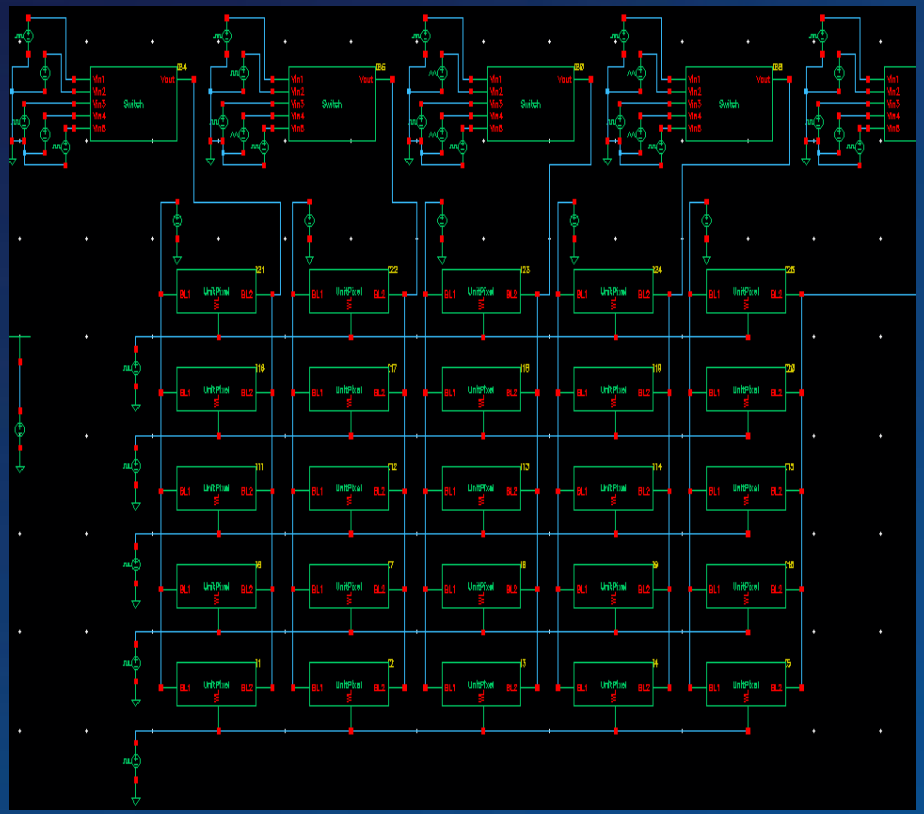
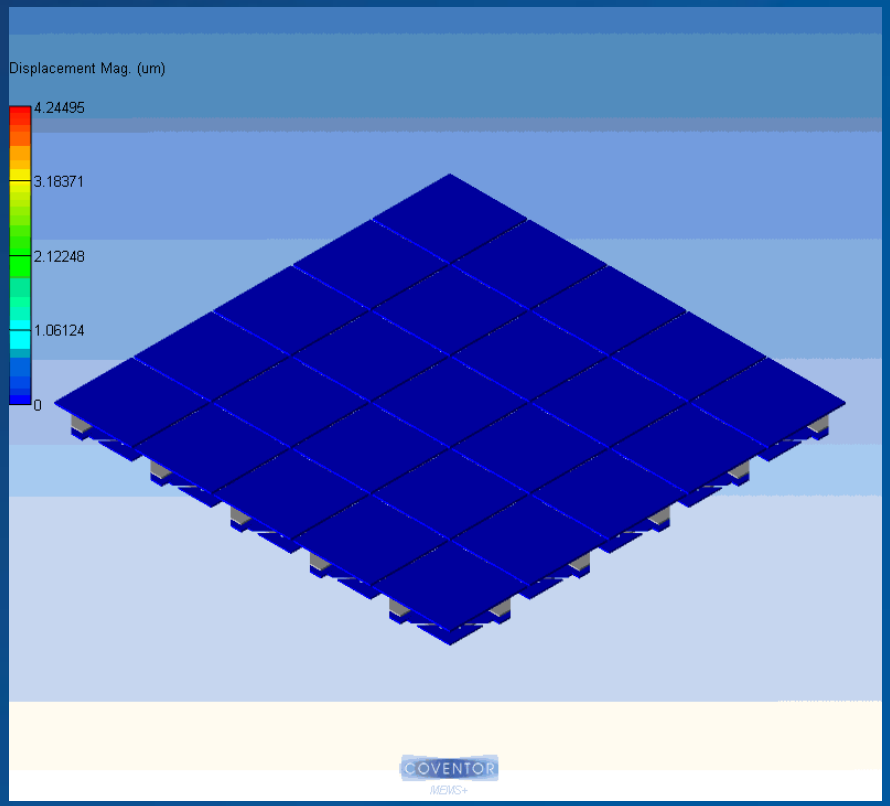
3D MEMS & Semiconductor SOFTWARE

COVENTOR

New paradigm for MEMS+IC Co-development





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MEMS 진보된 스마트 세상을 만듭니다.

Smarter

Smaller Superior

3D MEMS & Semiconductor SOFTWARE

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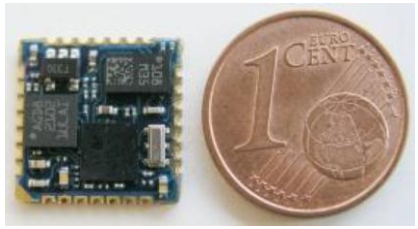
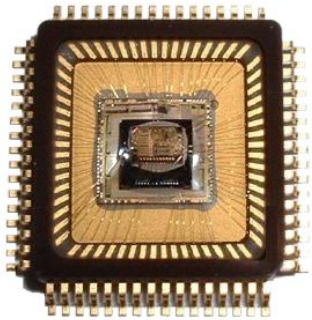
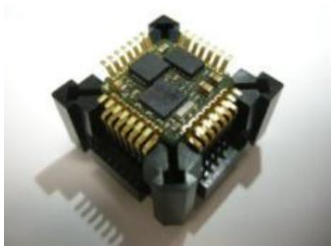
New paradigm for MEMS+IC Co-development

Worldwide First MEMS+IC Co-development Solution







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New paradigm for MEMS+IC Co-development













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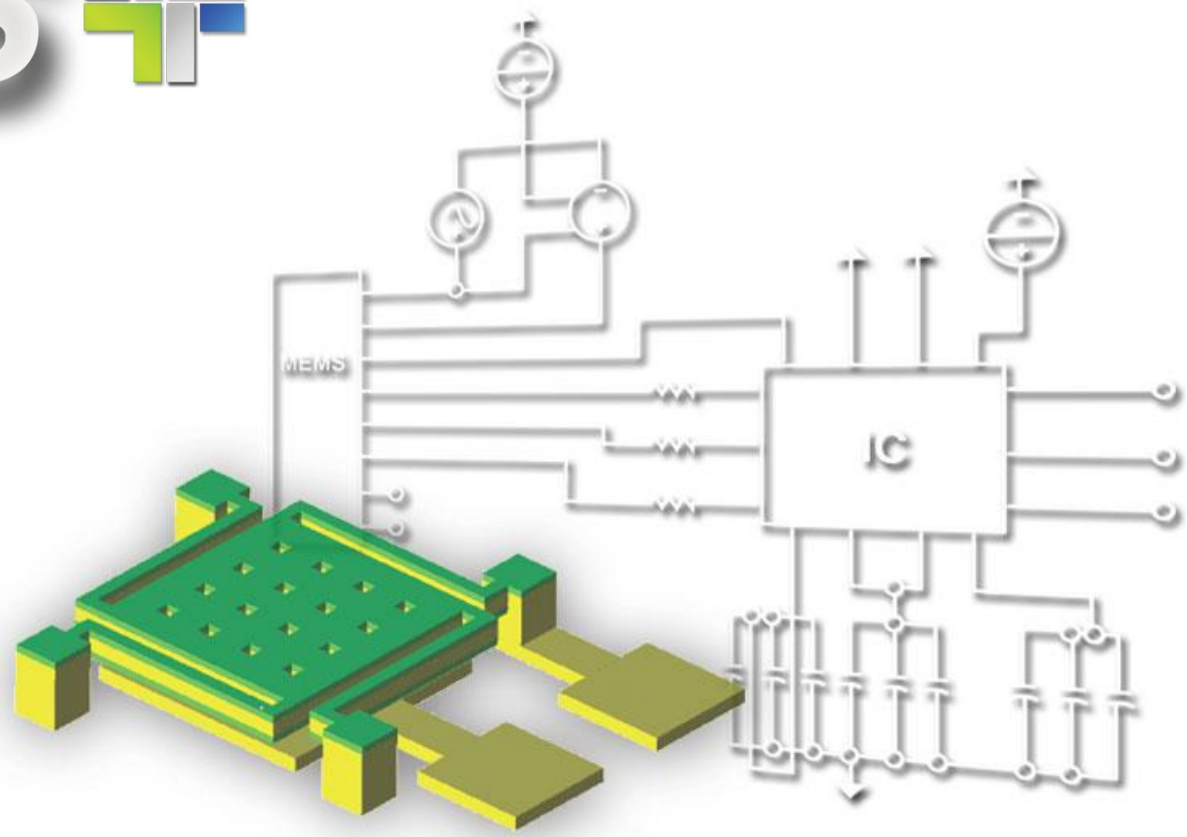
MEMS+



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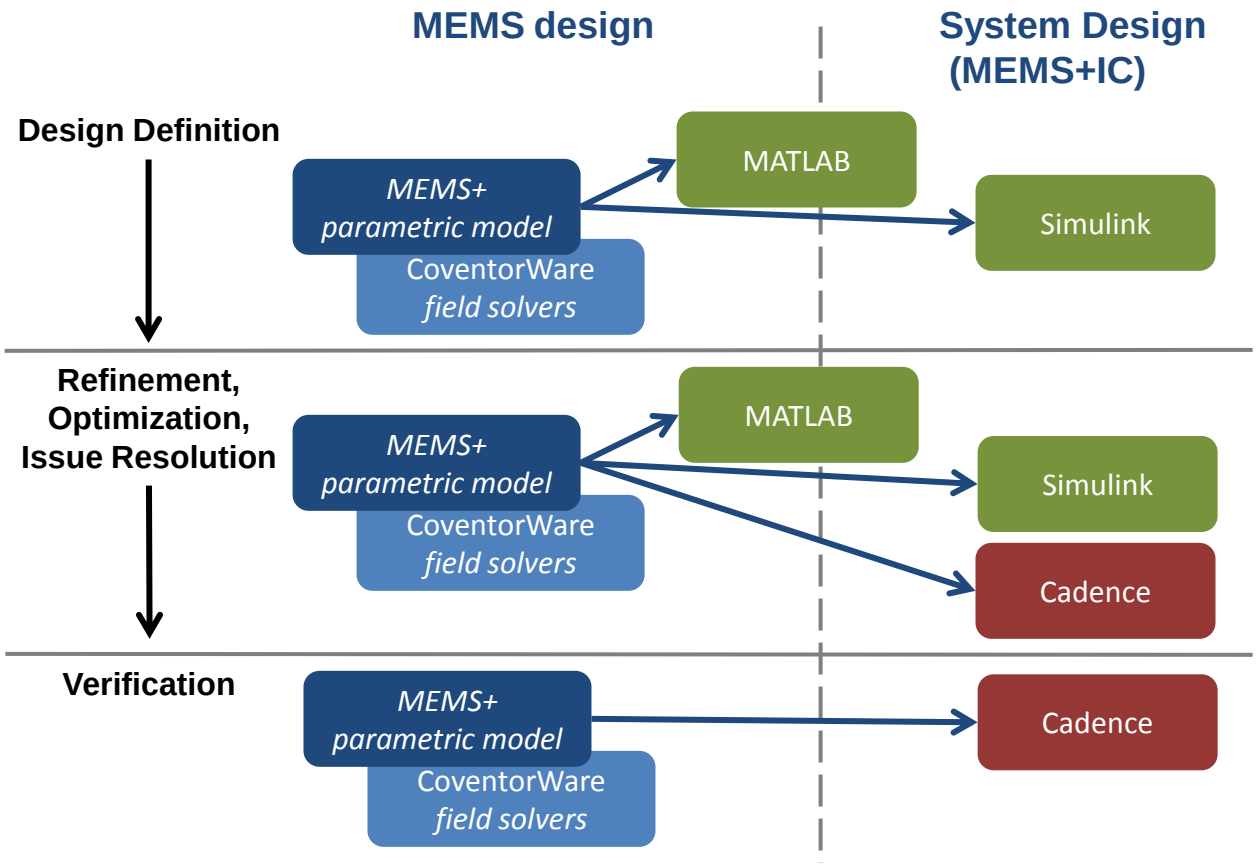
New paradigm for MEMS+IC Co-development

A New Paradigm for MEMS+IC Development



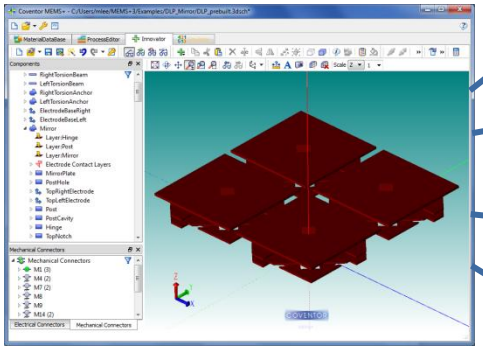
Agenda

- What is ***MEMS+***
- Why use ***MEMS+***
- How does ***MEMS+*** work
- What's New in **MEMS+** 4.0
- Conclusion

What is *MEMS*+?

A tool for creating **compact finite element models** that run in MATLAB, Simulink, and Cadence

Enter Design in 3D



Simulate and Analyze

MEMS+ Simulator

MATLAB

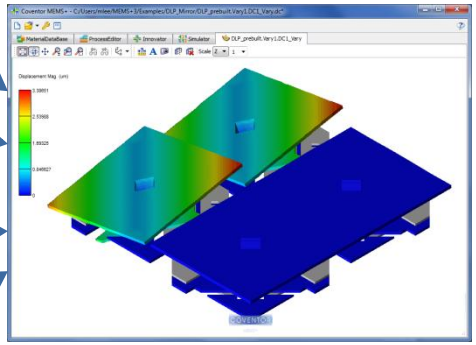
MathWorks

Simulink

cadence

Virtuoso

Visualize Results in 3D

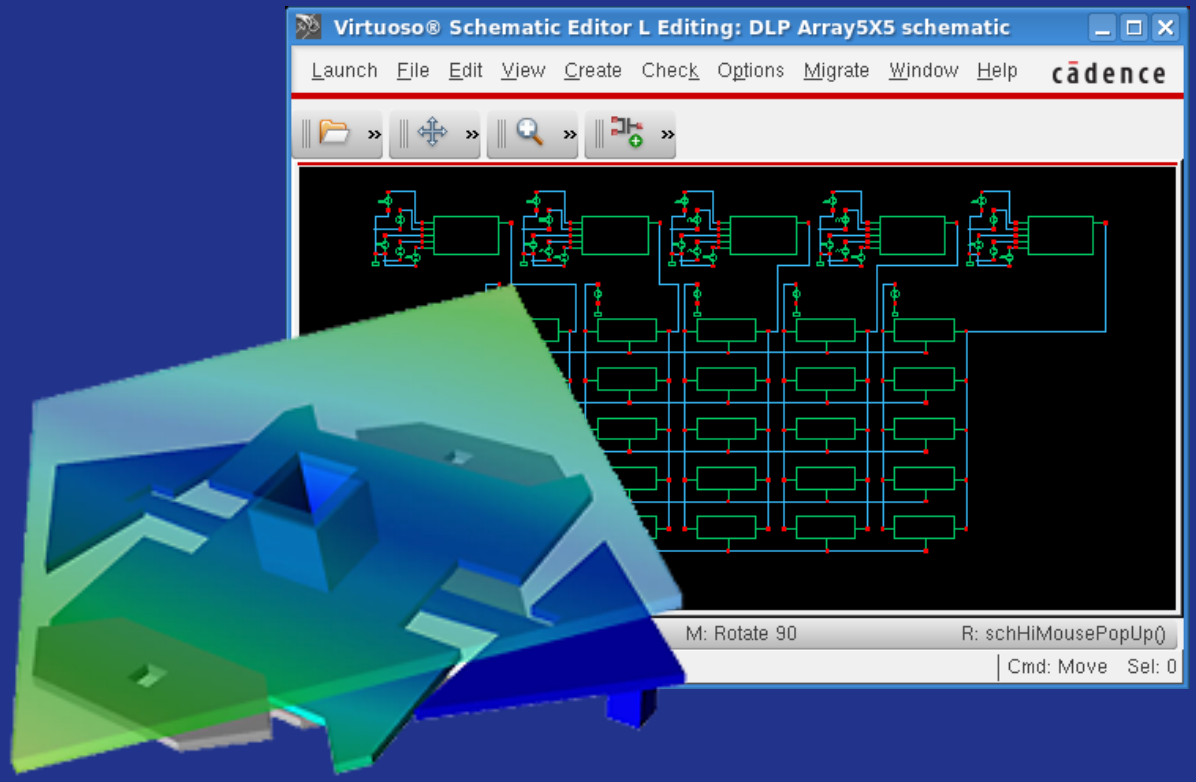


***MEMS*+ Finite Element Library:**

MEMS-specific, 3D, high-order, parametric

Why Use MEMS+ ?

or what MEMS+ can do for you…



Why use *MEMS+*

MEMS present specific simulation challenges

MEMS are multi-physics

Mechanics
+ electrostatics
+ fluidic effects
+ packaging effects
+ etc.

***MEMS+* can simulate fully coupled physics**

- Dynamic response
- Rapid design studies
- Design optimization

MEMS are part of a system

- MEMS + control system
- MEMS + IC

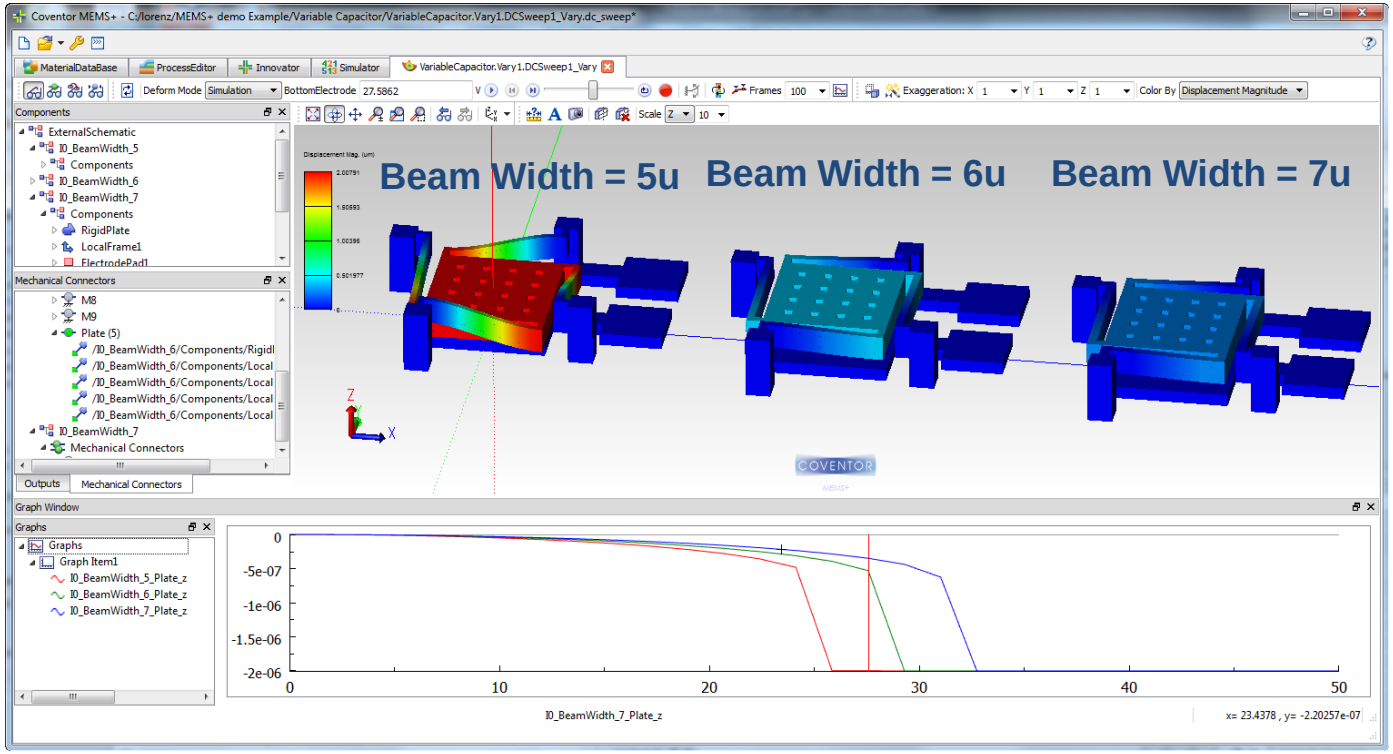
***MEMS+* models work in system and IC tools**

- Closed-loop operation
- Noise analysis
- Device arrays

Why use *MEMS*+?
MEMS are multi-physics

Need to quickly evaluate design concepts?

MEMS+ has an easy-to-use UI for building parametric models, with built-in simulator, and MATLAB and Python scripting interfaces

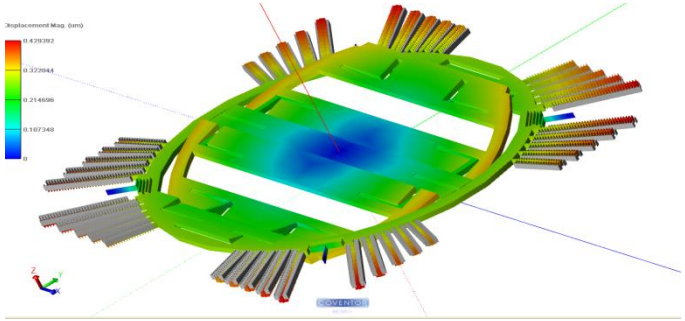


Result of a vary analysis exploring different design geometries

Why use *MEMS*+?
MEMS are multi-physics

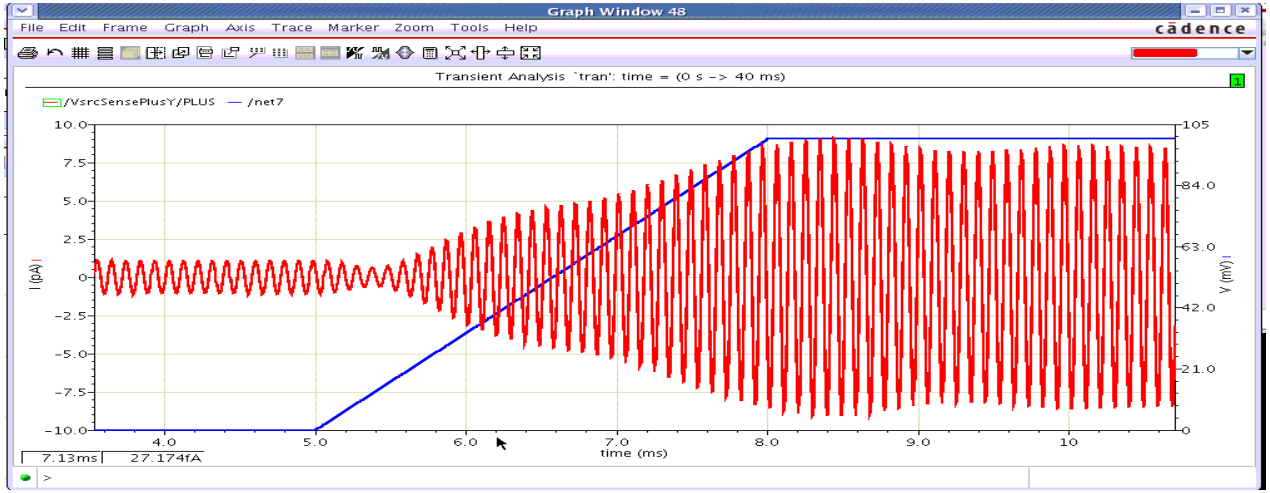
Need to study the dynamic response of your sensor?

MEMS+ model of a gyroscope,



MEMS+ model includes mechanical, electrical and gas damping effects, and is small enough for fast transient simulations in Simulink or Cadence

Transient response to angular acceleration, simulated in minutes on a laptop

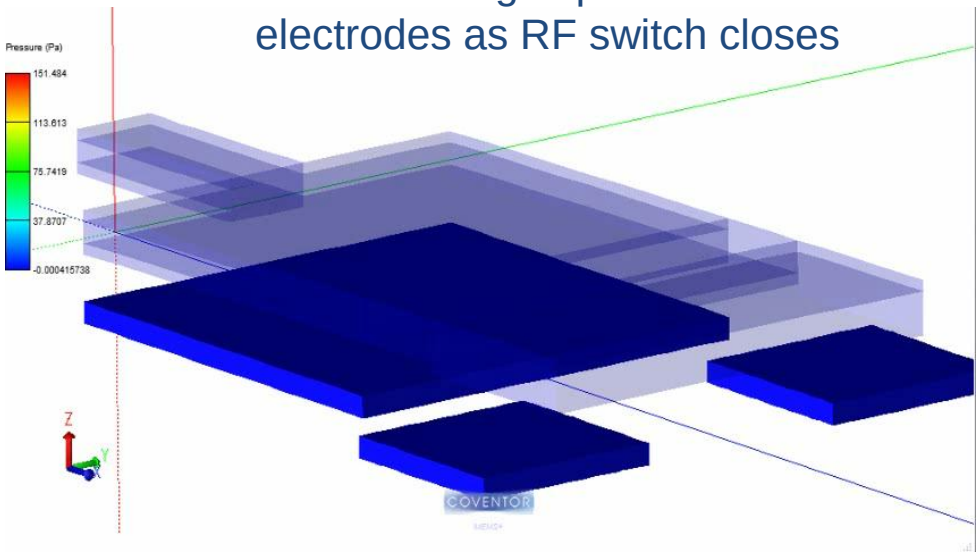


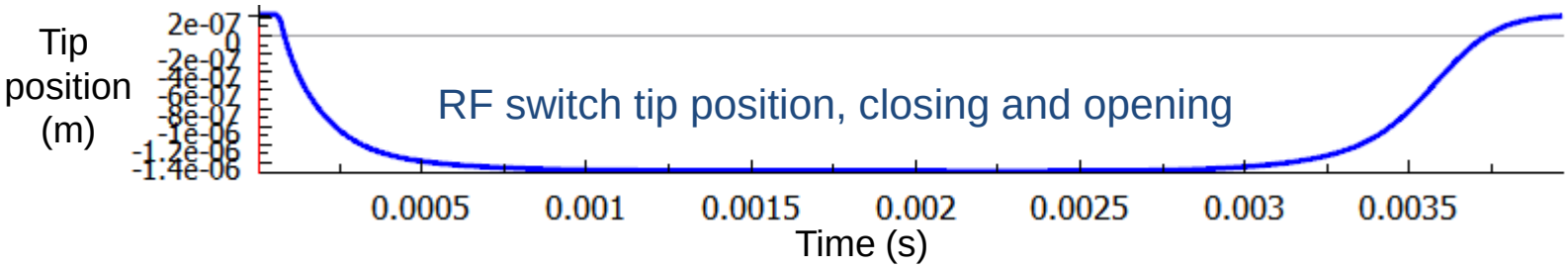
Why use *MEMS*+?
MEMS are multi-physics

Need to study the dynamic response of your actuator?

MEMS+ models are very fast and can easily combine mechanical, electrical and fluidic effects in a transient simulation

Simulated gas pressure on electrodes as RF switch closes

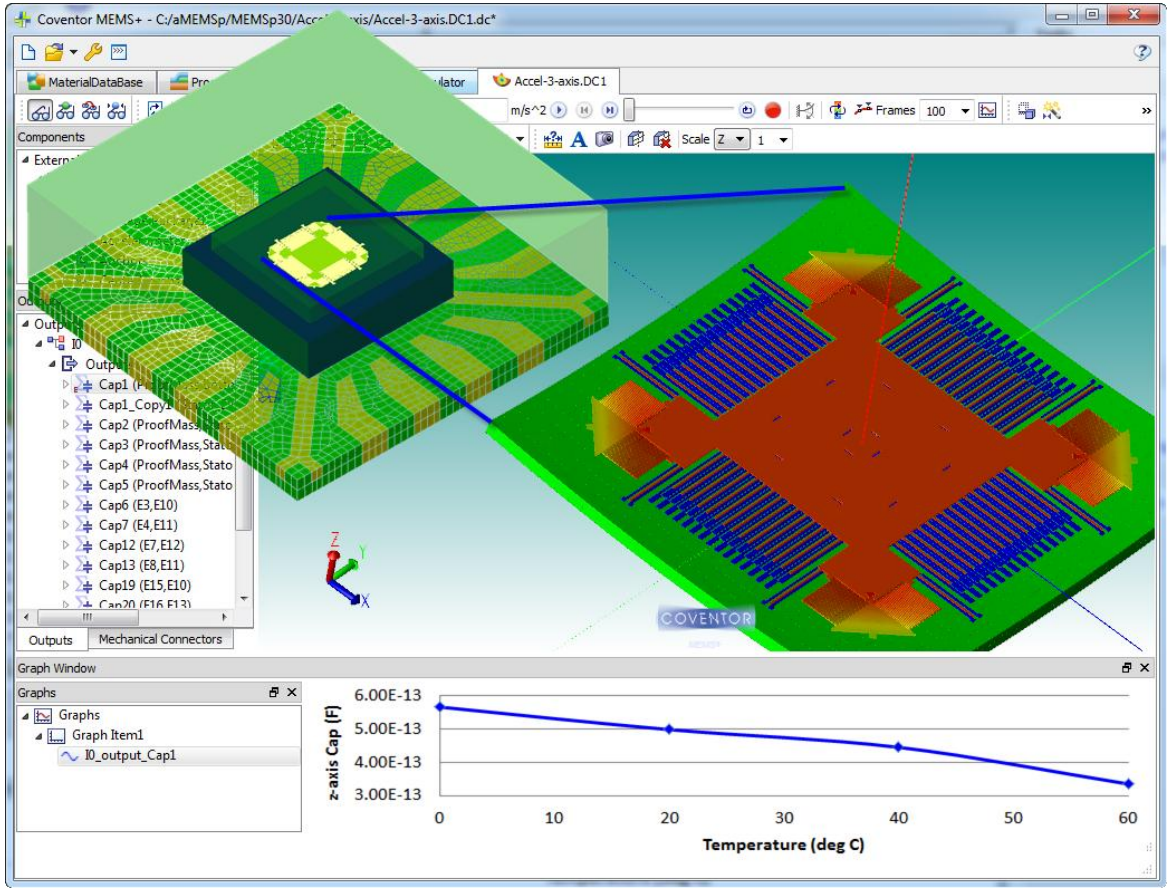




RF switch tip position, closing and opening

Why use *MEMS*+?
MEMS are multi-physics

Need to assess packaging effects on your sensor?



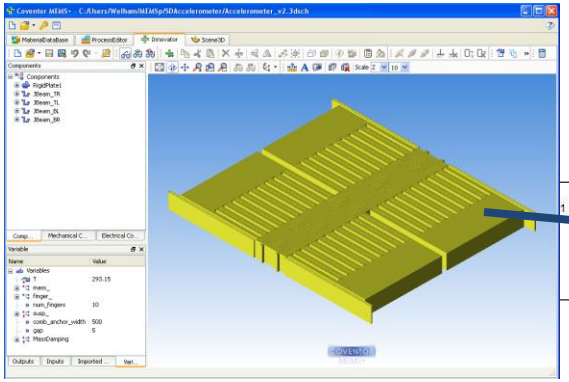
MEMS+ can predict how thermal effects on your package will affect critical sensor outputs such as zero-offset in accelerometers

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

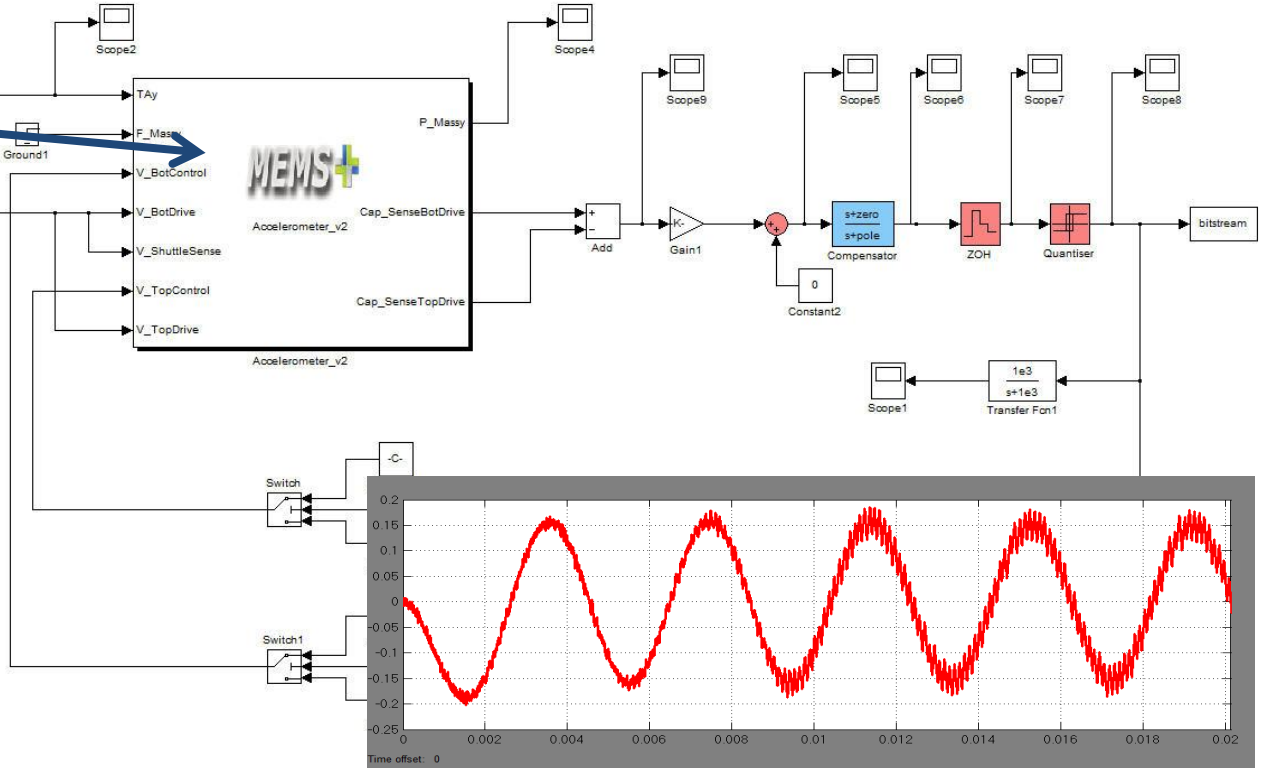
Why use *MEMS*+?
MEMS are part of a system

Need to simulate closed-loop control of your sensor?

3D accelerometer design in *MEMS*+



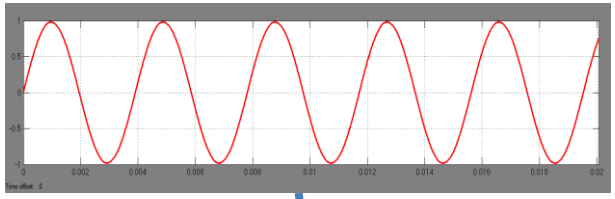
Simulink diagram:
accelerometer with sigma-delta controller



MEMS+ models plug into Simulink

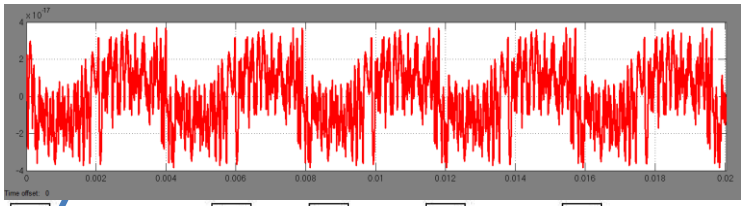
- Non-linear
- Parametric
- Fast and accurate

Force-feedback control of accelerometer

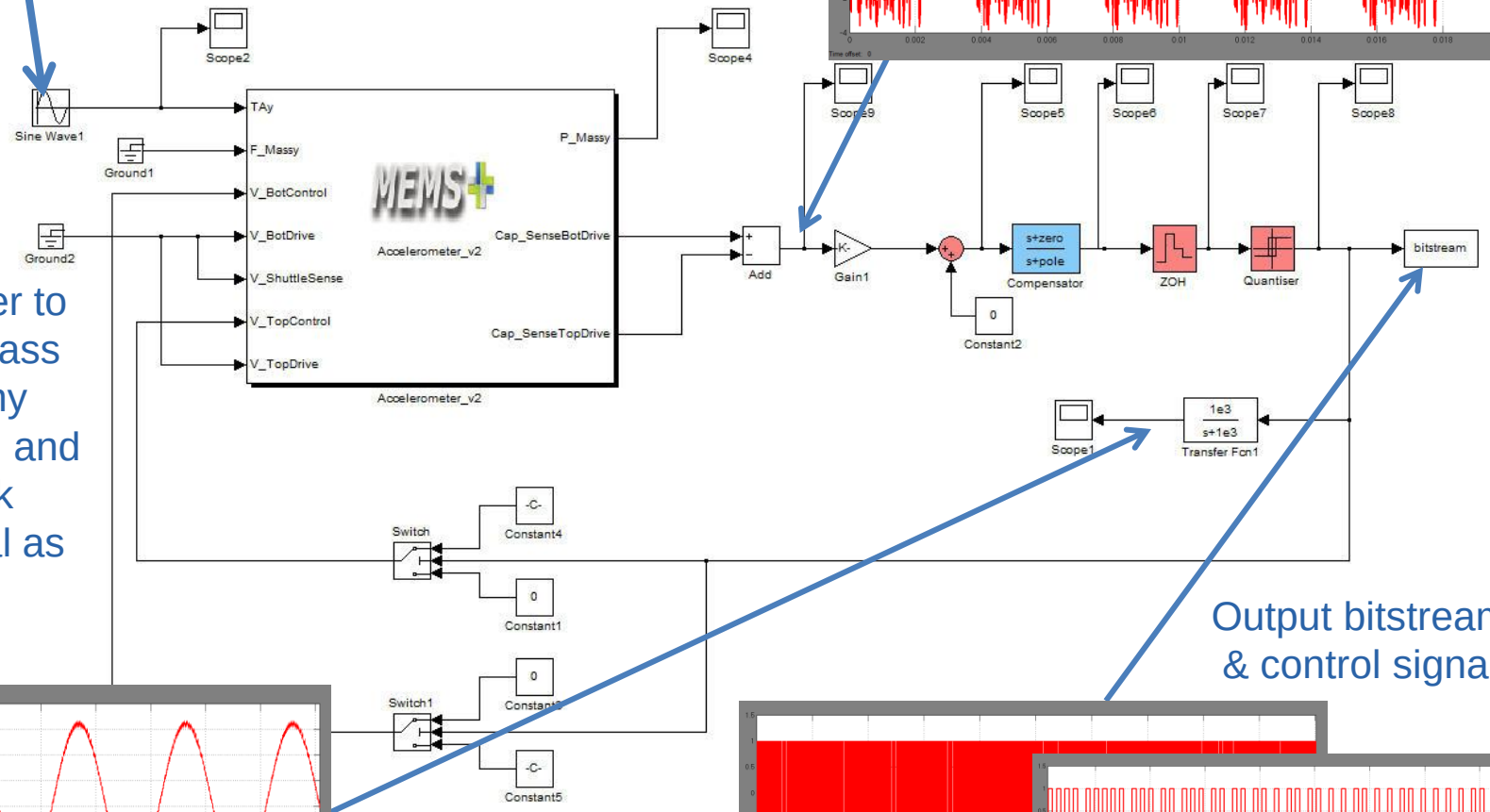


Input acceleration:
$a_y = \sin(\omega t)$ at 256 Hz

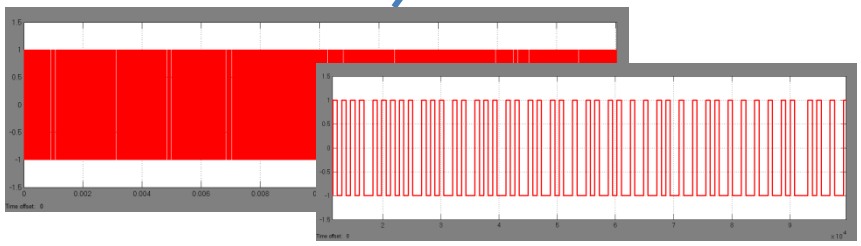
Error capacitance

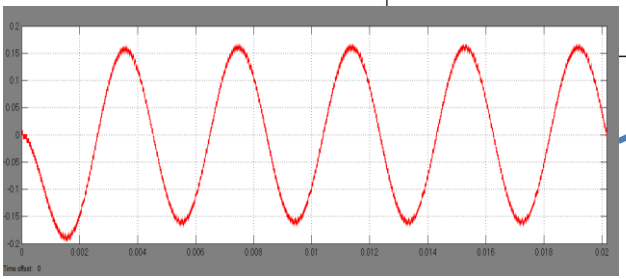


Concept:
Use controller to hold proof mass steady for any acceleration, and use feedback control signal as output.



Output bitstream & control signal

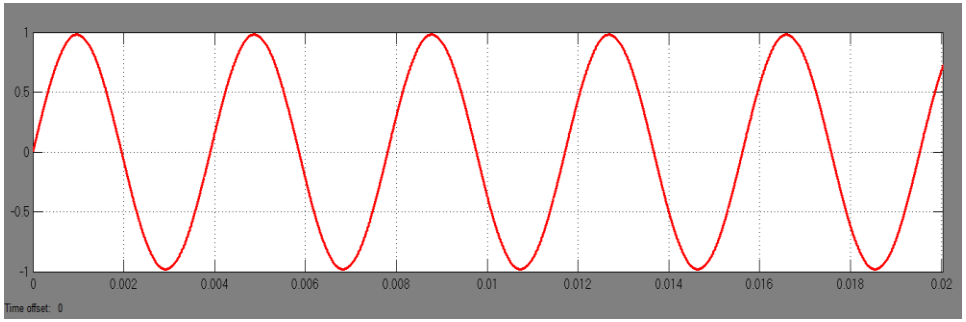




Low-pass filtered output signal

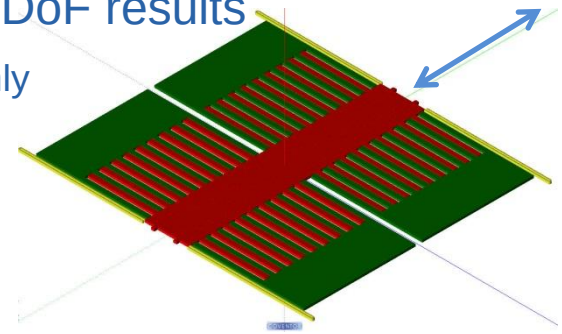
System stability simulations in Simulink with *MEMS*+ model

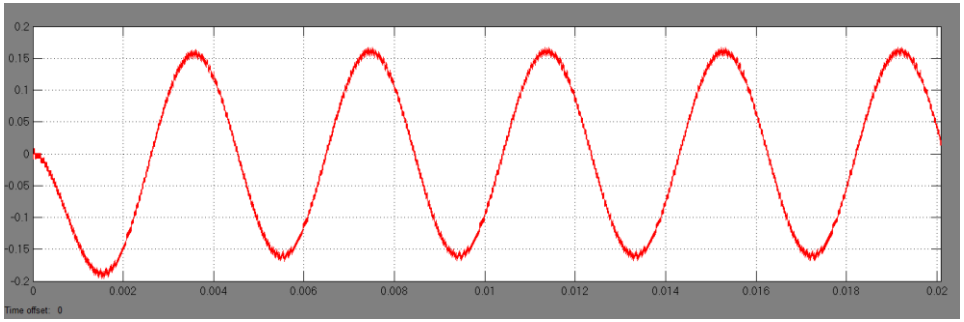
256 Hz input acceleration



Single-DoF results

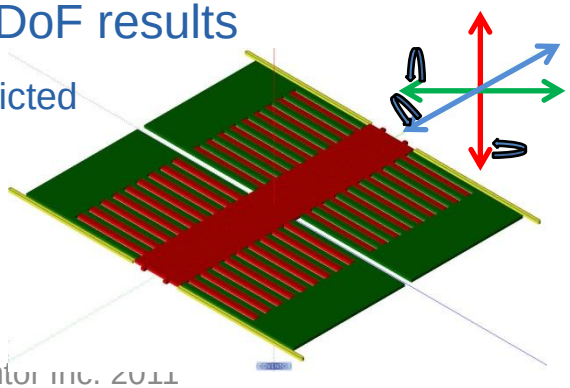
y DoF only

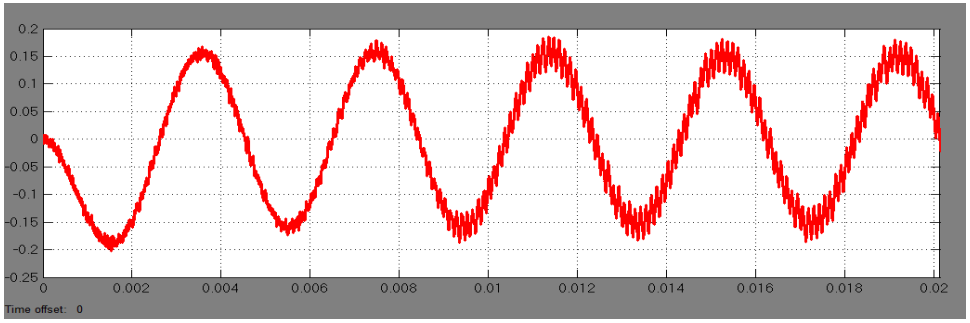




Multi-DoF results

Unrestricted motion

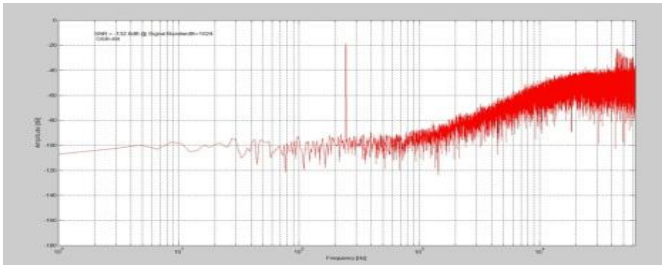




Unstable: “Noise” grows until the combs pull-in!

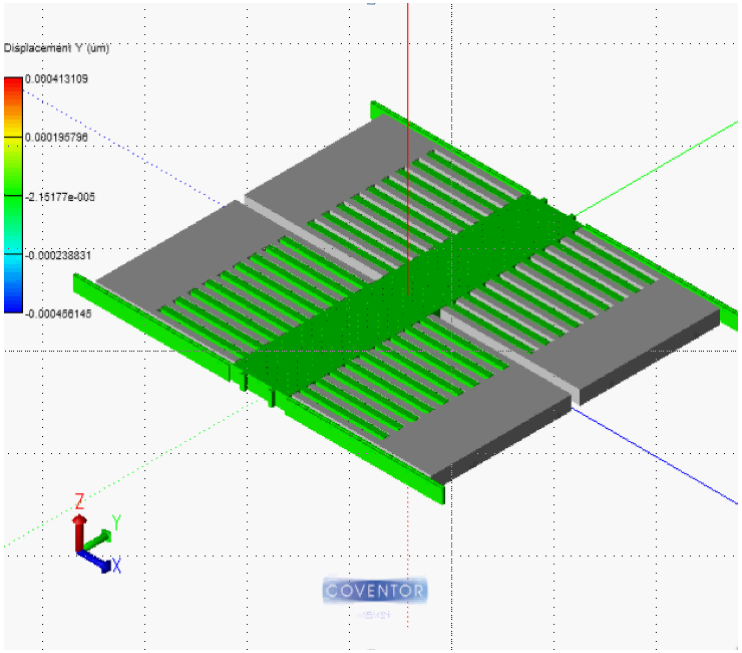
System stability simulations
MEMS are part of a system

Need help to understand your measured results?



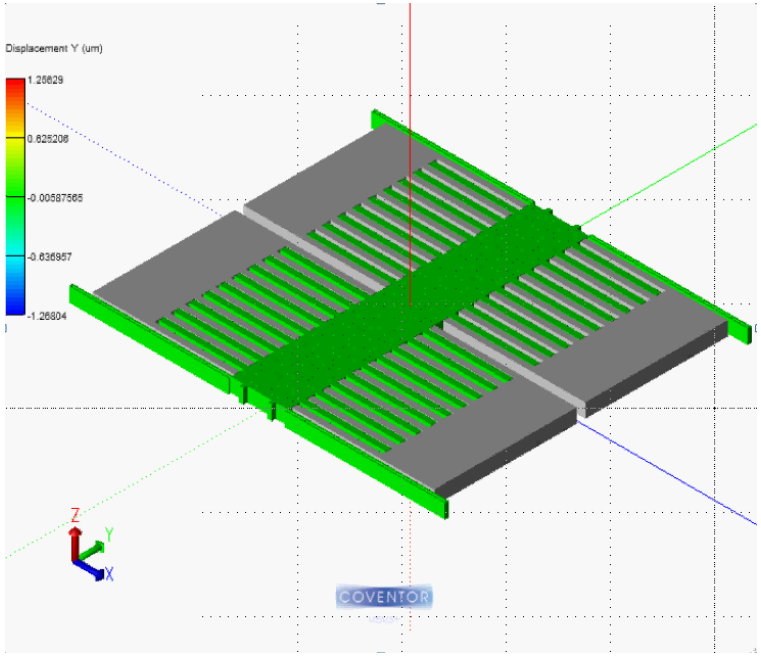
Instead, load into *MEMS*+ to visually observe device behavior:

1-DOF model in *MEMS*+



1-DOF model erroneously considers the system stable

Multi-DoF model MEMS+

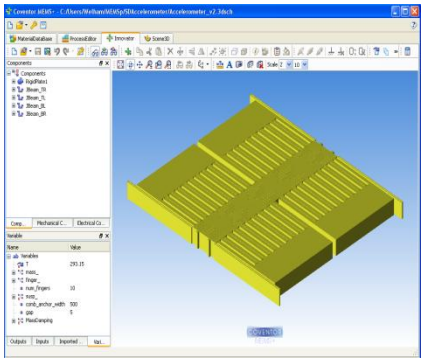


Controller excites suspensions into flapping uncontrollably

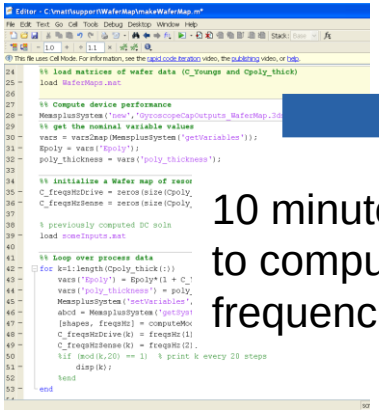
MEMS+ models enable parametric studies

Need to study manufacturability?

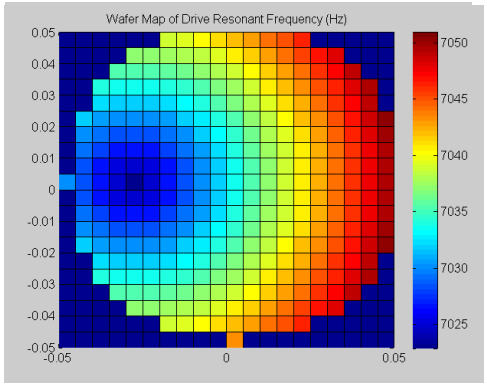
MEMS+ model



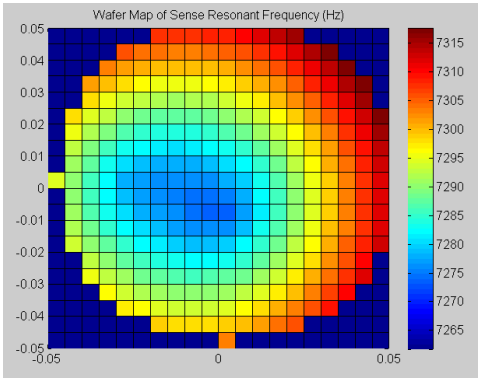
\+ MATLAB script



10 minutes CPU time to compute 400 mode frequencies



Y-mode Frequency



Z-mode Frequency

Example: Modal frequencies vs. process variations across wafers

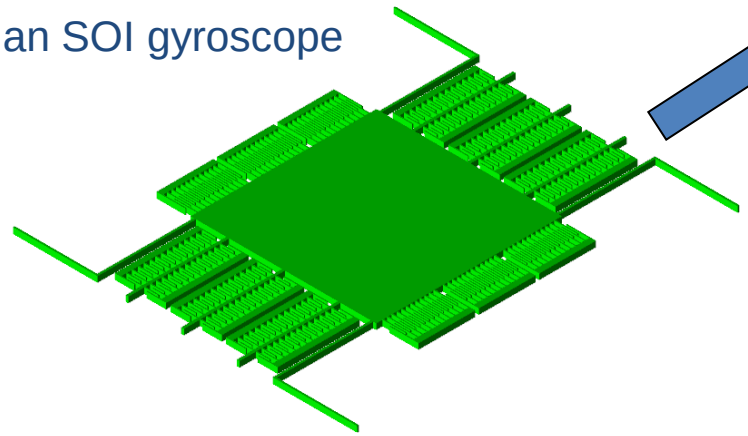
Why use *MEMS*+?
MEMS are part of a system

Need to provide a MEMS model to your IC designers?

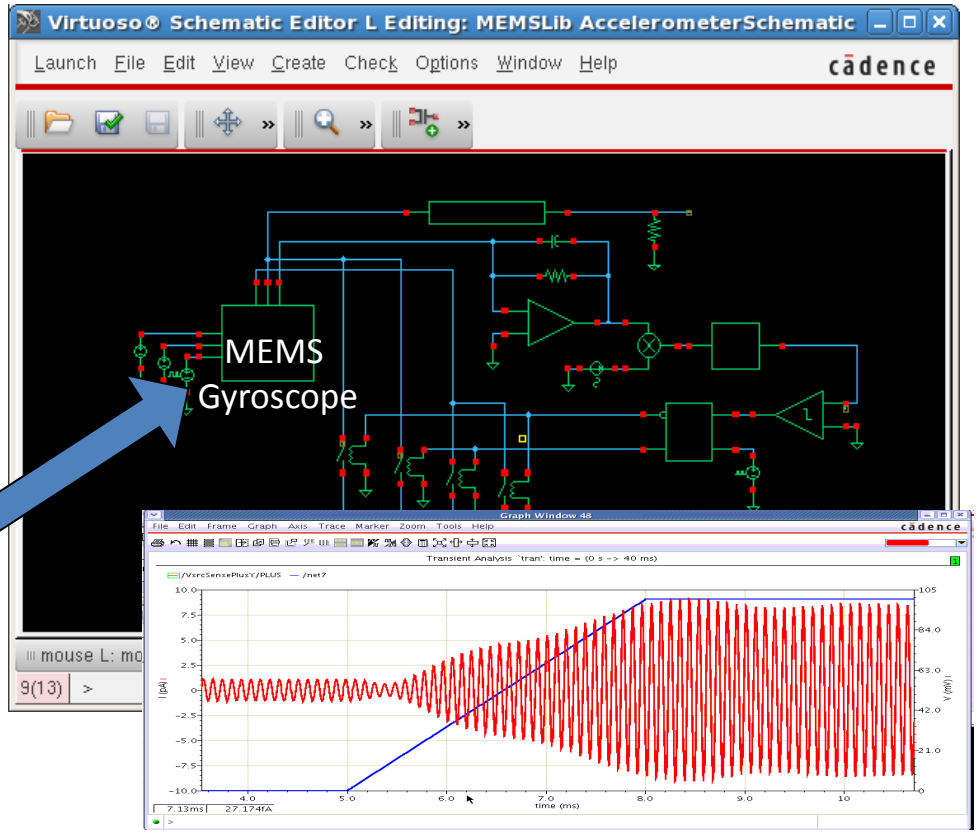
Import a *MEMS*+ model to a Cadence Virtuoso schematic with a few button clicks

- Include all essential nonlinearities
- Selectively linearize for speed

MEMS+ model of an SOI gyroscope



Cadence Virtuoso schematic

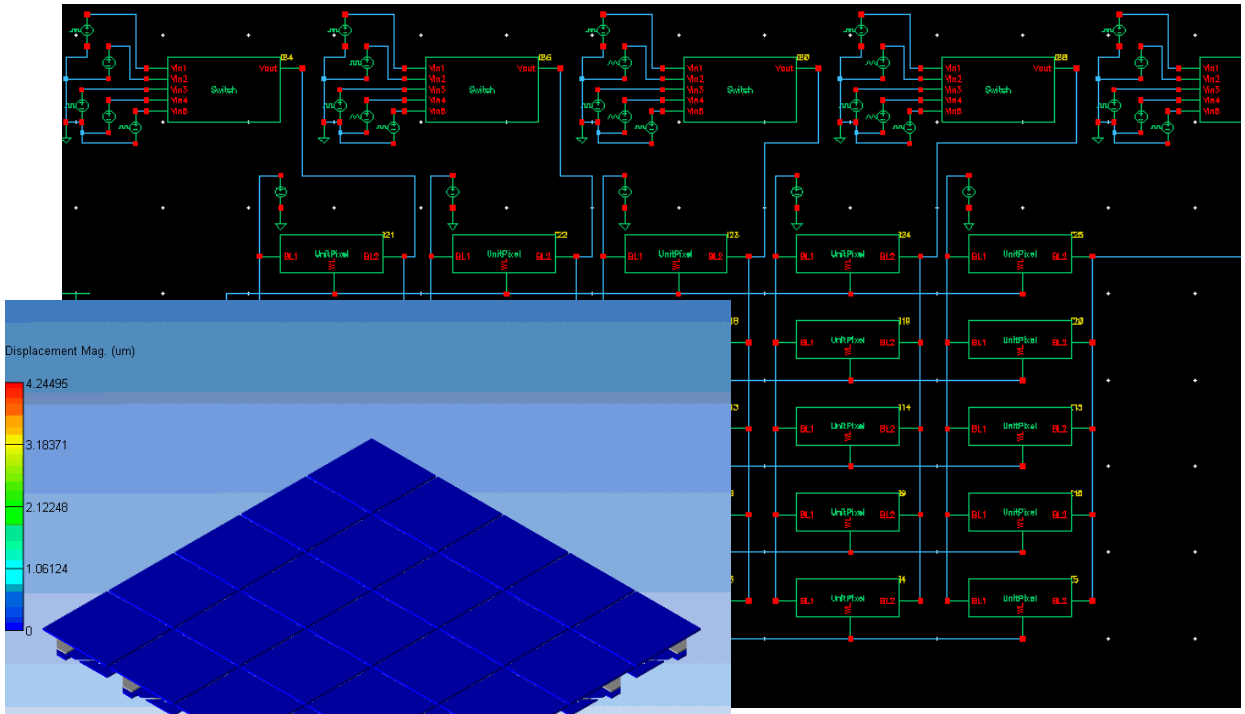


Why use *MEMS*+?
MEMS are part of a system

Need to simulate an array of actuators?

MEMS+ models capture non-linear effects and simulates fast

Cadence Virtuoso schematic of a mirror array



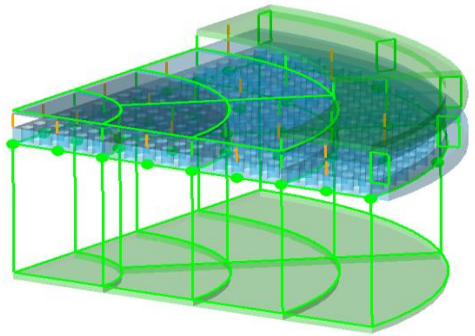
Cadence Spectre simulation results visualized in *MEMS*+

Why use *MEMS*+?
MEMS are part of a system

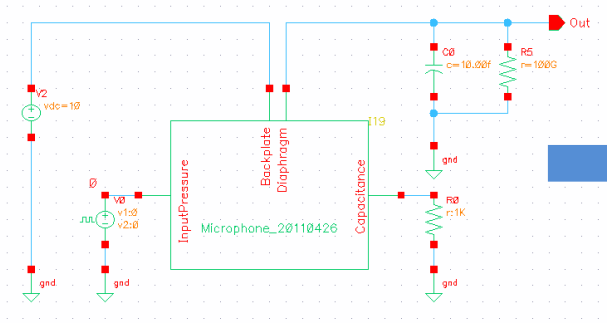
Need to perform noise analysis of your sensor?

- *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 improve your signal to noise ratio

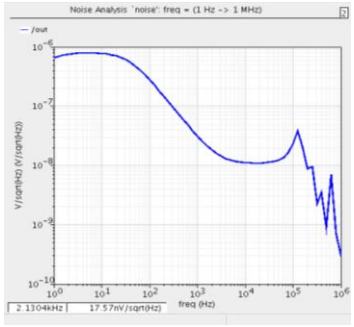
MEMS+ model of a microphone



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



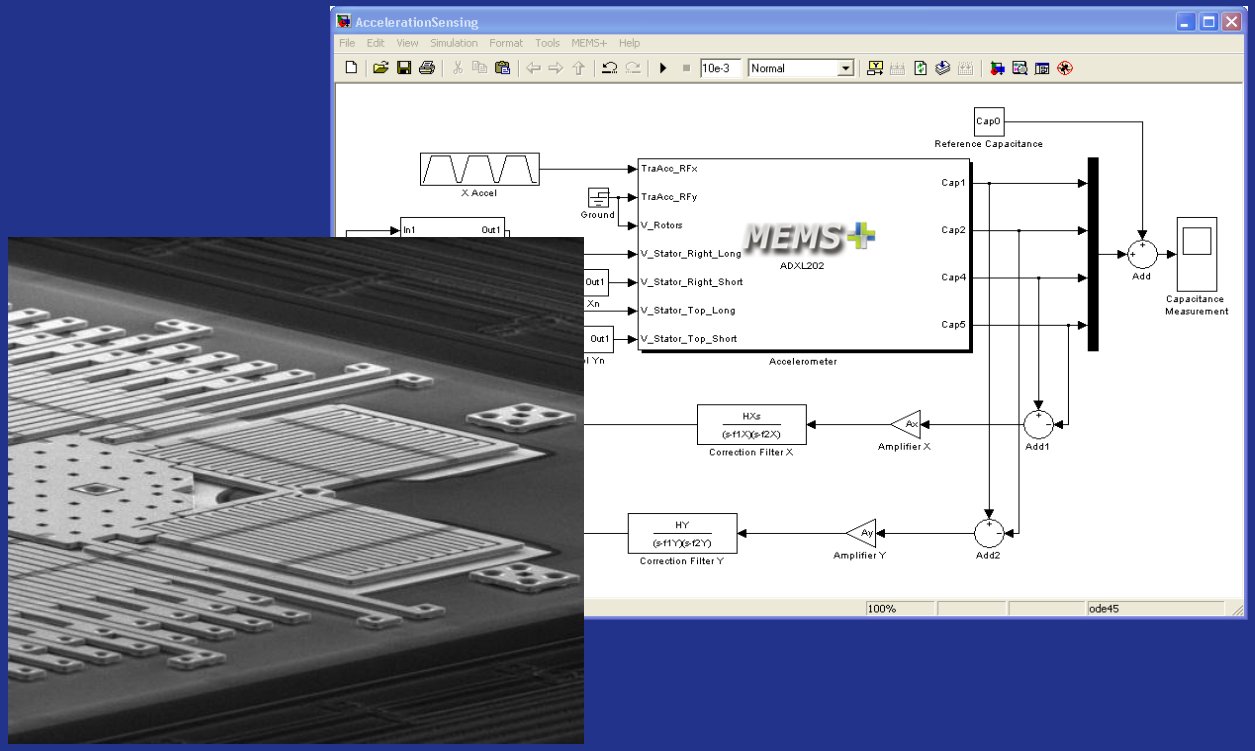
MEMS+ symbol in a Cadence Virtuoso schematic



Noise analysis in Cadence Spectre

How does MEMS+ work?

or how to create compact FE model…



MEMS+
a different kind of FEA

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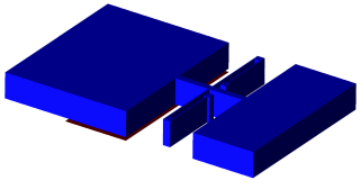
Traditional Finite Element Analysis

3D Geometry

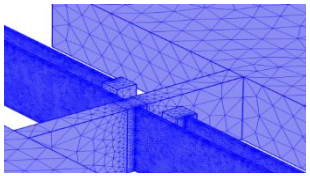


Library of **generic, low-order** finite elements

Brick, tet, shell, and beam elements

Mesh Generator

Meshed Model

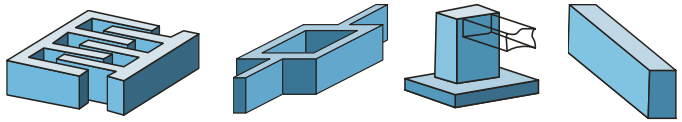


Large

10k to 10M DoF

MEMS+ Finite Element Analysis

Library of **parametric, MEMS-specific, high-order** finite elements

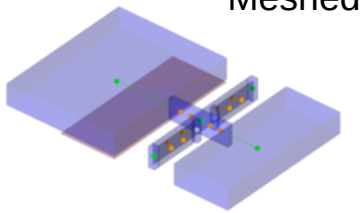


3D Design Entry in Graphical UI

or

Scripting in MATLAB or Python

Meshed Model



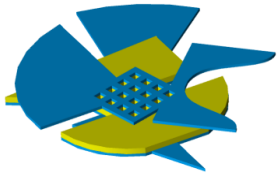
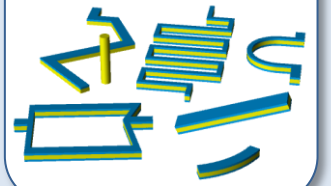
Small

10 to 1000 DoF

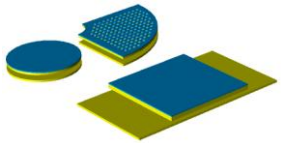
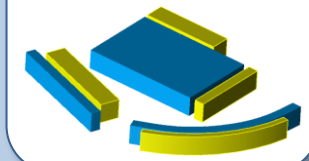
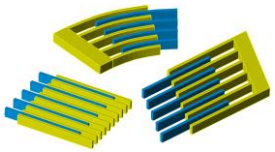
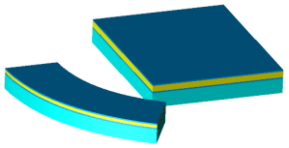
Overview of the *MEMS*+ Element Library

COVENTOR

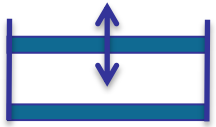
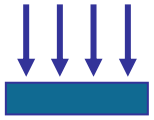
Start with Mechanical Components

- Rigid Shapes 
- Flexible Shapes 
- Beams 
- Suspensions 

Add Electro-Mechanical Coupling

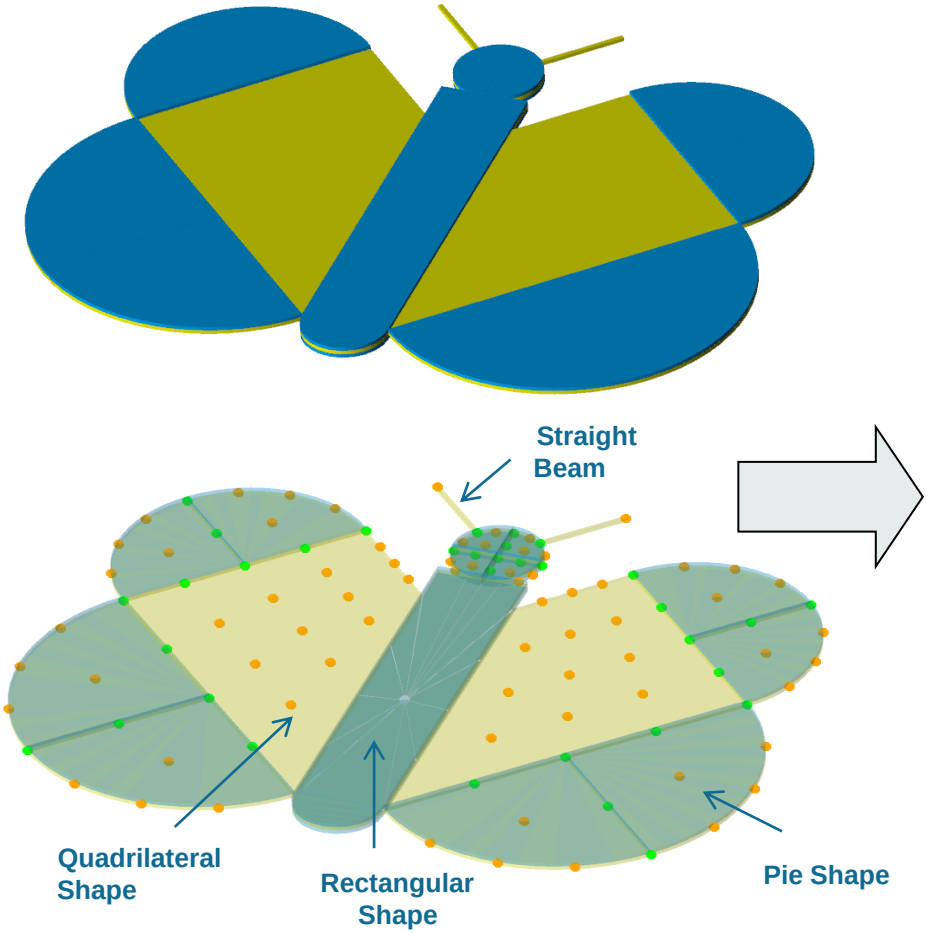
- In-Plane Electrodes 
- Side Electrodes 
- Interdigitated Combs 
- Piezo Layers 

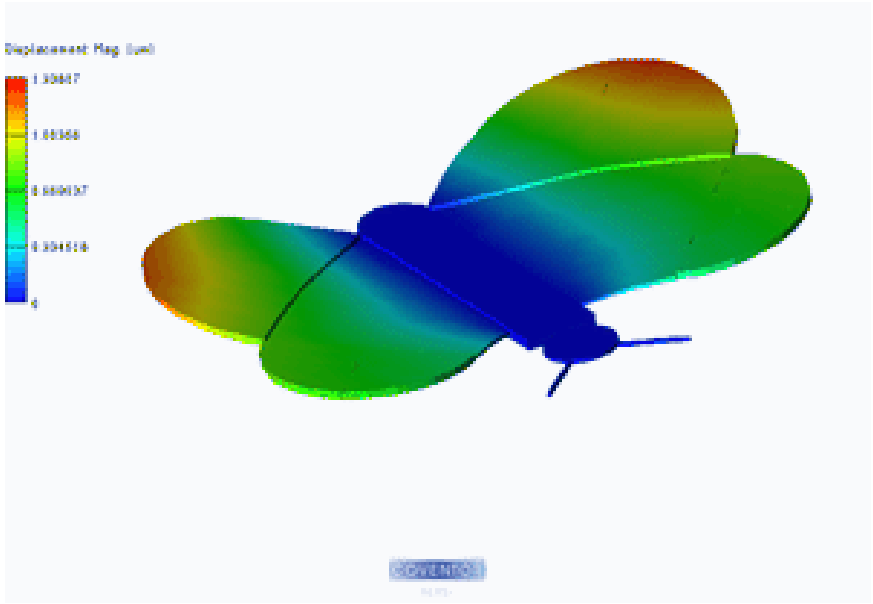
Add Fluid Damping and Loading

- Squeezed-Film Damping 
- Fluid Chambers 
- Pressure Loads 

MEMS+ Meshed Models

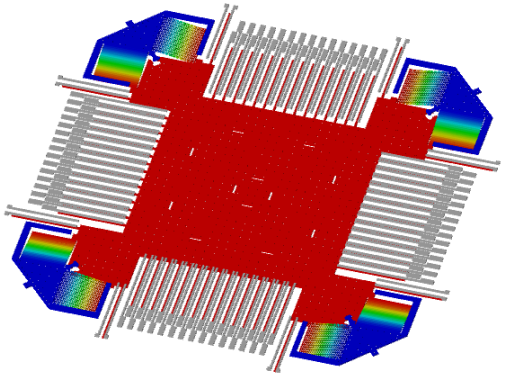
Users assemble MEMS-specific, high-order finite elements to create complex structures:



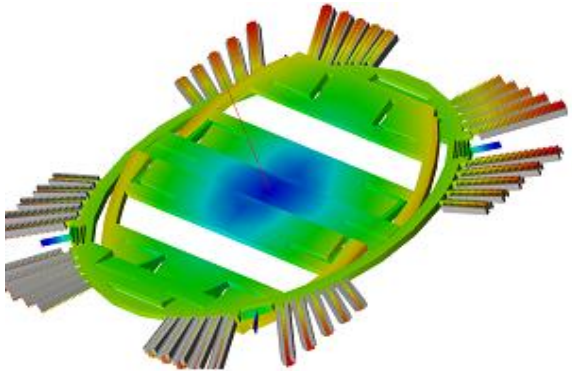


MEMS+ Application Examples

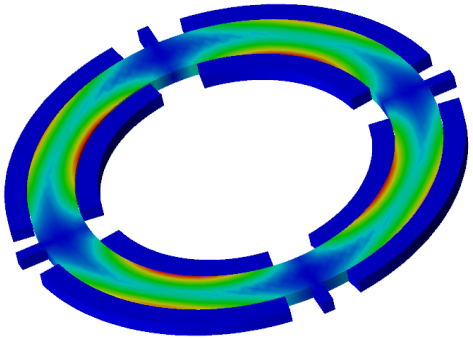
Accelerometer, 67 DoF



Gyroscope, 96 DoF

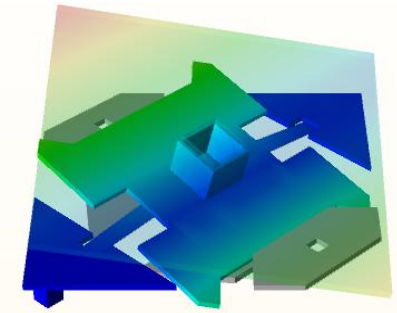


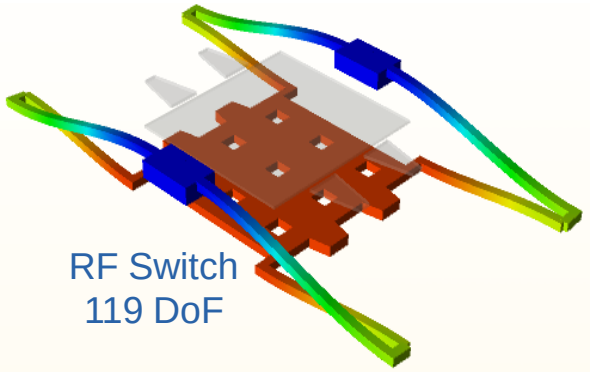
Ring Gyro, 345 DoF



Ring Resonator, 727 DoF

DLP mirror, 11 DoF





RF Switch
119 DoF

***The MEMS+* approach is general: it has been used to create compact, accurate models of many real-world MEMS designs**

MEMS+ benefits

Benefits of the MEMS+ high-order FEM approach:

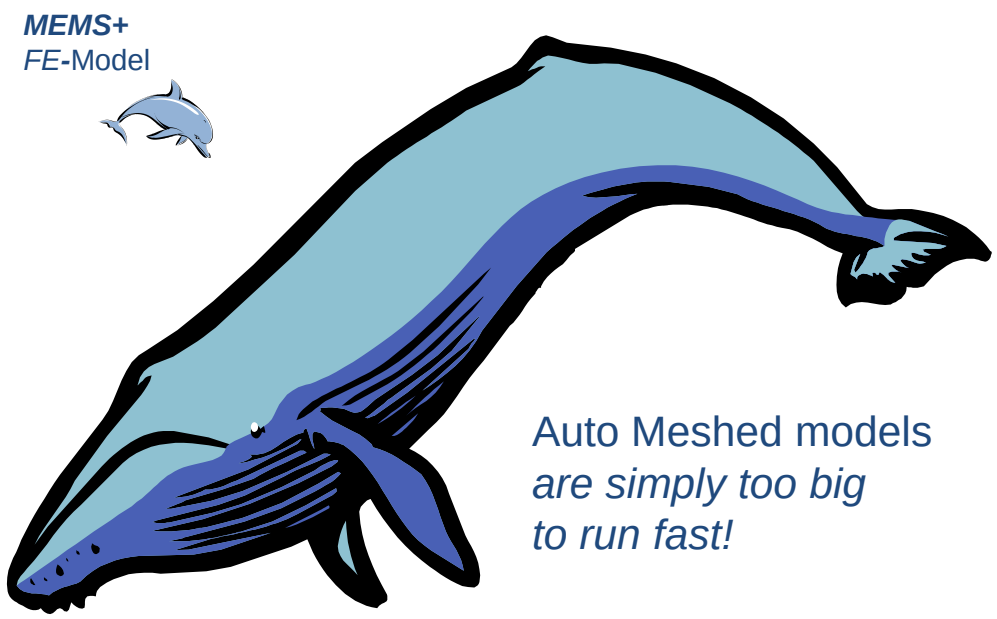
- **Simulation Speed**
- **Parameterization**
- **Compatibility**

MEMS+ Benefit: Simulation Speed

- Auto-meshed models are huge and require long simulation times
- ***MEMS+*** models are tiny in comparison

User Benefits:

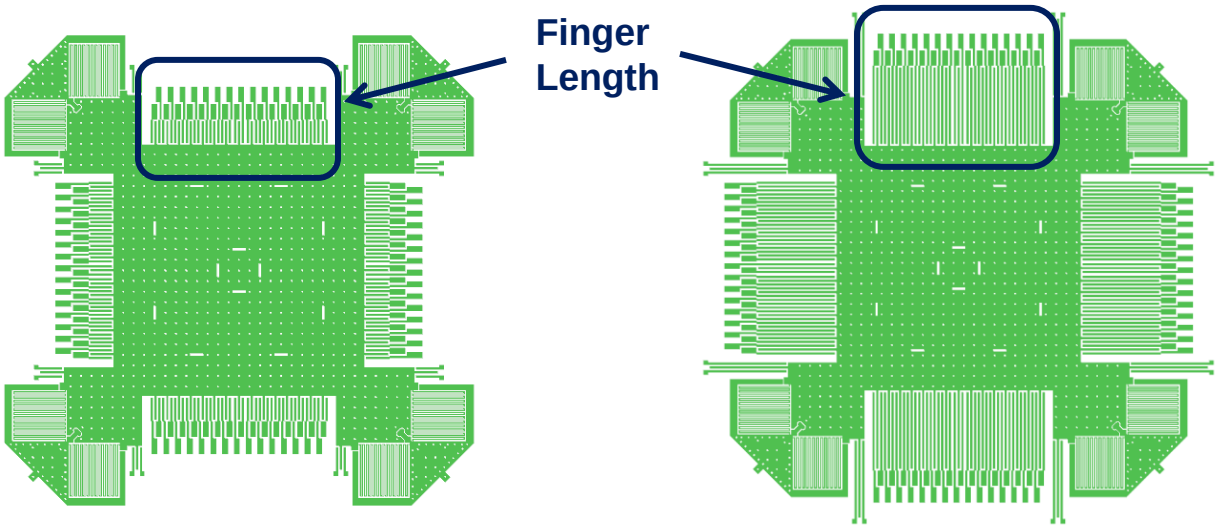
- Multi-physics analysis in minutes
- Transient simulations in minutes or hours
- Arrays



MEMS+ Benefit: Parameterization

- ***MEMS+*** offers a direct way to create efficient parametric models using high-order, MEMS-specific finite elements

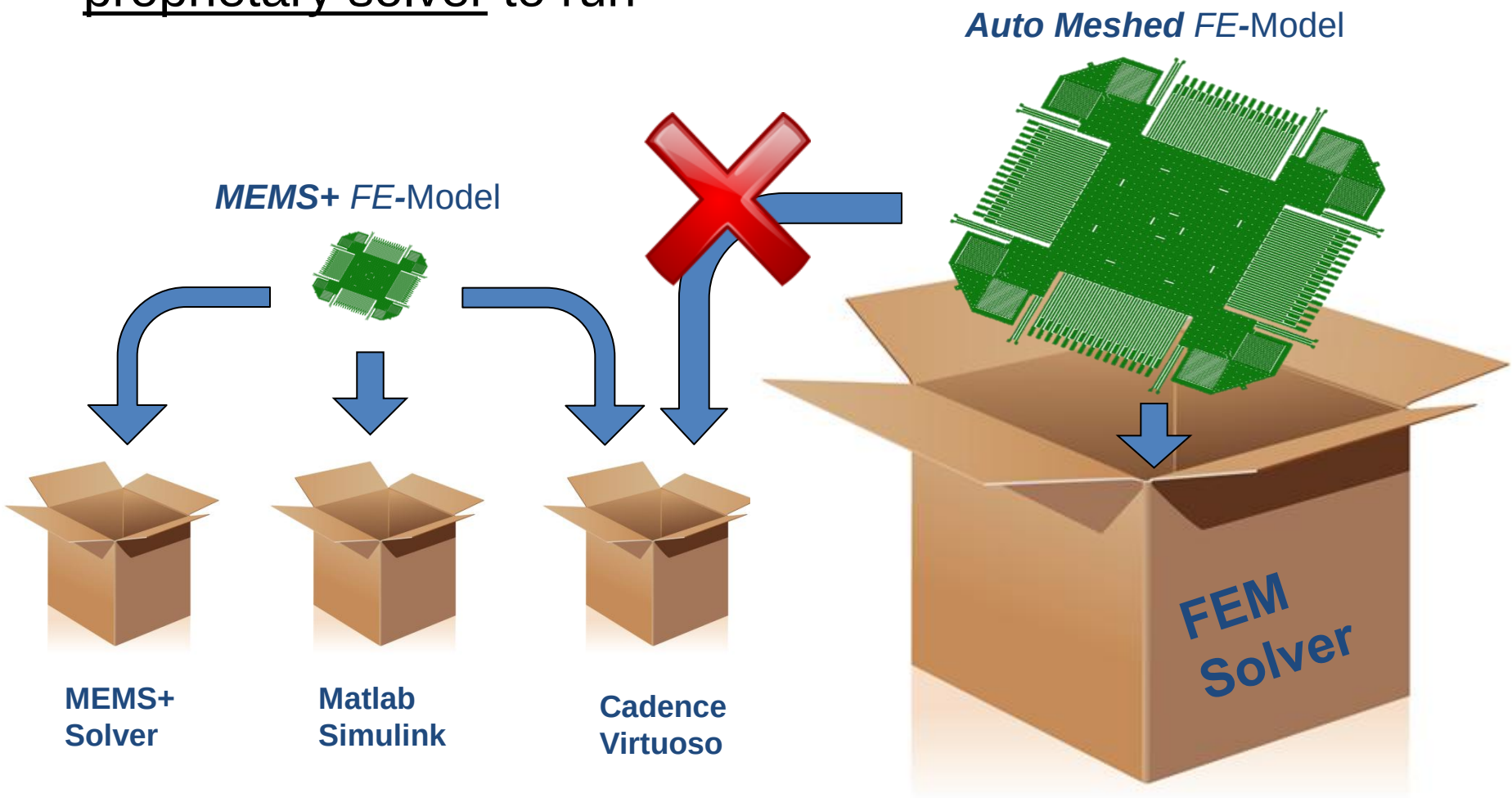
Parameters may include geometric, process, material and environmental variables



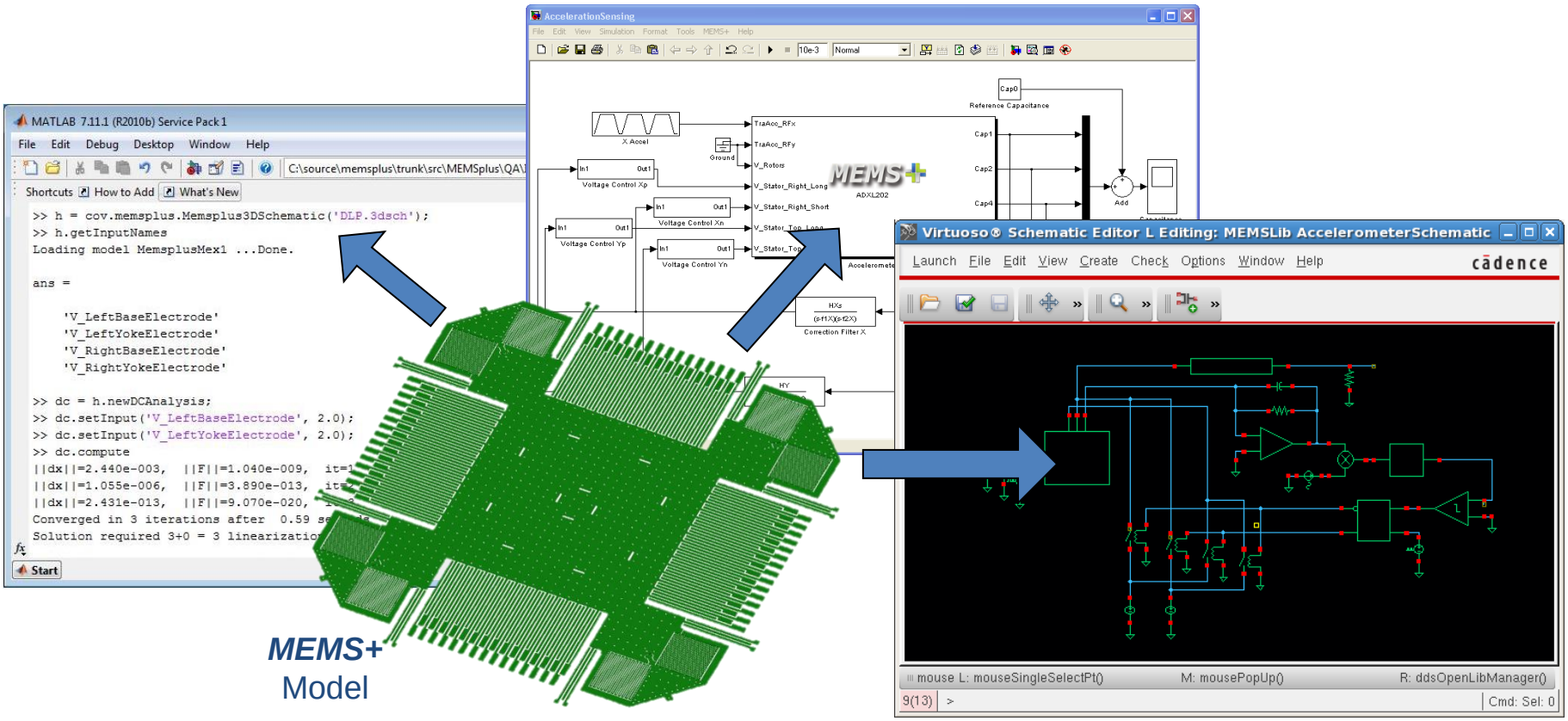
➢ Enables design optimization, parameter studies, sensitivity, yield and Monte Carlo analysis

MEMS+ Benefit: Compatibility

- Auto-meshed models are huge and require proprietary solver to run



MEMS+ Benefit: Compatibility



- Enables system level, MEMS/IC co-simulation and noise analysis
- Provides access to many existing tool boxes for design and system optimization

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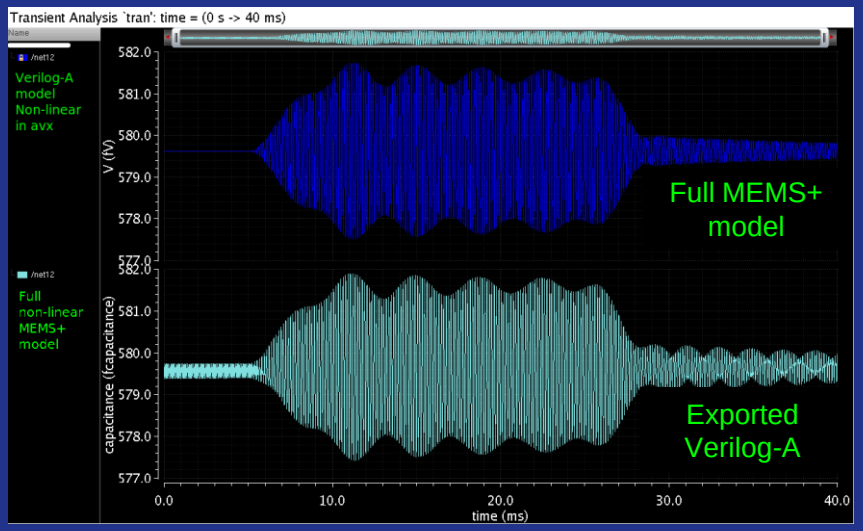
What's New in *MEMS*+ 4.0
— a new paradigm for MEMS+IC co-design



What's New in *MEMS*+ 4.0

Ability to export models in Verilog-A format

- Exported models simulate up to 100X faster
- Compatible with most A/MS simulators, not just Cadence
- Enables MEMS designers to share models with ASIC developers

More capacity and speed…

- Full 64-bit implementation to handle larger, more detailed models
- New sparse solver for modal analysis
- Faster loading of large models

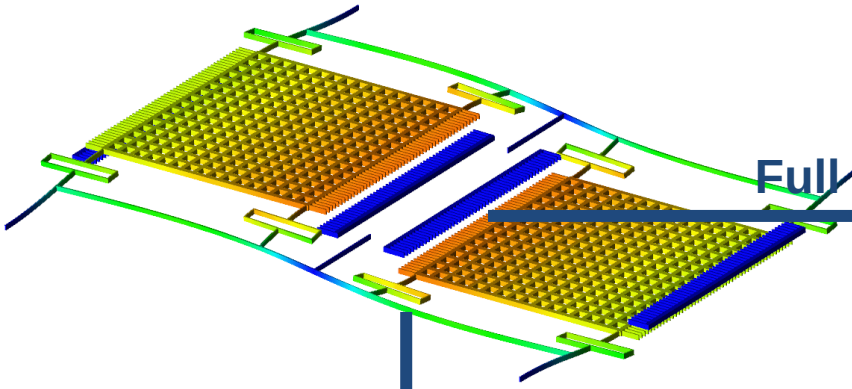
More modeling options…

- New geometry options for curved combs, useful in gyro designs
- Selectively include fringing fields for in-plane motion
- Out-of-plane angle and length scale for imported package
- Save reaction forces and moments for verification

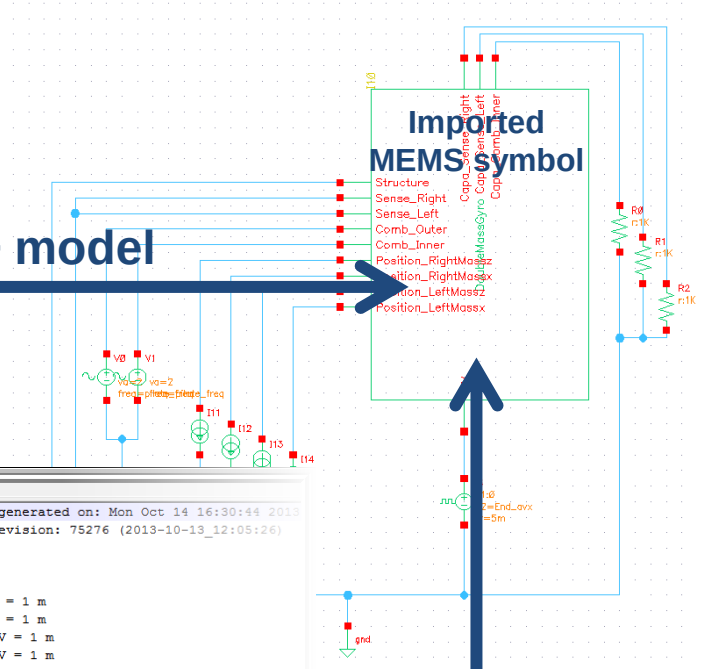
MEMS+ 4.0 offers two paths to MEMS+IC co-design

MEMS+ model

MEMS+IC schematic

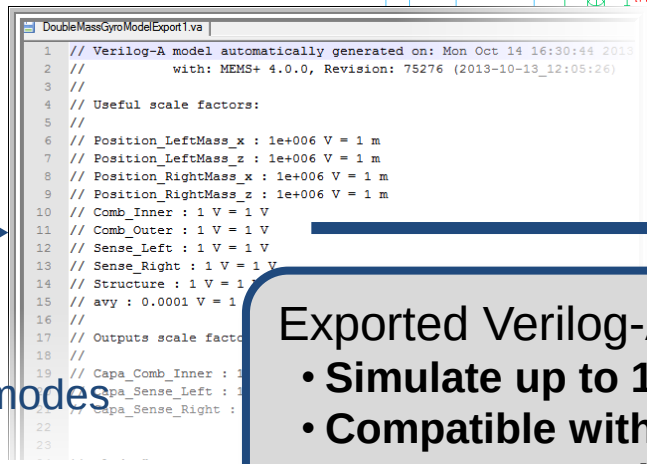


Full *MEMS*+ model



New

Exported Verilog-A



Model Order Reduction (MOR)

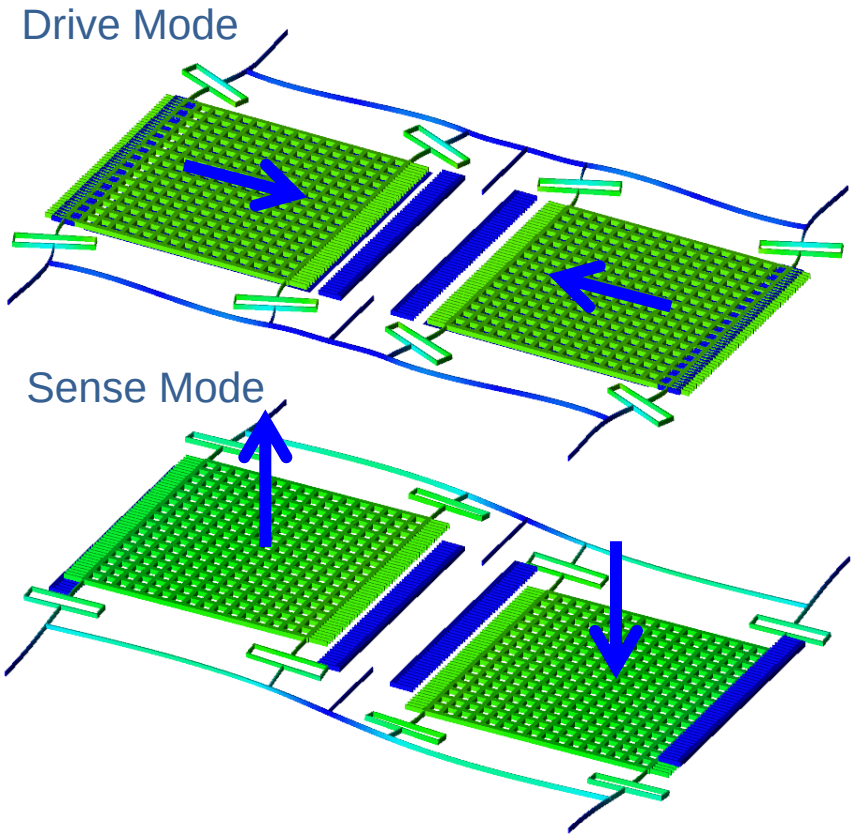
- Preserves selected mechanical modes
- Reduces from 1000s to <10 DoF
- Preserves selected non-linear inputs

Exported Verilog-A models

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

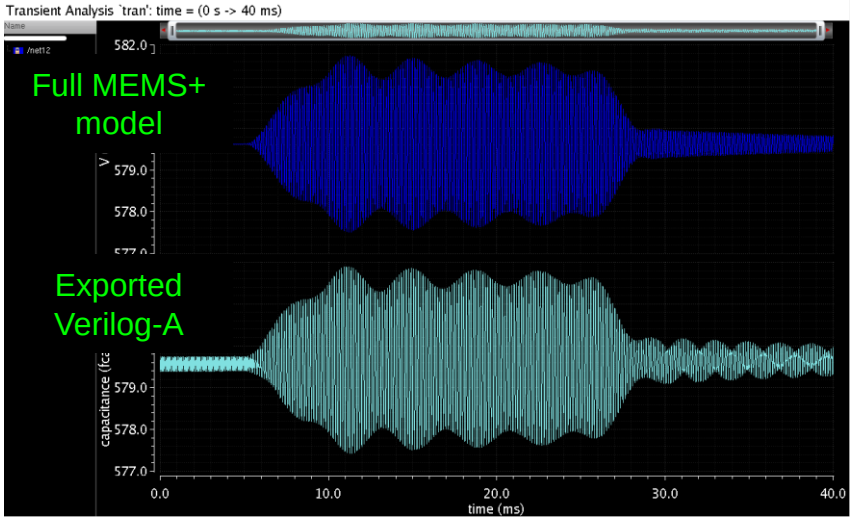
Dual-Mass Gryo Example

Key Mechanical Modes



Transient Simulation in Cadence Spectre

response to angular acceleration pulse, 40ms real time



Verilog-A model with 2nd-order non-linearities	Simulation time per real time (s/ms)	Speed-up vs. full *MEMS+* model
Coriolis force	0.27	255X
Coriolis force and DC bias	1.15	61X

Exported Verilog-A vs. Full *MEMS*+ Models

Model Characteristic	Full *MEMS*+	Exported Verilog-A
Included MEMS physics	Mechanics, electrostatics, gas damping, piezo effects, package effects	Same as full model except noise simulation
Nonlinearities	All input and state vars	Selected input vars
Parametric	Yes	No
3D Result Visualization	Yes	No
Applicable device types	Sensors (motion, mics,…), resonators, actuators	Same, except devices that depend on pull-in instability
Simulation speed	Selective simplification for speed/accuracy trade-off	**Up to 100X faster**
Compatible simulators	Cadence Spectre and APS	**Most A/MS simulators**
Protects MEMS device IP	No	**Yes**

Expected usage: Verilog-A models will be used for routine simulations while full *MEMS*+ models will be used to investigate anomalous behavior and design corners

Applicable Device Types for Exported Verilog-A

Applicable to sensors and resonators, devices that have small displacement compared to air gap, including

- Accelerometers
- Gyros
- Microphones
- Pressure sensors
- Electrostatically-actuated resonators
- Energy harvesters
- Scanning mirrors (small motion)

Not applicable for electrostatic pull-in analysis of sensors, or actuators that depend on pull-in for intended function, including

- Switches
- Varactors (tunable capacitors)
- Digital display mirrors
- Shutters
- Scanning mirrors (large motion)

These limitations apply to MEMS+ 4.0.
Future releases will have more capabilities

Customer Quote on Exported Verilog-A

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Tero Sillanpää, ASIC Design Manager, Murata:

"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

Licensing of Verilog-A Export

"Verilog-A Export" requires a new license key

- The license key is required to export Verilog-A from *MEMS*+
- Running exported Verilog-A in Cadence or any other A/MS simulator is unlicensed.

"Verilog-A Export" is a new option on our price list

- It is an add-on to any *MEMS*+ bundle
- For multi-seat quotes, the number of Verilog-A Export licenses should be the same as the number of seats
- Positive customer response indicates this is a high-value feature.

In Conclusion:

MEMS+ models have significant benefits over traditional FEA

- Much **faster** simulations due to reduced degrees of freedom
- **Parameterization** enables rapid design exploration and optimization
- **Compatible** with MATLAB, Simulink and Cadence simulators

MEMS+ goes well beyond traditional FEA capabilities

- Simulate the **dynamic** response of sensors and actuators with fully coupled physics
- Simulate closed-loop operation of sensors
- Perform noise analysis of sensors

MEMS+ 4.0 enables a new level of MEMS+IC co-design

- Exported Verilog-A models simulate much faster with sufficient accuracy
- Compatible with most A/MS simulators that take Verilog-A input
- Share models with partners and customers while protecting MEMS IP

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감사합니다

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