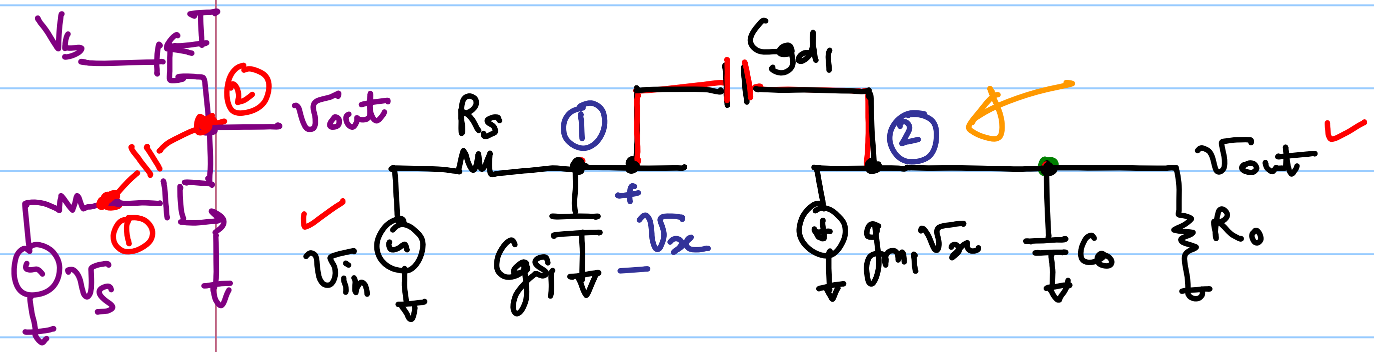
ECE 511 – Lecture 17

Note Title 3/20/2014



$R_o = r_{o_1} || r_{o_2}$

$C_o = C_{db} + C_{dg_2} + \ldots$

Solve for v_x and substitute in (2)

$$v_x = -\frac{v_{out}\left(C_{gd_1}s + \frac{1}{R_o} + C_o s\right)}{g_{m_1} - sC_{gd_1}}$$

N^r

2^{nd}-order Transfer function

$$\frac{V_{out}}{V_{in}}(s) = \frac{\boxed{(C_{gd_1}s - g_{m_1})R_o}}{\left\{R_sR_o\xi s^2 + \left[R_s(1+g_{m_1}R_o)C_{gd_1} + R_sC_{gs_1} + R_o(C_{gd_1}+C_o)\right]s + 1\right\}}$$

$D^r \Rightarrow$

where $\xi = C_{gs_1}C_{gd_1} + C_{gs_1}C_o + C_{gd_1}C_o$

$N^r \Rightarrow$

$$(sC_{gd_1} - g_{m_1})R_o = \underbrace{-g_{m_1}R_o}_{\text{DC gain} \to A_v}\underbrace{\left(1 - \frac{s}{\omega_z}\right)}_{}$$

$$\omega_z = \frac{g_{m_1}}{C_{gd_1}}$$

zero

zero at $\boxed{s = \omega_z = +\frac{g_{m_1}}{C_{gd_1}}}$ R.H.P. zero

RHP zero

"In Bode phase plot an RHP zero pulls the phase down by 90°"

$D^r \Rightarrow$ 2nd-order system $\Rightarrow$ two-poles $\longrightarrow$ real or complex - conjugate

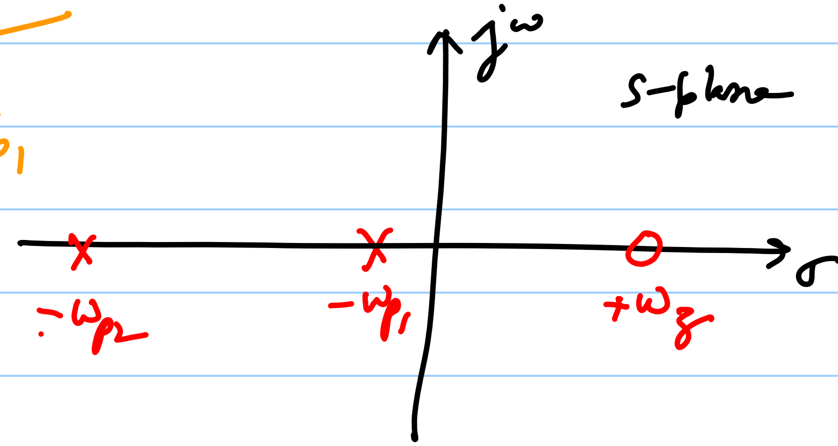
If we assume $|\omega_{p1}| \ll |\omega_{p2}|$

Assumption $\Rightarrow$ poles are real

then

$$D(s) = \left(1 + \frac{s}{\omega_{p1}}\right)\left(1 + \frac{s}{\omega_{p2}}\right)$$

$$\Rightarrow D(s) = \underbrace{\frac{s^2}{\omega_{p1}\omega_{p2}}}_{} + \underbrace{\left(\frac{1}{\omega_{p1}} + \frac{1}{\omega_{p2}}\right)}_{\simeq \frac{s}{\omega_{p1}}} s + 1$$



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

$$\Rightarrow \frac{1}{\omega_{p1}} \gg \frac{1}{\omega_{p2}}$$

$\Rightarrow$ Coeffn of 's' $\simeq \frac{1}{\omega_{p1}}$

$$\boxed{\omega_{p1} = \frac{1}{R_S\underbrace{(1+\underbrace{g_{m1}R_o}_{|A_v|})C_{gd1}}_{} + R_S C_{gs1} + \boxed{R_o(C_{gd1}+C_o)}}}$$ ①

C_{in} from Miller

Extra term

↳ contribution from node ②

2nd pole

coeffn for s^2 was $(\omega_{p1}\cdot\omega_{p2})^{-1}$

$$\Rightarrow \quad \omega_{p2} = \frac{1}{\omega_{p1}} \times \frac{1}{R_S R_o \xi}$$

$$= \frac{1}{\omega_{p1}} \times \frac{1}{R_S R_o\left[C_{gs1}C_{gd1} + C_{gs1}C_o + C_{gd1}C_o\right]}$$

$$\Rightarrow \boxed{\omega_{p2} = \frac{R_s(1+g_mR_o)C_{gd1} + R_sC_{gs1} + R_o(C_{gd1}+C_o)}{R_sR_o\left[C_{gs1}C_{gd1} + C_{gs1}C_o + C_{gd1}C_o\right]}} \leftarrow ②$$

If $\quad C_{gs1} >> (1+g_mR_o)C_{gd1} + \frac{R_o}{R_s}(C_{gd1}+C_o)$

$$\omega_{p2} \simeq \frac{1}{R_o(C_{gd1}+C_o)} \Leftarrow$$

Same as ω_{out}

Valid only when C_{gs1} dominate the response

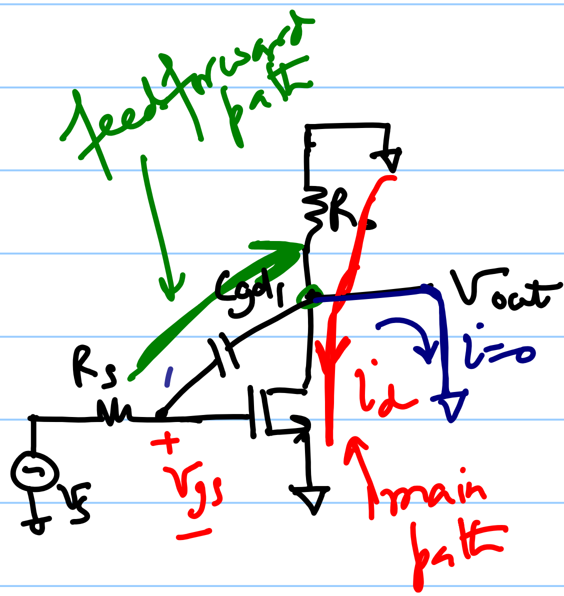
↳ otherwise not

$$\boxed{\frac{v_{out}}{v_{in}}(s) = \frac{A_v\left(1-\frac{s}{\omega_z}\right)}{\left(1+\frac{s}{\omega_{p1}}\right)\left(1+\frac{s}{\omega_{p2}}\right)}}, \qquad A_v = -g_{m1}R_o$$

Zero

$$\omega_z = \frac{+g_{m1}}{C_{gd1}} \Rightarrow \text{RHP zero}$$

Az picture



$= -i_d R_o$

$= -g_{m1} v_{in} R_o$

at $\omega = \omega_z \Rightarrow$ net Az current $= 0$

at $s = s_z \Rightarrow \frac{V_{out}}{V_{in}}(s) = 0$

$\Rightarrow$ for a finite $v_{in} \Rightarrow \underline{\underline{V_{out}(s_z) = 0}}$

$$g_{m1} \cancel{v_{gs}} = \frac{v_{gs}}{1/s_z C_{gd1}} = s_z C_{gd1} \cancel{v_{gs}}$$

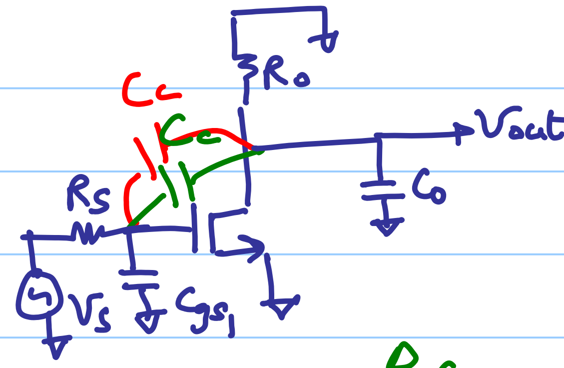
$$\boxed{S_z = +\frac{g_{m1}}{C_{gd1}}}$$

* RHP zero reduces phase

$\Rightarrow$ @ high frequencies the signal thru C_{gd1} adds to the main path in the opposite phase

* also $\omega = \omega_z \Rightarrow$ net AC current to $V_{out} \rightarrow 0$

"Pole splitting"



$$\omega_z = \frac{g_{m1}}{C_{gd1}}$$

$$\omega_{p1} = \frac{1}{R_s[(1+|A_v|)C_c + C_{gs1}] + R_o(C_c + C_o)}$$

$$C_c \triangleq C_{gd1}$$

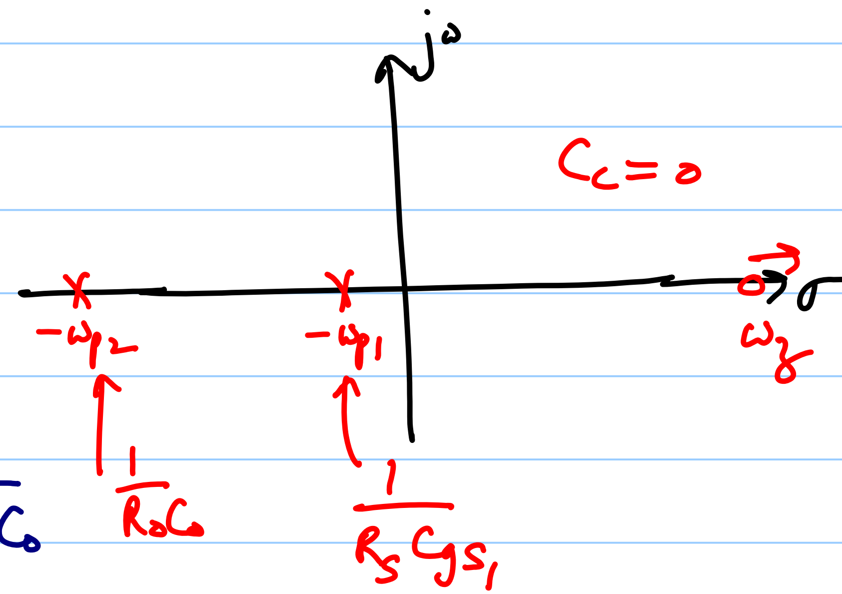
$$\omega_{p2} = \frac{R_s(1+g_m R_o)C_c + R_s C_{gs1} + R_o(C_c + C_o)}{R_s R_o[C_{gs1}C_c + C_{gs1}C_o + C_c C_o]}$$

① $C_c = 0$ & large C_o

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

$$\omega_{p2} \simeq \frac{R_s C_{gs1} + R_o C_o}{R_s R_o C_{gs1} C_o} \simeq \frac{1}{R_o C_o}$$

$\omega_z \to \infty$



Now increase C_c

Consider when $C_c >> C_{gs_1}$

$$\omega_{p_1} \simeq \frac{1}{R_s(1+|A_v|)C_c + R_o(C_c + C_o)}$$

$$\omega_z = \frac{+g_{m_1}}{C_c}$$

$$\omega_{p_2} \simeq \frac{R_s(1+g_{m_1}R_o)C_c + \cancel{R_o(C_c + C_o)}}{R_s R_o C_c [C_o + C_{gs_1}]}$$

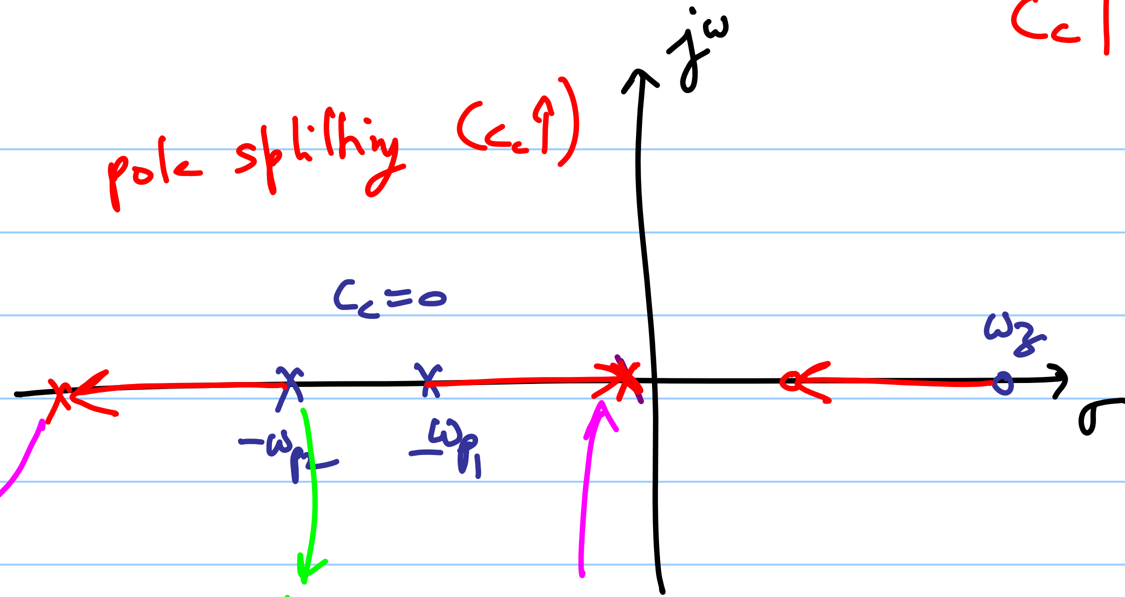
$$\simeq \frac{\cancel{R_s}(1+g_{m_1}R_o)\cancel{C_c}}{\cancel{R_s} R_o \cancel{C_c}(C_o + C_{gs_1})} \simeq \frac{g_{m_1}}{C_o + C_{gs_1}}$$

	$C_c = 0$	$C_c \gg C_{gs1}$, $C_c \overset{\Delta}{\simeq} C_o$
ω_{p1}	$\simeq \dfrac{1}{R_s C_{gs1} + R_o C_o}$	$\simeq \dfrac{1}{R_s(1+\lvert A_v \rvert)\underline{\underline{C_c}} + R_o[\underline{\underline{C_c}} + C_o]}$ $\quad C_c \uparrow$ ω_{p1} is smaller
ω_{p2}	$\simeq \underbrace{\dfrac{1}{R_o C_o}}$	$\simeq \dfrac{g_{m1}}{C_o + C_{gs1}} \overset{\Delta}{\simeq} \dfrac{g_{m1}}{C_o} = g_{m1} R_o \left(\underbrace{\dfrac{1}{R_o C_o}} \right)$ $\Rightarrow$ ω_{p2} is increased by a large value
ω_z	$\dfrac{g_{m1}}{C_{gd1}}$	$\dfrac{g_{m1}}{C_c}$ $\leftarrow$ RHP zero is at lower frequency

Miller Compensation $\Rightarrow$ pole splitting $\Rightarrow$ $C_c \uparrow$

$C_c \uparrow$

pole splitting ($C_c \uparrow$)



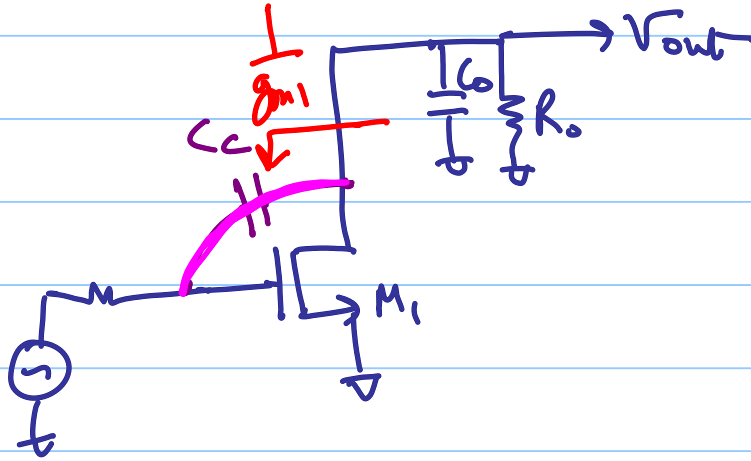
$\simeq \dfrac{g_{m1}}{C_o}$ $\quad$ $\dfrac{1}{R_oC_o}$ $\quad$ $\omega_{p1} \simeq \dfrac{1}{R_S|A_v|C_c} = \dfrac{1}{g_{m1}R_oR_SC_c}$

low frequency pole

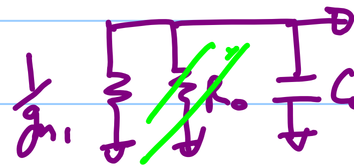
↳ dominant pole (ω_{p1})

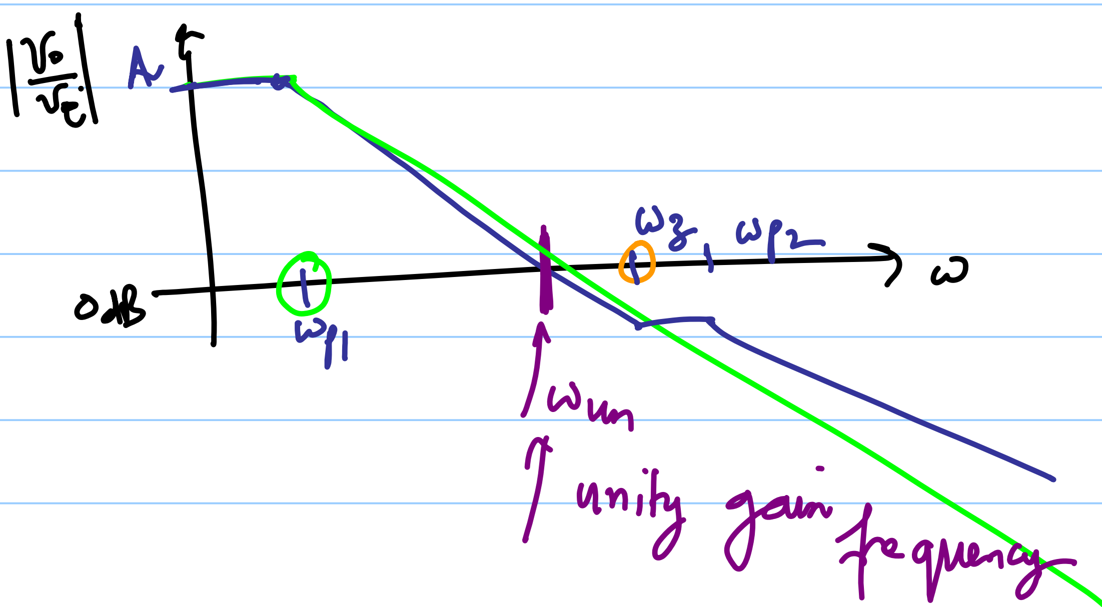
non-dominant pole (ω_{p2})

for a large C_c
at high frequencies.

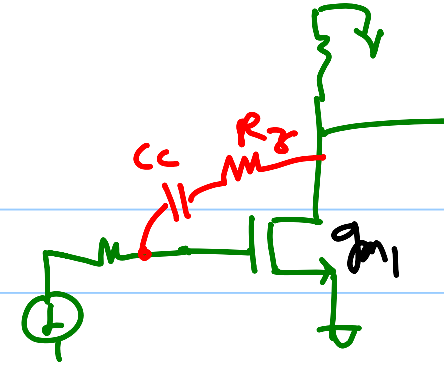


$$\omega_{p2} \simeq \frac{g_{m1}}{C_o}$$

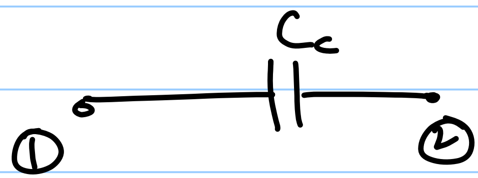




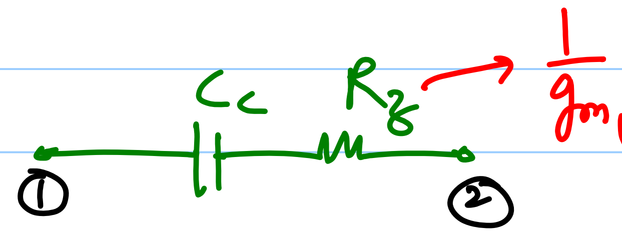
Cancel the RHP zero.



$$\omega_z = +\frac{g_{m1}}{C_c}$$



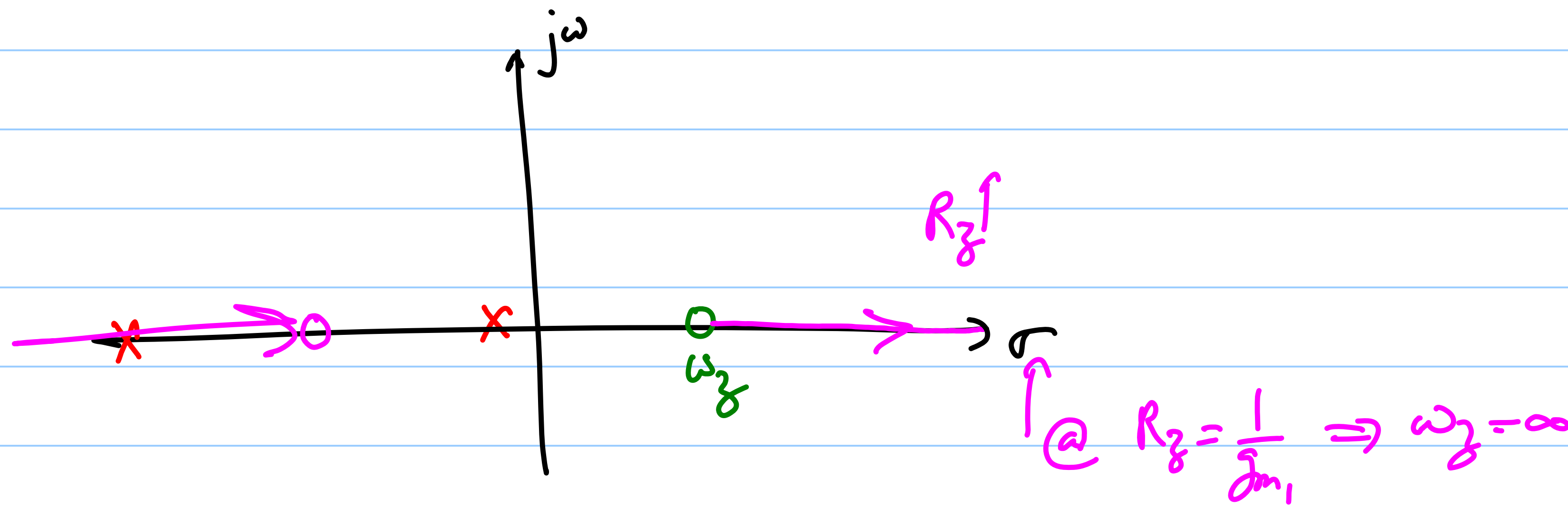
$\Rightarrow$



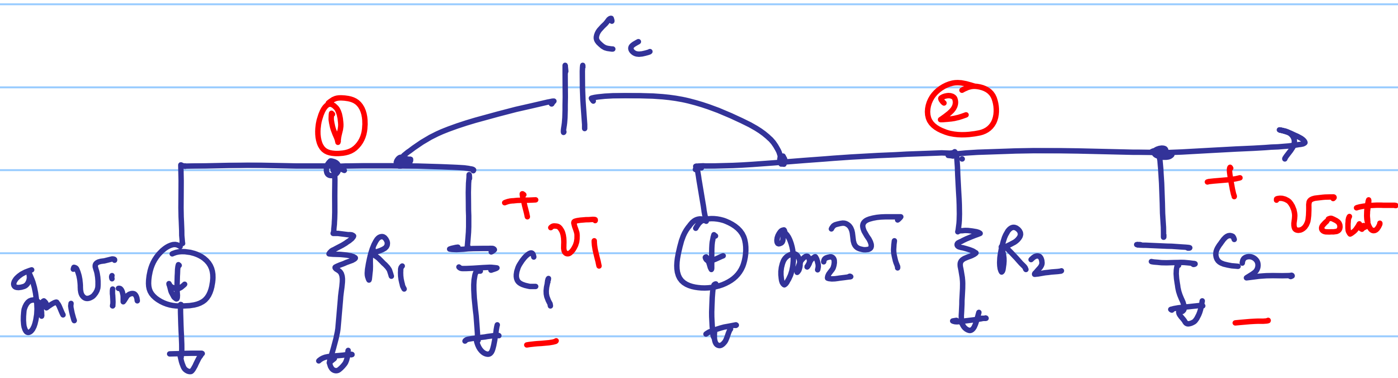
$$\omega_z = \frac{1}{C_c\left(\frac{1}{g_{m1}} - R_z\right)}$$

If $R_z = \frac{1}{g_{m1}} \Rightarrow \omega_z \to \infty$ zero disappears

$R_z > \frac{1}{g_{m1}} \Rightarrow$ zero appears in the LHP.


jω
σ
ω_z
$R_z \uparrow$
@ $R_z = \frac{1}{g_{m1}} \Rightarrow \omega_z = \infty$

Pole splitting Summary



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

$$\omega_{p1} = \frac{1}{R_2(C_2+C_c) + R_1(C_1 + C_c[1+g_{m2}R_2])} \simeq \boxed{\frac{1}{g_{m2}R_2R_1C_c}}$$

$$\boxed{\omega_{p2} \simeq \frac{g_{m2}C_c}{C_cC_1 + C_1C_2 + C_cC_2}} \overset{\Delta}{\simeq} \frac{g_m}{C_2} \quad \text{for } C_c \simeq C_2 \gg C_1$$

$$\boxed{\omega_z = \frac{g_{m2}}{C_c}}$$

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