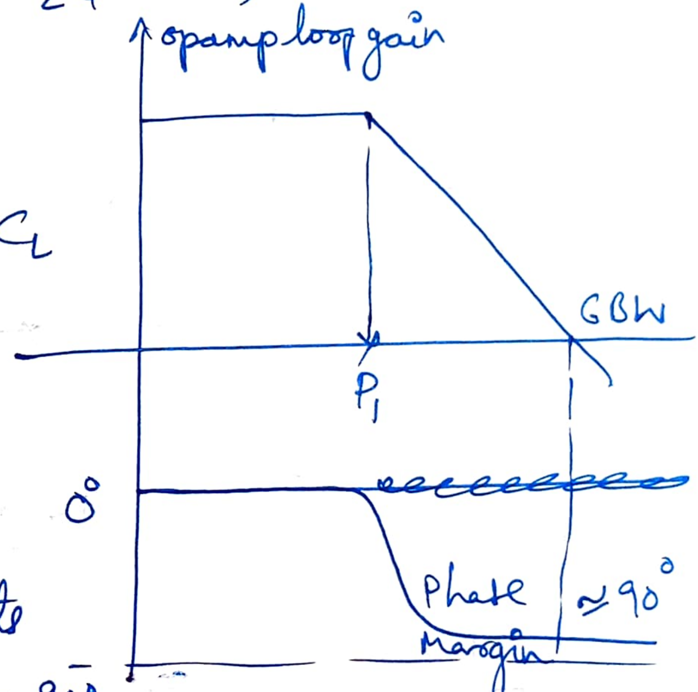


⇓ Small Signal



r_{o1} = resistance of M_4 & M_2 (parallel)

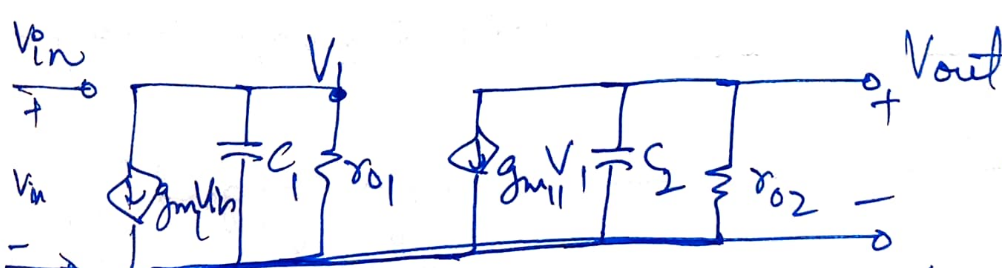




C_1 – Capacitance of DS of Mosfet M_4, M_2

$C_2 \simeq C_L$

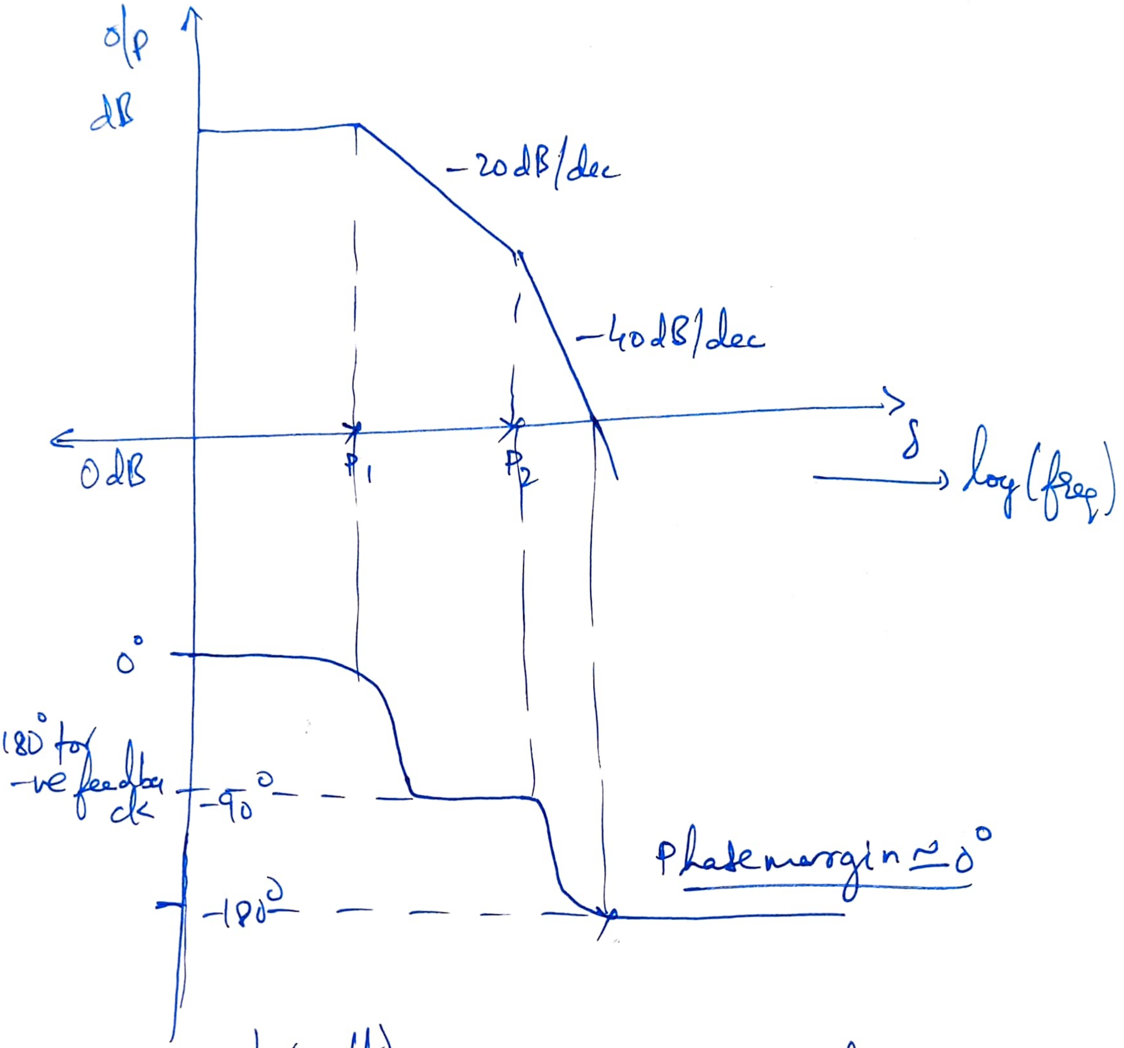
r_{o2} = resistance of Mosfets M_9 parallel to M_{10}



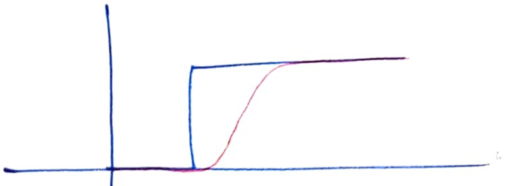
2port N/w.

$$P_1 = \frac{1}{r_{o1} C_1}$$

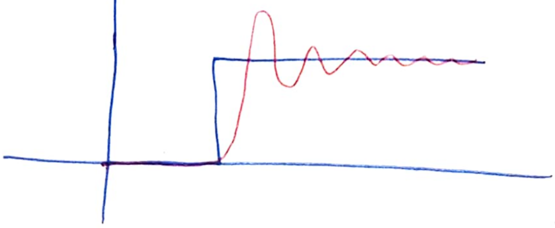
$$P_2 = \frac{1}{r_{o2} C_2}$$



for u(t)



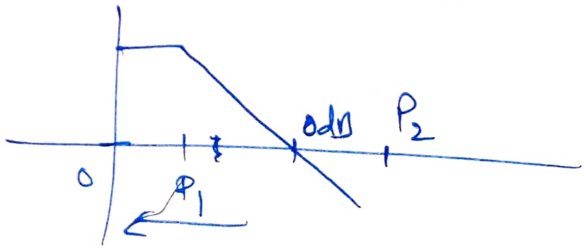
for very good phase margin



for not good phase margin

$\left.\begin{array}{l}60^\circ \rightarrow \text{very good} \\ 45^\circ \rightarrow \text{min}\end{array}\right\}$ phase margin

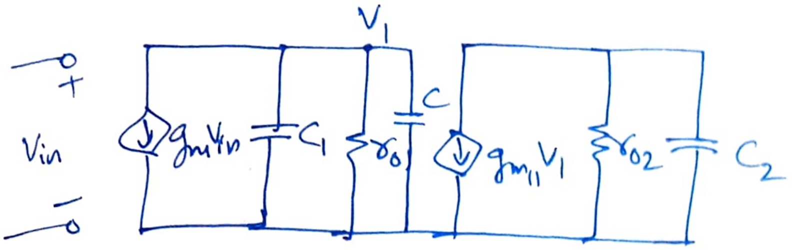
$P_1 \rightarrow$ dominant Pole we move it back such that gain crosses 0dB before P_2



$P_1 = \frac{1}{r_{o1} C_1}$; $P_2 = \frac{1}{r_{o2} C_2}$

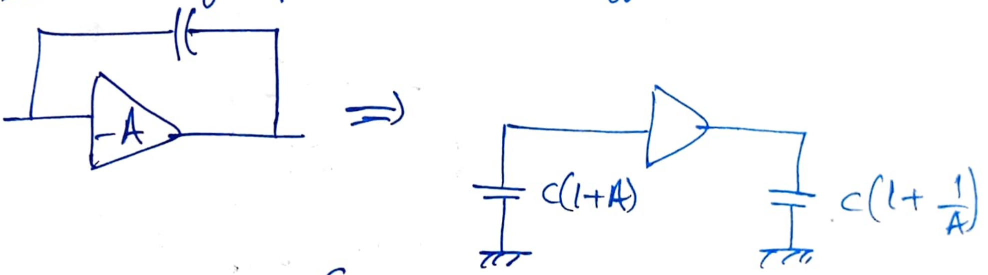
C_1 can be changed

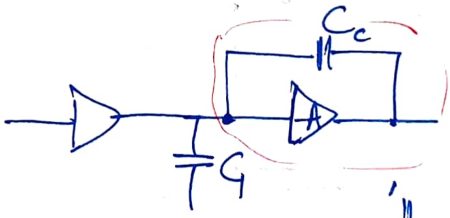
$C_1 \uparrow \quad P_1 \downarrow$



$P_1 = \frac{1}{r_{o1} C_1} \sim \frac{1}{r_{o1}(C_1 + C_2)}$ $\quad C \rightarrow$ should be bigger

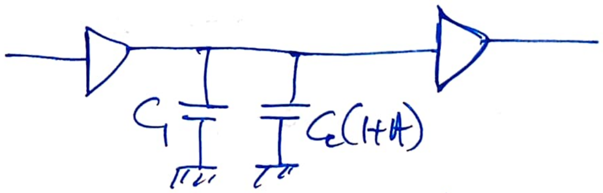
<u>To avoid big cap we use Miller Effect</u>



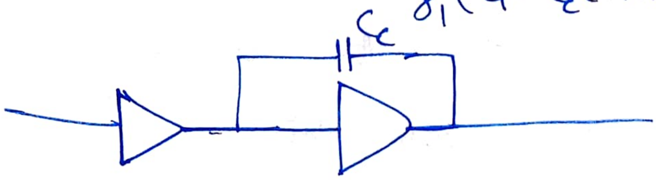


<u>Miller Capacitor!</u>

$\Downarrow$

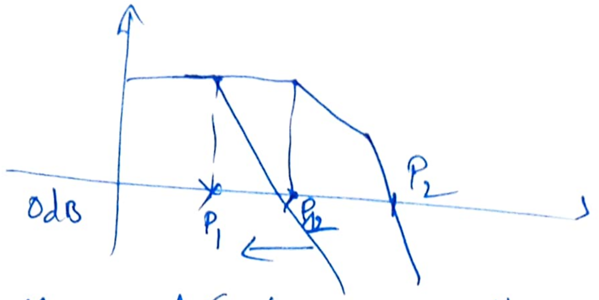


$P_1 = \frac{1}{r_1(C_1 + C_c(1+A))}$

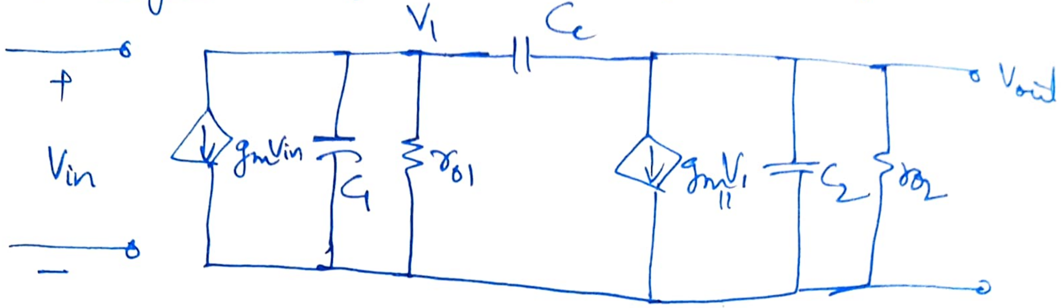


Initial $P_1 = \frac{1}{r_{o1} C_1}$

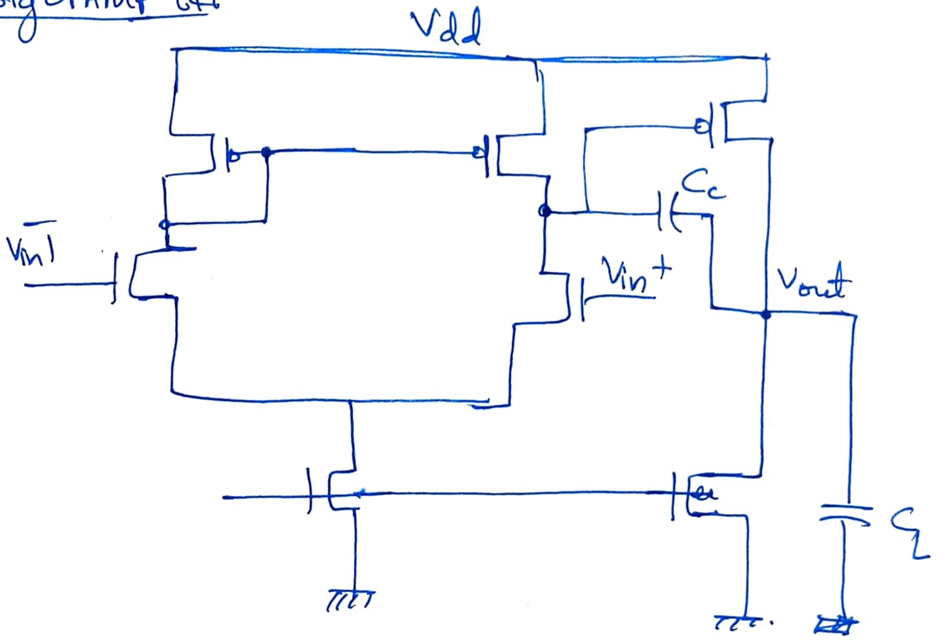
later $P_1 = \frac{1}{r_{eq}[C_1 + C_c(1+A)]}$



Small signal (2 stage OPAMP with Compensated Cap).



2 stg OPAMP Ckt

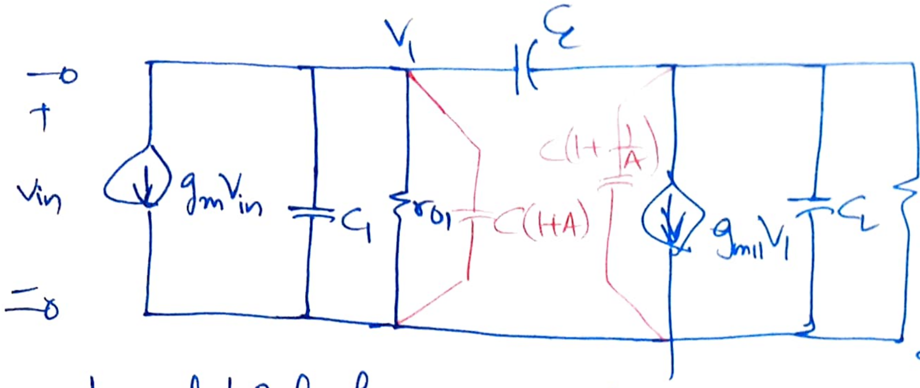


→ Phase Margin, -Poles, -Zeros, GBW etc,
→ Slew Rate
→ Swing Limits

~~Phase Margin~~:- from ~~small sig~~ SSA (small signal Analysis)

use Miller theorem which says ~~that~~ C_c can be split into 1 cap at i/p & other at o/p.

$$\frac{V_o}{V_{in}} =$$



Miller theorem

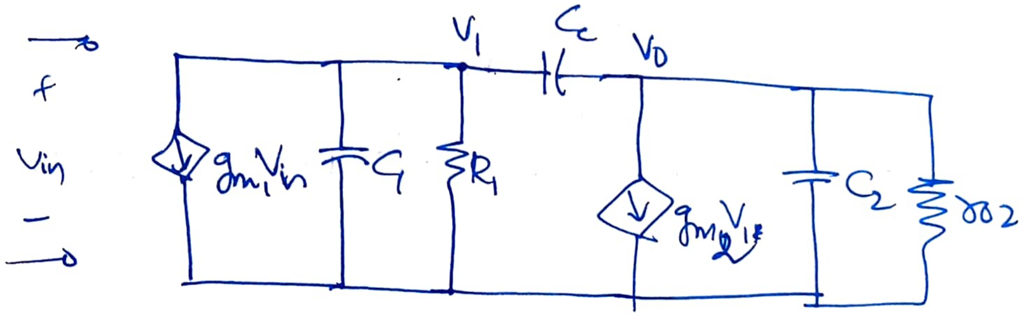
cannot use it b cs

1) Pole splitting.

2) zeros.

bcs at high freq C_c acts as a short ckt which cannot be replicated by splitting it.

$$\frac{V_1}{V_{in}} \times \frac{V_O}{V_1} = \underline{\underline{\frac{V_O}{V_{in}}}}$$



$R_2 = r_{o2}$

$R_1 = r_{o1}$

$$\frac{V_1}{\frac{1}{SC_1}} + \frac{V_1}{R_1} + g_{m1} V_{in} + \frac{V_1 - V_O}{1/SC_c} = 0$$ } Nodal eqn

$$V_1\left(SC_1 + \frac{1}{R_1} + SC_c\right) + g_{m1} V_{in} - V_O SC_c = 0$$

$$\boxed{V_1 = \frac{V_O\, SC_c R_1 - g_{m1} V_{in} R_1}{1 + SR_1(C_1 + C_c)}} \quad \text{—— (1)}$$

$$\frac{V_O}{1/SC_2} + \frac{V_O}{R_2} + g_{m2} V_1 + \frac{V_O - V_1}{1/SC_1} = 0;$$

$$V_O\left(S(C_2 + C_c) + R_2\right) = V_1\left(SC_c - g_{m2}\right)$$

$$V_1 = \frac{V_o\,[s(C_2+C_c)+R_2]}{[sC_c - g_{m_2}]}$$

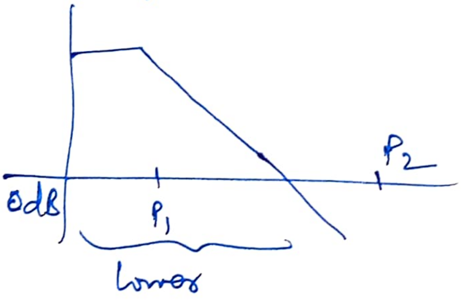
put in (1).

$$V_o\left(s(C_2+C_c)+\frac{1}{R_2}\right) = \frac{\left(V_o s C_c R_1 - g_{m_1} R_1 V_{in}\right)\left(sC_c - g_{m_2}\right)}{1+s(C_1+C_c)R_1}$$

$$V_o\left[s(C_2+C_c)R_2+1\right]\left[1+s(C_1+C)R_1\right] = \left[\left(V_o \cdot sC_cR_1 - g_{m_1}R_1V_{in}\right)\left(sC_c - g_{m_2}\right)\right]$$

$$\frac{V_o}{V_{in}} = \frac{g_{m_1}R_1\,g_{m_2}R_2\left(1-\frac{sC_c}{g_{m_2}}\right)}{s^2\left[R_1R_2(C_1C_2+C_1C_c+C_2C_c)\right]+s\left[R_2(C_c+C_2)+R_1(C_c+C_1)+C_c g_{m_2}R_1R_2+1\right.} \quad \text{—(2)}$$

For simplification



DC => $j\omega = s = 0$ [dc gain]

at lower freq

- the coeff of s is dominant

$$\frac{V_{out}}{V_{in}} = \frac{A_{DC}\left[1-\frac{s}{z}\right)}{\left(1+\frac{s}{P_1}\right)\left(1+s/P_2\right)}$$

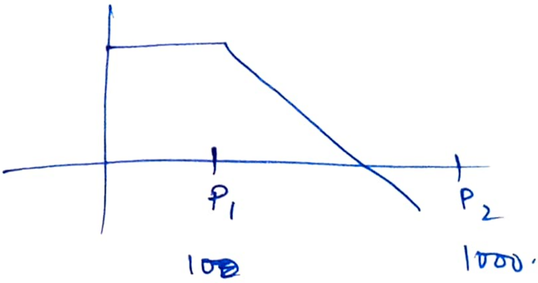
$$= \frac{A_{DC}\left(1-\frac{s}{z}\right)}{1+\frac{s^2}{P_1P_2}+s\left(\frac{1}{P_1}+\frac{1}{P_2}\right)} \quad \text{—(3)}$$

Comparing (3) with (2)

we get

$$P_1P_2 = R_1R_2[C_1C_2+C_1C_c+C_2C_c]$$

$$\frac{1}{P_1}+\frac{1}{P_2} = R_2[C_c+C_2]+R_1[C_c+C_1]+C_c g_{m_2}R_1R_2+1$$



$$s\left(\frac{1}{P_1}+\frac{1}{P_2}\right) \approx \frac{s}{P_1}$$

$$\frac{1}{P_1} = \text{coeff of } 's'$$

$$\text{coeff of } s^2 \Rightarrow \frac{1}{P_1 P_2}$$

$g_{m2}R_2 \rightarrow$ gain of one stage

$$P_1 \simeq \frac{1}{R_2(C_c+C_2)+R_1(C_c+C_1)+\underbrace{g_{m2}R_2R_1C_c}}$$ (dominant/Large)

$$\boxed{P_1 \simeq \frac{1}{g_{m2}R_2R_1C_c}}$$ 1st pole

$$P_1P_2 = \frac{1}{R_1R_2(C_1C_2+C_1C_c+C_2C_c)}$$

$$P_2 \simeq \frac{g_{m2}C_c}{C_1C_2+C_1C_c+\underline{C_2C_c}}$$

$$P_2 \simeq \frac{g_{m2}\cancel{C_c}}{C_2\cancel{C_c}} \simeq \frac{g_{m2}}{C_2}$$

$$\boxed{P_2 \simeq \frac{g_{m2}}{C_2}}$$ 2nd pole

$$\boxed{Z = \frac{g_{m2}}{C_c}}, \quad \boxed{P_1 = \frac{1}{g_{m2}C_cR_1R_2}}, \quad \boxed{P_2 = \frac{g_{m2}}{C_2}}$$

$$A_{DC} = \left(\frac{V_{out}}{V_{in}}\right)_{s=0}$$

$$\boxed{A_{DC} = g_{m_1} R_1 g_{m_2} R_2}$$

Gain Bw Product (DC Gain × P_1)

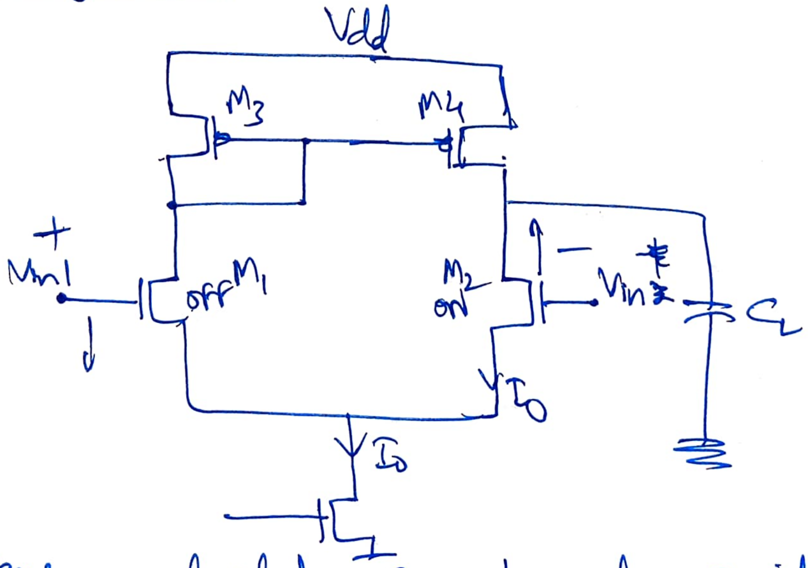
$$GBW = \cancel{DC}\, A_{DC} \times P_1$$

$$= \frac{g_{m_1} \cancel{g_{m_2}} \cancel{R_1} \cancel{R_2} \times 1}{\cancel{g_{m_2}} \cancel{R_1} \cancel{R_2} C_c} = \frac{g_{m_1}}{C_c}$$

$$\boxed{GBW = \frac{g_{m_1}}{C_c}}$$

Slew Rate:-

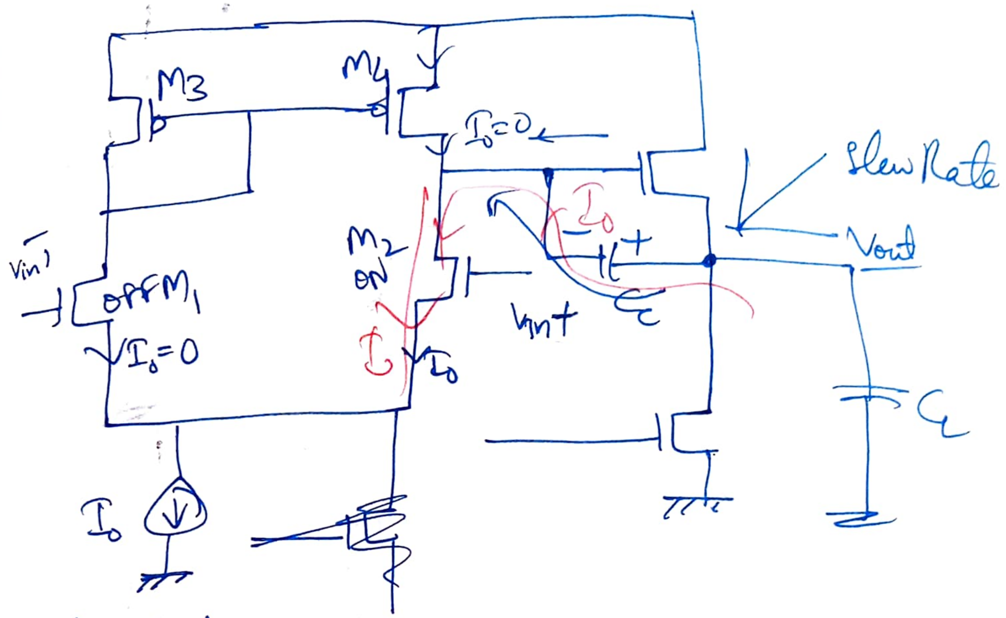
single stage OPAMP:-



Signs are decided + & - bcs at -ve if we increase Vin the drain Voltage decreases. so it goes into triode region So when there's a sudden change in i/p, extreme case is M_2 is ON & M_1 is OFF so. complete current goes through M_2. As this is a current mirror no current passes through

M_3 & M_4, so for I_o to flow it should come from cap
So here slew Rate was decided by C_L

<u>In 2 stage</u>

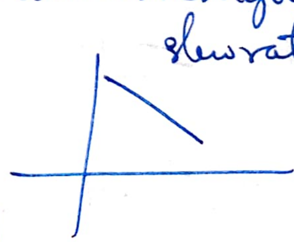


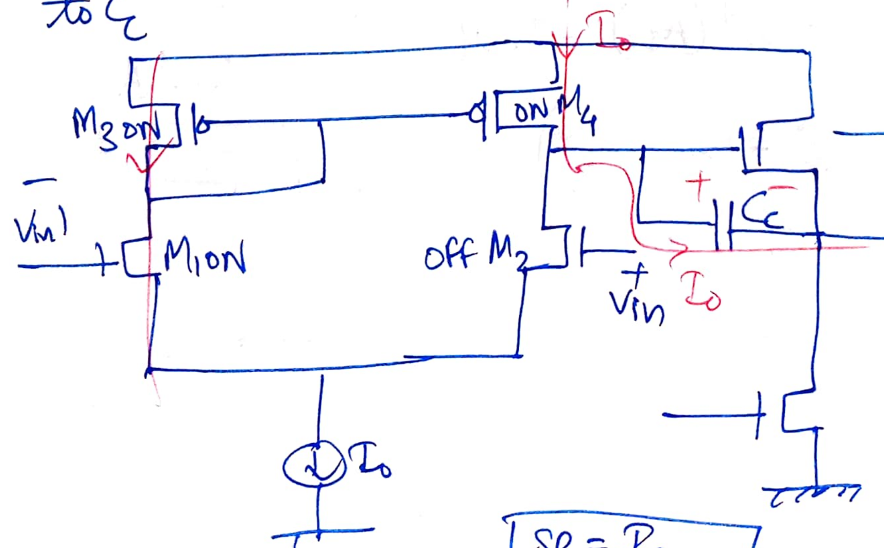
Slew Rate

C-1 For quick change in I/p for extreme case M_1 ~~one~~ is off & M_2 is ON. Bcs of current mirror no current will flow across M_1, M_3, M_4. and all current should pass through M_2 should come from C_c

$$\boxed{\text{So Slew Rate (SR)} = \frac{I_o}{C_c}}$$

C-2 Now $M_2 \to$ OFF, $M_1 \to$ ON, $M_3, M_4 \to$ ON, So all current goes to C_c



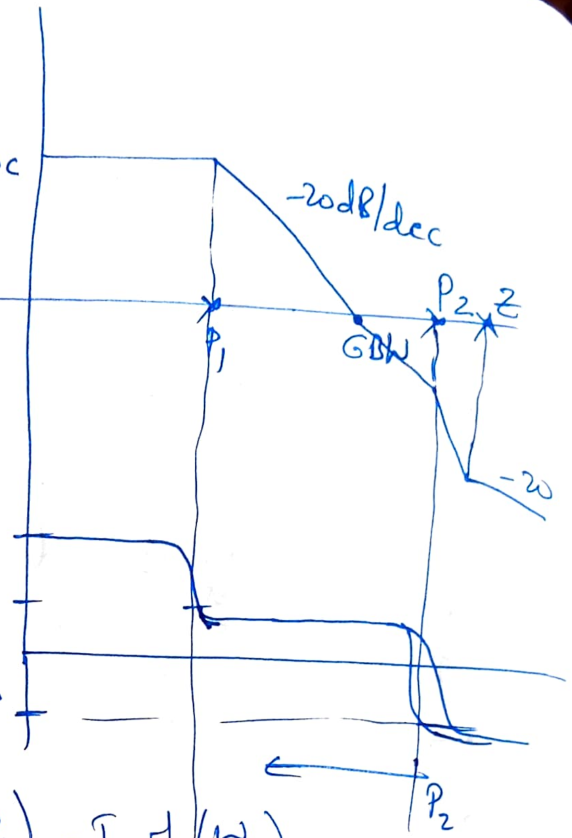


$$\boxed{SR = \frac{I_o}{C_c}}$$

Phase Margin:-

If P_2 moves left the phase Margin decreases so we've to keep P_2 away from GBW

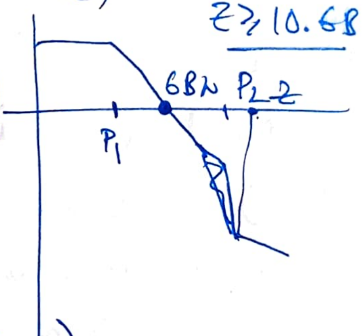
$\boxed{Z \geq 10.GB}$ — (1)



$$\angle \frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{\omega}{Z}\right)$$

$$-\tan^{-1}\left(\frac{\omega}{P_1}\right) - \tan^{-1}\left(\frac{\omega}{P_2}\right)$$

$$\angle \frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{\omega}{Z}\right) - \tan^{-1}\left(\frac{\omega}{P_1}\right) - \tan^{-1}\left(\frac{\omega}{P_2}\right)$$



$$\angle \frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{GBW}{Z}\right) - \tan^{-1}\left(\frac{GBW}{P_1}\right) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$= -\tan^{-1}\left(\frac{\cancel{GBW}}{10\cancel{GBW}}\right) - \tan^{-1}\left(\frac{g_{m_1}/C_c}{1/g_{m_2}R_1R_2C_c}\right)$$

$$- \tan^{-1}\left(\frac{g_{m_1}/C_c}{g_{m_2}/C_2}\right)$$

$$\angle \frac{V_o}{V_{in}} = -\tan^{-1}(0.1) - \tan^{-1}\left(g_{m_1}g_{m_2}R_1R_2C_c\right) - \tan^{-1}\left(\frac{g_{m_1}C_2}{g_{m_2}C_c}\right)$$

$$\angle \frac{V_o}{V_{in}} = -\tan^{-1}(0.1) - \tan^{-1}(A_{DC}) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

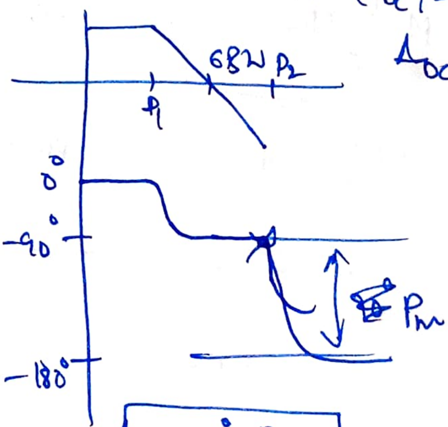
$\tan^{-1}(A_{DC}) \simeq 90°$

$A_{DC} >>>>$

$$-180° + P_m = -5.71 - 90° - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$P_m = 90° - 5.71 - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$P_m = 84.29 - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$



$\boxed{-180° + P_m}$

~~$P_m = 45^\circ$~~

for $P_m = 60^\circ$

$$60^\circ = 84.29^\circ - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$\tan^{-1}\left(\frac{GBW}{P_2}\right) = 24.29^\circ$$

$$\frac{GBW}{P_2} = 0.4513$$

$$\boxed{P_2 = \frac{GBW}{0.4513}} \Rightarrow \boxed{P_2 \geq 2.2\,GBW} \text{ for } PM = 60^\circ$$

For $P_m = 45^\circ$

$$45^\circ = 84.29^\circ - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$\boxed{P_2 \geq 1.22\,GBW} \text{ for } PM = 45^\circ$$

$$P_2 = \frac{g_{m2}}{C_2} \geq 2.22\frac{g_{m1}}{C_c} \quad \text{as } C_2 \simeq C_L$$

$$\Rightarrow \frac{g_{m2}}{C_L} \geq 2.2\frac{g_{m1}}{C_c}$$

also $Z = 10 \cdot GBW$

$$\frac{g_{m2}}{\cancel{C_c}} = 10\,\frac{g_{m1}}{\cancel{C_c}}$$

$$\Rightarrow \frac{10}{C_L} \geq \frac{2.2}{C_c}$$

$$\boxed{\frac{g_{m2}}{g_{m1}} = 10}$$

$$\Rightarrow \boxed{C_c \geq 0.22\,C_L}$$

$$\boxed{g_{m2} = 10\,g_{m1}}$$