# Matisse: Carnegie Mellon Update

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***Matisse Meeting, October 18, 2001***

# Carnegie Mellon's Role in Matisse

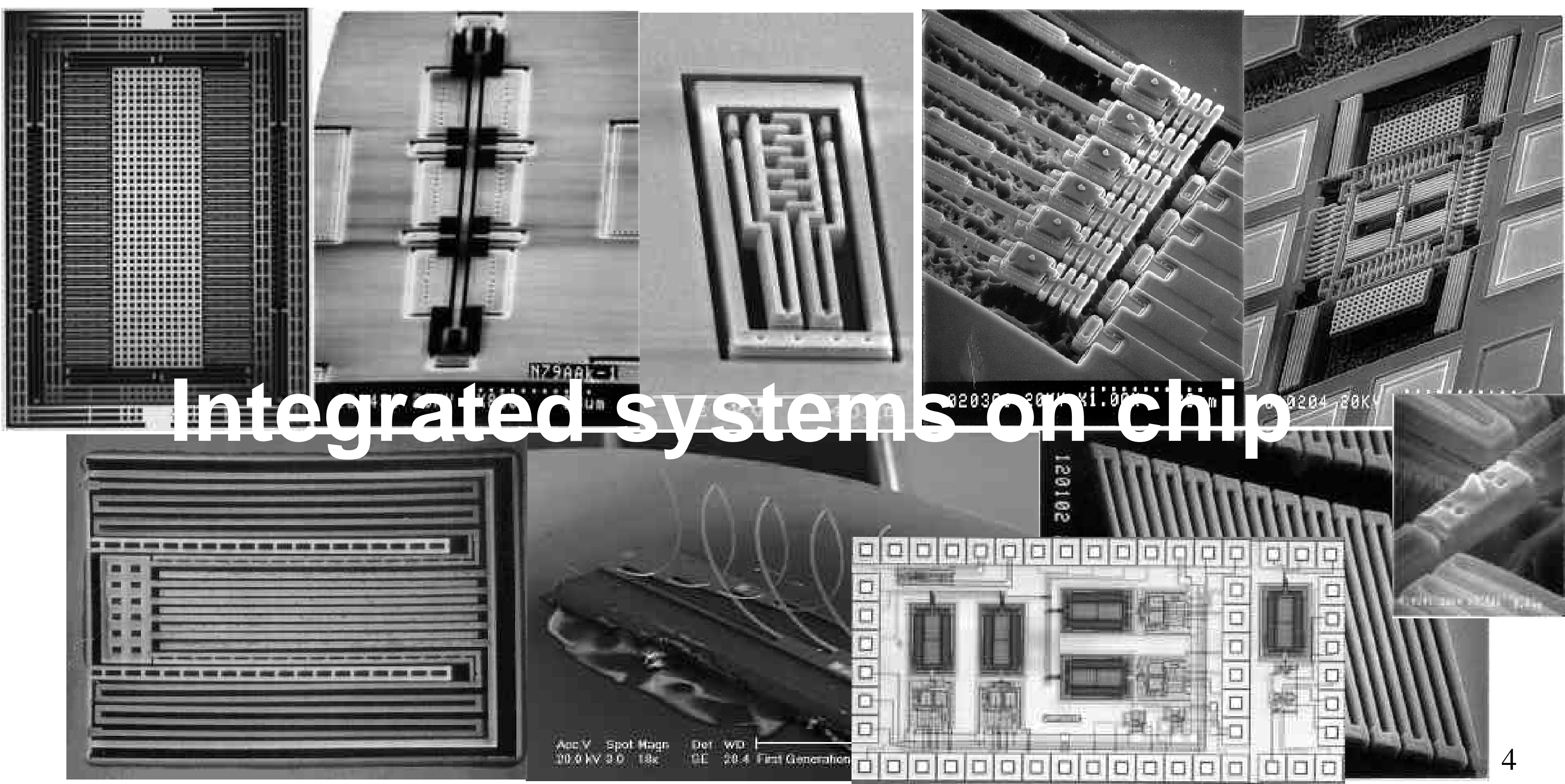
- As Matisse user, leverage large design and characterization effort at Carnegie Mellon
- Active MEMS system-level CAD effort for linkages to platforms

## Phase II Status

- **MIT Microvision System Upgraded**
  - Supernet routing tuned to > 150 Mbps
  - Mirau interferometer integrated into system
    - Z-axis and tilt for fringe adjustment
    - Phase unwrapping software
- **NODAS Schematic MEMS CAD Verification**
  - Mirau measurements of CMOS-MEMS curling
  - AC response comparisons
    - MUMPS resonator (with D. Freeman's group)
    - CMOS-MEMS thermally stabilized accelerometer

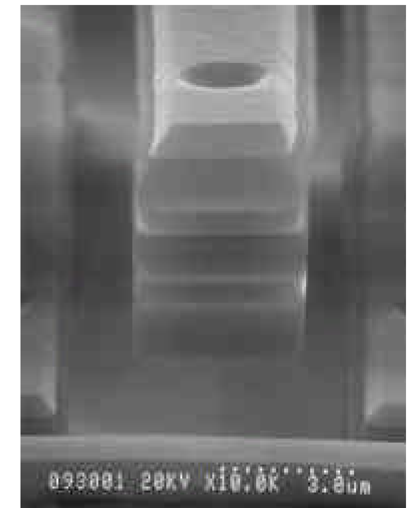
# CMOS MEMS Fabrication at Carnegie Mellon

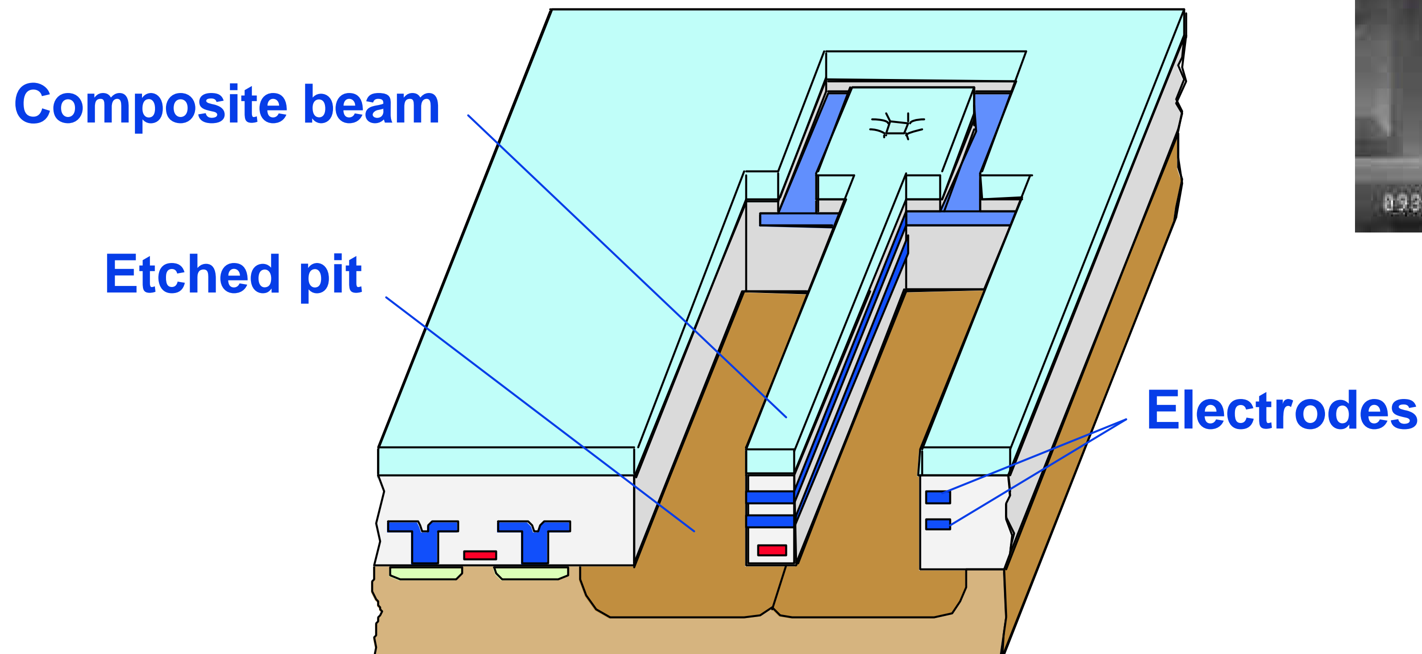
**Applications: Inertial sensors, RF MEMS, infrared sensors, acoustic speakers, ultrasonic sensors, flow and force sensors, … with on-chip detection and conditioning**



# Post-CMOS Micromachining

- Start with foundry digital CMOS
- Structures made from CMOS metal-dielectric layers
- Post-CMOS steps for structure definition and release



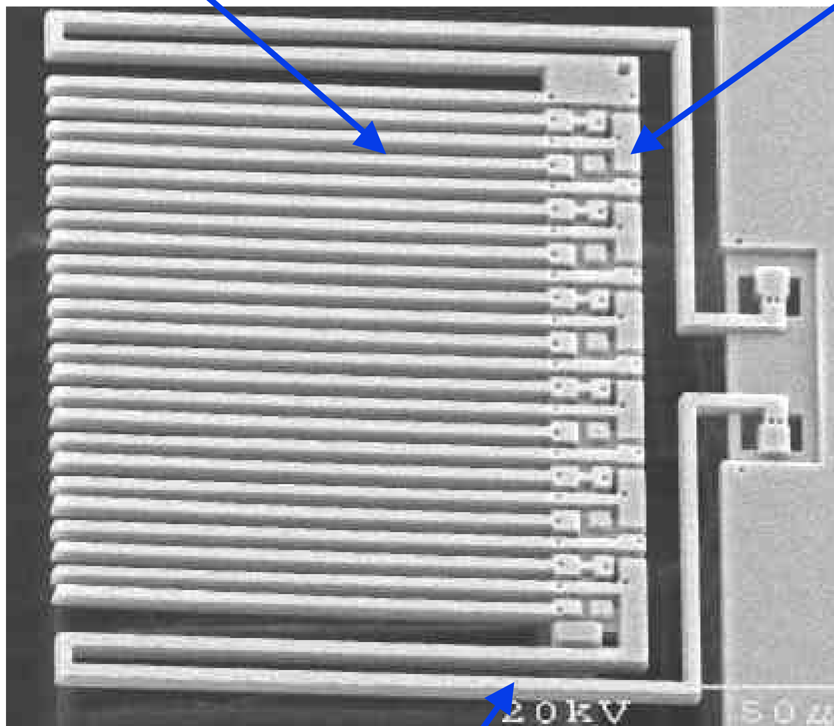



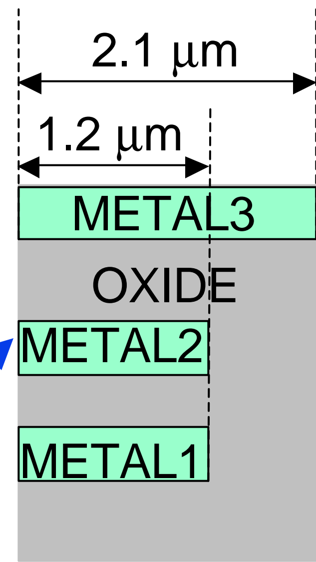

G. K. Fedder, S. Santhanam, M. L. Reed, S. C. Eagle, D. F. Guillou, M. S.-C. Lu, and L. R. Carley, “Laminated High-Aspect-Ratio Microstructures In A Conventional CMOS Process,” *Sensors & Actuators A*, vol. A57, no. 2, pp. 103-110, March 1997.

# Test Structure for Curl Characterization

Alternate symmetrical and misaligned beams

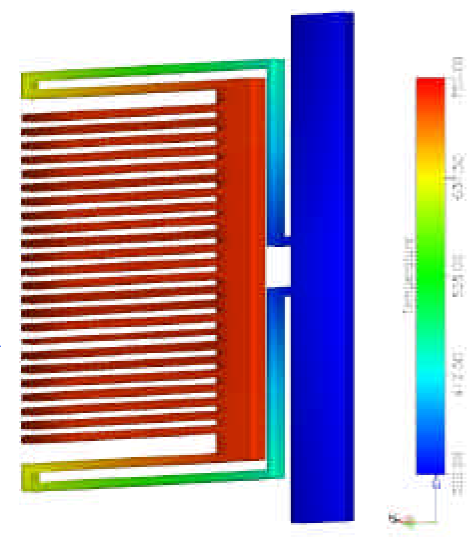
Integrated polysilicon heater

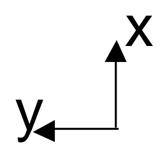



Misaligned beam cross-section

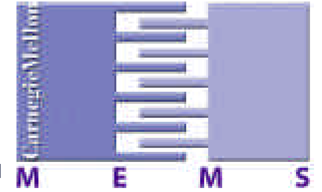
Temperature distribution

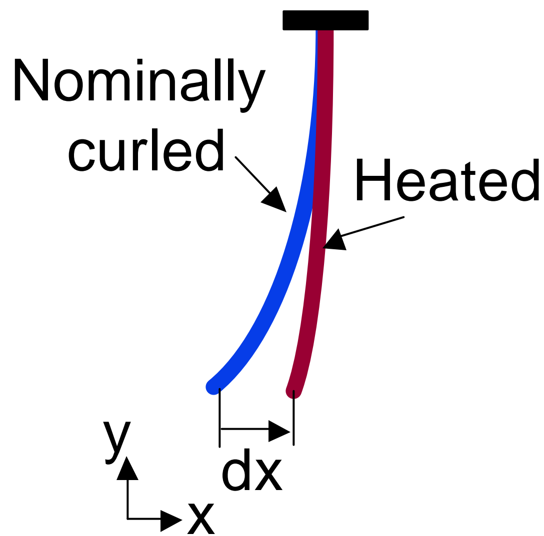


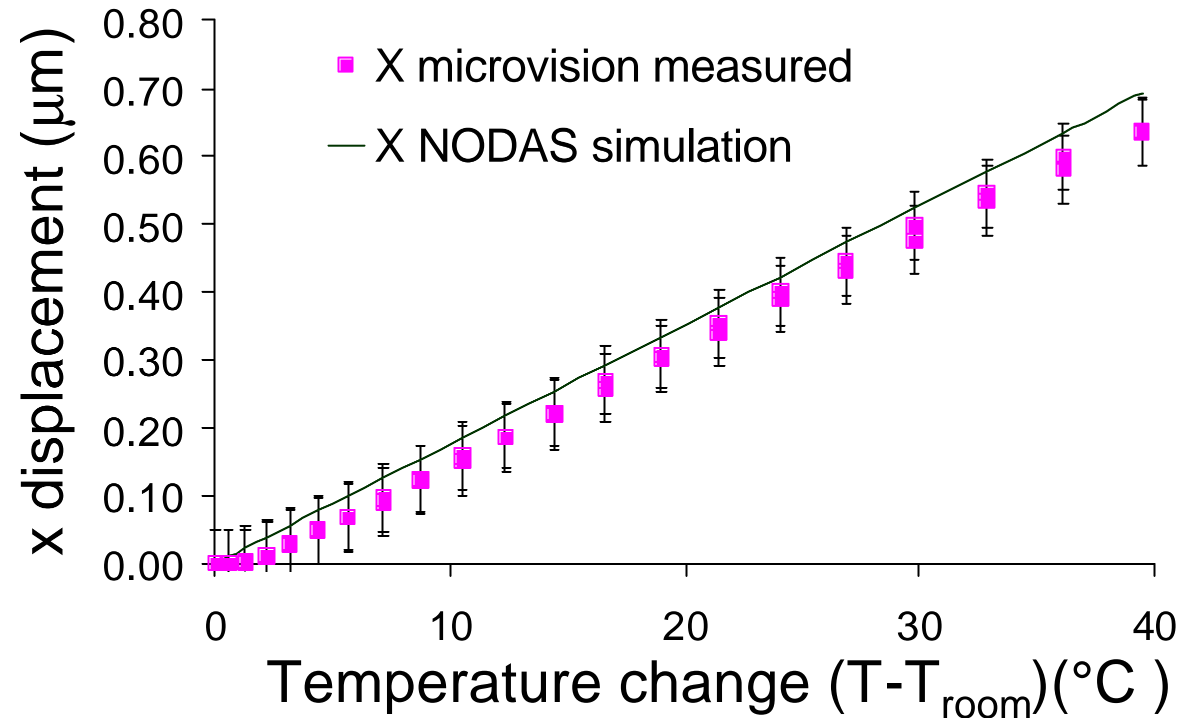



Thermal isolation spring

# Lateral Curling

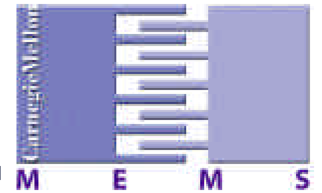


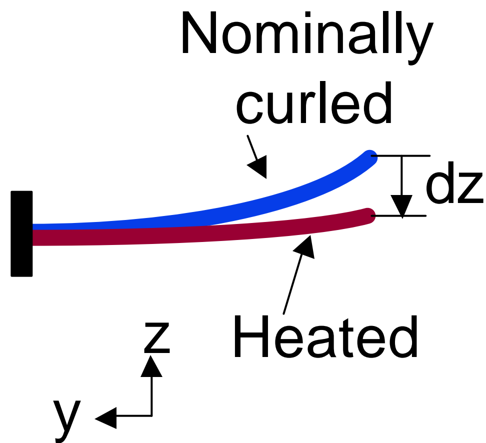



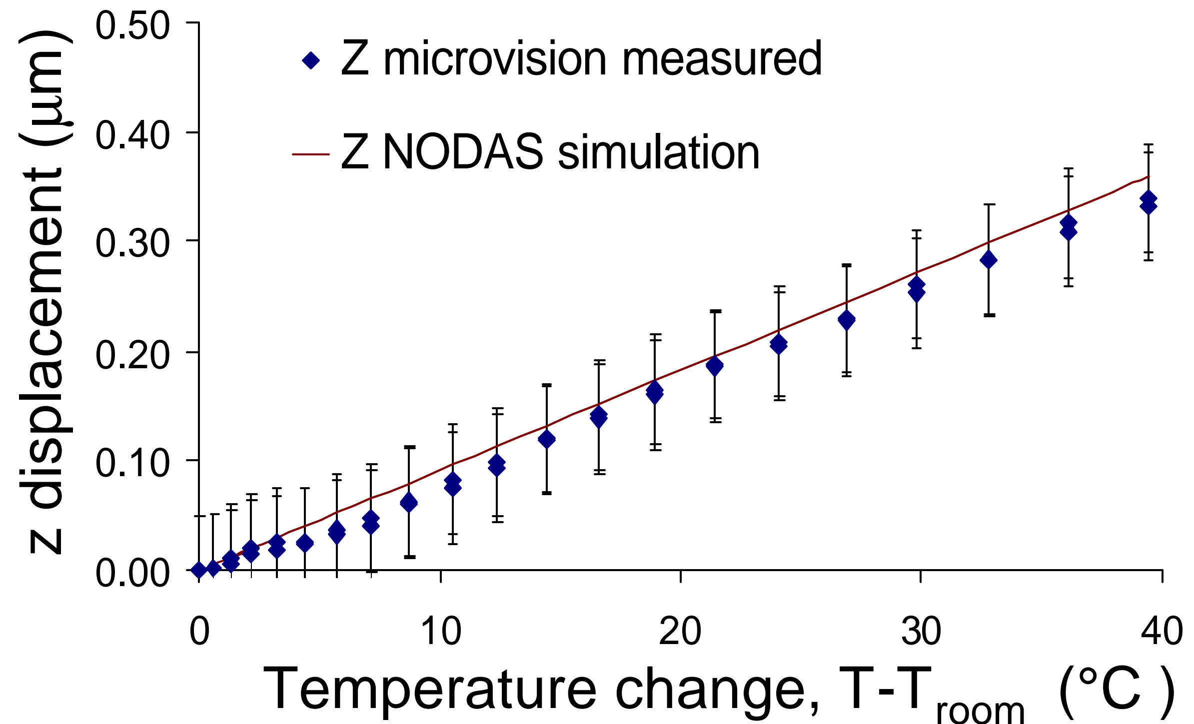




- **Deflection measured from nominal curled position**
- **x matches to within 15%**
- **Within measurement error bar**

## Vertical Curling



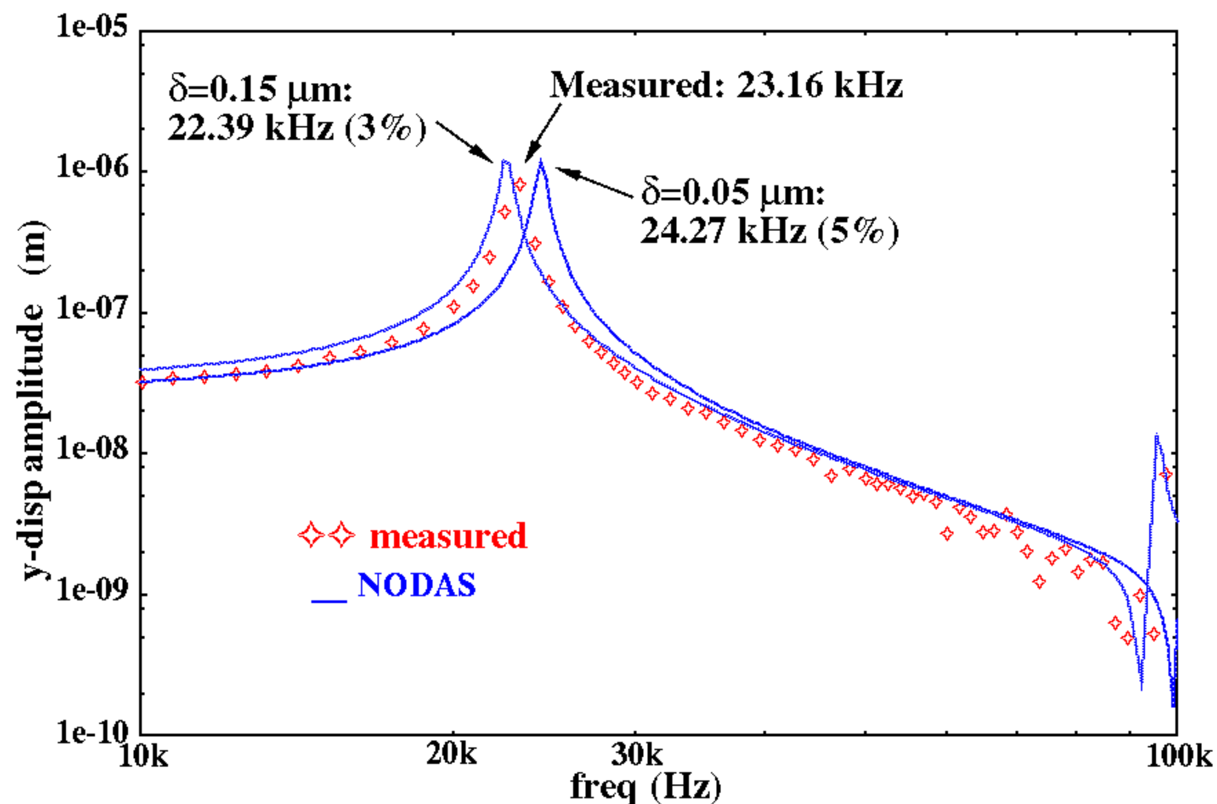




- **z matches to within 10%**
- **Well within measurement error bar**

## Simulation Example: Folded-flexure Resonator

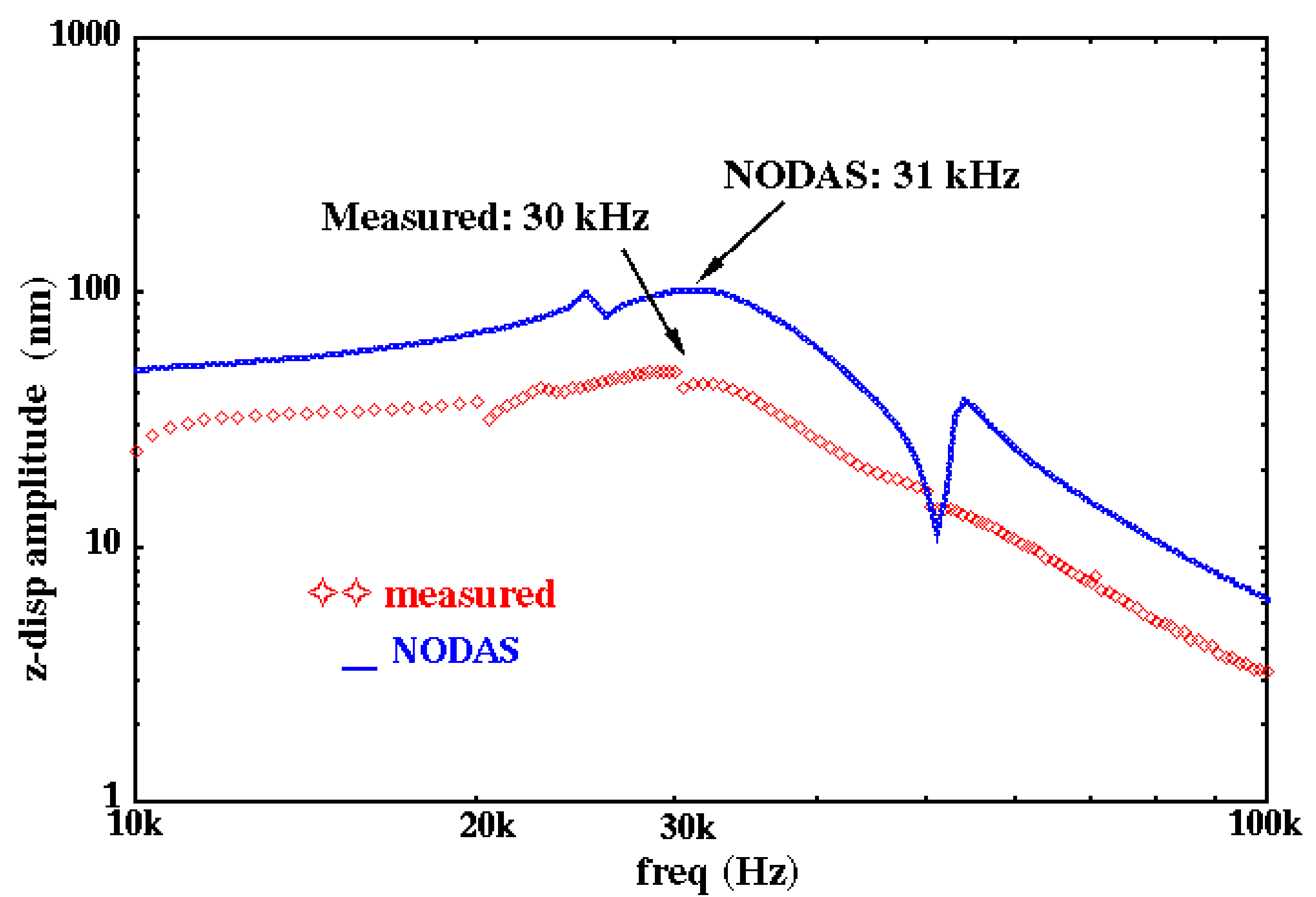
- **Device designed and measured at MIT** *(Salil Desai, et al., MEMS'01)*
- **Simulated in Spectre™**
- **With linear beam model and estimated overetch d**

***Frequency response***



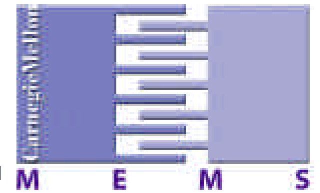
- displacement in z-direction

*Frequency response*



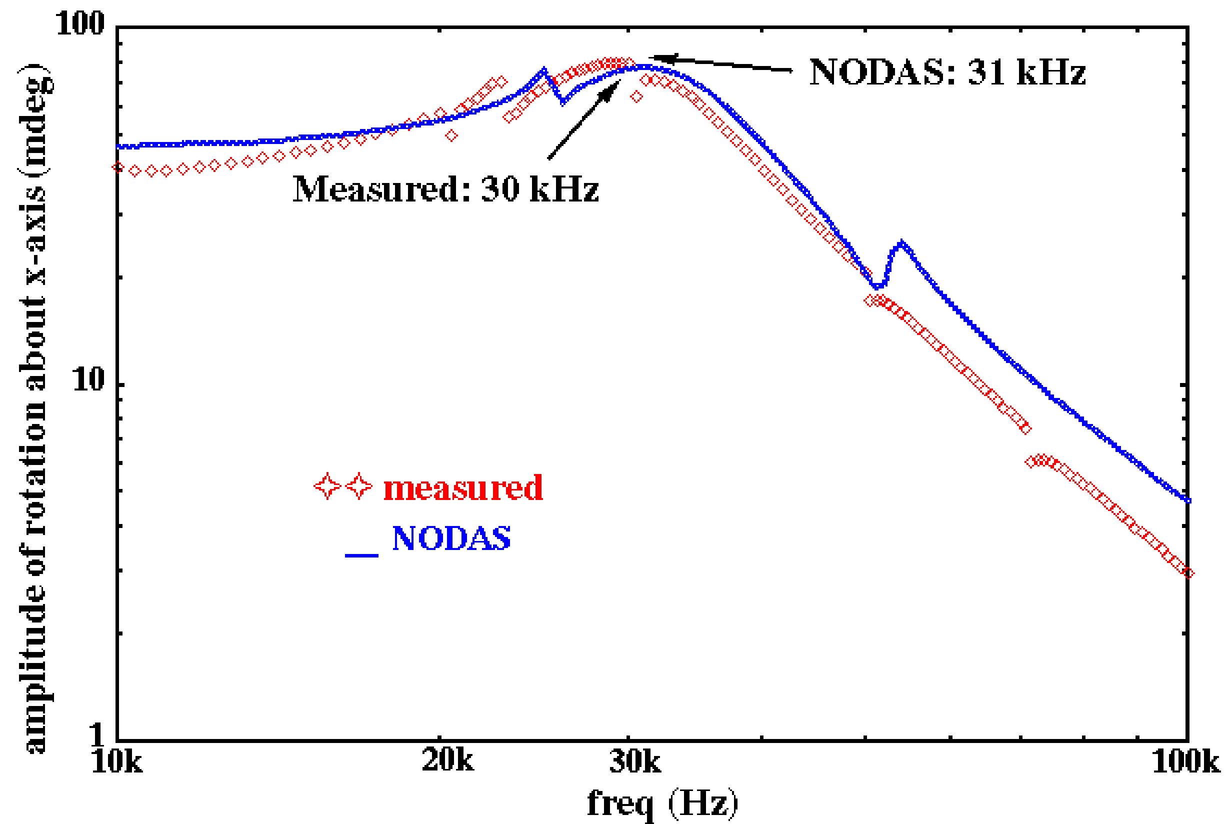

Q. Jing, S. Desai, D. Freeman, G. K. Fedder

# Simulation Example: Folded-flexure Resonator

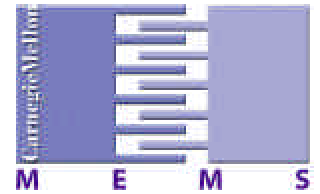



- **rotation about x-axis**

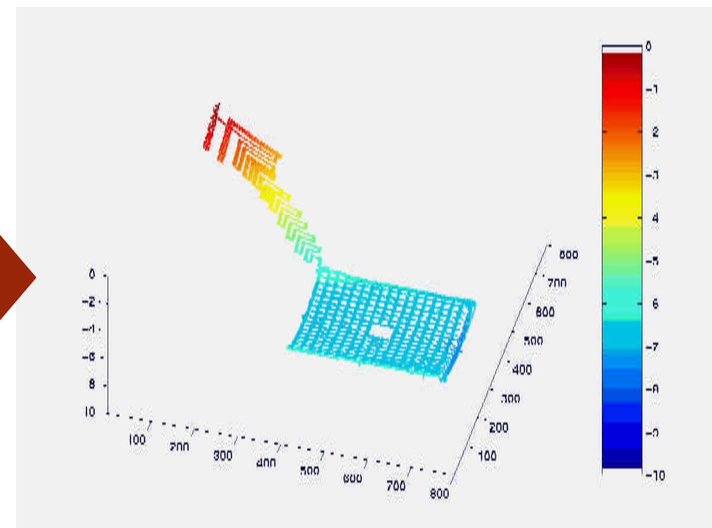
***Frequency response***



# Large-Displacement Dynamic Shape Measurement

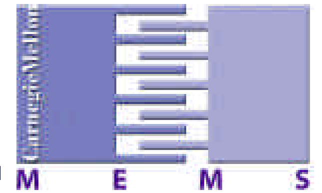



- **Phase unwrapping of interferometric images provides a surface map of the device**
  - Cannot provide information about relative motion between structures
  - Limited by the coherence length of the source
  - Combination Microvision strobing algorithm and phase unwrapping used to image thermal motion

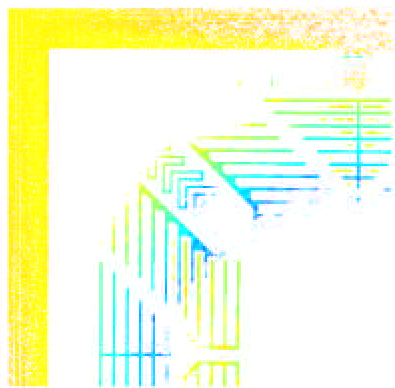


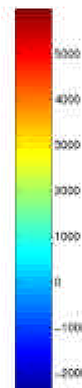
**Modified Microvision system**

# Large Displacement Dynamic Shape Measurement




- **Solution:**
  - Create surface maps of the device at different z displacements and “reconstruct” the image.
  - The relative displacement between disconnected part “glued” together using intensity variation of the LED fringe pattern during the phase unwrapping process.
  - Combination of white light interferometry and phase unwrapping algorithms



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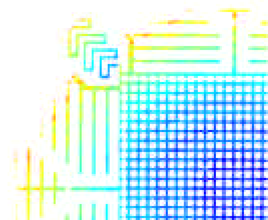

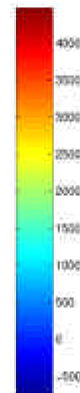


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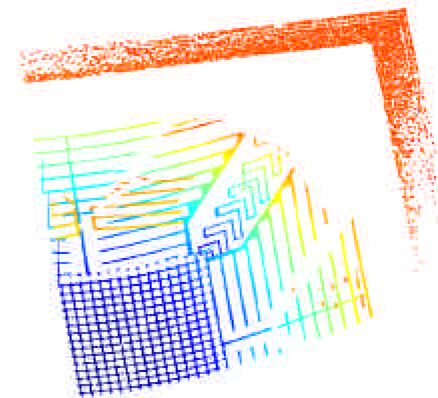
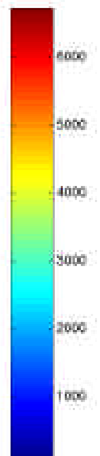
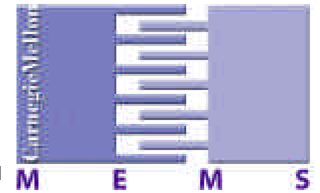
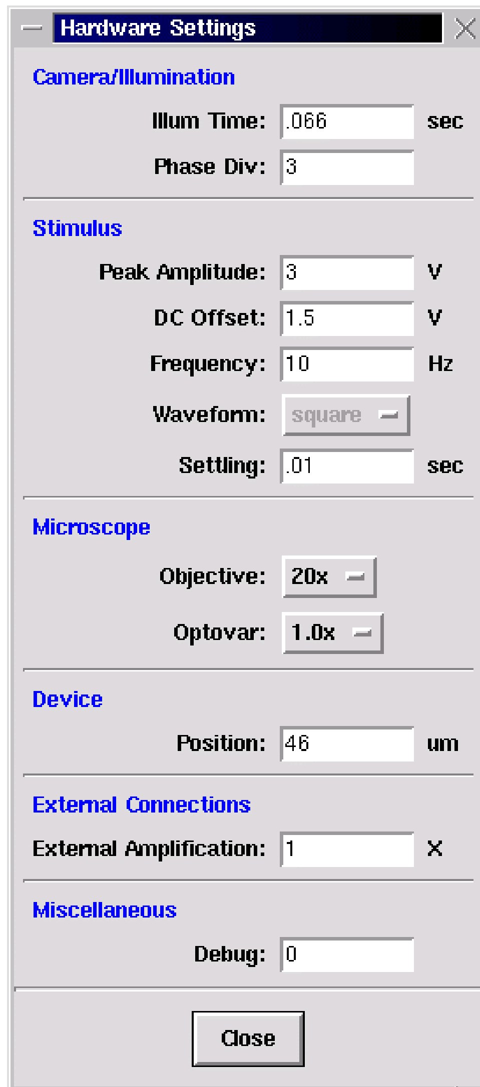




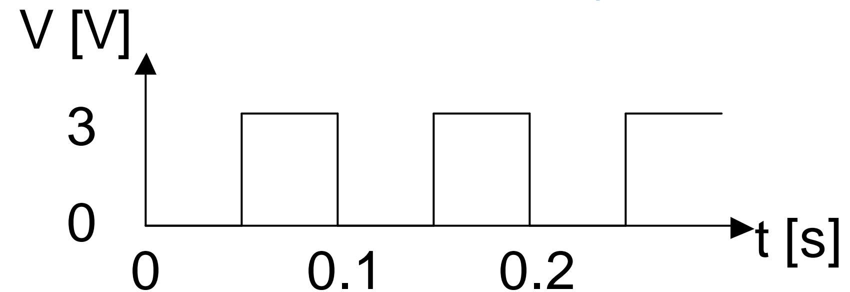

**Phase unwrap set 1** **Phase unwrap set 2** **Final reconstructed Image**

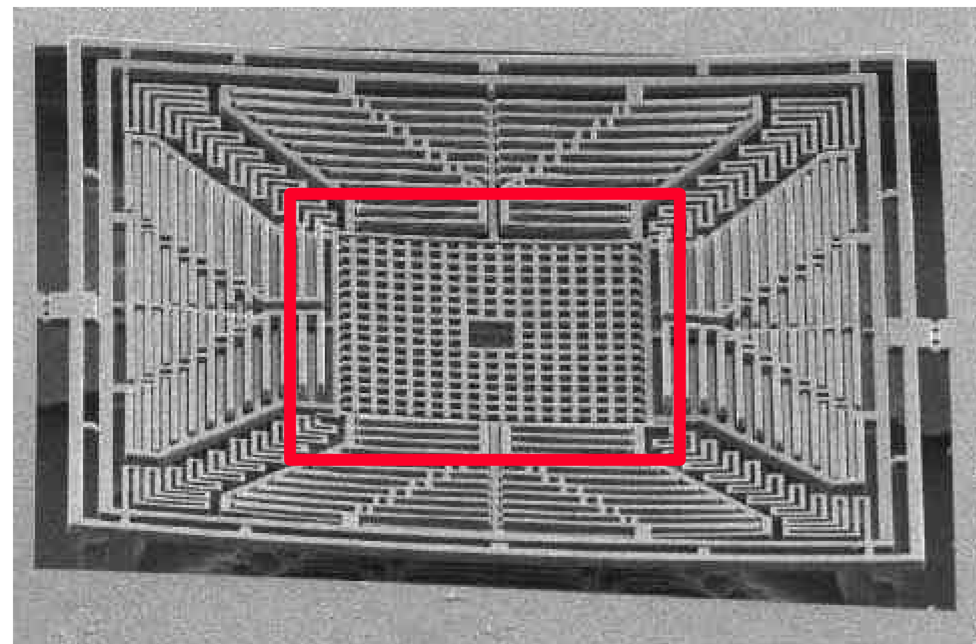
# Microvision Mirau Measurement Demo



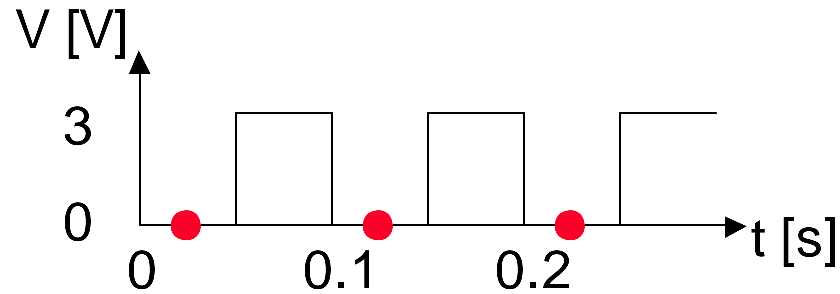

- Z-axis CMOS-MEMS accelerometer
- Image acquisition of the center plate
- Embedded heater driven by square wave

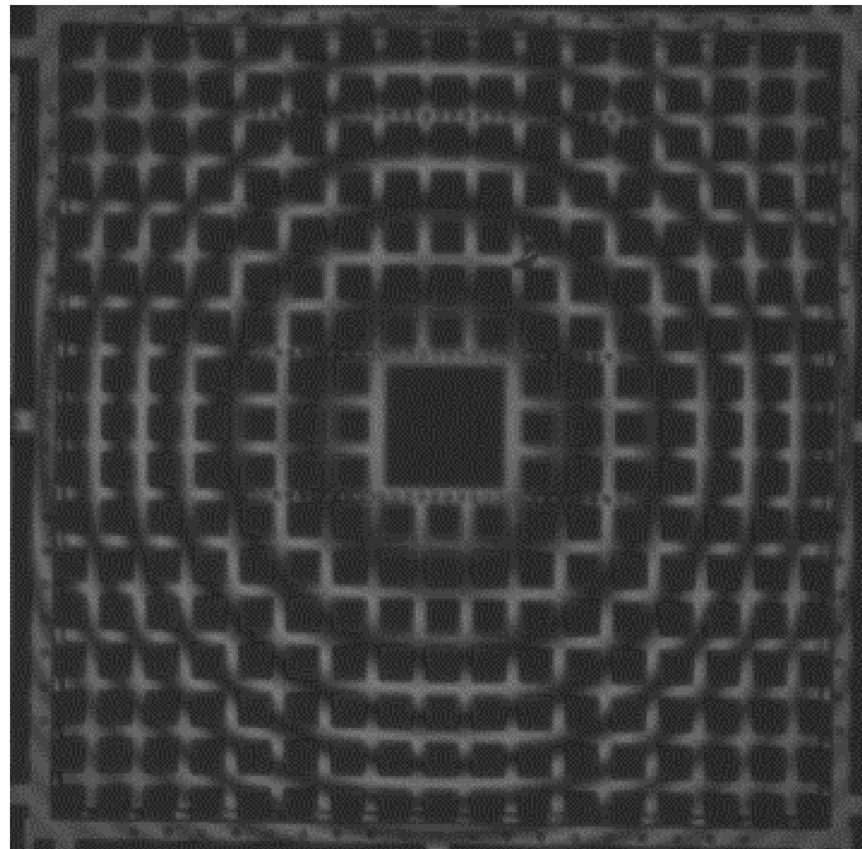


# Dynamic Mirau Measurement Phase #1

- **Measurement at one phase when heater voltage = 0V**
- **Fringes at maximum curl**
- **6 steps in z-axis focal plane spanning 0.27 mm range**

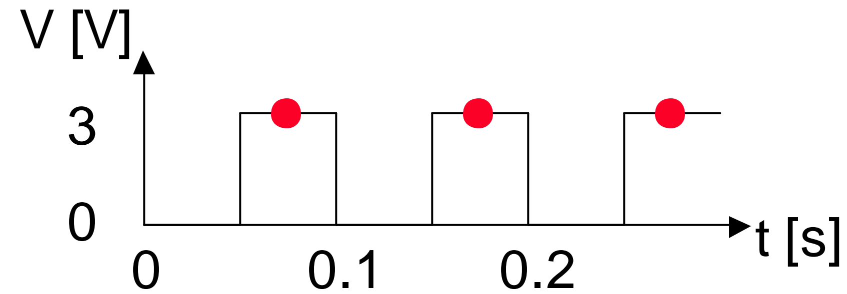


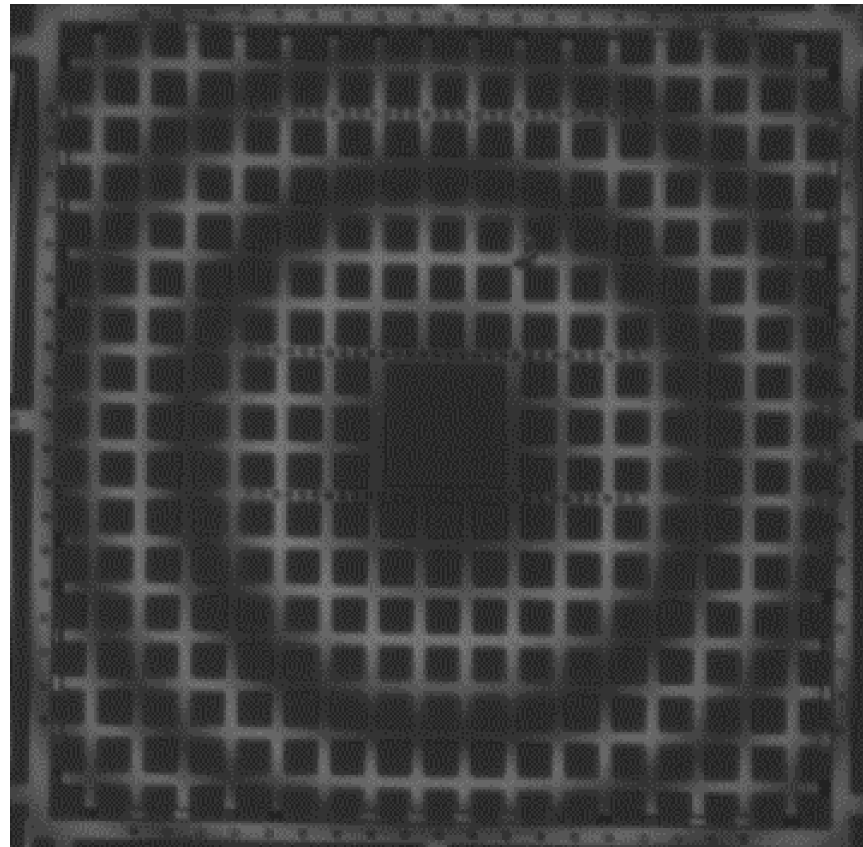



# Dynamic Mirau Measurement Phase #2

M E M S

- Measurement at one phase when heater voltage = 3V
- Fringes at minimum curl
- 6 steps in z-axis focal plane spanning 0.27 mm range
- Plate moves up about 5.5 mm

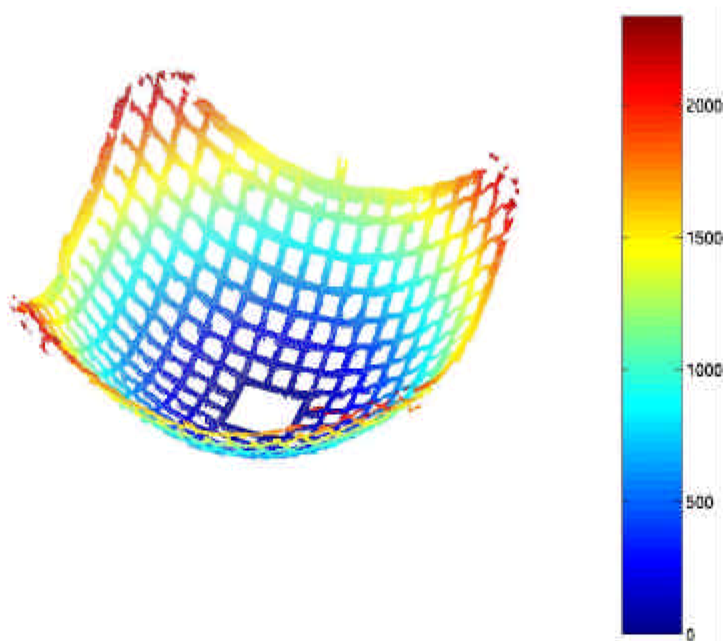


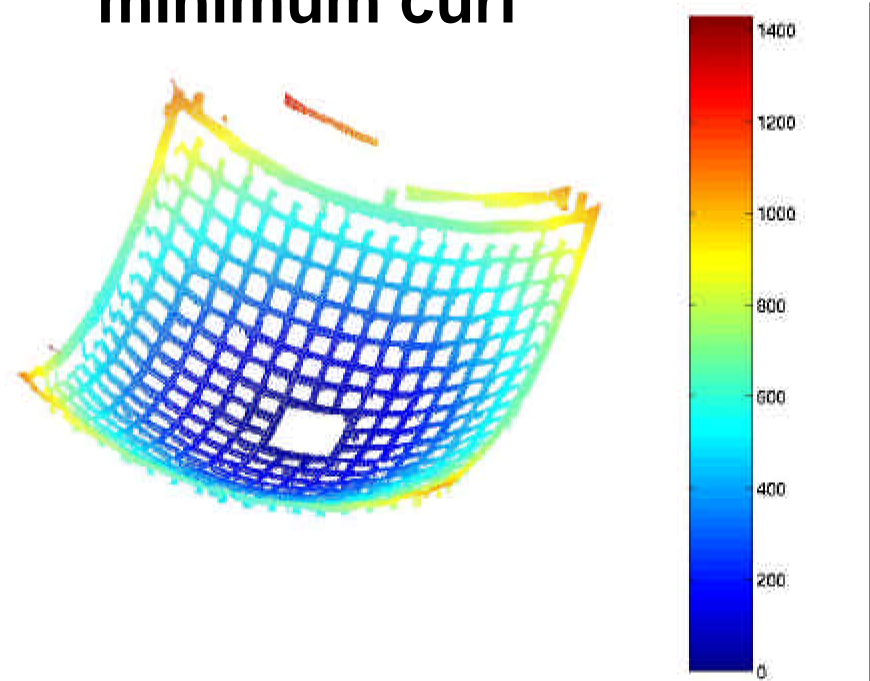
# Phase Unwrapping

- C-code for unwrapping
- Viewing in MATLAB

- V = 0V,
  maximum curl



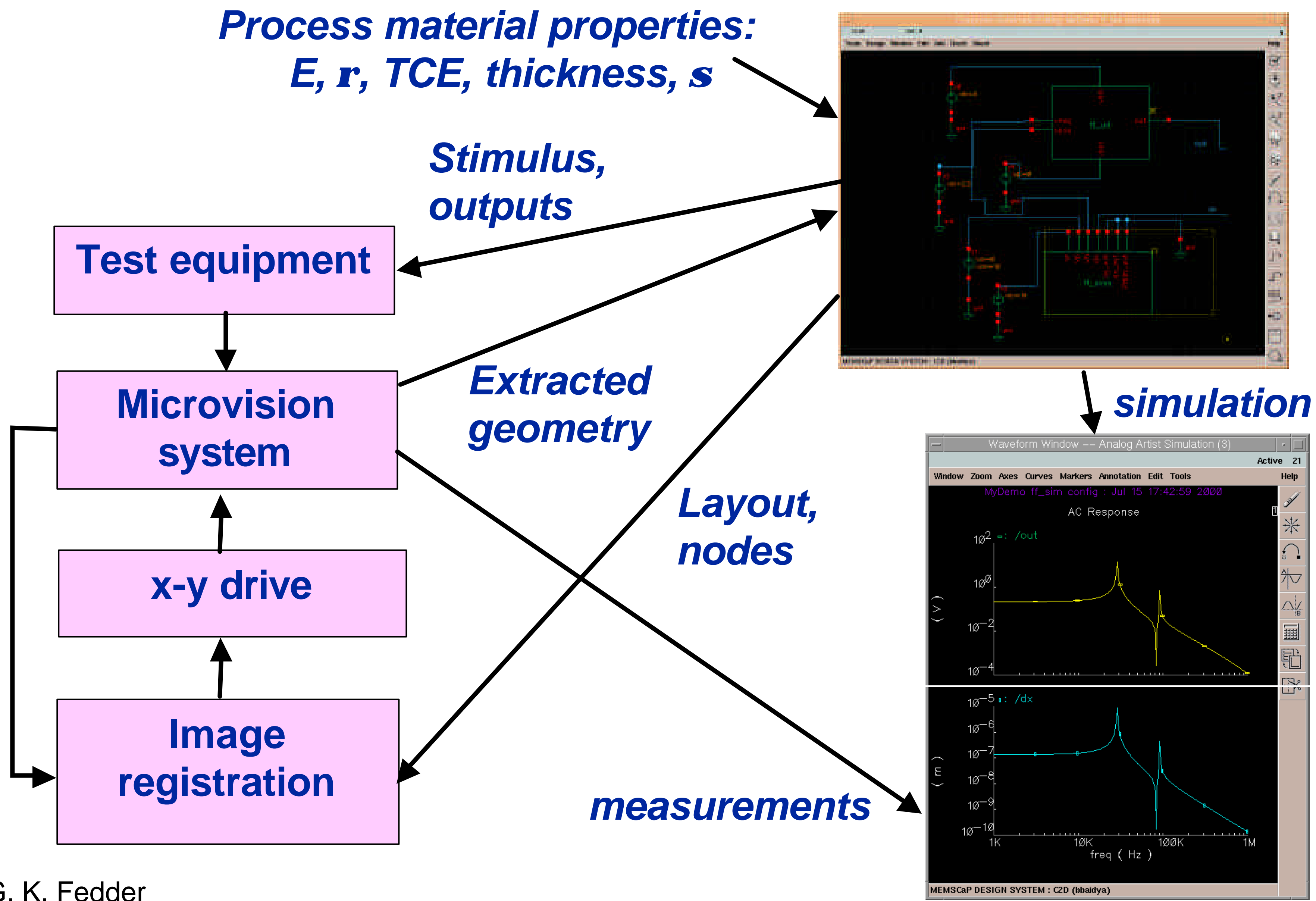

- V = 3V,
  minimum curl



## Carnegie Mellon Planned Thrusts (with help!)

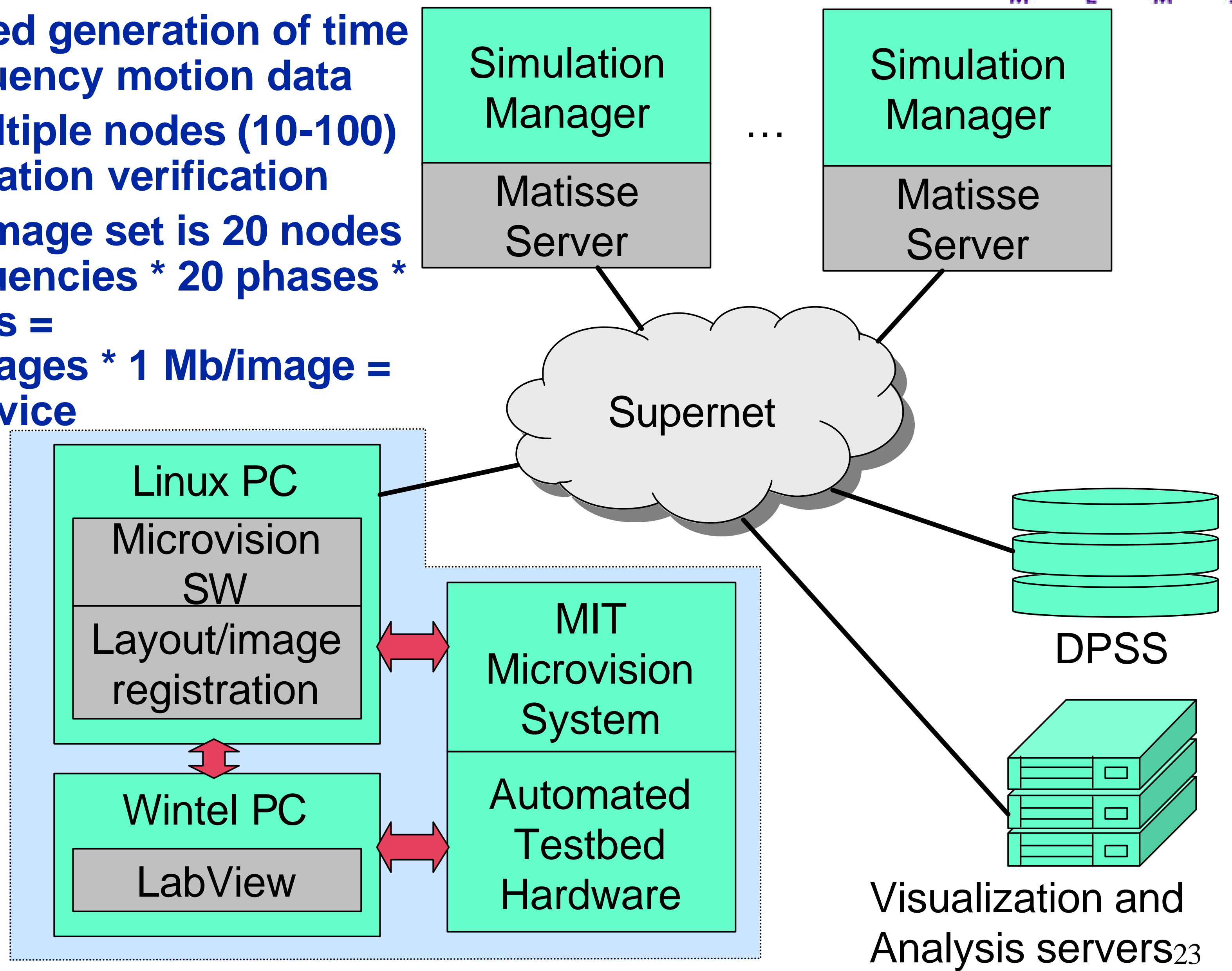
- **Integrate Mirau microvision analysis in Matisse**
  - Calculations using computing cluster over Supernet
  - Automate phase stitching for large z motion
- **Continue to verify and refine modeling and simulation using Microvision**
- **Linking the Microvision System with MEMS Circuit-Level and Device-Level CAD Tools**
  - Flow A) MEMS metrology system
    - Extract structure (size and defects)
    - Generate solid model and mesh
    - Back annotate to MEMS schematic
  - Flow B) MEMS Automated Testbed
    - Design and simulate microstructures
    - Download testbed configuration to Microvision system
    - Compare simulated and measured results

# Proposed Testbed Data Flow

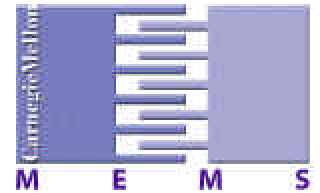


# Automated Microvision Testbed

- Automated generation of time and frequency motion data
- Need multiple nodes (10-100) for simulation verification
- Typical image set is 20 nodes * 20 frequencies * 20 phases * 10 z steps = 80000 images * 1 Mb/image = 80 Gb/device



# MEMS Automated Testbed (Work in Progress)




- **Probe manipulators (4)**
- **X-Y stage moving chip and manipulators**
- **Sinks**
  - Mirau Microvision
  - Voltmeter, ammeter, ohmmeter
  - Spectrum analysis
  - Oscilloscope
- **Sources**
  - High DC voltages
  - Signal generators

Microvision

Supernet access

Test Instruments

PC's

Air table

# NODAS MEMS Cell Library

- NODAS is the MEMS schematic design library developed at Carnegie Mellon
- Goal: Develop and validate NODAS cell library and tools

layout generation

circuit extraction

G. K. Fedder and Q. Jing, "A Hierarchical Circuit-Level Design Methodology for Microelectromechanical Systems," *IEEE Trans. on Circuits and Systems-II*, vol. 46, no. 10, October 1999, pp.1309-1315.

# Integrated MEMS/Electronics Design Flow

layout generation

extraction

design MEMS schematic

MEMS simulation

circuit simulation

design circuit schematic

layout generation

extraction

simulation of integrated design schematic

generate MEMS layout

top level schematic

generate circuits layout

simulation of integrated extracted schematic

extracted MEMS schematic

MEMS simulation

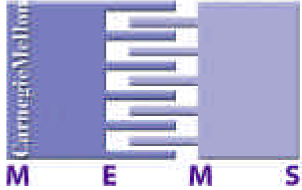
extracted electrical parasitics

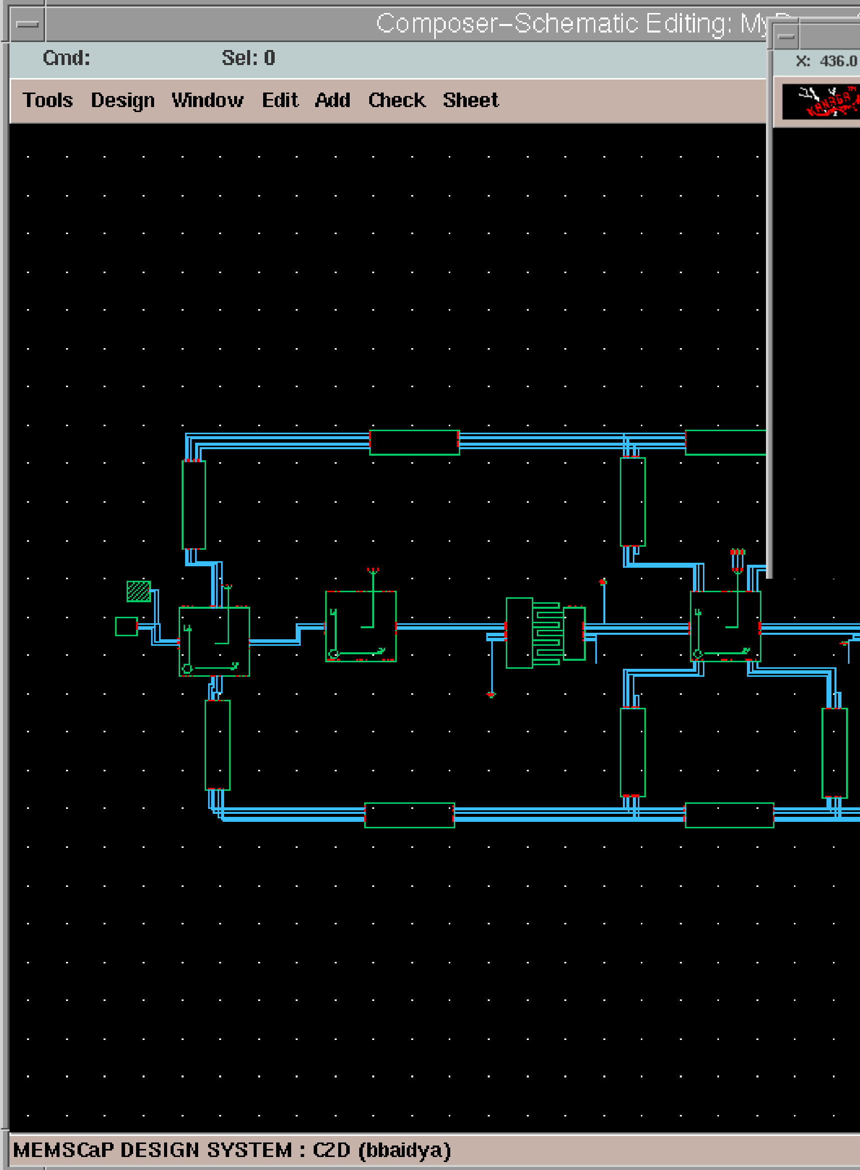
circuit simulation

extracted circuit schematic

T. Mukherjee and G. K. Fedder, “Design Methodology for Mixed Domain Systems on a Chip,” *Kluwer Journal of VLSI Signal Processing on System Design*, vol. 21, no. 3, pp. 233-249, July 1999.

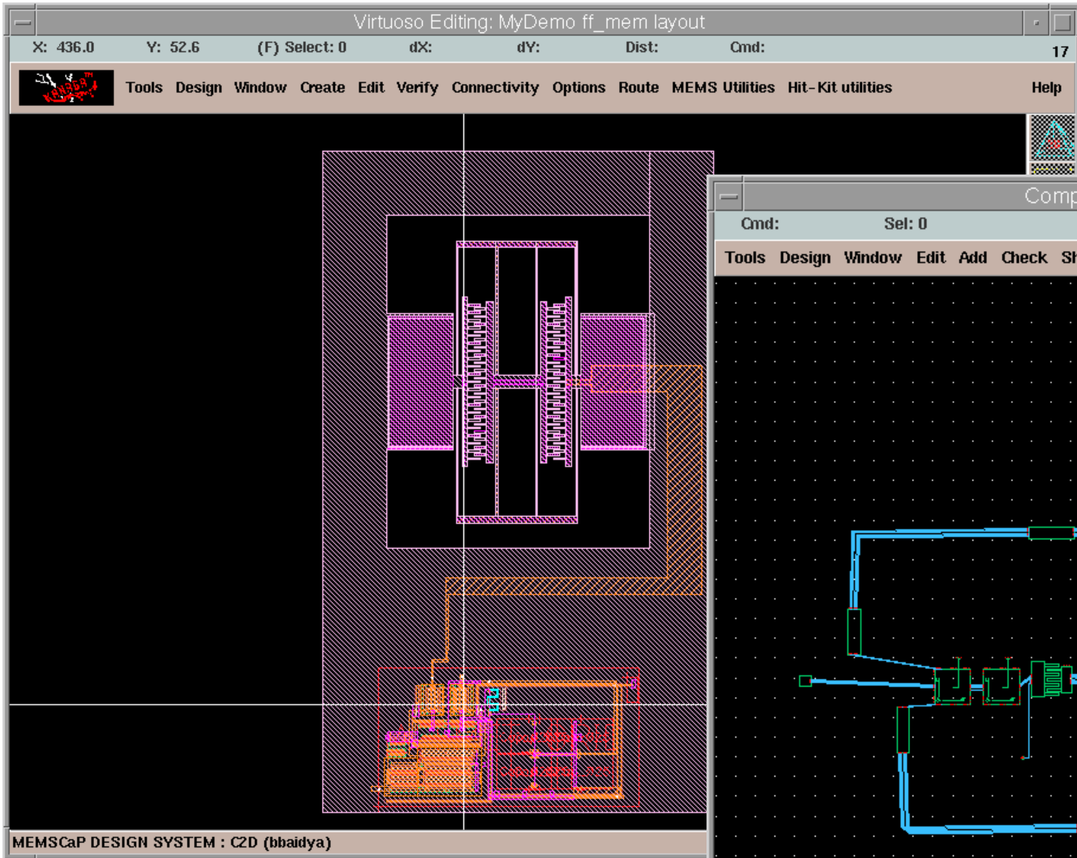
# NODAS MEMS Schematic & Layout Generation

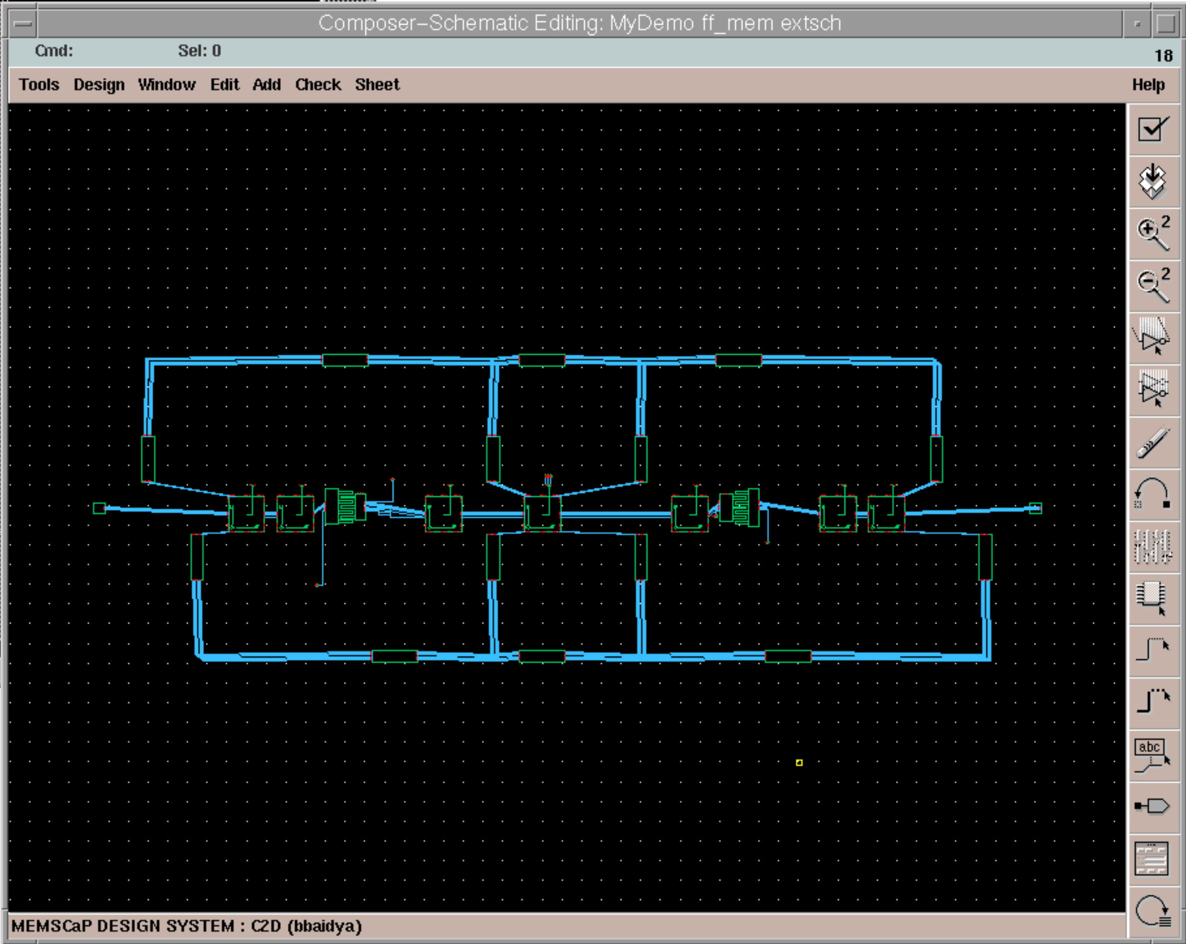



T. Mukherjee and G. K. Fedder

# NODAS MEMS Extraction




B. Baidya and T. Mukherjee, "Extraction for Integrated Electronics And MEMS Devices," *Transducers '01*, June 2001, pp. 280-283.

# Schematic vs. Extracted comparison

- **CMOS MEMS has more complex design requirements, and thus make sophisticated system-level models and CAD capabilities essential**