Simulating Microsystems

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Overview

- Microsystems overview
- Simulation software
- Case study: gap-closing actuator

Microsystem basics

- MEMS == Micro Electro Mechanical Systems
- Micromachines made with IC fab technology
- Micro: micrometer scale features
- Electromechical (optical, thermal, fluidic, etc): multiple energy domains
- Systems: heirarchical designs with subsystems and interfaces

Microsystem applications

- Inertial sensors: accelerometers, gyros
- Fluidics: ink jet printers, biolab chips
- Optics: optical switches, projectors
- Pressure sensors: industrial, medical, auto
- RF devices: cell phone, radar components
- Other: microrelays, sensors, disk heads

(List from “Microsystem Design” by S. Senturia)

Microscale physics

- Surface area / volume ratio is large (compared to most macroscopic structures)
- Gravitational forces negligible
- Electrostatic forces substantial
- Frictional forces (particularly “stiction”) important
- Air behaves like a very viscous fluid ($Re << 1$)
- Still classical (vs. nanosystems)

MEMS fabrication

- Basic cycle: deposition, lithography, etch
- Not precision machining!
- Process characterization is important
- Robustness to process variation is important
- MUMPS == multi-user MEMS processes (not a sparse linear algebra package)

Simulation questions

- What would this design do?
- What is the safe operating range?
- How sensitive is the design to variations?
- How can I optimize my design?
- How do I interpret my experimental results?

Simulation levels

Level of abstraction in device design:

- Process level
- Device level
- System level

Level of abstraction in simulation:

- Physical simulation
- Behavior simulation

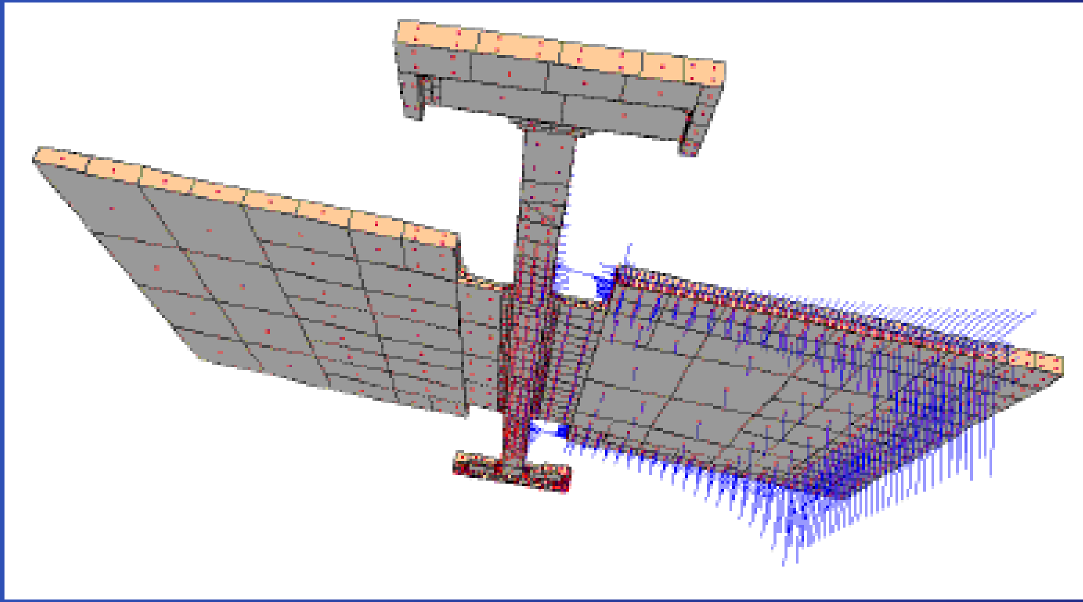
Approaches to modeling

- Finely discretize PDEs
- Reduce order of fine discretization
- Weighted residuals with simple trial form
- Equivalent circuit or spring-mass-damper
- Back-of-envelope calculations

Software

- Finite / boundary elements: ANSYS, Coventor
- System level modeling: Coventor, NODAS, SUGAR

Software: Coyote/Coventor



Software: SUGAR

- Name and heritage from SPICE
- Written in Matlab and C
- Version 2.0 beta (*many* subreleases)
- Web interface available

SUGAR web

cfm@bsac.eecs.berkeley.edu

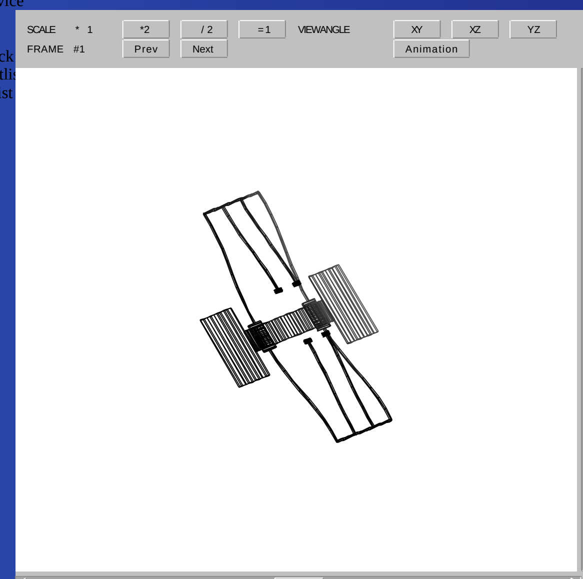
M&MEMS - A Millennium-based MEMS Simulator

> File Manage
> Turn Help O
> Change Password
> Admin
> About
> Logout

tang.net
> Display Device
> Simulations
> Edit Netlist
> Syntax Check
> Rename Netlis
> Delete Netlist

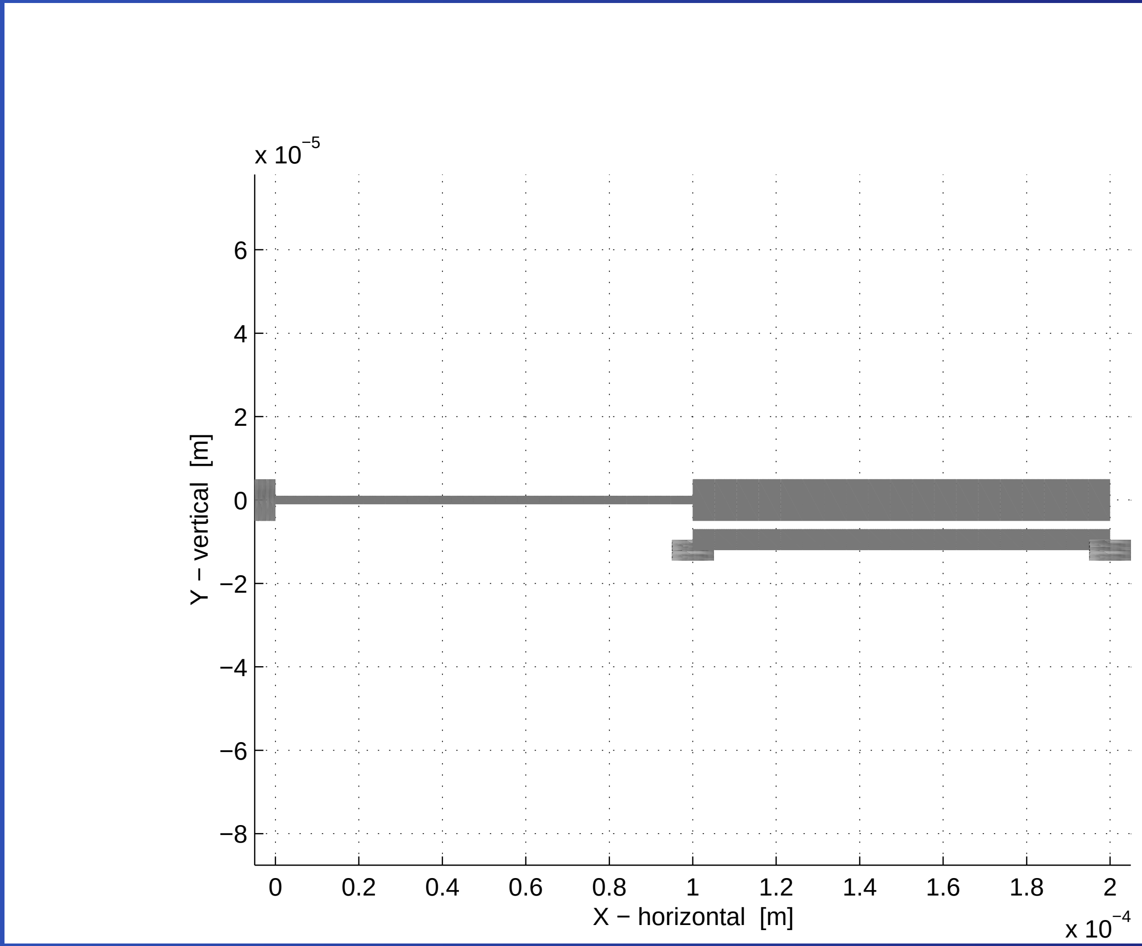
Modal Simulation Results in Java Viewer

Frame	Contents
1.	Structure with Frequency 128651.92
2.	Original Structure



Direct M&MEMS/SUGAR questions, comments, and bug reports to:

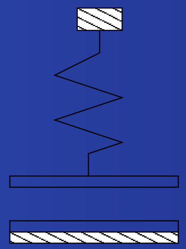
Case study: gap-closing actuator



SUGAR netlist

```
param V = 10
Vsrc      *   [A f] [V=V]
eground   *   [f] []
anchor    p1 [A] [l=5u w=10u oz=deg(180)]
beam2de p1 [A b] [l=100u w=2u h=2u oz=0 R=100]
gap2de    p1 [b c D E] [l=100u w1=10u w2=5u oz=0
                        gap=2u R1=100 R2=100]
eground   *   [D] []
anchor    p1 [D] [l=5u w=10u oz=-deg(90)]
anchor    p1 [E] [l=5u w=10u oz=-deg(90)]
eground   *   [E] []
```

Simplified version: hand analysis

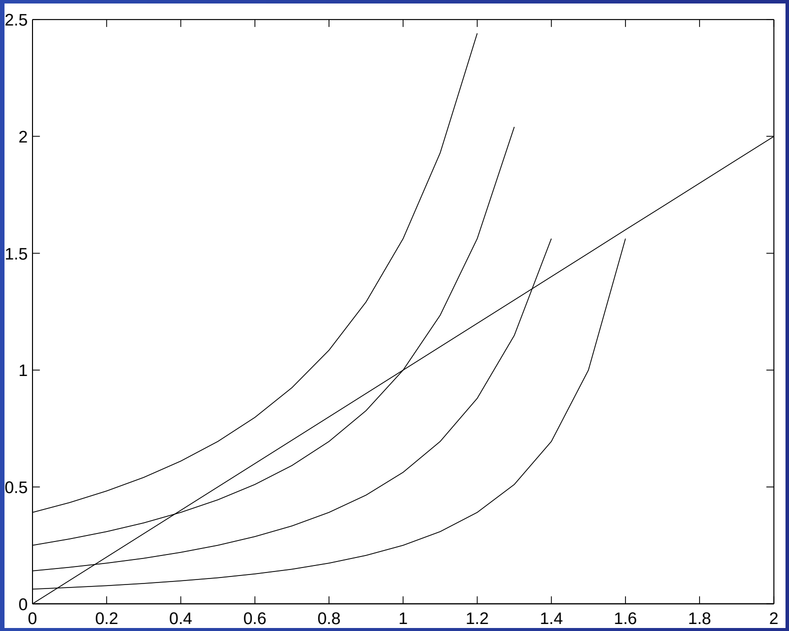


If displacement down is y, initial gap is g_0:

$$F_{elastic} = K_s y$$

$$F_{electric} = -K_e \frac{V^2}{(g_0 - y)^2}$$

Force magnitudes v. displacement



Straight line is elastic force; curved lines are electrostatic forces with varying voltages.

Electrostatic pull-in

For the simplified model:

- For $V < V_{pullin}$ there is one stable and one unstable equilibrium.
- For $V > V_{pullin}$ there is no equilibrium.
- The gap at pull-in is $1/3$ the initial gap.

Pulled-in gaps often never come apart.

Pull-in and model detail

- Pull-in occurs in less over-simplified models
- But the nature of the bifurcation varies with model!
- How detailed a model is needed to catch "important" bifurcations?

Pull-in and M-test

- Pull-in is dramatic – easy to see and measure
- Pull-in voltage depends on material properties
- M-Test idea: Use measured pull-in voltages for arrays of test structures to determine material properties
- Fitted a functional form to simulations in order to get approximate pull-in / measurement relation
- No attempt I know of to investigate sensitivity to overetch and other variations

Simulation and gap actuator

- Determine resonant frequencies
- Determine safe (quasi-static) operating ranges
- Determine relation between pull-in and material properties
- Experiment with stabilizing mechanisms