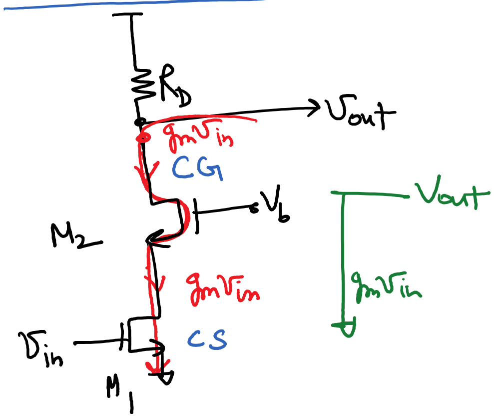
ECE 515 – Lecture 13

Thursday, October 4, 2018 11:02 AM

Folded Cascode:

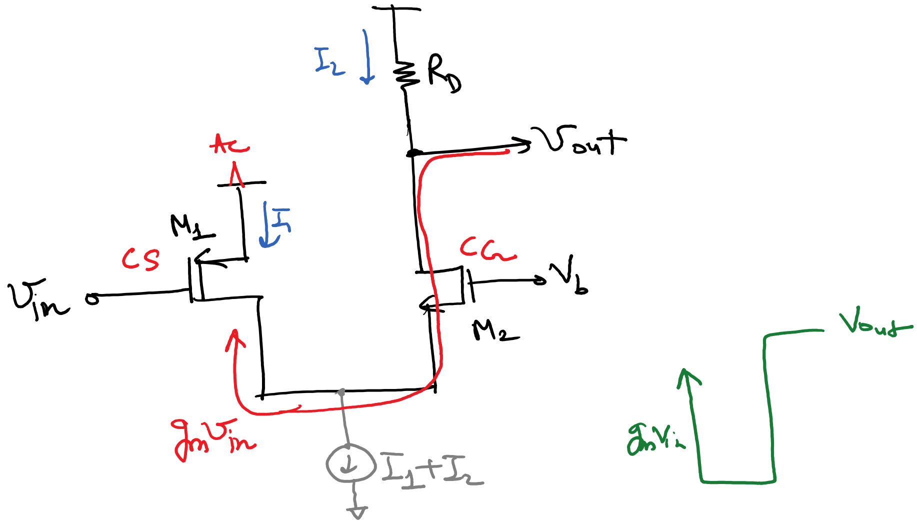
Cascode Amplifier



M_1 & M_2 are NMOS

headroom issues

Folded Cascode



Small signal current is "folded up"

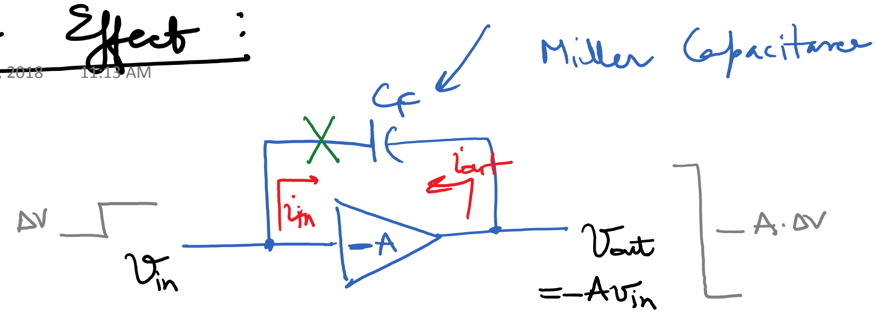
(+) better voltage headroom

(−) 2X bias current

We'll come back to this later.

Miller Effect:

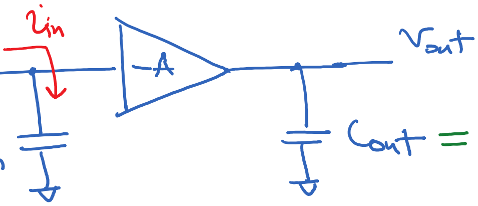
Thursday, October 4, 2018 11:15 AM



Capacitor sees voltage change $(A+1)\Delta V$

Capacitance multiplying effect

Miller approximation



$C_F(1+|A|) = C_{in}$

$C_{out} = C_F\left(1+\frac{1}{|A|}\right) \simeq C_F$

$$i_{in} = \frac{v_{in} - v_{out}}{1/sC_F} = sC_F(v_{in} - v_{out}) = sC_F(1+|A|)v_{in}$$

$$\Rightarrow \quad i_{in} = sC_F(1+|A|)v_{in}$$

$$Z_{in} = \frac{v_{in}}{i_{in}} = \frac{1}{sC_F(1+|A|)} = \frac{1}{sC_{in}}$$

$$\Rightarrow \quad C_{in} = C_F(1+|A|)$$

$$i_{out} = -i_{in} = -sC_F(v_{in} - v_{out})$$

$$= -sC_F\left(-\frac{v_{out}}{|A|} - v_{out}\right) = +sC_F v_{out}\left(1+\frac{1}{|A|}\right)$$

$$Z_{out} = \frac{v_{out}}{i_{out}} = \frac{1}{sC_F\left(1+\frac{1}{|A|}\right)} = \frac{1}{sC_{out}}$$

$$C_{out} = C_F\left(1+\frac{1}{|A|}\right) \simeq C_F \quad \text{for } |A| \gg 1$$

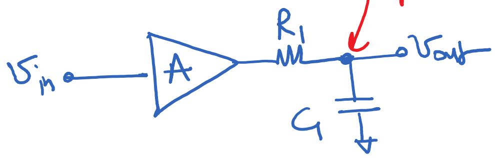
Doesn't capture the shorting of input & output at higher frequencies (misses a zero in the transfer function).

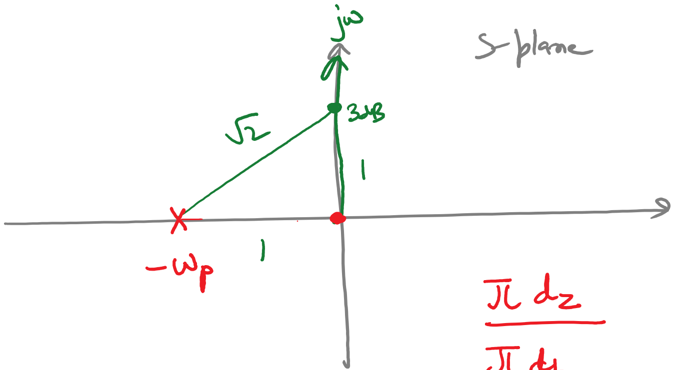
Poles and Zeros

Thursday, October 4, 2018 11:23 AM

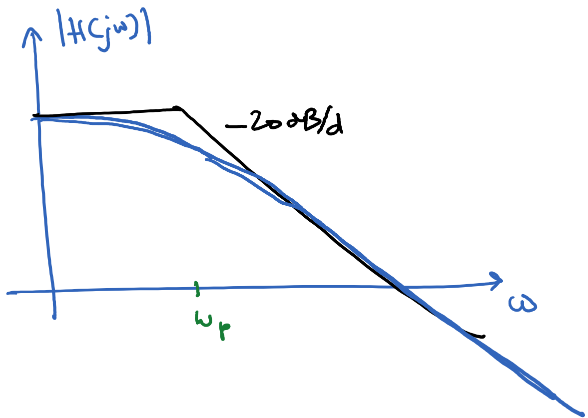
pole due to this node

$$H(s) = \frac{v_{out}}{v_{in}}(s) = \frac{A}{1+sR_1C_1} = \frac{A}{1+s/\omega_p} \qquad \omega_p = \frac{1}{R_1C_1}$$

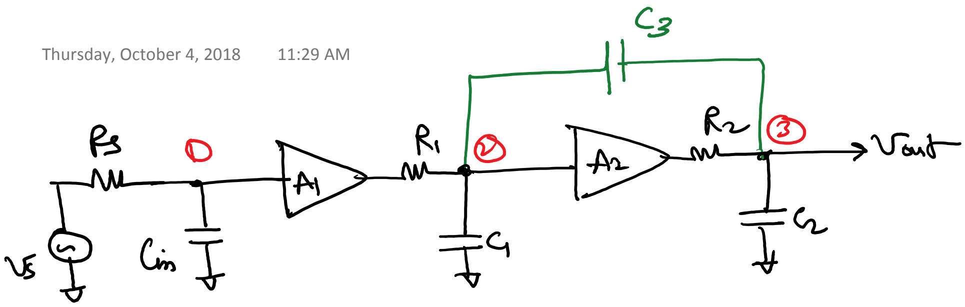




$$\frac{\Pi\, d_z}{\Pi\, d_p}$$



Thursday, October 4, 2018 11:29 AM



$$\frac{V_{out}}{V_{in}}(s) = \frac{1}{1+sR_sC_{in}} \cdot \frac{A_1}{1+sR_1C_1} \cdot \frac{A_2}{1+sR_2C_2}$$

3 poles

& nodes are not interacting with each other.

Add C_3 → nodes 2 + 3 are interacting with each other through C_3

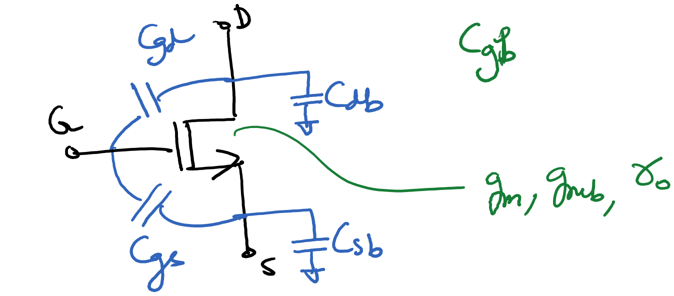
In general, we can't associate a pole to a node

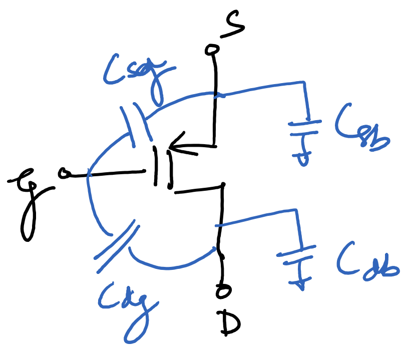
↳ All the nodes contribute to all the poles.

HF MOSFET Models

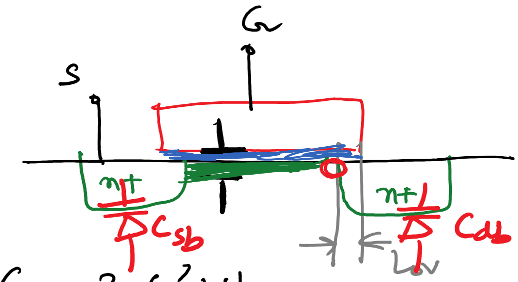
Thursday, October 4, 2018 11:34 AM

NMOS:





$$C_{ox}' = \frac{\varepsilon_0 \varepsilon_{ox}}{t_{ox}}$$



$$C_{gs} \simeq \frac{2}{3} C_{ox}' WL$$

$$C_{gd} = C_{ox}' \cdot L_{ov} \cdot W$$

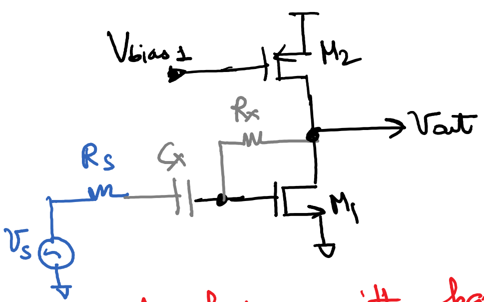
$$= CGDO \cdot W$$

$$C_{gs} >> C_{gd}$$

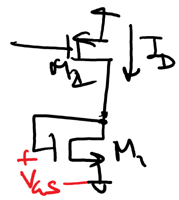
$$f_T \simeq \frac{g_m}{2\pi C_{gs}}$$

CS Stage

Thursday, October 4, 2018 11:42 AM



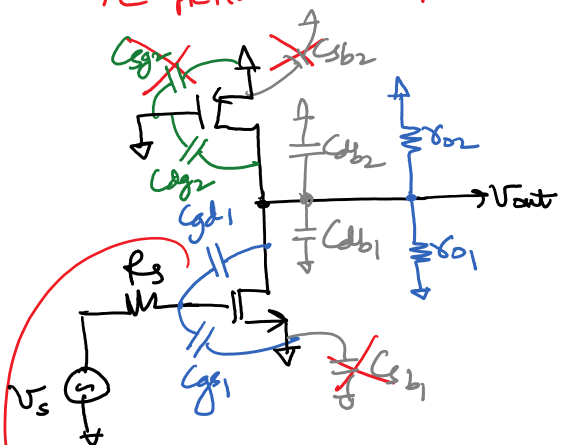
DC



$v_{R_x} = 0$

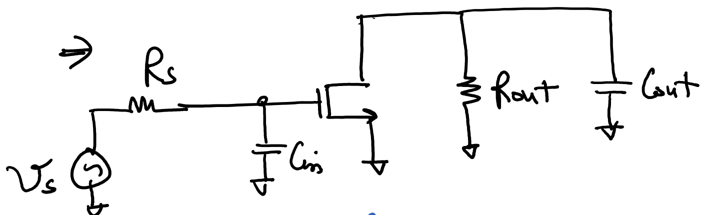
$\Rightarrow M_1$ is biased by the current source

A picture with parasitic caps



Miller Cap $\triangleq C_{gd1}$

Let's apply Miller approximation



$R_{out} = r_{o1} \| r_{o2}$

$C_{in} = C_{gs1} + C_{gd1}(1+|A|)$

$C_{out} = C_{gd1}\left(1+\frac{1}{|A|}\right) + C_{db1} + C_{db2} + C_{dg2}$

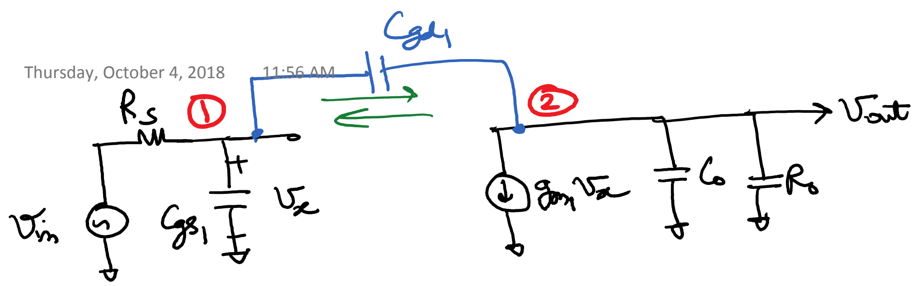
$A = -g_{m1} r_{o1} \| r_{o2}$

$$\omega_{in} = \frac{1}{R_S C_{in}} = \frac{1}{R_S\left[C_{gs1} + (1+A)C_{gd1}\right]}$$

$$\omega_{out} = \frac{1}{R_{out} C_{out}} = \frac{1}{(r_{o1}\|r_{o2})\left[C_{gd1} + C_{db} + C_{dg2}\right]}$$

$$\frac{V_{out}}{V_{in}}(s) = \frac{-\overset{g_{m1}(r_{o1}\|r_{o2})}{A}}{\left(1+\frac{s}{\omega_{in}}\right)\left(1+\frac{s}{\omega_{out}}\right)}$$

But this result is erroneous
→ we are missing a zero in the circuit



Write nodal equations at ① & ②

① $\dfrac{V_x - V_{in}}{R_s} + V_x s C_{gs_1} + (V_x - V_{out}) s C_{gd_1} = 0$

② $(V_{out} - V_x) s C_{gd_1} + g_{m_1} V_x + V_{out}\left(\dfrac{1}{R_o} + sC_o\right) = 0$

Solve for V_x in ① and substitute in ②

$$V_x = -\frac{V_{out}\left(sC_{gd_1} + 1/R_o + sC_o\right)}{g_{m_1} - sC_{gd_1}}$$

$$\frac{V_{out}}{V_{in}}(s) = \frac{\overbrace{(sC_{gd_1} - g_{m_1})R_o}^{N(s)}}{\underbrace{R_s R_o \xi s^2 + \left[R_s(1 + g_{m_1}R_o)C_{gd_1} + R_s C_{gs_1} + R_o(C_{gd_1} + C_o)\right]s + 1}_{D(s)}}$$

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

2nd order transfer function

Set $N^r = 0$

Numerator

$sC_{gd_1} - g_{m_1} = 0$

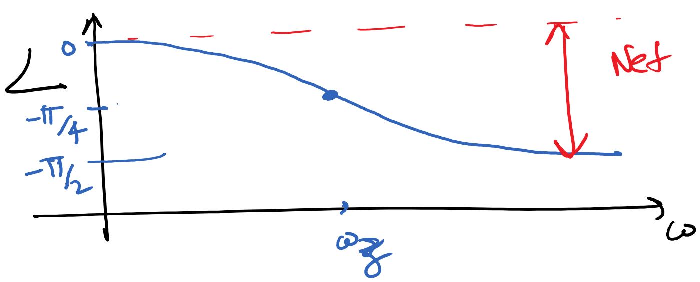
$\Rightarrow$ $\boxed{\omega_z = +\dfrac{g_m}{C_{gd_1}}}$

Right half s-plane

RHP zero

$\Rightarrow N_r(s) = -g_{m_1}R_o\left(1 - s/\omega_z\right)$

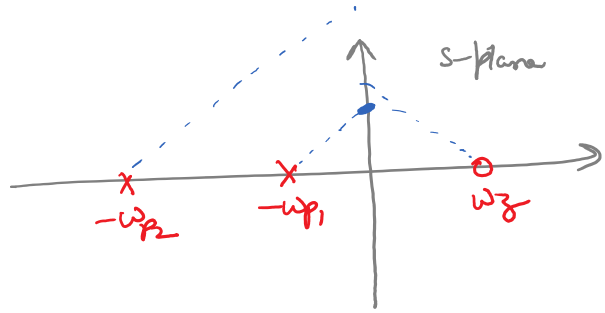
$$\text{phase shift} = \tan^{-1}\left(\frac{-\omega/\omega_z}{1}\right) = -\tan^{-1}\left(\frac{\omega}{\omega_z}\right)$$



Net phase shift is $-\pi/2$

$-90°$

Thursday, October 4, 2018 12:08 PM



Denominator, $D(s)$

2^{nd} order system

If we assume $|\omega_p| << |\omega_{p_2}|$

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

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

If $\omega_{p_1} << \omega_{p_2} \Rightarrow \frac{1}{\omega_{p_1}} >> \frac{1}{\omega_{p_2}}$

$$\omega_{p_1} = \frac{1}{R_s(1+g_mR_o)C_{gd_1} + R_sC_{gs_1} + R_o(C_{gd_1}+C_o)} \rightarrow \omega_{p_1}$$

Extra term

Compare with
$$\omega_{in} = \frac{1}{R_sC_{gs_1} + (1+g_mR_o)R_sC_{gd_1}}$$