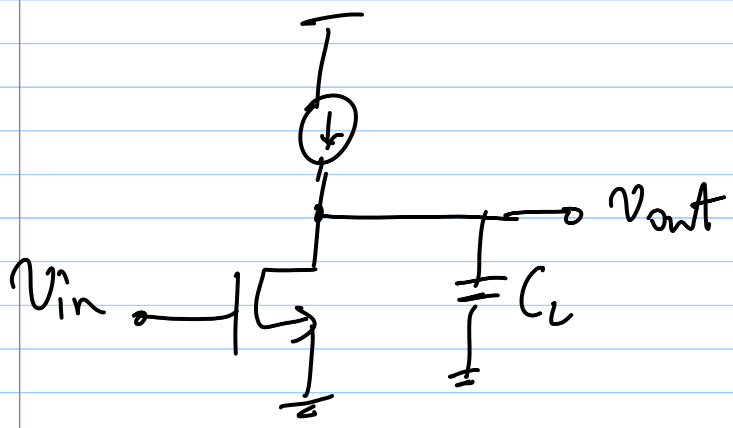
3-2-12

Lec 13

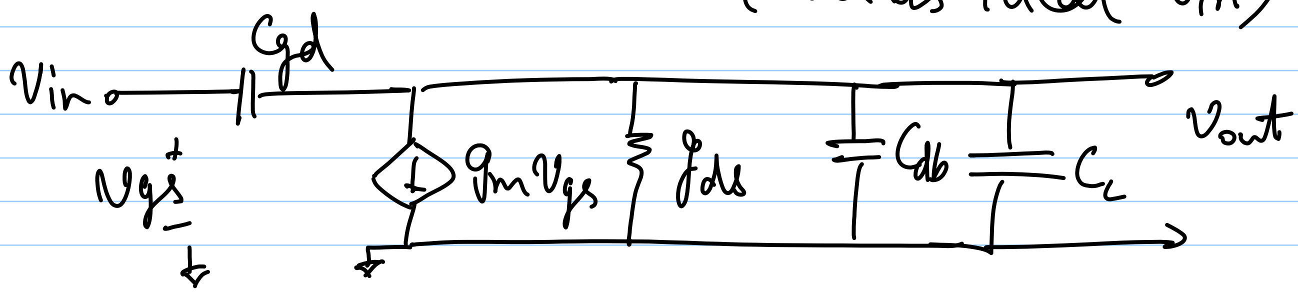
Freq. response

C.S. amp:



$v_{bs} = 0 \Rightarrow$ no effect from g_{mbs} & C_{sb}

neglect C_{gs}, C_{gb} (across ideal v_{in})

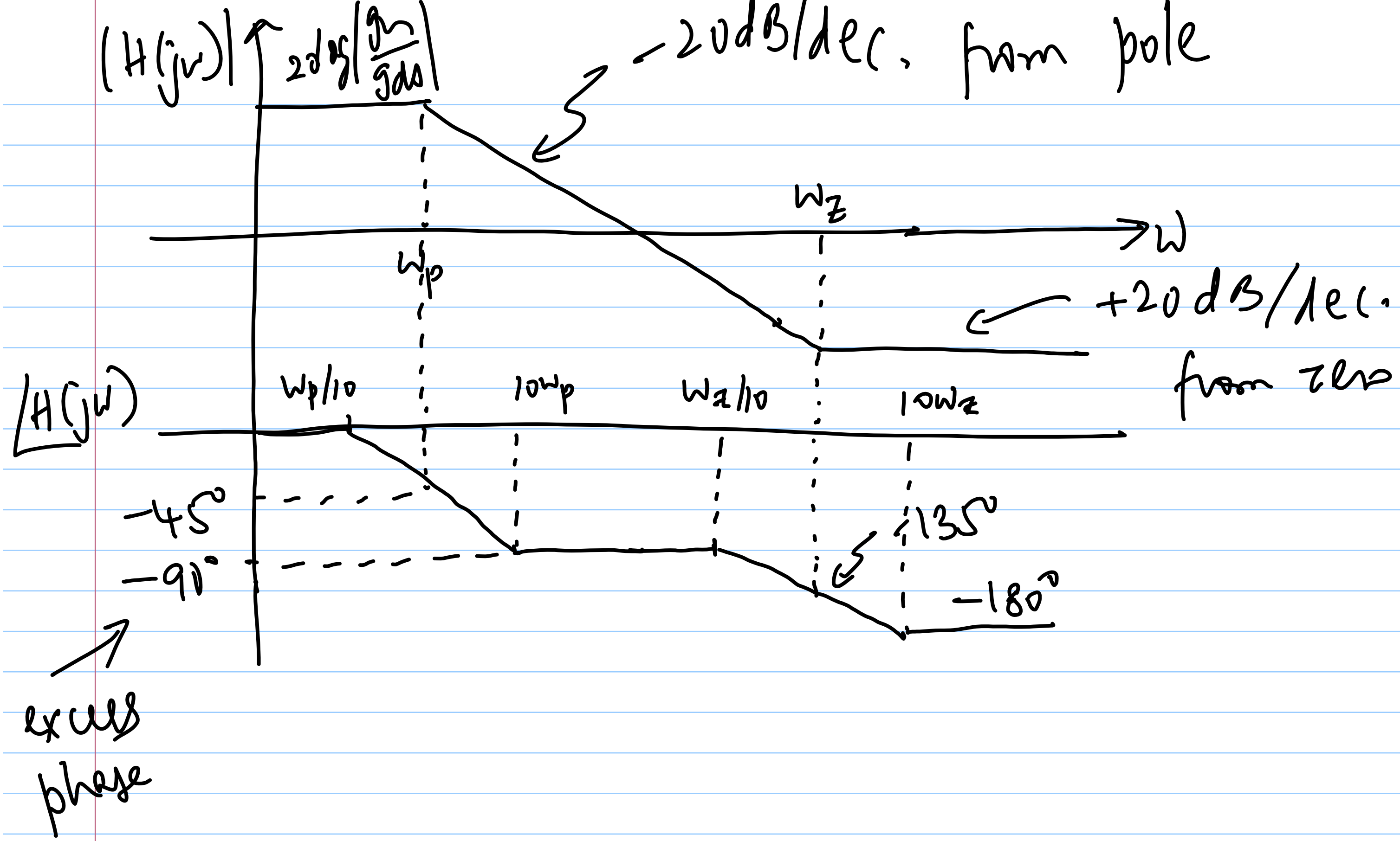


$$H(s) = \frac{v_{out}}{v_{in}}(s)$$

$$= \underbrace{\frac{g_m}{g_{ds}}}_{\text{(low-freq. gain)}} \frac{\left(1 - s\,C_{gd}/g_m\right)}{1 + \dfrac{s\left(C_{gd} + C_{db} + C_L\right)}{g_{ds}}}$$

$$\omega_z = \frac{g_m}{C_{gd}} \quad \text{RHP zero}$$

$$\omega_p = -\frac{g_{ds}}{C_{gd} + C_{db} + C_L} \quad \text{LHP pole}$$

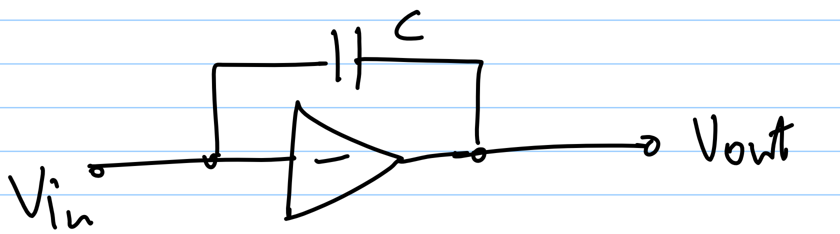


* LHP poles : (approx) every node in signal path

$$\omega_{pi} = \frac{g_i}{C_i} = \frac{1}{R_i C_i} \quad \left[\left.\begin{matrix} g_i \\ R_i \\ C_i \end{matrix}\right\} @ \text{ node } i \right]$$

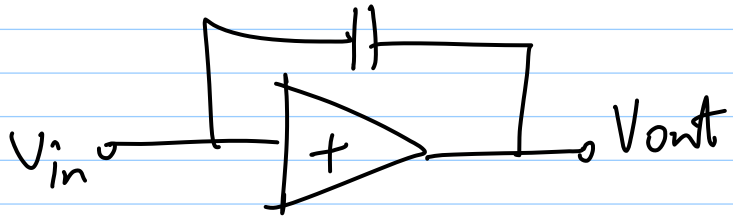
→ high impedance node ≡ low-freq. pole and vice versa

* RHP zero : occurs if there is a capacitive path from input to output



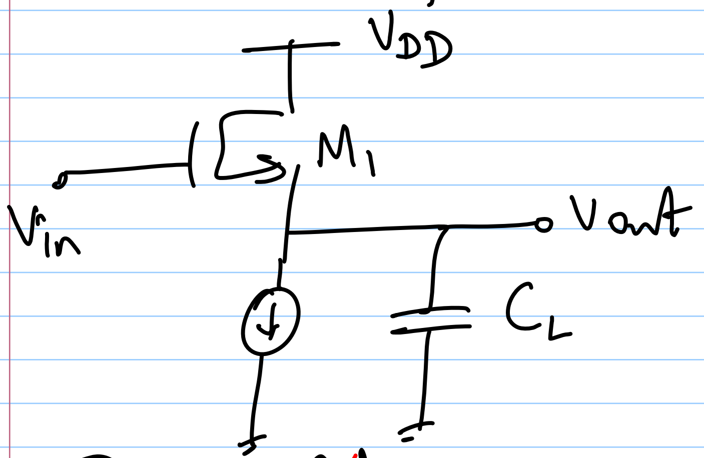
RHP zero @ $\frac{G_m}{C}$

G_m = effective transconductance between V_{in} and V_{out}

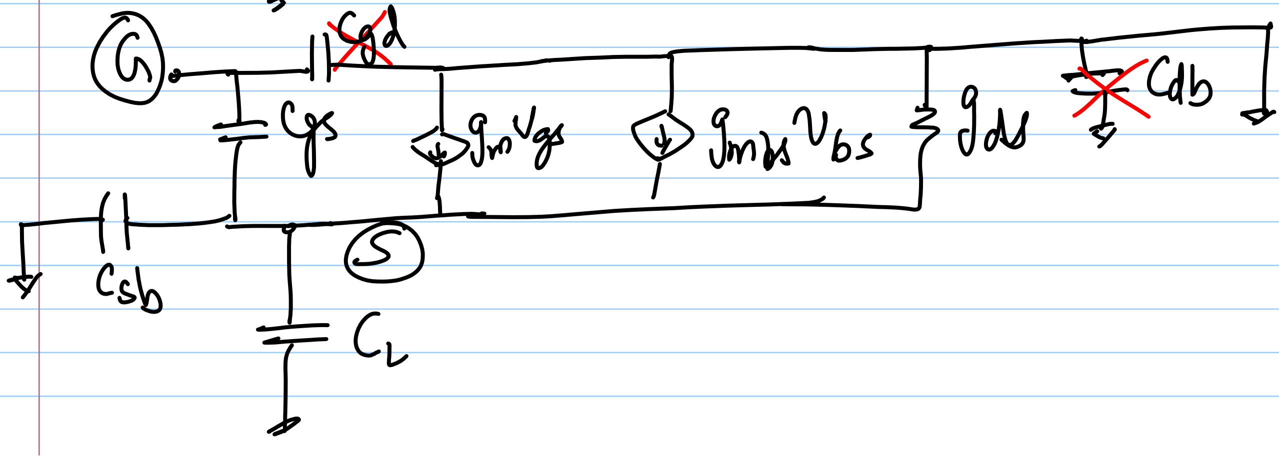


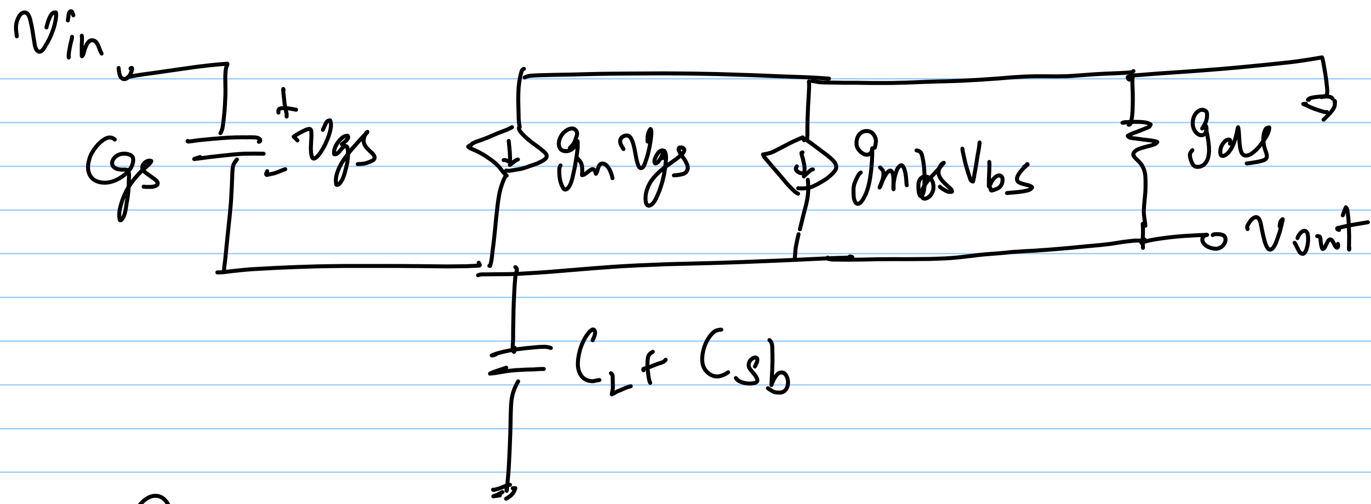
$\Rightarrow$ LHP zero @ $\frac{G_m}{C}$

Source follower



* neglect C_{db} (shorted)
* neglect C_{gd} (V_{in})





KCL @ S

$$sC_{gs}(V_{in}-V_{out}) + g_m(V_{in}-V_{out}) + g_{mbs}(-V_{out}) + g_{ds}(-V_{out}) = s(C_L + C_{sb})\cdot V_{out}$$

$$\frac{V_{out}}{V_{in}}(s) = \frac{g_m + sC_{gs}}{g_m + g_{mbs} + g_{ds} + s(C_{gs}+C_{sb}+C_L)}$$

$$= \frac{g_m}{g_m+g_{mbs}+g_{ds}} \cdot \frac{\left(1 + sC_{gs}/g_m\right)}{\left[1 + \dfrac{s(C_{gs}+C_{sb}+C_L)}{g_m+g_{mbs}+g_{ds}}\right]}$$

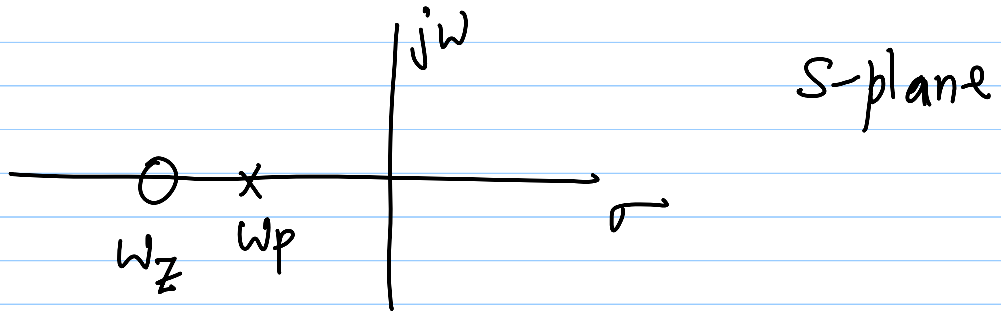
LHP zero : $\omega_z = \dfrac{-g_m}{C_{gs}}$

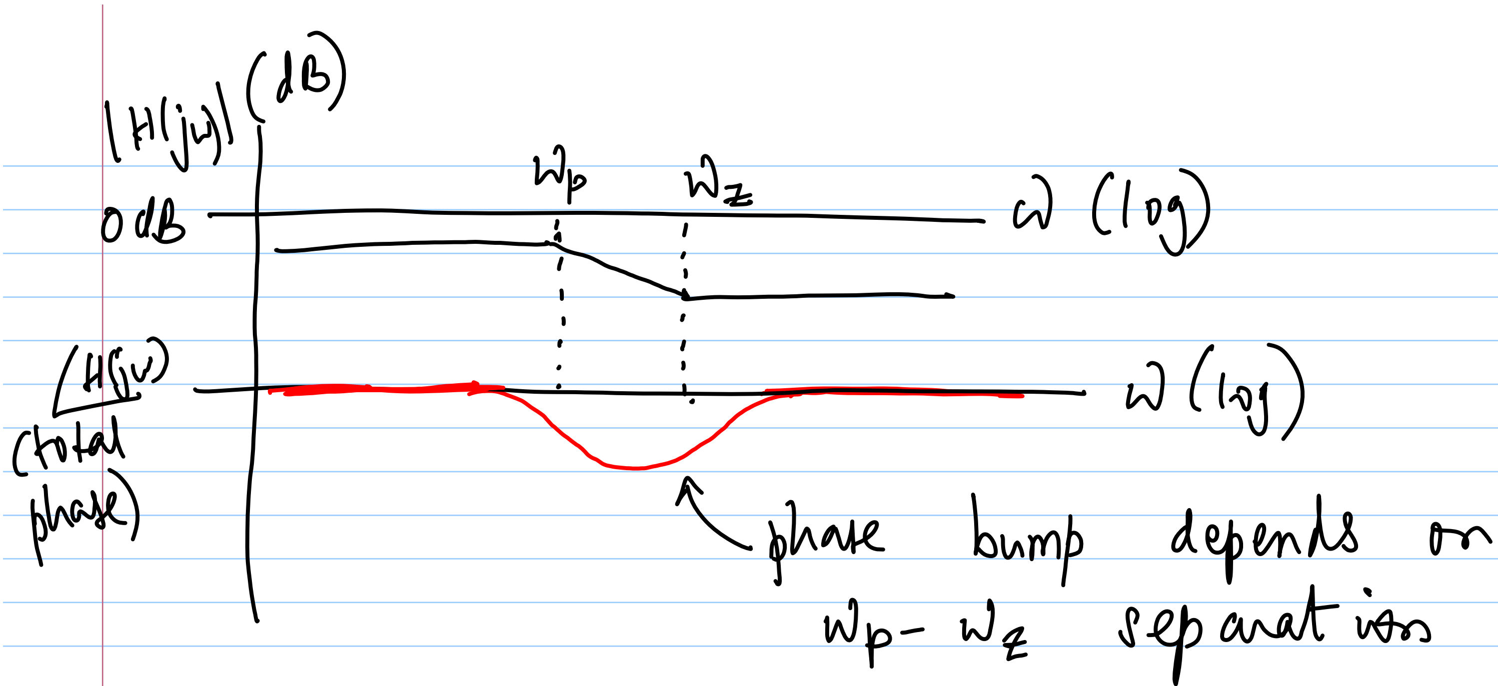
LHP pole:

$$\omega_p = \frac{-(g_m + g_{mbs} + g_{ds})}{(C_{gs} + C_{sb} + C_L)} \approx \frac{-g_m}{C_{gs}+C_{sb}+C_L}$$

Note that since $g_m \gg g_{mbs}, g_{ds}$

$$|\omega_p| < |\omega_z|$$

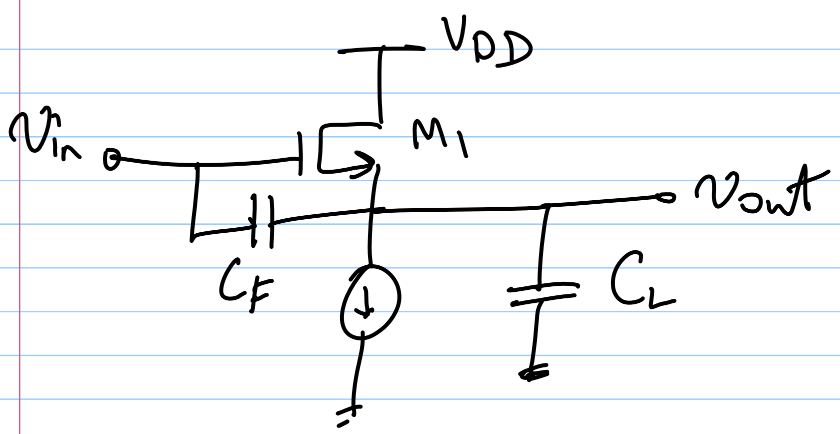




* If we increase C_{gs}, ω_z moves more than ω_p

→ increase C_{gs} so that $\omega_p = \omega_z$!

⇒ $\boxed{\text{Pole - zero cancellation}}$



$C_{gs}' \rightarrow C_{gs} + C_F$

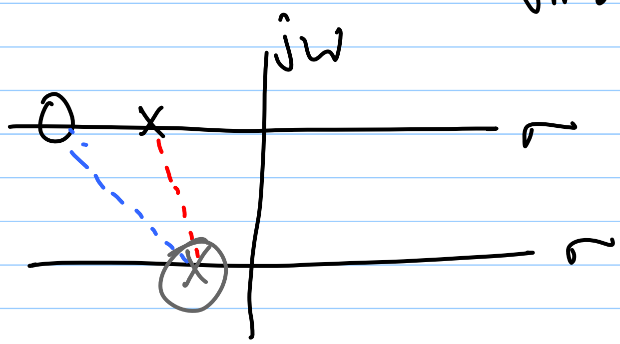
$$\omega_p = -\frac{(g_m + g_{mbs} + g_{ds})}{C_{gs} + C_F + C_{sb} + C_L}$$

$$\omega_z = \frac{-g_m}{C_{gs} + C_F}$$

set $\omega_p = \omega_z$

$$\Rightarrow \frac{g_m + g_{mbs} + g_{ds}}{C_{gs} + C_F + C_{sb} + C_L} = \frac{g_m}{C_{gs} + C_F}$$

$$\Rightarrow C_F = \frac{g_m}{g_{mbs} + g_{ds}} (C_{sb} + C_L) - C_{gs}$$



why?

$\Rightarrow$ broad band response!

Issues:

1) C_F is large $\sim 10\, C_L$

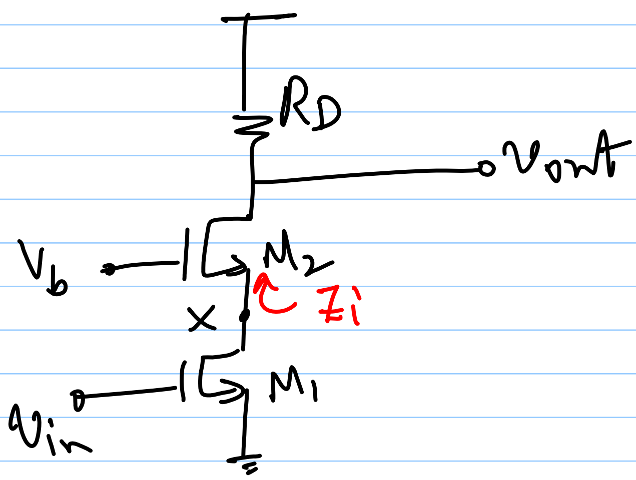
$\left\{ \text{note } C_F = \dfrac{g_m}{g_{mbs} + g_{ds}} \times \ldots \right\}$

2) If $\omega_p \neq \omega_z$ (inexact cancellation)

$\Rightarrow$ pole-zero doublet

$\Rightarrow$ very slowly settling transient response

Cascode freq. response



$$\frac{v_{out}}{v_{in}} \approx -g_m R_D$$

$\Rightarrow$ same as normal CS amp.

$Z_i \approx \dfrac{1}{g_{m_2}}$ if r_{ds_2} is large

If same $(W/L) \Rightarrow g_{m_1} = g_{m_2}$

$$\frac{v_x}{v_{in}} \approx \frac{g_{m1}}{g_{m2}} \approx 1$$

$\Rightarrow$ very little miller effect

If r_{ds2} is finite,

$$Z_i \approx \frac{1}{g_{m2}} + \frac{1}{g_{m2}} \cdot \frac{R_D}{r_{ds2}}$$

e.g. R_D is derived from a cascode current mirror

$\Rightarrow R_D \gg r_{ds2}$

$$\Rightarrow Z_i \gg \frac{1}{g_{m2}}$$

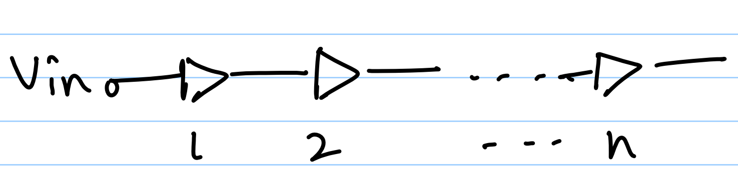
$\frac{v_x}{v_{in}} \gg 1$, but still $< \frac{v_o}{v_{in}}$

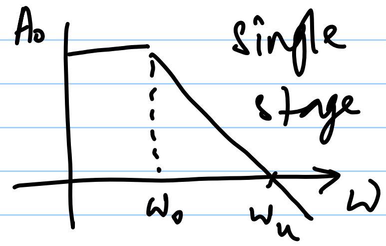
$\Rightarrow$ Miller effect with cascode is still lower than without

* Miller effect can be reduced further by using active cascode

* Cascode has low reverse-transmission

Multi-stage freq. response





* All n amplifiers are identical

* Each stage has single-pole response

$$A(s) = \frac{A_0}{1 + s/\omega_0}$$

overall cascade TF is

$$H(s) = \left(\frac{A_0}{1 + s/\omega_0}\right)^n$$

* find $-3dB$ BW of the cascade (ω_{on}):

at $\omega = \omega_{on}$, $|H(j\omega)| = \frac{1}{\sqrt{2}} |H(0)|$

$$\Rightarrow \left[\frac{A_0}{\sqrt{1 + \left(\frac{\omega_{on}}{\omega_0}\right)^2}}\right]^n = \frac{1}{\sqrt{2}} A_0^n$$

$$\Rightarrow \boxed{\omega_{on} = \omega_0 \sqrt{2^{1/n} - 1}}$$

BW shrinkage

Recall that $A_0 \omega_0 = \omega_u \Rightarrow \boxed{\omega_{on} = \frac{\omega_u}{A_0} \sqrt{2^{1/n} - 1}}$