Essentials of MOSFETs

Unit 1: Transistors and Circuits

Lecture 1.1: The MOSFET as a Black Box

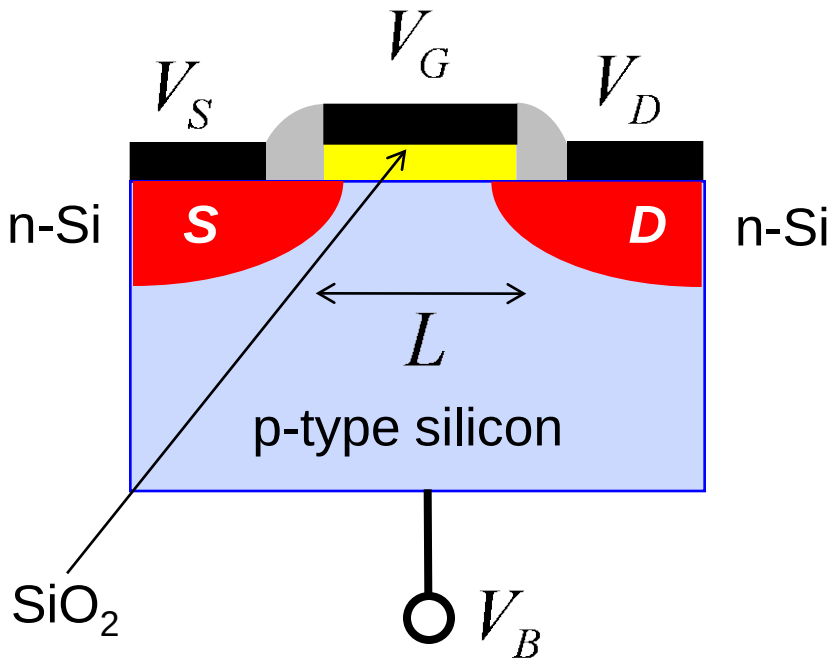
Mark Lundstrom

lundstro@purdue.edu
Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana USA

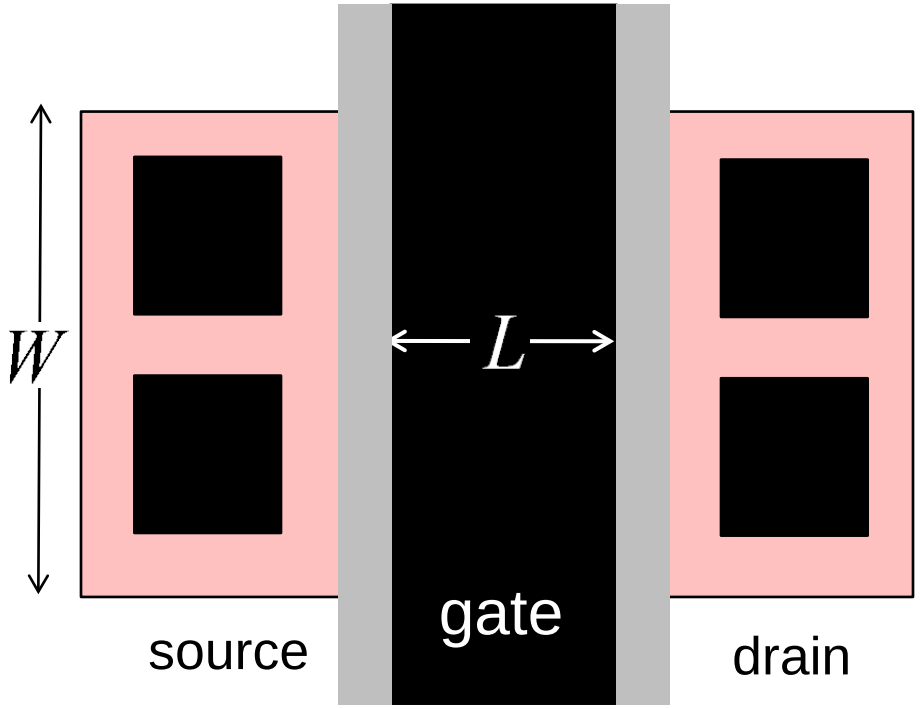
PURDUE UNIVERSITY

Side and top views of a MOSFET

Metal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor



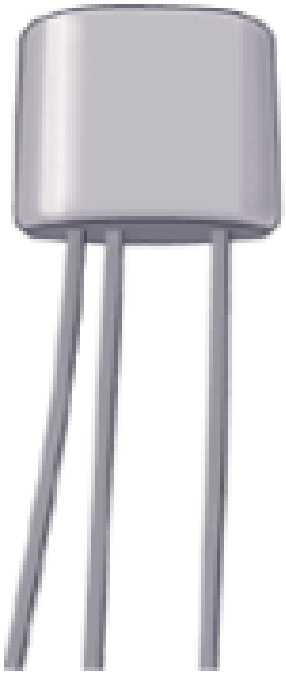
side view



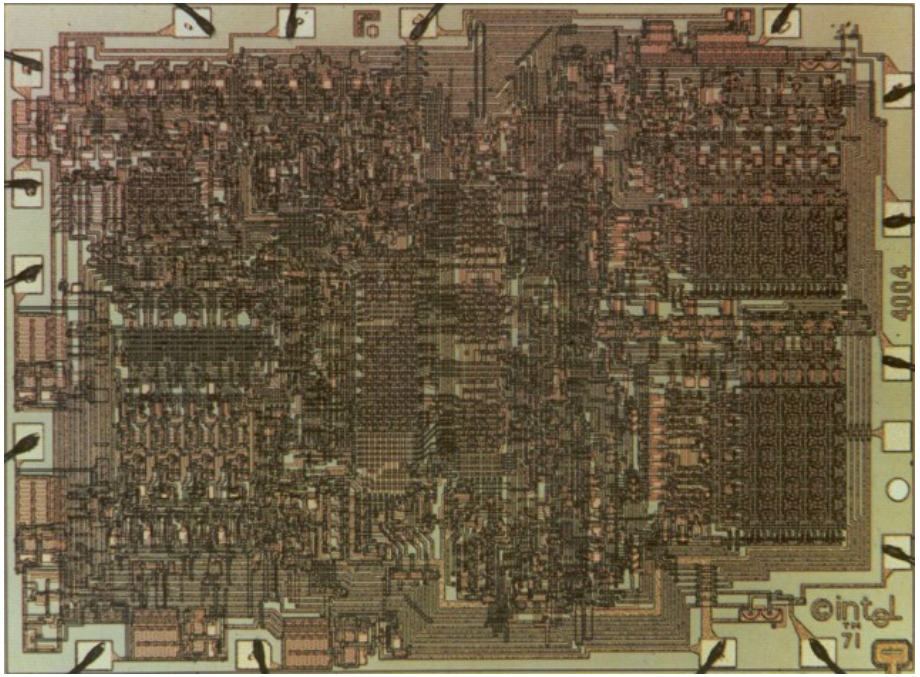
top view

Transistors

Discrete



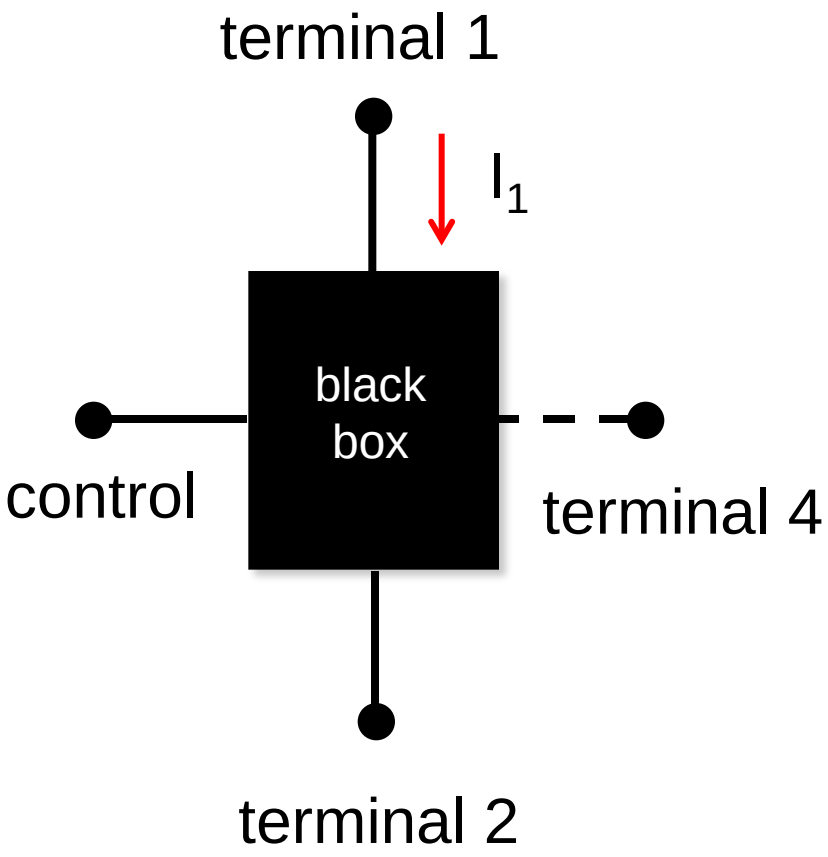
Integrated circuits



Intel 4004 (2300 transistors) 1971

https://www.extremetech.com/computing/105029-intel-4004-the-first-cpu-is-40-years-old-today

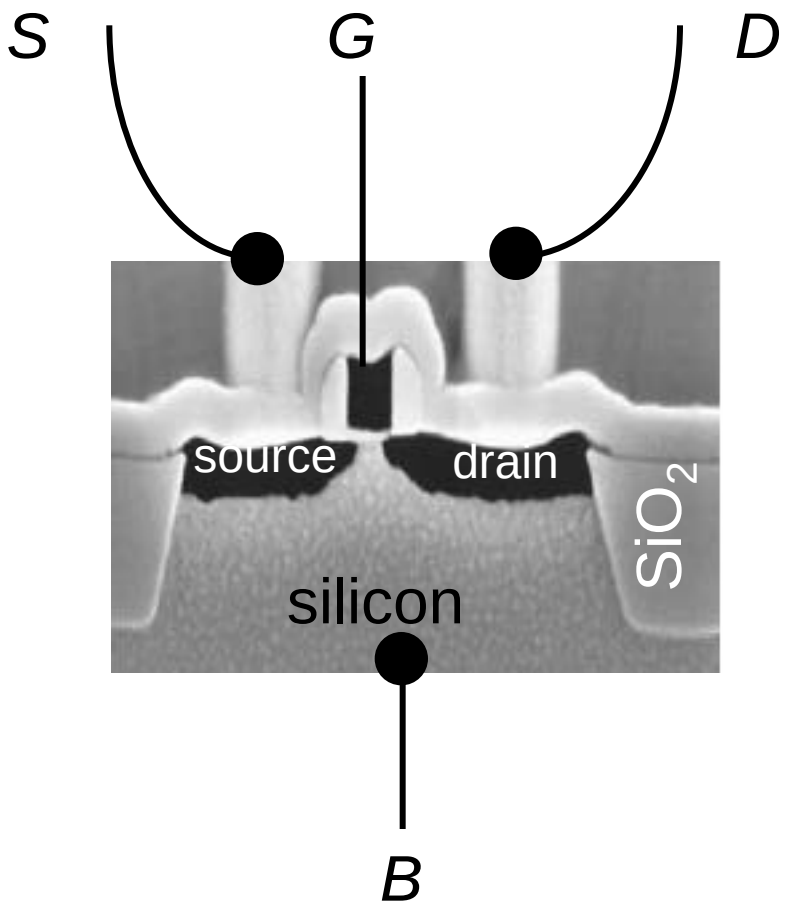
The transistor as a “black box”



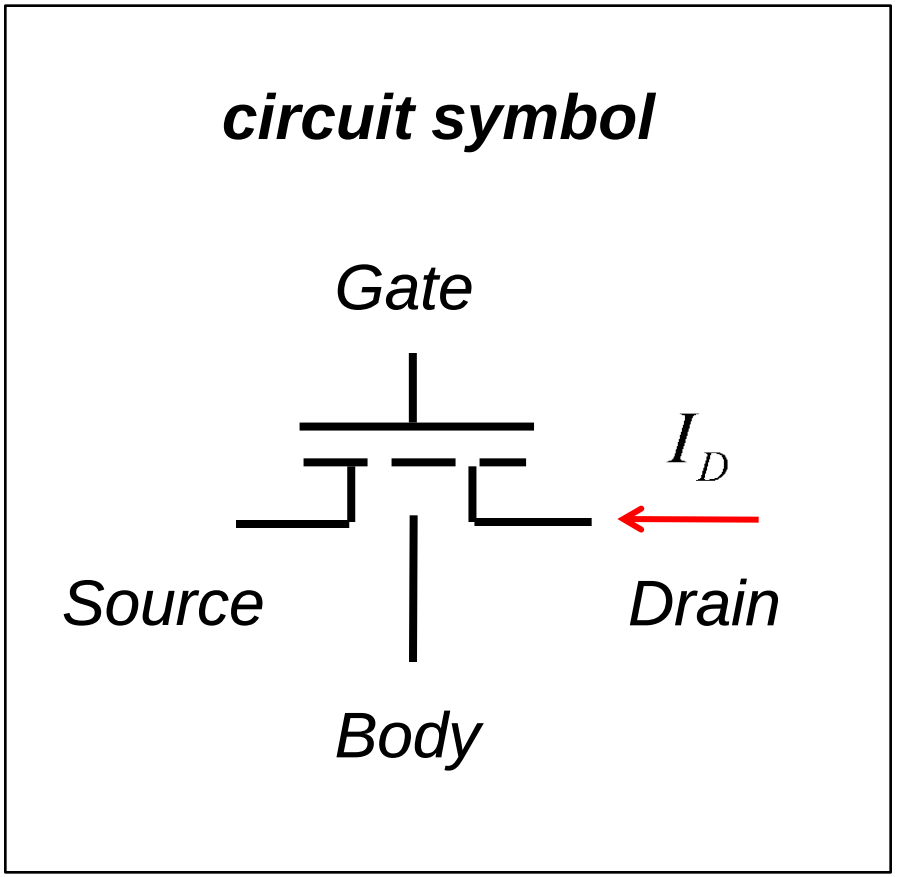
There are many kinds of transistors:

MOSFET
SOI MOSFET
FinFETs
SB FET
FinFET
MODFET (HEMT)
bipolar transistor
JFET
heterojunction bipolar transistor
BTBT FET
SpinFET
…

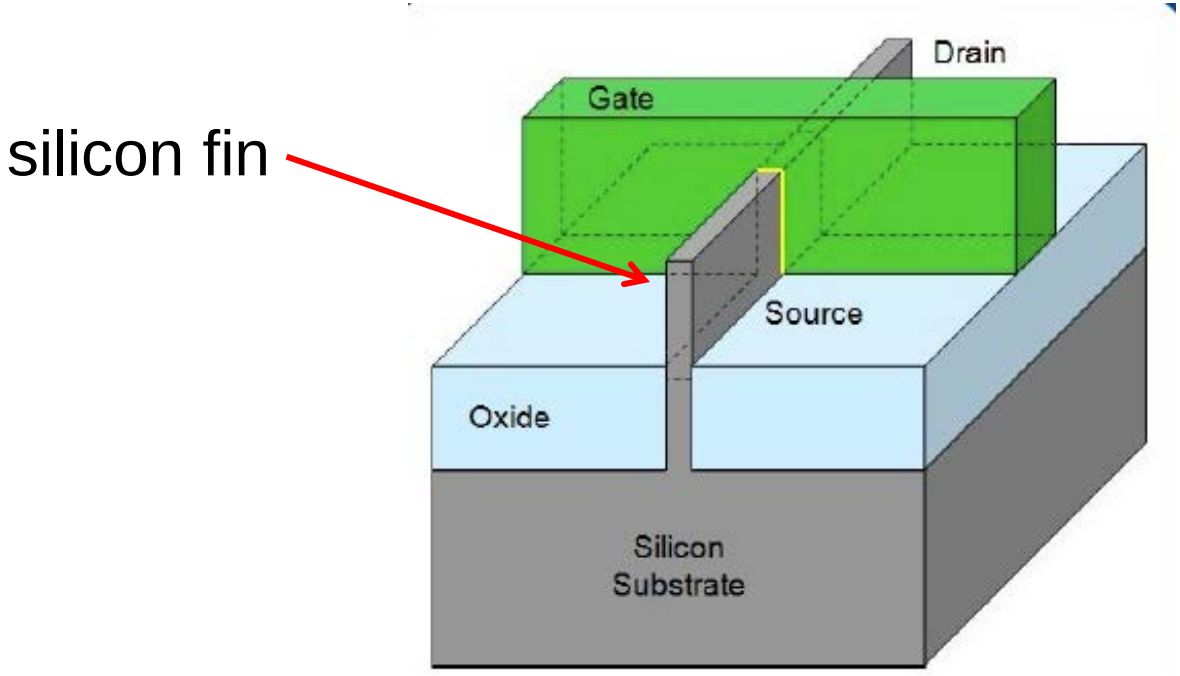
The bulk MOSFET



(Texas Instruments, ~ 2000)



Modern MOSFETs: The FinFET

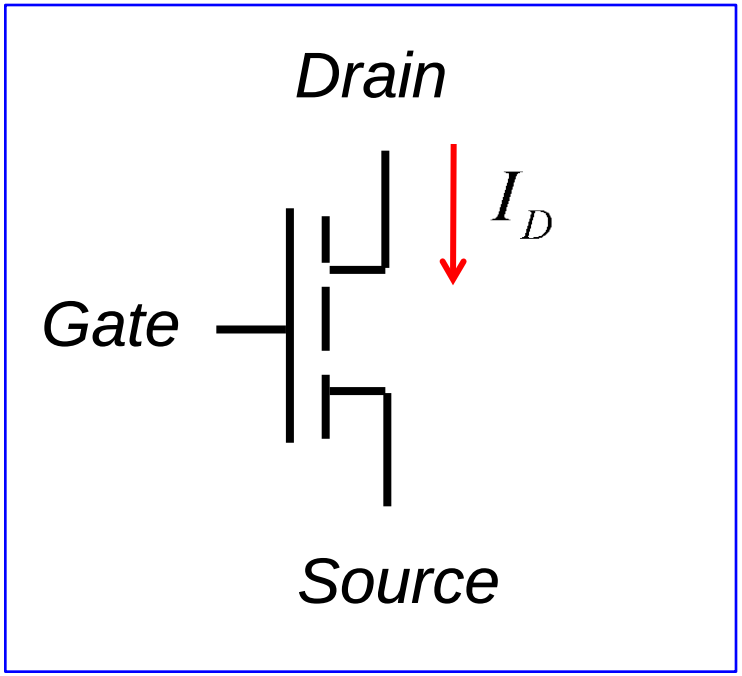


Source: Intel

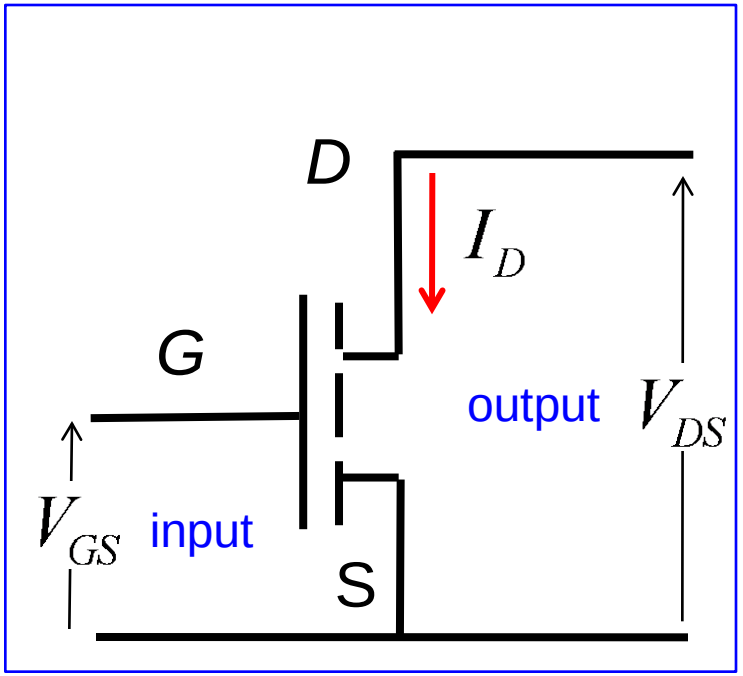
Digh Hisamoto, Wen-Chin Lee, Jakub Kedzierski, Hideki Takeuchi, Kazuya Asano, Charles Kuo, Erik Anderson, Tsu-Jae King, Jeffrey Bokor, Chenming Hu, "FinFET-a self-aligned double-gate MOSFET scalable to 20 nm," *IEEE Transactions on Electron Devices*, **47**, 2320-2325, 2000.

The MOSFET as a 2-port device

MOSFET circuit symbol



common source



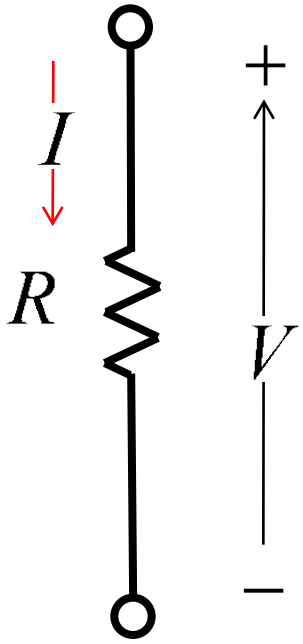
current vs. voltage (IV) characteristics

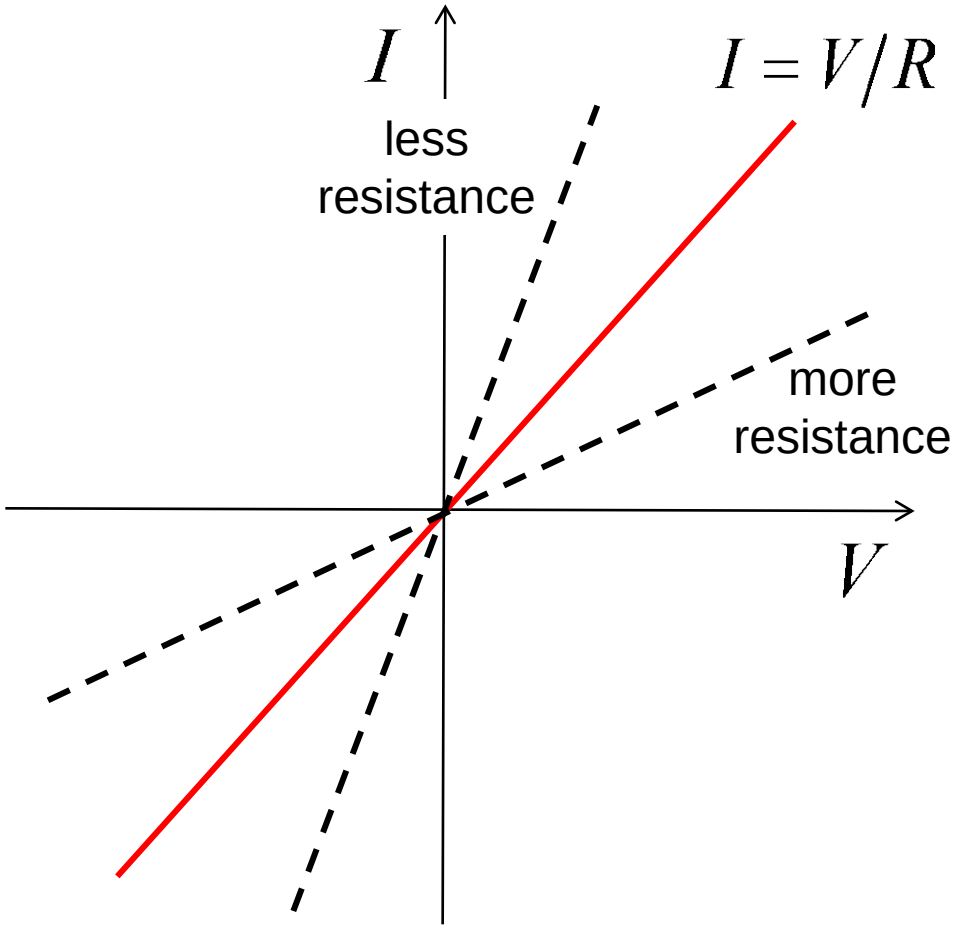
$$I_D\left(V_G, V_S, V_D\right)$$

$I_D\left(V_{GS}\right)$ at a fixed V_{DS} transfer

$I_D\left(V_{DS}\right)$ at a fixed V_{GS} output

IV characteristics: resistor

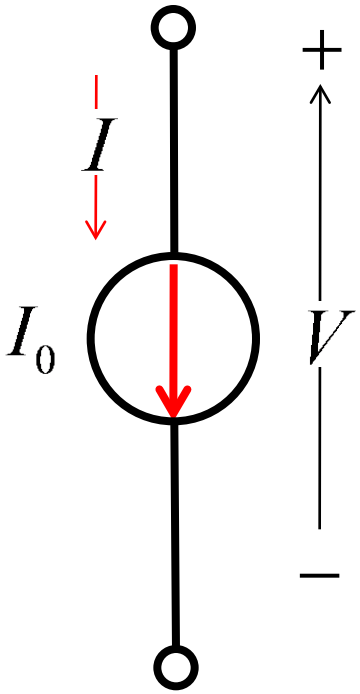




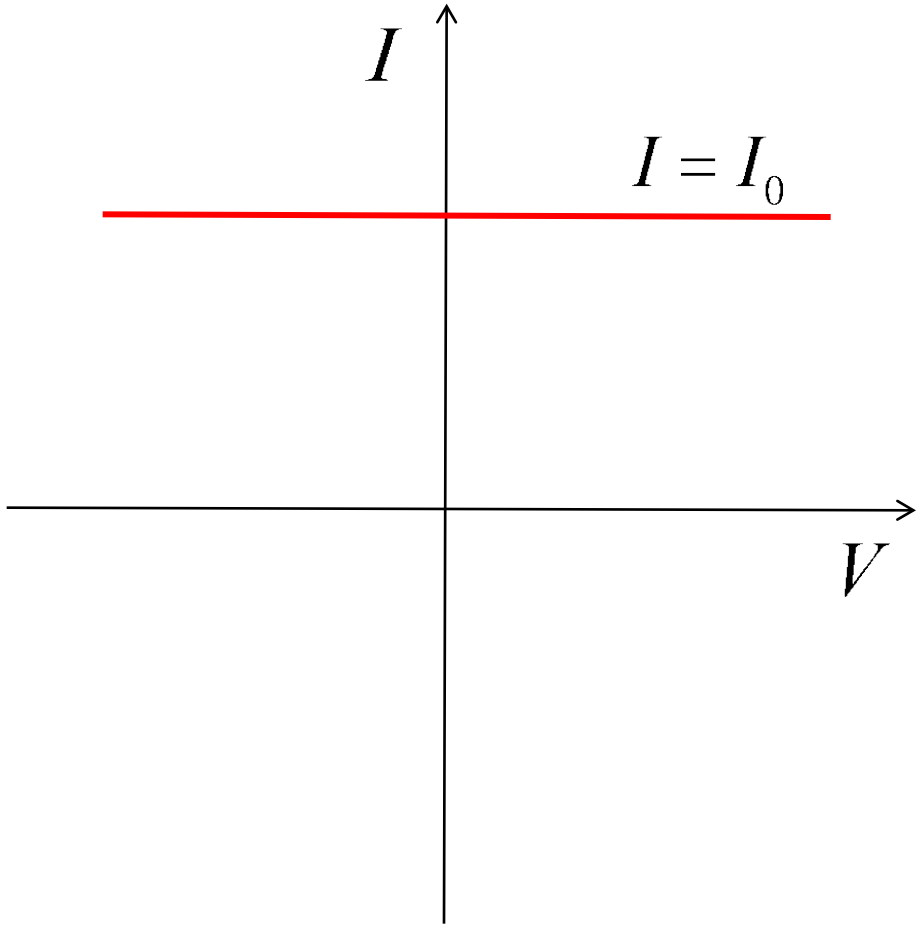
$I = V/R$ Ohm's Law

Georg Ohm, 1827

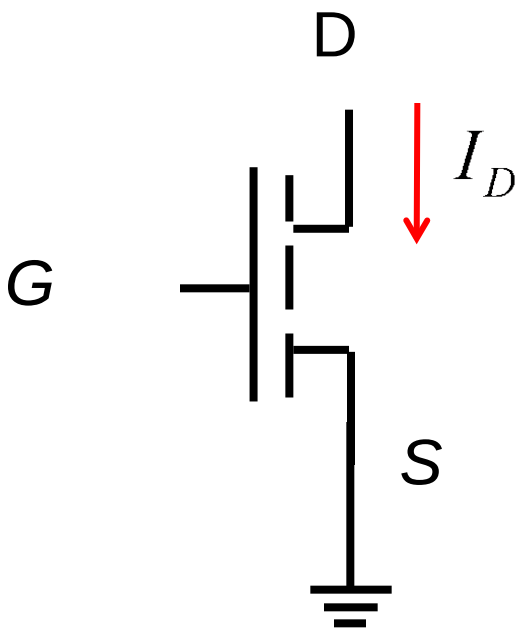
IV characteristics: ideal current source



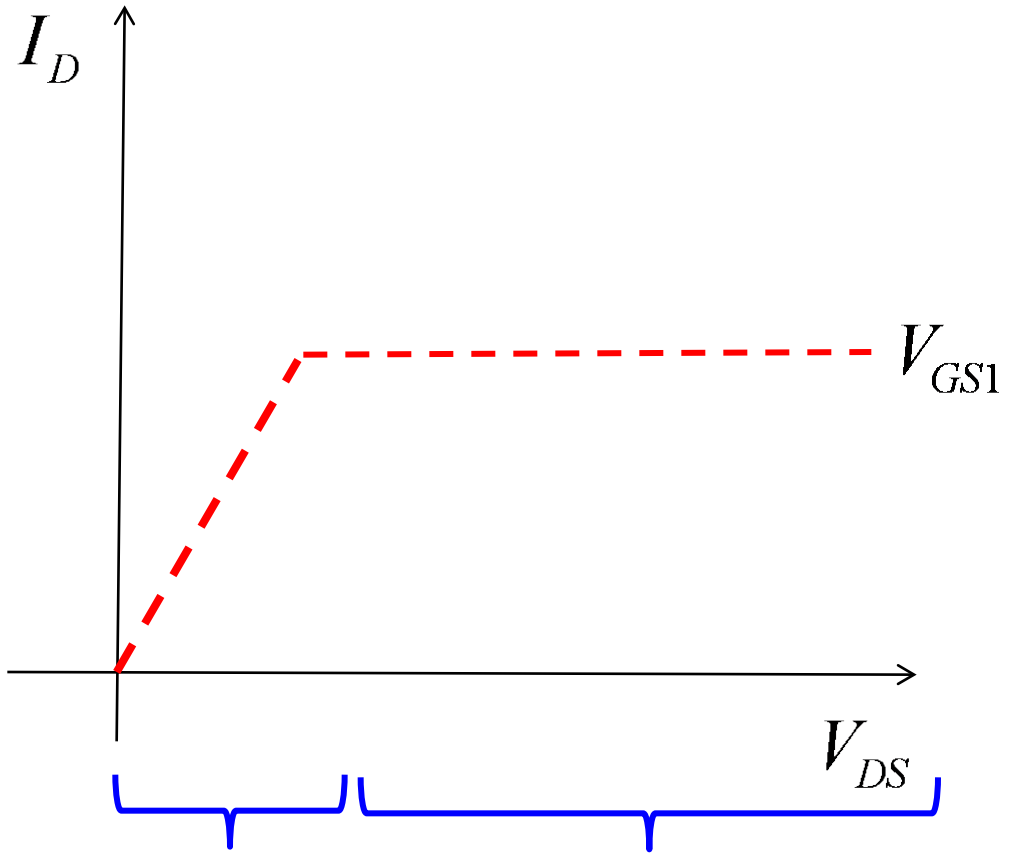
$I = I_0$



IV characteristics: transistors



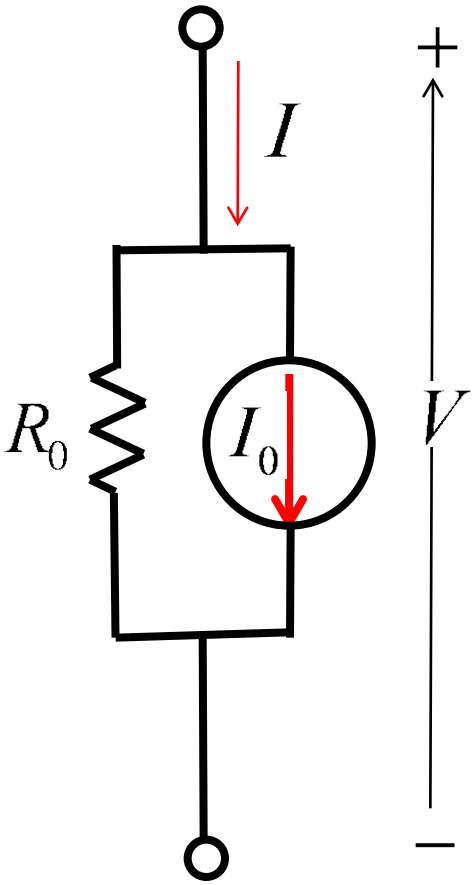
n-channel
enhancement
mode MOSFET

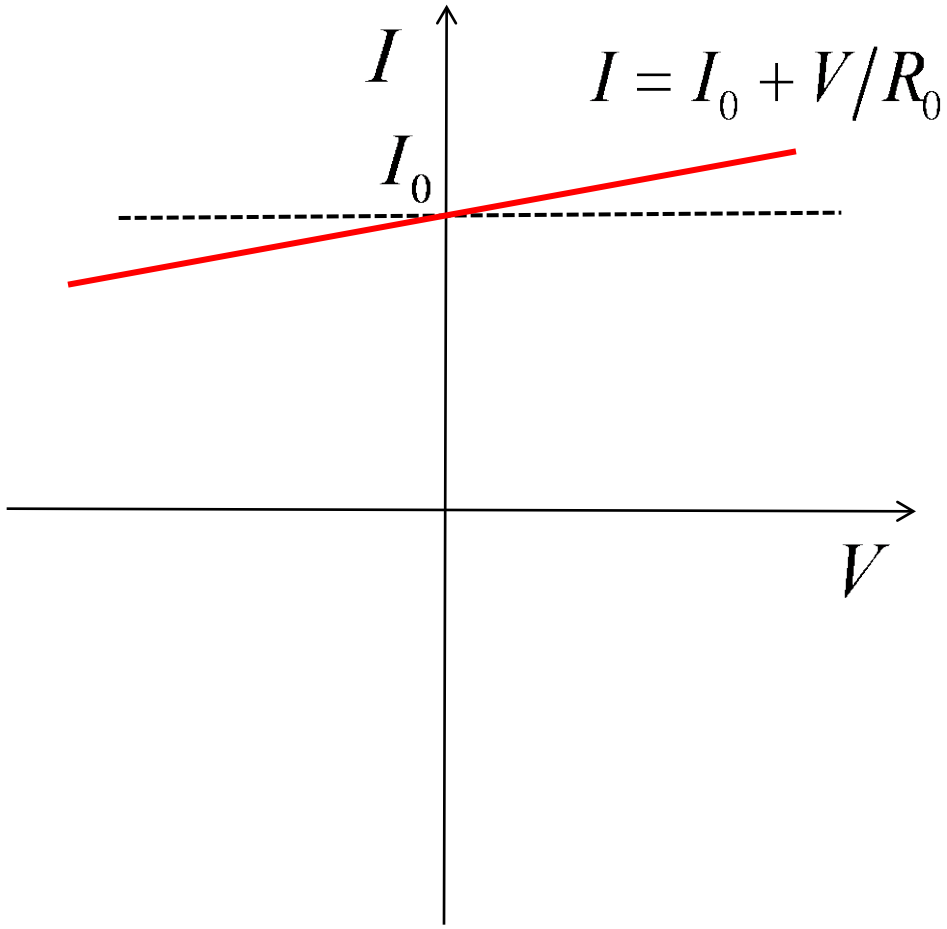


gate voltage
controlled resistor
“linear region”

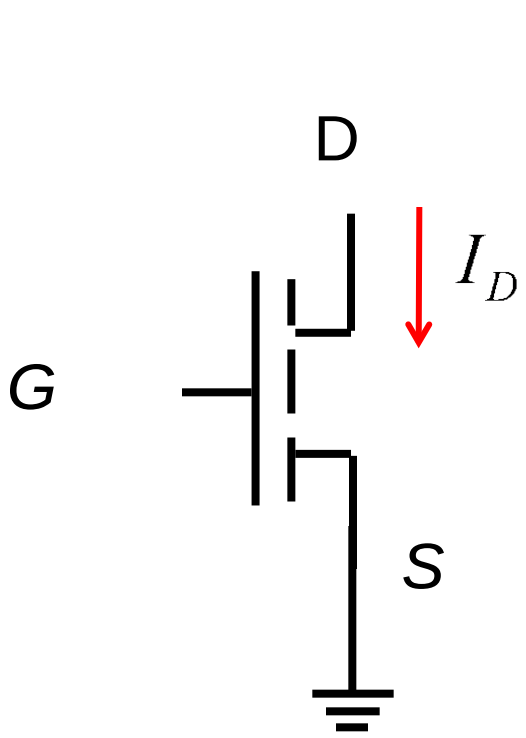
gate voltage controlled
current source
“saturation region”

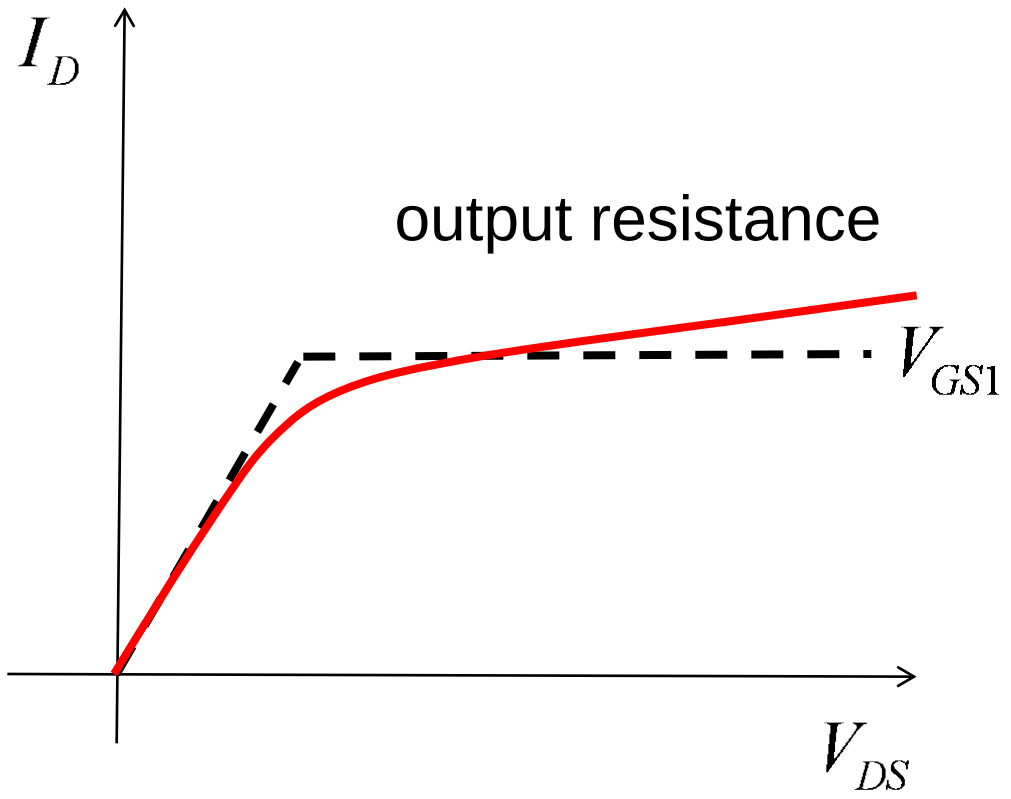
IV characteristics: real current sources





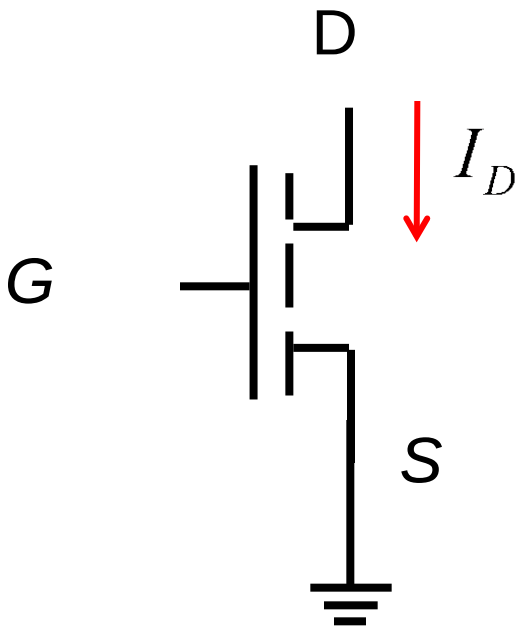
IV characteristics: transistors

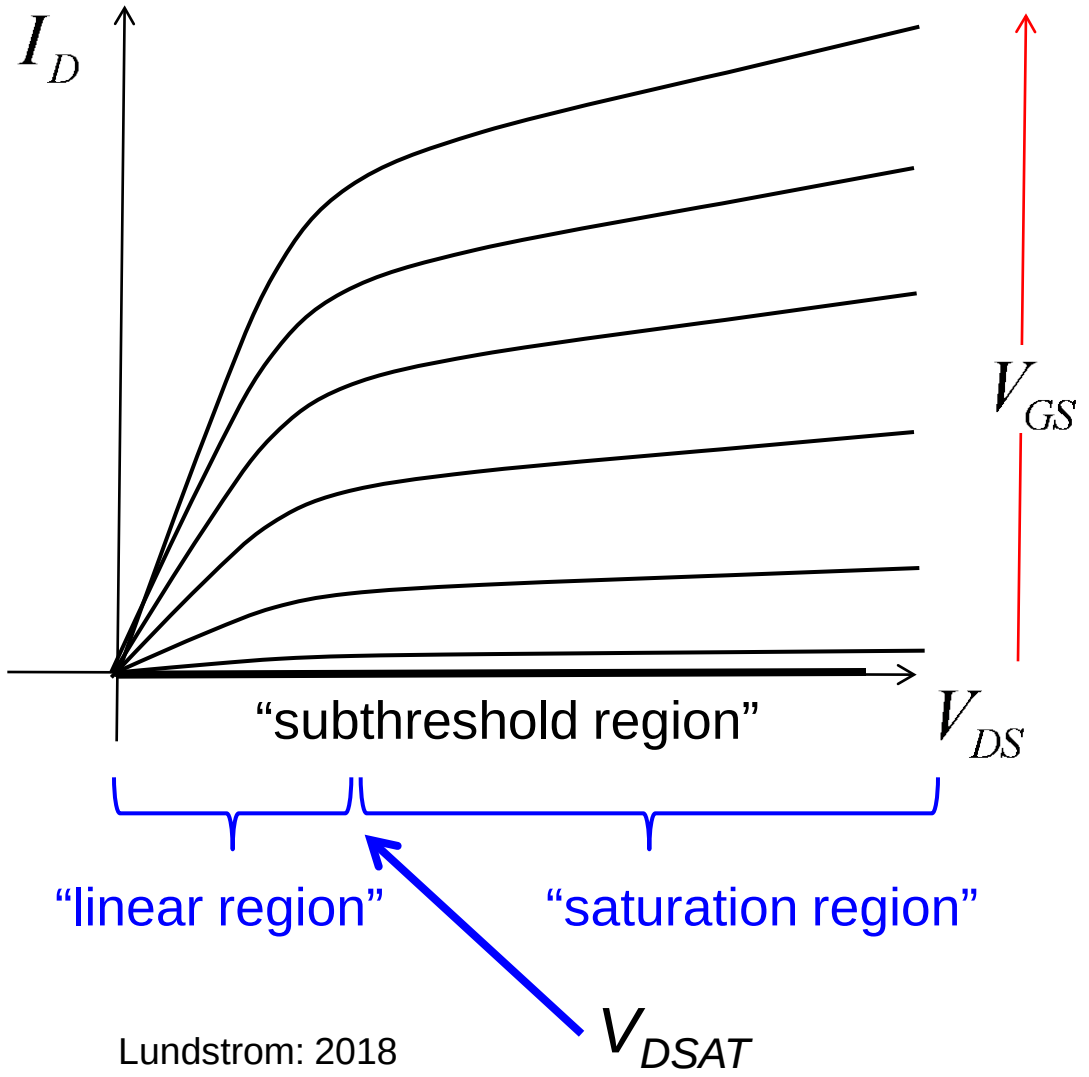




n-channel
enhancement
mode MOSFET

MOSFET IV: output characteristics

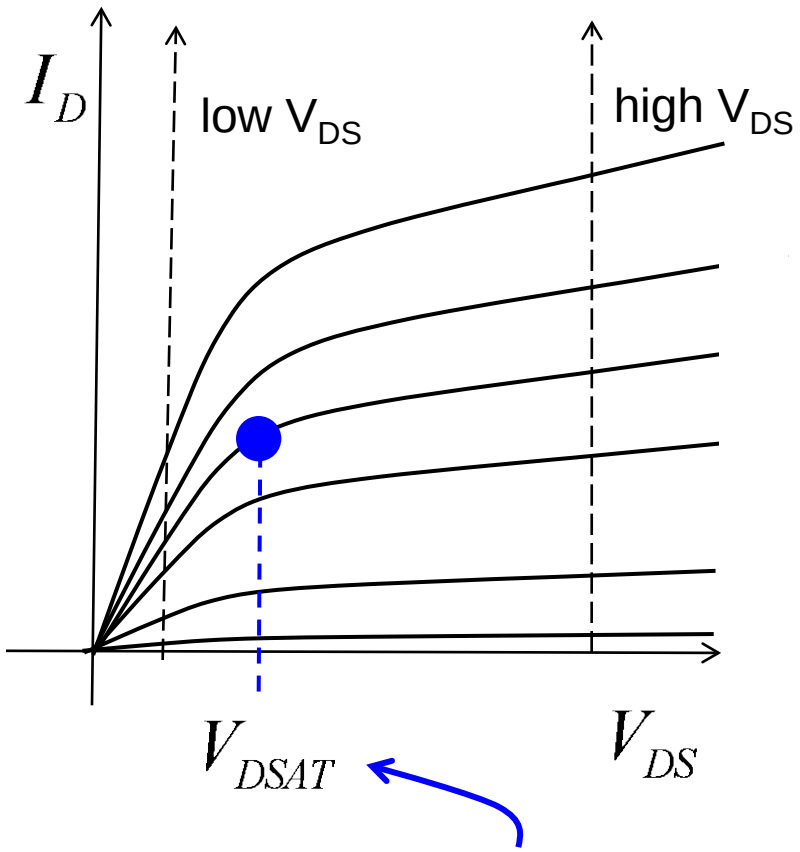


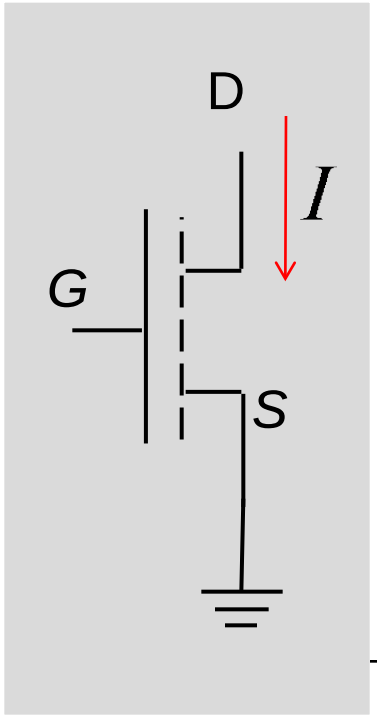


n-channel enhancement mode MOSFET

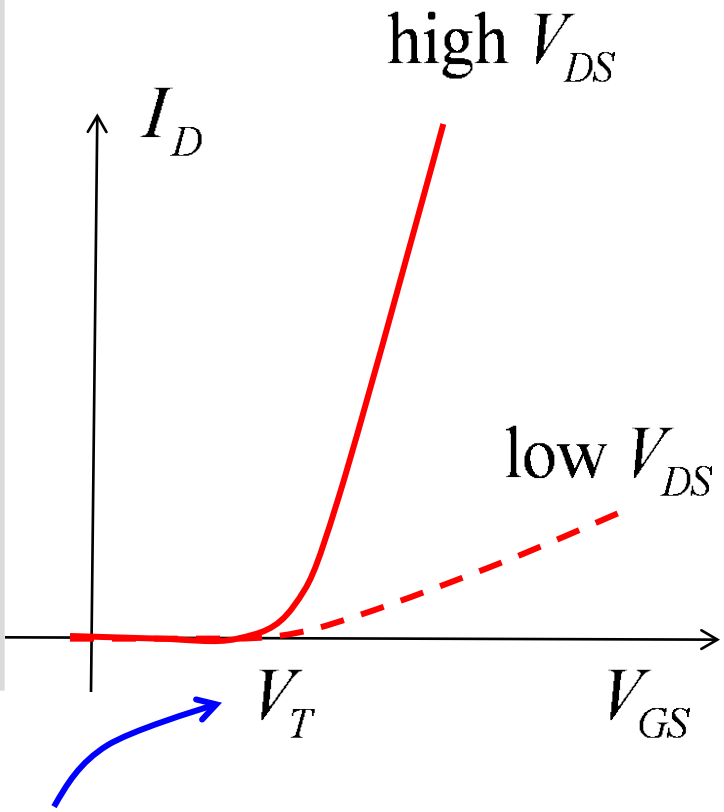
Output vs. transfer characteristics

output characteristics





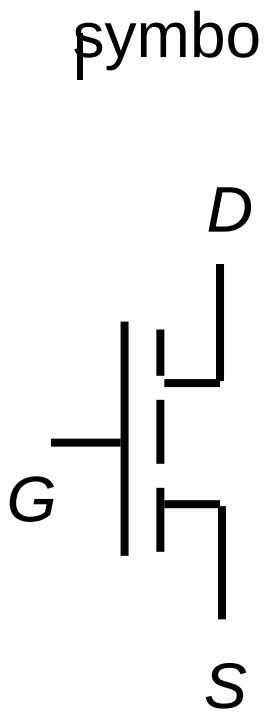
transfer characteristics

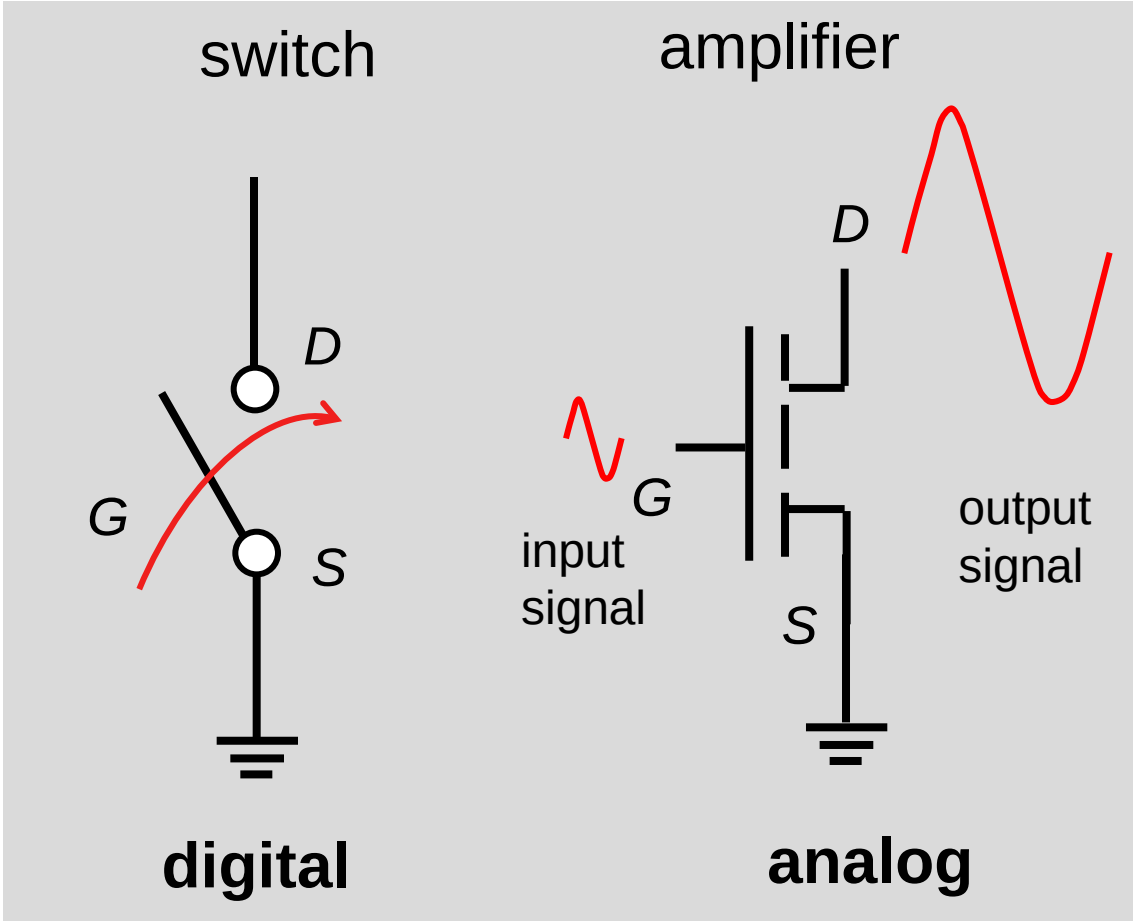


"saturation voltage"

"threshold voltage"

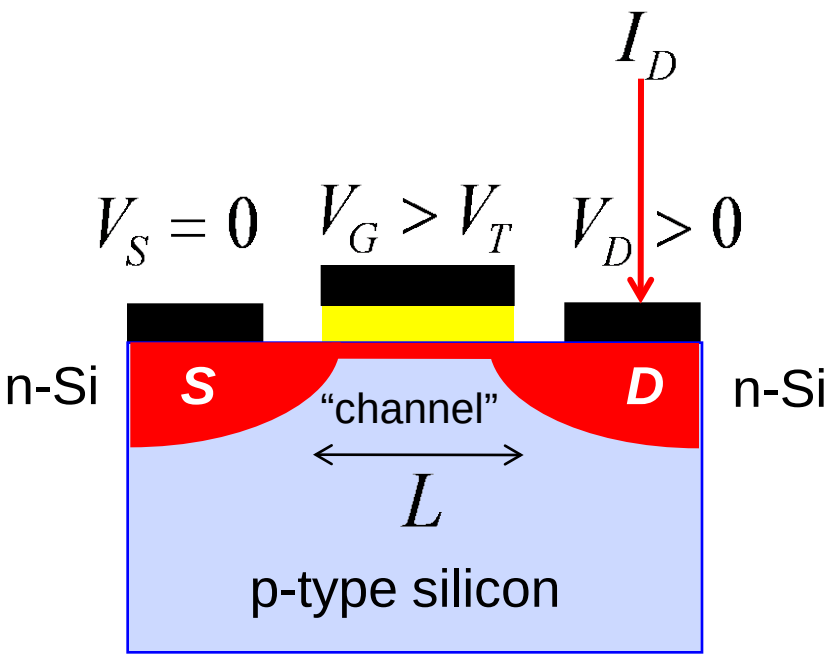
Applications of MOSFETs





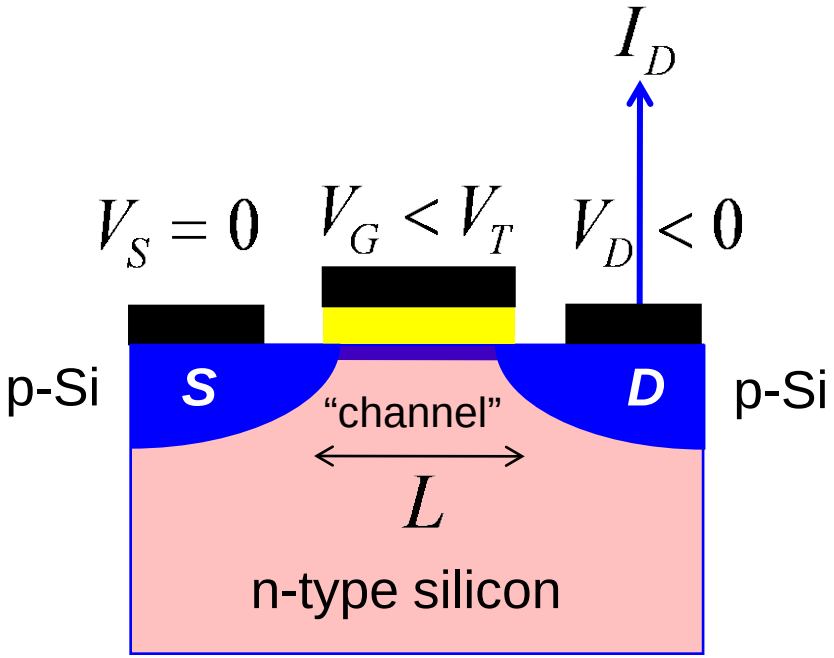
N-channel vs. P-channel MOSFETs

N-MOSFET



side view

P-MOSFET



side view

Summary

1) Transistors are three (or sometime four) terminal devices that control a large output current with an input voltage (or sometimes with a small input current).

2) Transistors can operate as a voltage controlled resistor or as a voltage controlled current course.

3) The shape of the IV characteristics make transistors useful in digital and analog circuits.

4) The shape of the IV characteristics is determined by the physics of the transistor.

Next topic: A primer on digital circuits

Device engineers assess MOSFETs in terms of a few key **device metrics**.

To understand these device metrics, we must first understand a little about digital and analog circuits.