ECE511 – Lecture 15

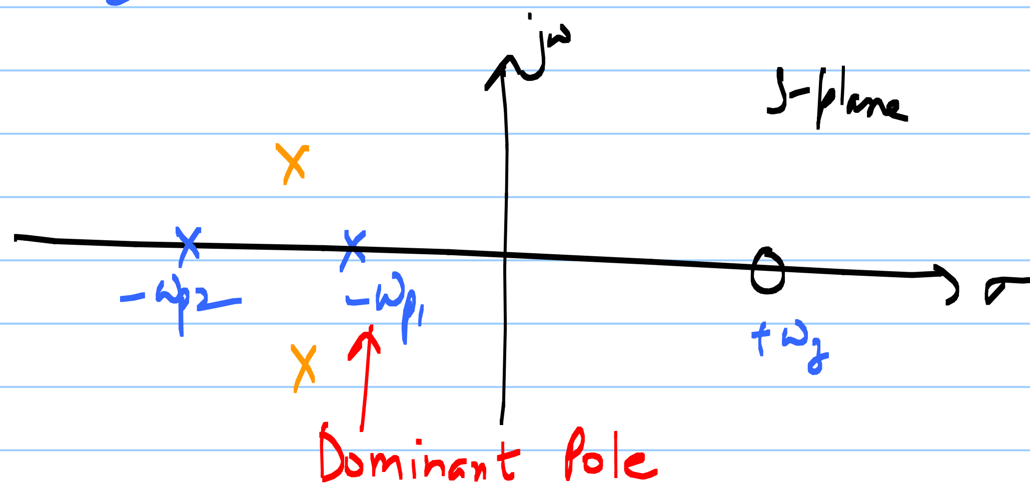
Note Title 3/19/2012

$$\omega_z = +\frac{g_{m1}}{C_{gd1}} \quad (RHP)$$

$$\frac{V_{out}}{V_{in}}(s) = \frac{(C_{gd1}s - g_{m1})R_o}{R_sR_o\xi \boxed{s^2} + [R_s(1+g_{m1}R_o)C_{gd1} + R_sC_{gs1} + R_o(C_{gd1}+C_{db2})]\boxed{s} + 1}$$

2nd order D^r

$$\xi = C_{gs1}C_{gd1} + C_{gs1}C_o + C_{gd1}C_o$$



Assume $|\omega_{p_1}| << |\omega_{p_2}|$

$$\Rightarrow \boxed{\frac{1}{\omega_{p_1}} >> \frac{1}{\omega_{p_2}}}$$

$$D(s) = \left(\frac{s}{\omega_{p_1}}+1\right)\left(\frac{s}{\omega_{p_2}}+1\right) = \frac{s^2}{\omega_{p_1}\omega_{p_2}} + \underbrace{\left(\frac{1}{\omega_{p_1}} + \cancel{\frac{1}{\omega_{p_2}}}\right)}\text{'}s\text{'} + 1$$

Coeff^n of 's' $\rightarrow \simeq \frac{1}{\omega_{p_1}}$

$$\omega_{p_1} \simeq \frac{1}{R_s(1+\underline{g_{m_1}R_o})\underline{C_{gd_1}} + R_s C_{gs_1} + \boxed{R_o(C_{gd_1}+C_L)}}$$

contribution from output node

Compare with "Miller Analysis"

$$\omega_{in} = \frac{1}{R_s C_{g_1} + (1 + |A|) R_s C_{gd_1}}$$

$$|A| = |g_m R_o|$$

Coeff^n of "s^2"

$$\omega_{p2} = \frac{1}{\omega_{p_1}} \times \frac{1}{R_s R_o \xi}$$

$$= \frac{1}{\omega_{p_1}} \cdot \frac{1}{R_s R_o [C_{gs_1} C_{gd_1} + C_{gs_1} C_o + C_{gd_1} C_o]}$$

$$\omega_{p2} = \frac{R_s(1+g_m\cancel{R_o})C_{gd_1} + R_sC_{gs_1} + R_o(\cancel{C_{gd_1}+}C_o)}{R_sR_o\left[C_{gs_1}C_{gd_1} + C_{gs_1}C_o + C_{gd_1}C_o\right]}$$

Let $C_{gs_1} \gg (1+g_mR_o)C_{gd_1} + \frac{R_o}{R_s}(C_{gd_1}+C_o)$

✓ $$\omega_{p2} \simeq \frac{1}{R_o(C_{gd_1}+C_o)}$$

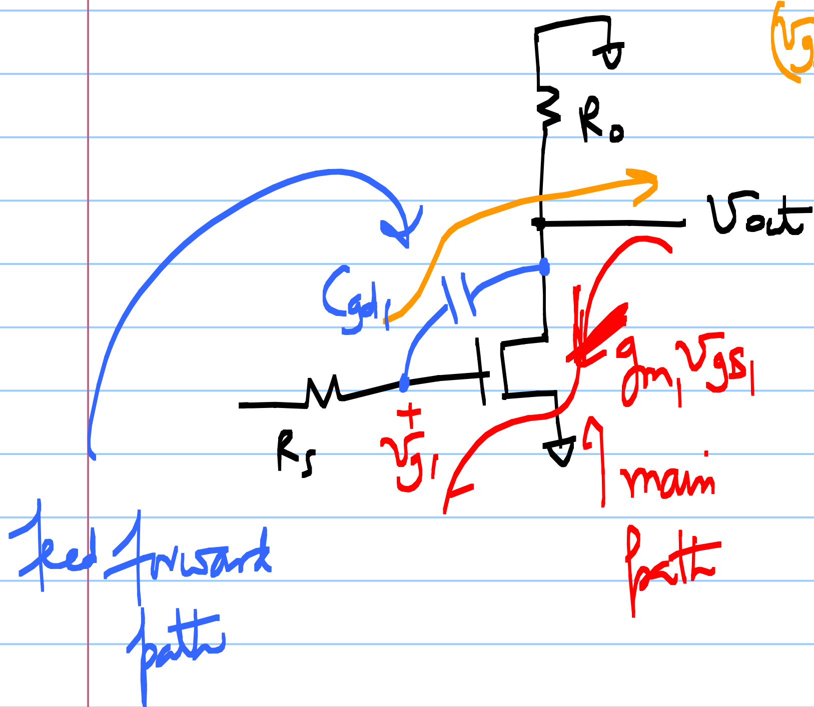
only valid when C_{gs} dominates the input cap

Same as in Miller analysis

"zero"

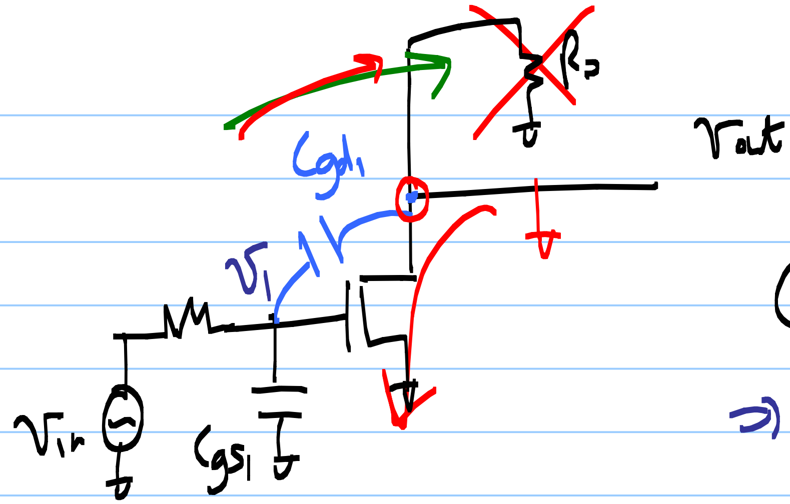
$$\omega_z = +\frac{g_{m1}}{C_{gd1}} \Rightarrow (RHP)$$

$(v_{gs1} - v_{out})\, s\, C_{gd1}$



* feedforward path causes gain flattening by +20 dB/dec

* RHP zero reduces phase @ high-f
∵ signal through C_{gd1} adds in opposite phase to $g_m v_{gs}$.



$\sigma + j\omega_z$

@ $s = s_z$

$\Rightarrow \quad v_{out}(s_z) = 0$

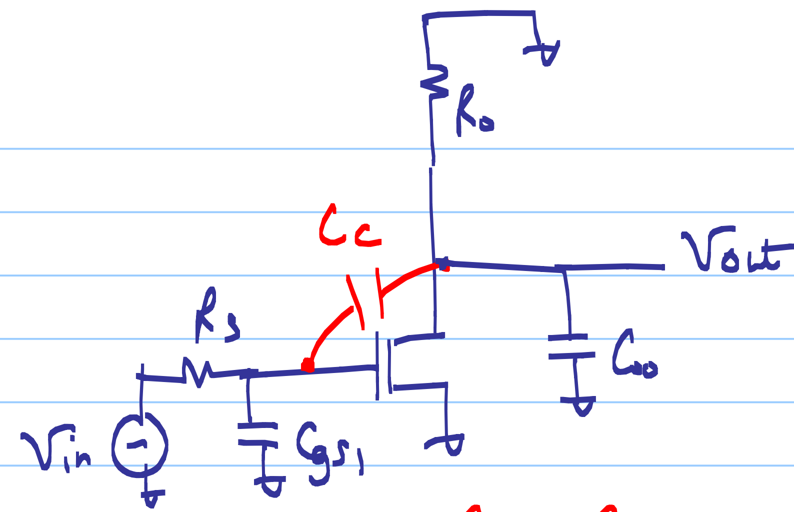
$\Rightarrow$

$$v_1 \cdot s_z C_{gd_1} + (-g_{m_1} v_1) = 0$$

$\Rightarrow \quad s_z \cdot C_{gd_1} = g_{m_1}$

$\Rightarrow \quad \boxed{s_z = + \frac{g_{m_1}}{C_{gd_1}}}$ RHP zero.

$$A(s) = A_v \cdot \frac{\left(1 - s/\omega_z\right)}{\left(1 + \frac{s}{\omega_{p1}}\right)\left(1 + s/\omega_{p2}\right)}$$



$C_c = C_{gd1}$ "Miller Cap"

① $$\omega_z = + \frac{g_{m1}}{C_c}$$

② $$\omega_{p1} \simeq \frac{1}{R_s\left[\left(1 + |A|\,C_c\right) + C_{gs1}\right] + R_o\left(C_c + C_o\right)}$$

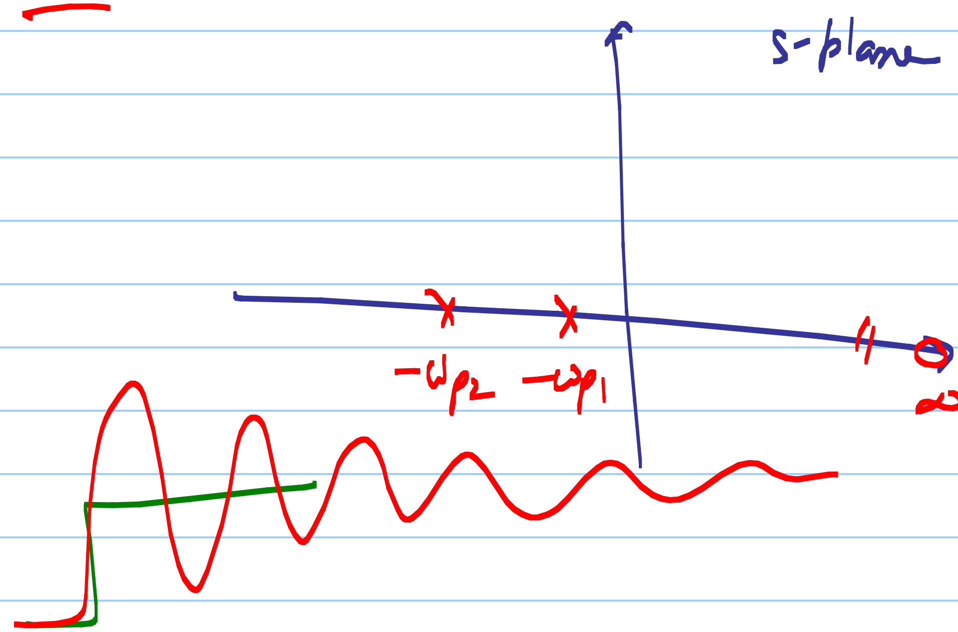
③ $$\omega_{p2} \simeq \frac{R_s\left(1 + g_{m1}R_o\right)C_c + R_s C_{gs1} + R_o\left(C_c + C_o\right)}{R_s R_o\left[C_{gs1}C_c + C_{gs1}C_o + C_c C_o\right]}$$

Case I: $C_c \simeq 0$ & C_o is large

$$\omega_{p1} \simeq \frac{1}{R_s C_{gs1} + R_o C_o}$$

$$\omega_{p2} \simeq \frac{1}{R_o C_o}$$

$$\omega_z \Rightarrow \infty$$



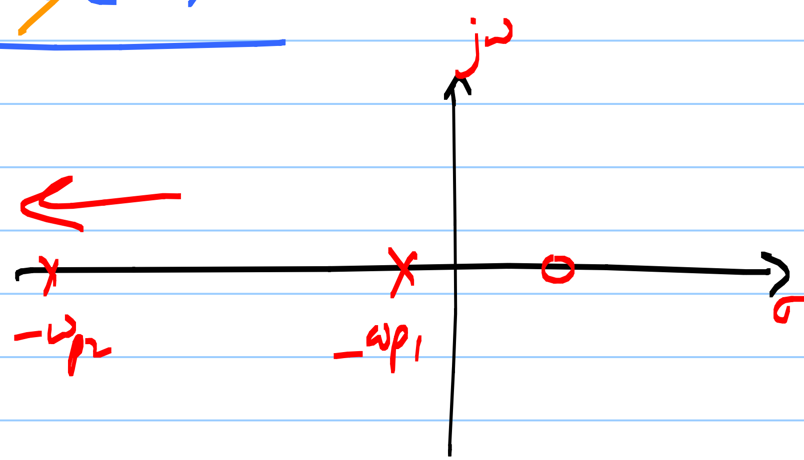
* $\underline{\text{increase } C_c}$

$\Rightarrow \quad C_c \gg C_{gs_1}$

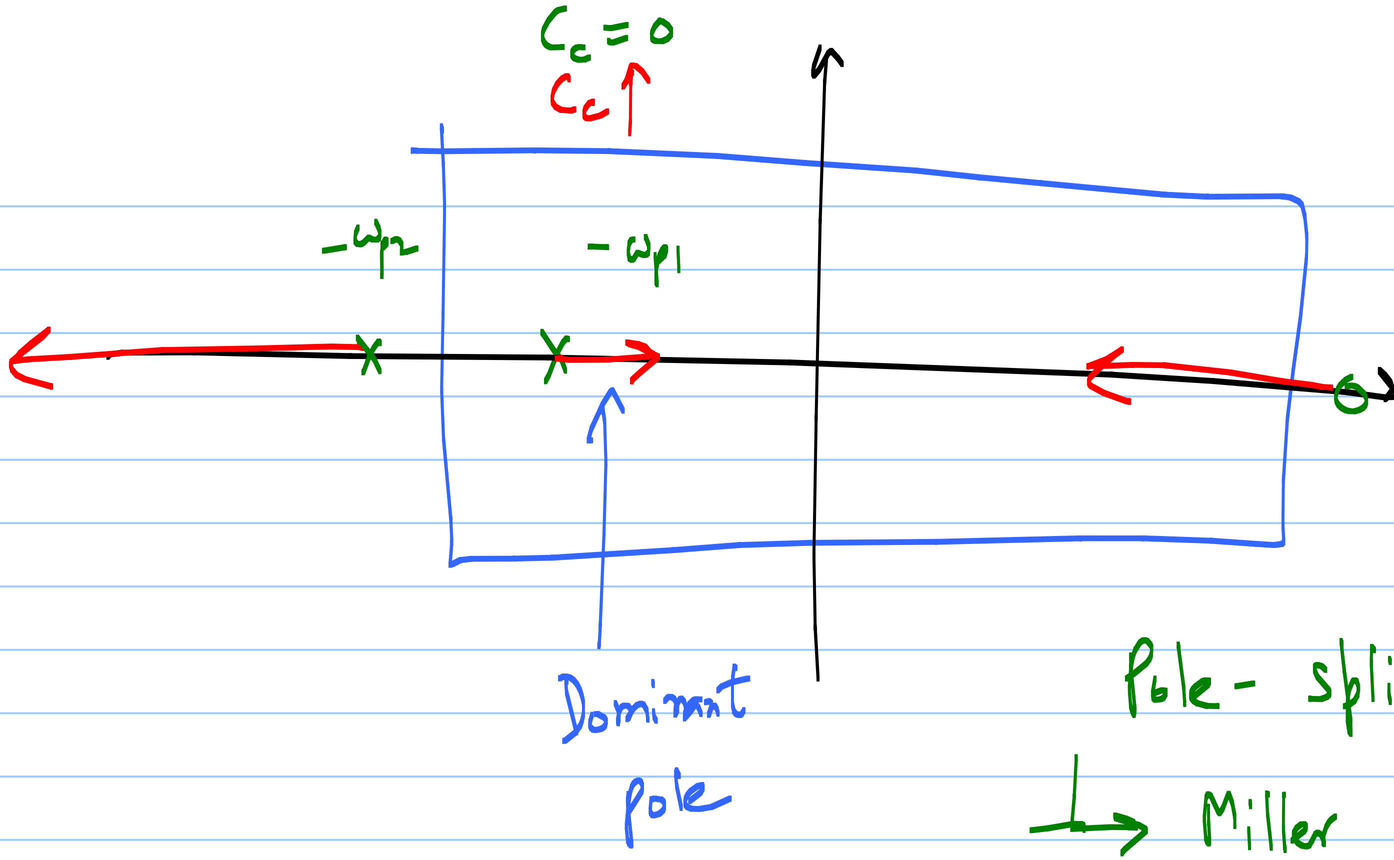
$$\omega_{p1} \simeq \frac{1}{R_s(1+|A_v|)C_c + R_o(C_c+C_o)}$$

$$\omega_{p2} \simeq \frac{\cancel{R_s}(\cancel{1}+g_{m_1}R_o)\cancel{C_c} + \cancel{R_o(C_c+C_o)}}{\cancel{R_s}R_o\,\cancel{C_c}[C_o+C_{gs_1}]}$$

$$\simeq \boxed{\frac{g_{m_1}}{C_o+C_{gs_1}}}$$



	$C_c = 0$	$C_c \gg C_{gs_1}$
ω_{p1}	$\simeq \dfrac{1}{R_s C_{gs_1} + R_o C_o}$	$\simeq \dfrac{1}{R_s (1+\lvert A\rvert) C_c + R_o (C_c + C_o)}$ ω_{p_1} is smaller
ω_{p2}	$\simeq \left(\dfrac{1}{R_o C_o}\right)$	$\simeq \dfrac{g_{m_1}}{C_o + C_{gs_1}} \simeq \dfrac{g_{m_1}}{C_o} = (g_{m_1} R_o) \left[\left(\dfrac{1}{R_o C_o}\right)\right]$ gain
ω_z	$\dfrac{g_{m1}}{C_{gd_1}}$	$\dfrac{g_{m_1}}{C_c}$

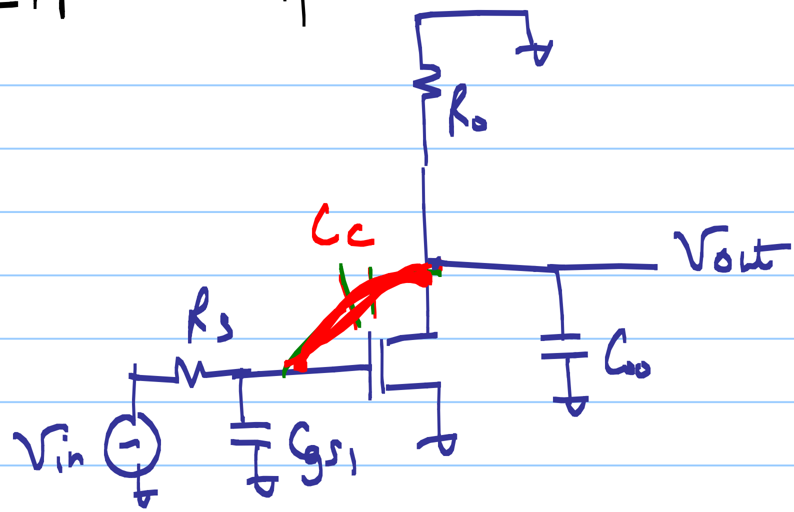


Pole-splitting

↳ Miller Compensation

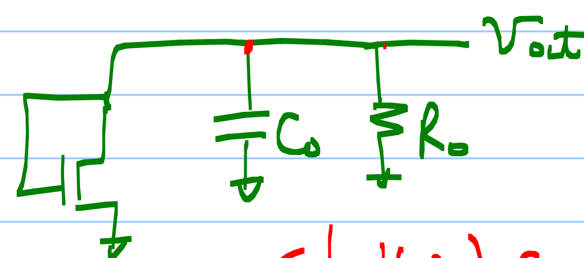
↳ stabilize two-pole amplifier

* Explanation for ω_{p2}



@ very high frequency

$\omega \geq \omega_{p2}$

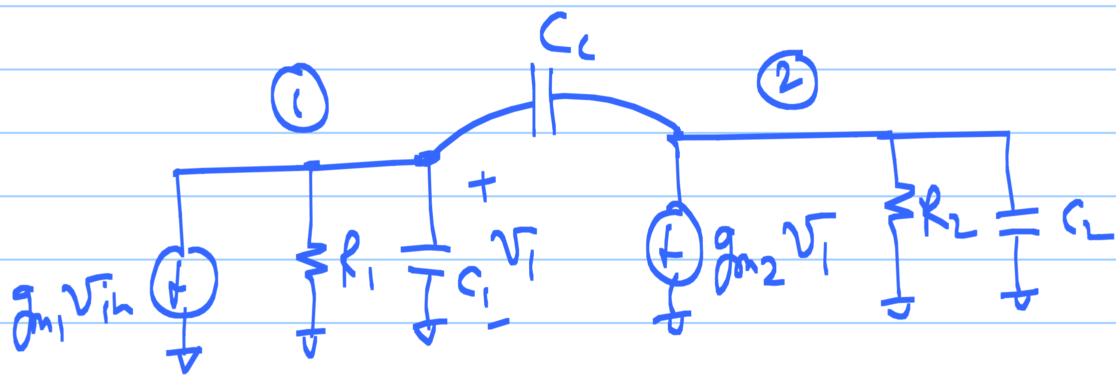


$$\tau_{out} = \left(\frac{1}{g_{m1}} \| R_o\right) C_o \simeq \frac{C_o}{g_{m1}}$$

$$\Rightarrow \quad \omega_{p2} \simeq \frac{g_{m1}}{C_o}$$

Pole Splitting Summary

Generic model for "2^{nd} order" amplifier.



$$A(s) = A_v \frac{\left(1 - s/\omega_z\right)}{\left(1 + s/\omega_{p1}\right)\left(1 + s/\omega_{p2}\right)}$$

$$A_v = g_{m1} R_1 \cdot g_{m2} R_2$$

$$\omega_{p1} \simeq \frac{1}{R_2(C_c + C_2) + R_1(C_1 + C_c(1 + g_{m2} R_2))} \simeq \frac{1}{g_{m2} R_2 R_1 C_c}$$

$$\omega_{p2} \simeq \frac{g_{m2} C_c}{C_c C_1 + C_1 C_2 + C_c C_2} \propto \frac{g_{m2}}{C_2} \quad \text{for } C_c \simeq C_2 \gg C_1$$

$$\omega_{un} = \frac{g_{m1}}{C_c} \quad \text{or unity-gain frequency}$$

$$A(s) = A_v \frac{\left(1 - s/\omega_z\right)}{\left(1 + s/\omega_{p1}\right)\left(1 + s/\omega_{p2}\right)}$$

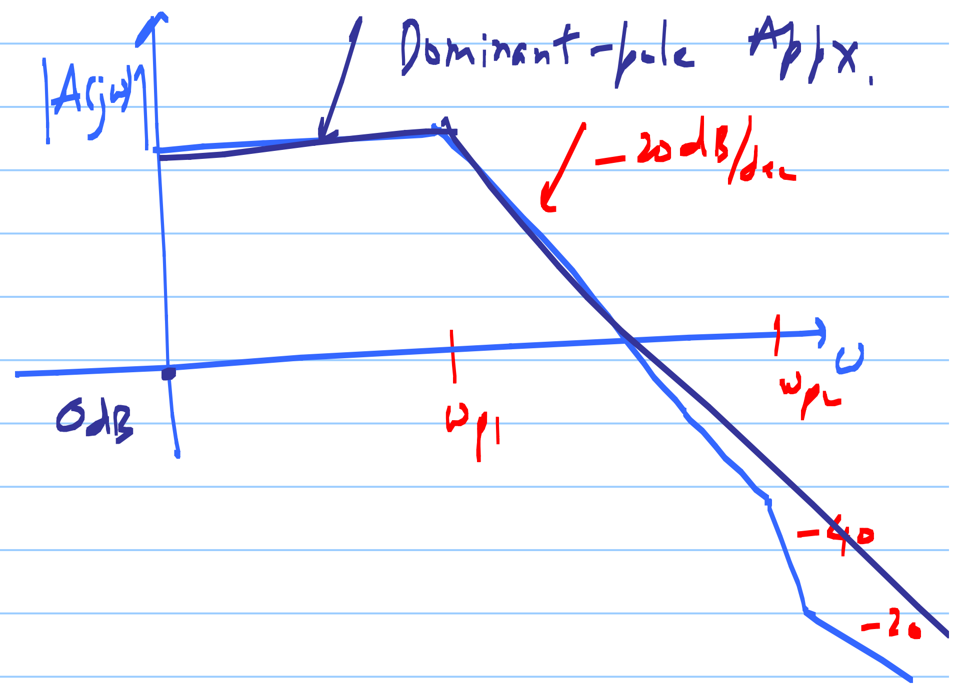
Compensated

$\omega_{p1} \ll \omega_{p2}$

$\uparrow$ dominant pole response

$\omega_z \to \infty$

$$A(s) \simeq \frac{A_v}{\left(1 + s/\omega_{p1}\right)}$$



$$A(s) = \frac{A_v}{\left(1 + s/\omega_{p_1}\right)}$$

$\omega_{p_1} \Rightarrow \omega_{3dB}$

DC gain

$$\simeq \frac{A_v}{1 + s/\omega_{3dB}}$$

3dB-BW

$$A_v = \overbrace{g_{m_1} R_1}\,\overbrace{g_{m_2} R_2}$$

$$\omega_{3dB} = \frac{1}{g_{m_2} R_2 R_1 C_c} \Rightarrow f_{3dB} = \frac{\omega_{3dB}}{2\pi} = \frac{1}{2\pi\, g_{m_2} R_2 R_1 C_c}$$

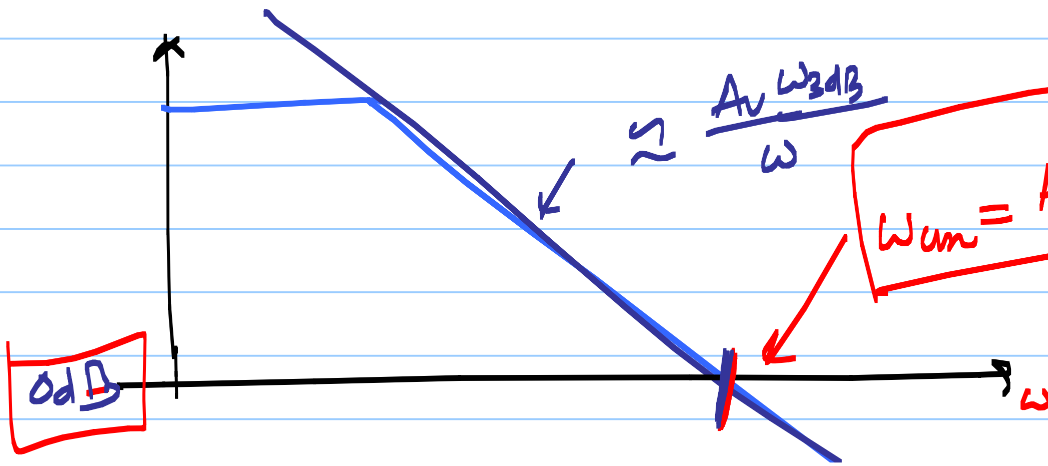
$$A_v \cdot \omega_{3dB} = \frac{g_{m_1}}{C_c}$$

$$\frac{A_v}{1 + s/\omega_{3dB}}$$

for $\omega >> \omega_{3dB}$

$$\simeq \frac{A_v}{s/\omega_{3dB}} = \frac{\boxed{A_v \omega_{3dB}}}{s} = \frac{\omega_{um}}{s}$$

$$\omega_{um} = \frac{g_{m1}}{C_c}$$

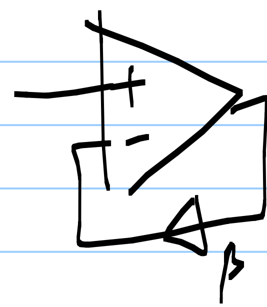


$$\simeq \frac{A_v \omega_{3dB}}{\omega}$$

$$\boxed{\omega_{um} = A_v \cdot \omega_{3dB}} = \frac{g_{m1}}{C_c}$$

constant

$\underline{\underline{\omega_{um}}} = A_{v} \cdot \omega_{3dB}$ ← Gain – BW trade-off for the amplifier



$\omega_{p2} \gg \omega_{um}$ ← ω_{p1} ← dominant pole response