Lecture13: CMOS amplifier, concept

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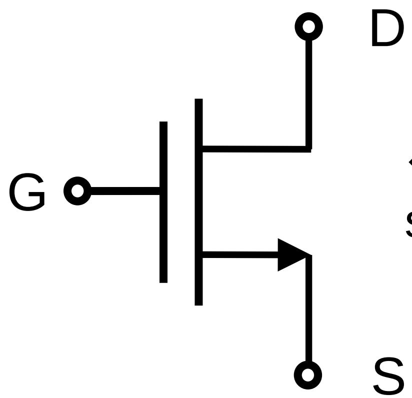
NMOSFET

- 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.
  - Its V_{TH} is usually negative.
  - 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.*

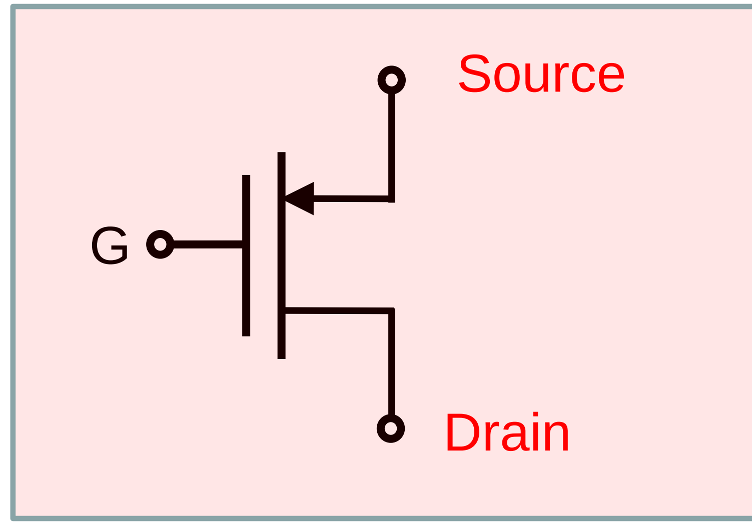
PMOSFET

- The PMOSFET



← NMOSFET symbol

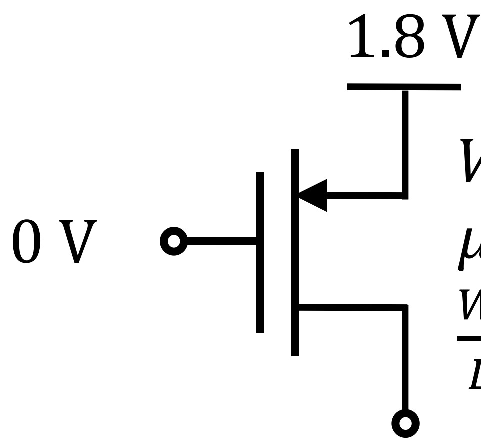
PMOSFET → symbol



  - The source voltage is the highest one.
  - For 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. The gate voltage of 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.

Biasing of PMOS devices

- Express the source current as a function of the drain voltage.
  - The absolute value of “gate overdrive” is 1.2 V.
  - It is not 0.6 V.



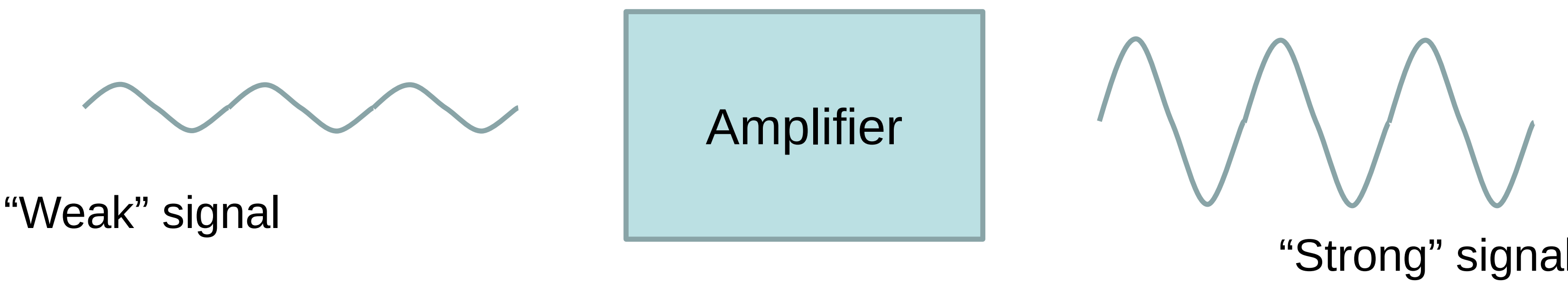
$$V_{TH} = -0.6\ \mathrm{V}$$
$$\mu_p C_{ox} = 75\ \mu\mathrm{A/V}^2$$
$$\frac{W}{L} = 2.0/0.18$$

Drain

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

Why amplifiers?

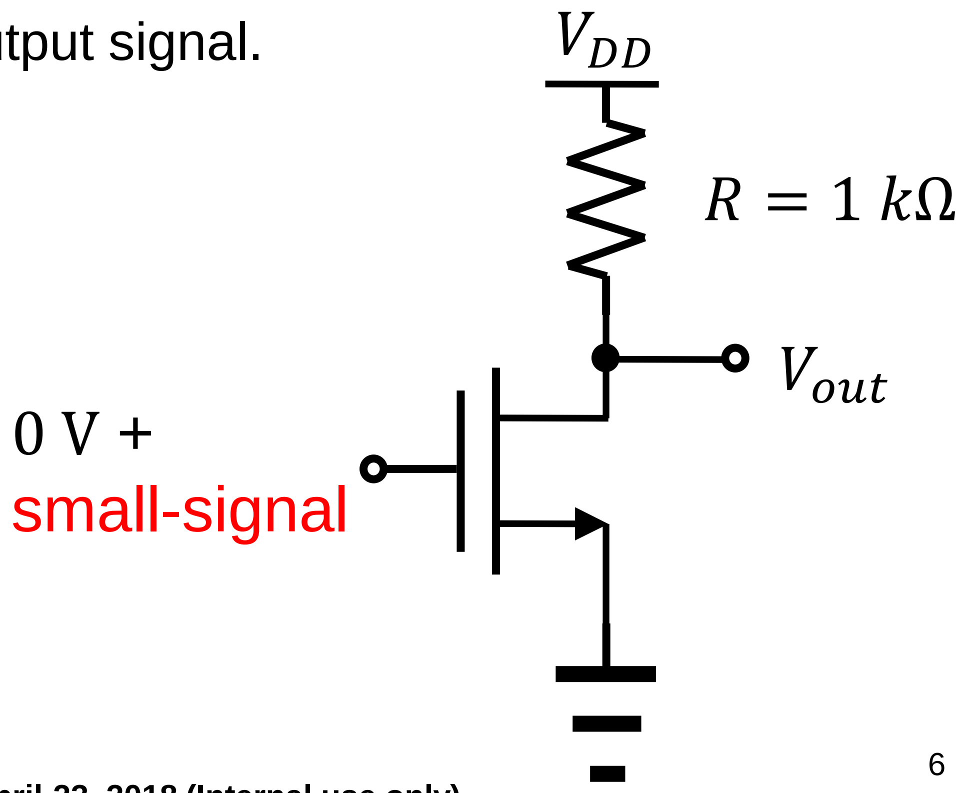
- Signal amplification
  - Usually, signals are “weak.” (in the $\mu\mathrm{V}$ or mV range)
  - It is too small for reliable processing.
  - If the signal magnitude is made larger, processing is much easier.



  - 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.)

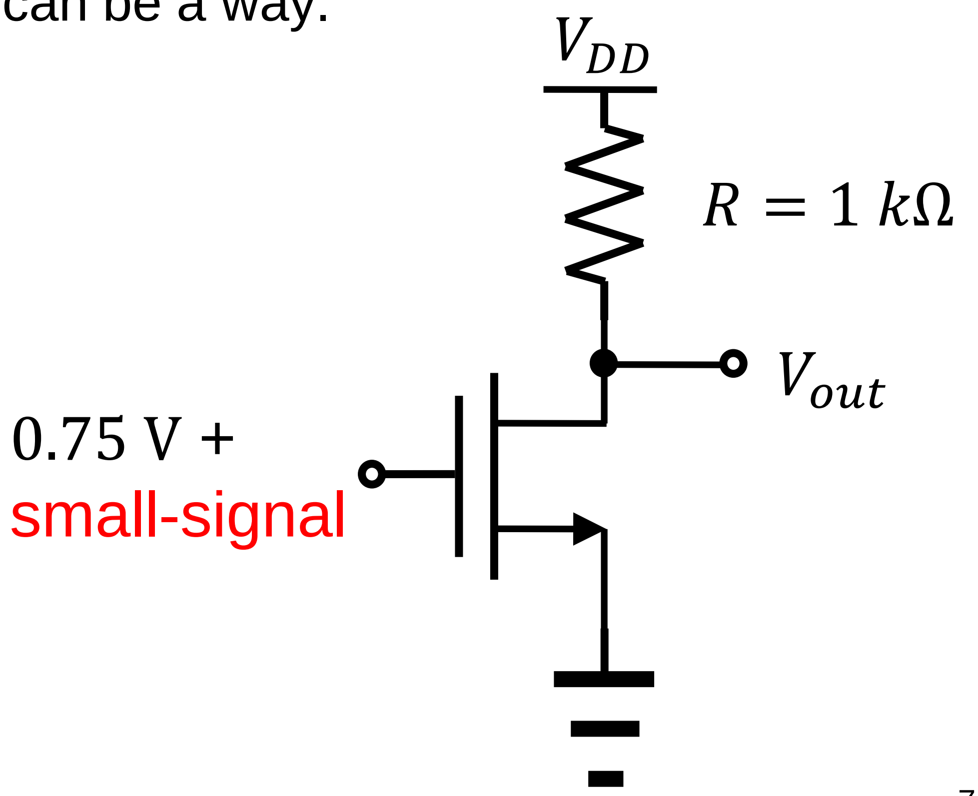
Transistor turned off

- In the circuit shown in this slide, $V_{out} = V_{DD} - I_D R$.
  - But, the transistor is not turned on. ($I_D \approx 0$)
  - The transconductance(g_m) is zero.
  - The small-signal change of the gate voltage does not change I_D.
  - The circuit generates no output signal.



This is a solution.

- The following circuit shows a revised circuit.
  - It has a meaningful value of g_m. (As much as $V_{TH} < 0.75\ \mathrm{V}$)
  - Then, how can we generate $0.75\ \mathrm{V}$, for example?
  - Use of a separate battery can be a way.



Homework#6 (1)

- Due: 09:00, April 30
- Write a program, which reads a netlist file.
  - In this program, the matrix describes a system:
  - For a voltage source:
    - The voltage difference between two terminals is fixed.
    - Sum of two terminal currents vanishes.
  - For a resistor:
    - The terminal current and the voltage difference satisfy Ohm's law.
    - Sum of two terminal currents vanishes.
  - For every element terminal, the terminal voltage is equal to the circuit node voltage.
  - For the GND node, the node voltage is zero.
  - For all other circuut nodes, the KCL is applied.

Homework#6 (2)

- (Continued)
  - For example, consider the example in Homework#4. A voltage source and a resistor are found.
  - The matrix is explicitly shown below.

$$
\begin{bmatrix}
0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & -1/R & 1/R & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\times
\begin{bmatrix}
I_1^V \\ I_2^V \\ V_1^V \\ V_2^V \\ I_1^R \\ I_2^R \\ V_1^R \\ V_2^R \\ V_0 \\ V_{in}
\end{bmatrix}
=
\begin{bmatrix}
V_{source} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0
\end{bmatrix}
$$

Homework#6 (3)

- (Continued)
  - In Homework#6, just solve the set of equations shown in the previous slide.
  - The fully functional code will be needed in Homework#7.

Homework#6 (4)

- Solve the following problems of the mid-term exam in 2018. (Not 2017)
  - P4
  - P27
  - P28
  - P35
  - P36
  - P41
  - P42