Early Stage Package Resonance Estimation Techniques

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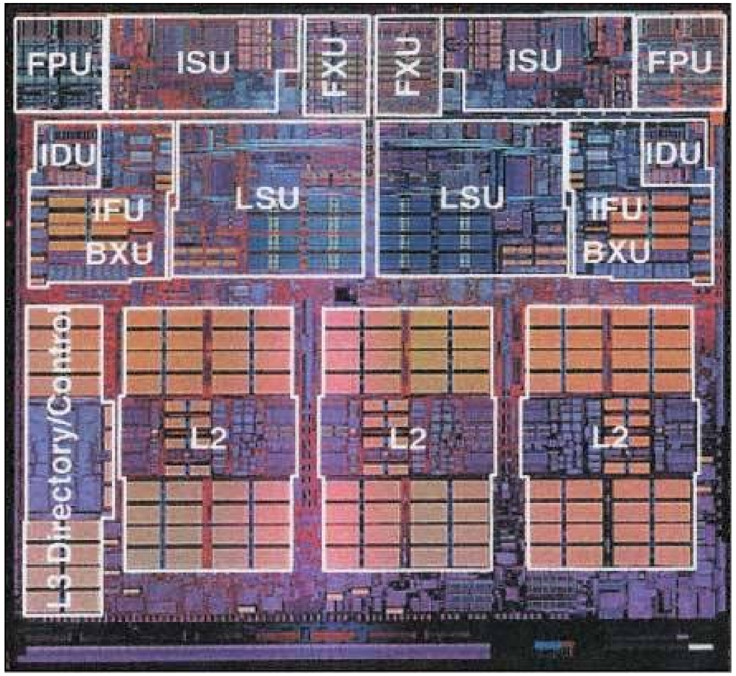
Outline

- Modern Power Distribution Design
- C4 Structures and Locality Property
- Resonance Problem
- Estimation Technique
- Experimental Results
- Conclusion

Modern Power Distribution Design

- Goals
  - DC drop < 30 mv under power density $1W/mm^2$
  - Dynamic fluctuation < 10% of normal Vdd
  - Common-mode noise < 200 mv under the worst case

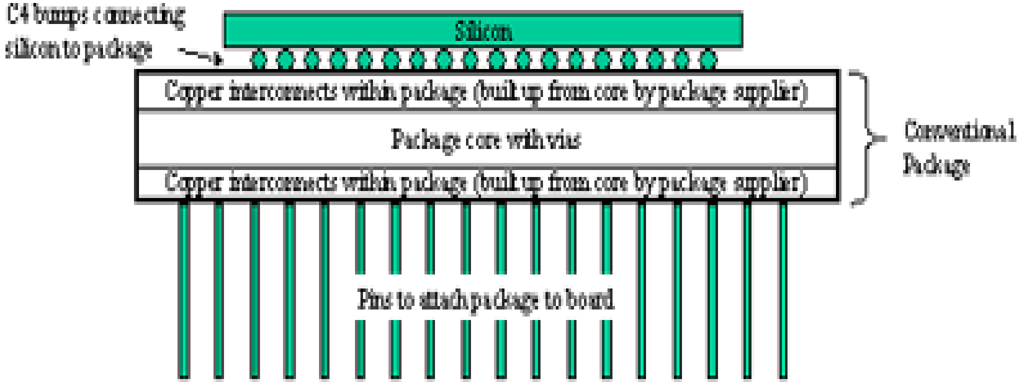


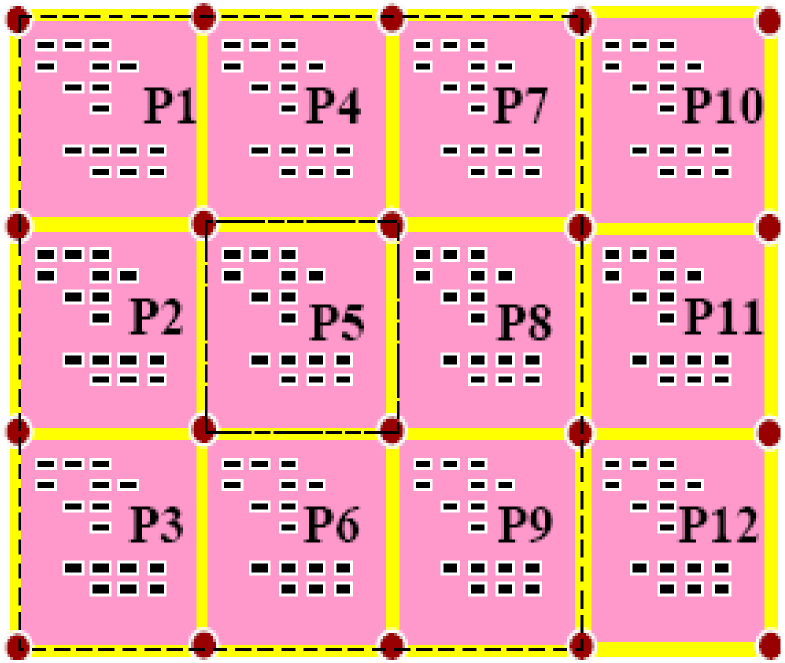
Modern Power Distribution Design

- New Dynamic Problems
  - Logical correlations can cause package resonance with decaps
  - Traditional design flow is lack of ability to detect such kinds of situations
  - Later stage adjustment is prohibitively expensive
  - Estimation in very early stage is needed

C4 Structures and Locality Property

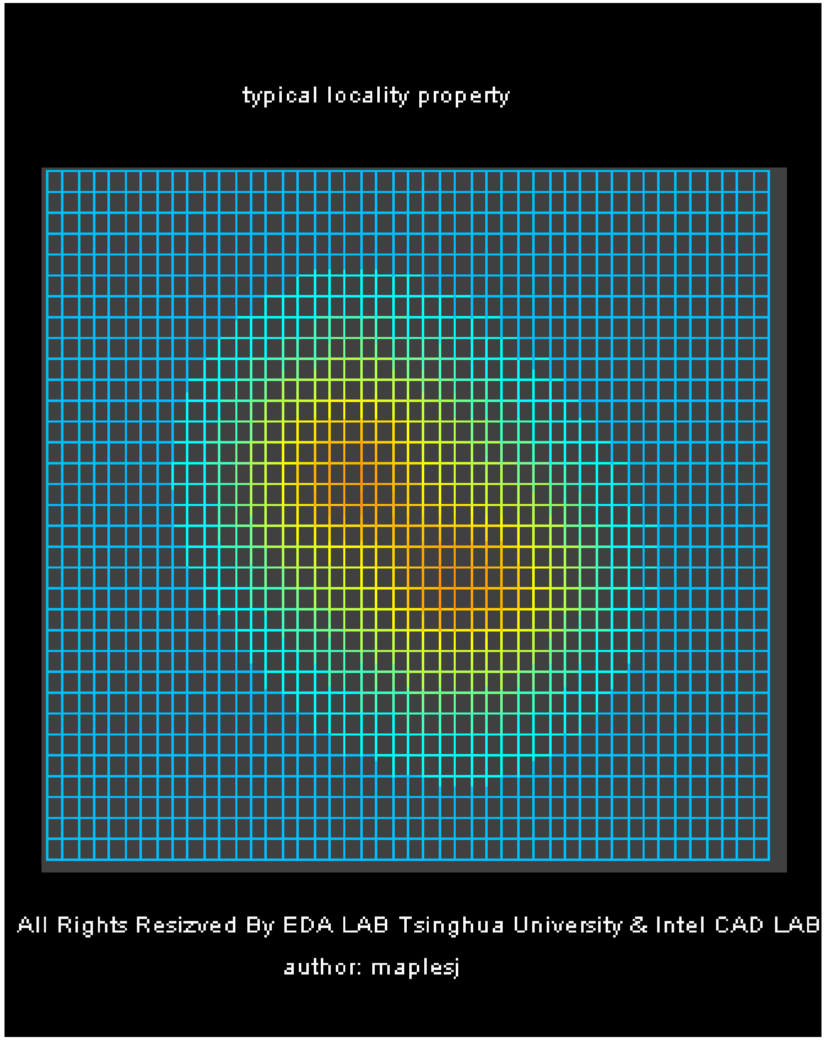
- C4 Bumps and Shells
  - Bump Array Divide Die Area into Natural Shells





C4 Structures and Locality Property

- Locality Property
  - Local current sources only affect voltage fluctuation in local area
  - Via Density controls the current flow direction

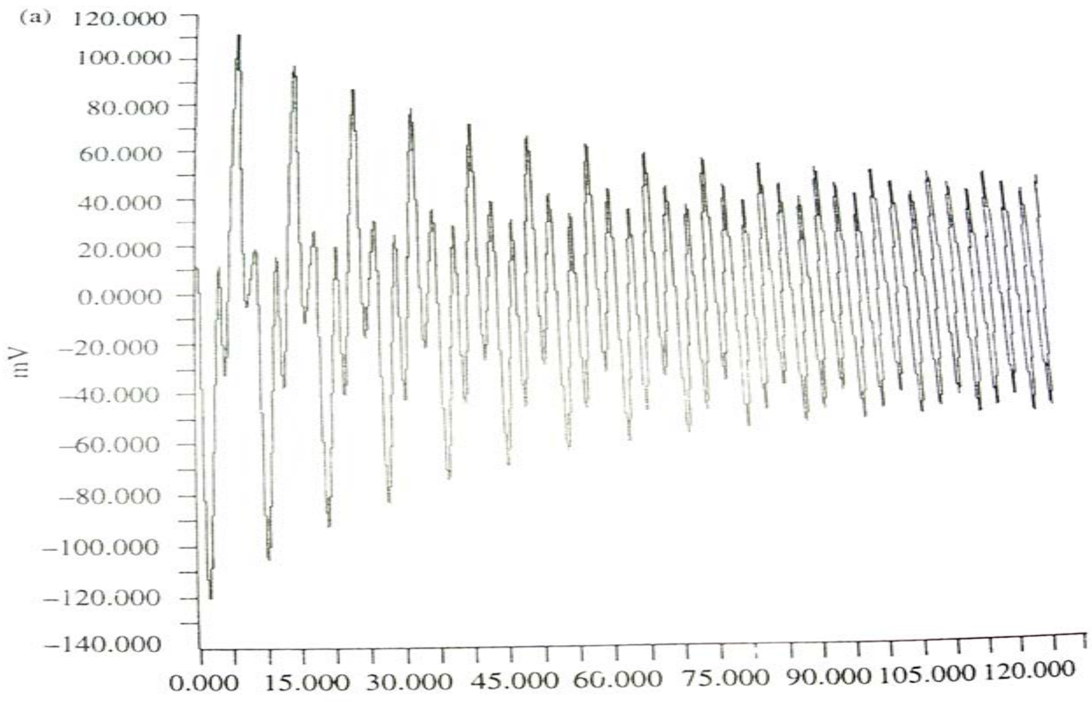


Resonance Problem

- Traditional Resonance Problem
  - Package Inductance & Decaps
  - Power Switching Events
  - Ringing for Several Cycles
  - Resonance Frequency < Clock Frequency

Resonance Problem

- A Power Grid Ringing Case

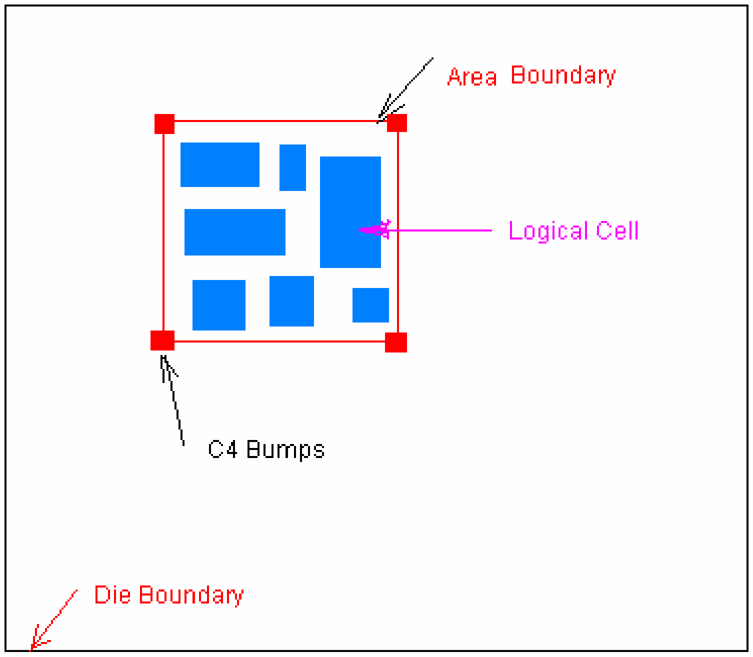


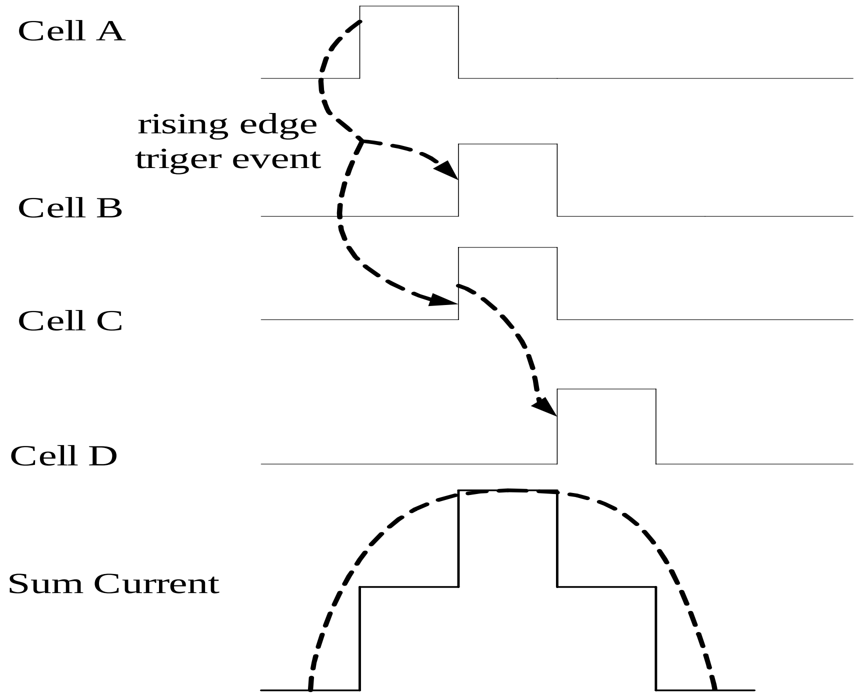
Resonance Problem

- C4 Structure is more easy to Resonance
  - Current Converges from Micros to Pads
  - Logic Correlations in Local Area can provide low frequency harmonics
  - Dynamic Logic should be verified
  - Hard Logic in Pipeline , SMT / HT and Clock Gating Events should be examined in the Early Stage

Resonance Problem

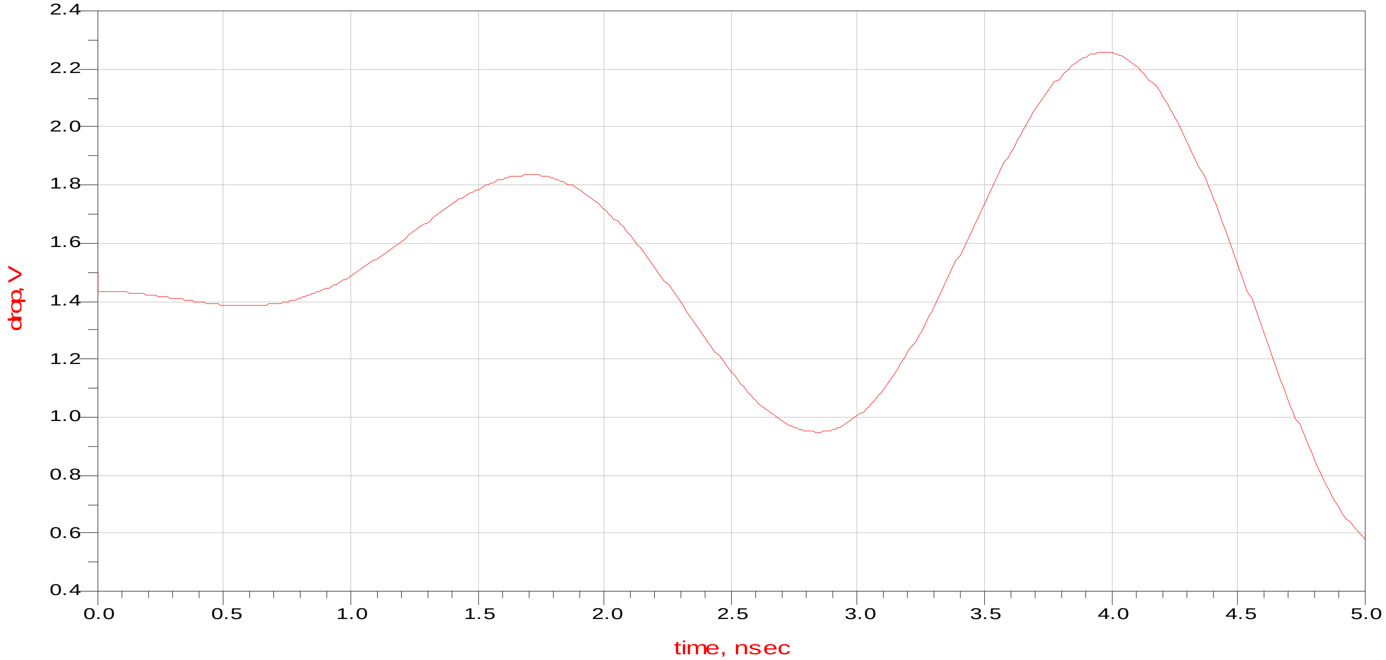
- A Resonance Case Study
  - Sum current contains low frequency harmonics





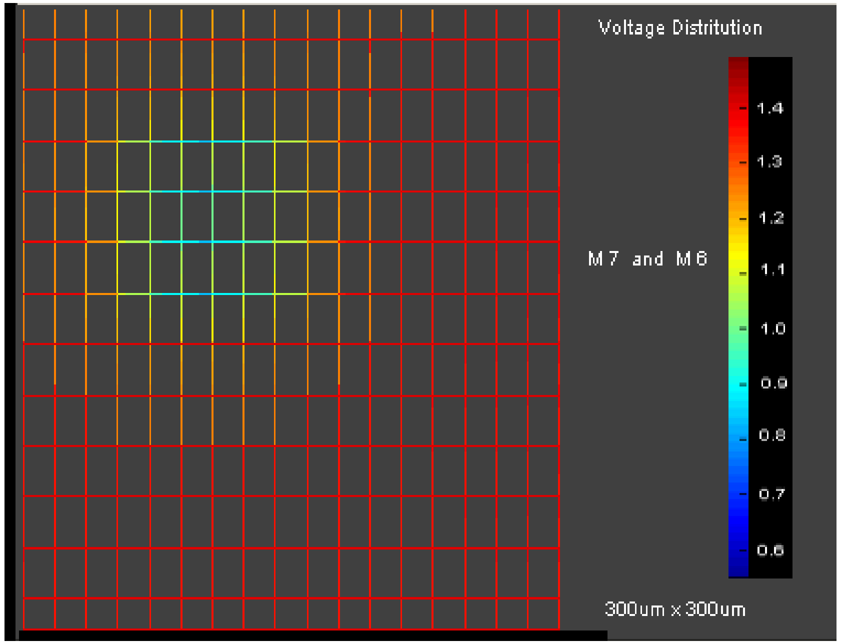
Resonance Problem

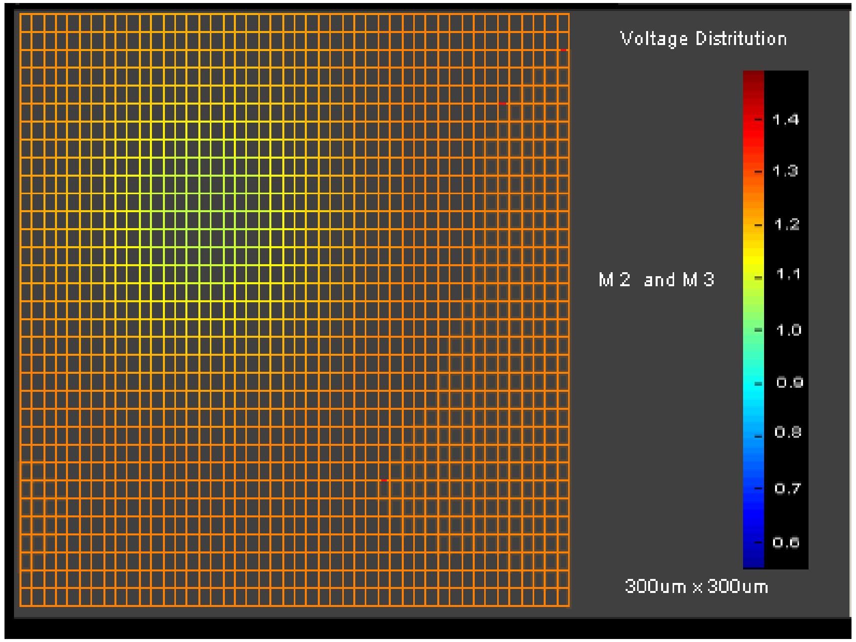
- A Resonance Case Study
  - Oscillation fades off in a heavy damped system
  - Oscillation can be amplified by continuing trigger events



Resonance Problem

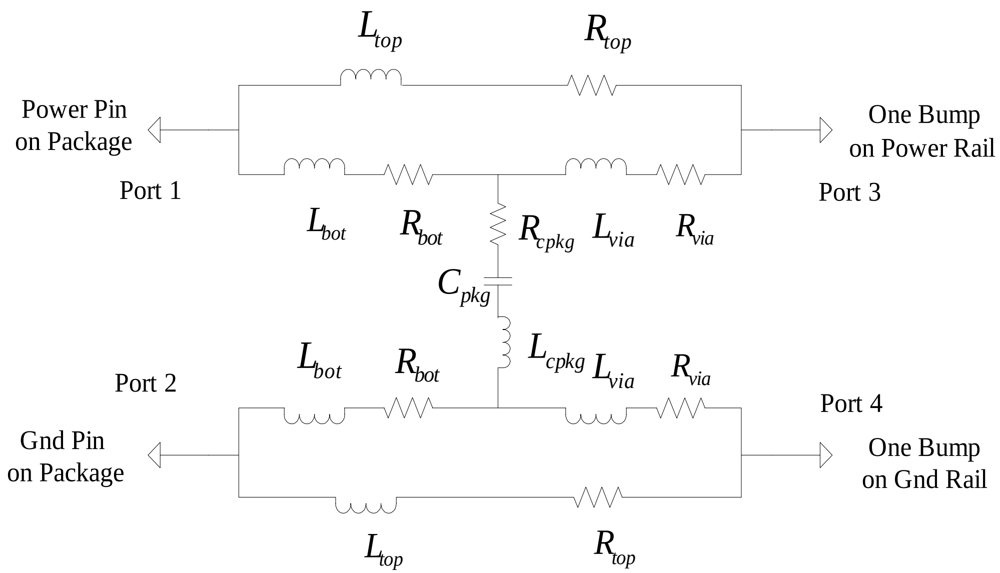
- A Resonance Case Study
  - Resonance can affect local/global area
  - Local resonance cause larger fluctuations in M7and smaller in M1

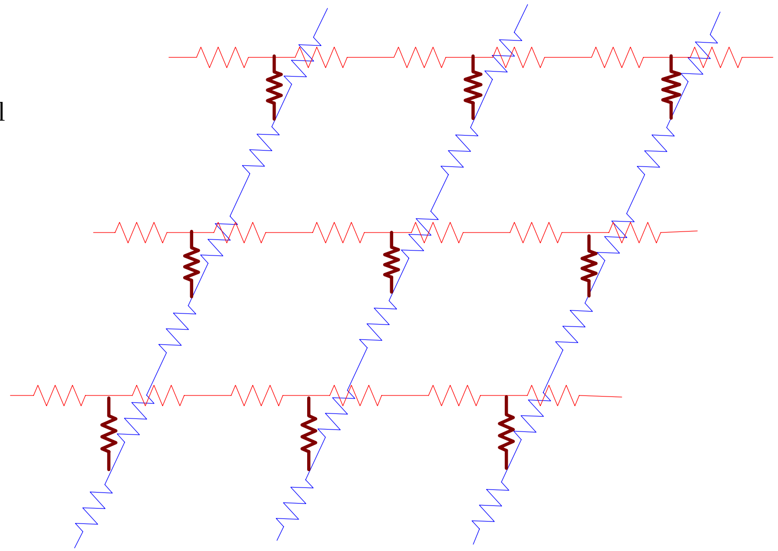




Estimation Technique

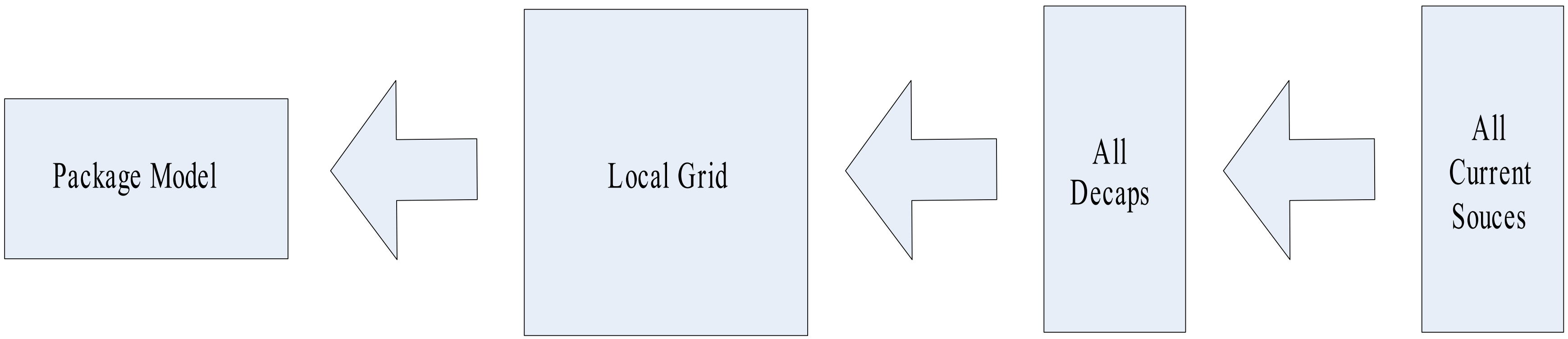
- Used Model
  - Package Model
  - Grid Model





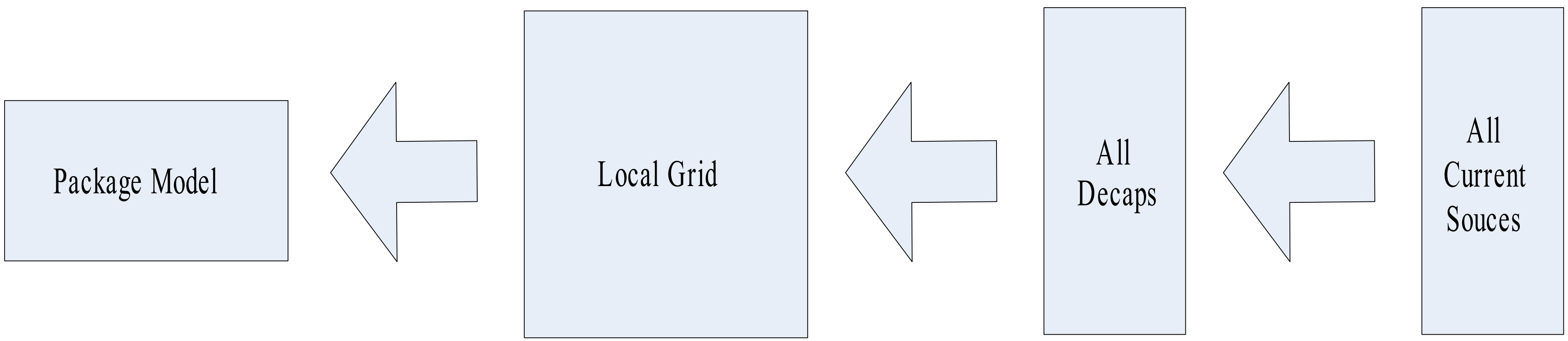
Estimation Technique

- Basic Idea
  - Compute the frequency response of package
  - Translate time-domain current sources into frequency-domain
  - Treat Decaps as Filters



Estimation Technique

- Basic Idea
  - Collect harmonics though local grid
  - Use these harmonics and frequency response of package to estimate voltage drop



Estimation Technique

- Estimation Algorithm
  - Use Regular Expression to describe the timing correlation of cells
  - Trace all trigger chains to get an on-off Matrix
  - Translate on-off Matrix into Time Domain form
  - Perform FFT on the time domain matrix to get spectrum matrix Z

Estimation Technique

- Estimation Algorithm
  - Filter row of matrix Z by a decap character vector
  - Sum all rows in Z matrix
  - Look up the package frequency response table to find the maximum drop

Estimation Technique

- Example
  - Four Micros A, B, C, D
  - Trigger Chain
    - A -> B 1 cycle later
    - A -> C 1 cycle later
    - C -> D 1cycle later
  - Use Regular Expression to Do Merge and Search
    - B A+1
    - C A+1
    - D C+1

Estimation Technique

- Example
  - On-off Matrix

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

  - Sample Matrix in Time domain

$$\begin{bmatrix} 0.5 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.2 & 0.2 & 0.2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.4 & 0.4 & 0.4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.7 & 0.7 & 0.7 \end{bmatrix}$$

Estimation Technique

- Example
  - Spectrum Matrix Z

$$
\begin{matrix} & f_1 & f_2 & f_3 & f_4 & f_5 & f_6 & f_7 & f_8 & f_9 \end{matrix}
$$

$$
Z = A + B \cdot i = \begin{bmatrix} z_{11} & z_{12} & z_{13} & z_{14} & z_{15} & z_{16} & z_{17} & z_{18} & z_{19} \\ z_{21} & z_{22} & z_{23} & z_{24} & z_{25} & z_{26} & z_{27} & z_{28} & z_{29} \\ z_{31} & z_{32} & z_{33} & z_{34} & z_{35} & z_{36} & z_{37} & z_{38} & z_{39} \\ z_{41} & z_{42} & z_{43} & z_{44} & z_{45} & z_{46} & z_{47} & z_{48} & z_{49} \end{bmatrix}
$$

  - Times Decap Filter Vector

$$
Z = Z(r \cdot) F
$$

$$
F = \frac{1}{2\pi jC} \begin{bmatrix} f_1 & f_2 & f_3 & f_4 & f_5 & f_6 & f_7 & f_8 & f_9 \end{bmatrix}
$$

Estimation Technique

- Example
  - Sum all row vector in Z matrix

$$z = \sum Z$$

$$z(1,i) = \sum_{1}^{n} Z(i,j)$$

  - Get the maximal drop according to package frequency response

Experimental Results

- Typical Non-Resonance Case

Cell Num	Area size um x um	Area Decap pF/um^2	Time Window	Total Power	Worst Droop on Package				Relative Error of Estimation
					Hspice	Run Time	FFT estimator	Run Time	
resonance is less likely to happen, contains harmonics away from resonance frequency									
20	100x100	400	30 ns	10W	8 mv	11 s	5 mv	<2 s	54%
45	300x300	400	30 ns	20W	13 mv	26 min	7 mv	<2 s	46%

Experimental Results

- Typical Resonance Case

Cell Num	Area size um x um	Area Decap pF/um^2	Time Window	Total Power	Worst Droop on Package				Relative Error of Estimation
					Hspice	Run Time	FFT estimator	Run Time	
resonance is likely to happen, contains harmonics near resonance frequency									
20	100x100	100	30 ns	10W	0.43 v	11 s	0.38 v	<2 s	11.6%
45	300x300	100	30 ns	20W	0.46 v	26 min	0.49 v	<2 s	6.5%

Conclusions

- A new method is proposed to perform resonance estimation in early design stage
- Although it is less accurate when the resonance is less probable to happen, it gives relative accurate result to reveal whether a certain logic correlation can cause resonance problem

Thank you!

Q & A