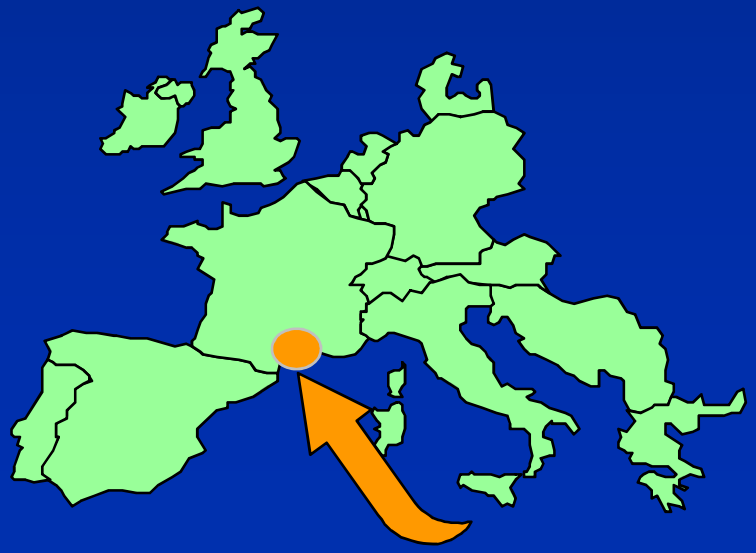
60th IFIP WG 10.4 Meeting

Taoyuan
July 2011

Testing for Realistic Defects in CMOS Technology: From a Deterministic to a Statistical View

M. Renovell

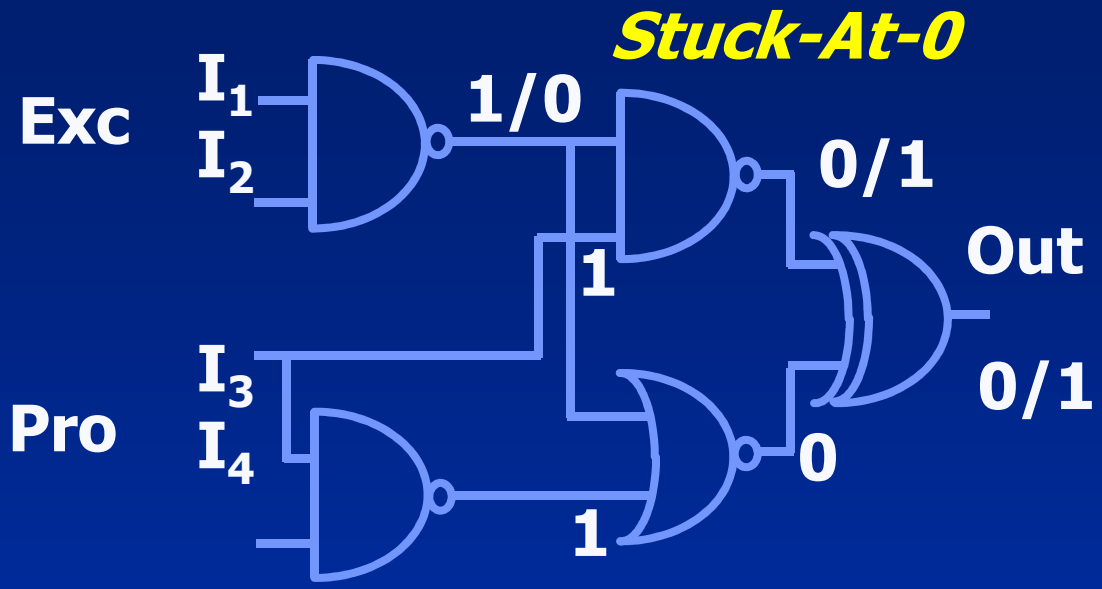
LIRMM - CNRS / University of Montpellier - FRANCE



Outline

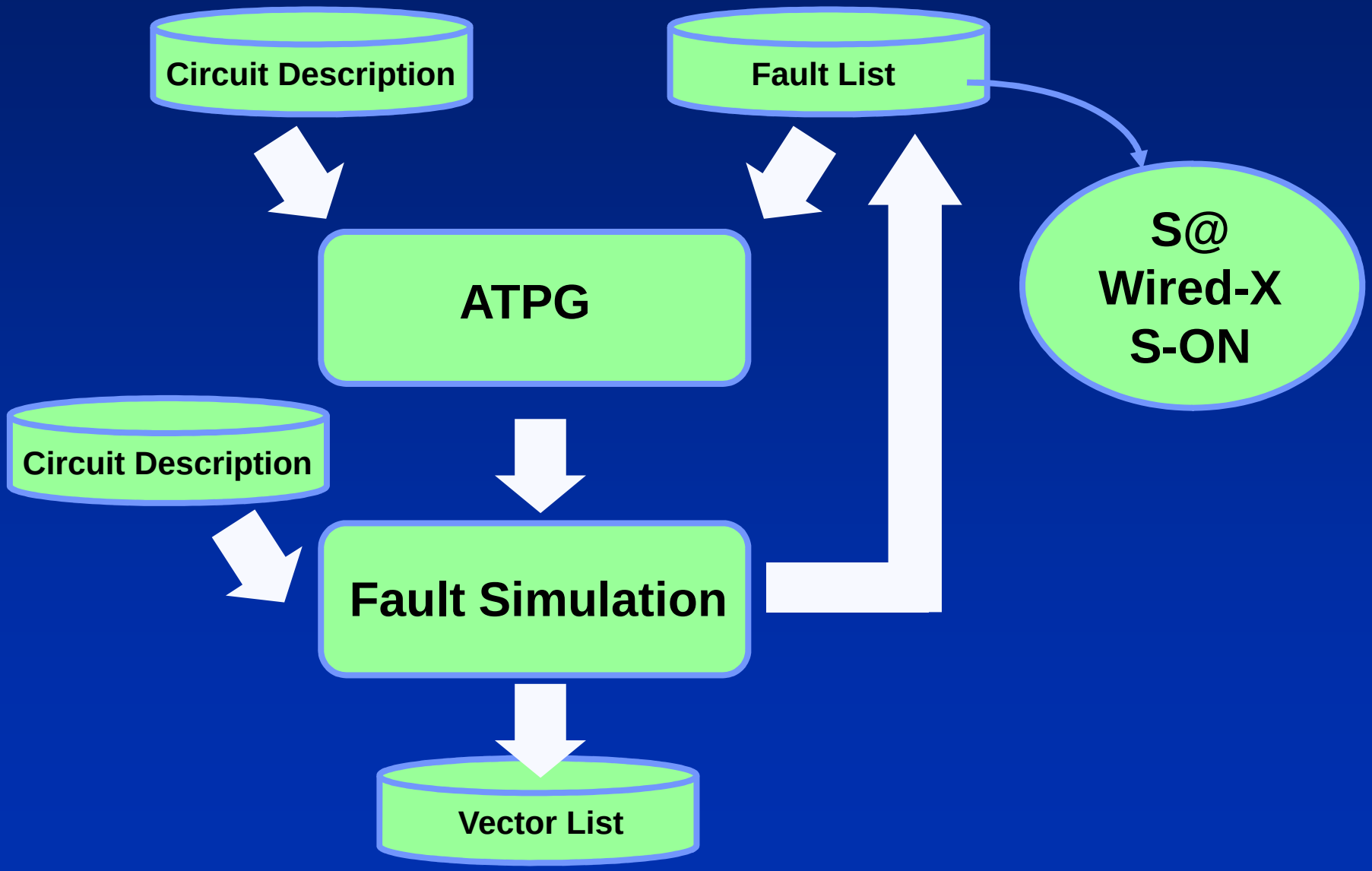
- Past
  - 1. Classical FM
  - 2. Defect with Realistic FM
- Today
  - 3. Defect with Probabilistic DM
- Future
  - 4. Defect with Statistical Chip

1. Classical FM

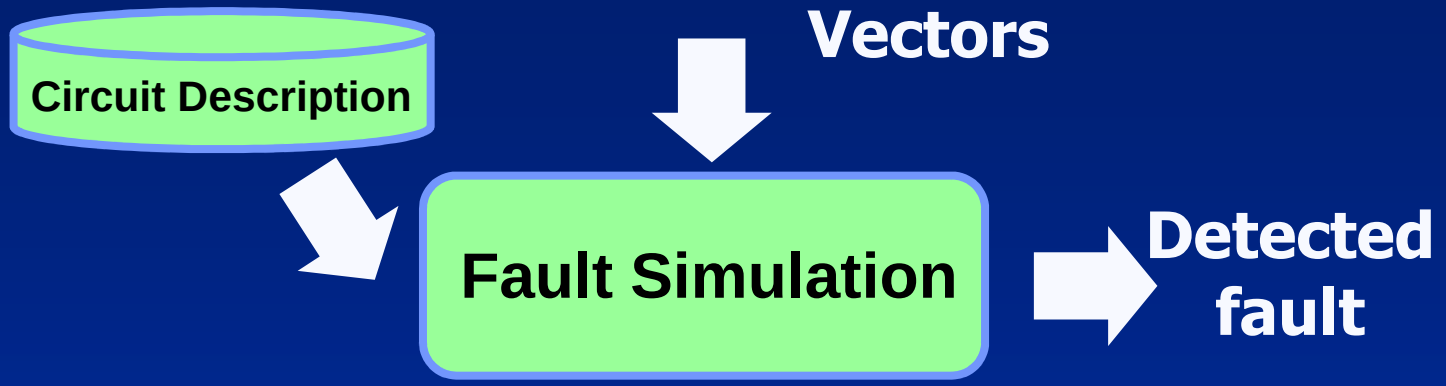


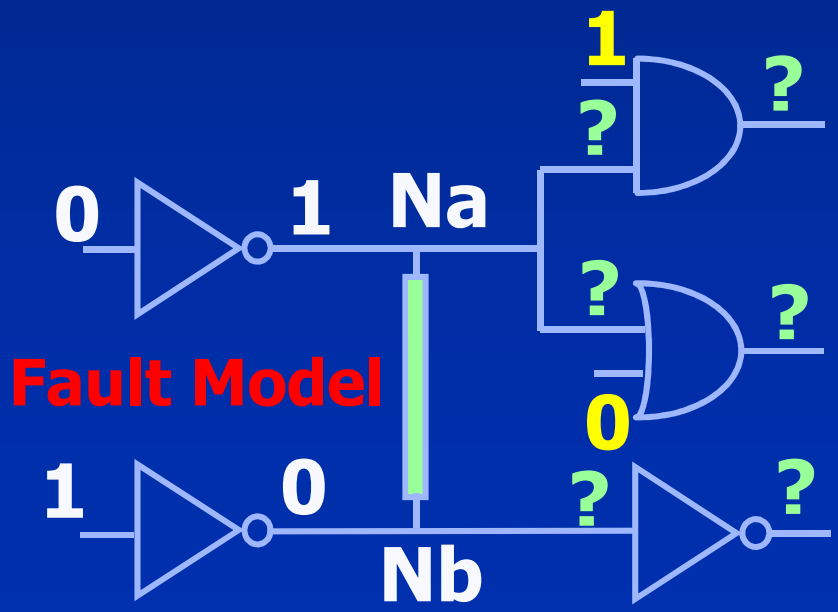
	Short	Open
Transistor	-	*Stuck-Open*
Interconnect	*Wired-X*	-

1. Classical FM



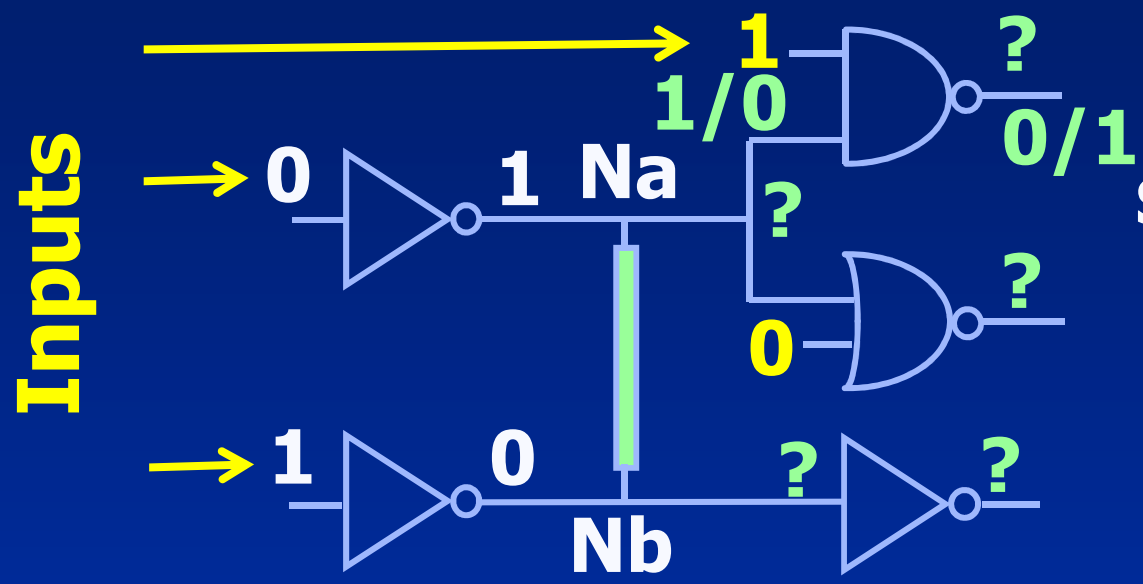
1. Classical FM





Na	Nb	Na*	Nb*
0	0	0	0
0	1	?	?
1	0	?	?
1	1	1	1

1. Classical FM



Simulation Time
ok

Wired-And

Na	Nb	Na.Nb
0	0	0
0	1	0
1	0	0
1	1	1

Dominant

Na	Nb	Na
0	0	0
0	1	0
1	0	1
1	1	1

Wired-Or

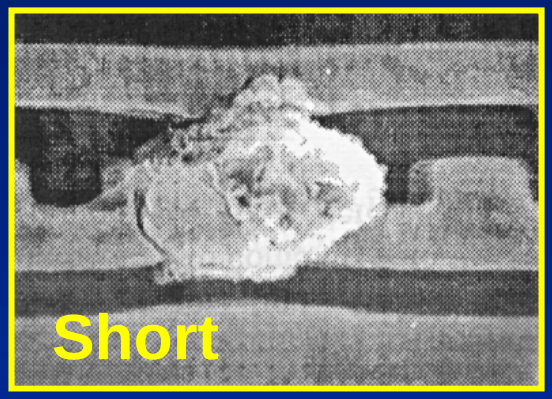
Na	Nb	Na+Nb
0	0	0
0	1	1
1	0	1
1	1	1

1. Classical FM

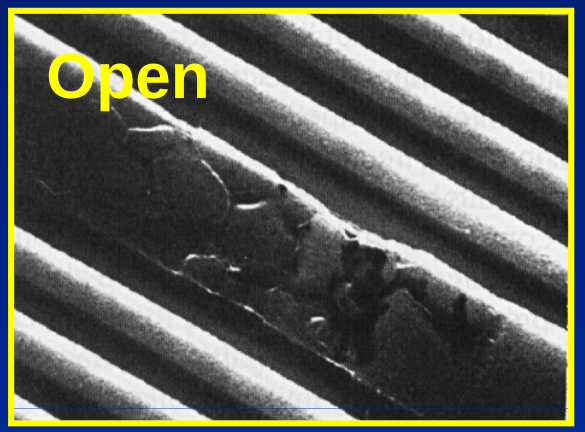
Classical Fault Model

Controlled

2. Defect with Realistic FM

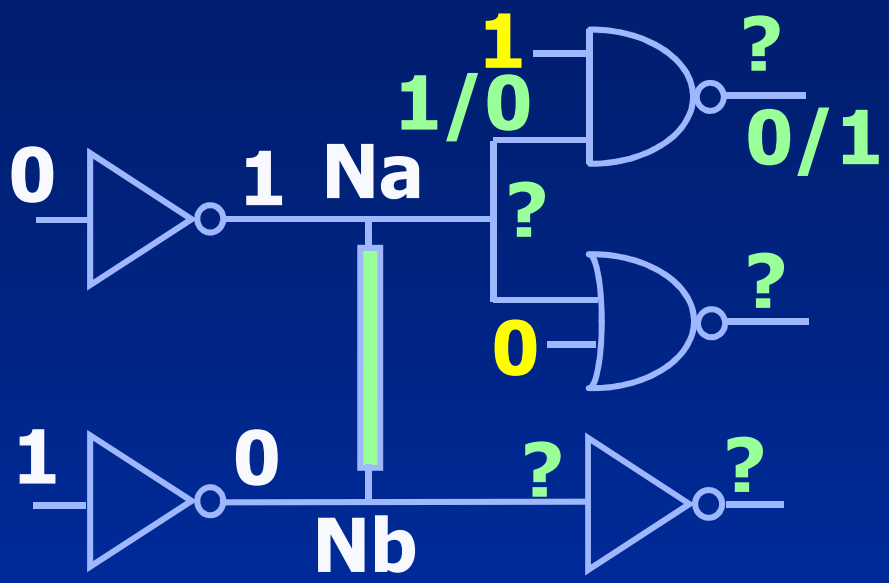


Defects



	Short	Open
Transistor	*Gate-Oxide-Short*	*Floating Gate*
Interconnect	*Short*	*Open*

2. Defect with Realistic FM



Wired-And

Na	Nb	Na.Nb
0	0	0
0	1	0
1	0	0
1	1	1

Dominant

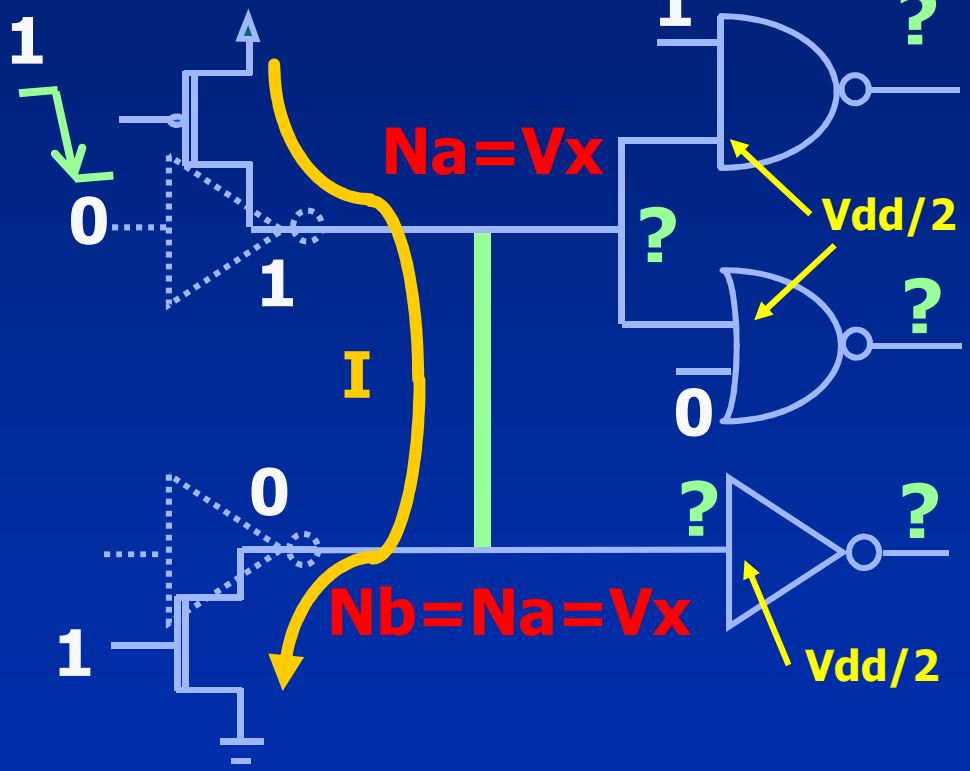
Na	Nb	Na
0	0	0
0	1	0
1	0	1
1	1	1

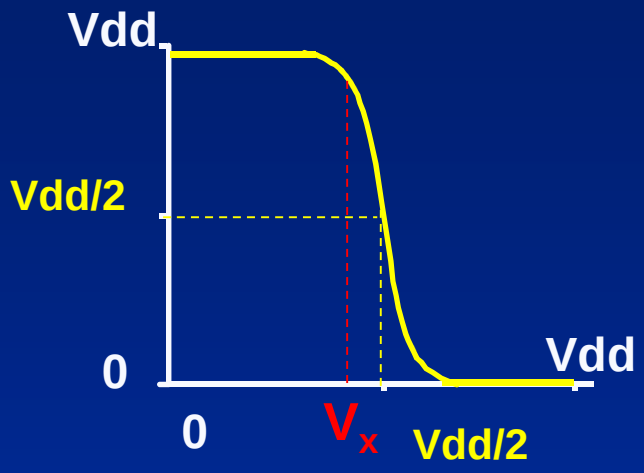
Wired-Or

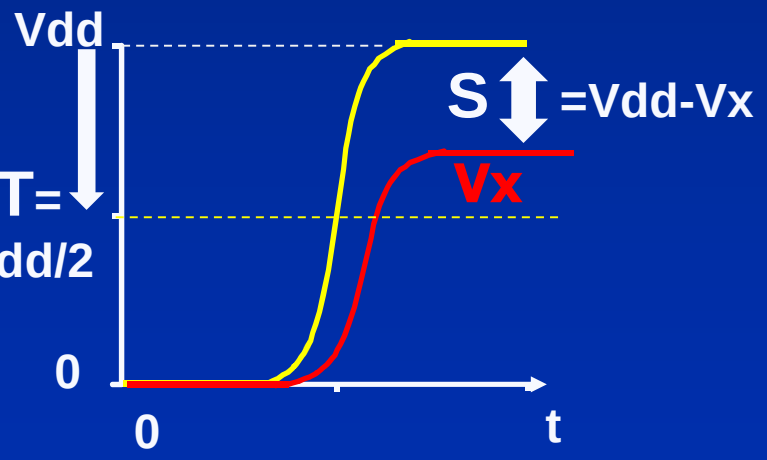
Na	Nb	Na+Nb
0	0	0
0	1	1
1	0	1
1	1	1

2. Defect with Realistic FM

- Voting



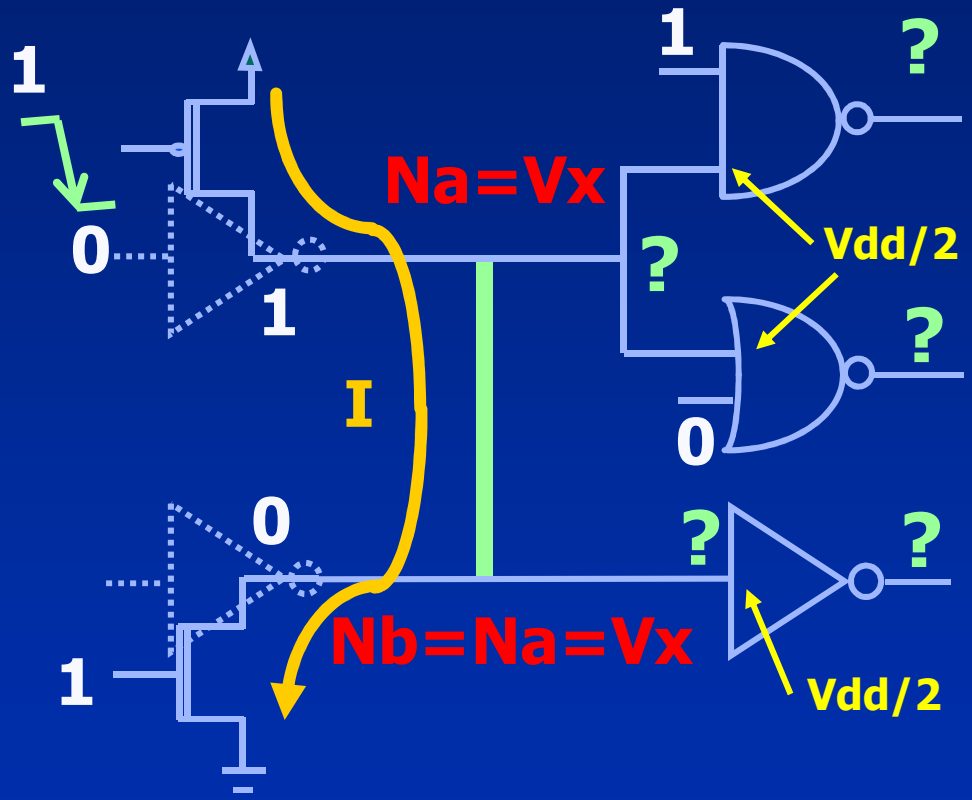




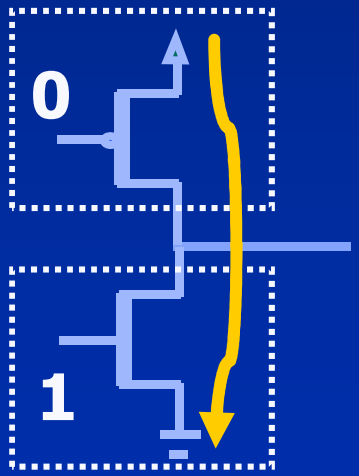
Defect Detection: Size > Threshold

2. Defect with Realistic FM

- Voting



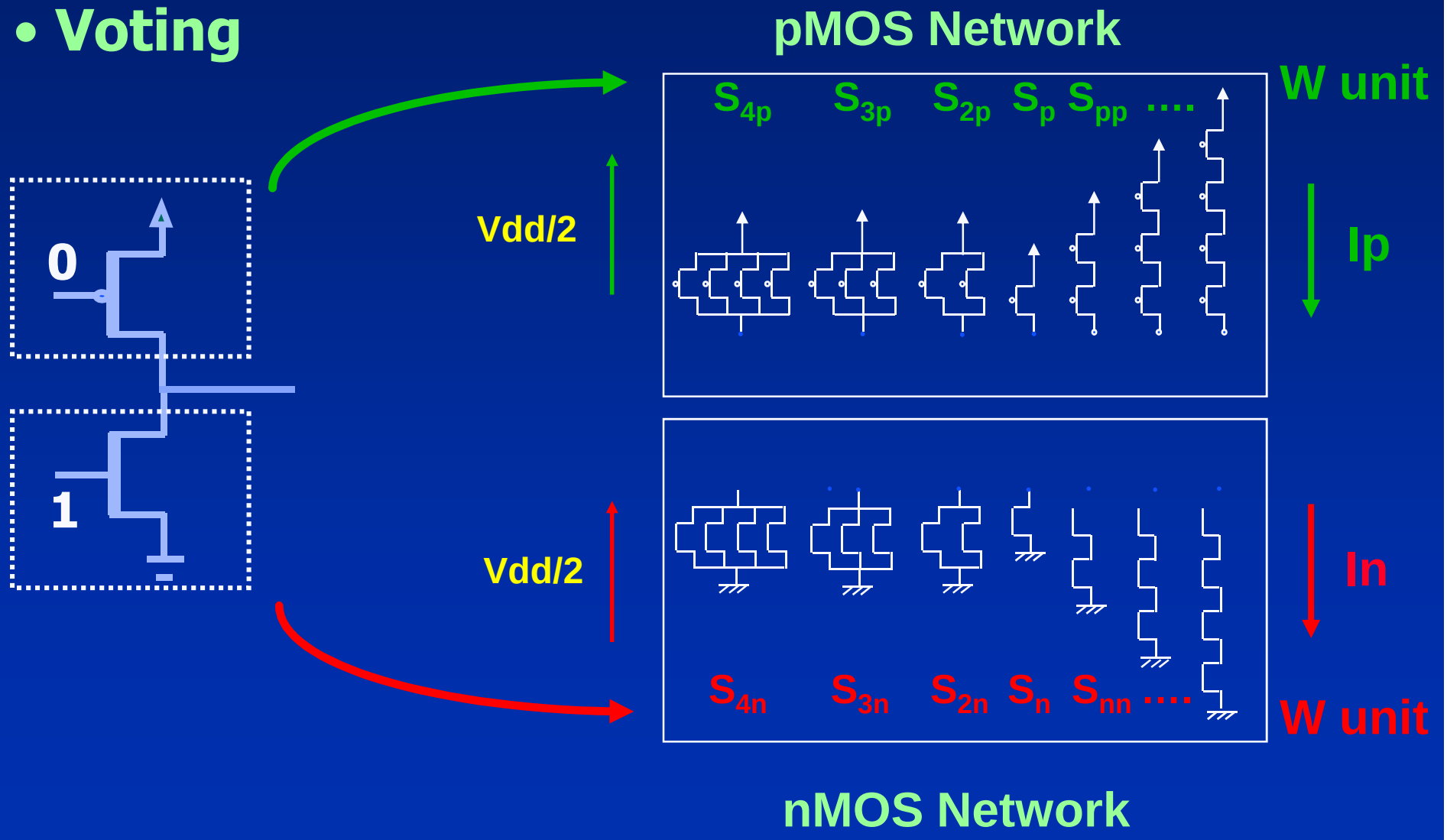
Compute Vx



Compare Vx & Vdd/2

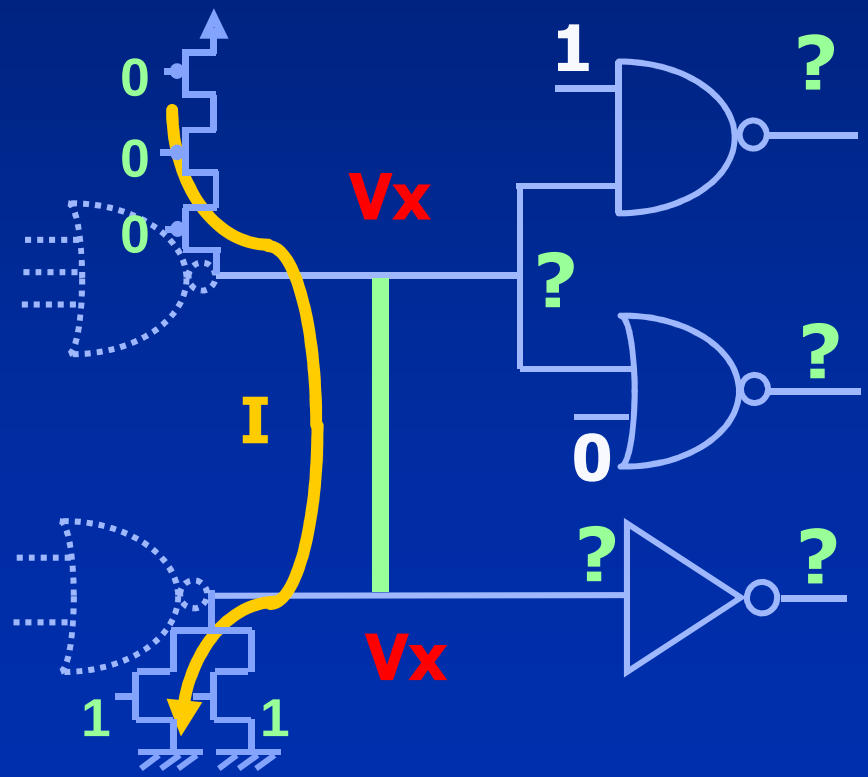
2. Defect with Realistic FM

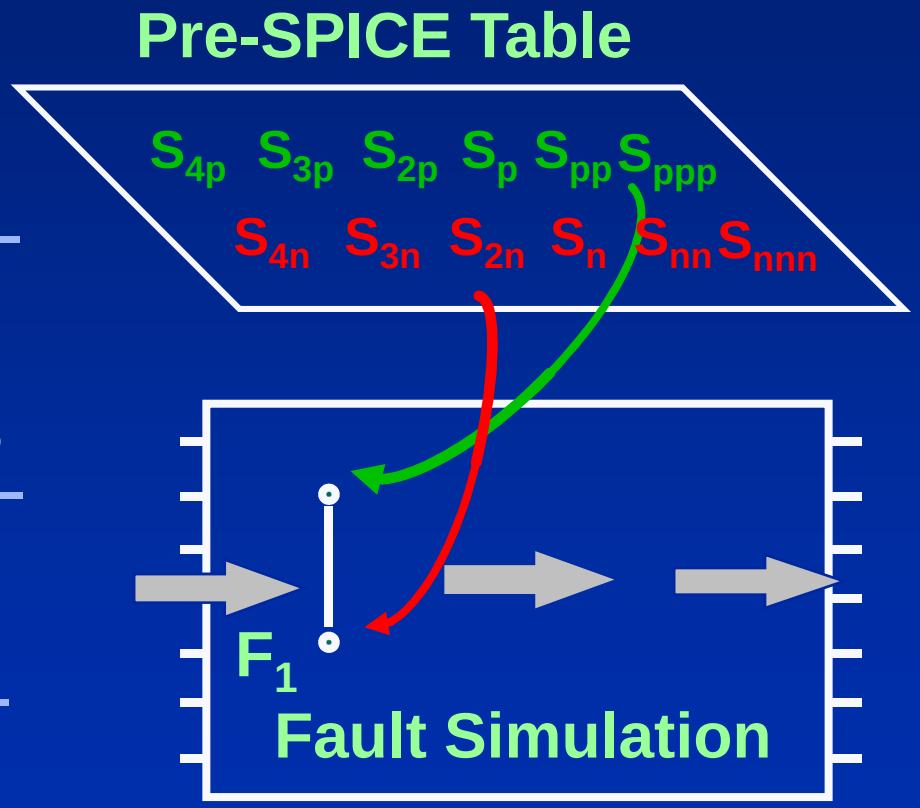
- Voting



2. Defect with Realistic FM

- Voting





2. Defect with Realistic FM

Classical FM

Controlled

I1
I2
.

CFM

Realistic FM

Controlled

I1
I2
.

Wn Vth | RFM | μ Cox

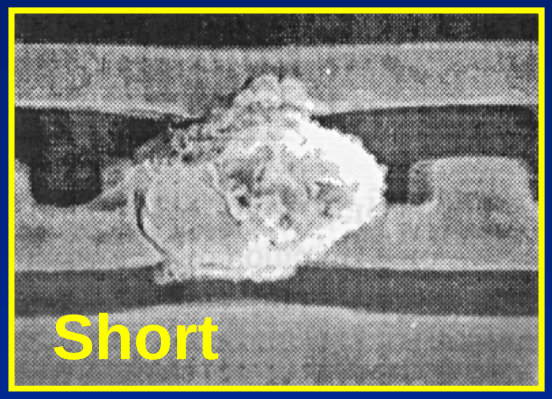
Induced

Imposed

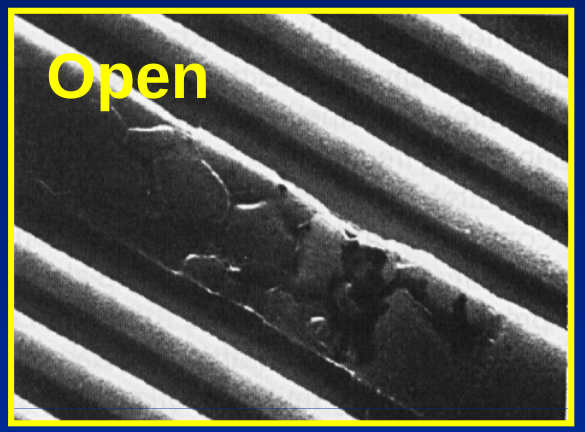
Size is Maximum
-

Compute Size
Compare Threshold

3. Defect with Probabilistic FM

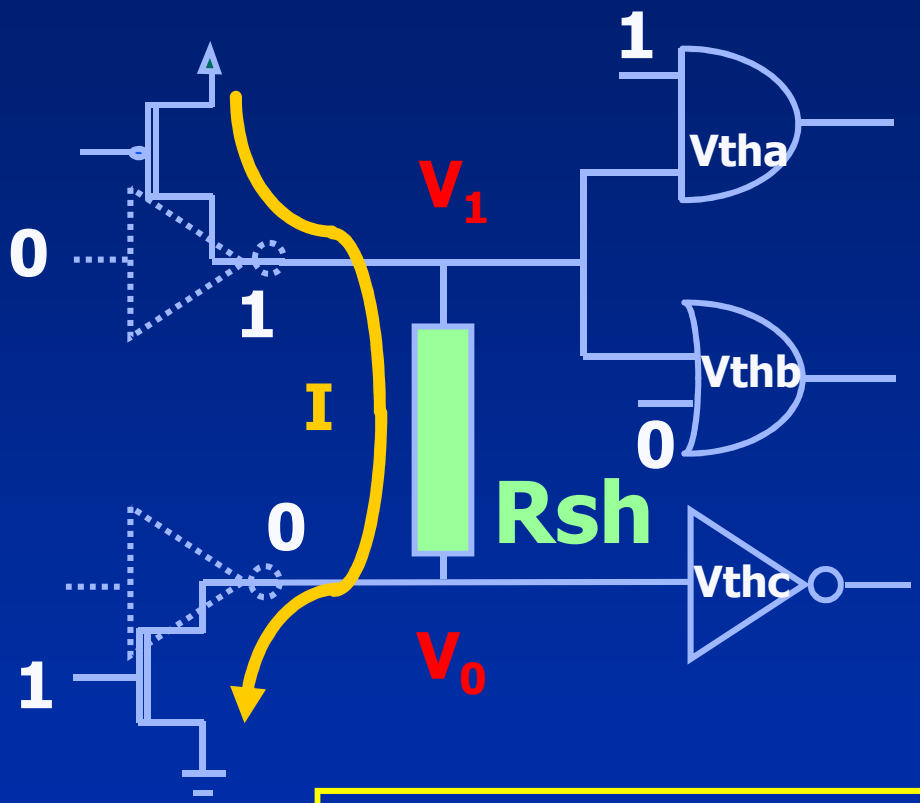


Defects



	Short	Open
Transistor	*Gate-Oxide-Short*	*Floating Gate*
Interconnect	*Resistive Short*	*Resistive Open*

3. Defect with Probabilistic FM



Defects are Unpredictable

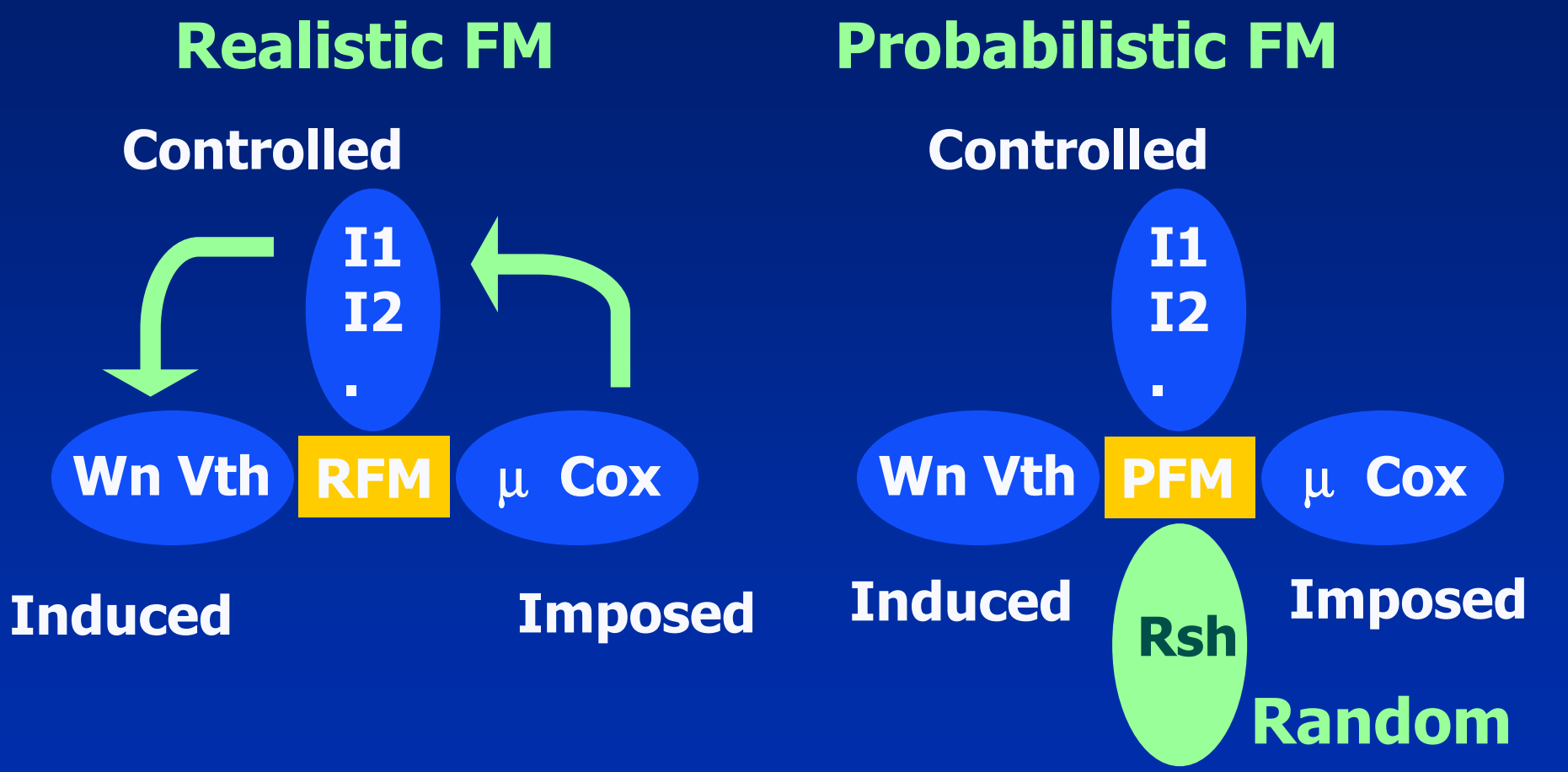
?

$$Vx = F(\ Rsh\ )$$

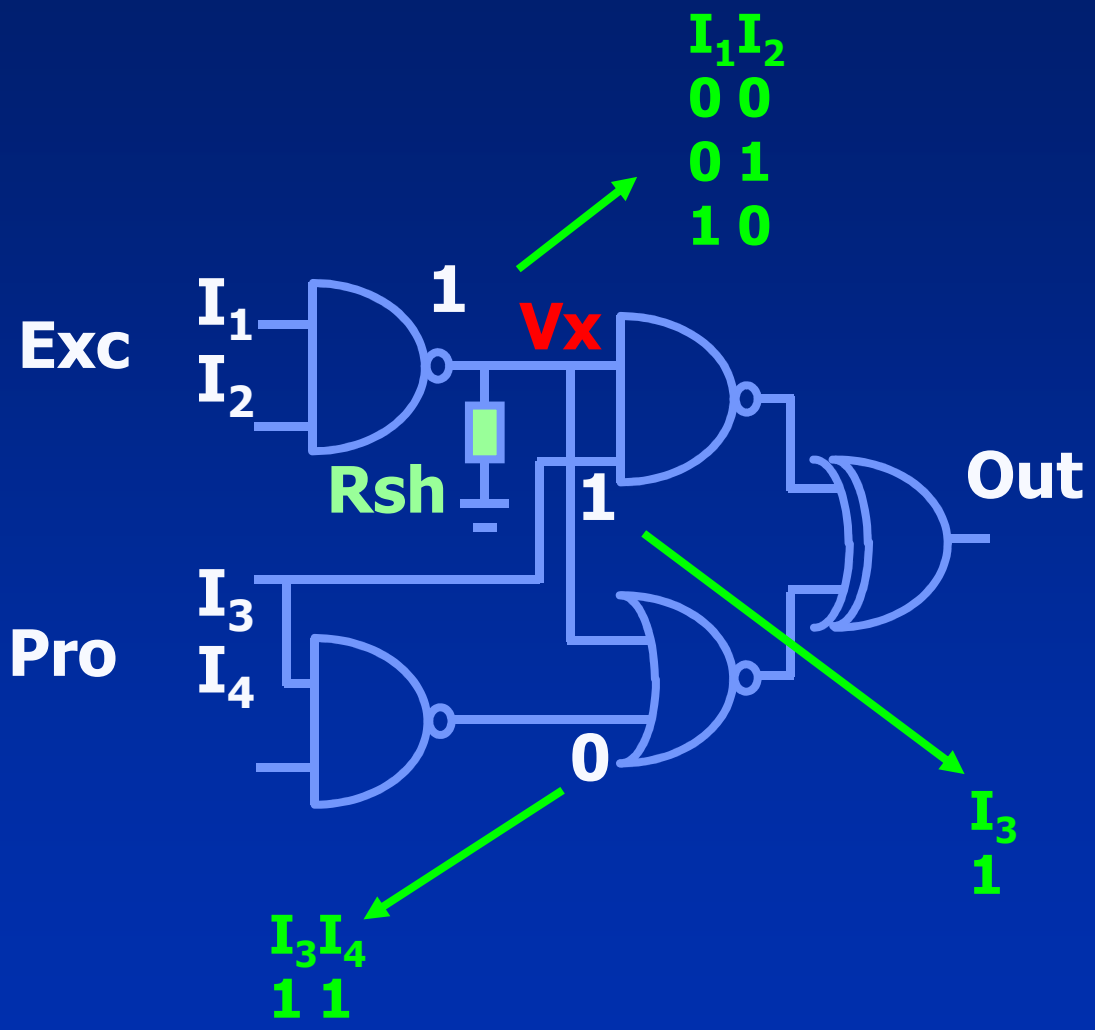
β Vtp Vtn Cox μ_p μ_n Vdd

Topology
Technology

3. Defect with Probabilistic FM



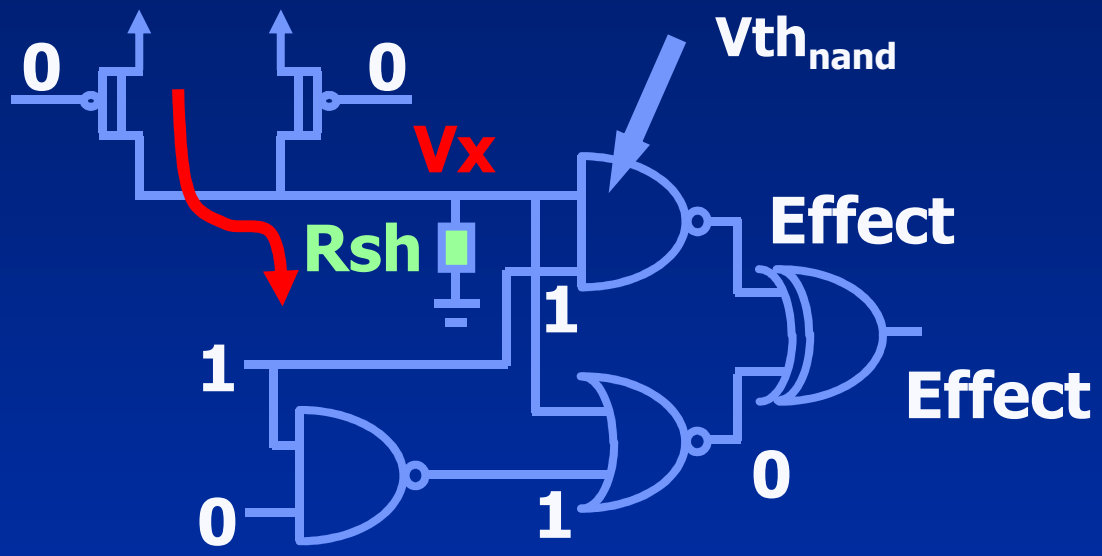
3. Defect with Probabilistic FM

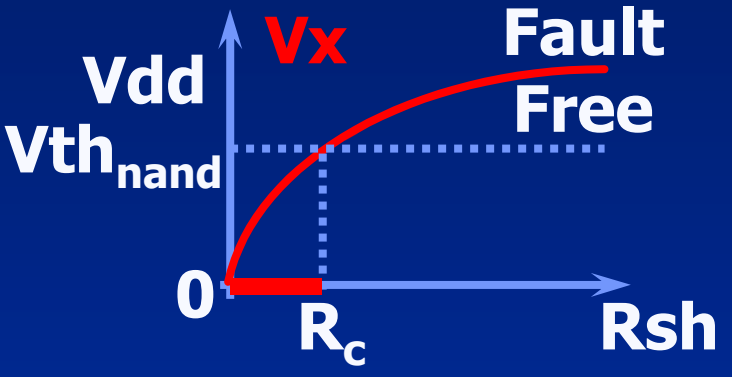


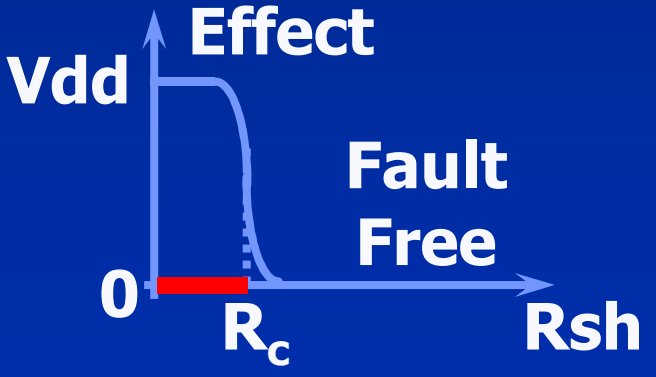
	I_1 I_2	I_3 I_4
#0	0 0	0 0
#1	0 0	0 1
#2	0 0	1 0
#3	0 0	1 1
#4	0 1	0 0
#5	0 1	0 1
#6	0 1	1 0
#7	0 1	1 1
#8	1 0	0 0
#9	1 0	0 1
#10	1 0	1 0
#11	1 0	1 1
#12	1 1	0 0
#13	1 1	0 1
#14	1 1	1 0
#15	1 1	1 1

3. Defect with Probabilistic FM

Vector #2





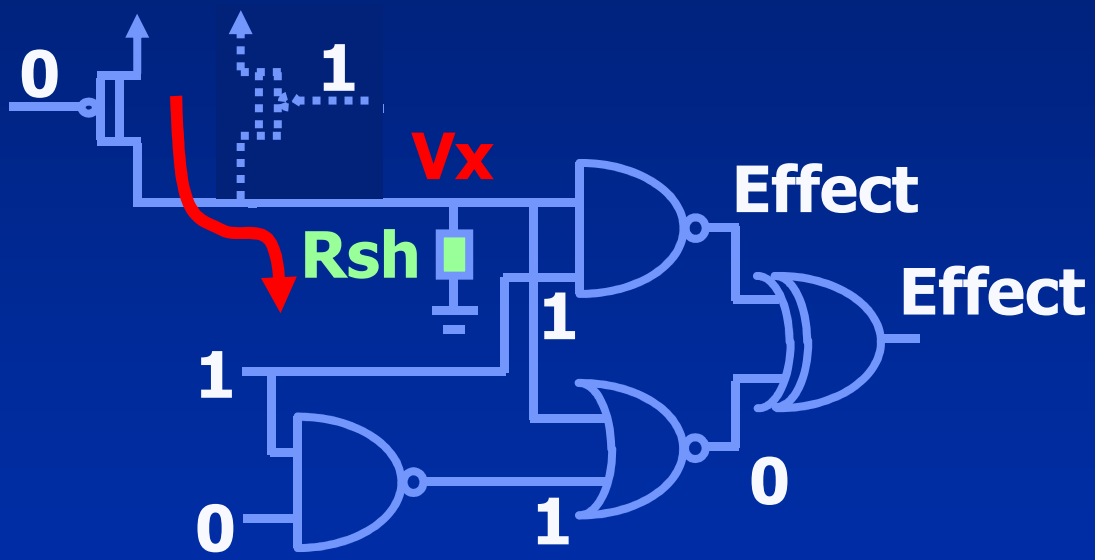


Defect is Detected
If Rsh ∈ [0 , Rc]

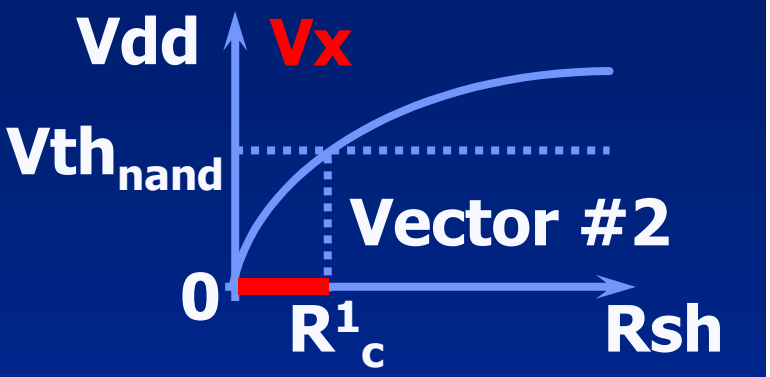
DI = [0 , Rc]

3. Defect with Probabilistic FM

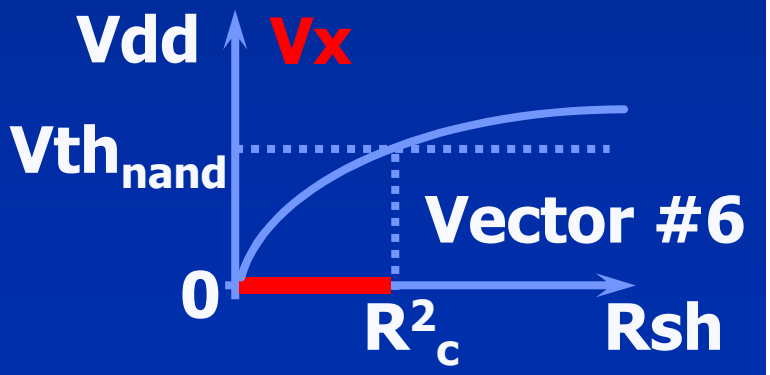
Vector#2 / Vector #6



➡ Defect excitation



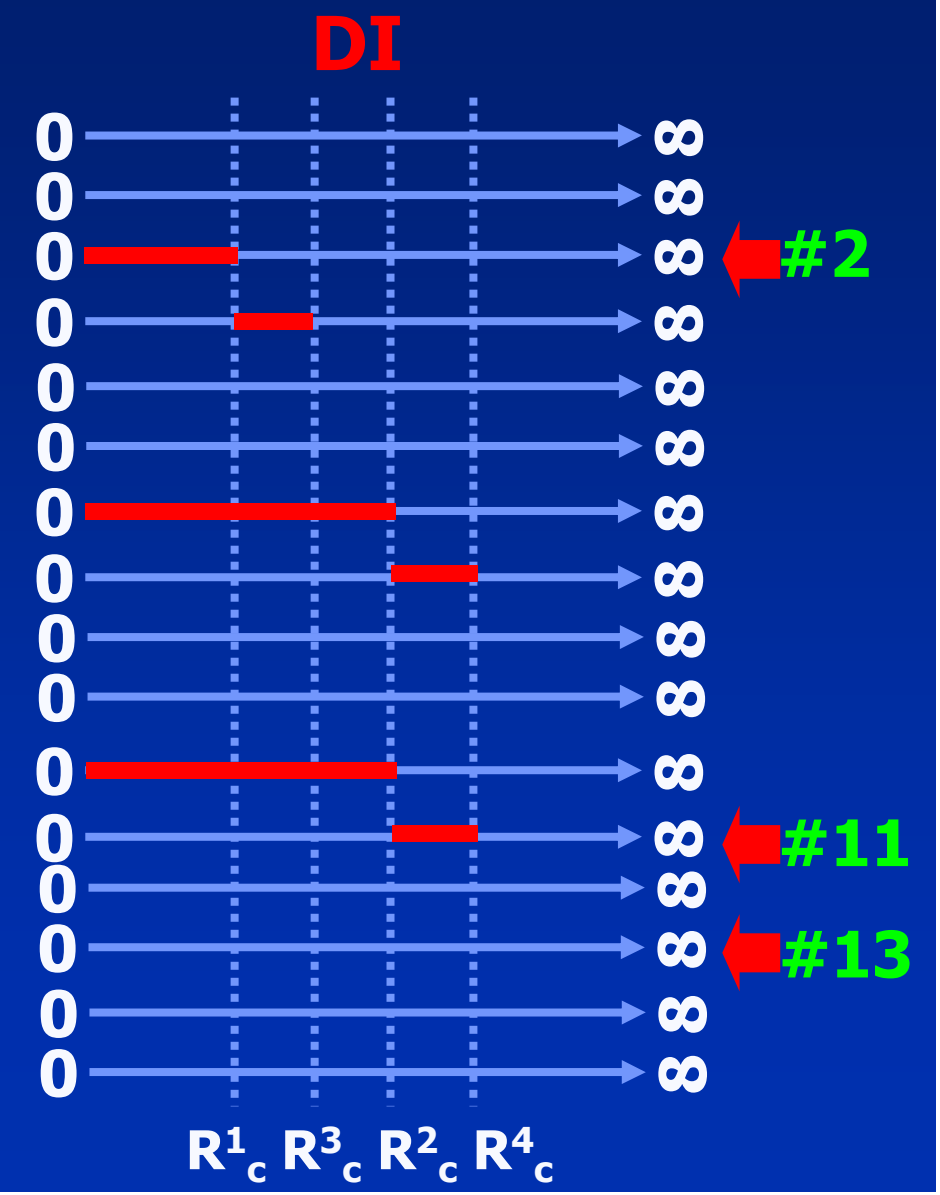
$DI^1 = [\ 0\ ,\ Rc^1\ ]$



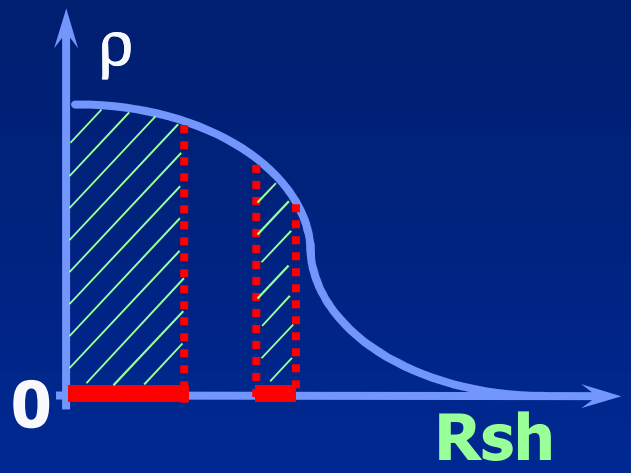
$DI^2 = [\ 0\ ,\ Rc^2\ ]$

3. Defect with Probabilistic FM

	I_1 I_2	I_3 I_4	
#0	0 0	0 0	ϕ
#1	0 0	0 1	ϕ
#2	0 0	1 0	$[0, R^1_c]$
#3	0 0	1 1	$[R^1_c, R^3_c]$
#4	0 1	0 0	ϕ
#5	0 1	0 1	ϕ
#6	0 1	1 0	$[0, R^2_c]$
#7	0 1	1 1	$[R^2_c, R^4_c]$
#8	1 0	0 0	ϕ
#9	1 0	0 1	ϕ
#10	1 0	1 0	$[0, R^2_c]$
#11	1 0	1 1	$[R^2_c, R^4_c]$
#12	1 1	0 0	ϕ
#13	1 1	0 1	ϕ
#14	1 1	1 0	ϕ
#15	1 1	1 1	ϕ

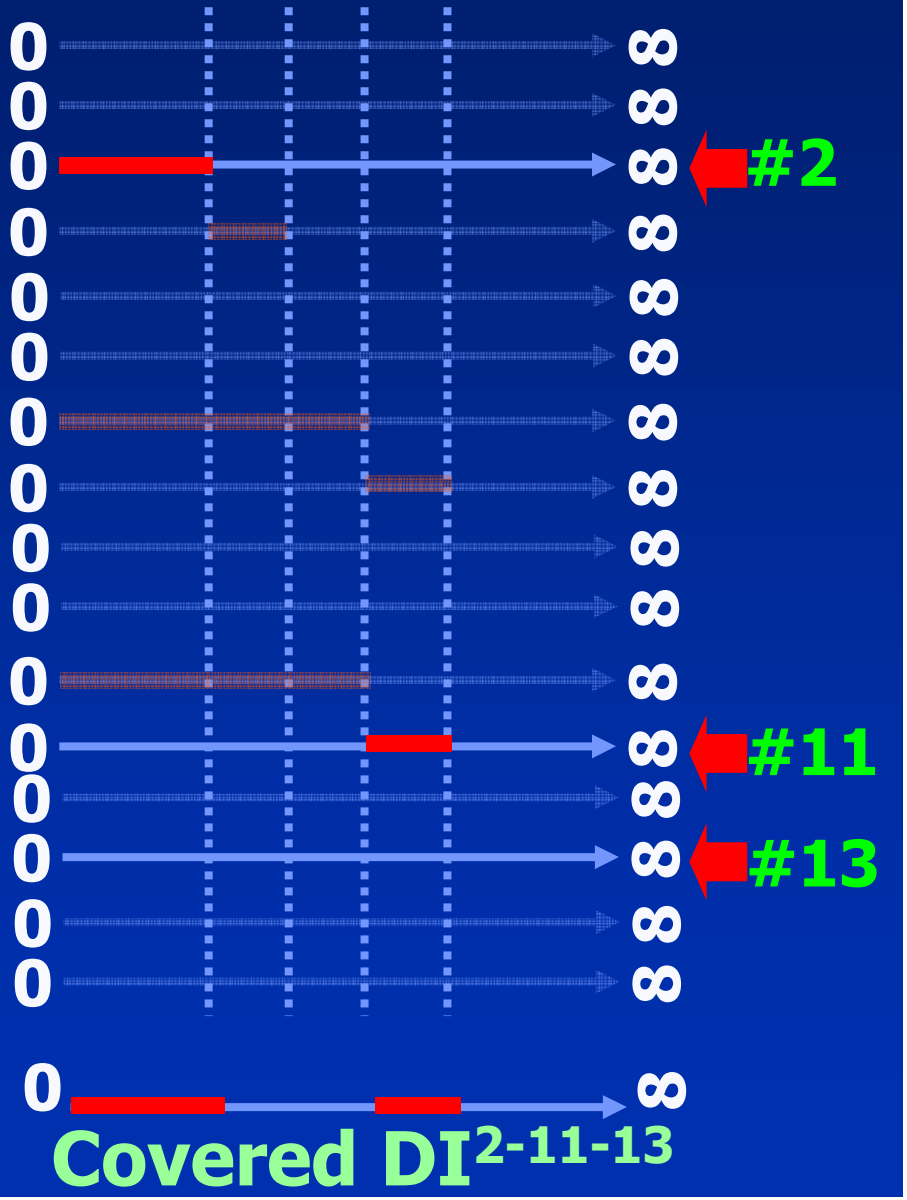


3. Defect with Probabilistic FM

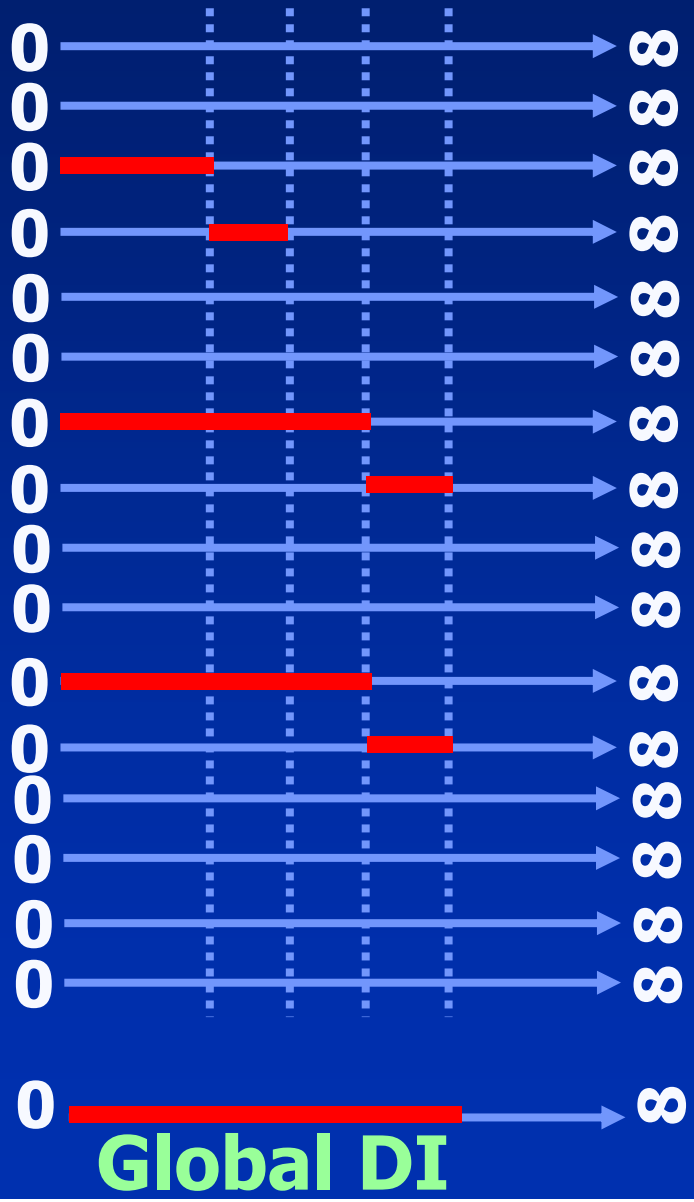


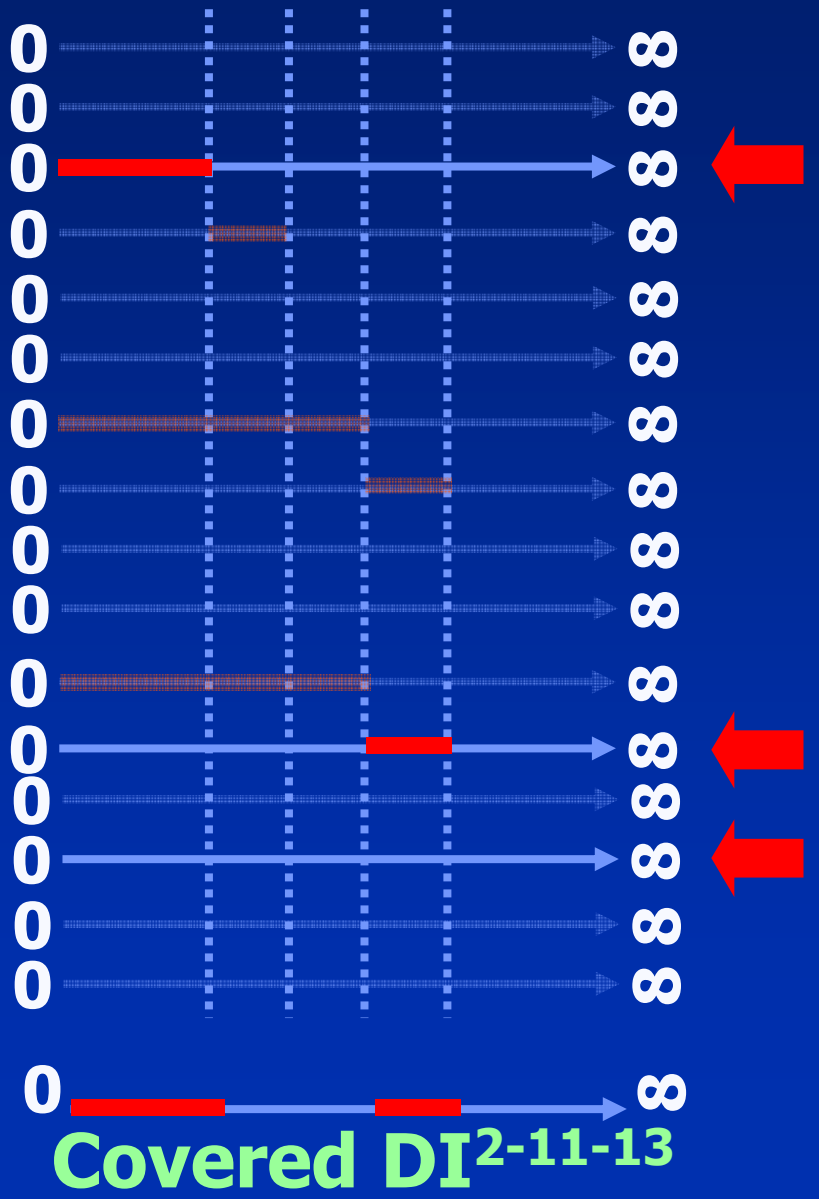
To know or not to know ?

$$P_D = \int_{C\text{-}DI_D} \rho(Rsh)\,dRsh$$

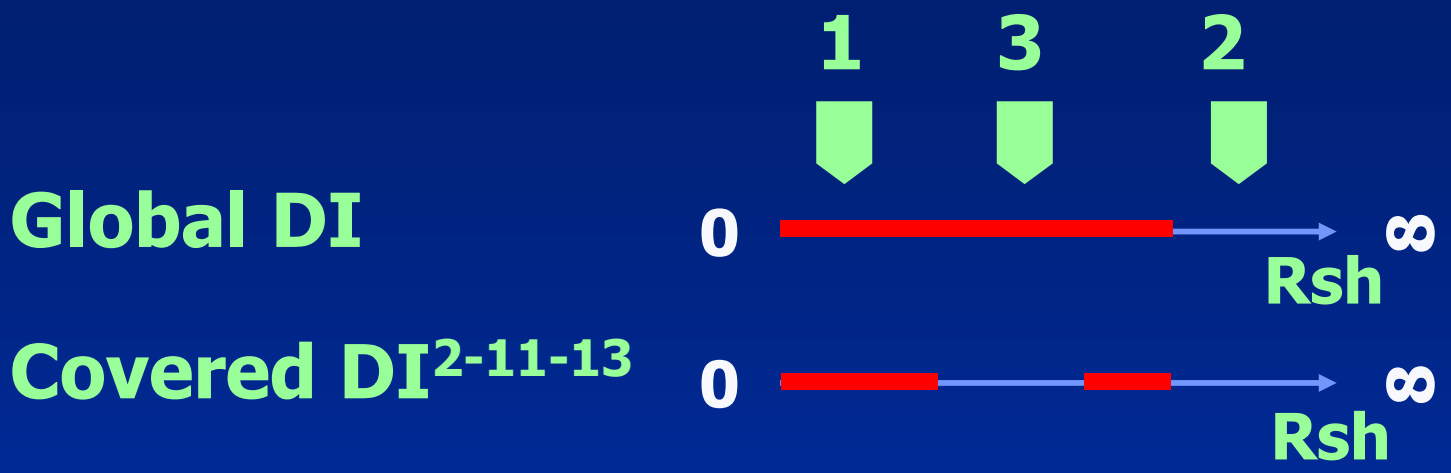


3. Defect with Probabilistic FM



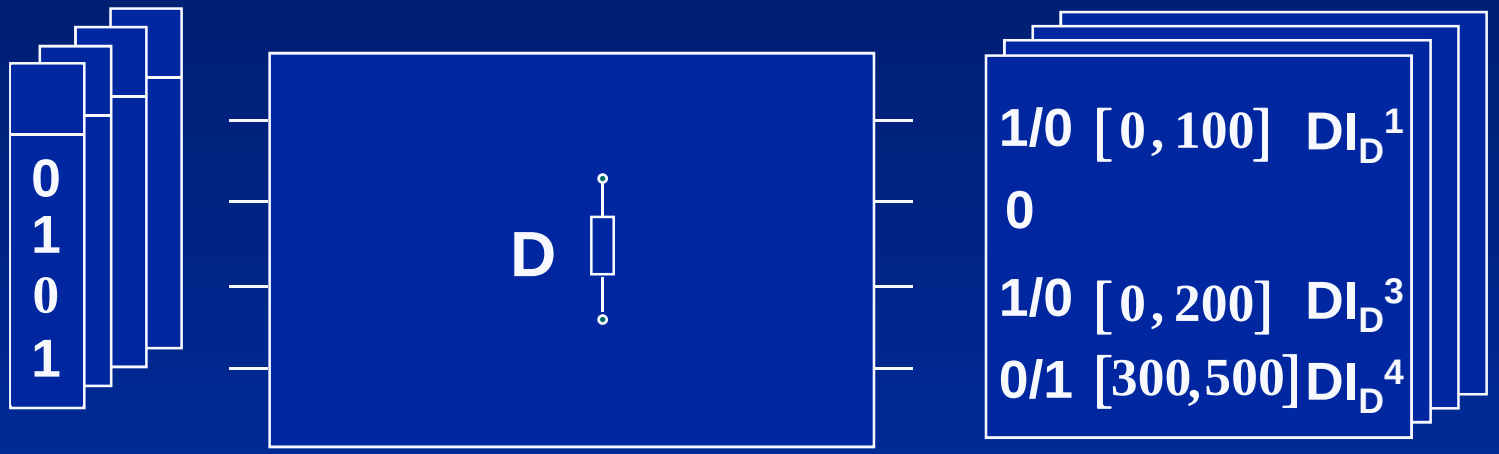


3. Defect with Probabilistic FM



$$E_D = \frac{\text{C-DI}}{\text{G-DI}} = \frac{\int_{\text{C-DI}_D} \rho(\text{Rsh})\,d\text{Rsh}}{\int_{\text{G-DI}_D} \rho(\text{Rsh})\,d\text{Rsh}}$$

3. Defect with Probabilistic FM



$$C\text{-}DI_D = \bigcup_{V_i} \bigcup_{PO_i} DI_D$$

$$G\text{-}DI_D = \bigcup_{V_{2^n}} \bigcup_{PO_i} DI_D$$

$$E_D = \frac{\int_{C\text{-}DI_D} \rho(Rsh)\,dRsh}{\int_{G\text{-}DI_D} \rho(Rsh)\,dRsh}$$

3. Defect with Probabilistic FM

Classical FM
Realistic FM

$$FC = \frac{\sum E_F}{N_F}$$

$$E_F = \begin{cases} 0 \\ 1 \end{cases}$$

Probabilistic FM

$$FC = \frac{\sum E_D}{N_D}$$

$$0 < E_D < 1$$

$$\frac{\int \text{C-DI}_D}{\int \text{G-DI}_D}$$

3. Defect with Probabilistic FM

Realistic FM

Controlled

I1
I2
.

Wn Vth | RFM | μ Cox

Induced | Imposed

Probabilistic FM

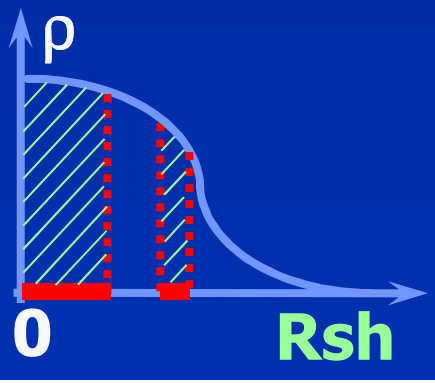
Controlled

I1
I2
.

Wn Vth | PFM | μ Cox

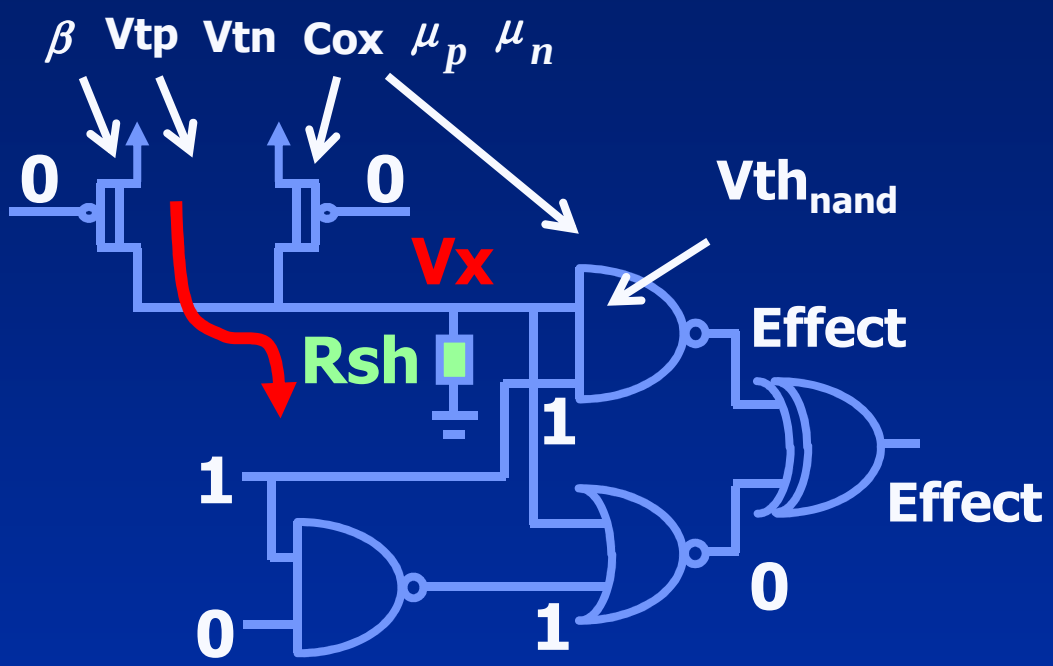
Rsh

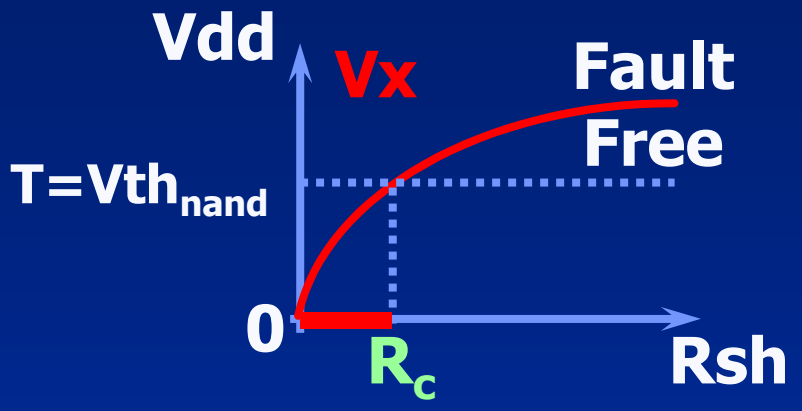
Induced | Imposed | Random



Size (P) => PDF
Threshold => DDomain

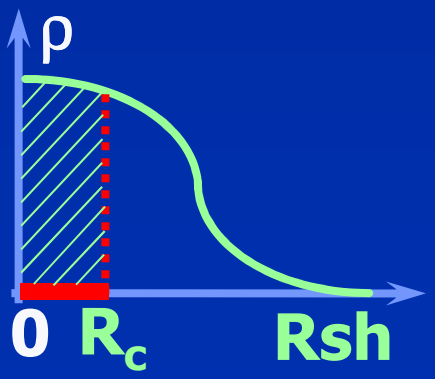
4. Defect with Statistical Chip





DDomain = [0 , Rc]

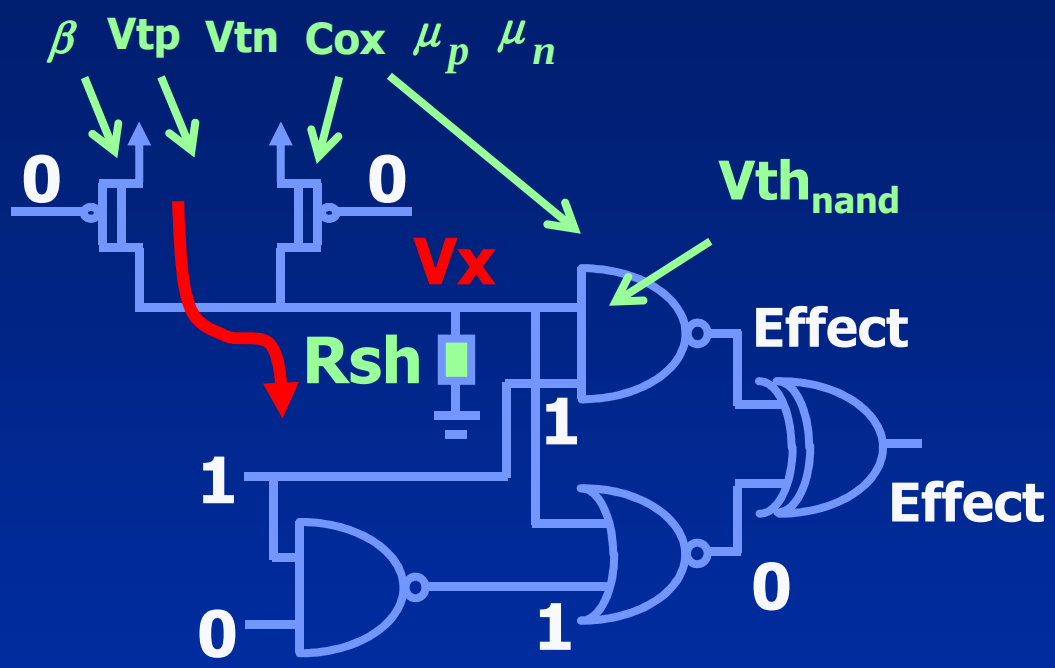
Size (P) => PDF
Threshold => DDomain

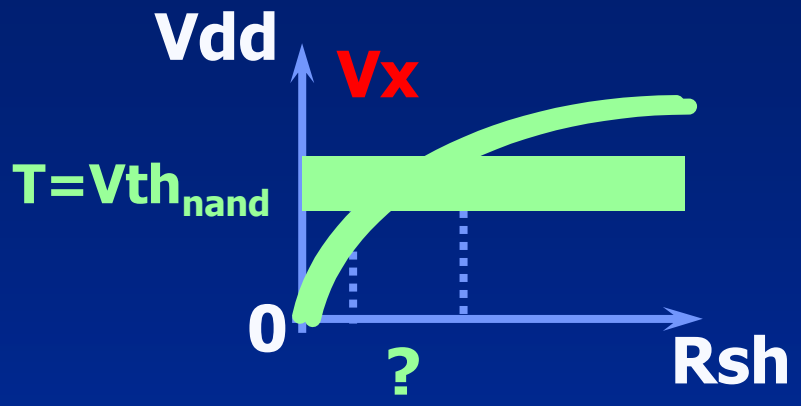


$$Vx = F(\ Rsh\ )$$

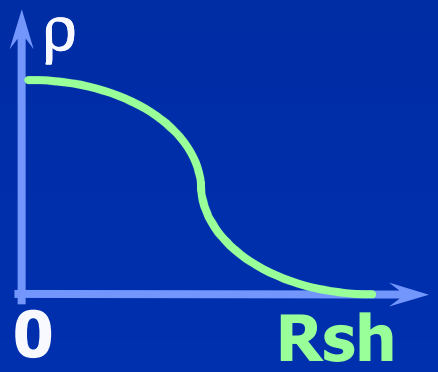
β Vtp Vtn Cox μ_p μ_n Vdd

4. Defect with Statistical Chip

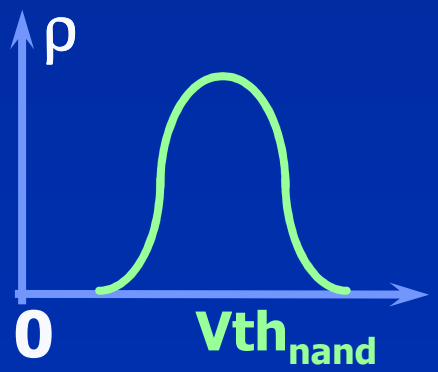




DDomain = [0 , ?]



Size (P) => PDF
Threshold => PDF

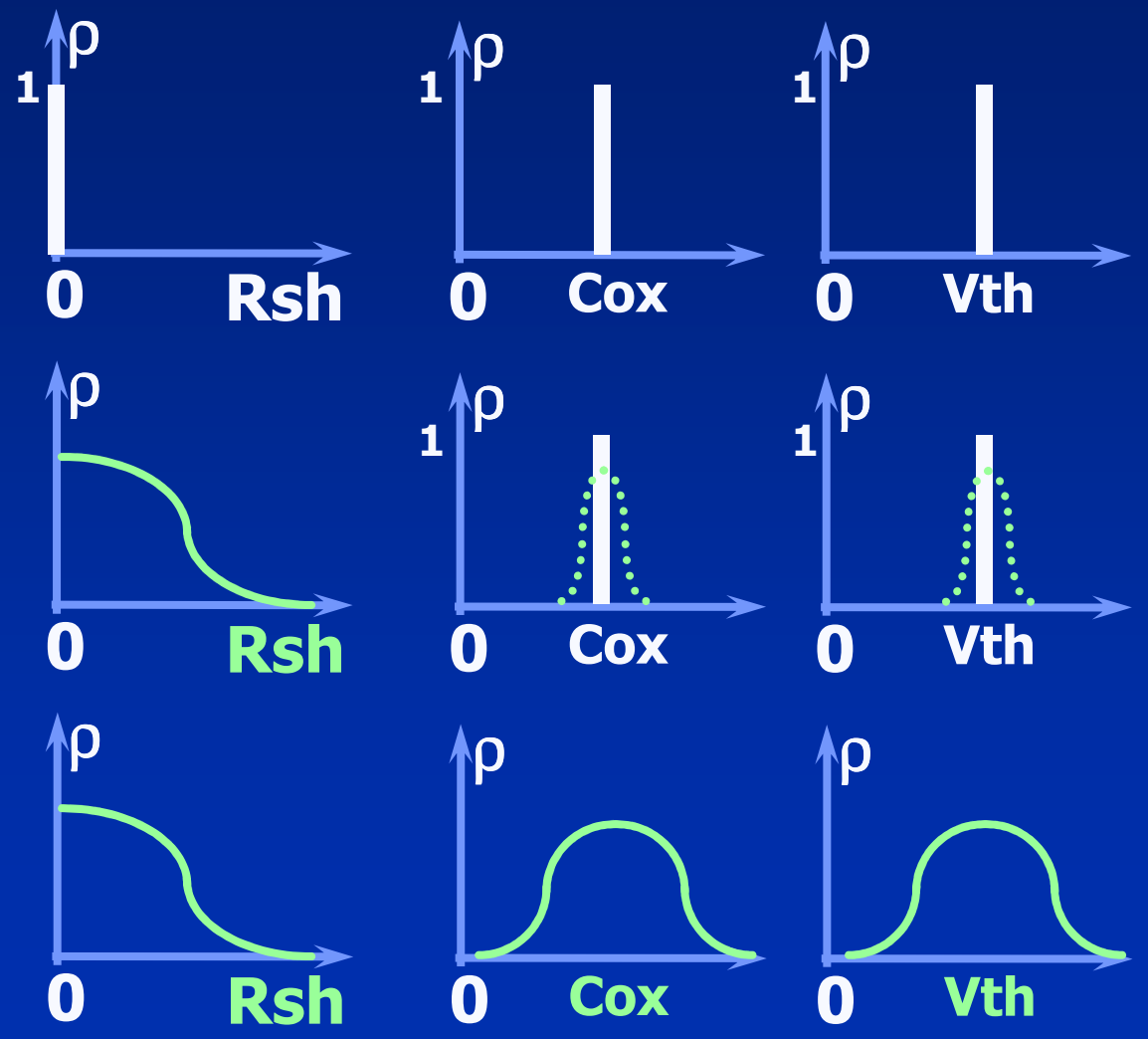


4. Defect with Statistical Chip

Realistic FM

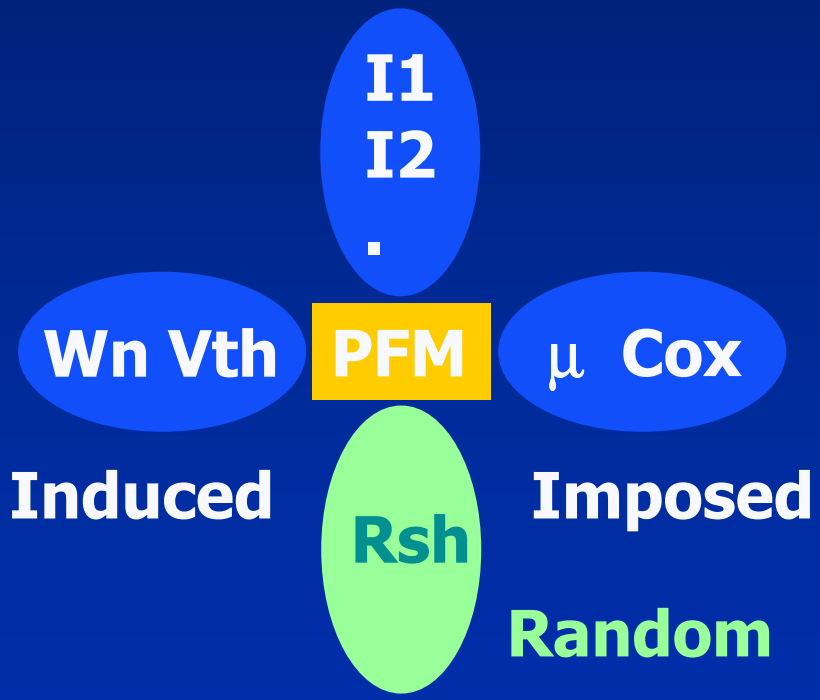
Probabilistic FM

Statistical Chip



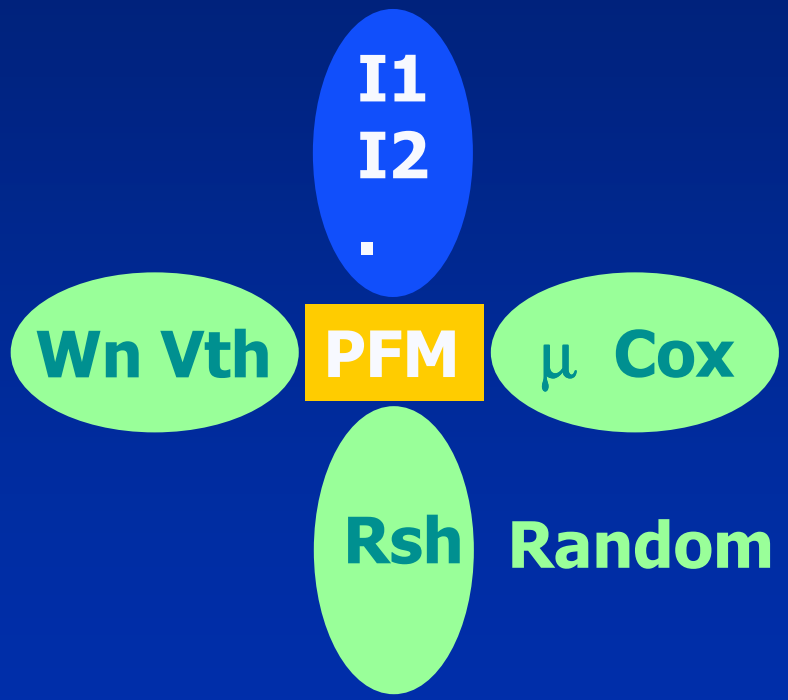
4. Defect with Statistical Chip

Probabilistic FM



Size (P) => PDF
Threshold => DDomain

Statistical Chip



P(Size > Threshold)
Size (P1,P2,…)
Threshold(P1,P2,…)

Conclusion

- Past
  - 1. Classical FM ➡ Chip Det /Fault Det
  - 2. Realistic FM ➡ Chip Det /Def Det
- Today
  - 3. Probabilistic FM ➡ Chip Det / Def Stat
- Future
  - 4. Statistical Chip ➡ Chip Stat / Def Stat