MEMS Modelling

May 12, 2015

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Technical Director – MEMS, Coventor

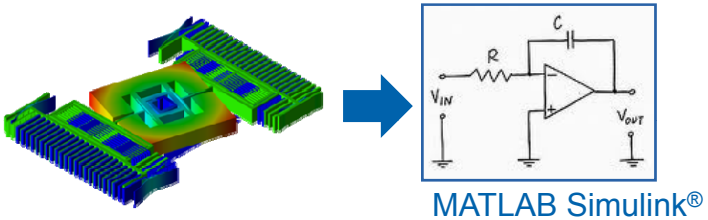
MEMS Modeling
微机电系统模型

COVENTOR

MEMS Design Automation 微机电系统自动化设计

MEMS+® high-order FEA
高阶有限元分析

Cadence Virtuoso®



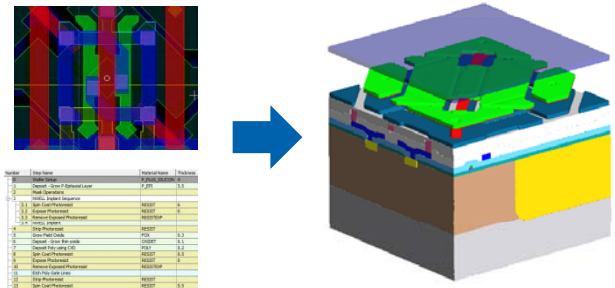
MATLAB Simulink®

CoventorWare® hybrid FEM/BEM
混合有限元、边界元方法

- Fast simulations for concept exploration and design optimization → **faster time-to-market**
  探索方案、优化设计、快速仿真 → **快速市场化**
- Integrated MEMS+CMOS design flow and design kits → **enables fabless MEMS/IOT market**
  整合MEMS+CMOS设计流程以及设计包 → **物联网的高效研发**
- MEMS multi-physics, nonlinear coupled electro-mechanics 多物理体系、非线性电子 - 机械耦合
- Live Demo 现场案例演示

Virtual Fabrication 工艺模拟

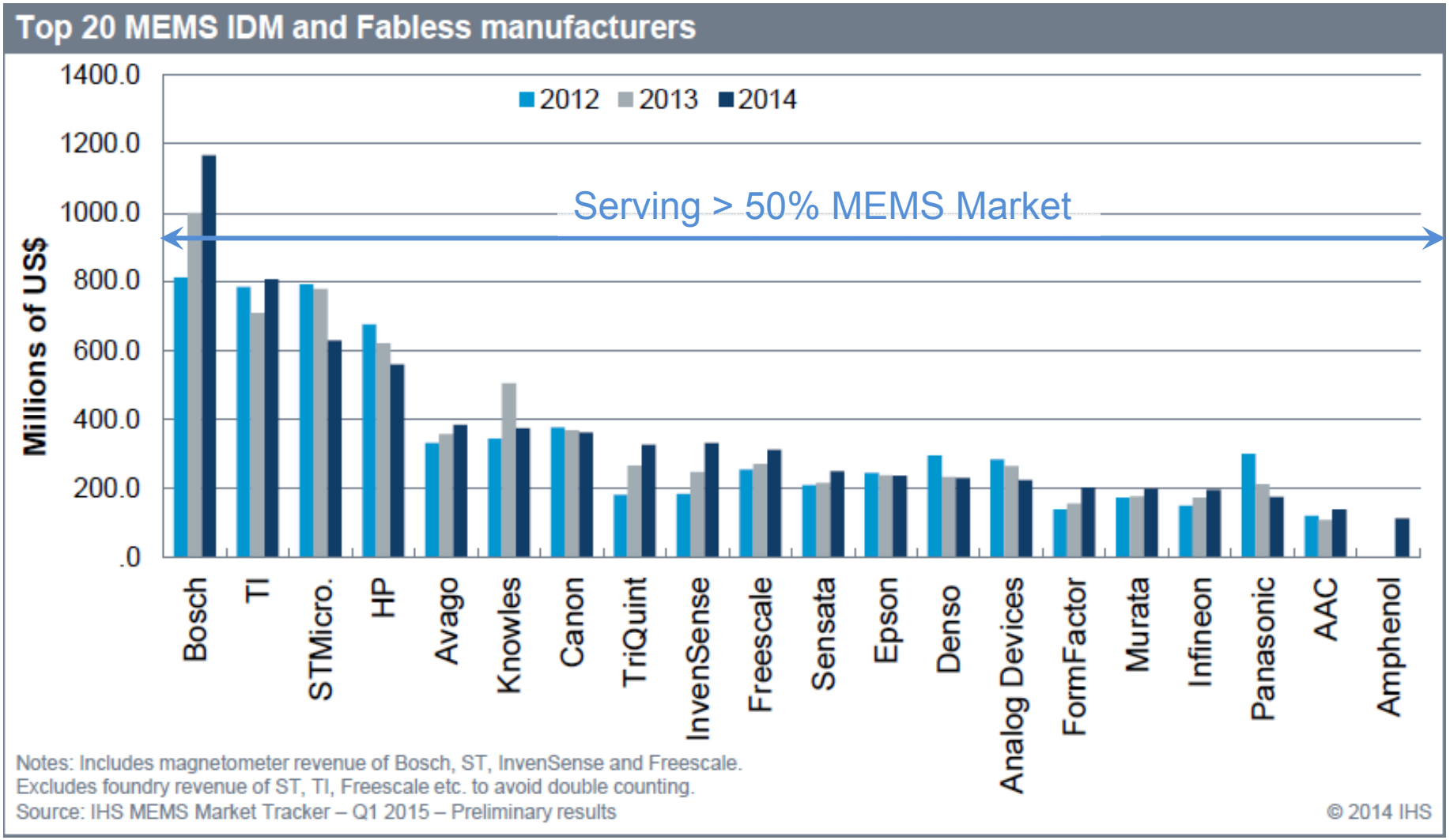
SEMulator3D®



- Process development → **shorten or avoid in-fab learning cycles**
  发展模拟制程 → **缩短或避免在产线上的学习周期**
- 3D verification for mask sign-off → **catch design errors before fabrication**
  掩膜版的3D验证 → **上产线之前发现、更正设计错误**
- **Structured, efficient communication** between designers & fab/foundry 设计-晶元代工厂之间更有效沟通
- Live Demo 现场案例演示

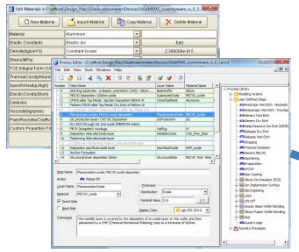
Coventor Customers Comprise > 50% of the MEMS Market

COVENTOR

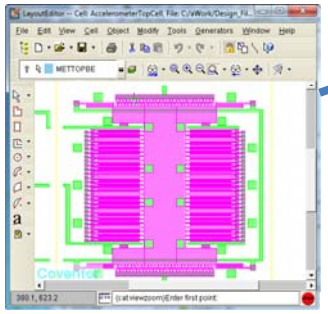


CoventorWare, from 2D Layout to 3D Simulations

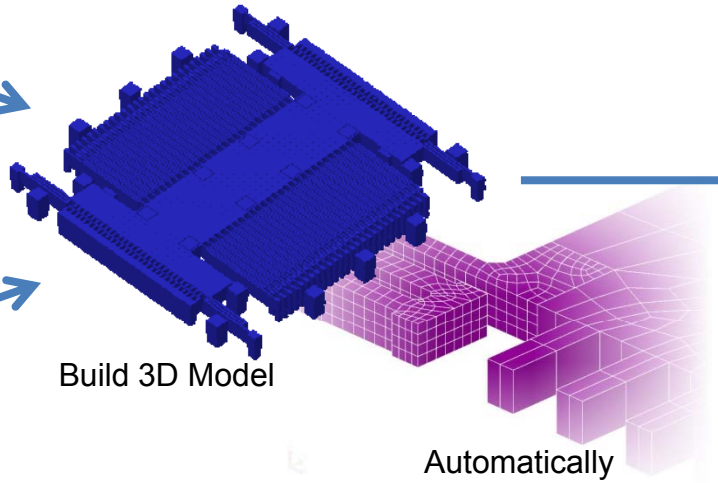
DESIGNER | ANALYZER



Materials & Process

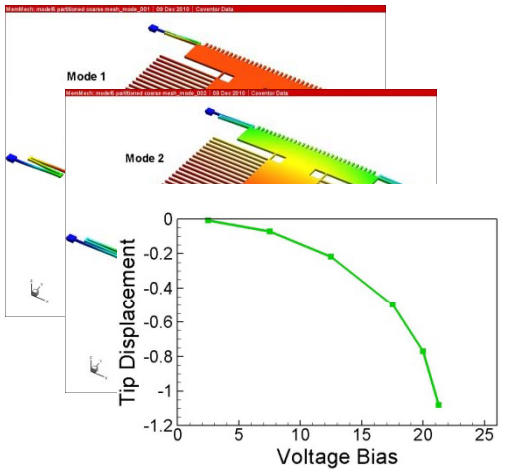


Create 2D Layout



Build 3D Model

Automatically Generate Mesh



Simulate, Visualize, and Analyze

Process-Centric Design Entry

Preprocessing and Mesh Generation Optimized for MEMS Geometry

Hybrid FEM/BEM Suite of Multi-Physics Field Solvers

Customer Publication with CoventorWare

A Monolithic 9 Degree of Freedom (DOF) Capacitive Inertial MEMS Platform

Ilker E. Ocak*, Daw D. Cheam, Sanchitha N. Fernando, Angel T.H. Li
Jaibir Sharma, Geng L. Chua, Bangtao Chen, Alex Y.D. Gu, Navab Sing

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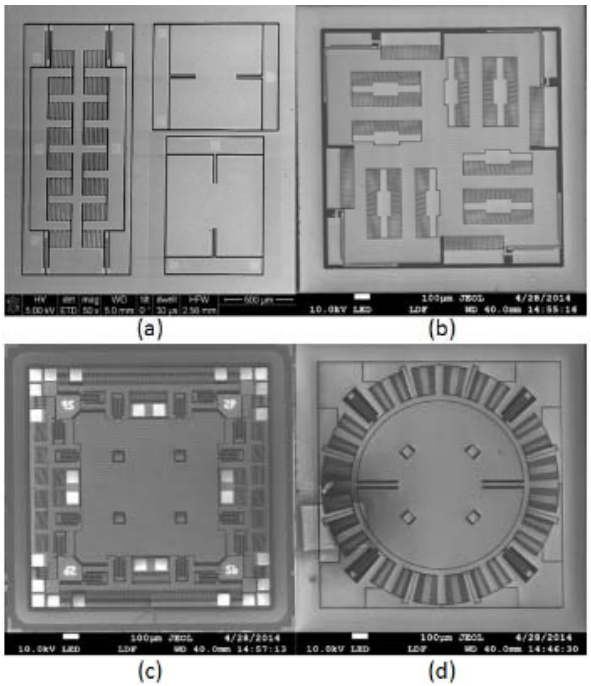

Figure 3: SEM images of fabricated sensors. (a) Three axis Lorentz Force magnetometer (b) Dual axis accelerometer (c) Z - axis tuning fork gyroscope (d) X & Y axis gyroscope

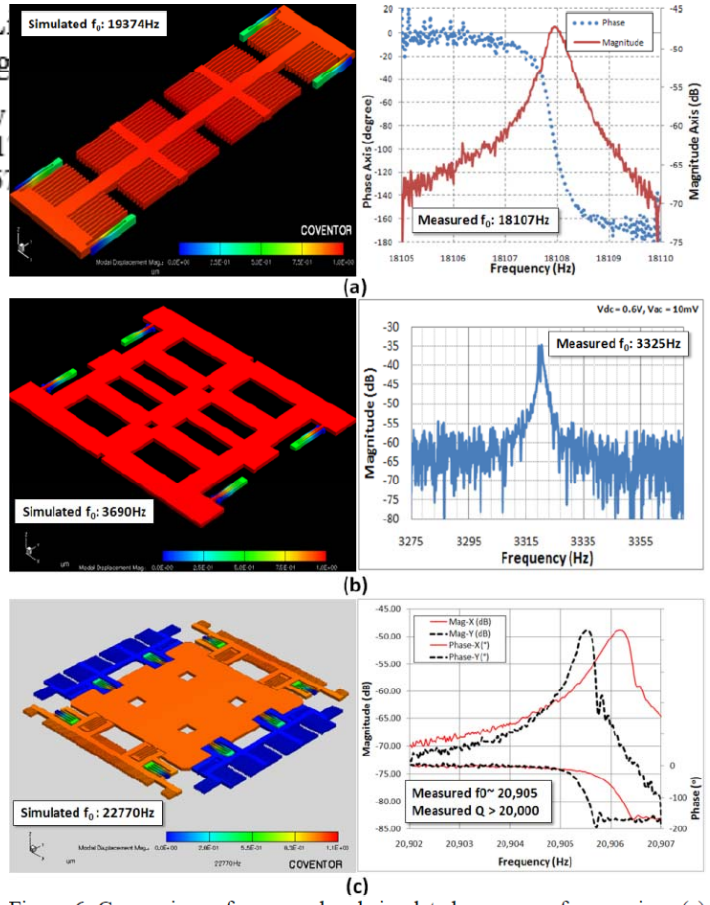

Figure 6: Comparison of measured and simulated resonance frequencies. (a) Magnetometer measured 18.1kHz and simulated 19.3kHz. (b) Accelerometer measured 3.3kHz and simulated 3.6 kHz. (c) Gyroscope measured 20.9kHz and simulated 22.7kHz.

CoventorWare Live Demo, A Gyroscope Example

Material & Process

Layout

Preprocessor

Modal Analysis

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MEMS Design Automation

MEMS Development Issues

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Design cycle time is unacceptable

- New concept to production often takes years

Designers lack MEMS-specific software automation

- General-purpose FEA does not address MEMS multi-physics
- General-purpose FEA is too slow and does not link to EDA flow

Redundancy of modeling effort

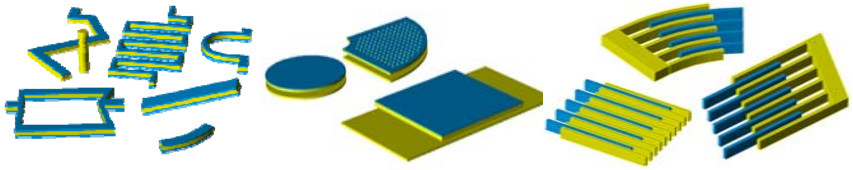
- MEMS designers create an FEA model of their device
- … then IC Designers need a SPICE/Verilog-A model of the MEMS
- … then System Designers need a MATLAB model of the MEMS
- … the list goes on for packaging, testing, failure analysis, etc.

Build-and-Test fab cycles are long and wasteful

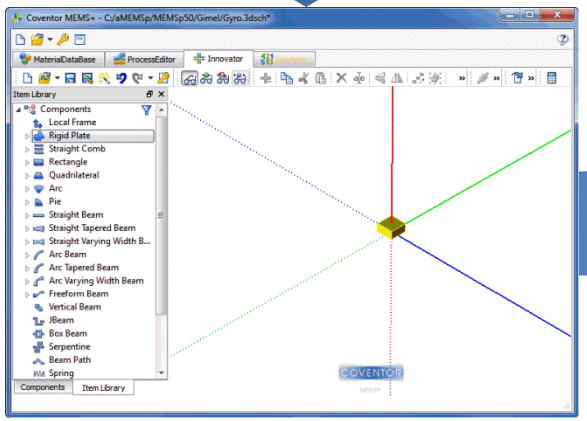
- Inadequate tools for MEMS process development

MEMS+ High-Order FEA

MEMS+ library of
high-order finite elements



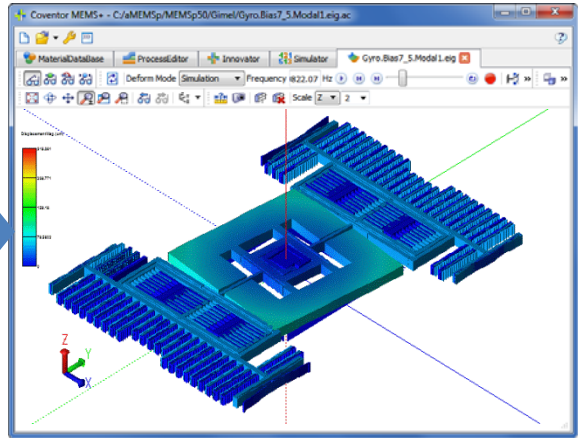
Typically 100X faster than conventional FEA



MATLAB
MathWorks
Simulink

cadence
Virtuoso

Exported Verilog-A or Simulink ROM



Enter Design | Simulate | Visualize Results

Customer Publication with *MEMS+*

COVENTOR

UVM-SystemC-AMS based Framework for the Correct by Construction Design of MEMS in their Real Heterogeneous Application Context

Torsten Maehne*, Zhi Wang*, Benoît Vernay*†, Liliana Andrade*, Cédric Ben Aoun*, Jean-Paul Chaput*, Marie-Minerve Louërat*, François Pêcheux*, Arnaud Krust†, Gerold Schröpfer†, Martin Barnasconi‡, Karsten Einwich§, Fabio Cenni¶, and Olivier Guillaume¶

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¶STMicroelectronics (Grenoble) SAS, Grenoble, France WWW: http://www.st.cor

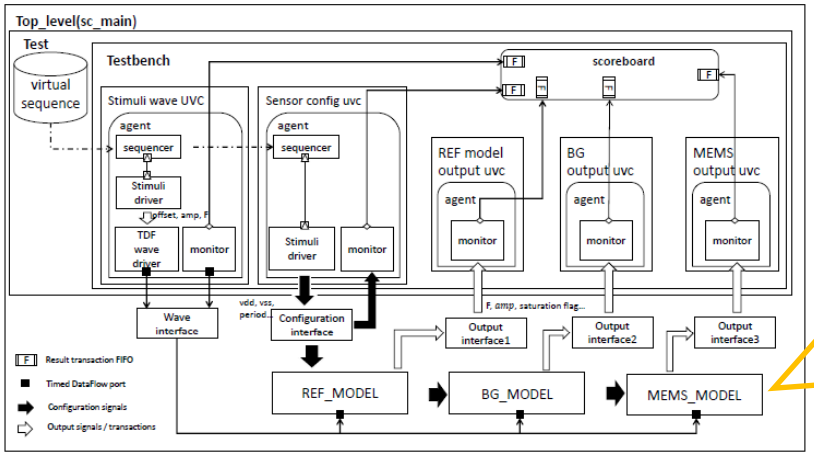
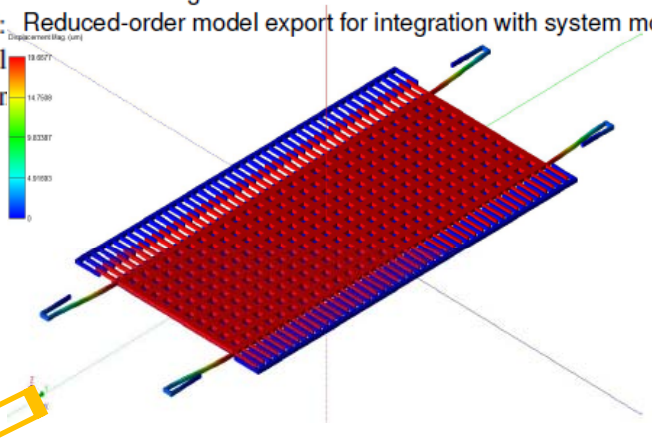


Figure 2. The complete UVM-SystemC-AMS testbench for the vibration sensor MEMS with refined scoreboarding.

Vibration sensor
Geometric design done in Coventor MEMS+®
Reduced-order model export for integration with system model



Electronics, Circuits and Systems (ICECS), 2014 21st IEEE International Conference on.

MEMS+ Live Demo, A Gyroscope example

COVENTOR

Material & Process

Innovator Model

Modal Analysis

Model Export for Matlab Simulink

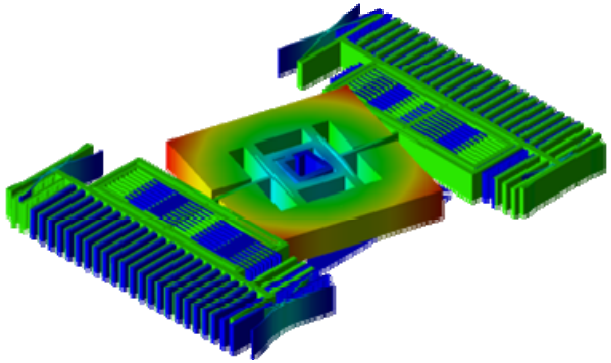
Model Export for Cadence Virtuoso

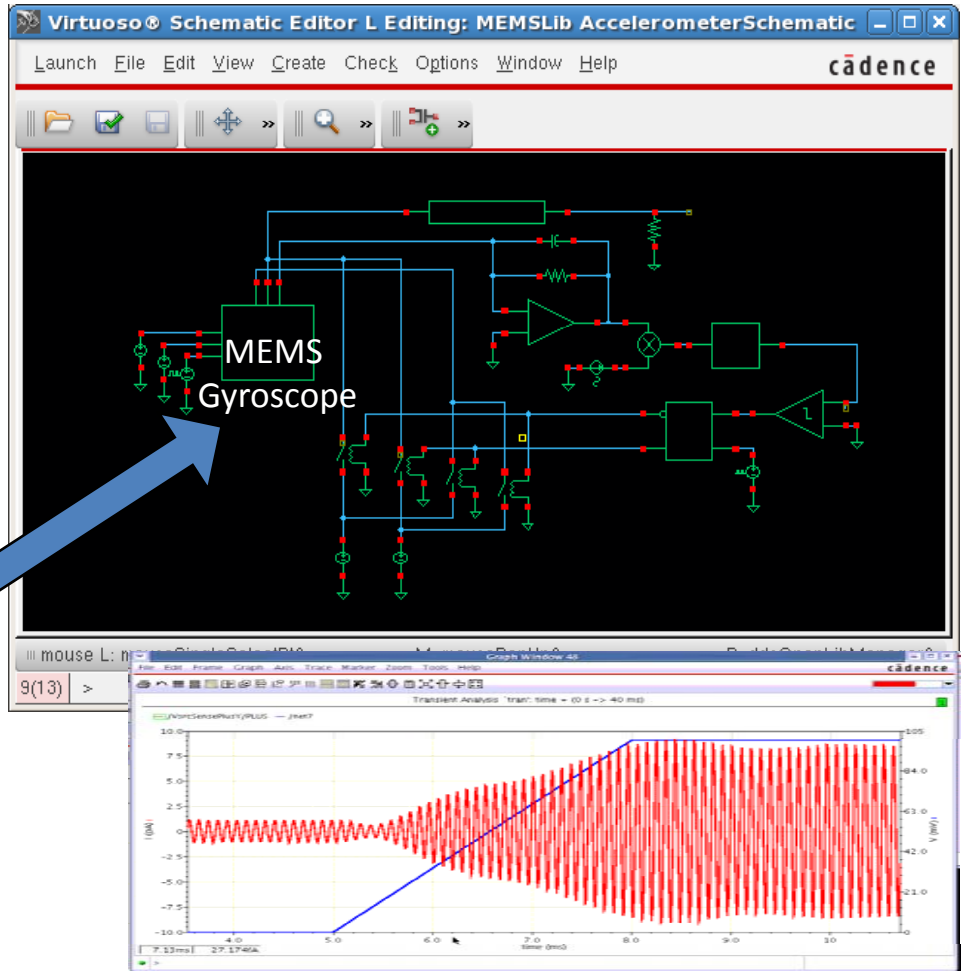
IC Designers need MEMS models for circuit design

Import a *MEMS*+ model to a Cadence Virtuoso schematic

- Include all essential nonlinearities
- Selectively linearize for speed

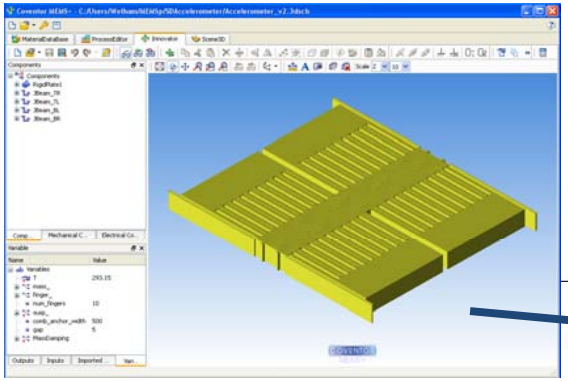
MEMS+ model of Murata Oy gyroscope



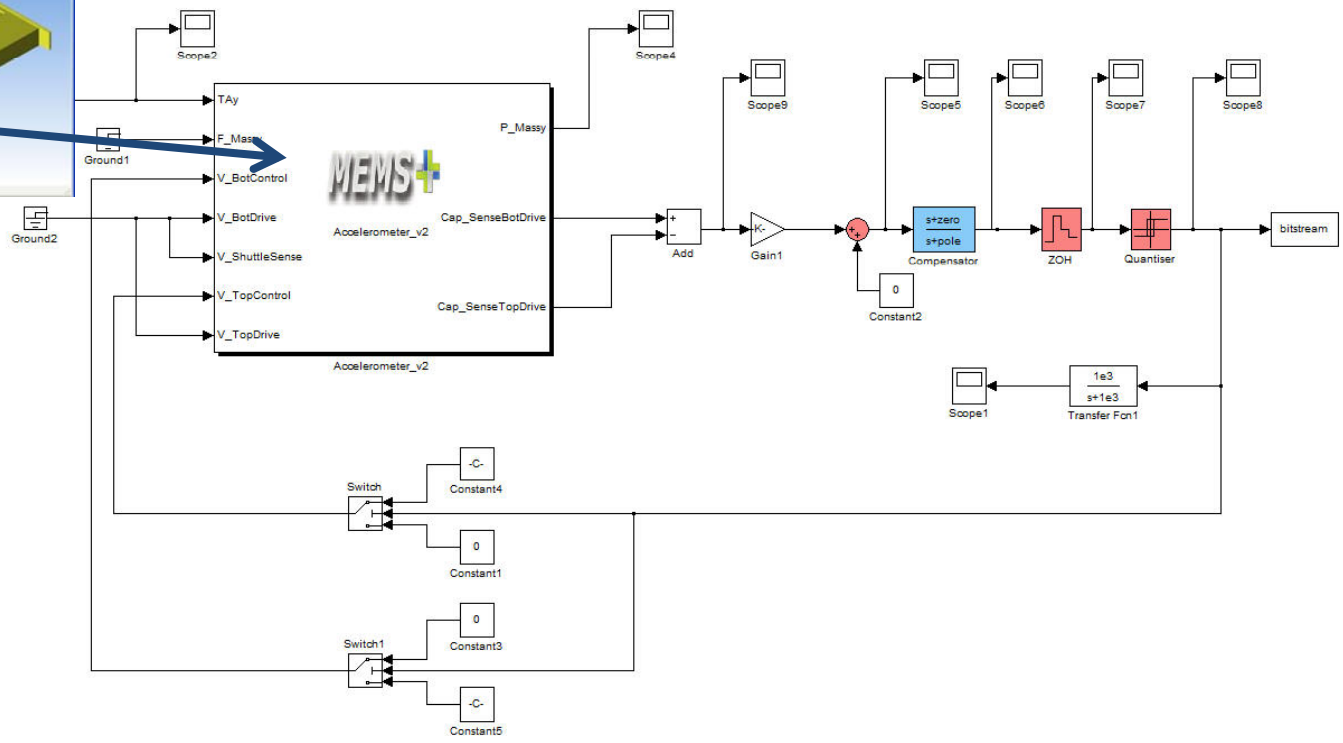


System Designers need MEMS models in MATLAB Simulink

3D accelerometer design in *MEMS*+



Simulink diagram:
accelerometer with sigma-delta controller



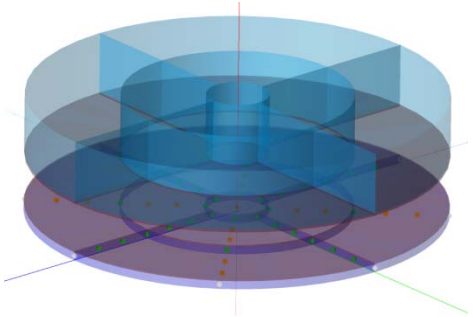
MEMS+ models plug into Simulink

- Non-linear
- Parametric
- Fast and accurate

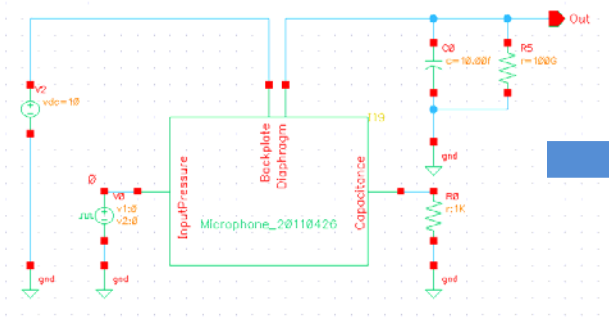
System Design Goal: Maximize S/N Ratio

- *MEMS*+ models support noise analysis in Cadence Spectre and accurately predict thermo-mechanical noise
- *MEMS*+ includes all relevant noise sources in your MEMS+IC system, enabling you to evaluate noise reduction strategies

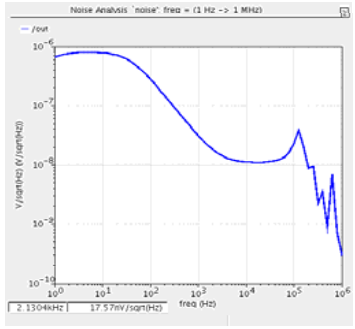
MEMS+ model of a microphone



MEMS+ model includes mechanics, electrostatics and fluidics (air pressure) effects

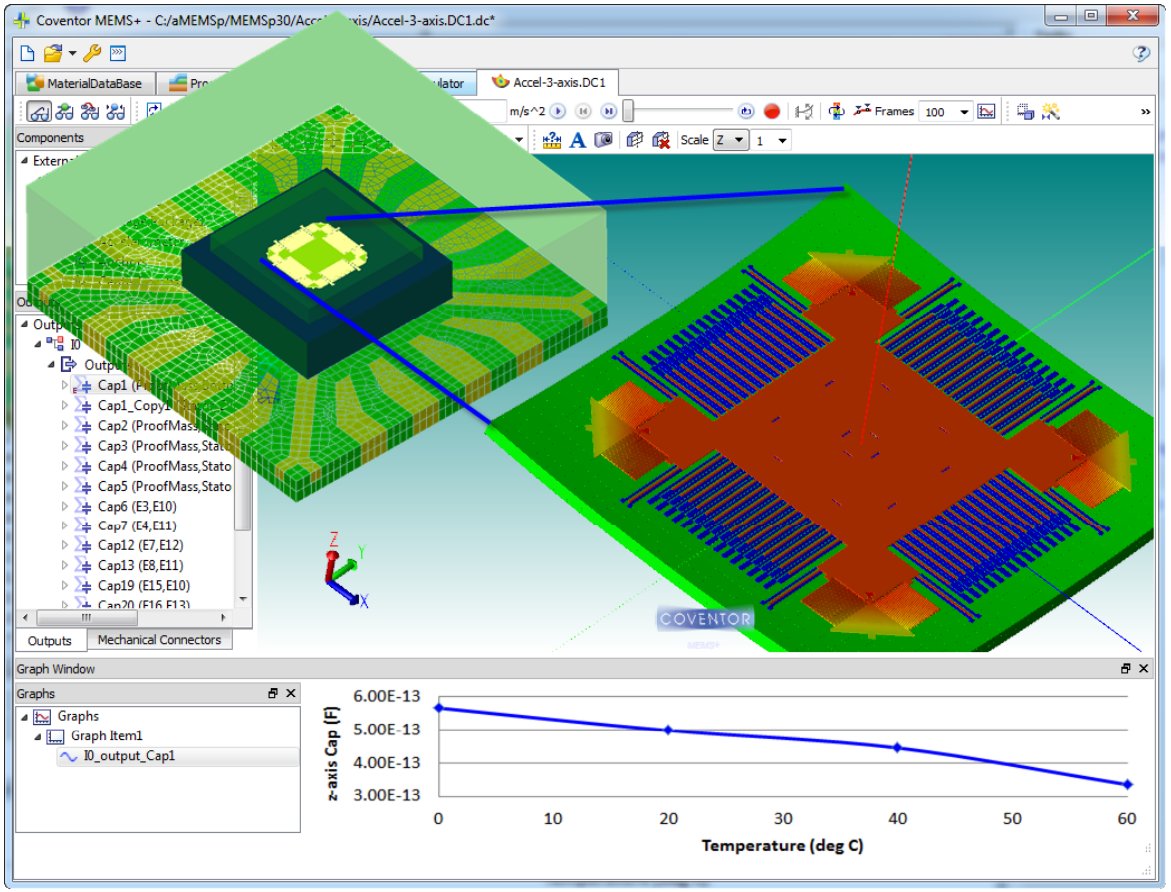


MEMS+ symbol in a Cadence Virtuoso schematic



Noise analysis in Cadence Spectre

Sensor Design Goal: Minimize thermal effects



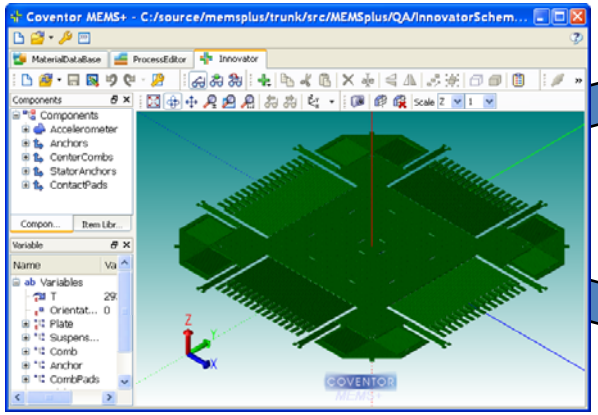
MEMS+ can predict how thermal effects on your package will affect critical sensor outputs such as zero-offset in accelerometers

Simulated zero-offset vs. temperature for z-axis of 3-axis accelerometer

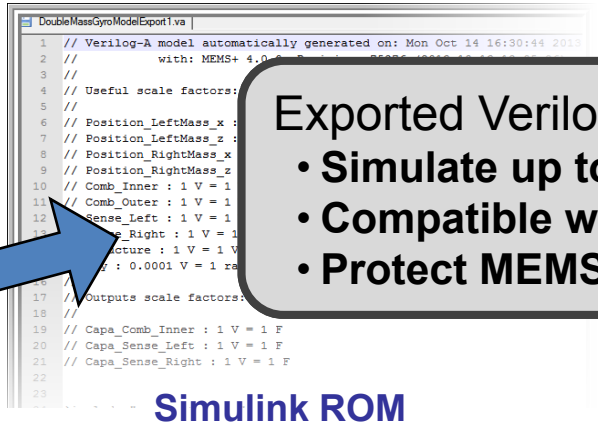
MEMS+ Automatically Generates Reduced Order Models (ROMs)

Nonlinear reduced-order model (ROM) export for very fast (100X) system simulations

MEMS+ User Interface



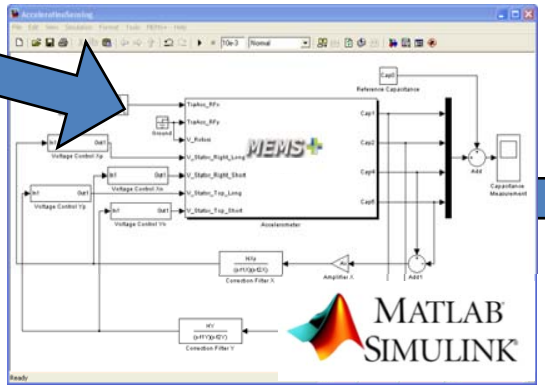
Verilog-A ROM



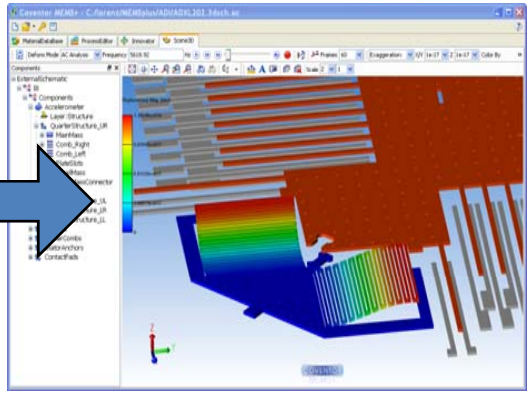
Exported Verilog-A ROMs

- **Simulate up to 100X faster**
- **Compatible with most A/MS simulators**
- **Protect MEMS design IP**

Simulink ROM

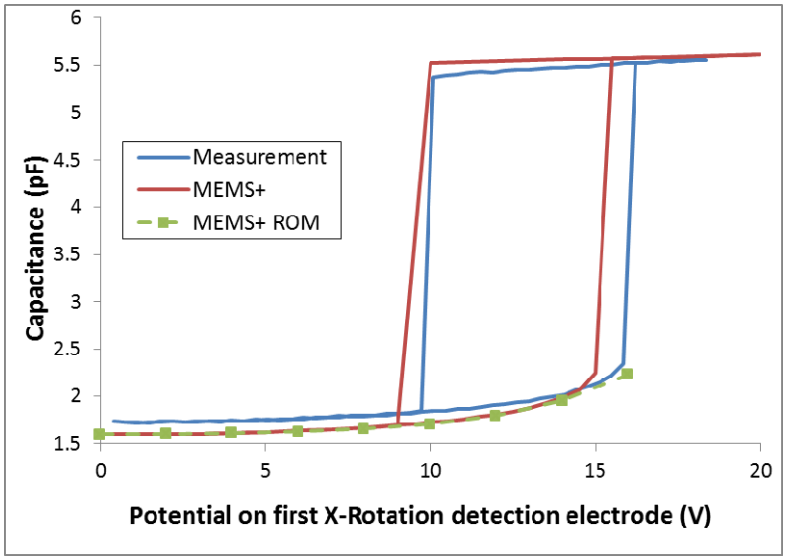


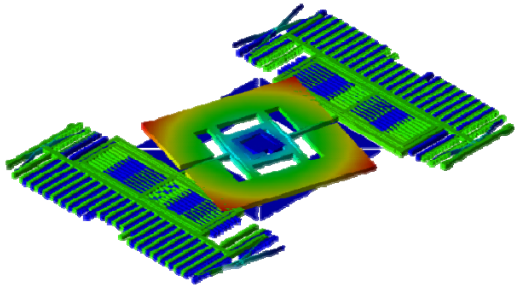
MEMS+
Result visualization

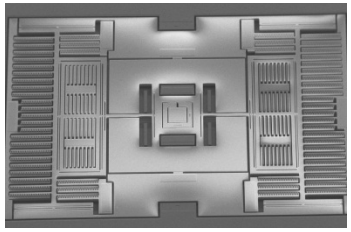


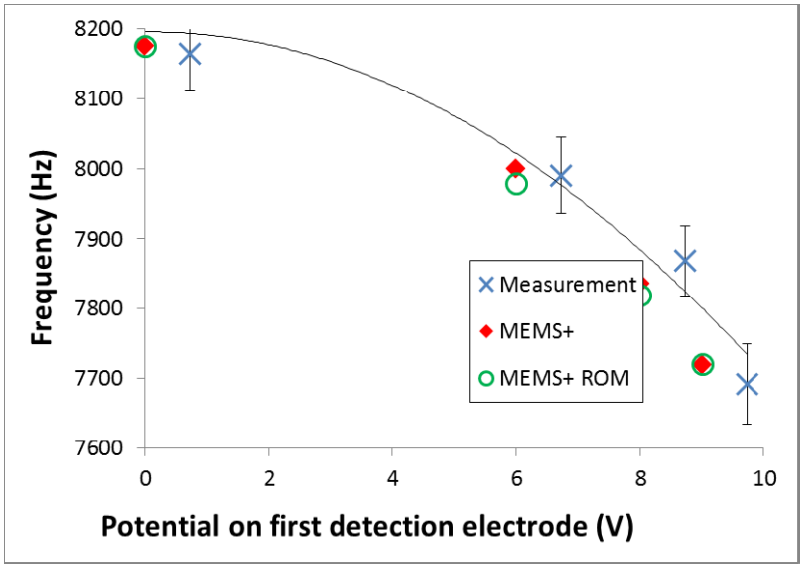
MEMS+ Validation Example

Murata 3-Axis Gyro, full *MEMS*+ model and exported ROM









A NOVEL MODEL ORDER REDUCTION APPROACH FOR GENERATING EFFICIENT NONLINEAR VERILOG-A MODELS OF MEMS GYROSCOPES
Arnaud Parent[1], Arnaud Krust[1], Gunar Lorenz[1], and Tommi Piirainen[2]
[1]Coventor sarl., France and [2]Murata Electronics Oy, Finland

Customer Quote

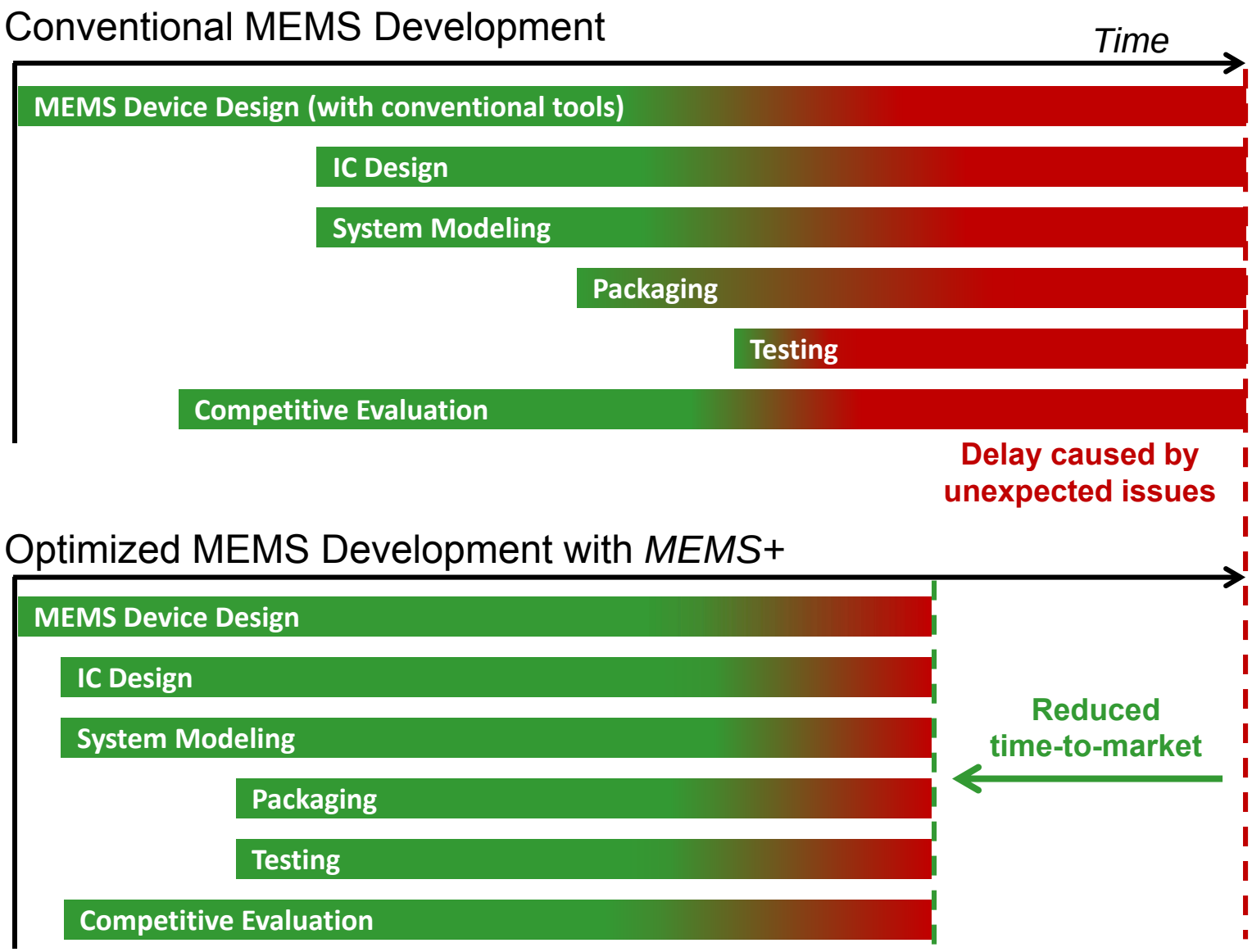
COVENTOR

Tero Sillanpää, ASIC Design Manager, Murata Oy:

"The Verilog-A Reduced Order Model (ROM) exported from *MEMS*+ 4.0 captures second order effects not seen in basic hand-crafted models without any compromise in simulation performance. We were able to create a Verilog-A ROM of a complex gyro design in just a few minutes, allowing our ASIC team to work in parallel with the MEMS team on further design iterations. Harmonic simulations in Cadence showed that the model maintained the expected modal frequencies and was stable. Moreover, transient startup simulations were very fast, on the order of 25s CPU time for 1s real time, before front-end electronic components including RC parasitic were added. The robust model exchange between MEMS and ASIC designers enabled by *MEMS*+ reduces the probability of design error and can help avoid costly redesign iterations needed to address unexpected behavior."

Exported Verilog-A models have significant advantages over hand-crafted models

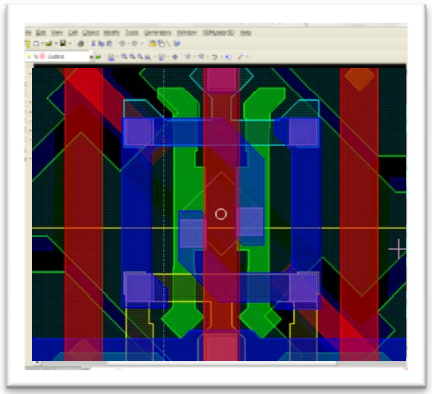
MEMS+ Enables Co-Design, Provides "Big Picture" Up Front

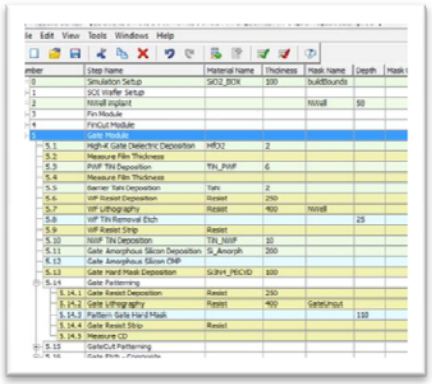


COVENTOR

Virtual Fabrication

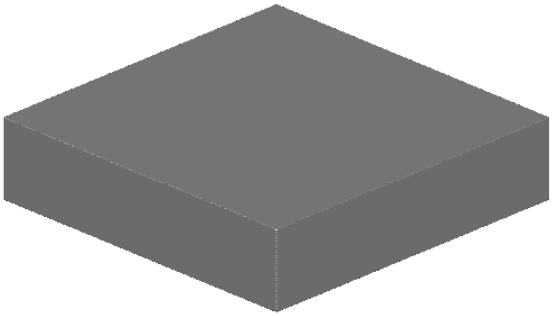
SEMulator3D™
Virtual Fabrication Platform





Design Data:
GDS2

Process:
Behavioral Description



3D Structural Model

- Handles complete process sequences and large areas
- Provides 3D structural models that are ***accurate***, not idealized
- Provides ***predictive*** insights on design/technology interactions

Customer Publication with SEMulator3D

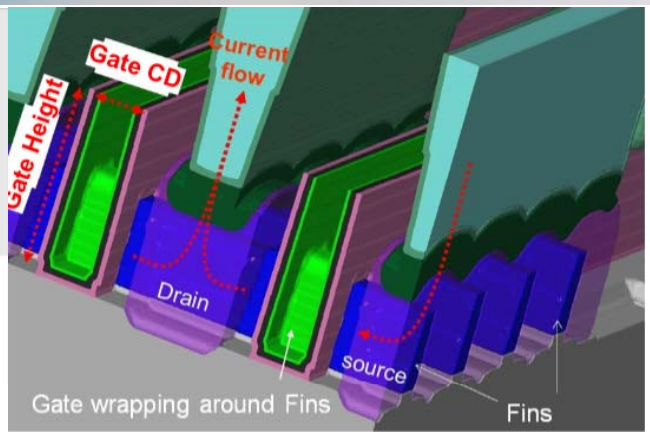
COVENTOR

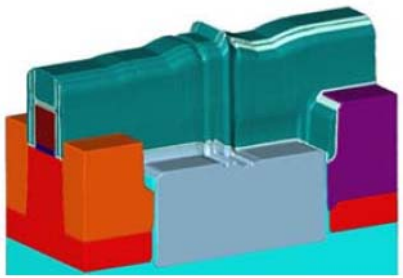
Cpk Based Variation Reduction: 14nm FinFET Technology

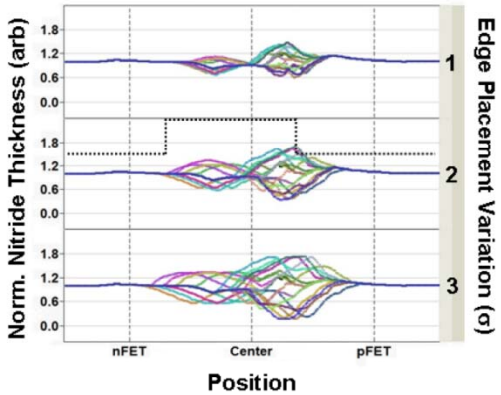
Rohit Pal, Alex Chen, Xing Zhang, Sruthi Muralidharan, Laks Vanamurthy, Girish Bohra, Chloe Yong, Mitsuhiro Togo, Changyong Xiao, Si-Gyung Ahn, Yuan-Hung Liu, Puneet Khanna, Dinesh Koli, Zhe Chen, Owen Hu, Karen Riding, Manfred Eller, Rick Carter, Srikanth Samavedam

SEMICON West2014

GLOBALFOUNDRIES







22nm Technology Yield Optimization Using Multivariate 3D Virtual Fabrication

B. Cipriany*, B. Jagannathan, G. Costrini, A. Noemaun, K. Onishi, S. Narasimha, B. Zhang, C. Sheraw, J. Meiring, M. Kumar, K. Nummy, N. Zhan, H. Nanjundappa, J. Norum, S. Furkay, R. Malik, P. Agnello
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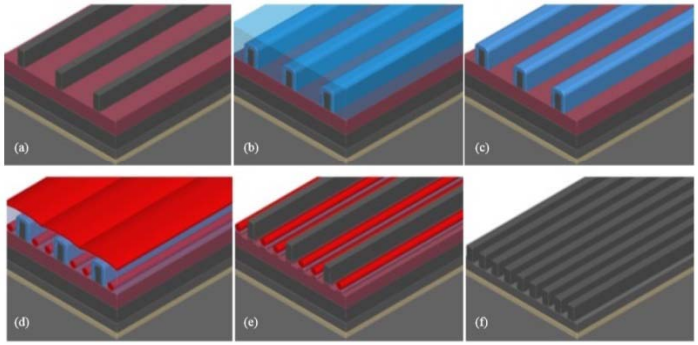
SISPAD International Conference on Simulation of Semiconductor Processes and Devices

A comparison of the pattern transfer of line-space patterns from graphoepitaxial and chemoepitaxial block co-polymer directed self-assembly

SPIE.

Dan B. Millward*[a], Gurpreet S. Lugani[a], Ranjan Khurana[a], Scott L. Light[a], Ardavan Niroomand[b], Phillip D. Hustad*[c], Peter Trefonas[c], Shih-Wei Chang[c], Christopher N. Lee[c], Dung Quach[c],
[a]Micron Technology, Inc., 8000 S. Federal Way, Boise, ID 83707, USA;
[b]Micron Technology, Inc. Belgium; Kapeldreef 75, 3001 Leuven, Belgium;
[c]Dow Electronic Materials, 455 Forest St., Marlborough, MA 01752 USA;



MEMS+ Live Demo, A Gyroscope example

Layout Editor

Process Creation and Calibration

Model Build

3D Viewer

Continue work: mesh export

Virtual Fabrication for MEMS Foundries

COVENTOR

MEMS foundries use SEMulator3D for:

- **Process development:** Predict and diagnose process issues and improve yield
- **Physical design verification:** Verify structures, release and electrical continuity before tape out
- **Customer support:** communicate process and design and information with customers
- **Failure analysis**

X-FAB MIXED-SIGNAL FOUNDRY EXPERTS

*"The benefits of visualizing accurate 3-D virtual MEMS prototypes include **increased probability** of achieving first-time success by minimizing analysis errors, **increased design efficiency** by identifying process errors early, avoiding undesired effects that would have reduced yield, and more **efficient communication** between design engineers and outside groups."*

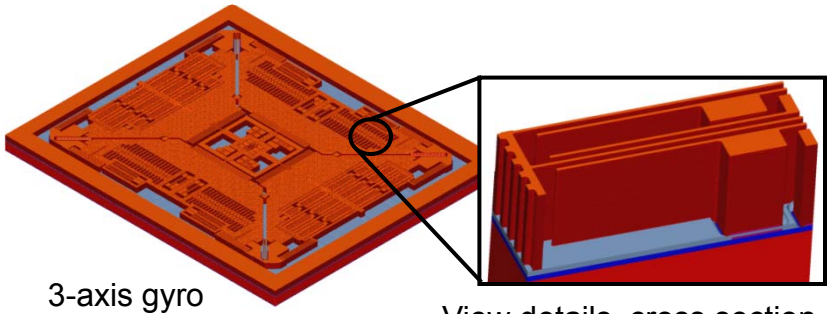
DALSA

*"SEMulator3D gives engineers the ability to do virtual test runs to verify that a device design is compatible with the manufacturing process, and that the **3D result is as expected**. Design mistakes and shortcomings can be identified, even if they are compatible with 2D layout rules."*

Virtual Fabrication: Uses for MEMS

COVENTOR

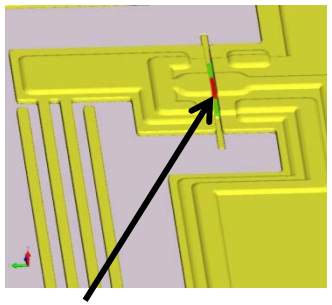
Communication: Visualize, Animate process, Designers←→Fab/Foundry, Tech transfer



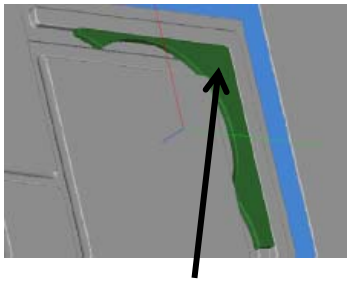
3-axis gyro
from chipworks teardown

View details, cross section

Physical Verification: Check structures, release completion, electrical continuity

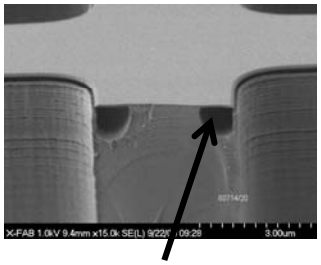


Design error passed 2D DRC

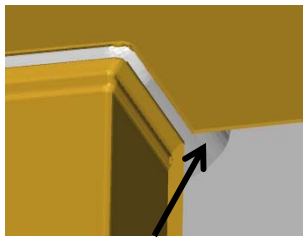


Incomplete release etch

Process Development: Predict/diagnose process problems

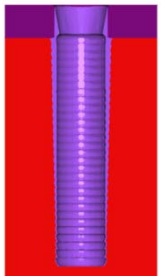


Issue: unexpected voids

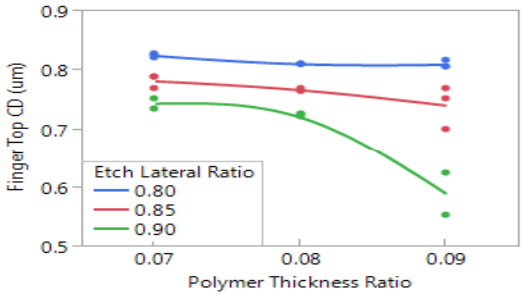


SEMulator3D model confirms root cause

Yield Optimization:

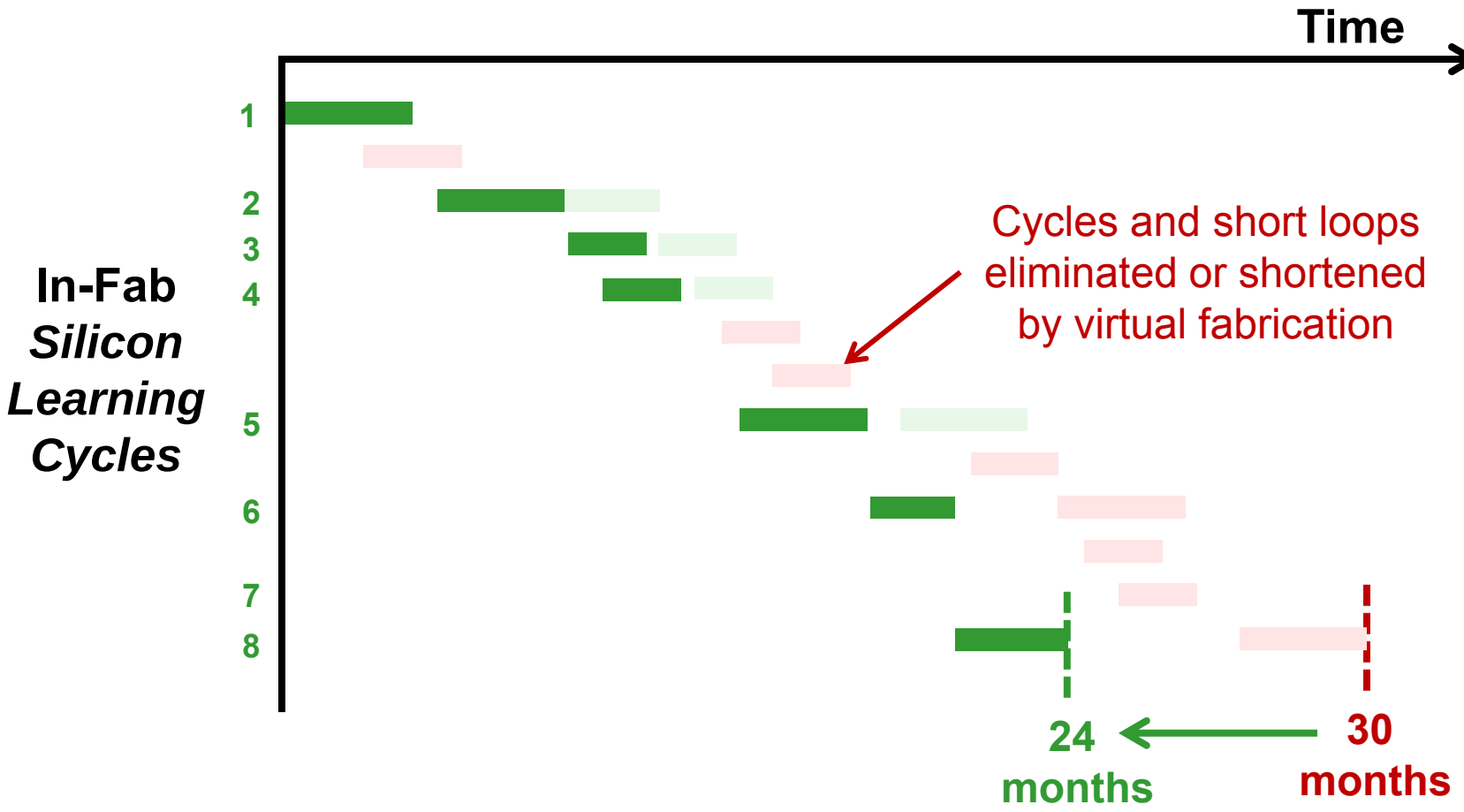


DRIE



Quantify sensitivity of structure CDs to process parameters

Benefit of Virtual Fabrication for MEMS Development

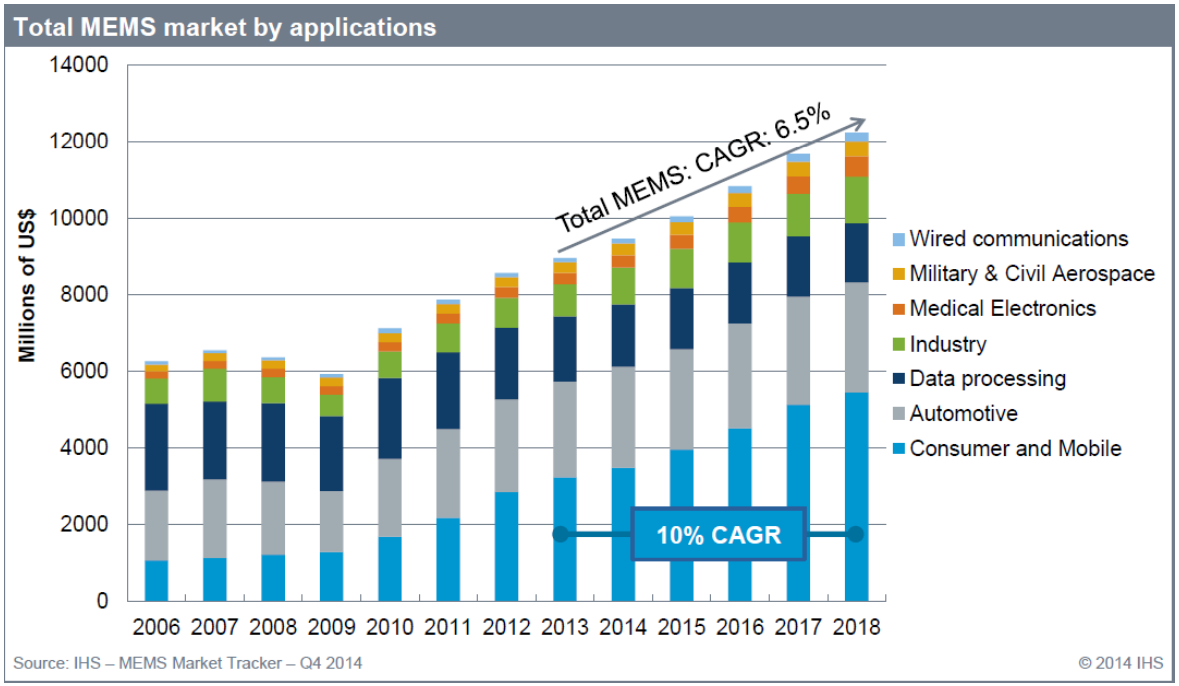


Virtual Learning optimizes Silicon Learning and can significantly **shorten time-to-market**

COVENTOR

Conclusion

High growth
Big opportunities



Examples:

- 9 DOF Integration, IME
- pMUT (Piezoelectric Micromachined Ultrasonic Transducers) for fingerprint sensors, UC Berkeley

MEMS Modeling

Coventor is the “de facto” MEMS design automation leader

Coventor enables:

Time-to-Market Reduction

Risk Mitigation

Project Cost Reduction

How?

- **SEMulator3D** Virtual Fabrication
- ***MEMS***+ “High-Order FEA”
- **CoventorWare** Hybrid FEM/BEM