Multi-level Co-Simulation of Mixed Technology Microsystems

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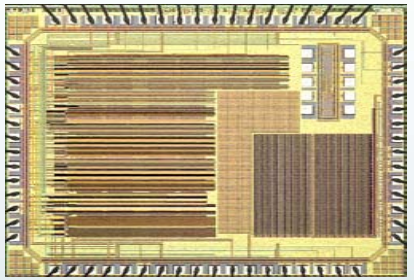
Motivation: CAD for Mixed Technology Micro-Systems

- Next generation micro-systems will utilize multiple technologies to perform *sensing, computing, control, communications*, and *actuation* tasks for diverse applications.

- The design and analysis of these systems is challenging: spanning multiple technologies, energy domains, length, and time-scales in a tightly coupled but heterogeneous micro-system

- *Chatoyant* – Multi Domain System Simulator
  - Performs end to end system level simulations
  - Analyzes performance of novel multi-technology microsystems



Electronics

vlsi.stanford.edu/smart_memories/testchips.html

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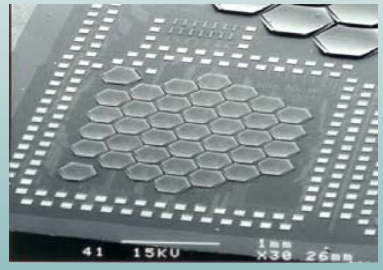

Optics

www.irisao.com/technology.html

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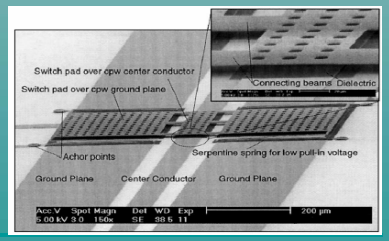
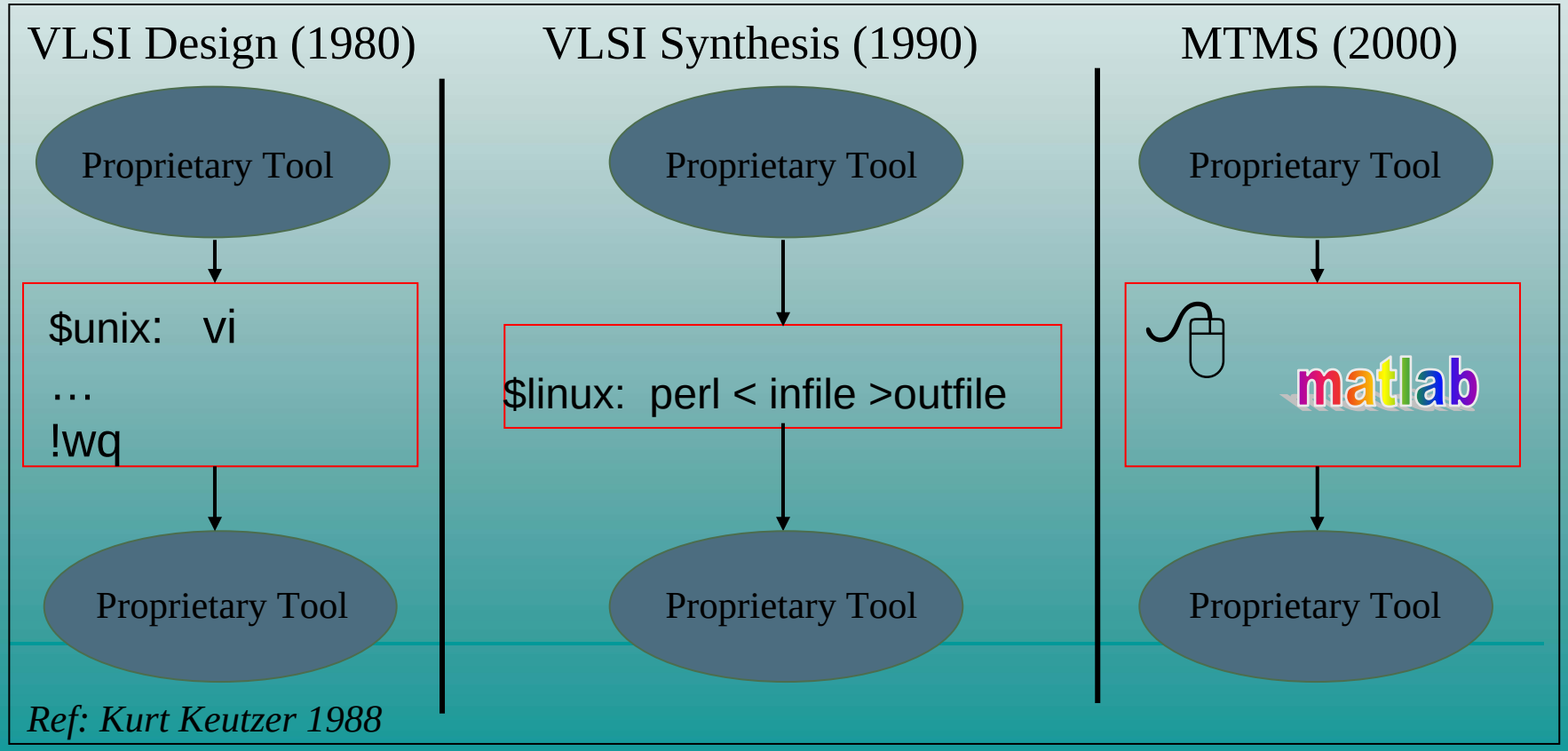


Micromechanics

www.eecs.umich.edu/~dperouli/ Research.htm

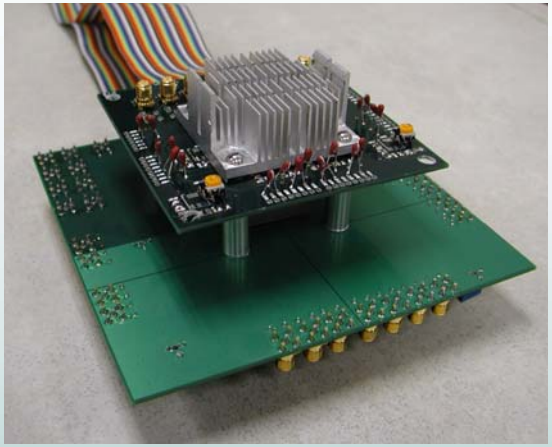
CAD Support for New Design Flows

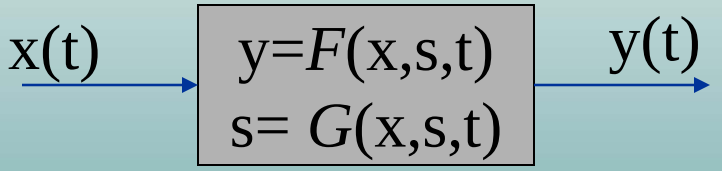
- Ideal: Top down, based on good models and fast simulation and analysis tools. Even better to have synthesis
- Real: Collections of tools in different domains cobbled together with script files

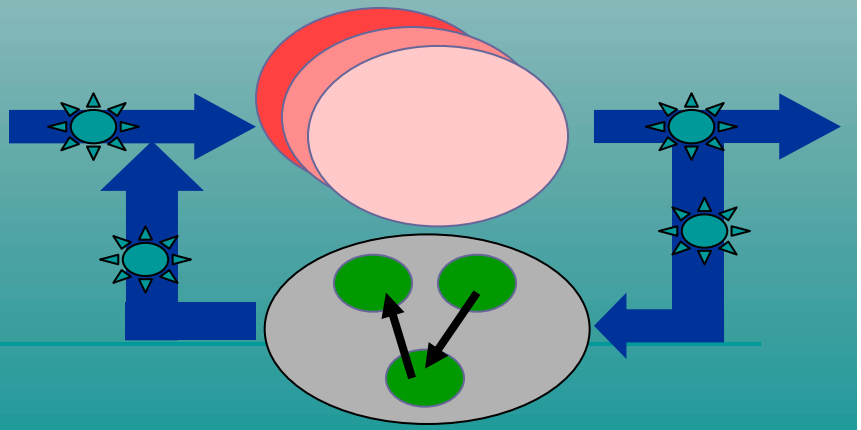


System Level Simulation

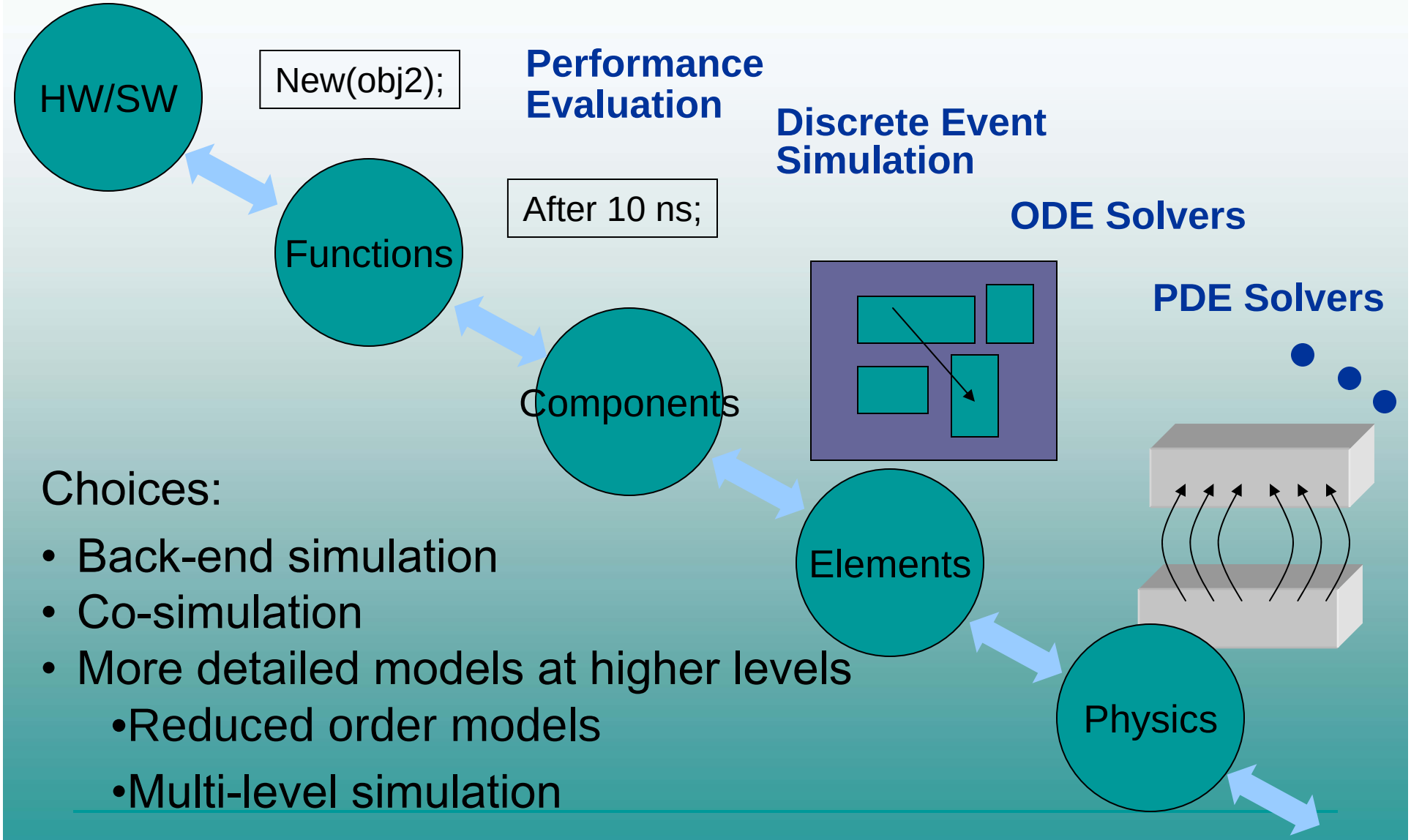
- Simulation of the entire system can provide:
  - Trade off analyses early in the design cycle
  - Tolerancing and reliability modeling
  - Optimization across technologies
  - Shorter design time, fewer prototypes, lower costs to design
- System Level Simulation:
  - Components, Signals, Transformations, Time
- Multi Technology Simulation
  - Multiple technology domains, Multi-level models, Mixed Signals, Multiple time scales







Evaluation / Simulation Choices

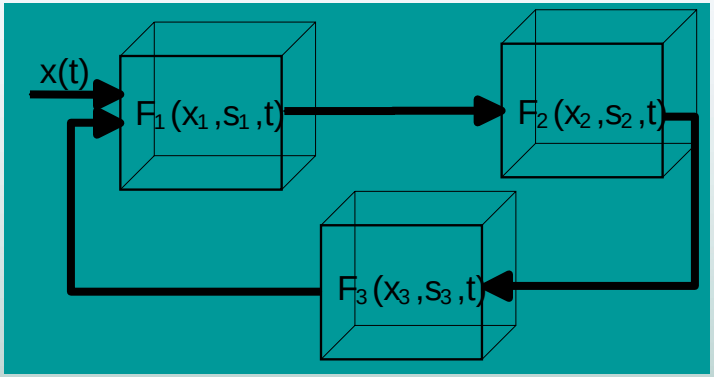


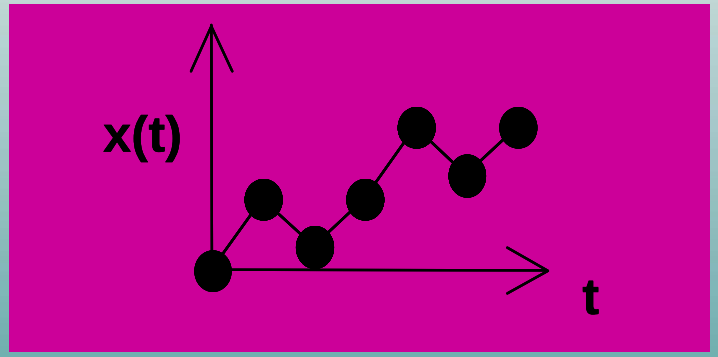
Choices:

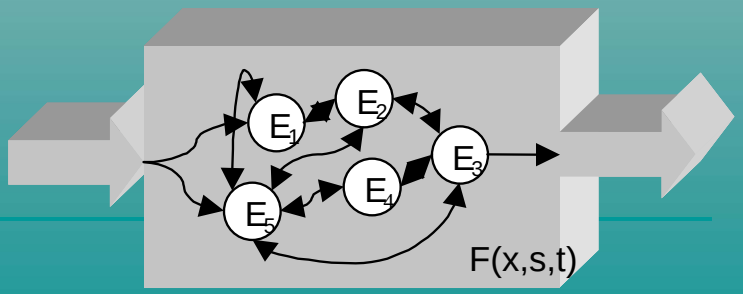
- Back-end simulation
- Co-simulation
- More detailed models at higher levels
  - Reduced order models
  - Multi-level simulation
  - Multi-granularity simulation

System Level Mixed Technology Modeling Approach

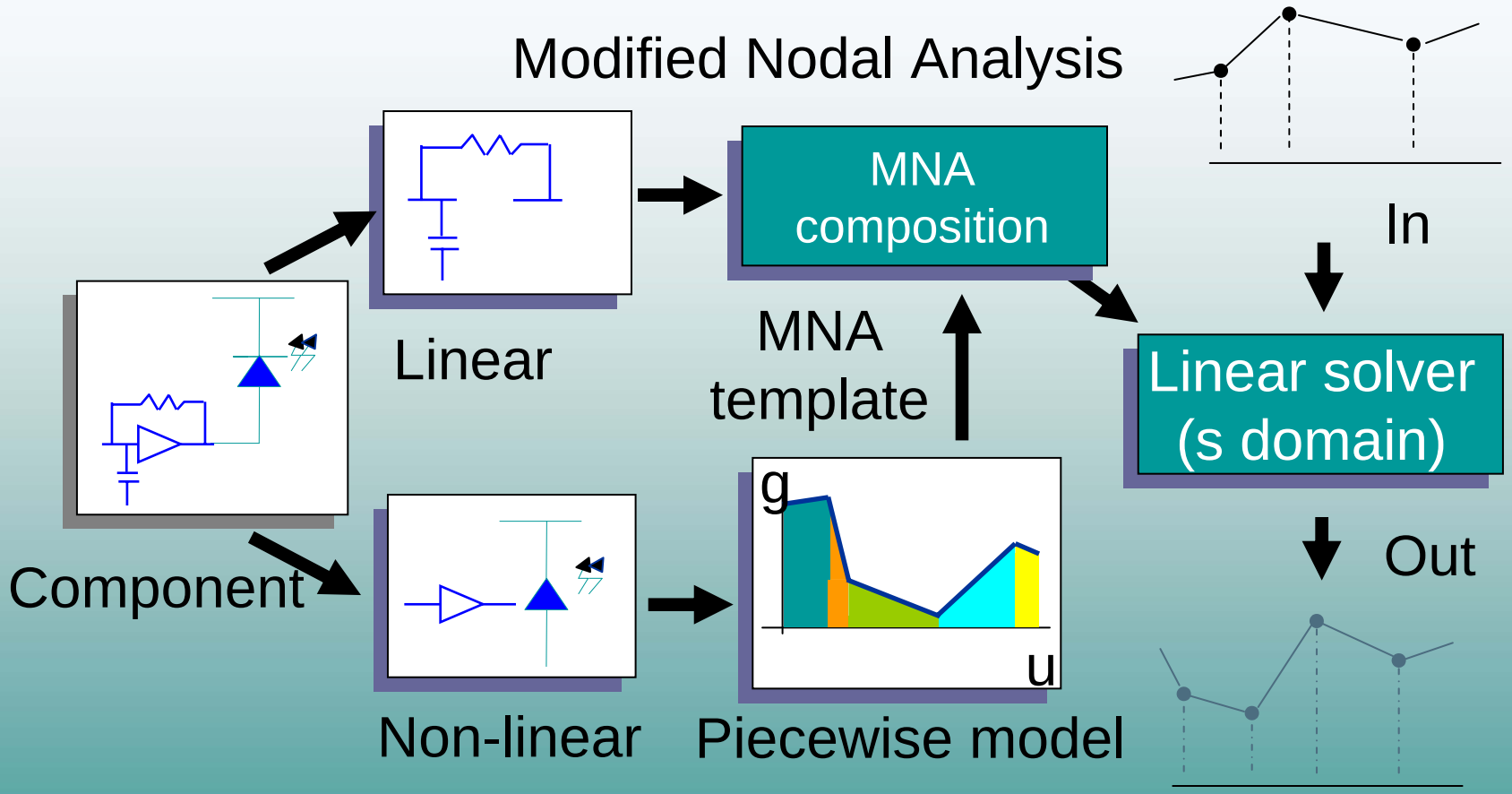
- Partition the system into components
  - reflect hierarchy
  - reduce complexity
  - provide technology based interfaces
- Capture the interaction between components by a discrete event model (multi-domain energy signals)
  - Optical, Electrical, Mechanical, etc.
- Model the dynamics of the multi-domain components by a set of piecewise linear ODEs for each of the elements in the component
- Co simulate with compatible discrete event simulators
  - Use PDES techniques





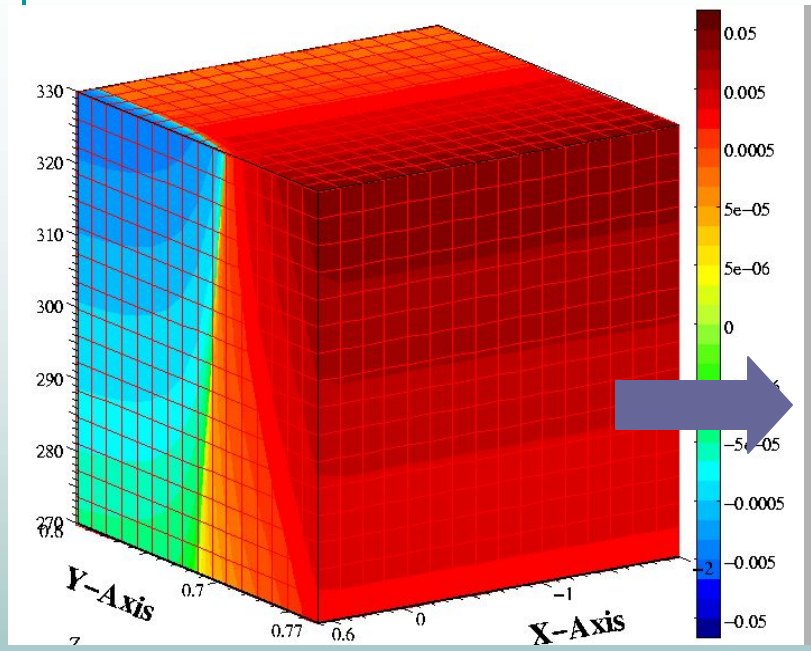


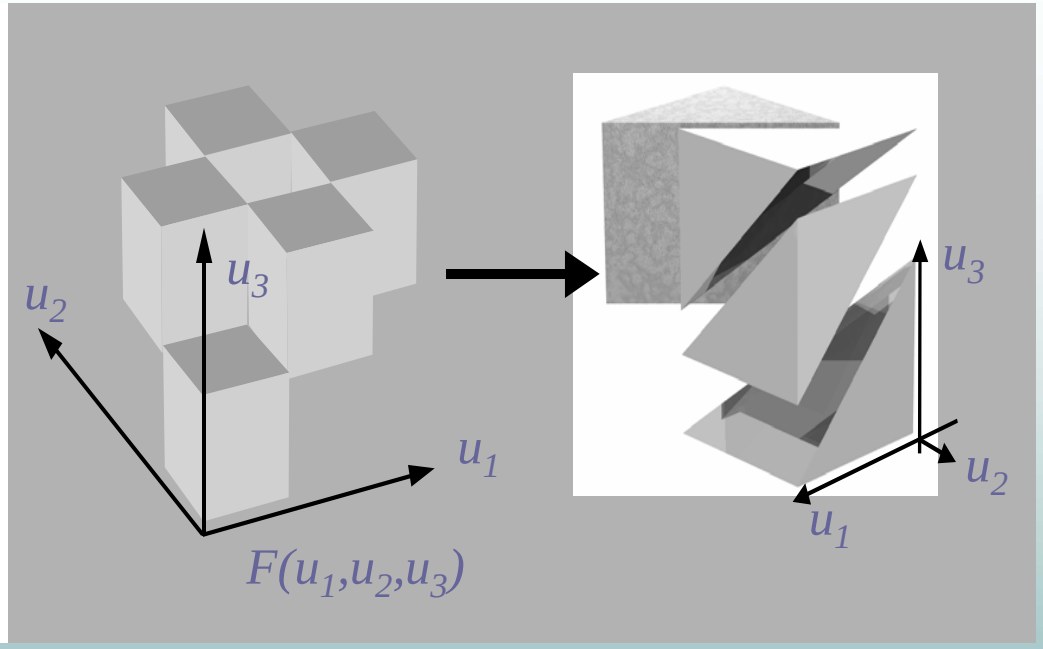
Piecewise Linear Fast Solver



- Nodal Analysis (Template based formulation) :
- Support for: Electronics → Full Spectre/Spice Netlists
- Mechanics → Structural Netlists

Linearizing Multivariable Functions

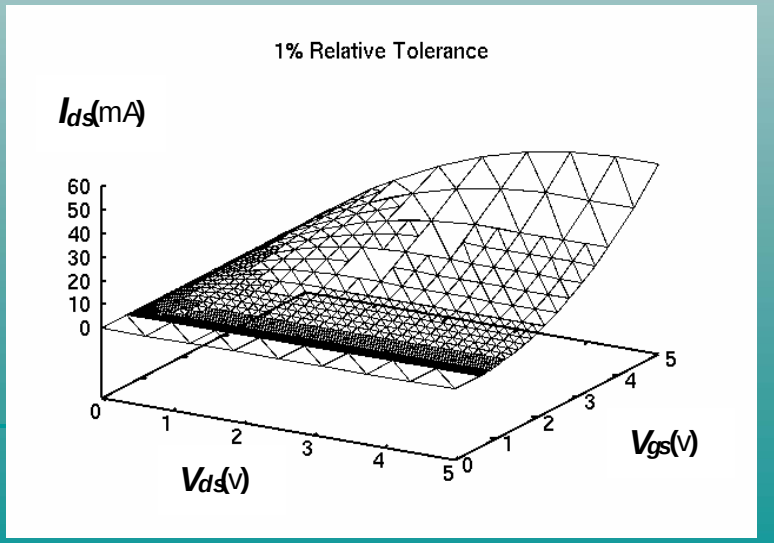




3D function

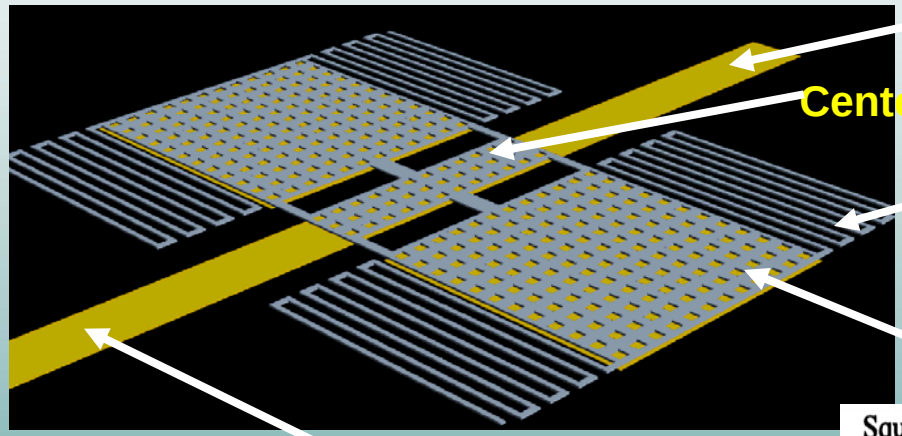
2D (NMOS)

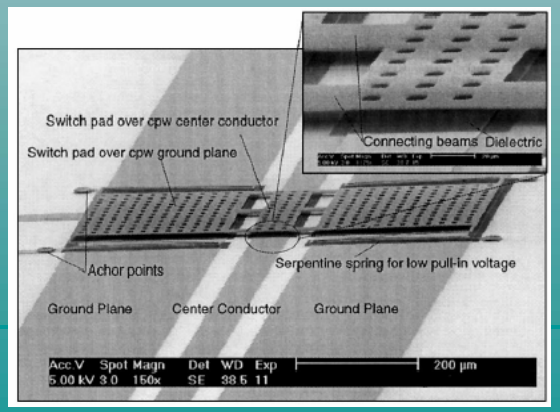
- Recursive decomposition into hypercubes
- Triangulate each hypercube into hyper-simplices

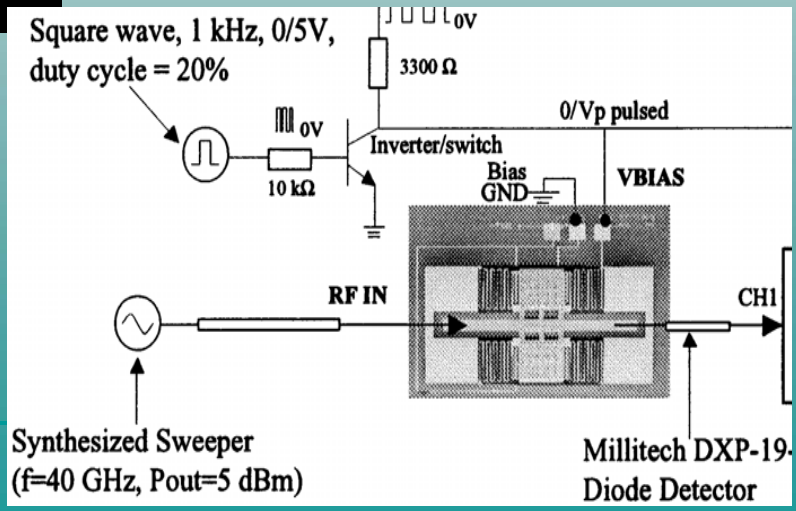


RF MEMS Switch System

- Electromechanical capacitance shunt switch designed for Low voltage actuation (from University of Michigan)







http://www.eecs.umich.edu/~dperouli/low-voltage_RF_mems.htm

RF System Switch Modeling Techniques

Traditional Modeling

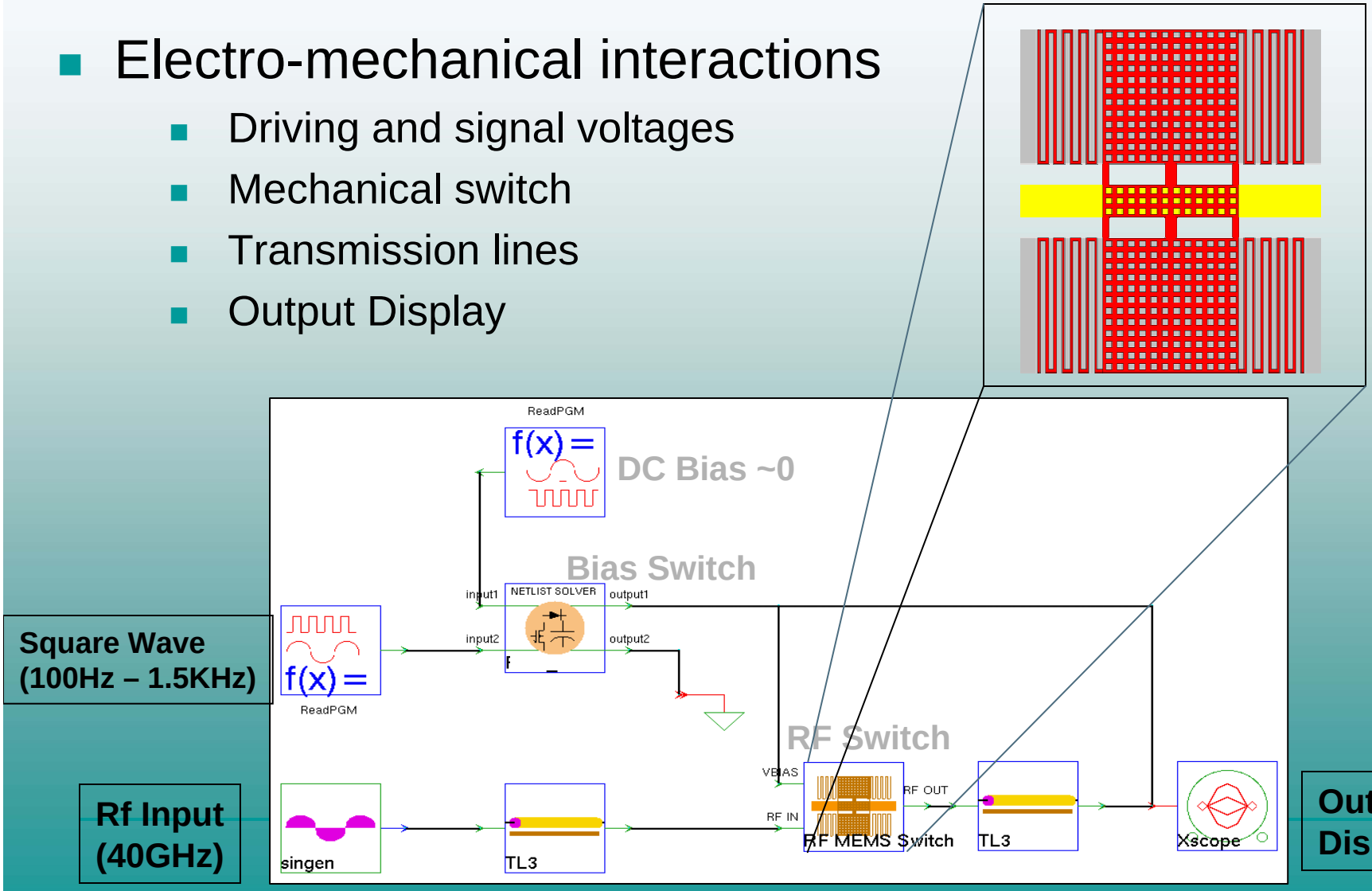
1. Mechanical Analysis
   1. Serpentine Spring Assembly
      1. Stiffness
      2. Modal Analysis
2. Electro-mechanical Analysis
   1. Capacitance Model
   2. Pull-in Voltage
3. Lumped Model Circuit Level Simulation
4. Integrate Results

System Level Modeling

- Assemble Mechanical Model
- Compose System Model
- Perform End to End System Simulation

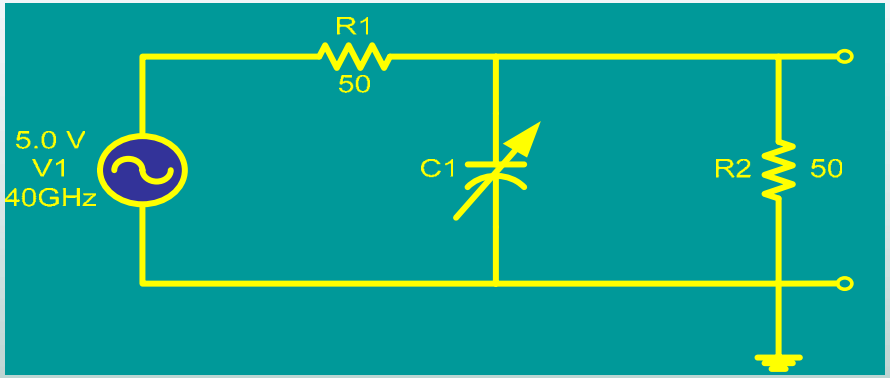
System Simulation Model

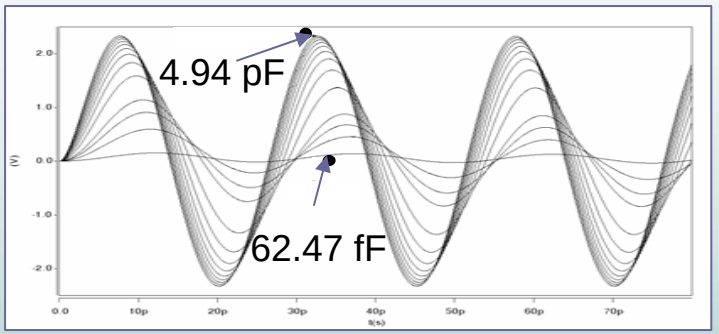
- Electro-mechanical interactions
  - Driving and signal voltages
  - Mechanical switch
  - Transmission lines
  - Output Display



End to End Simulation

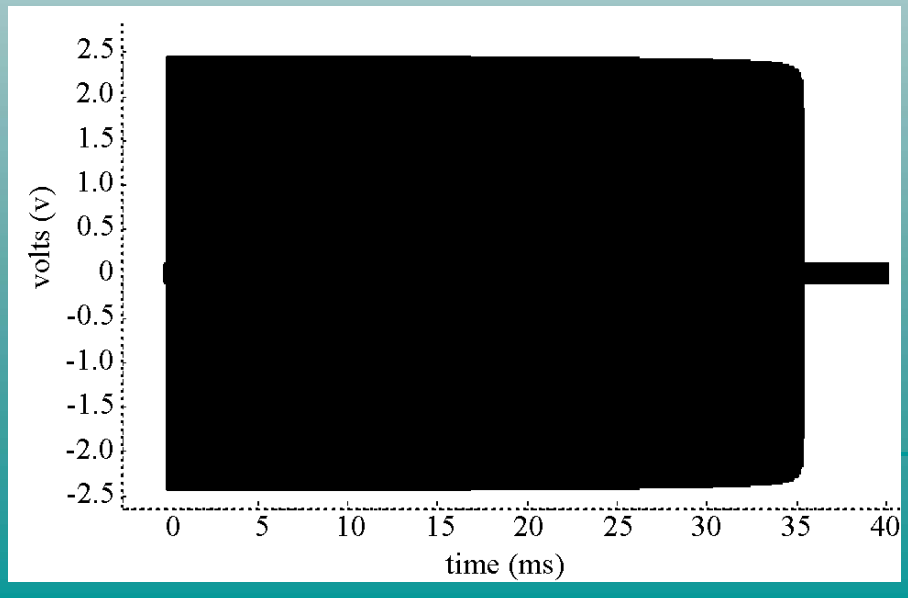
- Electrical response of switch operation



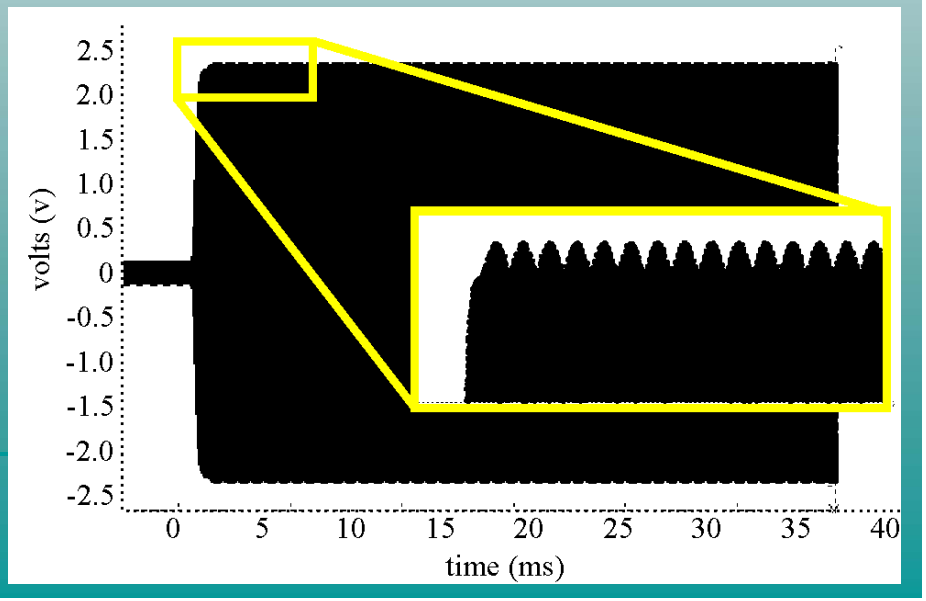


- Electro-mechanical response of switch

40 GHz Signal - Switch Actuation

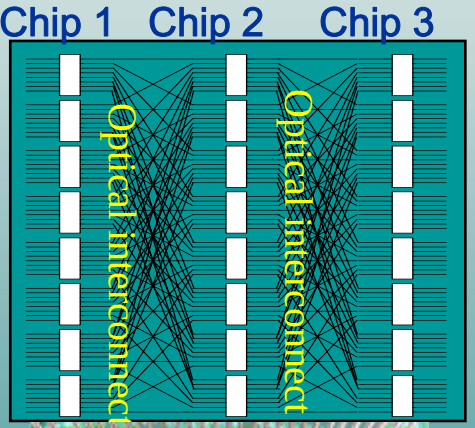


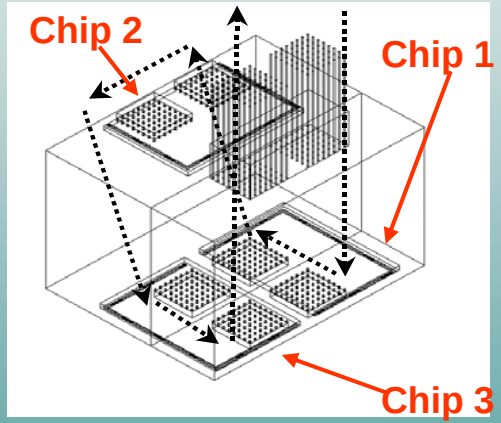
Switch Release - Bounce

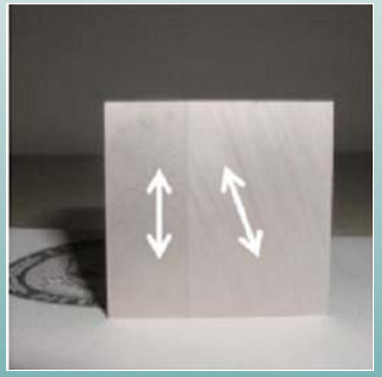


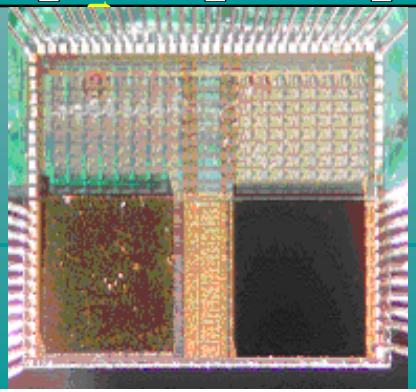
64-Channel 3-Chip Optoelectronic Switch

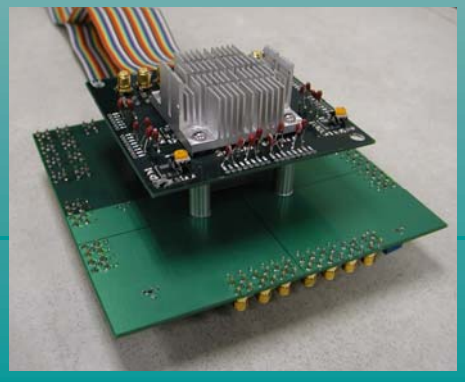
- 3-Chip OE-MCM using mixed analog/digital switch chips in UTSi SoS CMOS
- Each chip: 8 8x8 crossbars, 8x8 VCSEL driver array, 8x8 receiver array

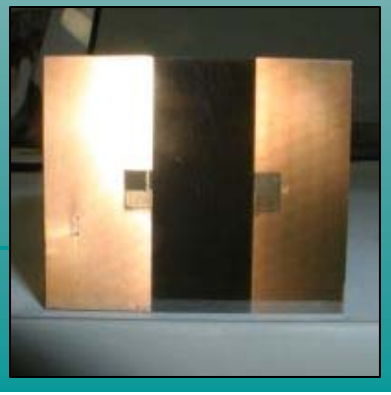




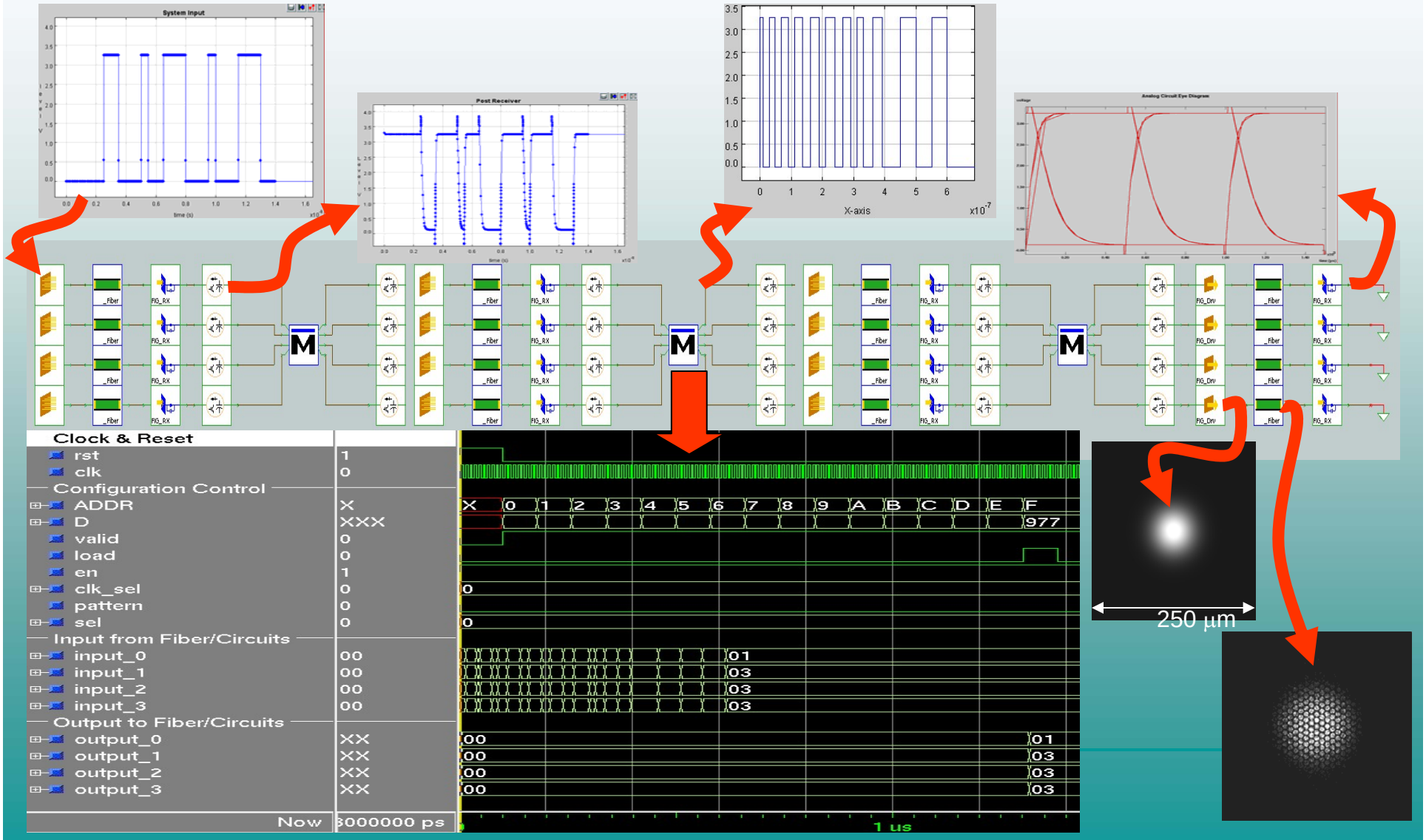






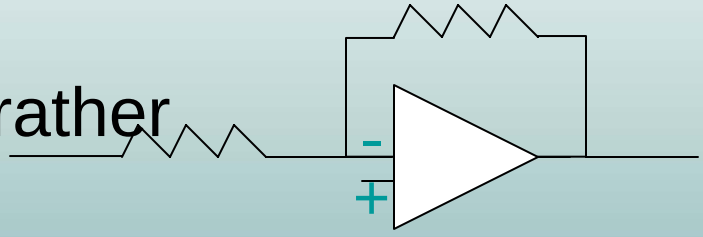


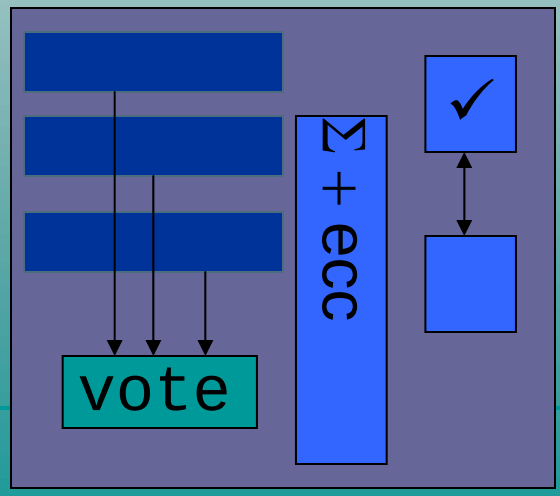
Analog/Digital Electronics and Optics



Challenges of Multi Technology Systems

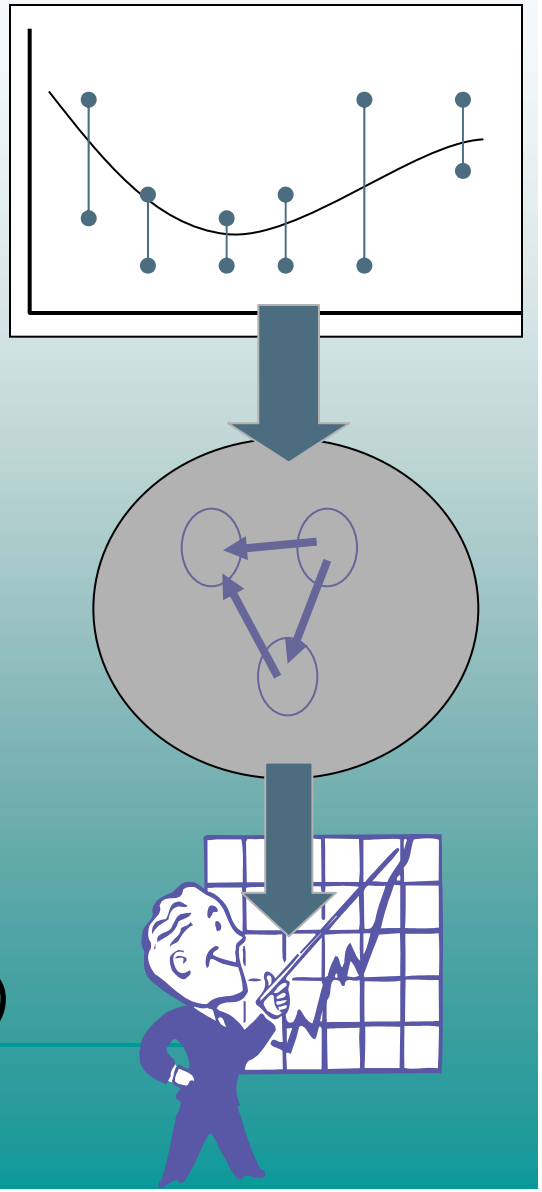
- Must understand the relationships between multiple fabrication processes and system performance
  - What went wrong?
- Must use architectural solutions rather than fighting process problems
  - How to design in robustness?
- Must increase reliability using
  - Redundancy
  - Integral error correction
  - Fault tolerance
  - Self-repair





Conclusions

- Bottom up tool building must precede top down design flow
  - Quality models, Transparent, Known fidelity
- Top down design required to support design exploration
  - Component based design
  - Quick feedback on design choices and trade-offs
- Multi-level modeling, simulation and analysis
  - Efficiently support complex models
  - Capture interactions (mixed –domain, multi-level)
  - Find the *unexpected* problems
    - Performance analysis
    - Multi-domain interactions



✓ *Reduce the need for prototyping (the 1st device)*

✺ *Support manufacturing (the 1,000,001st device)*