A Statistical Model for Estimating the Effect of Process Variations on Crosstalk Noise

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Reconfigurable Platforms for
Mobile Interoperability – FIRB

Agenda

- ✓Introduction
- ✓Proposed Method
- ✓Experimental Results
- ✓Conclusions

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Introduction

- The interconnects analysis in modern deep sub-micron technologies can not be faced with traditional analysis methodologies.
- Statistical analysis seems to be a good solution to obtain early prediction about interconnects non-ideal phenomena (e.g. cross-talk, delay, …).

Introduction

- To obtain a good prediction:
  - a good electrical model is required, combining accuracy and computational efficiency.
  - parasitic parameters must be available from 2D/3D extraction.
  - switching activities and time windows are required for all aggressor lines.

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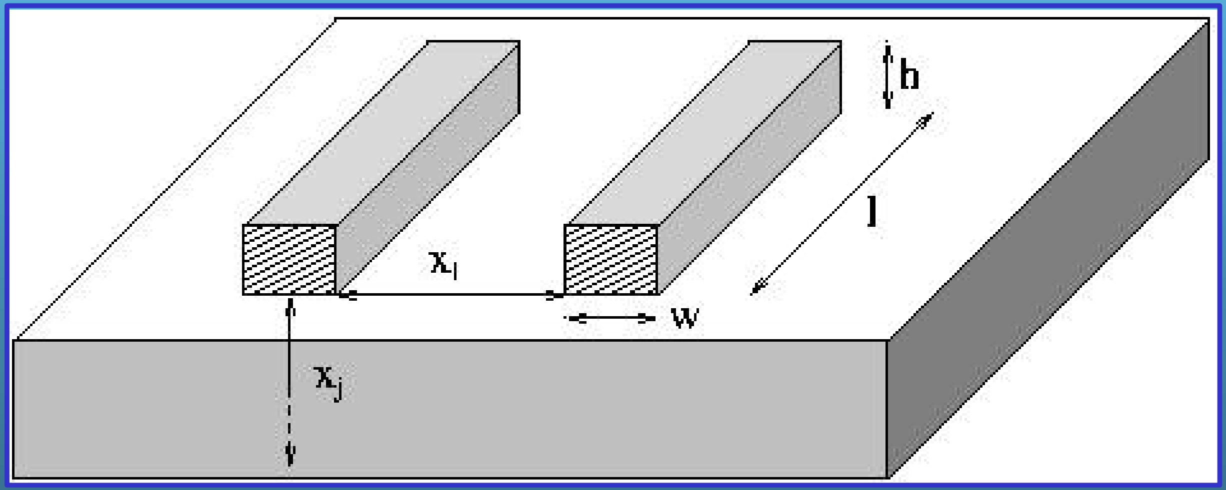
Case of study

- We concentrate on the case of coupled lines laying at the same metal level



- Current work is dealing with process variations and their impact on cross-talk noise.

Problem formulation - I

- Considering the cross-talk noise voltage as a function $V_x(t)=g(t,p_1, p_2, \ldots p_n)$ of n statistically independent parameters (p_i).
- Supposing each parameter exhibits a normal distribution $p_i \sim N(\mu_{pi}, \sigma_{pi})$ (e.g. $Cc \sim N(\mu_{Cc}, \sigma_{Cc})$).
- We can consider any time value t for this analysis, since we concentrate on synchronous systems we pose $t = t_s$.

Problem formulation - II

- Starting from the statistical distribution of interconnects electrical parameters (R, C, Cc), we would like to obtain a closed form approximation of the statistical distribution of the cross-talk voltage.
- Two approaches can been pursued:
  - Approximating the voltage curve with an exponential function.
  - Representing the voltage expression as a partial second order Taylor expansion.

Requirements

- This method needs:
  - To know the statistical distribution of interconnects electrical parameters.
  - The electrical parameters to be statistically independent.
  - A closed form expression of the cross-talk voltage on the victim line.

CAVEAT

- A first order Taylor expansion would lead to the sum of Gaussian variables.
- Mixed second order Taylor expansion term are not considered ($\partial^2 V/\partial p_i \partial p_j$) $\rightarrow$ it is not treatable as a closed form.
- Electrical parameters independence: actually it not true, however it is a simple case and a starting point to validate the methodology.

Proposed Method

- Let's introduce a new set of random variables $x_i=p_i-E[p_i]$
- Associating a random variable $h=V_x(t_s)$ to the cross-talk voltage and taking a partial second order Taylor exapansion we obtain:

$$h \approx h_0+\sum_{i=1}^{i=n} a_i x_i+\sum_{i=1}^{i=n} b_i x_i^2$$

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Experimental results - I

Tech: 0.18 µm

R_{driver}= 470 Ω

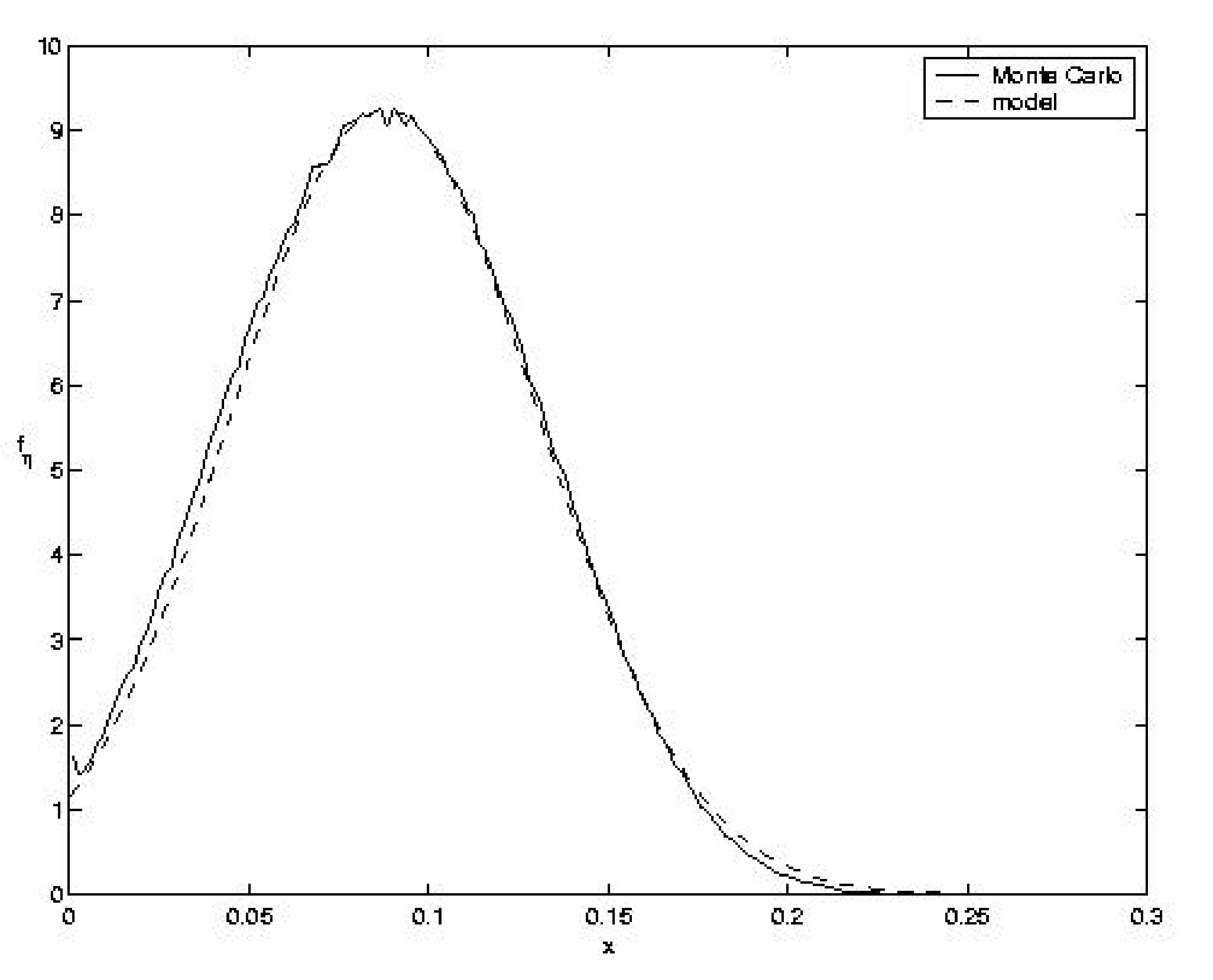
Line = 3 mm

Rising time = 10 ps

Sampling period = 1 ns

C_c variation = 30%

C_a, C_v variation = 20%



Experimental results - II

Tech: 0.18 μm

R_{driver} = 470 Ω

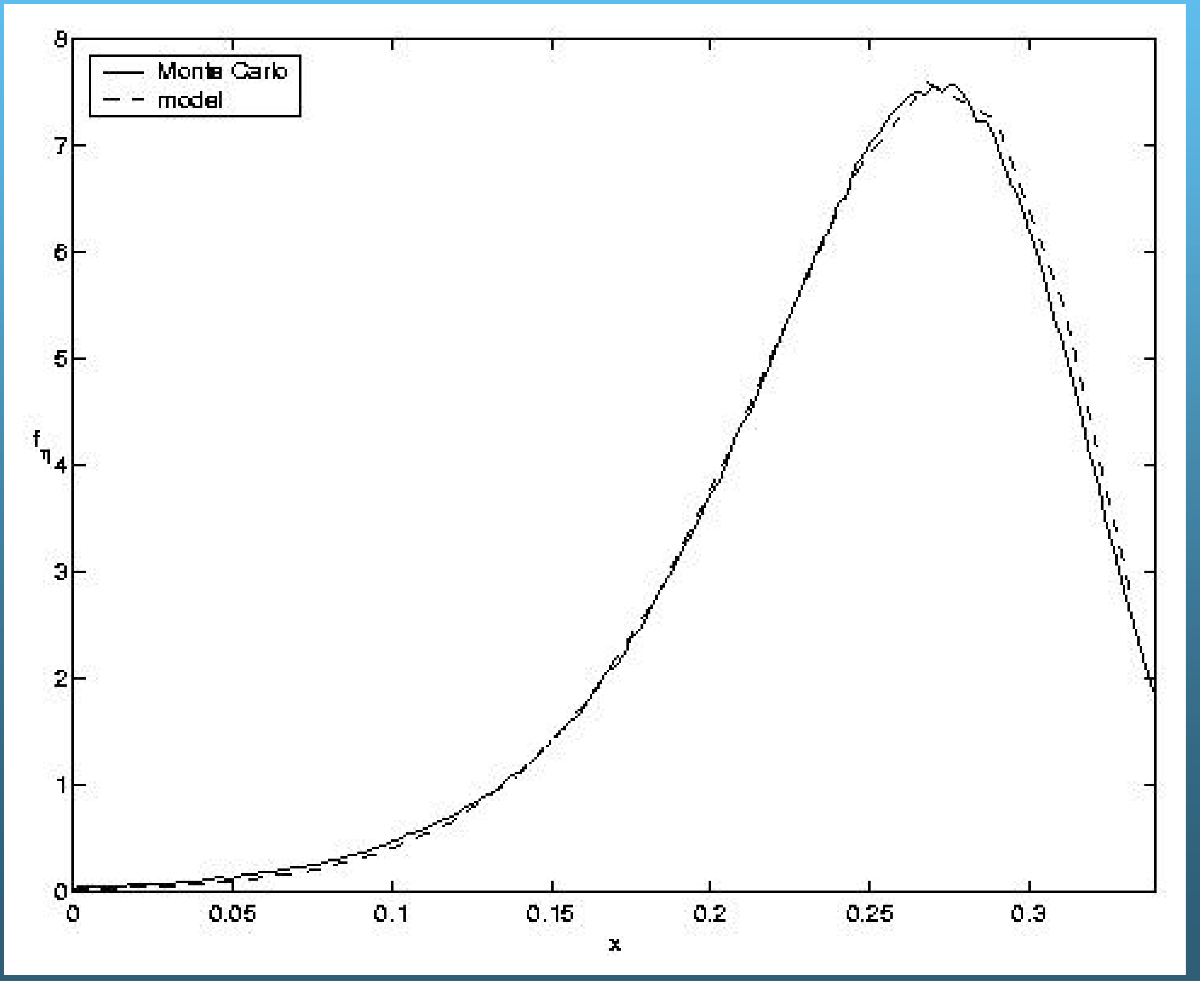
Line = 5 mm

Rising time = 10 ps

Sampling period = 1 ns

C_c variation = 30%

C_a, C_v variation = 20%



Experimental results - III

Tech: 0.18 µm

R_{driver} = 470 Ω

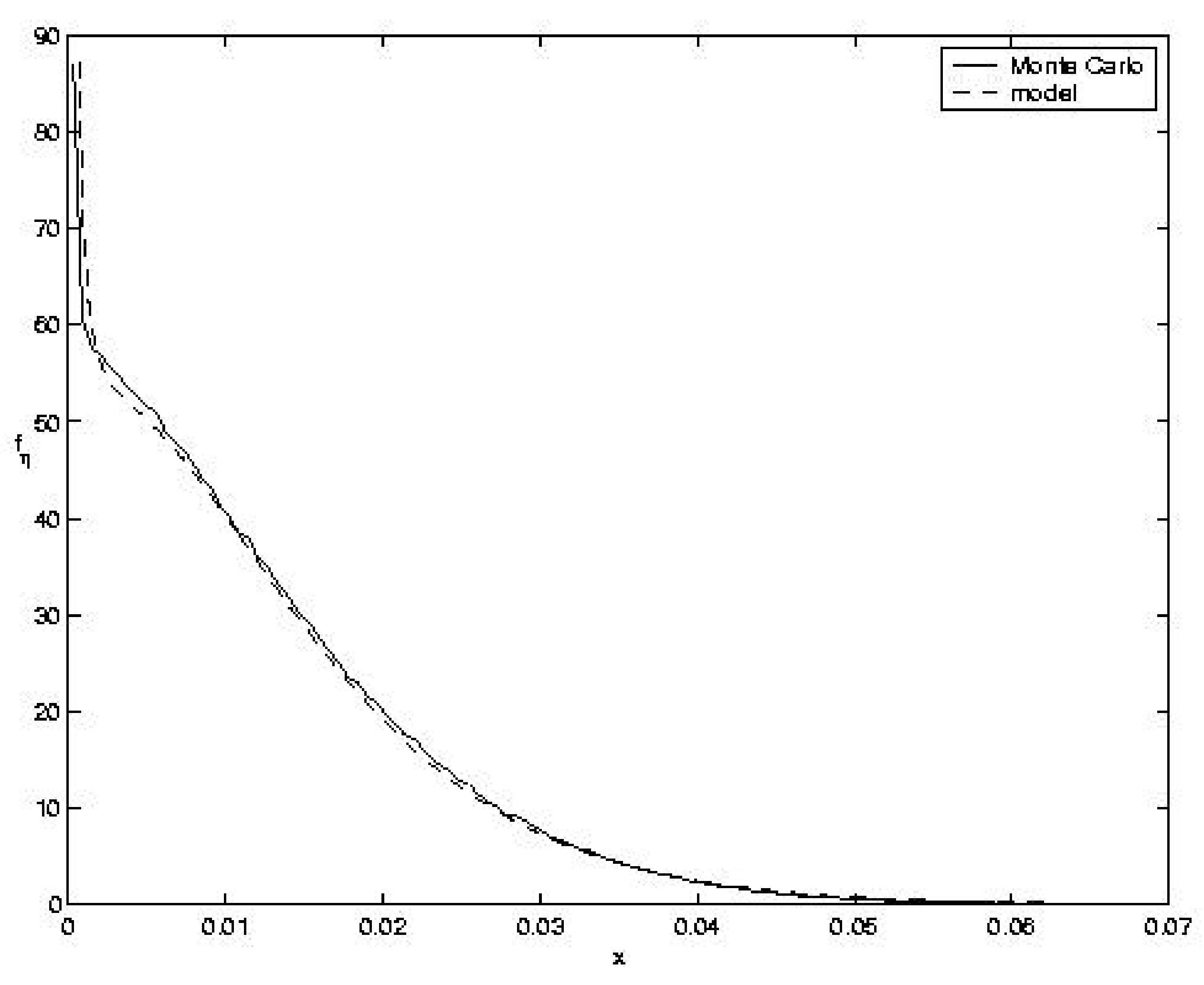
Line = 5 mm

Rising time = 10 ps

Sampling period = 5 ns

C_c variation = 30%

C_a, C_v variation = 20%



Experimental results - III

Tech: 0.13 μm

R_{driver} = 470 Ω

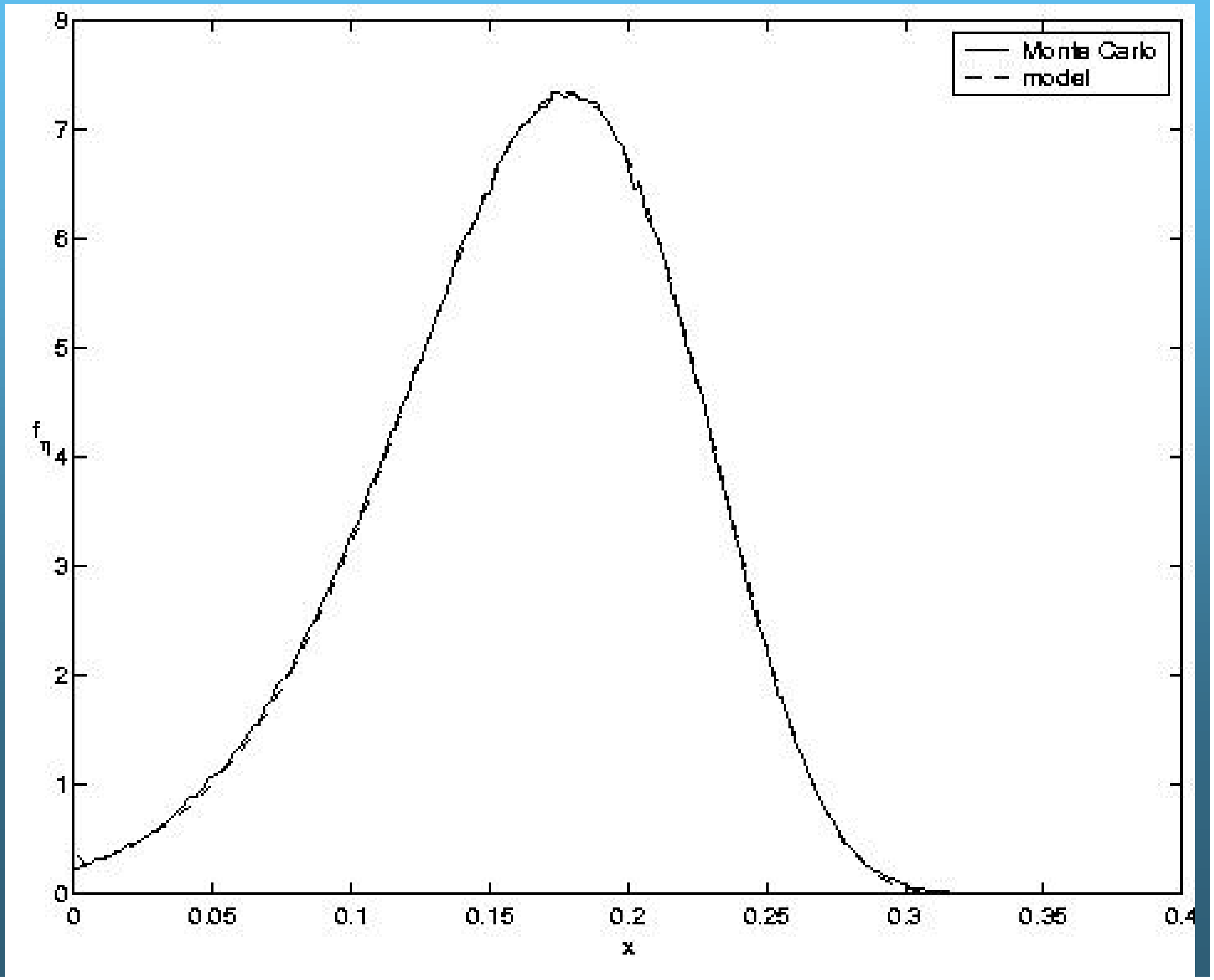
Line = 3 mm

Rising time = 10 ps

Sampling period = 1 ns

C_c variation = 30%

C_a, C_v variation = 20%



Experimental results - IV

Tech: 0.13 μm

R_{driver}= 470 Ω

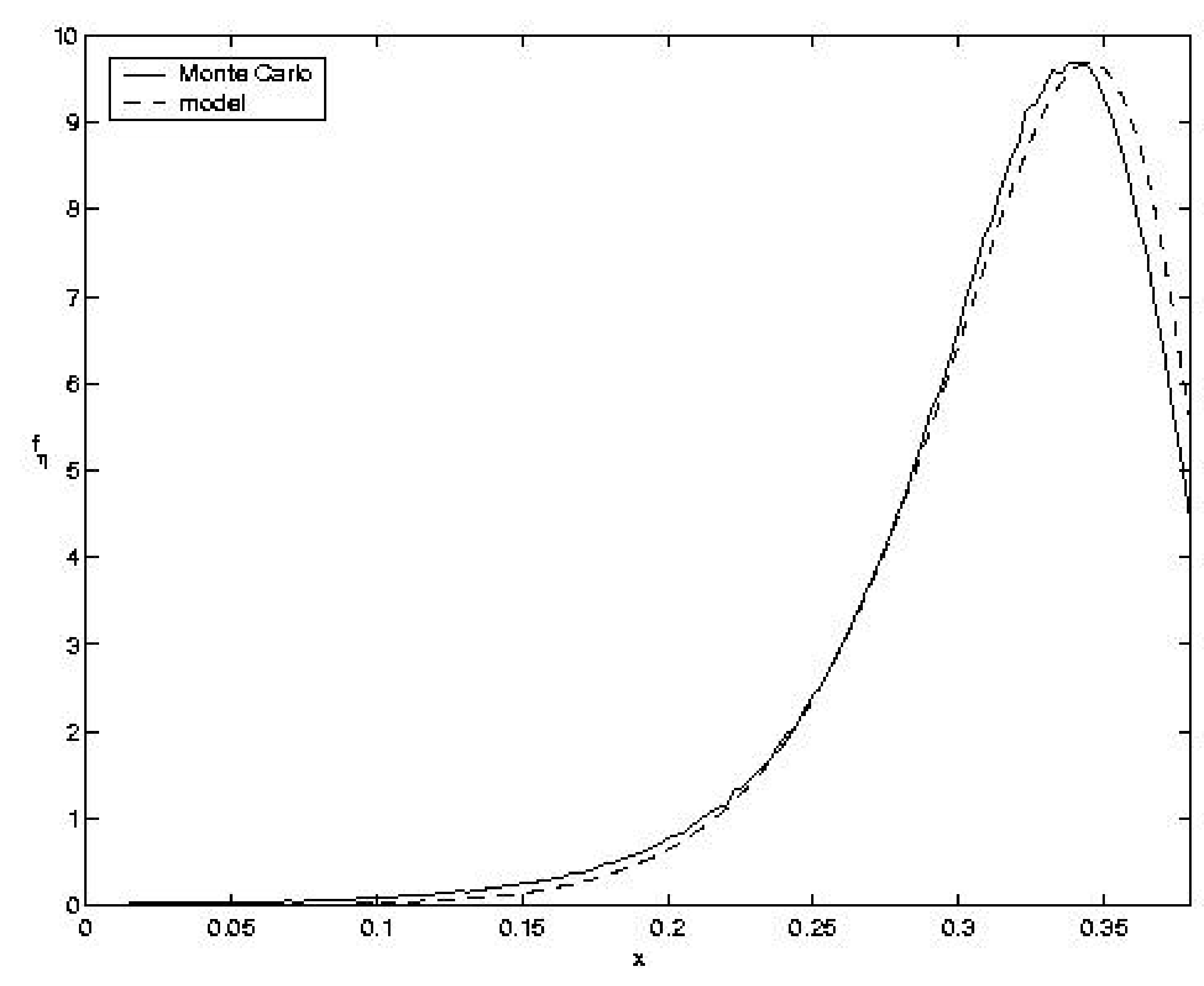
Line = 5 mm

Rising time = 10 ps

Sampling period = 1 ns

C_c variation = 30%

C_a, C_v variation = 20%



Experimental results - V

Tech: 0.13 μm

R_{driver} = 470 Ω

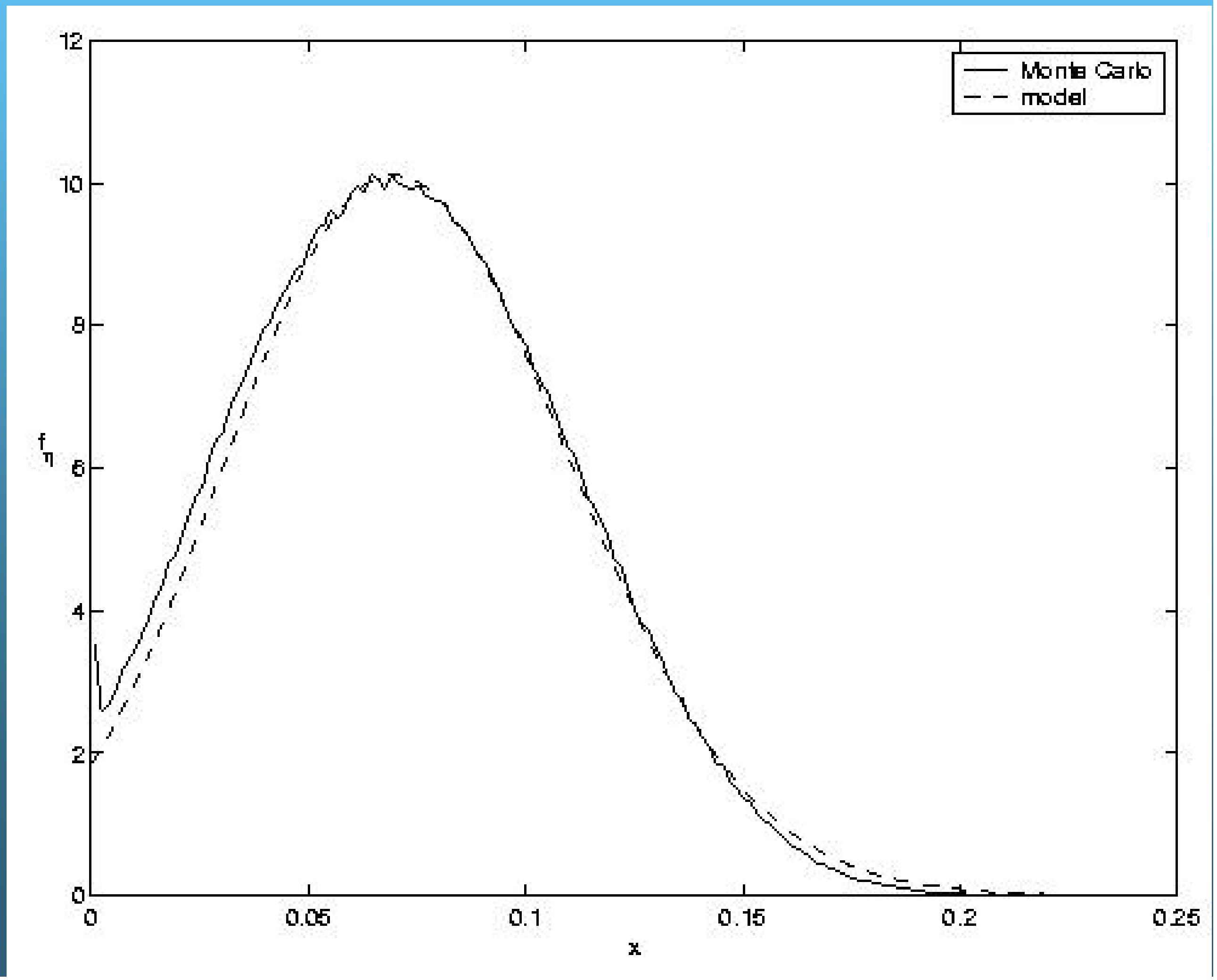
Line = 5 mm

Rising time = 10 ps

Sampling period = 5 ns

C_c variation = 30%

C_a, C_v variation = 20%



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Conclusions - I

- A statistical model for the evaluation of the cross-talk depending on process variations has been proposed
- Even if some assumptions are rather rough, preliminary results are interesting

Conclusions - II

- The following actions are planned
  - Taking into account parameters correlation
  - Trying the proposed model on more complex structures
  - Developing models based on pure numerical-simulative approach
  - Concentrate on the cross-talk delay phenomenon

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Proposed Method - II

- For 2 lines we obtain:

$$h \approx h_0 + a_1 x_1 + a_2 x_2 + b_1 x_1^2 + b_2 x_2^2$$

- Since $h = V_x(t_s)$, the cross-talk voltage statistical distribution can be evaluated from:

$$F_h(z) = P(h \le z)$$

$$= P(h_0 + a_1 x_1 + a_2 x_2 + b_1 x_1^2 + b_2 x_2^2 \le z)$$

Proposed Method - III

- We can introduce

$$z_i = a_i\, x_i + b_i\, x_i^{2}$$

- η statistical distribution can be obtained from ζ_i distribution:

$$P(h \pounds z) = P(h_0 + z_1 + z_2 \pounds z)$$

Proposed Method - IV

- So
  - If b > 0

$$P(z \text{ £ } z) = P(ax+bx^2 \text{ £ } z) = P(z_1 \text{ £ } x \text{ £ } z_2)$$

  - If b < 0

$$P(z \text{ £ } z) = P(ax+bx^2 \text{ £ } z) = P(x \text{ £ } z_2)+P(x \text{ ³ } z_1)$$

- Where z_1 and z_2 are the roots of

$$bx^2+ax-z = 0$$

Proposed Method - V

- Since p_i where assumed to be gaussian and independent $x_i=p_i-E[p_i]$ are gaussian and independent with $\mu_i = 0$
  - If b > 0

$$F_z(z) = P(z \leq z) = F_x(z_2) - F_x(z_1)$$

  - If b < 0

$$F_z(z) = P(z \leq z) = F_x(z_2) + 1 - F_x(z_1)$$

Proposed Method - VI

- To obtain the probability density function (pdf) of η we can calculate ζ pdf.

$$f_z(z) = dF_z(z)/dz$$

$$f_z(z) = 1/D[f_x(z_2) - f_x(z_1)]$$

- Where $\Delta = \sqrt{(a^2+4bz)}$

Proposed Method - VII

- Thus if $\theta = \zeta_1+\zeta_2$

$$f_q(z) = f_{z_1}(z) * f_{z_2}(z)$$

- So since $\eta=\eta_0+\theta$

$$f_h(y)=f_q(z-h_0)$$