Lecture21:
CMOS amplifiers (5)

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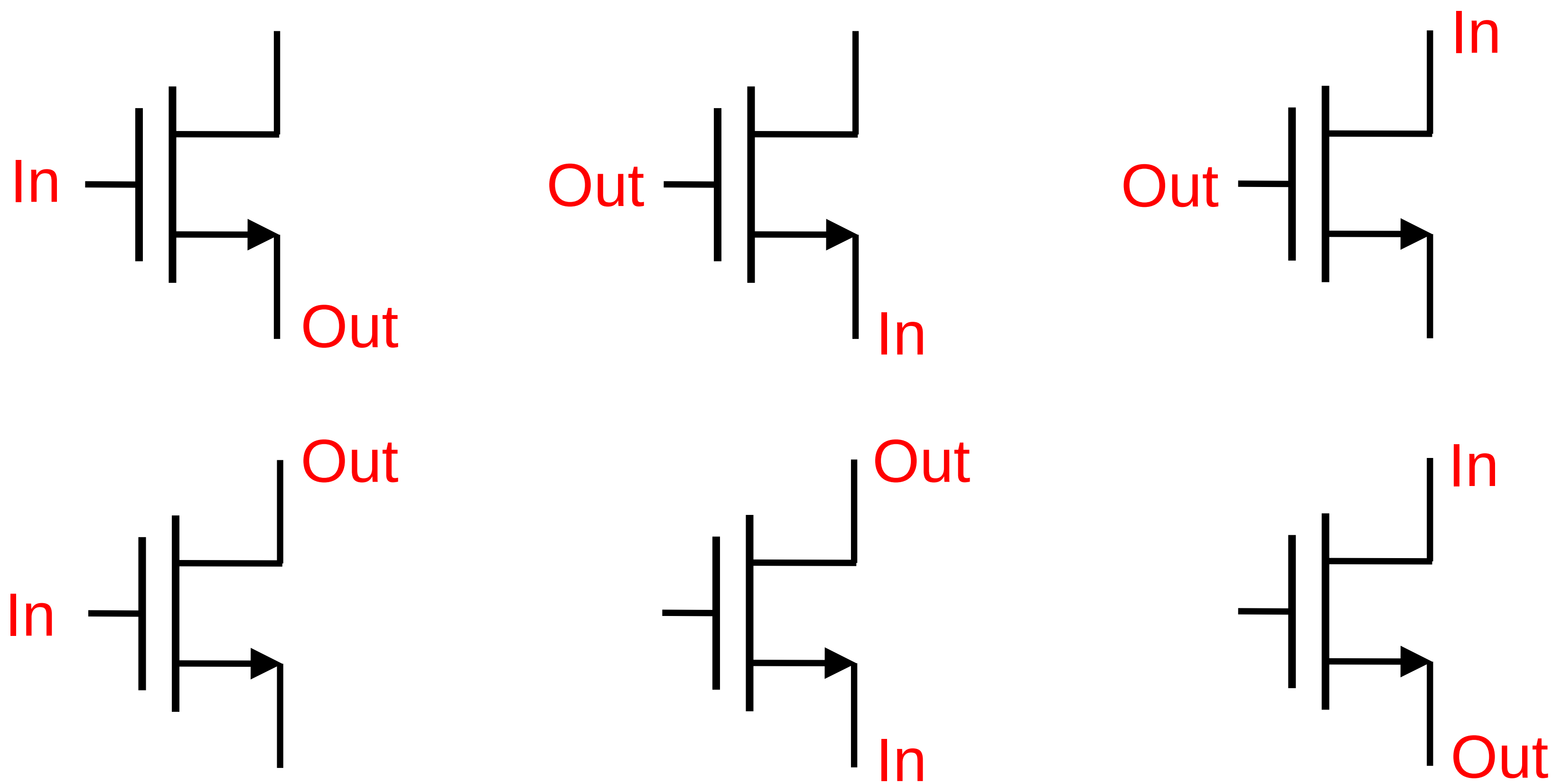
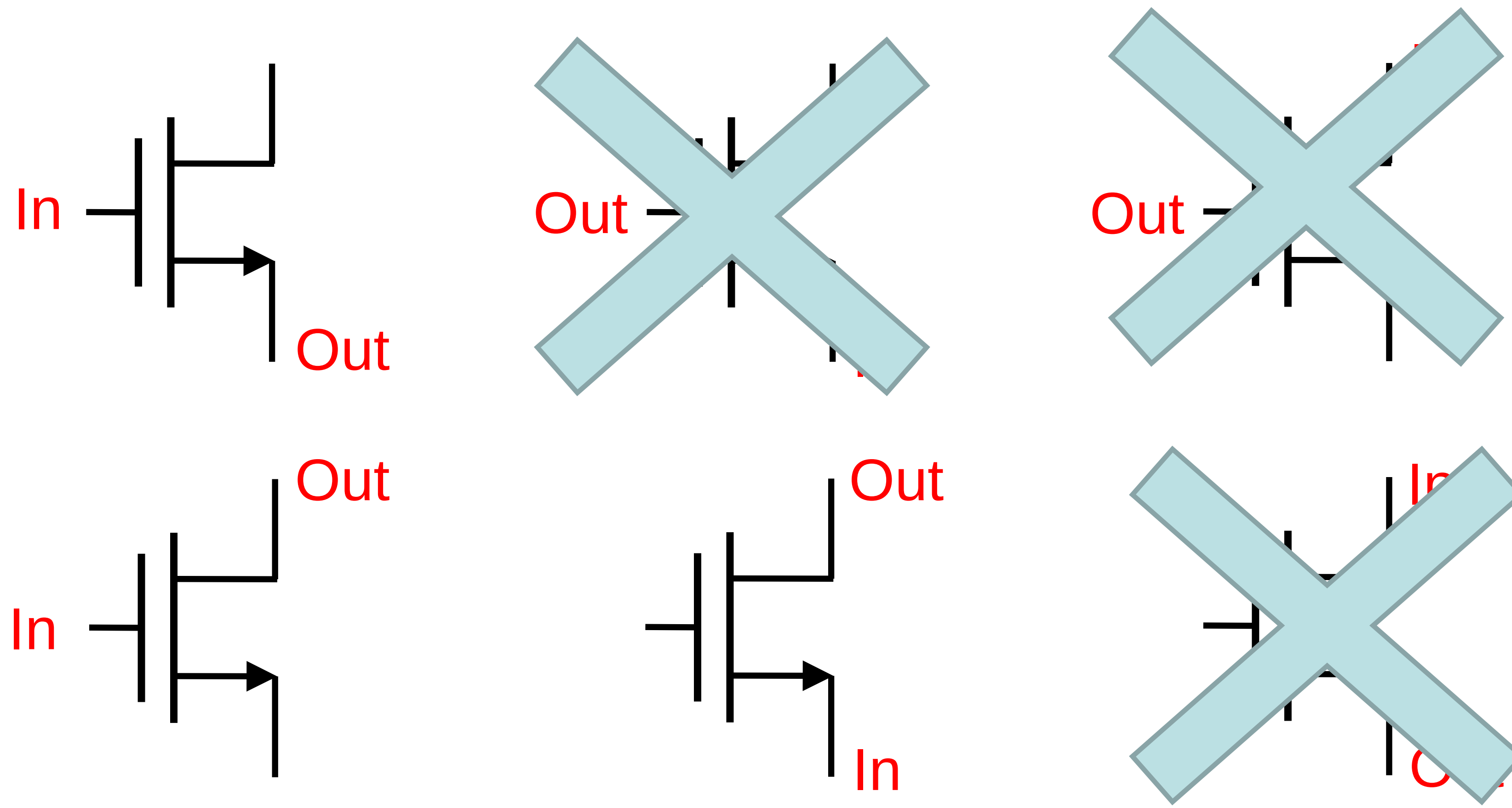
CMOS amplifiers (1/2)

- Select one input. Then, select one output.
  - What are possible topologies?



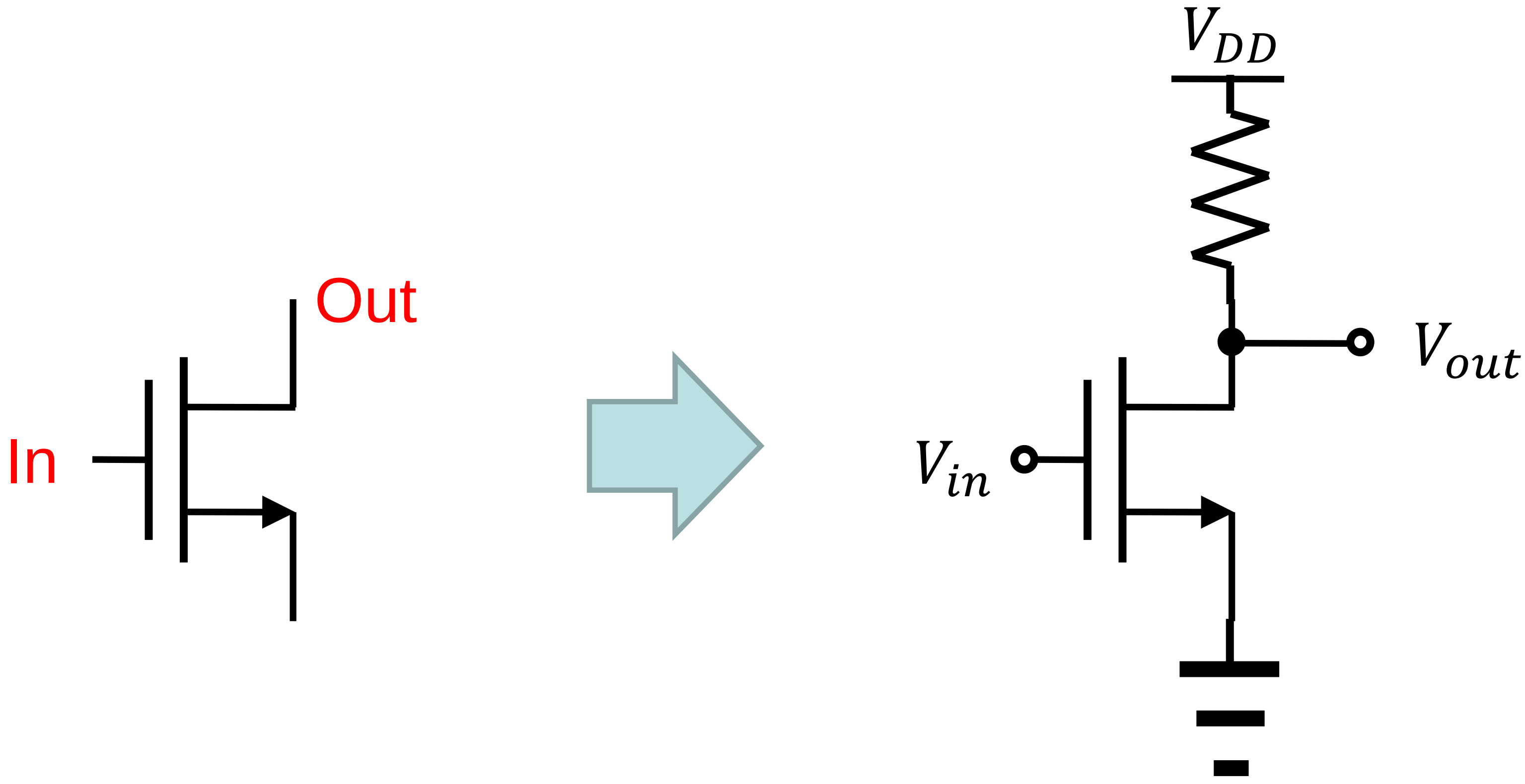
CMOS amplifiers (2/2)

- Only three are possible.
  - Each of them has own name.



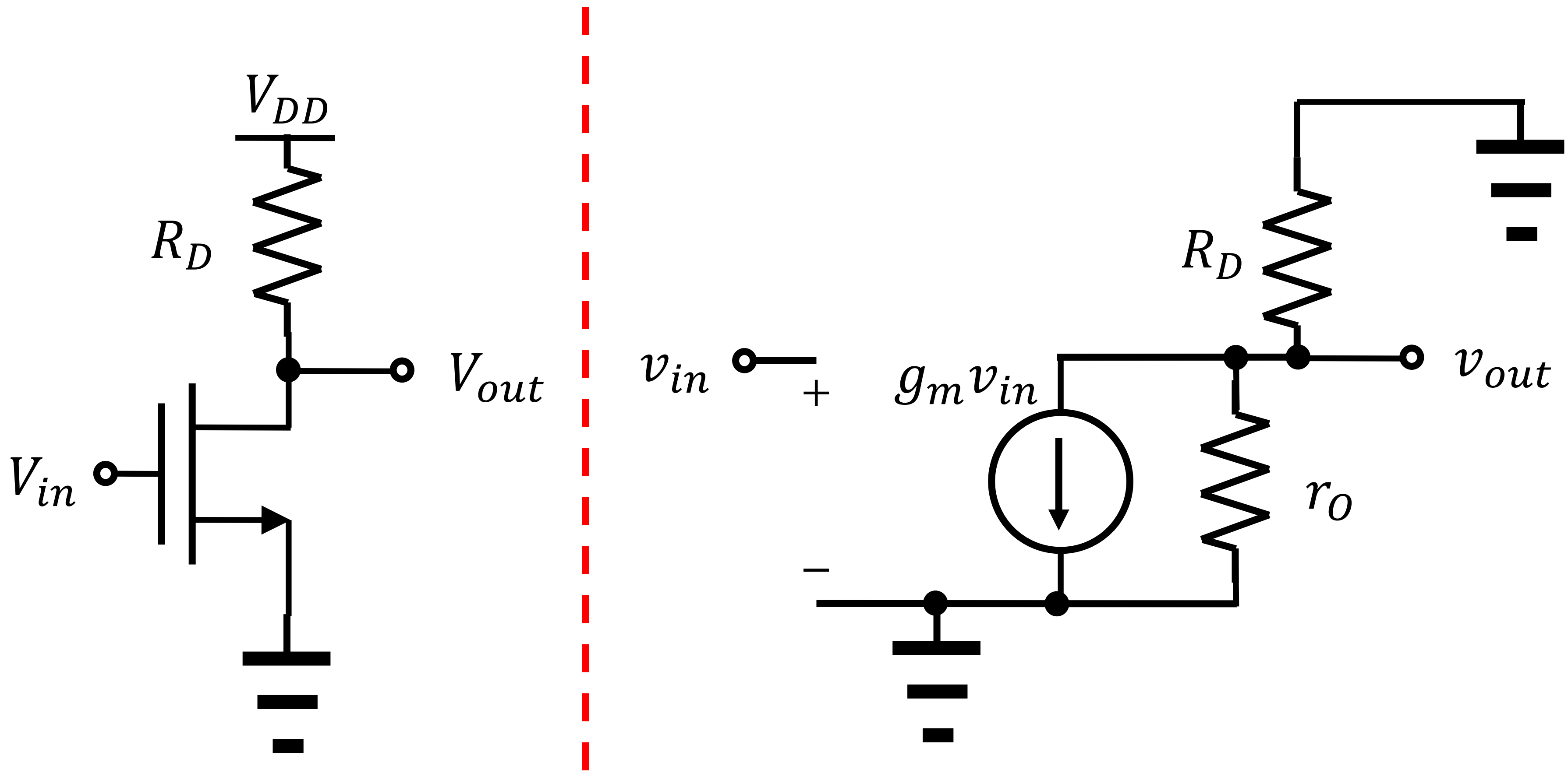
Common-source

- Source terminal is grounded.



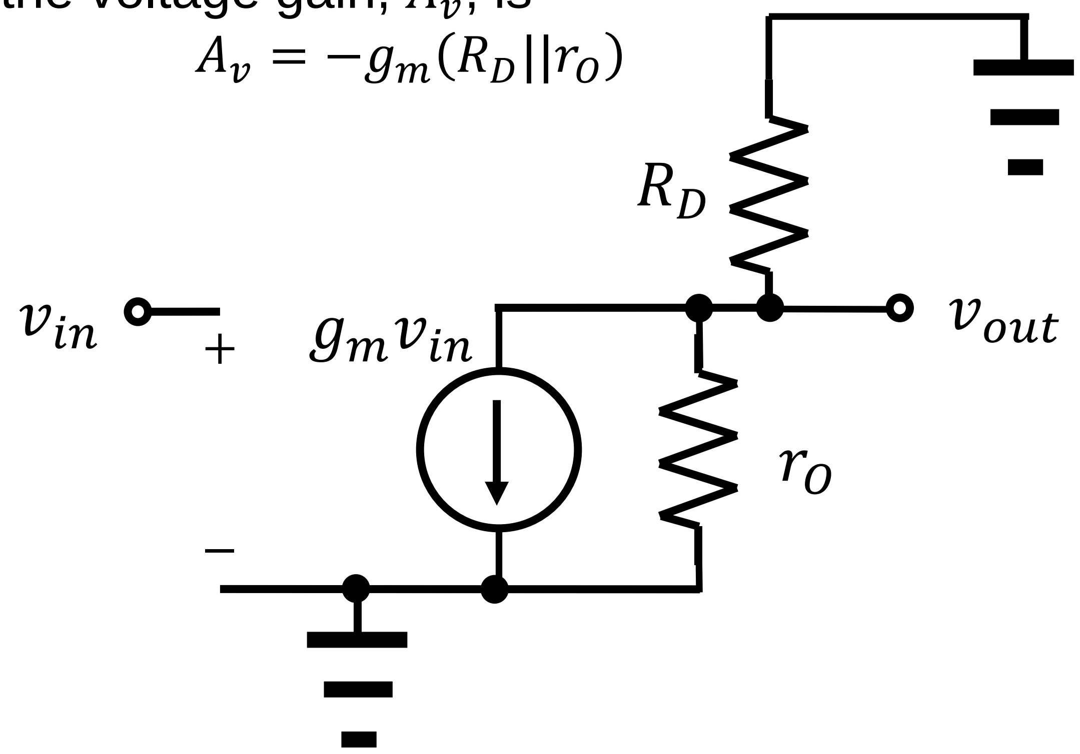
Small-signal model

- Let's draw the small-signal model together!



Gain

- Now, calculate the v_{out}.
  - KCL for the v_{out} node gives
$$v_{out} = -g_m(R_D||r_O)v_{in}$$
  - Therefore, the voltage gain, A_v, is
$$A_v = -g_m(R_D||r_O)$$



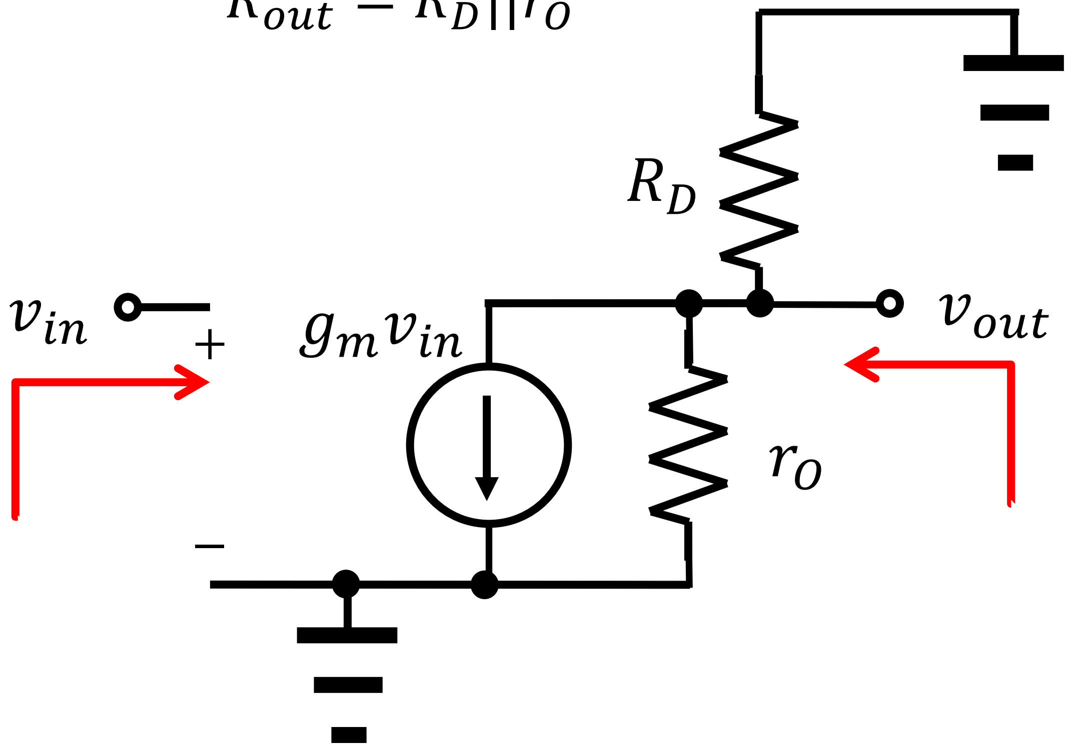
Input/output impedances

- Input impedance

$$R_{in} = \infty$$

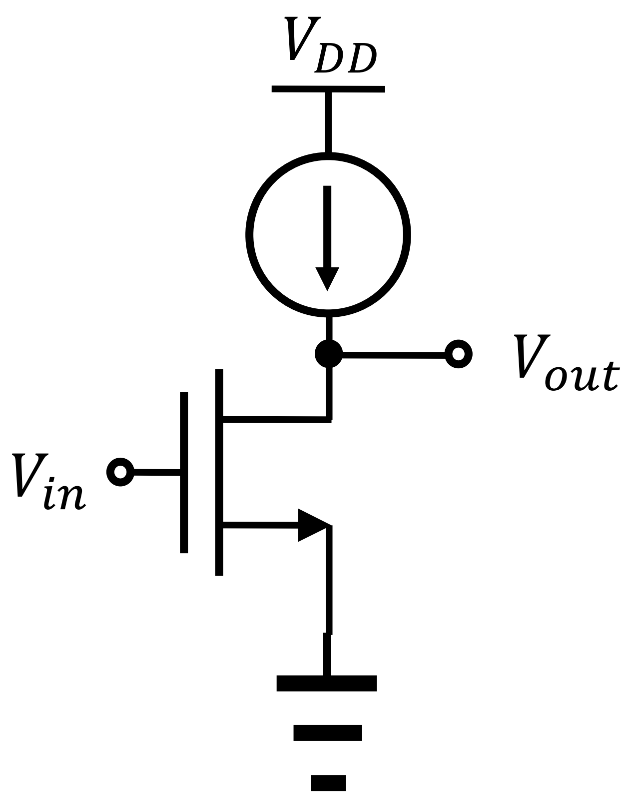
- Output impedance

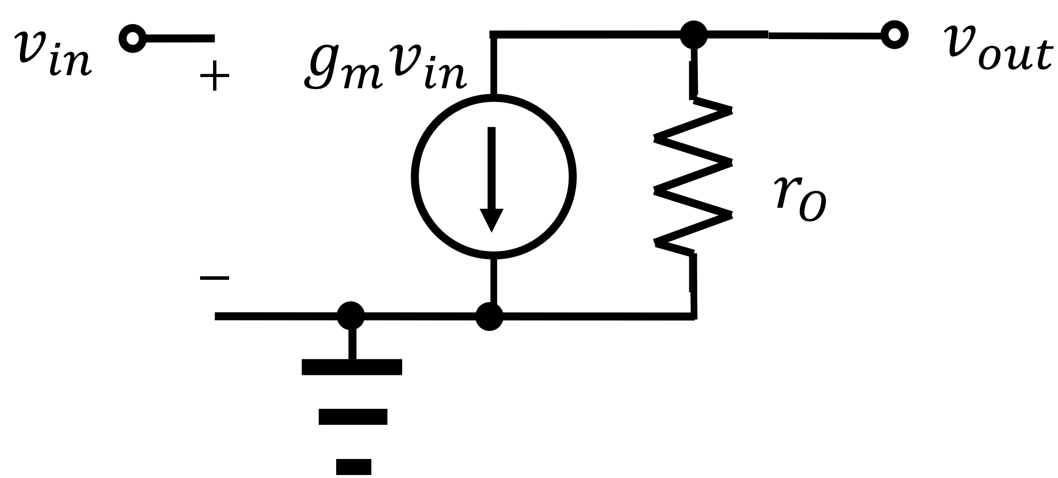
$$R_{out} = R_D || r_O$$



Current-source load

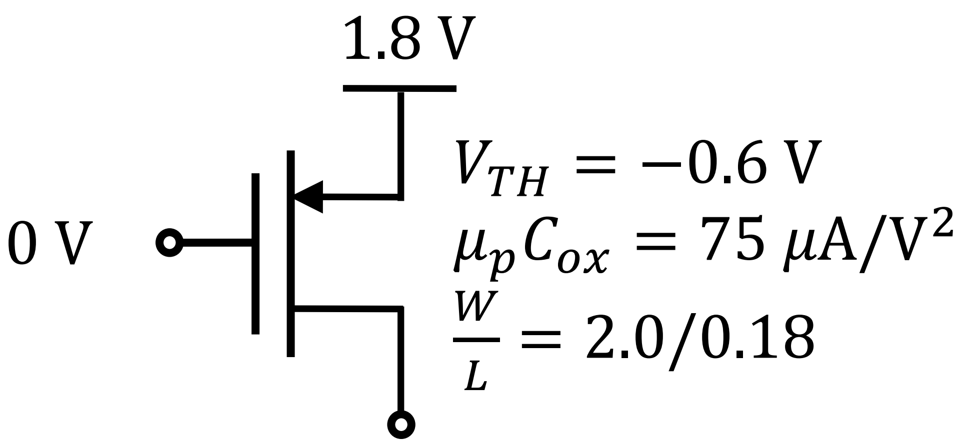
- When $R_D \to \infty$,
  - The gain can be maximized.





Biasing of PMOS devices

- Use a PMOS as a current source
  - The amount of “gate overdrive” is $1.2\ \mathrm{V}$.
  - It is not $0.6\ \mathrm{V}$.

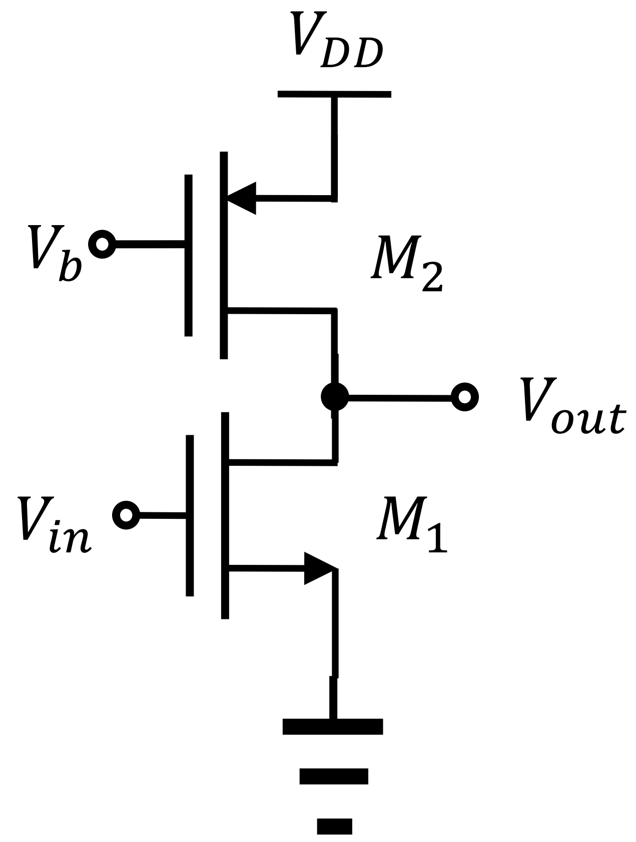


Real current-source load

- Use a PMOS as a current source.
  - It is not an ideal current source.

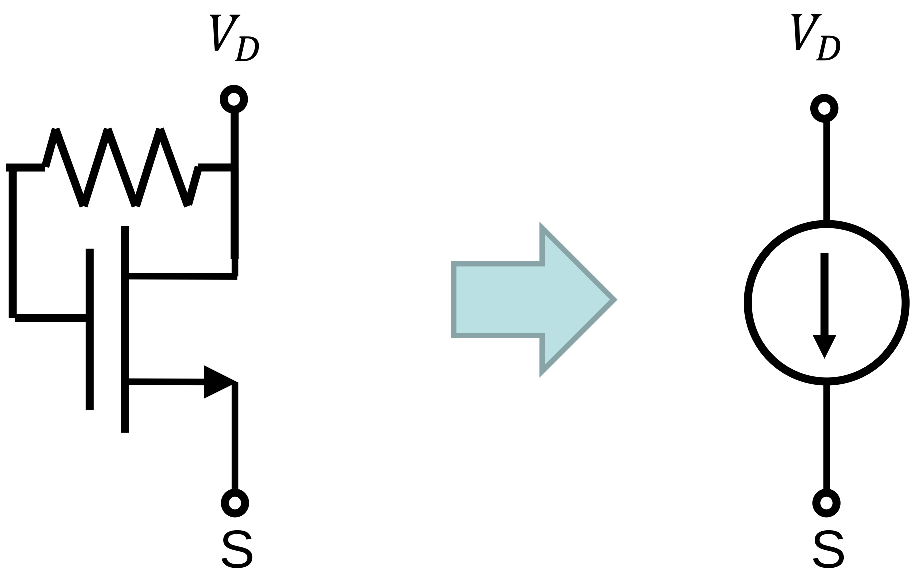
$$v_{out} = -g_{m1}(r_{O1}||r_{O2})v_{in}$$

$$A_v = -g_{m1}(r_{O1}||r_{O2})$$



Self-biasing

- Already covered in Example 6.13.
  - Always in the saturation region.



$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_D - V_S - V_{TH})^2$$

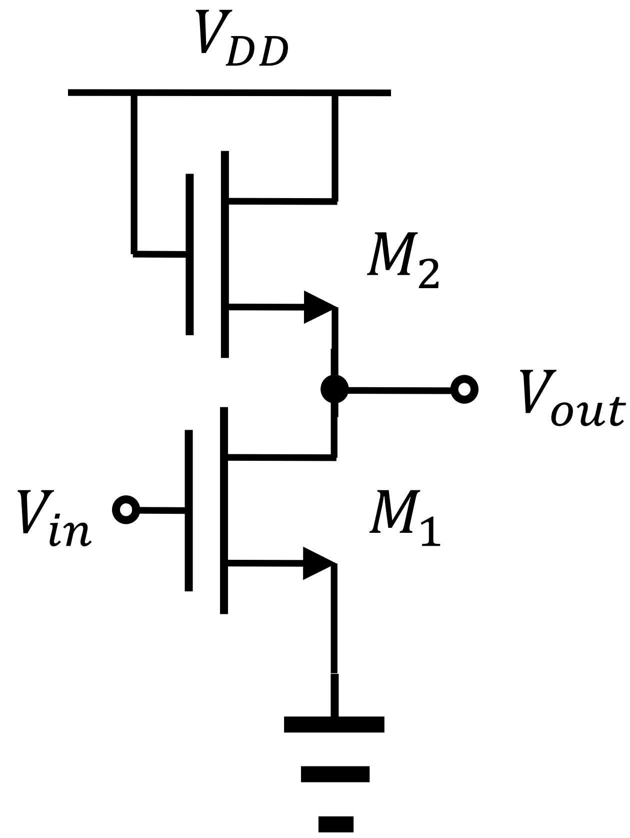
Gate and drain are tied.

In this case,

- Use a diode-connected load.
  - It is not an ideal current source.

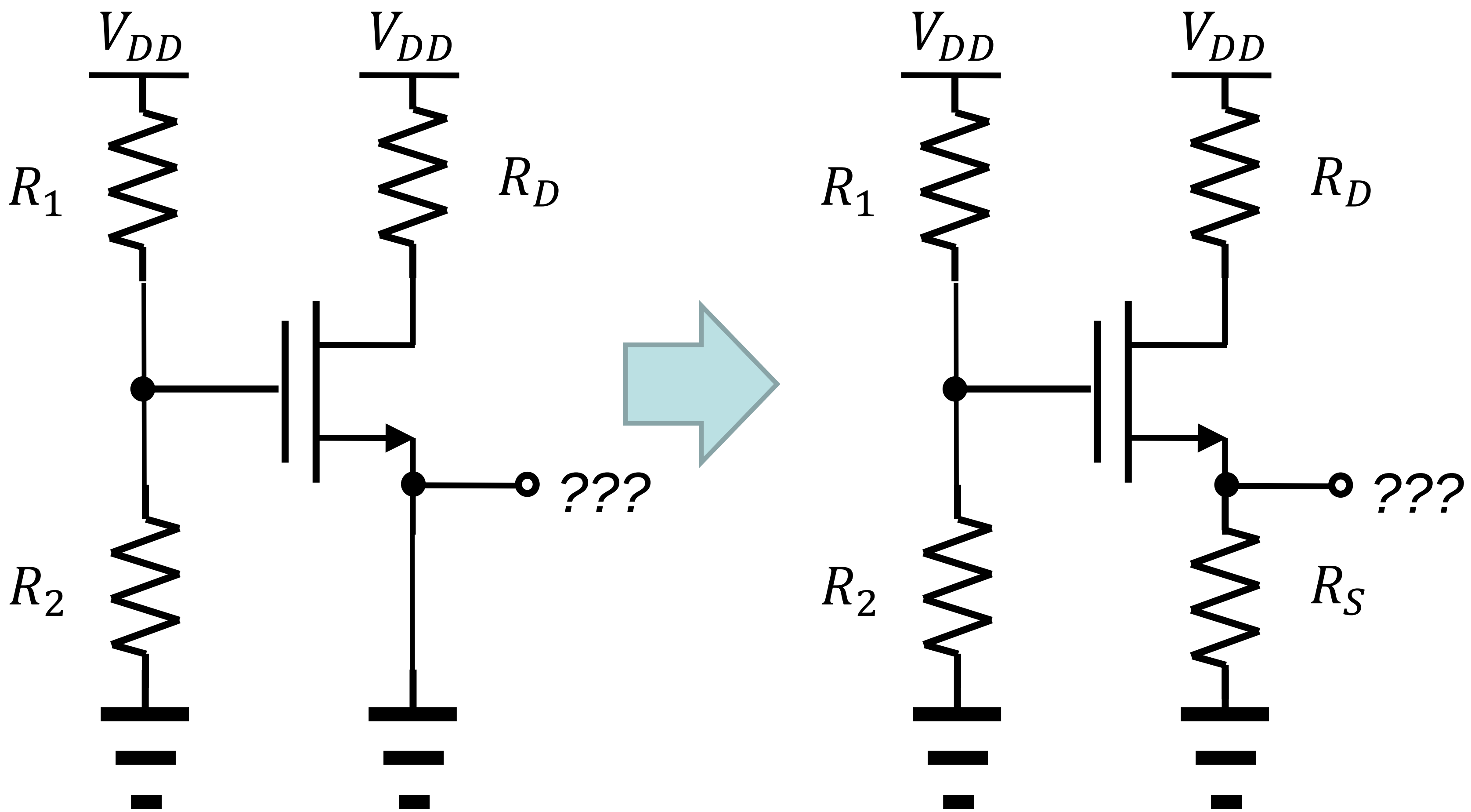
$$v_{out} = -g_{m1}\left(r_{O1}||\frac{1}{g_{m2}}||r_{O2}\right)v_{in}$$

$$A_v = -g_{m1}\left(r_{O1}||\frac{1}{g_{m2}}||r_{O2}\right)$$



Source degeneration (1/2)

- A resistor placed in series with the source terminal



Source degeneration (2/2)

- Now we have to find the source voltage.
  - (Saturation current of the MOSFET) = (Current flowing through R_S)
  - After a simple manipulation, we can find

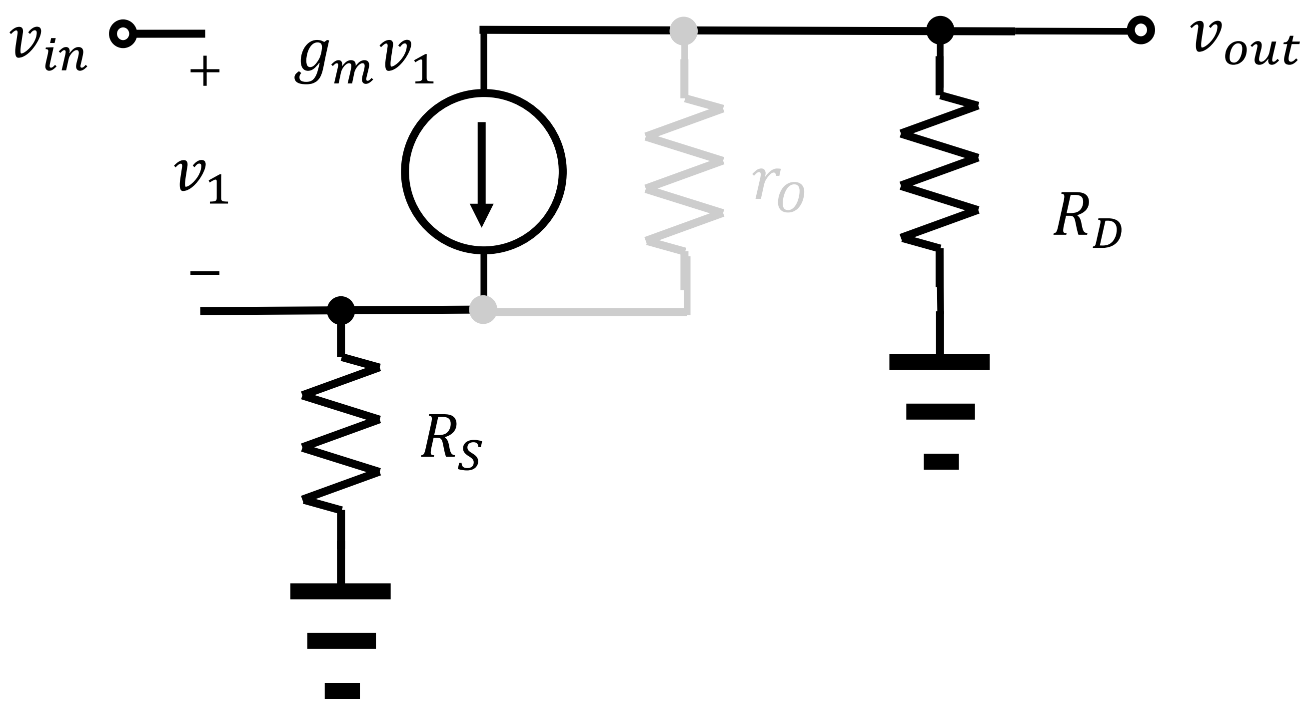
$$V_S = V_G + V_1 - V_{TH} - \sqrt{V_1^2 + 2(V_G - V_{TH})V_1}$$

  - Here,

$$V_1 = \frac{1}{\mu_n C_{ox} \frac{W}{L} R_s}$$

Effect of R_S (1/2)

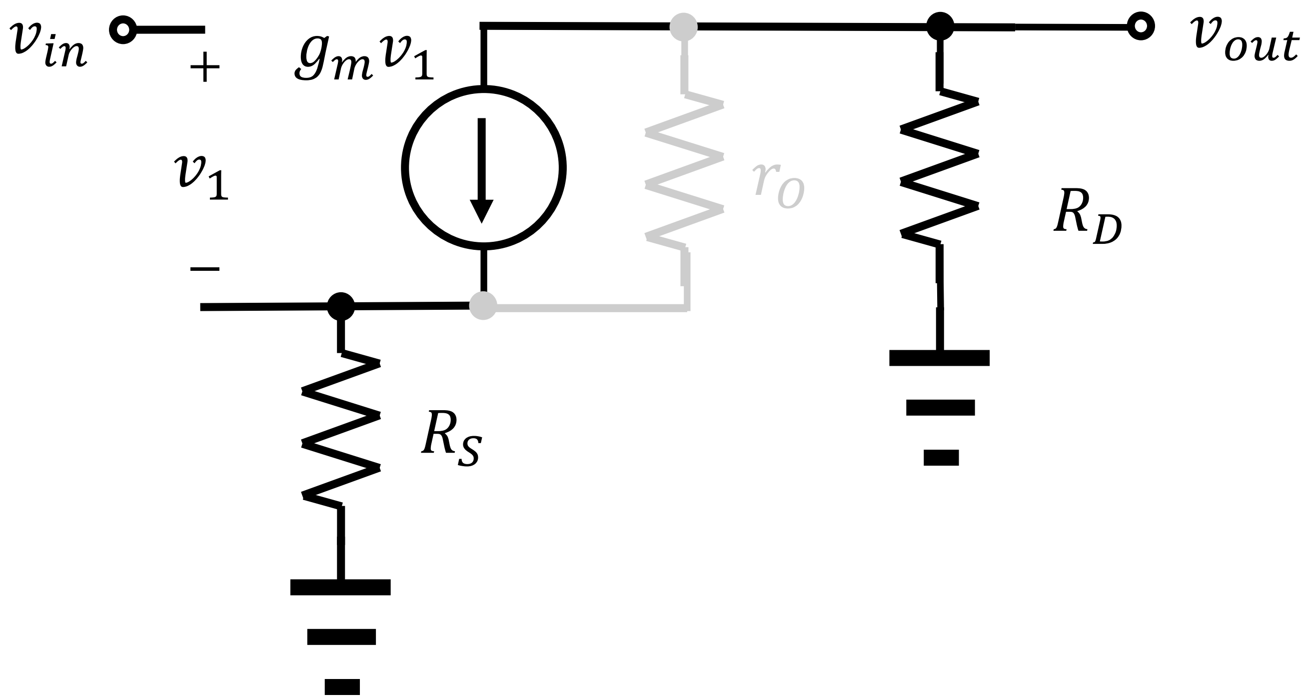
- Reduction of the gate-source voltage
  - Therefore, also reduction of the gain.
- For a while, neglect the channel-length modulation.



Effect of R_S (2/2)

- After a simple manipulation,

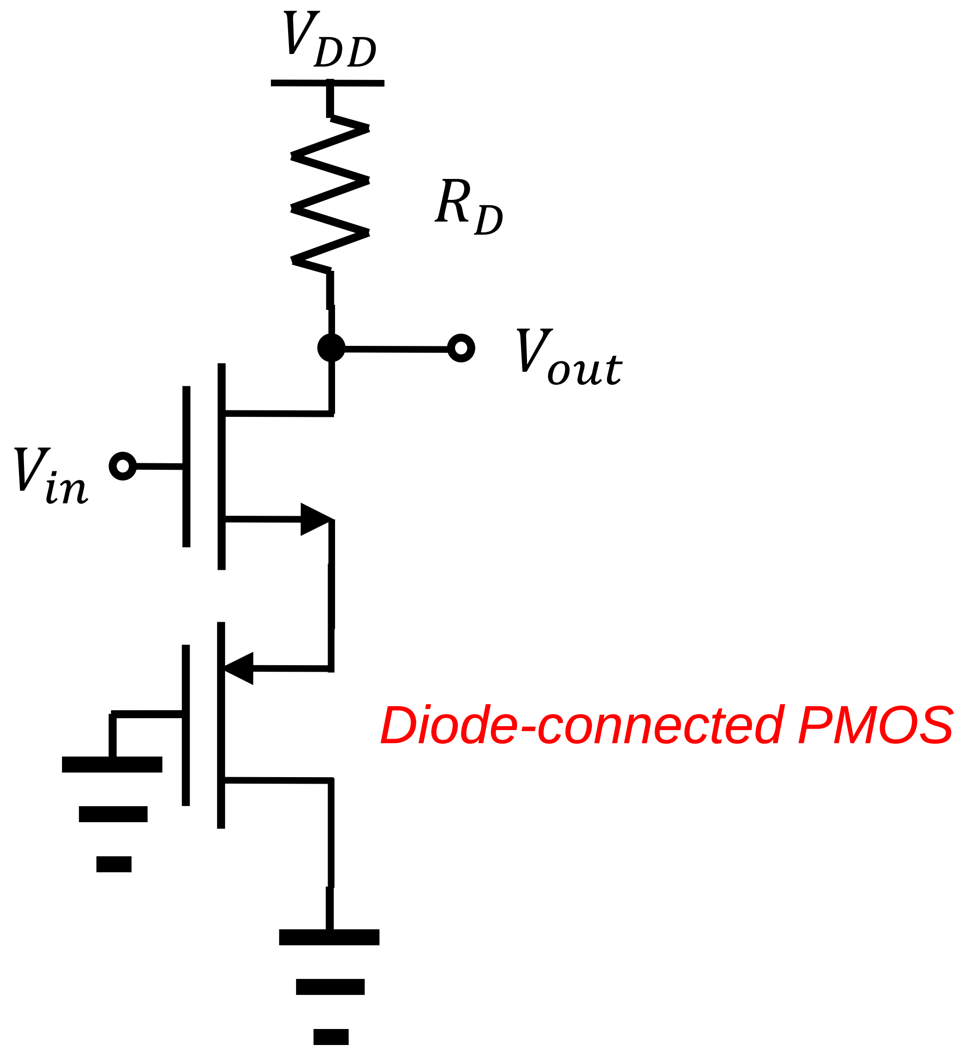
$$A_v = -\frac{g_m R_D}{1 + g_m R_S}$$



Example 17.20

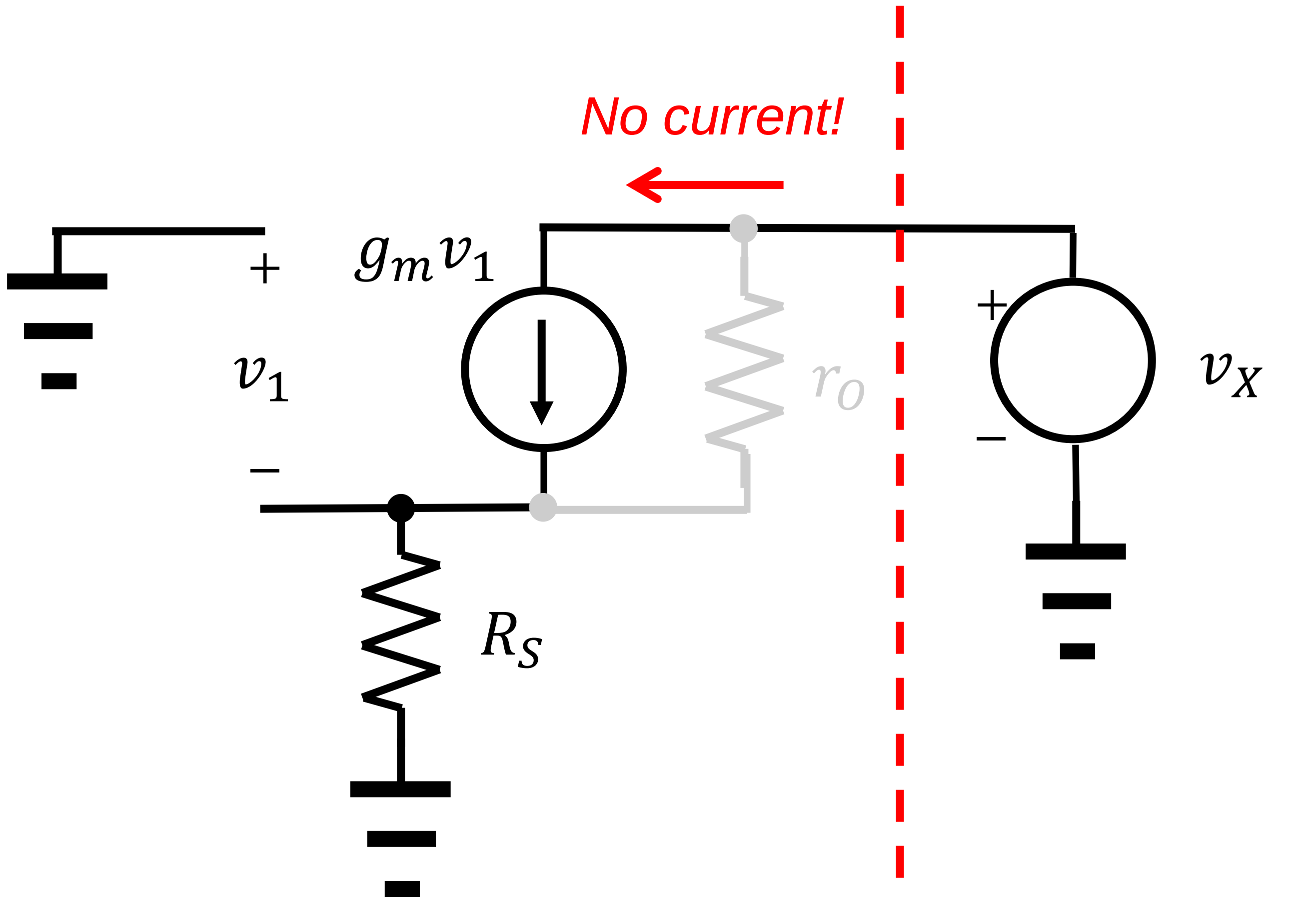
- CS with degeneration

$$A_v = -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$



Output impedance of CS (1/2)

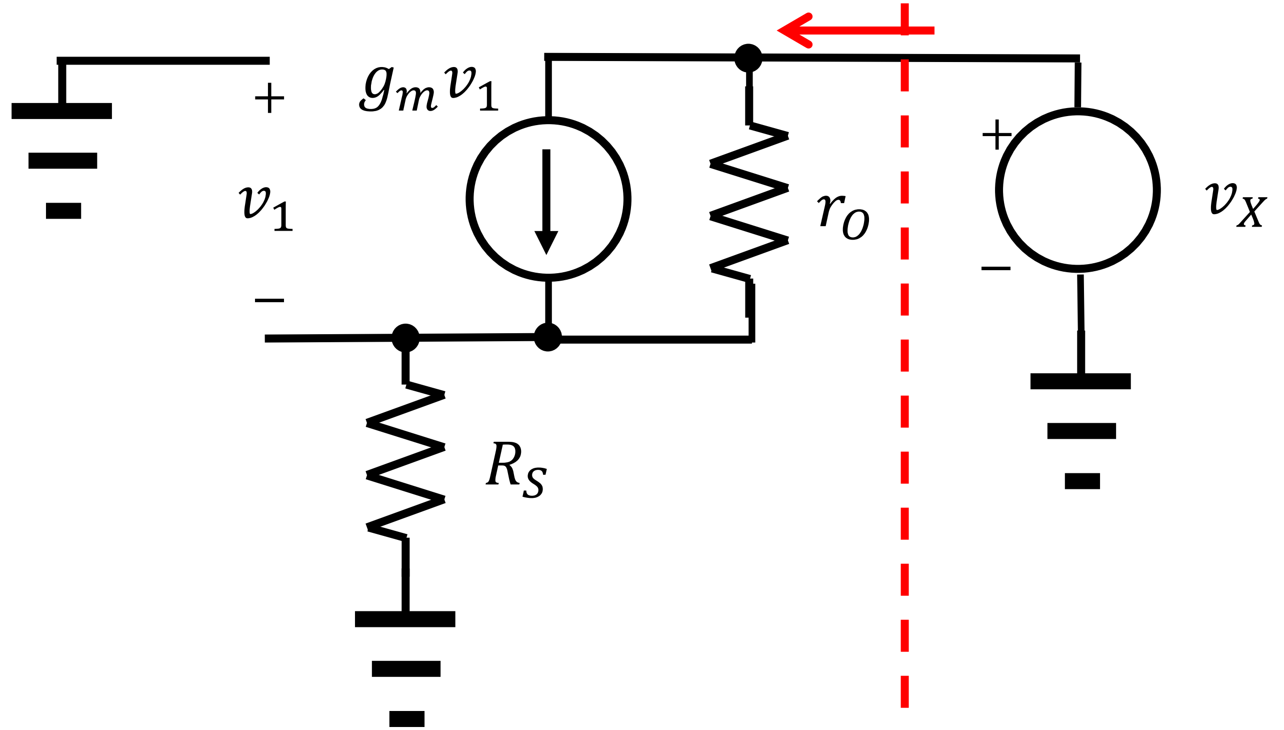
- Still neglecting the channel-length modulation
  - No current!



Output impedance of CS (2/2)

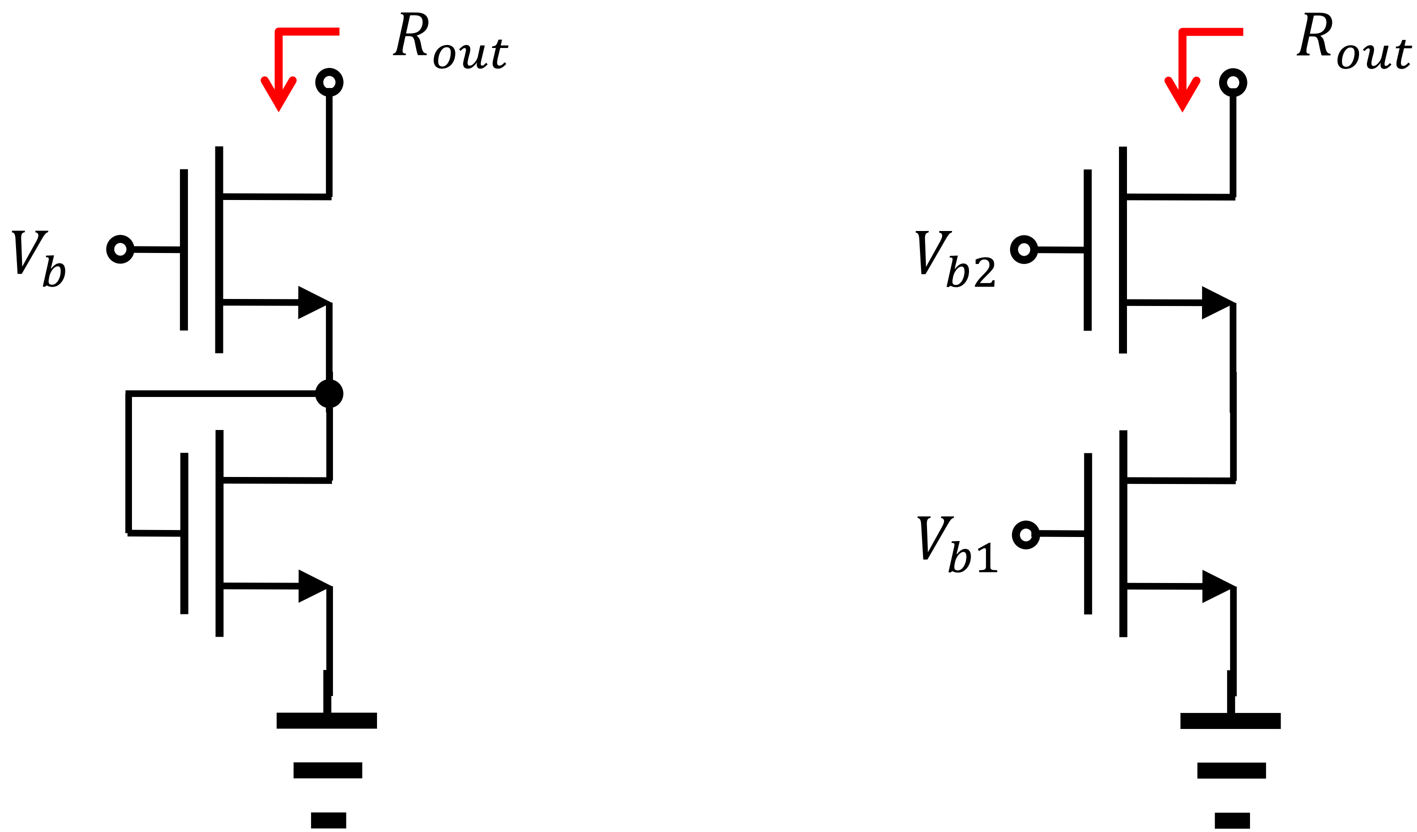
- Now considering the channel-length modulation
  - Output resistance is $r_O + (g_m r_O + 1)R_S$.

$$i_X = \frac{v_X}{r_O + g_m R_S r_o + R_S}$$



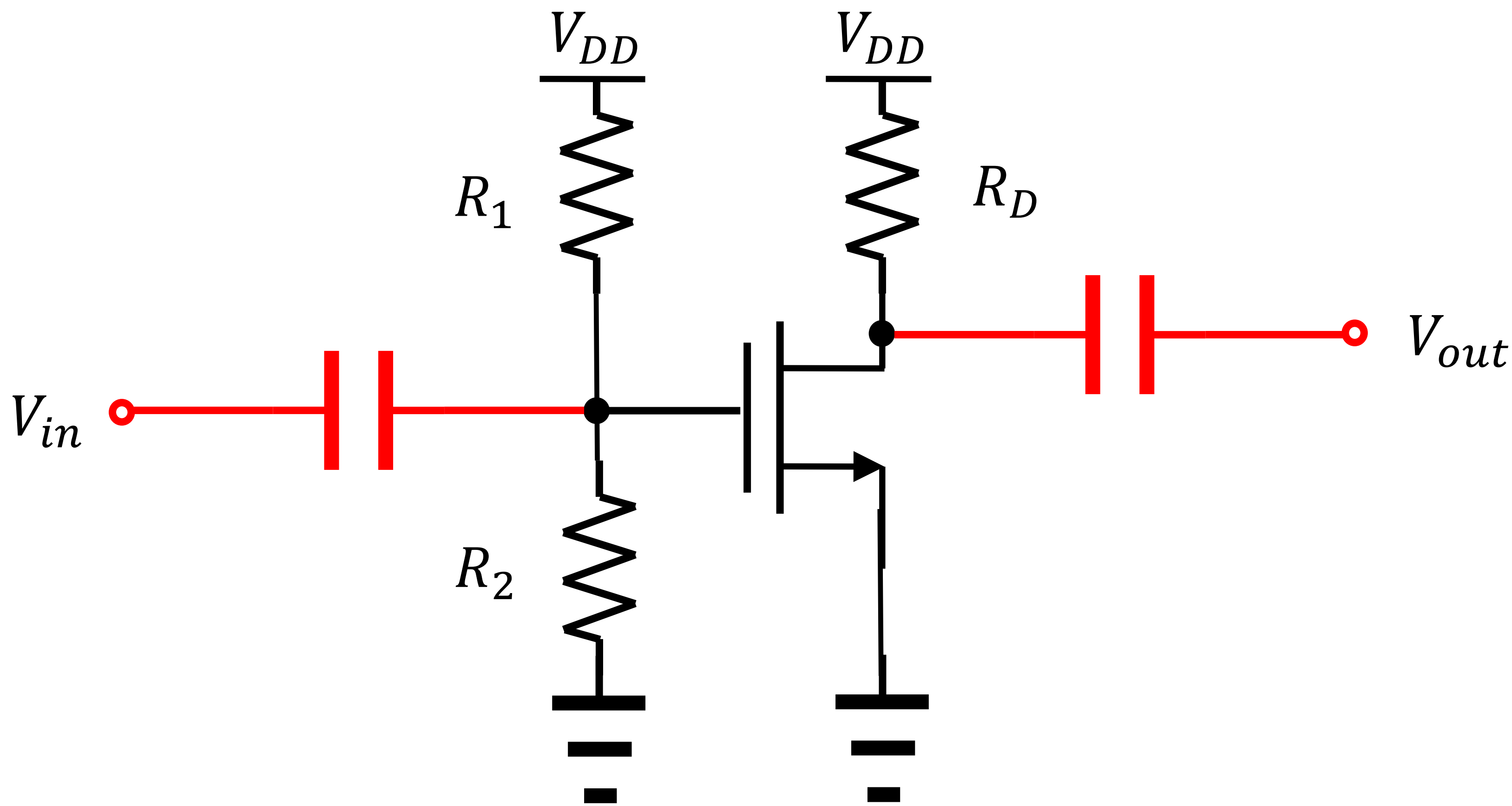
Examples 17.23 and 17.24

- Compute the output resistance.
  - What is the difference?



CS stage with biasing

- We need capacitive coupling at the input and output.



Low load impedance

- Example 17.27
  - With the load impedance, R_L, the gain becomes

$$A_v = g_m(R_D || r_O || R_L)$$

8 Ω

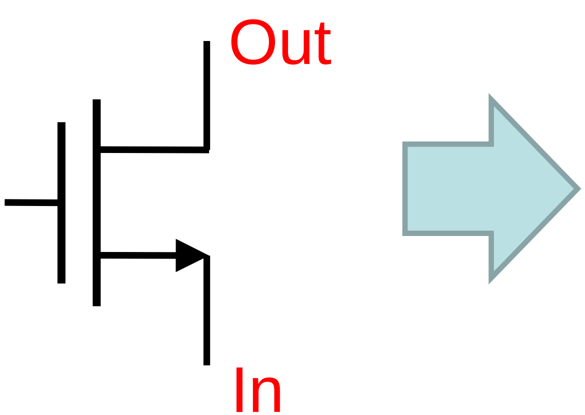
Very large

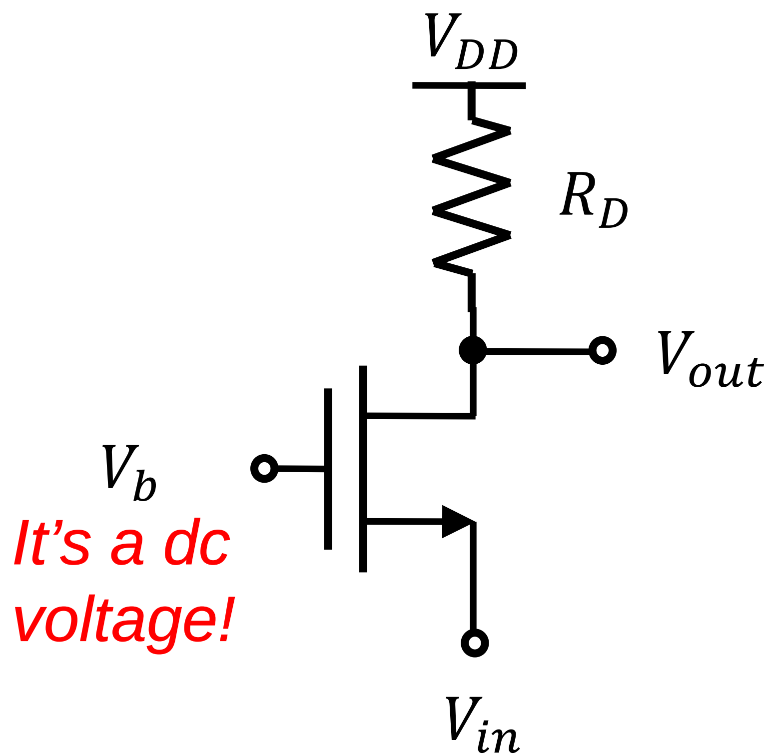
1 kΩ

  - Low load impedance drops the gain drastically!

Common-gate amplifier

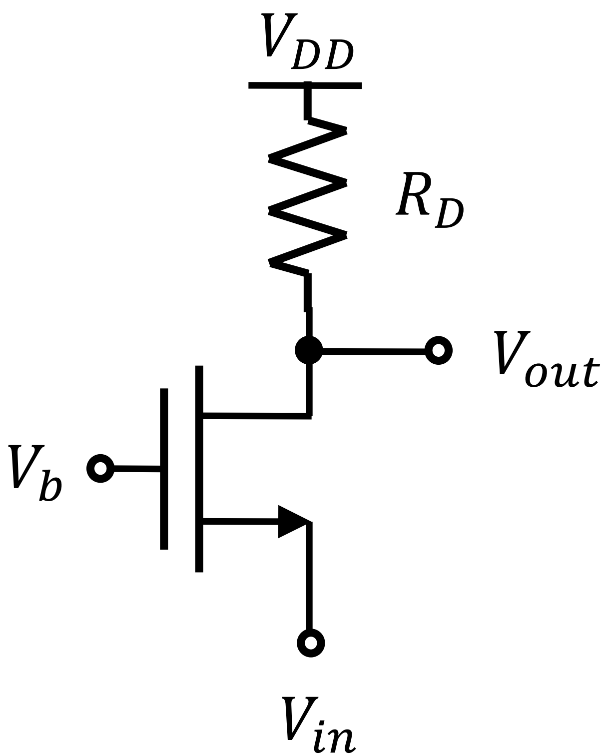
- Why do we study other amplification topologies?
  - Different circuit properties
- Common-gate amplifier
  - Gate terminal is ac-grounded.

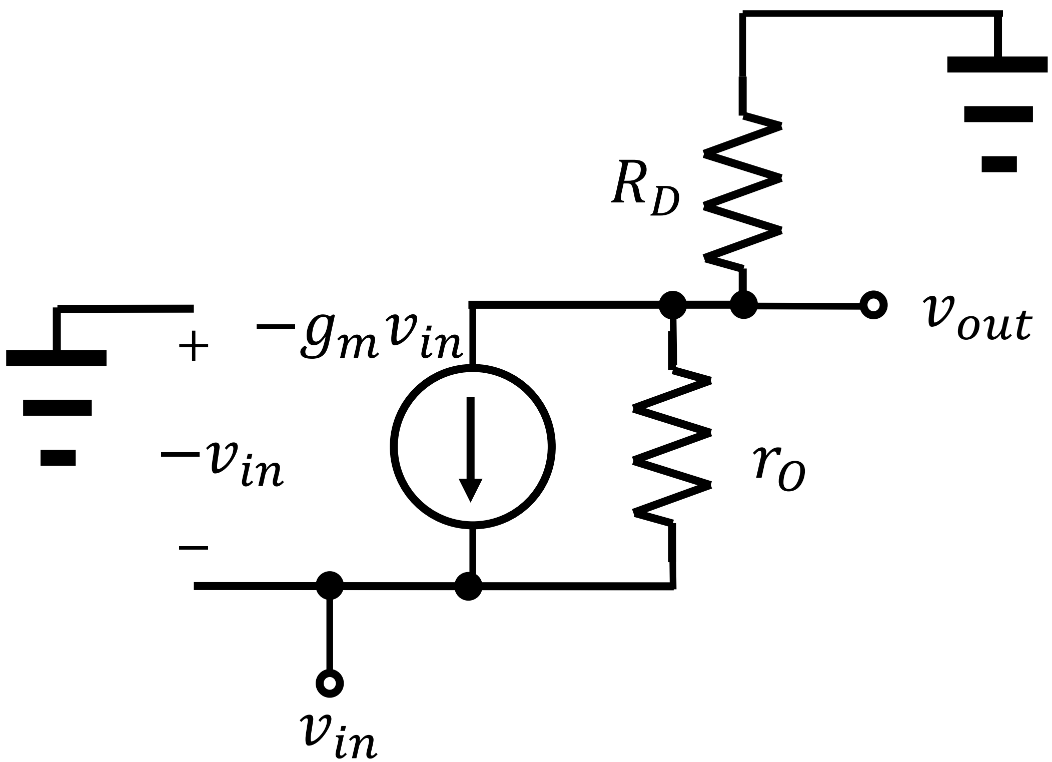




Small-signal model

- Let's draw the small-signal model together!





Gain and input impedance

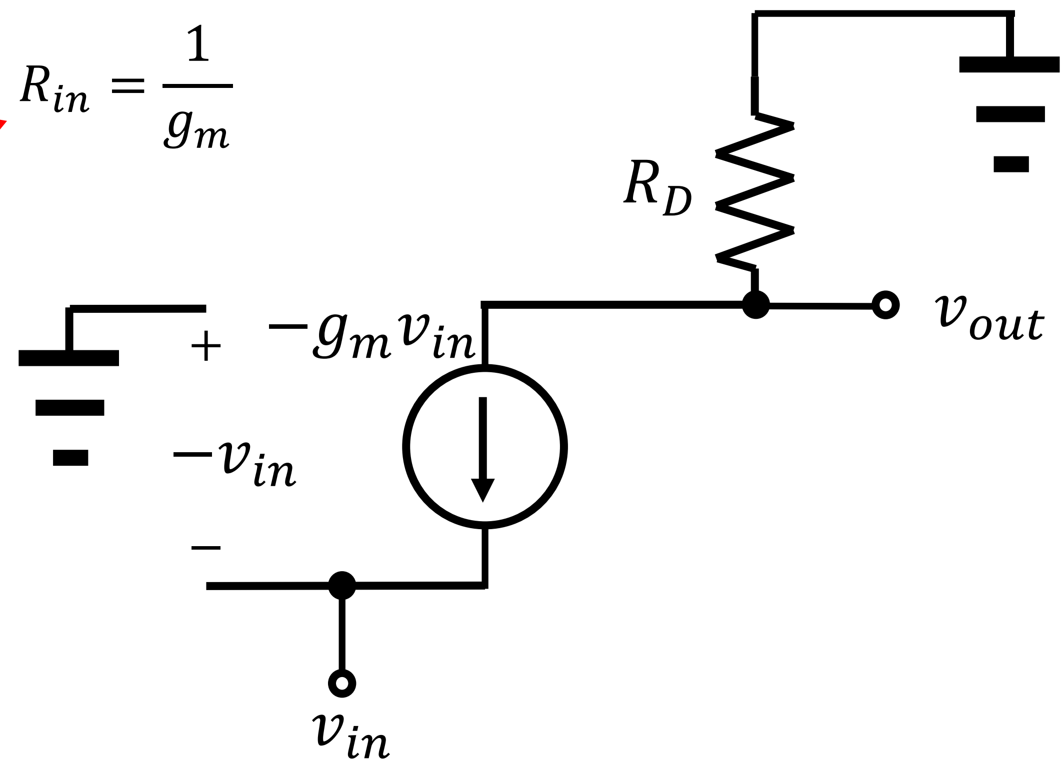
- Neglect the output resistance, r_O.
  - Voltage gain

$$A_v = +g_m R_D$$

  - Input impedance

$$R_{in} = \frac{1}{g_m}$$

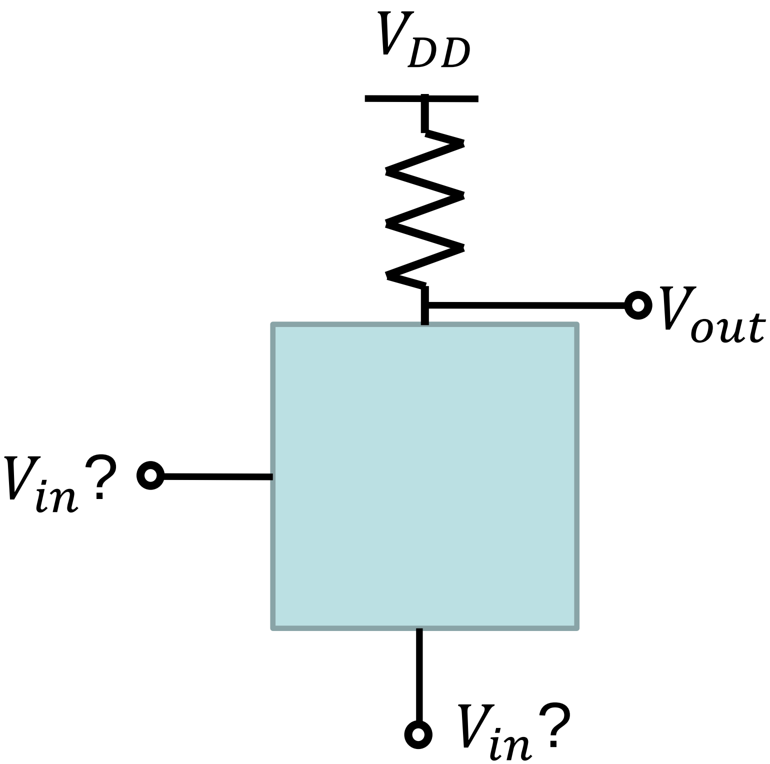
It's small!



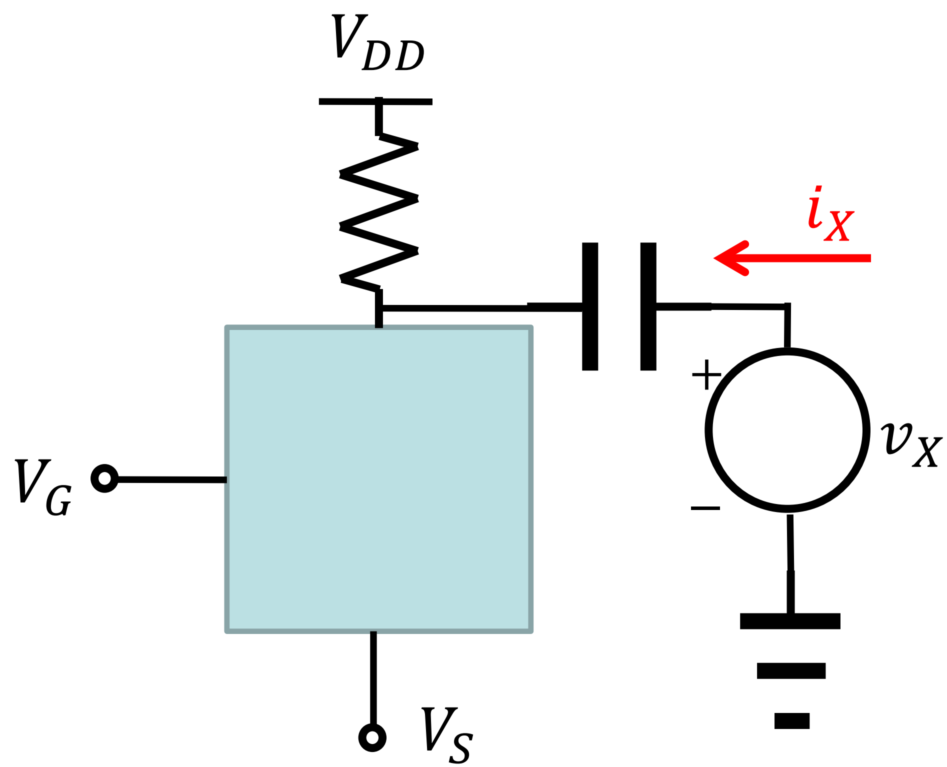
Output impedance

- Same with the CS stage

$$R_{out} = r_O \,||R_D$$



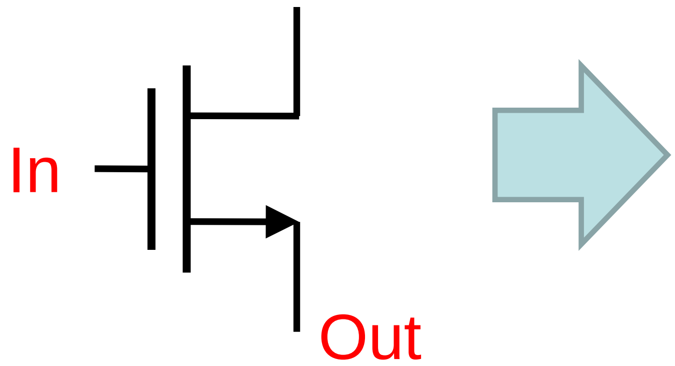
Generic form of CS and CG stages

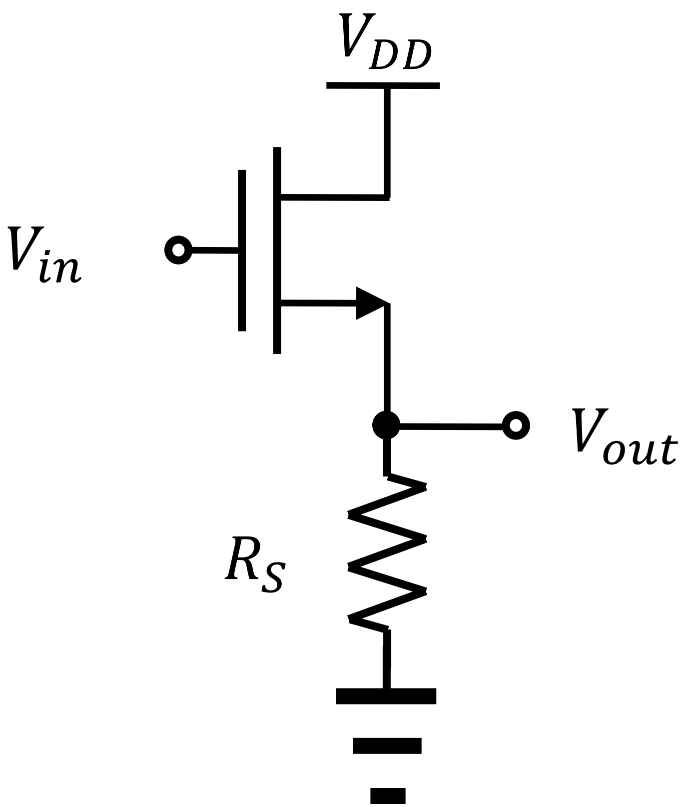


Setting for calculating R_{out}

Source follower

- Also called the “common-drain” stage
  - The drain is ac ground.
- Wait a minute!
  - Is it a real amplifier?

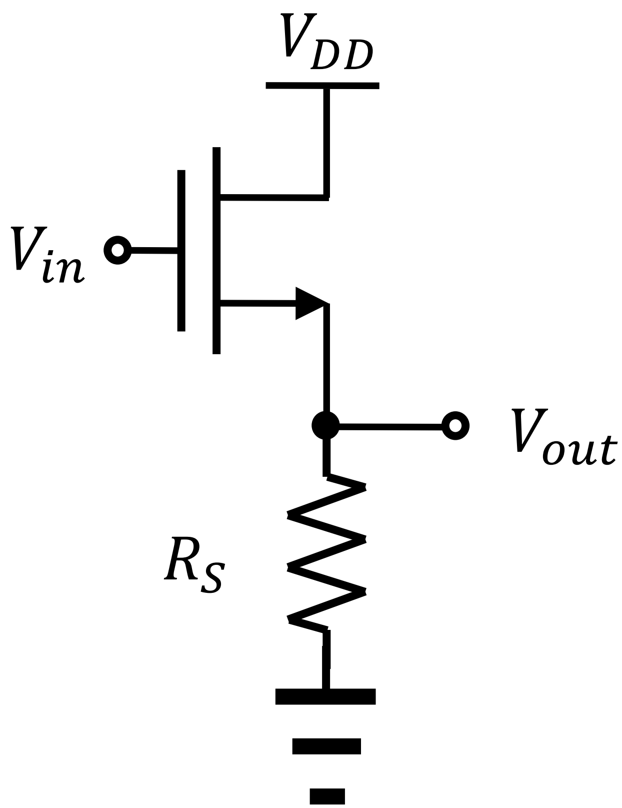




Its core

- Gain is less than 1??

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



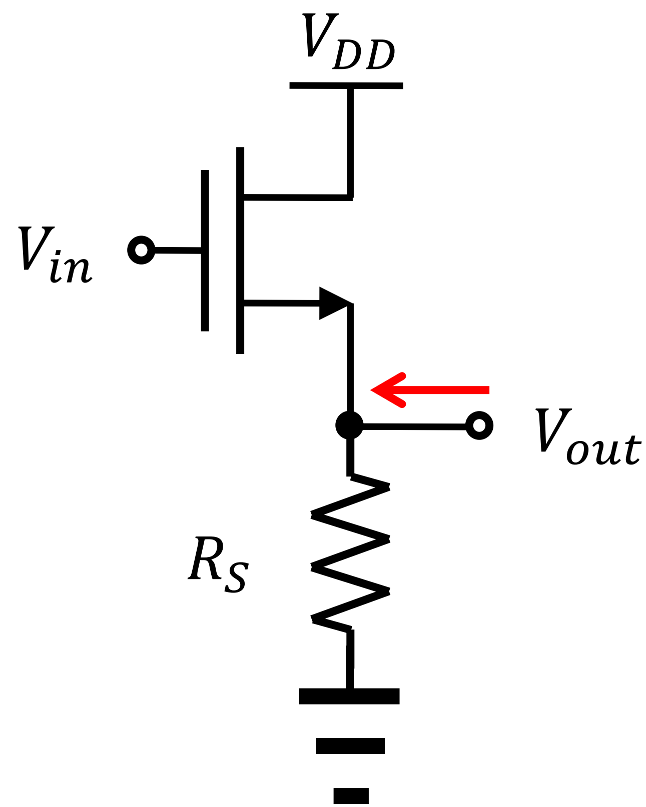
You should be able to draw the small-signal model.

Useless?

- Calculate the input and output impedances.
  - Since the gate is the input terminal, the input impedance is very high at low frequencies.
  - How about the output impedance?

$$R_{out} = \frac{1}{g_m} || r_O || R_S$$

  - It is relatively low.



- High input imp., low output imp.
  - They can serve as good “buffers.”