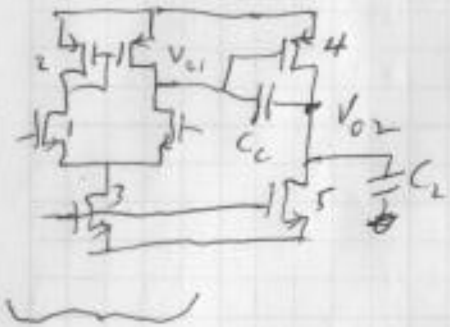
2 stage



$G_{m1} = g_{m1}$

$R_{o1} = r_{o1b} \| r_{o2b}$

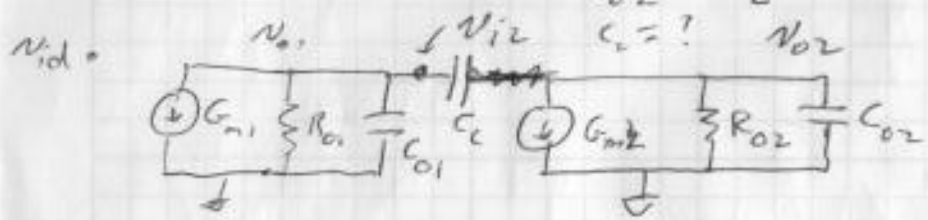
$G_{m2} = g_{m4}$

$R_{o2} = r_{o3} \| r_{o4}$ $(\| R_{Load})$

$C_{o1} \approx C_{gs4}$

$C_{o2} \approx C_L$

$C_c = ?$



If $C_c = 0$ (it doesn't. C_{gd4} at least, but if)

$A_{v1} = \frac{A_{v1DC}}{1 + s/\omega_{p1}}$ $\quad A_{v1,DC} = -G_{m1} R_{o1}$

$\omega_{p1} = \frac{1}{R_{o1} C_{o1}}$

$A_{v2} = \frac{A_{v2DC}}{1 + s/\omega_{p2}}$ $\quad A_{v2,DC} = -G_{m2} R_{o2}$

$\omega_{p2} = \frac{1}{R_{o2} C_{o2}}$

2 poles

mathematically never unstable $\angle A(j\omega) > -180$

phase margin goes to 0 though.

what about C_c?

Miller multiplied

looks like $C_{miller} = C_c(1 - A_{v2}(s))$

Can push ω_{p1} to lower frequency with less capacitance than just adding to C_{o1}

$\Rightarrow$ good. Smaller caps are cheaper (die area)

Magically, it also pushes ω_{p2} to higher freq.

$\Rightarrow$ great. More bandwidth

"pole splitting"

<u>Compensation</u>

Changing freq response of the open loop amplifier (typically by adding capacitive) to improve closed-loop performance

e.g. 1) to make it stable

2) to achieve desired phase margin (settling properties)

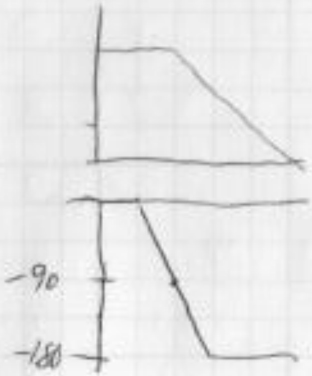
2-stage example

$$A_v = \frac{10^3}{(1+s/\omega_p)^2}$$

set PM to -45

1) adding cap to C_1

2) adding cap to C_2



to move 1 pole 10^3 lower freq, need 10^3 times as much capacitance.

so 1) increase C_{o1} by 1000x

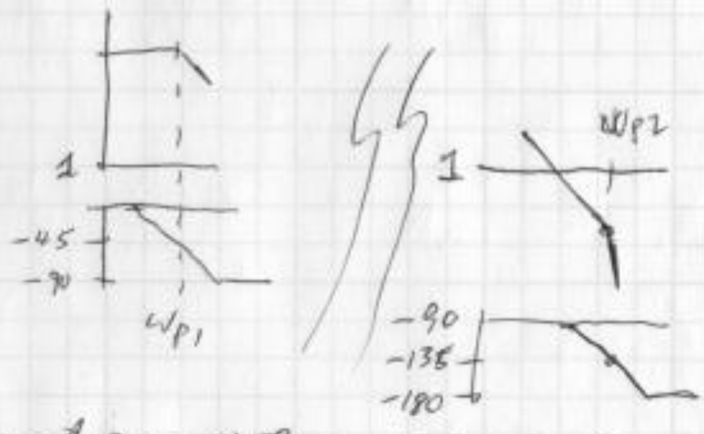
2) increase C_{o2} by 1000x

problem: might not know C_L

solution #1 tricky - need bounds on C_L

solution #2 OK, but may unnecessarily compromise performance.

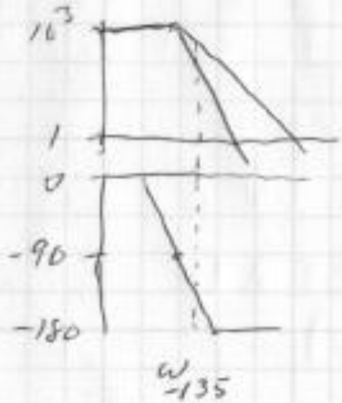
if we separate poles a <u>lot</u>



to set PM = 45° need $\omega_{p2} \geq \omega_u$

to set PM = 70° need $\omega_{p2} > 3\omega_u$

what is ~~max~~ min CL gain w/ <u>no</u> compensation?



need $|Af| \leq 1$

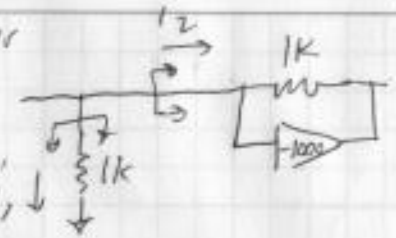
when $\angle Af = -135$

$|A(j\omega_{135})| \approx 100$

need $f \leq 0.01$

$A_{CL} \geq \frac{1}{f} = 100$

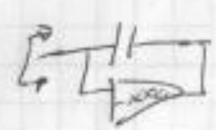
Miller



$i_1 = \frac{1mV}{1K} = 1\mu A$

$i_2 = \frac{(1mV - -1000mV)}{1K} = 1.001mA$

$Z_{in2} = \frac{1K}{1-A} \approx 1\Omega$



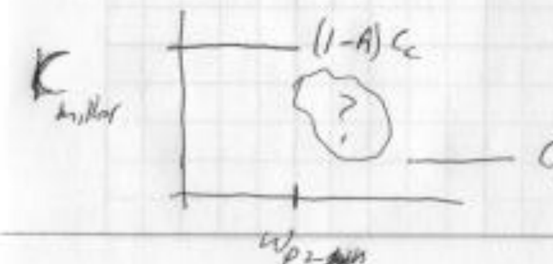
$i = C\frac{d}{dt}(v_{in} - -1000v_{in})$

$= 1001C\frac{dV_i}{dt}$ $\quad C_{eq} = (1-A)C$

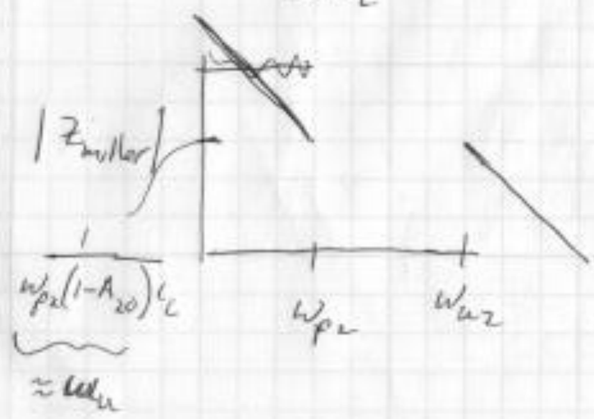
$A = \frac{A_{2DC}}{1 + s/\omega_{p2,u}}$

$A_{2,DC} = -G_{m2}R_{o2}$

$C_{miller} = \begin{cases} (1 + G_{m2}R_{o2})C_c & \omega < \omega_{p2,u} \\ C_c & \omega >> \omega_{u2} \end{cases}$



$Z_{miller} = \begin{cases} \frac{1}{\omega(1-A_{2o})C_c} & \omega < \omega_{p2} \\ \frac{1}{\omega C_c} & \omega > \omega_{u2} \end{cases}$



$$Z_{miller} = \frac{1}{s\left[1 + \left(\frac{A_{v2,0}}{1 + s/\omega_{p2}}\right)\right] C_c}$$

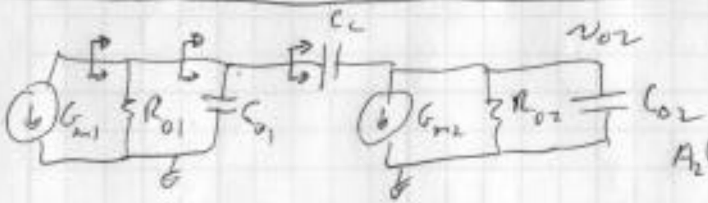
$$= \frac{1 + s/\omega_{p2}}{s\left[1 + s/\omega_{p2} + A_{v2,0}\right] C_c}$$

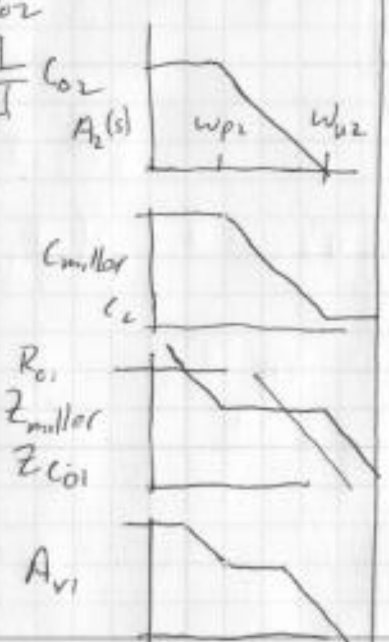
$$= \frac{1 + s/\omega_{p2}}{s(1 + A_{2,0})\left(1 + \frac{s}{\omega_{p2c}}\right) C_c}$$

$$\omega_{pzM} = \omega_{p2}(1 + A_{2,0}) \simeq \omega_{u2}$$

$$Z_{miller} = \begin{cases} \frac{1}{j\omega(1+A_{2,0})C_c} & \omega < \omega_{p2} \\ \frac{1}{\omega_{p2}(1+A_{2,0})C_c} & \omega_{p2} < \omega < \omega_{u2} \\ \frac{1}{sC_c} & \omega_{u2} < \omega \end{cases}$$

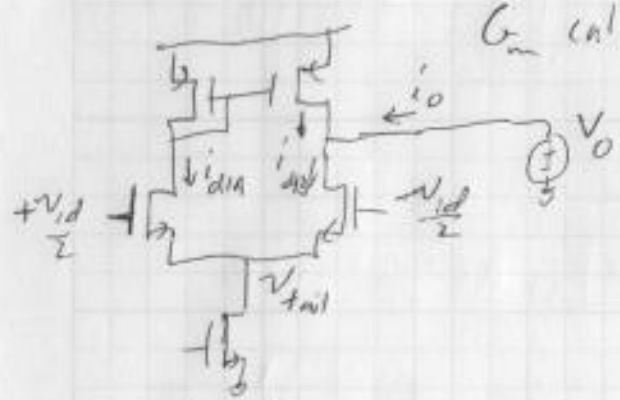
constant, real





No virtual ground

G_m calc

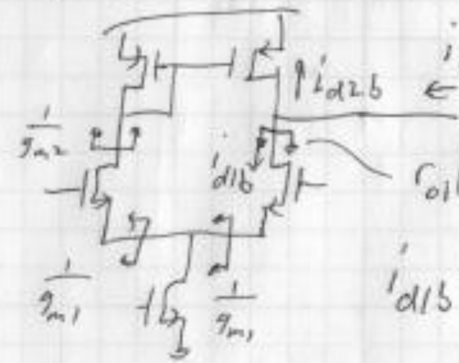


$G_{m1} = g_{m1}$

$i_o = i_{d1b} - i_{d1a}$

$= g_{m1b}\left(-\frac{v_{id}}{2} - v_{tail}\right) - g_{m1a}\left(\frac{v_{id}}{2} - v_{tail}\right) = -g_{m1} v_{id}$

R_o calc



$i_o = i_{d1b} + i_{d2b}$

$r_{o1}\left(1 + g_{m1}\frac{1}{g_{m1}}\right) = 2r_{o1}$

$i_{d1b} = \frac{v_o}{2r_{o1}}$

$i_{d2a} = i_{d1b}$

$R_{o1} = r_{o1} \| r_{o2}$

$i_{d2b} = i_{d1b} + \frac{v_o}{r_{o2}}$

$i_o = \frac{v_o}{2r_{o1}} + \left(\frac{v_o}{2r_{o1}} + \frac{v_o}{r_{o2}}\right) = v_o\left(\frac{1}{r_{o1}} + \frac{1}{r_{o2}}\right)$