

Electronics and Communication Systems

Electronics Systems

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Outline

✧ Review

- Sync. and Async Sequential Logic
- Finite State Machine (MEALY, MOORE, MEALY Rit.)

✧ Complementary CMOS Logic

- Synthesis
- Dynamic Analysis
- Examples: NAND, NOR and comparison
- Stick Diagram
- Body Effect
- Standard-cell AMS 0,35 um

✧ Example: Inverter Chain

- Driving an high value capacitor
- Dynamic Analysis
- Power-Speed Trade-Off

✧ Example: Pass Transistor Chain

- Dynamic Analysis
- Area – Speed Trade-Off

Logic

❖ Combinational Logic

- Output are a pure function of the present input only

❖ Sequential Logic

- Output depends not only on the present input but also on the history of the input

Sequential Logic

❖ **MEMORY concept**

❖ **Asynchronous sequential**

- Outputs of the circuit change directly in response to changes in inputs

❖ **Synchronous sequential**

- Outputs of the circuit change only with the rising (falling) edge of a reference control signal, named **clock**

Asynchronous sequential

❖ **Ripple Design**

❖ **Pro**

- **High Speed**
- **Low Power**

❖ **Cont**

- **Race Conditions**
- **Difficult Design**

Synchronous sequential

❖ Clocked Design

❖ Pro

- Easy Design
- Robust Design

❖ Cont

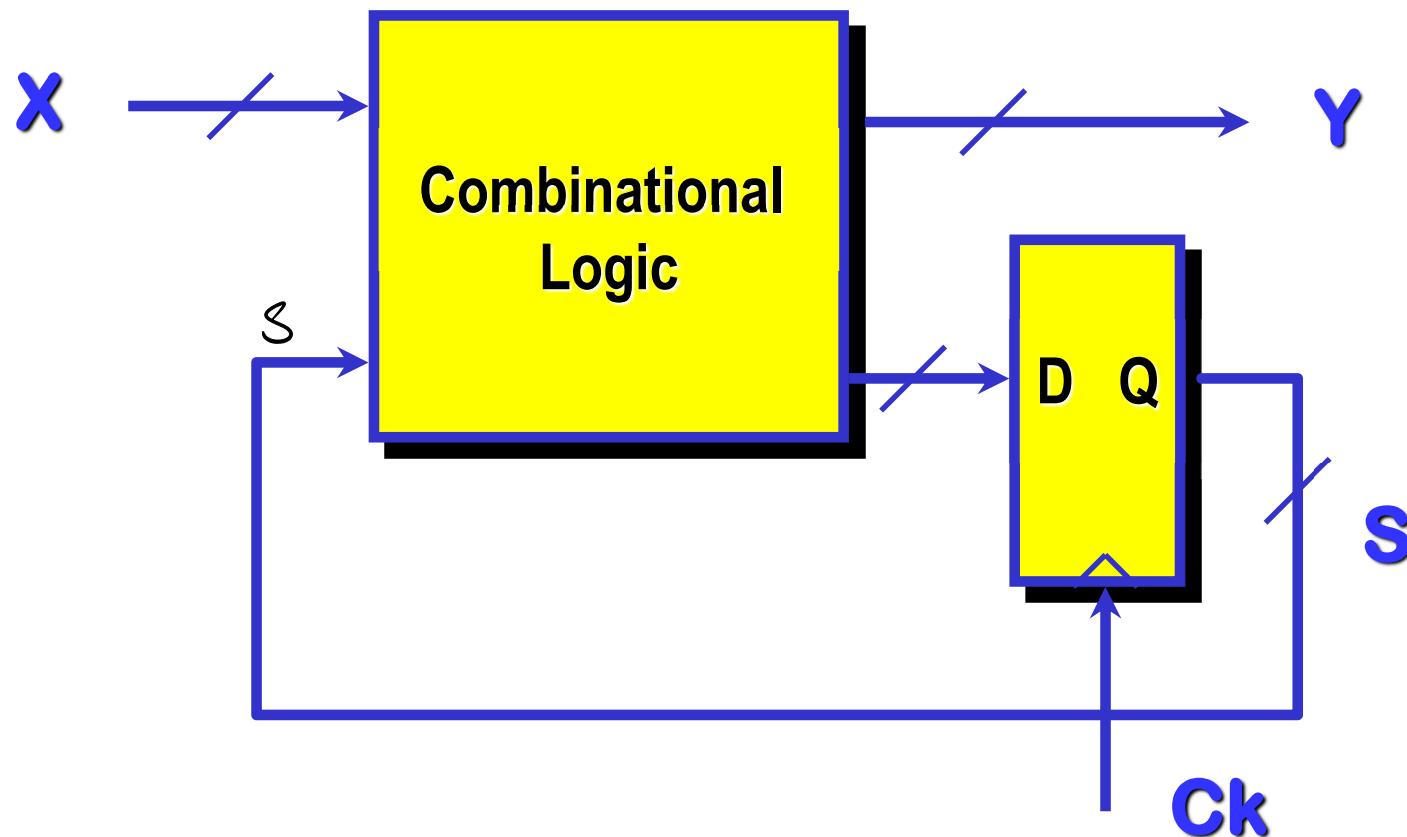
- High complexity
- High Power Consumption
- «Reduced» Speed

MEALY Machine1/2

- ✧ **Output values are determined both by its current state and the current inputs**
- ✧ **Asynchronous Logic**
- ✧ **Based on one combinational Logic**

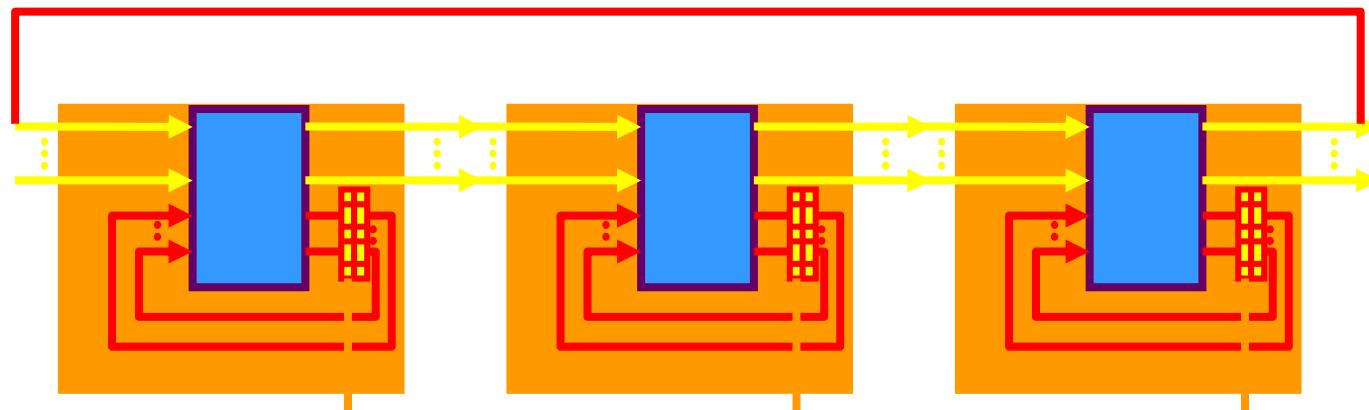
MEALY Machine 2/2

Block Diagram



Notes

- ❖ **Outputs are asynchronous**
- ❖ **Critical to have a cascaded of MEALY machines due to hidden asynchronous logic**

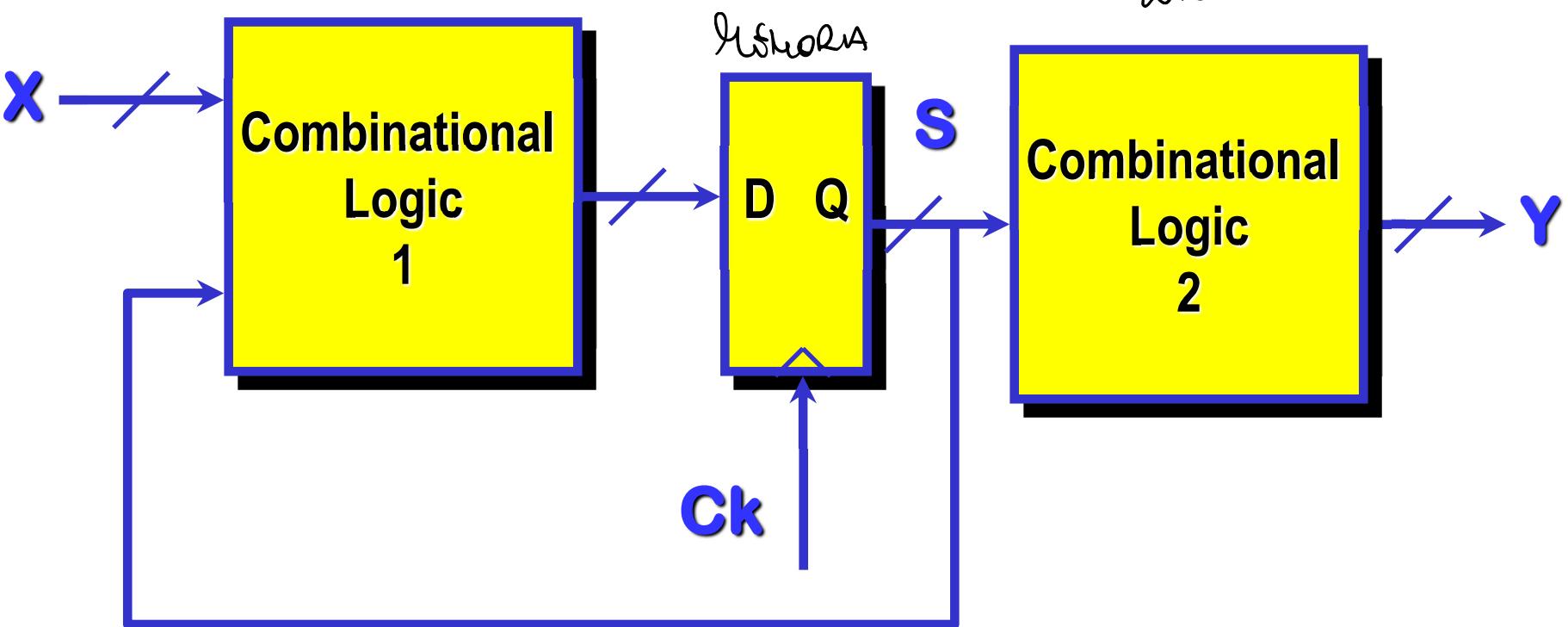


MOORE Machine 1/2

- ✧ **output values are determined solely by its current state**
- ✧ **Synchrounous Logic**
- ✧ **Required two Combinational Logics**
- ✧ **Never Unstable**

MOORE Machine 2/2

Block diagram



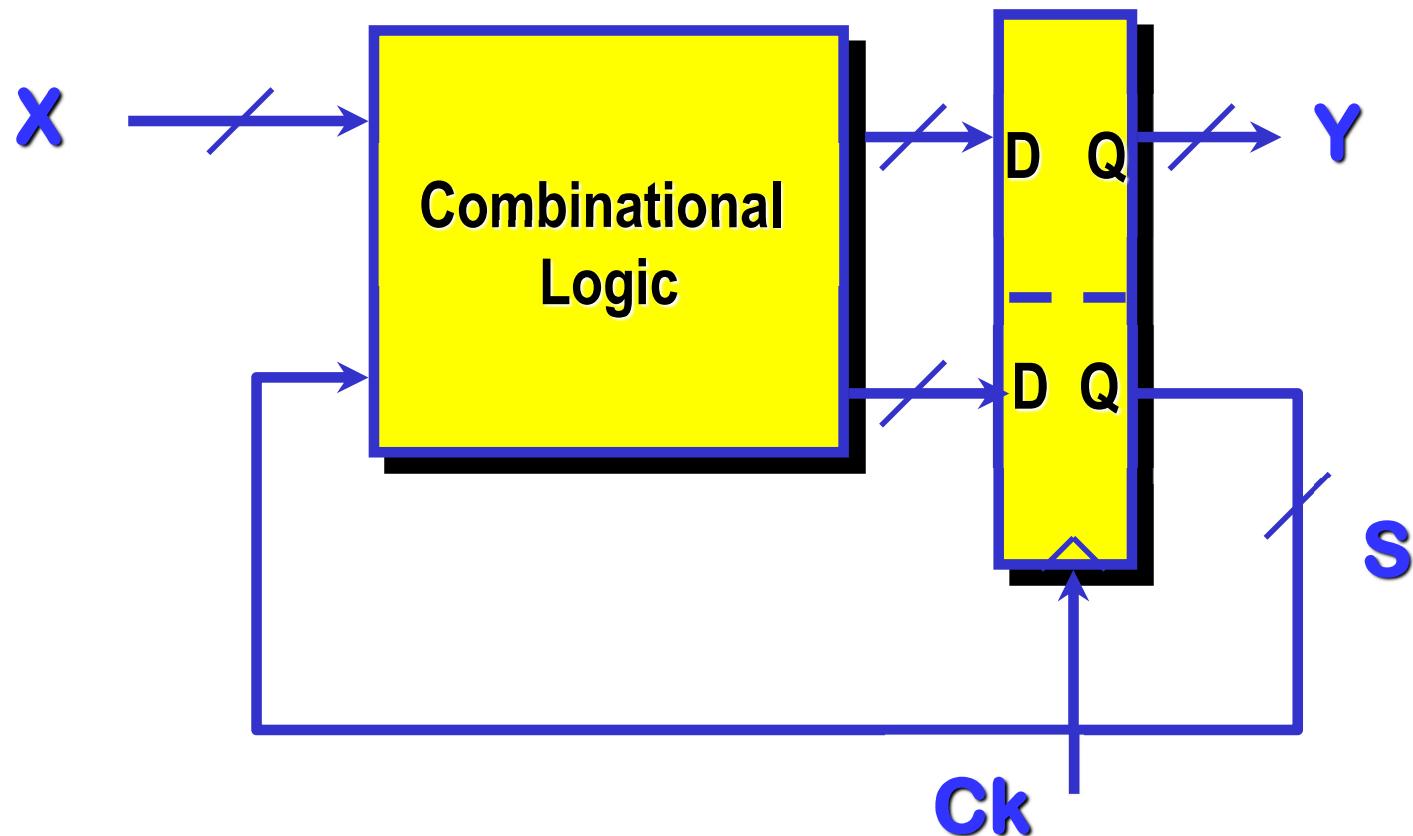
Modified MEALY machine 1/2

- ❖ **Output are synchronized to solve stability problem**
- ❖ **Output are delayed w.r.t MEALY**
- ❖ **Synchronous Logic**
- ❖ **It is a MOORE Machine**
- ❖ **Sometimes required one internal state less than MOORE Machine**

Modified MEALY machine 2/2

Block Diagram

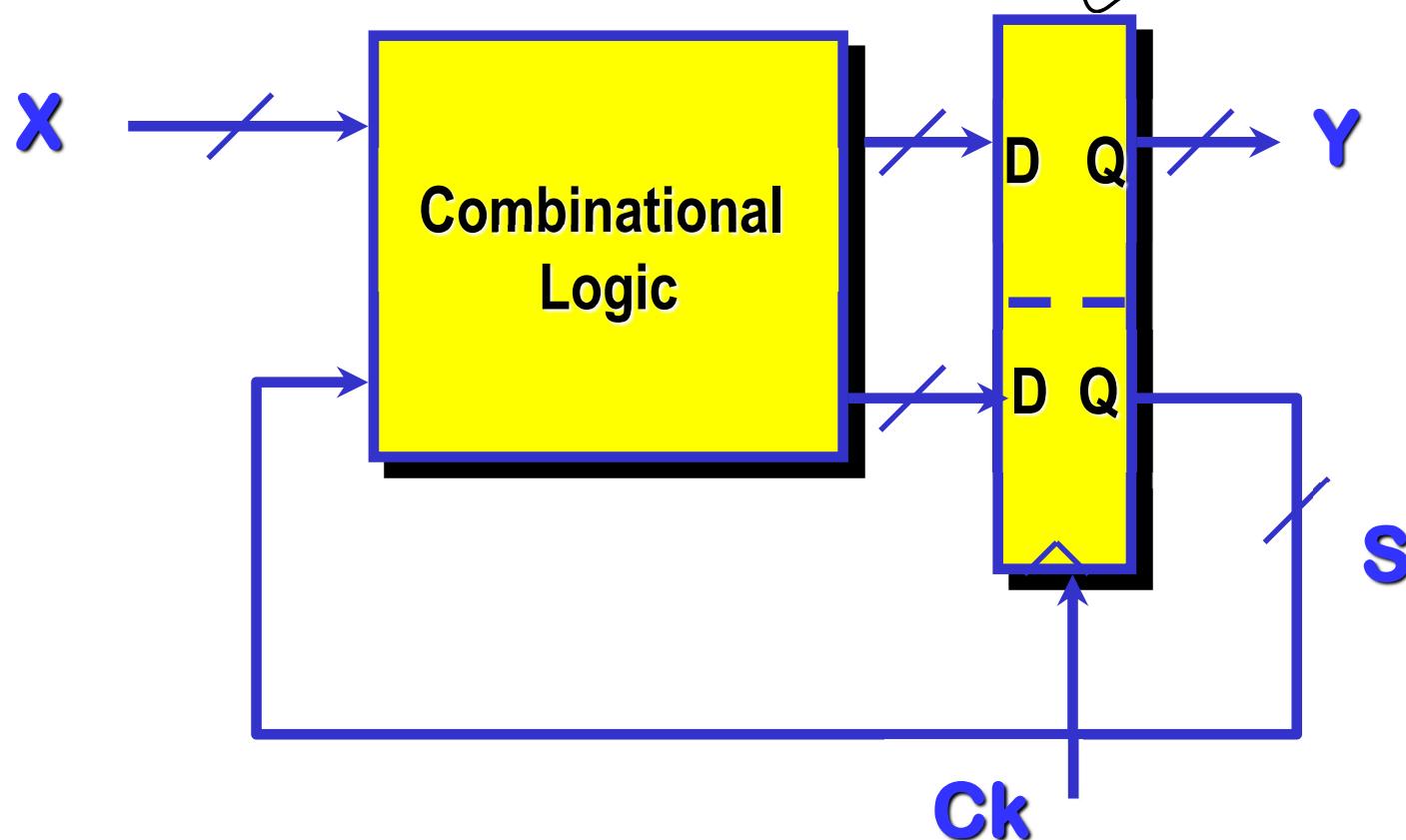
Sequential Logic



Finite State Machine: Basic Elements

Combinational Logic

Memory Element (Flip Flop D edge triggered)



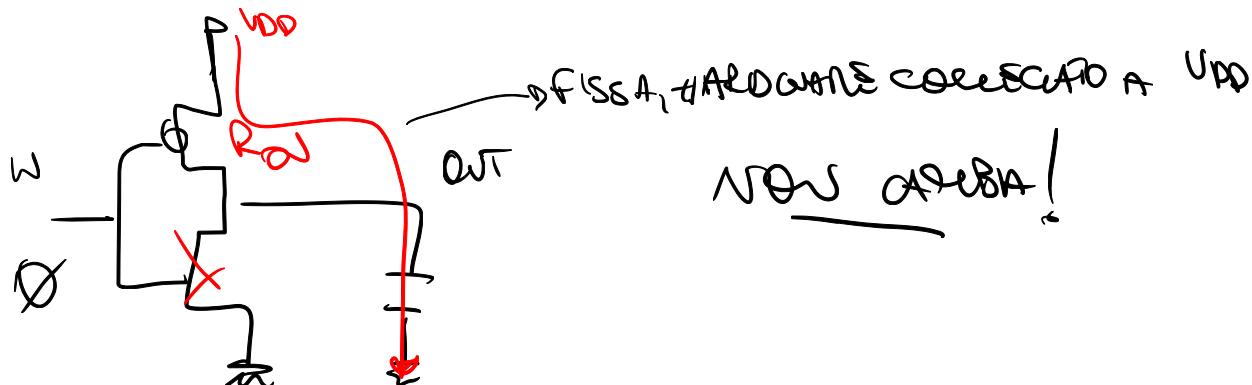
Finite State Machine: Basic Elements

❖ How to build them ?

- Static Logic (hard node)**
- Dynamic Logic (soft node)**

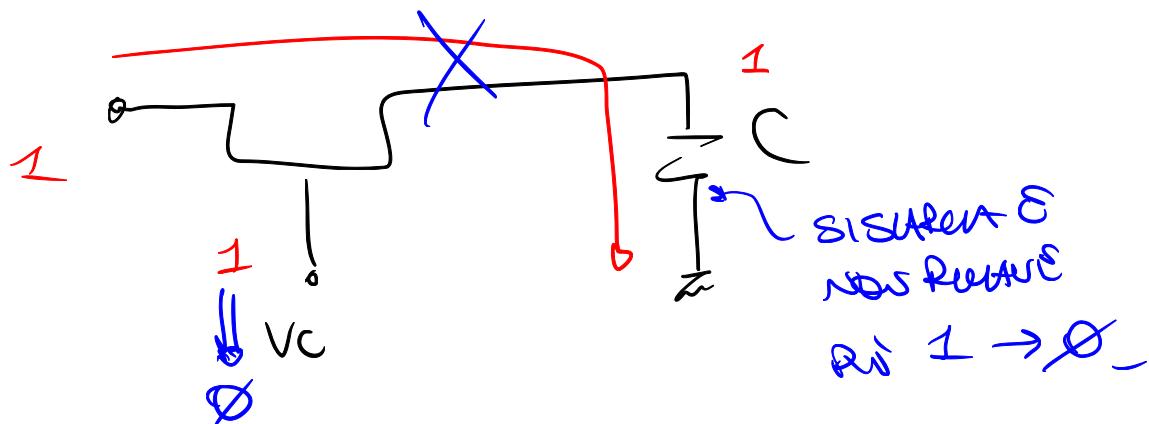
Hard-Node (Static Logic)

- ❖ Have positive feedback (regeneration) with an internal connection between the output and the input. Storage is performed through circuit topology
- ❖ Preserve state as long as the power is on
- ❖ Useful when updates are infrequent



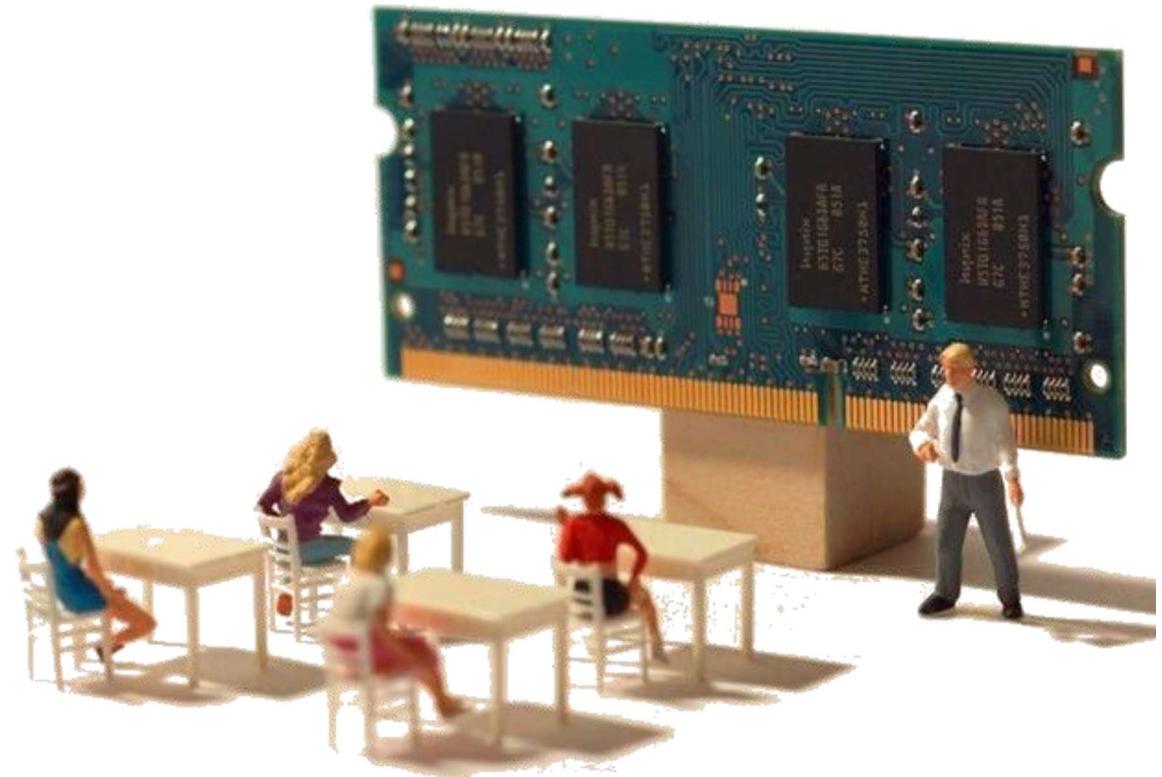
Soft Node (Dynamic Logic)

- ✧ Store state on parasitic capacitors
- ✧ Only hold state for short periods of time
- ✧ Require periodic refresh
- ✧ Usually simpler, so higher speed and lower power



End Review, Questions ?

- Sync. and Async Sequential Logic
- Finite State Machine (MEALY, MOORE, MEALY Rit.)



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❖ Example: Inverter Chain

- Driving an high value capacitor
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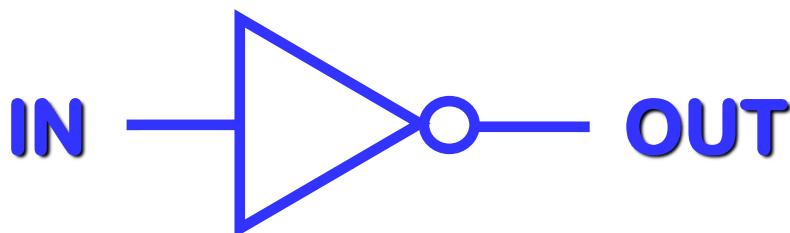
❖ Example: Pass Transistor Chain

- Dynamic Analysis
- Area – Speed Trade-Off

INVERTER

❖ Implementation of the logic NOT Function

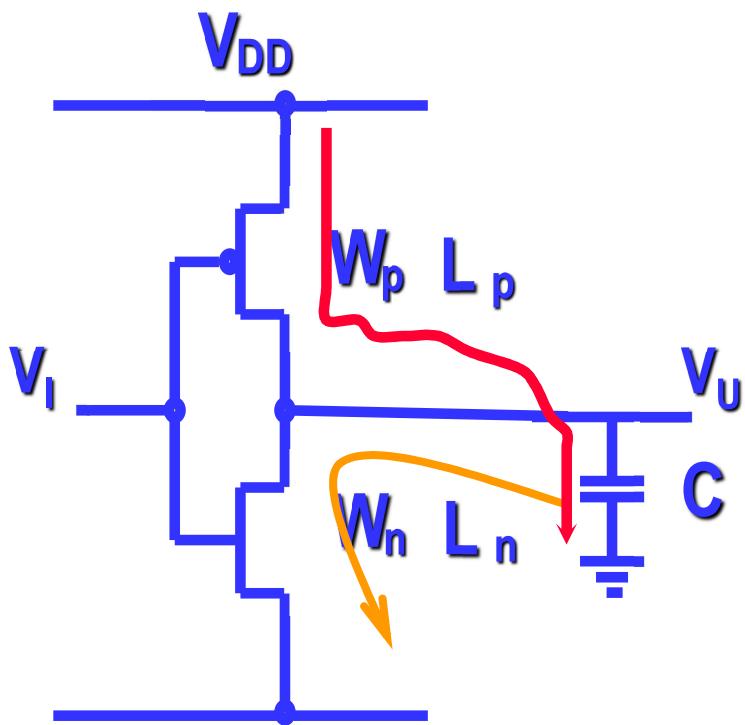
Logic Symbol



Truth Table

IN	OUT
0	1
1	0

Propagation Delay



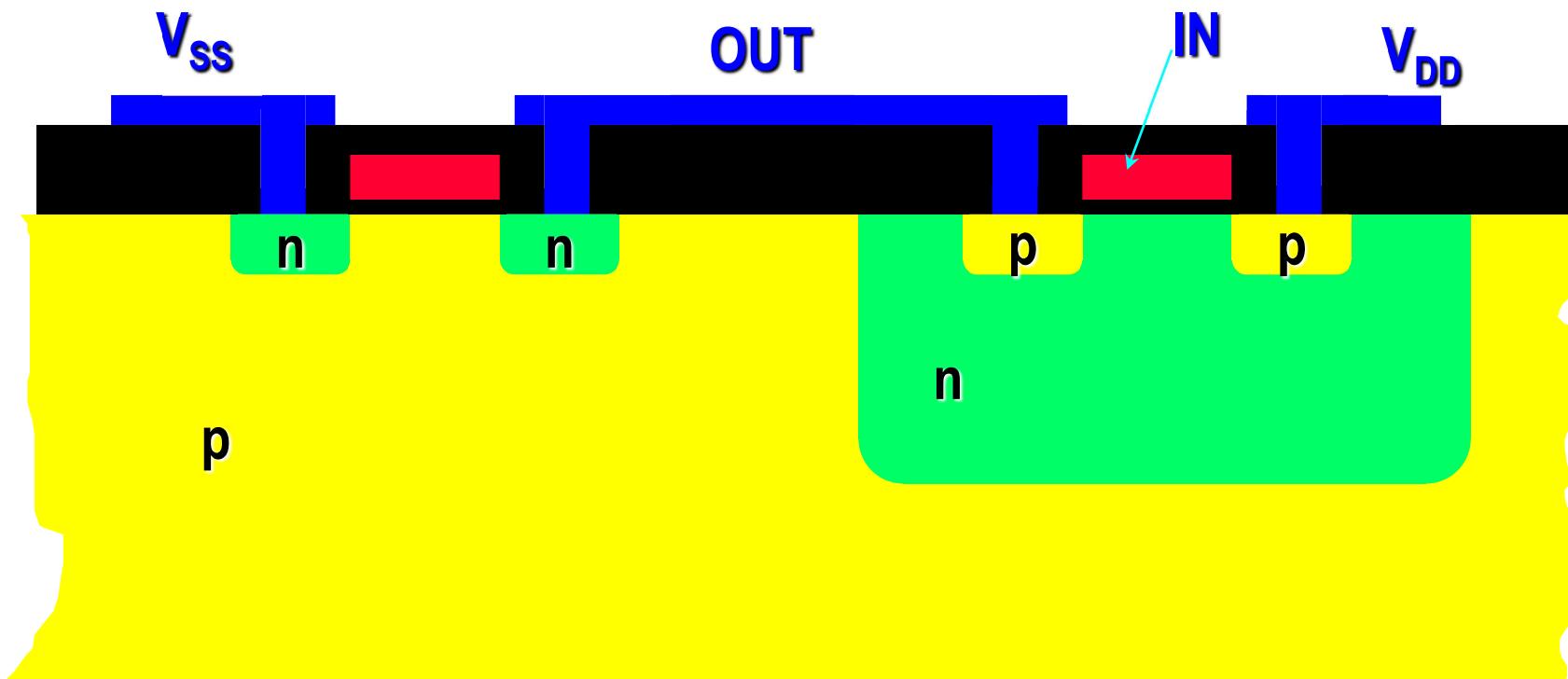
$$t_{pHL} \propto \frac{KC}{\beta_n} \frac{1}{V_{DD} - V_{Tn}}$$

$$t_{pLH} \propto \frac{KC}{\beta_p} \frac{1}{V_{DD} + V_{Tp}}$$

$$\beta_n = \mu_n C_{ox} \frac{W_n}{L_n} \quad \beta_p = \mu_p C_{ox} \frac{W_p}{L_p}$$

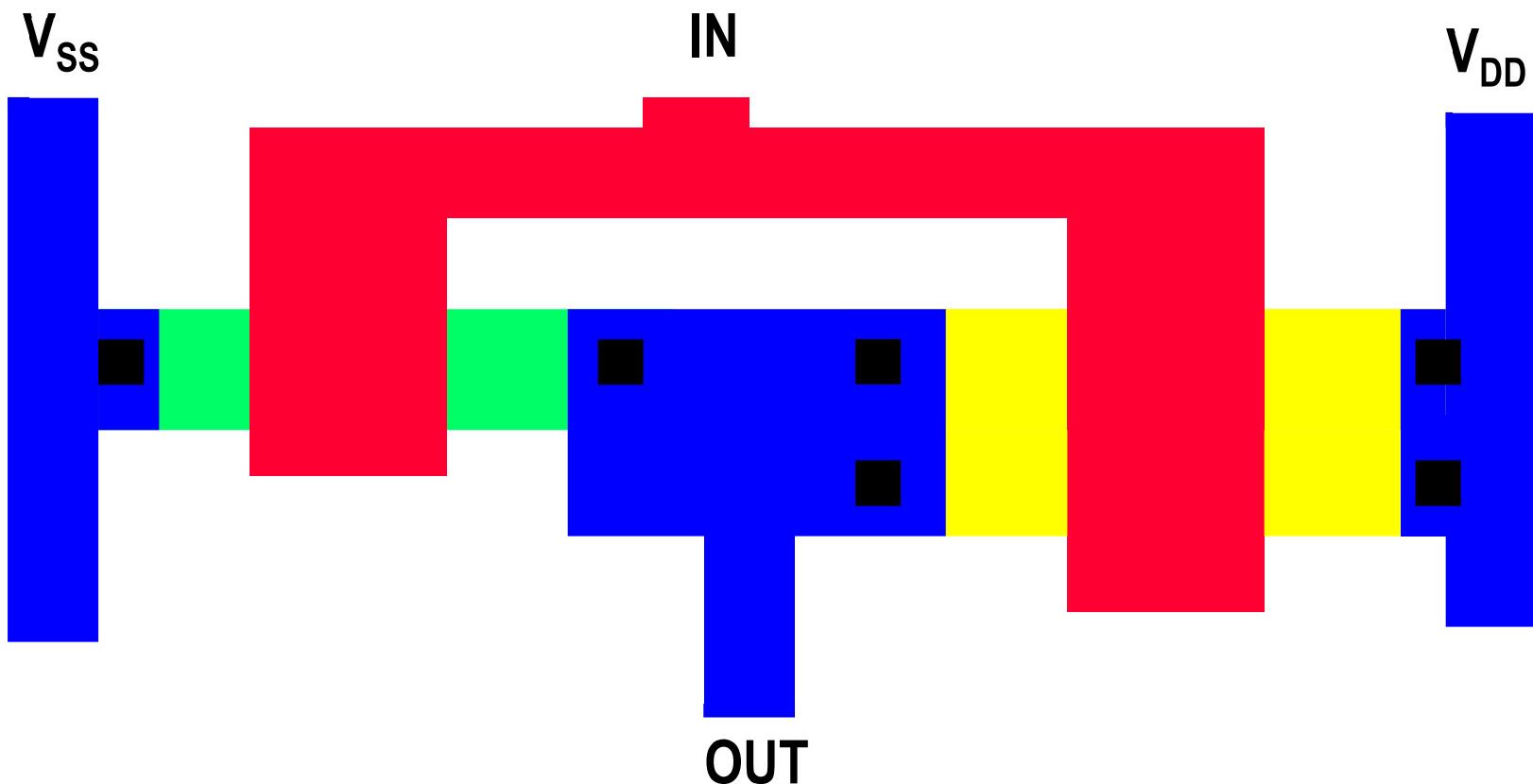
INVERTER Lay-out 1

✿ Cross Section for “n” well process



INVERTER Lay-out 2

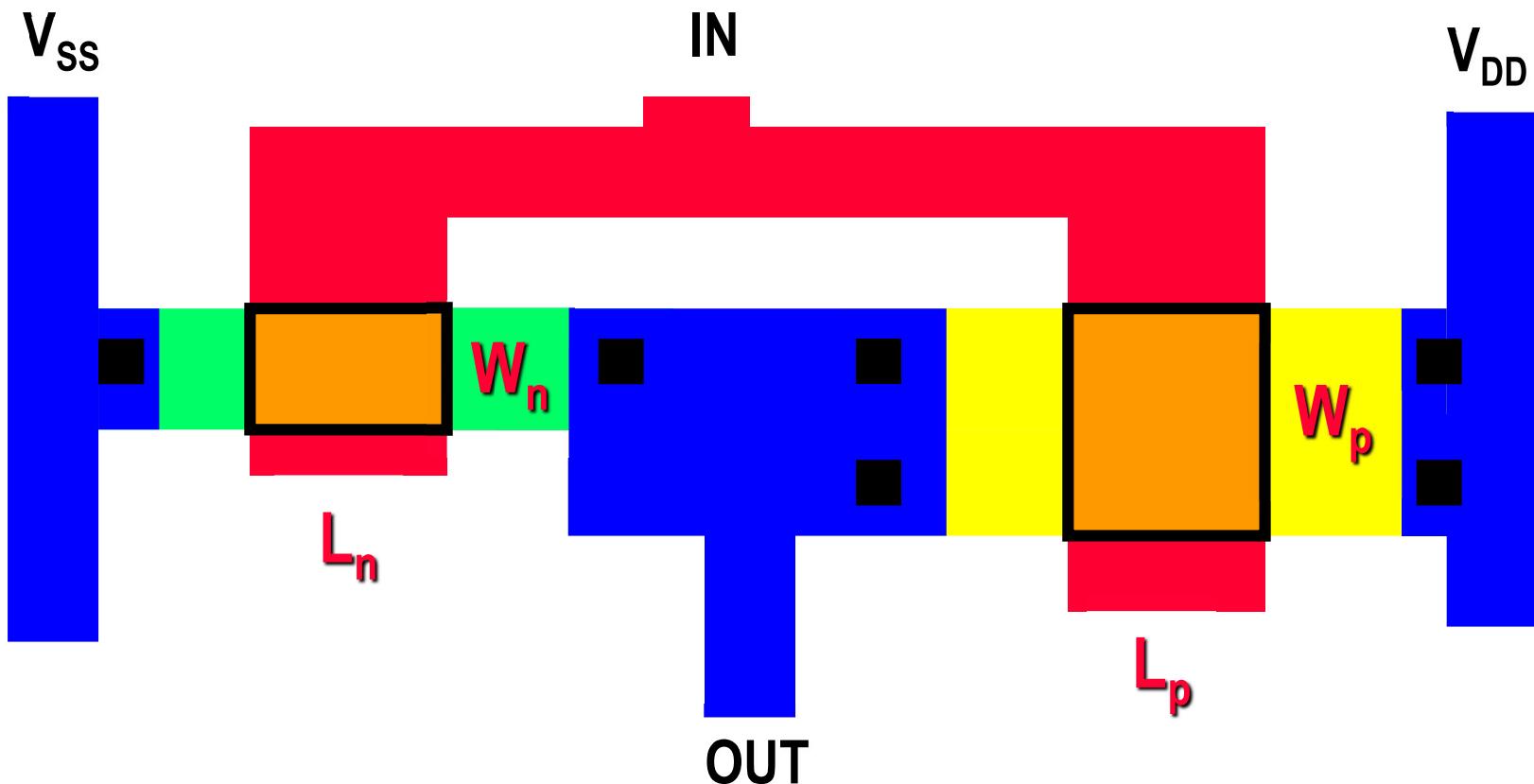
★ Top view



INVERTER Lay-out 2

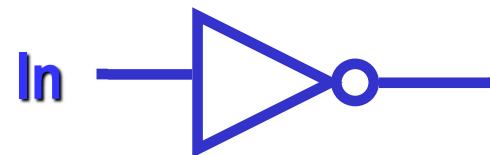
✿ Top view

$$A \sim W_n L_n + W_p L_p$$

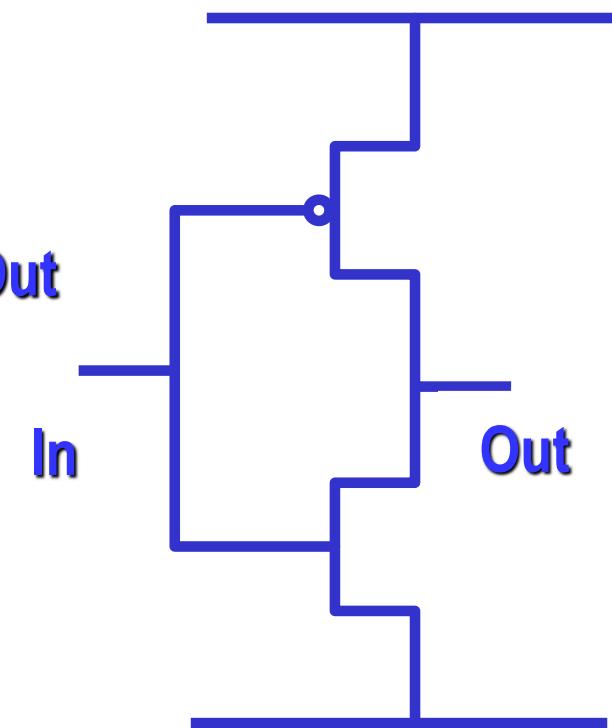


Stick Diagram

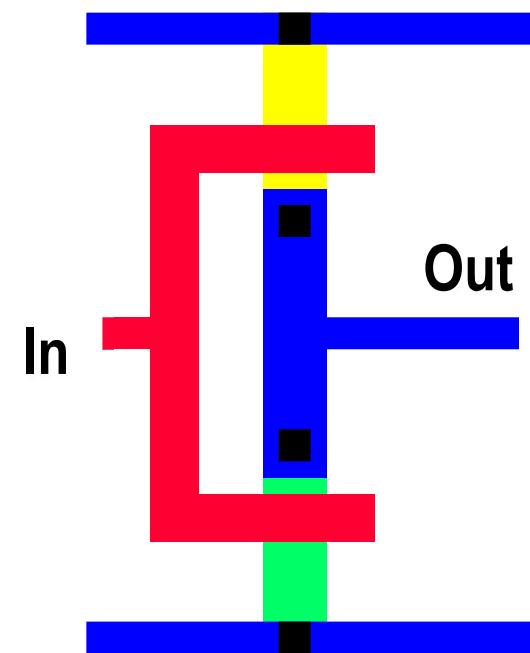
Logic Symbol



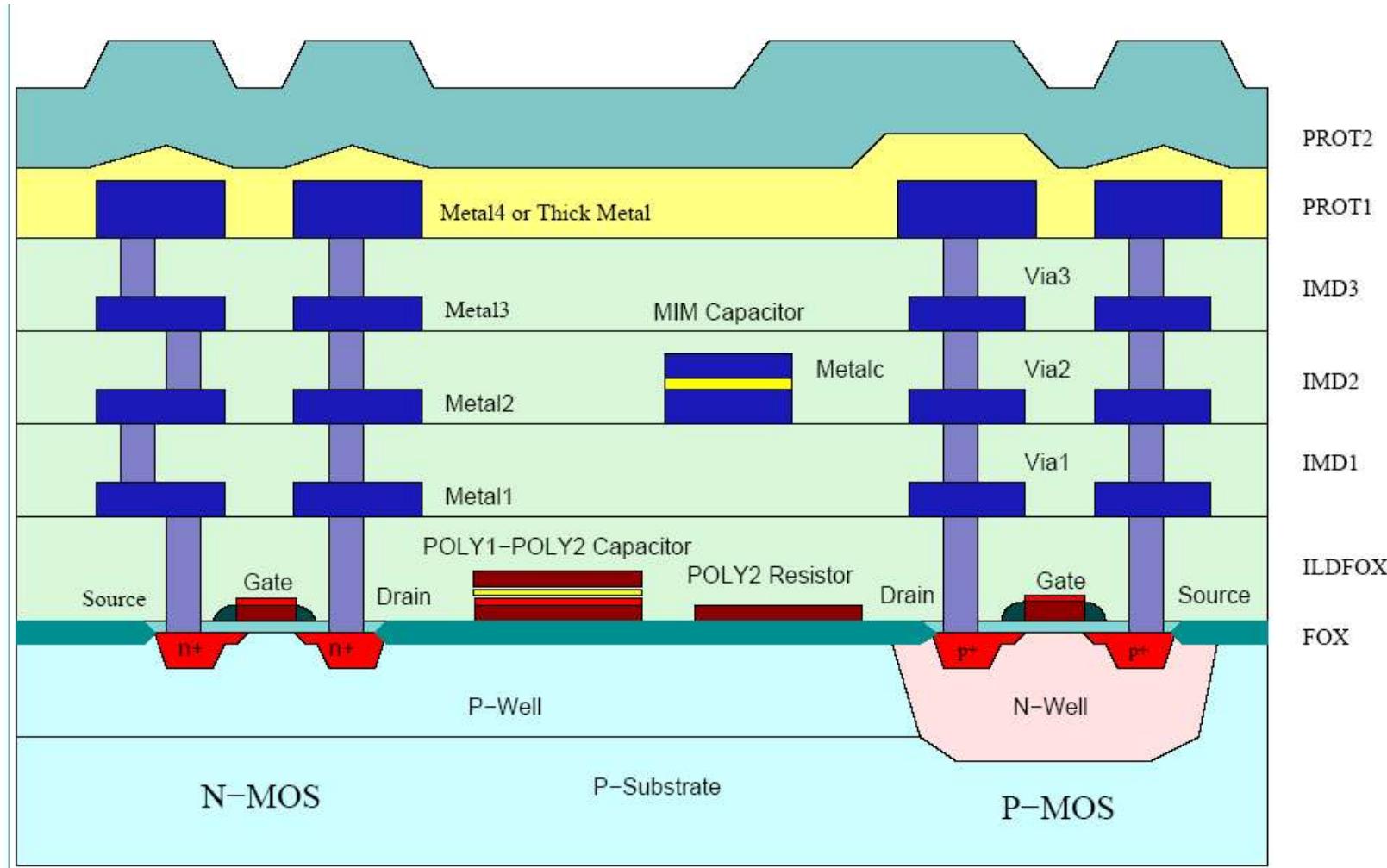
Circuit



Lay-out



Wafer Cross-Section Austriamicrosystems, 0,35 um CMOS



Austriamicrosystems, 0,35 um CMOS Technology Overview

LOWEST TECHNOLOGY

Process technology specifications	units	C35B3C3	C35B4C3
Drawn MOS Channel Length	µm	0,35	
Operating Voltage	V	2.5 - 3.6	10 - 5.5
Number of Masks	#	14	20
Number of Masking layers	#	19	24
Number of Metal Layers	#	3	4
Number of Poly Layers	#	2	
Substrate Type		p	
Diffusion Pitch	µm	0,9	
Metal1/2/3/4 Pitch	µm	0.95 / 1.1 / 1.1 / 1.2	
Metal1/2/3/4 connected Pitch	µm	1.05 / 1.2 / 1.2 / 1.3	
Poly1 Pitch	µm	0,8	
High Resistive Poly	kOhm/#	-	1,2
Poly1/Poly2 Precision Caps	fF/µm ²	0,9	
N/PMOS Channel Length	µm	0.30/0.30	
N/PMOS Saturation Current	µA/µm	520 / 240	

Standard-Cell Austriamicrosystems, 0,35 um CMOS Technology Library



0.35μm CMOS

Digital Standard Cell Databook

Inverter

INVX1

am

www.ams.com

CORNER CASE

Conditions for characterization library c35_CORELIBD_BC, corner c35_CORELIBD_BC_best: Vdd= 3.63V, Tj= -50.0 deg. C .
Output transition is defined from 20% to 80% (rising) and from 80% to 20% (falling) output voltage.
Propagation delay is measured from 50% (input rise) or 50% (input fall) to 50% (output rise) or 50% (output fall).

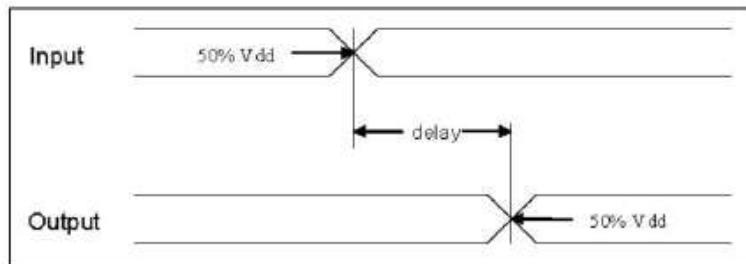
Strength	1
Cell Area	29.120 μm^2
Equation	$Q = \text{!}A$
Type	Combinational
Input	A
Output	Q



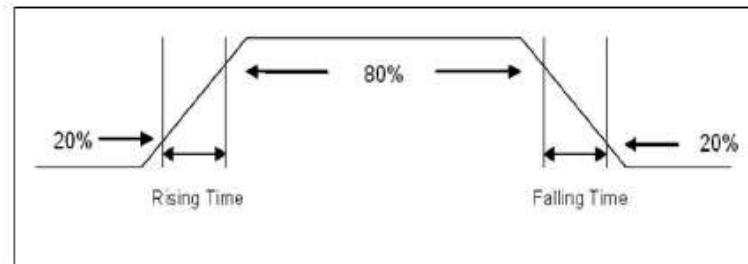
TRUE TABLE

State Table	
A	Q
L	H
H	L

Capacitance [fF]	
A	2.8210



Propagation Delay



Transition Time

Inverter

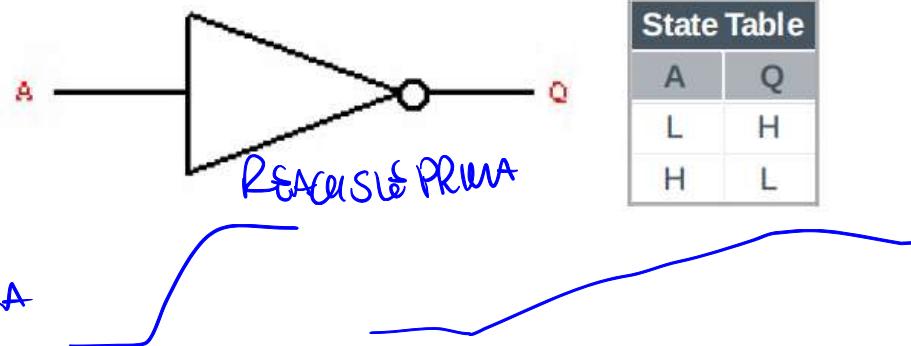
INVX1

am

www.ams.com

Conditions for characterization library c35_CORELIBD_BC, corner c35_CORELIBD_BC_best: Vdd= 3.63V, Tj= -50.0 deg. C .
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Strength	1
Cell Area	29.120 μm^2
Equation	$Q = \text{!A}$
Type	Combinational
Input	A
Output	Q



State Table	
A	Q
L	H
H	L

Capacitance [fF]	
A	2.8210

Propagation Delay [ns]				
Input Transition [ns]		0.01 4.00		
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	0.04	0.41	-0.36 0.63
A to Q	rise	0.06	0.67	0.83 1.88

Output Transition [ns]					
Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00	
A to Q	fall	0.04	0.54	0.70	1.43
	rise	0.08	1.03	0.62	1.58

Inverter

INVX1

am
www.ams.com

Conditions for characterization library c35_CORELIBD_BC, corner c35_CORELIBD_BC_best: Vdd= 3.63V, Tj= -50.0 deg. C .
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Strength	1
Cell Area	29.120 μm^2
Equation	$Q = \text{"!A"}$
Type	Combinational
Input	A
Output	Q



State Table	
A	Q
L	H
H	L

Capacitance [fF]	
A	2.8210

Dynamic Power Consumption [nW/MHz]					Leakage [pW]	
Input Transition [ns]		0.01		4.00		0.26
Load Capacitance [fF]		5.00	100.00	5.00	100.00	
A to Q	fall	1.93	2.35	516.63	510.09	
	rise	38.82	40.07	813.89	712.95	

Inverter

INVX1

am
www.ams.com

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Strength	1
Cell Area	29.120 μm^2
Equation	$Q = \text{!A}$
Type	Combinational
Input	A
Output	Q



State Table	
A	Q
L	H
H	L

Capacitance [fF]	
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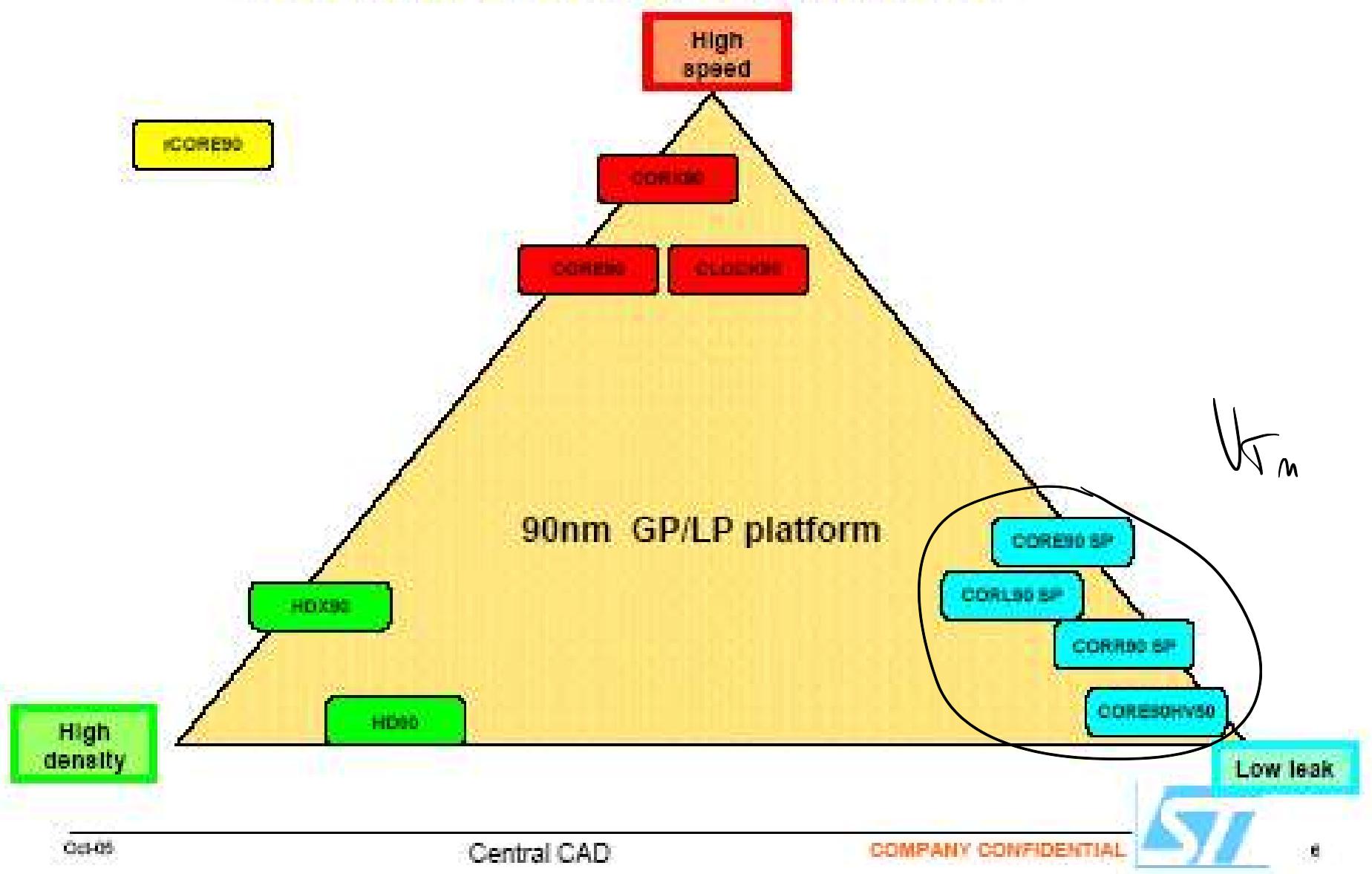
Leakage [pW]

0.26

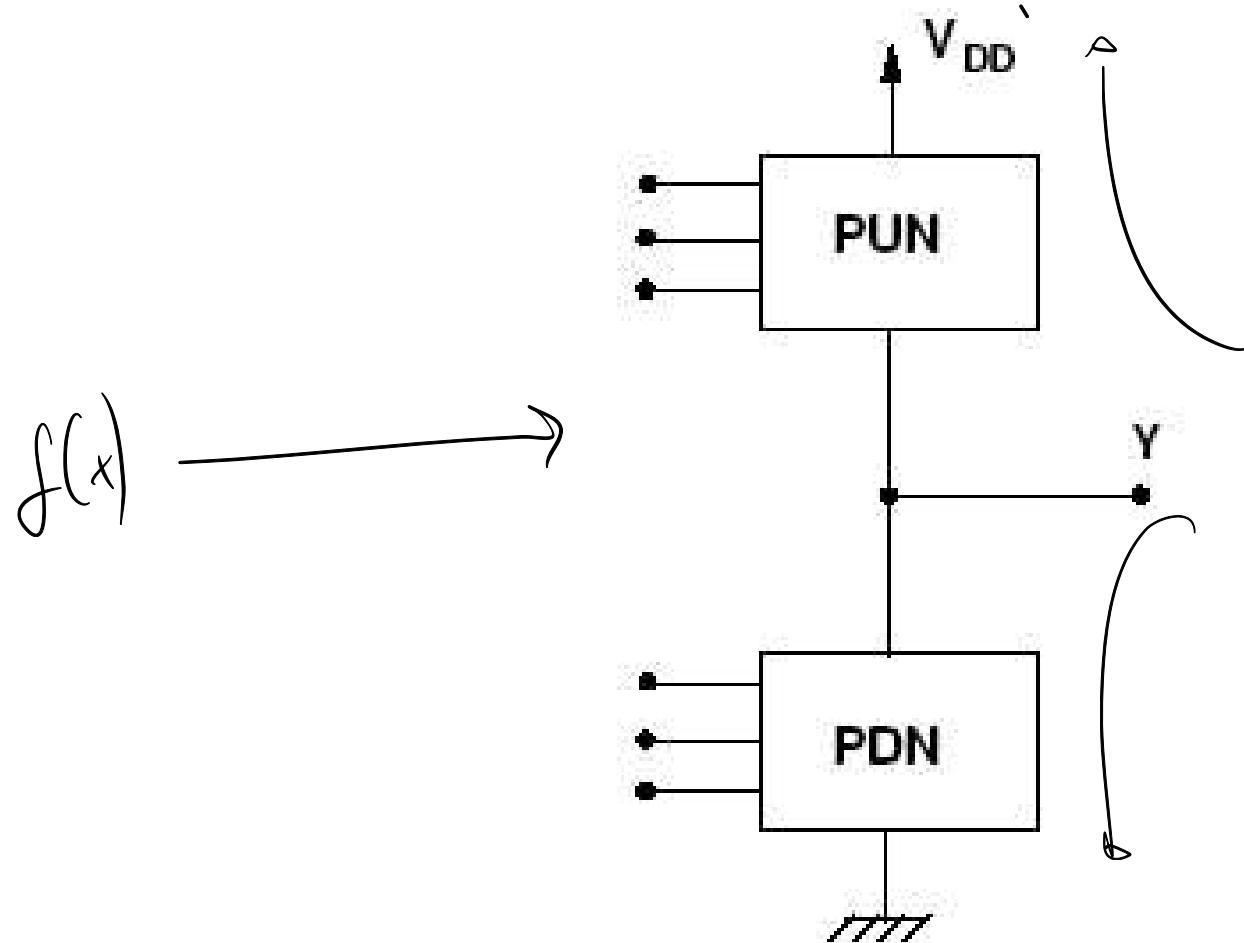
CMOS Technology Corners

	BEST	TYPICAL	WORST
Temperature	-40 - 0 °C	25 °C	85 - 125 °C
Power Supply	1,1*VDD	VDD	0,9*VDD
Process	FAST	TYP	SLOW

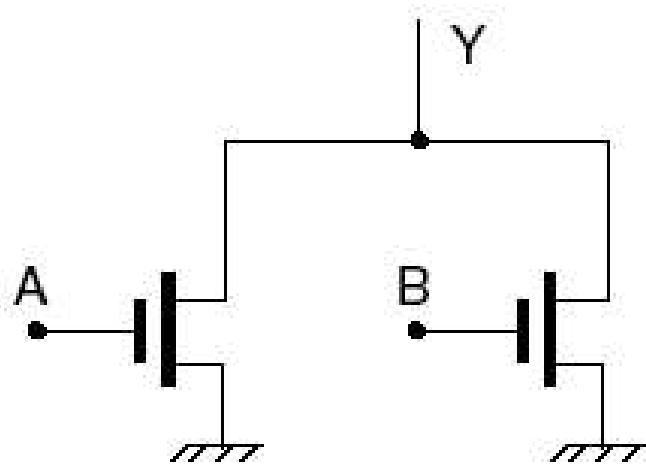
90nm Standard cells Libraries



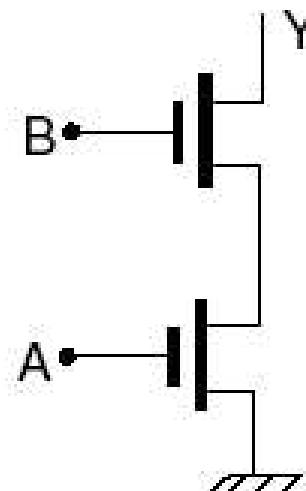
Complementary CMOS



PDN



$$\bar{Y} = A + B$$

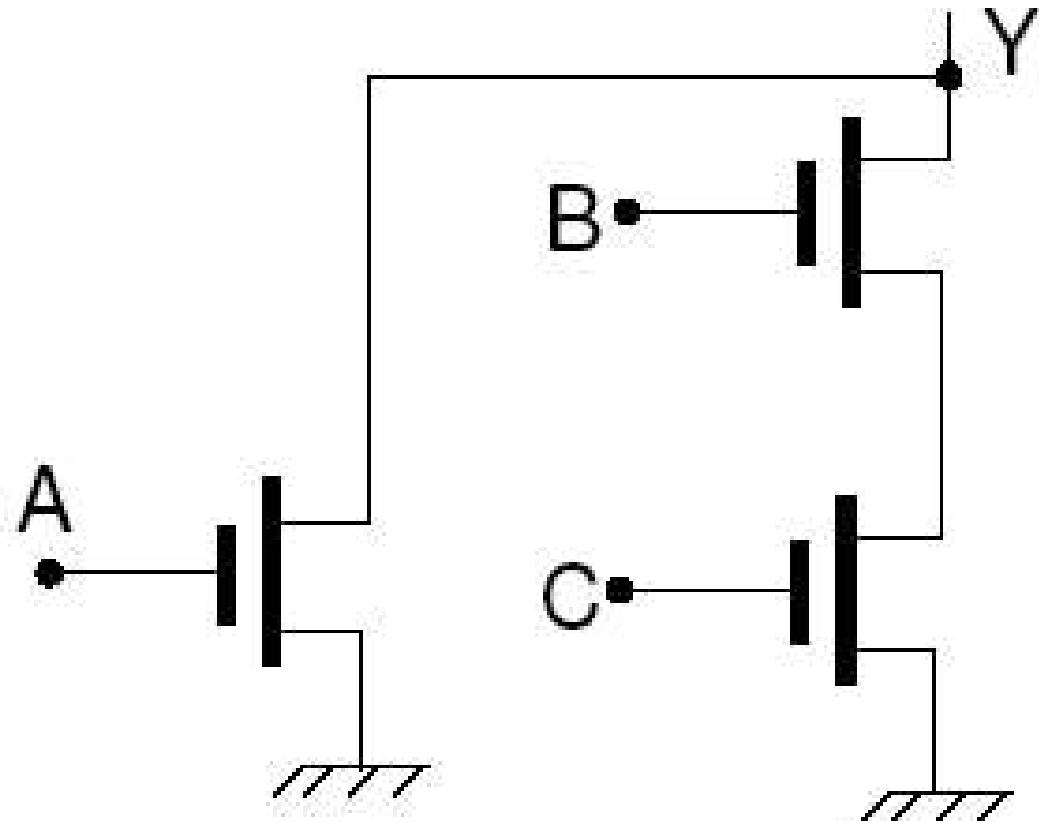


$$\bar{Y} = AB$$

A	B	OR	AND
0	0	0	0
0	1	1	0
1	0	1	0
1	1	1	1

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PDN



$$\bar{Y} = A + BC$$

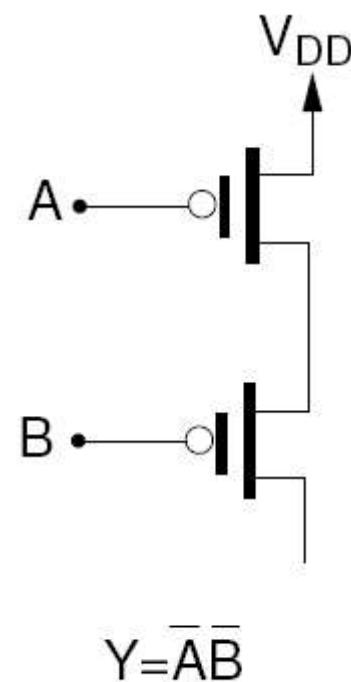
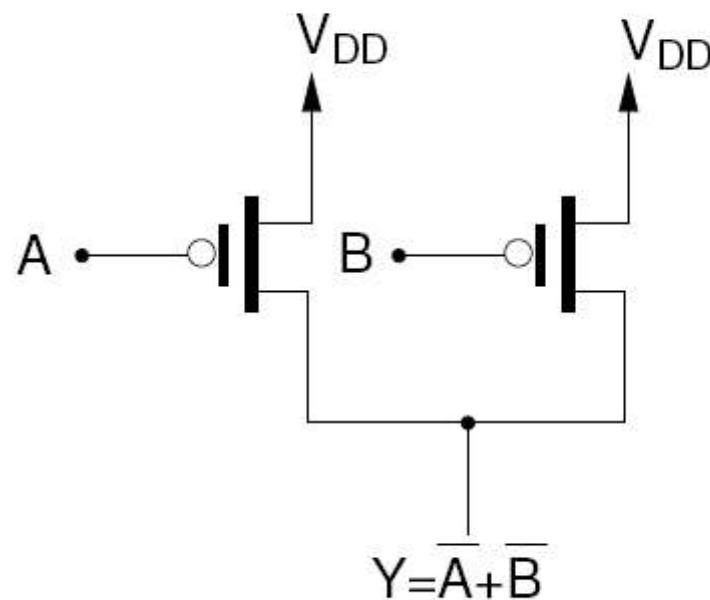
PUN

❖ PUN is DUAL of PDN → BASISA OSANIE CE CIGAR DI OS KOPAS

$$\text{❖ } \overline{A+B} = \overline{A} \cdot \overline{B}$$

$$\text{❖ } \overline{A \cdot B} = \overline{A} + \overline{B}$$

A	B	NAND
0	0	1
0	1	1
1	0	1
1	1	0



PDN / PUN

- ❖ $\overline{Y} = f_{PDN}(A, B)$
 - ❖ $Y = f_{PUN}(\overline{A}, \overline{B})$
- TUTTE GE FUNKTIONEN SIND RELEM

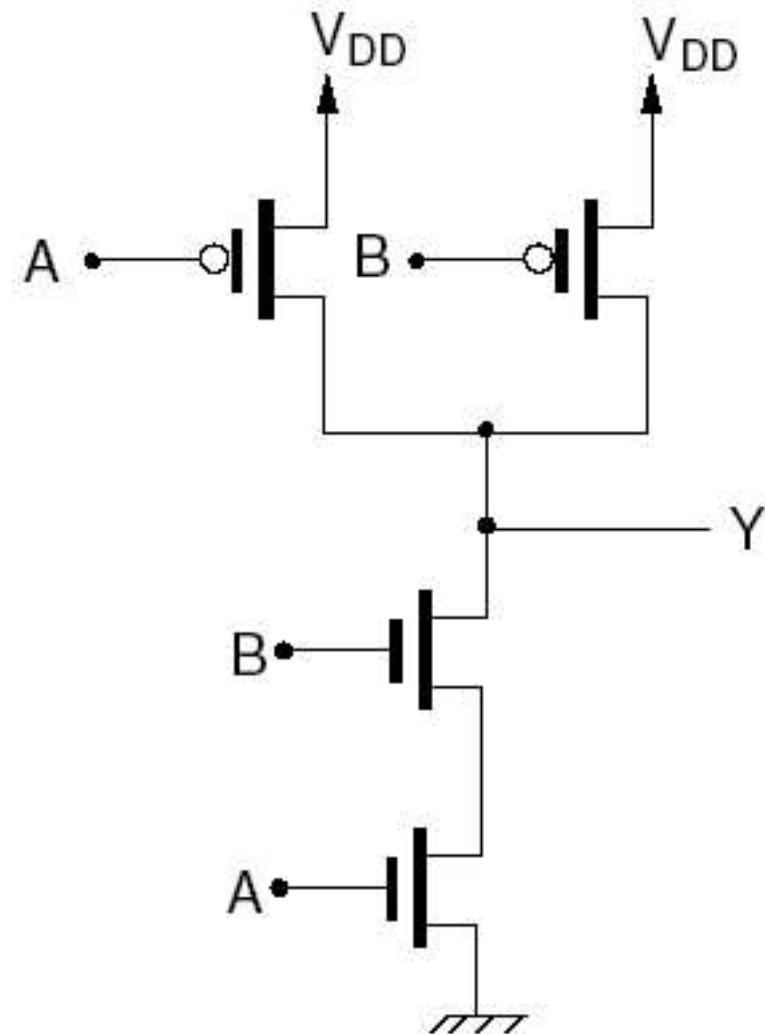
NAND 2

❖ $Y = \overline{A \cdot B}$ N_{AND}

❖ PUN $\rightarrow Y = \overline{\overline{A} + \overline{B}}$

❖ PDN $\rightarrow \overline{Y} = A \cdot B$

$$\overline{f} = A \cdot B$$



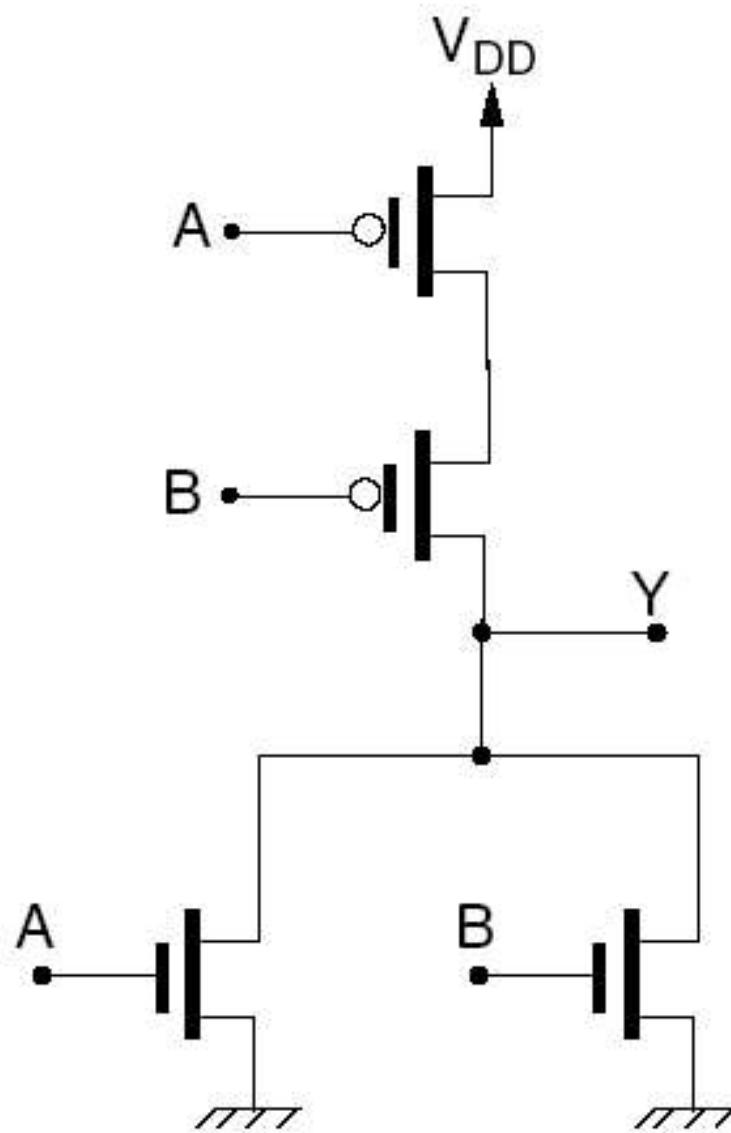
NOR 2

❖ $Y = \overline{A + B}$ *NOR*

❖ $PUN \rightarrow Y = \overline{\overline{A} \cdot \overline{B}}$

❖ $PDN \rightarrow \overline{Y} = A + B$

$$\overline{Y} = A + B$$



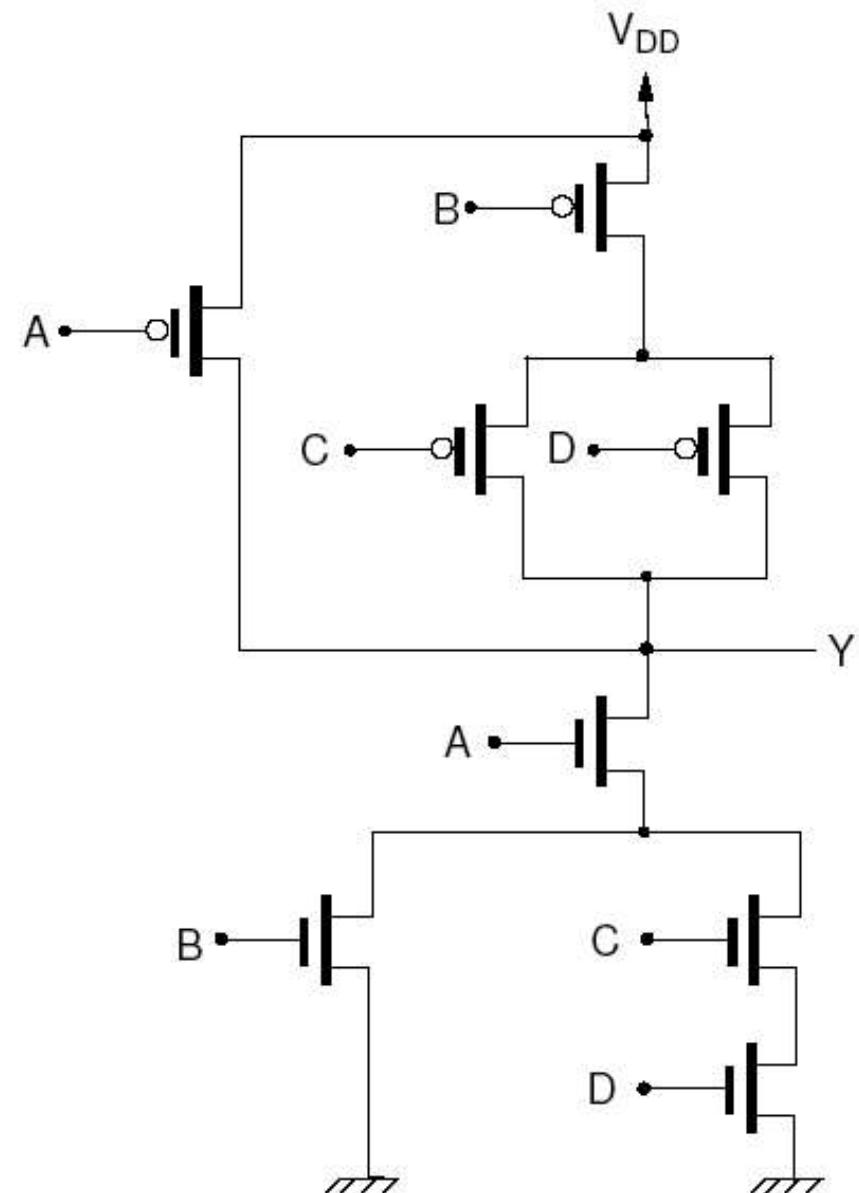
COMPLEX FUNCTION

$$Y = \overline{A(B + CD)}$$

PUN ->

$$\begin{aligned} Y &= \overline{A(B + CD)} \\ &= \overline{A} + \overline{B + CD} \\ &= \overline{A} + \overline{B} \overline{CD} \\ &= \overline{A} + \overline{B}(\overline{C} + \overline{D}) \end{aligned}$$

PDN -> $\overline{Y} = A(B + CD)$



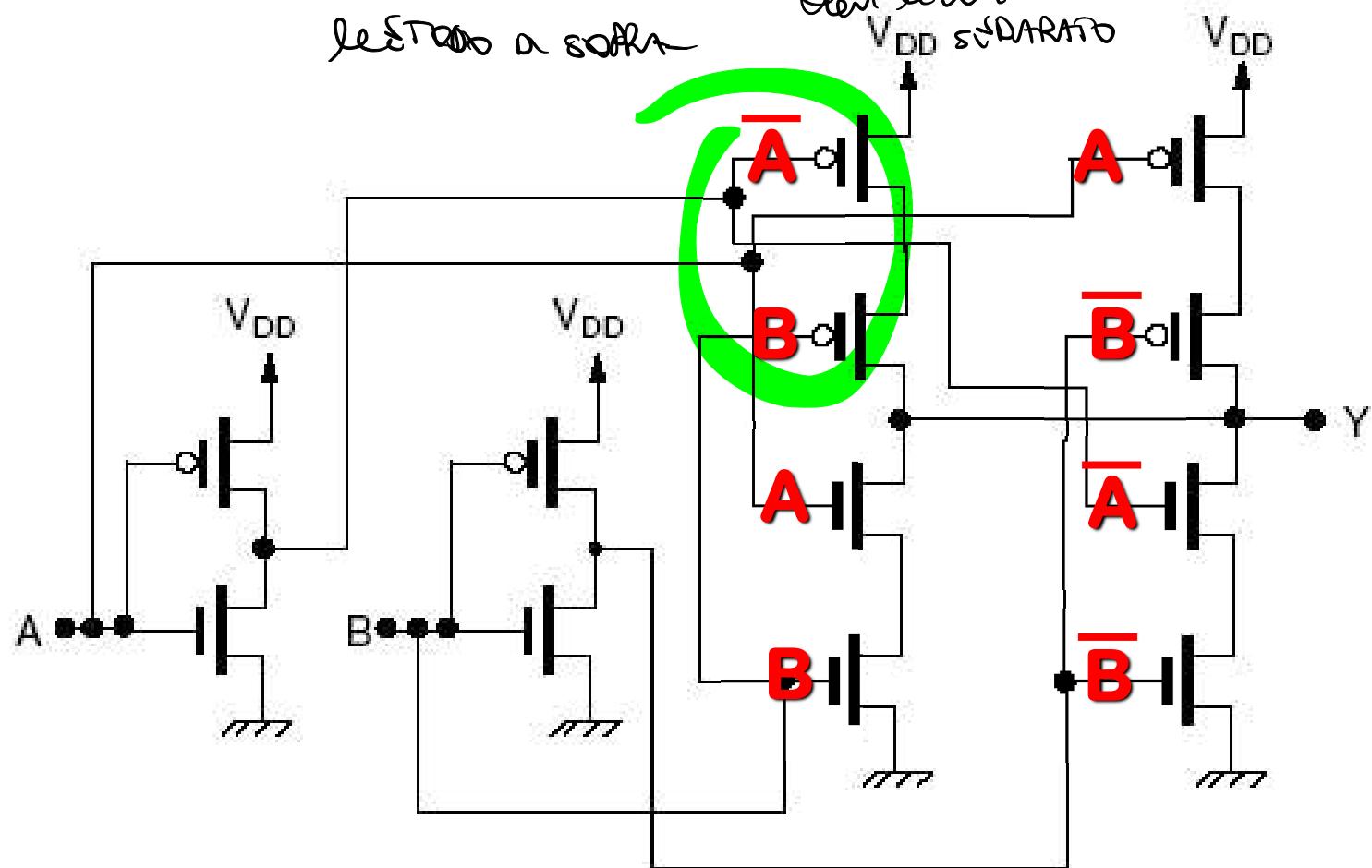
A	B	XOR
0	0	0
0	1	1
1	0	1
1	1	0

XOR

$$Y = A\bar{B} + \bar{A}B.$$

NON POSSO USARE IL
LESTO DI SOFT

Oltre un TRENTO
V_{DD} SUDARATO



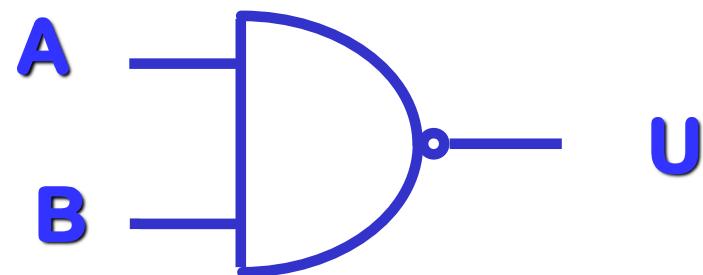
NAND

Truth Table

A	B	U
0	0	1
0	1	1
1	0	1
1	1	0

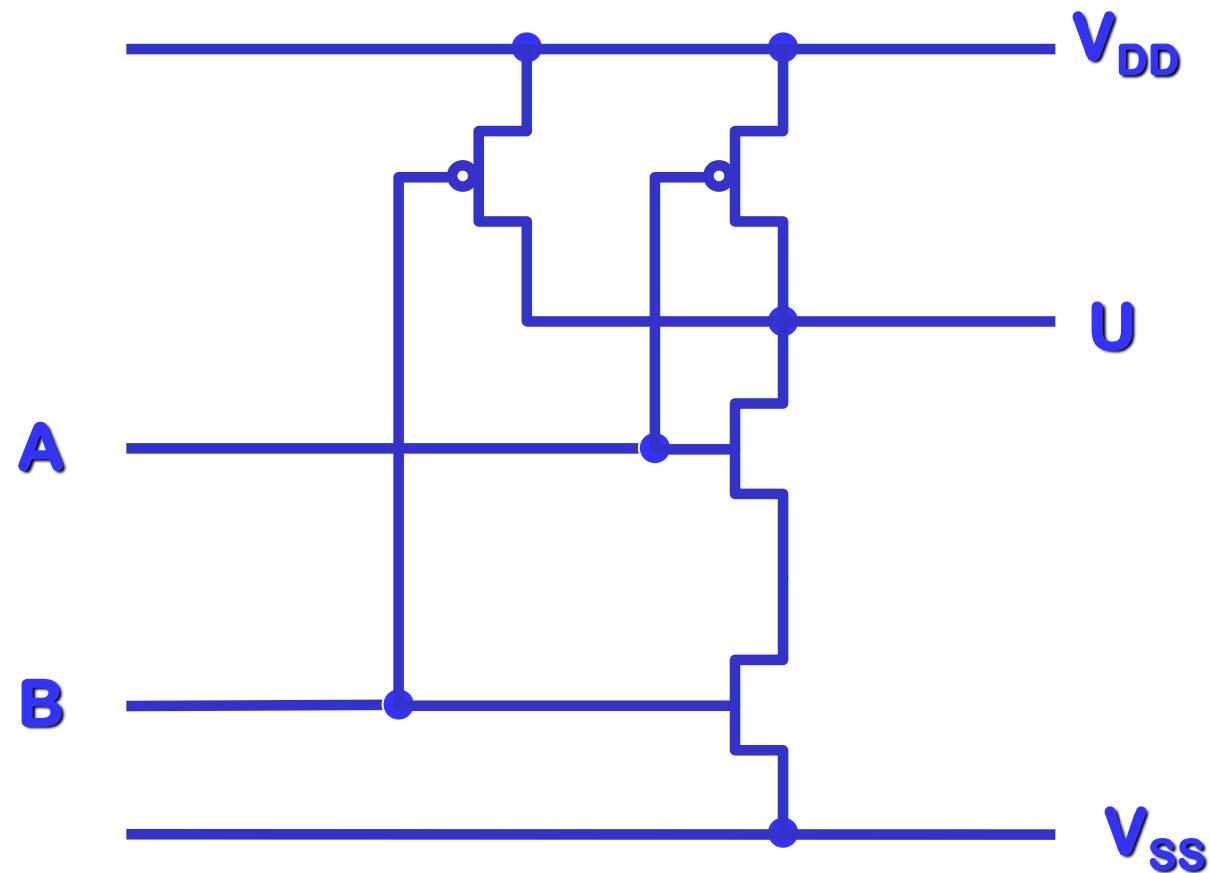
Logic Symbol

$$U = \overline{A * B}$$



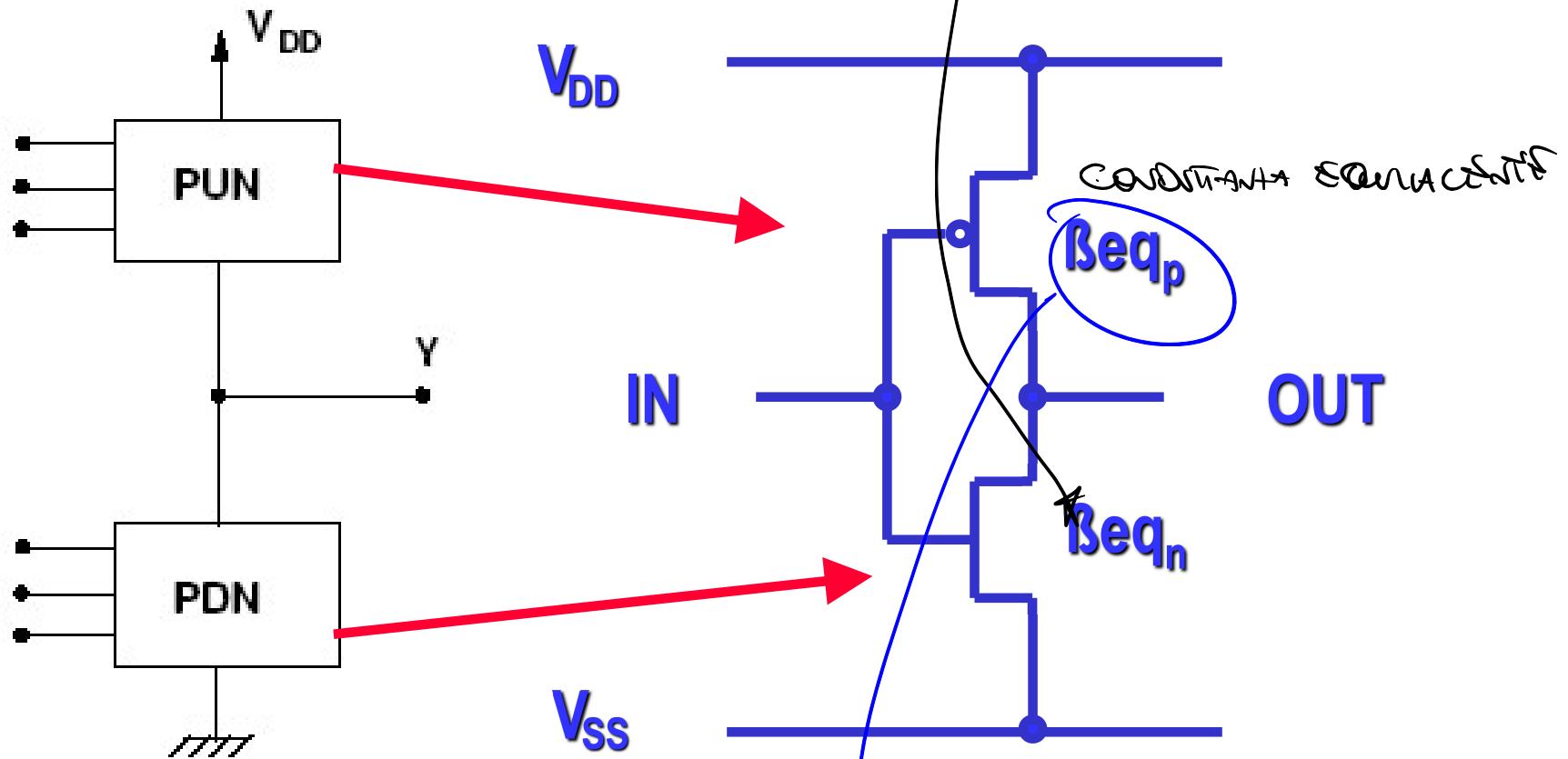
CMOS Implementation

Electric Circuit



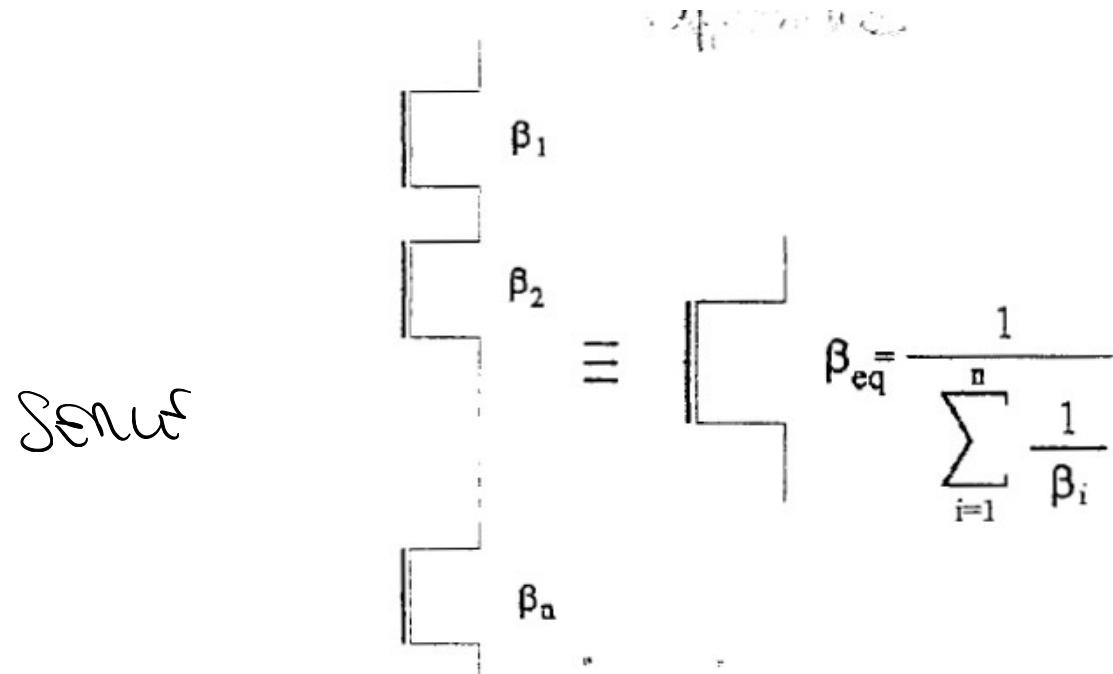
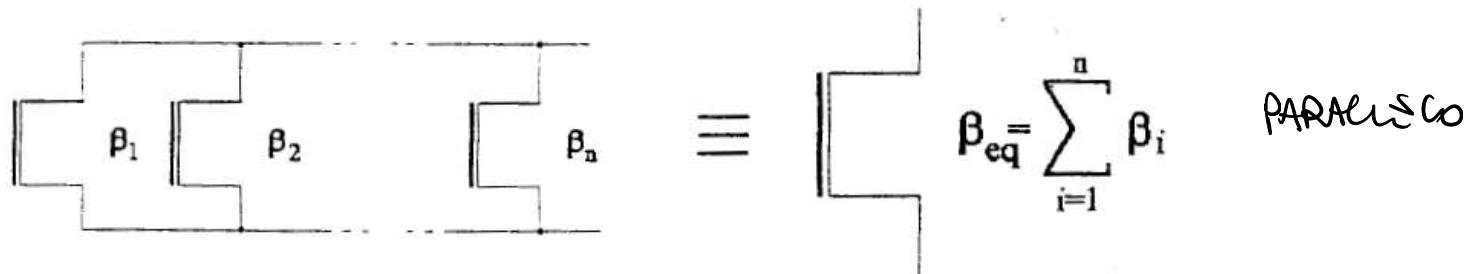
Dynamic A

$$t_{pHL} \propto \frac{KC}{\beta_n} \frac{1}{V_{DD} - V_{Tn}}$$



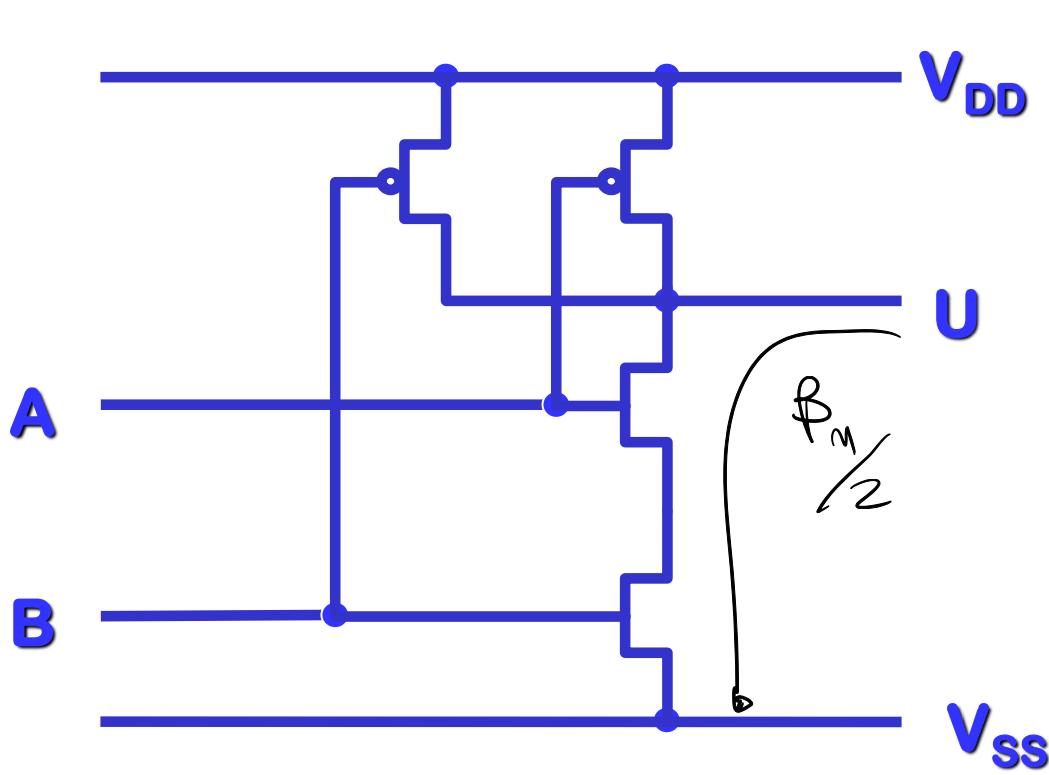
$$t_{pLH} \propto \frac{KC}{\beta_p} \frac{1}{V_{DD} + V_{Tp}}$$

Dynamic Analysis



Serial

Dynamic Analysis



A	B	U	
0	0	1	$2\beta_p$
0	1	1	β_p
1	0	1	β_p
1	1	0	$\beta_n/2$

$$t_{pLH} \propto \frac{KC}{\beta_{eqp}} = \frac{KC}{\beta_p}$$

CW025 CASE

$$t_{pHL} \propto \frac{KC}{\beta_{eqn}} = \frac{2KC}{\beta_n}$$

Dynamic Analysis

$$t_{pLH} \propto \frac{KC}{\beta_{eqp}} = \frac{KC}{\beta_p}$$

$$t_{pHL} \propto \frac{KC}{\beta_{eqn}} = \frac{2KC}{\beta_n}$$

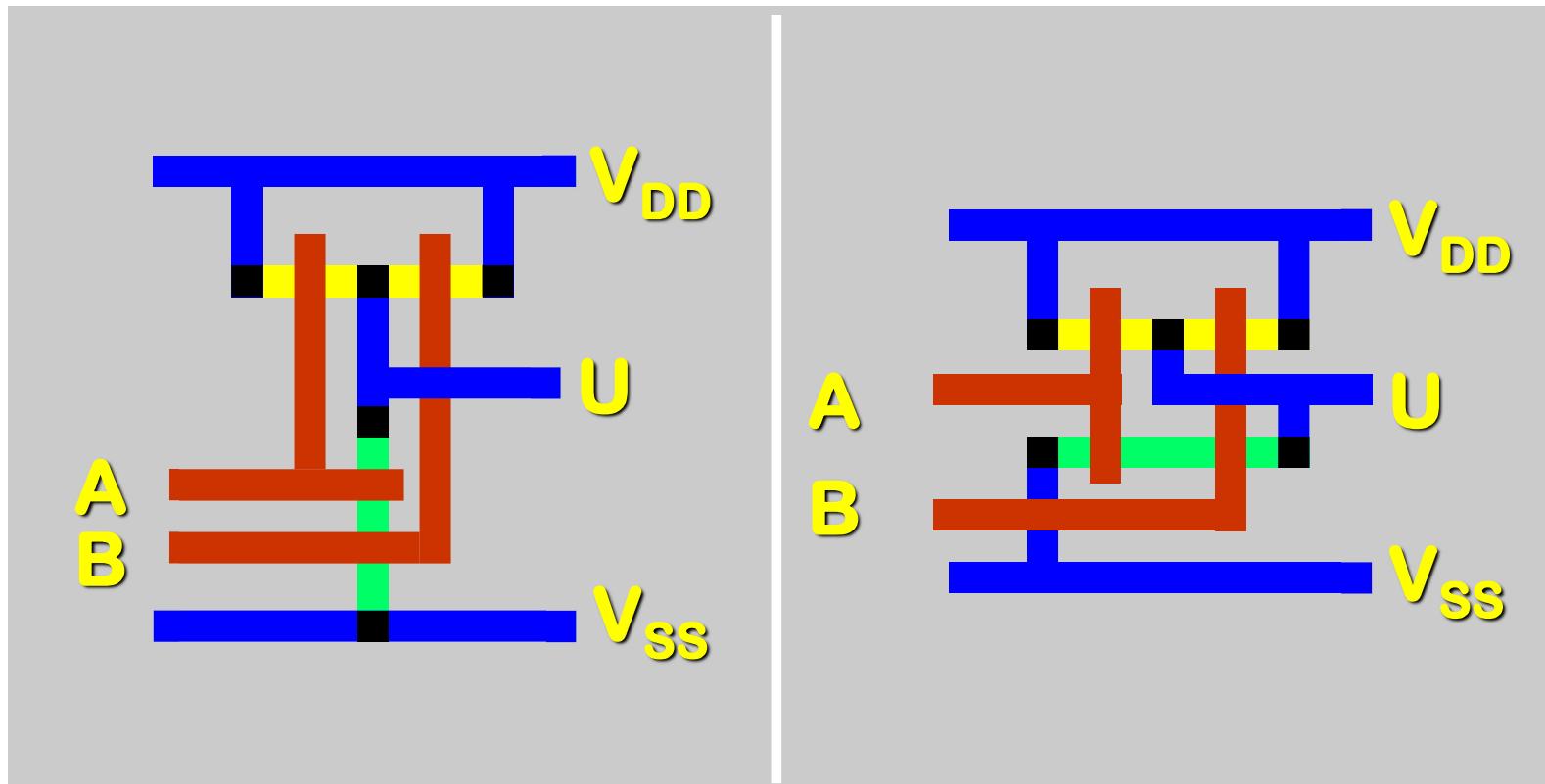
✧ **tp_{HL} = tp_{LH} in the worst case**

$$\beta_p = \frac{\beta_n}{2} \rightarrow \beta_n = 2\beta_p \rightarrow \boxed{\mu_n \frac{W_n}{L_n} = 2\mu_p \frac{W_p}{L_p}}$$

If $\mu_p = \frac{\mu_n}{2}$ $L_n = L_p = L_{\min}$ \longrightarrow $W_n = W_p$

Stick Diagram

❖ Different topological solutions



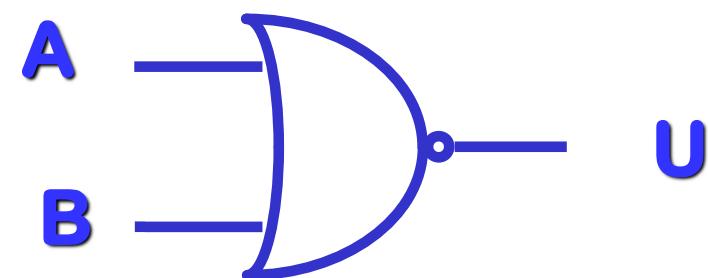
NOR

Truth Table

A	B	U
0	0	1
0	1	0
1	0	0
1	1	0

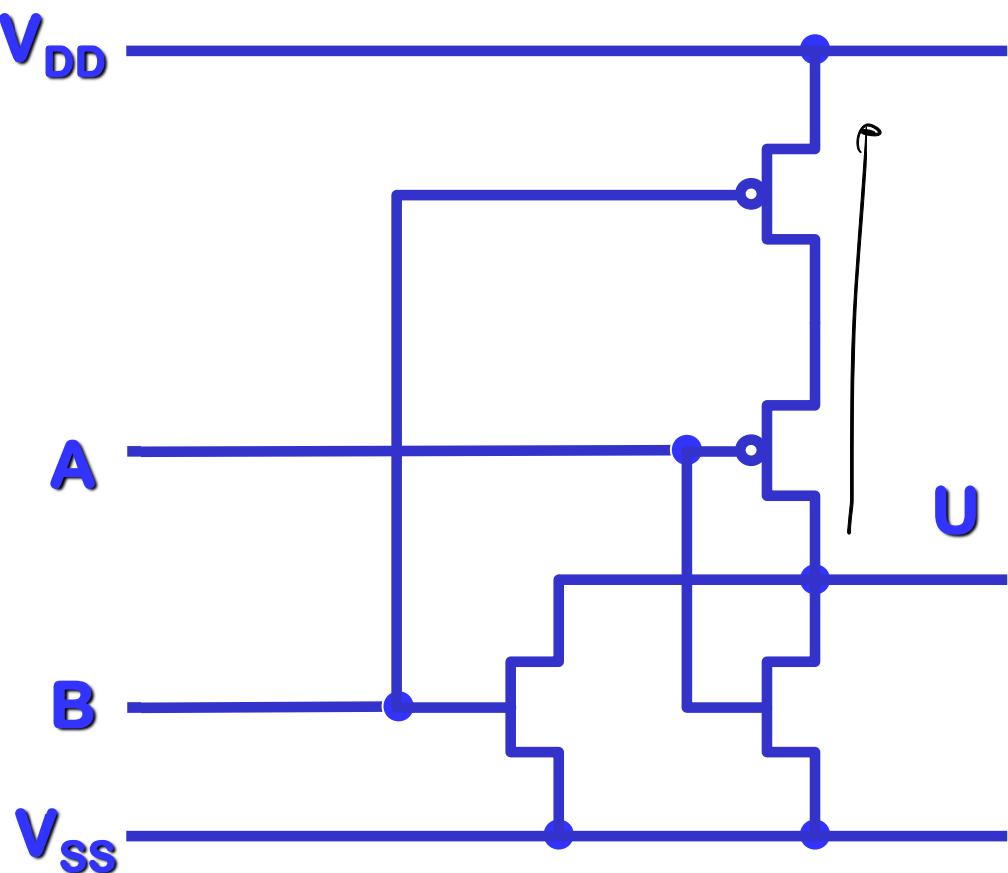
Logic Symbol

$$U = \overline{A + B}$$



Dynamic Analysis

Electric Circuit



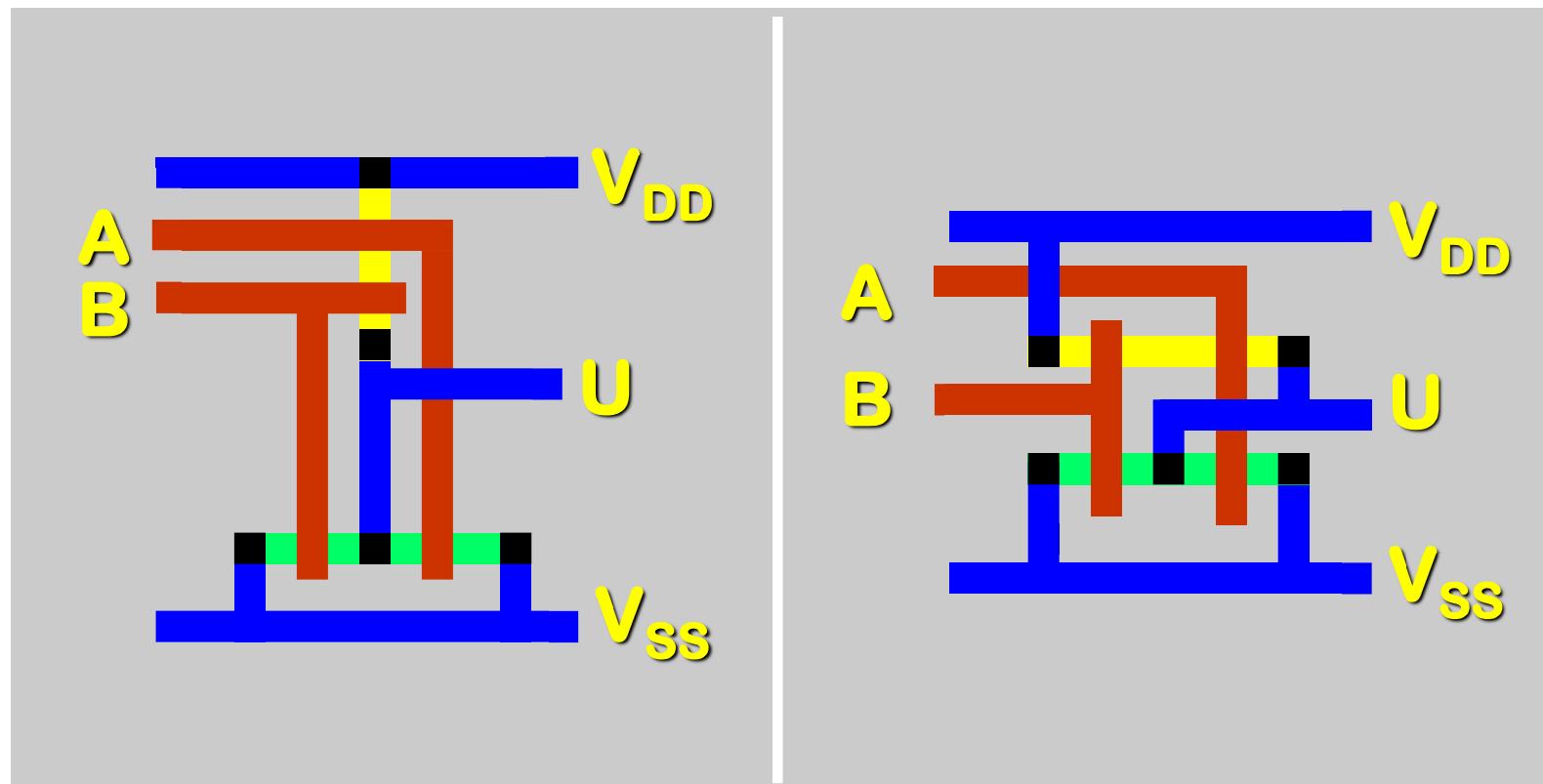
A	B	U
0	0	1 $\beta_p/2$
0	1	0 β_n
1	0	0 β_n
1	1	0 $2\beta_n$

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If $\mu_p = \frac{\mu_n}{2}$ $L_n = L_p = L_{\min}$ $\rightarrow W_p = 4W_n$

Stick Diagram

✧ Different topological solutions



NOR2 – NAND2 Comparison

$$\beta_{eq}^{NAND} = \beta_p^{NAND} = \frac{\beta_n^{NAND}}{2}$$

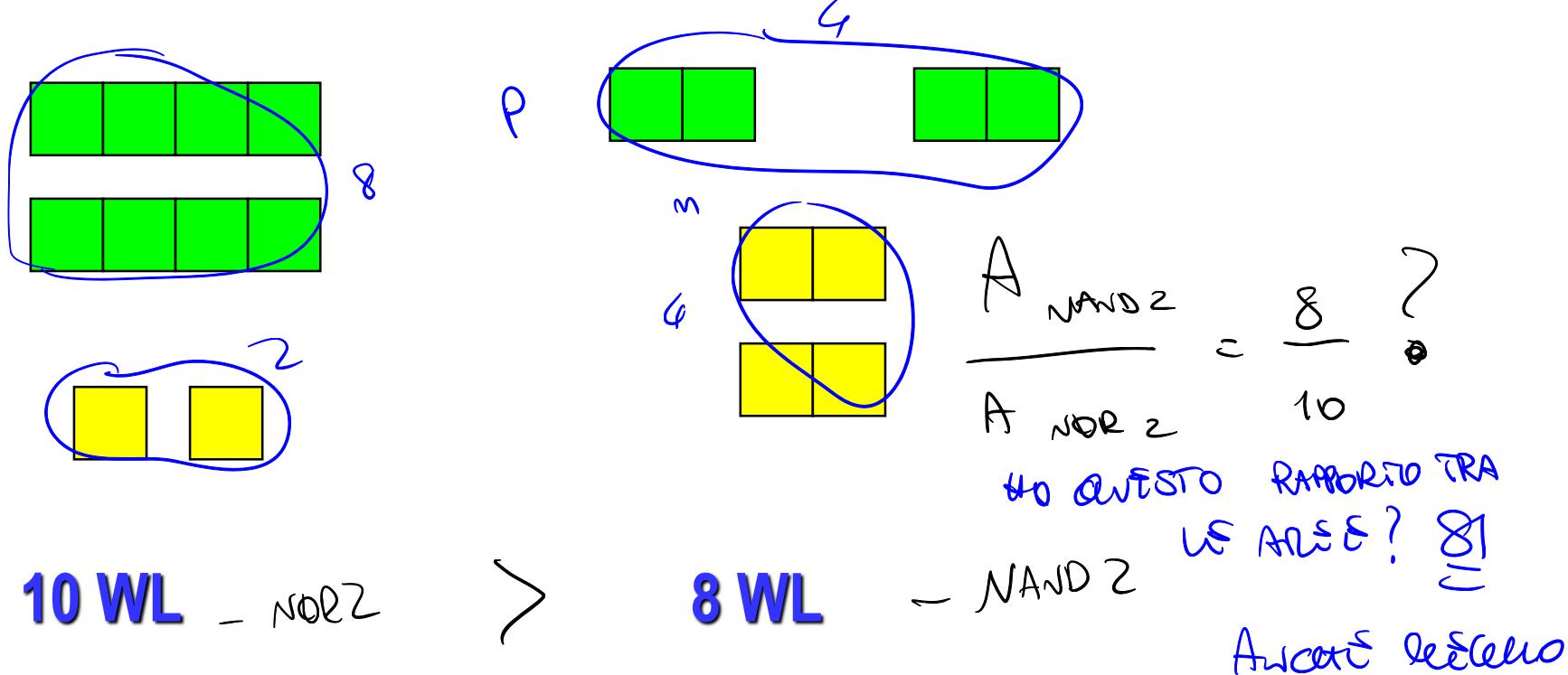
$$\beta_{eq}^{NOR} = \beta_n^{NOR} = \frac{\beta_p^{NOR}}{2}$$

$$W_n^{NOR} = W \quad W_p^{NOR} = 4W$$

$$\beta_n^{NAND} = 2\beta_n^{NOR} \Rightarrow W_n^{NAND} = 2W_n^{NOR} = 2W$$

$$\beta_p^{NAND} = \frac{\beta_p^{NOR}}{2} \Rightarrow W_p^{NAND} = \frac{W_p^{NOR}}{2} = \frac{4W}{2W} = 2W$$

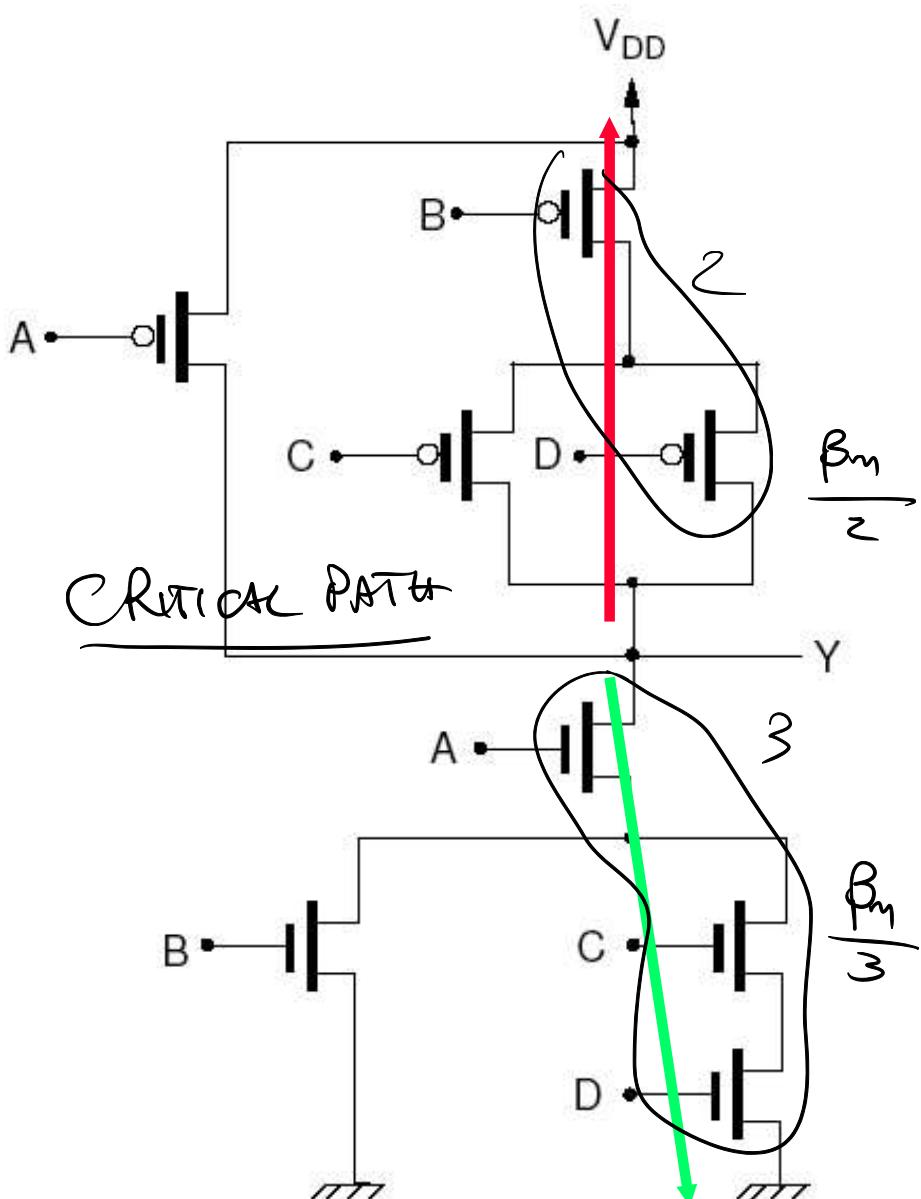
NOR2 – NAND2 Comparison



STESO PROBLEMA CON DECAY PER CONFRONTARSI.

A	B	C	D	Y	β
0	0	0	0	1	5/3
0	0	0	1	1	3/2
0	0	1	0	1	3/2
0	0	1	1	1	1
0	1	0	0	1	1
0	1	0	1	1	1
0	1	1	0	1	1
0	1	1	1	1	1
1	0	0	0	1	2/3
1	0	0	1	1	1/2
1	0	1	0	1	1/2
1	0	1	1	0	1/3
1	1	0	0	0	1
1	1	0	1	0	1
1	1	1	0	0	1
1	1	1	1	0	4/3

$$Y = \overline{A(B + CD)}$$



$$t_{pLH} \propto \frac{KC}{\beta eq_p}$$

$$t_{pHL} \propto \frac{KC}{\beta eq_n}$$

$$\beta eq_p = \frac{\beta_p}{2} = \frac{\mu_p}{2} \frac{W_p}{L_p} \quad \beta eq_n = \frac{\beta_n}{3} = \frac{\mu_n}{3} \frac{W_n}{L_n}$$

✧ **tp_{HL} = tp_{LH} in the worst case**

$$\frac{\mu_p}{2} \frac{W_p}{L_p} = \frac{\mu_n}{3} \frac{W_n}{L_n}$$

If $\mu_p = \frac{\mu_n}{2}$ $L_n = L_p = L_{\min}$

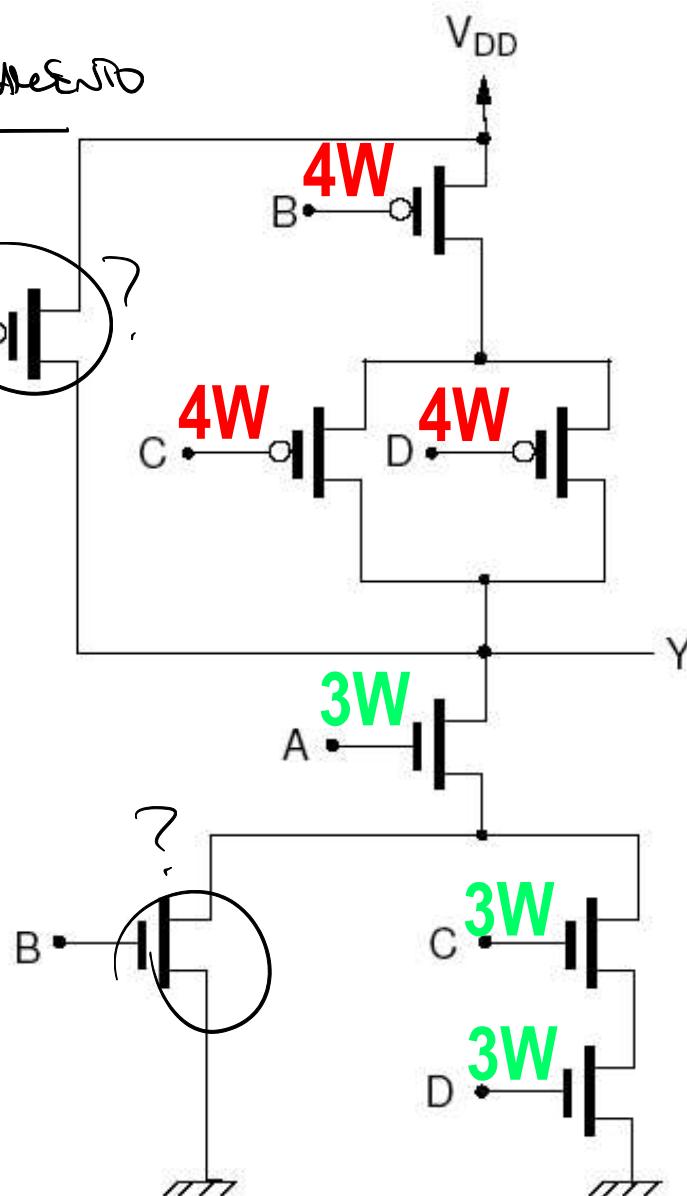


$$\frac{W_p}{W_n} = \frac{4}{3}$$

A	B	C	D	Y	β
0	0	0	0	1	5/3
0	0	0	1	1	3/2
0	0	1	0	1	3/2
0	0	1	1	1	1
0	1	0	0	1	1
0	1	0	1	1	1
0	1	1	0	1	1
0	1	1	1	1	1
1	0	0	0	1	2/3
1	0	0	1	1	1/2
1	0	1	0	1	1/2
1	0	1	1	0	1/3
1	1	0	0	0	1
1	1	0	1	0	1
1	1	1	0	0	1
1	1	1	1	0	4/3

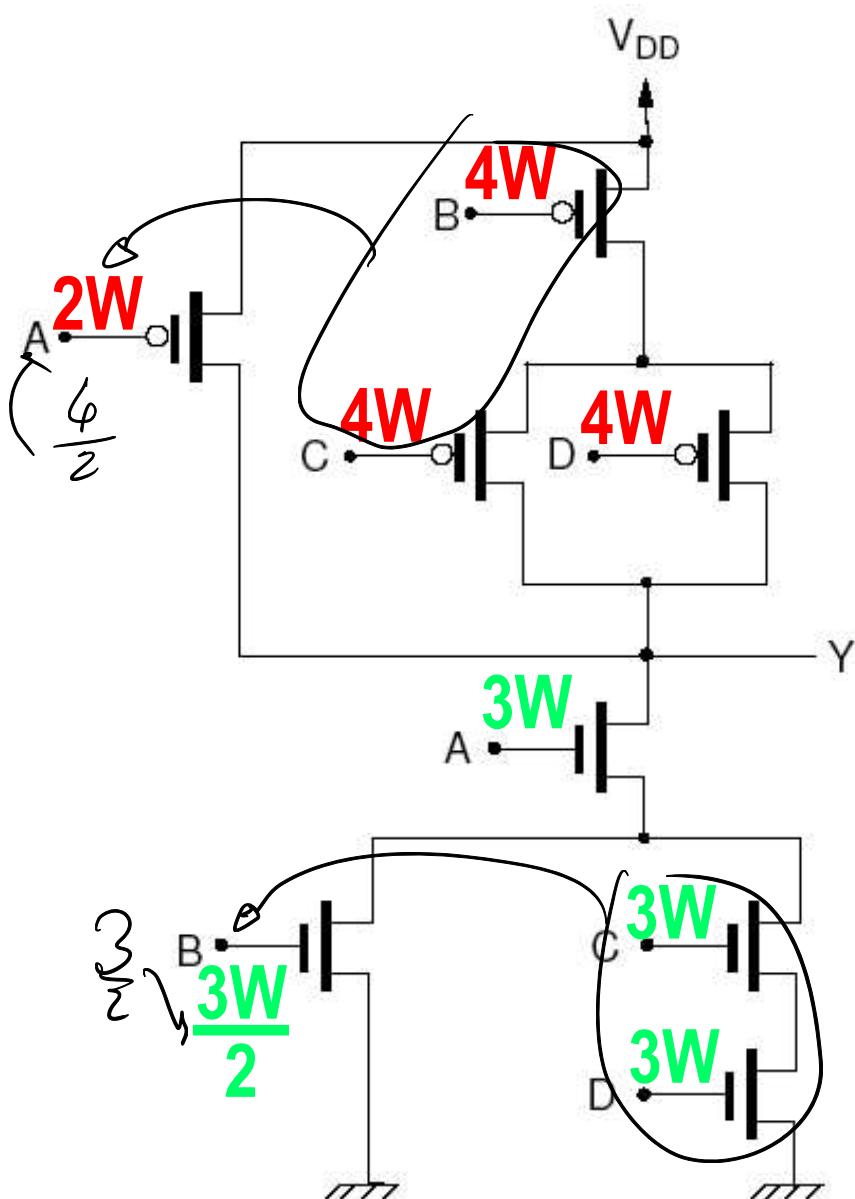
$$Y = \overline{A}(\overline{B} + \overline{C}\overline{D})$$

Dimensionamento

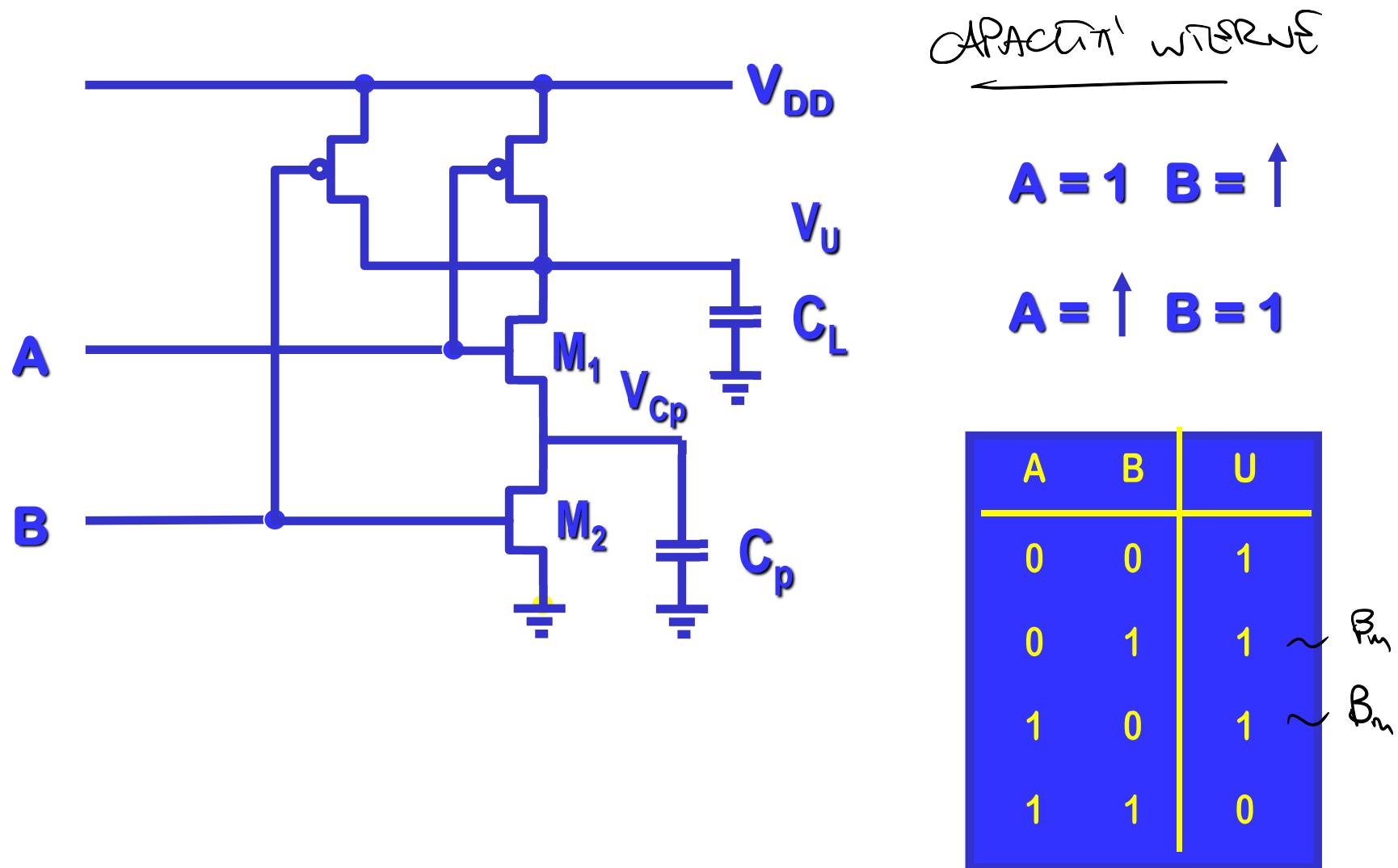


A	B	C	D	Y	β
0	0	0	0	1	5/3
0	0	0	1	1	3/2
0	0	1	0	1	3/2
0	0	1	1	1	1
0	1	0	0	1	1
0	1	0	1	1	1
0	1	1	0	1	1
0	1	1	1	1	1
1	0	0	0	1	2/3
1	0	0	1	1	1/2
1	0	1	0	1	1/2
1	0	1	1	0	1/3
1	1	0	0	0	1
1	1	0	1	0	1
1	1	1	0	0	1
1	1	1	1	0	4/3

$$Y = \overline{A}(\overline{B} + \overline{C}\overline{D})$$



CMOS gate - Body Effect

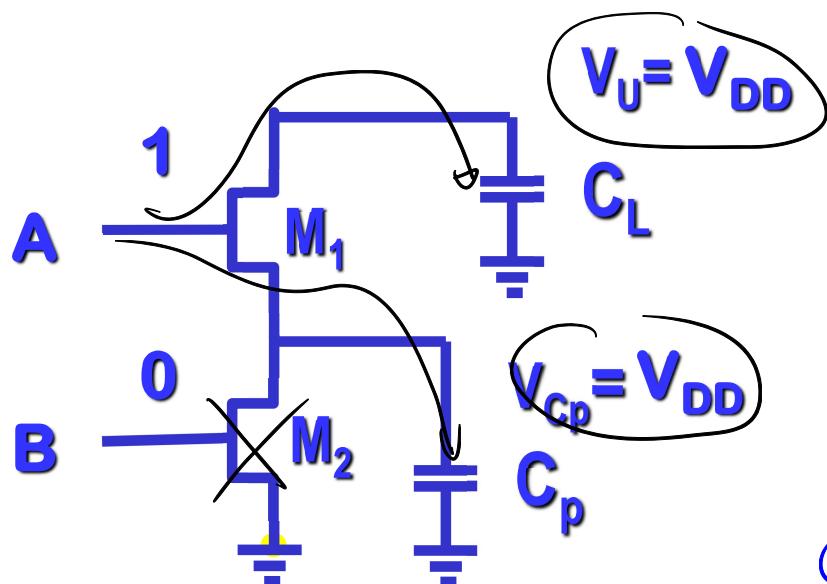


CMOS gate - Body Effect

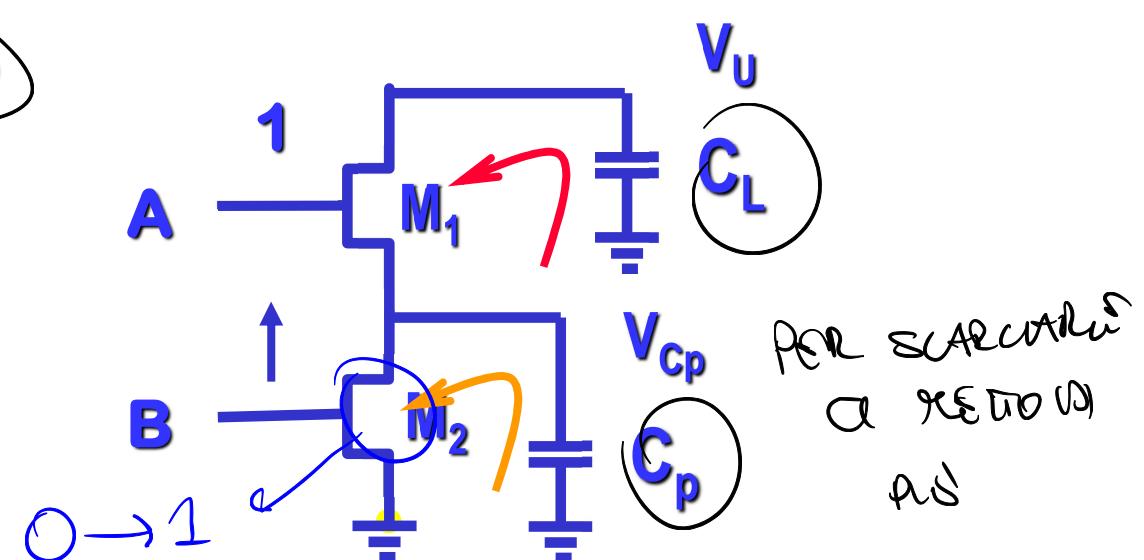
STARTING POINT

$$A = 1 \quad B = 0$$

$$t \leq 0$$



$$A = 1 \quad B = \uparrow$$



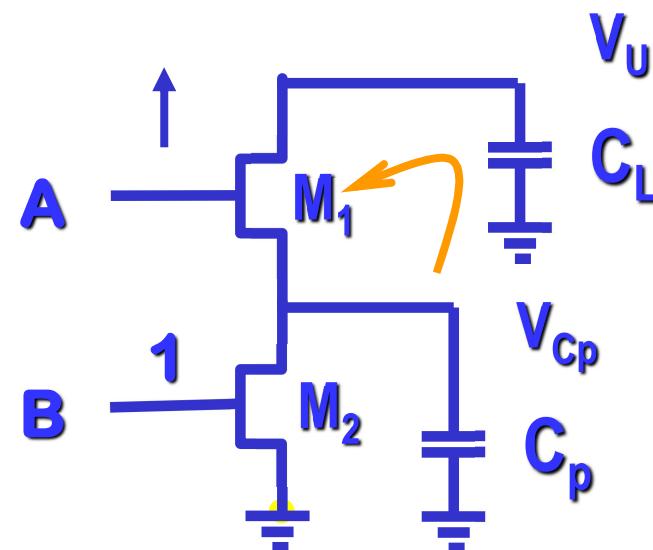
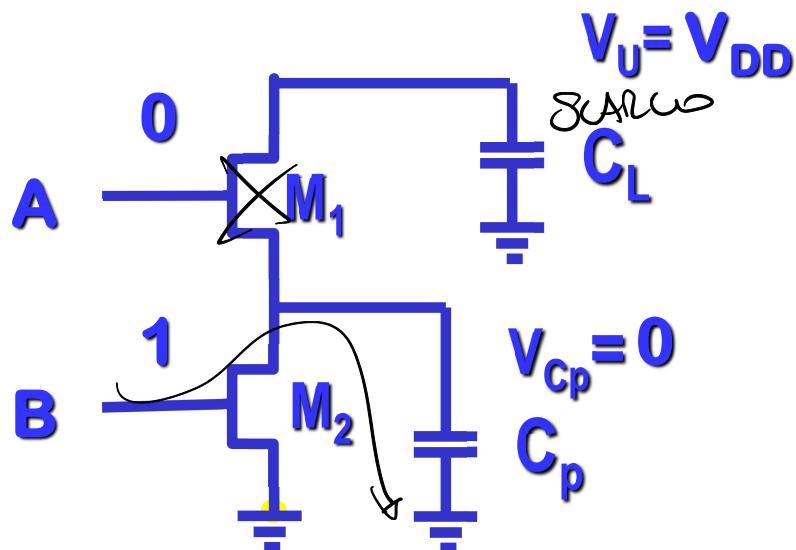
First C_p discharges through M_2 , M_1 starts with $V_s = V_{DD}$, so low M_1 current due to body effect. Longer propagation time w.r.t. to the one estimated with β_{eq}

CMOS gate - Body Effect

START

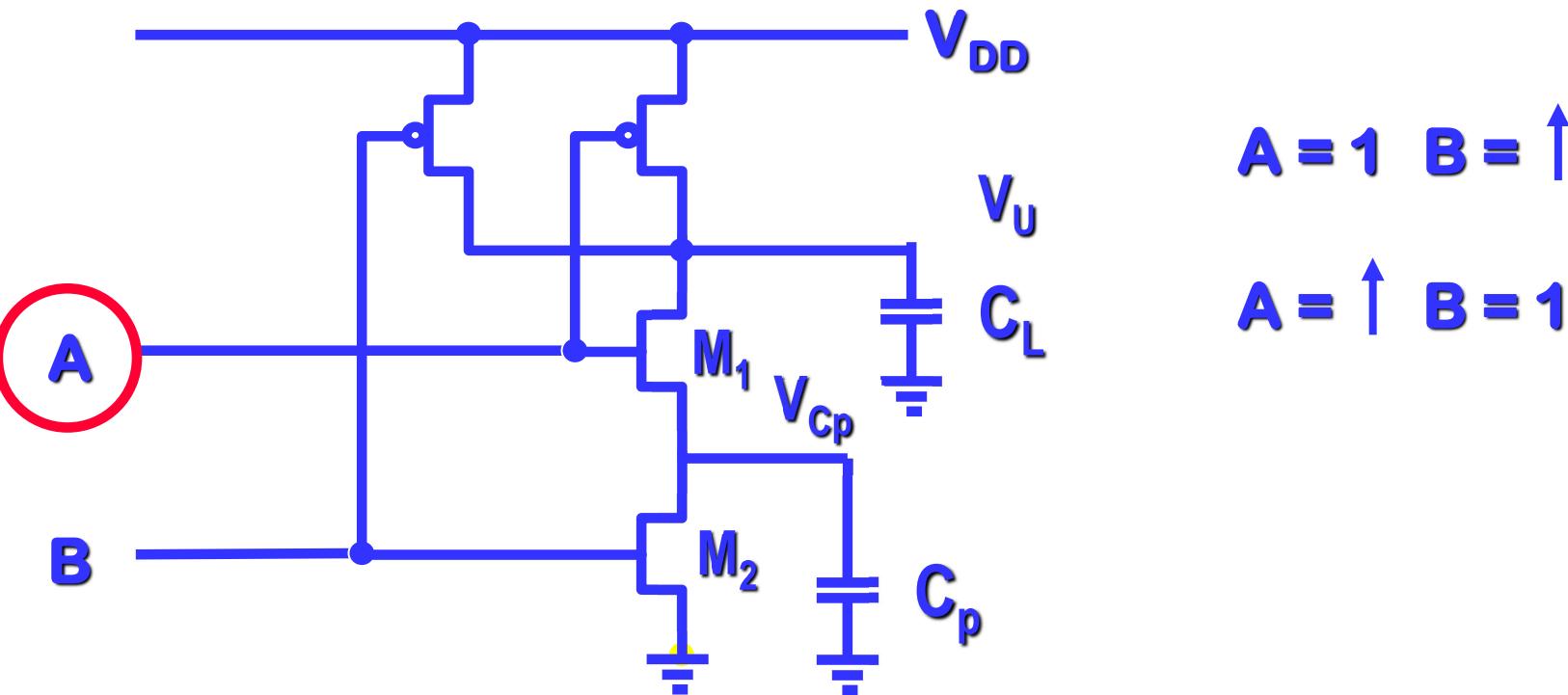
$A = 0 \ B = 1$

$t \leq 0$



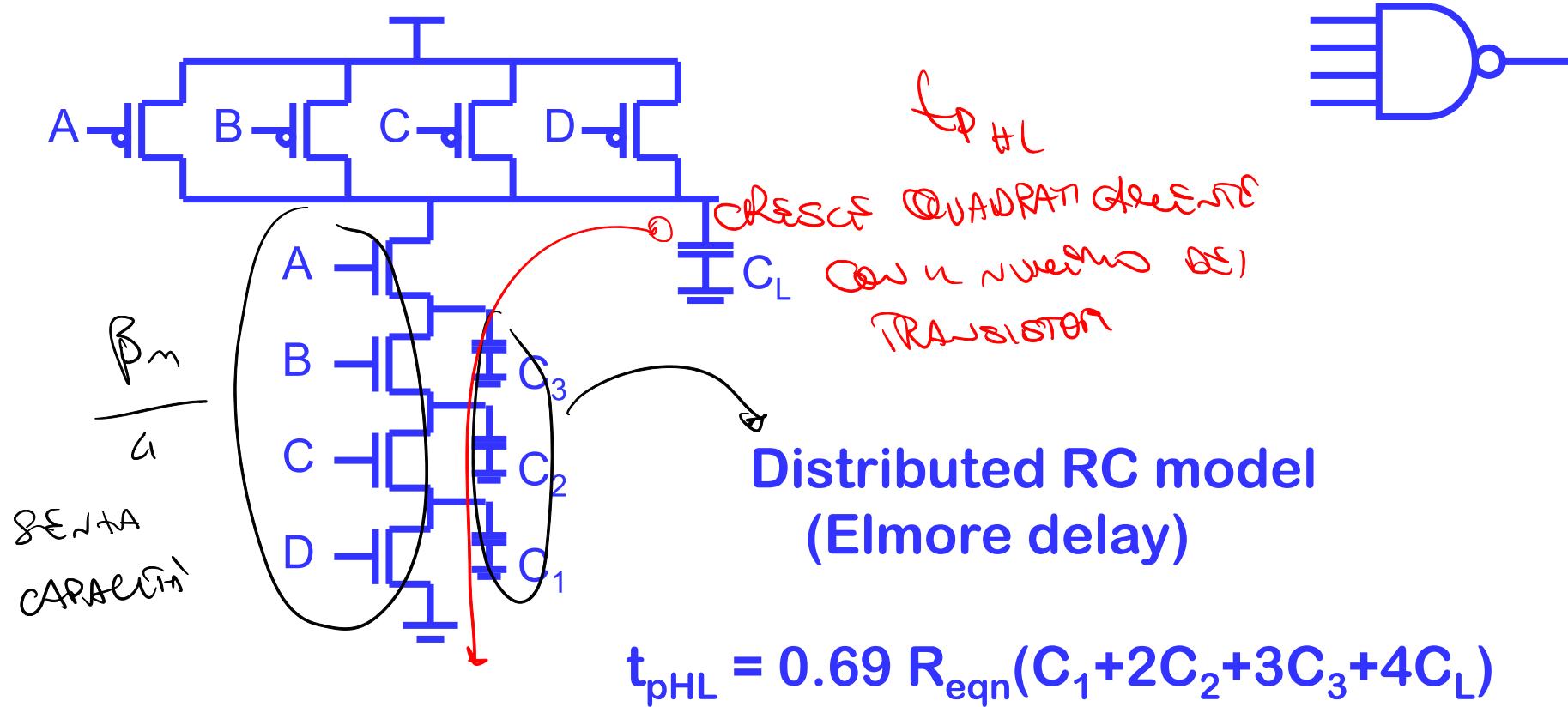
C_p is at ground. So after A input switching, M_1 source is at ground through C_p . Reduced body effect and so faster gate switching.

CMOS gate - Body Effect



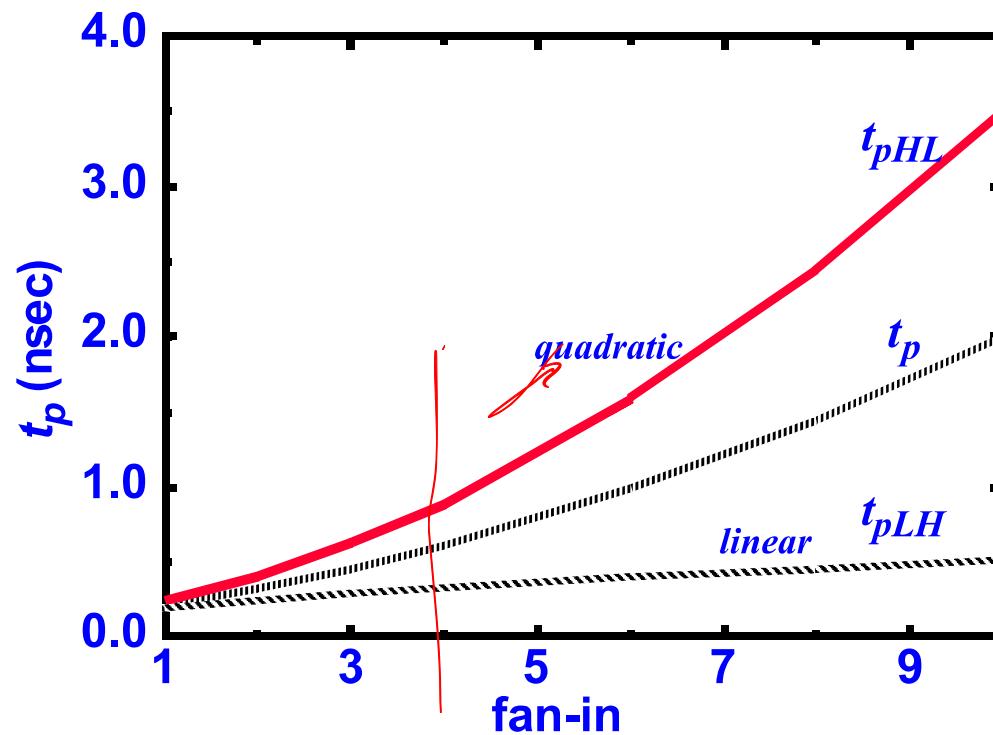
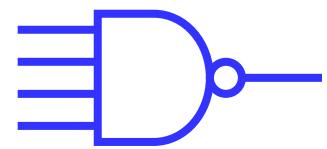
Faster output switching are the ones due to switching of
input closer to the output

Dynamic Analysis



Propagation delay deteriorates rapidly as a function of fan-in – quadratically in the worst case

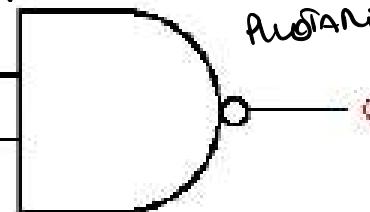
Dynamic Analysis



Gates with fan-in greater than 4 should be avoided

Strength	1
Cell Area	43.680 μm^2
Equation	$Q = \overline{A}(A \& B)$
Type	Combinational
Input	A, B
Output	Q

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Puxar



State Table		
A	B	Q
L	-	H
H	H	L
-	L	H

Propagation Delay [ns]

Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00	
A to Q	fall	0.06	0.58	-0.13	0.95
	rise	0.07	0.68	0.70	1.77
B to Q	fall	0.06	0.58	-0.37	0.60
	rise	0.08	0.69	0.91	1.87

Output Transition [ns]

Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00	
A to Q	fall	0.07	0.83	0.77	1.64
	rise	0.10	1.05	0.75	1.71
B to Q	fall	0.07	0.83	0.76	1.53
	rise	0.11	1.06	0.82	1.72

Capacitance [fF]	
A	2.7240
B	3.0190

Leakage [pW]	
	0.28

Dynamic Power Consumption [nW/MHz]

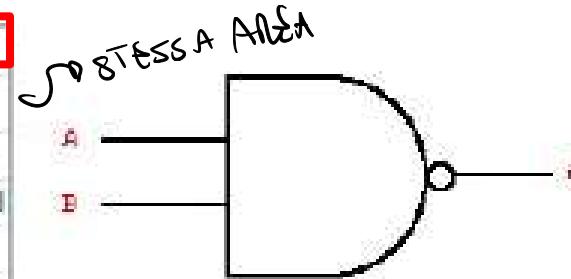
Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00	
A to Q	fall	8.00	8.49	555.73	471.83
	rise	54.46	55.63	732.49	629.72
B to Q	fall	7.37	7.81	616.29	518.84
	rise	64.63	64.73	837.28	703.47

FAN - OUT

NAND2X1

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Strength	2
Cell Area	43.680 μm^2
Equation	$Q = \overline{A}(\overline{A} \& B)$
Type	Combinational
Input	A, B
Output	Q



State Table		
A	B	Q
L	-	H
H	H	L
-	L	H

Propagation Delay [ns]

Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]		10.00	200.00	10.00	200.00
A to Q	fall	0.06	0.66	-0.09	1.13
	rise	0.06	0.75	0.61	1.81
B to Q	fall	0.06	0.66	-0.27	0.79
	rise	0.06	0.69	0.75	1.78

Output Transition [ns]

Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]		10.00	200.00	10.00	200.00
A to Q	fall	0.07	0.92	0.75	1.73
	rise	0.08	1.16	0.71	1.80
B to Q	fall	0.07	0.92	0.74	1.61
	rise	0.08	1.07	0.80	1.75

Capacitance [fF]		Leakage [pW]
A	3.8420	0.31
B	4.4020	

$\Delta t_{INENATA} \rightarrow C_{ox} [C_{in} \ln + C_{op}(P)]$

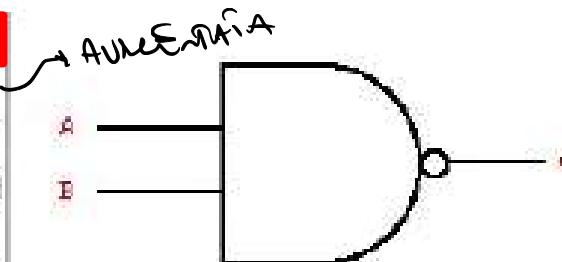
Dynamic Power Consumption [nW/MHz]

Input Transition [ns]		0.01		4.00	
Load Capacitance [fF]		10.00	200.00	10.00	200.00
A to Q	fall	5.99	6.95	974.79	808.95
	rise	64.40	64.67	1272.31	1068.90
B to Q	fall	4.28	5.14	1162.42	945.27
	rise	77.18	78.81	1504.40	1252.61

NAND2X2

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Strength	6
Cell Area	72.800 μm^2
Equation	$Q = \neg(A \& B)$
Type	Combinational
Input	A, B
Output	Q



State Table		
A	B	Q
L	-	H
H	H	L
-	L	H

Propagation Delay [ns]					
Input Transition [ns]	0.01	4.00			
Load Capacitance [fF]	30.00	600.00	30.00	600.00	
A to Q	fall	0.05	0.65	-0.04	1.16
	rise	0.05	0.68	0.51	1.68
B to Q	fall	0.05	0.65	-0.28	0.80
	rise	0.06	0.69	0.73	1.77

Output Transition [ns]					
Input Transition [ns]	0.01	4.00			
Load Capacitance [fF]	30.00	600.00	30.00	600.00	
A to Q	fall	0.06	0.92	0.72	1.70
	rise	0.07	1.06	0.70	1.73
B to Q	fall	0.06	0.92	0.72	1.59
	rise	0.08	1.07	0.78	1.74

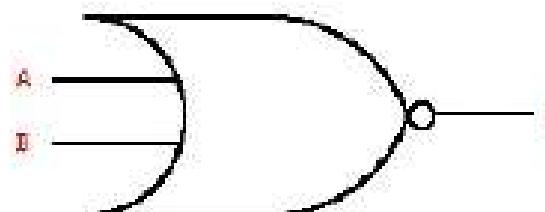
Capacitance [fF]	
A	10.1390
B	11.0760

Leakage [μW]	
	0.35

Dynamic Power Consumption [nW/MHz]					
Input Transition [ns]	0.01	4.00			
Load Capacitance [fF]	30.00	600.00	30.00	600.00	
A to Q	fall	5.73	8.27	3025.58	2459.24
	rise	155.47	156.48	3806.99	3246.79
B to Q	fall	5.87	8.76	3407.23	2766.61
	rise	196.60	199.91	4408.72	3647.73

NAND2X6

Strength	1
Cell Area	43.680 μm^2
Equation	$Q = \text{!}(A \mid B)$
Type	Combinational
Input	A, B
Output	Q



State Table		
A	B	Q
L	L	H
H	-	L
-	H	L

Propagation Delay [ns]				
Input Transition [ns]		0.01	4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	0.04	0.41	-0.64
	rise	0.11	1.17	1.28
B to Q	fall	0.05	0.42	-0.45
	rise	0.11	1.18	1.00
				2.25

Output Transition [ns]				
Input Transition [ns]		0.01	4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	0.04	0.55	0.73
	rise	0.15	1.81	0.62
B to Q	fall	0.05	0.55	0.94
	rise	0.15	1.81	0.80
				2.12

Capacitance [fF]	
A	2.6610
B	2.9400

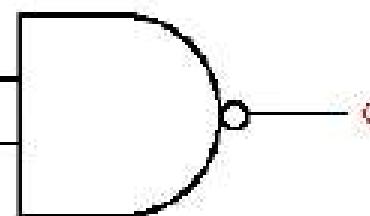
Leakage [pW]	
	0.26

Dynamic Power Consumption [nW/MHz]				
Input Transition [ns]		0.01	4.00	
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	4.63	5.12	326.27
	rise	45.80	47.19	661.91
B to Q	fall	7.48	7.98	453.09
	rise	55.57	56.53	796.35
				658.80

NOR2X1

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Strength	1
Cell Area	43.680 μm^2
Equation	$Q = \text{!}(A \& B)$
Type	Combinational
Input	A, B
Output	Q



State Table		
A	B	Q
L	-	H
H	H	L
-	L	H

Propagation Delay [ns]				
Input Transition [ns]		0.01		4.00
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	0.06	0.58	-0.13
	rise	0.07	0.68	0.70
B to Q	fall	0.06	0.58	-0.37
	rise	0.08	0.69	0.91
				1.87

Output Transition [ns]				
Input Transition [ns]		0.01		4.00
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	0.07	0.83	0.77
	rise	0.10	1.05	0.75
B to Q	fall	0.07	0.83	0.76
	rise	0.11	1.06	0.82
				1.53
				1.72

Capacitance [fF]	
A	2.7240
B	3.0190

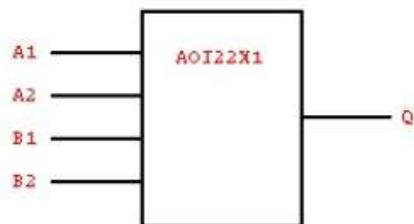
Leakage [pW]	
	0.28

Dynamic Power Consumption [nW/MHz]				
Input Transition [ns]		0.01		4.00
Load Capacitance [fF]	5.00	100.00	5.00	100.00
A to Q	fall	8.00	8.49	555.73
	rise	54.46	55.63	732.49
B to Q	fall	7.37	7.81	616.29
	rise	64.63	64.73	837.28
				518.84
				703.47

NAND2X1

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Strength	1
Cell Area	72.800 μm^2
Equation	$Q = \neg((A_1 \& A_2) (B_1 \& B_2))$
Type	Combinational
Input	A1, A2, B1, B2
Output	Q



State Table				
A1	A2	B1	B2	Q
L	-	L	-	H
L	-	-	L	H
H	H	-	-	L
-	L	L	-	H
-	L	-	L	H
-	-	H	H	L

Example

Propagation Delay [ns]				
Input Transition [ns]		0.01 4.00		
Load Capacitance [fF]		5.00	100.00	5.00 100.00
A1 to Q	fall	0.06	0.58	-0.27 0.88
	rise	0.11	1.15	1.15 2.47
A2 to Q	fall	0.06	0.58	-0.50 0.54
	rise	0.12	1.16	1.34 2.55
B1 to Q	fall	0.09	0.61	-0.05 0.98
	rise	0.15	1.19	0.85 2.10
B2 to Q	fall	0.09	0.61	-0.31 0.62
	rise	0.16	1.19	1.07 2.20

Output Transition [ns]				
Input Transition [ns]		0.01 4.00		
Load Capacitance [fF]		5.00	100.00	5.00 100.00
A1 to Q	fall	0.08	0.81	0.82 1.68
	rise	0.18	1.79	0.73 2.18
A2 to Q	fall	0.08	0.81	0.76 1.53
	rise	0.20	1.81	0.74 2.17
B1 to Q	fall	0.11	0.84	1.08 1.78
	rise	0.18	1.79	0.92 2.19
B2 to Q	fall	0.11	0.84	0.99 1.64
	rise	0.20	1.81	0.96 2.20

Capacitance [fF]	Leakage [pW]
A1	2.7590
A2	3.0640
B1	2.9460
B2	3.2810

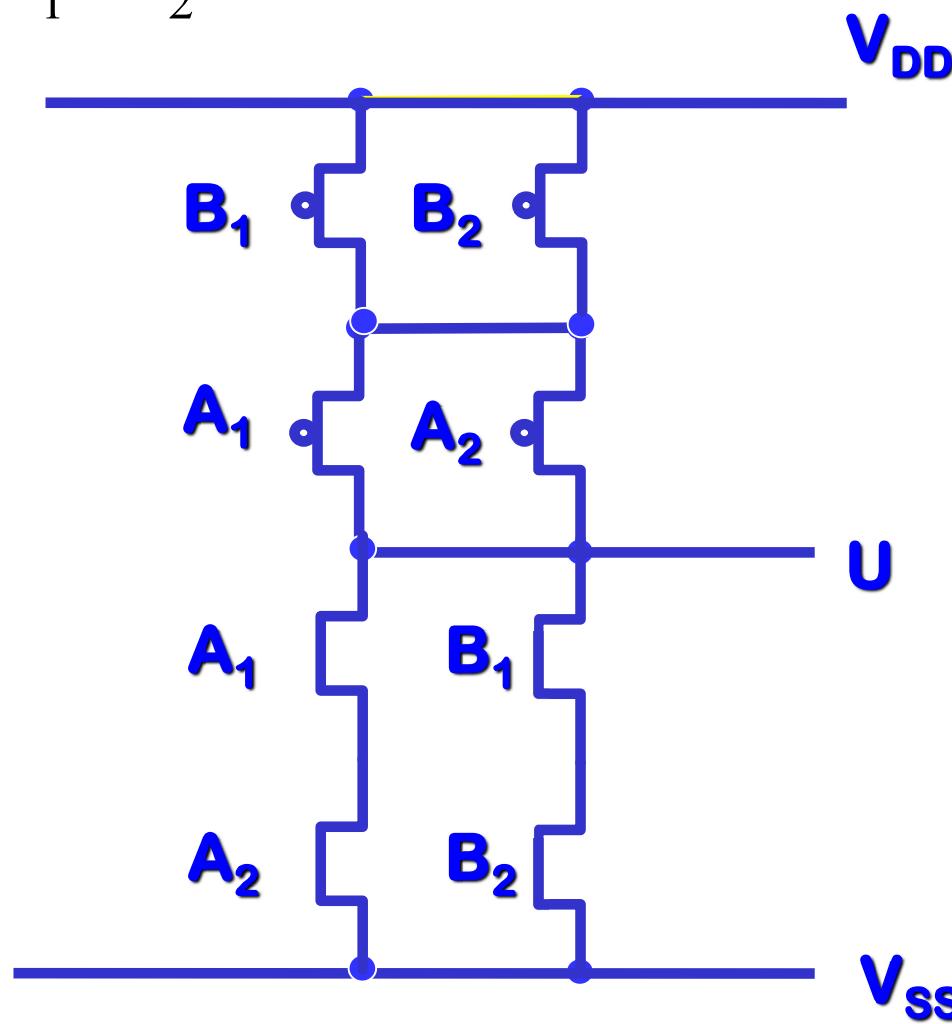
$$Y = \overline{A_1 \cdot A_2 + B_1 \cdot B_2}$$

Dynamic Power Consumption [nW/MHz]				
Input Transition [ns]		0.01 4.00		
Load Capacitance [fF]		5.00	100.00	5.00 100.00
A1 to Q	fall	4.83	5.56	391.57 372.83
	rise	52.43	53.92	647.45 530.25
A2 to Q	fall	5.18	5.94	412.34 403.16
	rise	61.25	62.04	717.55 579.91
B1 to Q	fall	34.51	39.00	524.97 460.07
	rise	76.53	77.52	743.28 605.54
B2 to Q	fall	34.58	39.00	569.64 500.92
	rise	84.07	85.01	833.81 670.42

AOI22X1

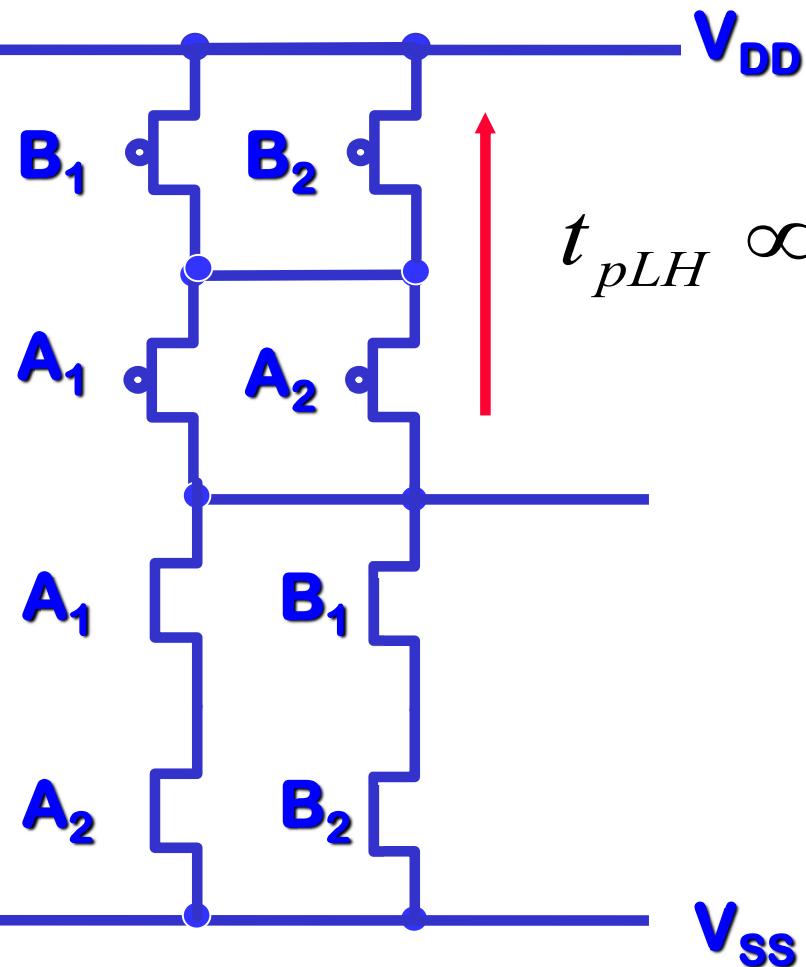
$$Y = \overline{A_1 \cdot A_2 + B_1 \cdot B_2}$$

PDN $\overline{Y} = A_1 \cdot A_2 + B_1 \cdot B_2$



$$Y = \overline{A_1 \cdot A_2 + B_1 \cdot B_2}$$

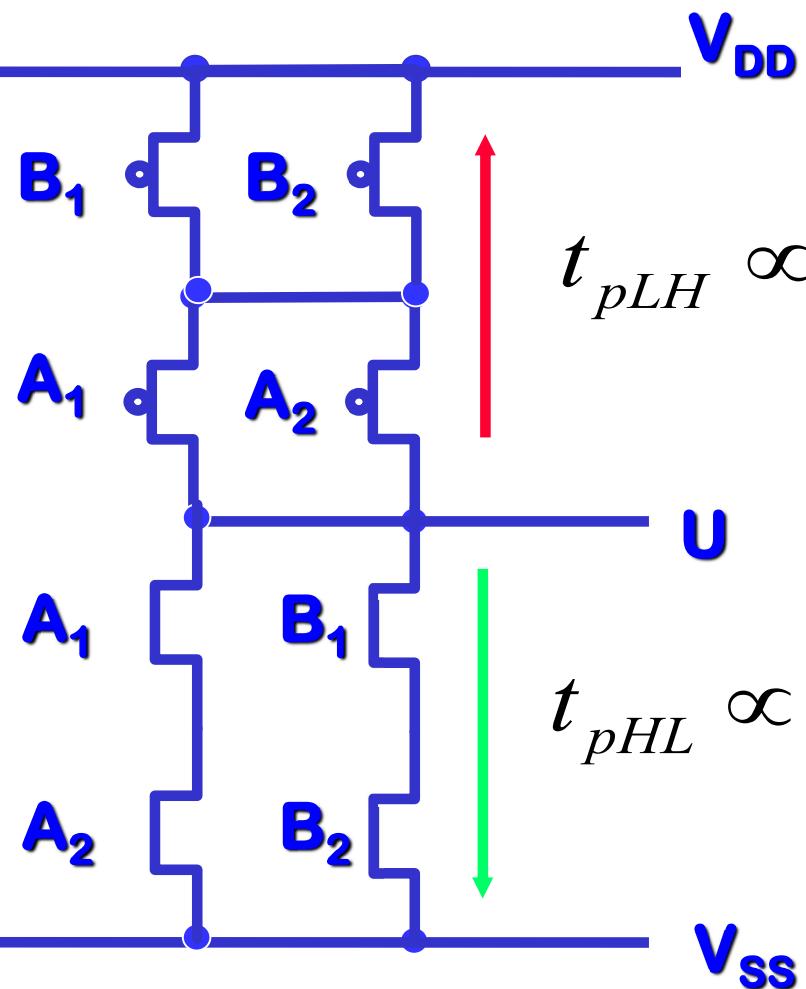
PDN $\overline{Y} = A_1 \cdot A_2 + B_1 \cdot B_2$



$$t_{pLH} \propto \frac{KC}{\beta eq_p} \quad \beta eq_p = \frac{\beta_p}{2} = \frac{\mu_p}{2} \frac{W_p}{L_p}$$

$$Y = \overline{A_1 \cdot A_2 + B_1 \cdot B_2}$$

PDN $\overline{Y} = A_1 \cdot A_2 + B_1 \cdot B_2$



$$t_{pLH} \propto \frac{KC}{\beta eq_p}$$

$$\beta eq_p = \frac{\beta_p}{2} = \frac{\mu_p}{2} \frac{W_p}{L_p}$$

$$t_{pHL} \propto \frac{KC}{\beta eq_n}$$

$$\beta eq_n = \frac{\beta_n}{2} = \frac{\mu_n}{2} \frac{W_n}{L_n}$$

$$t_{pLH} \propto \frac{KC}{\beta eq_p}$$

$$t_{pHL} \propto \frac{KC}{\beta eq_n}$$

$$\beta eq_p = \frac{\beta_p}{2} = \frac{\mu_p}{2} \frac{W_p}{L_p}$$

$$\beta eq_n = \frac{\beta_n}{2} = \frac{\mu_n}{2} \frac{W_n}{L_n}$$

✧ **tp_{HL} = tp_{LH} in the worst case**

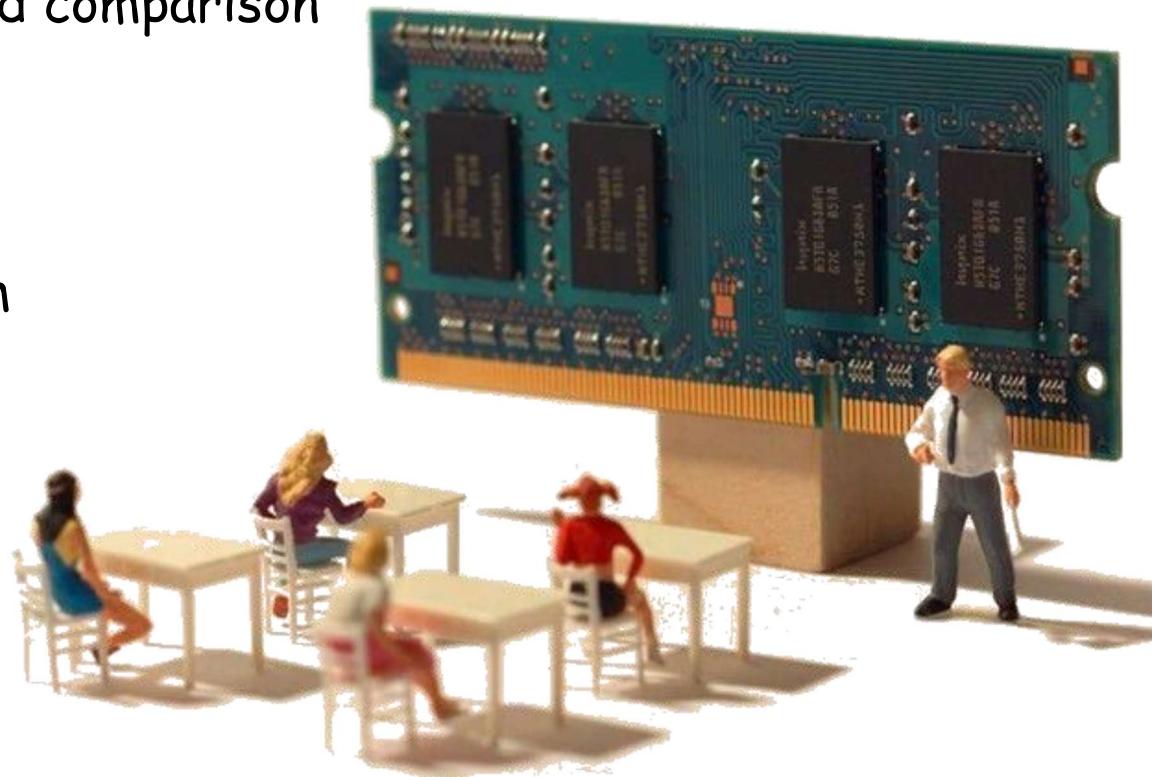
$$\frac{\mu_p}{2} \frac{W_p}{L_p} = \frac{\mu_n}{2} \frac{W_n}{L_n}$$

$$\frac{W_p}{W_n} = \frac{\mu_n}{\mu_p}$$

If $\mu_p = \frac{\mu_n}{2}$ $L_n = L_p = L_{\min}$ \rightarrow $\frac{W_p}{W_n} = 2$

End Complementary CMOS Logic, Questions ?

- Synthesis
- Dynamic Analysis
- Examples: NAND, NOR and comparison
- Stick Diagram
- Body Effect
- Standard-cell AMS 0,35 um



Outline

❖ Review

- Sync. and Async Sequential Logic
- Finite State Machine (MEALY, MOORE, MEALY Rit.)

❖ Complementary CMOS Logic

- Synthesis
- Dynamic Analysis
- Examples: NAND, NOR and comparison
- Stick Diagram
- Body Effect
- Standard-cell AMS 0,35 um

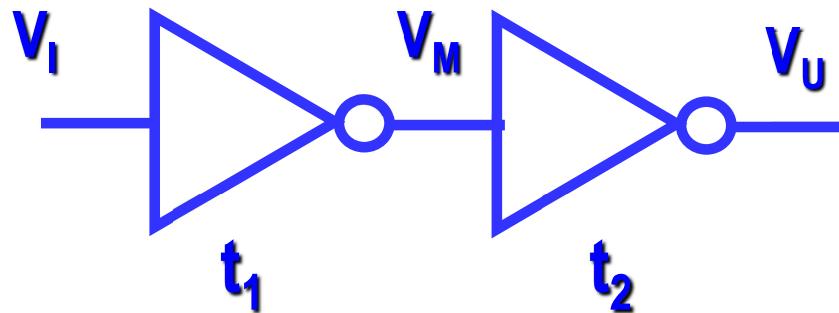
❖ Example: Inverter Chain

- Driving an high value capacitor
- Dynamic Analysis
- Power-Speed Trade-Off

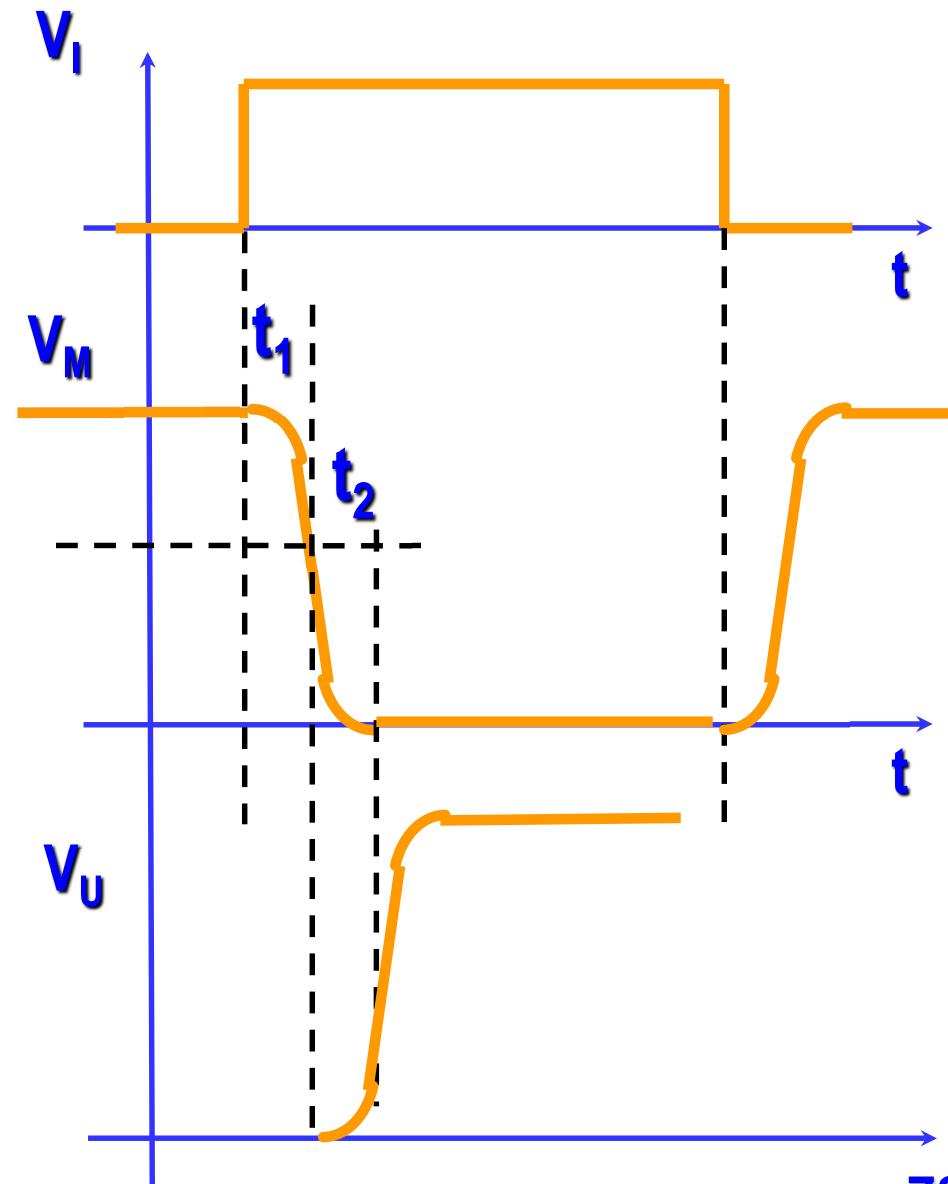
❖ Example: Pass Transistor Chain

- Dynamic Analysis
- Area - Speed Trade-Off

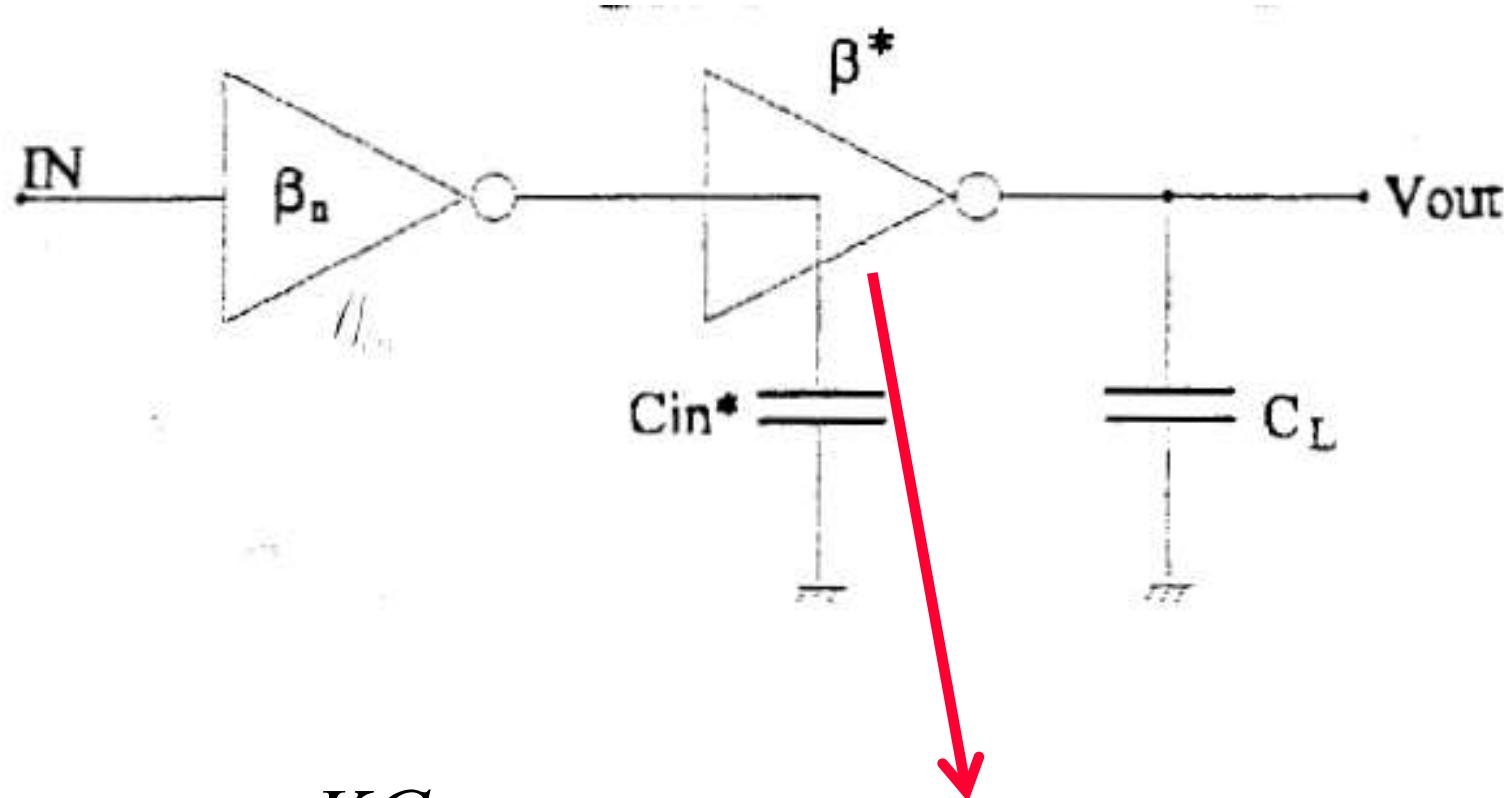
Inverter Chain



$$t_{TOT} \sim t_1 + t_2$$



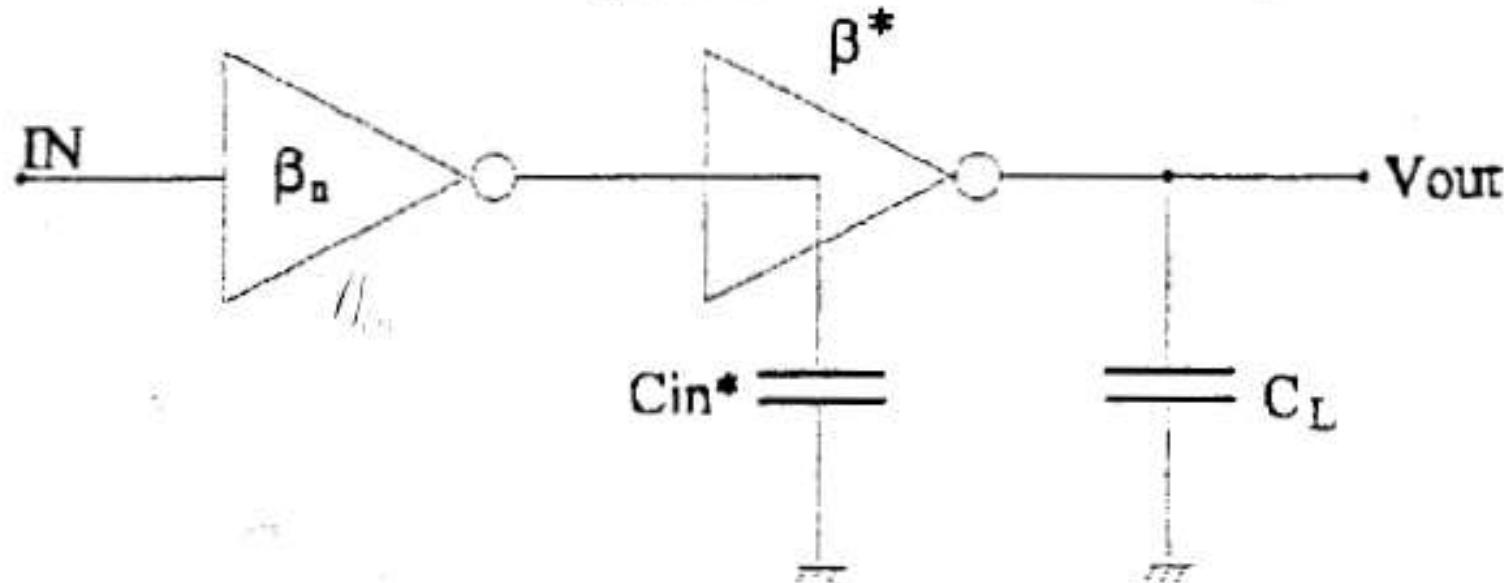
Inverter Chain



$$t_{phl} = t_{plh} = \frac{KC_{in}}{\beta_n}$$

$$\tau = \frac{KC_L}{\beta^*}$$

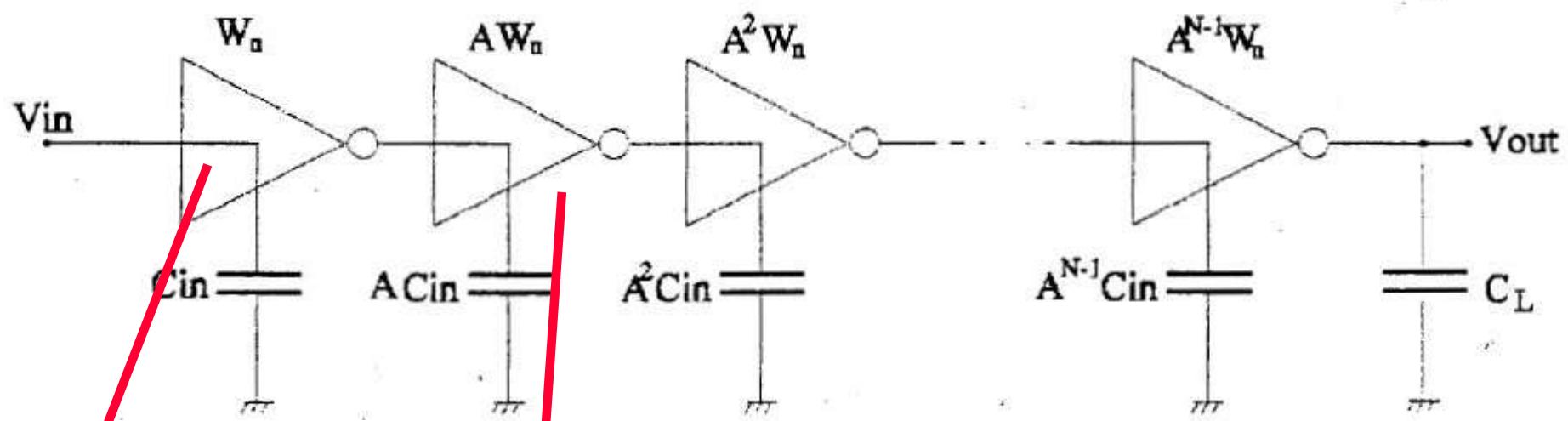
Inverter Chain



$$\tau = \frac{KC_L}{\beta^*} \quad \frac{KC_{in}}{\beta_n} = \frac{KC_L}{\beta^*} \rightarrow \beta^* = \frac{C_L \beta_n}{C_{in}} \approx 1000 \beta_n$$

$$W^* = \frac{W_n C_L}{C_{in}} \approx 1000 W_n$$

Inverter Chain



Driving Inverter

$$\tau_1 = K \frac{AC_{in}}{\beta_n} = A \tau_m \quad \tau_2 = K \frac{A^2 C_{in}}{A \beta_n} = A \tau_m = \tau_1$$

$$\tau_i = K \frac{A^i C_{in}}{A^{i-1} \beta_n} = A \tau_m = \tau_1 \quad \tau_{tot} = N A \tau_m$$

$$C_L = A^N C_{in}$$

$$\tau_m = \frac{K C_{in}}{\beta_n}$$

$$\boxed{\tau_{tot} = \frac{A}{\ln A} \tau_m \ln \frac{C_L}{C_{in}}}$$

Inverter Chain

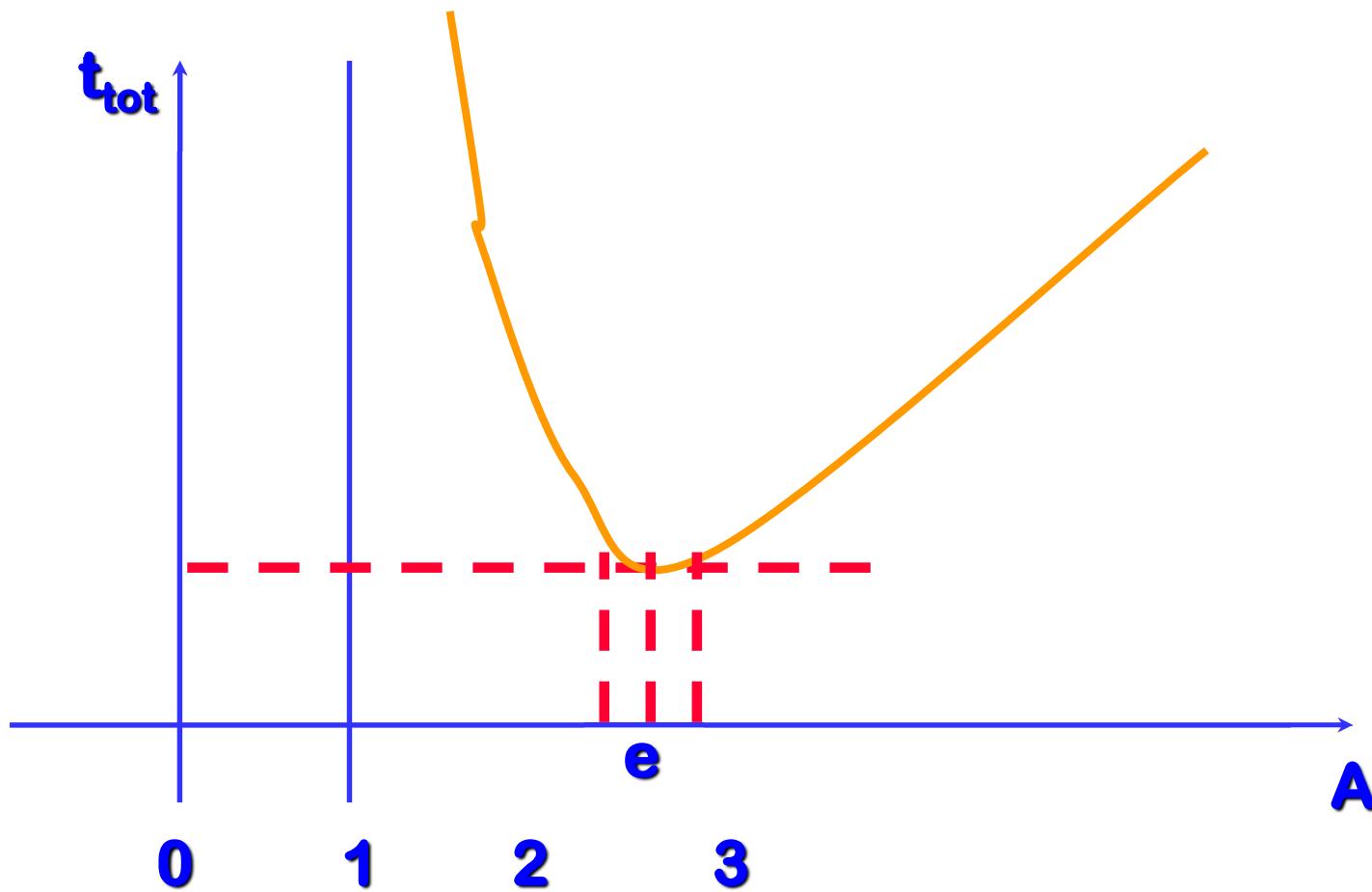
$$\tau_{tot} = \frac{A}{\ln A} \tau_m \ln \frac{C_L}{Cin} \quad \frac{\partial \tau_{tot}}{\partial A} = \frac{1 - \ln A}{\ln^2 A} \tau_m \ln \frac{C_L}{Cin}$$

$$1 - \ln A = 0 \quad \text{and so} \quad A = e (= 2.71\dots)$$

$$C_{in} = 10 \text{fF}, \quad C_L = 10 \text{pF}, \quad N = \frac{\ln(1000)}{\ln(3)} = 6,29 \quad \rightarrow 7$$

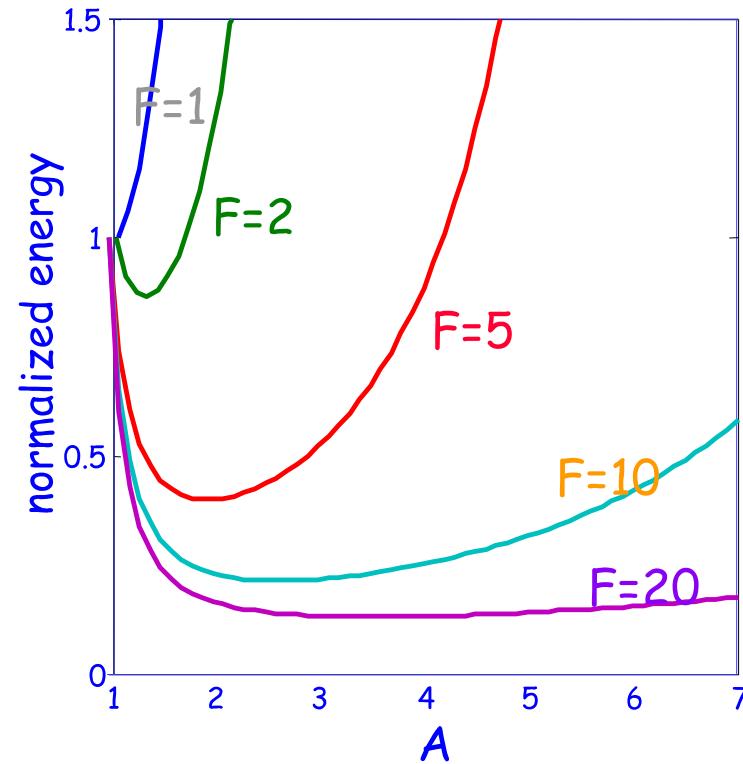
$$\tau_{tot} = 21\tau_m \quad w.r.t. \quad \tau_{tot} = 1000\tau_m$$

Inverter Chain



Dynamic Power as a Function of Device Size

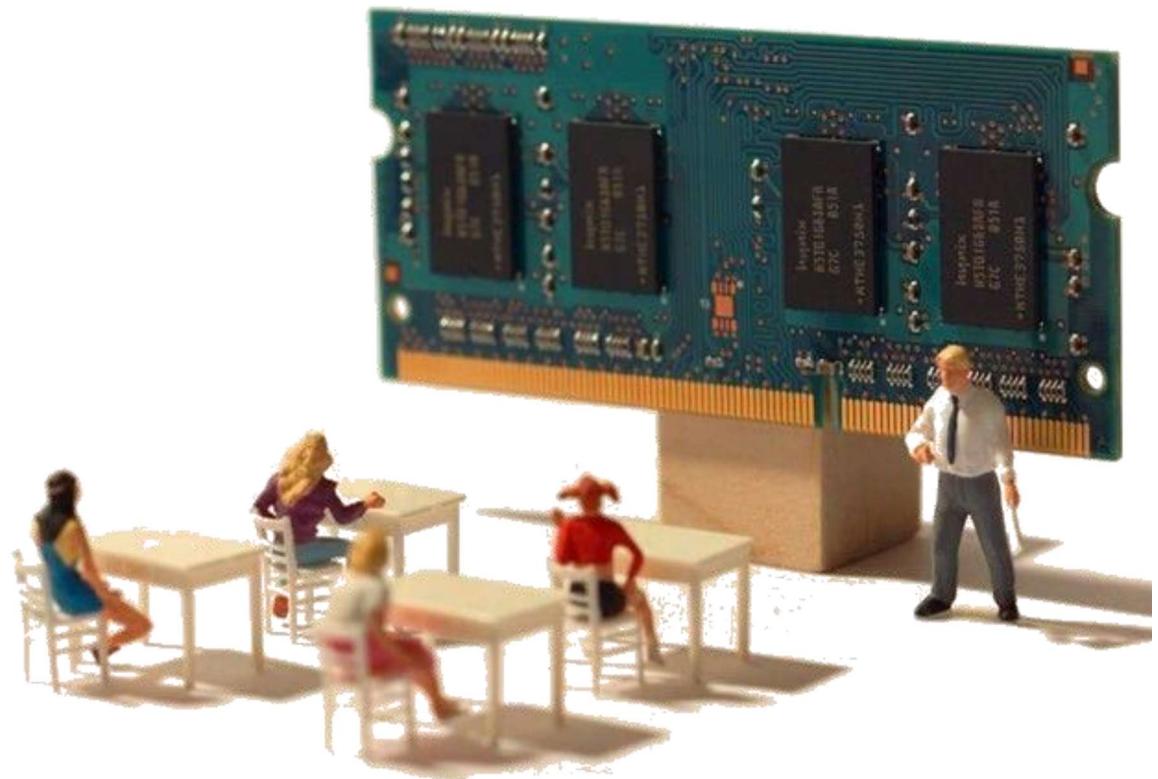
- ❖ Device sizing affects dynamic energy consumption
 - gain is largest for networks with large overall effective fan-outs ($F = C_L/C_{in}$)
- ❖ The optimal gate sizing factor (A) for dynamic energy is smaller than the one for performance, especially for large F's
 - e.g., for $F=20$,
 $A_{opt}(\text{energy}) = 3.53$ while
 $A_{opt}(\text{performance}) = 4.47$
- ❖ If energy is a concern avoid oversizing beyond the optimal



From Nikolic, UCB

End Inverter Chain Example, Questions ?

- Driving an high value capacitor
- Dynamic Analysis
- Power-Speed Trade-Off



Outline

❖ Review

- Sync. and Async Sequential Logic
- Finite State Machine (MEALY, MOORE, MEALY Rit.)

❖ Complementary CMOS Logic

- Synthesis
- Dynamic Analysis
- Examples: NAND, NOR and comparison
- Stick Diagram
- Body Effect
- Standard-cell AMS 0,35 um

❖ Example: Inverter Chain

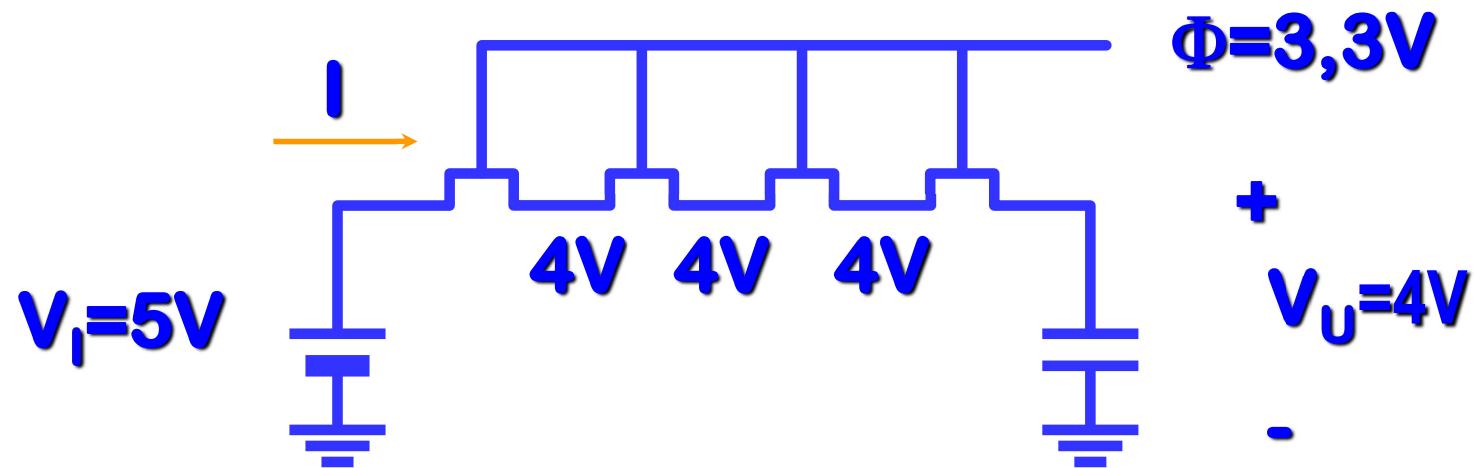
- Driving an high value capacitor
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❖ Example: Pass Transistor Chain

- Dynamic Analysis
- Area – Speed Trade-Off

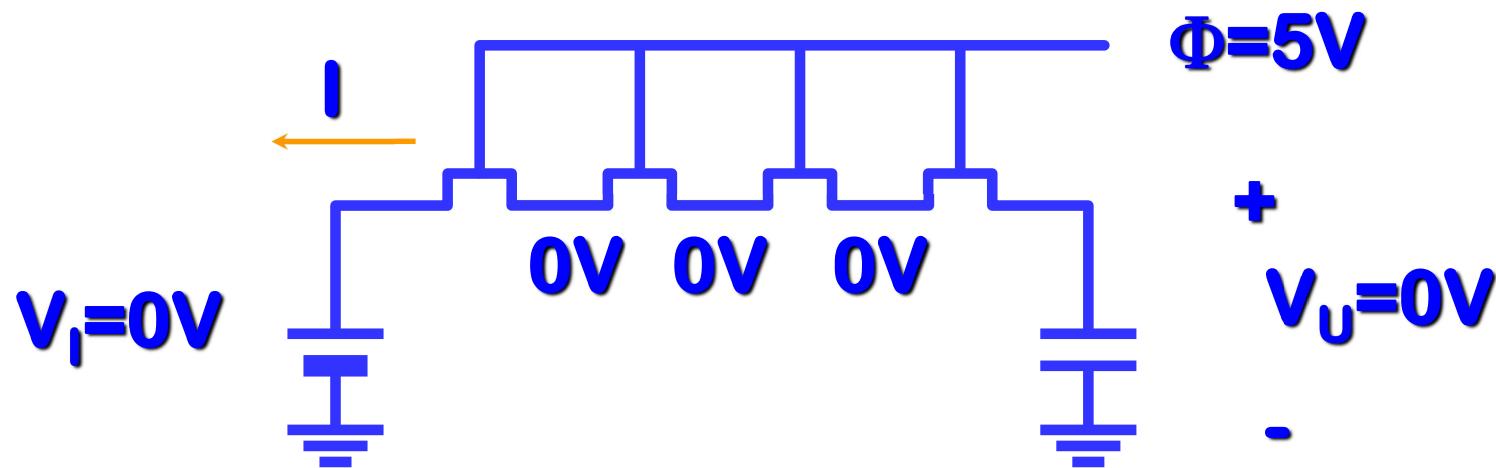
N pass transistor chain

❖ Threshold Drop at V_H



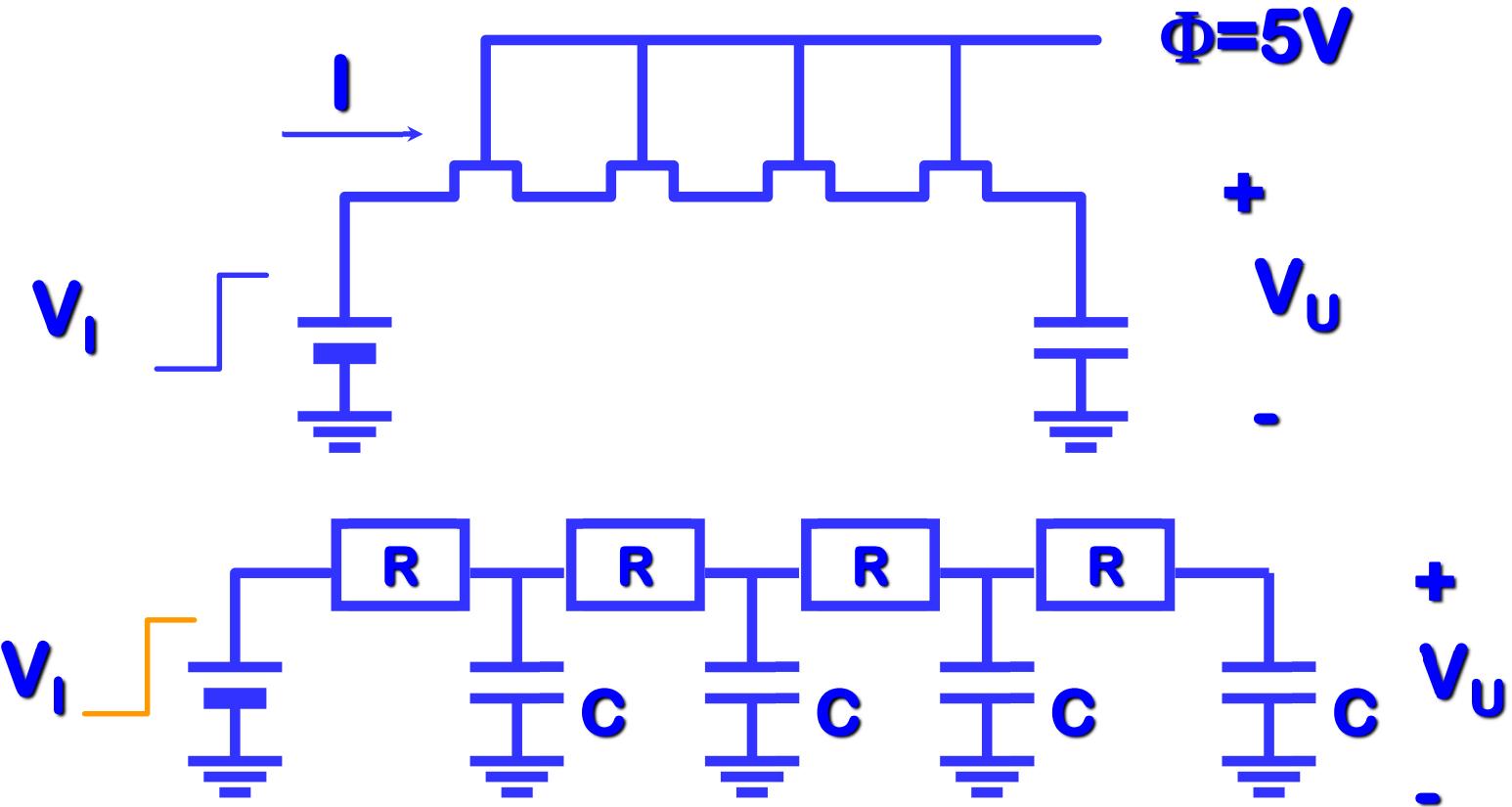
N pass transistor chain

❖ No Threshold Drop at V_L



N pass transistor chain

Dynamic Analysys

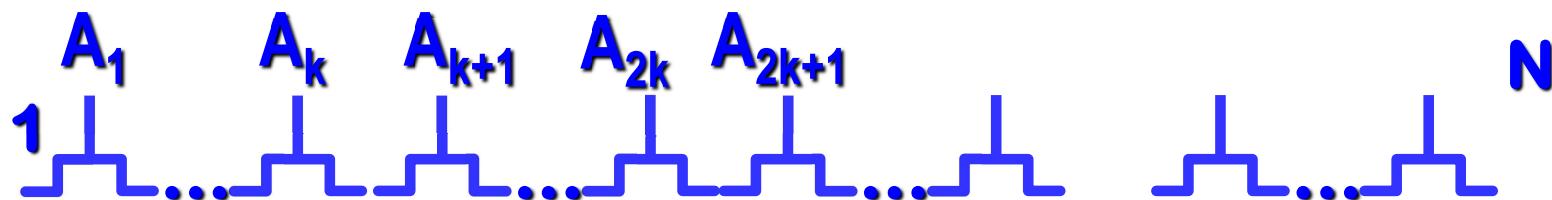


Delay

- ❖ T_p = delay of one R-C cell
- ❖ Overall delay grows with N^2
- ❖ $T_{TOT} = T_p N^2$
- ❖ Overall delay becomes very high just after few pass transistors

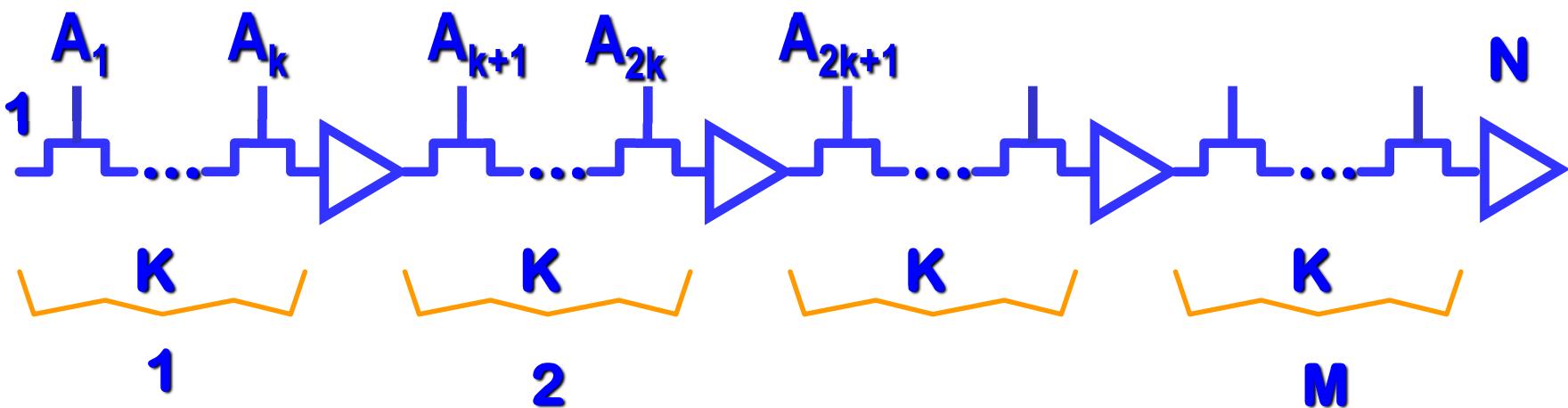
Delay Optimization

- Note:
 - Delay in a buffer chain grows linearly
- Solution
 - Introduce buffers in the pass transistor chain
- Let's consider a N pass transistor chain with «N» elements



Circuit Solution

- ❖ $T_P = \text{pass transistor delay}$
- ❖ $T_B = \text{buffer delay}$
- ❖ M groups made by K pass transistors



Analysis

$$N = K \bullet M; \quad M = \frac{N}{K}$$

$$T_{tot} = MT_B + M(K^2 T_P) = \frac{N}{K} T_B + \frac{N}{K} (K^2 T_P) = \frac{N}{K} T_B + NKT_P$$

$$\frac{dT_{tot}}{dK} = -\frac{N}{K^2} T_B + NT_P = 0$$

$$K = \sqrt{\frac{T_B}{T_p}}$$

Example

✧ Example: 16 Bit Manchester Carry Adder

$$N = 16 \quad T_B = 4 \text{ns} \quad T_P = 0,2 \text{ns}$$

$$K = \sqrt{\frac{T_B}{T_p}} = 4,47 \Rightarrow 4 \Rightarrow M = 16 : 4 = 4$$

$$T_{tot} = 4T_B + 4(16T_P) = 28,8 \text{ns}$$

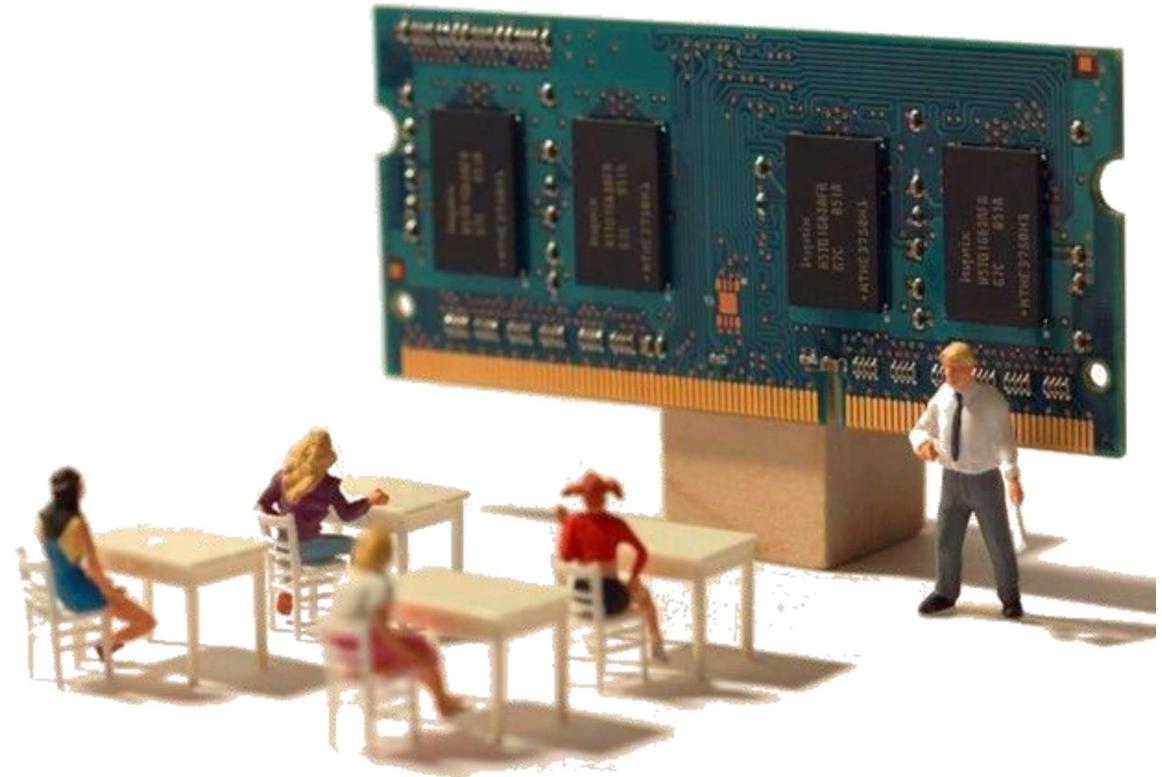
$$w.r.t. \quad N^2 T_P = 51,2 \text{ns}$$

Pass Gate Chain

- ❖ **No Threshold drop**
- ❖ **Pass gate delay is lower than pass transistor one**
- ❖ **Delay optimization works as just shown for the pass transistor chain**

End Pass Transistor Chain Example, Questions ?

- Dynamic Analysis
- Area - Speed Trade-Off



End, Questions ?

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○ Example: Inverter Chain

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○ Example: Pass Transistor Chain

- Dynamic Analysis
- Area - Speed Trade-Off

