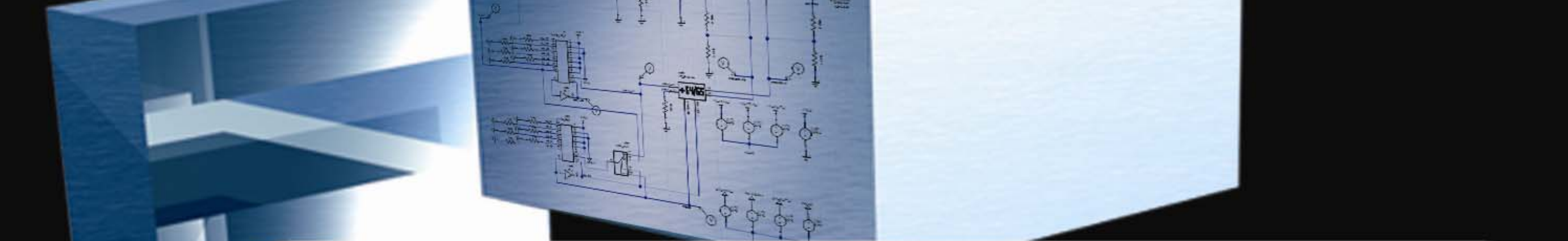
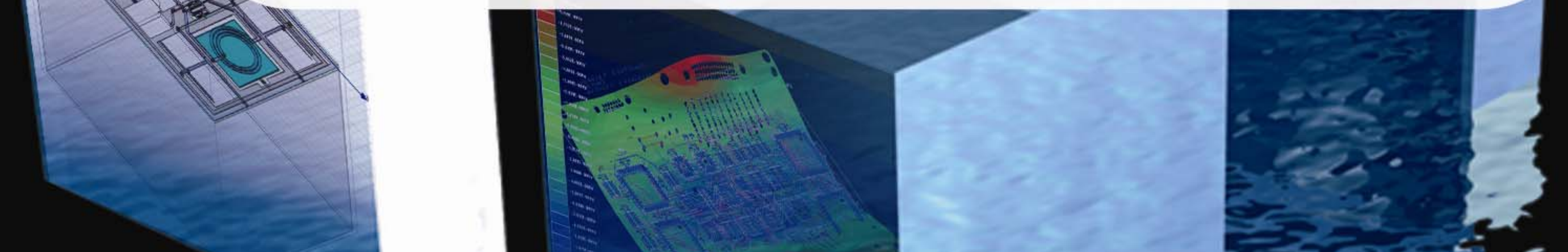


Recent Advancements in Circuit Simulation Technology

By

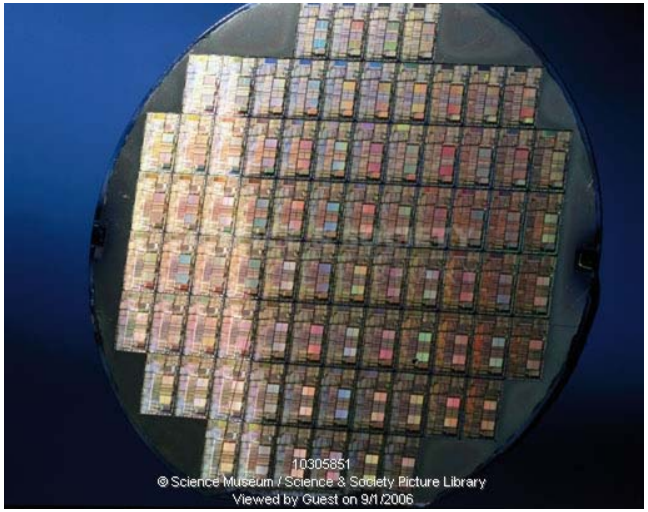
Deepak Ramaswamy
Michael Tsuk
Mary Tolikas
Mark Reichelt

ANSOFT



Circuit simulation that supports emerging electronic design trends

Trend: Nanometer-device geometries



Large simulation ***capacity*** to handle:

- Substrate coupling effects
- High level of integration

Circuit simulation that supports emerging electronic design trends

Trend: Bridging the gap between system to component design

Simulation ***flexibility*** to handle:

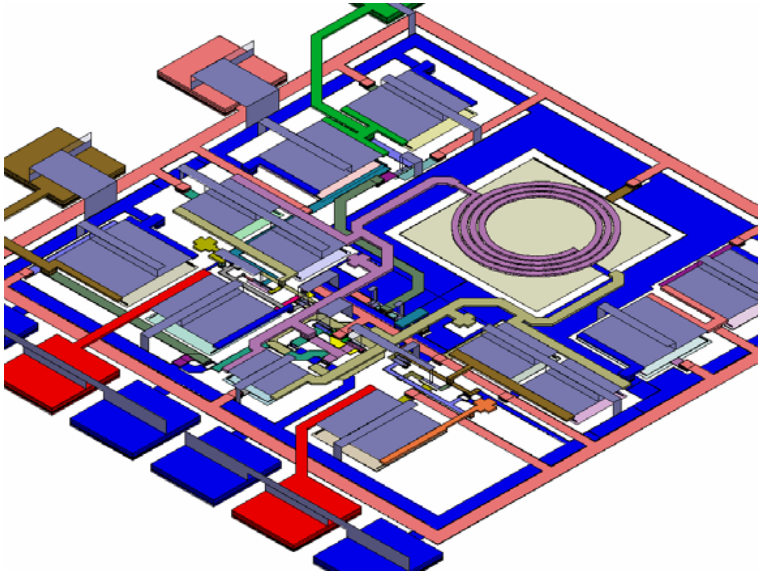
- Models from different vendors and description languages (Verilog, Spice, IBIS, TSTONE,…)
- Varying levels of model abstraction (physical, *circuit to behavioral)*

Circuit simulation that supports emerging electronic design trends

Trend: Identify and locate sources of unwanted coupling

Simulation ***link to EM*** to handle:

- Insight provided by EM simulators on the physical structures



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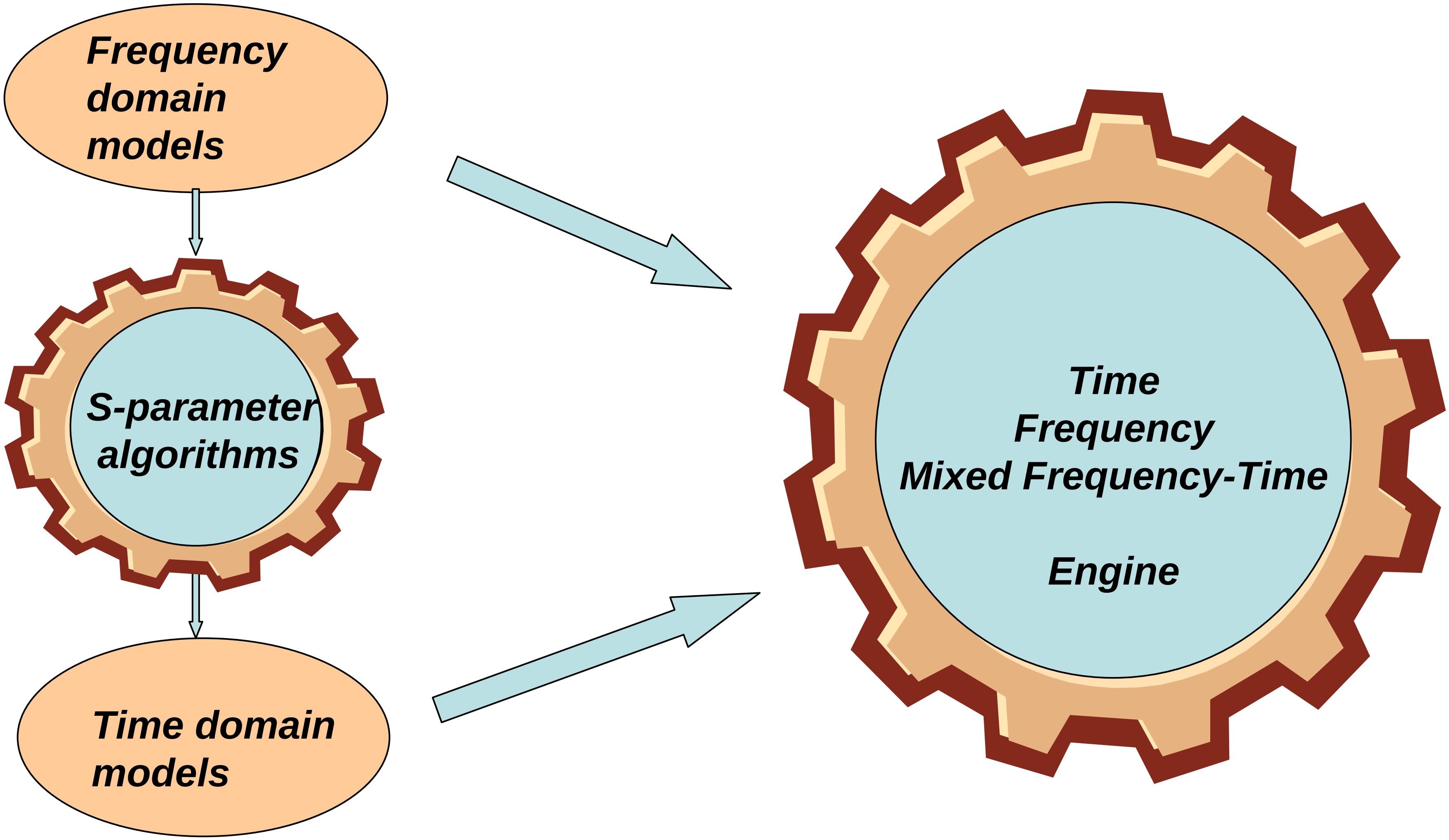
LeadingInsight
Application Workshops for High-Performance Design

What does this mean for circuit simulation?



Simple linear system at the core

Formulating equations from schematics

Matrix of conservation laws & constitutive equations

Sources

$$Ax = b$$

Vector of unknown node voltages & branch currents

Simple linear system at the core

$$Ax = b$$

Even larger circuits

Ever more couplings
& nonlinearities

→

A (and x) increase in size!

A less sparse

"Invert" huge matrix as fast as possible to obtain x!

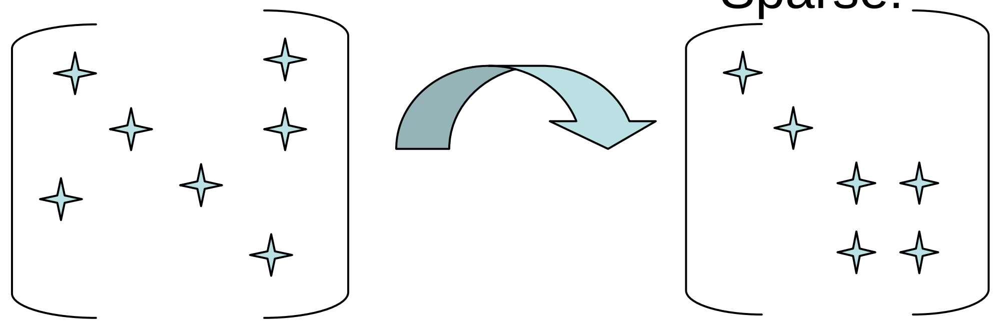
Simulation speed depends on sparsity of A

- Sparse solver for matrix ***A***

Original

Matrix ***A***

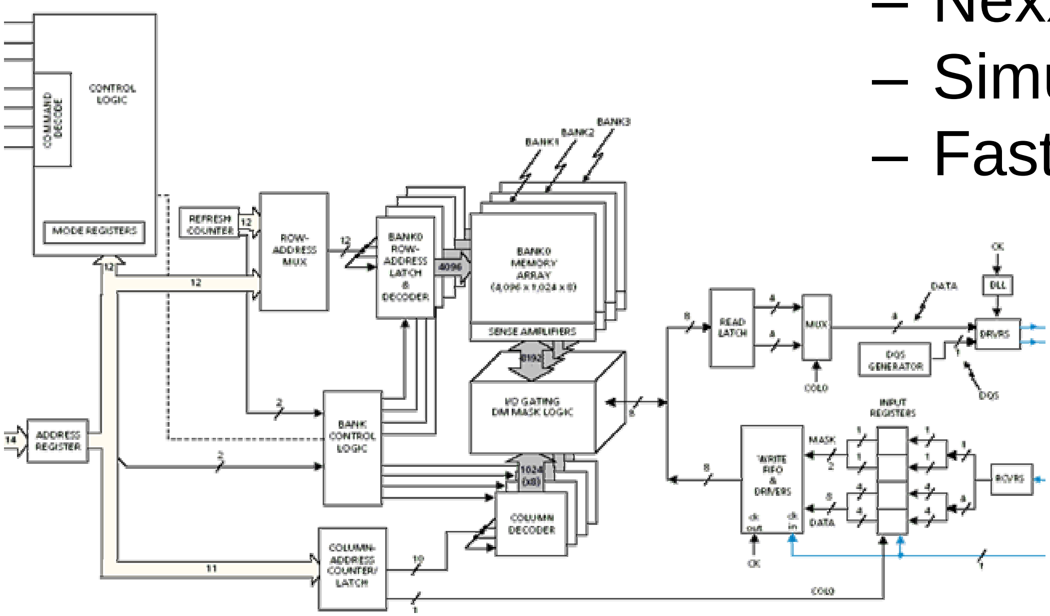
Factored Matrix is Sparse!



  - Nexxim's efficiency stems from:
    - Smart application of a number of Graph-Based Sparse Matrix Algorithms
    - Particularly important in transient analysis

Direct sparse solution for large circuits

- Transient Simulation on digital AND analog section of DDR SDRAM
  - Nexxim: 3 hours
  - SimulatorB: 12 hours
  - Fast Spice: Wrong results



Other analyses require iterative solvers & preconditioners

- Iterative solver for matrix ***A***
  - Looks for x in the space

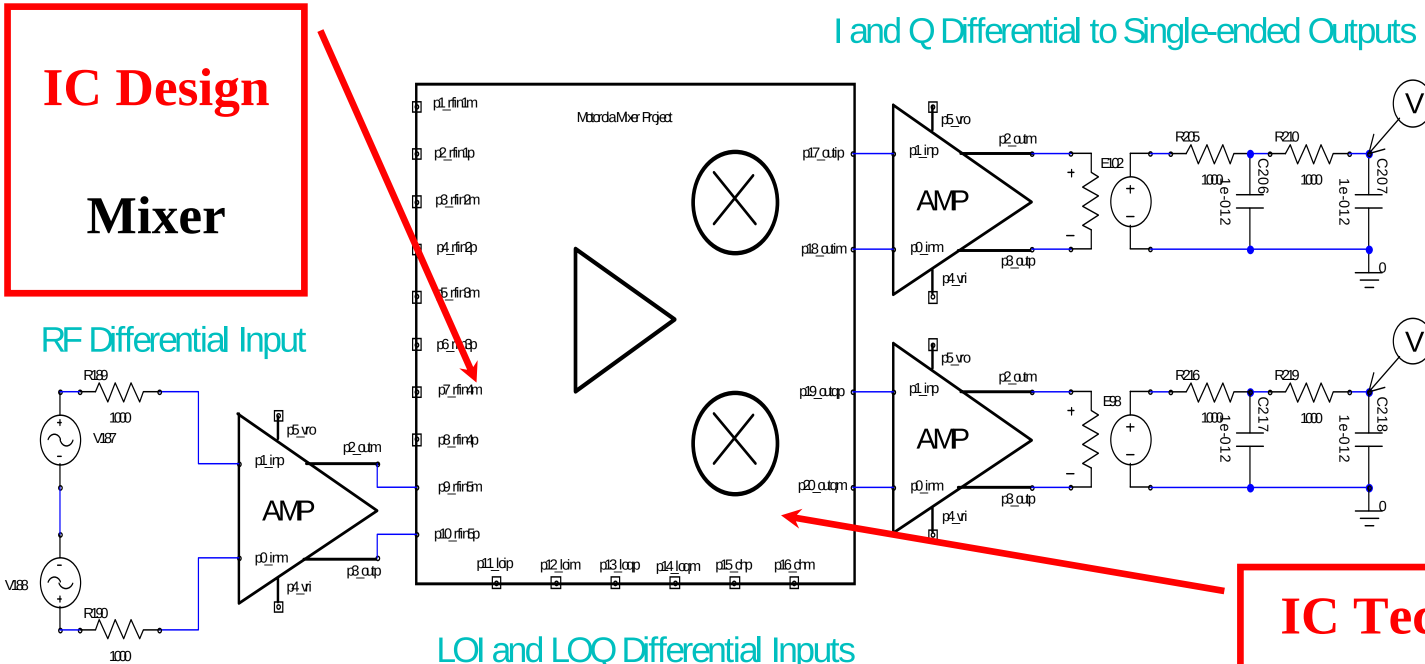
$$x \in \{b, Ab, A^2b, \ldots., A^{k-1}b\} \ \ where\ k << size(A)$$

  - Nexxim uses “Preconditioner’’ ***P*** that makes ***k*** as small as possible

$$PAx = Pb$$

  - Nexxim’s Efficiency from choice of P and a family of Iterative Solvers

Iterative solution for large circuits

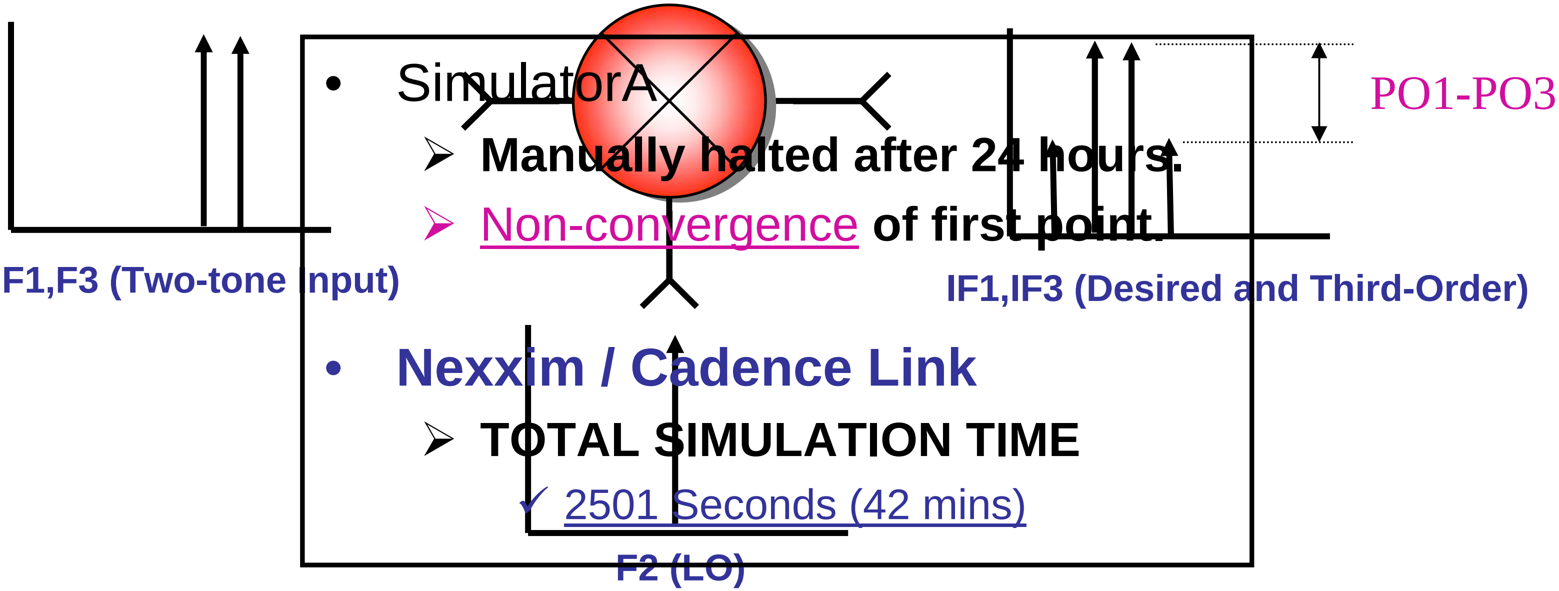


IC Technology

Post-layout parasitics

95,127 total components
~ 1,500 MOSFETs
~ 90,000 RC parasitics

Smart preconditioning enables fast linearity simulations



- SimulatorA
  - Manually halted after 24 hours.
  - Non-convergence of first point.
- **Nexxim / Cadence Link**
  - **TOTAL SIMULATION TIME**
    - ✓ 2501 Seconds (42 mins)

3-Tone Harmonic Balance [F1,F2,F3]

- **F1 = 1.07GHz (RF #1) with 2 Harmonics**
- **F2 = 1.00GHz (LO) with 1 Harmonic**
- **F3 = 1.06GHz (RF #2) with 2 Harmonics**
- **Input Power : 5 points sweep**

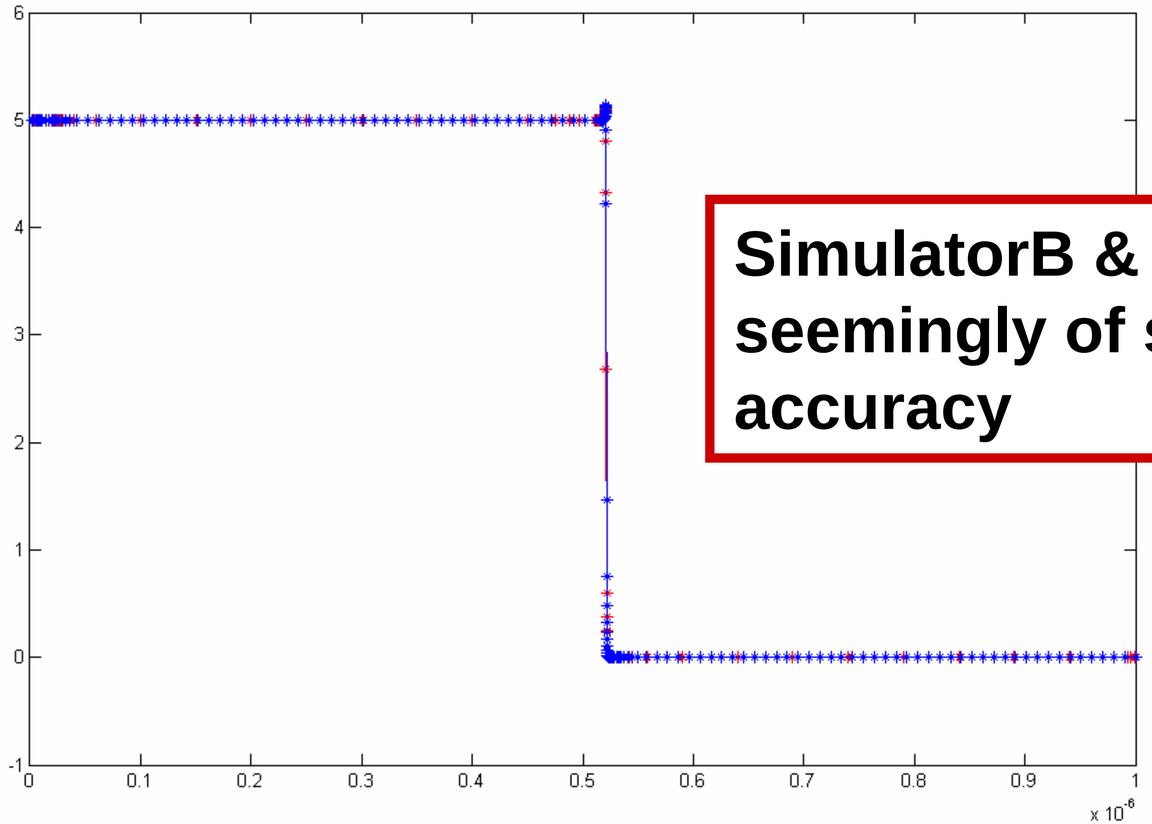
Efficient algorithms for accuracy

- Choose Time points With Efficient Error Control Algorithm

Transient analysis:

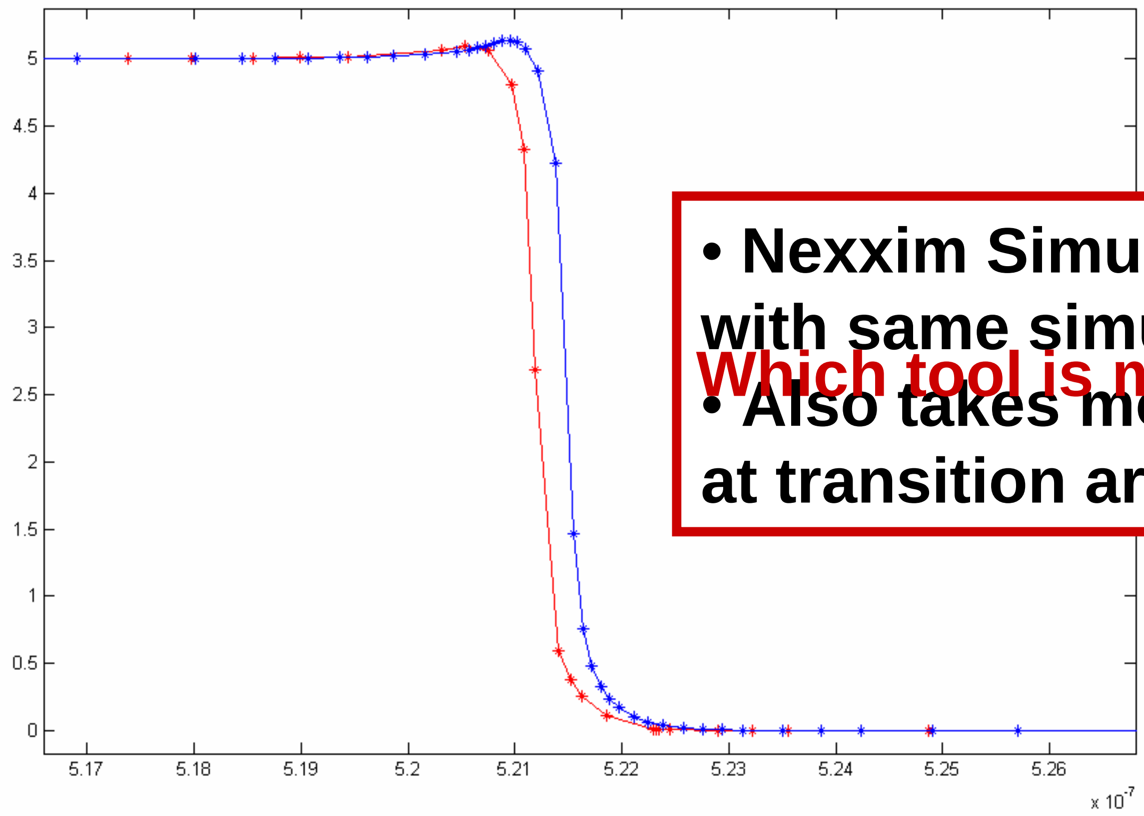
Efficient algorithms for accuracy

- CMOS inverter chain



SimulatorB & Nexxim seemingly of same accuracy

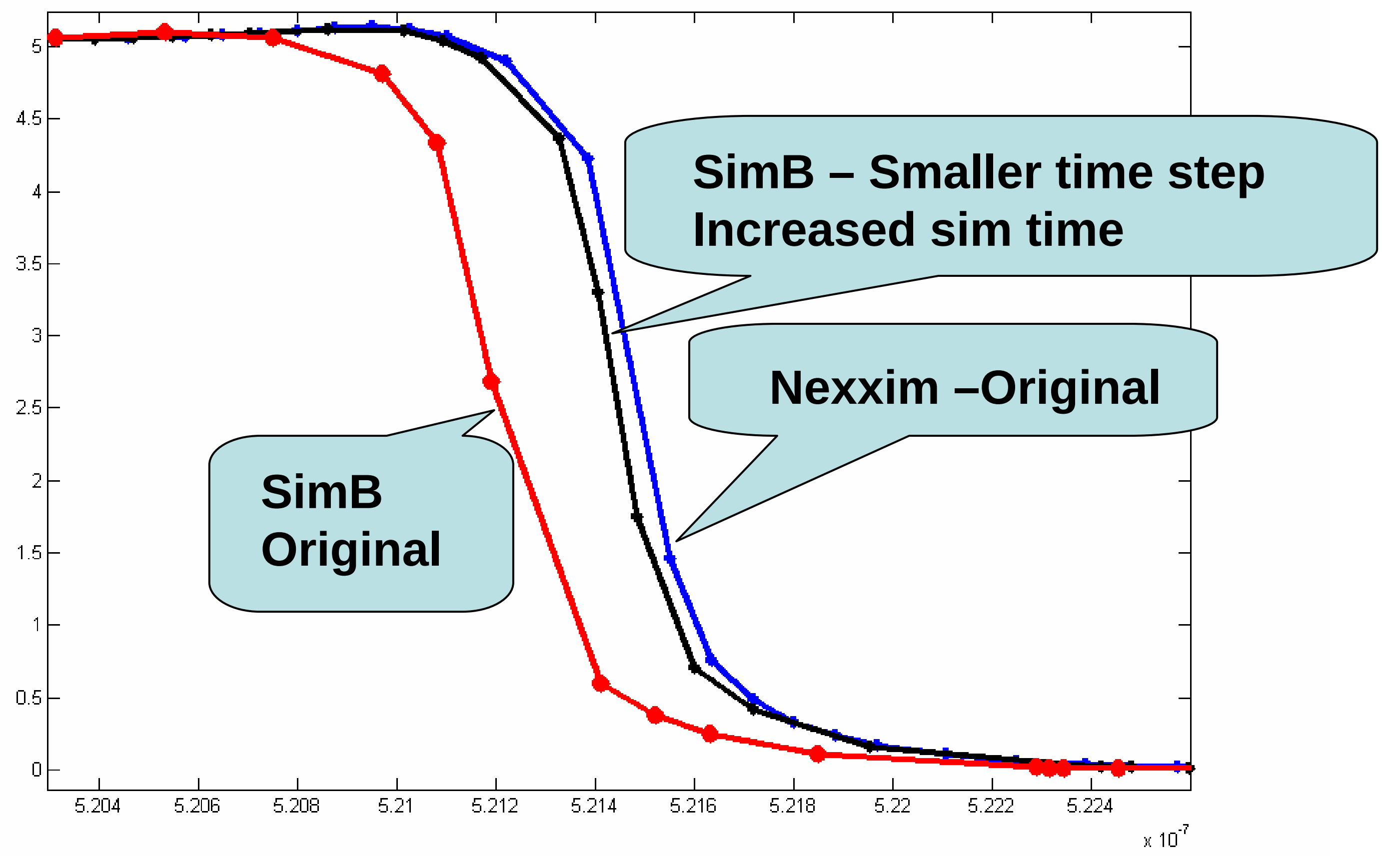
Efficient algorithms for accuracy



- **Nexxim Simulation speed faster with same simulation tolerances**
- **Also takes more time points at transition areas**

Which tool is more accurate?

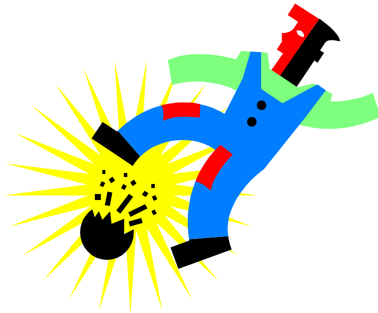
Efficient algorithms for accuracy



Ensuring accuracy across simulation domains

- S-parameters
  - Fundamental issue: S-parameters in frequency domain, simulation in time domain.

  - On surface, simple: inverse FFT, impulse response, convolution



Ensuring accuracy across simulation domains

Transient Simulation of S-parameters

Causality and passivity

- For causality, effects follow causes
  - Impulse responses must be 0 for $t < 0$
- For passivity, does the S-parameter block generate or absorb power?
  - At each frequency, the maximum singular value (SVD) of the S matrix <= 1

Ensuring accuracy across simulation domains

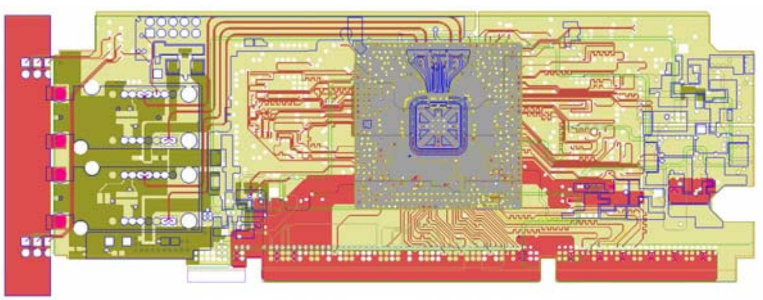
- Traditional method of ***Convolution***
  - Can be slow (numerical integration)
  - Limited frequency of data
  - Windowing effects in iFFT
  - If data not on uniform grid, Interpolation, not necessarily causal or passive
  - Need care to avoid filtering effects

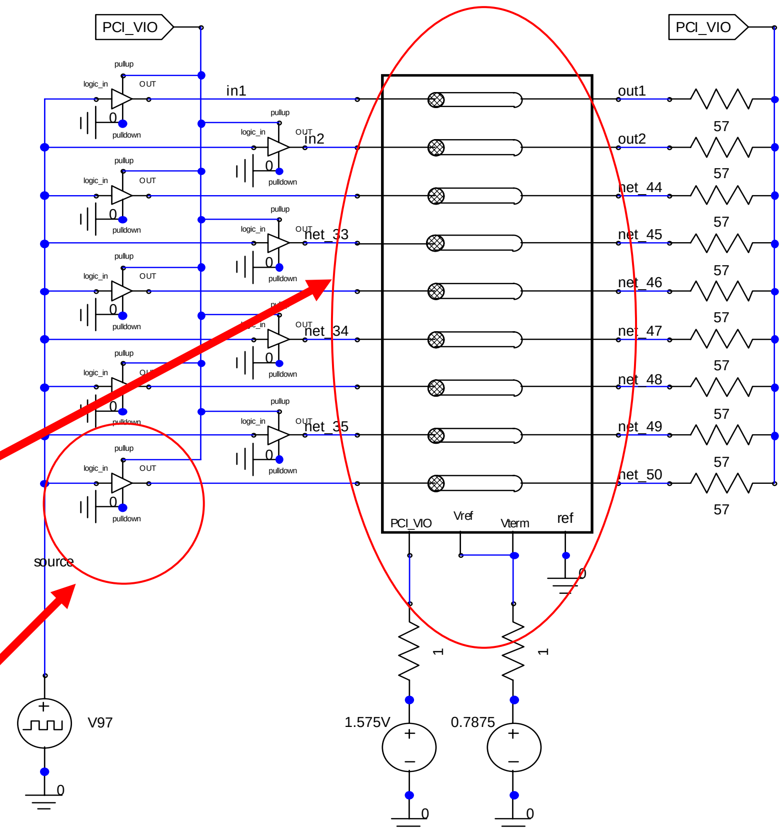
Ensuring accuracy across simulation domains

- Nexxim's preferred approach is ***State Space***
  - Pole-residue fit to frequency-domain data
  - Only stable poles used: causal
  - Very efficient transient simulation
    - Simple first-order differential equation
  - Passivity not guaranteed
    - But can be enforced for moderate-sized problems

Board design example

Simultaneous Switching and Power Integrity





57 Port S-parameter block
DC to 5GHz

IBIS Drivers

Board design

Solving the circuit with state-space

57 Port S-parameter block used to generate state-space model

In frequency domain: **Y(s) = H(s) U(s)**

In time domain (state space model):

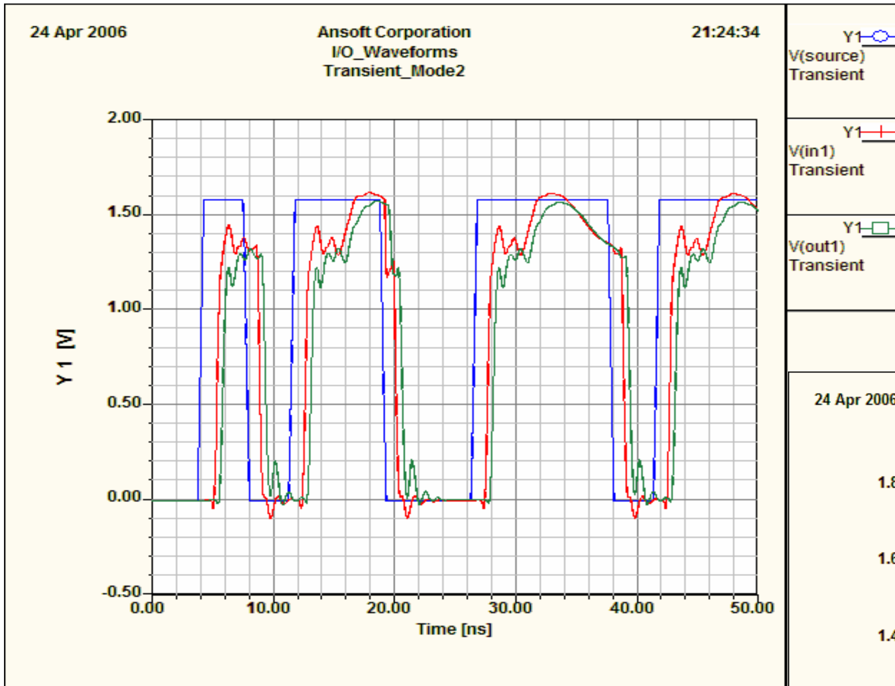
$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$y(t) = Cx(t) + Du(t)$$

using the equivalence:

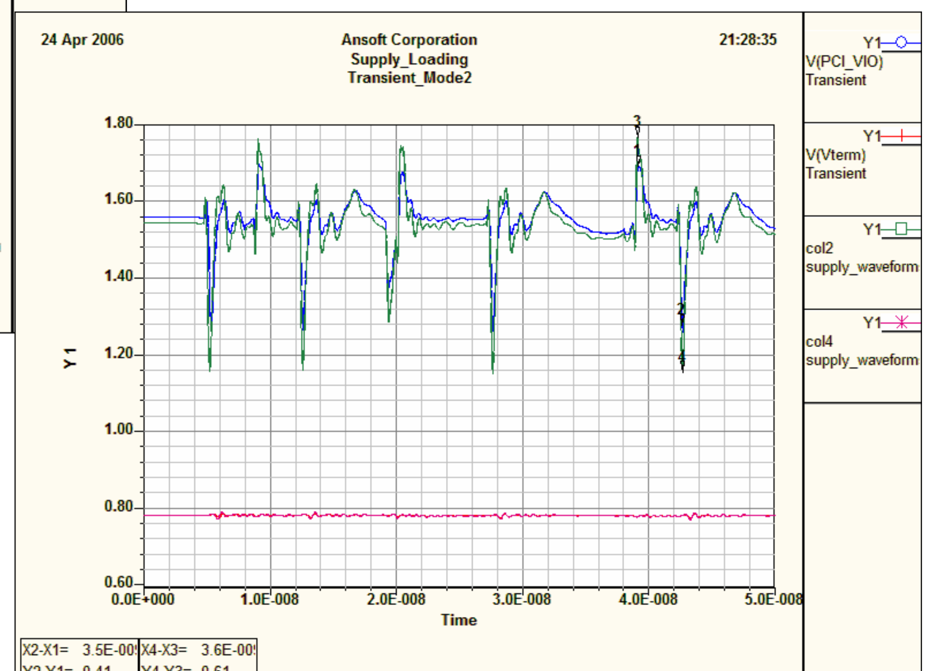
$$H(s) = C(sI - A)^{-1}B + D$$

Transient analysis results using Nexxim



18 IBIS Drivers
57 Port S-parameter model

Transient simulation time: 366s



Taking advantage of state-space caching

Improvements to Nexxim's handling of S-parameters, including model-order reduction and passivity enforcement of the state-space formulation take computation time; in the case of passivity enforcement, a lot of time!

Run simulation for the 1st time

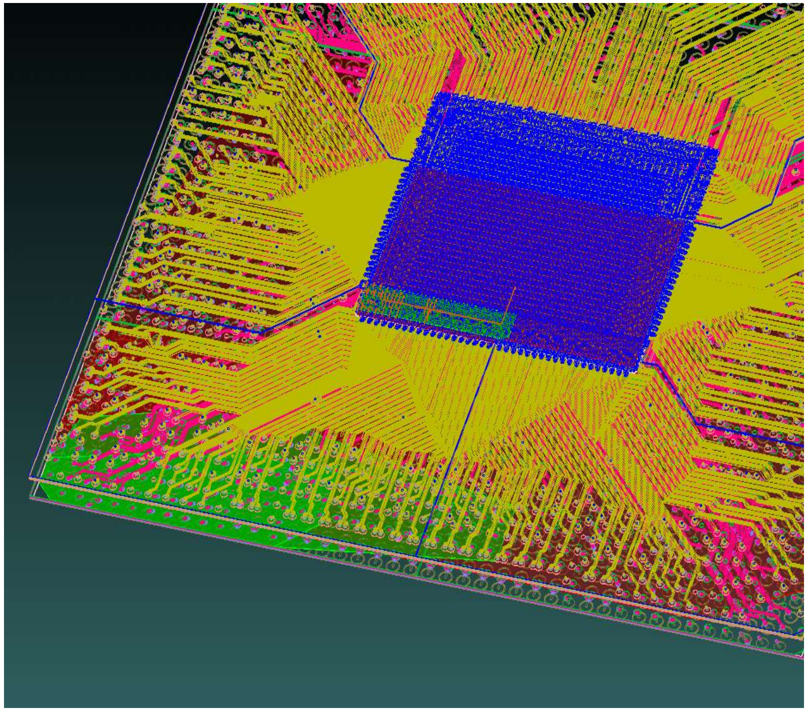
State-space fitting

Generation of a .sss file with the state space model details

Used in subsequent runs with unchanging S-parameter data

Save simulation time! No need to regenerate the state space model

Pushing the envelope in capacity, speed and accuracy



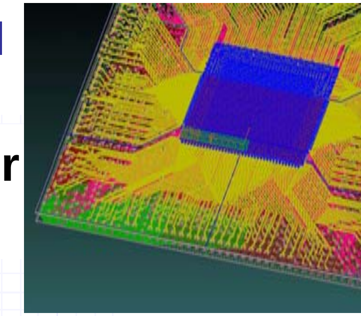
SIwave Package Model

44-port S-parameter model
Frequency range of 0-10GHz

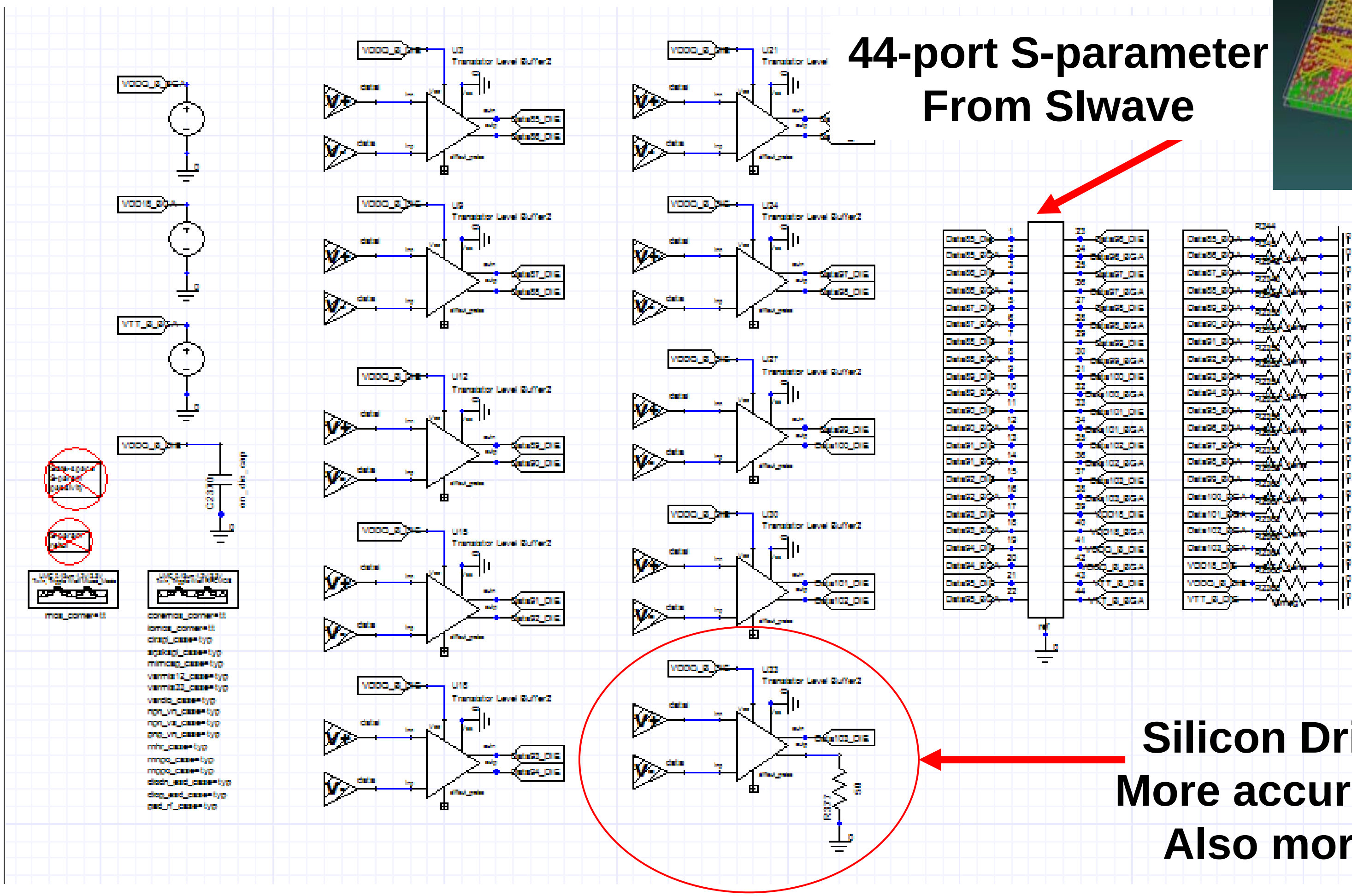
Model includes both power structures and signal nets

Chip and Package Design

Setting up the circuit simulation in DesignerSI



44-port S-parameter From SIwave

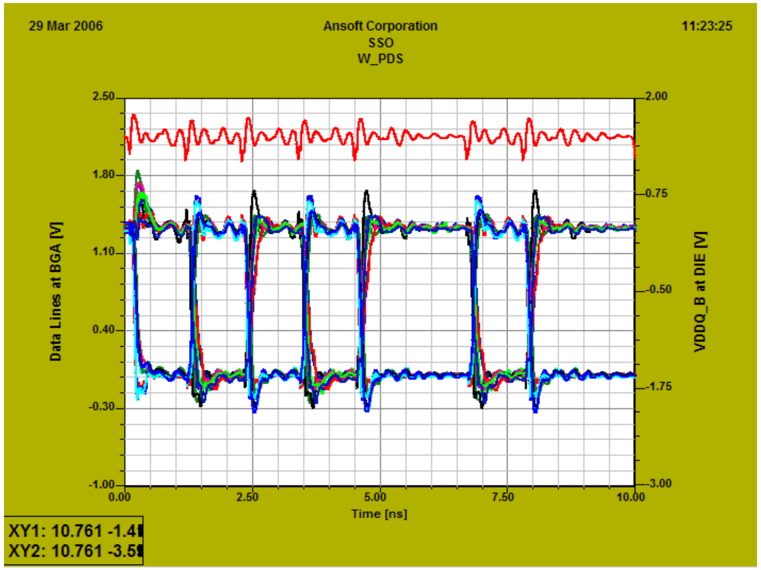


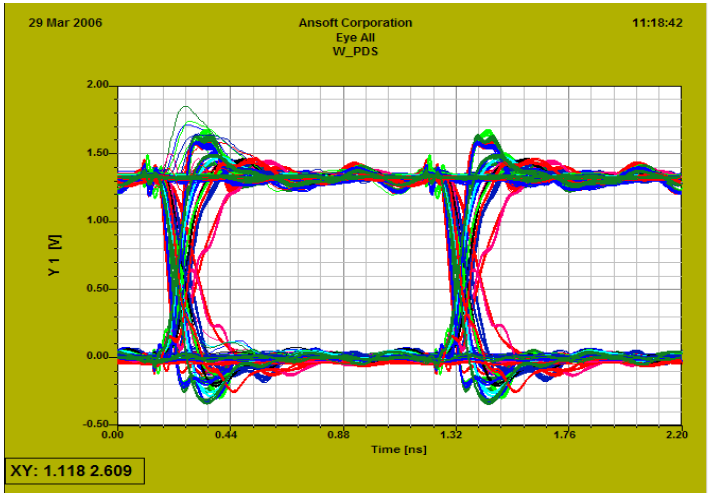
Silicon Driver Models More accurate than IBIS Also more complex

Chip and Package Design

64-bit Nexxim

44 port S-parameter model
148,000 MOSFETs
1.7 Million Capacitors
500,000 Resistors





Nexxim solution time: 36 hrs

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Application Workshops for High-Performance Design

Conclusion

Capacity, Speed, Accuracy

for increasingly large and complex circuits