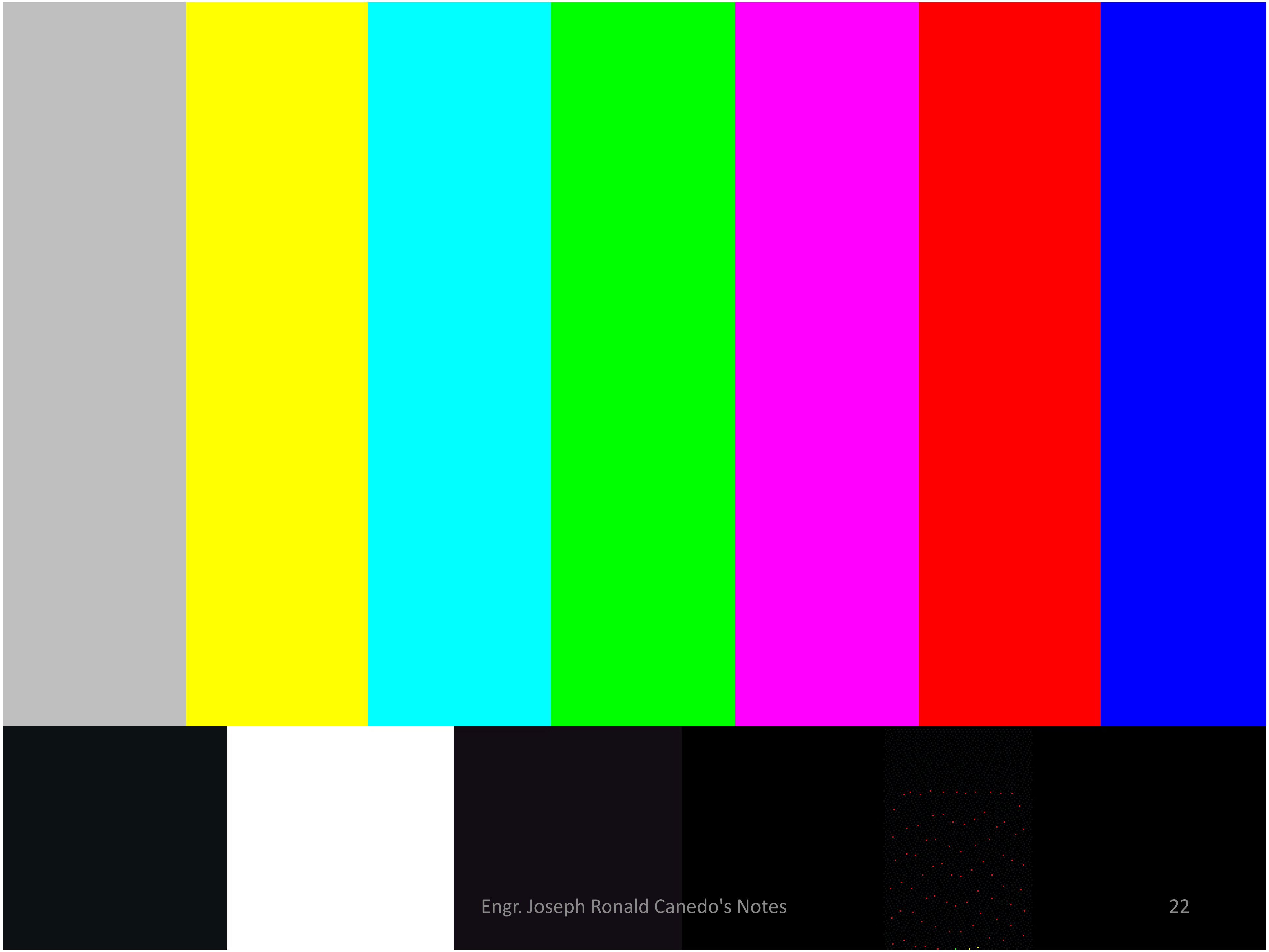

Modeling and Simulations for Microelectromechanical System (MEMS)

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Introduction

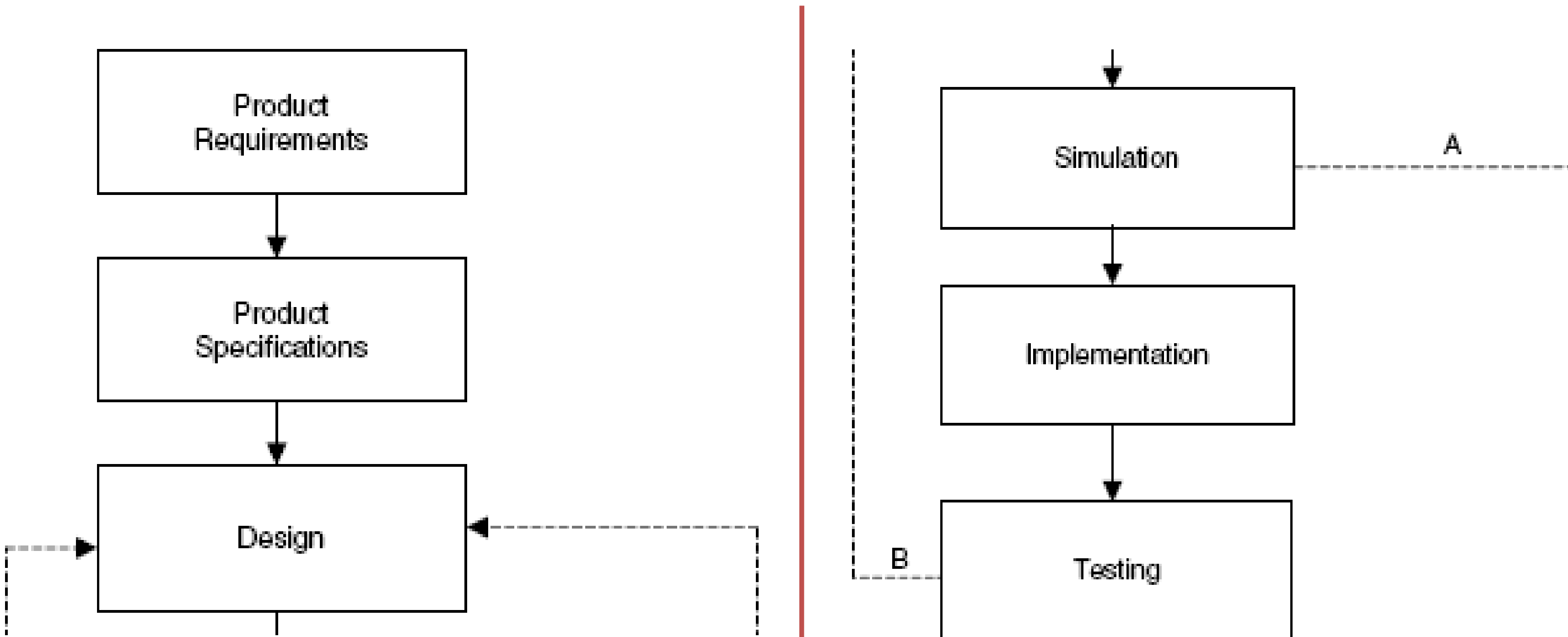
- Accurate modeling and efficient simulation, in support of greatly reduce development cycle time and cost, are well established techniques in the miniaturized world of ICs.
- Eventually, MEMS simulation environments should also be capable
  1. To predict the performance of a design
  2. To analyze an already existing component, or
  3. To support automated synthesis of a design.

Introduction

- For our discussion of modeling and simulation, the salient characteristics of MEMS are:
  1. Inclusion and interaction of multiple domains and technologies.
  2. Both two- and three-dimensional behaviors.
  3. Mixed digital (discrete) and analog (continuous) input, output, and signals, and
  4. Micro- (or nano-) scale feature sizes.

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes

- A typical Very Larges Scale Integration (VLSI) digital circuit or system process flow.



Product design process. A: mature technology, B: immature technology

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes

- There are many characteristics of digital systems which make this possible.
  1. Existence of a small set of basic digital circuit elements. All Boolean functions can be realized by combinations of the logic functions AND, OR, NOT.
  2. A small set of standardized and well-understood technologies, with well-characterized fabrication processes that are widely available.
  3. A well-developed educational infrastructure and prototyping facilities.
  4. “Levels and views” (abstraction and encapsulation or “information hiding”)
  5. Well-developed models for basic elements that clearly delineate effects due to changes in design, fabrication process, or environment.
  6. Mature tools for design and simulation, which have evolved over many generations and for which moderately priced versions are available from multiple sources.

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes

- There are many characteristics of digital systems which make this possible.
  7. Integrated development systems that are widely available and that provide support for a variety of levels and views, extensive component libraries, user-friendly interfaces and online help, as well as automatic translation between domains, along with error and constraint checking.

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes

Levels	Views		
	Behavioral	Structural	Physical
4	Performance Specifications	CPUs, Memory, Switches, Controllers, Buses	Physical Partitions
3	Algorithms	Modules, Data Structures	Clusters
2	Register Transfers	ALUs, MUXs, Registers	Floorplans
1	Boolean Equations, FSMs	Gates, Flip-flops	Cells, Modules
0	Transfer Functions, Timing	Transistors, Wires, Contacts, Vias	Layout Geometry

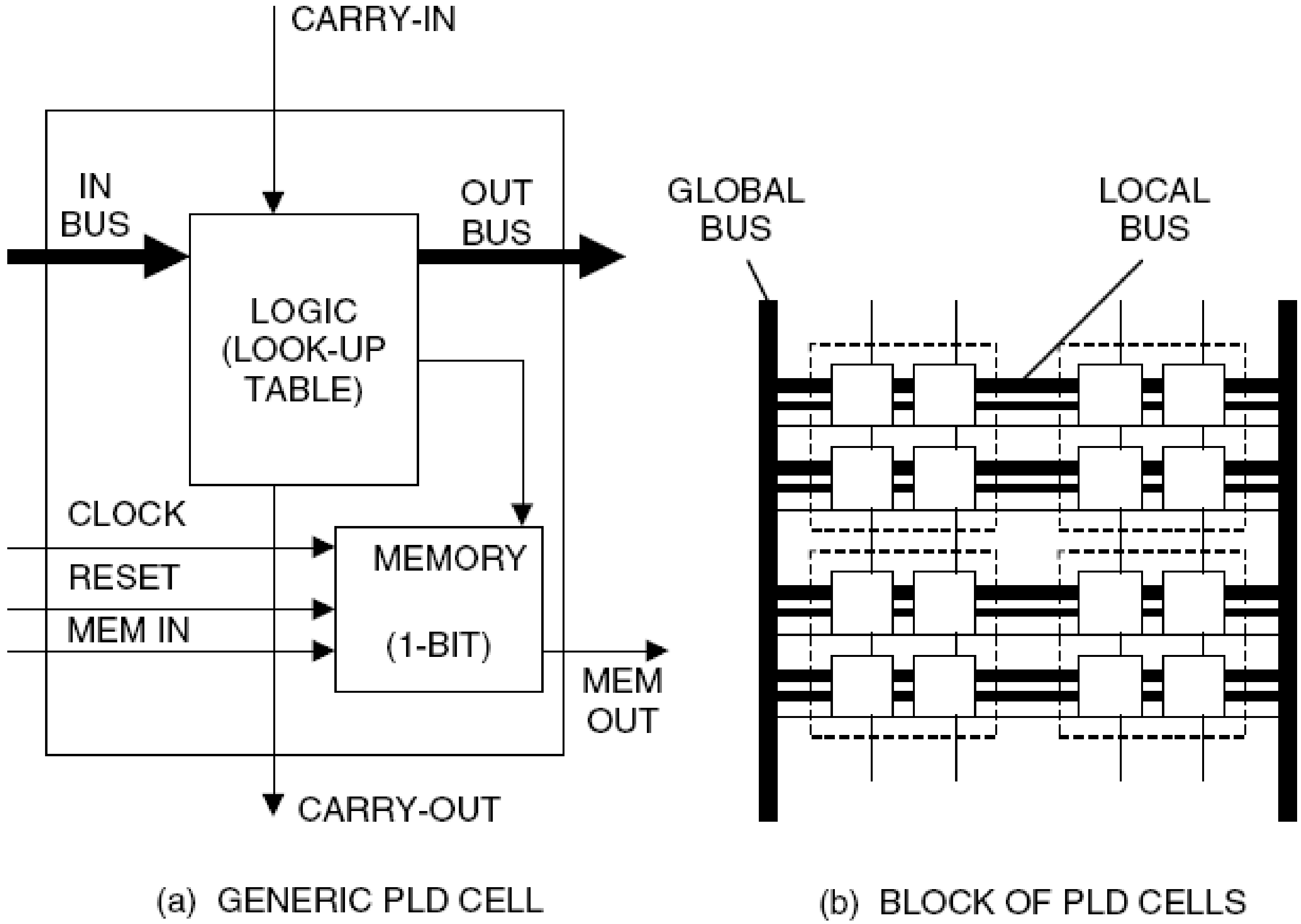
standard VLSI classifications,

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes

Levels	Views		
	Behavioral	Structural	Physical
4	Performance Specifications	Sensors, Actuators, Systems	Physical Partitions
3		Multiple Energy Domain Components	Clusters
2		Domain-Domain Components	Floorplans
1		Single Energy Domain Components	Cells, Modules
0	Transfer Functions, Timing	Beams, Membranes, Holes, Grooves, Joints	Layout Geometry

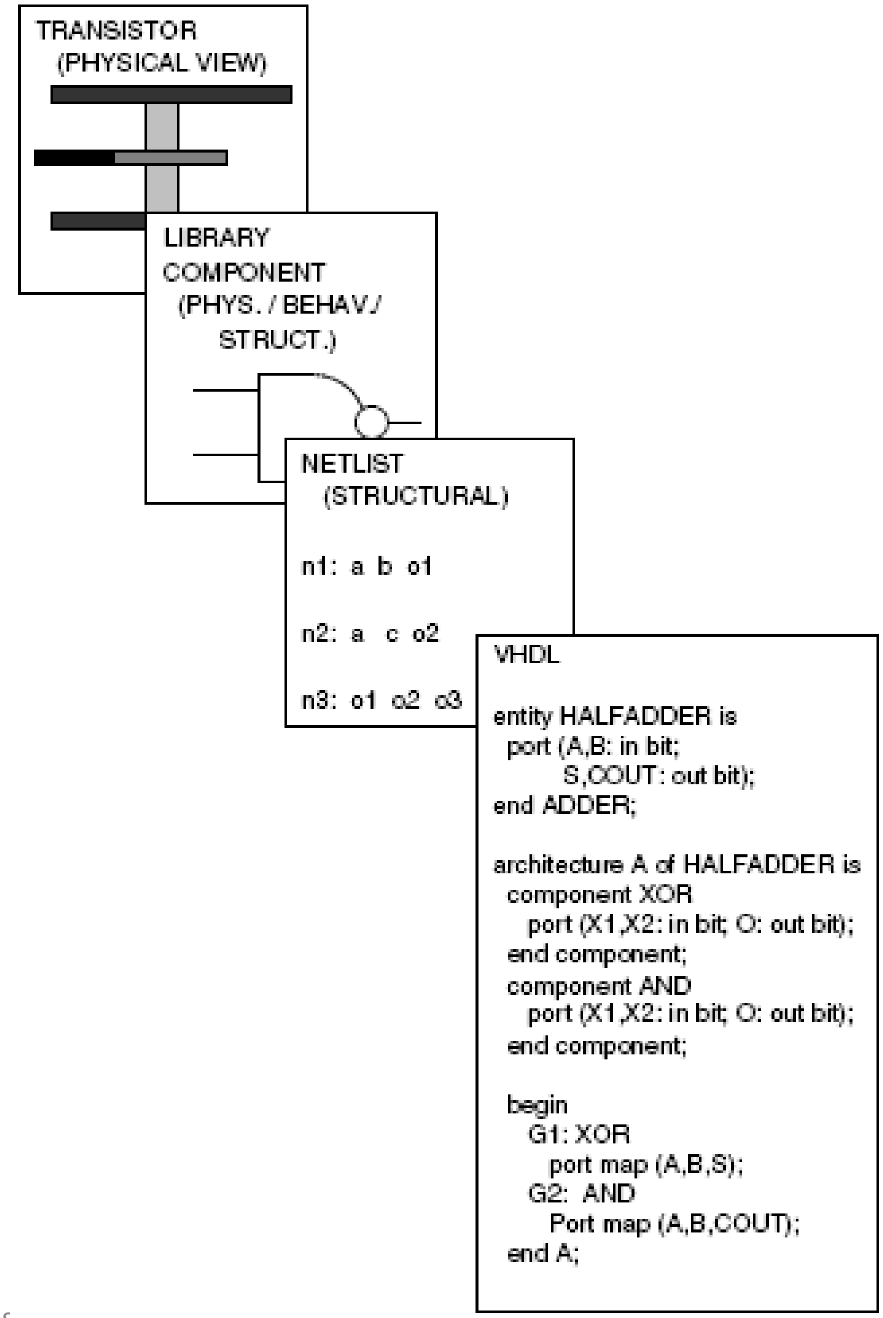
a partial classification for MEMS components.

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes



A generic programmable logic device architecture.

The Digital Circuit Development Process: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes



Analog and Mixed-Signal Circuit Development: Modeling and Simulating Systems with Micro- (or Nano-) Scale Feature Sizes and Mixed Digital (Discrete) and Analog (Continuous) Input, Output, and Signals

- Let us examine the factors given above for the success of digital system simulation and development to see how the analog domain compares. We assume a development cycle similar to that digital.
  1. Is there a small set of basic circuit elements?
  2. Is there a small set of well-understood technologies?
  3. Is there a well-developed educational infrastructure and prototyping facilities?
  4. Are encapsulation and abstraction widely employed?
  5. Are there well-developed models, mature tools, and integrated development systems which are widely available?

Basic Techniques and Available Tools for MEMS Modeling and Simulation

- We need to make the following choices:
  1. What kind of behavior are we interested in?
  2. Will the computation be symbolic or numeric?
  3. Will use of an exact equation, nodal analysis, or finite element analysis be most appropriate?

Basic Techniques and Available Tools for MEMS Modeling and Simulation

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A Catalog of Resources for MEMS Modeling and Simulation

A. Widely Available Tools for General Numeric and Symbolic Computation
   - Mathematica
   - Matlab
B. Tools Originally Developed for Specific Energy Domains
   - SPICE (analog circuits)
   - APLAC
   - VHDL-AMS
   - ANSYS
   - CFD software

A Catalog of Resources for MEMS Modeling and Simulation

C. Tools Developed Specifically for MEMS

– SUGAR
  - It uses nodal analysis and modified nodal analysis to model electrical and mechanical elements. Mechanical elements must be built from a fixed set of components including beams and gaps.

– NODAS v 1.4
  - a library of parameterized components (beams, plate masses, anchors, vertical and horizontal electrostatic comb drives, and horizontal electrostatic gaps) that can be interconnected to form MEMS systems. The tool outputs parameters that can be used to perform electromechanical simulations with the Saber simulator.

A Catalog of Resources for MEMS Modeling and Simulation

D. "Metatools" Which Attempt to Integrate Two or More Domain-Specific Tools into One Package
   - MEMCAD
   - MemsPro

E. Other Useful Resources
   - The MEMS Clearinghouse website
     - contains links to products, research groups, and conference information.
   - The Cronos website
     - provides prototyping and production-level fabrication for all three process approaches (surface micromachining, bulk micromachining, and high aspect ratio manufacturing).

A “Recipe” for Successful MEMS Simulation

1. Be sure you have access to the necessary domain-specific knowledge for all energy domains of interest before undertaking the project.
2. Never use a simulator unless you know the range of answers beforehand.
3. Never simulate more of the system than is necessary.
4. Always use the simplest model that will do the job.
5. Use the simulator exactly as you would do the experiment.

A “Recipe” for Successful MEMS Simulation

6. Use a specified procedure for exploring the design space. In most cases this means that you should change only one parameter at a time.
7. Understand the simulator you are using and all the options it makes available.
8. Use the correct multipliers for all quantities.
9. Use common sense.
10. Compare your results with experiments and make them available to the MEMS community.
11. Be sensitive to the possibility of microlevel phenomena, which may make your results invalid.

Conclusion: Continuing Progress in MEMS Modeling and Simulation

- In the past fifteen years, much progress has been made in providing MEMS designers with simulators and other tools which will give them the ability to make MEMS as useful and ubiquitous as was predicted in.
- One of the main challenges remaining for modeling and simulation is to complete the design and development of a high-level MEMS description language, along with supporting models and simulators, both to speed prototyping and to provide a common user-friendly language for designers. One candidate for such a language is VHDL-AMS.