1-3-12

Lec 24

7) Input CM range:

$V_{min} = V_{GS_1} + V_{DSAT_0}$

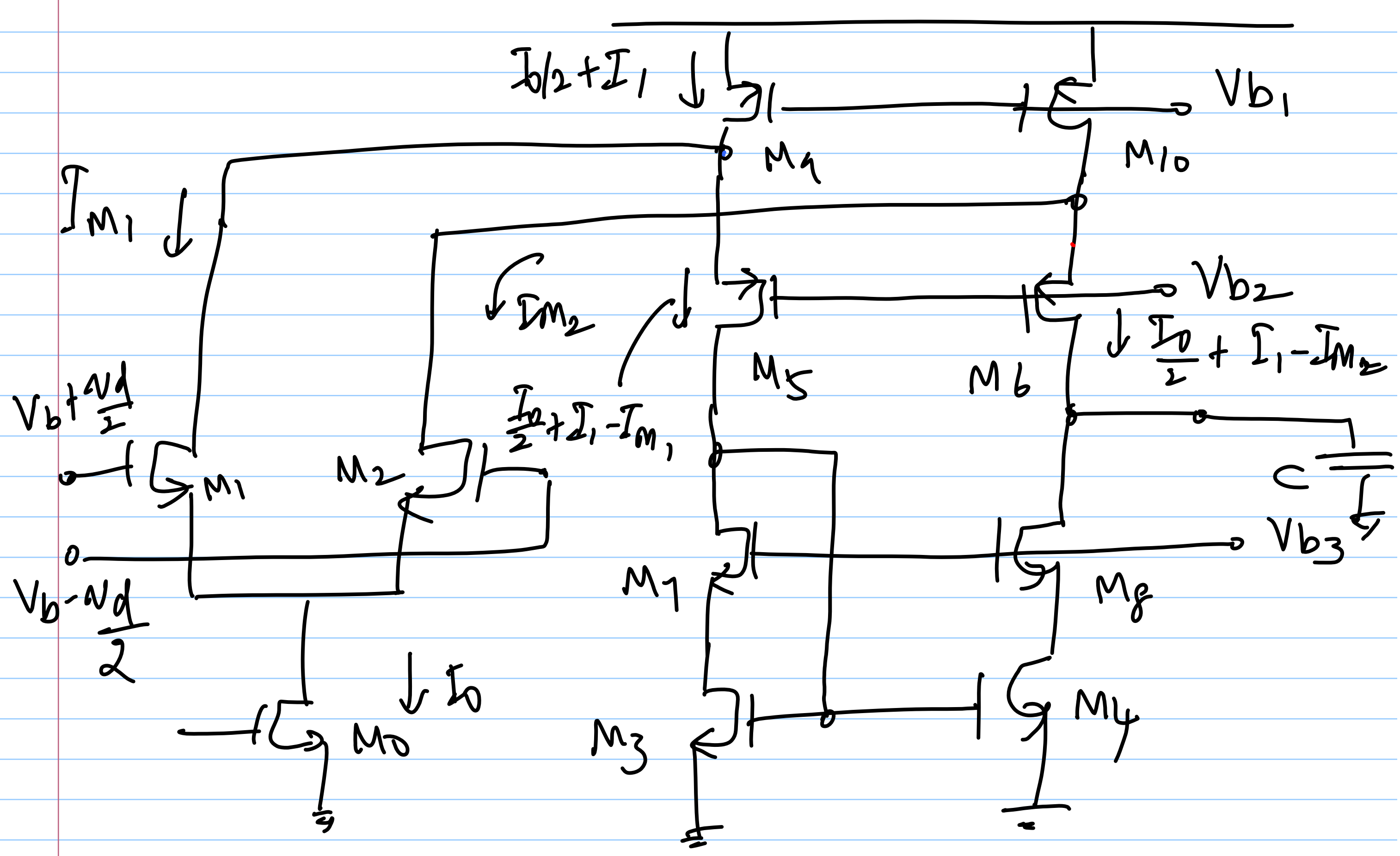
$V_{max} = V_{b_2} + V_{SG_5} + V_{T_1}$ (can be $> V_{DD}$)

8) <u>Slew Rate</u>

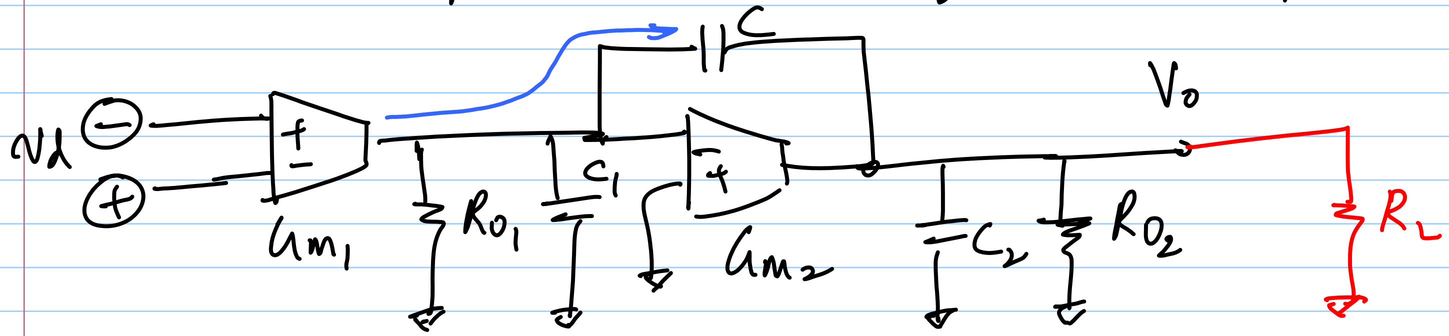
$$I = \text{smaller}\left(I_1, \frac{I_0}{2}\right)$$

$$SR = \min\left(\frac{I_0}{C}, \frac{2I_1}{C}\right)$$

ideal case $\Rightarrow I_1 = \frac{I_0}{2}$ (rest is wasted)



Transimpedance Topology (2-stage opamp)



$$\left.\frac{v_o}{v_d}\right|_{DC} = G_{m_1} R_{o_1} \cdot G_{m_2} R_{o_2}$$

$$\left.\frac{v_o}{v_d}\right|_{DC} \simeq \underbrace{G_{m_1} R_{o_1}}_{\text{boosts DC gain}} (G_{m_2} R_L)$$

$\Rightarrow$ better than before

* Stage 1 DC gain is not changed

$\rightarrow$ optimise stage 1 for DC gain

$\Rightarrow$ $\boxed{\text{2-stage opamp}}$ most common opamp

1) DC gain $A_0 = G_{m_1} R_{o_1} \, G_{m_2} R_{o_2}$

2) $v_o(s) \simeq \frac{G_{m_1}}{sC} \cdot v_i(s)$ {to a first order}

$$\Rightarrow \omega_u \simeq \frac{G_{m_1}}{C}$$

2 poles, 1 zero

$$\frac{V_o}{V_d} = \frac{G_{m1}(G_{m2} - sC)}{\left\{ s^2(C_1C + CC_2 + C_1C_2) + s\left(C(G_{m2} + G_{o1} + G_{o2}) + G_{o2}C_1 + G_{o1}C_2\right) + G_{o1}G_{o2} \right\}}$$

$$\left.\frac{v_o}{v_d}\right|_{DC} = \frac{G_{m1}G_{m2}}{G_{o1}G_{o2}} \checkmark$$

$$z_1 = +\frac{G_{m2}}{C} \quad \text{(RHP zero)}$$

$$ax^2 + bx + c = 0$$

If x_1 & x_2 (roots are far apart),

$$x_1 \simeq -\frac{c}{b} \; ; \quad x_2 = -\frac{b}{a}$$

$$x_1 << x_2 \quad \{p_1 << p_2\}$$

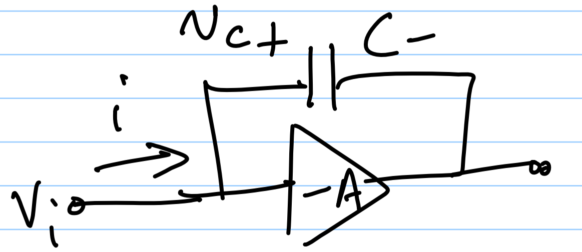
For an opamp, p_2 = dominant pole, p_1 = N.D. pole

$$p_1 \simeq -\frac{c}{b} = -\frac{G_{o1}G_{o2}}{C(G_{m2} + G_{o1} + G_{o2}) + G_{o2}C_1 + G_{o1}C_2}$$

$$\approx -\frac{G_{o1}}{C\left(\frac{G_{m2}}{G_{o2}}+1+\frac{G_{o1}}{G_{o2}}\right)+C_1+\frac{G_{o1}}{G_{o2}}C_2}$$

originally $\rightarrow$ $\dfrac{G_{o1}}{C_1}$ Miller Effect

now $\rightarrow$ cap $= C\left(1+\dfrac{G_{m2}}{G_{o2}}\right)$



$-AV_i$ $\quad i = (A+1)sC\cdot v_i$

$v_c = (A+1)V_i$

Other terms : * Non ideal Gm stages (Gout etc.)

* probably negligible compared with first terms

* this expression is approx. (quadratic solution)

as $C \uparrow \Rightarrow p_1 \downarrow$

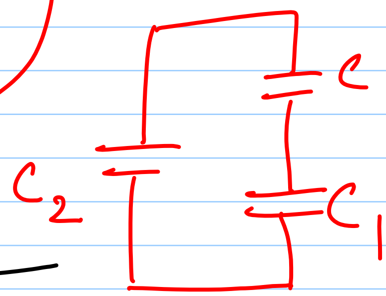
$$p_1 \approx \frac{G_{o1}}{\text{eff. cap. across } G_{o1}}$$

$$p_2 \simeq -\frac{b}{a} = -\frac{C(G_{m2}+G_{o1}+G_{o2})+C_1G_{o2}+C_2G_{o1}}{C_1C+CC_2+C_1C_2}$$

divide Nr. & Dr. by $(C+C_1)$

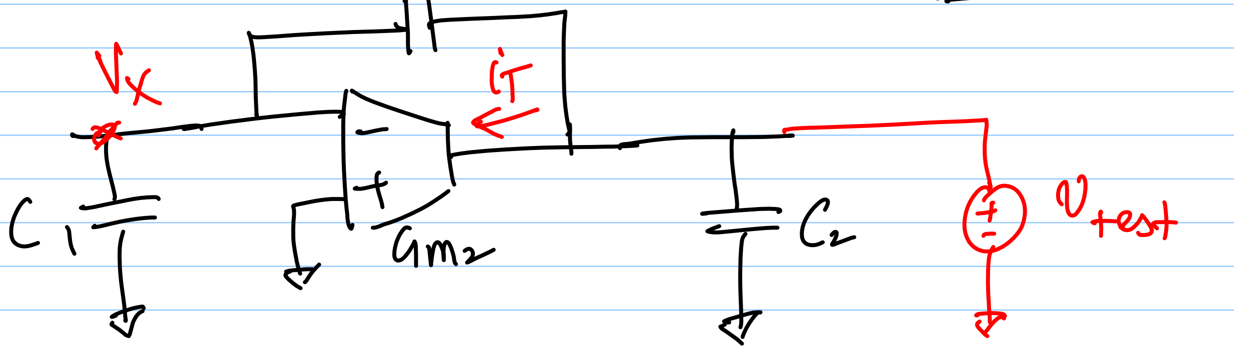
$$p_2 = -\frac{\frac{C}{C+C_1}G_{m2}+G_{o2}+G_{o1}\cdot\frac{C+C_2}{C+C_1}}{C_2+\frac{C_1C}{C+C_1}}$$

cap. ckt does look like this @ o/p node



$G_{o2} \rightarrow$ directly @ o/p

$\frac{C}{C+C_1}G_{m2}$ is dominant term due to feedback

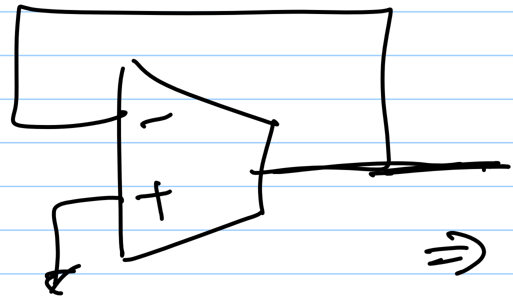


$$v_X = \frac{C}{C+C_1}v_{test}$$

$$i_T = \frac{C}{C+C_1}v_{test}\cdot G_{m2}$$

$$G_{eff.} = \frac{i_T}{v_{test}} = \frac{C}{C+C_1} \cdot G_{m2}$$

Note:



= resistance of value $1/G_{m2}$

⇒ full feedback

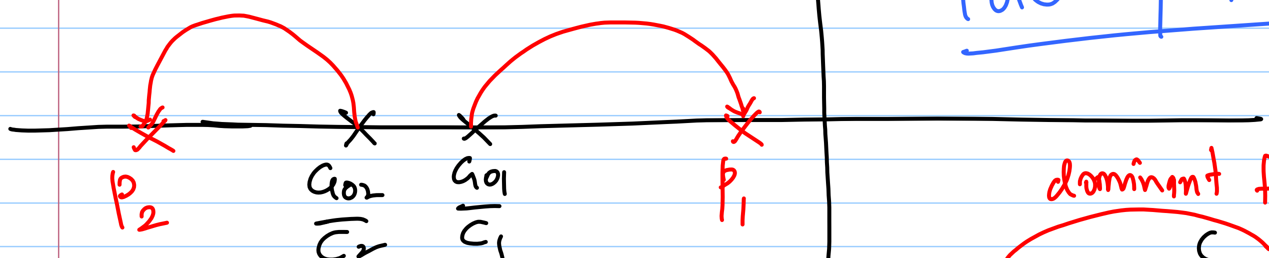
$C=0$, no f.b. ⇒ $G_{eff.}=0$

G_{o1} term ⇒ because of finite G @ G_{m1} output in $\parallel^{l}$ with C_1

If $C=0$, no zero,

poles @ $-\frac{G_{o1}}{C_1}$ & $-\frac{G_{o2}}{C_2}$

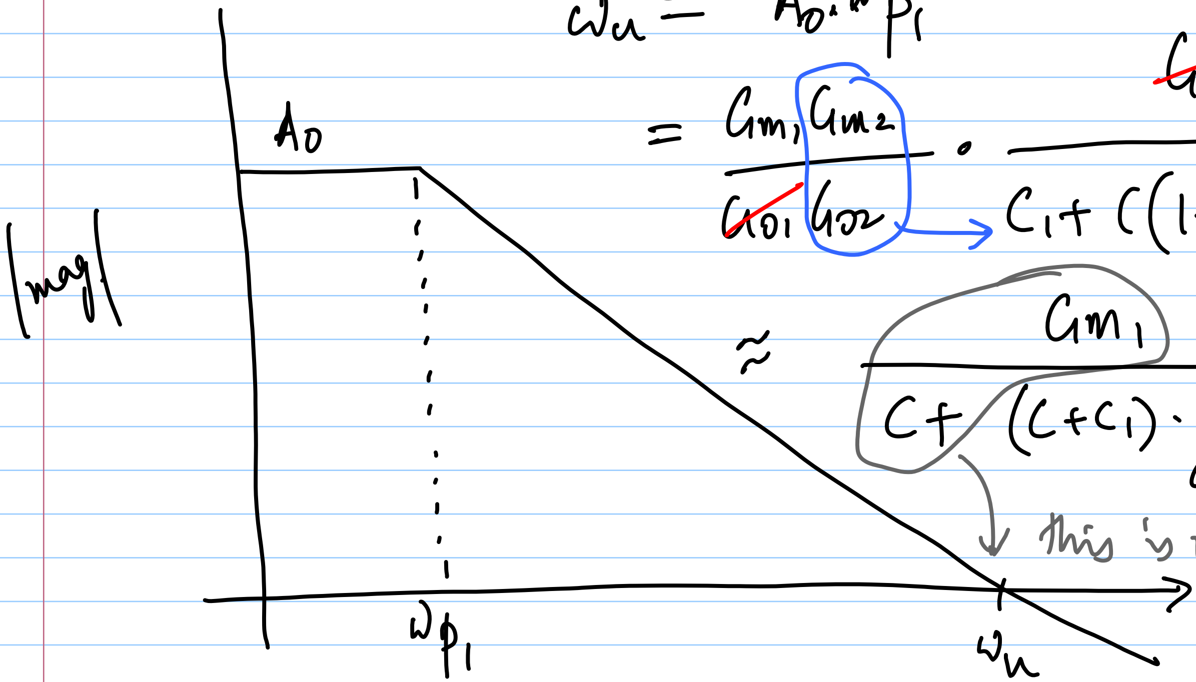
Pole-splitting



$$p_1 \approx -\frac{G_{o1}}{C_1 + \underbrace{C\cdot\frac{G_{m2}}{G_{o2}}}_{\text{dominant term}} + \cdots}$$

$$p_2 \approx -\frac{\overbrace{G_{m2}\cdot\frac{C}{C+C_1}}^{\text{dominant term}} + \cdots}{C_2 + \frac{C C_1}{C+C_1}}$$

Pole splitting is a feature of a <u>coupled</u> <u>system</u>.



$$\omega_u = A_0 \cdot \omega_{p1}$$

$$= \frac{G_{m1}G_{m2}}{\cancel{G_{o1}}G_{o2}} \cdot \frac{\cancel{G_{o1}}}{C_1 + C\left(1 + \frac{G_{m2}}{G_{o2}}\right) + \cdots}$$

$$\approx \frac{G_{m1}}{C + (C+C_1)\cdot\frac{G_{o2}}{G_{m2}} + \cdots}$$

this is what we wanted!

Two-stage opamp

$$\omega_u = \frac{G_{m1}}{C}$$

$$z_1 = +\frac{G_{m2}}{C} \quad \text{(RHP)} \longleftarrow \text{bad!}$$

phase lag

$$|p_1| \approx \frac{G_{o1}}{C_1 + C\left(\frac{G_{m2}}{G_{o1}} + 1\right) + \cdots}$$

(LHP)

$$|p_2| \approx \frac{G_{m2}\cdot\frac{C}{C+C_1} + G_{o2} + \cdots}{C_2 + \frac{CC_1}{C+C_1}}$$

(LHP)

Conditions:

$|\omega_{p_2}| > \omega_u$

$$\phi_{UG} = \underbrace{\frac{-\pi}{2}}_{\omega_{p_1}\text{ (Dominant pole)}} - \underbrace{\tan^{-1}\left(\frac{\omega_u}{\omega_{p_2}}\right)}_{\omega_{p_2}} - \underbrace{\tan^{-1}\left(\frac{G_{m_1}}{G_{m_2}}\right)}_{\omega_z\text{ (not good)}}$$

1) ω_z

$G_{m_1} = G_{m_2}$ is not good $\because$ zero already gives $-45°$ phase @ ω_u

$G_{m_2} \gg G_{m_1}$ is good (3-4x)

$G_{m_2} < G_{m_1} \Rightarrow$ unstable

2) ω_{p_2}

$\frac{\omega_u}{\omega_{p_2}}$ should be small $\{\omega_{p_2} \gg \omega_u\}$

$\rightarrow$ G_{m_2} should be large

$\therefore$ Given ω_u (i.e. G_{m_1} & C), to improve PM, increasing G_{m_2} is the only option

$\uparrow W \Rightarrow C_1, C_2 \uparrow \Rightarrow$ affects cap (denominator) too

$\therefore$ $\uparrow$ current (while keeping W small)

$\Rightarrow$ V_{ov} $\downarrow$ $\Rightarrow$ swing limits $\downarrow$

* You want $C \gg C_1, C_2$, so choose G_{m1} & C carefully so that

$$\omega_u = \frac{G_{m1}}{C}$$

* what to do about the zero?