2065-2

Advanced Training Course on FPGA Design and VHDL for Hardware Simulation and Synthesis

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Digital CMOS Design

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Outline

□ Digital CMOS design

- ○ Boolean algebra

- ○ Basic digital CMOS gates

- ○ Combinational and sequential circuits

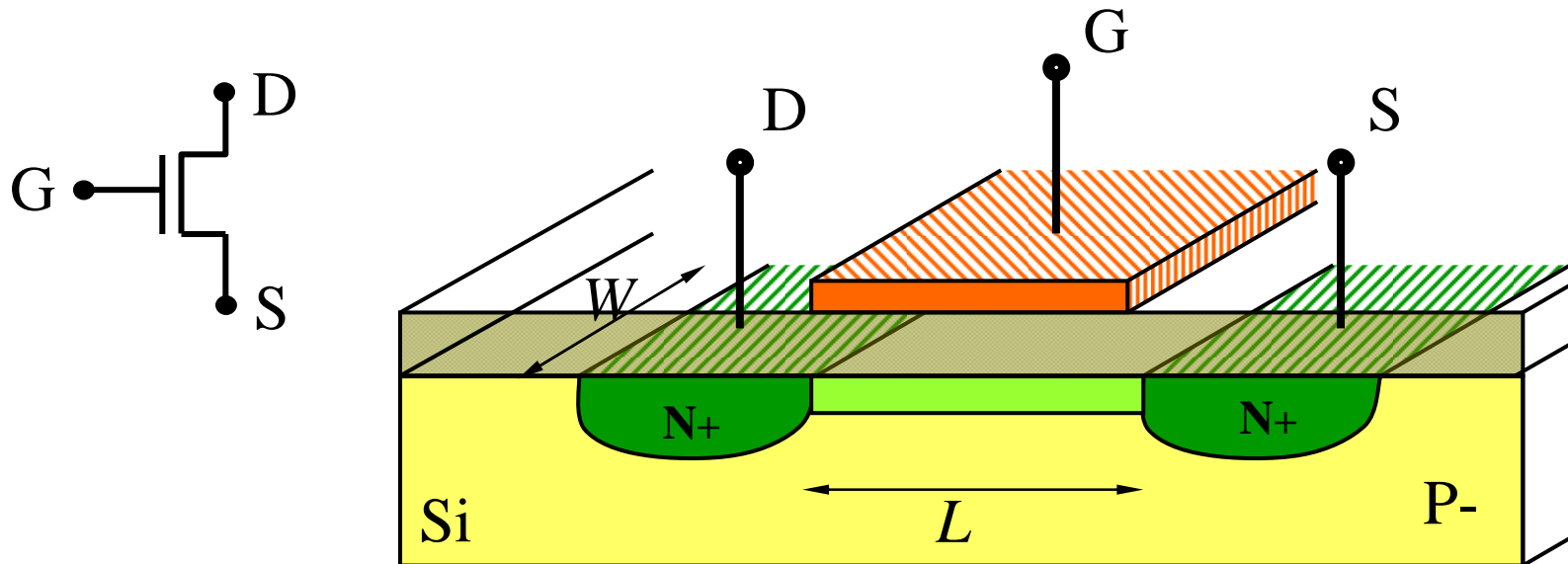- ○ Coding - Representation of numbers

Basic CMOS Gates

How to implement Boolean functions

in CMOS technology ?
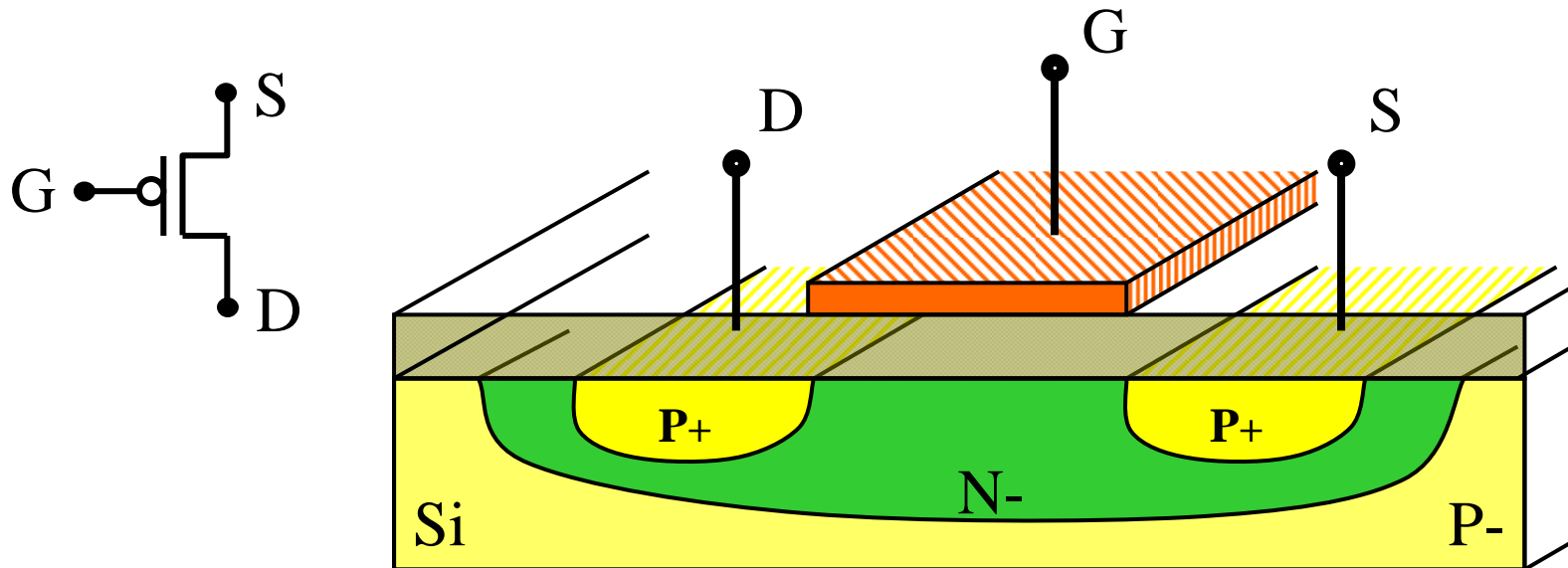
Which functionalities are available

Basic CMOS Gates

N-MOS transistor

Basic CMOS Gates

P-MOS transistor

Basic CMOS Gates

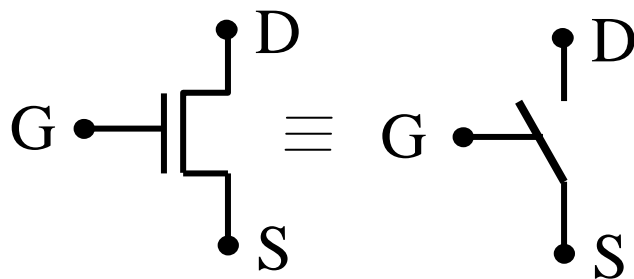The electrical behavior of a MOS transistor

is very complex

Design of a multi-million transistor circuit ?
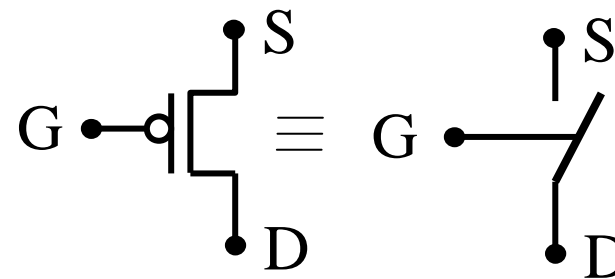
Basic CMOS Gates

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

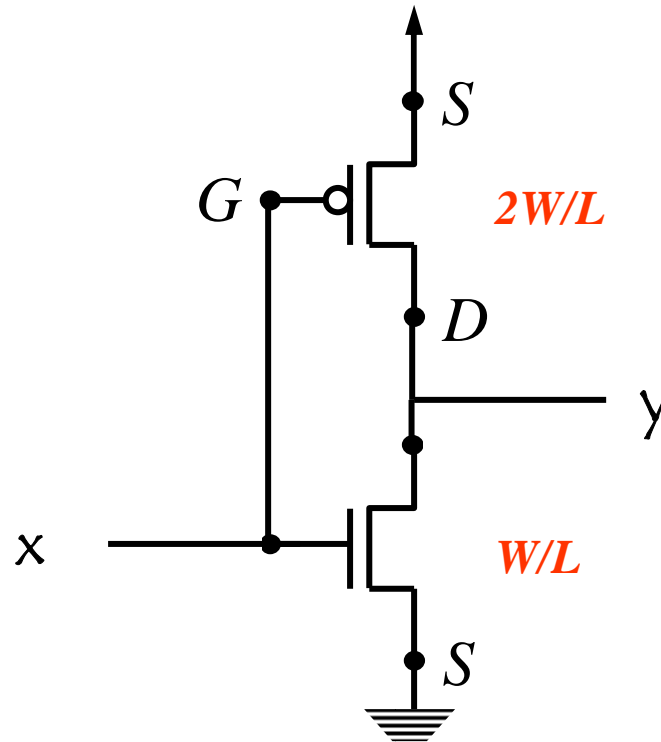# Basic CMOS Gates

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

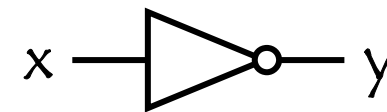A N-MOS is a good transmitter of 0

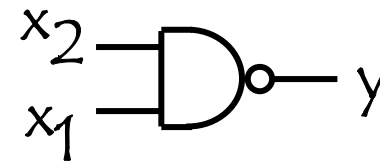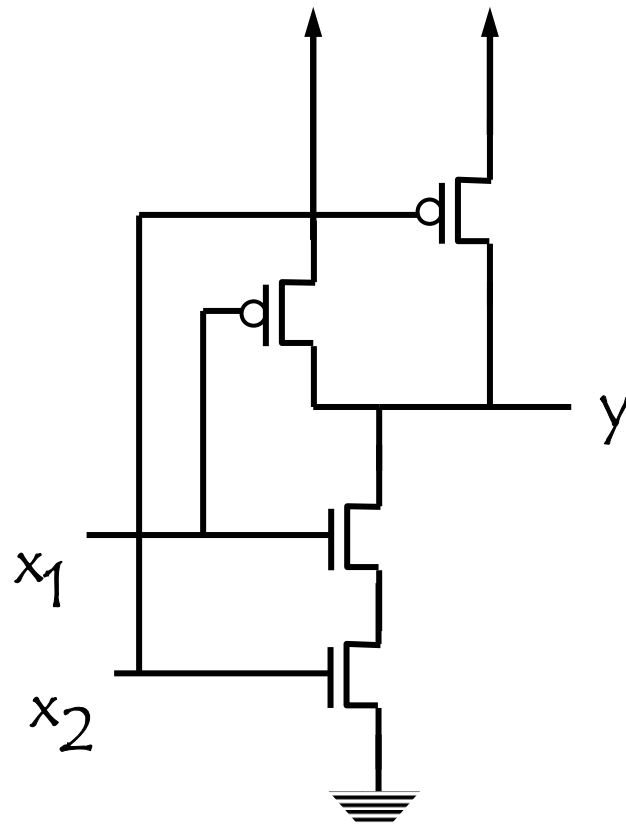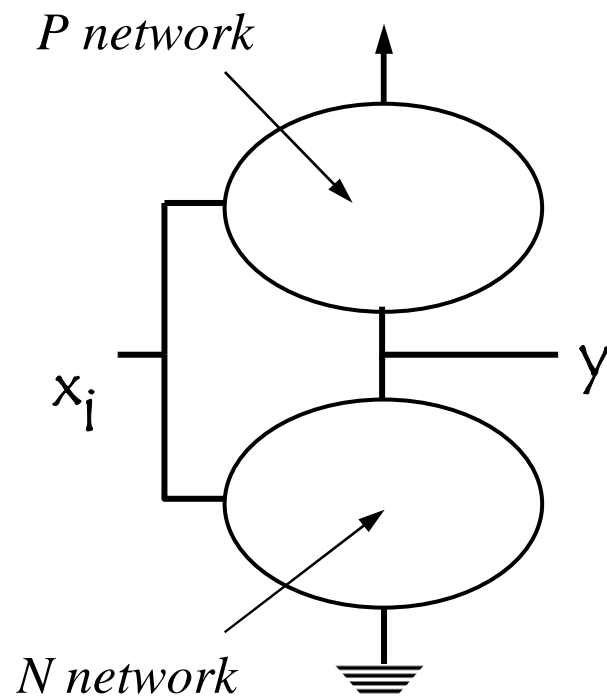A P-MOS is a good transmitter of 1

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

P network

N network

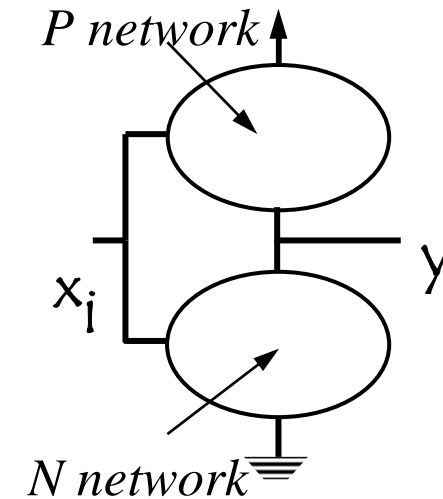x_i

y

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

Series $\longrightarrow$ Parallel
Parallel $\longrightarrow$ 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

$$\prod x_i = 1$$

P network

x_i

y

N network

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

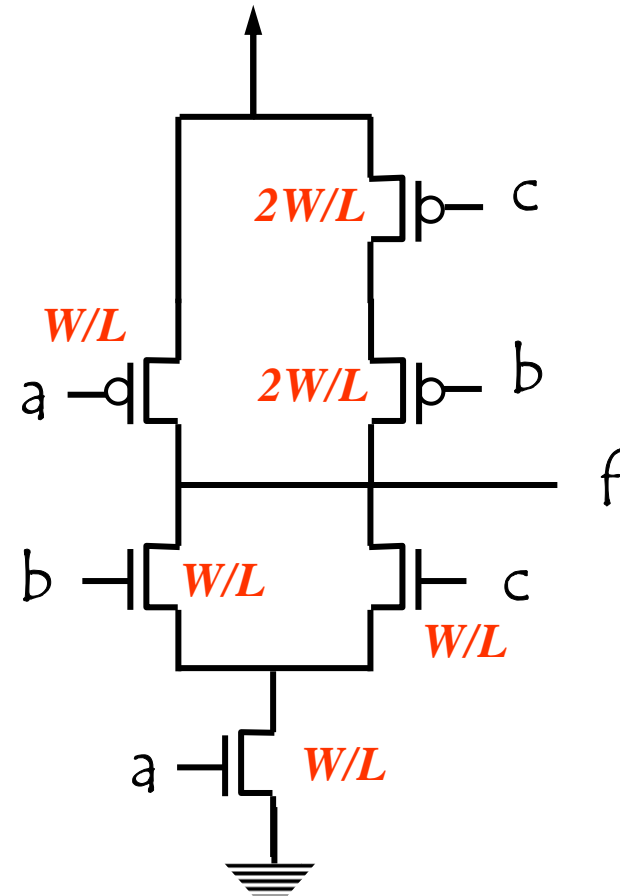- Avoid putting more than 3 transistors in series

Basic CMOS Gates

Example :

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

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

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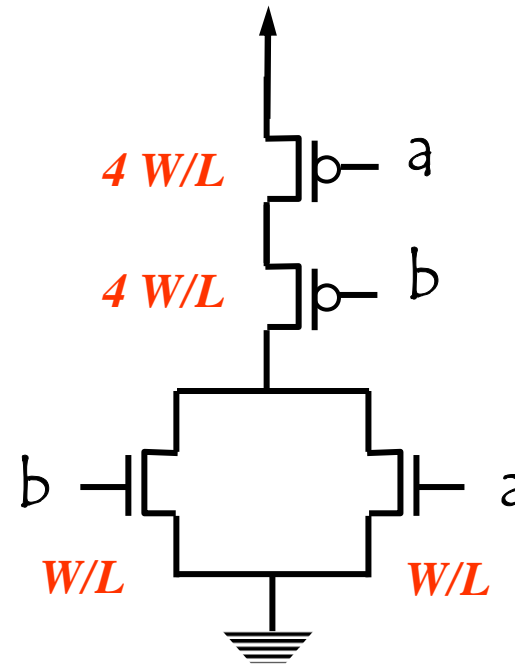
$$g = a \cdot (b+c)$$

Basic CMOS Gates

Some gates :

Inverter : $f = \overline{a}$

Nand : $f = \overline{a.b}$
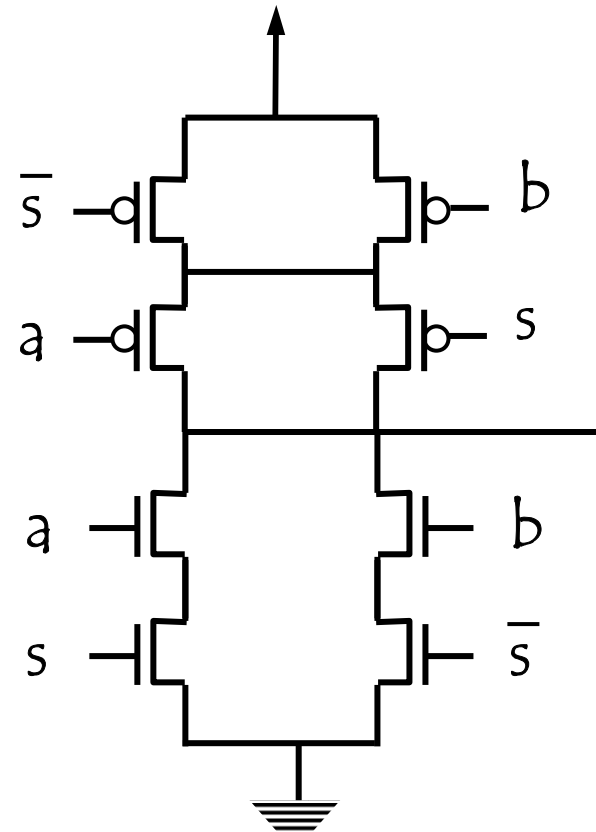
Nor : $f = \overline{a+b}$
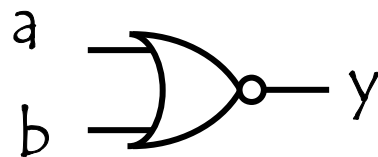
4 W/L

4 W/L

W/L   **W/L**

a

b

b   a

a

b

y

Basic CMOS Gates

Some gates :
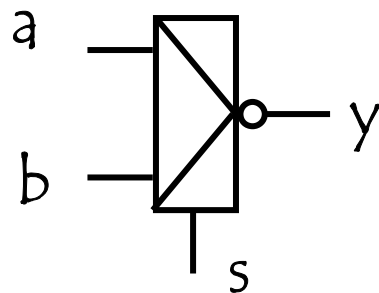
Multiplexer :

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

Basic CMOS Gates

Some gates :   Multiplexer :

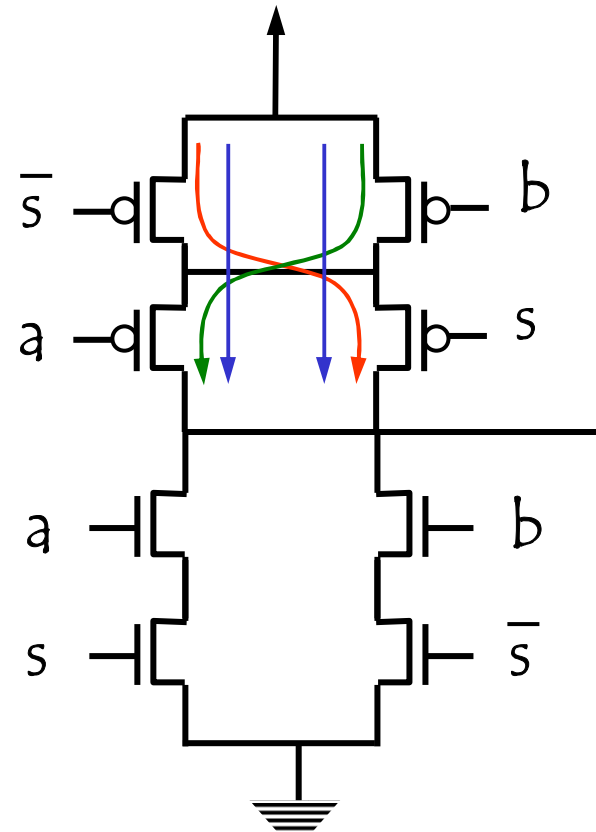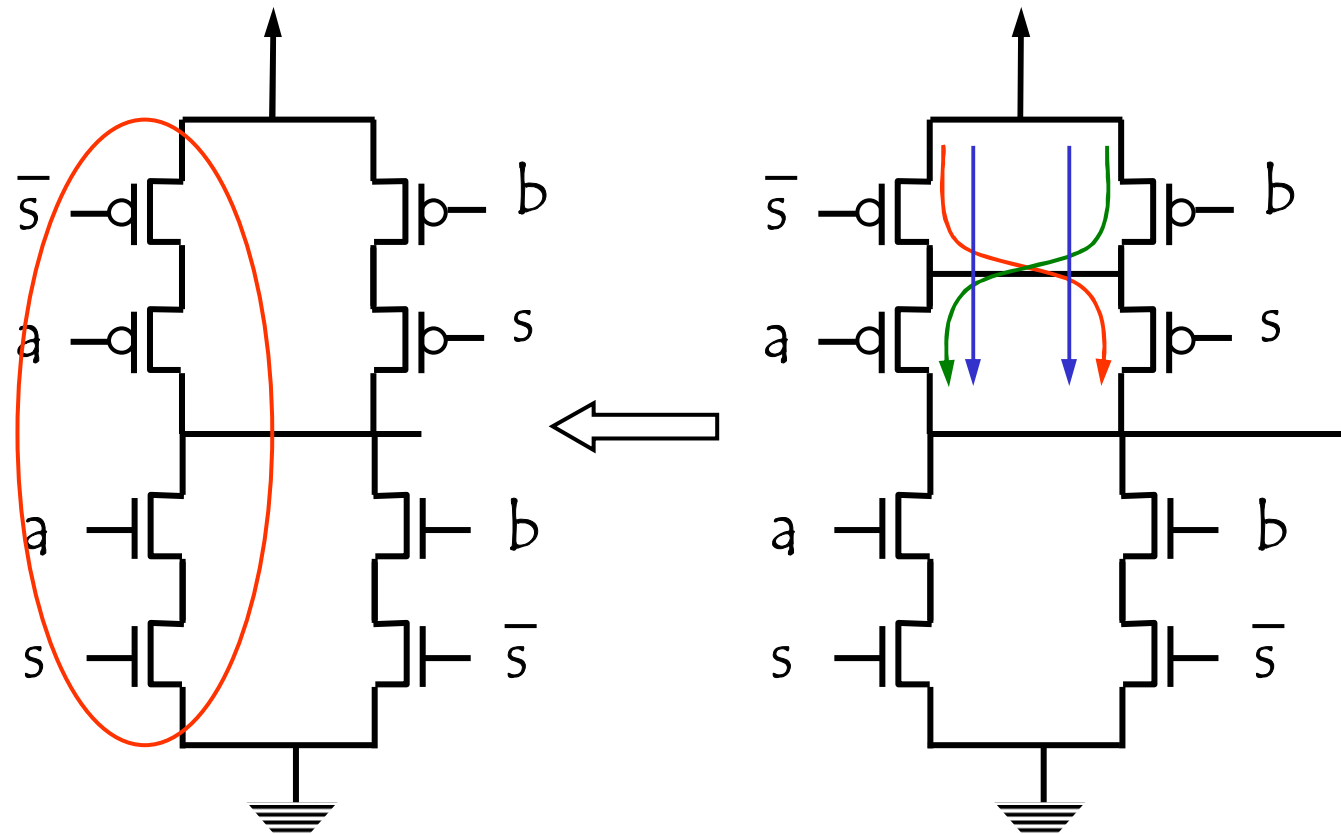$$f = \overline{a.s_1.s_2 + b.s_1.\overline{s_2} + c.\overline{s_1}.s_2 + d.\overline{s_1}.\overline{s_2}}$$
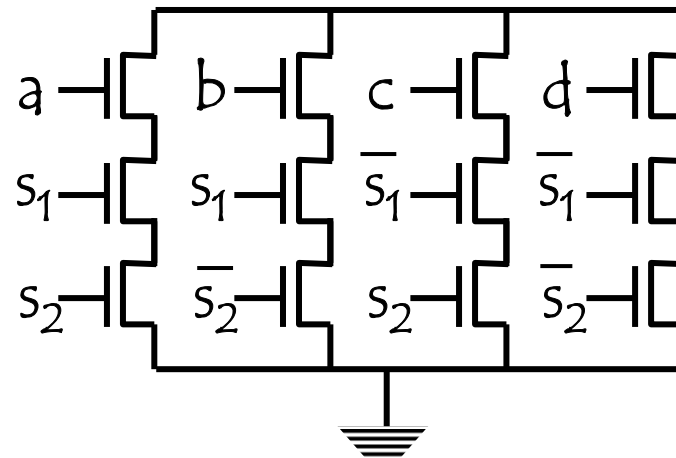
Basic CMOS Gates

Some gates :

Multiplexer :

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

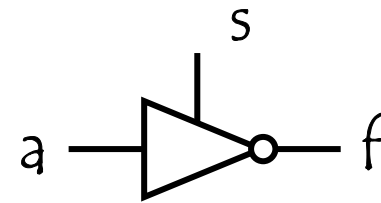# Basic CMOS Gates

Basic CMOS Gates

$\overline{s}$
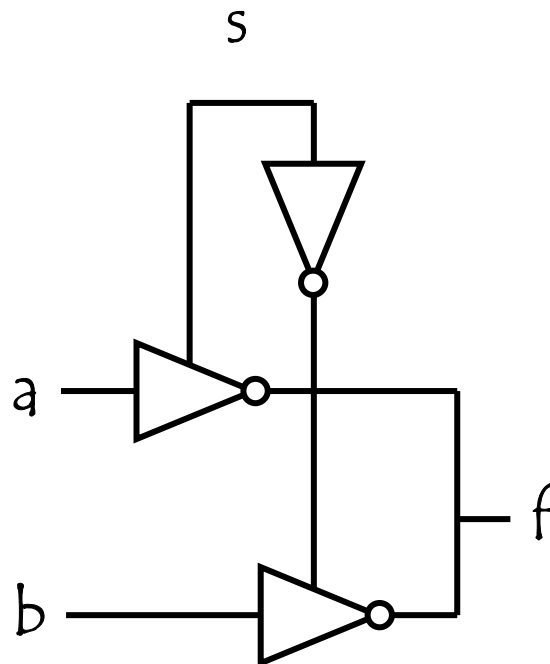
a

f

a

s
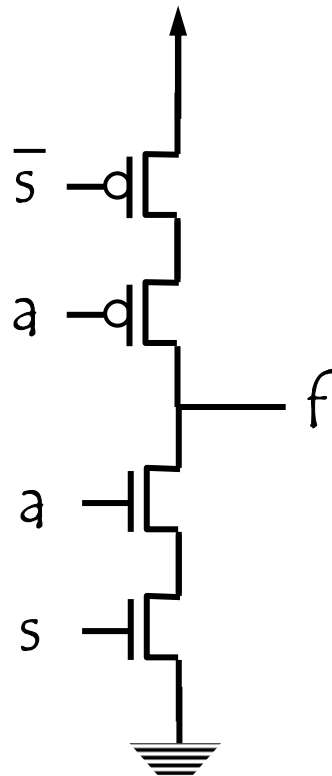
If s = 1

$f = \overline{a}$

If s = 0

f is not defined

s

a —▷∘— f

Tri-state driver

Basic CMOS Gates
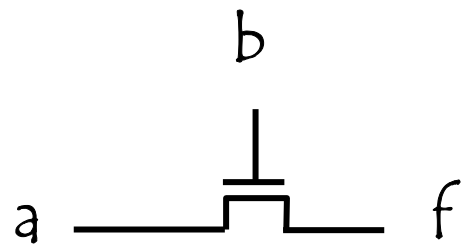
Some gates :   Multiplexer :

Basic CMOS Gates

Some gates :   Multiplexer :

The multiplexer schematic shows four tri-state inverters:
- input a controlled by $s_1.s_2$
- input b controlled by $s_1.\overline{s_2}$
- input c controlled by $\overline{s_1}.s_2$
- input d controlled by $\overline{s_1}.\overline{s_2}$

all connected to output f.

Basic CMOS Gates

Some gates :

b

a ⊥ f
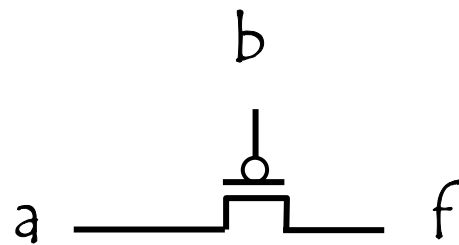
If b = 1   If b = 0

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 :

b

a ⎯⎯⎯⎯⎯⎯⎯ f

If b = 0   If b = 1

f = a   f is not defined

If a = 1   then f = 1

If a = 0   then f = O⁺

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
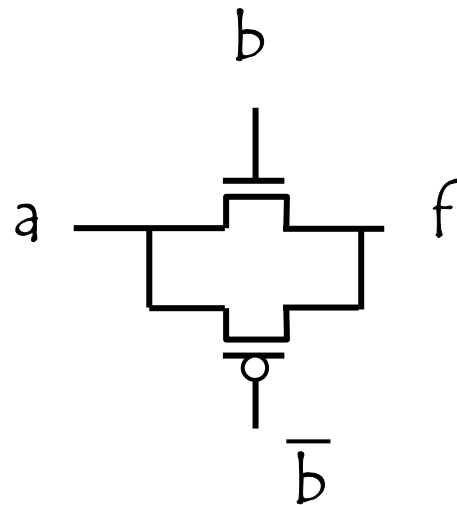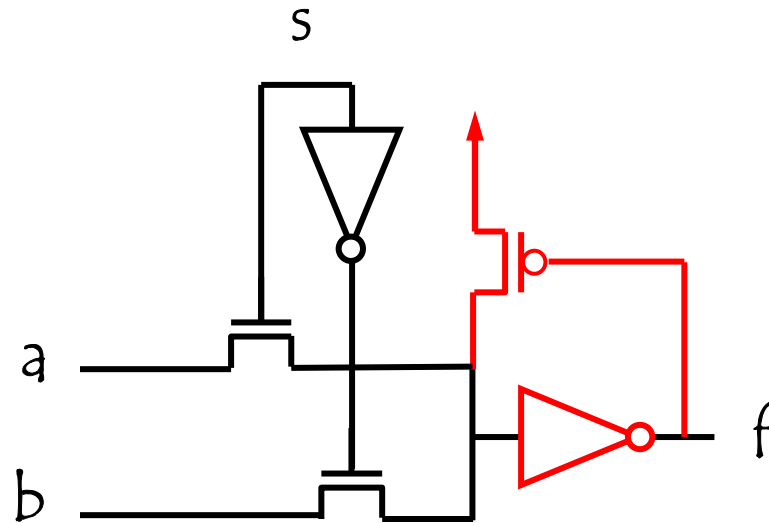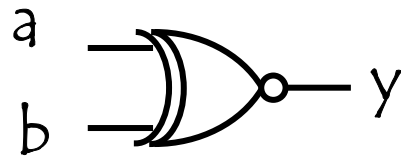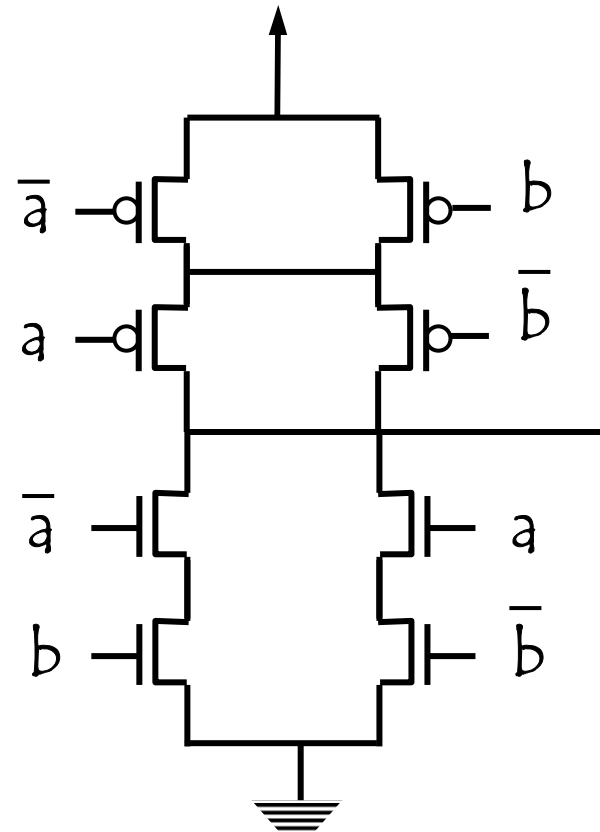
Some gates :

Multiplexer :

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

Basic CMOS Gates

Some gates :

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

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

Basic CMOS Gates

Some gates :

Xor   with Pass-transistors :

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

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