Design for Mixed Technology Integration

Composite CAD

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Design Technology for Micro-fabricated, Mixed-Technology Systems

Will Enable the Design of These Targeted Mixed-Technology Applications:

- Complex MEMS sensor / actuator integrated with control electronics
- Micro-fluidic testing lab (control electronics, fluidic processing nodes and channels), processing or hydraulic system
- Microwave T/R modules with integrated high frequency electronics, MEMS switches, A/D or D/A converters and optical signal coupling
- “Robotic” (3D mechanics) actuation and electronic control for optic couplers, etc.

Focus on monolithic or minimally assembled structures (mass fabrication)

Composing systems with new, unique device technologies and local processing will create the most capable weapon, sensor, and actuator systems

Design for Mixed Technology Integration (Composite CAD)

ETO

Enable the early exploitation of revolutionary micro-fabricated technologies by developing the necessary design technology

with a focus on designing integrated mixed-technology single IC's.

- •Enable analysis and optimization of 100's to 1000's of analog, digital, MEMS and optical devices integrated into a single design
- •Increase dramatically the explorable space of design options for devices and systems
- •Develop an integrated, design tool framework for micro-fabricated systems of devices
- •Shorten MEMS device development time by 100x

- •**Invent** coupled analysis of 3D shapes with a focus on device modeling and analysis.
  - •3D shape-based, ***coupled energy-domain analysis*** with integrated adaptive meshing for simultaneous mechanical, electrical, electro-magnetic, and fluidic analysis
  - •3D shape modeling and visualization of structures and results
- •**Develop** composable design environment for micro-fabricated system design
  - •Create and adopt interchange formats for shape, fabrication and functional design tools
  - •New Layout-versus-Schematic (LVS) consistency and manufacturing Design Rule Checkers (DRC)
  - •Shape extrusion from fabrication masks based on process modeling for multiple technologies
- •**Create** tools to extract manufacturable, parameter-based, device and interconnect component libraries
  - •Lumped / table-based model extraction from coupled energy analysis
- •**Research** mixed-technology system specification and synthesis with a focus on modeling based analysis and processing / material variance based optimization

Composite CAD Will Enable Design of Key Components

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Military | Dual-Use | Manufacturing, Design

Systems

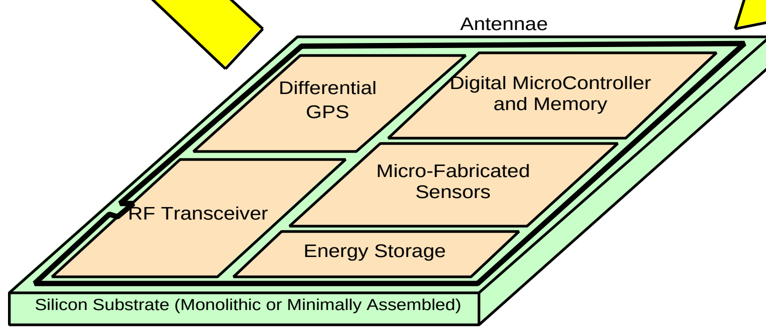
Personal Intertial Navigation Chip

Solid State, Monolithic Phased Array Element

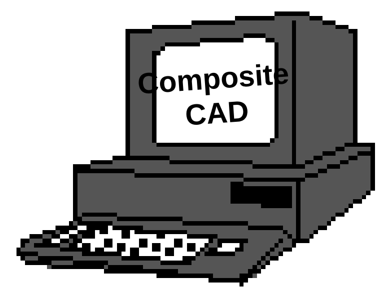
MicroFluidic Testing Chip

Components

Target Goal:



Highly Integrated, Co-designed & Fabricated Single “Chip” System



Workstation Based Integrated Design Tool

Problems Designing Mixed-Technology Systems Today

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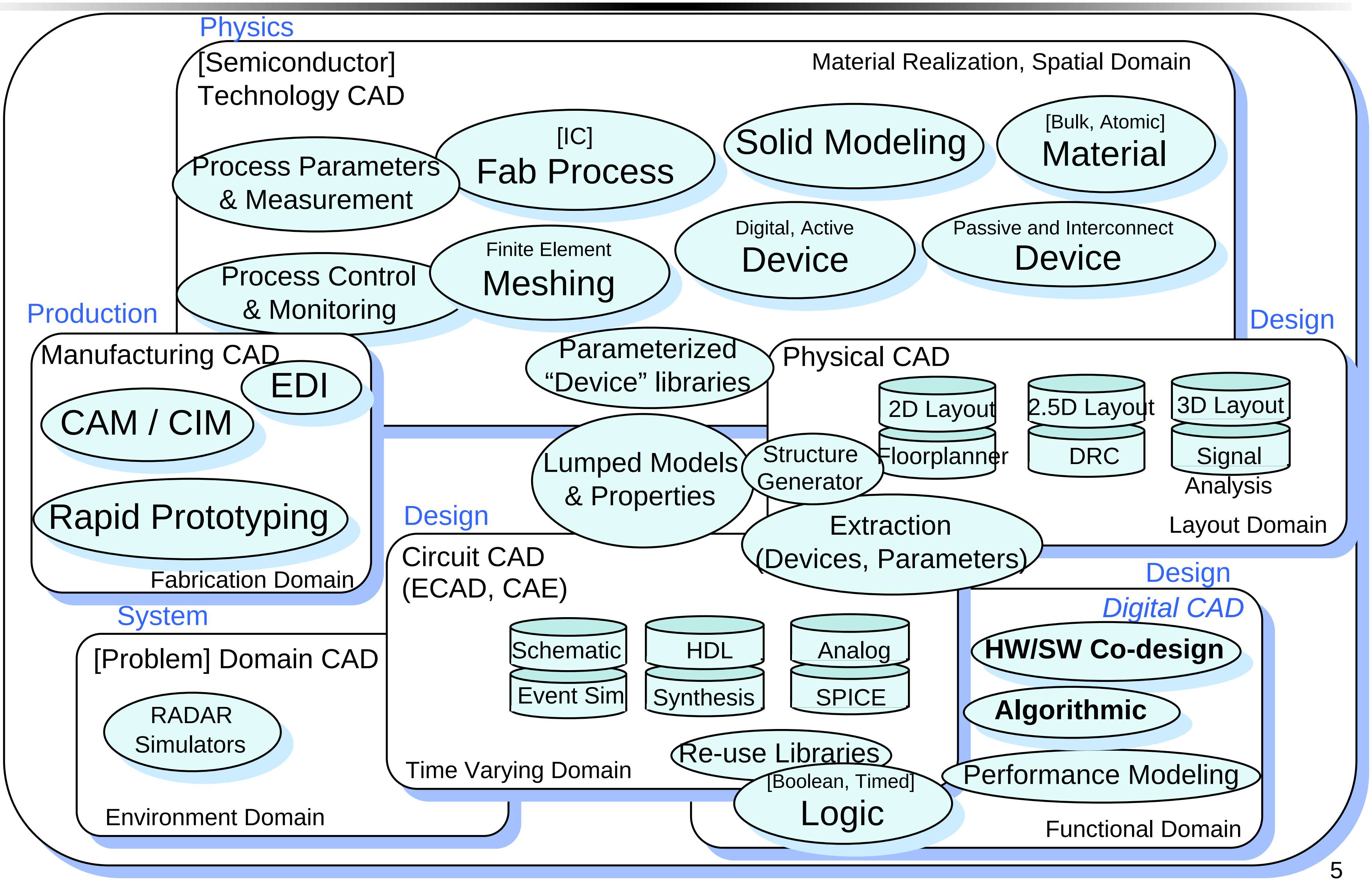
- Integrated microdevice and system design not large enough to catch the attention of ECAD / TCAD design tool companies (paradigm shift)
- Stove pipe TCAD tools have not developed common interfaces between shape, meshing, solver, visualization tools that allow needed extensions
- Microdevices have coupled energy domain behavior that is not intuitive
- First order generalized 3D device analysis is not computationally feasible
- Increasing need for optimizing second and third order effects that cannot be accounted for in isolation
- Lumped element, multi-node device models cannot be readily created
- No parameterized, fabrication-sensitive device models are available for design
- Mixed technology design is currently a long layout-build-verify process with little optimization possible
- No design framework for emerging microdevice based system tools (micro-optics, microfluidics, etc.)
- Single MEMS devices take more than one year to design and validate

Diversity of Computer-Aided Design (CAD) Tools



Mixed Technology Design Methodology

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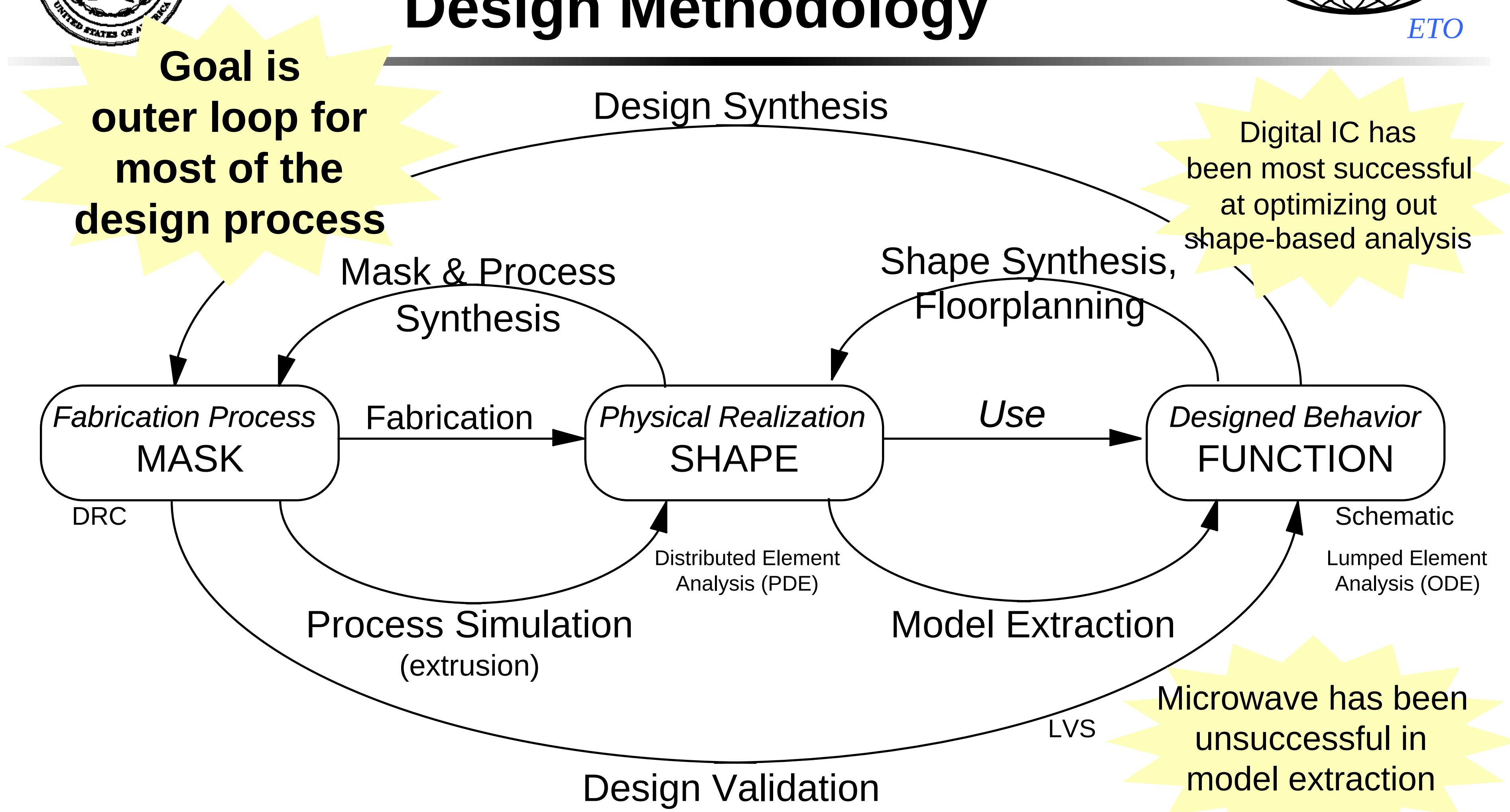


Optimization issues:

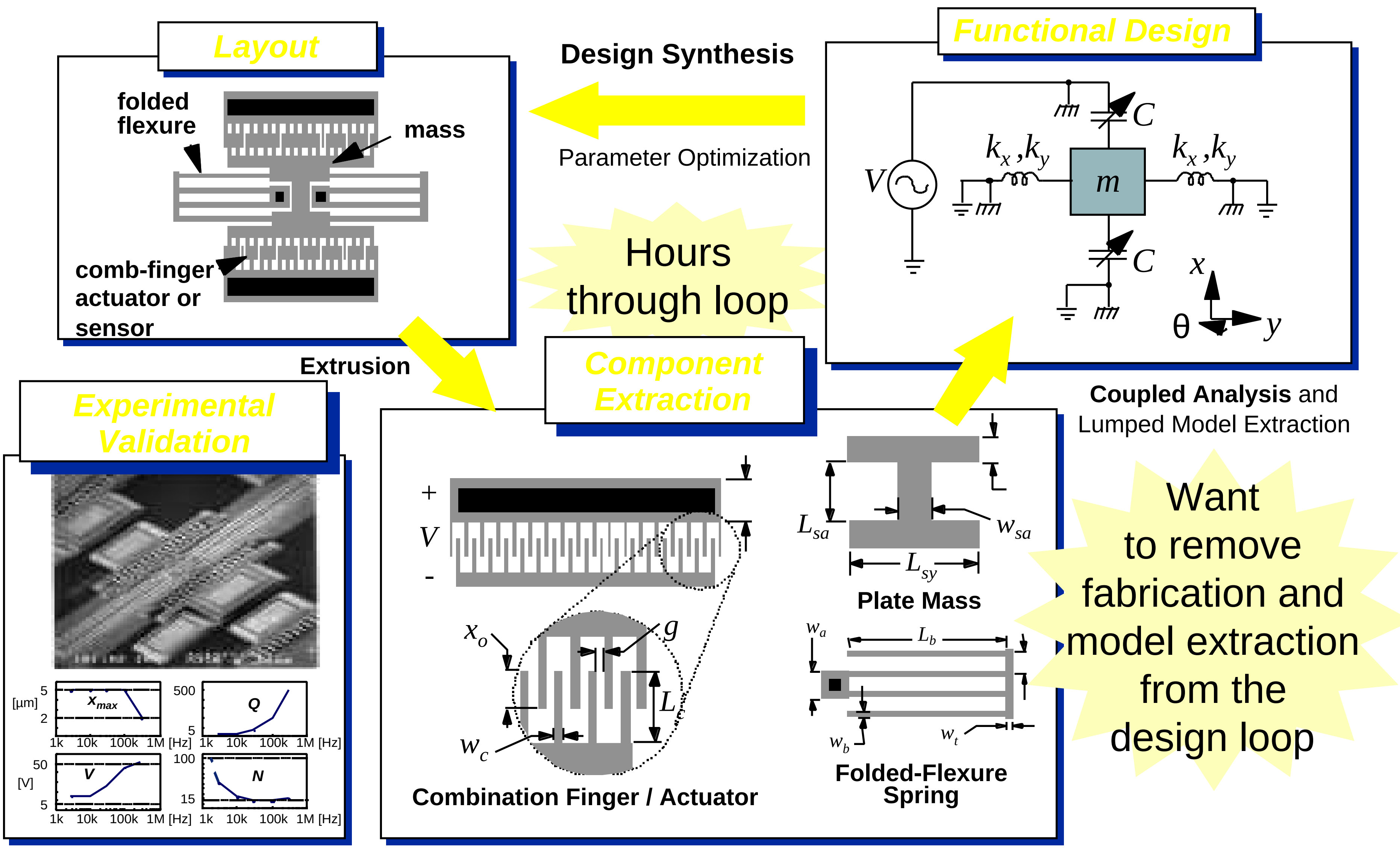
Cost, Produceability

Power, Thermal Dissipation, Stress/strain, Volume/Area, Environmental Immunity

Flexibility, Functionality

Diagram adapted from: Antonsson, Erik K. (Ed); “Structured Design Methods for MEMS”, NSF Workshop, Nov 1995, **http://red.caltech.edu/NSF_MEMS_Workshop**

Resonator Design after Composite CAD



Adapted from: G. Fedder, CMU

BAA 96-16 Selections

(actual or near award)

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TITLE	Contractor	Team Members	Rome Laboratory POC	Contractor Technical POC
Foundations of MEMS Synthesis	Carnegie Mellon Univ.	MIT, Univ of Penn, UCB	Mark Pronobis, pronobis@rl.af.mil, (315)-330-3841	Prof. Gary K. Fedder, fedder@ece.cmu.edu, (412)-268-8443
Portable Coupled Field CAD (BEM)	Coyote Systems	UCB, HP, Sandia, TI, Draper	Clare Thiem thiemc@rl.af.mil (315)-330-4891	Dr. Per Ljung pbljung@tin.me.berkeley.edu (510)-486-0347
CAD for Cheminical Transport in MicroFab	Microcosom Technologies	Applied Bio, Stanford	Peter Rocci roccip@rl.af.mil (315)-330-4654	Dr. John Gilbert jrg@memcad.com (617)-255-0094
CAD for Integrated MEMS Devices	Analog Devices, Inc.	Microcosm	Bob Hillman hillmanr@rl.af.mil (315)-330-4961	Donal Murphy donal.murphy@analog.com (617)937-1639
Adv CAD sys for Electromagnetic Mems Interactive Analysis (ACADEMIA)	Stanford University	Texas Instruments	Mark Stoklosa stoklosam@rl.af.mil (315)-330-4891	Dr. Robert Dutton dutton@gloworm.stanford.edu (415)-723-4138
Simulation & Analysis of Mixed Tech Sys	Analogy Inc.		Steve Drager dragers@rl.af.mil (315)-330-2735	Darrel Teegarden darrell@analogy.com (503)-520-2731
Design Support for Mixed Technology Integration (Composite CAD)	Tanner Research	Univ of Mich, MIT	Paul Ratazzi ratazzi@rl.af.mil (315)-330-3766	Peter Parrish peter.parrish@tanner.com (818)-432-5731

Foundations of MEMS Synthesis

Carnegie Mellon University (lead)

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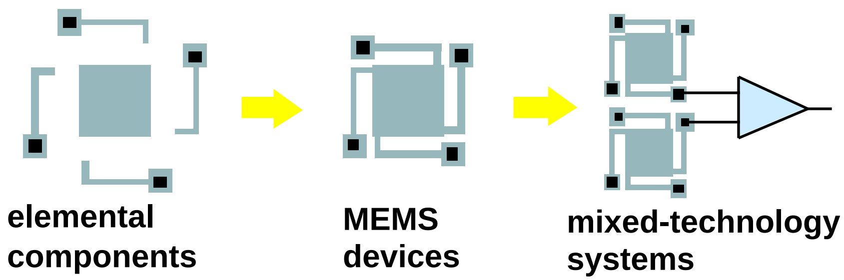
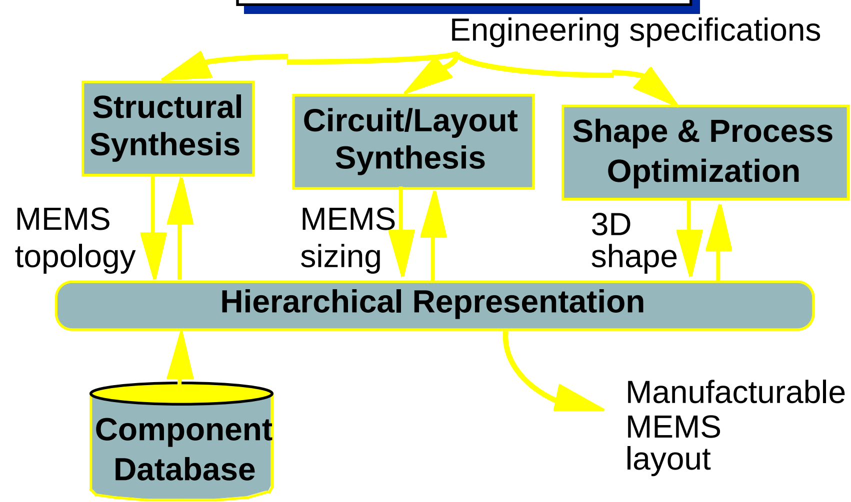
Goal/Objectives

Reduce design time of manufacturable, mixed-domain, multi-device MEMS from years to days by developing a hierarchical design methodology and associated synthesis tools.



Tasks/Approach



Status/Accomplishments

In first 6 months, develop initial:

- hierarchical representation
- component library
- design rule approach
- optimization models

and install software and equipment

Schedule/Milestones

- 9/97 ■ 6-DOF microresonator synthesis example
- 6/98 ■ Graphical design representation
- 9/98 ■ Synthesis with circuits; Accelerometer synthesis example; calculation of quasistatic surface sensitivities to process variations
- 6/99 ■ MEMS connectivity grammar
- 9/99 ■ Synthesis with manufacturing constraints; Gyroscope synthesis example; dynamic surface sensitivity calculation

8/96-8/99; POC: Gary K. Fedder, (412) 268-8443, fedder@ece.cmu.edu

Portable Coupled Field CAD

DARPA ETO

Lead Organization: Coyote Systems

Objectives	**Approach**
• Radically simplify MEMS modeling • Develop portable tool	• Employ boundary element method • Portable MATLAB implementation • Solvers address coupled linear/ nonlinear/timevarying field equations • Fast O(N log N) computations • Incremental release of software
Status	**Schedule**
• Preliminary teaming arrangement established with Sandia National Laboratories, Hewlett-Packard, Draper Labs, Texas Instruments, University of California • Prototype 3D boundary element method (BEM) code working	• Software release every six months starting at contract award • First Year - scalar/vector solvers & visualization, 2D/3D Navier & Laplace discretization • Second Year - GUI, coupled & iterative solvers, nonlinear/ timevarying & 2D/3D Helmholtz discretization • Third Year - mask input, fast solvers, modal analysis & adaptive discretization

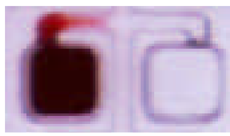
36 Months POC: Dr. Per Ljung, (510) 486-0347, email: pbljung@coyotesystems.com

NetFlow: CAD For Chemical Transport In Microfabricated Fluid Interconnects

ETO

Goals

Develop Design Automation Tools Which Will Enable Rapid Design of Complex Microchemical Fluidic Networks Within MEMS



Tasks

Develop Tools For:

- Generating Fluidic Networks (NetFlow-G)
- Analyzing Microfluidic Containment (NetFlow-C)
- Analyzing Microfluidic Transport (NetFlow-T)

Status

- Team Assembled
- Subcontracts Drafted
- Design and Experimental Work Commencing

Schedule

- **Year 1:** NetFlow-C,T,G v1.0, Test & Validate NetFlow-C
- **Year 2:** NetFlow-C,T,G v2.0, Test & Validate NetFlow-T
- **Year 3:** NetFlow-C,T,G v3.0, Test & Validate NetFlow-T

Duration: 36 mos

Start: 29 Aug 96
Complete: 29 Aug 99

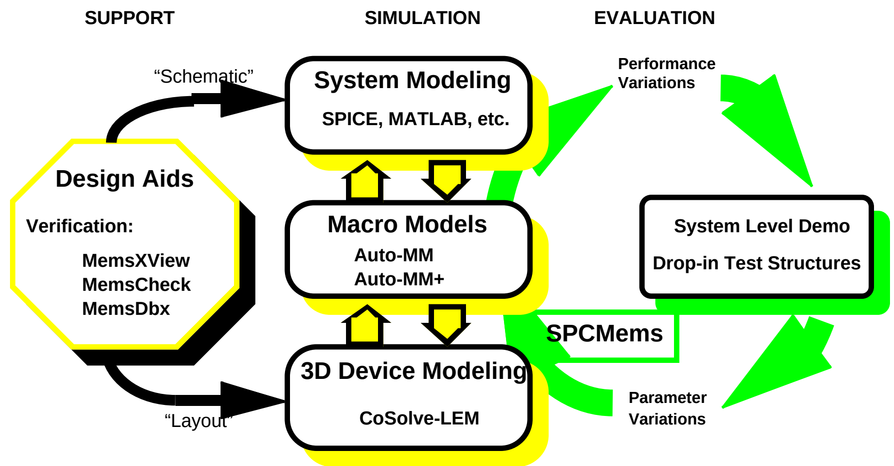
PI: Dr. JohnGilbert, Microcosm, Inc.
617-225-0094 jrg@memcad.com

Analog Devices * Microcosm

ETO

Objective

Develop a Suite of CAD Tools that provide a Self-Consistent Modeling enviornment enabling the effective *Design*, *Simulation, Verification*, and *Manufacturing* of large, rigid, complex MEMS devices



Status / Accomplishments

- **New employee requisitions are completed and both Analog Devices and Microcosm are actively staffing up for the program.**
- **Memcad 3.0 software and its required hardware has been purchased.**
- **Preliminary work on automatic macro-model generation has been begun.**

Sept 96-Aug 99

Schedule / Milestones

Modeling Tools (Q4-99)
- ***Co-Solve-Lem* Large Rigid Structures**
- ***AutoMM* electro-mechanical model generator**

Design Tools
- ***MemsXVIEW* Design Manager (Q3-97)**
- ***MemsCheck (Q4-98), MemsDbx (Q1-99)***

Manufacturing Analysis (Q3-97 +)
- **In-line Monitoring Test Structures**
- **Manufacturing Analysis Package to enhance Behavioral Modeling**

POC: Donal Murphy (617) 937-1639 Donal.Murphy@analog.com

ακαδεμια ***---Advanced CAD for MEMS***

Goals/Objectives:

•Develop gridding & FEM analysis for CAD MEMS infrastructure that supports rapid prototyping.

•Testing and demonstration of system and tools (gridding & FEM) based on practical examples relevant to DoD.

•Benchmarking and calibration of models, including influence of thin-film materials properties.

Tasks/Approach:

•Develop gridding tools using framework standards that directly support the MEMS requirements

•Use the RF switch for MAFET as one test vehicle, along with broader applications through Stanford IC Lab

•Develop specific test structures that extract fundamental properties of materials for MEMS.

Status/Accomplishments:

•Progress in SWR 0.3 and tools that support the SUPREM OO7 architecture provide major leverage

•Collaboration with several MEMS groups (TI, UCB, MIT...) provides additional end-user perspective.

•Unique fabrication and metrology already in place at Stanford

Schedule/Milestones:

•Advanced geometry & gridding (Q1/98)

•Test structure design/evaluation (Q4/98)

•Develop/Integrate FEM tool(s) (Q1/99)

•Benchmarking joint with TI (Q1/99)

•User access/testing via NNUN (Q4/99)

•Multi-layer materials testing (Q4/99)

•System testing/evaluation (Q4/99)

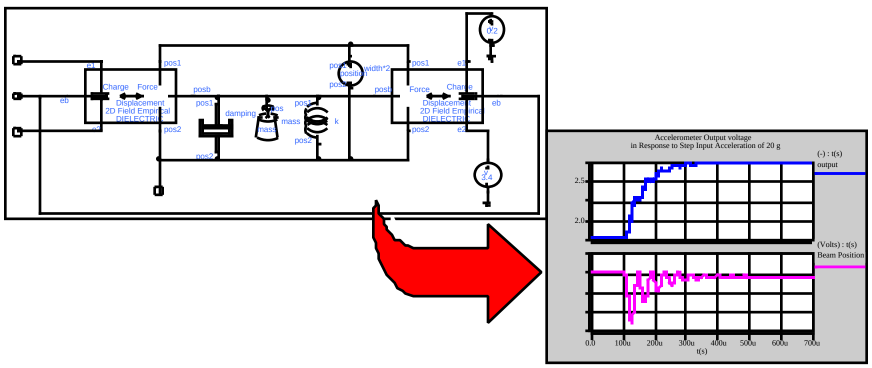
duration 9/96 - 8/99 PI: Robert W. Dutton ph: 415-723-4138 dutton@gloworm.stanford.edu

Simulation and Analysis of Mixed-Technology Systems

ETO

Objective:

• Develop a general ODE modeling environment to facilitate top down design and simulation of microelectromechanical systems



Approach:

• Develop a portable, multi-abstraction level, mixed technology simulation environment for use with digital, analog, mechanical, optical, and fluidic MEMS systems
• Utilize the IEEE standard, VHDL-AMS, as the modeling language
• Develop and implement a parallel, single kernel simulation engine

Accomplishments:

• MEMS simulation using MAST(R)
• Prototype of VHDL and MAST(R) in single kernel simulation
• Preliminary system requirements

Milestones:

• Concept prototype (9/96)
• Architectural prototype (3/97)
• Product prototype (7/98)
• Product shipment (10/98)

Goals/Objectives

- Develop desktop productivity tools for MEMS design entry, design verification, macromodeling and simulation.
- Expand access to MEMS design and prototyping.
- Offer tools for commercial sale, with timely upgrades and technical support at affordable prices.
- Offer cross-platform support

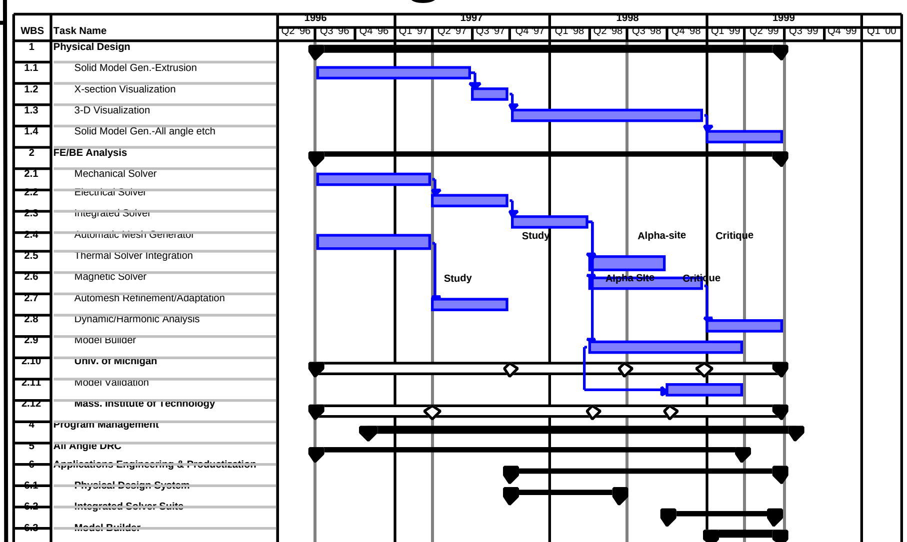
Status/Accomplishments

- Reviewed EDA Industry Stds. Roadmap and CFI TCAD Committee Standard
- Designing and prototyping design entry features and "properties" data structures.
- Defining all angle DRC capabilities
- Developed all angle rotation of instances, arcs/toruses, variable angle etch/undercut, polygon area calculation, parametrized layout generator

Tasks/Approach

- 3D Solid Modeling with cross-section and results visualization.
- Mixed energy domain Finite Element-Boundary Element analysis: mechanical, thermal, quasistatic EM.
- Efficient macromodel (behavioral model) generation

The Program Plan



Peter Parrish, (818) 432-5731
peter.parrish@tanner.com

Tanner Research * University of Michigan * MIT

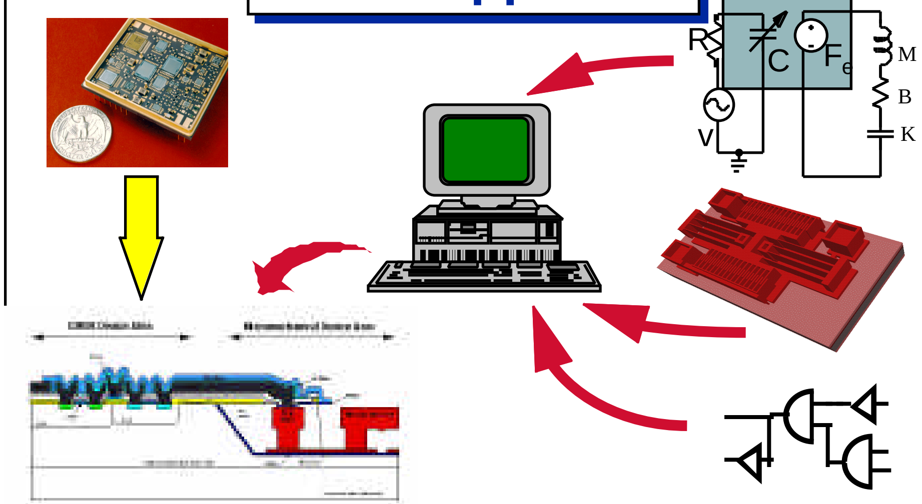
MEMS Time Stress Measurement Device (TSMD)

ETO

Goal/Objectives

- **Design a monolithic integrated MEMS-based TSMD for monitoring electronics**
- **6:1 size reduction over current hybrid TSMD technology with greatly improved power, unit cost and reliability**
- **Baseline Composite-CAD tools**
- **Demonstrate a system-on-a-chip design methodology**

Tasks/Approach



Status/Accomplishments

- **Performance level VHDL model in progress**
- **Baseline Composite CAD tools being installed**
- **Assembler for TSMD source code completed**
- **TSMD source code ported to VHDL (6895K SLOC)**

Schedule/Milestones

In next 6 months:

- **Complete VHDL performance model**
- **Fabricate MCNC MEMS pathfinder**
- **Complete MEMS TSMD specification**
- **Start 3D model generation effort**
- **Install software and equipment**

36 Months POC: Mark Pronobis, (315)-330-384, pronobism@rl.af.mil