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:
  \( A_{C_{gd}} = \) negative, large number (-100)
  - Miller multiplied cap has detrimental impact on bandwidth
- Common drain amplifier:
  \( A_{C_{gd}} = \) 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

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

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

\[ R_s + v_{out} + v_{in} + \frac{C_{gs} + C_{gd}}{g_m v_{gs}} + \frac{R_o}{g_m v_{gs}} \]

Higher-Order Time Constants

- General two-pole transfer function:
  \[
  A(j\omega) = A_0 \frac{1}{1 + a_1\omega + a_2(\omega \omega_2)}
  \]
  \[
  a_1 = \frac{1}{\omega_1^2} + \frac{1}{\omega_2^2} \quad a_2 = \frac{1}{\omega_1 \omega_2^2}
  \]

- Coefficient \(a_1\):
  \[
  a_1 = R_1 C_1 + R_2 C_2
  \]

- Coefficient \(a_2\):
  \[
  a_2 = R_1^2 C_1 R_2^2 C_2 = R_1 C_1 R_2 C_2
  \]

  This is exact!

- If \(\omega_2 < \omega_1\):
  \[
  a_1 = \frac{1}{\omega_1^2} \quad a_2 = \frac{1}{\omega_2^2}
  \]

Gain-Bandwidth Product

Result from Miller:

\[
\omega_p \approx (R_s) \left( C_{gs} + (1 + g_m R_o) C_{gd} \right)
\]

Low-frequency gain:

\[
A_{\infty} = \left. \frac{v_{out}}{v_s} \right|_{R_S, R_L} = -g_m R_{out}
\]

Gain-Bandwidth Product

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

\[
A(j\omega) = \frac{A_{\infty}}{1 + j \omega \alpha} = \frac{A_{\infty} \omega_1 \omega_2}{\omega_1 \omega_2 + \omega^2}
\]

\[
A(j\omega) = 1 \Rightarrow \omega^* = A_{\infty} \omega \alpha
\]
Gain-Bandwidth Product

For common-source amplifier:

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

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

\[ |A_{vo}|_{\omega p1} \approx \frac{g_m R_L}{R_S (C_{gs} + g_m R_L C_{gd})} \ll \omega_T \quad \text{not that great!} \]

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

\[ C_{in} = C_{gd} + C_M = C_{gd} + (1 - A_{VCgs}) C_{gs} \]

\[ C_{ip} = C_{gd} + \frac{1}{1 + \frac{1}{g_m R_L} C_{gs}} \]

\[ C_{in} \approx C_{gd} \]

Common-Drain Amplifier

\[ V_{DD} \]

\[ R_s \]

\[ v_o \]

\[ R_L \]

\[ v_{OUT} \]

\[ v_s \]

\[ V_{GS} - V_{SS} \]

Two-Port CD Model with Capacitors

Ignore \( g_{mb} \)

Find Miller capacitor for \( C_m \) – note that the gate-source capacitor is between the input and output

Bandwidth of CC Amplifier

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

\[ \omega_p = R_S \left( C_{gd} + \frac{C_M}{1 + g_m R_L} \right) \]

Substitute favorable values of \( R_S, R_L \):

\[ R_S \approx 1/g_m \quad R_L \gg 1/g_m \]

\[ \omega_p^{-1} = \frac{1}{g_m} \left( C_{gd} + \frac{C_M}{1 + g_m R_L} \right) = \frac{C_{gd}}{g_m} \]

Model not valid at these high frequencies

\[ \omega_p \approx g_m / C_{gd} > \omega_T \]

Bandwidth of the Common-Gate Amplifier

\[ V_{in} \]

\[ + \]

\[ R_L \]

\[ R_{out} \]
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)