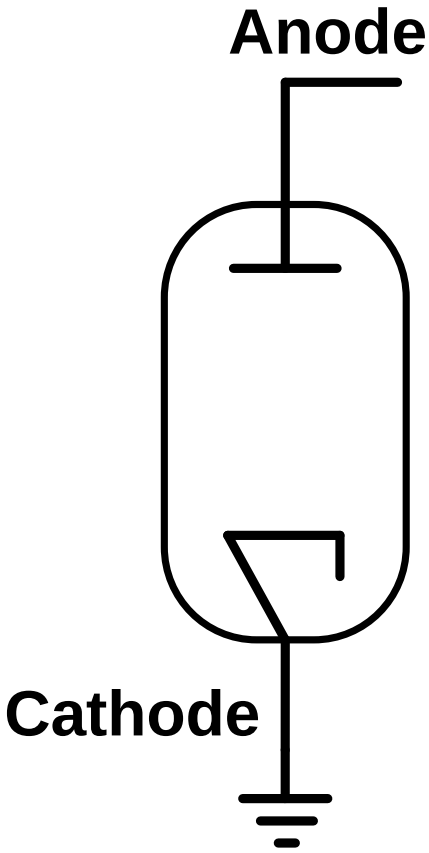
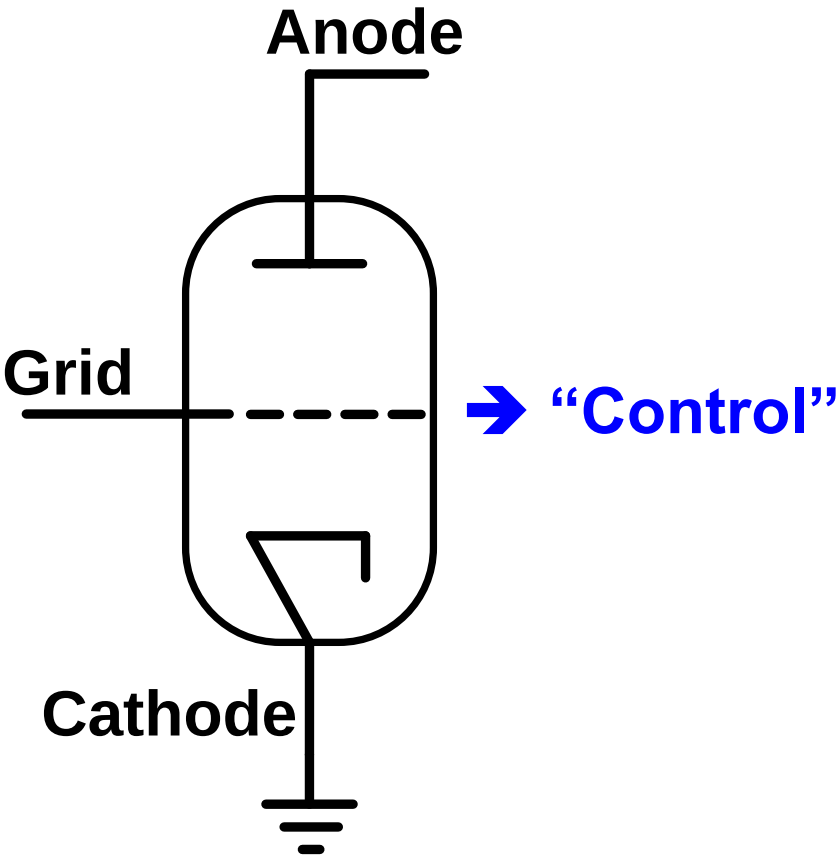
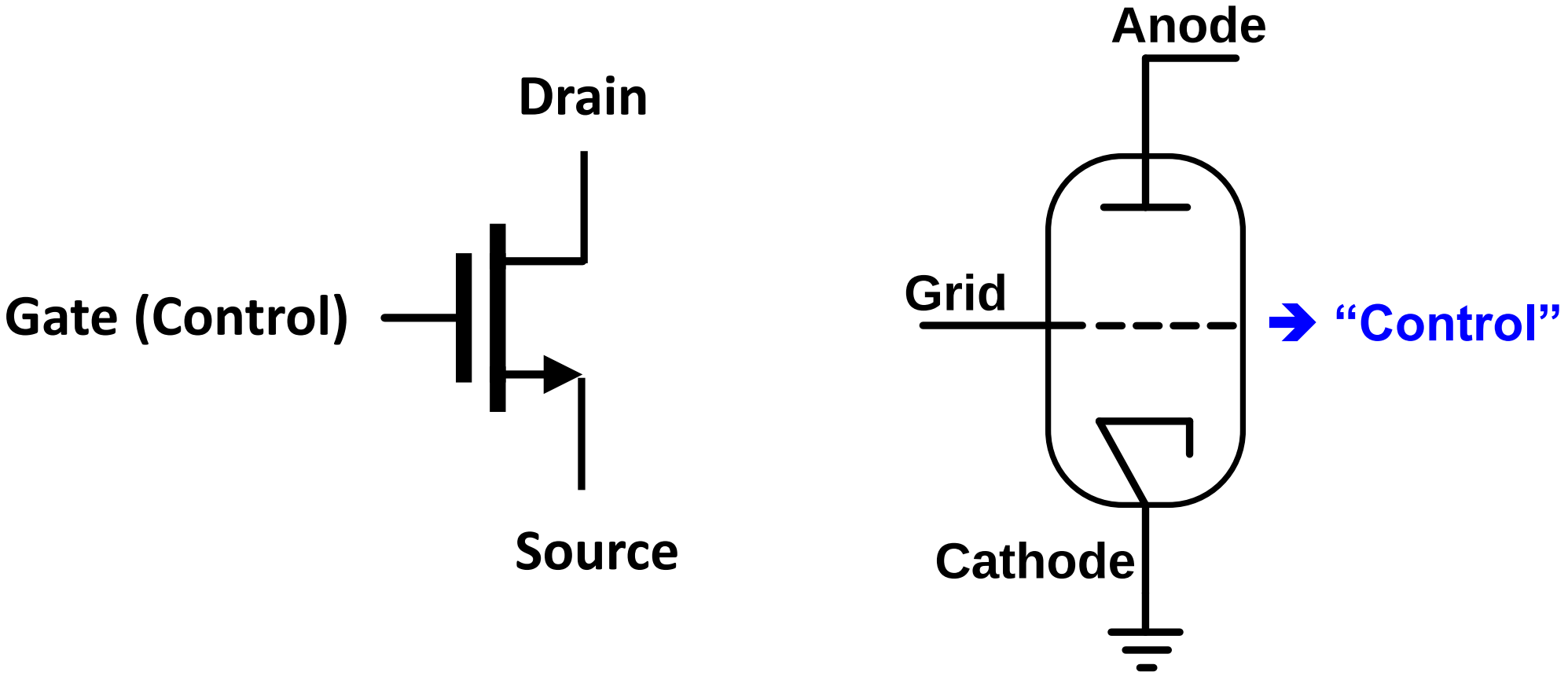
Vacuum Tube

- Diode vs. Triode





MOSFET as a Triode Device



Cascode Stage

Hanwool Jeong

hwjeong@kw.ac.kr

Generating Voltage or Current

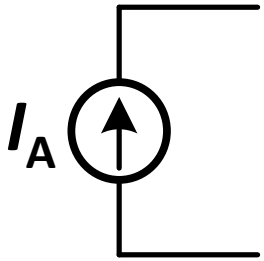
- Consider the voltage/current source in the circuit as follows



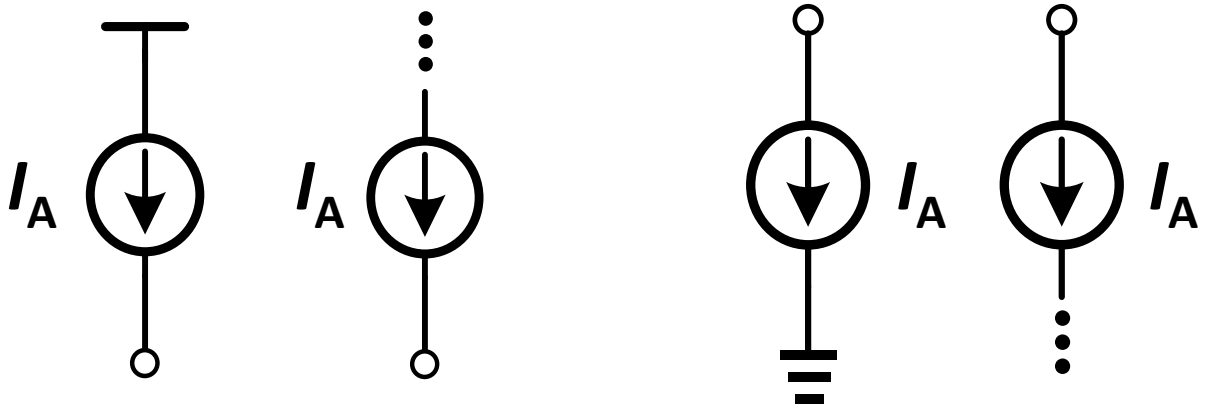
- Now, you must be able to consider the existences of nonidealities of the above sources.
- In terms of WHAT?
- In fact, none of the circuit component is ideal and they are under the condition of power game.

Current Source?

- You may come up with



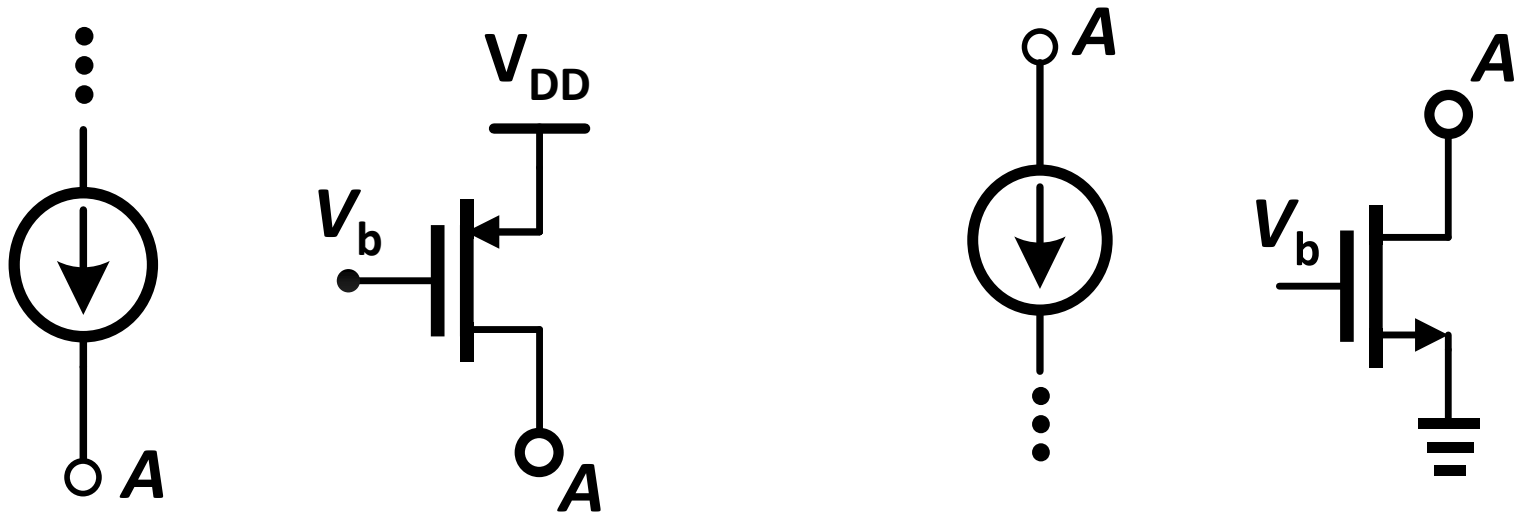
- But there are one-ended structures as



- Non-ideality?

What is a Good Current Source?

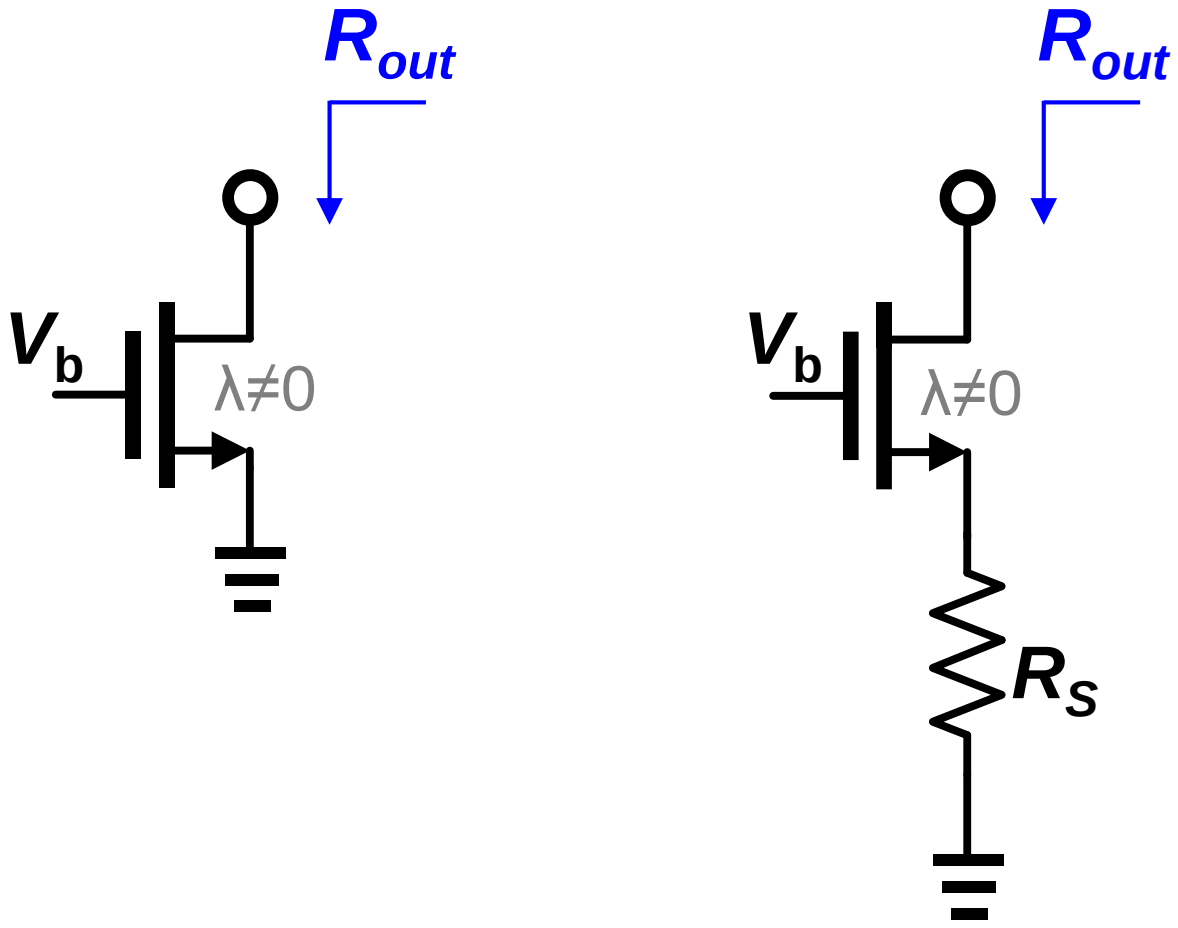
- Suppose that supply voltage level can be provided. How is it really implemented?
- Can you say it in the respect of R_{out}? Why does R_{out} matter?



- How can we make R_{out} larger?

Revisit Source Degeneration

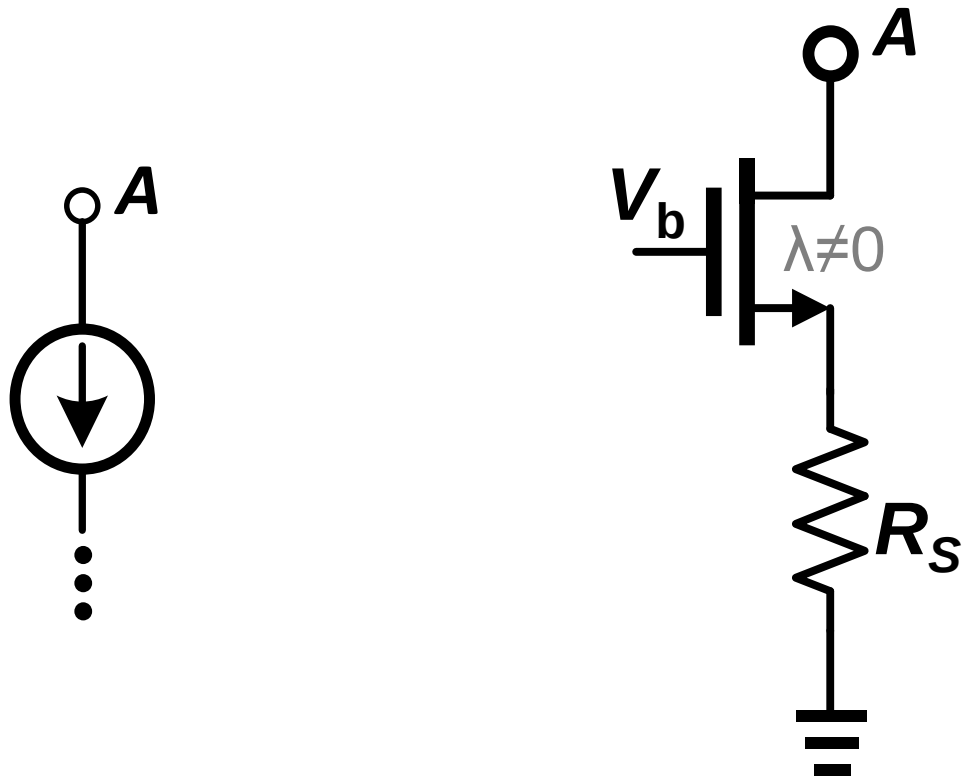
- You remember?



How Can We Make R_{out} Larger?

- Yes! We can utilize the source degeneration

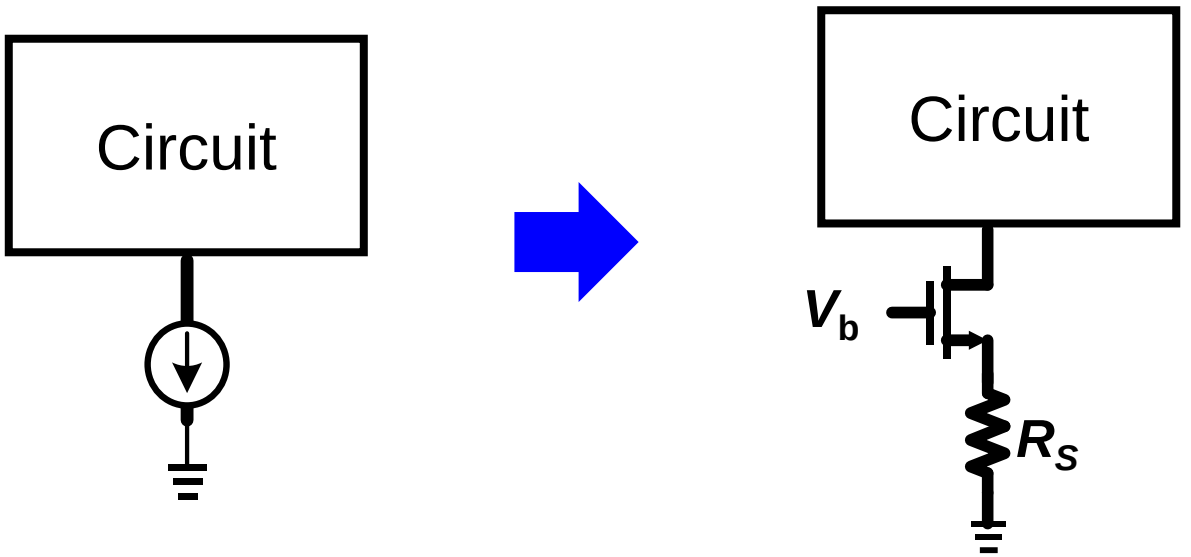
$$R_{out} = (1+g_m r_O)R_S + r_O$$



Limitation of Source Degeneration

- Suppose that
  - We want to use the current source to bias a circuit to known current.
  - And V_{DD} is limited value, like 1.8V or 3.3V
- To keep the current constant for large range. How R_S should be?
- Larger R_s means larger voltage drop in the current source

➔ Trade-off between voltage headroom & R_{out}



Is there Any Better Way?

- We want
  - Larger Rout
  - Smaller IR drop
  - With the same I_{source}
- Is it possible?

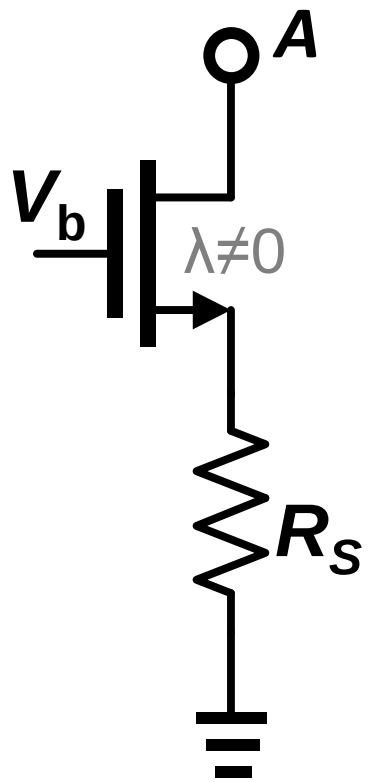
➔Maybe. This is because

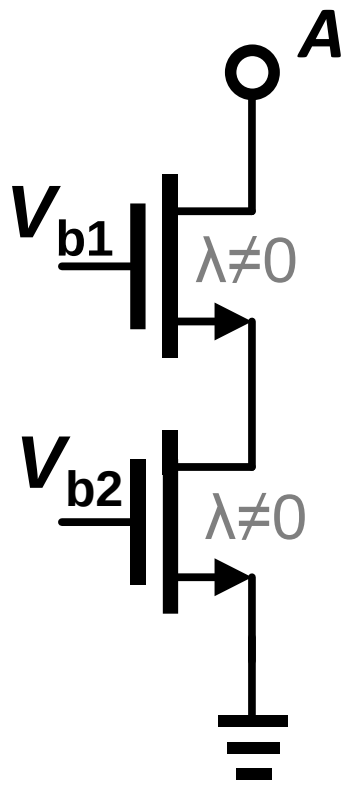
  - IR drop can be obtained in large signal
  - while Small R_{out} is to be obtained small signal

We Need a Component Such That

- Large R in small signal
- Small R in large signal

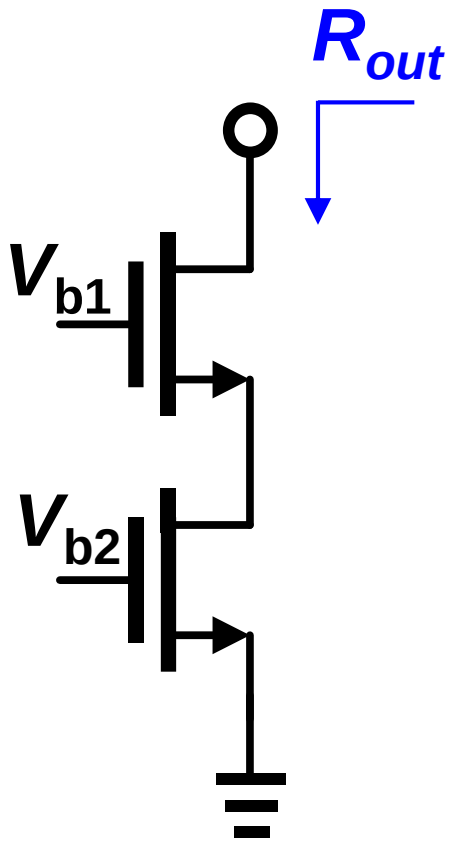
Better Implementation of Current Source





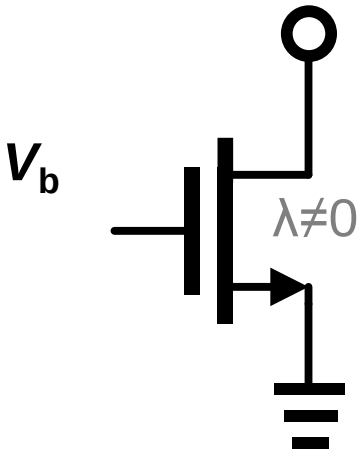
Can You Derive R_{out}?

$$R_{out} = (1 + g_{m1}r_{O2})r_{O1} + r_{O2}$$
$$\approx g_{m1}r_{O1}r_{O2},$$

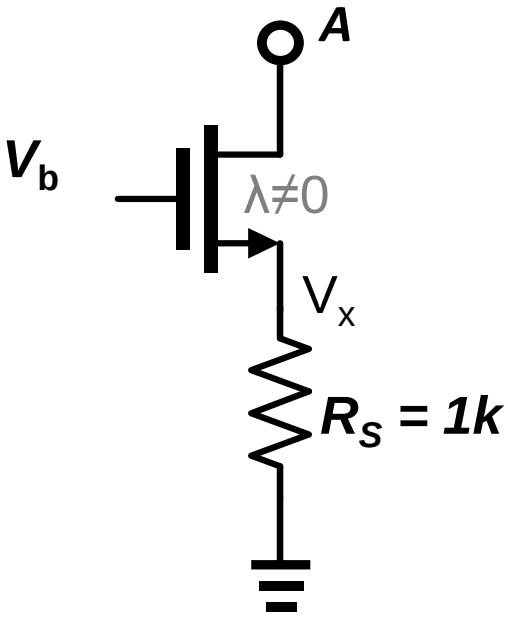


What Really Happens

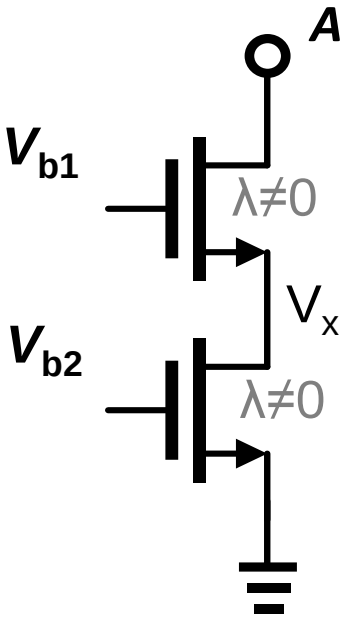
- Assume:
  - To achieve 1mA, $(V_{GS}-V_{TH}) = 0.6V$ while $V_{TH} = 0.4V$.
  - $r_O = 50k$.



$R_{out} = r_O$



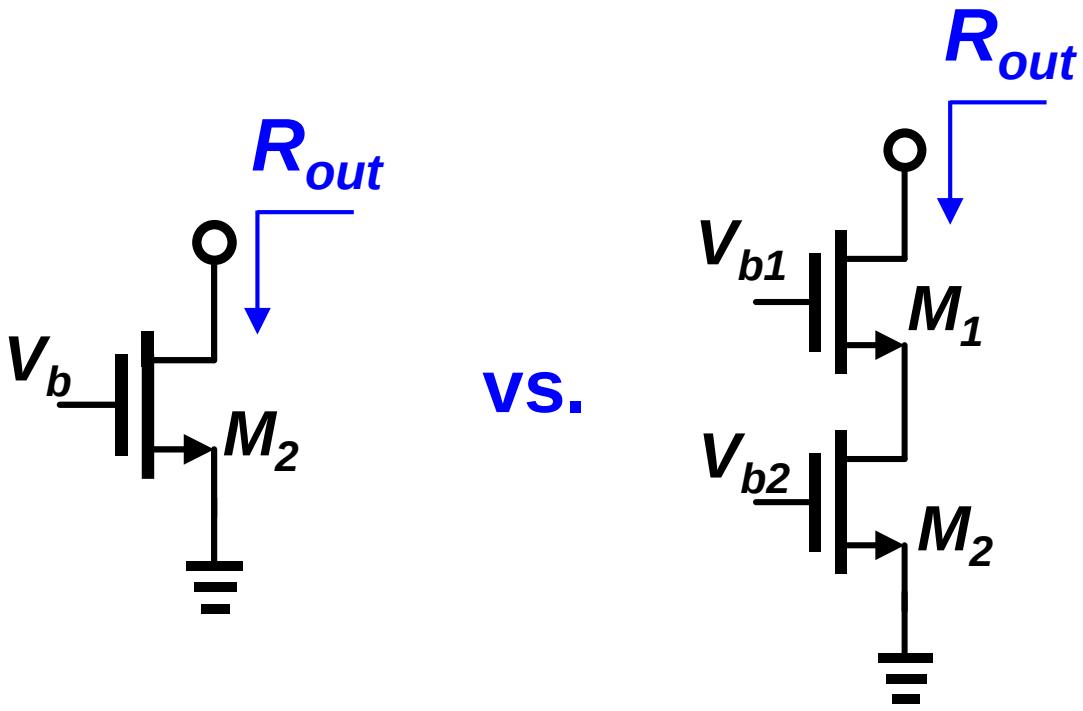
$R_{out} = R_S+(1+g_mR_S)r_O$



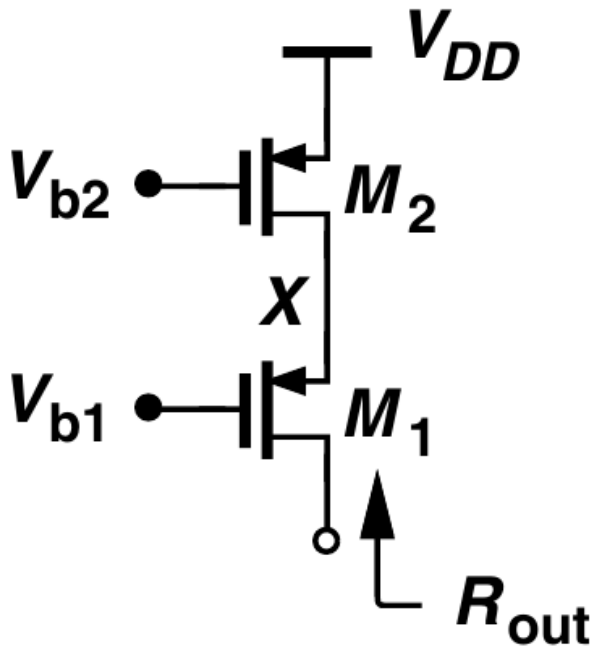
$R_{out} = r_{O2} + (1+g_{m1}r_{O2})r_{O1}$

We Can Say It Has a Boosting Effect

- Stack boosts the resistance!

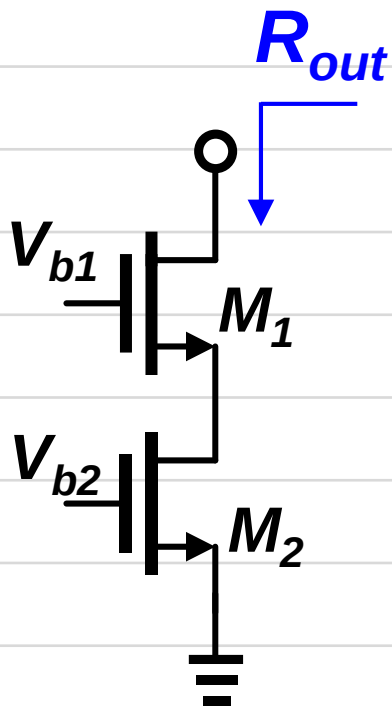


PMOS Cascode Current Source?



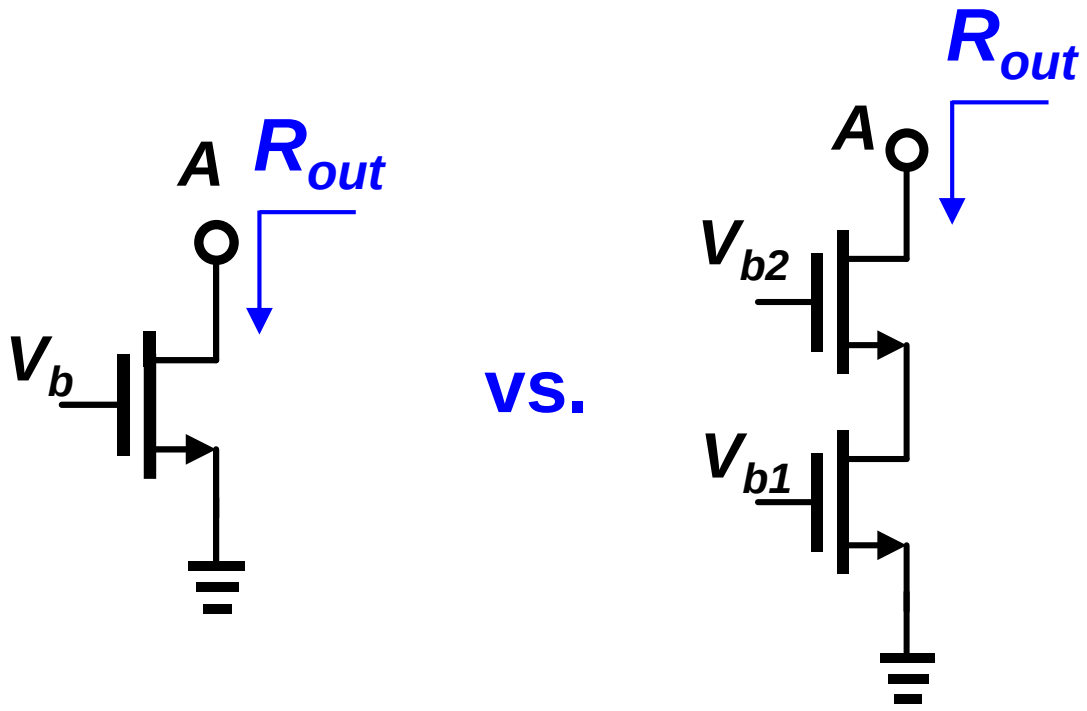
Example 9.5

Design an NMOS cascode for an output impedance of 500 kΩ and a current of 0.5 mA. For simplicity, assume M_1 and M_2 in Fig. 9.8 are identical (they need not be). Assume $\mu_n C_{ox} = 100\,\mu\text{A/V}^2$ and $\lambda = 0.1\,\text{V}^{-1}$.



Large Signal View

- What if V_A changes? How is the current in the path determined?



Example 9.6

During manufacturing, a large parasitic resistor, R_P, has appeared in a cascode as shown in Fig. 9.11. Determine the output resistance.

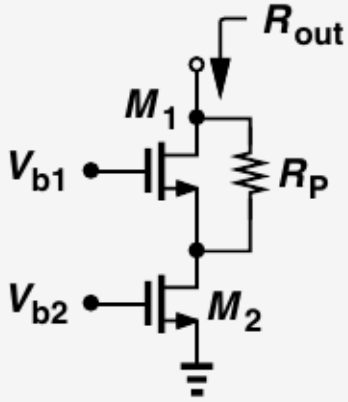
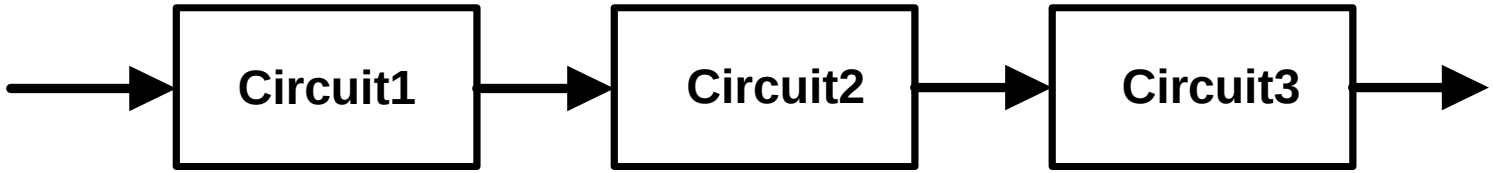


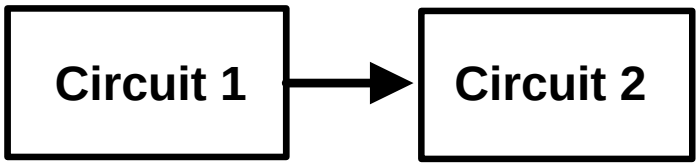
Figure 9.11

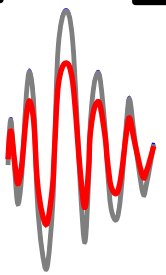
Large R_{out} in Amplifier?

- Was it good or bad? Can you explain the reason?
- How is the voltage transfer ratio determined?



- Effect of the following stage





Why?

Can you explain it in terms of R_{in2} & R_{out1}?

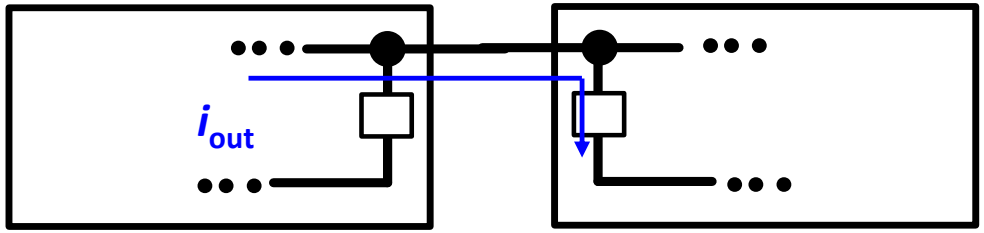
➔ Then, can we conclude larger R_{out} is bad?

Can We Deliver Current as An Output?

- Sure. Why not? But you should rethink of connection shape!
- Generally, the circuit is connected as follows.



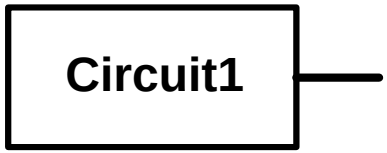
- You can consider the inside circuit as follows when the current is transferred.



- Can you relate it with Norton equivalent circuit?

R_{out} Meaning in Current Output

- R_{out} means how the circuit is willing to transfer the current to the next stage.

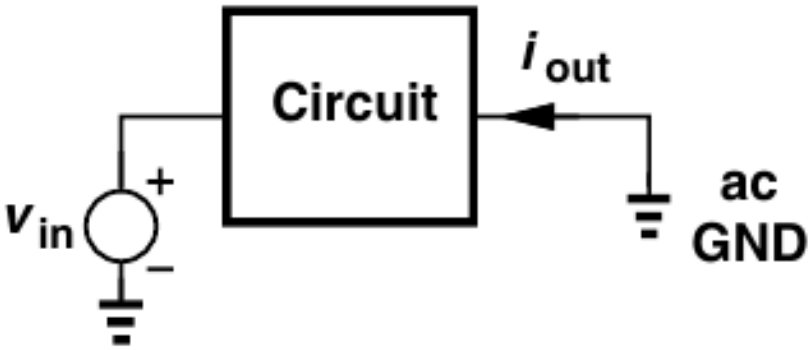


- Thus, larger R_{out} is desirable in this case.

Voltage Input ➔ Current Output

- When the input is voltage and the output is voltage in a circuit, I_{out}/V_{in} does matter (instead of V_{out}/V_{in})
- We called it the transconductance of a circuit

$$G_m = \left.\frac{i_{out}}{v_{in}}\right|_{vout=0}$$



- i_{out} measured in the above case only can be obtained AC ground is connected. How about general following circuit?
- You can state a desirable condition of R_{in} in this case.

Example 9.7

Calculate the transconductance of the CS stage shown in Fig. 9.13(a).

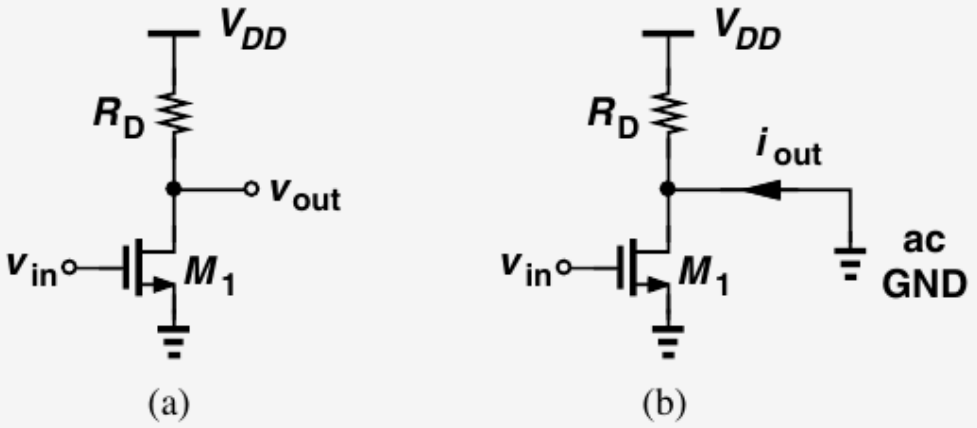
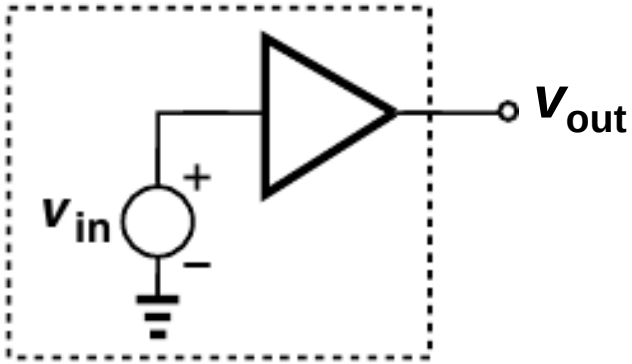
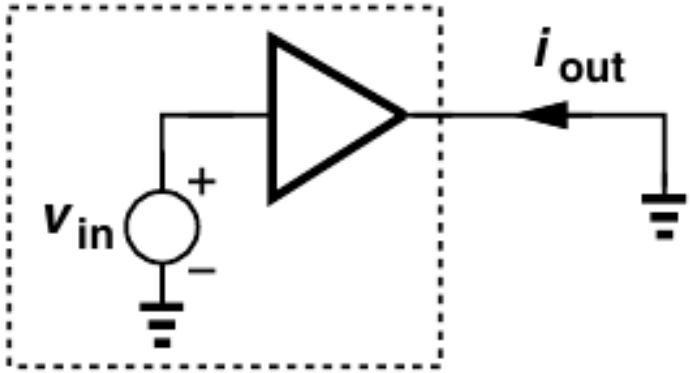


Figure 9.13

Relation of A_v & G_m

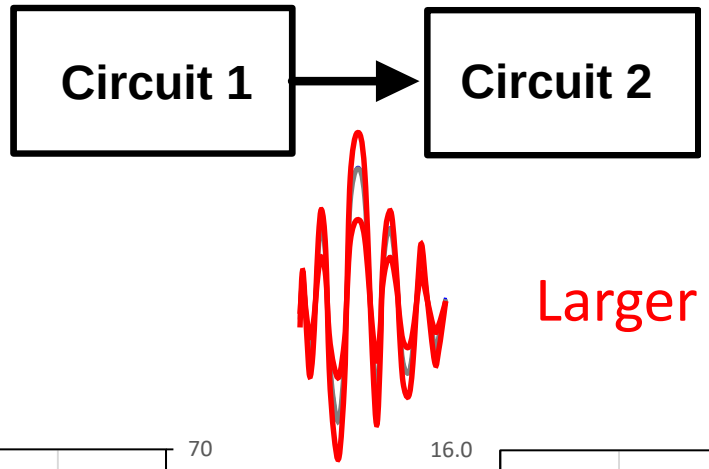




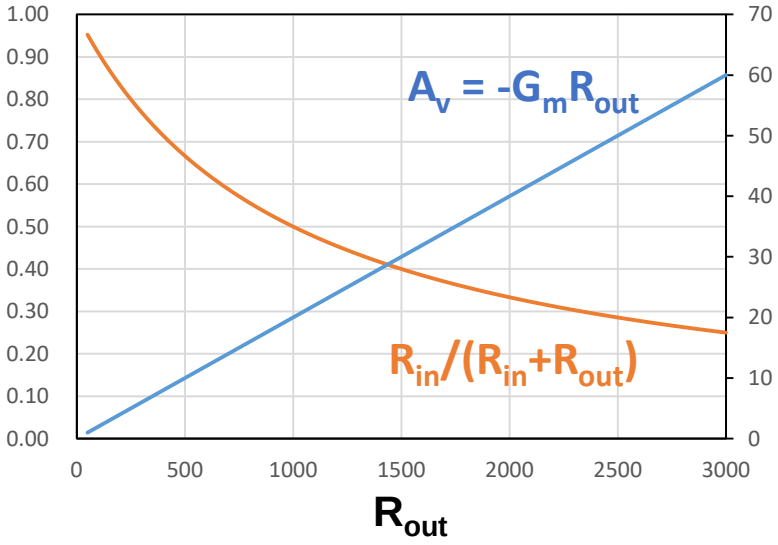
$$\frac{v_{out}}{v_{in}} = -G_m R_{out}$$

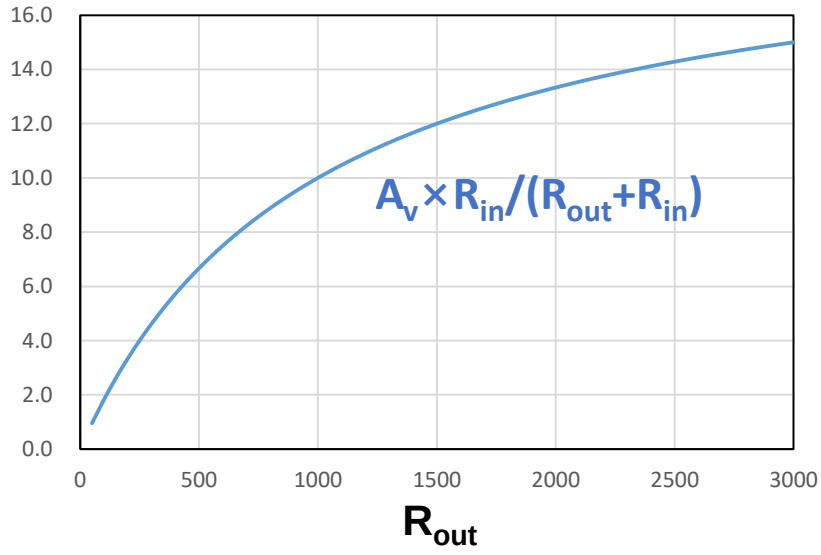
Revisit Cascading Stage

- When G_m is constant, $R_{out} \uparrow \rightarrow A_V$



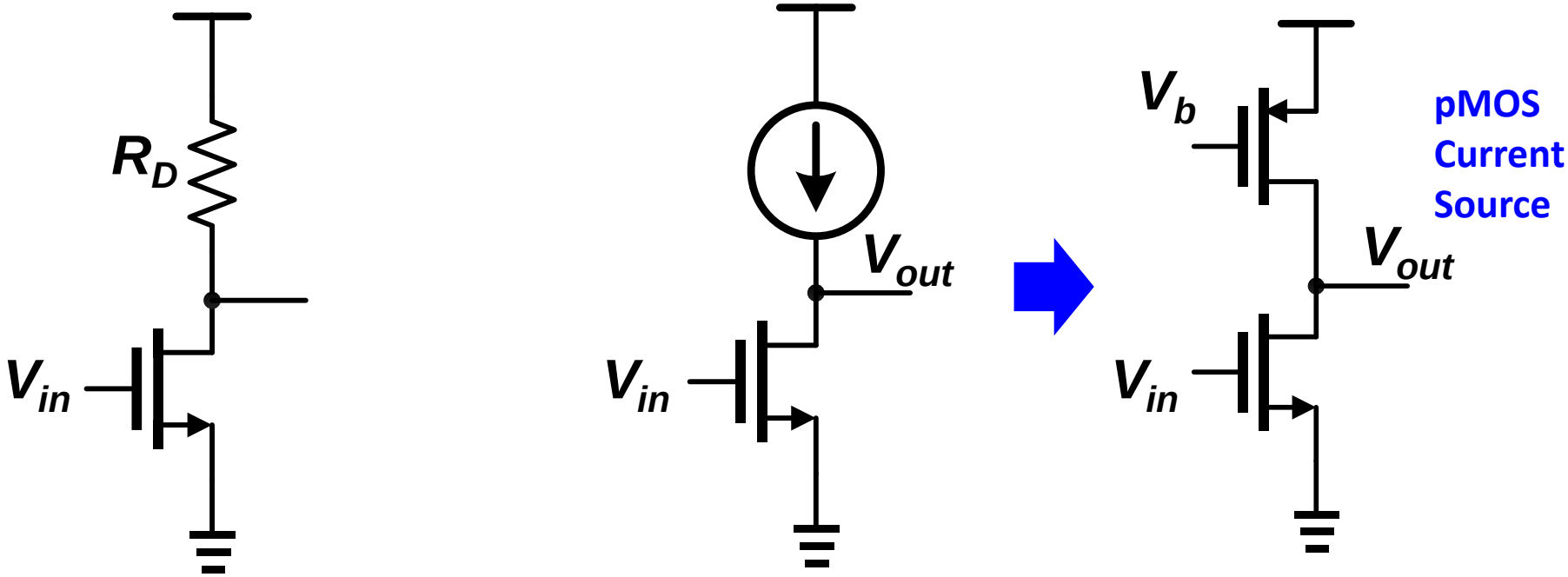
Larger R_{out}





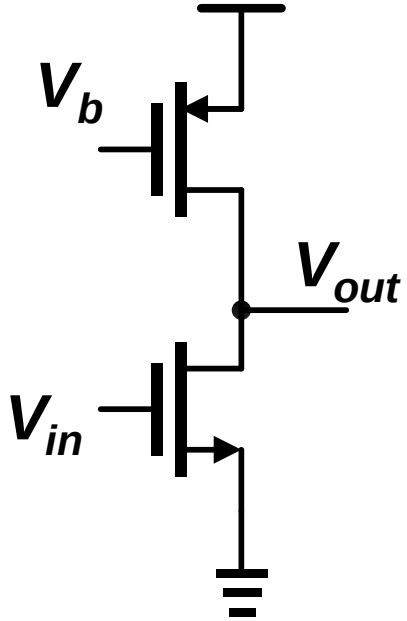
How Can You Maximize R_{out} in CS?

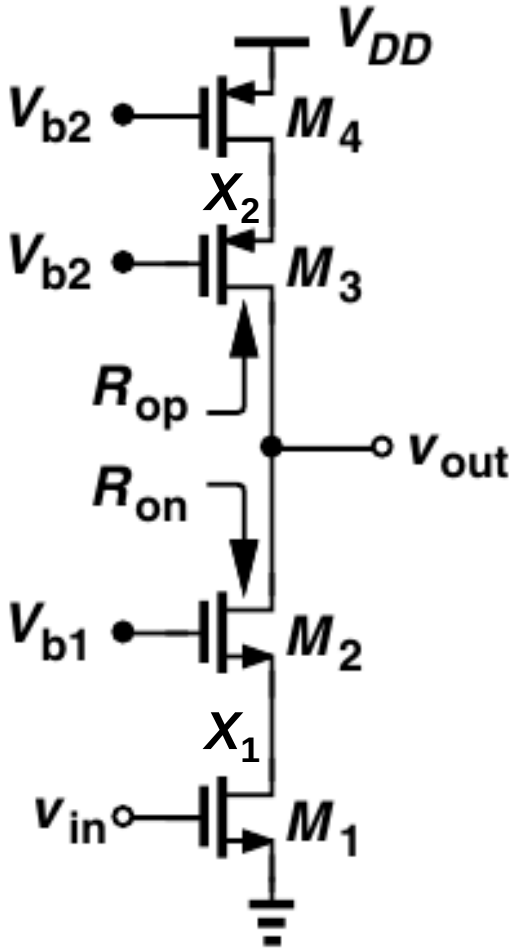
- You remember?
- Can you comment on the voltage headroom respect as well?



Can You Further Improve?

- In terms of
  - R_{out}
  - Voltage head room





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

Example 9.11

The cascode amplifier of Fig. 9.20(b) incorporates the following device parameters: $(W/L)_{1,2} = 30$, $(W/L)_{3,4} = 40$, $I_{D1} = \cdots = I_{D4} = 0.5$ mA. If $\mu_n C_{ox} = 100\,\mu\text{A/V}^2$, $\mu_p C_{ox} = 50\,\mu\text{A/V}^2$, $\lambda_n = 0.1\,\text{V}^{-1}$ and $\lambda_p = 0.15\,\text{V}^{-1}$, determine the voltage gain.

