Computational Prototyping of an RF MEMS Switch using Chatoyant

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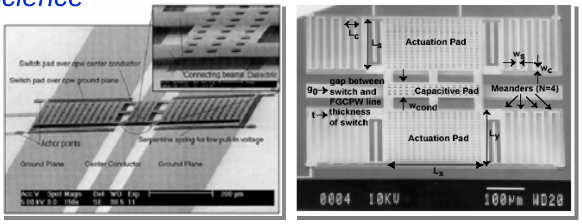
Motivation:

Modeling and simulation of Micro-Opto-Electro-Mechanical Systems (MOEMS) requires the use of mixed-signal, multi-domain solvers. We present Chatoyant, which has the ability to perform end to end system level simulations across electrical, mechanical, and optical domains.

Current Research Objectives:

- Model and simulate a complete system incorporating a RF MEMS switch
- Verify mechanical and electro-mechanical results using ANSYS and CoventorWare

SEM of RF MEMS Switch



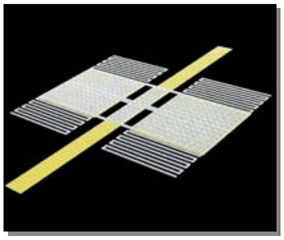
http://www.eecs.umich.edu/~dperouli/low-voltage_RF_mems.htm

CoventorWare Lumped Model and Finite Element Analysis Approach

CoventorWare uses lumped-model elements as the building blocks for simulation.

Tasks:

- Model spring stiffness and modal response
- Create finite element lumped elements for transient simulation



Analyzer FEA Models. Solid Models are created from the Architect Schematics.

Comparative Results

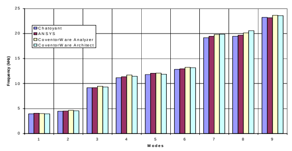
- We compare Chatoyant to Coventor Architect, ANSYS (FEM) and Coventor Analyzer (FEM).
- We show the modal results of these analyses for the first nine natural frequencies.
- There is good agreement between all tools.
- The table shows runtimes for these analyses based on a P4 3.00 GHz processor with 2GB SDRAM.
- Pull-in Voltage Analysis from Chatoyant, CoventorWare Architect, and ANSYS

Simulation Time - Spring Modal Analysis

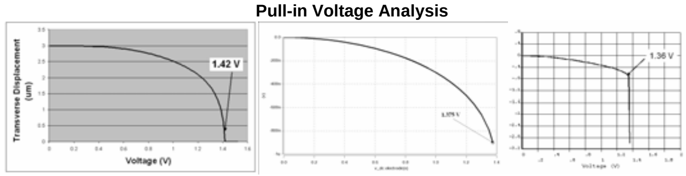
Solver	Simulation Time	Notes
Chatoyant	1.107 seconds	Two Nodes per Element with Six Degrees of Freedom per Node
CoventorWare Architect	2.330 seconds	Nonlinear - One Segment Beam with Six Degrees of Freedom at Each Beam End
CoventorWare Analyzer FEM*	134.000 seconds	Manhattan Bricks - 27-Node Parabolic Elements (1664 Elements)
ANSYS FEM*	30.000 seconds	3-D 20-Node Structural Solid Element, Solid95 (1664 Elements)

*The FEM Element size is 2.5um x 2.5um x 2um

RF-Switch Spring Meander Modal Response: Chatoyant, ANSYS, CoventorWare Analyzer, CoventorWare Architect



Pull-in Voltage Analysis



Chatoyant **CoventorWare Architect** **ANSYS**

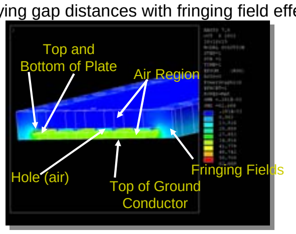
ANSYS Finite Element Analysis Approach

Ansys uses the finite element technique for the characterization of mechanical structures.

Tasks:

- Model and simulate the mechanical and electromechanical properties of the RF MEMS Switch
- Include the spring stiffness and modal response in the model
- Simulate fringing capacitance using CMATRIX
- Create finite lumped elements for pull-in simulation

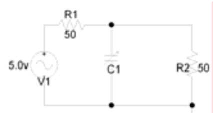
CMATRIX Results of Center Capacitor. The plate is modeled as a perfect conductor. CMATRIX produces capacitance values at varying gap distances with fringing field effects.



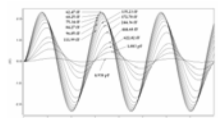
Capacitance analysis at the cross-section of the center capacitor

HSPICE®

Circuit Level Simulation. The RF Switch is modeled as a variable capacitor at the circuit level. Decreasing the gap results in a -23 dB loss of the signal



SPICE Circuit Schematic

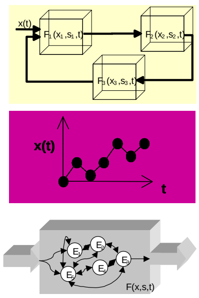


Switch Analysis With Variable Capacitor

Chatoyant

Chatoyant system level multi-domain 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



The MNA formulation uses a standard set of matrices, and the PWL solver must fit nonlinear components into these matrices.

General motion equation

$$F = [K][U] + [B][\dot{U}] + [M][\ddot{U}]$$

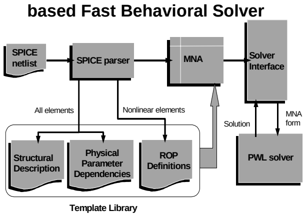
Standard ODE Transformation

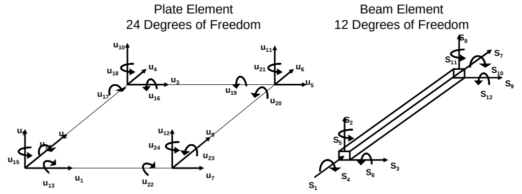
$$\begin{bmatrix} 0 & M \\ M & B \end{bmatrix}\begin{bmatrix} \ddot{U} \\ \dot{U} \end{bmatrix} + \begin{bmatrix} -M & 0 \\ 0 & K \end{bmatrix}\begin{bmatrix} \dot{U} \\ U \end{bmatrix} = \begin{bmatrix} 0 \\ I \end{bmatrix} F$$

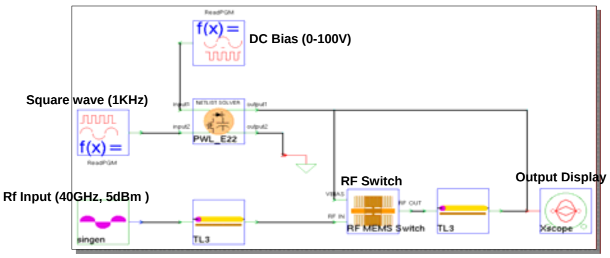
Templates for every basic element (e.g. beam)

$$X = \begin{bmatrix} \dot{U} \\ U \end{bmatrix}; \quad [Mb]\dot{X} + [Mk]X = [E]F$$

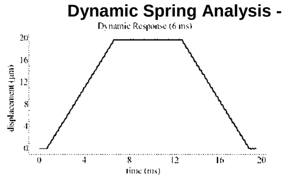
Extensible MNA Piecewise Linear based Fast Behavioral Solver



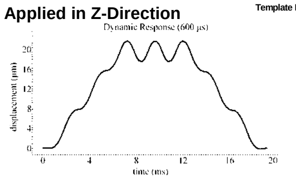




Dynamic Spring Analysis - 1μN Applied in Z-Direction



Spring Displacement (6ms rise time)



Spring Displacement (600μs rise time)

Mixed Domain Analysis:

•The RF Switch is placed in a system level schematic and the transient of the system can be observed.

•The envelope represents the mechanical switch attenuating the 40GHz input signal.