Lecture16:
PMOSFET & amplifier

Sung-Min Hong (smhong@gist.ac.kr)

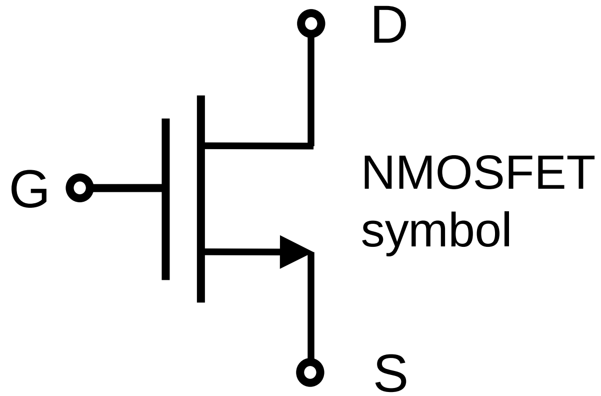
Semiconductor Device Simulation Lab.
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology

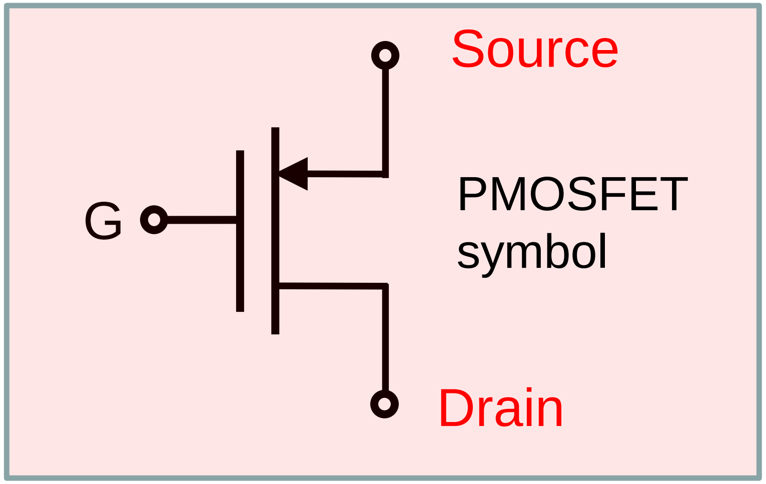
NMOSFET

- In the NMOSFET, electrons are mobile carriers.
  - When V_{GS} is lower than V_{TH}, holes are depleted from the Si/SiO_2 interface.
  - When V_{GS} is larger than V_{TH}, electrons are collected at the Si/SiO_2 interface. (Electron inversion)
- Imagine its "dual" device with a negative V_{TH}.
  - When V_{GS} is larger than V_{TH} ($|V_{GS}| > |V_{TH}|$), electrons are depleted from the Si/SiO_2 interface.
  - When V_{GS} is smaller than V_{TH} ($V_{GS} < V_{TH}$), holes are collected at the Si/SiO_2 interface. (Hole inversion)
  - Is there such a device? *Yes.*

PMOSFET

- The PMOSFET

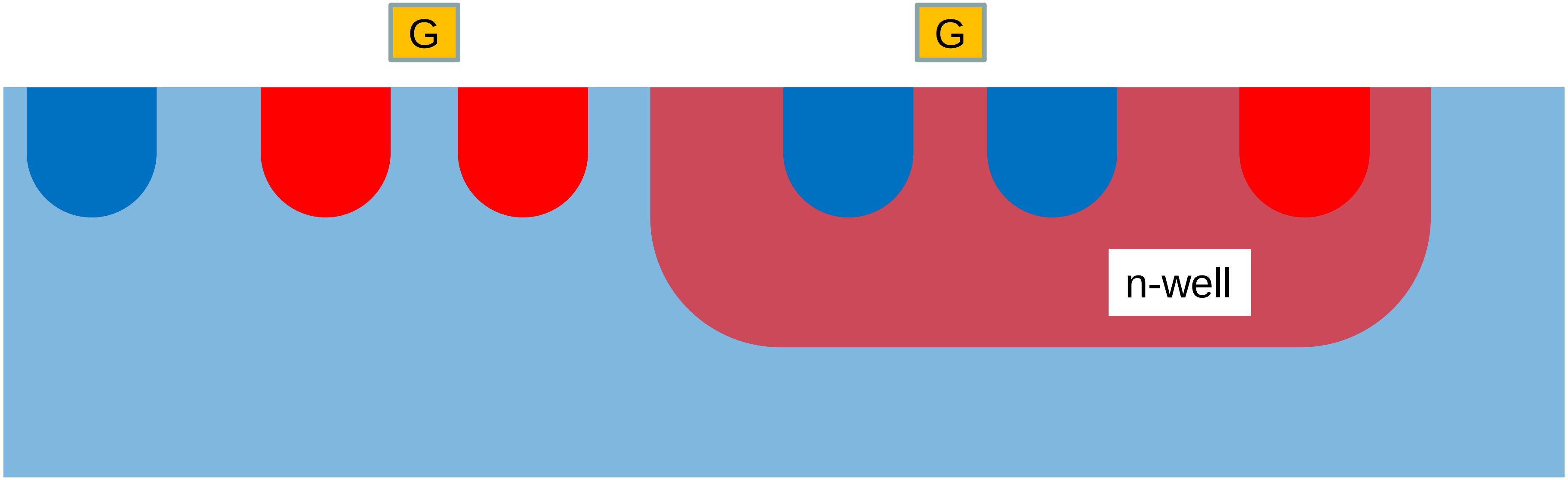




  - Example) $V_{TH,P} = -1.5\ \mathrm{V}$. Assume that V_S is 3 V. The gate voltage of 2 V does not turn on the transistor. 1 V turns on the transistor.
  - The drain voltage is lower than the source voltage. In the usual operation condition, the drain current is negative.

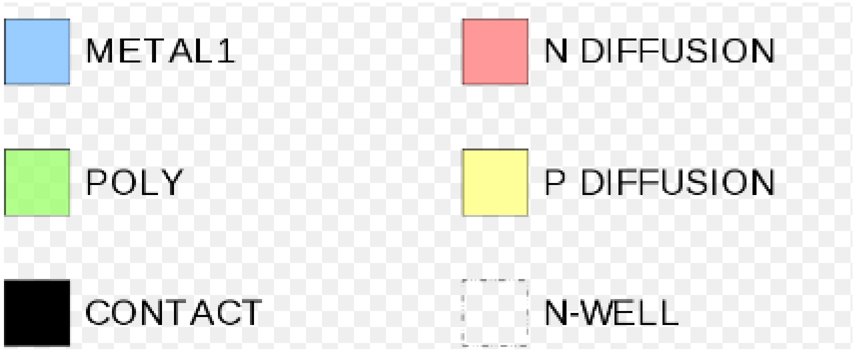
How to fabricate it

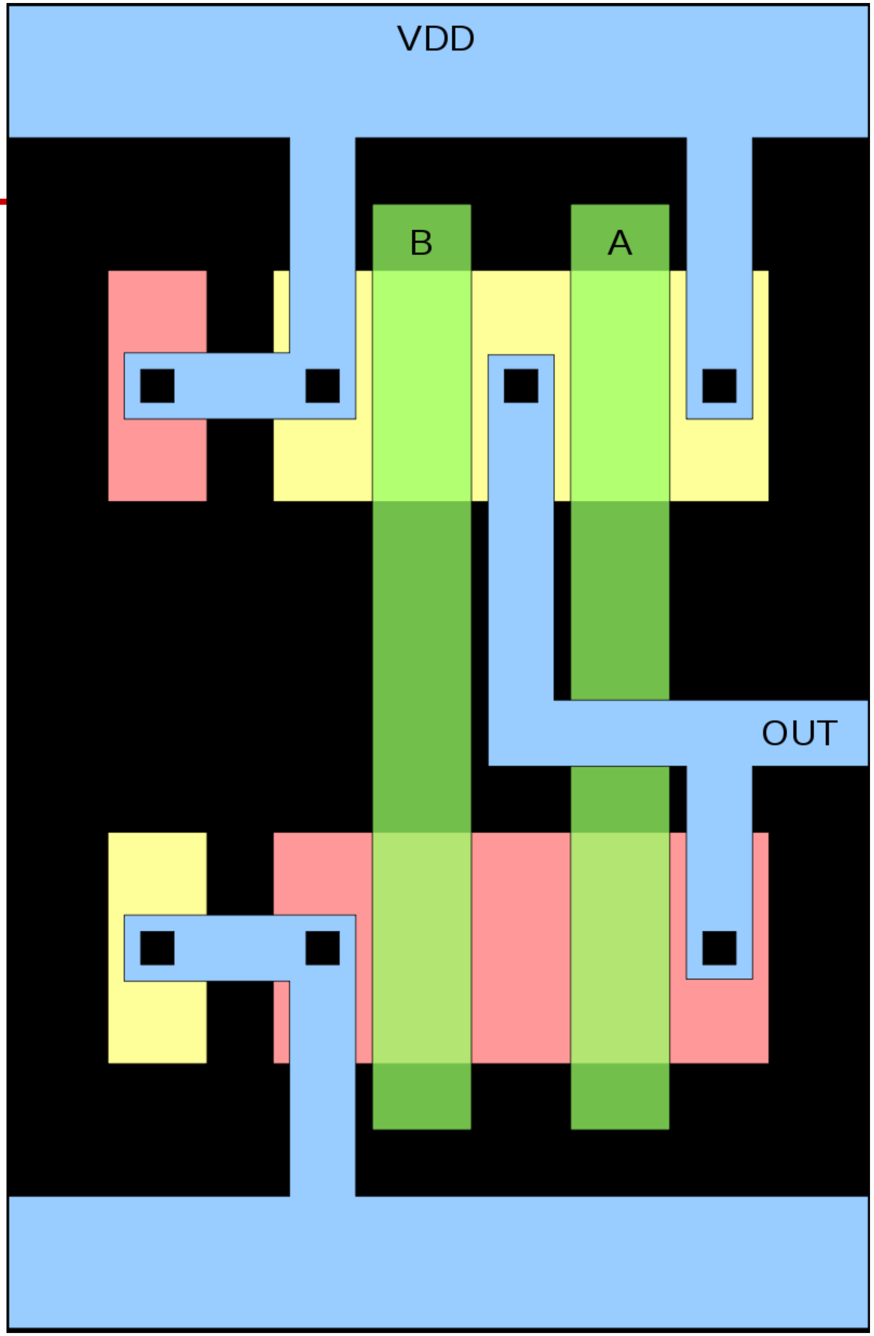
- We need an n-type substrate.
  - Also two highly doped p-type regions are required.



Layout example

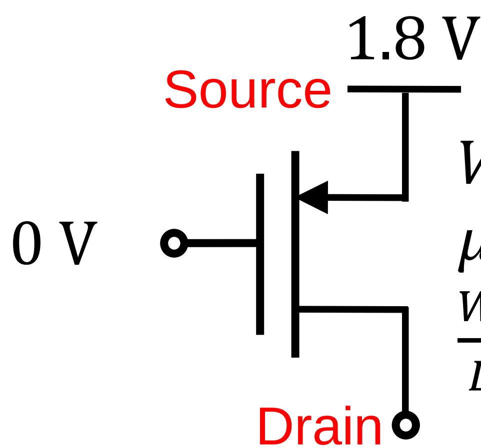
- Taken from Wikipedia
  - Draw its circuit schematic.





Biasing of PMOS devices

- Express the source current as a function of the drain voltage.
  - The absolute value of "gate overdrive" is $1.2\ \mathrm{V}$.
  - It is not $0.6\ \mathrm{V}$.



$$V_{TH} = -0.6\ \mathrm{V}$$
$$\mu_p C_{ox} = 75\ \mu\mathrm{A/V}^2$$
$$\frac{W}{L} = 2.0/0.18$$

- Do the same job with the gate voltage of 1.8 V.

Why amplifiers?

- Signal amplification
  - Usually, signals are “weak.” (in the $\mu\mathrm{V}$ or mV range)
  - It is too small for reliable processing.
  - If the signal magnitude is made larger, processing is much easier.

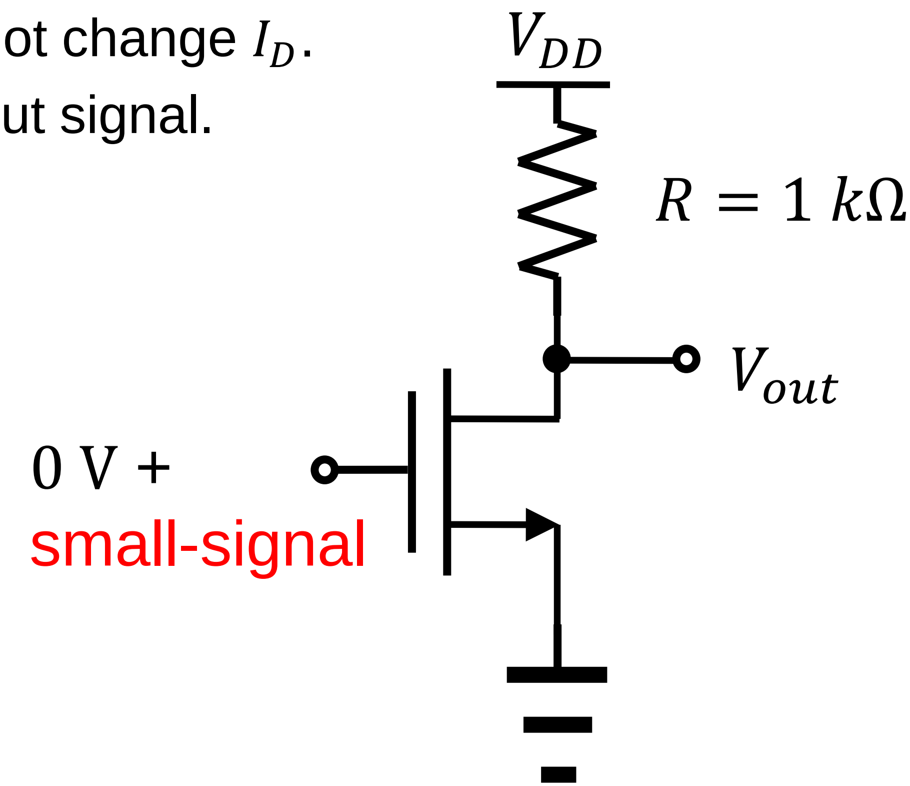
Voltage gain

- Voltage gain
  - For example, a voltage amplifier amplifies the input voltage signal. Its output is also a voltage.
  - When $V_{in}(t) = V_{DC,in} + v_{in}(t)$, ideally,we want to have $V_{out}(t) = V_{DC,out} + A_v v_{in}(t)$.
  - A_v is the voltage gain. (Of course, it is a unitless quantity.)

- How can we have a voltage-voltage relation?
  - Combining a transistor and a resistor!

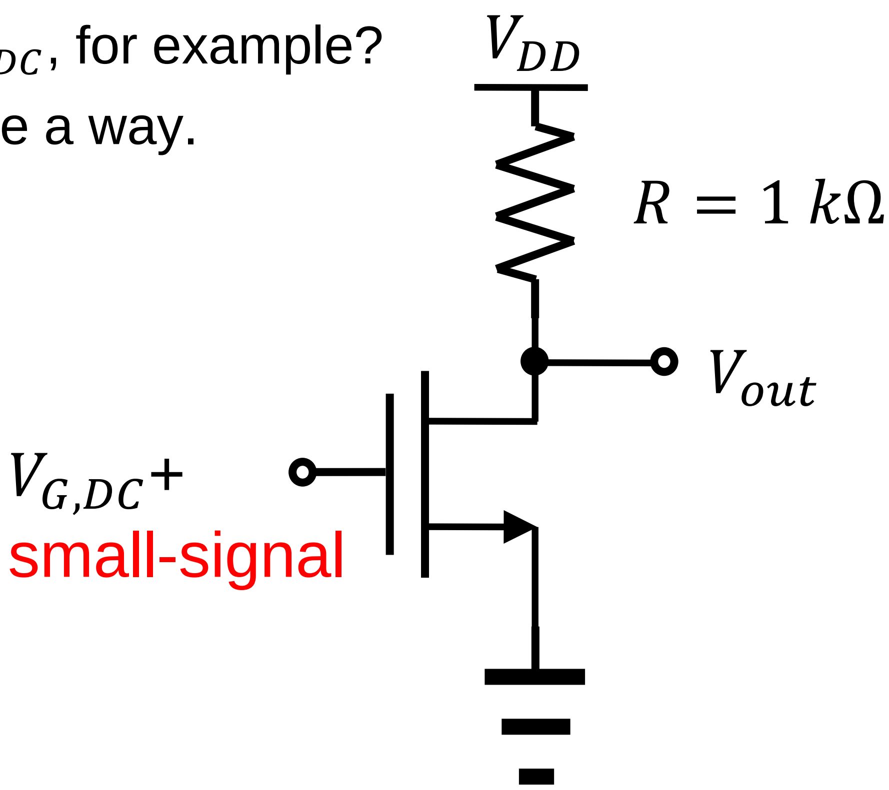
Transistor turned off

- Note that $V_{out} = V_{DD} - I_D R$.
  - But, the transistor is not turned on. ($I_D \approx 0$)
  - The transconductance(g_m) is zero.
  - A small increase in V_G does not change I_D.
  - The circuit generates no output signal.



This is a solution.

- The following circuit shows a revised circuit.
  - Assume that $V_{G,DC} > V_{TH}$.
  - It has a meaningful value of g_m.
  - Then, how can we generate $V_{G,DC}$, for example?
  - Use of a separate battery can be a way.



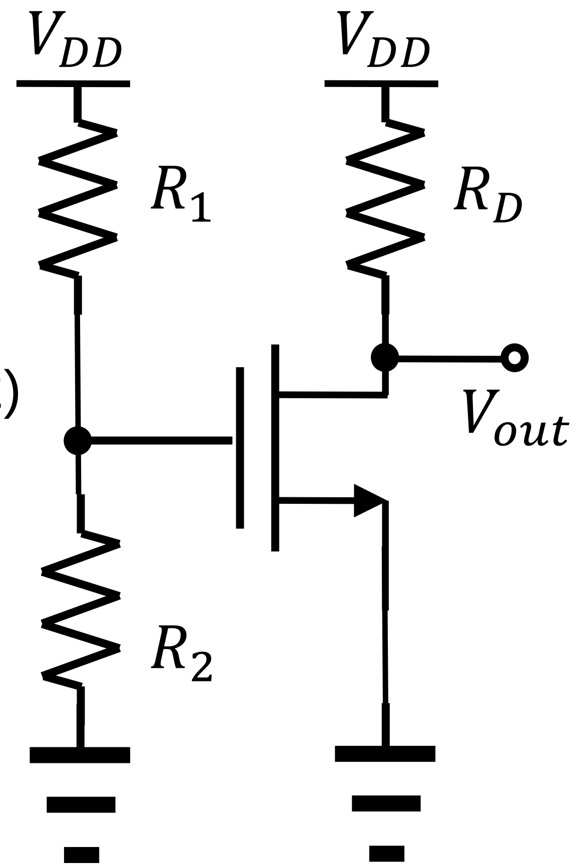
Simple biasing (1/3)

- A better way to provide the gate voltage
  - The gate bias voltage is

$$V_{GS} = \frac{R_2}{R_1+R_2} V_{DD} \qquad \text{(Razavi 17.10)}$$

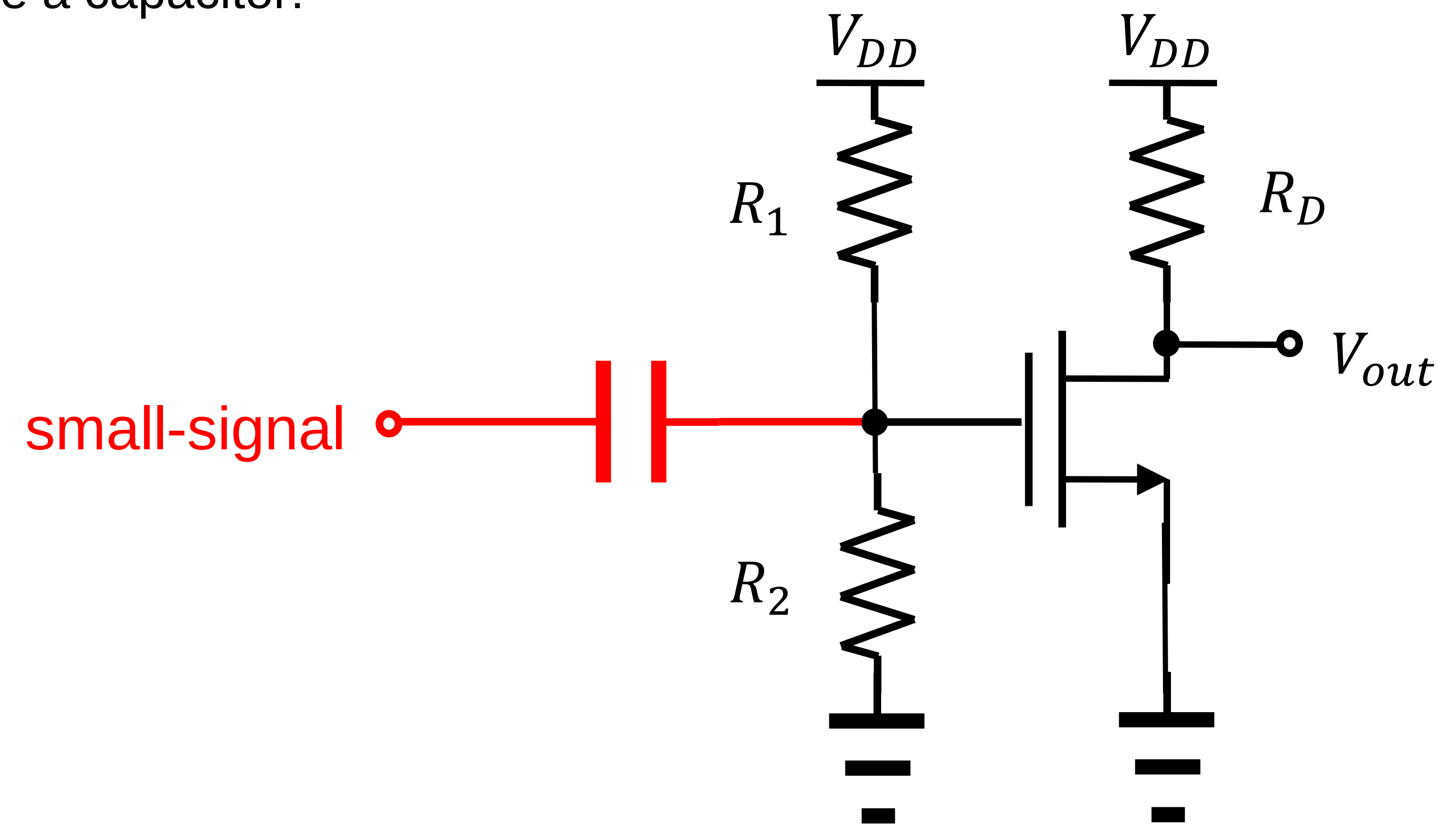
  - The drain current is

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(\frac{R_2}{R_1+R_2}V_{DD} - V_{TH}\right)^2 \quad \text{(Razavi 17.12)}$$



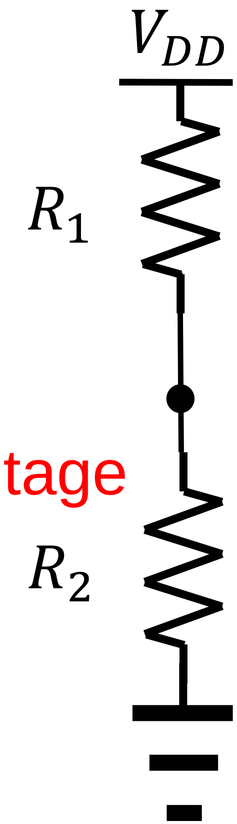
Simple biasing (2/3)

- How to apply the small-signal input
  - Use a capacitor!



Simple biasing (3/3)

DC:
The capacitor
& small-signal voltage
do not contribute.



AC:
small-signal
voltage