# EE105 - Fall 2005

## Microelectronic Devices and Circuits

**Lecture 20**

**Common Source Amplifier Frequency Response**

## Announcements

- **Homework 9 due next Tuesday**
- **Lab 7 this week**
- **Lab 8 next week (please read Chapter 9)**
- **Reading: Chapter 10 (10.2, 10.3.2, 10.4.3-5 )**

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## Lecture Material

- Last lecture
  - Second-order circuits
  - Started frequency response of amplifiers
- This lecture
  - Common source amplifier – frequency response
  - Miller effect
  - Zero-order time constants

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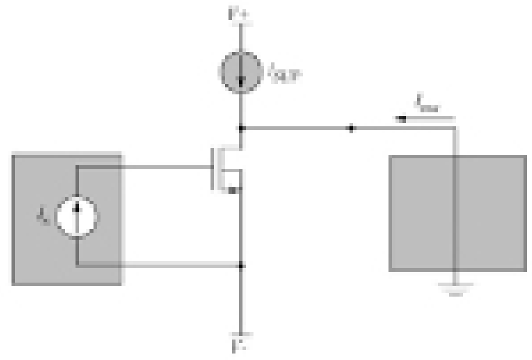
## Common Source Amplifer: $A_i(j\omega)$



DC Bias is problematic: what sets $V_{GS}$?

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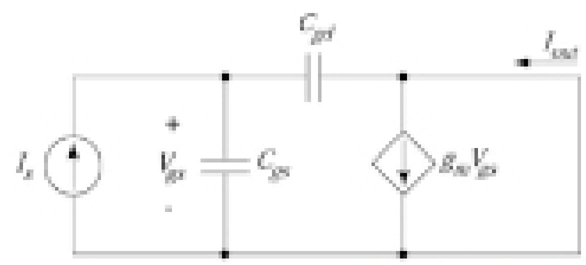
## CS Short-Circuit Current Gain




Transfer function: $$A_i(j\omega) = \frac{g_m(1 - j\omega C_{gd}/g_m)}{j\omega(C_{gs} + C_{gd})}$$

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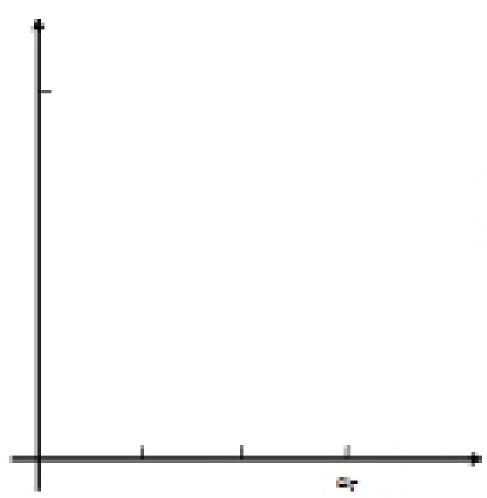
## Magnitude Bode Plot




Transition frequency:
Current gain = 1

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## MOS Unity Gain Frequency

- Since the zero occurs at a higher frequency than pole, assume it has negligible effect:

$$A_i \approx \frac{g_m}{j\omega(C_{gs}+C_{gd})} = 1 \longrightarrow \omega_T = \frac{g_m}{(C_{gs}+C_{gd})}$$

$$\omega_T \approx \frac{g_m}{C_{gs}} = \frac{\mu C_{ox}\frac{W}{L}(V_{GS}-V_T)}{\frac{2}{3}WLC_{ox}} = \frac{3}{2}\frac{\mu(V_{GS}-V_T)}{L^2}$$

Performance improves with $L^2$ for long channel devices!
For short channel devices the dependence is ~ $L^1$

$$\omega_T \approx \frac{3}{2}\frac{\mu(V_{GS}-V_T)}{L^2} \sim \frac{\mu\frac{V_{GS}-V_T}{L}}{L} = \frac{\mu E_{sat}}{L} = \frac{v}{L} = \tau_t$$

Time to cross channel

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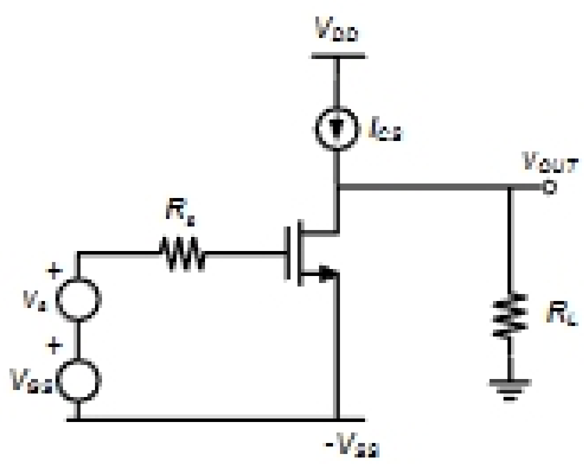
## Common-Source Voltage Amplifier




Small-signal model: omit $C_{cs}$ due to avoid complicated analysis

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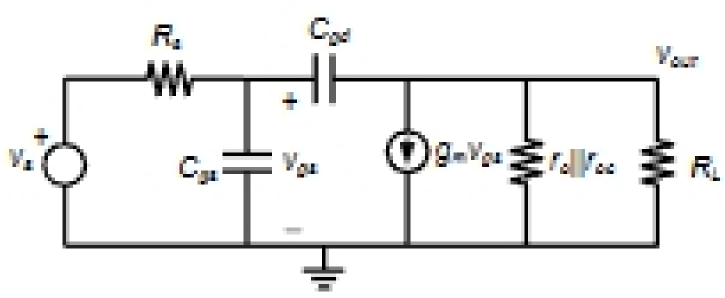
## CS Voltage Amp Small-Signal Model

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## Frequency Response

KCL at input and output nodes; analysis is made complicated due to $Z_{gd}$ branch → see H&S pp. 639-640 (for common emitter)

$$\frac{V_{out}}{V_{in}} = \frac{-g_m[r_o \,||\, r_{oc} \,||\, R_L](1-j\omega/\omega_z)}{(1+j\omega/\omega_{p1})(1+j\omega/\omega_{p2})}$$

Low-frequency gain:

Zero: $\omega_Z > \omega_T = \dfrac{g_m}{C_{gs}+C_{gd}}$

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## Poles

$$\omega_{p1} \approx \frac{1}{R_S\{C_{gs}+(1+g_m R'_{out})C_{gd}\}+R'_{out}C_{gd}}$$

$$\omega_{p2} \approx \frac{R'_{out}/R_S}{R_S\{C_{gs}+(1+g_m R'_{out})C_{gd}\}+R'_{out}C_{gd}}$$

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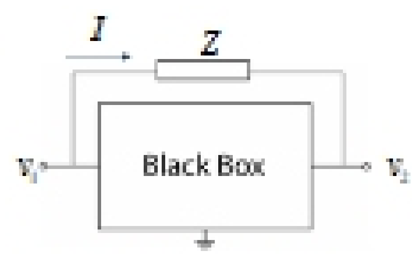
## Miller Impedance

- Consider the current flowing through an impedance Z hooked up to a "black-box" where the voltage gain from one terminal to the other is fixed

$$A_v = \frac{v_2}{v_1}$$




$$I = \frac{v_1 - v_2}{Z} = \frac{v_1 - A_v v_1}{Z} = v_1\frac{1-A_v}{Z}$$

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## Miller Impedance

- Notice that the current flowing into Z from terminal 1 looks like an equivalent current to ground where Z is transformed down by the Miller factor:

$$I = v_1 \frac{1-A_v}{Z} \rightarrow Z_{M,1} = \frac{Z}{1-A_v}$$

- From terminal 2, the situation is reciprocal

$$-I = \frac{v_2 - v_1}{Z} = \frac{v_2 - A_v^{-1} v_2}{Z} = v_2 \frac{1-A_v^{-1}}{Z}$$

$$Z_{M,2} = \frac{Z}{1-A_v^{-1}}$$

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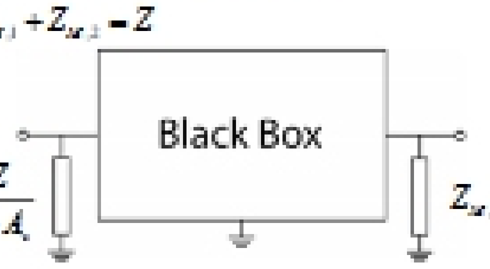
## Miller Equivalent Circuit

Note: $Z_{M,1} + Z_{M,2} = Z$

$Z_{M,1} = \frac{Z}{1-A_v}$




$Z_{M,2} = \frac{Z}{1-A_v^{-1}}$

- We can decouple these terminals if we can calculate the gain $A_v$ across the impedance $Z$
- Often the gain $A_v$ is weakly depedendent on $Z$
- The approximation is to ignore $Z$, calculate $A_v$, and then use the decoupled Miller impedances

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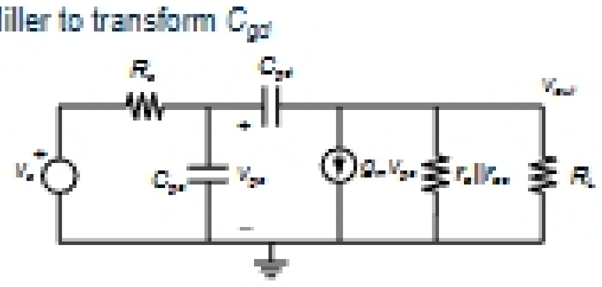
## CE Amplifier using Miller Approx.

Use Miller to transform $C_{gd}$

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## Comparison with "Exact Analysis"

Miller result:

$$\omega_{p1}^{-1} =$$

Exact result:

$$\omega_{p1}^{-1} = (R_S \parallel r_\pi)\{C_\pi + (1 + g_m R'_{out})C_\mu\} + R'_{out} C_\mu$$

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## Some Examples

Common source amplifier:

$A_{vC_{gd}}$ = negative, large number (-100)

Miller multiplied cap has detrimental Impact on bandwidth

Common drain amplifier:

$A_{vC_{gd}}$ = slightly less than 1

"Bootstrapped" cap has negligible impact on bandwidth!

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## Method of Open Circuit Time Constants

- This is a technique to find the dominant pole of a circuit (only valid if there really is a dominant pole!)
- For each capacitor in the circuit you calculate an equivalent resistor "seen" by capacitor and form the time constant $\tau_i = R_i C_i$
- The dominant pole then is the sum of these time constants in the circuit

$$\omega_{p,dom} = \frac{1}{\tau_1 + \tau_2 + \cdots}$$

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