ECE 342
Electronic Circuits

Lecture 13
CD and CG MOS Amplifiers

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MOS Body Effect

• The threshold voltage $V_T$
  – Depends on equilibrium potential
  – Controlled by inversion in channel

• The body effect
  – $V_T$ varies with bias between source and body
  – Leads to modulation of $V_T$
Body Effect

Potential on substrate affects threshold voltage

\[ V_T (V_{SB}) = V_{To} + \gamma \left[ (2|\phi_F| + V_{SB})^{1/2} - (2|\phi_F|)^{1/2} \right] \]

\[ |\phi_F| = \left( \frac{kT}{q} \right) \ln \left( \frac{N_a}{n_i} \right) \]

Fermi potential of material

\[ \gamma = \left( \frac{2qN_a \varepsilon_s}{C_{ox}} \right)^{1/2} \]

Body bias coefficient
Body Effect – (Con’t)

Define $g_{mb}$ as the body transconductance

$$g_{mb} = \left. \frac{\partial I_D}{\partial V_{BS}} \right|_{V_{GS}=\text{constant}, V_{DS}=\text{constant}}$$

Can show that $g_{mb} = \chi g_m$

where $\chi = \frac{\partial V_T}{\partial V_{SB}} = \frac{\gamma}{2 \sqrt{\phi_F + V_{SB}}}$
Source Follower Configuration

For the source follower (common drain) configuration, the source is supplied at the gate and the output is collected at the source terminal.

The drain terminal is connected to the power supply $V_{DD}$. Incrementally, the drain is grounded.

The source is connected to a load resistance $R_L$.

Define

$$G_L = \frac{1}{R_L}$$
**Source Follower Configuration**

**Incremental model for source follower** - Since source is not tied to the substrate, we need to model the body effect. Note: substrate is always tied to ground.

Define $g_{ds} = \frac{1}{r_{ds}}$ and $G = g_{ds} + g_{mb} + G_L$
Source Follower

\[ v_{out} = \frac{g_m v_{gs}}{G} = \frac{g_m (v_{in} - v_{out})}{G} \]

\[ v_{out} g_{ds} + v_{out} G_L + g_{mb} v_{out} = g_m v_{gs} \]

\[ v_{out} G = g_m v_{gs} \Rightarrow v_{out} = \frac{g_m v_{gs}}{G} = \frac{g_m (v_{in} - v_{out})}{G} \]

\[ v_{out} G = g_m v_{in} - g_m v_{out} \]
Source Follower

\[ v_{out} G = g_m v_{gs} \Rightarrow v_{out} (G + g_m) = g_m v_{in} \]

\[ A_{GS} = \frac{g_m}{g_m + G} = \frac{g_m}{g_m + g_{mb} + g_{ds} + G_L} \]

\[ A_{GS} = \frac{g_m}{g_m + G} = \frac{g_m}{g_m + g_{mb} + g_{ds} + G_L} \]
Source Follower

Neglecting $G_L$ and $g_{ds}$ (since they are small)

$$A_{GS} = \frac{g_m}{g_m + g_{mb}} \approx 1$$  \hspace{1cm} \text{This value is close to 1}

Output impedance of source follower

$$R_{out} = \frac{1}{g_m} \parallel \frac{1}{g_{mb}} \parallel r_{ds} \parallel R_L$$

Internal output impedance

$$r_{out} = \frac{1}{g_m} \parallel \frac{1}{g_{mb}} \parallel r_{ds} \leftarrow \text{This value is low}$$
Source Follower

Source follower exhibits

- Voltage gain close to unity
- High input impedance
- Low output impedance

Source follower is ideal as a *Buffer* stage
Common Gate Configuration

In the common gate configuration, the signal is supplied through the source and the output is collected at the drain terminal.

The gate terminal is connected to a power supply $V_{bias}$. Incrementally, the gate is grounded.

The drain is connected to a load resistance $R_D$.

Define

$$G_L = \frac{1}{R_L}$$
Common Gate Amplifier

Small-Signal Equivalent Circuit

Define

\[ G_D = \frac{1}{R_D} \]

The midband gain is

\[ A_{MB} = \frac{v_{out}}{v_{in}} \]
Common Gate Amplifier

\[ A_{MB} = \frac{g_m + g_{mb} + g_{ds}}{G_D + g_{ds} + \left(g_m + g_{mb} + g_{ds}\right)G_D / G_g} \]

\[ g_{ds} \ll \left(g_m + g_{mb}\right) \text{ to get} \]

\[ A_{MB} = \frac{\left(g_m + g_{mb}\right)R_D}{1 + \left(g_m + g_{mb}\right)R_g} \]

Common Gate (CG)
- CG amplifier is non-inverting
- CG amplifier has low input impedance
- CG is unity current-gain amplifier
# MOS Topologies - Ideal

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