

2384-1

**ICTP Latin-American Advanced Course on FPGA Design for Scientific
Instrumentation**

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Digital 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

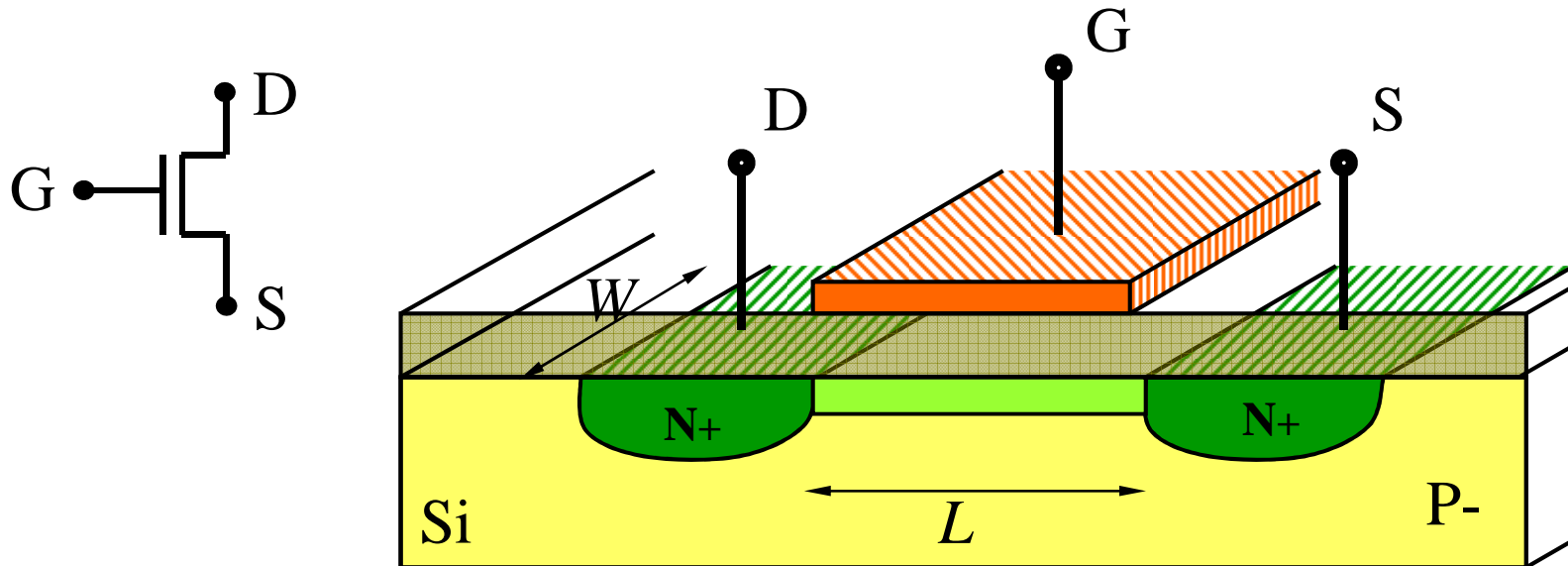
How to implement Boolean functions
in CMOS technology ?

Which functionalities are available



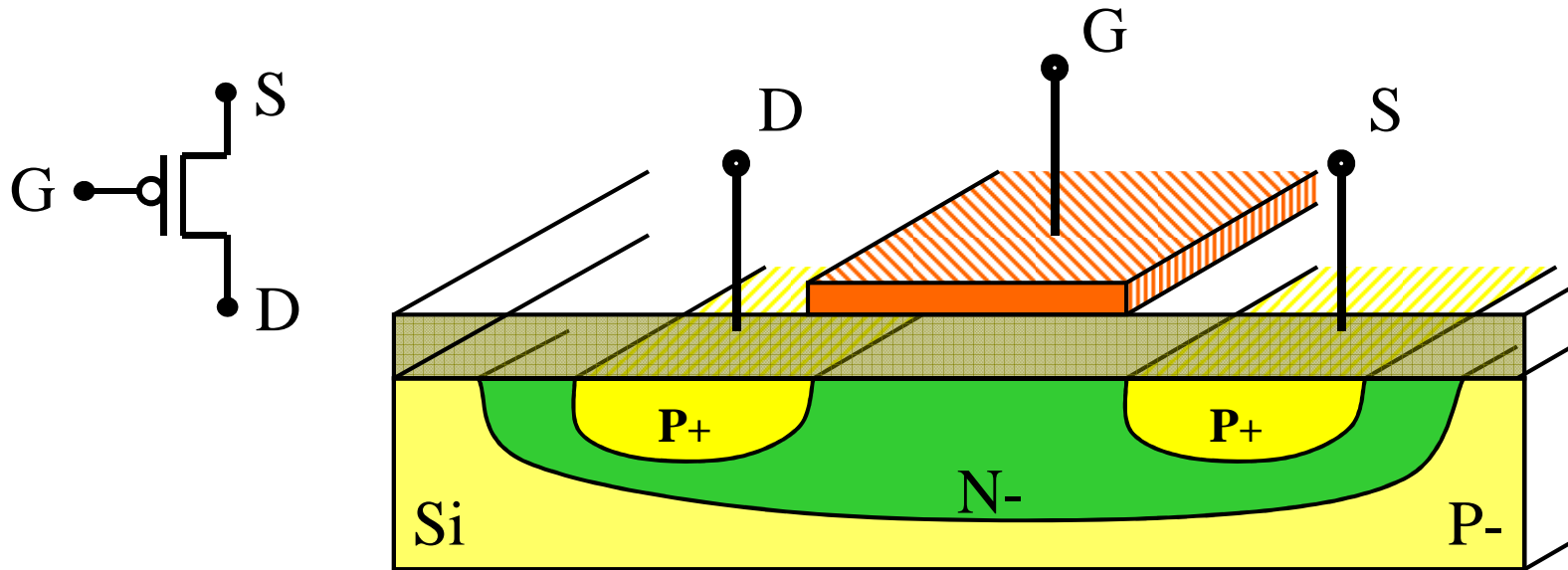
Basic CMOS Gates

○ N-MOS transistor



Basic CMOS Gates

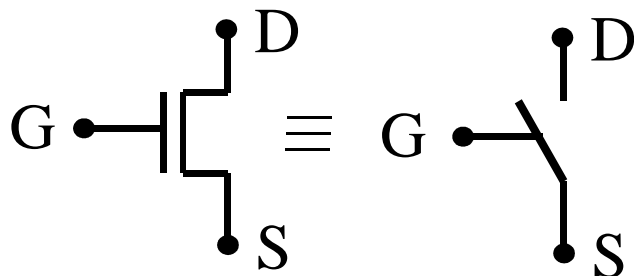
○ P-MOS transistor



Basic CMOS Gates

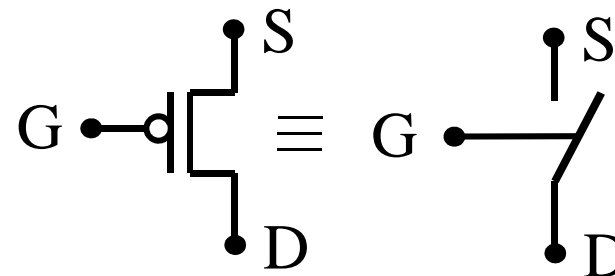
In a digital circuit a MOS transistor can be seen as a **Switch**

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

$$\text{Conductance} \propto \frac{W}{L}$$

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

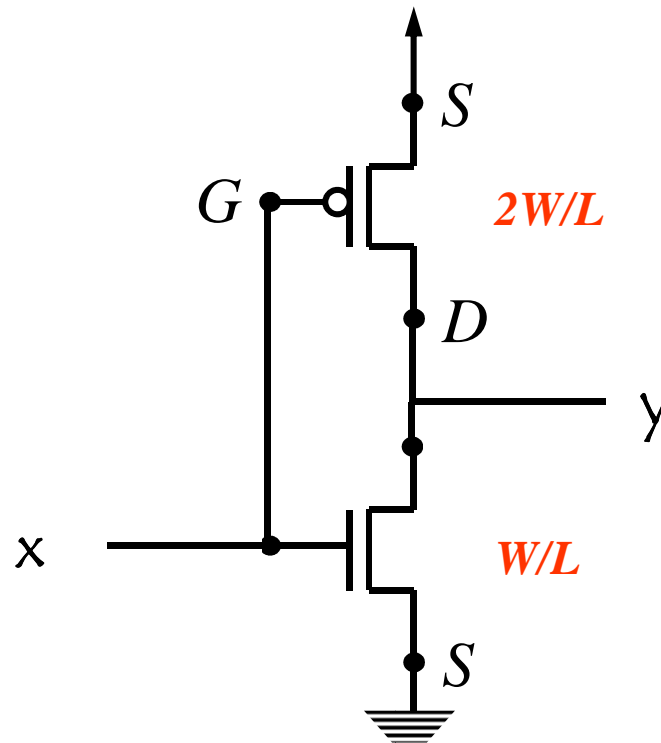
A N-MOS is a good transmitter of 0

A P-MOS is a good transmitter of 1

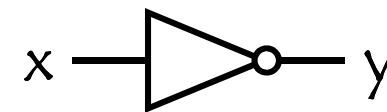


Basic CMOS Gates

$$y = \text{Not } x$$

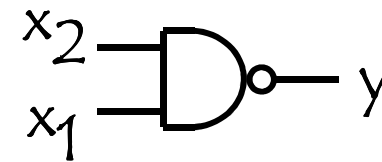
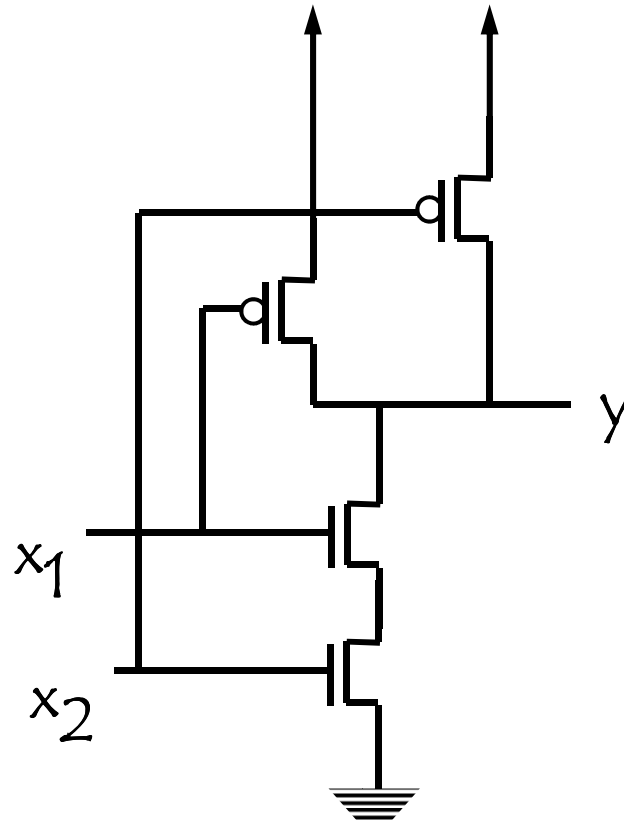


Dual CMOS gate



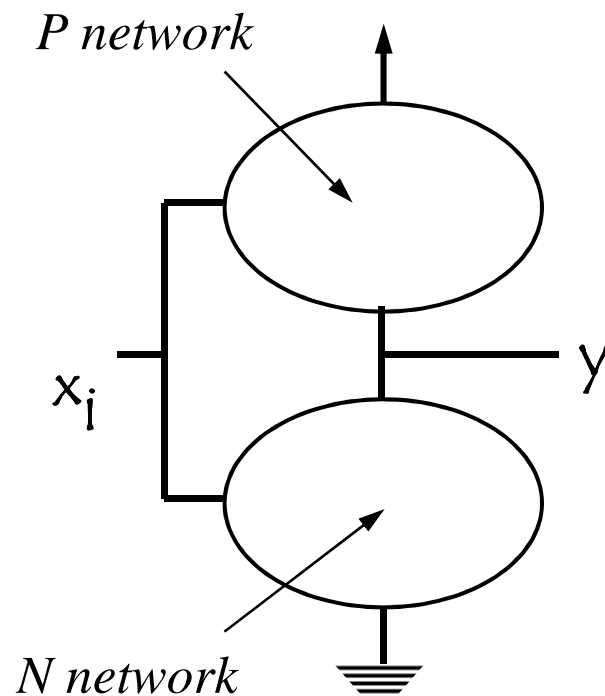
Basic CMOS Gates

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



Basic CMOS Gates

Design of a dual gate



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

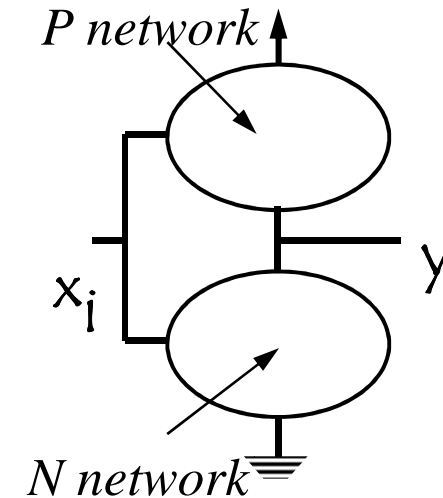
Series \longrightarrow Parallel
Parallel \longrightarrow Series

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

$$\prod x_i = 1$$



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

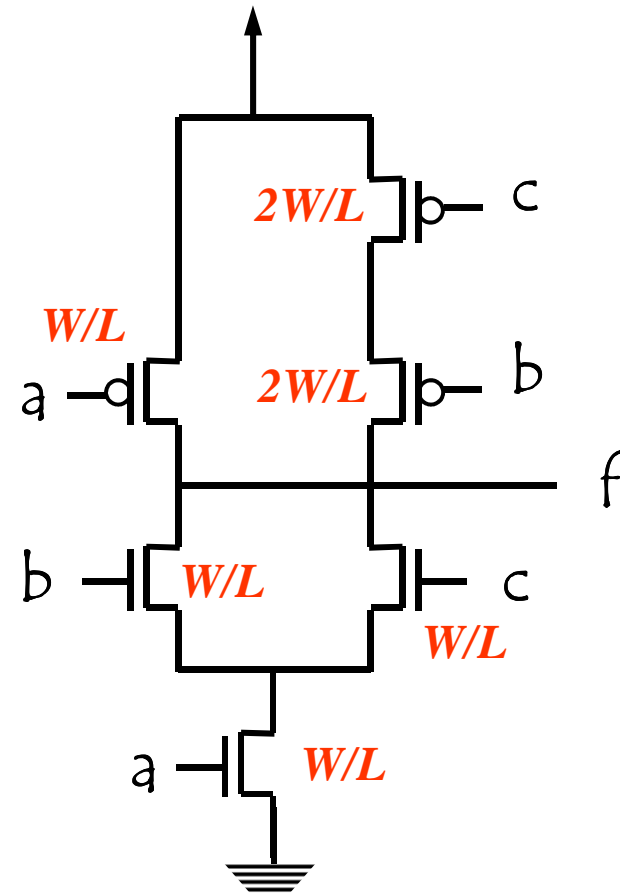
Example :

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

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

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

$$g = a \cdot (b+c)$$



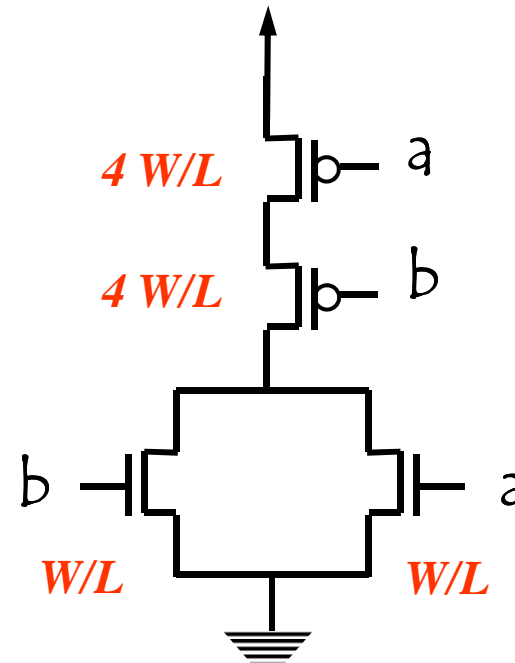
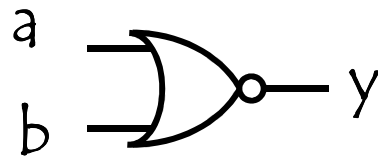
Basic CMOS Gates

Some gates :

Inverter : $f = \bar{a}$

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

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

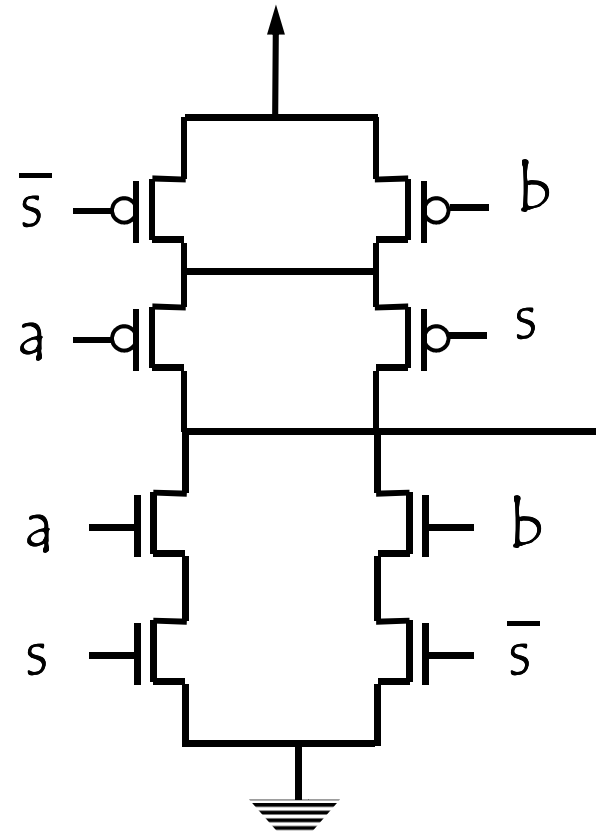
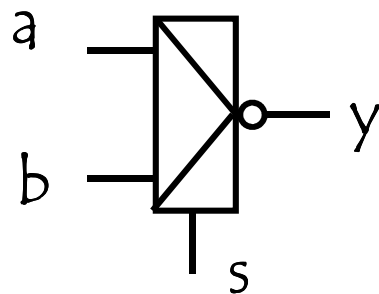


Basic CMOS Gates

Some gates :

Multiplexer :

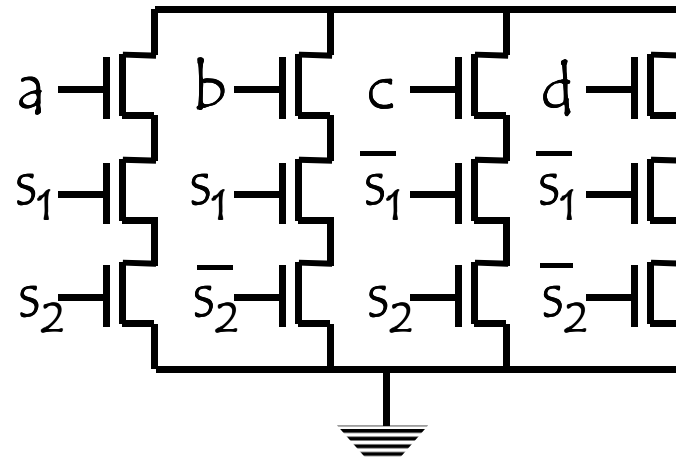
$$f = a.s + b.\bar{s}$$



Basic CMOS Gates

Some gates : Multiplexer :

$$f = a.s_1.s_2 + b.s_1.\bar{s}_2 + c.\bar{s}_1.s_2 + d.\bar{s}_1.\bar{s}_2$$

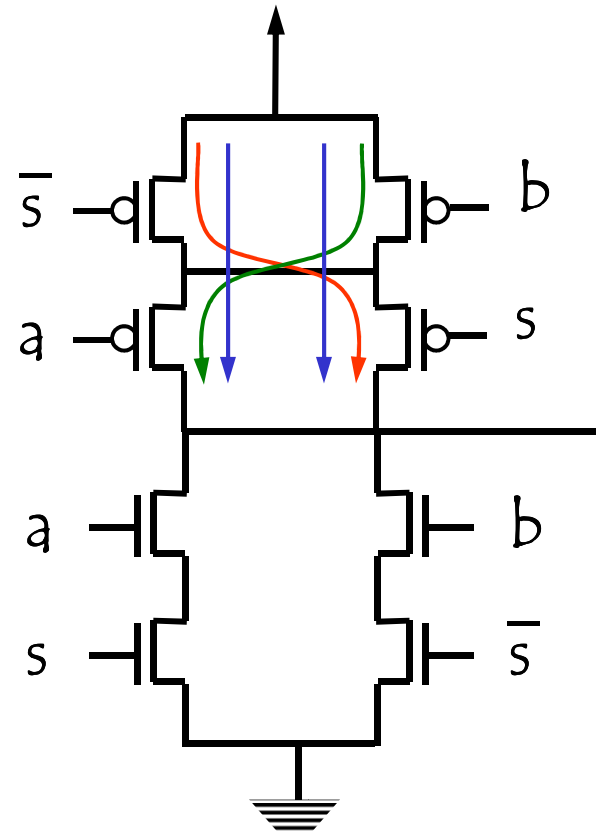


Basic CMOS Gates

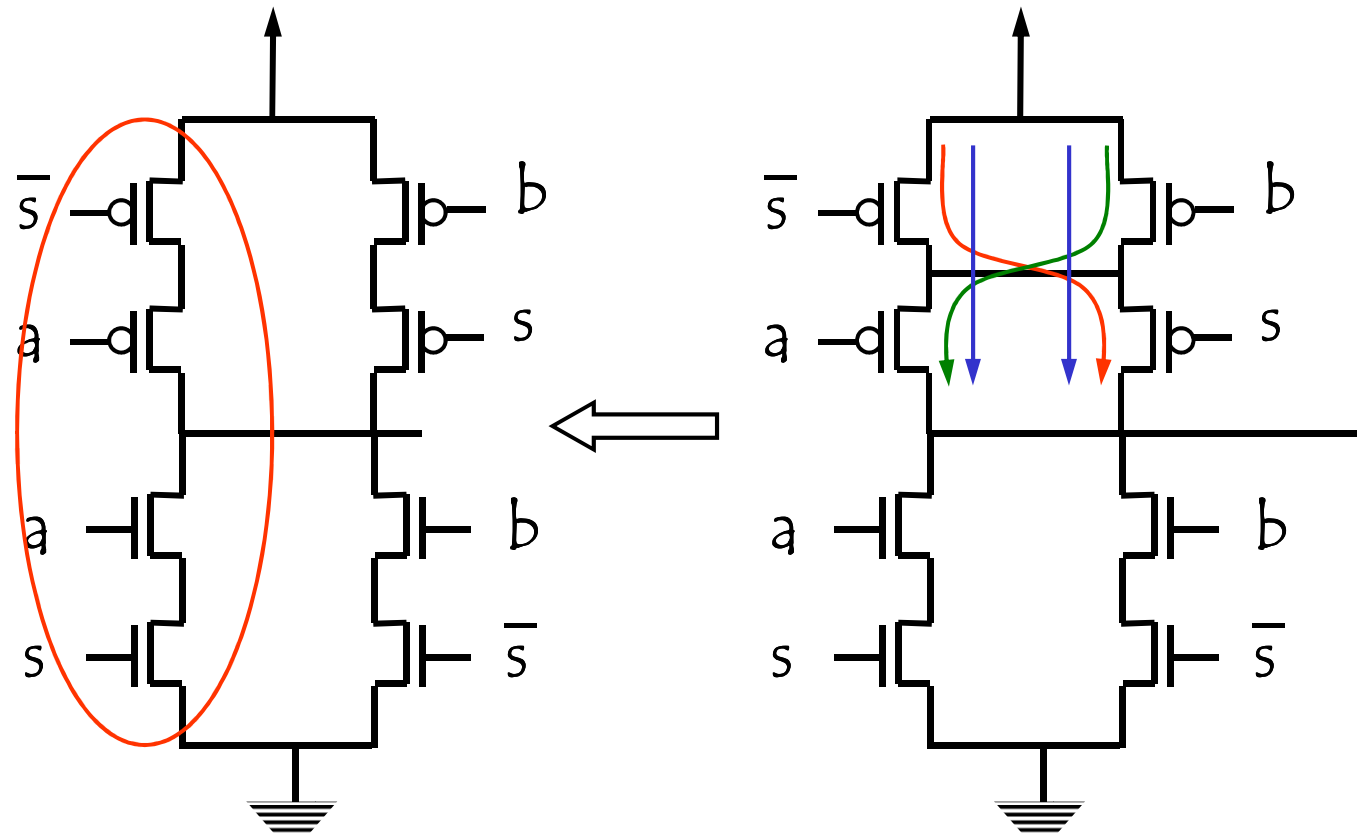
Some gates :

Multiplexer :

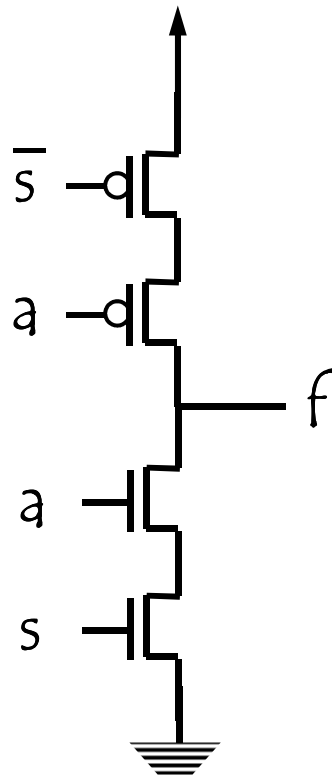
$$f = a.s + b.\bar{s}$$



Basic CMOS Gates



Basic CMOS Gates

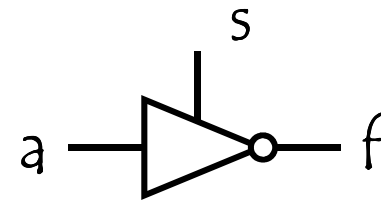


If $s = 1$

$$f = \overline{a}$$

If $s = 0$

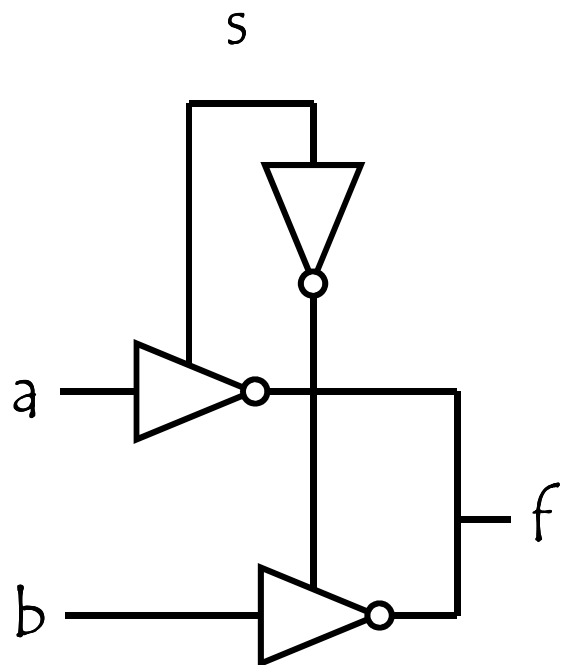
f is not defined



Tri-state driver

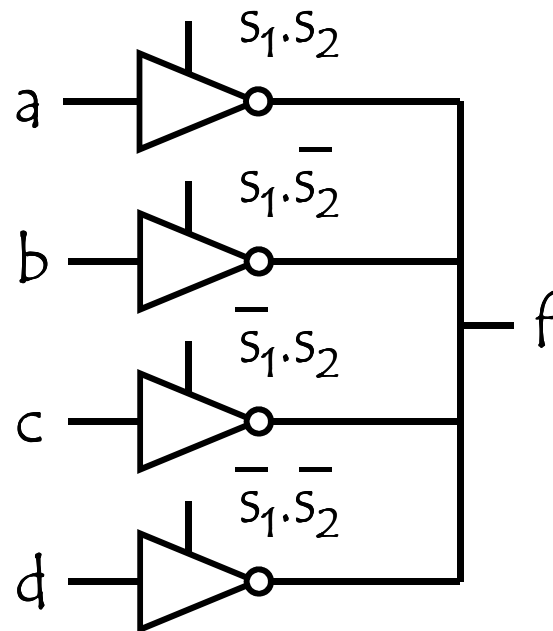
Basic CMOS Gates

Some gates : Multiplexer :



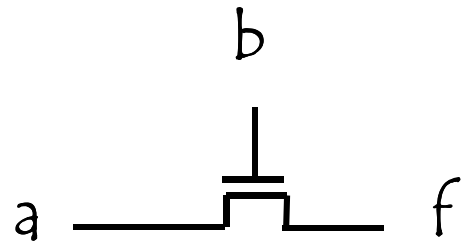
Basic CMOS Gates

Some gates : Multiplexer :



Basic CMOS Gates

Some gates :



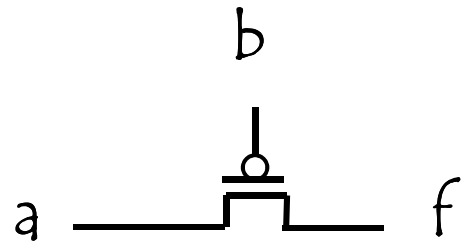
If $b = 1$ If $b = 0$
 $f = a$ f is not defined

→ If $a = 0$ then $f = 0$
→ If $a = 1$ then $f = 1$

Pass-transistor

Basic CMOS Gates

Some gates :



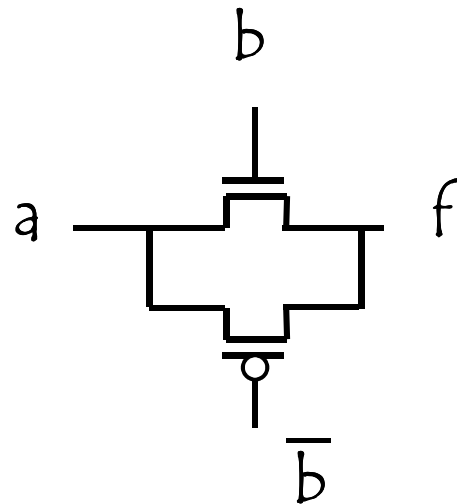
If $b = 0$ If $b = 1$
 $f = a$ f is not defined

→ 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 $f = 1$

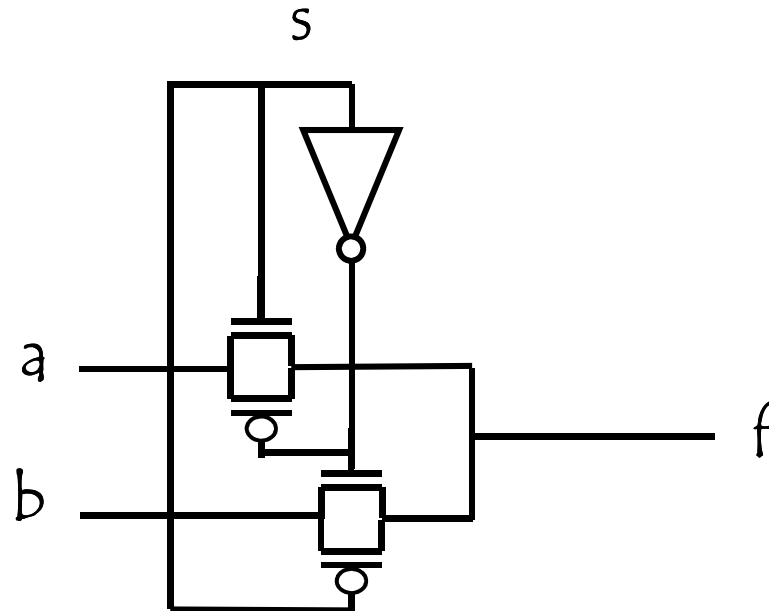
CMOS Switch

Basic CMOS Gates

Some gates :

Multiplexer :

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

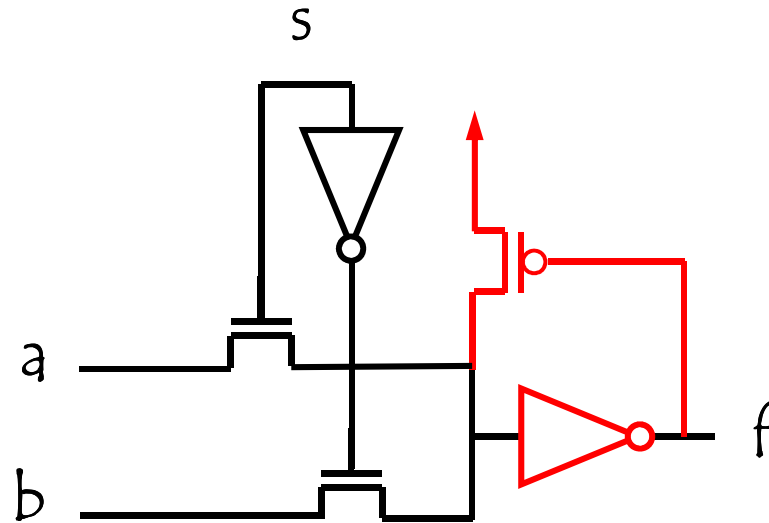


Basic CMOS Gates

Some gates :

Multiplexer :

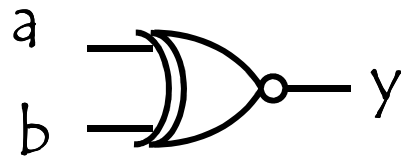
$$f = a.s + b.\bar{s}$$



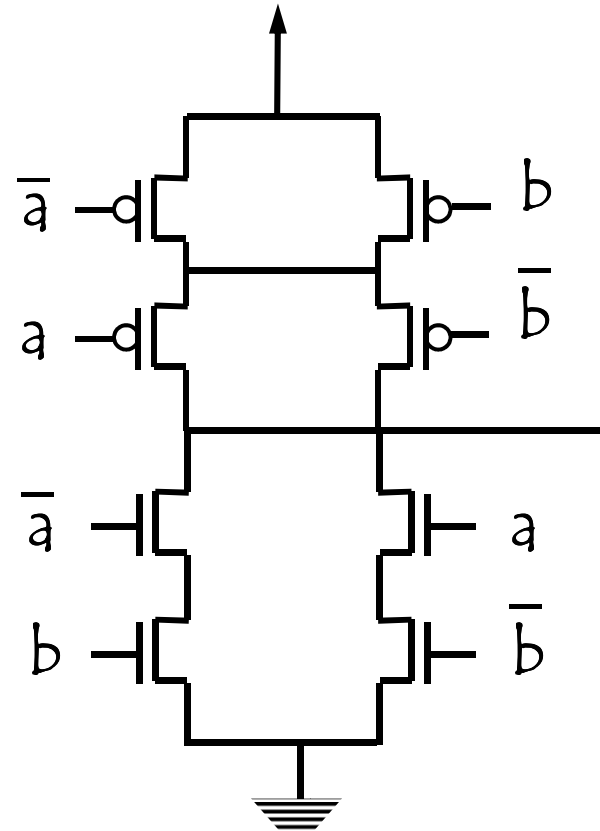
Basic CMOS Gates

Some gates :

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



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



Basic CMOS Gates

Some gates :

Xor with Pass-transistors :

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

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

