Simulating RF MEMS

David Bindel

UC Berkeley, CS Division

Collaborators

Faculty	Grad students
A. Agogino (ME)	D. Bindel (CS)
Z. Bai (Math/CS)	J.V. Clark (AS&T)
J. Demmel (Math/CS)	D. Garmire (CS)
S. Govindjee (CEE)	T. Koyama (CEE)
R. Howe (EE)	R. Kamalian (ME)
	J. Nie (Math)
	S. Bhave (EE)

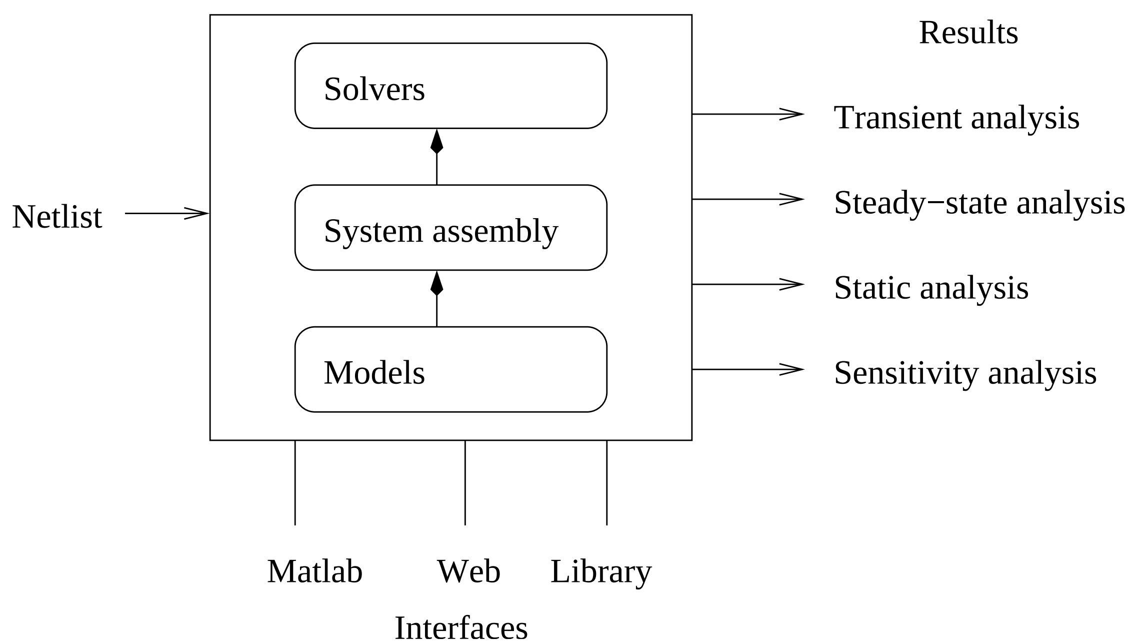
MEMS Basics

- Micro-electro-mechanical systems
  - Chemical, fluid, thermal, optical (MECFTOMS?)
- Applications:
  - Sensors (inertial, chemical, pressure)
  - Ink jet printers, biolab chips
  - RF devices
- Use IC fabrication technology
- Large surface area / volume ratio
- Still mostly classical (vs. nanosystems)

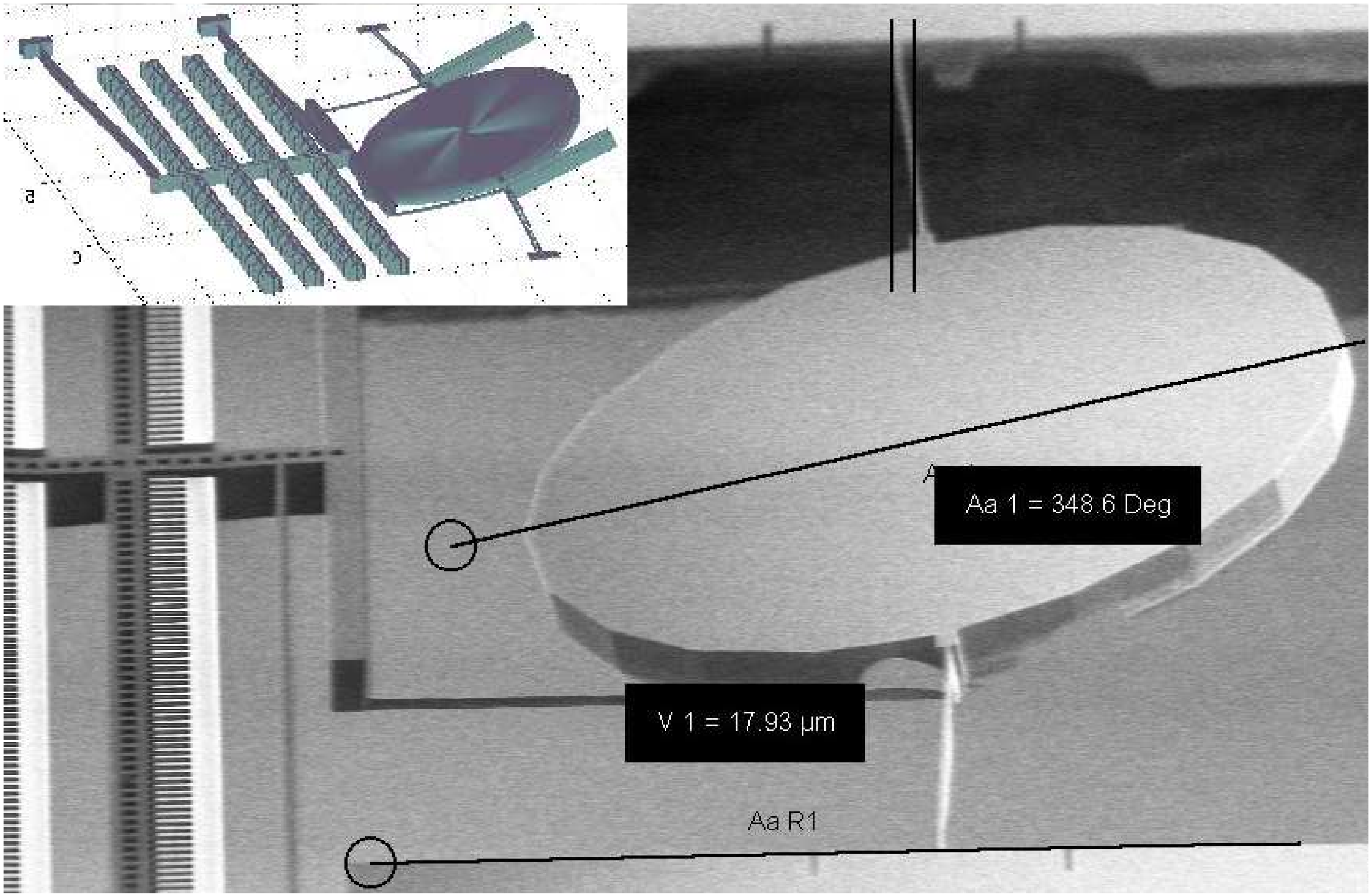
SUGAR

Goal: "Be SPICE to the MEMS world"

- Fast enough for early design stages
- Simple enough to attract users
- Support design, analysis, optimization, synthesis
- Verify models by comparison to measurement

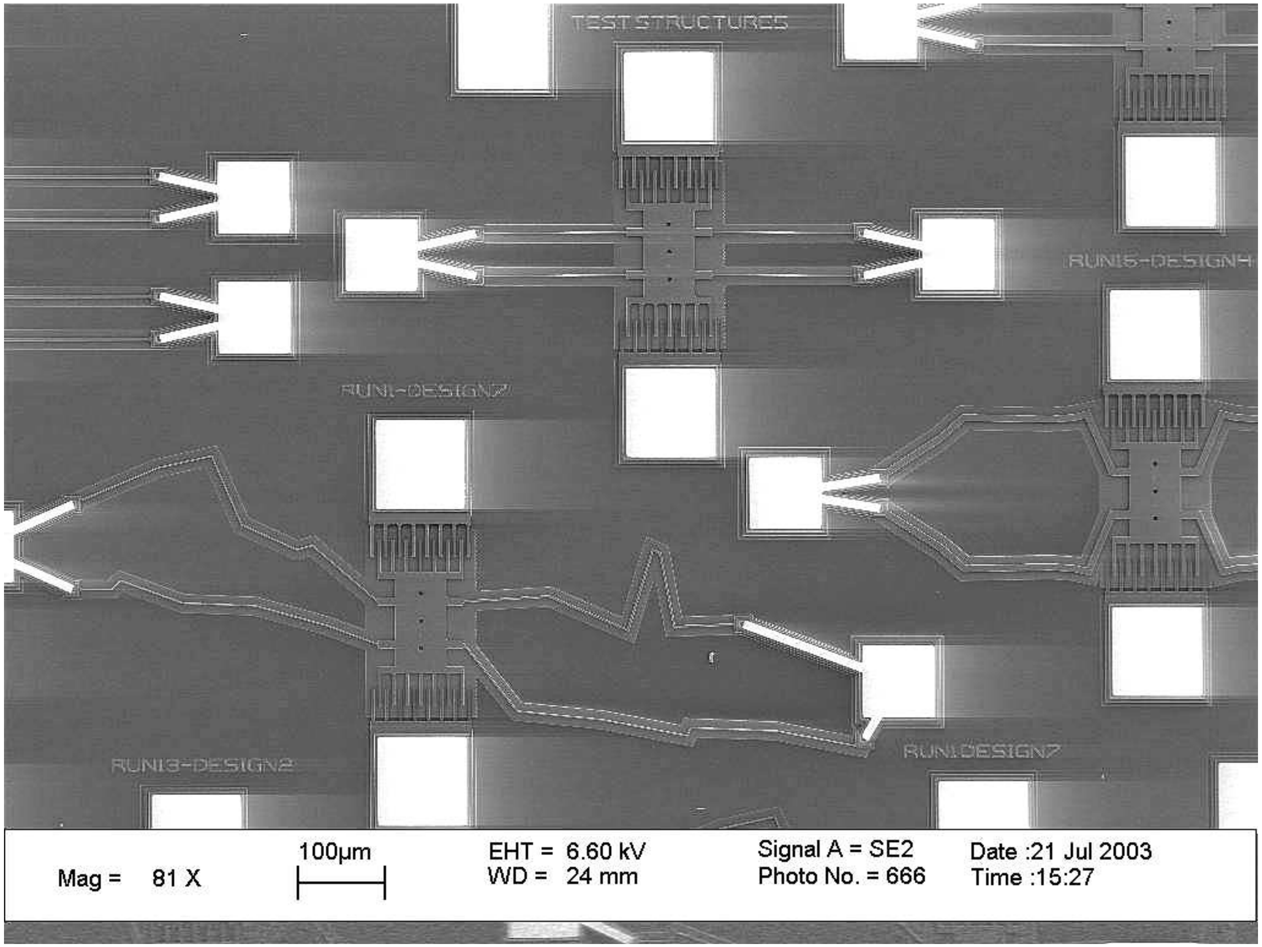


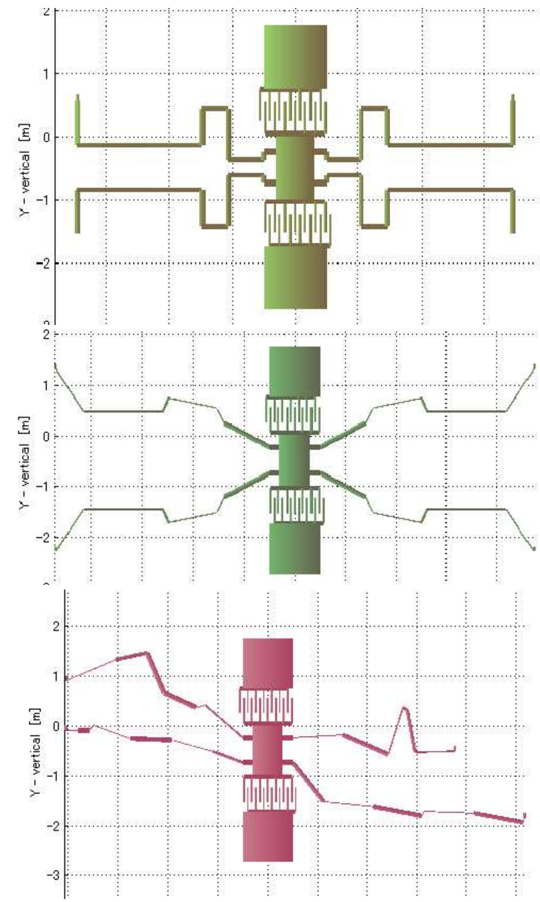
SUGAR: Analysis of a micromirror



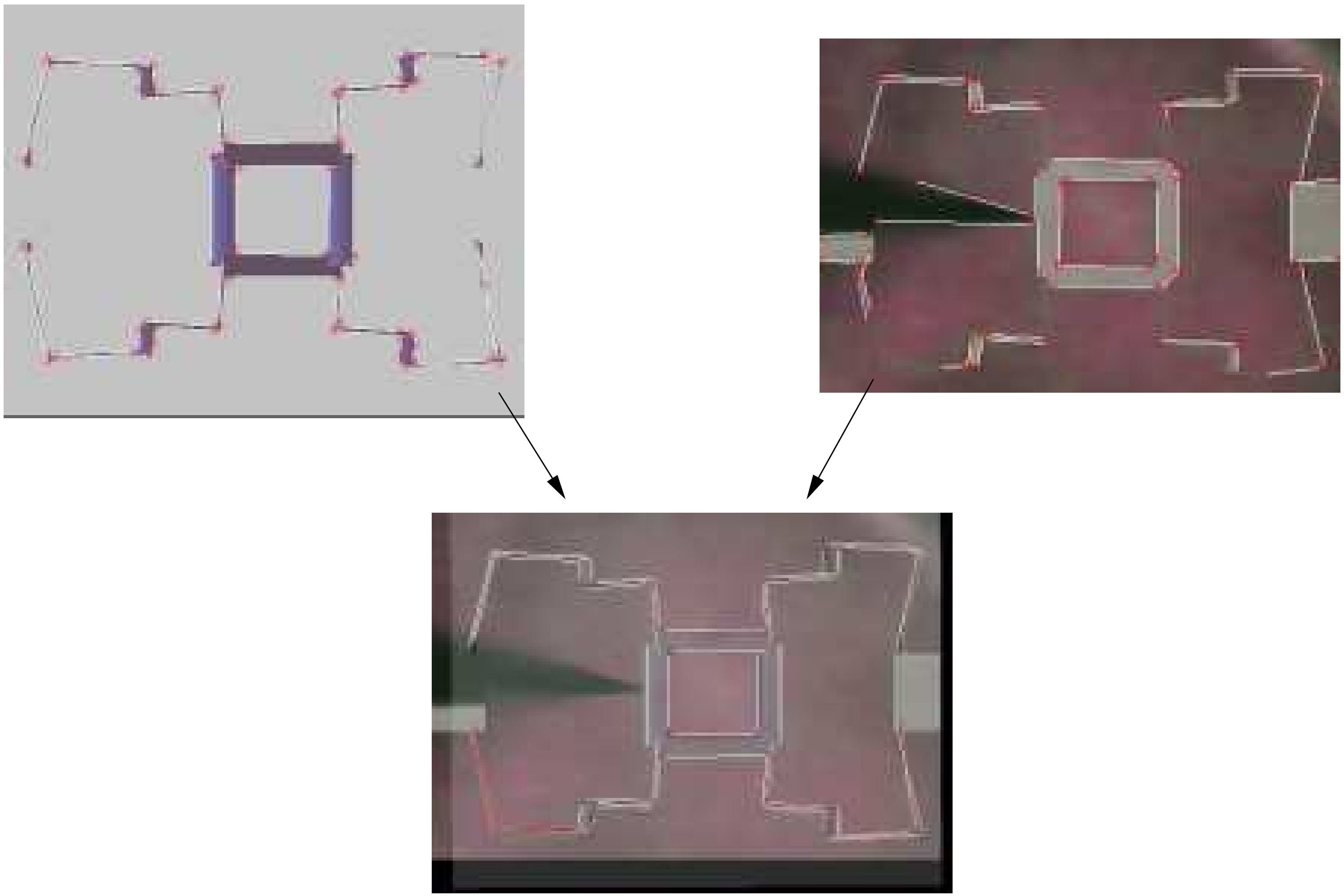
(Mirror design by M. Last)

SUGAR: Design synthesis

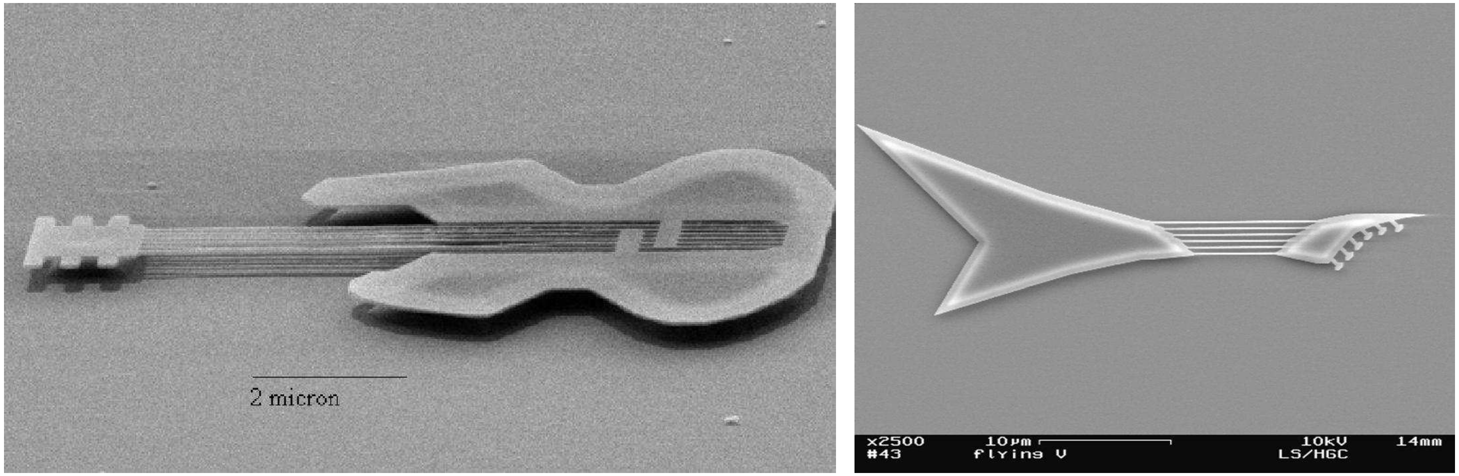




SUGAR: Comparison to measurement



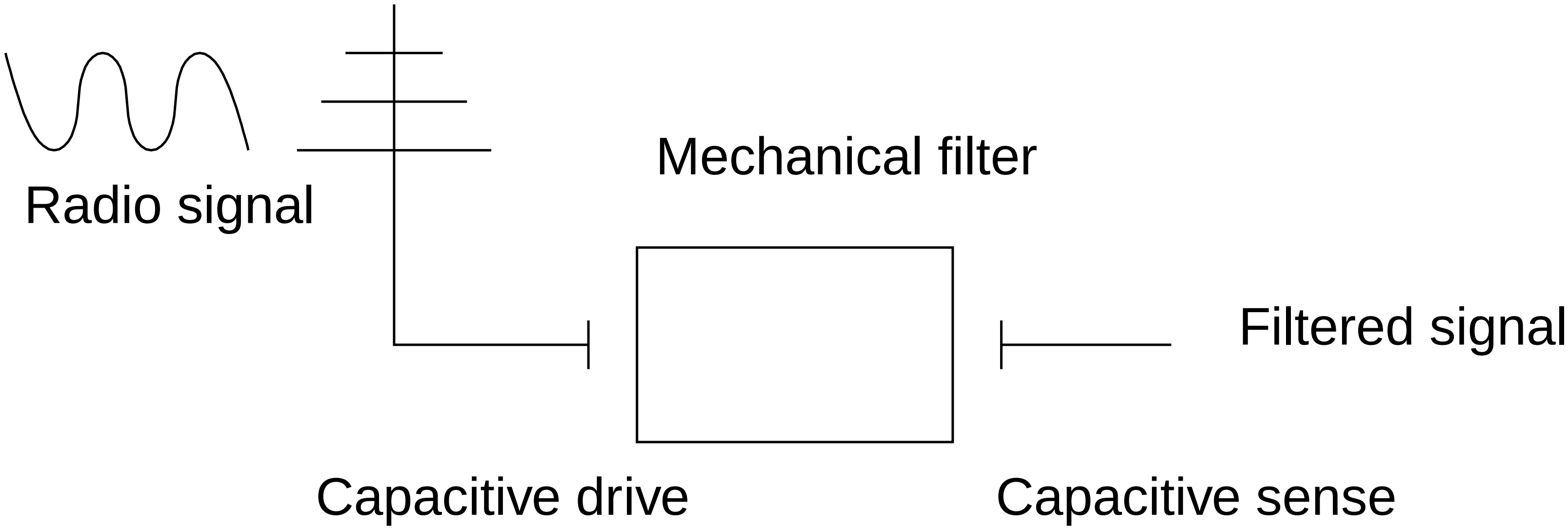
Why RF resonators?



Microguitars from Cornell University (1997 and 2003)

- Frequency references
- Sensing elements
- Filter elements
- Neural networks
- Really high-pitch guitars

Micromechanical filters



- Mechanical high-frequency (high MHz-GHz) filter
- Saves power and cost over electronic filters
- Advantage over piezo-actuated quartz SAW filters
  - Integrated into chip
  - Low power

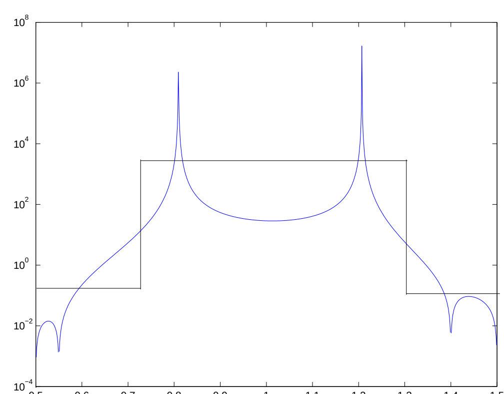
Governing equations

Time domain:

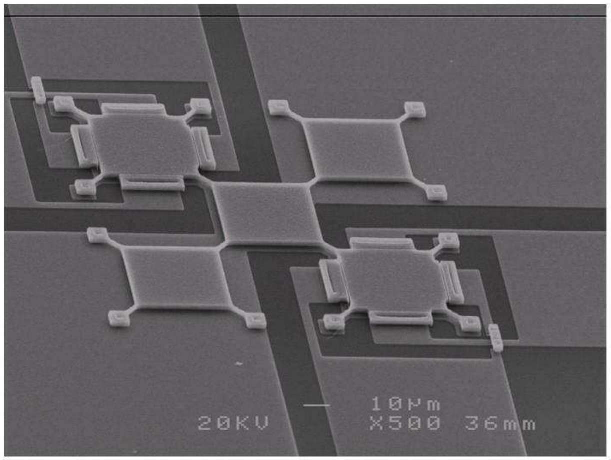
$$
\begin{aligned}
Mu'' + Cu' + Ku &= P\phi \\
y &= V^T u
\end{aligned}
$$

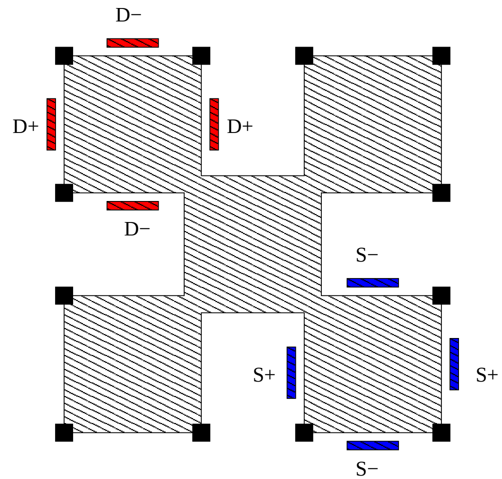
Frequency domain:

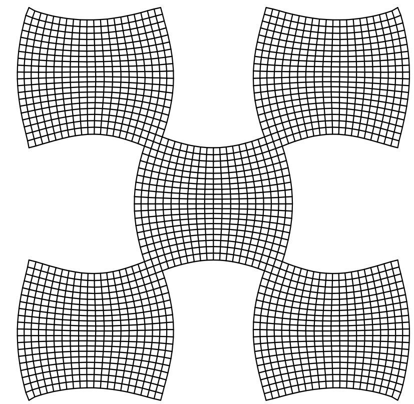
$$
\begin{aligned}
H(\omega) &= V^T(-\omega^2 M + i\omega C + K)^{-1} P \\
\hat{y} &= H\hat{\phi}
\end{aligned}
$$



First proposed design: Checkerboard

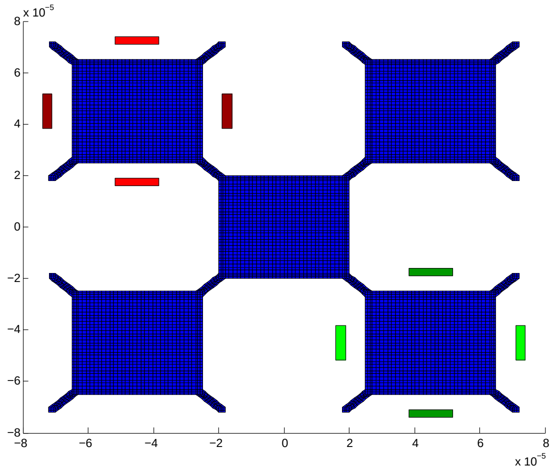


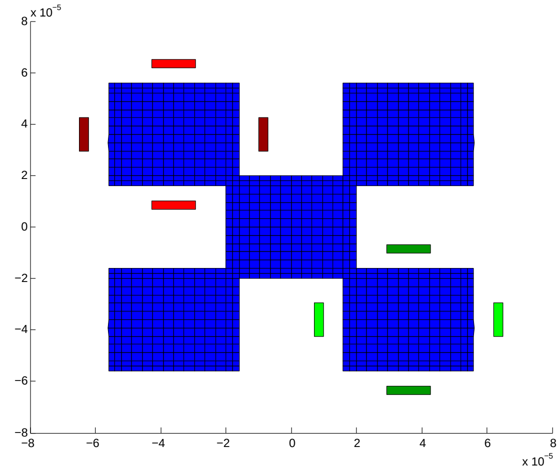




- Array of loosely coupled resonators
- Anchored at outside corners
- Excited at northwest corner
- Sensed at southeast corner
- Surfaces move only a few nanometers

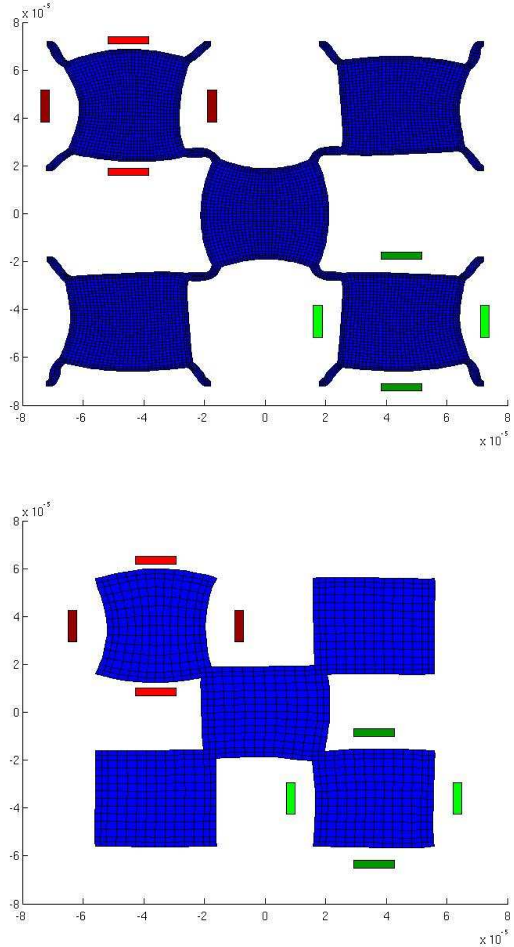
Design questions



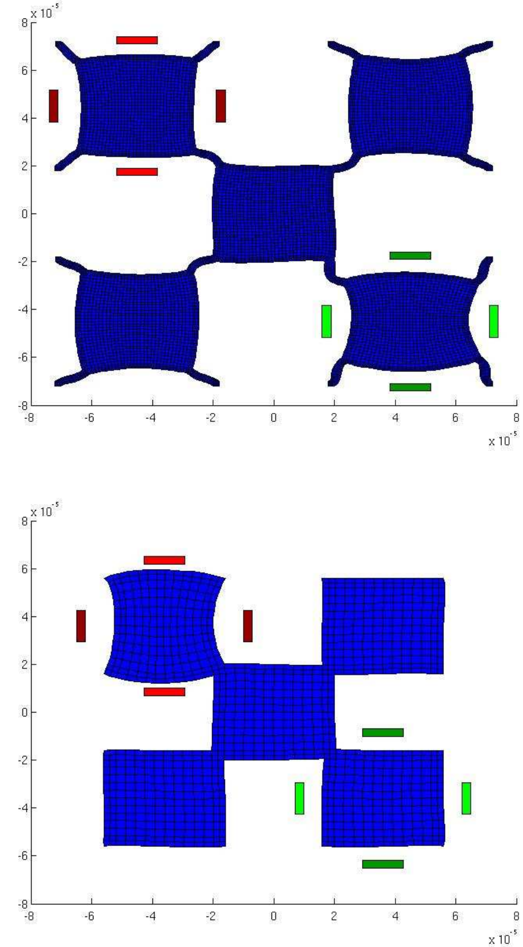


- Where should drive and sense be placed?
- How should the individual resonators be connected?
- How should the system be anchored?
- How many components? What topology?

Checkerboard response

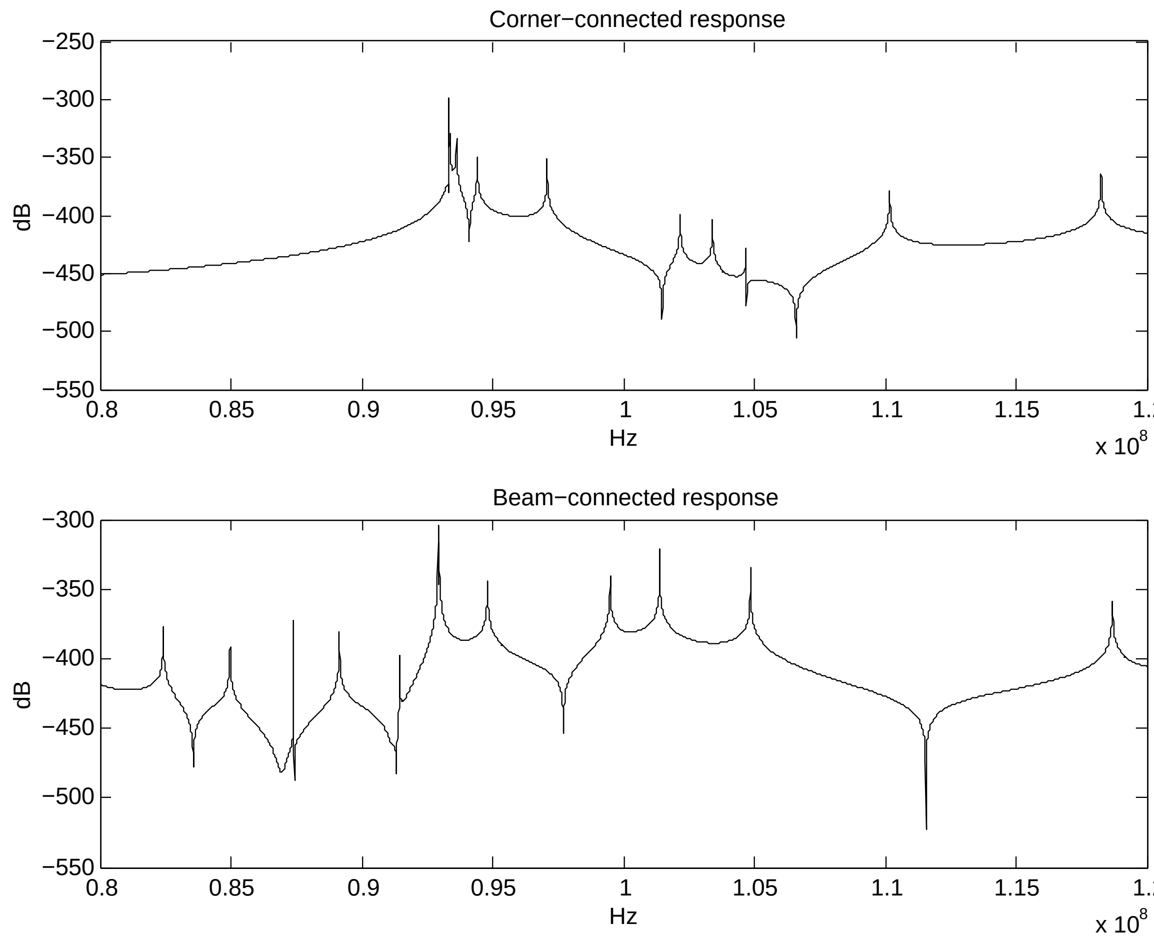


95 MHz



100 MHz

Checkerboard response



Corner-connected details   Beam-connected details

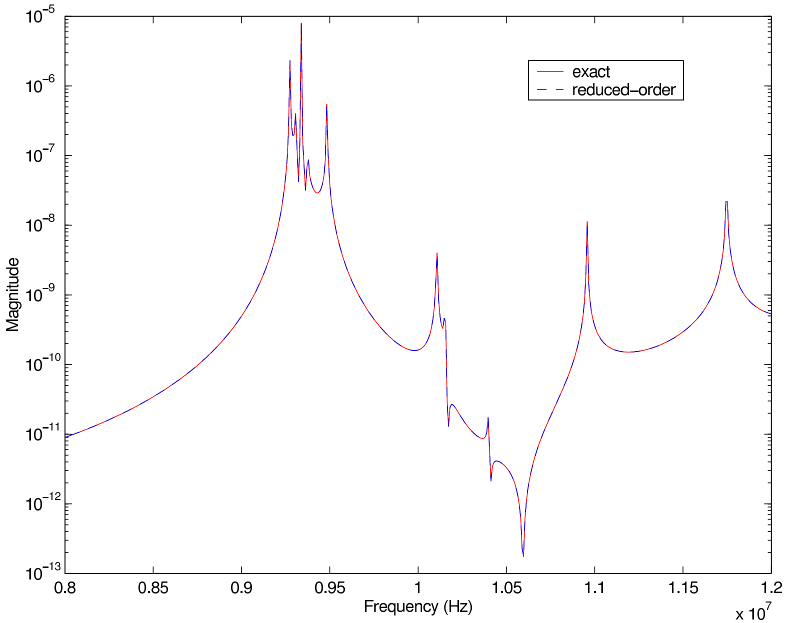
Current questions

- How do we model damping?
- How do we compute frequency response quickly?
- How do we track dependence on geometry?
- How do we optimize designs?

Energy loss and Q

- Goal: strong output signal and high Q
- Challenge: Model details of energy loss
  - Anchor loss
  - Thermoelastic damping
  - Akheiser damping
  - Air damping
- How are losses affected by fabrication errors (e.g. anchor misalignment)?

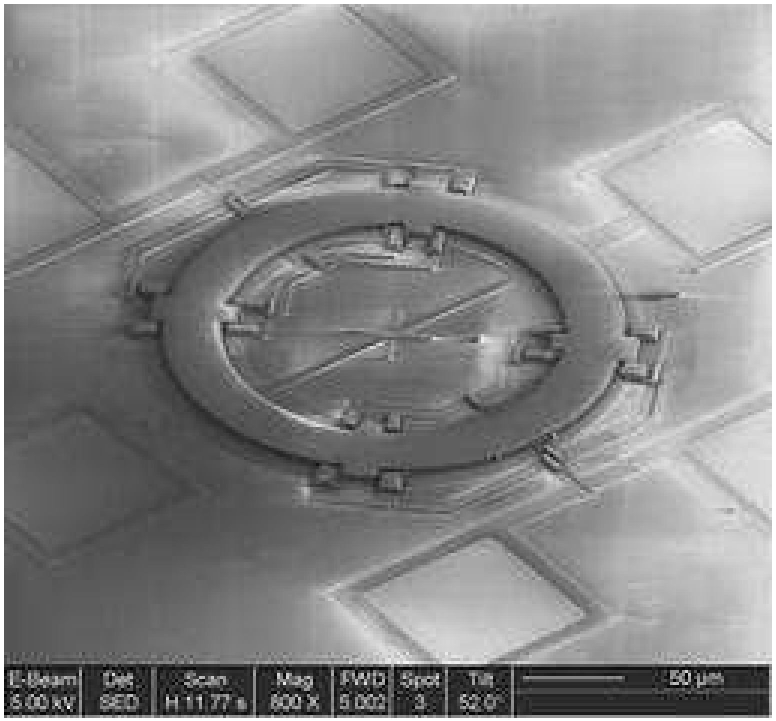
Model reduction

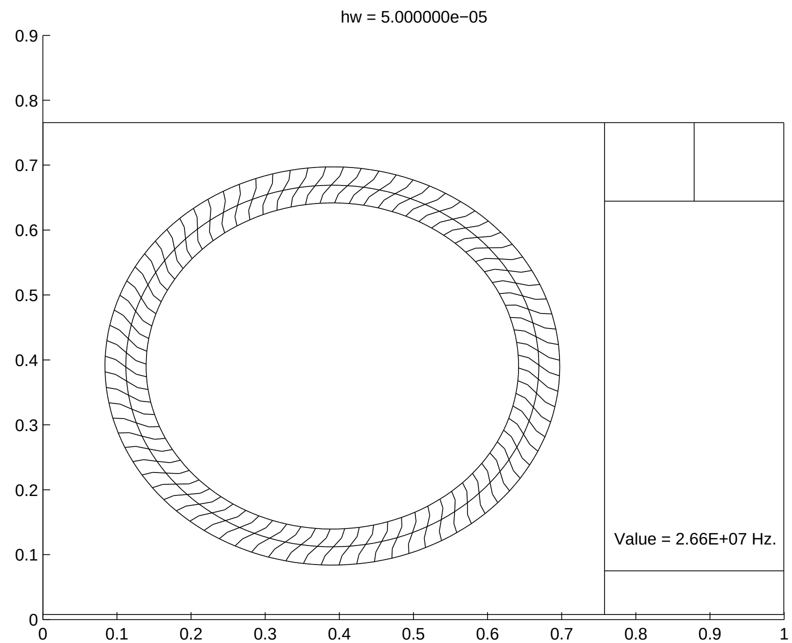


Sun Ultra 10	Sec	n
ROM:	28	4834
Full:	1474	50

- Project onto an unusual Krylov subspace
- Preserve second order system structure
- Plan to use substructuring

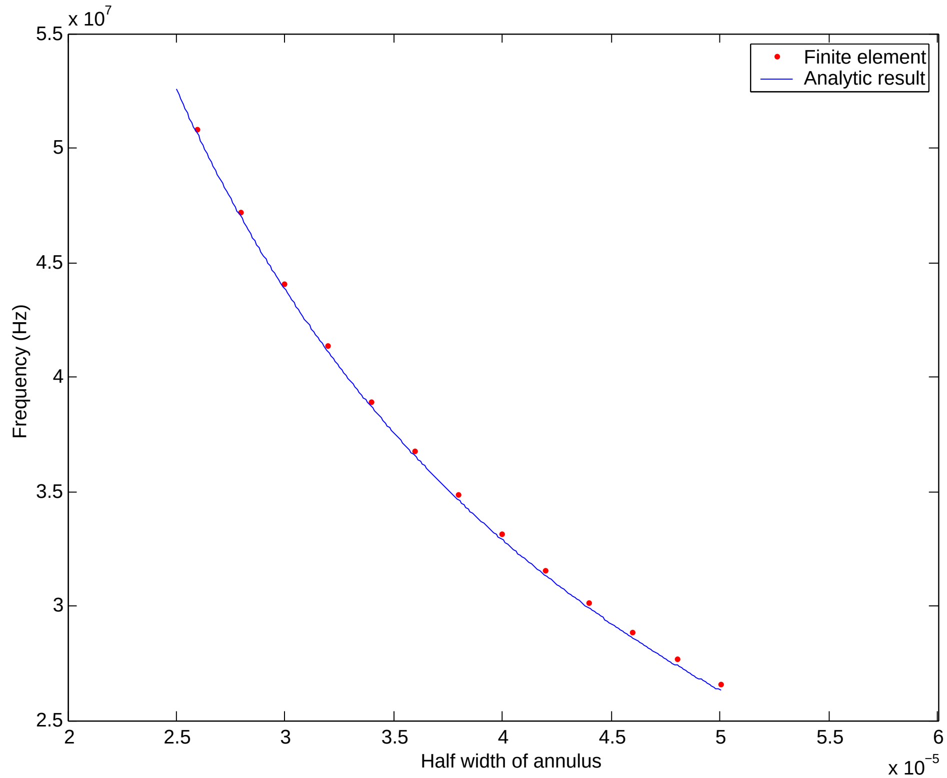
Mode tracking: Shear ring resonator





- Ring is driven in a shearing motion
- Can couple ring to other resonators
- How do we track the desired mode?

Mode tracking: Results



- Predictor-corrector iteration
- Convergence criteria, step control based on $|q(s_k)^T q(s_{k+1})|$

Transfer function optimization

- Choose geometry to make a good bandpass filter
- What is a “good bandpass filter?”
  - $|H(\omega)|$ is big on $[\omega_l, \omega_r]$
  - $|H(\omega)|$ is tiny outside this interval
- How do we optimize?
  - Overton’s gradient sampling method
  - Use Byers-Boyd-Balikrishnan algorithm for distance to instability to minimize $|H(\omega)|$ on $[\omega_l, \omega_r]$
  - Small Hamiltonian eigenproblem (with ROM)

Conclusions

- RF MEMS are an interesting source of problems
  - Understanding the physics
  - Applying numerical tools

`http://bsac.berkeley.edu/cadtools/sugar/sugar/`

`http://www.cs.berkeley.edu/~dbindel/feapmex.html`