The Abdus Salam
International Centre
for Theoretical Physics

2499-8

International Training Workshop on FPGA Design for Scientific Instrumentation and Computing

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Introduction to VLSI Digital Design
Gates

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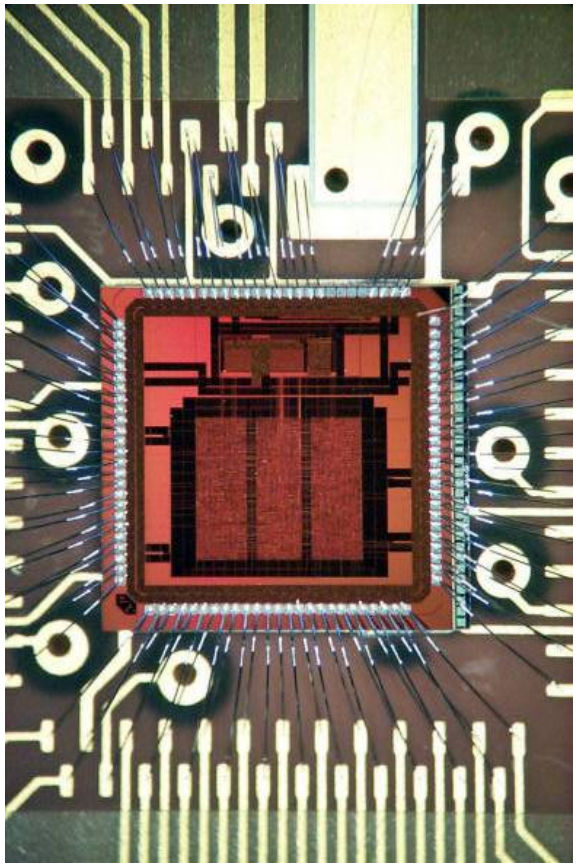
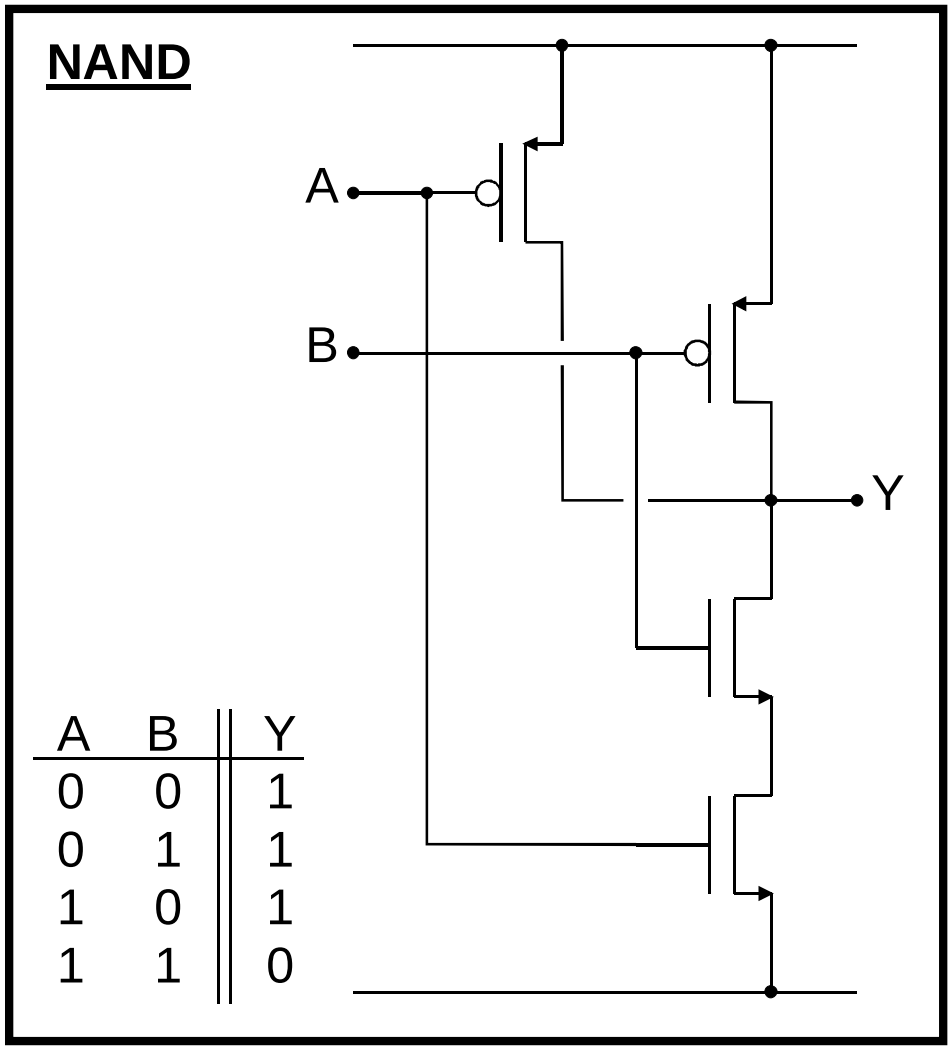
Outline

- Introduction
- Transistors
- The CMOS inverter
- Technology
- Scaling
- Gates
  - The NAND gate
  - "Reading" CMOS gates
  - Designing CMOS gates
- Sequential circuits
- Storage elements
- Phase-Locked Loops
- Example



Many slides are a courtesy of Paulo Moreira

NAND 2-inputs



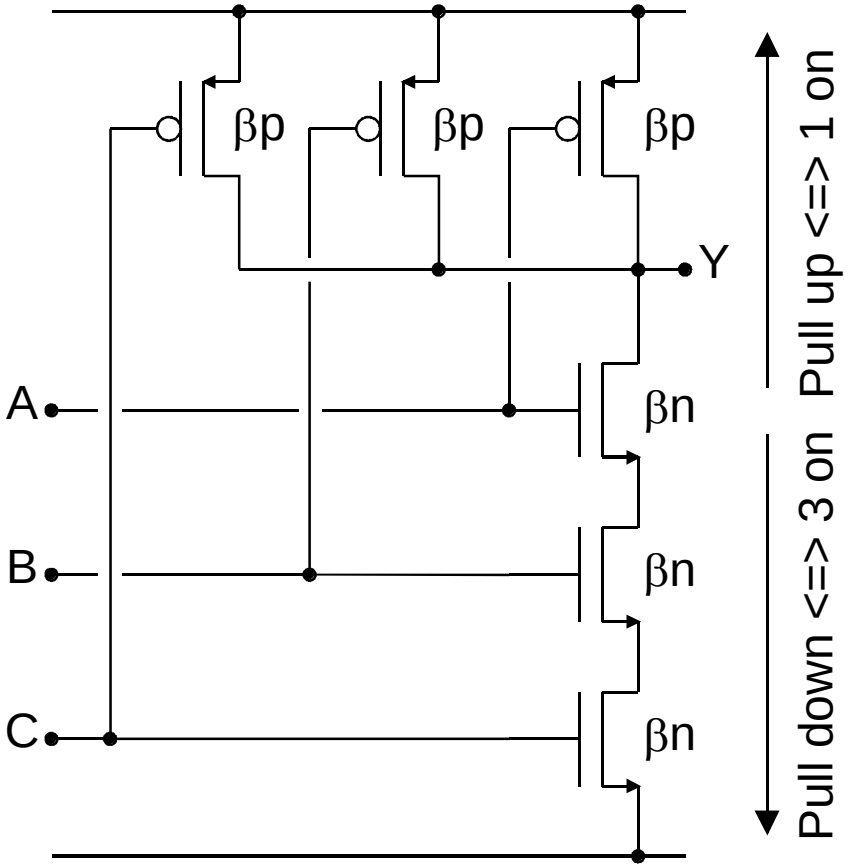
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

"Gates are inverters in disguise!"

- Pull-down: NMOS in series
  - Need 2 NMOS "on" to pull-down
- Pull-up: PMOS in parallel
  - One PMOS "on" is sufficient to pull-up

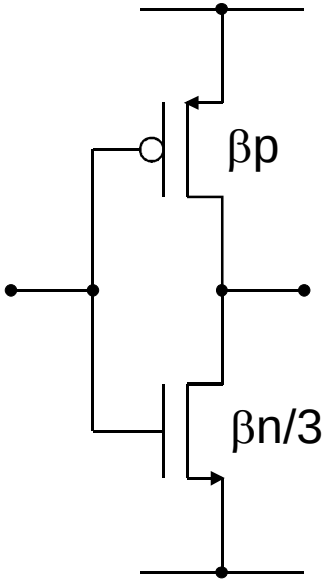
NAND 3-inputs

NAND 3 inputs



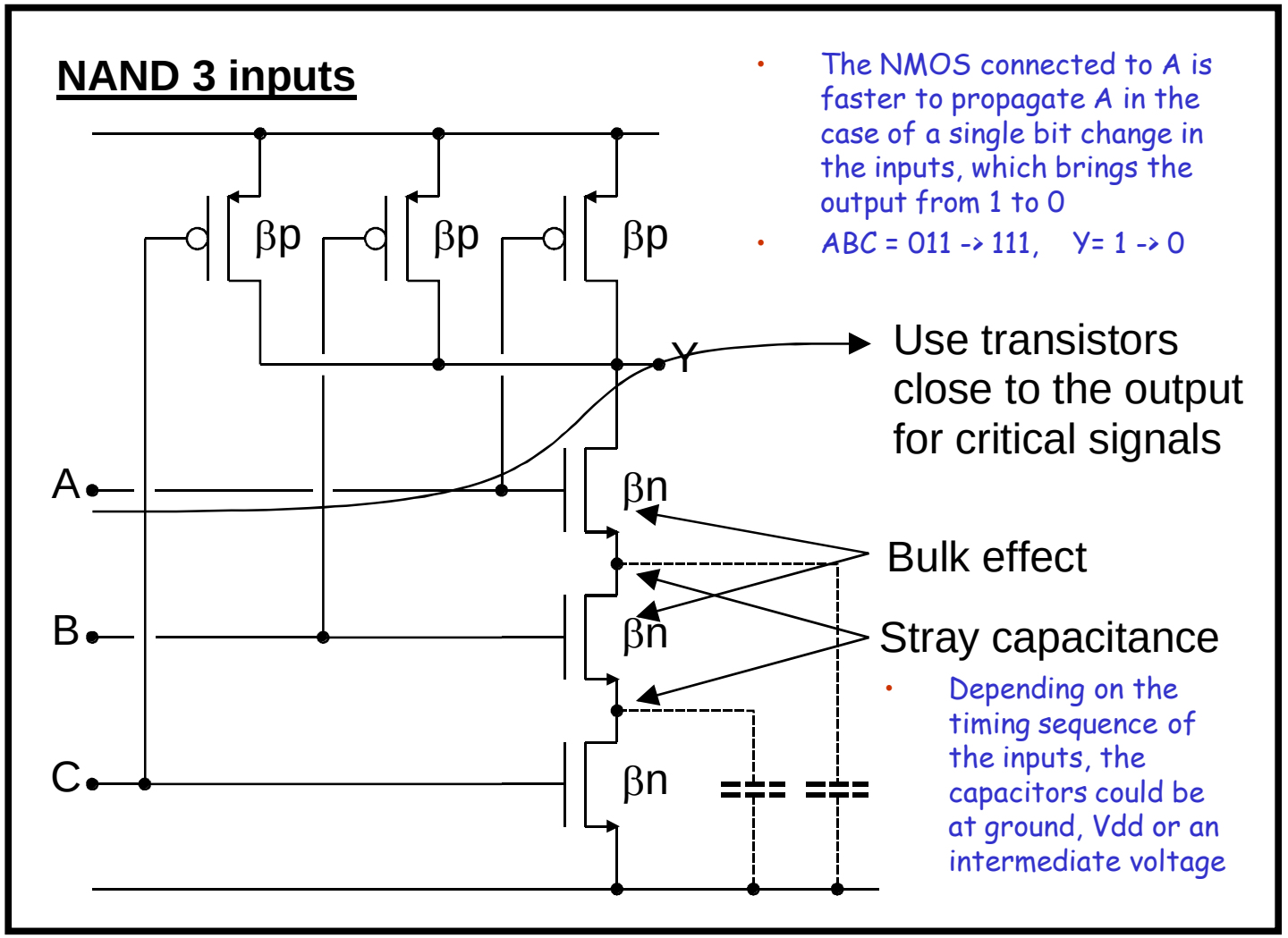
"Delay equivalent" inverter

- Approximates delay

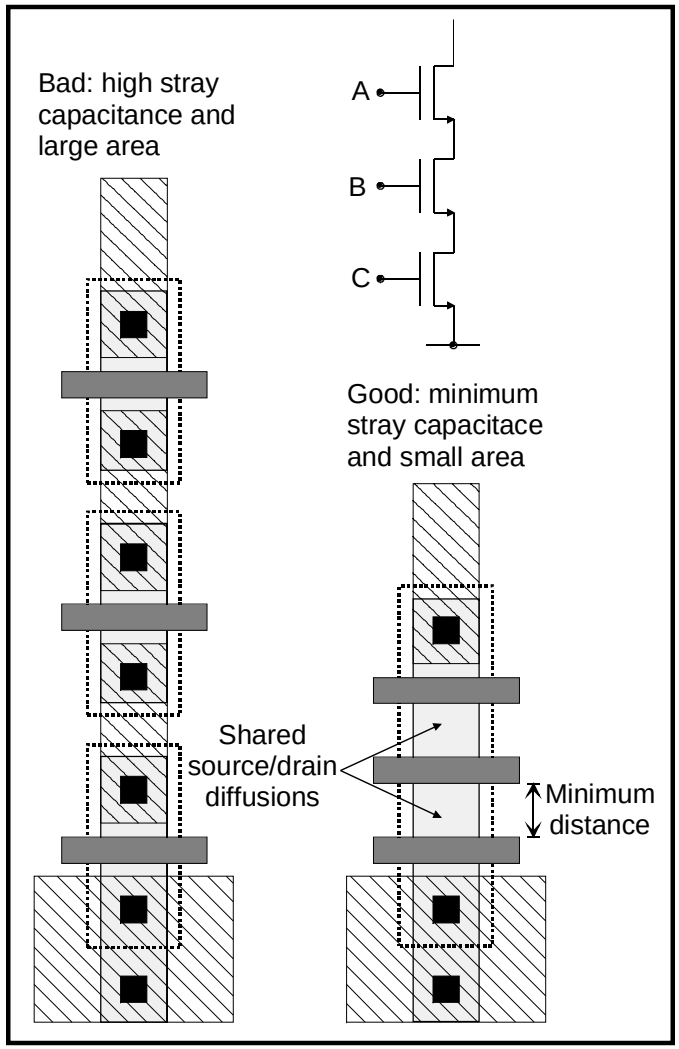


- Neglects different operating point of NMOSes:
  - Vgs, Vds, bulk effect, "memory" of nodes

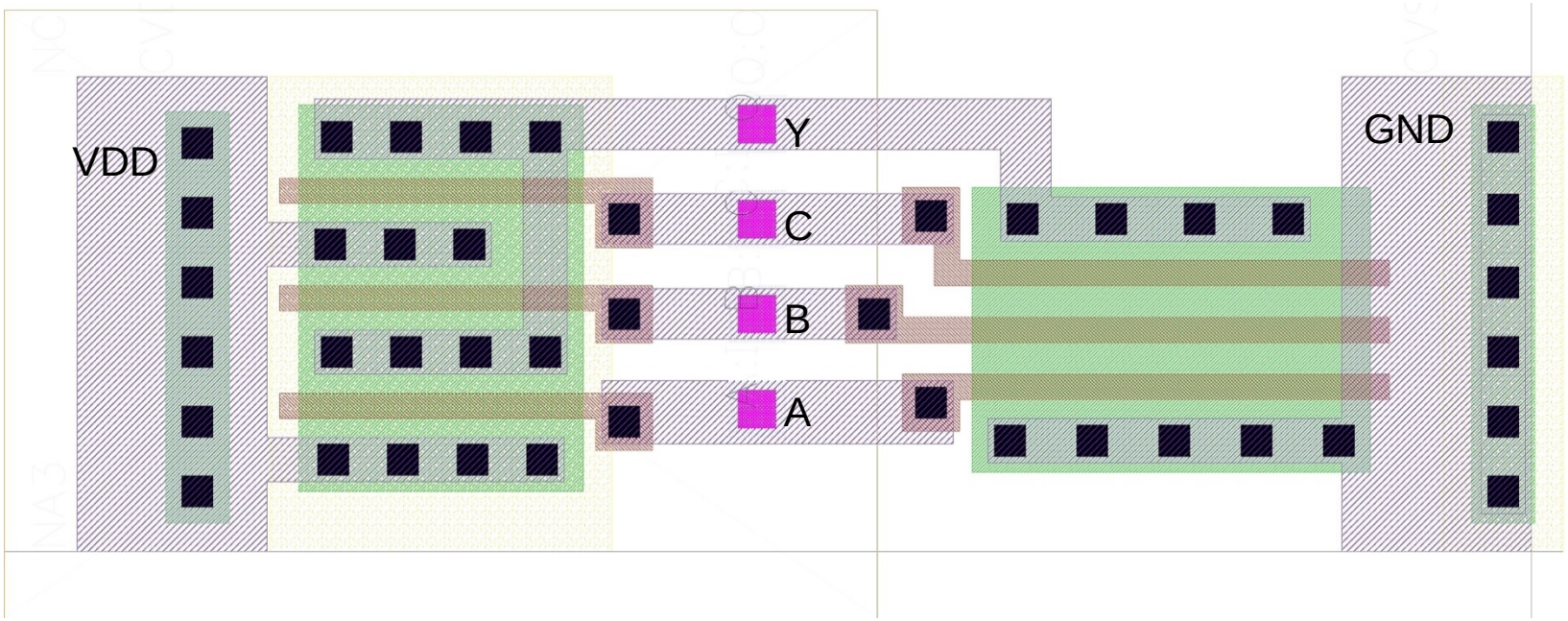
NAND 3-inputs



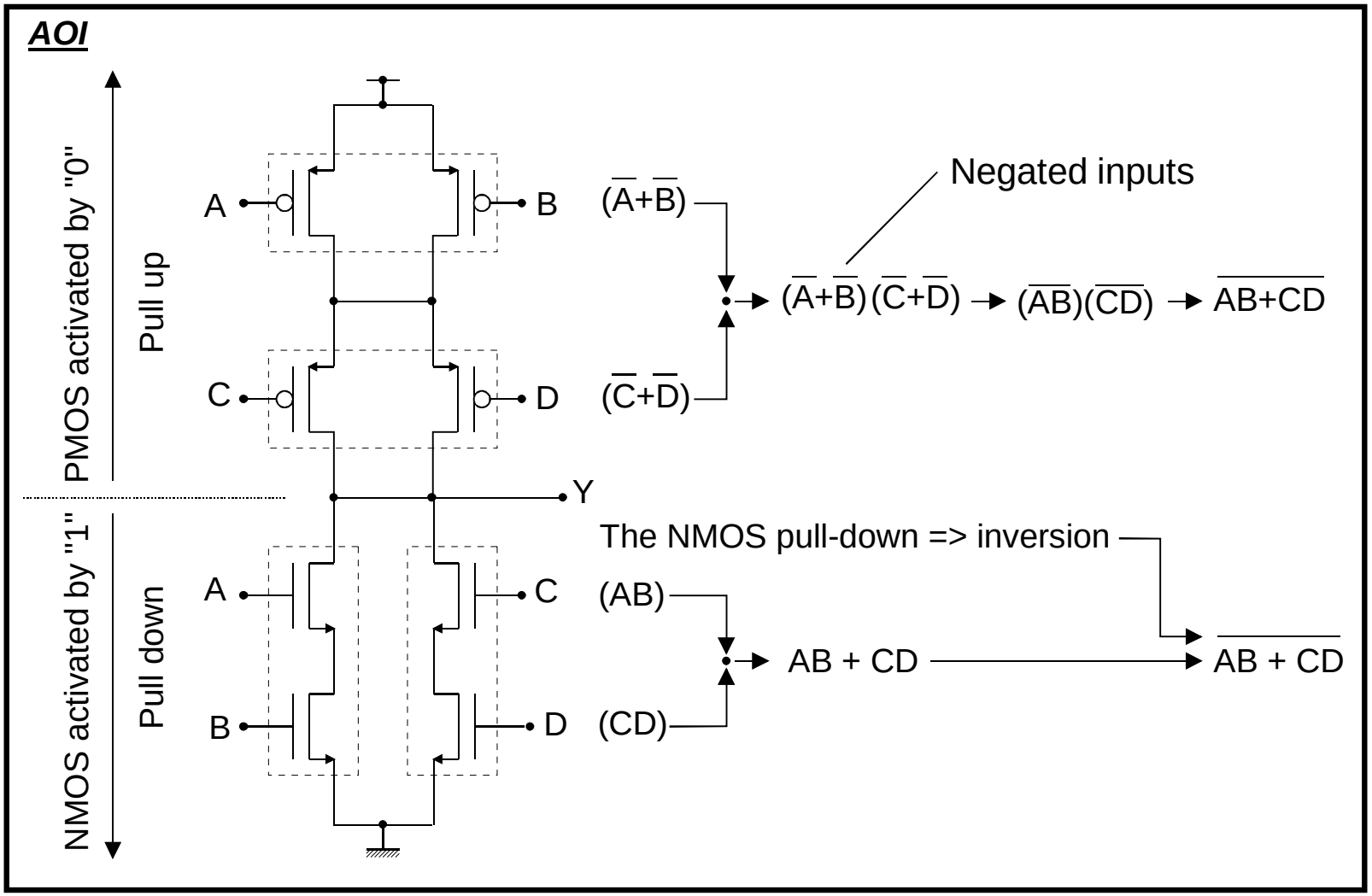
NAND 3-inputs



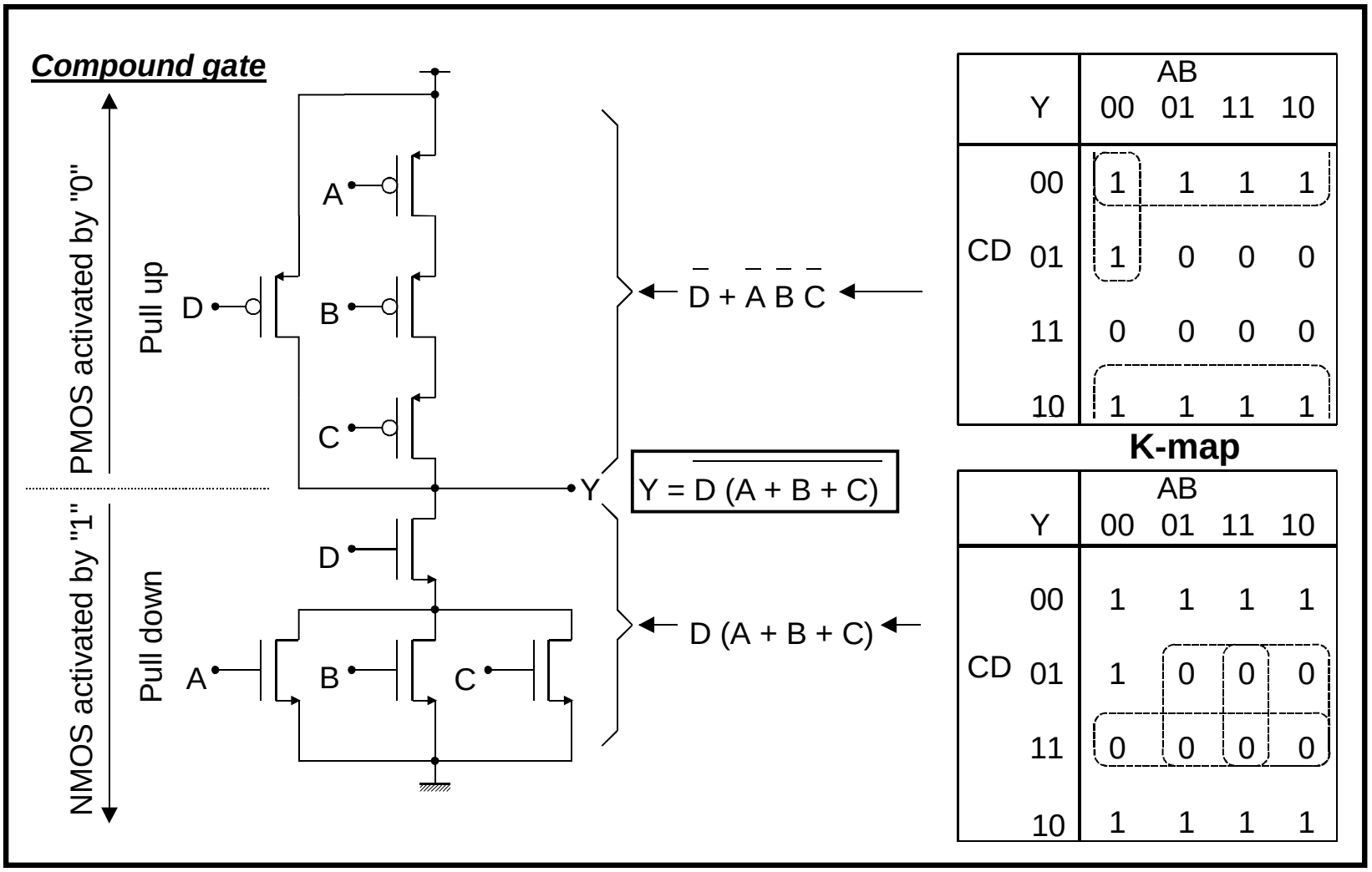
NAND 3-inputs



"Reading" CMOS gates



Designing CMOS gates



Y	AB 00	01	11	10
CD 00	1	1	1	1
CD 01	1	0	0	0
CD 11	0	0	0	0
CD 10	1	1	1	1

K-map

Y	AB 00	01	11	10
CD 00	1	1	1	1
CD 01	1	0	0	0
CD 11	0	0	0	0
CD 10	1	1	1	1

Complex CMOS gates

- Can a compound gate be arbitrarily complex?
  - NO, propagation delay is a strong function of fan-in:

$$t_p = a_0 \cdot FO + a_1 \cdot FI + a_2 \cdot (FI)^2$$

  - FO $\Rightarrow$ Fan-out, number of loads connected to the gate:
    - 2 gate capacitances per FO + interconnect
  - FI $\Rightarrow$ Fan-in, Number of inputs in the gate:
    - Quadratic dependency on FI due to "RC" signal path across the channels:
      - The resistance increases with the number of transistors in series
        - » E.g. (FI) R_o series NMOS for a NAND
      - Each drain and source diffusion adds additional parasitic capacitance
        - » E.g. (FI) C_d drain diffusion of PMOS for a NAND
        - » -> $FI^2 R_o C_d$
  - Avoid large FI gates (Typically FI $\leq$ 4)