EE223 Analog Integrated Circuits
Fall 2018

Lecture 9: Common Gate Amplifiers

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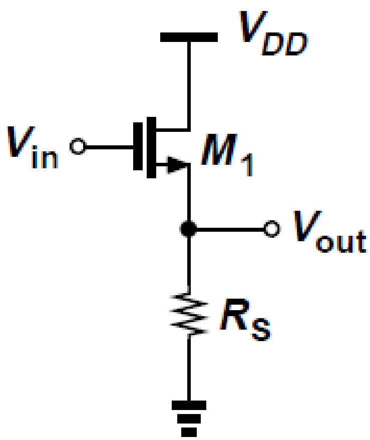
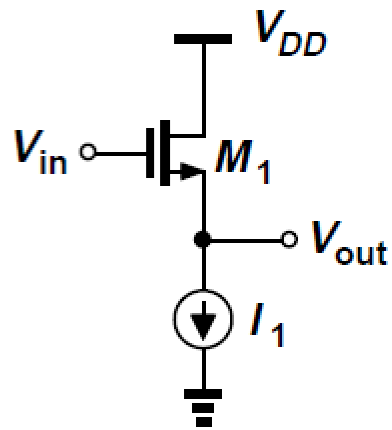
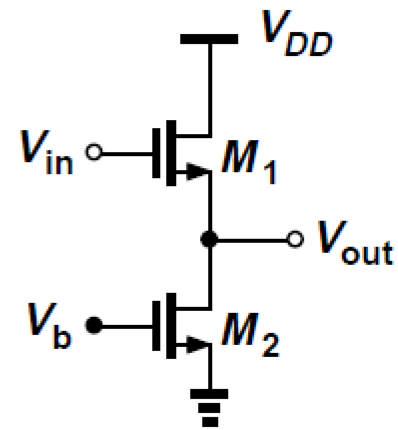
ENG-259

Issue with Source Follower





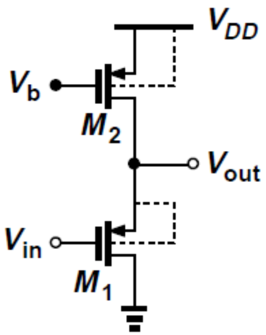


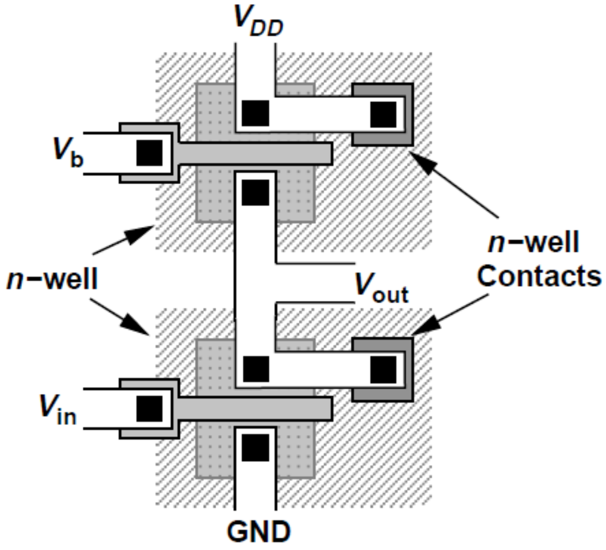
- Voltage headroom limitation
- Nonlinear dependence of V_{TH} on the source potential
- r_O changes substantially with V_{DS}

Issue with Source Follower

- **Nonlinearity can be eliminated if the bulk is tied to the source**

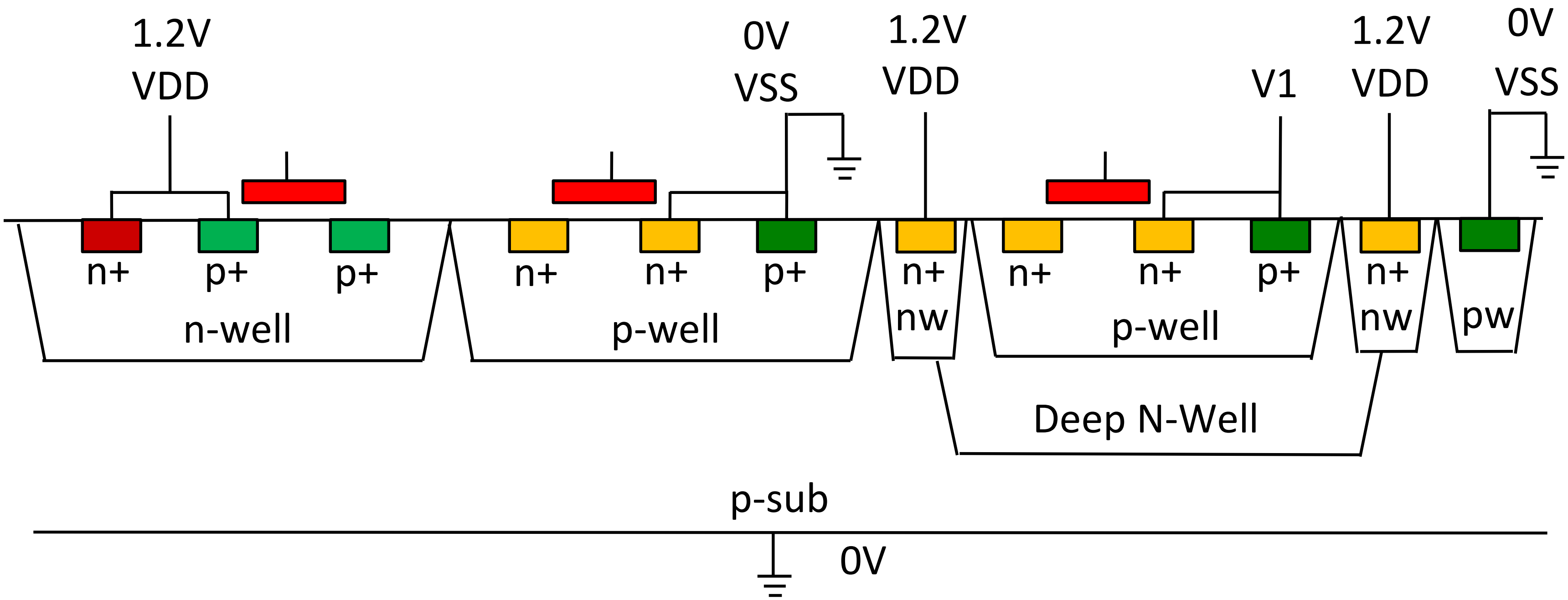
- **PMOS source follower employing two separate n-wells can eliminate the body effect of *M_1***





Issue with Source Follower

- Can we create separate p-wells for NMOS Source Follower?

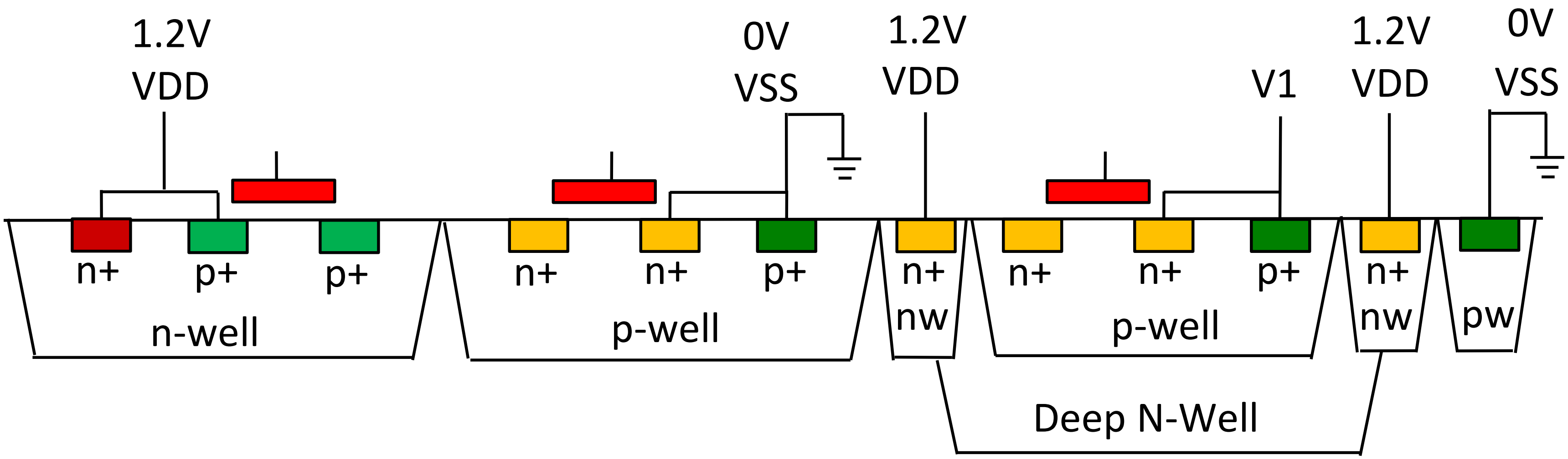


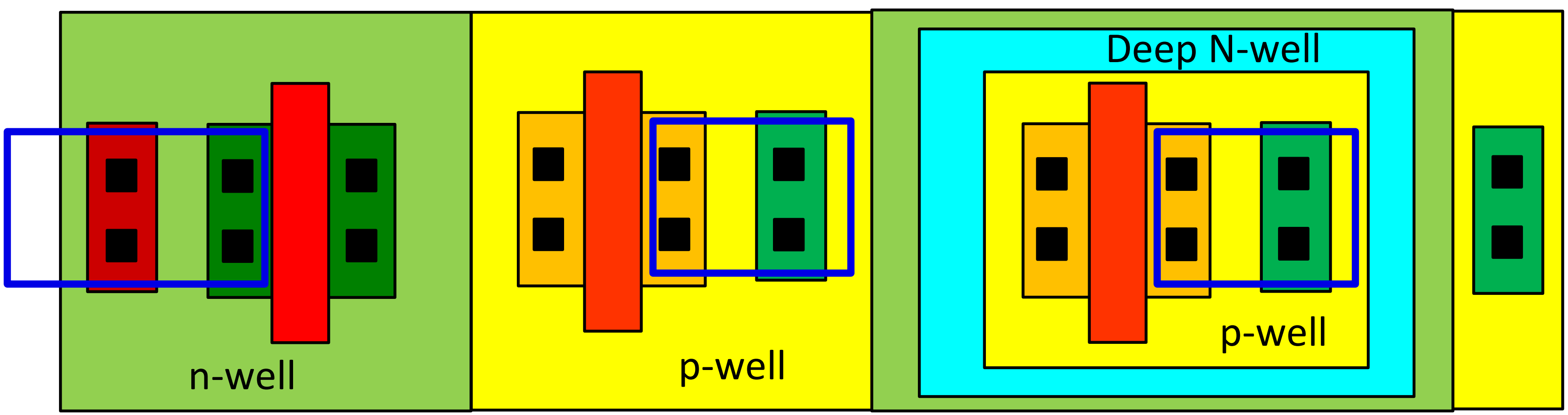
What voltage V1 should be?

All pn junctions must be reverse-biased at all times.

Layout of NMOS Source Follower

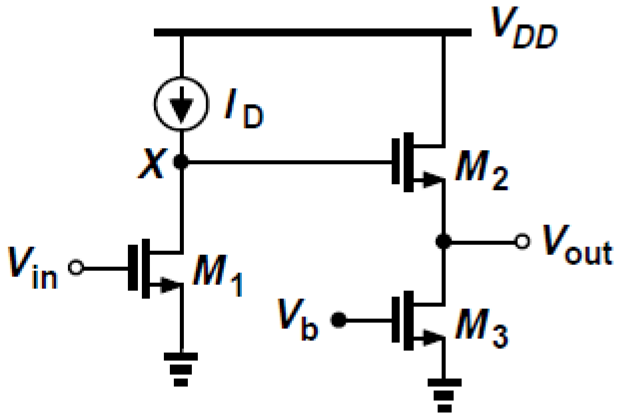
- Can we create separate p-wells for NMOS Source Follower?





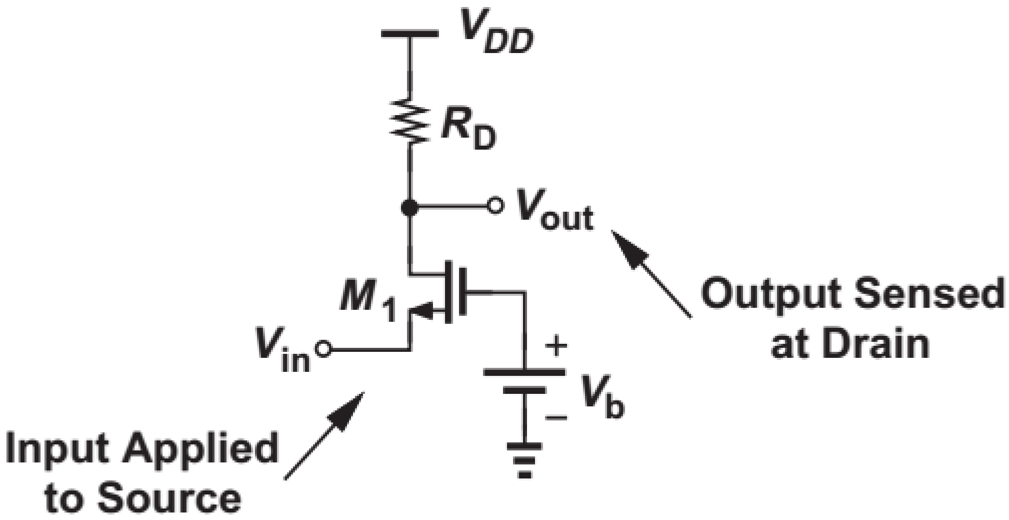
Issue with Source Follower

- **Voltage headroom**

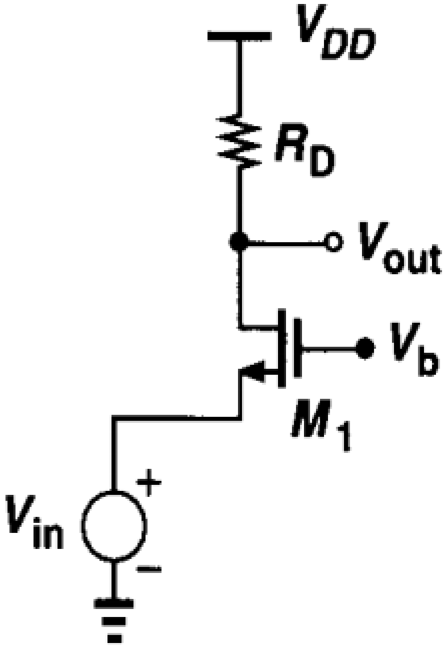


  - **CS Amp only : V_X needs $V_{DS} > V_{GS1}-V_{TH1}$**
  - **With Source Follower, $V_X > V_{GS2}+(V_{GS3}-V_{TH3})$**

Common-Gate Topology



Common-Gate Amplifier



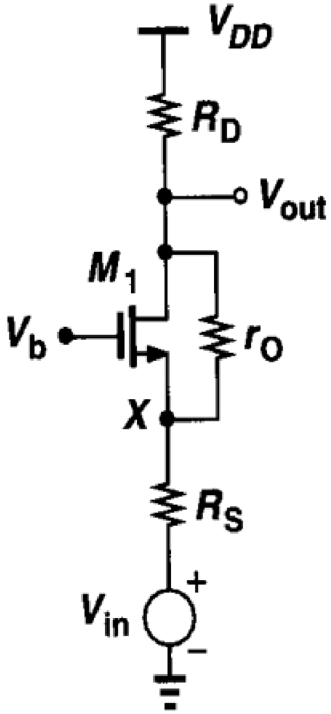
$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_b - V_{in} - V_{TH})^2$$

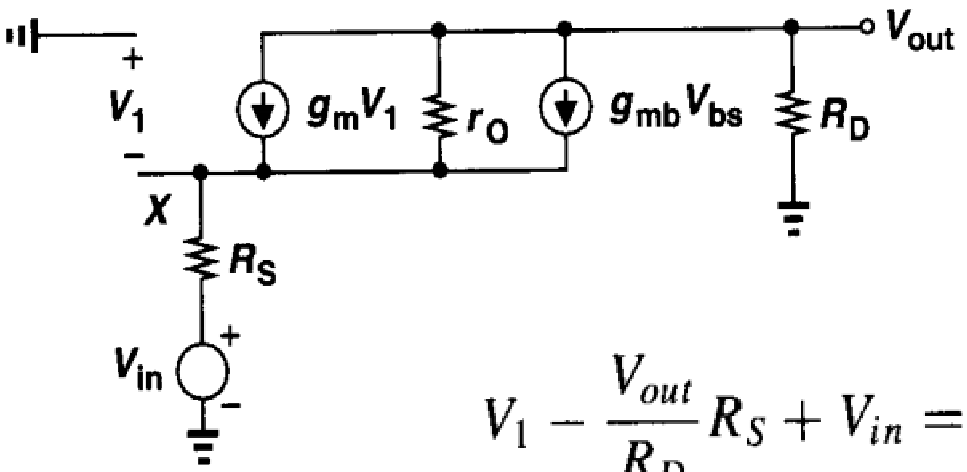
$$V_{out} = V_{DD} - \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_b - V_{in} - V_{TH})^2 R_D$$

$$\frac{\partial V_{out}}{\partial V_{in}} = +\mu_n C_{ox}\frac{W}{L}(V_b - V_{in} - V_{TH})\, R_D$$

$$= g_m R_D$$

CG Amplifier with R_s



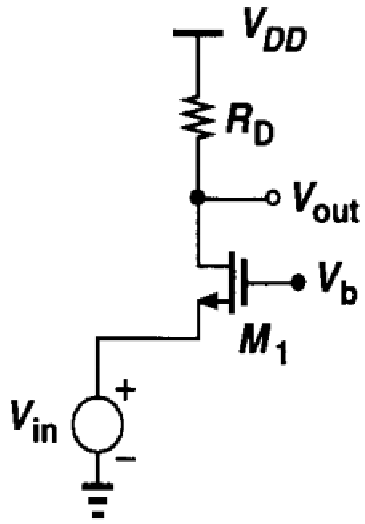


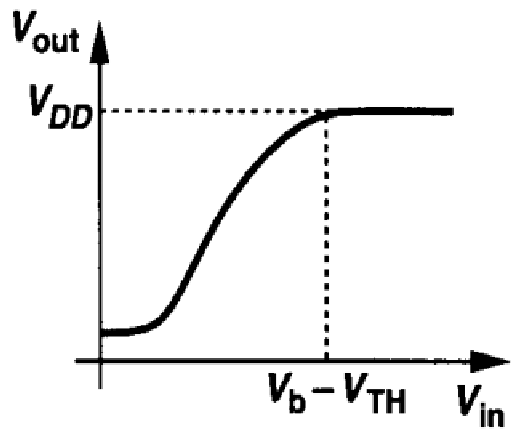
$$V_1 - \frac{V_{out}}{R_D} R_S + V_{in} = 0$$

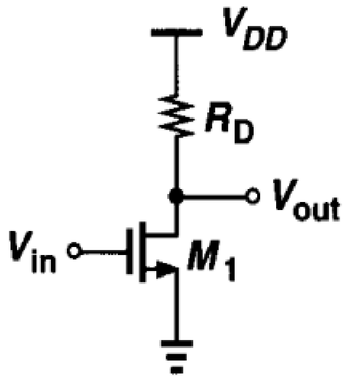
$$r_O \left(\frac{-V_{out}}{R_D} - g_m V_1 - g_{mb} V_1 \right) - \frac{V_{out}}{R_D} R_S + V_{in} = V_{out}$$

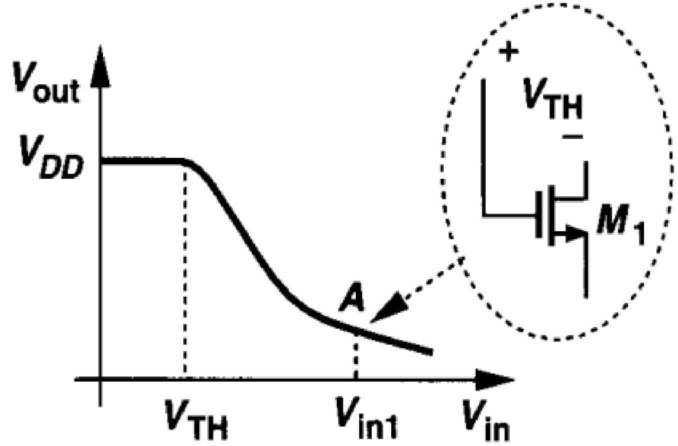
$$\frac{V_{out}}{V_{in}} = \frac{(g_m + g_{mb}) r_O + 1}{r_O + (g_m + g_{mb}) r_O R_S + R_S + R_D} R_D \approx \frac{g_m r_o R_D}{r_o + g_m r_o R_S} = \boxed{\frac{R_D}{\frac{1}{g_m} + R_S}}$$

CG Amplifier vs. CS Amplifier

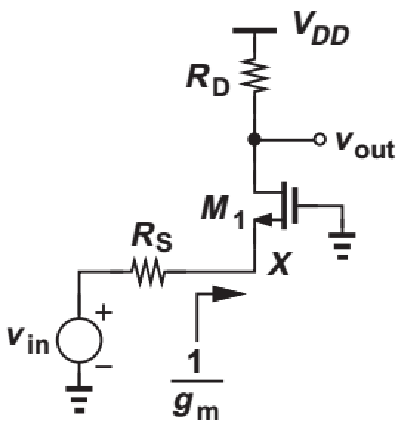


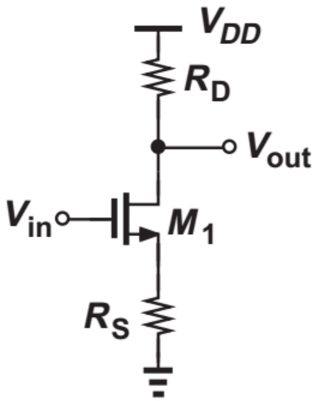






Summary : Gain of CG and CS with Rs





$$A_v = \frac{R_D}{\frac{1}{g_m} + R_S}$$

$$A_v = -\frac{R_D}{\frac{1}{g_m} + R_S}$$

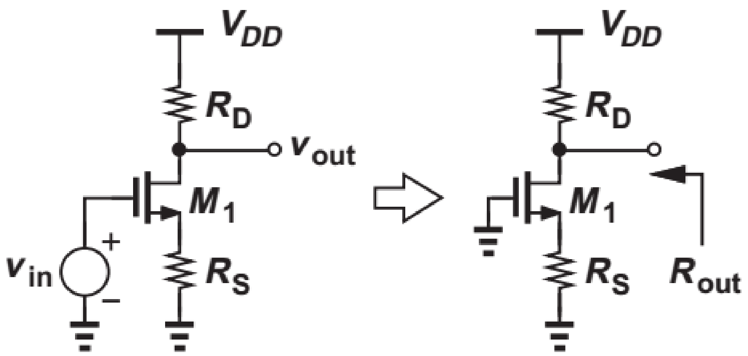
$$\rightarrow \frac{Resistance\ seen\ at\ the\ drain}{Total\ resistance\ seen\ in\ the\ source\ path}$$

Same magnitude for both structures

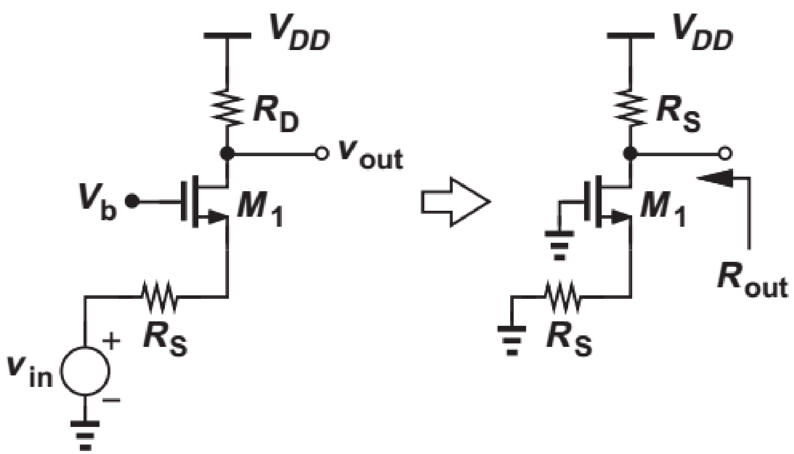
Summary : R_{out} of CG and CS with Rs

$R_{out} = r_o + R_S + (g_m r_o) \cdot R_S$ → Same for both structures

CS with Rs

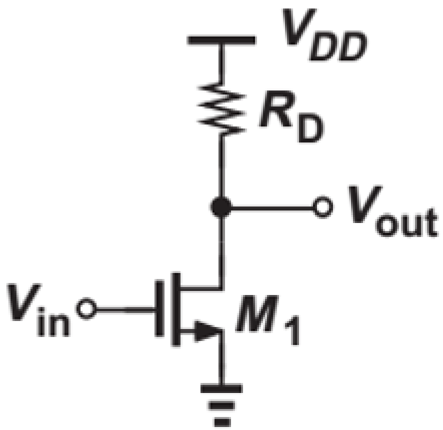


CG with Rs



Summary of Amplifiers

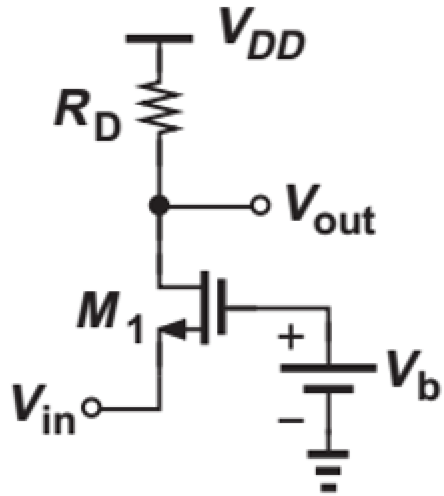
CS Amp



Inverting

$$A_v = -g_m R_{out}$$
$$= -g_{m1}(R\uparrow // R\downarrow)$$
$$= -g_{m1}(R_D // r_{o1})$$

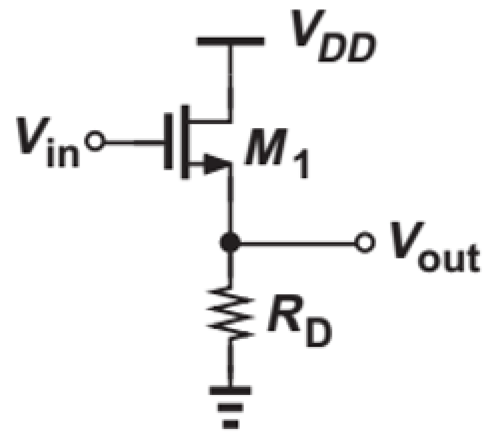
CG Amp



Non-Inverting

$$A_v = g_m R_{out}$$
$$= g_{m1}(R\uparrow // R\downarrow)$$
$$= g_{m1}(R_D // r_{o1})$$

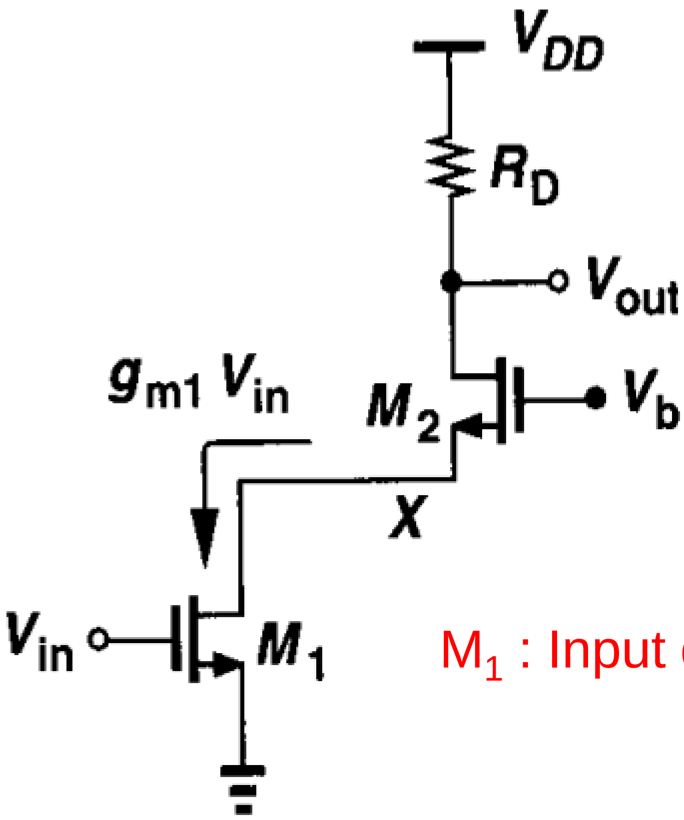
CD Amp



Non-Inverting

$$A_v = g_m R_{out}$$
$$= g_m(R\uparrow // R\downarrow)$$
$$= g_m\left(\frac{1}{g_{m1}} // R_D\right)$$

Cascode Stage

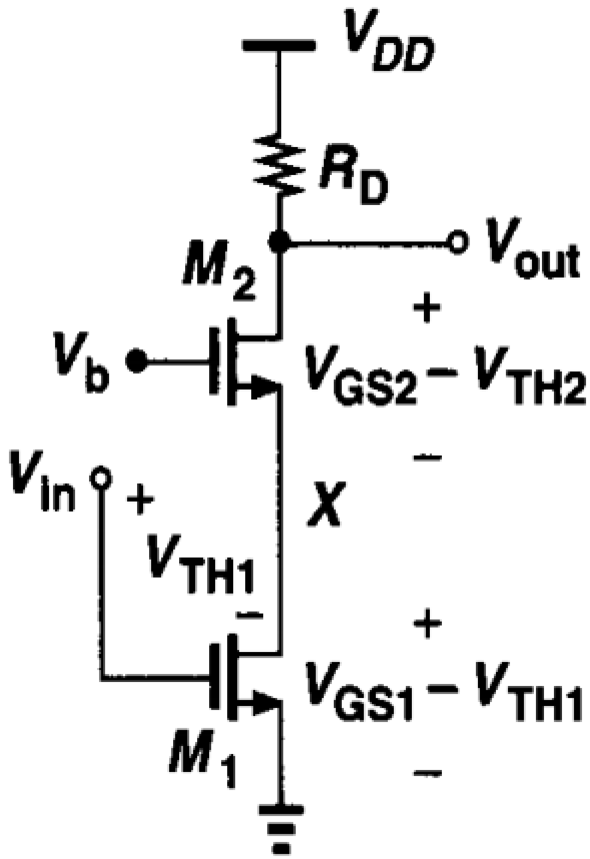


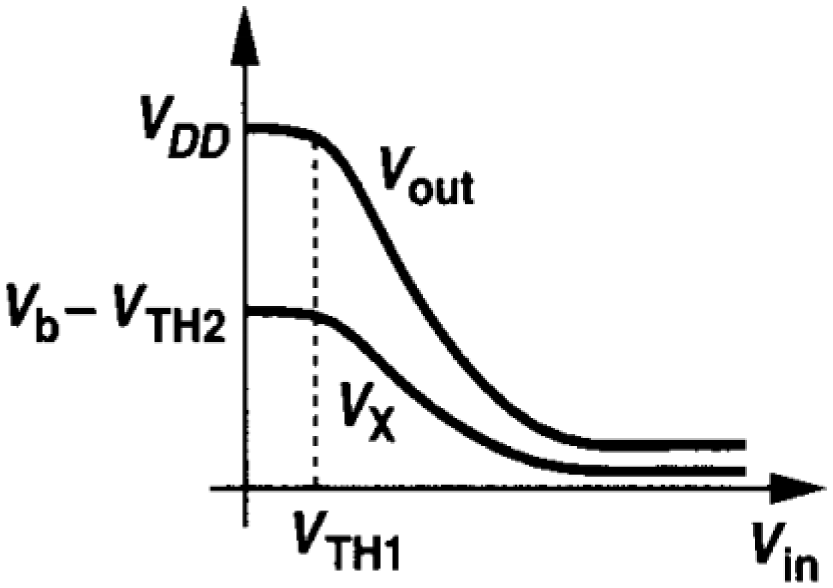
M_2 : Cascode device

M_1 : Input device

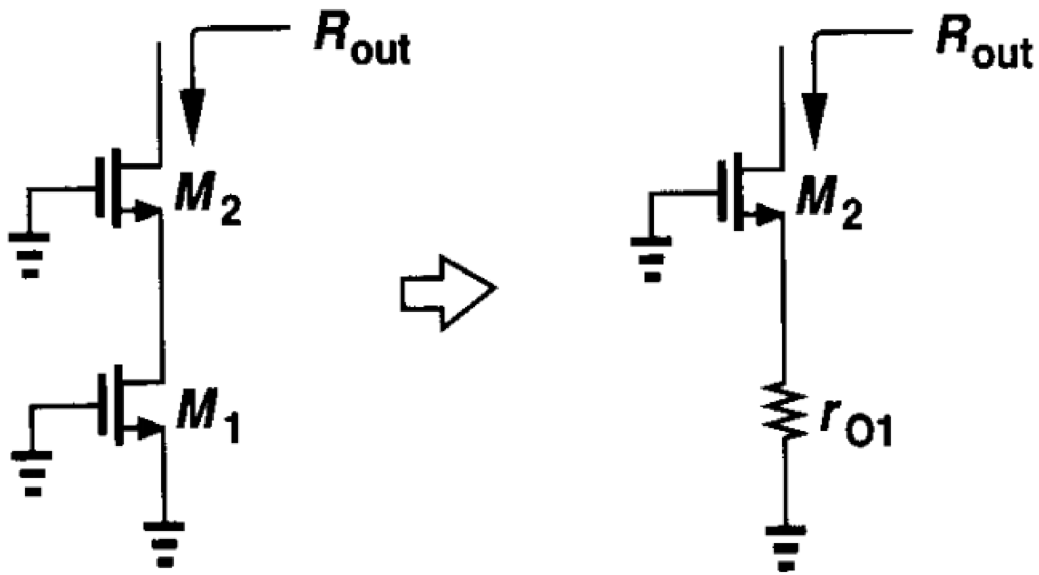
Cascode Topology : Cascade of CS stage and CG stage

I/O Characteristics of Cascode Stage





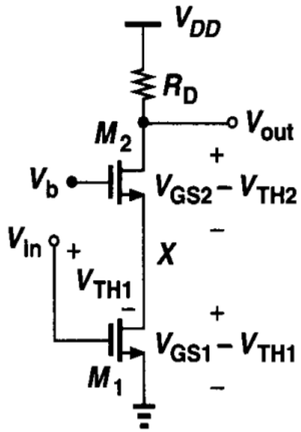
Output Impedance of Cascode Stage

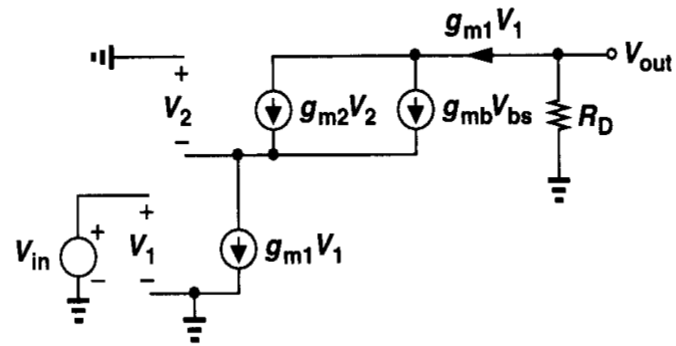


$$R_{out} = r_{o1} + r_{o2} + (g_{m2}r_{o2})r_{o1}$$

$$R_{out} = r_{o1} + r_{o2} + (g_{m2} + g_{mb2})r_{o2}r_{o1}$$ if $g_{mb} \neq 0$

Gain of Cascode Stage





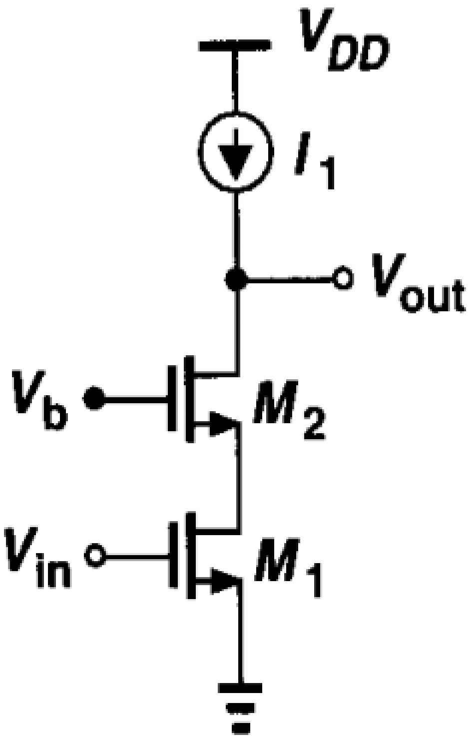
$$A_v = \frac{V_{out}}{V_{in}} = -g_{m1}R_{out}$$

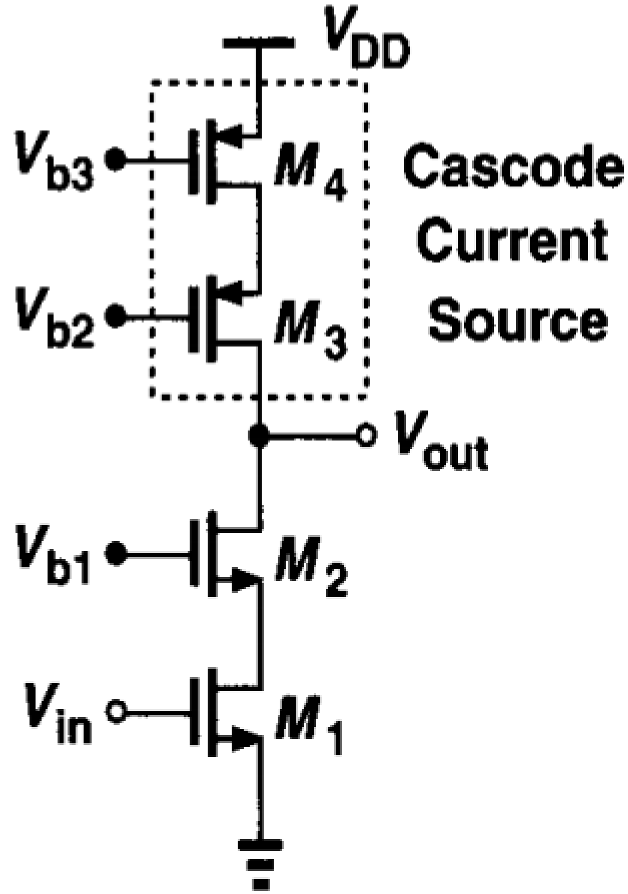
$$R_{out} = \{r_{o1} + r_{o2} + (g_{m2} + g_{mb2})r_{o2}r_{o1}\} // R_D$$

$$\approx (g_{m2}r_{o2})\, r_{o1} // R_D$$

$$A_v \approx -g_{m1}(g_{m2}r_{o2})\, r_{o1} = -(g_m\, r_o)^2$$ *if R_D is neglected*

Cascode Amp with Cascode Current Source





$$A_v \approx -g_{m1}[\{(g_{m2}r_{o2})\, r_{o1}\}||\{(g_{m3}r_{o3})\, r_{o4}\}] \approx -\frac{(g_m r_o)^2}{2}$$