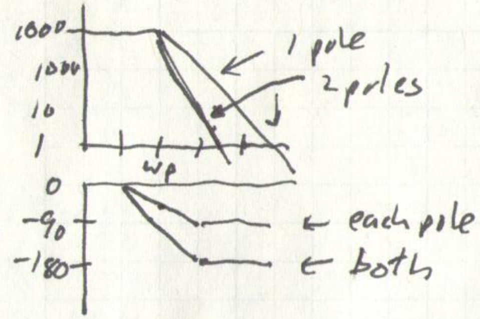
Some examples

co-located poles, gain of 1000

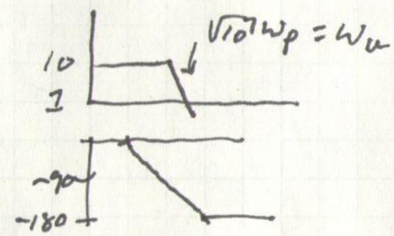


$\omega_u = \sqrt{1000}\,\omega_p$

$\angle A(j\omega_u) = -180$

PM = 0 BAD!

co-located, gain of 10

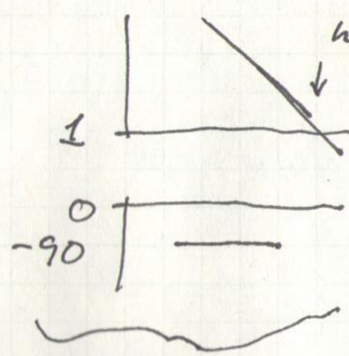


$\angle A(j\omega_u) = -135$

PM = 45 OK!

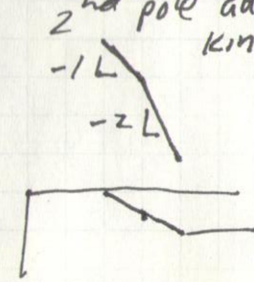
Big gain

2 well separated poles



effect of low freq pole

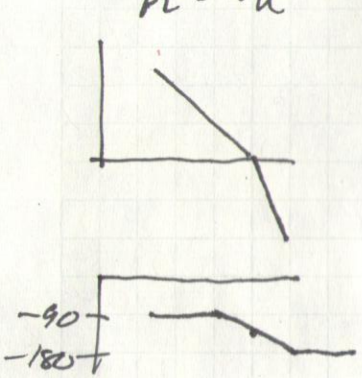
2nd pole adds kink



and another -45

Always want at least 45° PM, so must choose $\omega_{p2} \geq \omega_u$

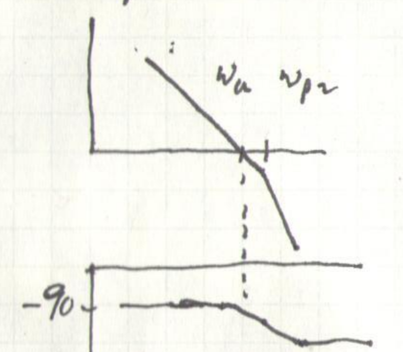
$\omega_{p2} = \omega_u$



$\angle A(j\omega_u) = -135$

PM = 45 OK

$\omega_{p2} = 3\,\omega_u$



$\angle A(j\omega_u) \cong -90 - 22.5$

PM ≅ 67 good!

<u>Compensation</u> changing the freq response of the open loop amplifier (typically by adding capacitance) so that the closed loop amplifier ① is <u>stable</u>
② has desired settling properties (phase margin)

How to compensate

single stage: doesn't need it (only 1 pole, PM≈90) important

2 stage:

3 natural points: output of 1st stage

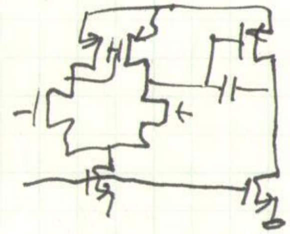
output of 2nd stage

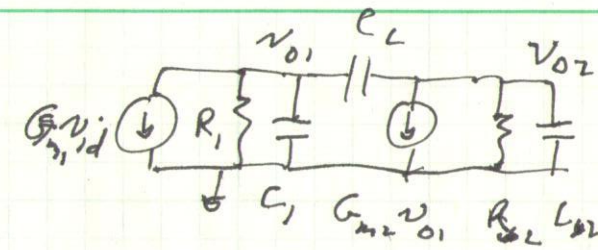
→ across 2nd stage ←

Miller compensation

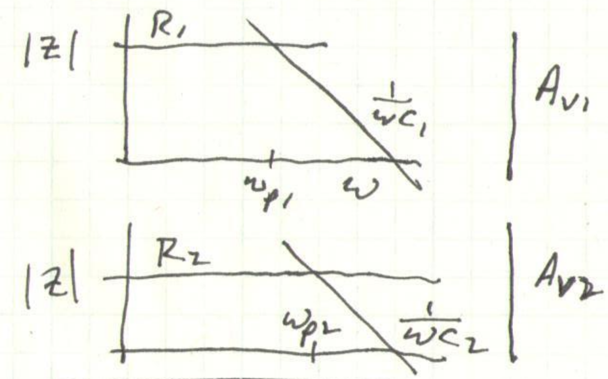
moves ω_{p1} lower w/ smaller cap

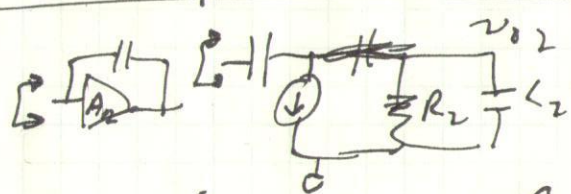
moves ω_{p2} higher!





with no C_c



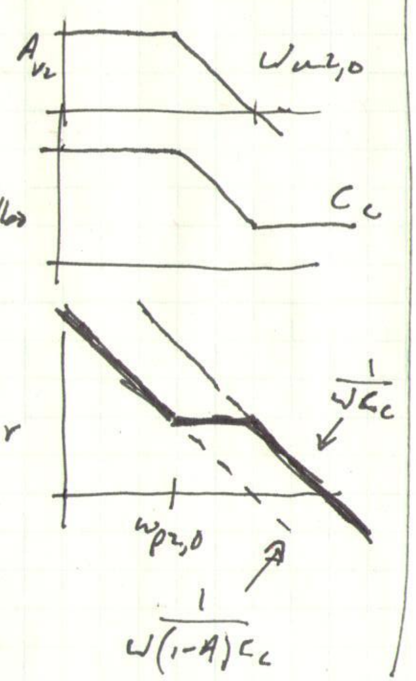


$C_{miller} = (1 - A_{v2})\, C_c$

$Z'_{miller} = \frac{1}{j\omega C_{miller}}$

$= \frac{1}{j\omega(1-A_{v2})\, C_c}$

where $A_{v2} = \frac{-A_{v2,0}}{1 + s/\omega_{p2,0}}$



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

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

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

$(1+A_{v2,0})\,\omega_{p2,0} \approx \omega_{u2,0}$

Z_{miller} low freq $s = j\omega$ $\omega < \omega_{p2,0}$

$$Z_{miller} \cong \frac{1}{s(1+A_{v2,0})C_c} = \frac{1}{j\omega C_{miller}}$$

mid freq $\omega_{p2,0} < \omega < \omega_{u2,0}$

$$Z_{miller} \cong \frac{\cancel{1+} s/\omega_{p2,0}}{s(1+A_{v2,0})C_c} = \frac{1}{\omega_{p2,0} C_{miller}}$$

constant real ! Resistive

capacitance $\sim \frac{1}{\omega A_v}$ $A_v \sim \frac{1}{\omega}$

high freq $\omega_{u2,0} < \omega$

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

$$= \frac{1}{sC_c}$$