EE105 - Fall 2005
Microelectronic Devices and Circuits

Lecture 21
Time Constants
Frequency Response of Common Drain/
Common Source Amplifiers

Announcements

- Homework 9 due today
- Homework 10 due next Tuesday
- Lab 8 this week (please read Chapter 9)
  - Friday is a University holiday (no lab/discussion)
  - Friday lab 8 on November 18
  - No new lab next week
- Midterm 2 next Thursday (Nov. 17)
  - Review session on Tuesday, Nov. 15, 6:30-8pm
- Reading: Chapter 10 (10.2, 10.3.2, 10.4.3-5, 10.5-10.6)
Lecture Material

- Last lecture
  - Common source amplifier – frequency response
  - Miller effect
- This lecture
  - Zero-order time constants
  - Common drain, common gate frequency response

Miller Effect Examples

Common source amplifier:
\[ A_{VC_{gd}} = \text{negative, large number (-100)} \]

Miller multiplied cap has detrimental impact on bandwidth

Common drain amplifier:
\[ A_{VC_{gd}} = \text{slightly less than 1} \]

“Bootstrapped” cap has negligible impact on bandwidth!
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

\[
\omega_{p,\text{dom}} = \frac{1}{\tau_1 + \tau_2 + \cdots}
\]

Equivalent Resistance “Seen” by Capacitor

- For each “small” capacitor in the circuit:
  - Open-circuit all other “small” capacitors
  - Short circuit all “big” capacitors
  - Turn off all independent sources
  - Replace cap under question with current or voltage source
  - Find equivalent input impedance seen by cap
  - Form RC time constant
- This procedure is best illustrated with an example...
Example Calculation

\[ \begin{align*}
R_s & \quad C_{gs} \\
C_{ps} & \quad v_{gs} \\
R_{C} & \quad v_{out}
\end{align*} \]

Higher-Order Time Constants

General two-pole transfer function:

\[
A(j\omega) = A_0 \frac{(1 + j\omega/\omega_{z1})(1 + j\omega/\omega_{z2})}{(1 + j\omega/\omega_{p1})(1 + j\omega/\omega_{p2})}
\]

\[
A(j\omega) = A_0 \frac{N(j\omega)}{1 + a_1j\omega + a_2(j\omega)^2}
\]

\[
a_1 = \frac{1}{\omega_{p1}} + \frac{1}{\omega_{p2}} \quad a_2 = \frac{1}{\omega_{p1}\omega_{p2}}
\]
Higher-Order Time Constants

- Coefficient $a_1$
  \[ a_1 = R_{011}^0 C_1 + R_{022}^0 C_2 \]

- Coefficient $a_2$:
  \[ a_1 = R_{211}^2 C_1 R_{022}^0 C_2 = R_{011}^0 C_1 R_{122}^1 C_2 \]

- This is exact!

- If $\omega_{p1} \ll \omega_{p2}$:
  \[ a_1 \approx \frac{1}{\omega_{p1}} \quad a_2 \approx \frac{a_1}{\omega_{p2}} \]

Example Calculation
Gain-Bandwidth Product

Result from Miller:

\[ \omega_{p1}^{-1} \approx (R_S) \left( C_{gs} + (1 + g_m R'_{out}) C_{gd} \right) \]

Low-frequency gain:

\[ A_{vo} = \left. \frac{V_{out}}{V_s} \right|_{R_S, R_L} = -g_m R'_{out} \]

Gain-Bandwidth Product

Considering only the first pole
(assuming zero and 2\textsuperscript{nd} pole are at much higher frequencies):

\[ |A_v(j\omega)| \approx \left| \frac{A_{vo}}{1 + j \omega/\omega_p1} \right|, \quad \omega \approx \omega_p1 \]

\[ |A_v(j\omega^*)| = 1 \Rightarrow \omega^* = A_{vo} \omega_p1 \]
**Gain-Bandwidth Product**

For common-source amplifier:

\[ |A_v|_{\omega p1} = \frac{g_m R'_\text{out}}{R_S C_{gs} + R_S (1 + g_m R'_\text{out}) C_{gd}} \]

Special case: \( R_S \approx R_L < r_o, r_{oc} \)

\[ |A_v|_{\omega p1} \approx \frac{g_m R_L}{R_S (C_{gs} + g_m R_L C_{gd})} << \omega_T \] (not that great!)

**Common-Drain Amplifier**

![Common-Drain Amplifier Circuit Diagram](image)
Two-Port CD Model with Capacitors

Ignore $g_{mb}$

Find Miller capacitor for $C_{gs}$ -- note that the gate-source capacitor is between the input and output

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Voltage Gain $A_{vC\pi}$ Across $C_{\pi}$

$$A_{vCgs} = \frac{R_{out}}{R_L + R_{out}} \approx 1$$

Note: this voltage gain is neither the two-port gain nor the "loaded" voltage gain

$$C_{in} = C_{gd} + C_M = C_{gd} + (1 - A_{vCgs})C_{gs}$$

$$C_{in} = C_{gd} + \frac{1}{1 + g_m R_L} C_{gs}$$

$$C_{in} \approx C_{gd}$$
Bandwidth of CC Amplifier

Input low-pass filter’s –3 dB frequency:

$$\omega_p^{-1} = R_S \left( C_{gd} + \frac{C_{gs}}{1+g_m R_L} \right)$$

Substitute favorable values of $R_S$, $R_L$:

$$R_S \approx \frac{1}{g_m} \quad R_L \gg \frac{1}{g_m}$$

$$\omega_p^{-1} \approx \left( \frac{1}{g_m} \right) \left( C_{gd} + \frac{C_{gd}}{1+BIg} \right) \approx \frac{C_{gd}}{g_m}$$

$$\omega_p \approx g_m / C_{gd} > \omega_T$$

Model not valid at these high frequencies

Bandwidth of the Common-Gate Amplifier
Two-Port CB Model with Capacitors

No Miller-transformed capacitor!

Unity-gain frequency is on the order of $\omega_T$ for small $R_L$

Summary of Single-Stage Amplifiers

- CS: suffers from Miller-magnified capacitor for high-gain case
- CD: Miller transformation $\rightarrow$ nulled capacitor $\rightarrow$ "wideband stage"
- CG: no "Millerized" capacitor $\rightarrow$ wideband stage (for low load resistance)