Accuracy Issues in a High-Level Model for MEMS Varactors

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Outline

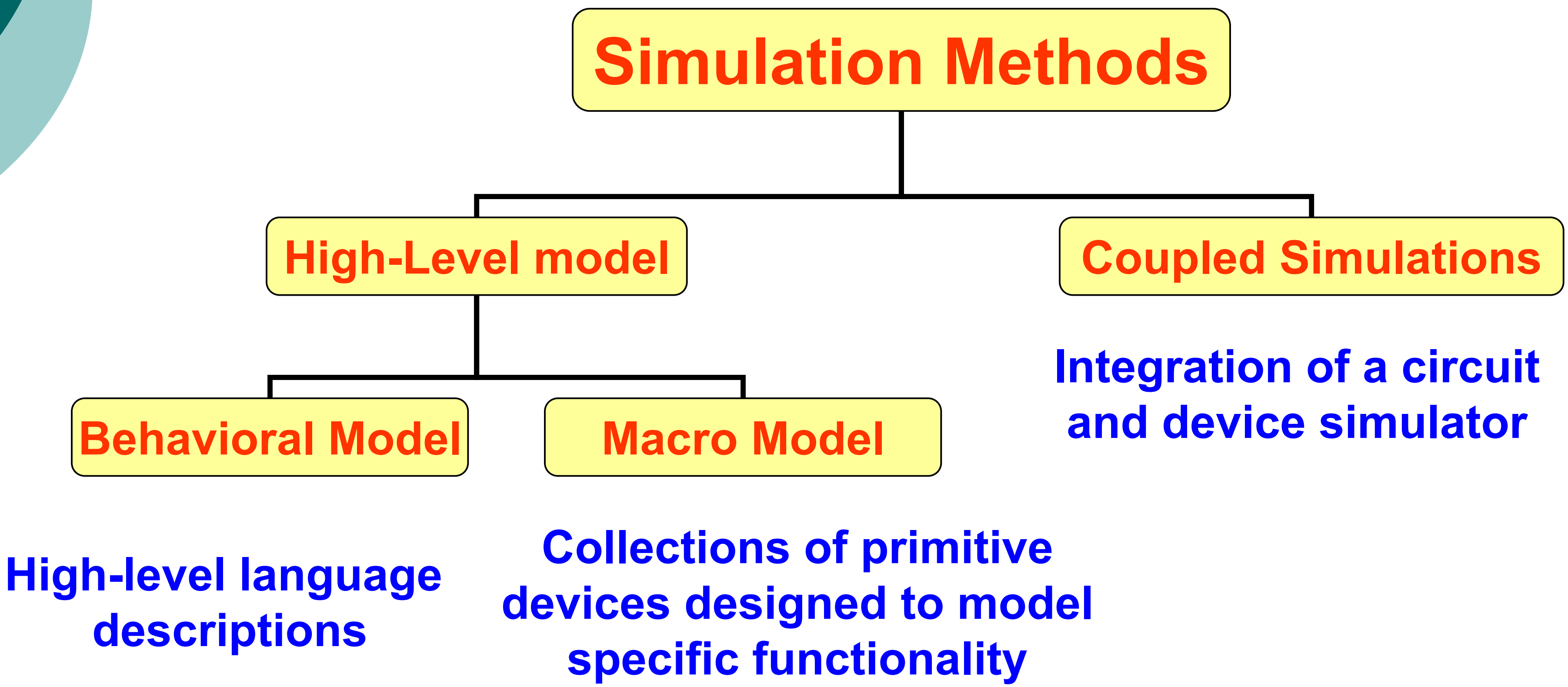
- **Introduction**
- **MEMS based capacitors**
- **High-level models**
- **Coupled simulations**
- **Results**
- **Conclusion**

Introduction

- **MEMS variable capacitors**
  - High Q
  - Wide tuning range
  - Withstand larger voltages
- **MEMS VCOs**
  - Low phase noise
  - Involve mixed technologies
  - Different physical effects need to be taken into account for efficient design

⇨ **Require accurate models for MEMS devices**

MEMS Simulation

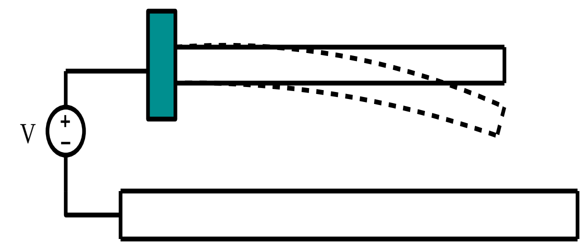


MEMS Simulation

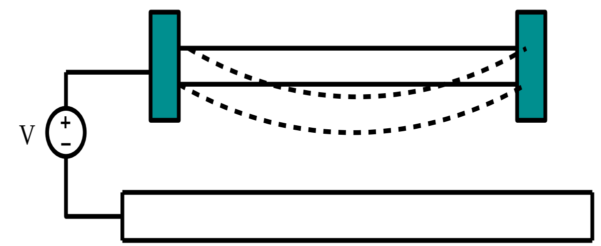
- **High-level models**
  - Easy implementation of models
  - Faster
- **Coupled simulations**
  - Requires integration of device/circuit simulators
  - Comparatively much slower but very accurate

MEMS Capacitor Structures

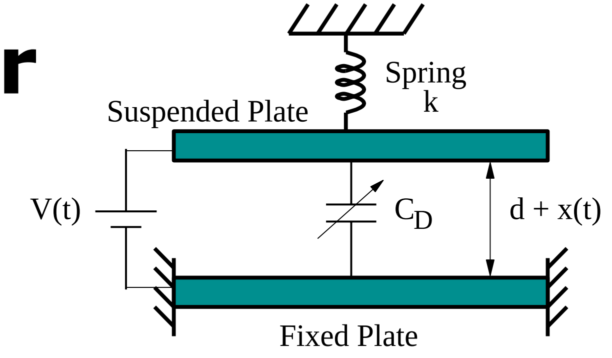
- Cantilever beams



- Fixed-fixed beams



- Parallel plate capacitor with suspension structures

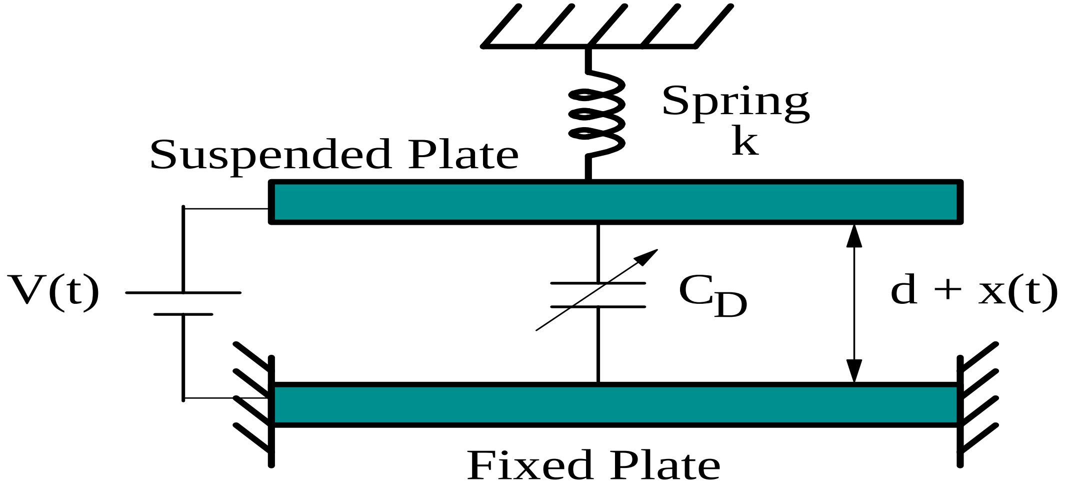


MEMS Capacitor Working Principle

In equilibrium

$$k\,x = -\,\epsilon_0 AV^2 / 2(d_1 + x)^2$$

Restoring Force (kx) | **Electrostatic Force** ($-\epsilon_0 AV^2 / 2(d_1 + x)^2$)

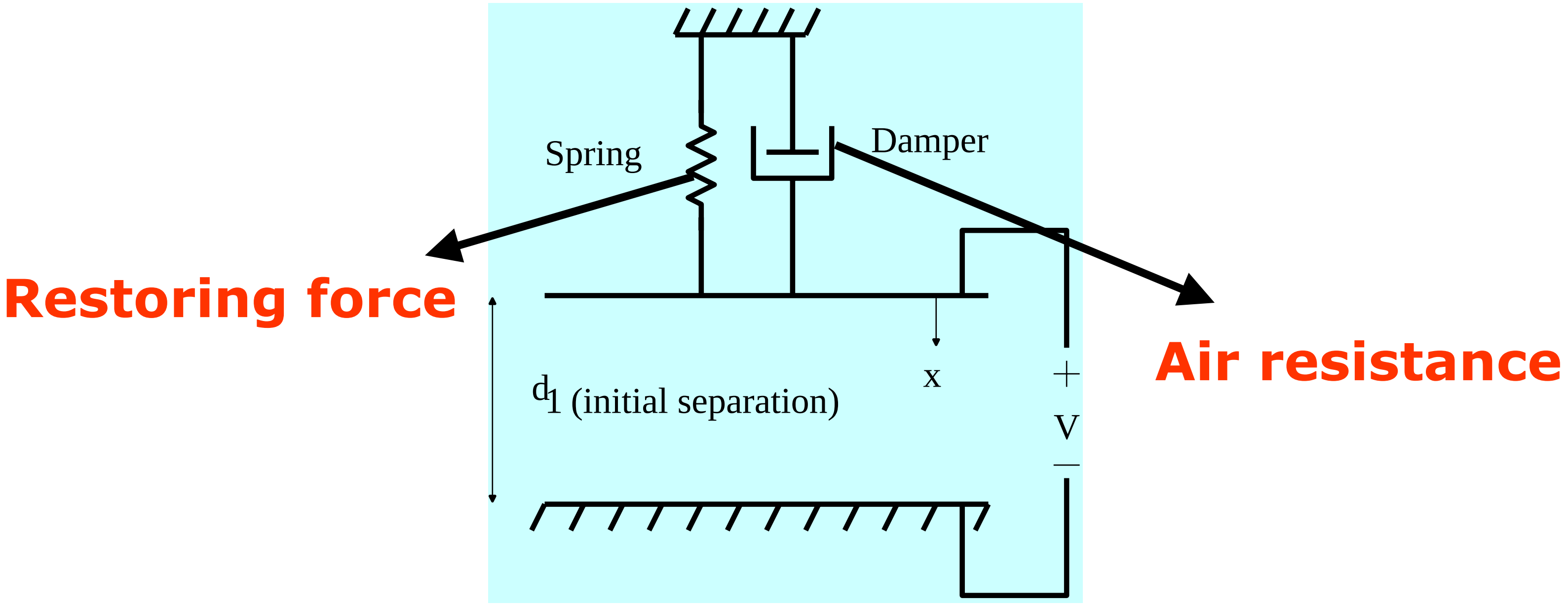


Electro-Mechanical Dynamics

Governing Equation

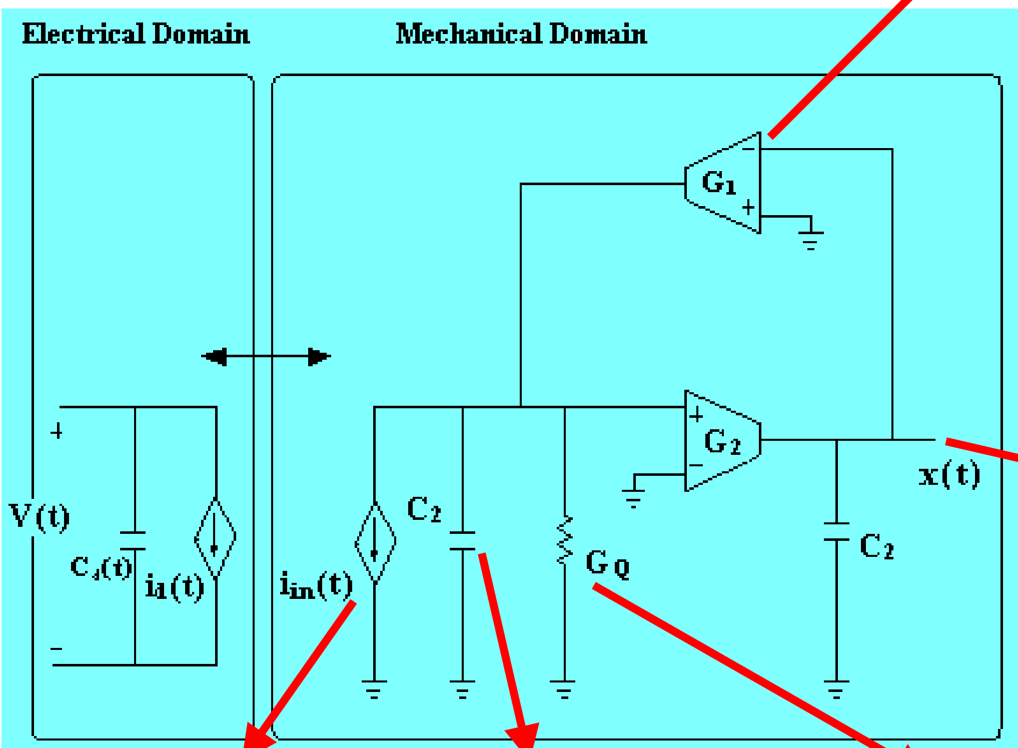
$$m\, d^2x/dt^2 + r\, dx/dt + k\, x = -\, \epsilon_0\, AV^2 / 2(d_1 + x)^2$$

Mass Spring Damper Model



Equivalent Circuit Model

* Dec and Suyama, *IEEE Trans. MTT*, pp. 2587-2595, Dec 1998



Restoring force as transconductance

Displacement as voltage

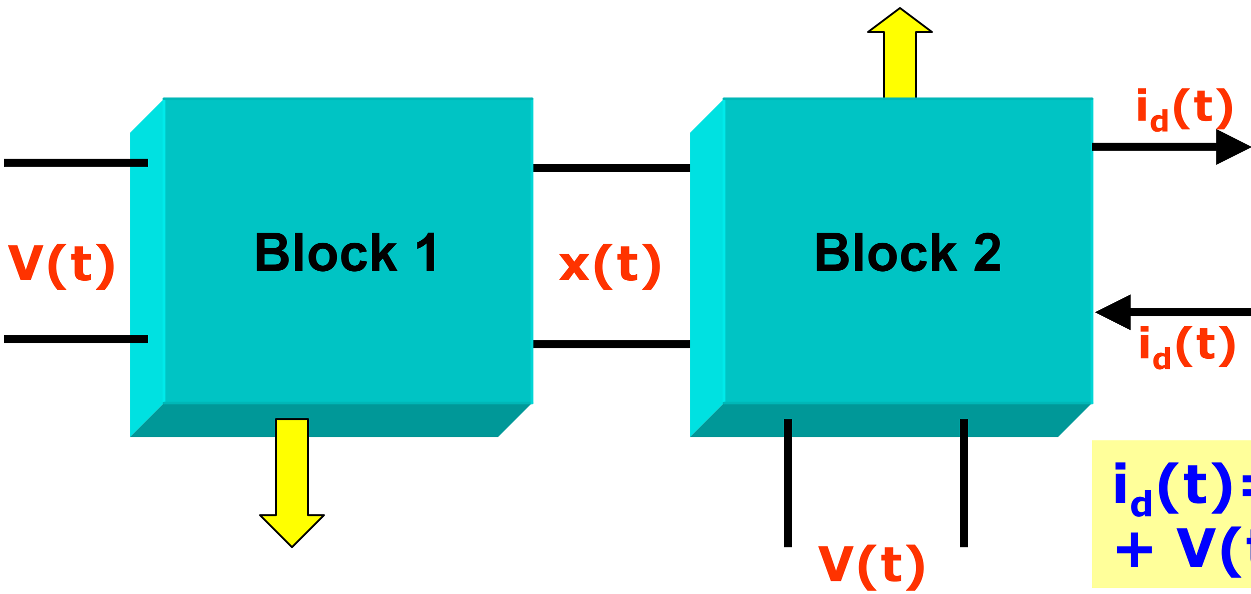
Electrostatic force as VCCS

Mass as capacitor

Damping coefficient as conductance

AHDL Behavioral Model

Block 2 defines the capacitance of the MEMS capacitor.



$$i_d(t)=C_d(t)dV(t)/dt + V(t)dC_d(t)/dt$$

Block 1 computes the displacement x(t) from the input voltage v(t)

Coupled Simulations

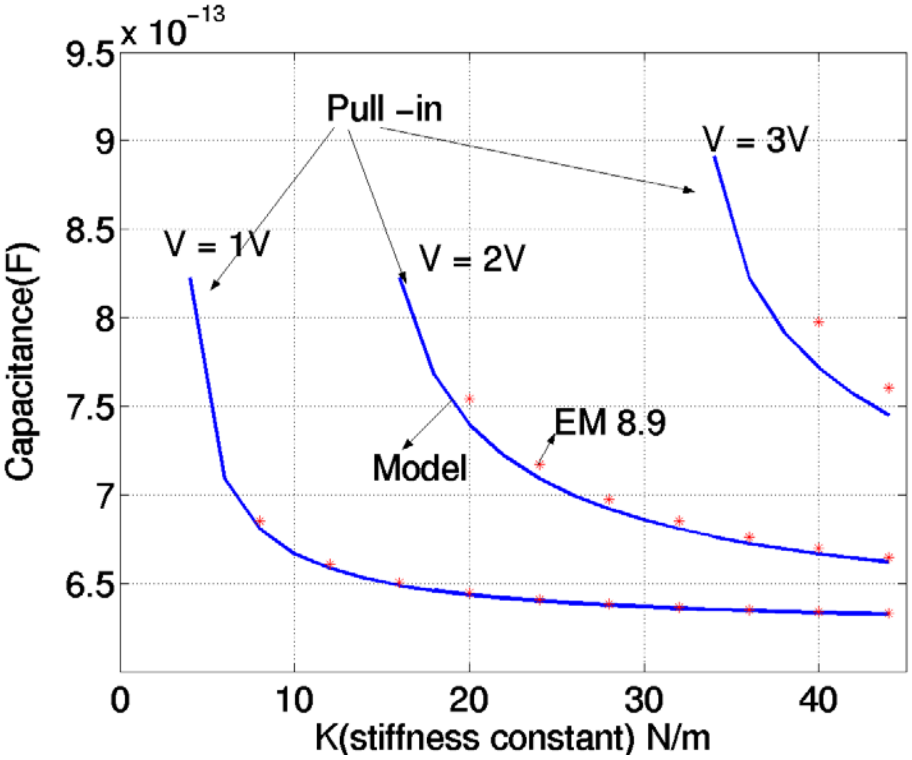
- **The circuit simulator : Spice3f5**
  - Industry standard
  - Supports different kinds of devices and analyses
  - Open source
- **The device simulator : EM8.9**
  - Simulator for electrostatic MEMS analysis
  - Employs a meshless method

Results

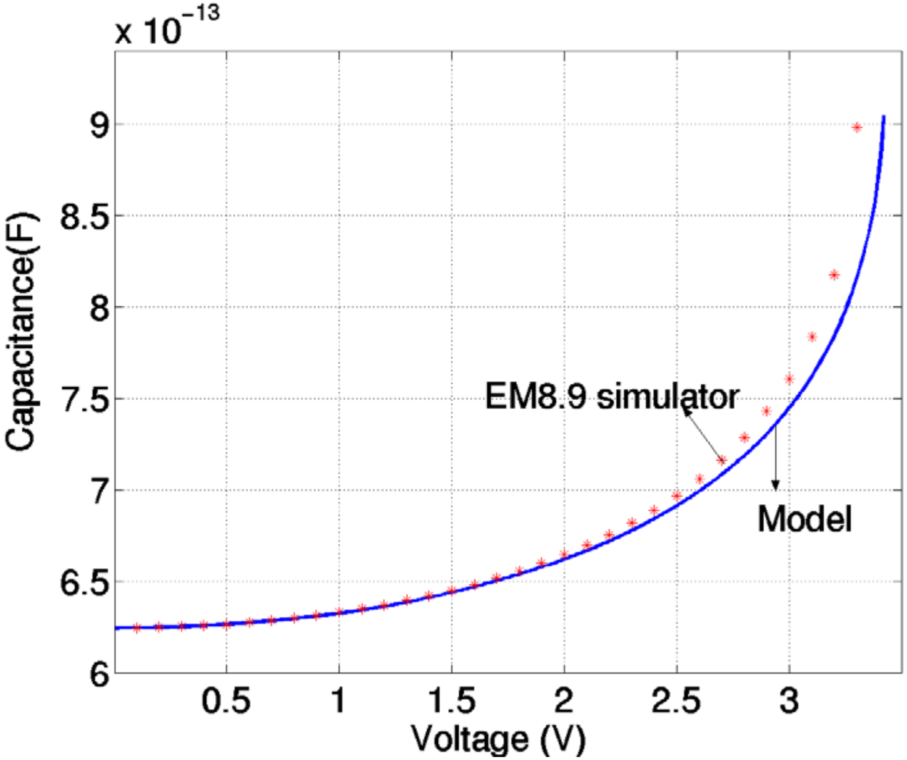
- **Simulations of the MEMS capacitor using both the high-level models and the numerical solver EM8.9**
- **Simulations of different MEMS structures, materials and other design parameters**
- **Accuracy issues in the context of a RF MEMS VCO**

Capacitance for Varying Stiffness Constants

- **Deviation in the curves increases near pull-in**
- **High capacitance sensitivity near pull-in**



Tuning Characteristics for Parallel Plate Capacitor



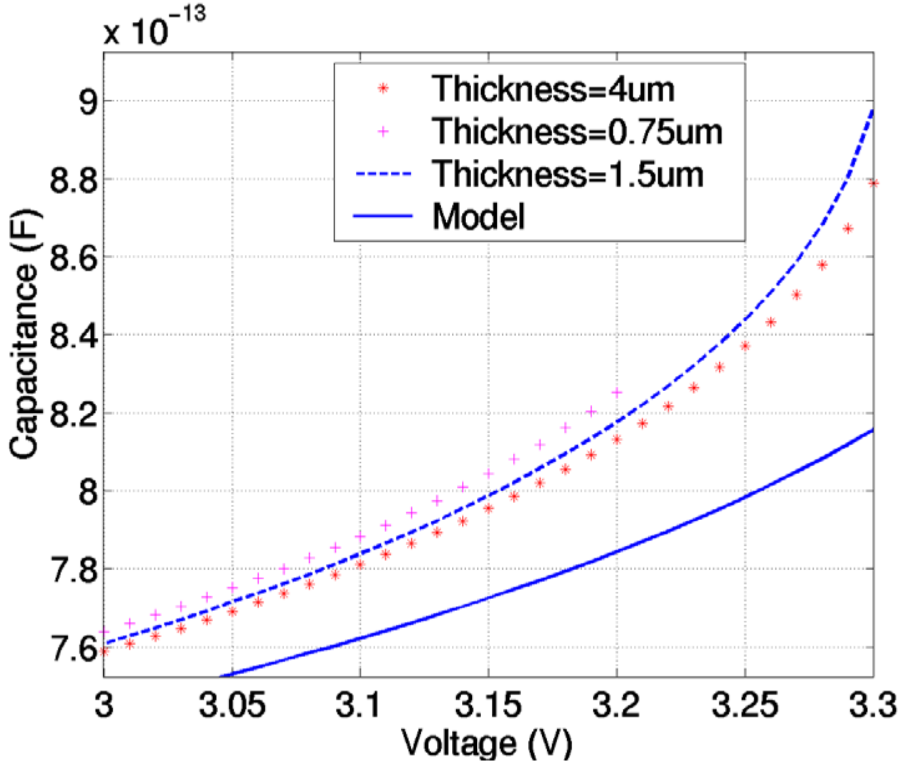
Increased deviation near pull-in voltage

Discrepancy in the stiffness constant between EM8.9 and the model

Tuning Characteristics for Varying Thickness

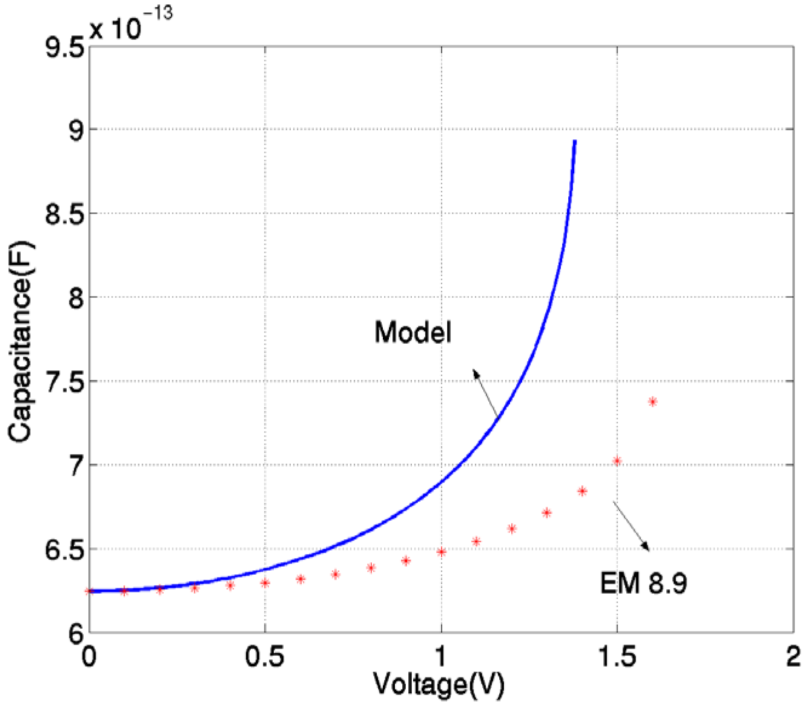
- Model does not predict variation in capacitance characteristics with thickness of top plate

- Top plate contributes to overall stiffness constant

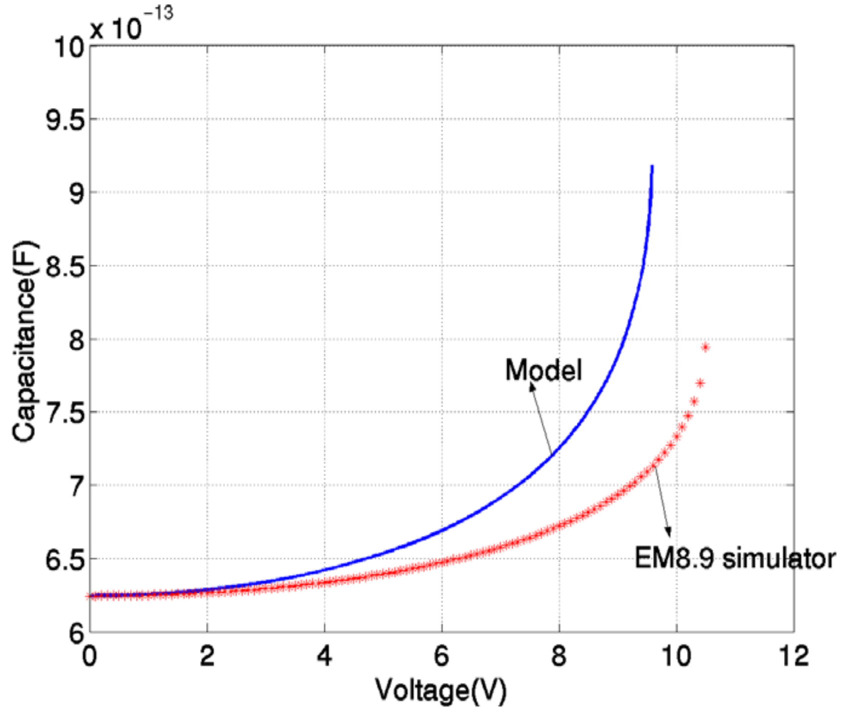


Other MEMS Structures

Cantilever Beam

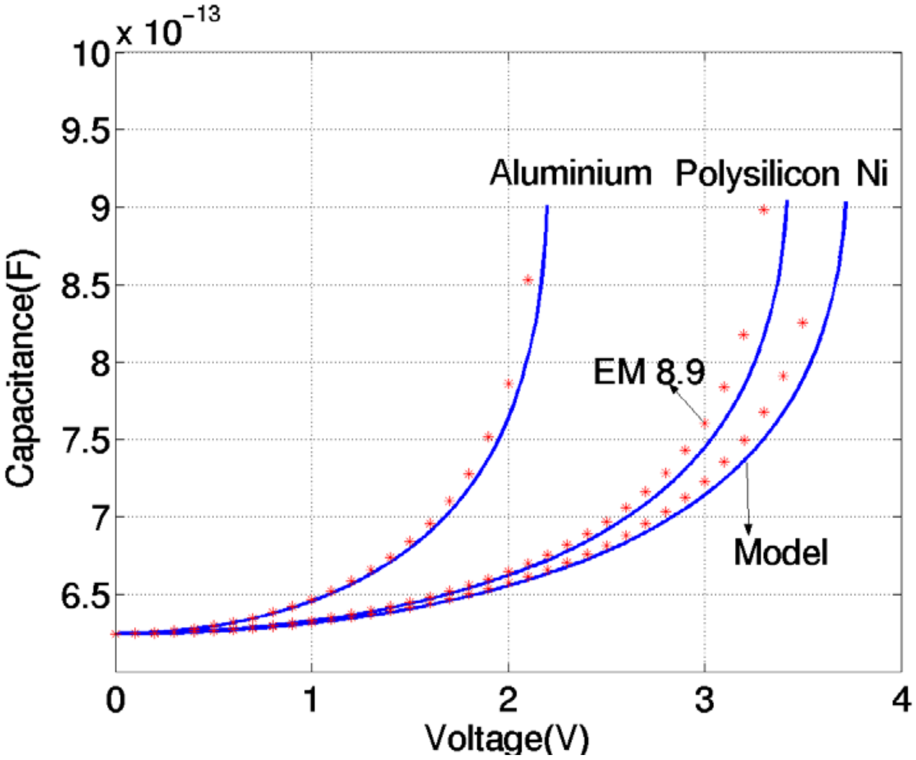


Fixed-Fixed Beam



Tuning Characteristics for Different Materials

- **High-level model includes material properties**
- **Discrepancy near pull-in voltage**

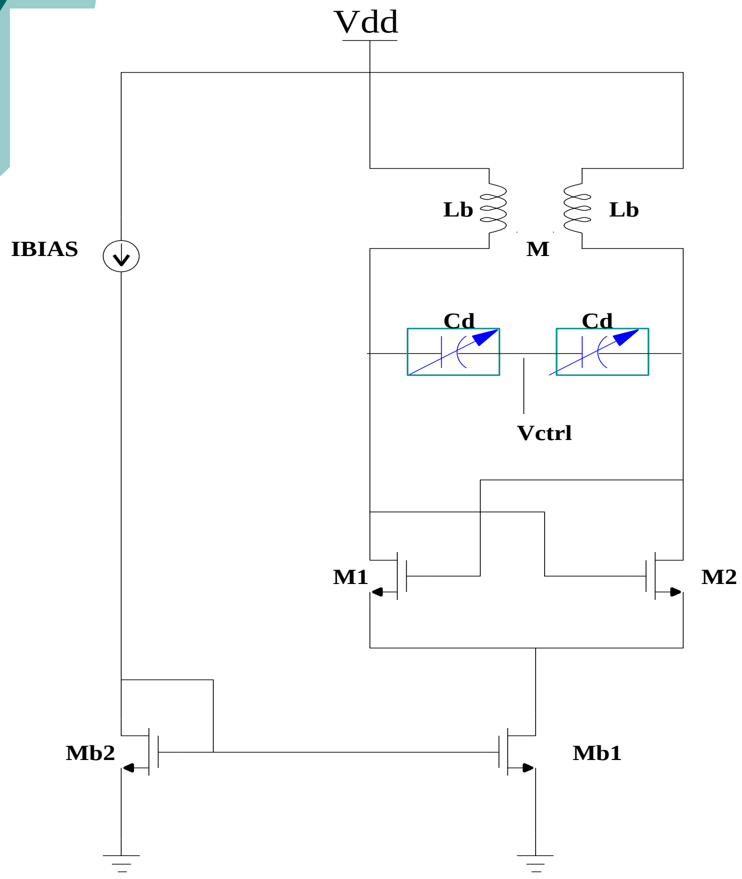


VCO Simulation

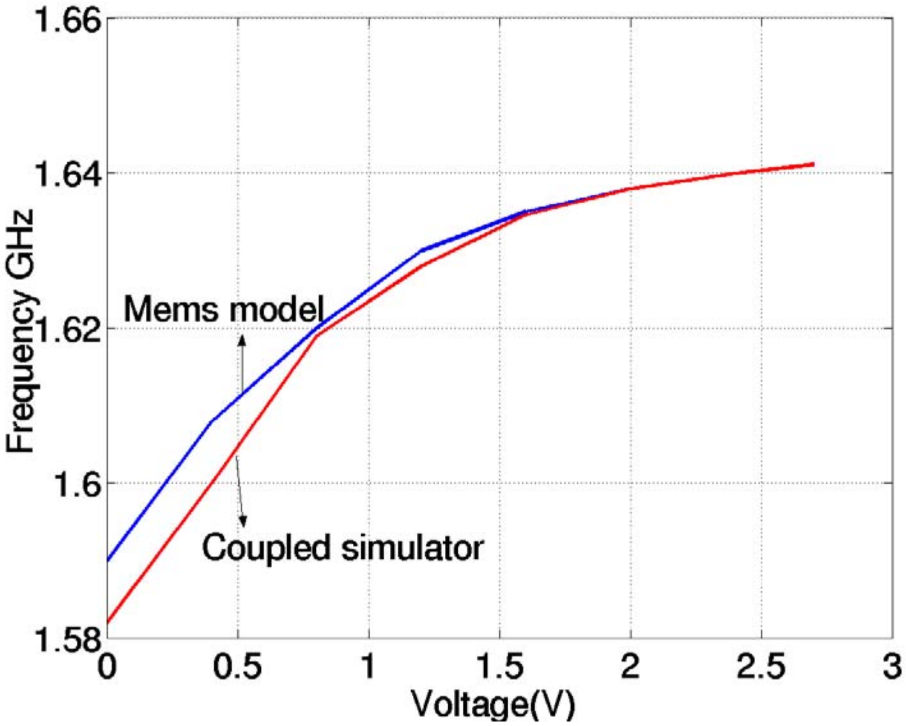
- 1.6 GHz VCO in a TSMC 0.35 μm process
- Simulations performed with the high-level model and the coupled circuit/device simulator
- Amplitude of oscillation is in agreement
- Differences in frequency tuning characteristics are consistent with the C-V curves

Results

VCO Circuit



Frequency Tuning Characteristics



Conclusions

- **High-level models fail to account for the stiffness constant contributed by the top plate**
  - **⇨ Inaccurate near pull-in**
- **Simulations for different materials show similar trends**
- **High-level model inaccurate in simulating different structures**