The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
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International Atomic Energy Agency

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ICTP Latin-American Basic Course on FPGA Design for Scientific Instrumentation

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Digital Design II
(sequential elements, Mealy and Moore FSM)

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Outline

- Digital CMOS design
  - Boolean algebra
  - Basic digital CMOS gates
  - Combinational and sequential circuits
  - Coding - Representation of numbers

Basic CMOS Gates

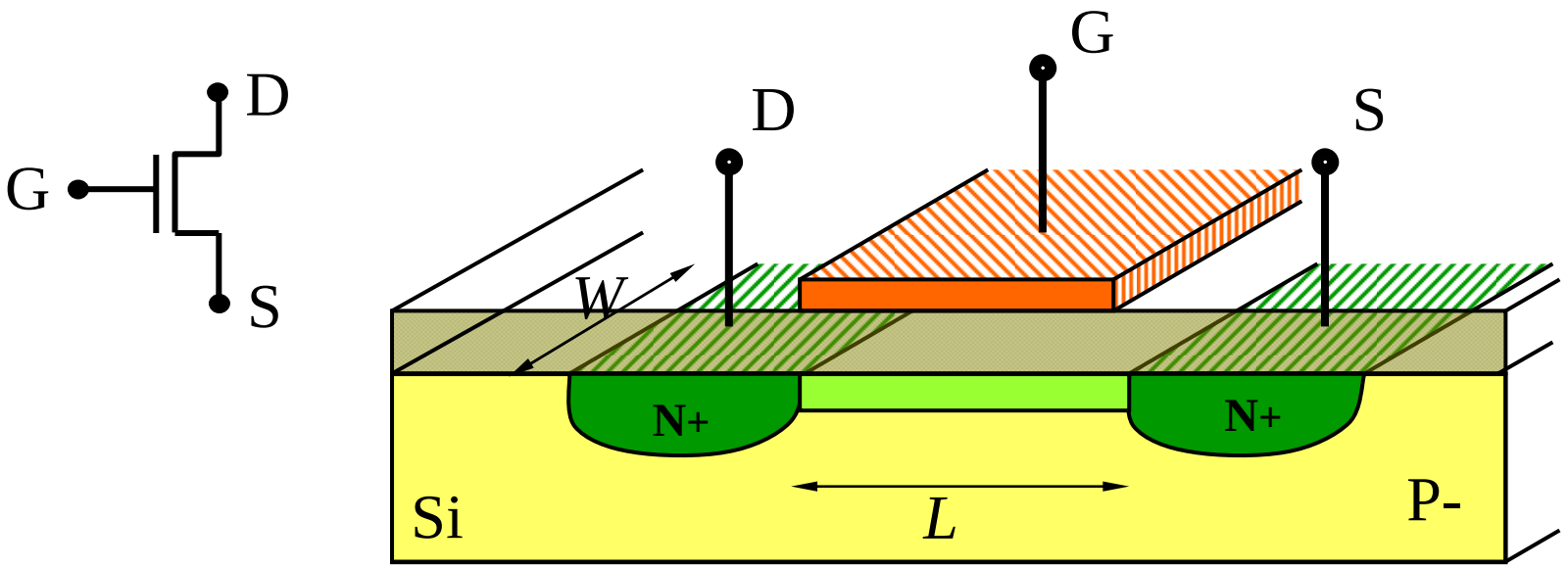
How to implement Boolean functions

in CMOS technology ?

Which functionalities are available

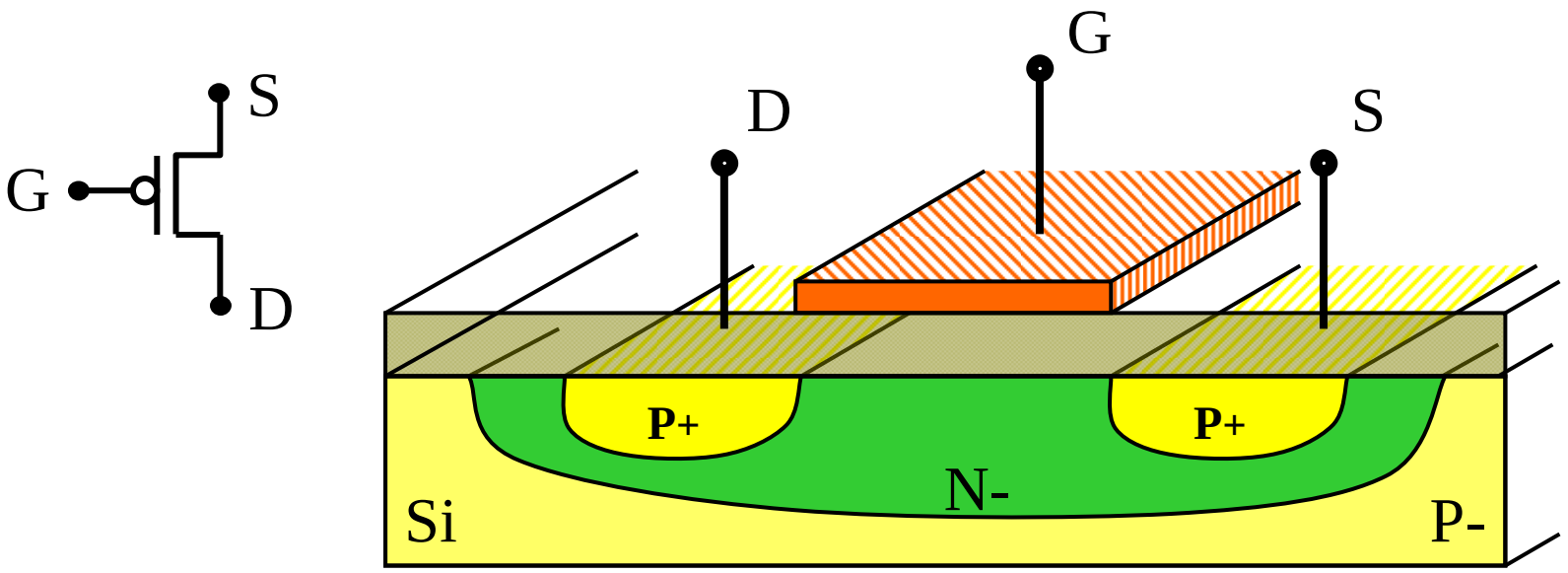
Basic CMOS Gates

- N-MOS transistor



Basic CMOS Gates

- P-MOS transistor



Basic CMOS Gates

The electrical behavior of a MOS transistor

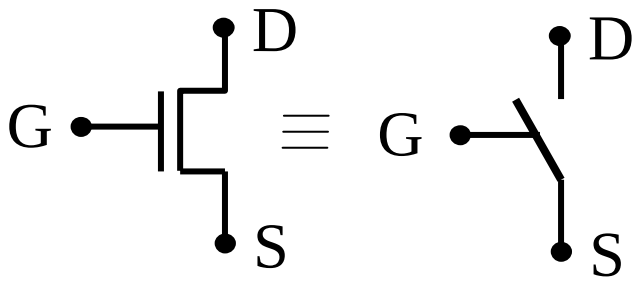
is very complex

Design of a multi-million transistor circuit ?

Basic CMOS Gates

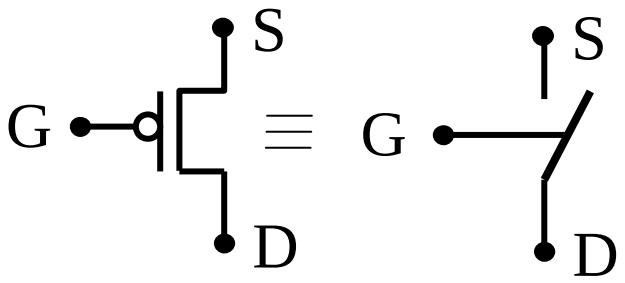
In a digital circuit a MOS transistor can be seen as a Switch

N-MOS



D = S when G = 1

P-MOS



D = S when G = 0

Basic CMOS Gates

When driving, a MOS transistor can be seen as a Resistor

$$R \propto \frac{L}{W}$$

For the same size, a P-MOS is twice more resistive than an N-MOS

Basic CMOS Gates

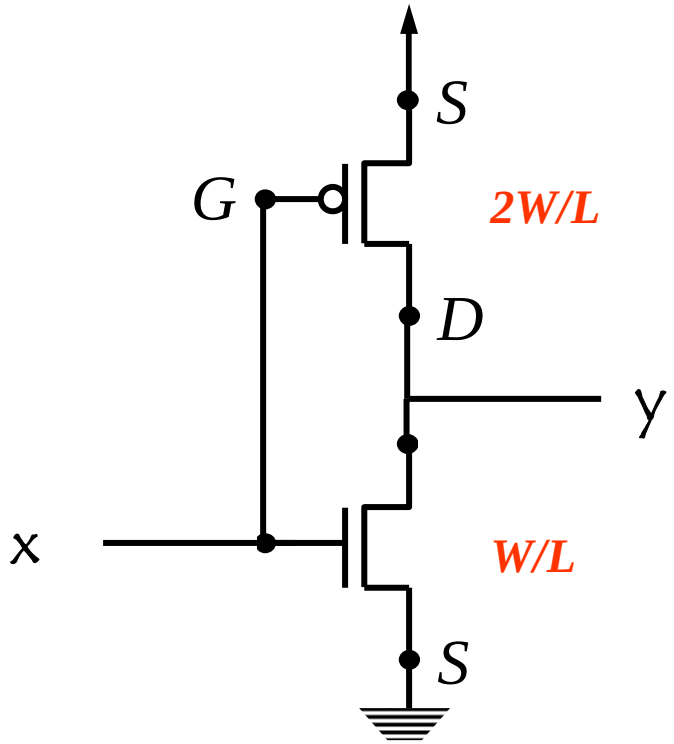
The N-MOS and P-MOS are not exactly symmetrical

A N-MOS is a good transmitter of 0

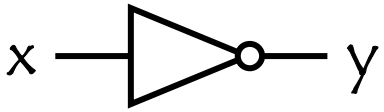
A P-MOS is a good transmitter of 1

Basic CMOS Gates

y = *Not* x

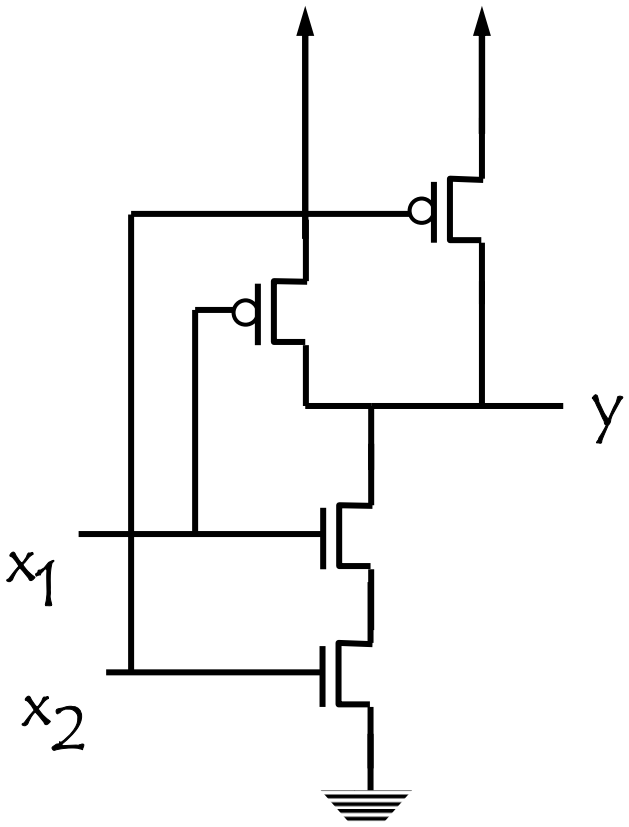


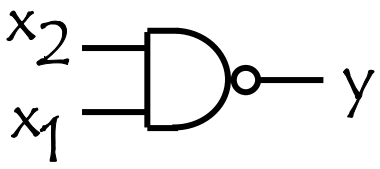
Dual CMOS gate



Basic CMOS Gates

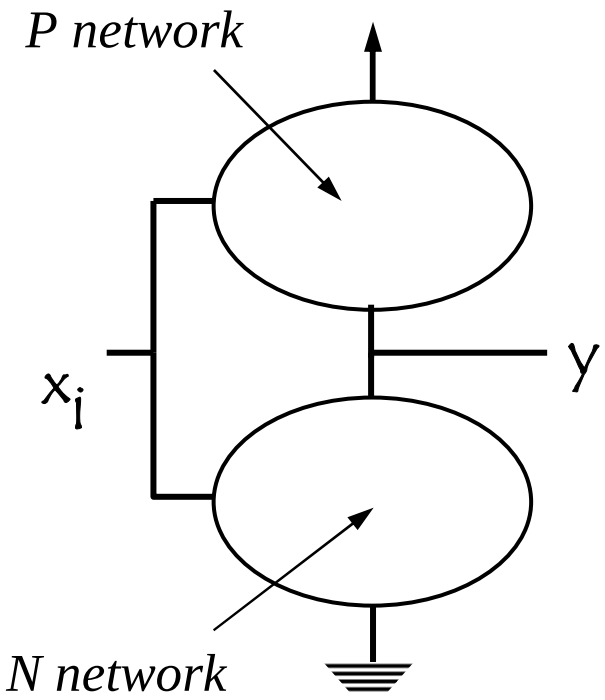
$y = \overline{x_1 \cdot x_2}$





Basic CMOS Gates

Design of a dual gate



The P-network must be the dual of the N-network

Series ⟶ Parallel

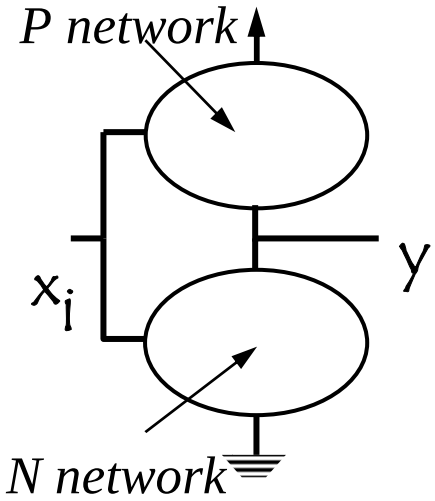
Parallel ⟶ Series

Take care of the size of transistors

Basic CMOS Gates

- To set the output to 0 a path has to be created through the N network
- A series of N-transistor must be conducting

$$\prod x_i = 1$$



Only negative (inverting) functions can be created

Basic CMOS Gates

Implementing a Boolean function with a CMOS gate ?

- The function must be inverting in regard of all the variables
- Put the function in the form of $f = \overline{g}$
- Design the N-network of g

Basic CMOS Gates

Implementing a Boolean function with a CMOS gate ?

- In the expression of g each '.' are two paths in series
- In the expression of g each '+' are two paths in parallel
- The P-network is the dual network of the N-network
- Avoid putting more than 3 transistors in series

Basic CMOS Gates

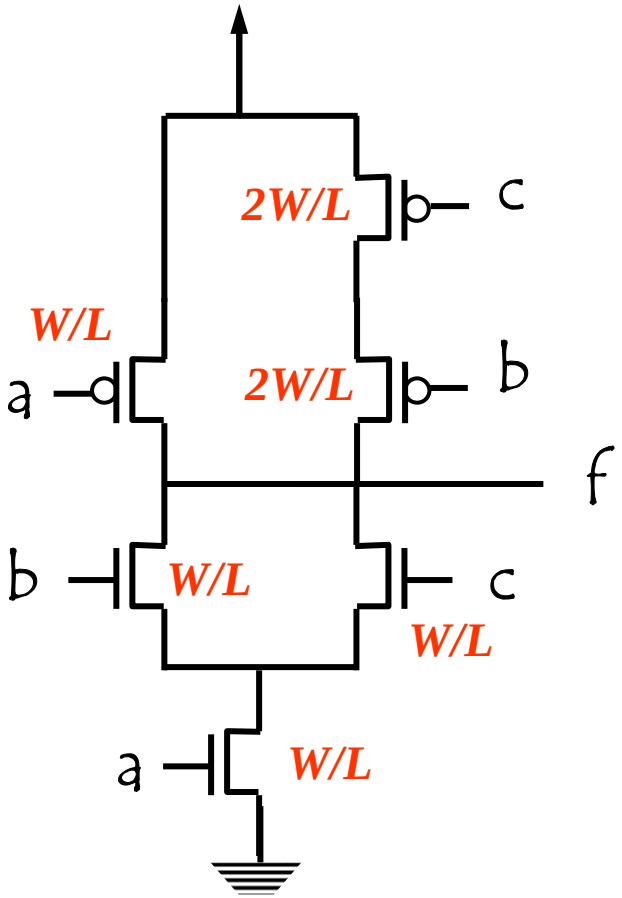
Example :

$$f = \overline{a} + (\overline{b}.\overline{c})$$

$$f = \overline{a} + \overline{(b+c)}$$

$$f = \overline{a \,.\, (b+c)}$$

$$g = a \,.\, (b+c)$$



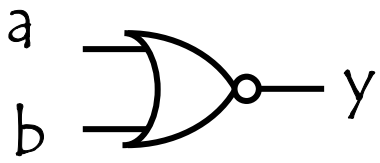
Basic CMOS Gates

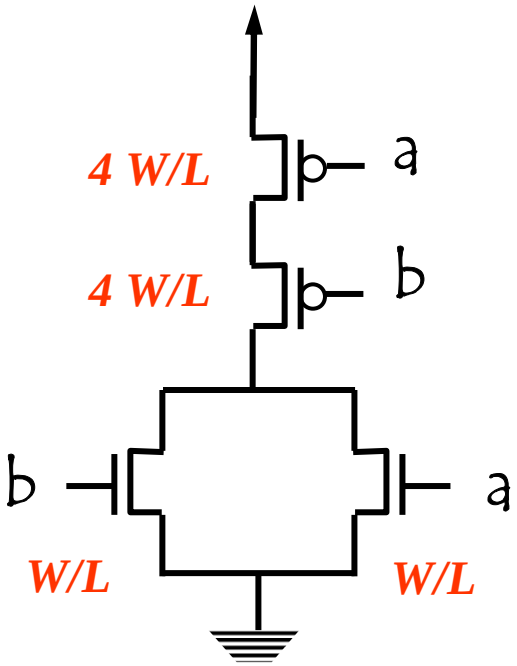
Some gates :

Inverter : $f = \overline{a}$

Nand : $f = \overline{a.b}$

Nor : $f = \overline{a+b}$



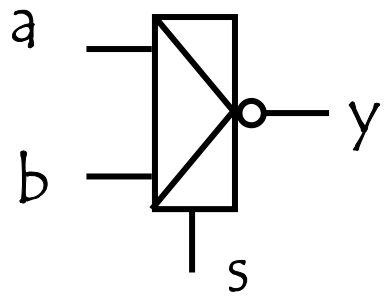


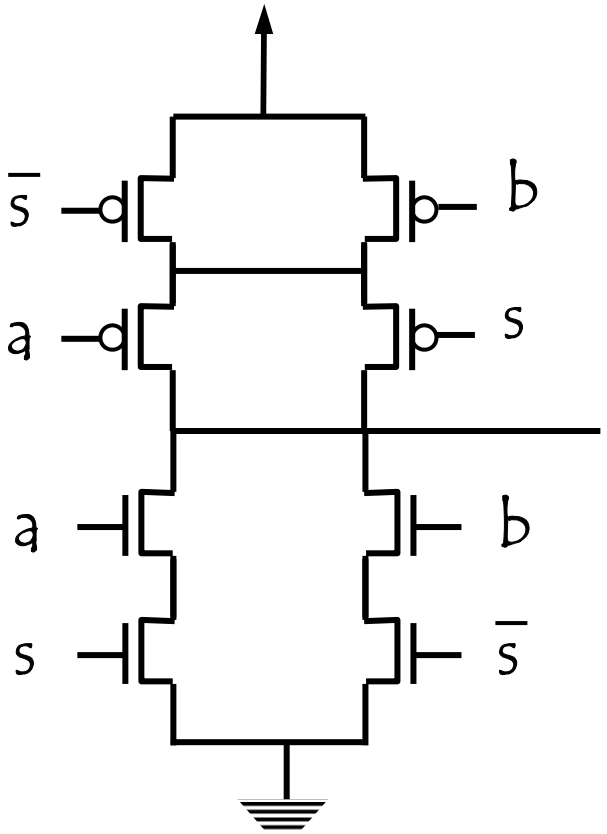
Basic CMOS Gates

Some gates :

Multiplexer :

$$\overline{f = a.s + b.\overline{s}}$$

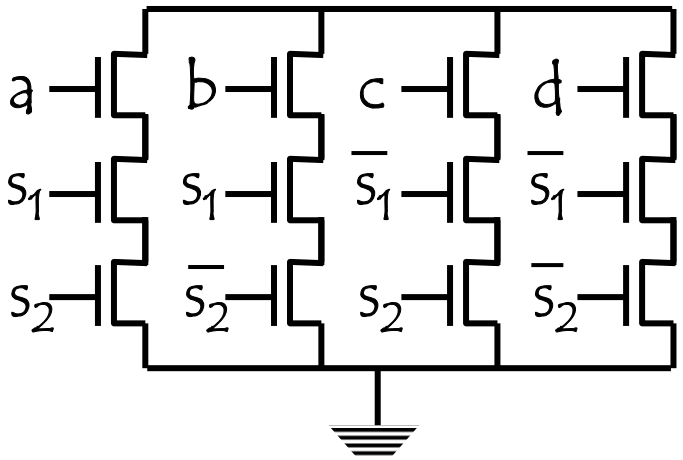




Basic CMOS Gates

Some gates : Multiplexer :

$$\overline{f = a.s_1.s_2 + b.s_1.\overline{s_2} + c.\overline{s_1}.s_2 + d.\overline{s_1}.\overline{s_2}}$$

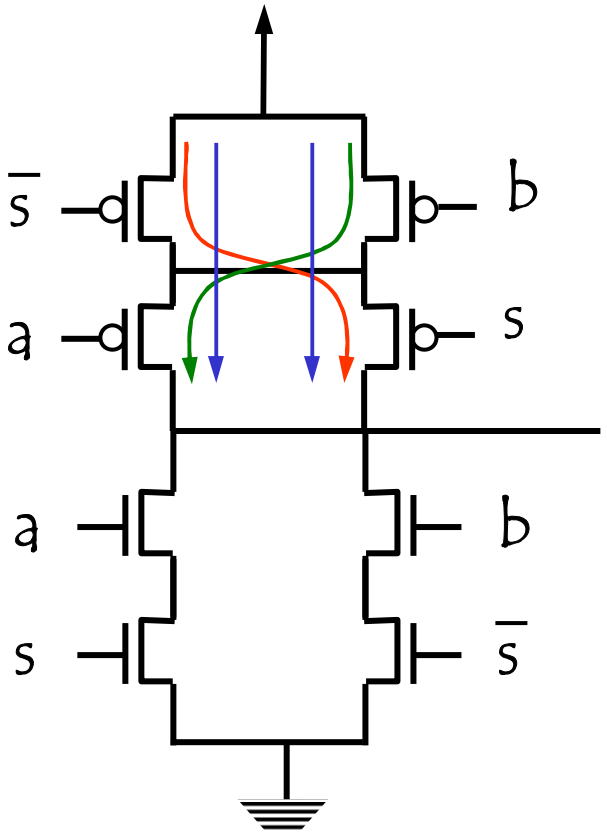


Basic CMOS Gates

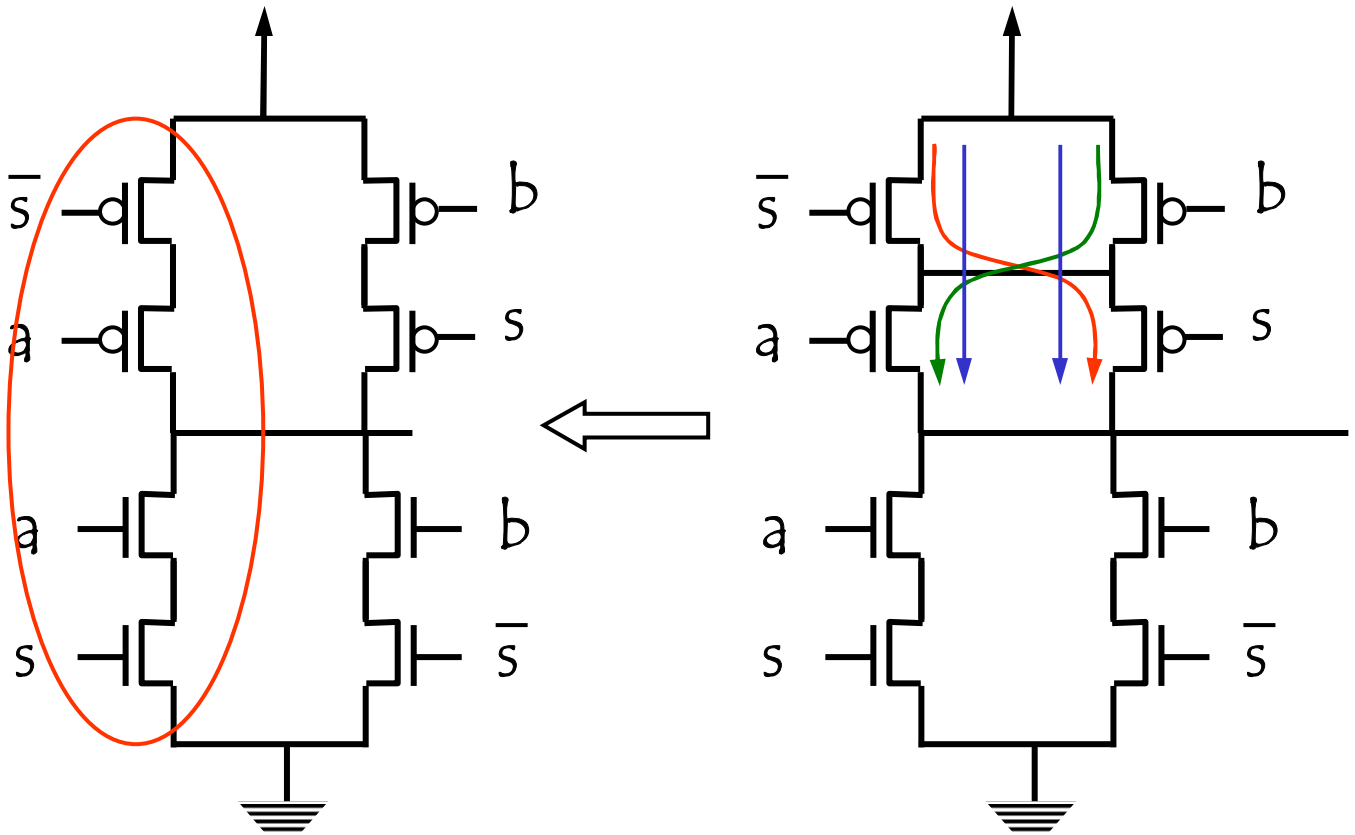
Some gates :

Multiplexer :

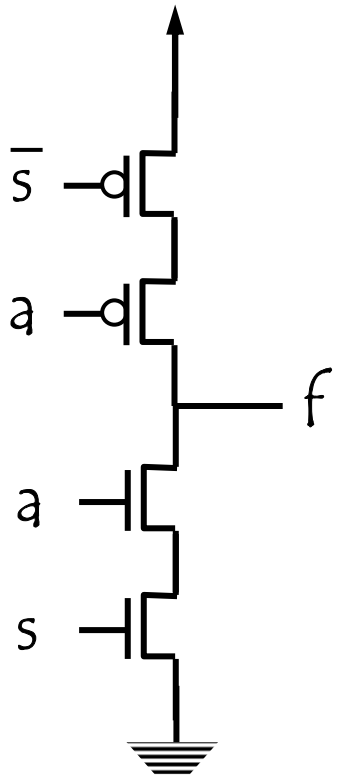
$$f = \overline{a.s + b.\overline{s}}$$



Basic CMOS Gates



Basic CMOS Gates

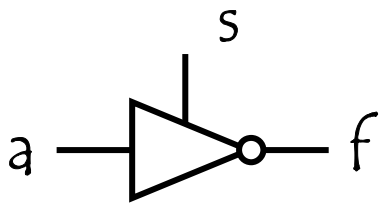


If s = 1

$f = \overline{a}$

If s = 0

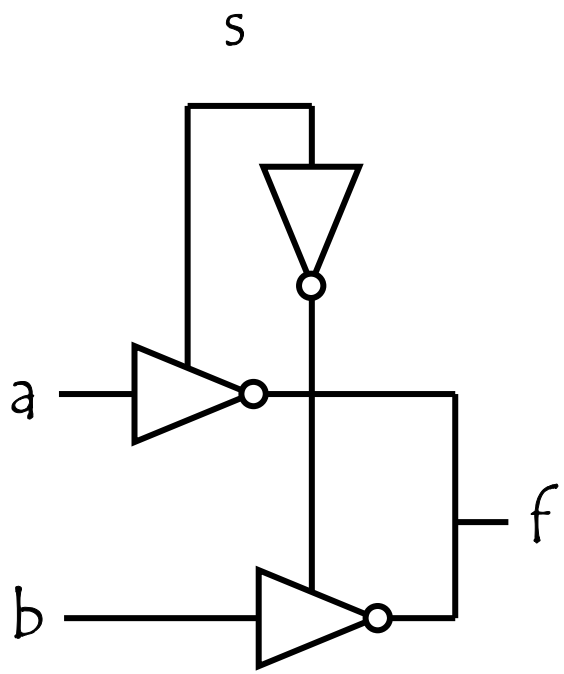
f is not defined



Tri-state driver

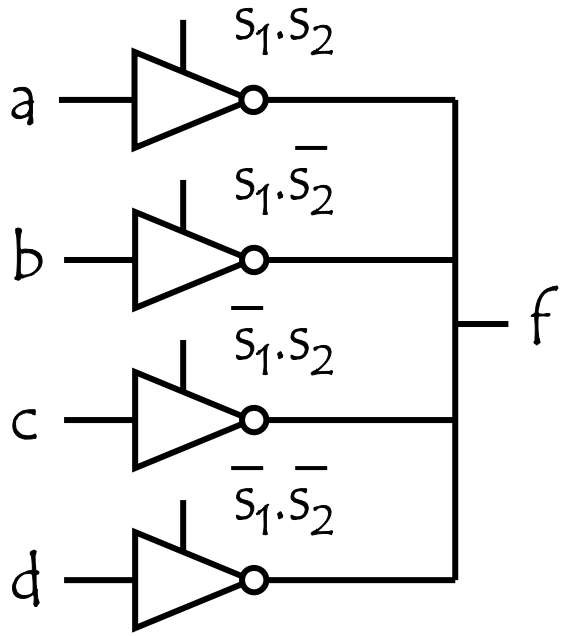
Basic CMOS Gates

Some gates : Multiplexer :



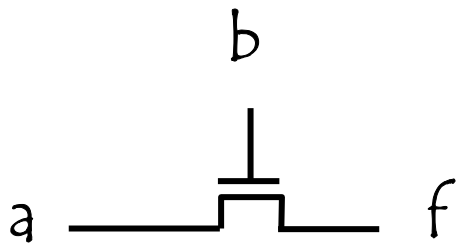
Basic CMOS Gates

Some gates : Multiplexer :



Basic CMOS Gates

Some gates :



If b = 1 If b = 0

f = a f is not defined

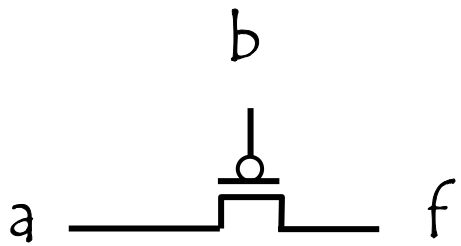
If a = 0 then f = 0

If a = 1 then f = 1⁻

Pass-transistor

Basic CMOS Gates

Some gates :



If b = 0 f = a

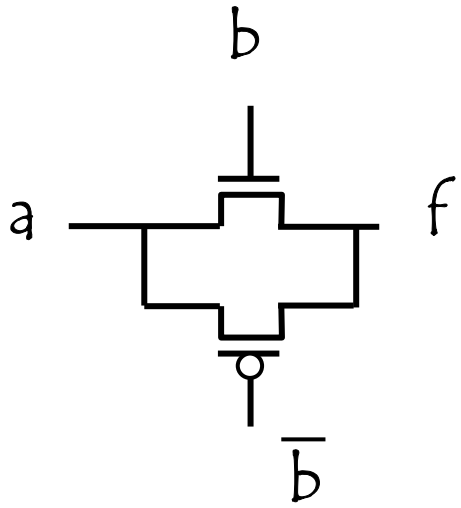
If b = 1 f is not defined

- If a = 1 then f = 1
- If a = 0 then f = 0^+

Pass-transistor

Basic CMOS Gates

Some gates :



If b = 1 If b = 0

f = a f is not defined

If a = 0 then f = 0

If a = 1 then f = 1

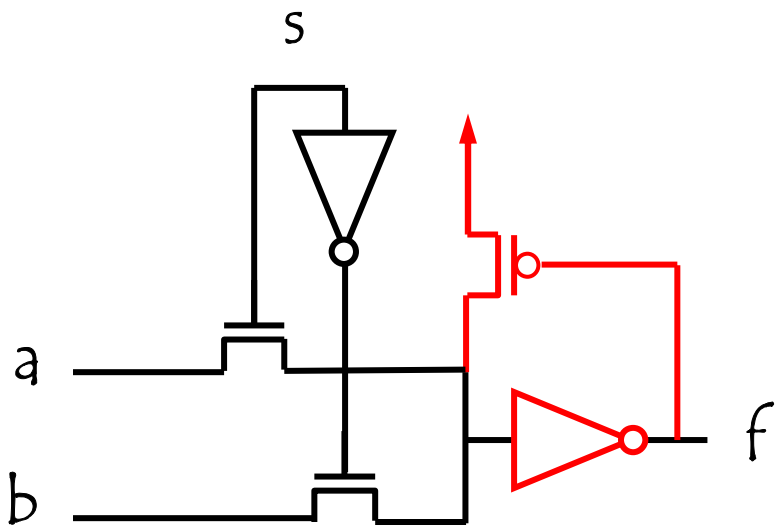
CMOS Switch

Basic CMOS Gates

Some gates :

Multiplexer :

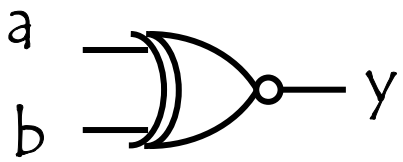
$$f = \overline{a.s + b.\overline{s}}$$



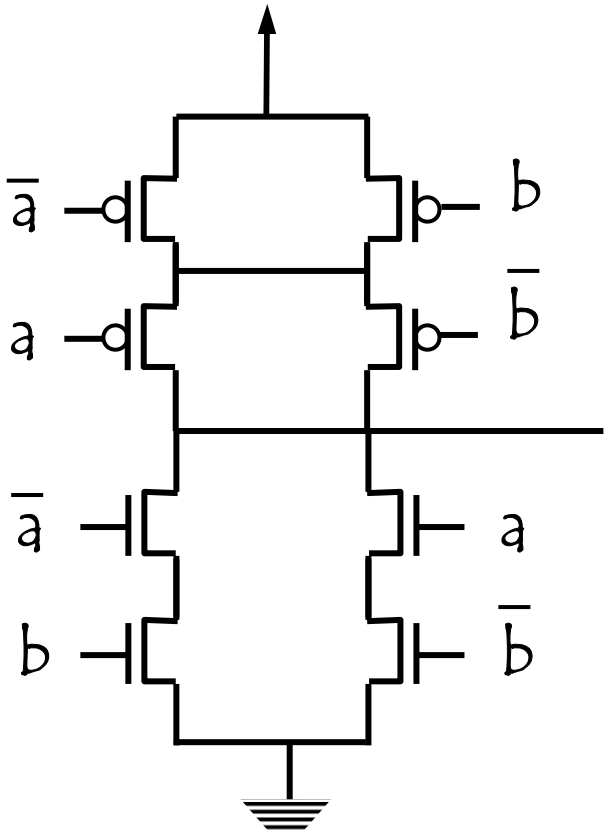
Basic CMOS Gates

Some gates :

Nxor : $f = \overline{\bar{a}.b + a.\bar{b}}$



I need $\bar{a}$ and $\bar{b}$



Basic CMOS Gates

Some gates :

Xor with Pass-transistors :

$$f = \overline{\overline{a}.b + a.\overline{b}}$$

a	b	f
0	0	1
0	1	0
1	0	0
1	1	1