ECEN474: (Analog) VLSI Circuit Design
Fall 2011

Lecture 11: Frequency Response (cont.)

Sebastian Hoyos

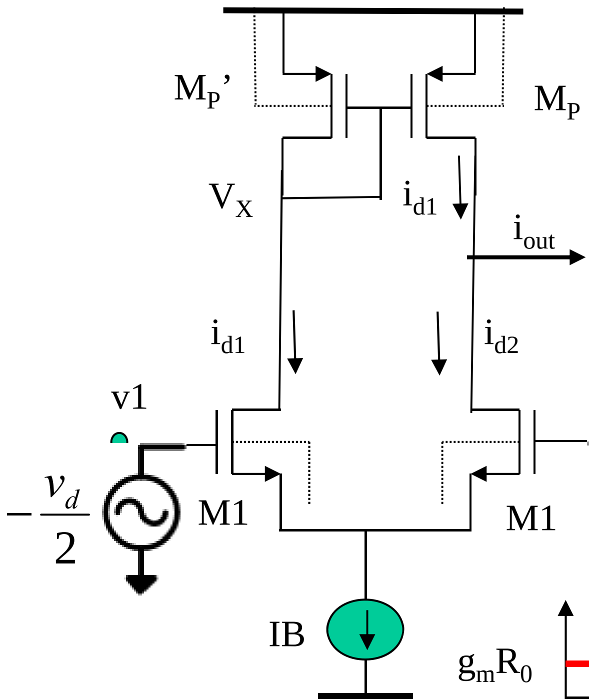
Analog & Mixed-Signal Center

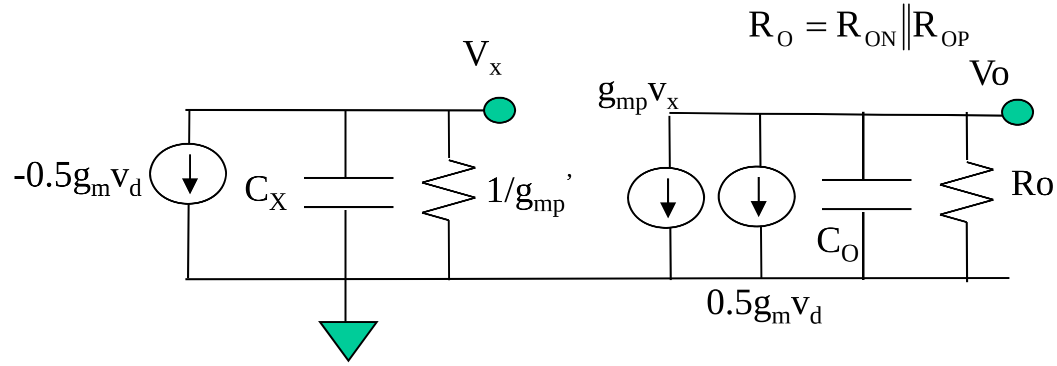
Texas A&M University

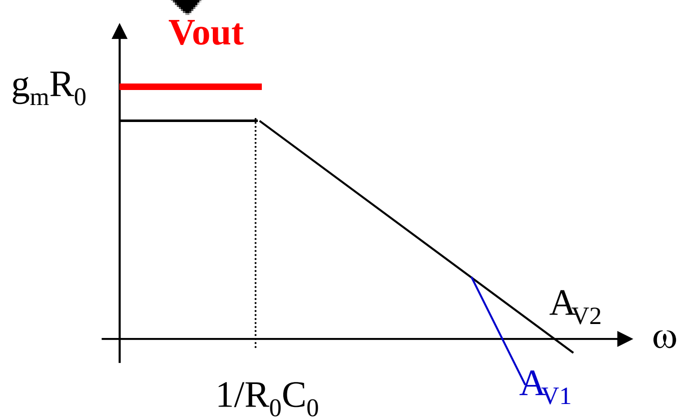
Agenda

- Differential Pairs
- Common-Drain Amp Frequency Response
- Common-Gate Amp Frequency Response
- Cascode Amp Frequency Response

Low Frequency Response





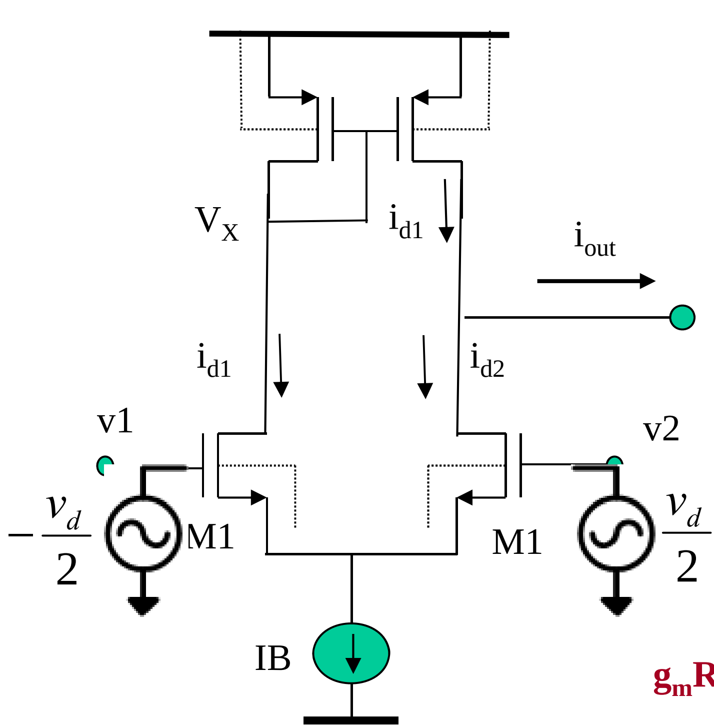


$$v_o = -g_m\left(\frac{v_d}{2}\right)R_o - g_m\left(-\frac{v_d}{2}\right)R_x\left(-g_{mp}R_o\right)$$

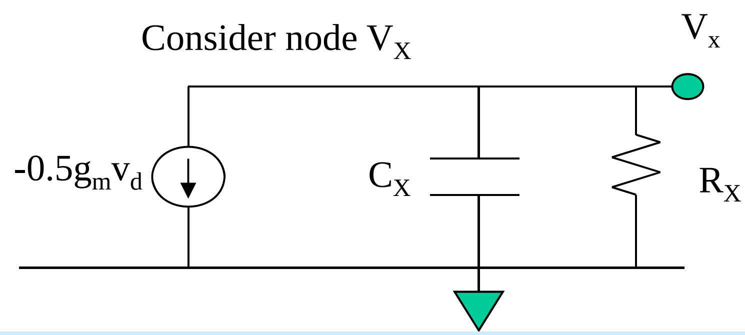
$$R_x \approx \frac{1}{g_{mp}}$$

$$v_o = -g_m v_d R_o$$

Frequency Response



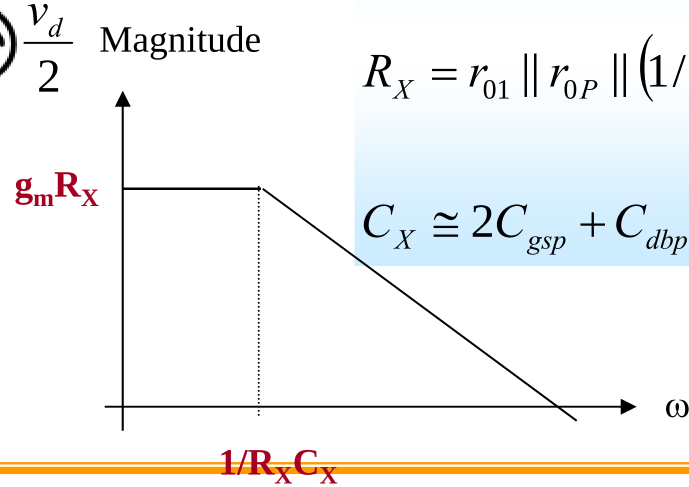
Consider node V_X



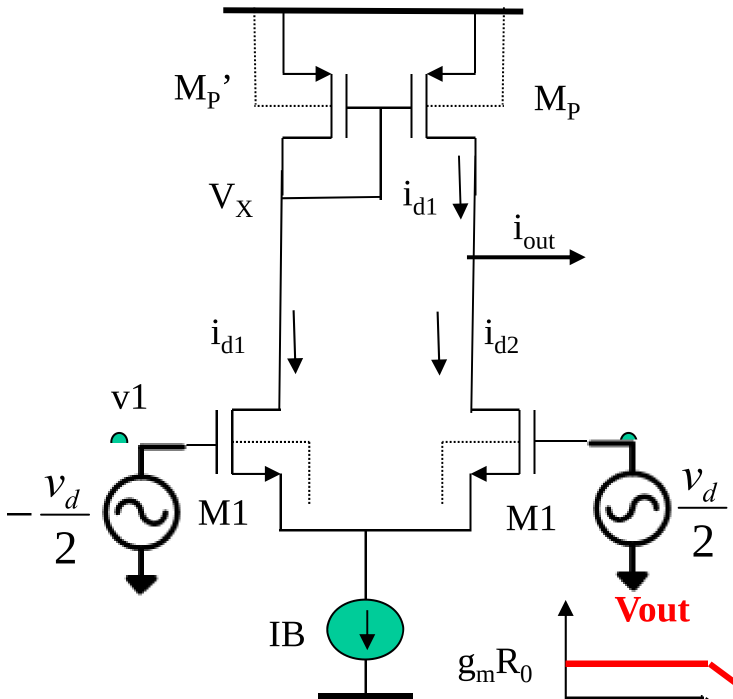
$$V_X = \frac{0.5 g_m R_X}{1 + S R_X C_X} V_d$$

$$R_X = r_{01} \,||\, r_{0P} \,||\, (1/g_{mp})$$

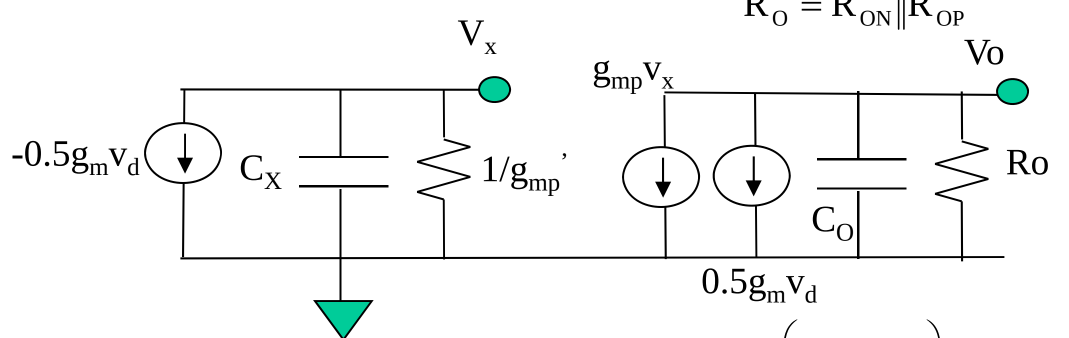
$$C_X \cong 2C_{gsp} + C_{dbp} + (1 + miller\ factor)C_{dgp} + C_{dbn}$$



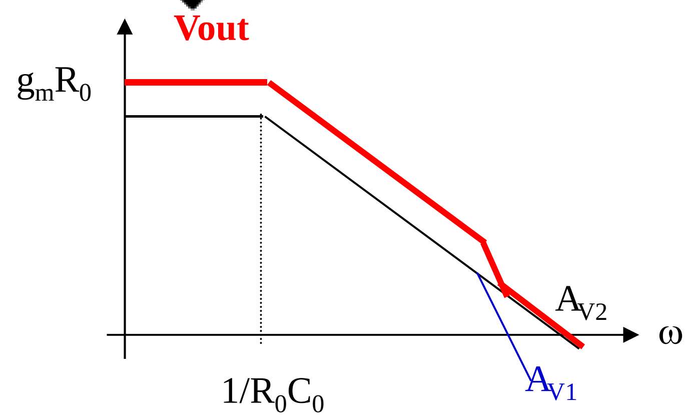
Frequency Response



$R_O = R_{ON} \| R_{OP}$



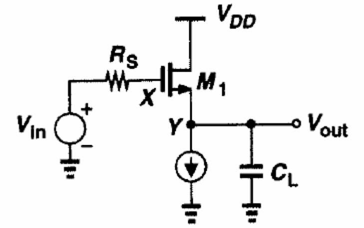
$$v_o = -g_m\left(\frac{v_d}{2}\right)\frac{R_o}{1+sR_oC_o} - g_m\left(\frac{v_d}{2}\right)\left(\frac{1/g_{mp}}{1+s\frac{C_x}{g_{mp}}}\right)\frac{g_{mp}R_o}{1+sR_oC_o}$$



$$v_o = -g_mR_o\left(\frac{v_d}{2}\right)\frac{1}{1+sR_oC_o}\left[1+\frac{1}{1+s\frac{C_x}{g_{mp}}}\right]$$

$$v_o = -g_mR_o\left(\frac{v_d}{2}\right)\frac{1}{1+sR_oC_o}\left[\frac{2+s\frac{C_x}{g_{mp}}}{1+s\frac{C_x}{g_{mp}}}\right]$$

Common-Drain Amplifier: High Frequency Response



$$\frac{V_{out}}{V_{in}}(s) = \frac{g_m + C_{GS}s}{R_S(C_{GS}C_L + C_{GS}C_{GD} + C_{GD}C_L)s^2 + (g_m R_S C_{GD} + C_L + C_{GS})s + g_m}$$

- From this simplified transfer function:

$$A_{dc} = \frac{g_m}{g_m} = 1 \quad \textbf{(Optimistic)}$$

$$\textbf{Exact} \quad A_{dc} = \frac{g_m}{g_m + g_o + g_{mb}}$$

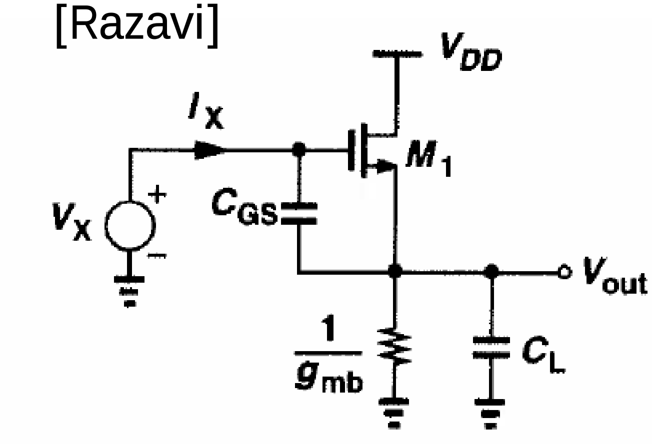
$$\omega_z = -\frac{g_m}{C_{gs}}$$

2 poles, If we assume that they are spaced far apart :

$$\omega_{p1} \approx \frac{g_m}{g_m R_S C_{GD} + C_L + C_{GS}} = \frac{1}{R_S C_{GD} + \dfrac{C_L + C_{GS}}{g_m}}$$

Common-Drain Amp Input Impedance

[Razavi]



$$Z_{in} = \frac{1}{C_{GS}s} + \left(1 + \frac{g_m}{C_{GS}s}\right)\frac{1}{g_{mb} + C_L s}$$

Low Frequency: $Z_{in} \approx \frac{1}{C_{GS}s}\left(1 + \frac{g_m}{g_{mb}}\right) + \frac{1}{g_{mb}}$

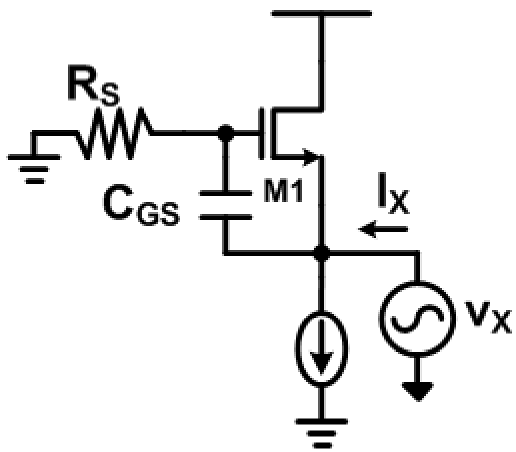
Equivalent to a series capacitve term $C_{gs}\left(\frac{g_{mb}}{g_m + g_{mb}}\right)$ **and resistive term** $\frac{1}{g_{mb}}$

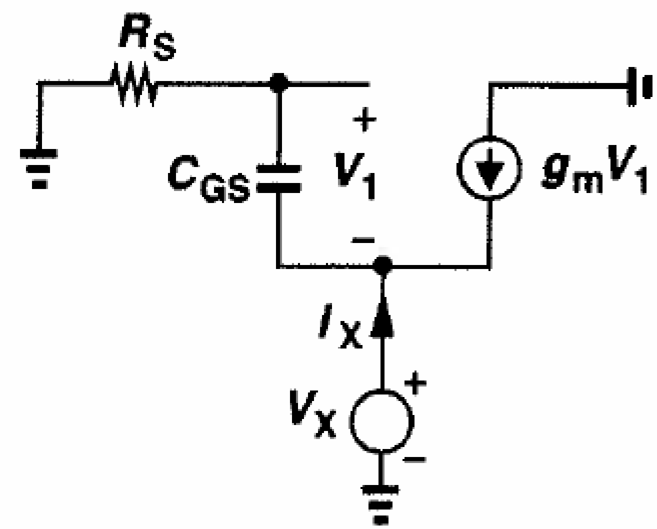
High Frequency: $Z_{in} \approx \frac{1}{C_{GS}s} + \frac{1}{C_L s} + \frac{g_m}{C_{GS}C_L s^2}$

Series combination of C_{gs} **and** C_L **and a negative resistance term** $\left(-\frac{g_m}{C_{gs}C_L\omega^2}\right)$

The negative resistance term can be utilized in oscillator design

Common-Drain Amp Output Impedance

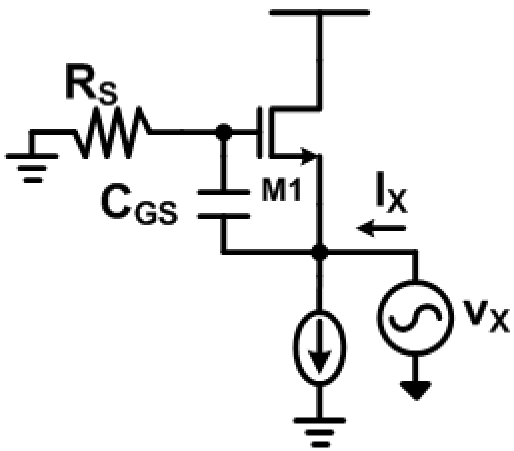




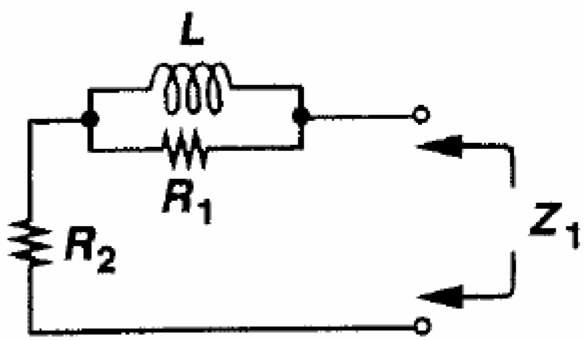
$$Z_{out} = \frac{V_X}{I_X} = \frac{R_S C_{GS} s + 1}{g_m + C_{GS} s}$$

- Pole at very high frequency
- Zero at potentially low frequency if R_S is large
  - Impedance can increase with frequency, i.e. display inductive behavior

Common-Drain Amp Output Impedance



$$Z_{out} = \frac{V_X}{I_X} = \frac{R_S C_{GS} s + 1}{g_m + C_{GS} s}$$

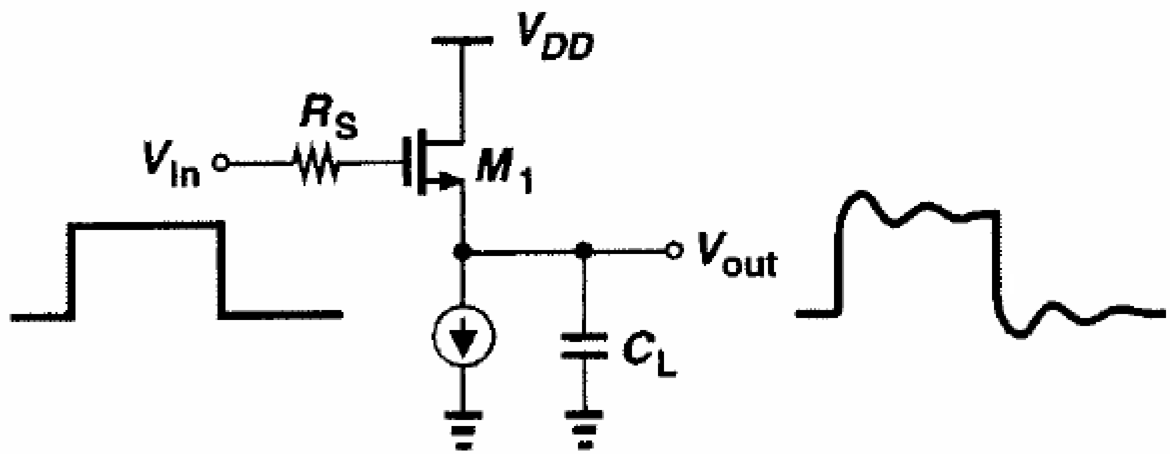


$$R_2 = \frac{1}{g_m}$$

$$R_1 = R_S - \frac{1}{g_m}$$

$$L = \frac{C_{GS}}{g_m}\left(R_S - \frac{1}{g_m}\right) \approx \frac{R_S C_{GS}}{g_m} \quad \textbf{if} \quad R_S >> \frac{1}{g_m}$$

Transient Behavior w/ Large C_L

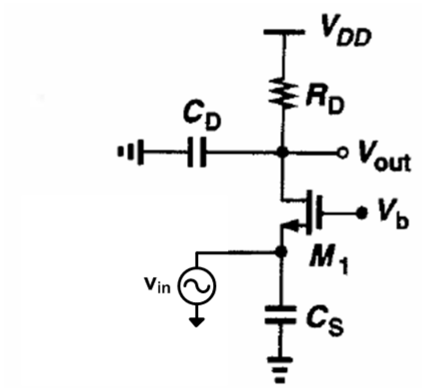


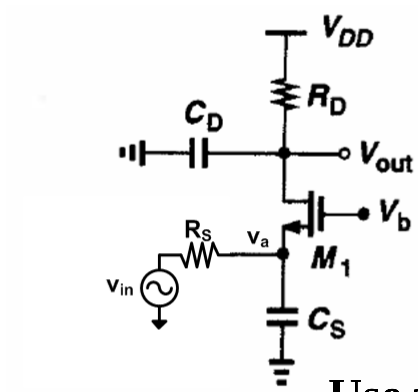
- Inductive output impedance in combination with a large load capacitance can create undesired "ringing" in the transient response
- If we have a large RS and CL, then the assumption that we have one dominant pole is no longer valid
- Both poles (potentially complex) should be considered in the analysis

$$\frac{V_{out}}{V_{in}}(s) = \frac{g_m + C_{GS}s}{R_S(C_{GS}C_L + C_{GS}C_{GD} + C_{GD}C_L)s^2 + (g_m R_S C_{GD} + C_L + C_{GS})s + g_m}$$

Common-Gate Amp Low Frequency Response

- No R_S
- With R_S





Neglecting transistor r_o

$$\frac{v_{out}}{v_{in}} = (g_m + g_{mb})R_D$$

$\frac{v_{out}}{v_a}$ **is given from left**

How to get from v_{in} to v_a?

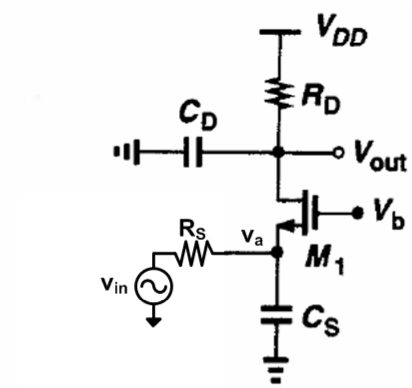
Use amplifier input impedance and voltage divider

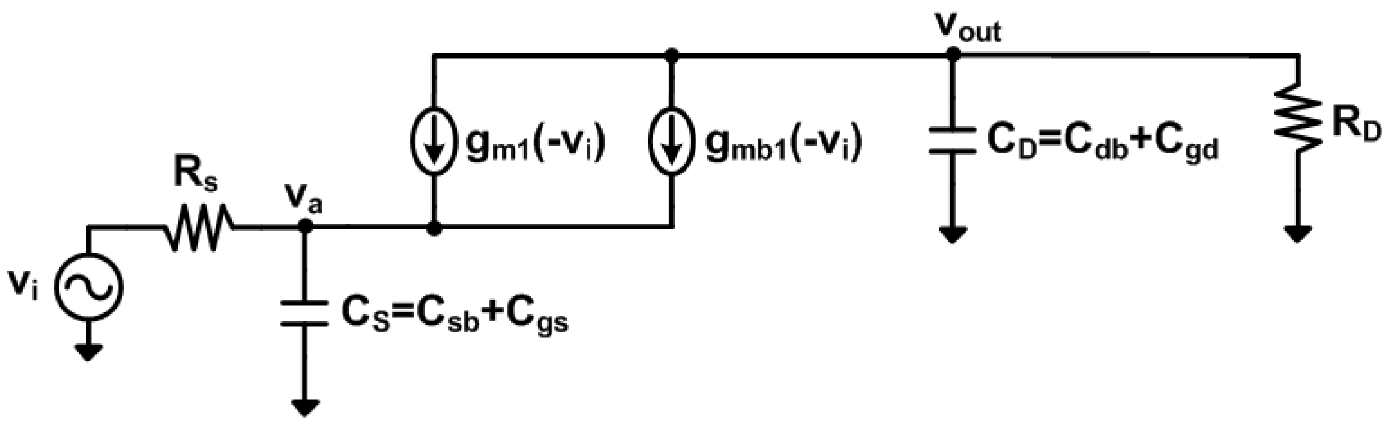
$$R_{in} = \frac{1}{g_m + g_{mb}}$$

$$v_a = \frac{\frac{1}{g_m + g_{mb}}}{R_S + \frac{1}{g_m + g_{mb}}} v_{in} = \frac{1}{1 + (g_m + g_{mb})R_S} v_{in}$$

$$\frac{v_{out}}{v_{in}} = \frac{v_a}{v_{in}} \frac{v_{out}}{v_a} = \frac{(g_m + g_{mb})R_D}{1 + (g_m + g_{mb})R_S} \approx \frac{R_D}{R_S}$$ **if R_S is large**

Common-Gate Amp Frequency Response



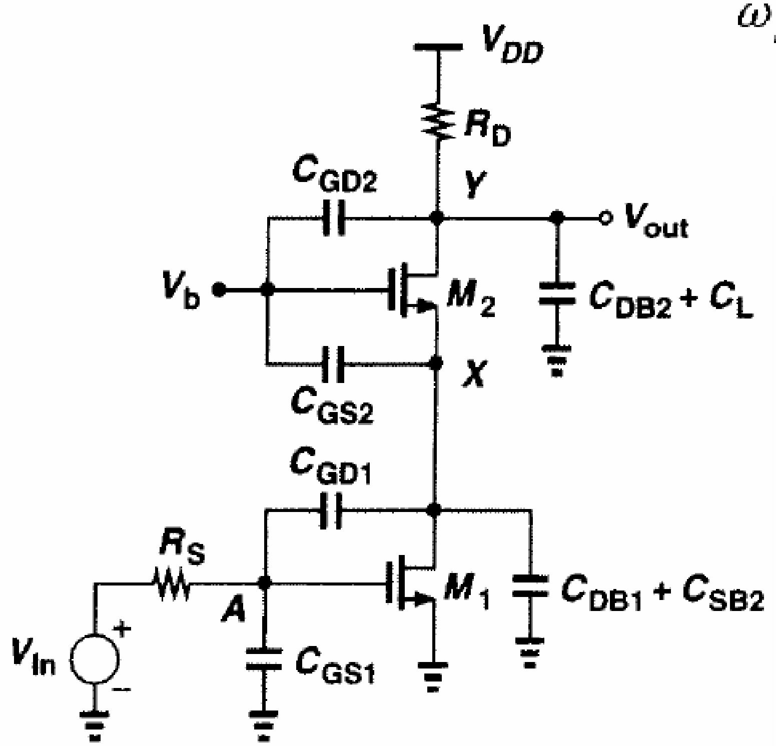


$$\frac{V_{out}}{V_{in}}(s) = \frac{(g_m + g_{mb})R_D}{1 + (g_m + g_{mb})R_S} \frac{1}{\left(1 + \frac{C_S}{g_m + g_{mb} + R_S^{-1}} s\right)(1 + R_D C_D s)}$$

- No zero
- No Miller capacitor multiplication
- Low input impedance limits effectiveness as a voltage amplifier
- Useful as a current-to-voltage (transimpedance) amplifier

Cascode Amp Frequency Response

- If we associate the poles with the nodes A, X, and Y
  - Note, this is only an approximation, as it ignores interactions caused by "feedforward" caps (C_{gd}) and resistors
- 3 pole system



Input Pole

$$\omega_{p,A} = \frac{1}{R_S\left[C_{GS1} + \left(1 + \frac{g_{m1}}{g_{m2} + g_{mb2}}\right) C_{GD1}\right]}$$

Internal Pole – High Frequency

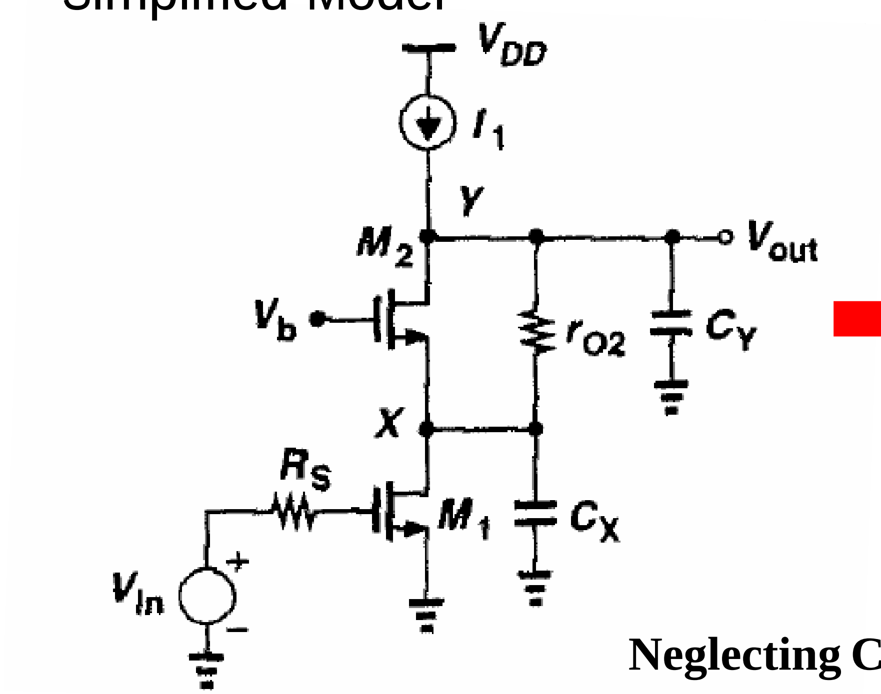
$$\omega_{p,X} = \frac{g_{m2} + g_{mb2}}{2C_{GD1} + C_{DB1} + C_{SB2} + C_{GS2}}$$

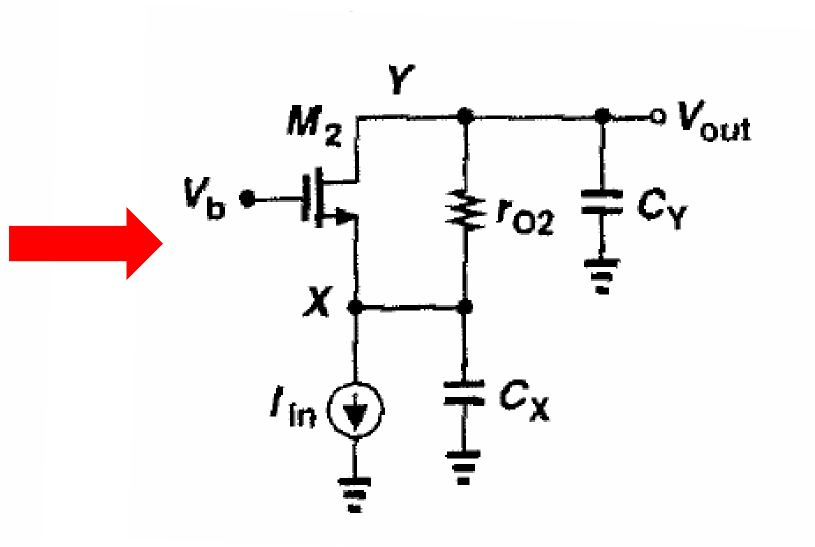
Output Pole

$$\omega_{p,Y} = \frac{1}{R_D(C_{DB2} + C_L + C_{GD2})}$$

Cascode Amp Output Impedance

- Simplified Model





Neglecting C_{GD1} and C_Y

$$Z_{out} = r_{o2} + Z_X + g_{m2} r_{o2} Z_X$$

where $Z_X = r_{o1} \left\| \frac{1}{sC_X} \right.$

Output Impedance Pole $\omega_{\mathbf{Zout}} = \dfrac{1}{r_{o1} C_X}$

Next Time

- Noise