ECE 515 - Lecture 17

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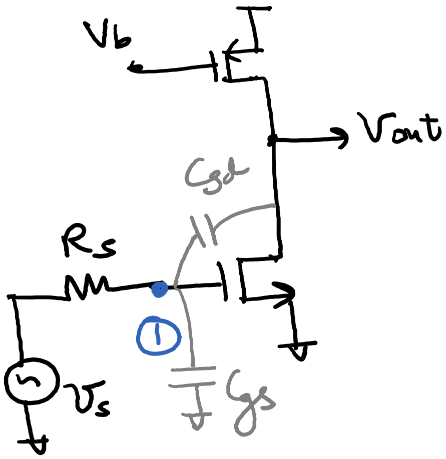
$$D(s) = \frac{s^2}{\omega_{p_1}\omega_{p_2}} + \left(\frac{1}{\omega_{p_1}} + \frac{1}{\omega_{p_2}}\right)s + 1$$

very small



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

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

$$\omega_{p_1} \Rightarrow \frac{1}{\text{coeff of 's'}}$$

$$= \frac{1}{R_s(1+g_{m_1}R_o)C_{gd_1} + R_sC_{gs_1} + R_o(C_{gd_1} + C_o)}$$

2nd pole: coeff " of s^2 is $\frac{1}{\omega_{p_1}\omega_{p_2}}$

$$\omega_{p_2} = \frac{1}{\omega_{p_1}} \cdot \frac{1}{R_sR_o\xi}$$

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$$\Rightarrow \omega_{p2} = \frac{1}{\omega_{p1}} \times \frac{1}{R_s R_o [C_{gs1} C_{gd1} + C_{gs1} C_o + C_{gd1} C_o]}$$

$$= \frac{R_s(1+g_m R_o) C_{gd1} + \boxed{R_s C_{gs1}} + R_o (C_{gd1} + C_o)}{R_s R_o [C_{gs1} C_{gd1} + C_{gs1} C_o + C_{gd1} C_o]}$$

If $C_{gs1} \gg (1+g_m R) C_{gd1} + \frac{R_o}{R_s}(C_{gd1} + C_o)$

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

$\Leftarrow$ Same as ω_{out} in the Miller approximation

Valid only when C_{gs1} dominates the response, otherwise not.

Pole Splitting

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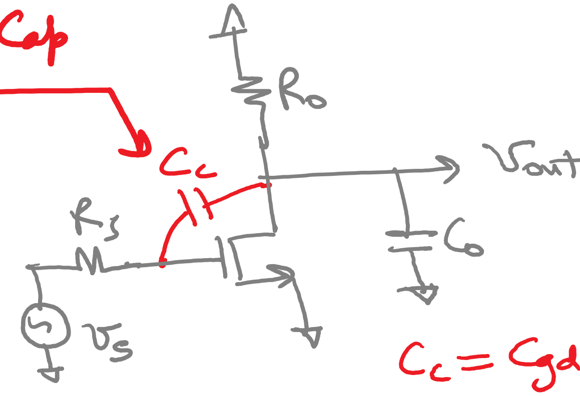
Miller Cap



$C_c = C_{gd_1}$

$$\omega_z = +\frac{g_{m_1}}{C_{gd_1}} \quad \text{(RHP zero)}$$

$$\omega_{p_1} = \frac{1}{R_s\left[(1+|A_v|)c_c + C_{gs_1}\right] + R_o(C_c + C_o)}$$

$$\omega_{p_2} = \frac{R_s(1+g_m R_o)C_c + R_s C_{gs_1} + R_o(C_c + C_o)}{R_s R_o\left[C_{gs_1}C_c + C_{gs_1}C_o + c_c C_o\right]}$$

* for $C_c = 0$ and a large C_o

$$\omega_{p_1} \simeq \frac{1}{R_s C_{gs_1} + R_o C_o}$$

$$\omega_{p_2} \simeq \frac{R_s C_{gs_1} + R_o C_o}{R_s R_o C_{gs_1} \cdot C_o} = \frac{1}{R_o C_o} + \frac{1}{R_s C_{gs_1}}$$

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

Now, increase C_c

$C_c \gg C_{gs1}$

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

$$\omega_{p2} \simeq \frac{\cancel{R}_s(1+g_{m1}R_o)\cancel{C}_c + \cancel{R_o(C_c+C_o)}}{\cancel{R}_s R_o \cancel{C}_c [C_o + C_{gs1}]}$$

very small

$$\simeq \frac{g_{m1}}{C_o + C_{gs1}}$$

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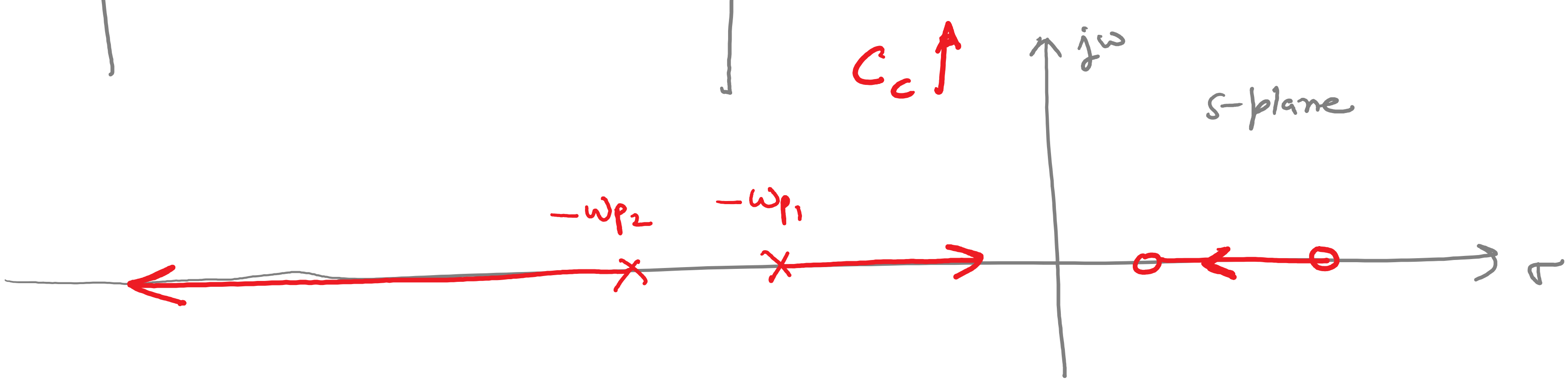
	$C_c = 0$	$C_c \gg C_{gs1}$
ω_{p1}	$\simeq \dfrac{1}{R_s C_{gs1} + R_o C_o}$	$\dfrac{1}{R_s(1+\lvert A \rvert) C_c + R_o [C_c + C_o]}$
ω_{p2}	$\simeq \dfrac{1}{R_o C_o}$	$\simeq \dfrac{g_{m1}}{C_o + C_{gs1}} \simeq \dfrac{g_{m1}}{C_o} = g_{m1} R_o \cdot \left[\dfrac{1}{R_o C_o} \right]$
ω_z	$\dfrac{g_{m1}}{C_{gd1}}$	$\dfrac{g_{m1}}{C_c}$

"Miller Compensation".



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

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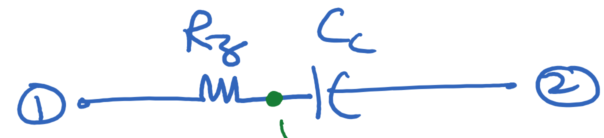
RHP zero Cancellation

$\Rightarrow$



additional pole at very high frequencies

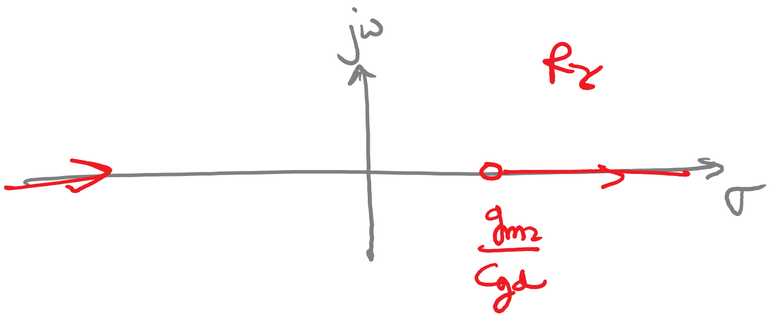
$$\omega_z = \frac{1}{C_c\left(\frac{1}{g_{m2}} - R_z\right)}$$

Set $R_z = \frac{1}{g_{m2}}$ $\longrightarrow$ zero is pushed to ∞ (it disappears)

$R_z > \frac{1}{g_{m2}}$ $\rightarrow$ zero is pushed into the LHP

$\rightarrow$ LHP zero

↳ add to the phase

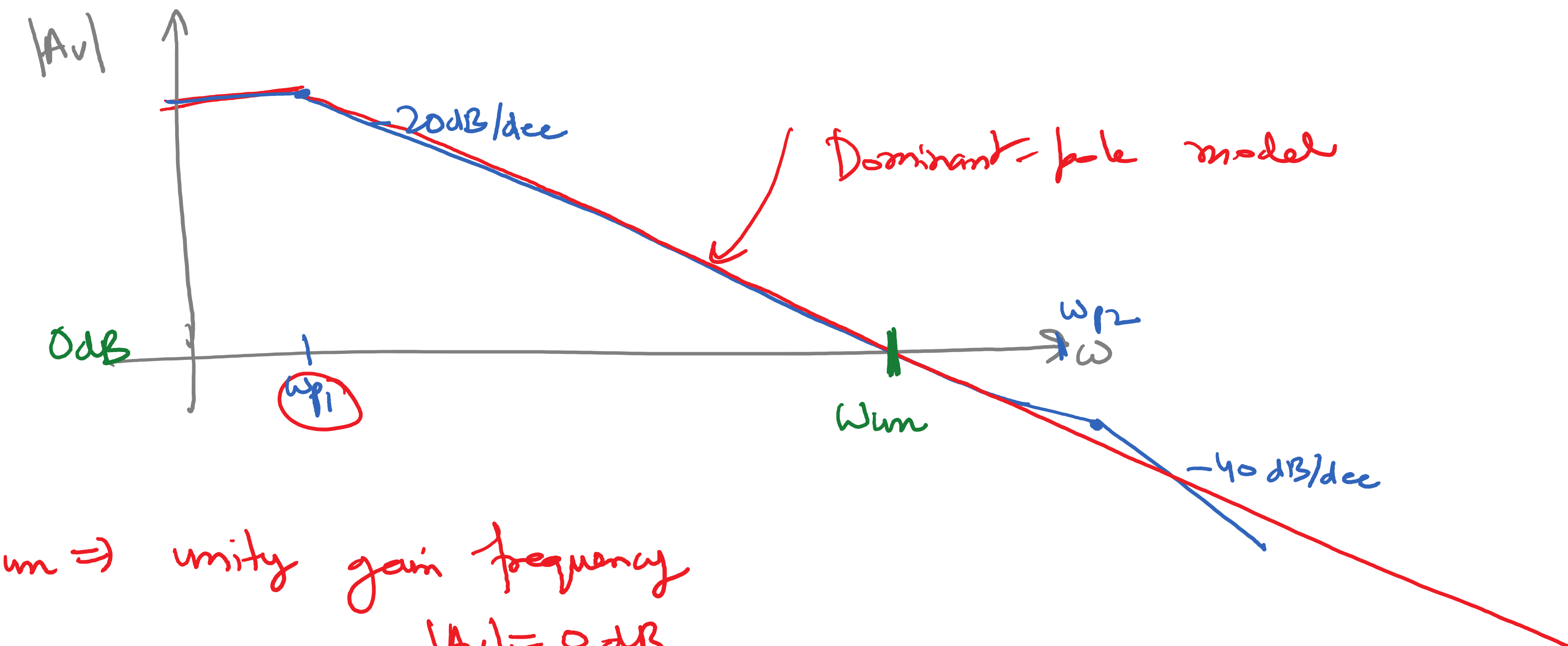


* Typically we just use R_z for zero-nulling.

zero nulling

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

$$\omega_{p1} << \omega_{p2}$$



$W_{um} \Rightarrow$ unity gain frequency

$|A_v| = 0\,dB$

$\omega_{um} \Rightarrow$ depends upon $f_T \Rightarrow$ $f_{um} \simeq \frac{f_T}{20}$ Empirical number

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

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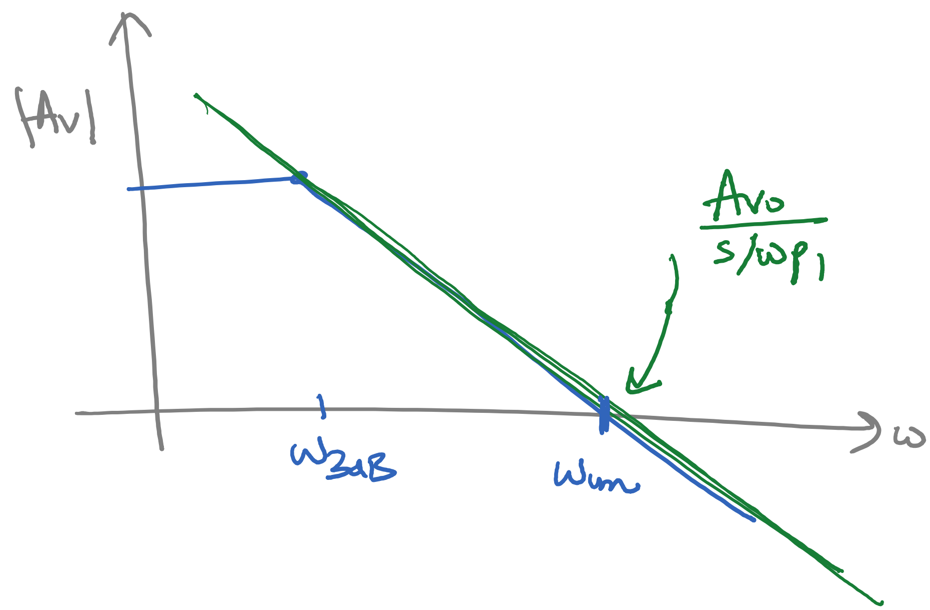
Dominant pole Model

$$A_v(s) = \frac{A_{vo}}{(1 + s/\omega_{p_1})} \overset{\Delta}{=} \frac{A_{vo}}{(1 + s/\omega_{3dB})}$$

$$A_{vo} = g_{m1} R_1 \, g_{m2} R_2$$

$$\omega_{3dB} = \frac{1}{g_{m2} R_2 R_1 C_c}$$



Around $\omega \simeq \omega_{um}$

$$A_v(s) \simeq \frac{A_{vo}}{s/\omega_{3dB}}$$

$$A_v(s) \simeq \frac{A_{vo}\,\omega_{3dB}}{s} \Rightarrow$$

$$A_v(j\omega_{um}) = \left|\frac{A_{vo}\,\omega_{3dB}}{j\omega_{um}}\right| = 1$$

$$\omega_{um} \simeq A_{vo} \cdot \omega_{3dB}$$

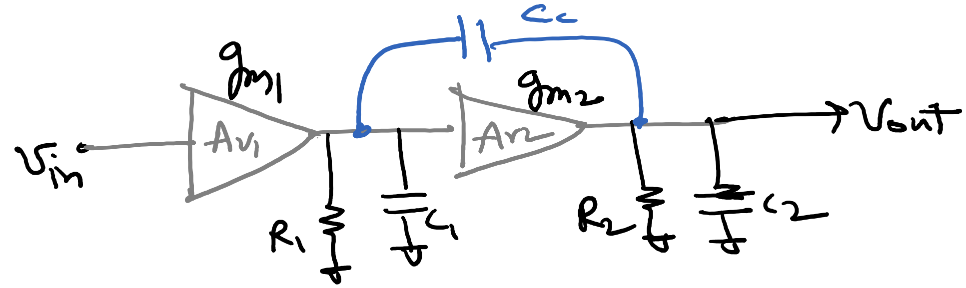
Gain - BW

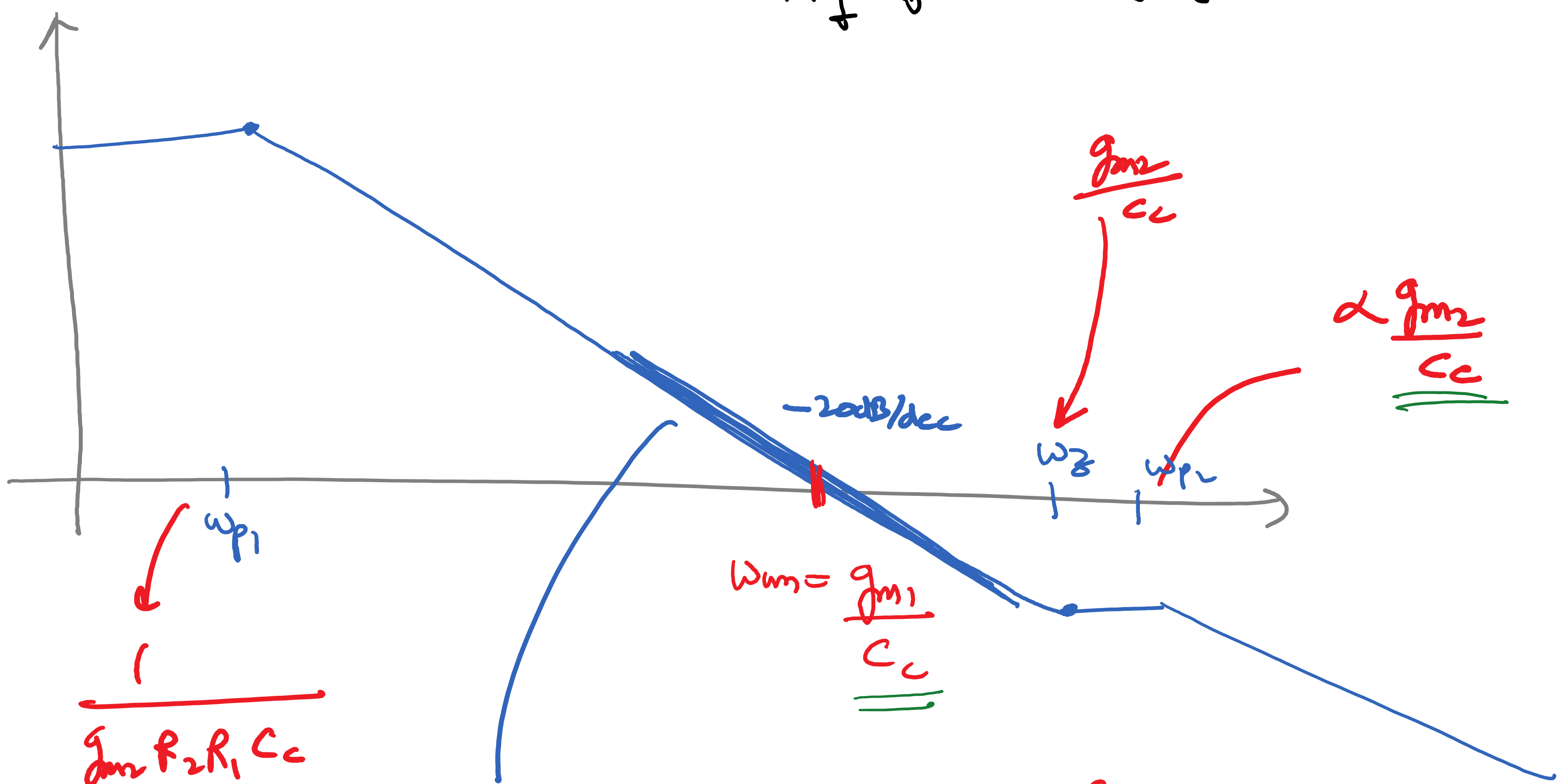
$$\omega_{um} = A_{v0} \cdot \omega_{3dB}$$

$$= g_{m1}\cancel{R_1} \cdot \cancel{g_{m2}R_2} \cdot \frac{1}{\cancel{g_{m2}}\cancel{R_2}\cancel{R_1} C_c}$$

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

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





$g_{m2} > g_{m1}$

* Should look like a first order system around $\omega \leq \omega_{un}$

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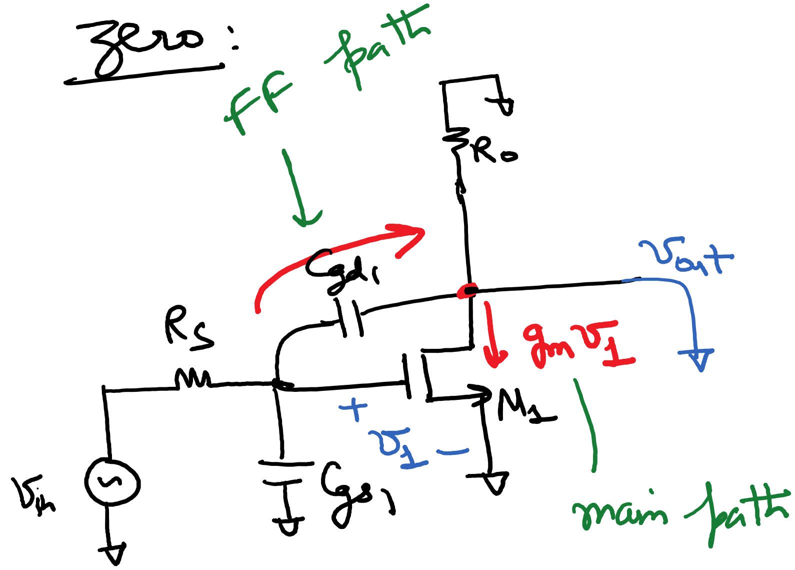
Zero:



* C_{gd1} provides a feed-forward path that conducts input signal to the output at high frequencies.

↳ adds to $g_m v_1$ in opposite phase

↳ bring the phase down

↳ RHP zero

At frequency $\omega = \omega_z \Rightarrow$ these two currents cancel each other

↳ gives rise to the zero.

* To estimate zero, output can be shorted to ground at $s = j\omega_z$

$\therefore v_{out}(s = j\omega_z) = 0$

$\Rightarrow$

$$v_1 \cdot C_{gd1} \cdot s_z = g_m v_1$$

$$\Rightarrow s_z = \frac{g_m}{C_{gd1}} \qquad \Rightarrow \omega_z = \frac{g_m}{C_{gd1}}$$

Source Follower Frequency Response:

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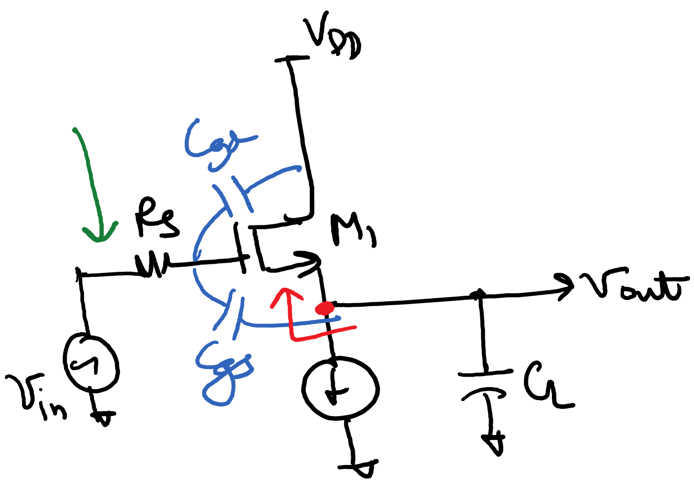

$$\frac{1}{RC} = \frac{1}{\frac{1}{g_m} \cdot C_L} = \frac{g_m}{C_L}$$