ELEC401: Analog CMOS Integrated Circuit Design

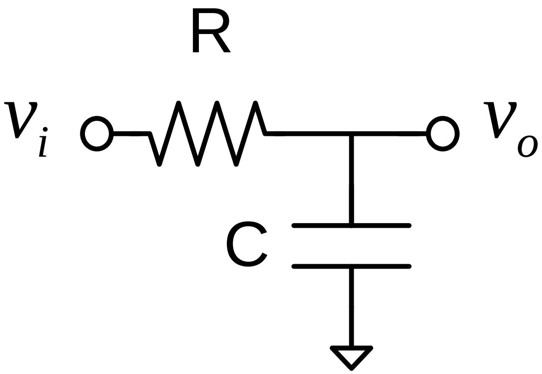
Set 5

Frequency Response of Amplifiers

Shahriar Mirabbasi
Department of Electrical and Computer Engineering
University of British Columbia
shahriar@ece.ubc.ca

Simple Pole

$$v_o / v_i = \frac{1/sC}{R + 1/sC}$$

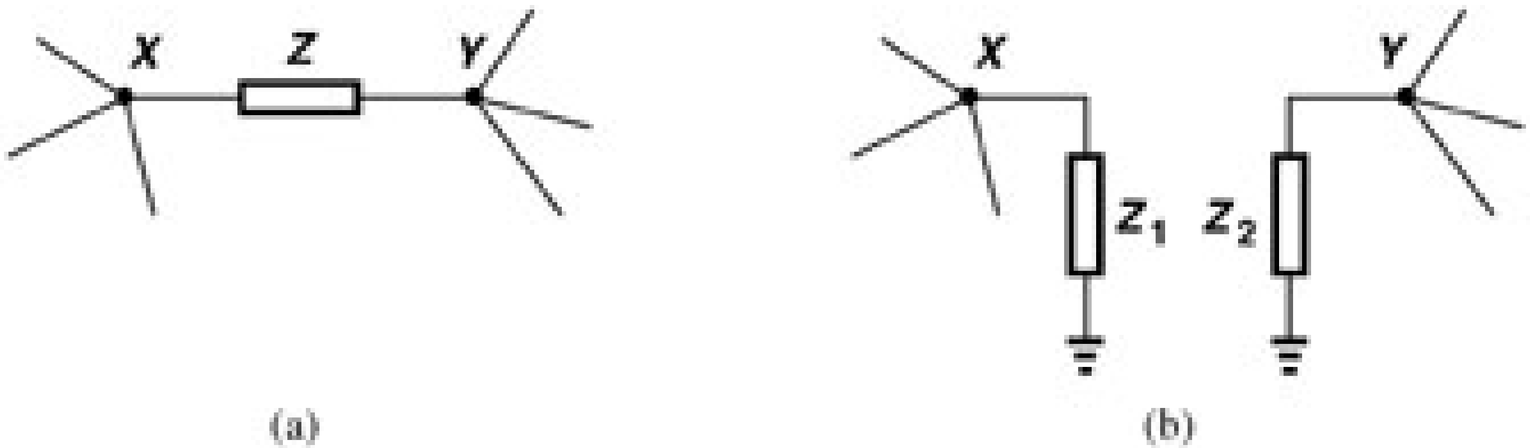


$$v_o / v_i = \frac{1}{sRC + 1}$$

$$\frac{v_o}{v_i}(f) = \frac{1}{1 + j2\pi fRC}$$

$$\frac{v_o}{v_i}(f) = \frac{1}{1 + j(\frac{f}{f_p})} \quad , \quad f_p = \frac{1}{2\pi RC}$$

Miller Effect

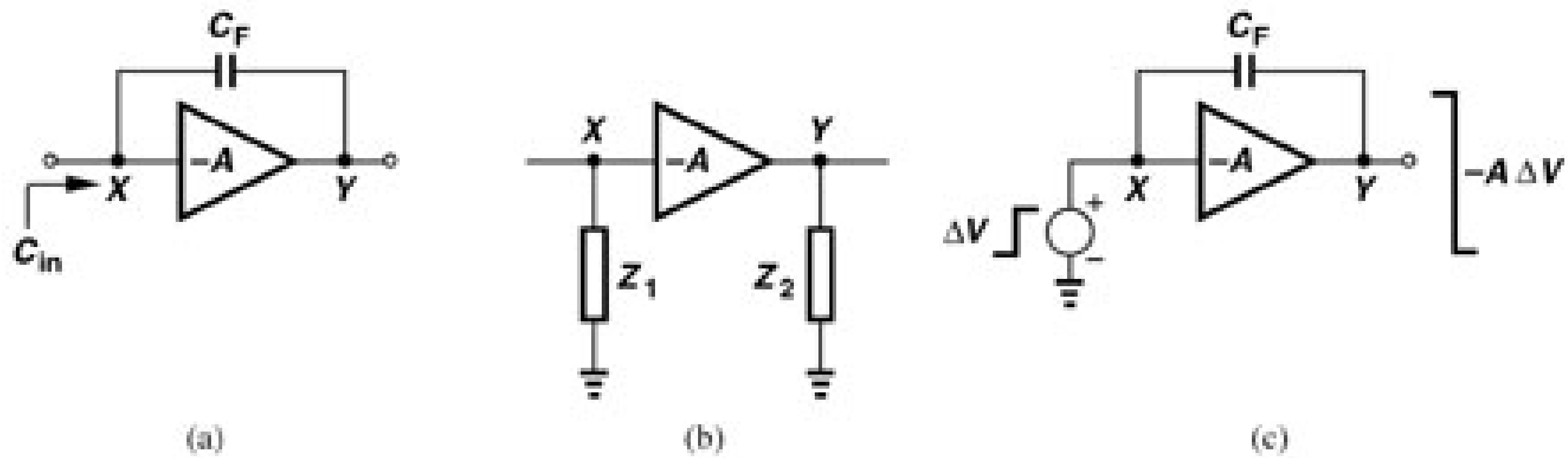


$$Z_1 = \frac{Z}{(1 - A_v)}$$

$$Z_2 = \frac{Z}{(1 - A_v^{-1})}$$

Board Notes

Miller Capacitive Multiplication

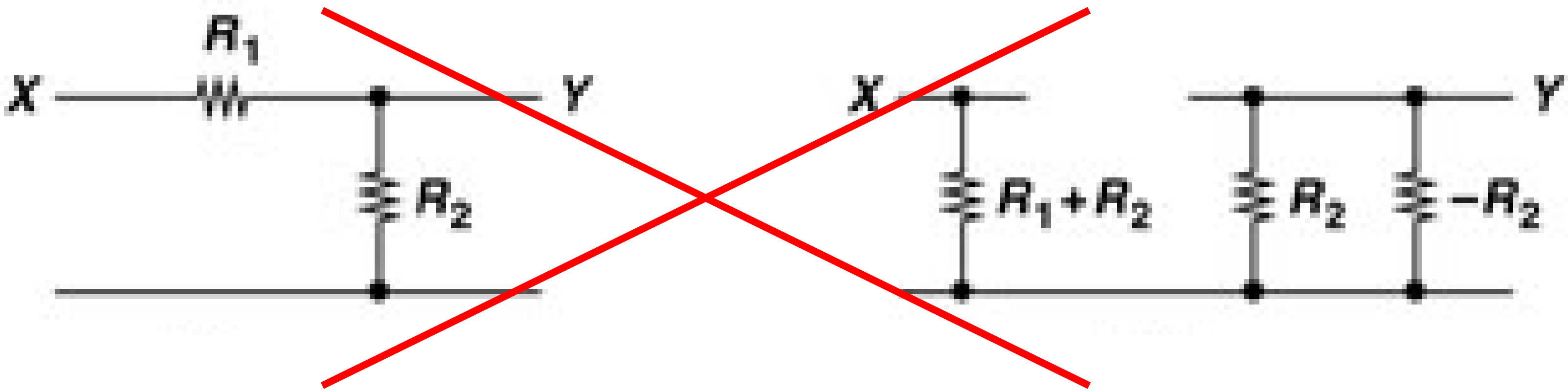


$$C_1 = C_F(1 - A_v)$$

$$C_2 = C_F(1 - A^{-1}{}_v) \approx C_F$$

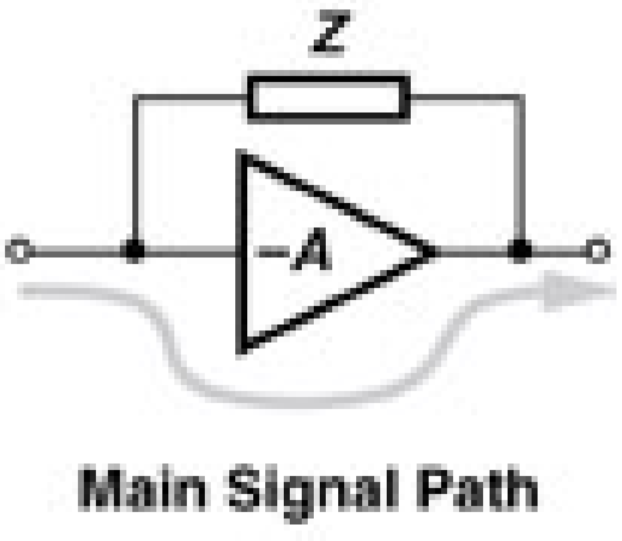
Applicability of Miller's Theorem

If the only signal path between X and Y is through impedance Z then Miller's theorem is typically not applicable.

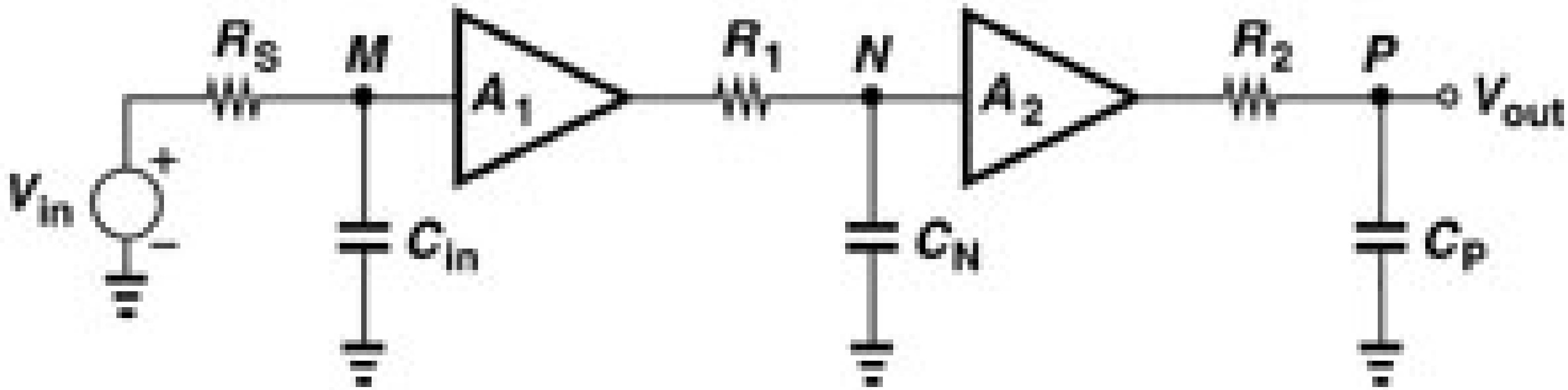


Applicability of Miller’s Theorem

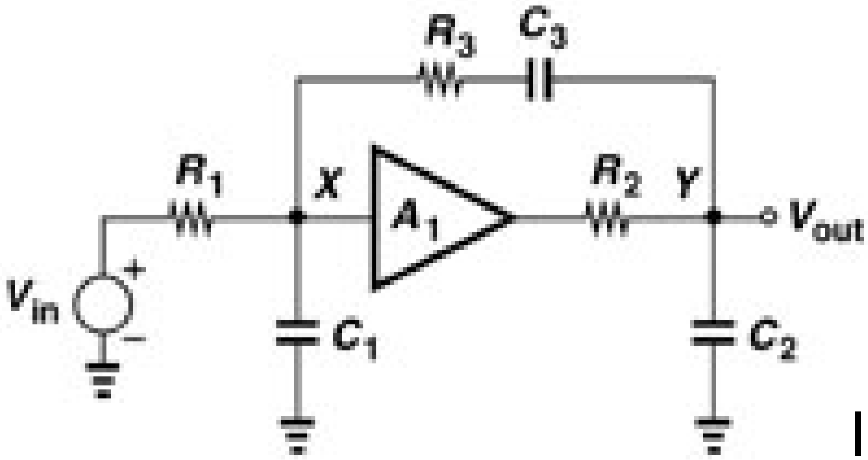
Miller’s Theorem is typically useful in the cases where there is impedance in parallel with the main signal path.



Poles and Nodes

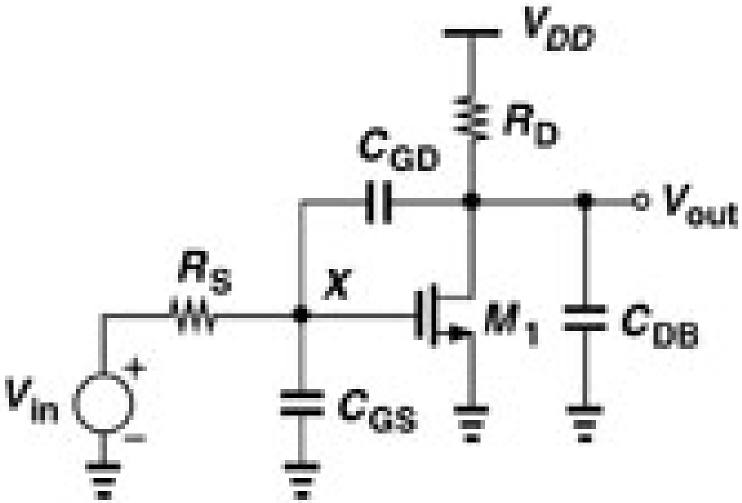


Non-Interacting Poles: One pole associated with each node



Interacting Poles

Common Source

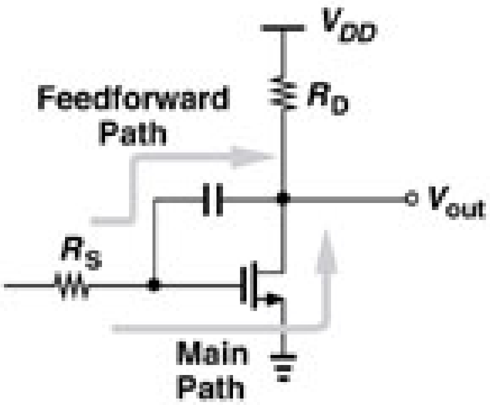


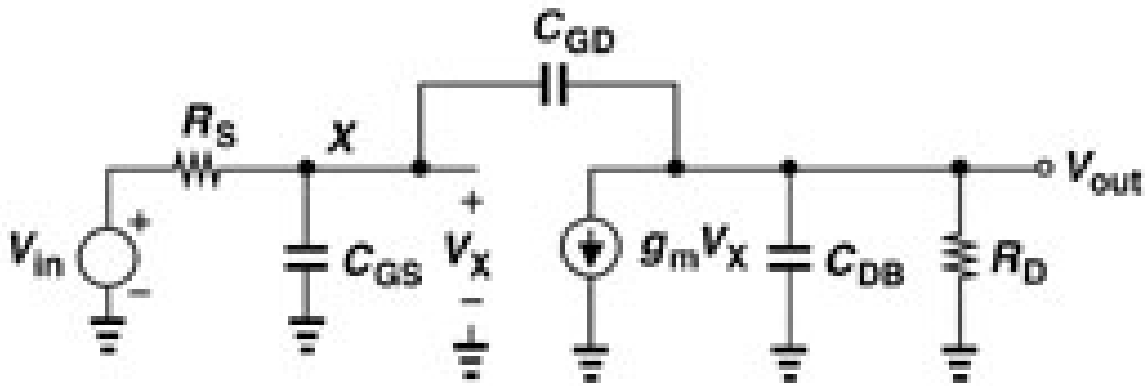
Neglecting input/output interaction,

$$f_{p,in} = \frac{1}{2\pi R_S\left[C_{GS} + (1 + g_m R_D)C_{GD}\right]}$$

$$f_{p,out} = \frac{1}{2\pi\left[(C_{GD} + C_{DB})R_D\right]}$$

Common Source





$$\frac{v_o}{v_i} = \frac{(sC_{GD} - g_m)R_D}{s^2R_SR_D(C_{GS}C_{GD} + C_{GS}C_{DB} + C_{GD}C_{DB}) + s\left[R_S(1+g_mR_D)C_{GD} + R_SC_{GS} + R_D(C_{GD} + C_{DB})\right] + 1}$$

$$Assume\ \ D = \left(\frac{s}{\omega_{p1}} + 1\right)\left(\frac{s}{\omega_{p2}} + 1\right) = \frac{s^2}{\omega_{p1}\omega_{p2}} + \frac{s}{\omega_{p1}} + 1\ ,\quad \omega_{p2} >> \omega_{p1}$$

$$f_{p,in} = \frac{1}{2\pi\left(R_S\left[C_{GS} + (1+g_mR_D)C_{GD}\right] + R_D(C_{GD} + C_{DB})\right)}$$

Common Source

$$f_{p,out} = \frac{R_S(1+g_m R_D)C_{GD} + R_S C_{GS} + R_D(C_{GD} + C_{DB})}{2\pi R_S R_D(C_{GS}C_{GD} + C_{GS}C_{DB} + C_{GD}C_{DB})}$$

$$f_{p,out} \approx \frac{1}{2\pi R_D(C_{GD} + C_{DB})}, \text{ for large } C_{GS}$$

$$f_{p,out} \approx \frac{g_m R_S R_D C_{GD}}{2\pi R_S R_D(C_{GS}C_{GD} + C_{GS}C_{DB} + C_{GD}C_{DB})}$$

$$\approx \frac{gm}{2\pi(C_{GS} + C_{DB})}, \quad \text{for large } C_{GD}$$

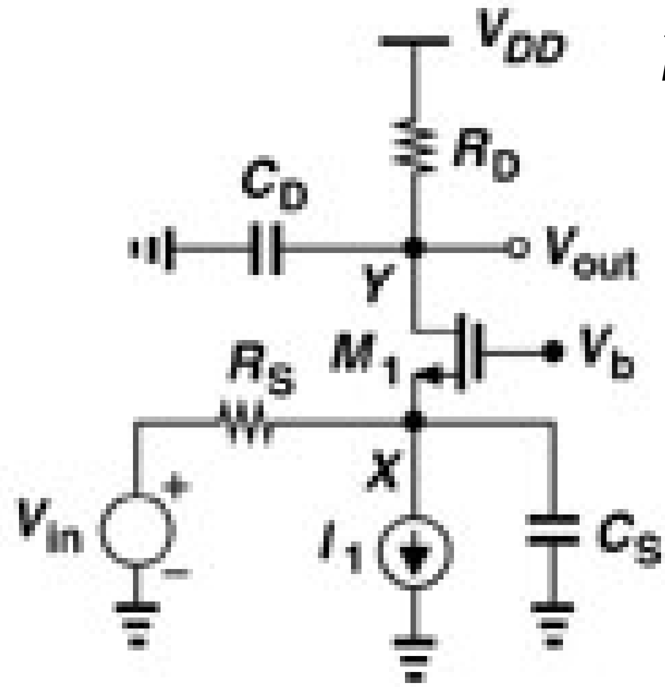
Common Source

Right half plane zero, from the numerator of v_o/v_i

$$\frac{vo}{vi} = \frac{(sC_{GD} - g_m)R_D}{s^2 R_S R_D (C_{GS}C_{GD} + C_{GS}C_{SB} + C_{GD}C_{DB}) + s\left[R_S(1 + g_m R_D)C_{GD} + R_S C_{GS} + R_D (C_{GD} + C_{DB)}\right] + 1}$$

$$\frac{sC_{GD} - g_m}{\cdots} \quad \rightarrow \quad f_z = \frac{+g_m}{2\pi C_{GD}}$$

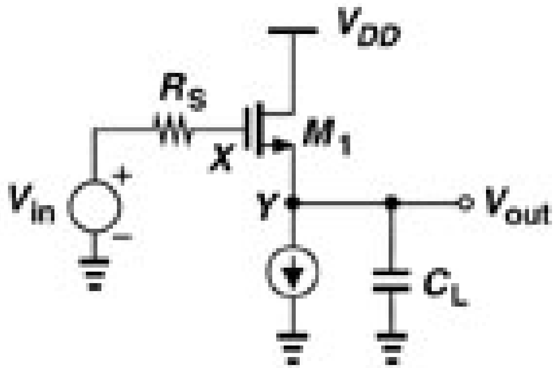
Common Gate

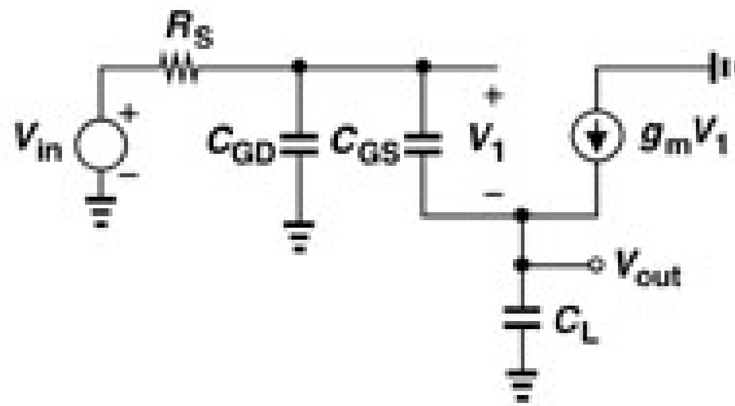


$$f_{pX} = \frac{1}{2\pi\left[(C_{GS}+C_{SB})\left(R_S \parallel \left(\frac{1}{g_m + g_{mb}}\right)\right)\right]}$$

$$f_{pY} = \frac{1}{2\pi\left[(C_{GD}+C_{DB})R_D\right]}$$

Source Follower (Common Drain)



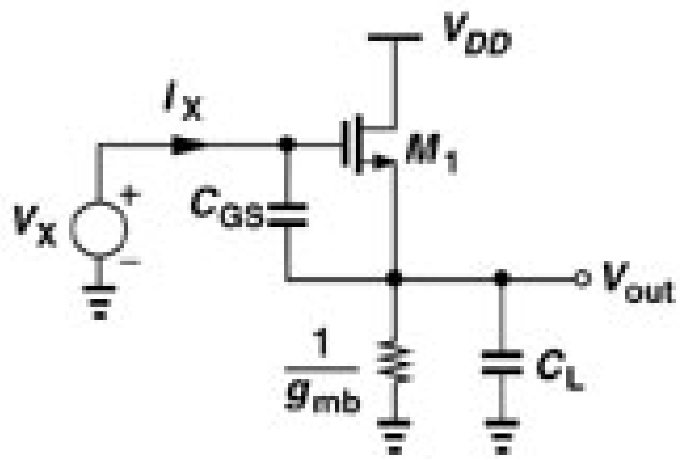


$$\frac{vo}{vi} = \frac{g_m + sC_{GS}}{s^2 R_S (C_{GS}C_L + C_{GS}C_{GD} + C_{GD}C_L) + s\left(g_m R_S C_{GD} + C_L + C_{GS}\right) + g_m}$$

$$f_{p1} \approx \frac{g_m}{2\pi\left(g_m R_S C_{GD} + C_L + C_{GS}\right)} \text{ , assuming } f_{p2} >> f_{p1}$$

$$= \frac{1}{2\pi\left(R_S C_{GD} + \dfrac{C_L + C_{GS}}{g_m}\right)}$$

Source Follower Input Impedance



Neglecting C_{GD} ,

$$Z_{in} = \frac{1}{sC_{GS}} + \left(1 + \frac{g_m}{sC_{GS}}\right)\frac{1}{g_{mb} + sC_L}$$

At low frequencies, $g_{mb} >> |sC_L|$

$$Z_{in} \approx \frac{1}{sC_{GS}}(1 + g_m / g_{mb}) + 1/g_{mb}$$

$$\therefore \quad C_{in} = C_{GS} g_{mb} / (g_m + g_{mb}) + C_{GD} \quad (same \ \ as \ \ Miller)$$

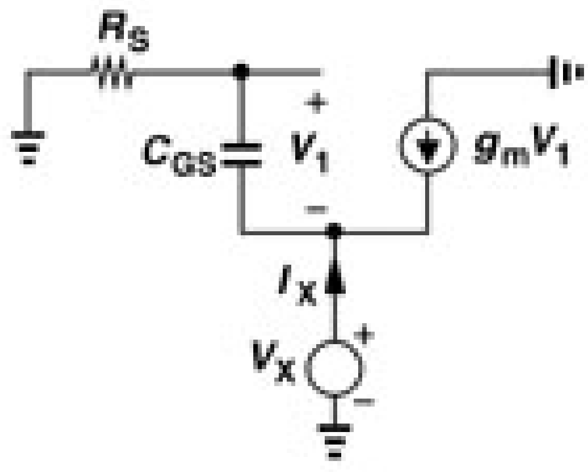
Source Follower

At high frequencies, $g_{mb} << |sC_L|$

$$Z_{in} \approx \frac{1}{sC_{GS}} + \frac{1}{sC_L} + \frac{g_m}{s^2 C_{GS} \mathrm{C_L}}$$

At high frequencies, overall input impedance includes C_{GD} in parallel with series combination of C_{GS} and C_L and a *negative* resistance equal to $-g_m/(C_{GS}C_L\omega^2)$.

Source Follower Output Impedance

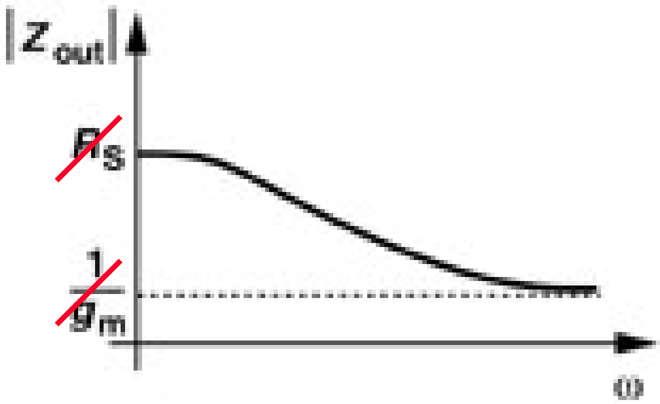


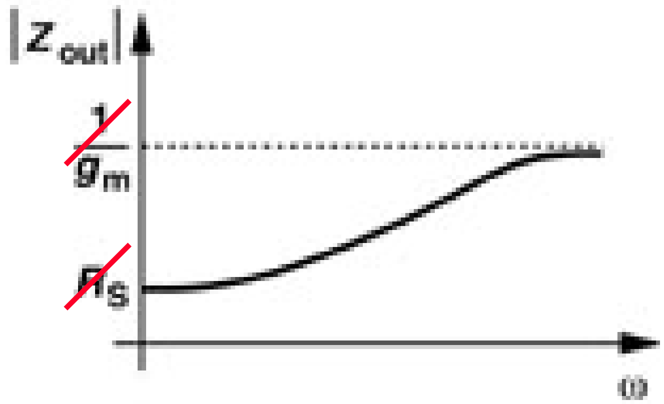
$$Z_{OUT} = V_X / I_X$$

$$= \frac{sR_SC_{GS} + 1}{gm + sC_{GS}}$$

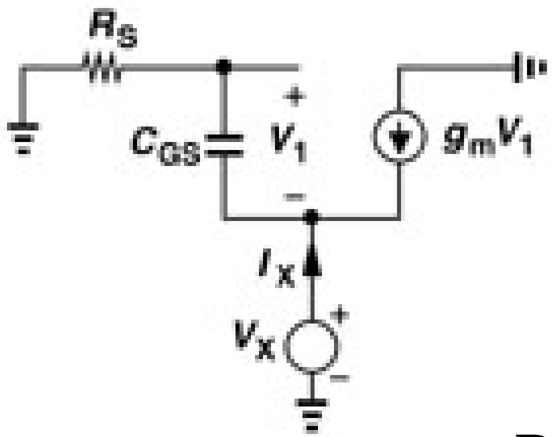
$$\approx 1/g_m \text{ , at low frequencies}$$

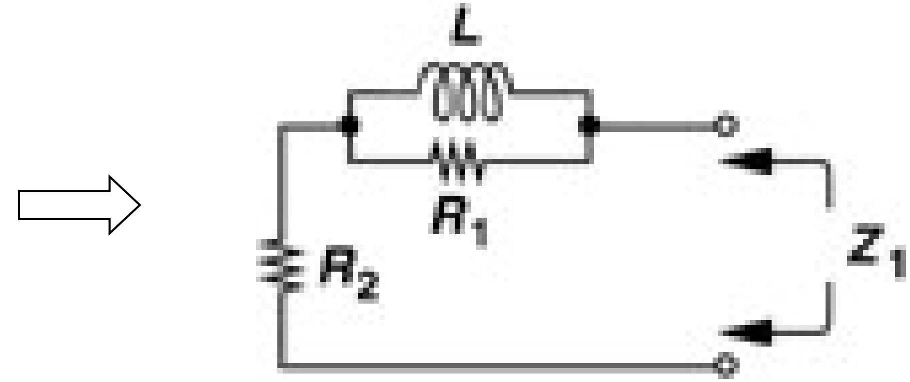
$$\approx R_S \text{ , at high frequencies}$$





Source Follower Output Impedance





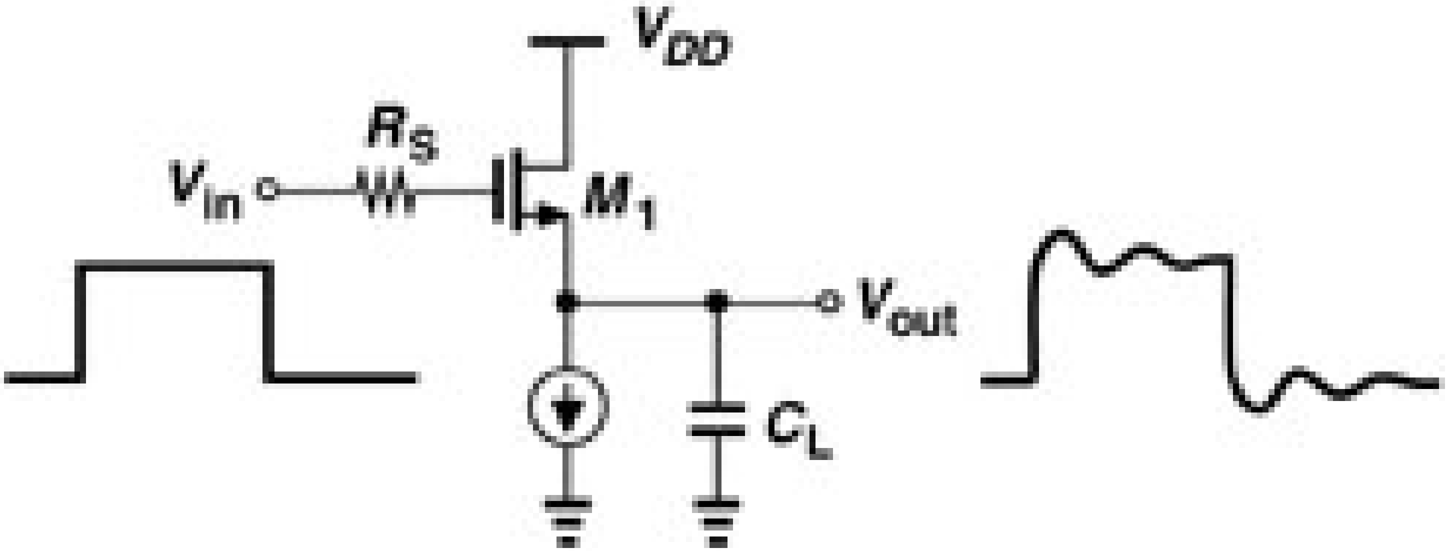
$$R_2 = 1/g_m$$

$$R_1 = R_S - 1/g_m$$

$$L = \frac{C_{GS}}{g_m}\left(R_S - 1/g_m\right)$$

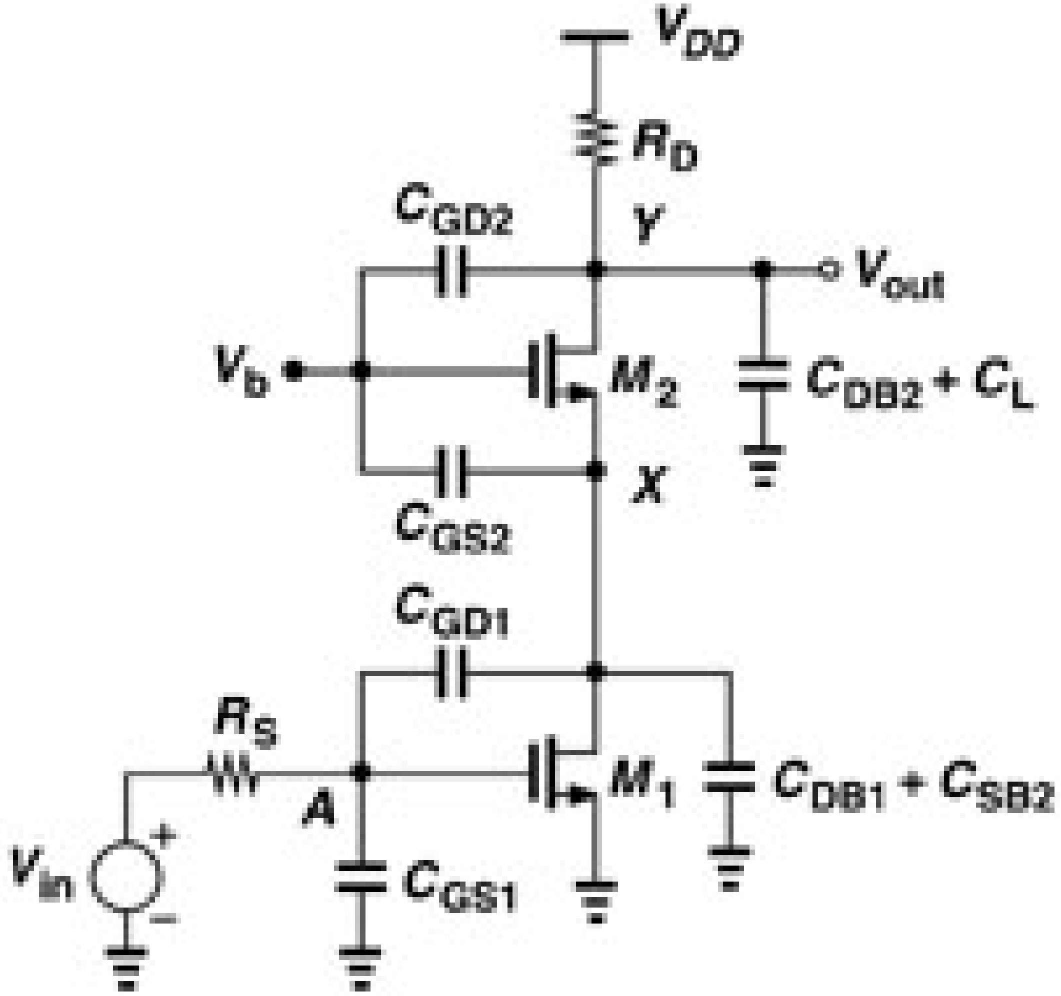
Output impedance inductance dependent on source impedance, R_S!

Source Follower Ringing



Output ringing due to tuned circuit formed with C_L and inductive component of output impedance.

Cascode Stage



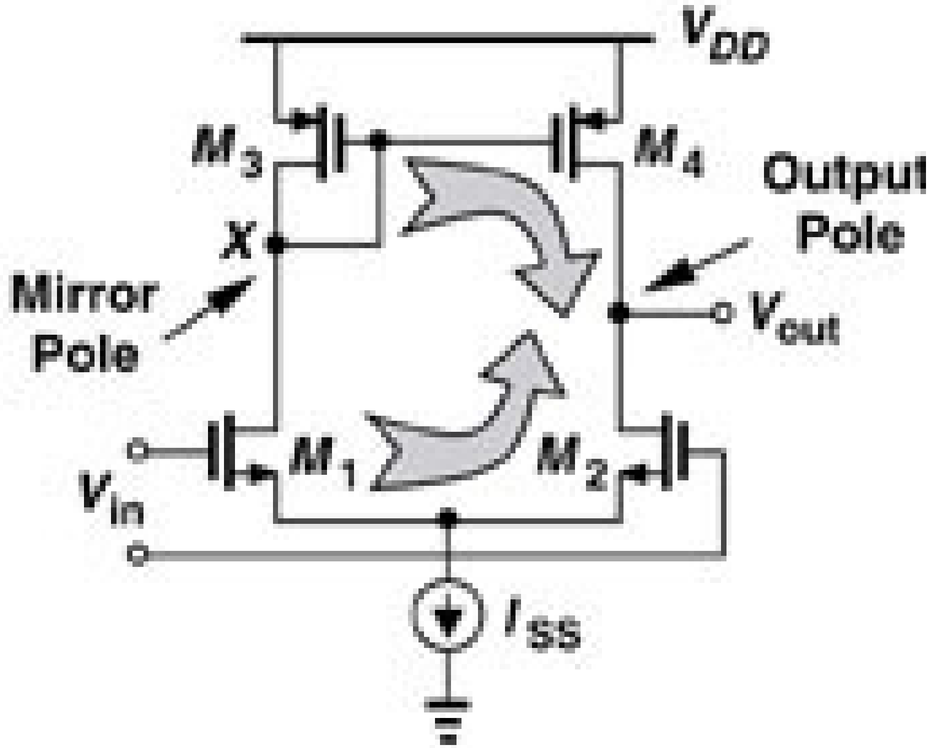
Cascode Stage

$$f_{pA} = \frac{1}{2\pi R_S \left[C_{GS1} + C_{GD1}\left(1 + \frac{g_{m1}}{g_{m2} + g_{mb2}}\right) \right]}$$

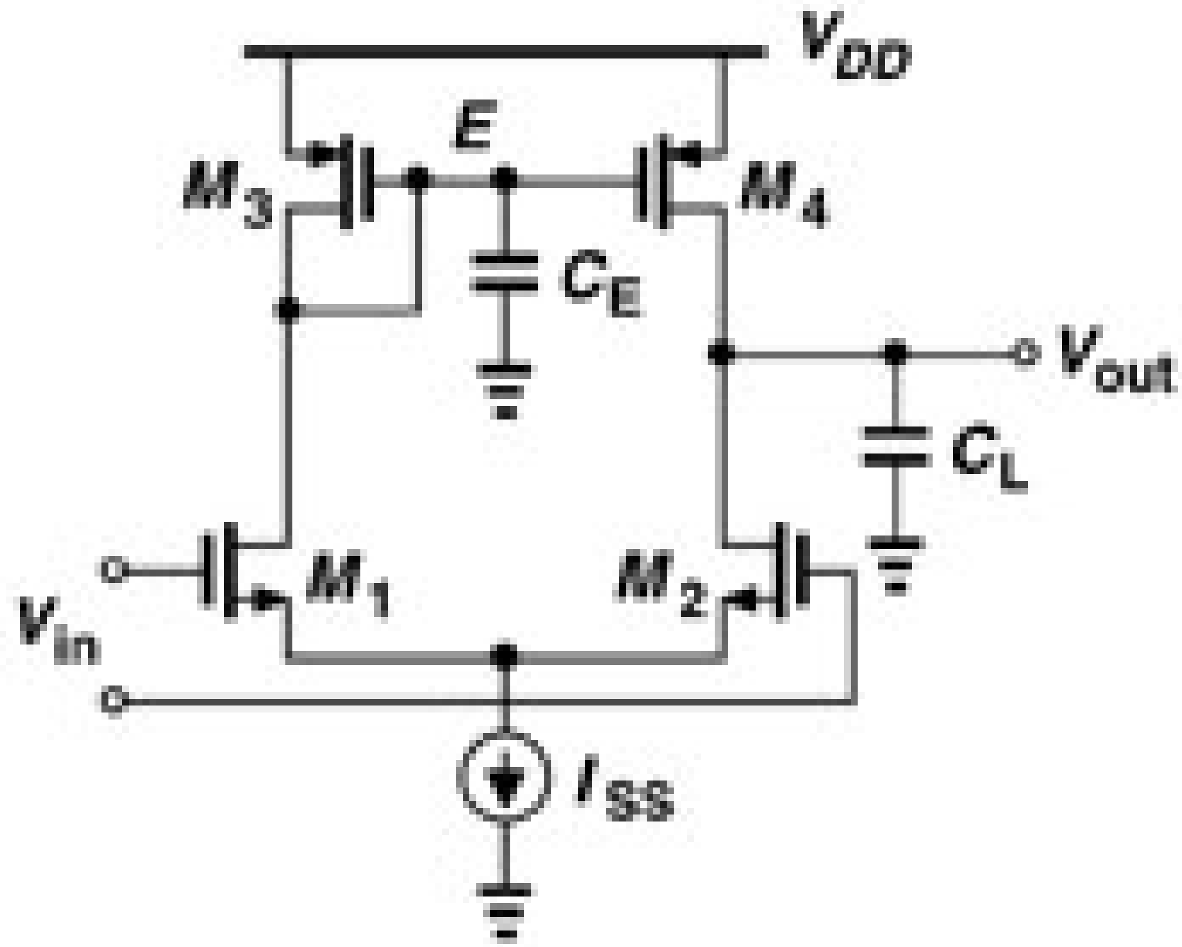
$$f_{pX} = \frac{g_{m2} + g_{mb2}}{2\pi\left(2C_{GD1} + C_{DB1} + C_{SB2} + C_{GS2}\right)}$$

$$f_{pY} = \frac{1}{2\pi R_D \left(C_{DB2} + C_L + C_{GD2}\right)}$$

Differential Pair



Differential Pair



Differential Pair

$$f_{p1} \approx \frac{1}{2\pi(r_{oN} \parallel r_{oP})C_L}$$

$$f_{p2} = \frac{g_{mP}}{2\pi C_E}$$

$$f_Z = 2f_{p2} = \frac{2g_{mP}}{2\pi C_E}$$