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

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

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

Fermi potential of material

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

Body bias coefficient

Body Effect – (Con't)

Define g_{mb} as the body transconductance

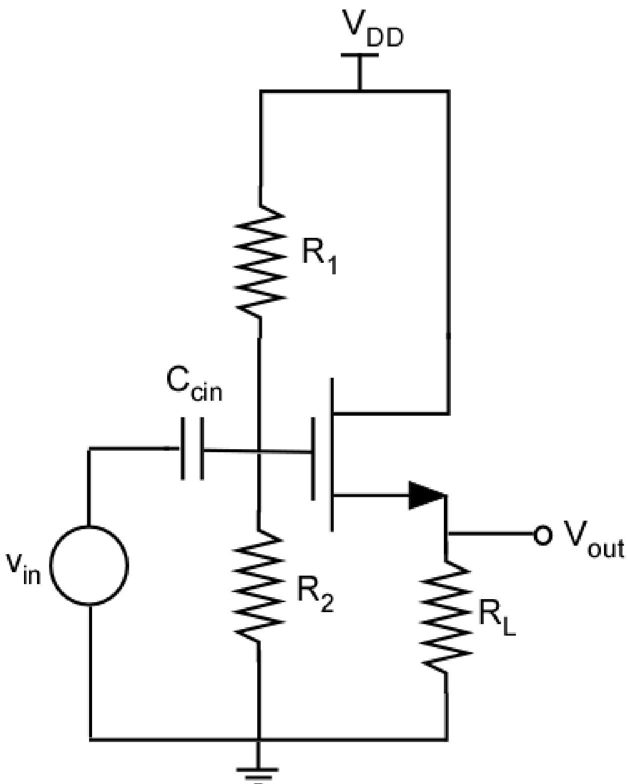
$$g_{mb} = \left.\frac{\partial I_D}{\partial V_{BS}}\right|_{\substack{V_{GS}=\text{constant} \\ V_{DS}=\text{constant}}}$$

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.



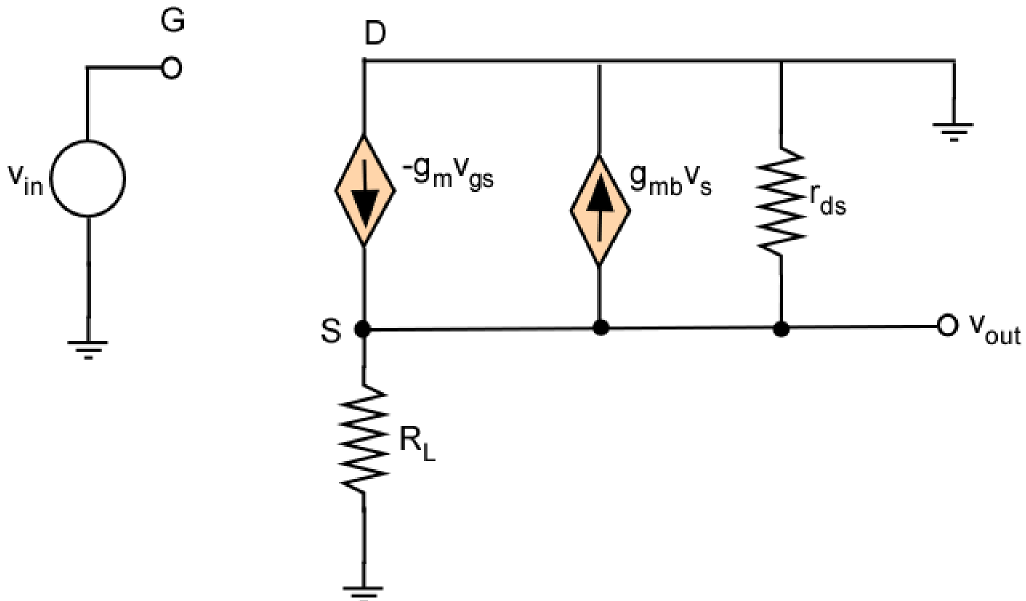
The drain terminal is connected to the power supply V_{DD}. Incrementally, the drain is grounded

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

$$v_{out} = \frac{g_m v_{gs}}{G} = \frac{g_m \left(v_{in} - v_{out}\right)}{G}$$

$$v_{out} g_{ds} + v_{out} G_L + g_{mb} v_{out} = g_m v_{gs}$$

$$v_{out} G = g_m v_{gs} \Rightarrow v_{out} = \frac{g_m v_{gs}}{G} = \frac{g_m \left(v_{in} - v_{out}\right)}{G}$$

$$v_{out} G = g_m v_{in} - g_m v_{out}$$

Source Follower

$$v_{out}G = g_m v_{gs} \Rightarrow v_{out}\left(G + g_m\right) = g_m v_{in}$$

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

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

Source Follower

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

$$A_{GS} = \frac{g_m}{g_m + g_{mb}} \approx 1$$

This value is close to 1

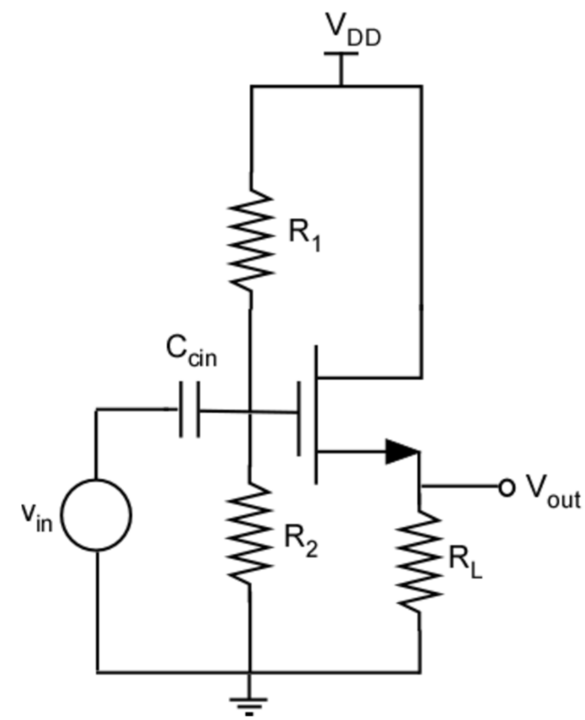
Output impedance of source follower

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

Internal output impedance

$$r_{out} = \frac{1}{g_m} \,||\, \frac{1}{g_{mb}} \,||\, r_{ds} \leftarrow \textit{This value is low}$$

Source Follower



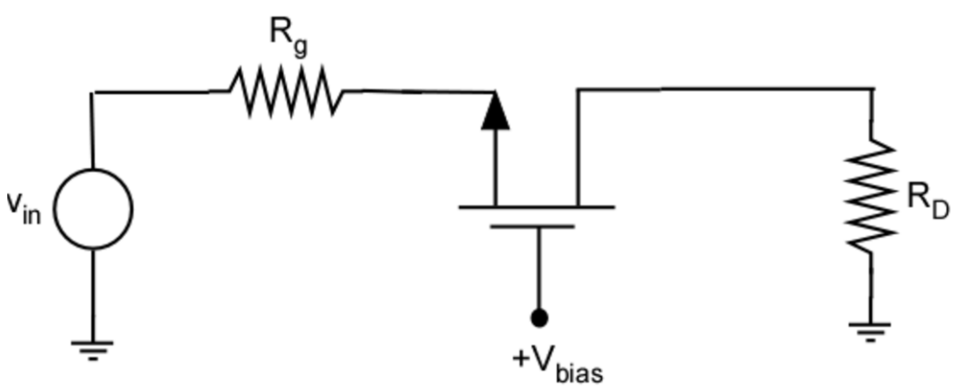
Source follower exhibits

- 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.



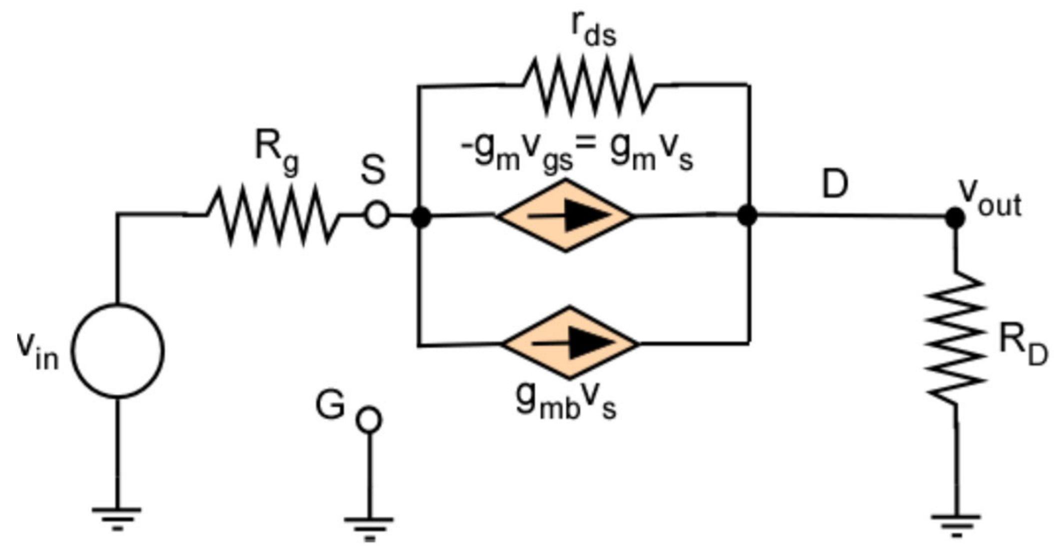
The gate terminal is connected to a power supply V_{bias}. Incrementally, the gate is grounded

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 $G_D = \dfrac{1}{R_D}$

The midband gain is $A_{MB} = \dfrac{v_{out}}{v_{in}}$

Common Gate Amplifier

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

$$g_{ds} \ll \left(g_m + g_{mb}\right) \textit{ to get}$$

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

Common Gate (CG)

- CG amplifier is non-inverting
- CG amplifier has low input impedance
- CG is unity current-gain amplifier

MOS Topologies - Ideal

	CS	CG	SF
A_{vo}	$-g_m R_D$	$g_m R_D$	1
R_{in}	∞	$\frac{1}{g_m}$	∞
R_{out}	R_D	R_D	$\frac{1}{g_m}$