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MEMS Passive Latching Mechanical Shock Sensor

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Motivation

- **Low Power**
  - Sense an inertial event (shock, impact, vibration) without requiring power before, during, or after the event
- **Latching**
  - After sensing an event, the device remains in a stable state until interrogated
- **Sense and Survive High-g Impacts (100g's – 25000g's)**
  - Shipping, Handling, Normal Operation (< 100g)
  - Rough handling, undamped impacts (100 – 1000g)
  - Pyrotechnic shock or "Pyroshock" (300g – 300kg)
- **Self-Test**
  - Opening and closing the switch prior to an inertial event
- **Reusable**
  - Ability to unlatch and reset
- **Small Size**
  - Multiple devices on a single chip for redundancy, arrays of thresholds, and/or multiple sense directions
- **Electrical Readout**
  - Allows automation and eases system integration
  - Continuity check (Metal-to-metal contacts provide detectable switch closure)
- **Frictionless motion**
  - Important in a MEMS device for reliable performance
  - Latch behavior based on force differential rather than mechanical latches

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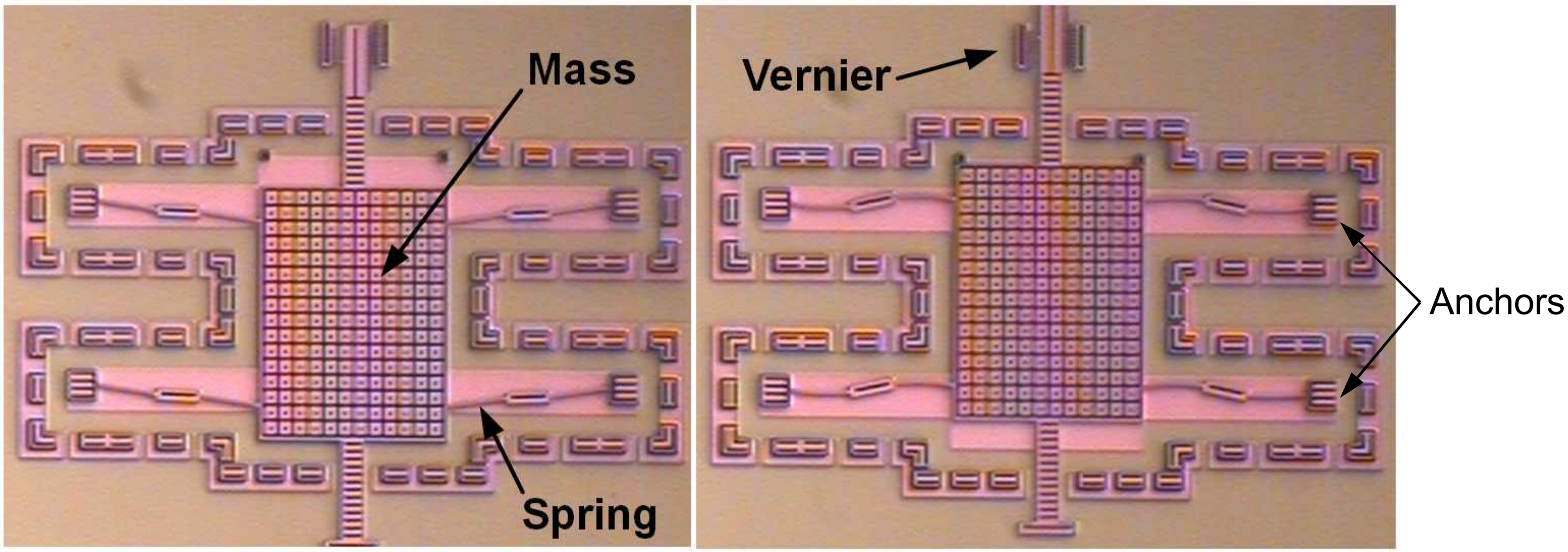
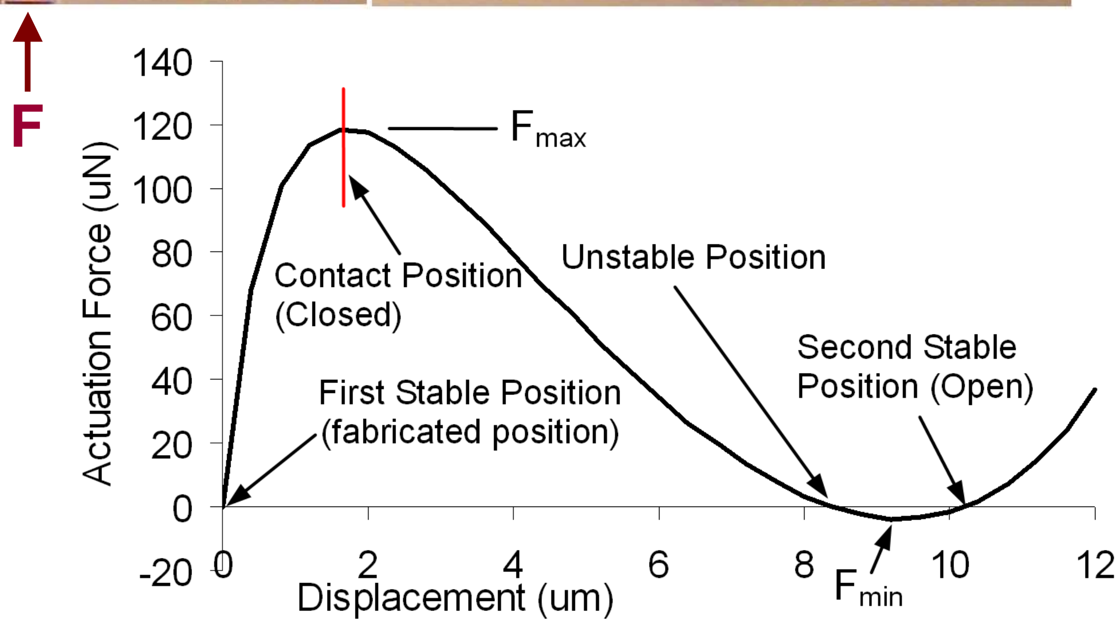
Bistable Micro Mechanism with Inertial Mass





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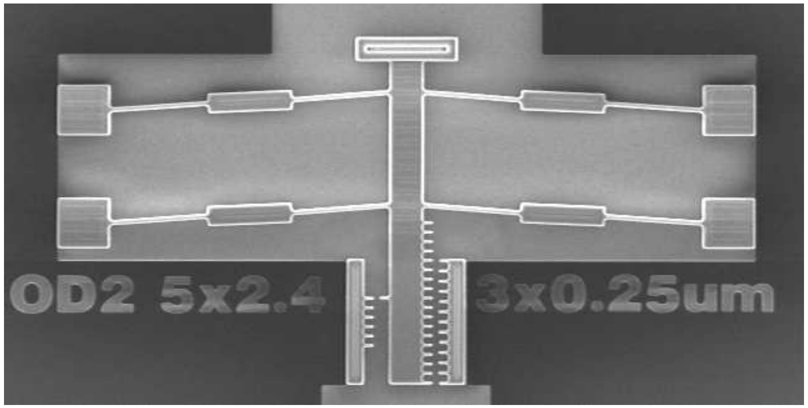
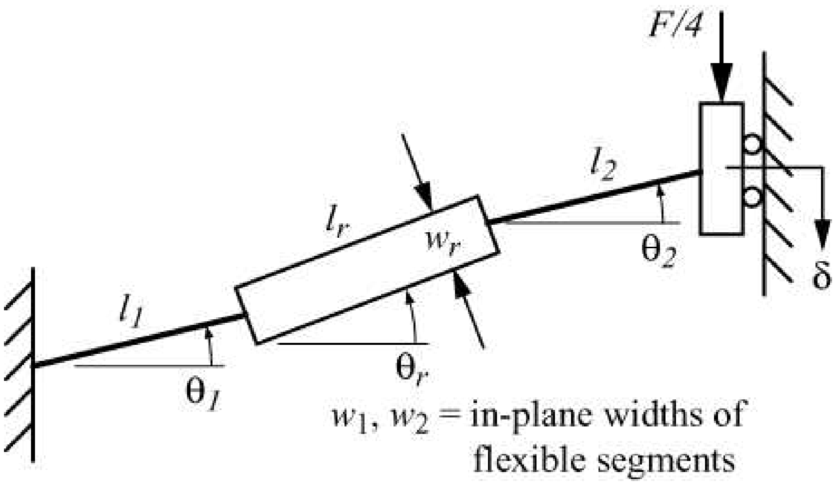
Design and Modeling



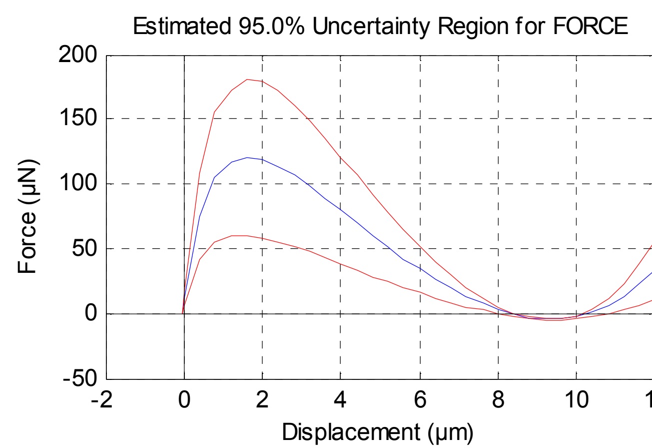


Main Design Parameters

- Beam lengths: L_1, L_2, L_r
- Beam angles: θ_1, θ_2, θ_r
- Beam widths: w_1, w_2

Robust Optimization

Minimize sensitivity to process variations.



IMAGES FROM: Wittwer, J.W., Baker, M.S., and Howell, L.L., "Robust Design and Model Validation of Nonlinear Compliant Micromechanisms," *Journal of Microelectromechanical Systems*, Vol. 15, No. 1, pp. 33-41, 2006.

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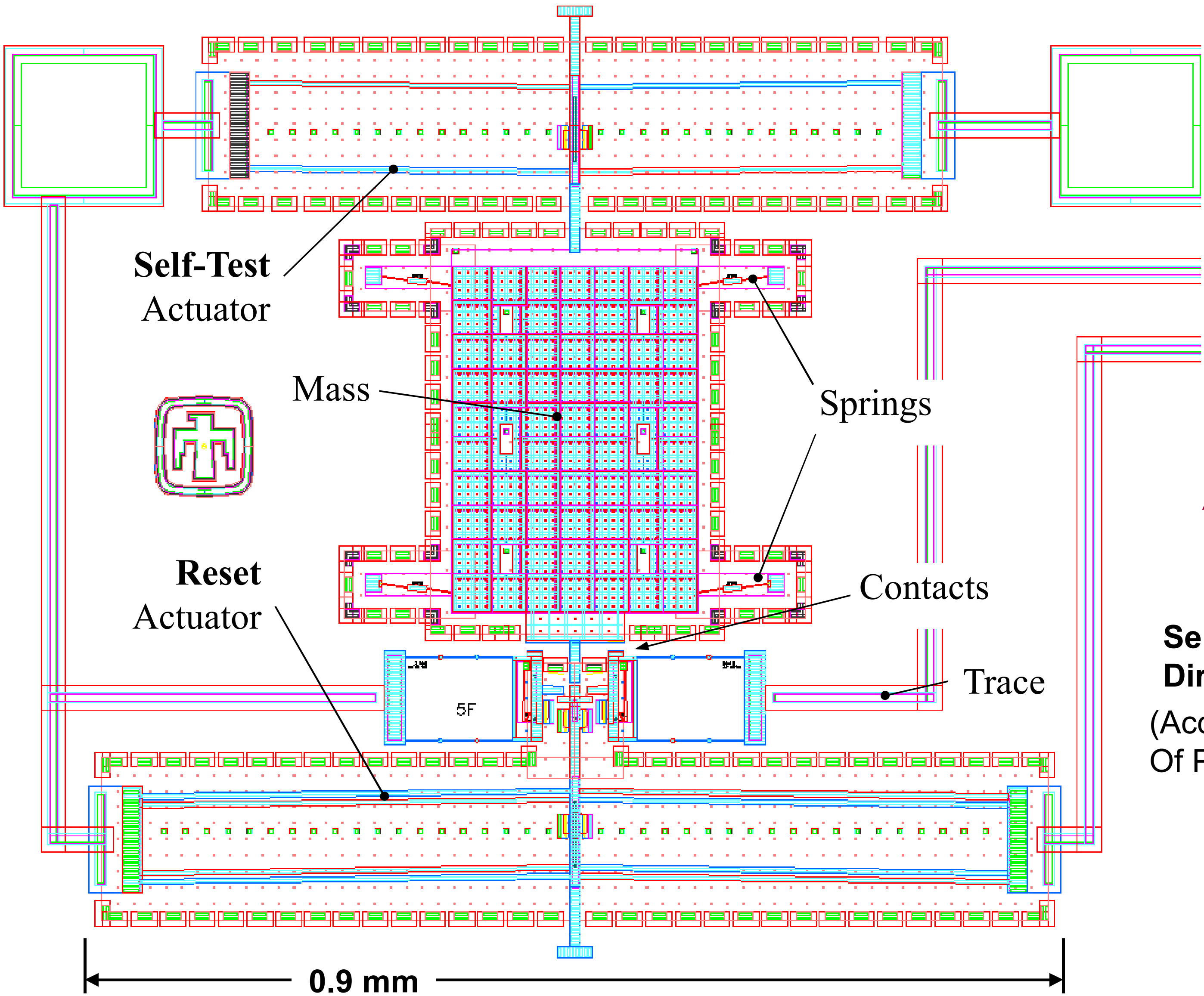
Fabrication and Operation



Sense Direction
(Acceleration Of Package)

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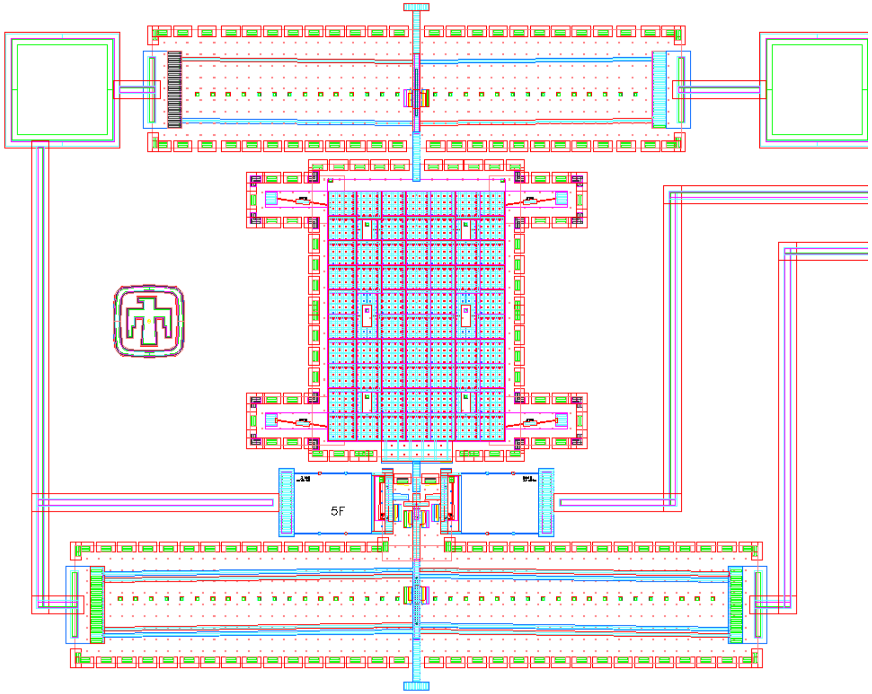
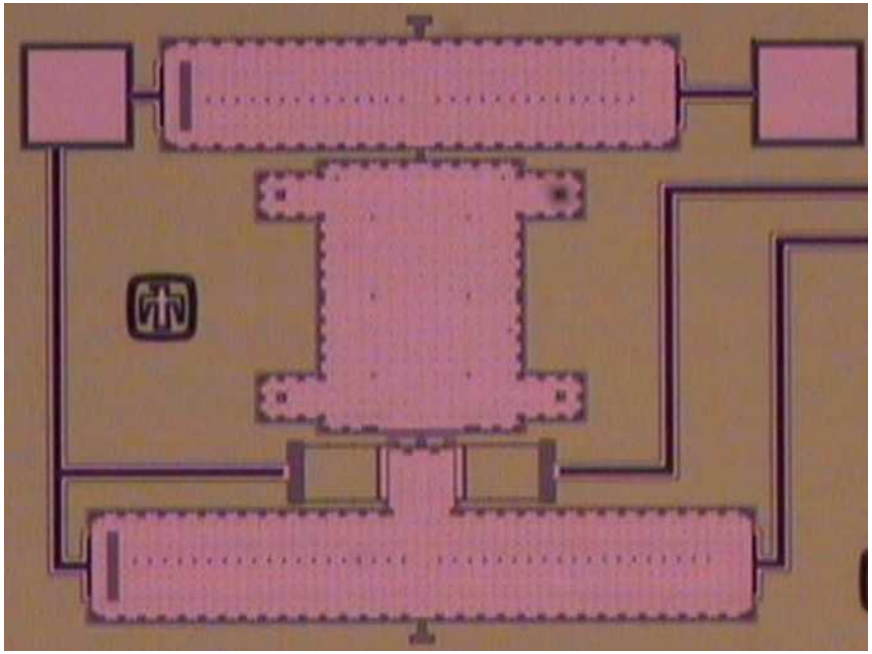
Metallization

- **Metal deposited on surface using evaporation, with the die held at 45° and rotated during deposition**
- **Top layer of Poly used as a shadow mask for the actuators and mechanism to prevent shorting**





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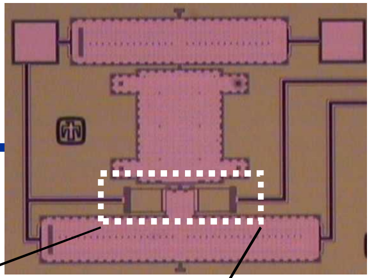
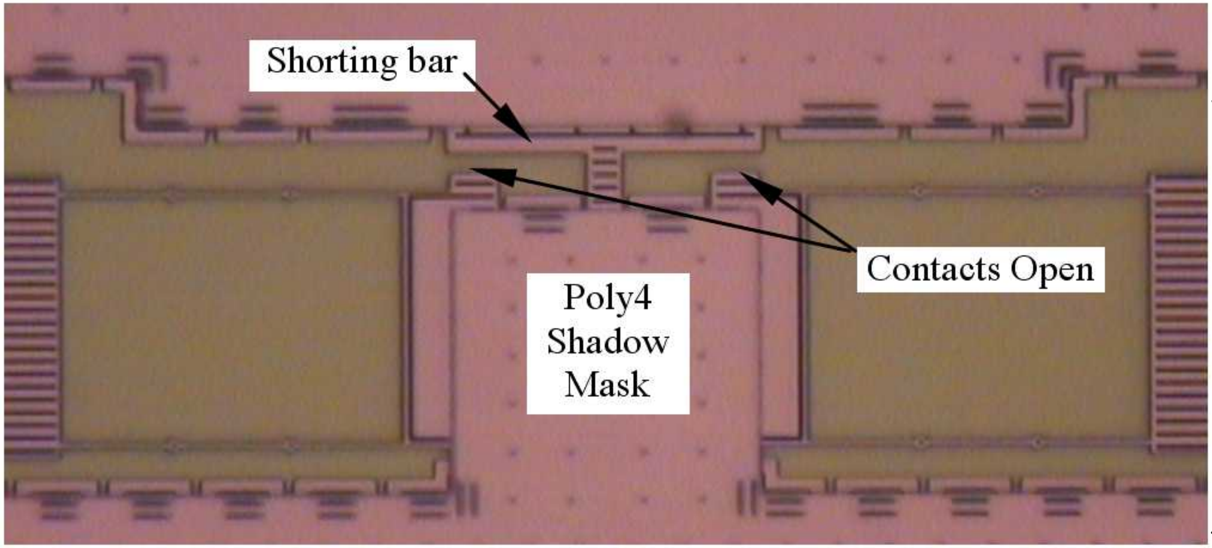
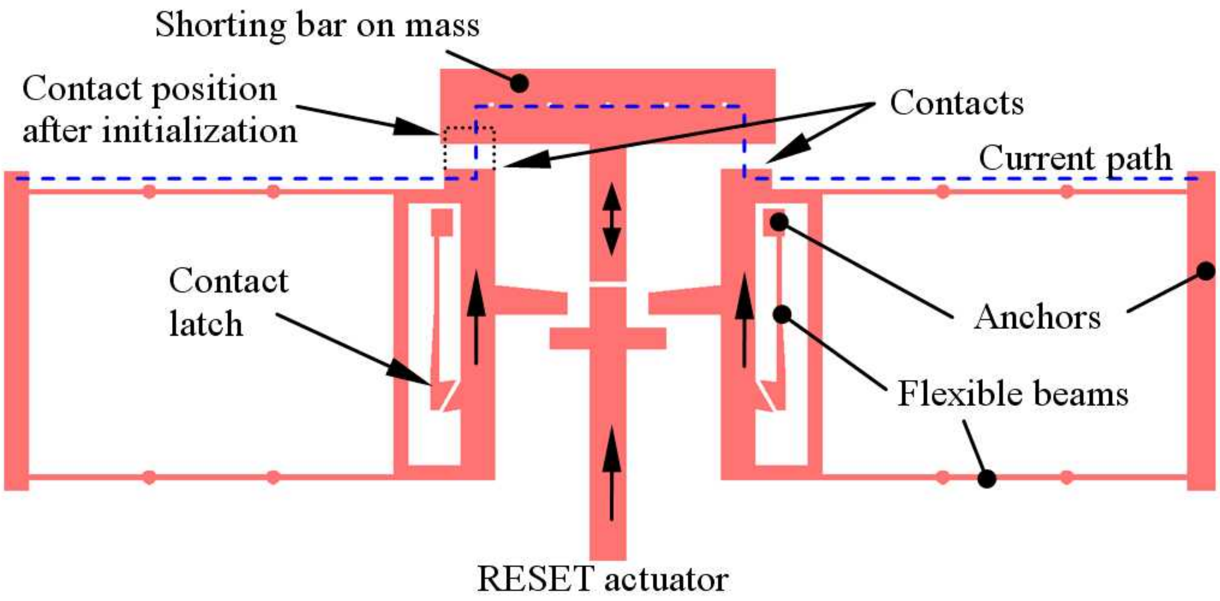
Initialization







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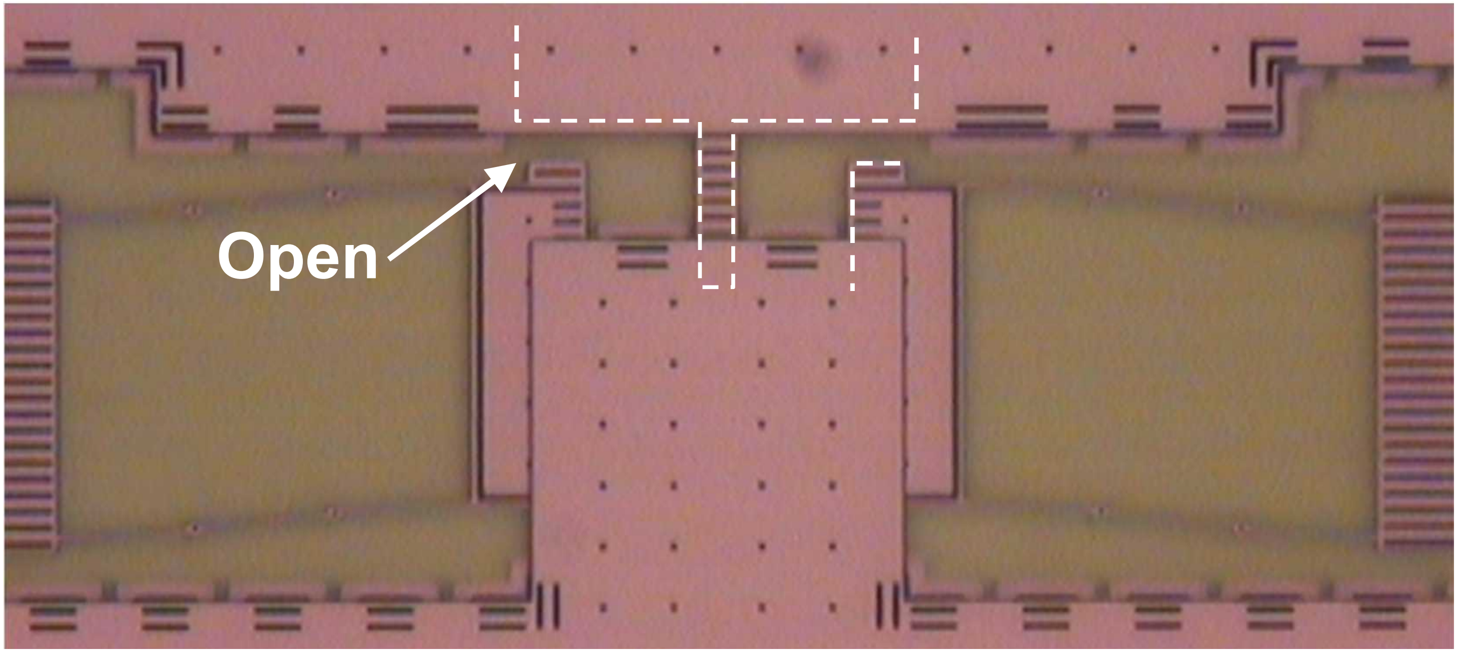
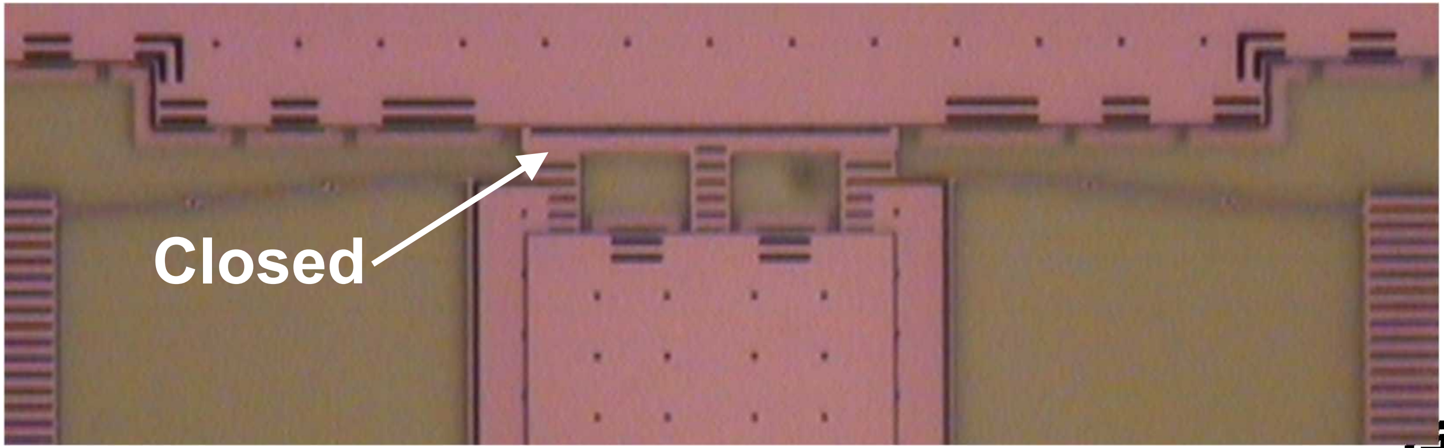
Open and Closed Positions





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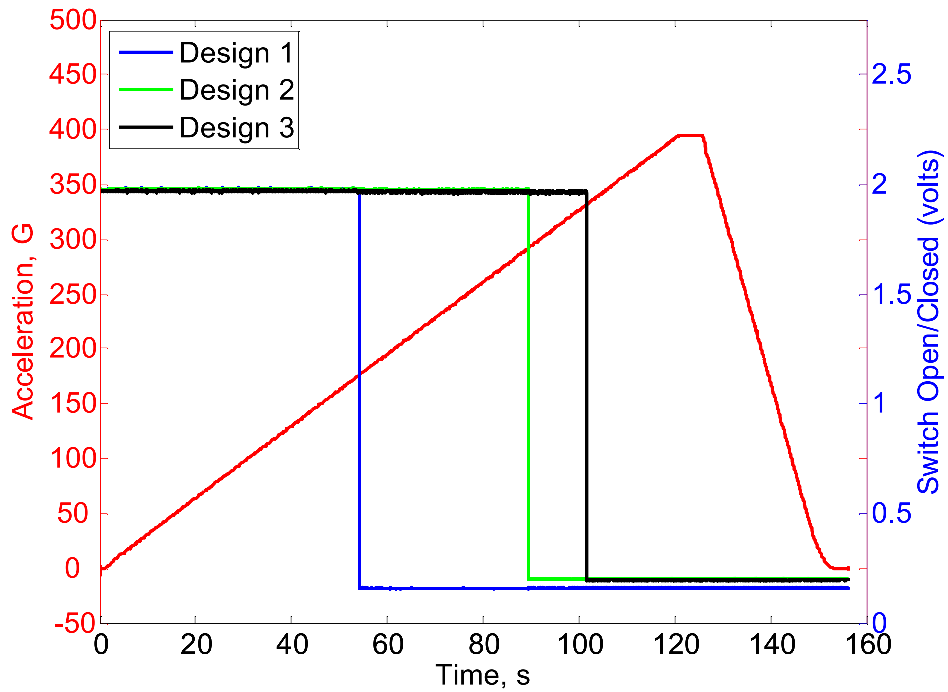
Centrifuge Testing

- **0g – 400g quasi-static loading**
- **Useful for model validation**



	Measured		**Modeled**	
	Mean	StDev	Nominal	StDev
Design 1	153 g	25 g	84 g	4.9 g
Design 2	273 g	33 g	145 g	10 g
Design 3	*342 g	*53 g	315 g	15 g

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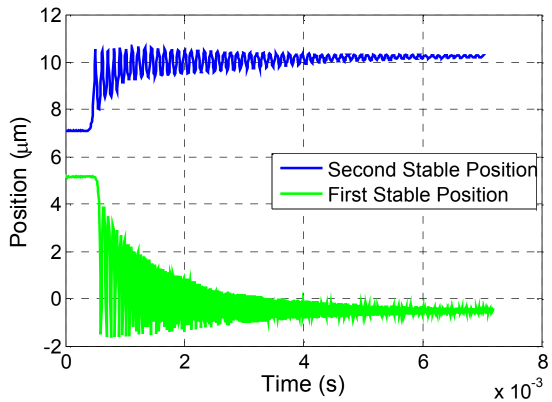
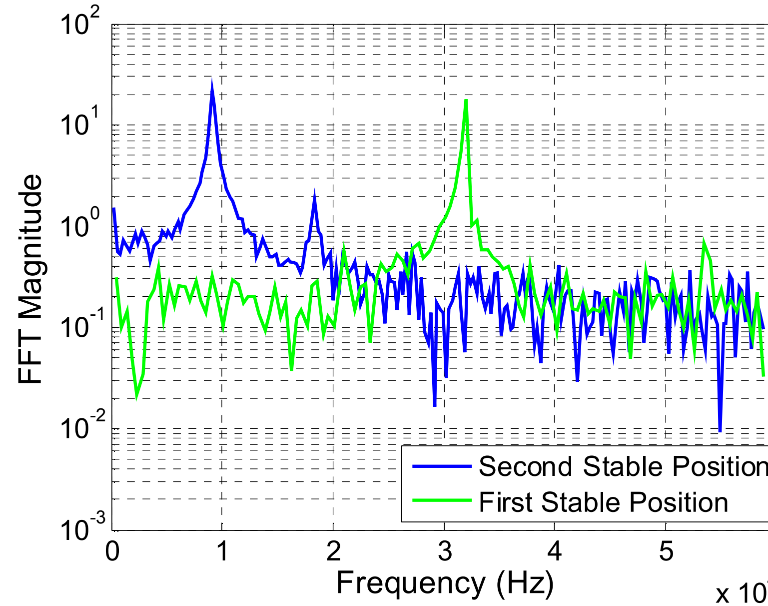
Resonant Frequency Testing

- **High-speed camera + image tracking**
- **Ring-down (Q in air ~150)**
- **Model validation**





Measured Data

	First Stable Pos.		Second Stable Pos.	
	Position μm ±0.125	Freq. kHz ±0.24	Position μm ±0.125	Freq. kHz ±0.18
Design 1	-0.25	30.0	9.75	7.9
	-0.5	32.0	10.25	9.1
	-0.75	34.3	10.75	10.5
Design 3	0	60.9	10.5	13.9
	-0.25	63.7	10.75	15.9
	-0.25	65.7	11.25	17.7

Modeled Predictions

	Mass	FSP		SSP	
	(μg)	***k*** (N/m)	***f*** (kHz)	***k*** (N/m)	***f*** (kHz)
Design 1	4.013	99.8	25.1	4.32	5.2
Design 2	1.940	99.8	36.1	4.32	7.5
Design 3	1.940	223.0	54.0	9.26	11.0

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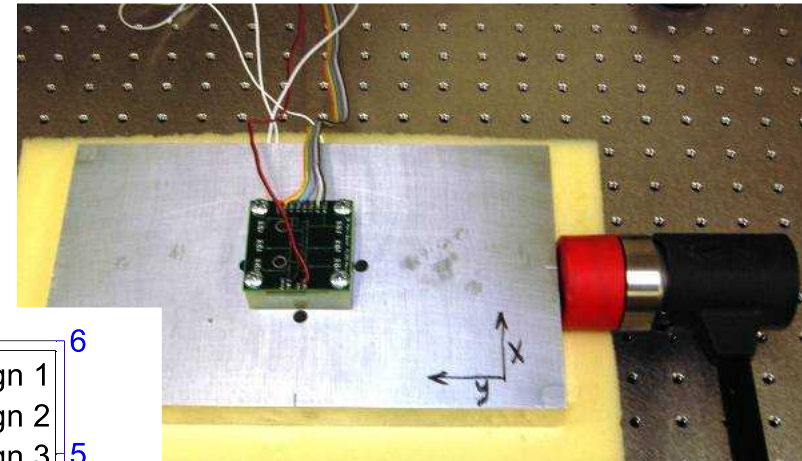
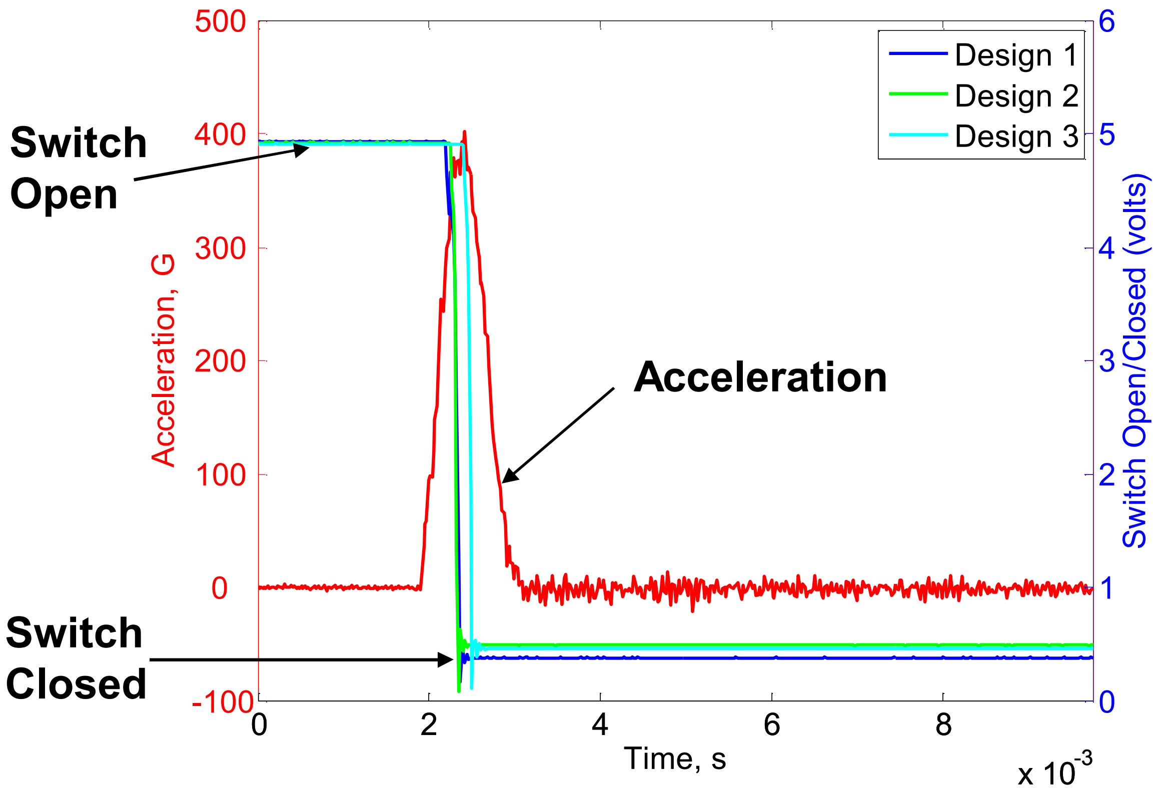
Hammer Strike Testing

- 100g – 1000g discrete events
- Wide range of pulse widths and amplitudes
- Simple setup
- Multiple tests to bracket threshold





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Summary

- Presented a novel MEMS passive latching shock switch
  - Low power, small size, latching, electrical contact, self-test, reusable
- Demonstrated successful sensing of shock events using Hammer strike tests
- Used centrifuge testing and resonant frequency measurements for comparison to model predictions
  - Original single-leg beam element model under predicting the actual response

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Future Work

- Characterize the Dynamic Behavior
  - Acceleration vs. Pulse width
  - Frequency response (acceleration vs. frequency)
- Evaluate the Off-Axis Sensitivity
- Drop Table Testing (1,000g – 15,000g)
- Hopkinson Bar Testing (15,000g – 50,000g)
- Packaging
  - Transmissibility
  - Residual stress sensitivity (CTE mismatches)
- Survivability
- Long-term Reliability
- Environmental Testing
  - Temperature cycling
  - Vibration environments
  - Normal and Abnormal environments
- More Model Development and Validation

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Questions

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