Lecture14: PMOSFET

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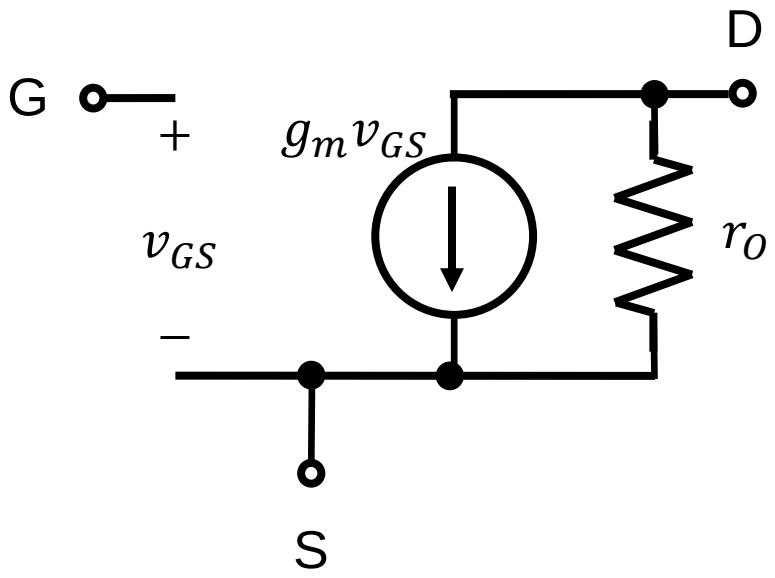
Small-signal MOSFET model

- Small-signal MOSFET model
  - Two branches are related with two partial derivatives.



Simple math

- Following relations are useful.
  - Sine and cosine functions can be expanded with $e^{+j\omega t}$ and $e^{-j\omega t}$.

$$\sin \omega t = -\frac{j}{2} e^{+j\omega t} + \frac{j}{2} e^{-j\omega t}$$

$$\cos \omega t = \frac{1}{2} e^{+j\omega t} + \frac{1}{2} e^{-j\omega t}$$

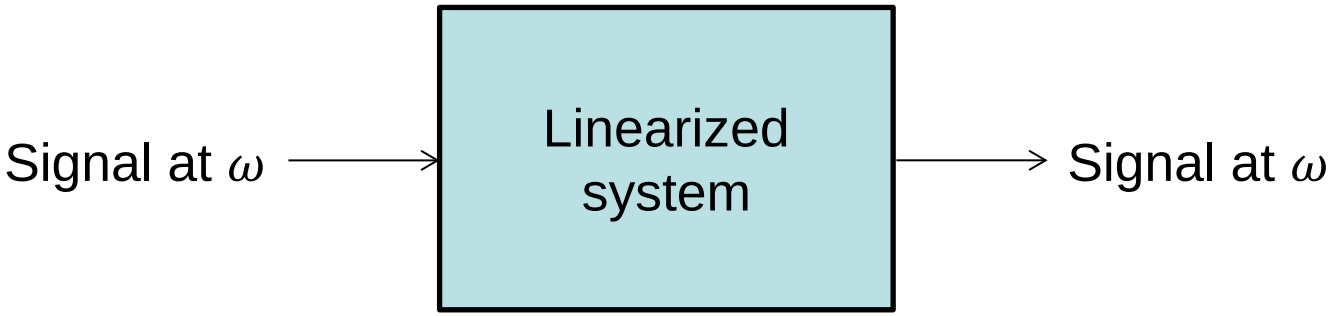
  - Therefore, for a function of $f(t) = f_s \sin \omega t + f_c \cos \omega t$, the expansion is

$$f(t) = \left(-j\frac{f_s}{2} + \frac{f_c}{2}\right) e^{+j\omega t} + \left(+j\frac{f_s}{2} + \frac{f_c}{2}\right) e^{-j\omega t}$$

  - A single complex number, $-j\frac{f_s}{2} + \frac{f_c}{2}$, is enough to represent $f(t)$.

Linearized system

- Our circuit is nonlinear in general.
- However, we have *linearized* it.
  - When the input signal has an angluar frequency, ω, the output signal has the same one.
  - It is sufficient to consider the input-output relation at ω.



Impedance

- Resistance, $V(t) = R\, I(t)$
  - It is assumed that $V(t)$ and $I(t)$ are in the same phase.
- Impedance, $V(\omega) = Z(\omega) I(\omega)$
  - Consider $V(t) = V_0 \sin \omega t$ and $I(t) = I_0 \cos \omega t$. (Different phases)
  - We introduce a phasor voltage, $V(\omega)$, and a phasor current, $I(\omega)$.
  - The relation between $V(t)$ and $V(\omega)$ is $V(t) = Re\left[V(\omega) e^{j\omega t}\right]$.
  - When $V(t) = V_0 \sin \omega t$, the phasor voltage is $V(\omega) = -jV_0$.
  - When $I(t) = I_0 \cos \omega t$, the phasor voltage is $I(\omega) = I_0$.
  - In this example, $Z(\omega) = -j \frac{V_0}{I_0}$. A purely imaginary number.

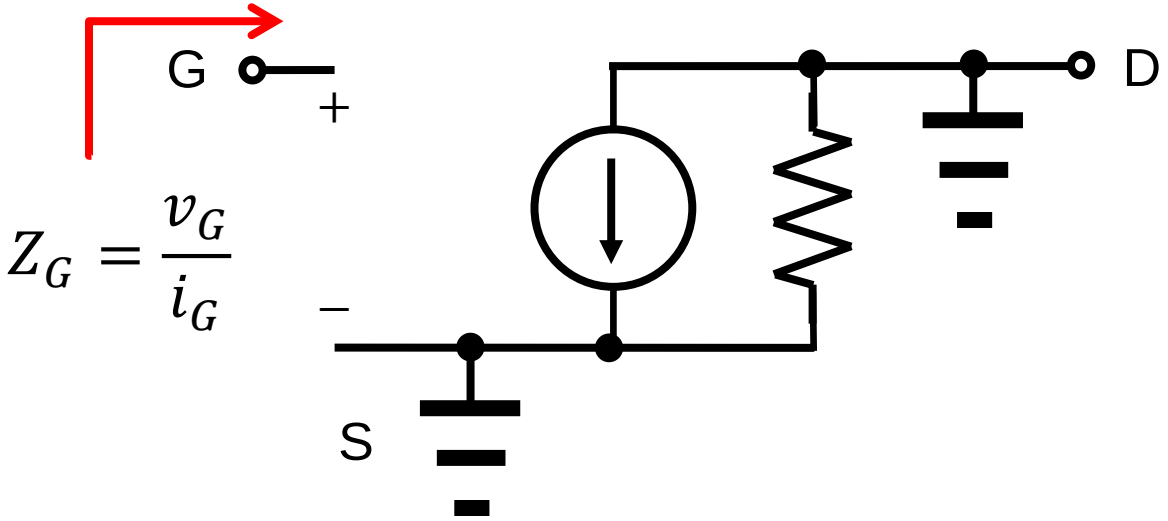
Multi-terminal devices

- When the number of terminals is 3,
  - We can define 9 (= 3 X 3) different impedances.

- Termination condition is important.
  - Depending on the termination condition, the impedance can be heavily changed.
  - In many cases, it is obvious from the problem.

Impedances of MOSFET

- "Looking into the *TERMINAL*," we see the impedance of the *TERMINAL*.
  - Example) Looking into the gate. The source and drain are ac-grounded.



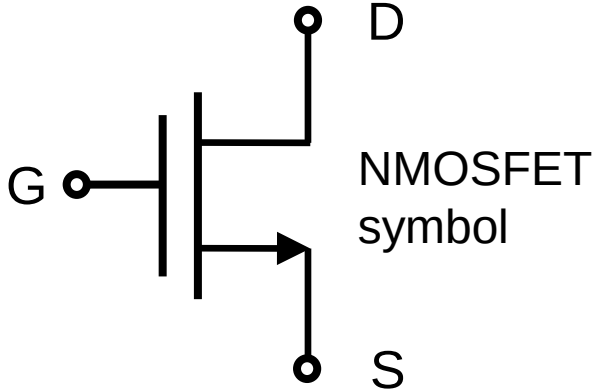
  - Similar for other terminals

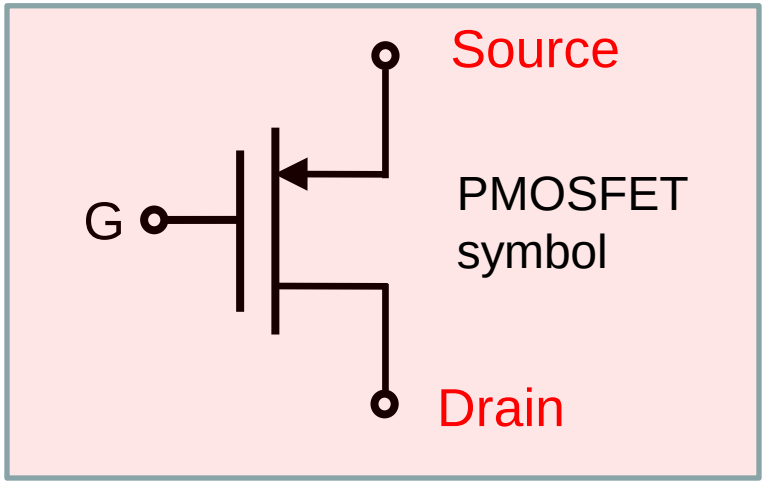
NMOSFET

- 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

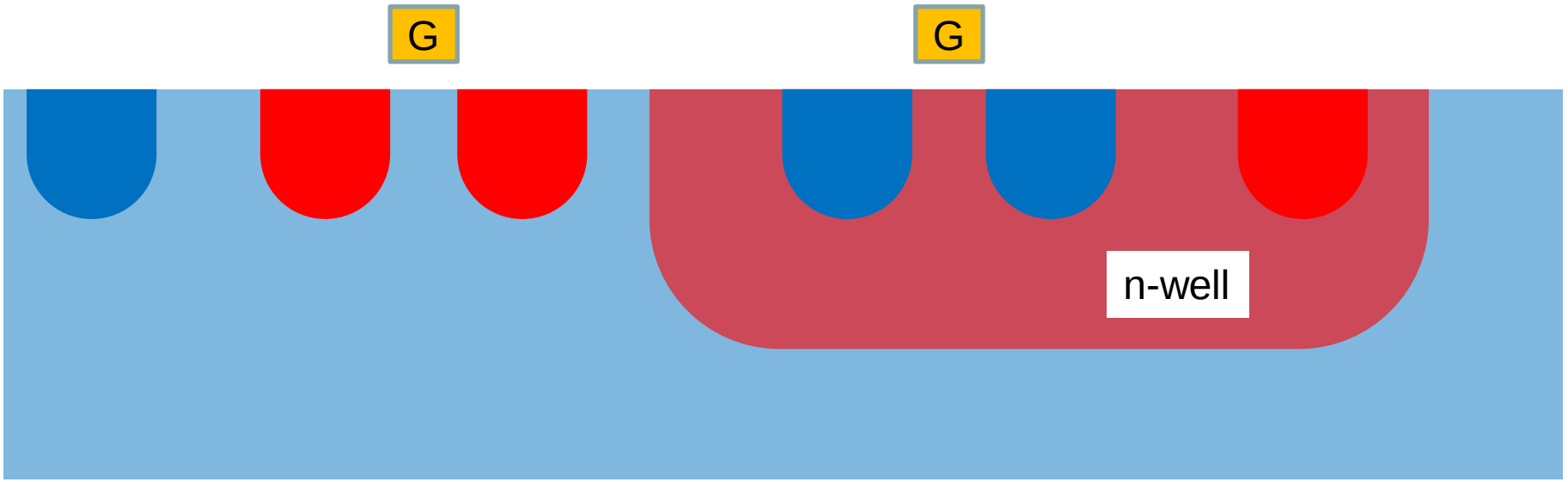




  - Example) $V_{TH,P} = -1.5$ V. Assume that V_S is 3 V. The gate voltage of 2 V does not turn on the transistor. 1 V turns on the transistor.
  - The drain voltage is lower than the source voltage. In the usual operation condition, the drain current is negative.

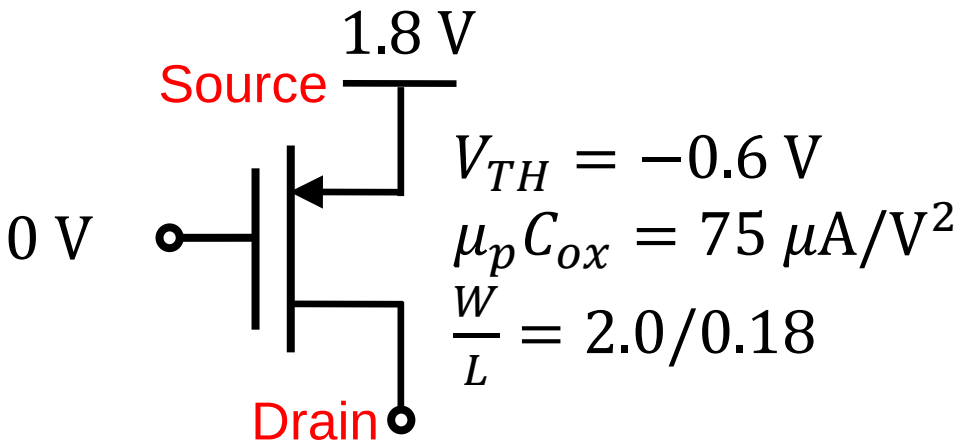
How to fabricate it

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



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 $0.6\ \mathrm{V}$.



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

Homework#6

- Due: 09:00, April 29 (Mon)
- Solve the following problems of the ***2019*** mid-term exam.
  - P9, P11, P14, P16, P18, P24, P26, P29, P32, P33, P34, P35, P37, P39, and P40
  - In total, 15 problems.