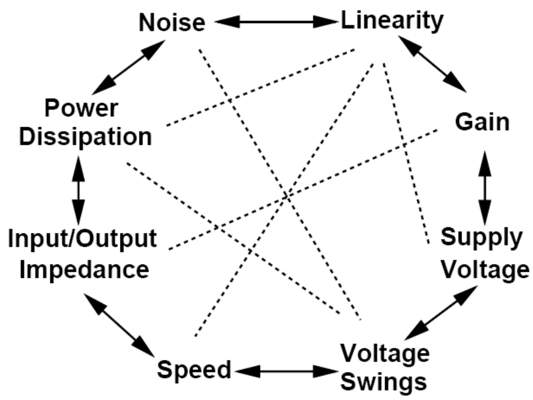
B. Razavi

Single-Stage Amplifiers

Many aspects of the performance of amplifiers are citical. We summarize the tarde-offs as whown below.



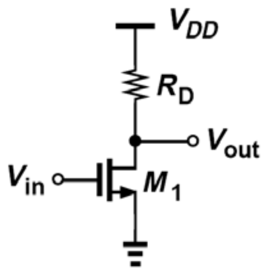
The amplifiers to be studied here include: CS and CG stages, source followers, and cascades. For each stage, we wish to study both the large-signal and small-signal properties.

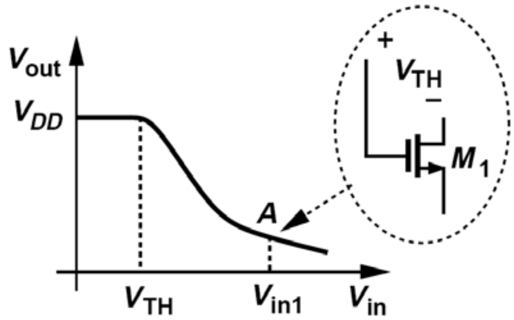
Amplifier Categories

Common−Source Stage	Source Follower	Common−Gate Stage	Cascode
With Resistive Load	With Resistive Bias	With Resistive Load	Telescopic
With Diode−Connected Load	With Current−Source Bias	With Current−Source Load	Folded
With Current−Source Load			
With Active Load			
With Source Degeneration			

Common Source Stage

- Large-Signal Behavior





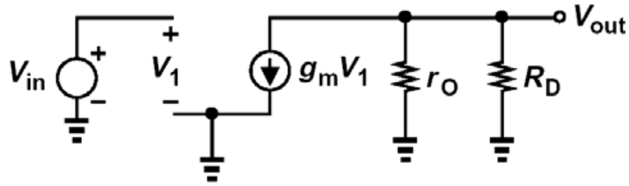
What is the small-signal gain in this region?

At point A: $V_{in1} - V_{TH} = V_{DD} - R_D \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{TH})^2$

How do we maximize the gain?

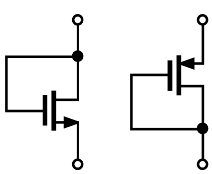
- Small-Signal Analysis

We assume that the bias currents and voltages are chosen such that M_1 is in saturation and Q_l in forward active region.

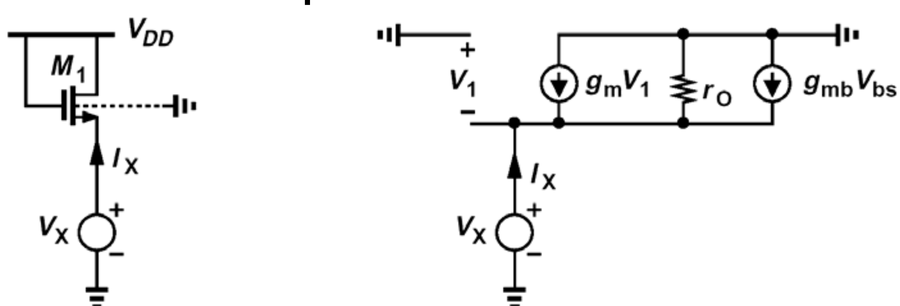


Voltage Gain:

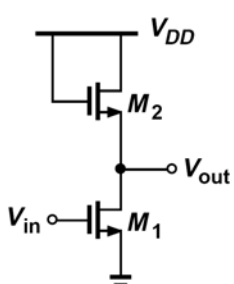
Sometimes we don't want to use a resistive load. So we try other tricks:



This device can operate as a resistor. How about this:

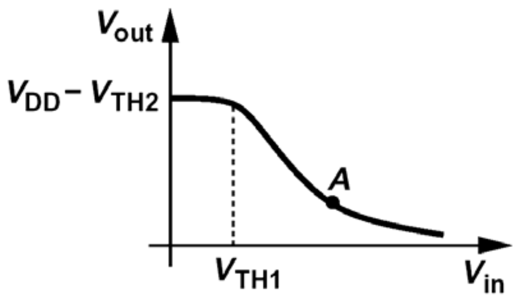


<u>Common Source with "Diode" Load</u>

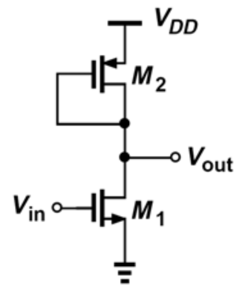


How do we maximize the voltage gain here?

Large Signal Behavior:

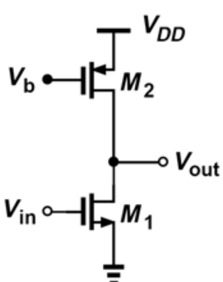


Example: Common Source with PMOS Diode Load



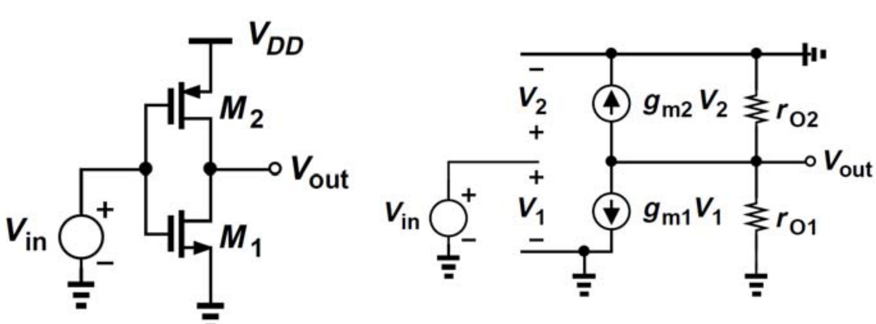
Both versions suffer from serious headroom limitations at low supply voltages.

CS Stage with Current Source Load

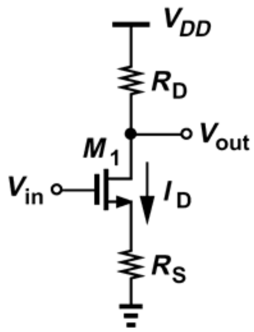


What happens to the gain as I_D decreases?

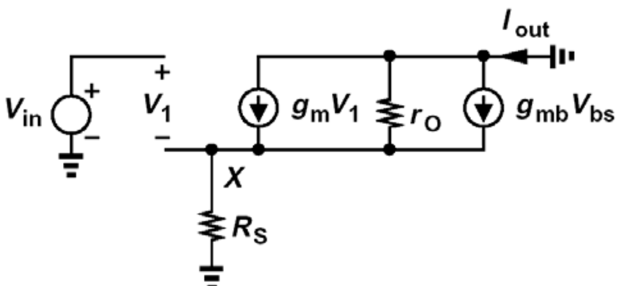
CS Stage with Active Load



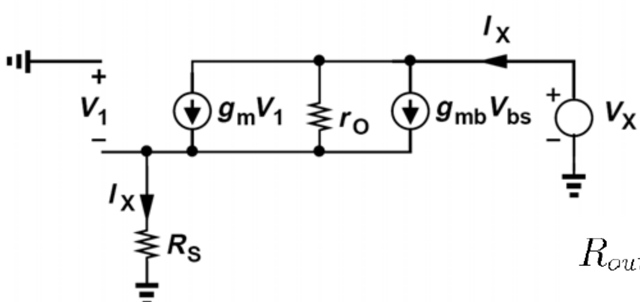
CS Stage with Source Degeneration



It is useful to find the Gm of the stage:

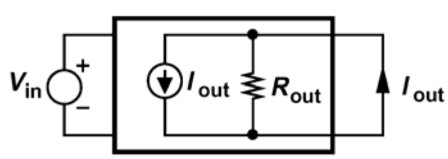


Also, the output impedance:



$$
\begin{aligned}
R_{out} &= [1 + (g_m + g_{mb})R_S]r_O + R_S \\
&= [1 + (g_m + g_{mb})r_O]R_S + r_O.
\end{aligned}
$$

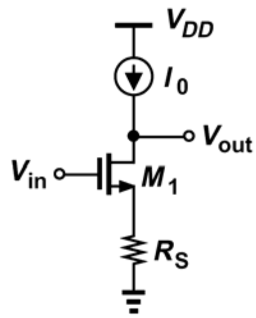
Now let's compute the gain by noting that:



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

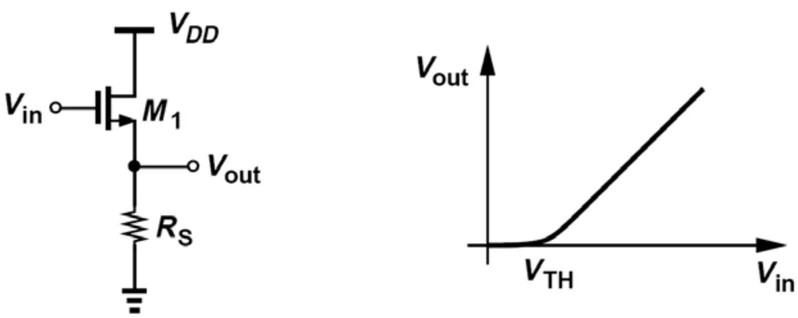
If λ=0 and g_{mb}=0, then:

Example



Source Followers

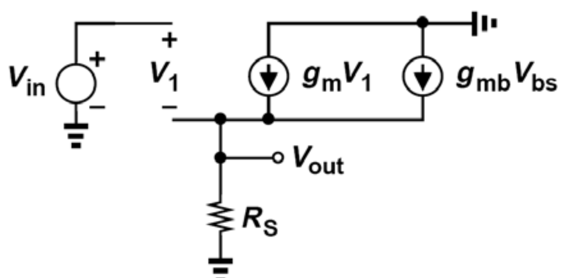
- Large-Signal Behavior



(a) (b)

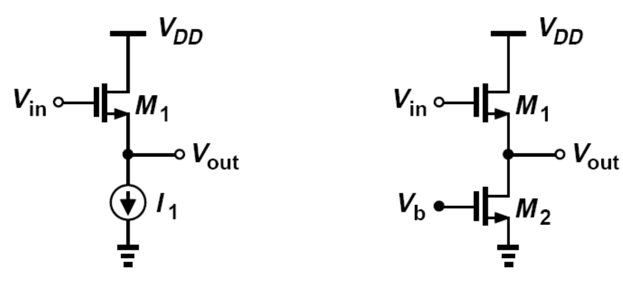
Sketch the gain vs. input.

- Small-Signal Behavior



$$A_v = \frac{g_m R_S}{1 + (g_m + g_{mb}) R_S}$$

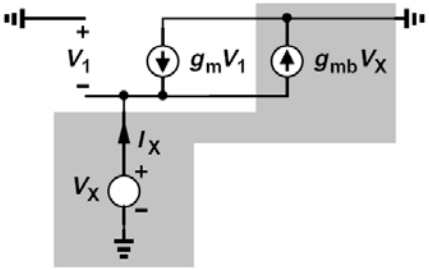
- **Often use a current source in place R_S to have a better definition of the bias current.**



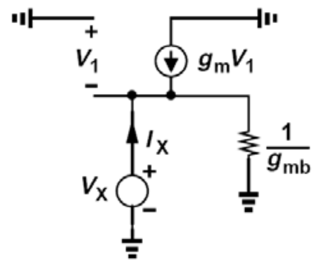
(a) (b)

How good a buffer is a source follower? Input impedance =

Output Impedance:

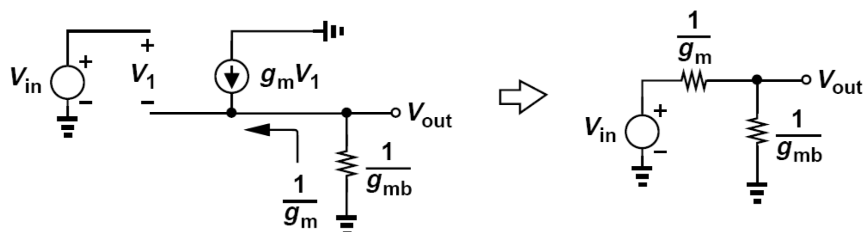


(a)

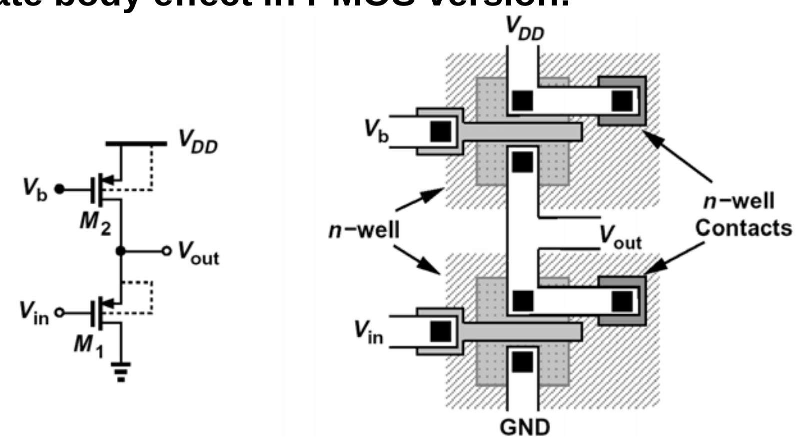


(b)

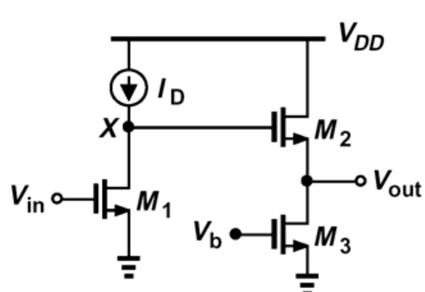
Another method of finding the gain:



- **Can eliminate body effect in PMOS version:**

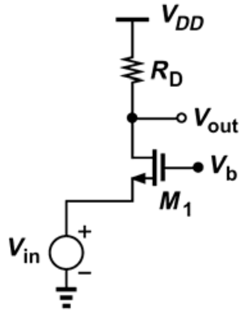


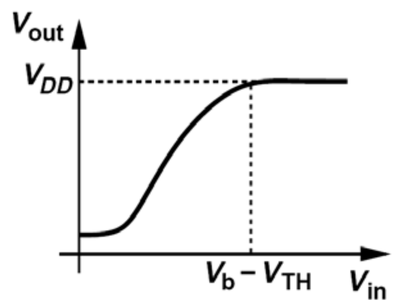
- **Source followers are used only occasionally. They introduce noise and consume voltage headroom. For example:**



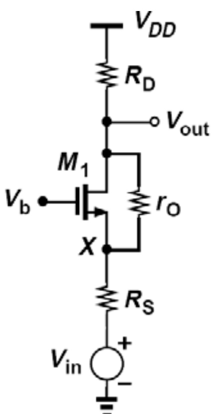
Common-Gate Stage

- Large-Signal Behavior

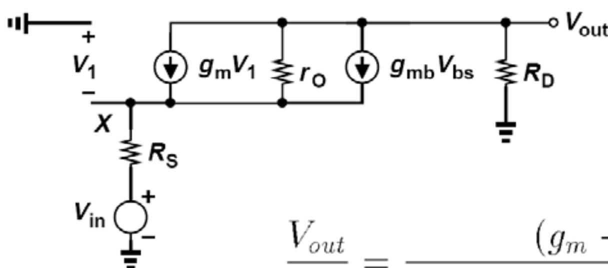




- Small-Signal Behavior



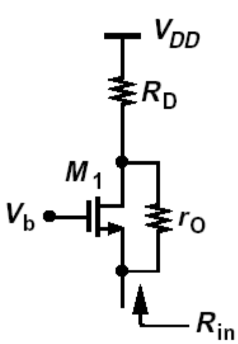
(a)

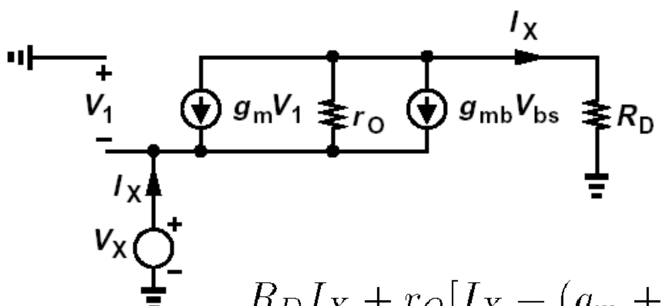


(b)

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

- **Input Impedance**



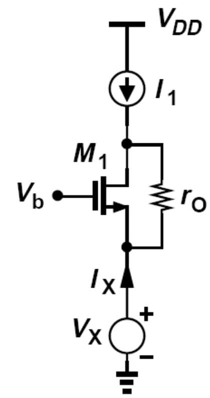


$$R_D I_X + r_O[I_X - (g_m + g_{mb})V_X] = V_X.$$

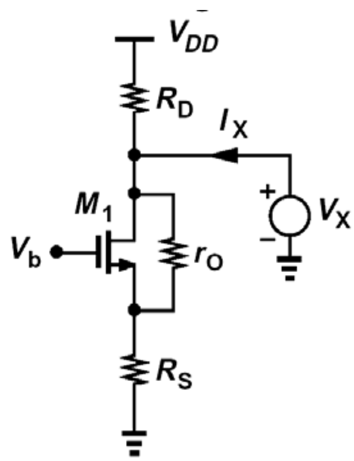
$$\frac{V_X}{I_X} = \frac{R_D + r_O}{1 + (g_m + g_{mb})r_O}$$

$$\approx \frac{R_D}{(g_m + g_{mb})r_O} + \frac{1}{g_m + g_{mb}}$$

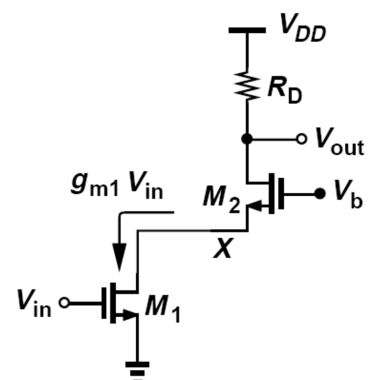
Example



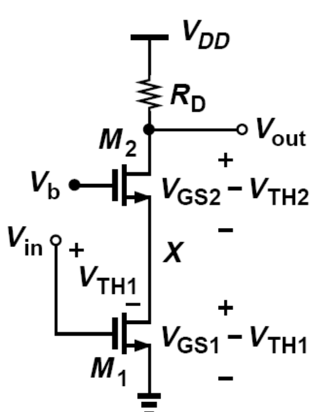
- **Output Impedance**

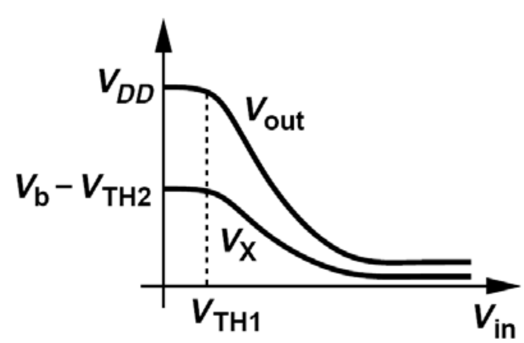


Cascode Stage



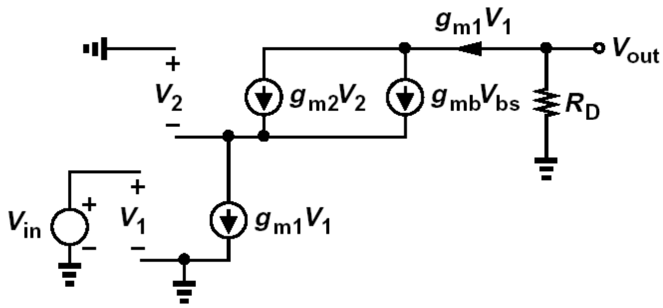
How do we choose the bias conditions?



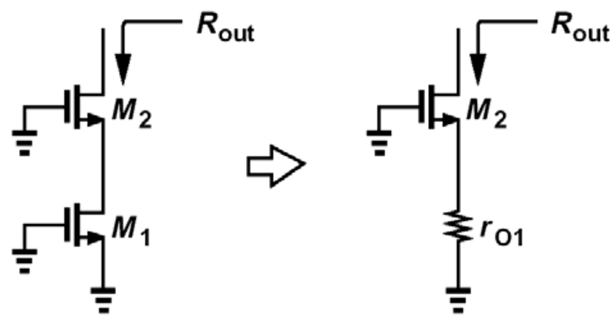


What is the maximum output voltage swing?

Gain Calculation:

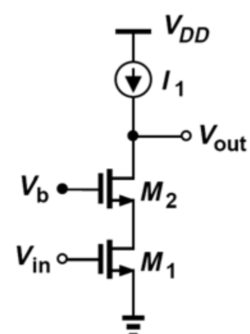


Output Impedance:

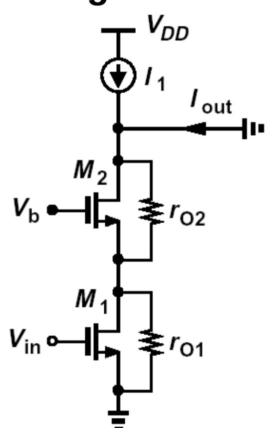


Cascode Stage with Current Source Load

Bias currents and voltages are chosen such that all MOSFETs are in saturation.



Voltage Gain:



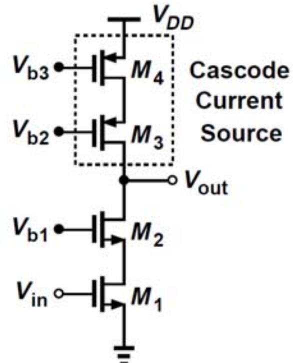
$$I_{out} = g_{m1} V_{in} \frac{r_{O1}}{r_{O1} + \dfrac{1}{g_{m2} + g_{mb2}} || r_{O2}}$$

$$G_m = \frac{g_{m1} r_{O1} [r_{O2}(g_{m2} + g_{mb2}) + 1]}{r_{O1} r_{O2}(g_{m2} + g_{mb2}) + r_{O1} + r_{O2}}$$

$$\begin{aligned} |A_v| &= G_m R_{out} \\ &= g_{m1} r_{O1} [(g_{m2} + g_{mb2}) r_{O2} + 1] \end{aligned}$$

How do we maximize the voltage gain?

Actual realization:



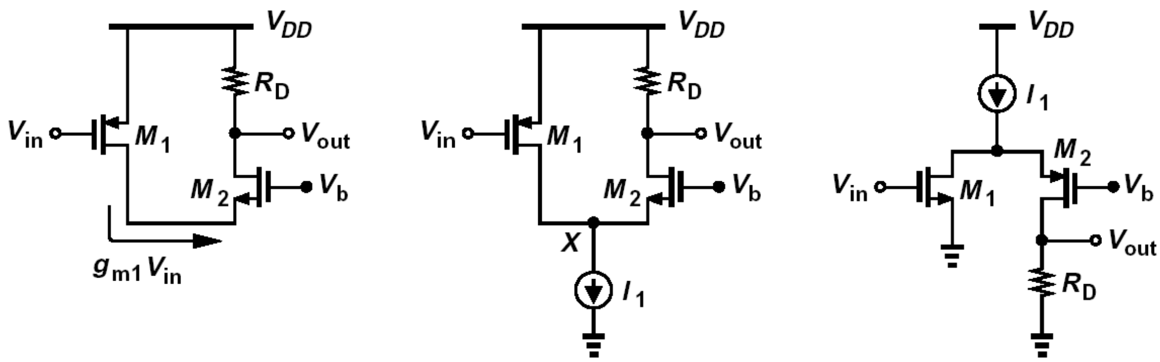
Gain calculation:

$$R_{out} = \{[1 + (g_{m2} + g_{mb2})r_{O2}]r_{O1} + r_{O2}\}||\{[1 + (g_{m3} + g_{mb3})r_{O3}]r_{O4} + r_{O3}\}$$

$$A_v \approx g_{m1}[(g_{m2}r_{O2}r_{O1})||)g_{m3}r_{O3}r_{O4})]$$

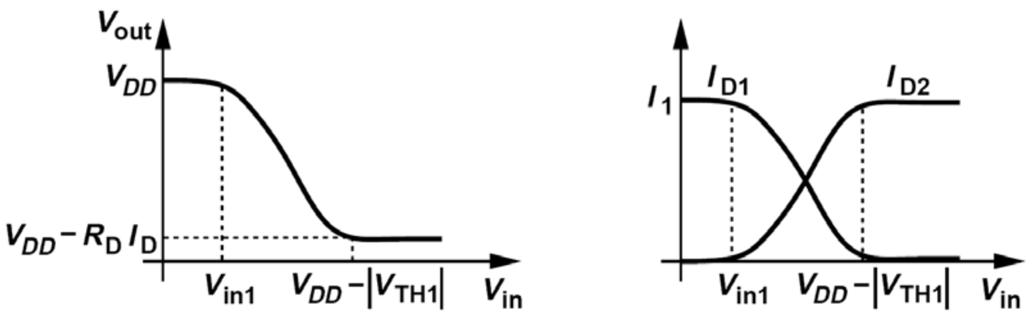
<u>Folded Cascode</u>

The input and cascode devices need not be of the same type.



(a) (b) (c)

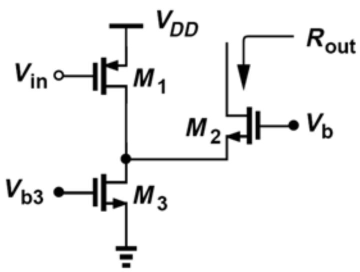
- Large-Signal Behavior
Let the input decrease from V_{DD} to zero.



$$V_{in1} = V_{DD} - \sqrt{\frac{2I_1}{\mu_p C_{ox}(W/L)_2}} - |V_{TH1}|$$

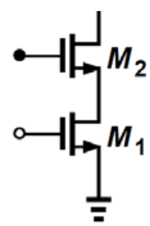
- Small-Signal Behavior
Similar to that of simple cascode.

<u>Example</u>

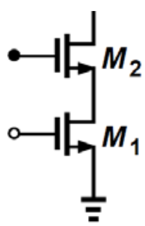


<u>Other Applications of Cascodes</u>

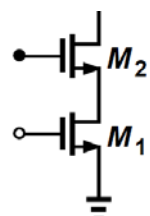
1. Reduction of Miller Effect



2. Shielding



3. Stability



4. Reduction of Device Stress