# Statistical Corner Conditions of Interconnect Delay (Corner LPE Specifications)

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# Outline

### Introduction <sup>\*</sup>

- Statistical Corner Conditions in Single Layer
- Statistical Corner Correction between Layers
- Effects
- Conclusions

### **Basic Concept of Statistical ideas**

Points on the Circle is necessary and sufficient.



# **Ordinary LPE Flow**

One library is used for RC extraction of every design.



### **Conventional Corner Conditions**

No statistical care, and over-margins are caused.



# Problem of Conventional Corners (1)

To set all Process Parameters to Corner is too pessimistic !



# What is difficult ? (1)

It is not clear,

- Where the delay corner points are.
- Number of corner points.



## Problem of Conventional Corners (2)

To set all Layers to Corner is too pessimistic !



# What is difficult ? (2)

Corner points can't be fixed in an ordinary method.





To solve these 2 problems by excluding the situations that are statistically unlikely to happen.

- To set all Process Parameters to Corner is too pessimistic
- To set all Layers to Corner is too pessimistic



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### Implementation to Library Generator

- Process variations are defined in input cross-section.
- Corner conditions are automatically calculated.
- Library with statistical corner coefficients is generated.



### **Process Parameters**

T, W : Treated Statistically
 D<sub>1</sub>, D<sub>2</sub>, ε : Treated Non-statistically



### How to find Corner Points

Calculation of R, C and τpd along the circle.



### Structures for R and C simulations

Typical patterns of signal lines in designs



# Variations of R and C

 θ maximizing or minimizing R and C are constant: 30° or 210°

- → x1-pitch, case1
- x2-pitch, case1
- → x1-pitch, case2
- x2-pitch, case2

🔺 x4-pitch, case2



### Circuit for $\tau pd$ simulations

- Delay/1-stage of Inverter chain
  - Interconnect patterns
    - Interconnect pitch : x1, x2, x4
    - upper and lower layers exist or not
  - Interconnect length : 10um ~ 2mm
  - Inverter size : x1 ~ x32



# Variations of $\tau pd$ (1)

#### Inverter size dependence

•  $\theta$  maximizing or minimizing  $\tau$ pd are constant: 30° or 210°



# Variations of $\tau pd$ (2)

#### Interconnect pattern dependence

•  $\theta$  maximizing or minimizing  $\tau$ pd are constant: 30° or 210°



# Variations of $\tau pd$ (3)

### Interconnect length dependence

•  $\theta$  maximizing or minimizing  $\tau$ pd are constant: 30° or 210°



### Found Corner points

θ in W-T plane maximizing or minimizing τpd are constant : 30 ° and 210°

→ In general,

Corner Points = 2 angles ( $\theta_1$  and  $\theta_2$  (= $\theta_1$ +180°))



# **Corner Conditions in Single Layer**

- $\theta$  in W-T plane : 2 angles ( $\theta_1$  and  $\theta_2$ )
- $D_1$ ,  $D_2$ ,  $\epsilon$ ,  $R_{via}$ : Full-swing to maximize or minimize  $\tau pd$

#### → 2 x 2 = 4 corner conditions



Corner	W	Т	D <sub>1</sub> , D <sub>2</sub>	3	$R_{via}$
Conditions					
RCmax	<b>3cos</b> (θ <sub>2</sub> ) σ	$3sin(\theta_2) \sigma$	<b>-3</b> σ	+3σ	+3σ
Cmax	$3\cos(\theta_1) \sigma$	$3sin(\theta_1) \sigma$	<b>-3</b> σ	+3σ	+3σ
RCmin	$3\cos(\theta_1) \sigma$	$3sin(\theta_1) \sigma$	+3σ	<b>-</b> 3σ	<b>-</b> 3σ
Cmin	<b>3cos</b> (θ <sub>2</sub> ) σ	$3sin(\theta_2) \sigma$	+3σ	<b>-</b> 3σ	<b>-3</b> σ

 $(0 < \theta_1 < \theta_2 (= \theta_1 + 180^\circ) < 360^\circ)$ 

## Schematic view of RC Library

- R and C at Center Condition
- Coefficients at Corner Conditions



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### Implementation to RC Extraction

 RC extractor automatically dose "Statistical Corner Correction".



### Concepts

Corner Correction for nodes composed of layers



### **Corner Correction**

Corner coefficients are corrected to be closer to 1.

Center	Corner Condition without	Corner Condition <b>with</b>		
	Statistical Correction	Statistical Correction		
R1	$\beta_{R} 1 \cdot \mathbf{R} 1$	β <sub>R</sub> 1' · R1		
C1	$\beta_{C}$ 1 · C1	<mark>β</mark> c <mark>1</mark> ' · C1		
R2	$\beta_{R} 2 \cdot \mathbf{R} 2$	β <sub>R</sub> 2' · R2		
C2	$\beta_{C}^{2} \cdot C^{2}$	β <sub>C</sub> 2' · C2		





# Calculations of $\gamma$

- Each layer's length is used for approximate calculation
  - Two assumptions are set ;
    - Capacitance for each unit length is constant.
    - Coefficient of the corner condition ( $\beta$ ) is constant.



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### Effect: Corner Conditions in Single Layer

About x0.7 Corner Width reduction (1 -> 1/2<sup>1/2</sup>)



# Effect: Corner Correction between Layers

About x0.7 Corner Width reduction





### **Total Effects**

- Corner Conditions in Single Layer
  -> Corner width reduction : x0.7
- Corner Correction between Layers
  - -> Corner width reduction : x0.7

# ... Total Corner width reduction : x0.5



- Reduction of power consumption
- Full advantage of process technology in its performance.

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### Conclusions

- Statistical Ideas are newly introduced to the corner conditions for interconnect RC extraction
  - Statistical corner conditions in a single layer
  - Statistical corner correction between layers
- Proposed method is ready for implementation to LPE tools
- Guard-band width from the fast corner to the slow corner decreases by half