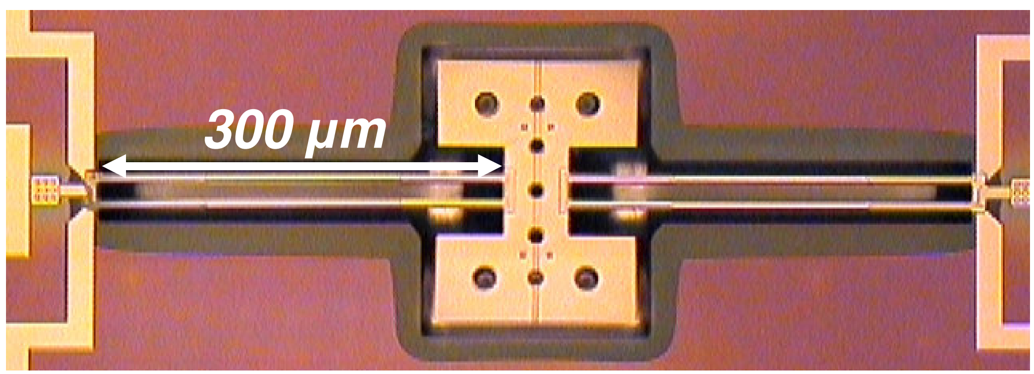
SAND2007-5735C

POST-CMOS COMPATIBLE AlN RESONANT ACCELEROMETERS

- **Goal:** To develop small, low power accelerometers that can be placed directly on-top of foundry CMOS circuitry.
  - Resolution < 10 mG/√Hz
  - Bandwidth 10 Hz – 1 kHz
  - CMOS compatible materials, max. processing temp = 400 °C
- **Approach:**
  - Develop post-CMOS compatible, piezoelectric thin film MEMS process
  - Design and fabricate accelerometers
  - Design readout circuitry and measure acceleration resolution

Team: Roy Olsson (PI), Ken Wojciechowski, Mike Baker, Ken Pohl, Steve Yepez, Jim Stevens, Melanie Tuck, and Jim Fleming



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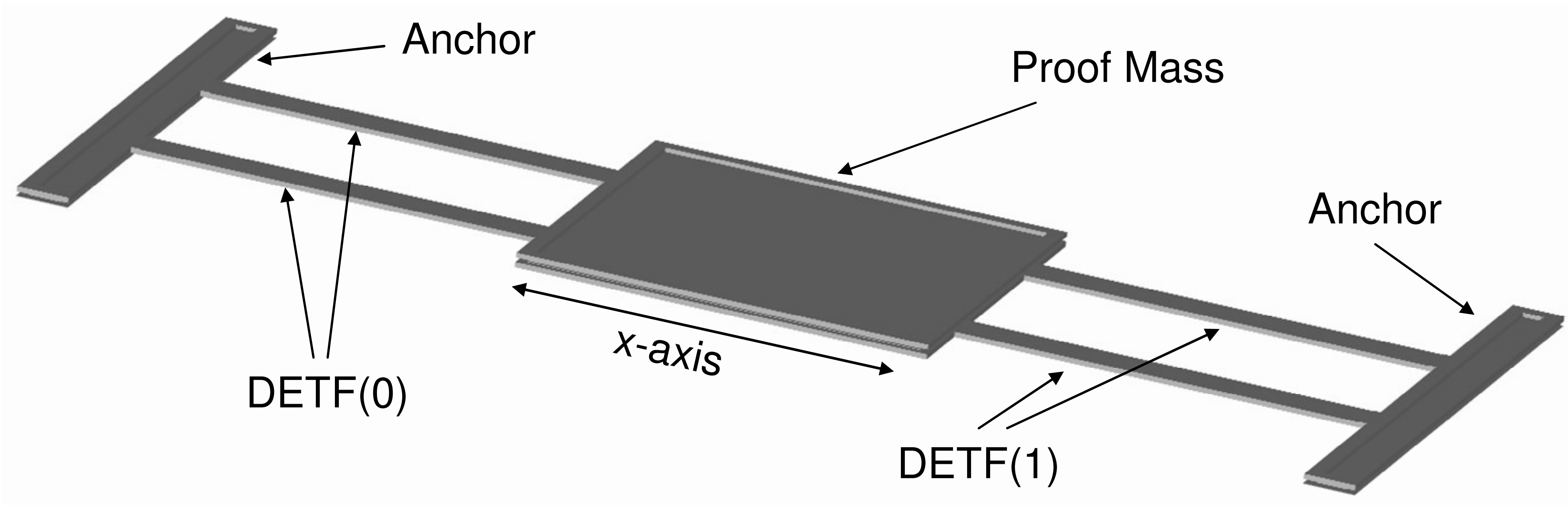
Resonant Accelerometer Operation and Properties



- Double-ended tuning forks (DETF) placed in oscillation loop
- Positive x acceleration increases frequency of DETF(0), decreases frequency of DETF(1)
- Differential design improves cross-axis rejection, reduces temperature sensitivity, high dynamic range
- Low power digital output
- Measures strain not displacement, high stiffness, lower masses, more reliable and easier to fabricate

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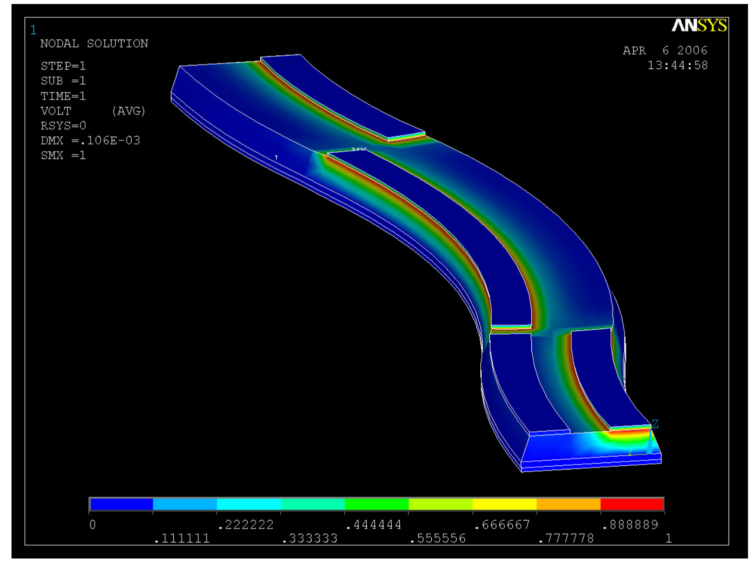
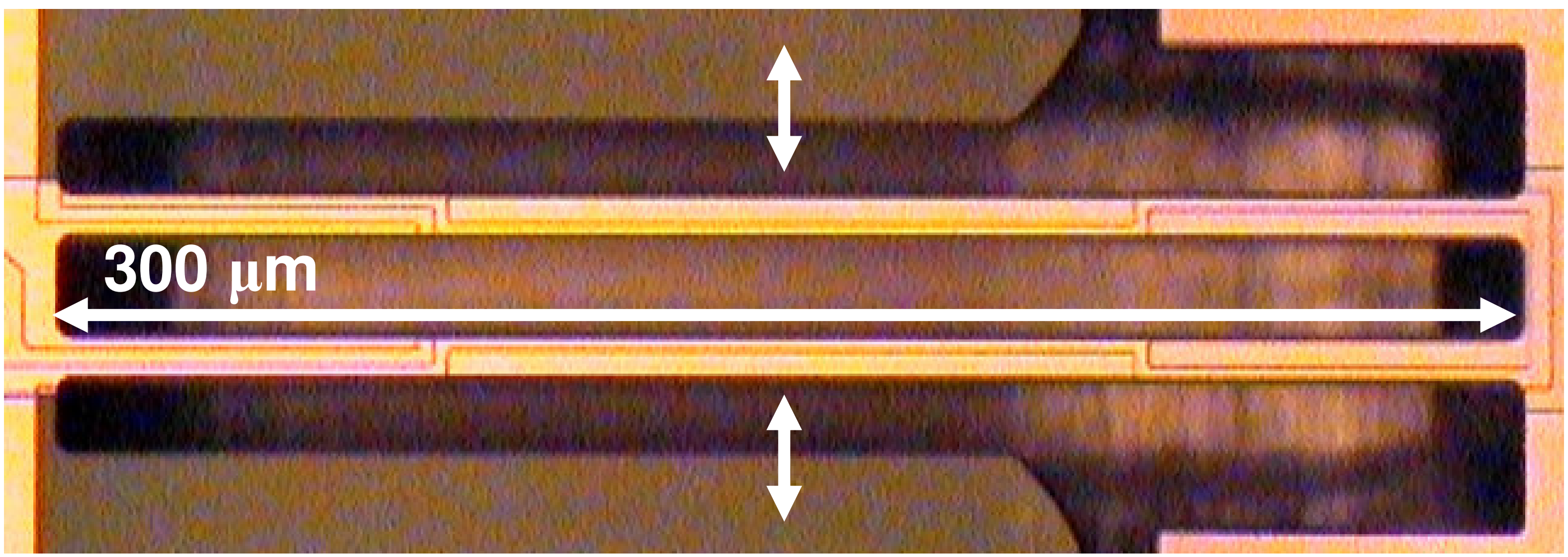
DETF Sensing Beams

- **Double-Ended Tuning Fork (DETF)**
  - ➢ Electric field across AlN film causes lateral displacement due to d_{31} piezoelectric coefficient
  - ➢ DETF mode driven through electrode layout
  - ➢ DETF mode reduces anchor losses





890 kHz Double-ended tuning fork resonant sensing beams

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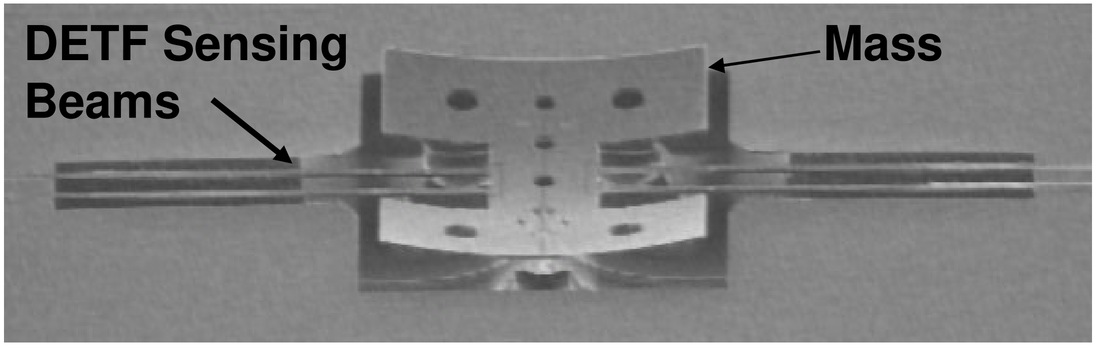
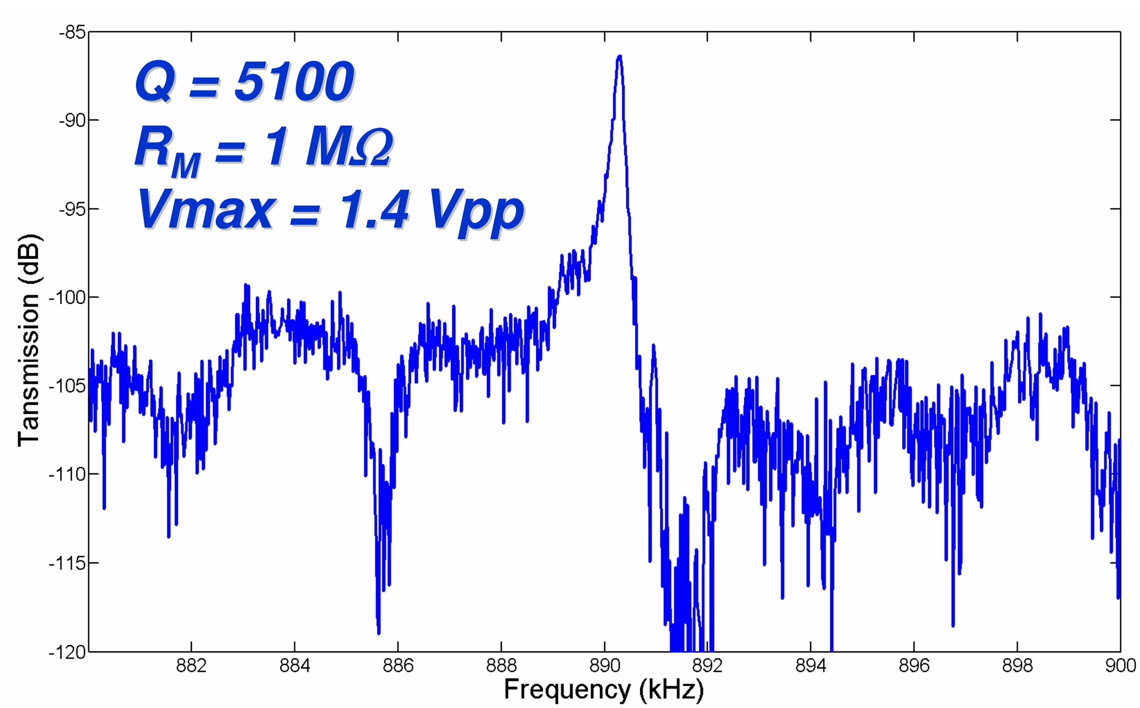
Aluminum Nitride Piezoelectric Transduction



AlN Resonant Accelerometer



Frequency Response of DETF Sensing Beams

Piezoelectric Transduction

- Low Impedance
- Linear with Drive Voltage (10x Higher Power Handling)
- 1.4x Lower Q than Electrostatic Si Beam Sensors (Offset by Improved Power Handling)
- Post CMOS Compatible Materials

High-Q enables very accurate frequency and thus acceleration measurement

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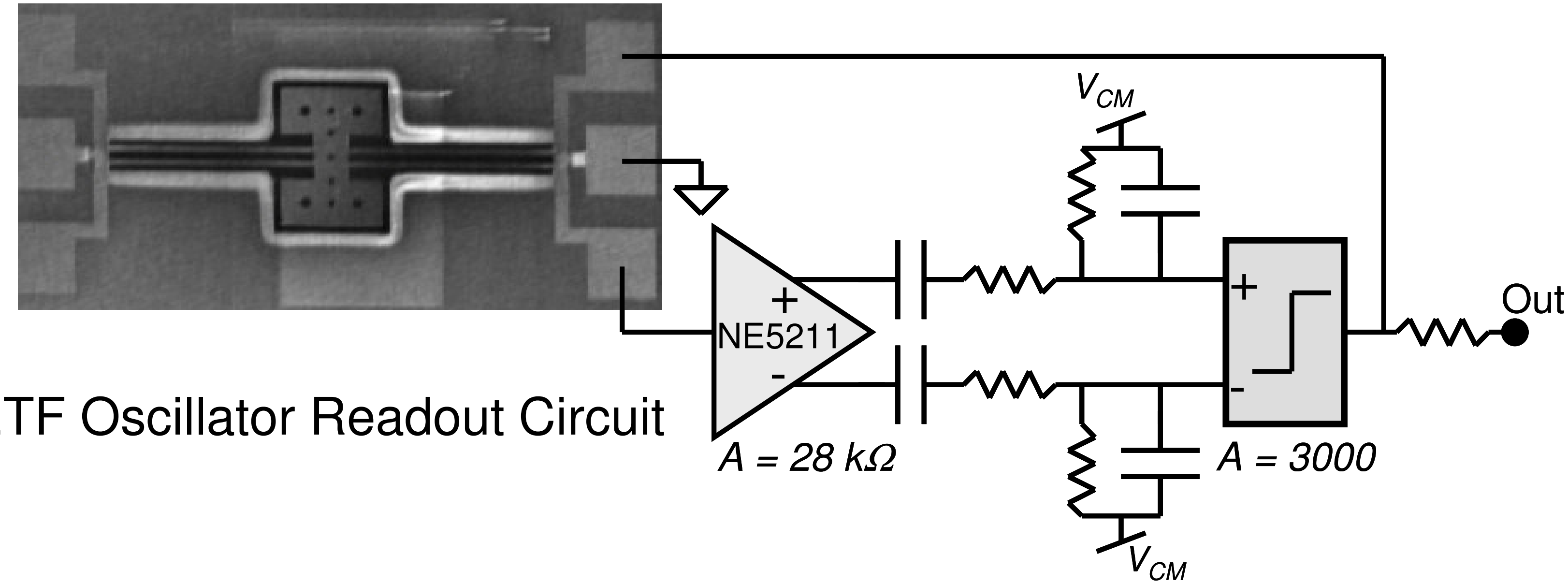
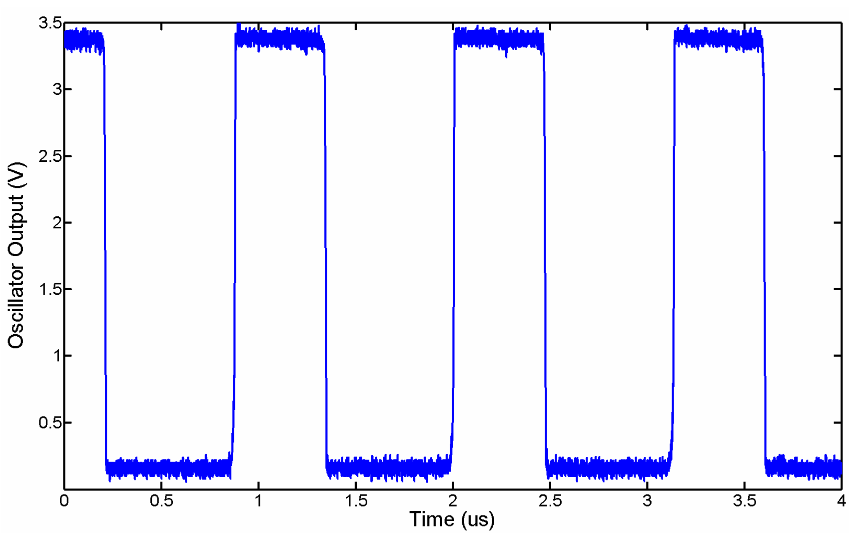
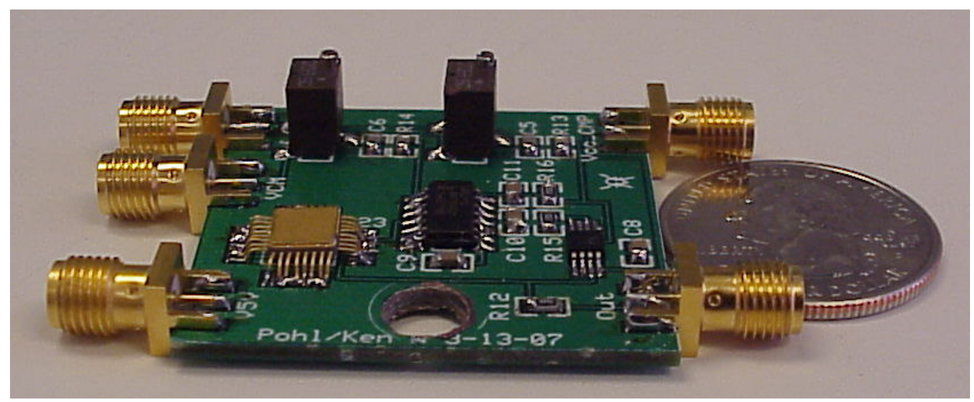
DETF Oscillator Readout Circuit



DETF Oscillator Readout Circuit



Output of the DETF Oscillator



Packaged Accelerometer and PCB Readout Electronics

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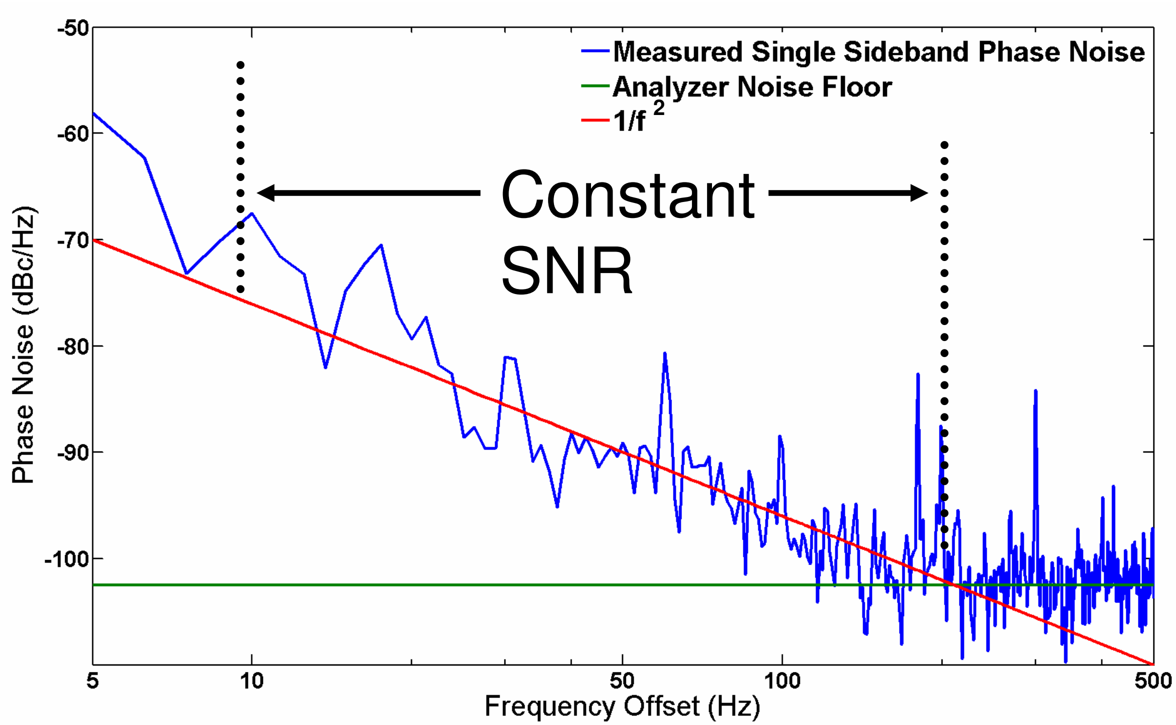
Accelerometer Performance Analysis

Readout Oscillator Circuit Phase Noise

$$L_{osc}(\Delta f) = 10\log\left[\frac{2KT}{P_{sig}}\left(\frac{f_0}{2Q\Delta f}\right)^2\right]$$



Vibration Induced Signal

$$L_v(\Delta f_v) = \left(\frac{\left|\vec{\Gamma}\right| f_0 \vec{a}(f_v))}{2 f_v}\right)^2$$

Accelerometer Resolution

$$\frac{a_{\min}(f_v)}{\sqrt{Hz}} = \frac{2 f_v \sqrt{L_{osc}(\Delta f_v)}}{\vec{\Gamma} f_0}$$

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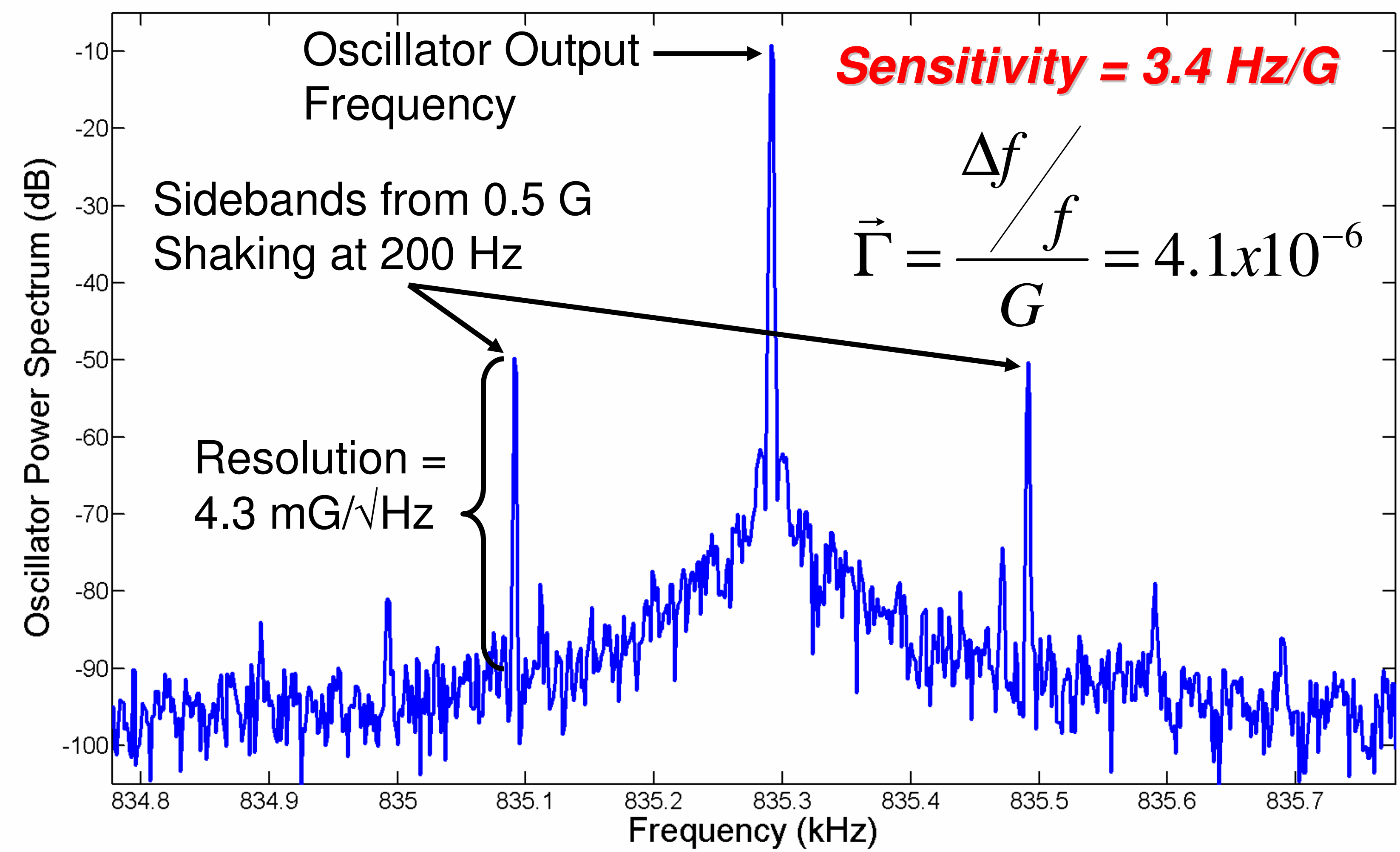
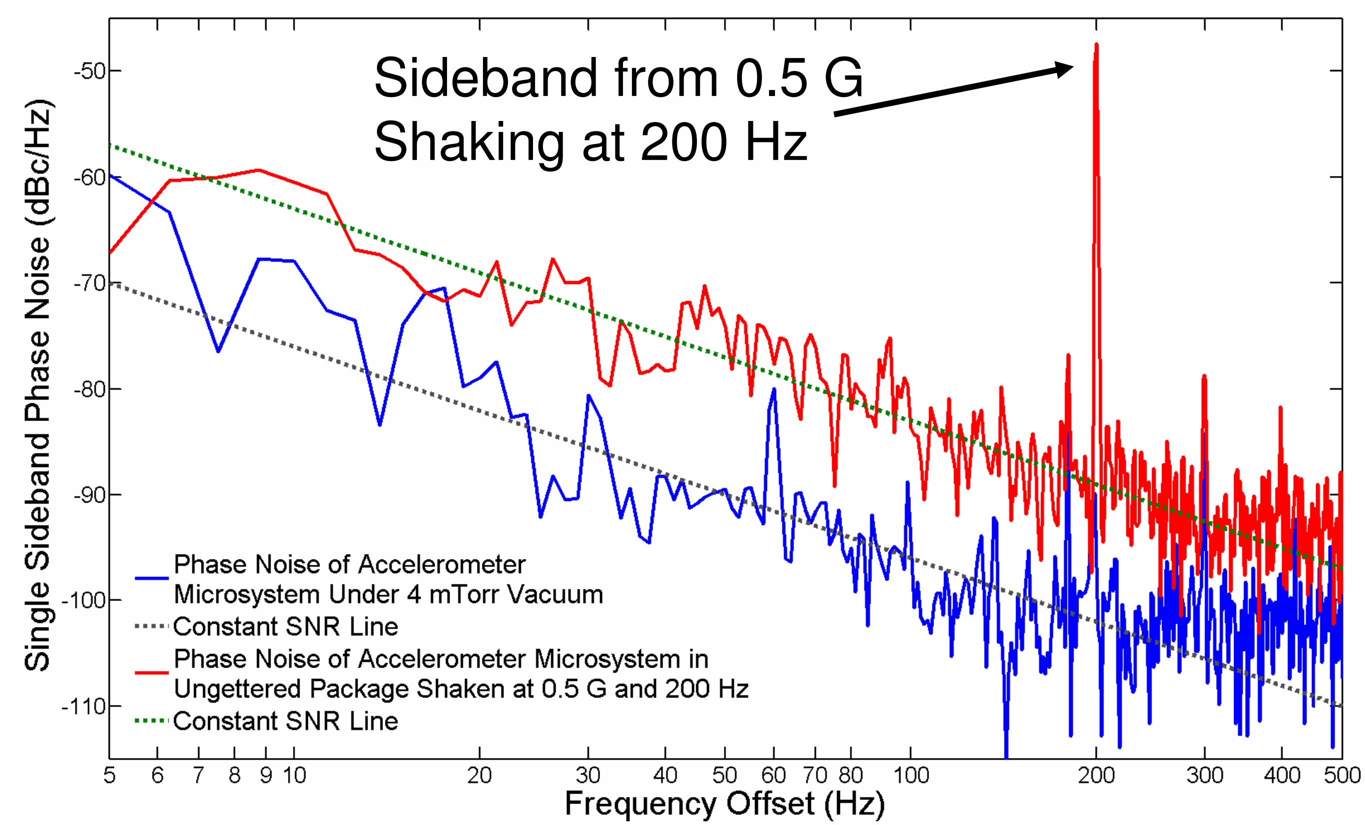
Acceleration Measurement



Shaker Testing on an AlN Resonant Accelerometer in a Chip Scale Vacuum Package Without Getters

Accelerometer Performance

Vacuum	Mass Width	Mass Length	Thickness	Mass	Resolution
Ungettered	200 µm	150 µm	1.35 µm	120 ng	4 mG/√Hz
4 mTorr	200 µm	150 µm	1.35 µm	120 ng	0.9 mG/√Hz
4 mTorr	2 mm	2 mm	1.35 µm	15.6 µg	7 µG/√Hz



Significance

- Very high resolution for a given proof mass (30x > than capacitive sensing)
- Inertial sensors integrated over custom CMOS signal processing and RF communications circuitry

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