Results from preliminary testing of a new generation of high-shock accelerometers with extreme survivability performance

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Initial development and testing

- MSS, SJC (Endevco) has been developing a lightly damped accelerometer for fuze applications
  - Silicon MEMS sensor
  - High-g shock
  - Mechanical stops
  - High survivability
  - Complements the silicon MEMS sensor which is currently the industry standard
- Previous papers describe initial development work
  - NDIA 53rd annual Fuze Conference (2009)
  - 80th SAVIAC Symposium (2009)
- Basic design and performance characteristics
  - Light damping, high resonant frequency, stops, low power
  - Sensitivity, ZMO, Survivability

Recent test results

- Test results on new damped/stopped unit
  - 20,000 g full scale range
  - Conducted at high-g shock lab at Eglin AFB
  - Under the direction of Jason Foley (AFRL) and Alain Beliveau of Applied Research Associates.
- Testing designed to:
  - Characterize performance of the prototype damped/stopped MEMS accelerometer
  - Evaluate a new fixture designed by MSS-SJC for use in testing a high-g accelerometer which is housed in an SMT mounted LCC package.

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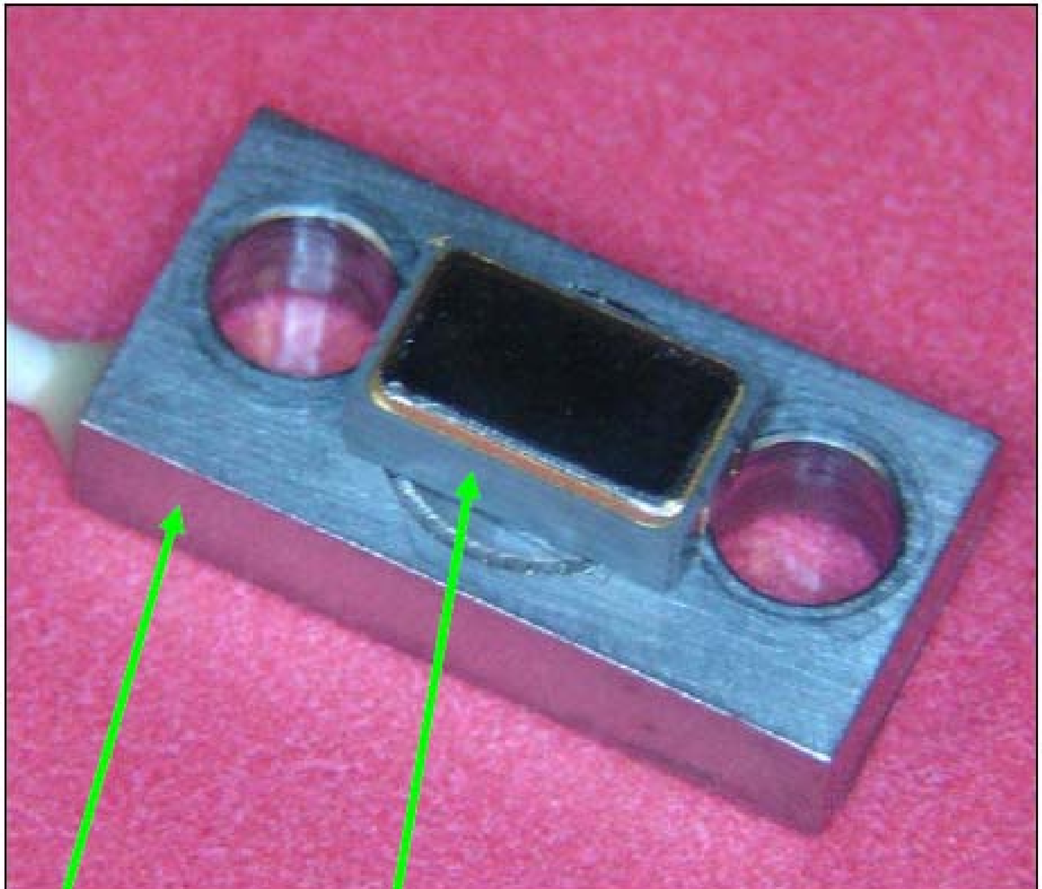
Package comparison



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Test methods and equipment

- It is anticipated that the new accelerometer will be controlled under the ITAR regulations
  - References to specific model numbers, test equipment, etc. are limited.
  - However these details can be divulged to properly vetted persons in industry, academics, or government.
- Series of tests performed on new damped/stopped accelerometer at AFRL Fuzes Lab at Eglin AFB
  - Testing performed on a new 1.5 inch diameter Hopkinson bar.
  - Outputs referenced to a laser vibrometer
  - Also referenced to the industry standard accelerometer for high g shock.

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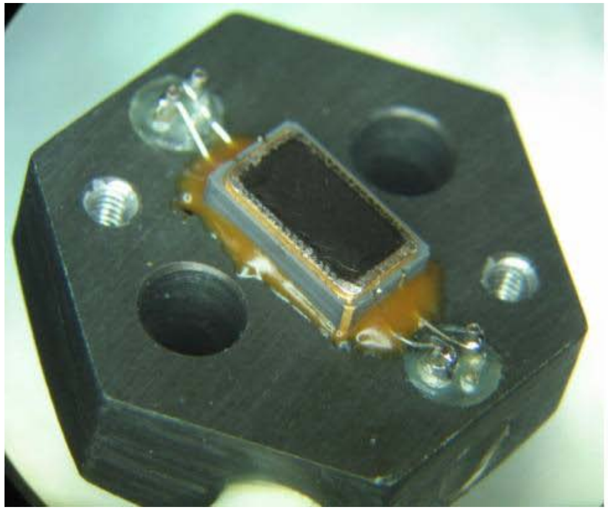
Test fixture



- SMT packages are a particular problem for high g shock testing
  - Custom fixture was designed
  - Easy installation and removal
  - Retains test unit at 180,000 g shocks

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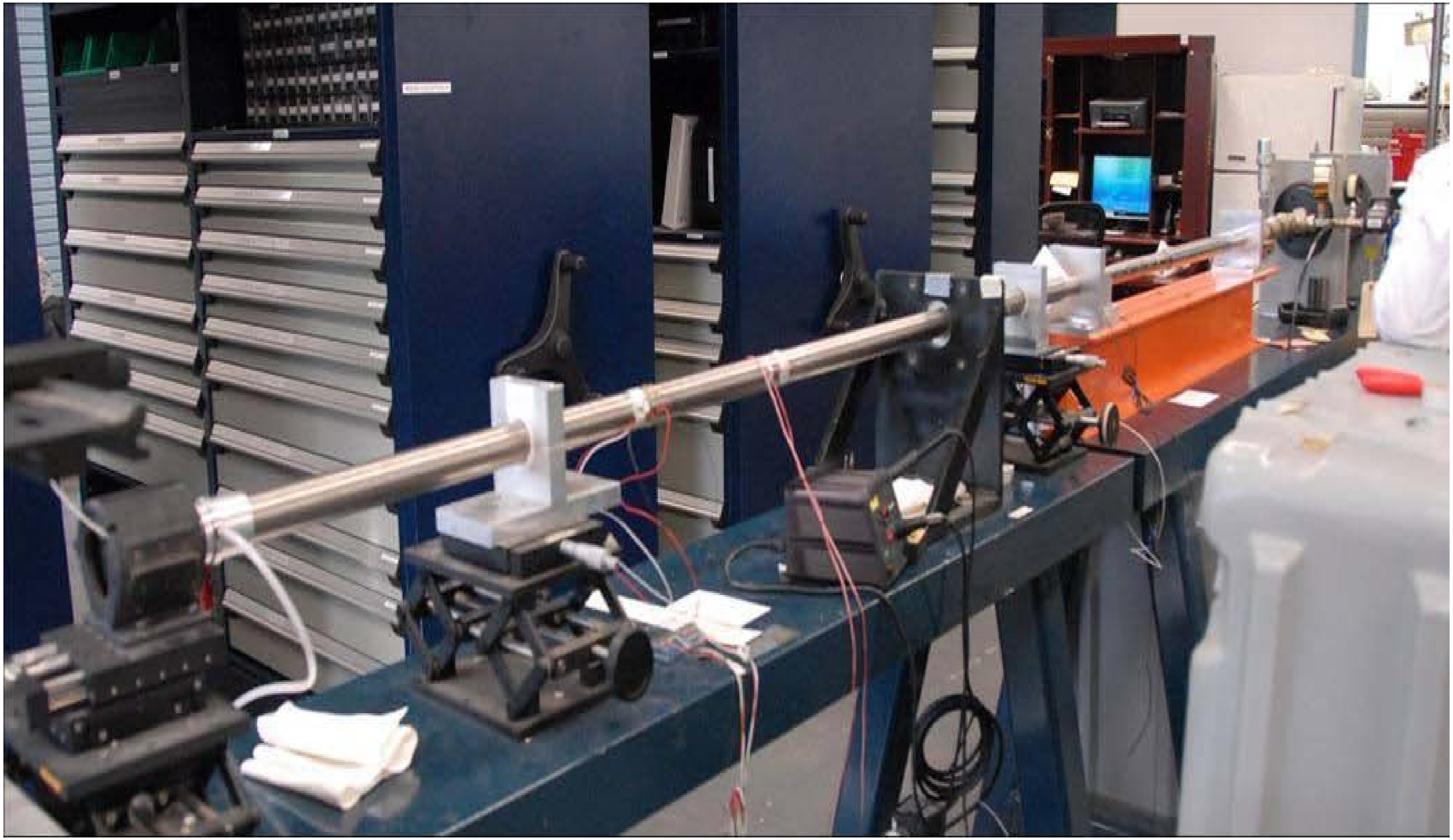
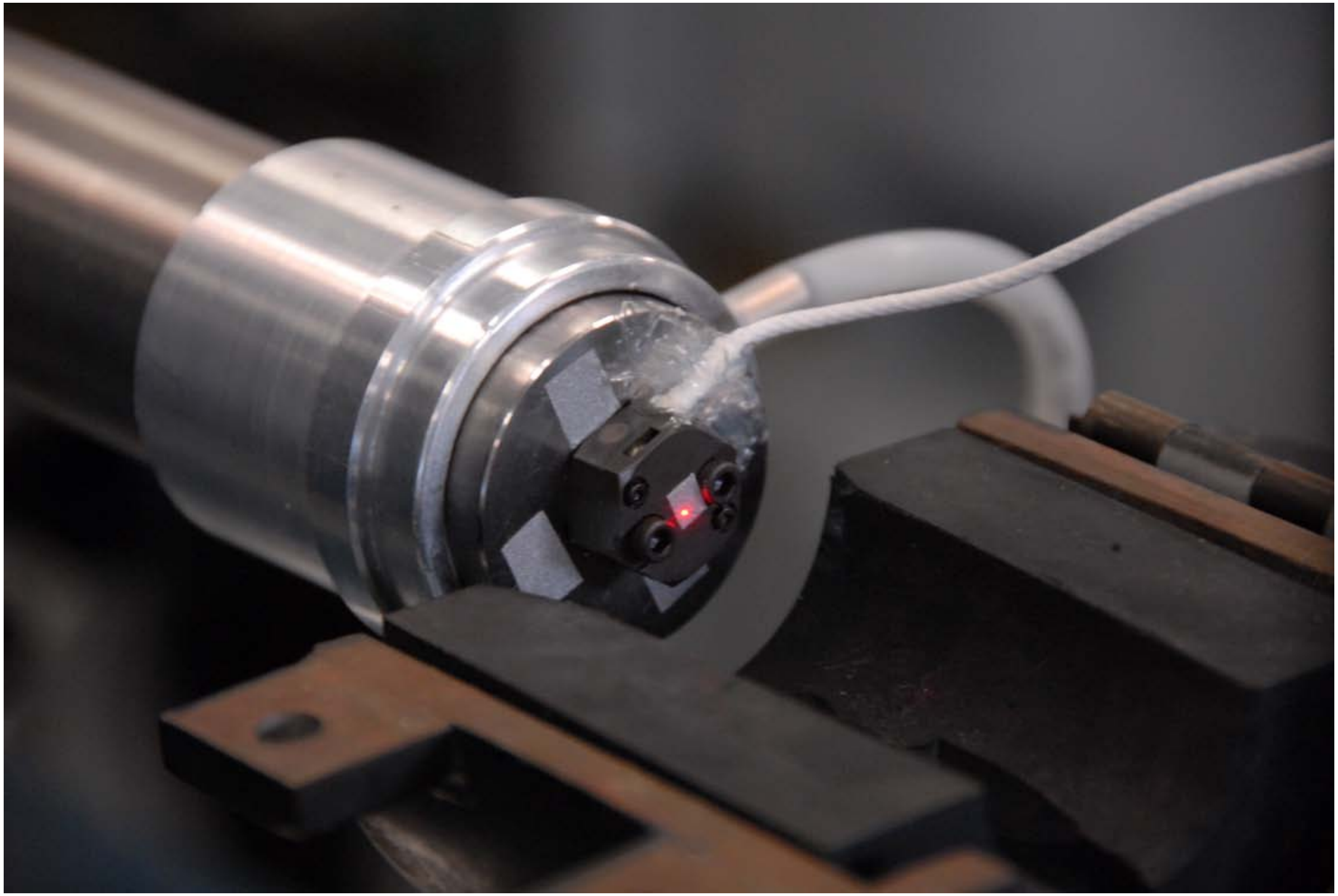
Hopkinson bar



Laser vibrometer

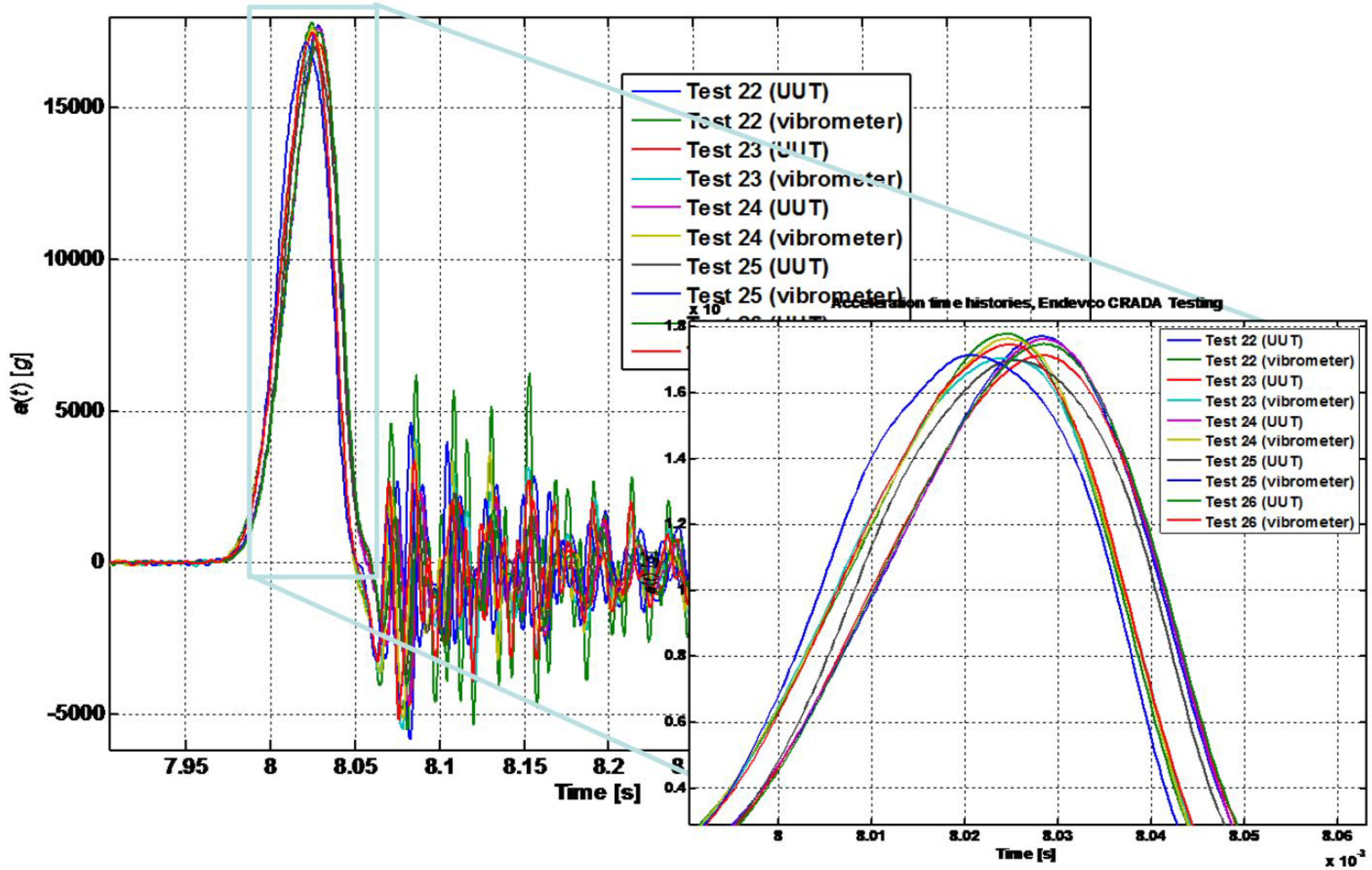


Tests conducted

- Testing was conducted to determine the following performance characteristics:

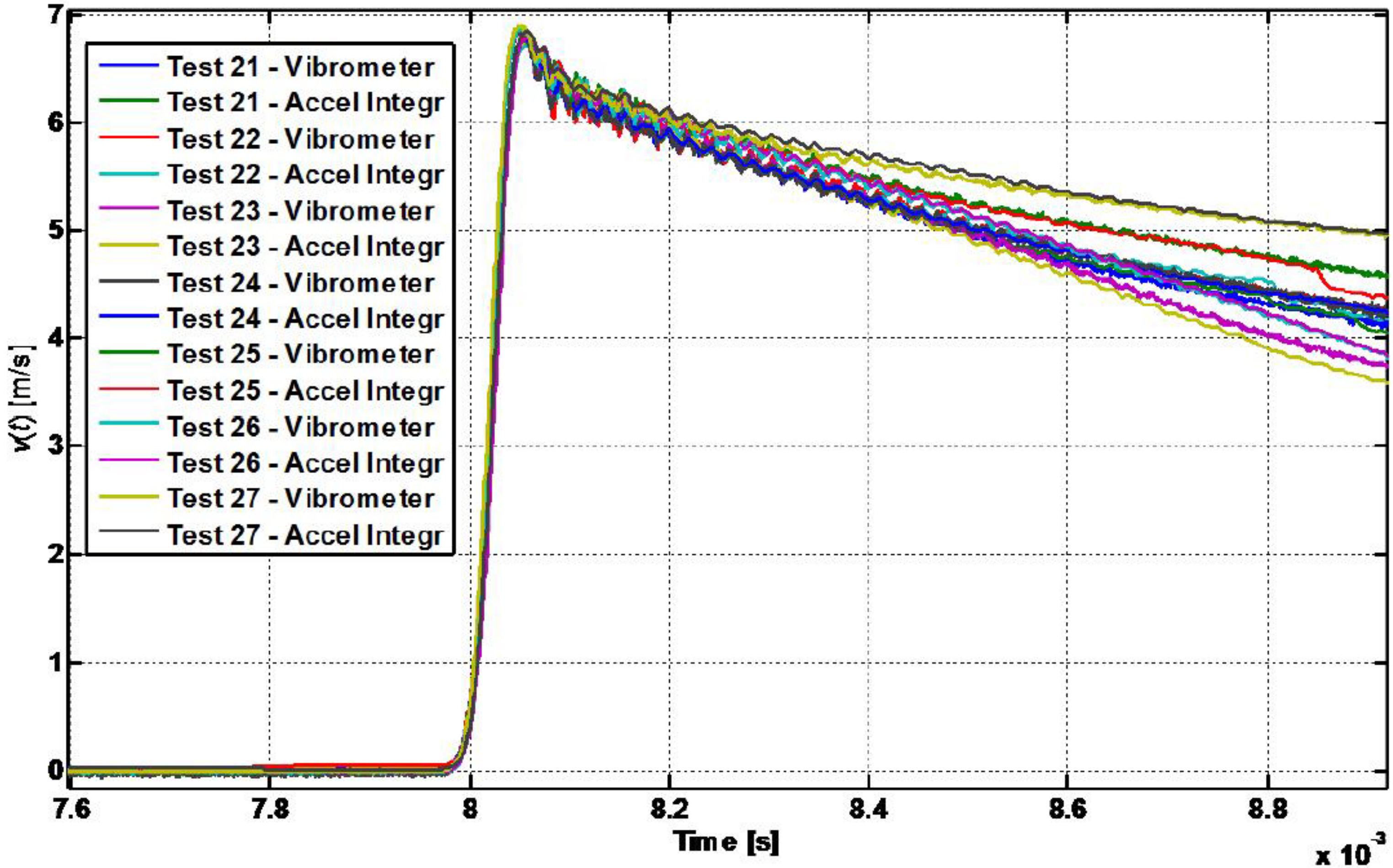
- 1. Survivability to 4 x rated range (80,000 g)
- 2. Zero shift following shock
- 3. Damping
- 4. Stop effects
- 5. Frequency response

Test repeatability



- Time histories of multiple tests conducted at full range acceleration.

Test Repeatability

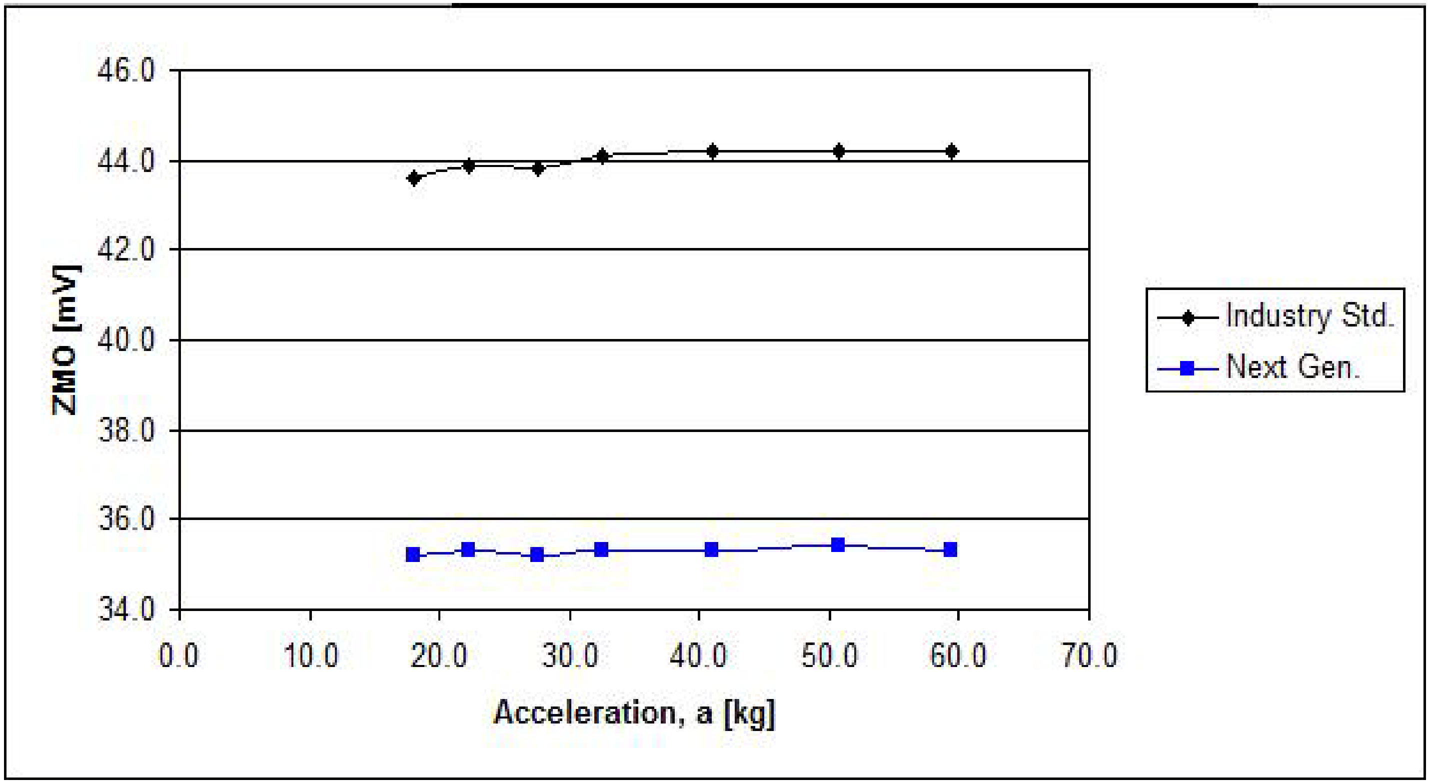


- Integrated accelerometer time history vs. laser vibrometer velocity data taken over seven consecutive 20,000 g shocks.

Survivability

- A total of 50 high-g shock tests were conducted on two different prototypes of the new damped accelerometer.
  - There were no out of spec readings noted during the testing
  - The worst case zero shift observed was 0.15 mV at 5.0 Vdc excitation
- The highest g level impact recorded was 84 kg (approximately 4 times full range).

Zero shift after shock



Typical zero shift following a shock event

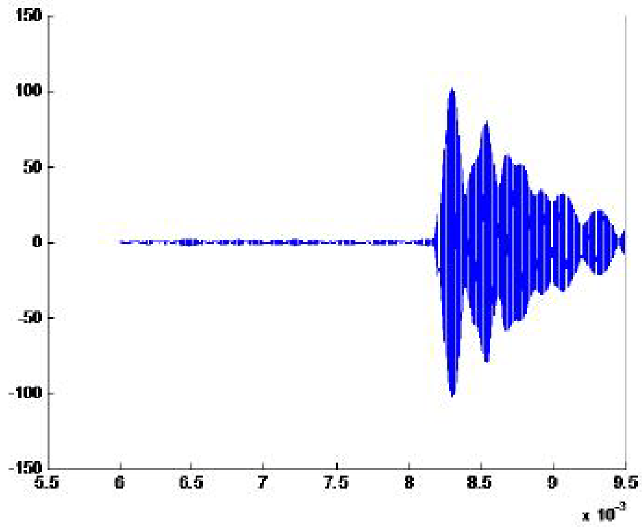
Damping – Log decrement method

- Measure amplitude of two successive peaks
  - A_k and A_{k+1}
- The ratio of the two is δ
- Damping can be found

$$\delta = \ln\left(\frac{A_k}{A_{k+1}}\right) = \frac{2\xi\pi}{\sqrt{1-\xi}}$$

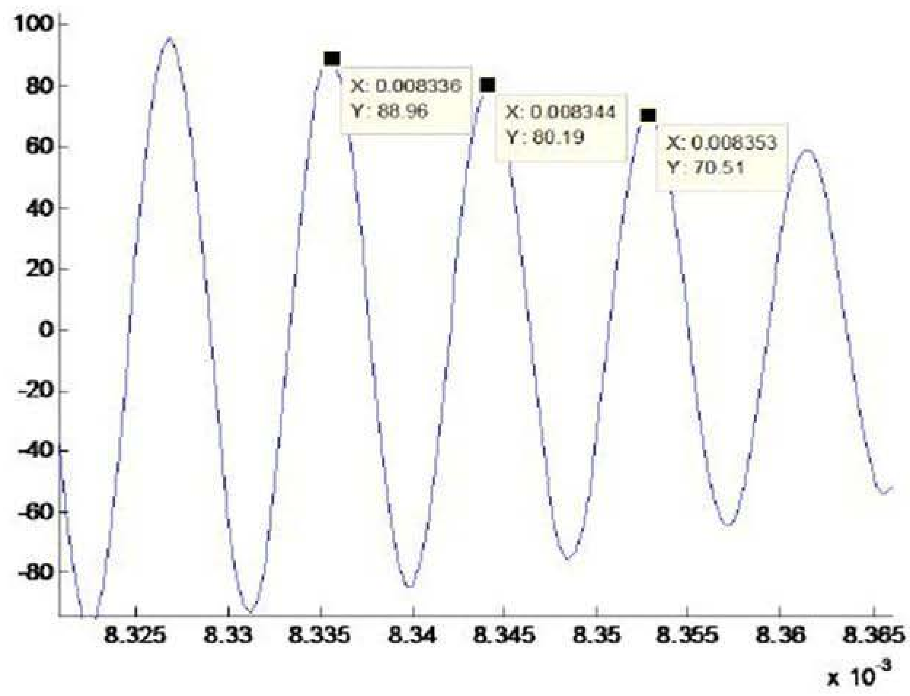
$$\xi = \frac{\delta}{\sqrt{4\pi^2 - \delta^2}}$$

- Utilize bandpass filter
  - 1st resonance at 113.4 kHz



Damping calculation

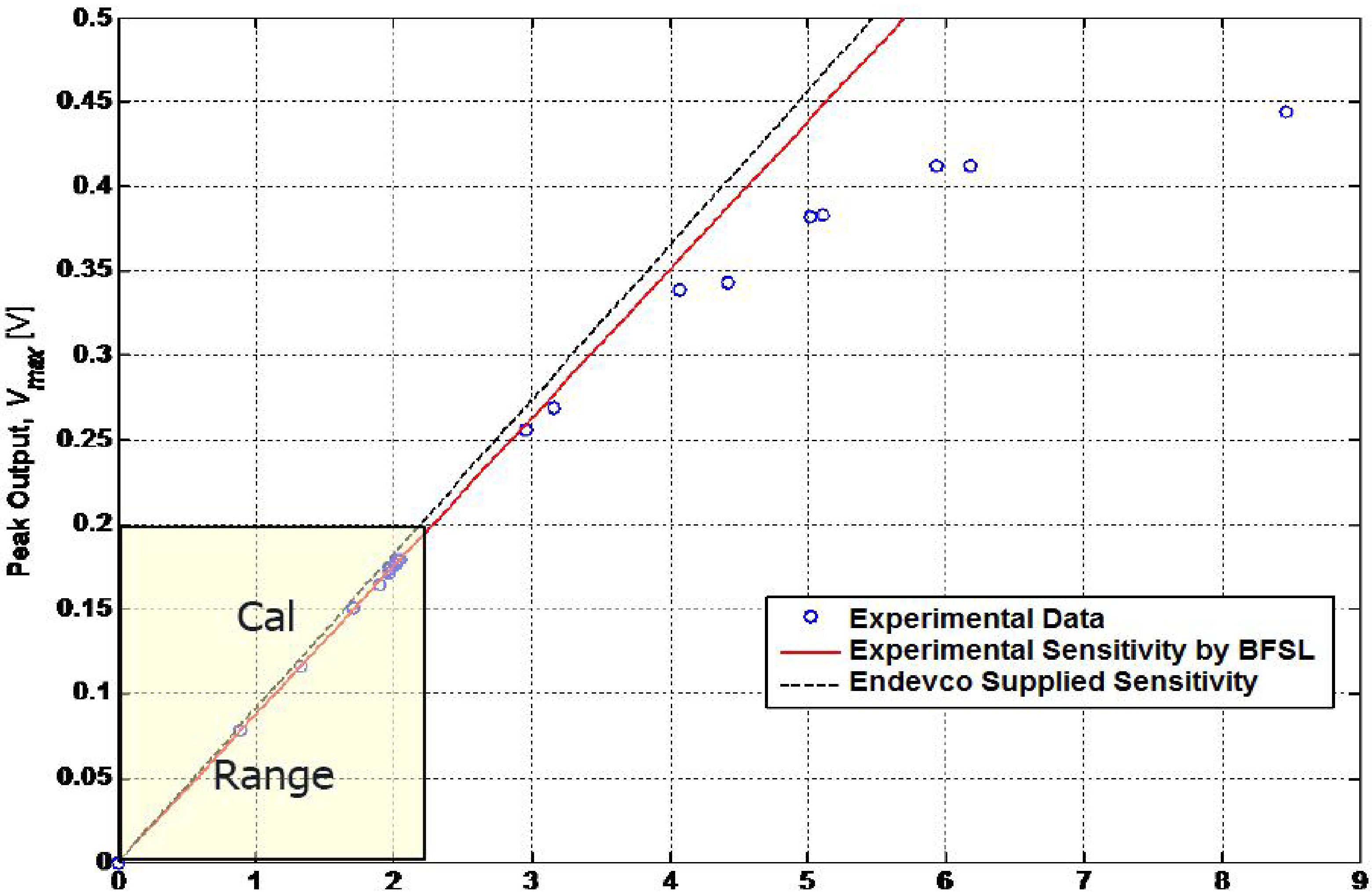
- Damping at 113.6 kHz is thus $\xi = 0.0165$ and 0.0205, or 1.65-2% (consistent with narrow peaks)



In-house damping calculation

- Similar damping testing at our Sunnyvale silicon foundry measured closer to 10% damping.
  - In-house testing was done at full range (mechanical displacement of the proof mass from the stops)
  - Eglin AFB testing was done at 100 g.
  - It is likely that the damping varies with displacement.

Linearity



Acceleration measured by laser vibrometer in kg

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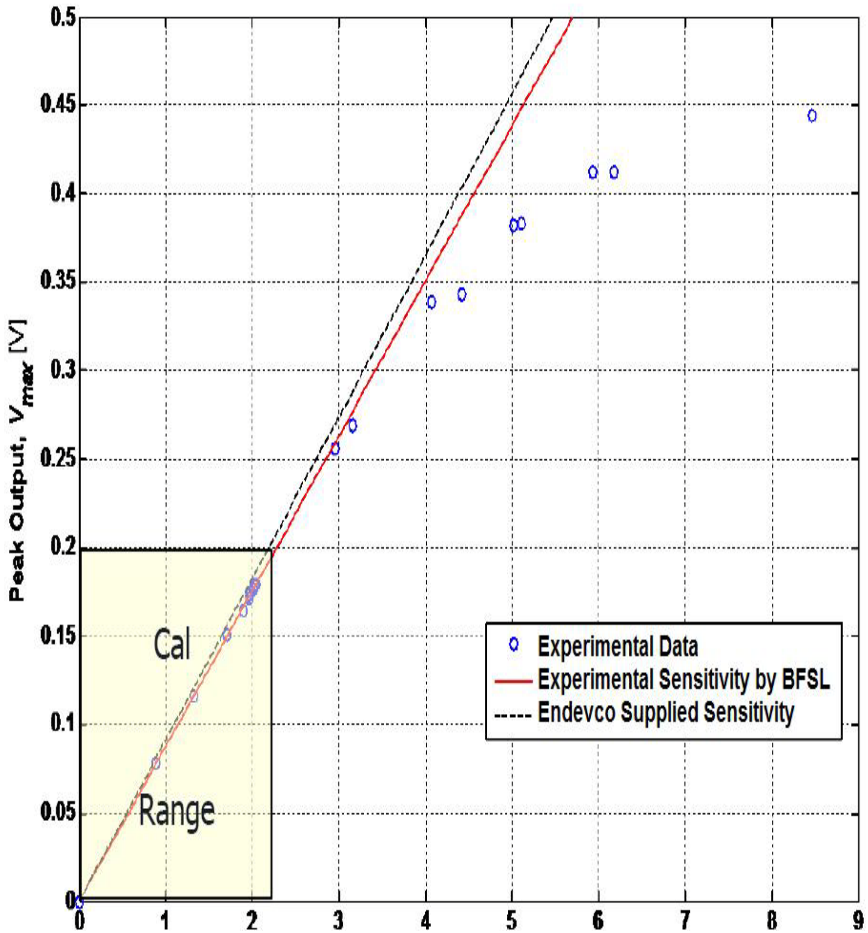
Linearity

- Experimental data for the new damped accelerometer fits very nicely to a straight line in the 20,000 g range
- Note the multiple readings at approximately full scale
- An extrapolation of the sensitivity measured at MSS-SJC indicates an error in our calibration.
    - Further testing is needed to validate the calibration methodology for damped high-g shock accelerometers

Mechanical Stops

- Gradual roll-off of sensitivity as g level increases.
- Such "soft" stops are almost ideal; there is no sudden change in momentum of the proof mass as the stops are engaged - just a gradual or progressive decrease in displacement.



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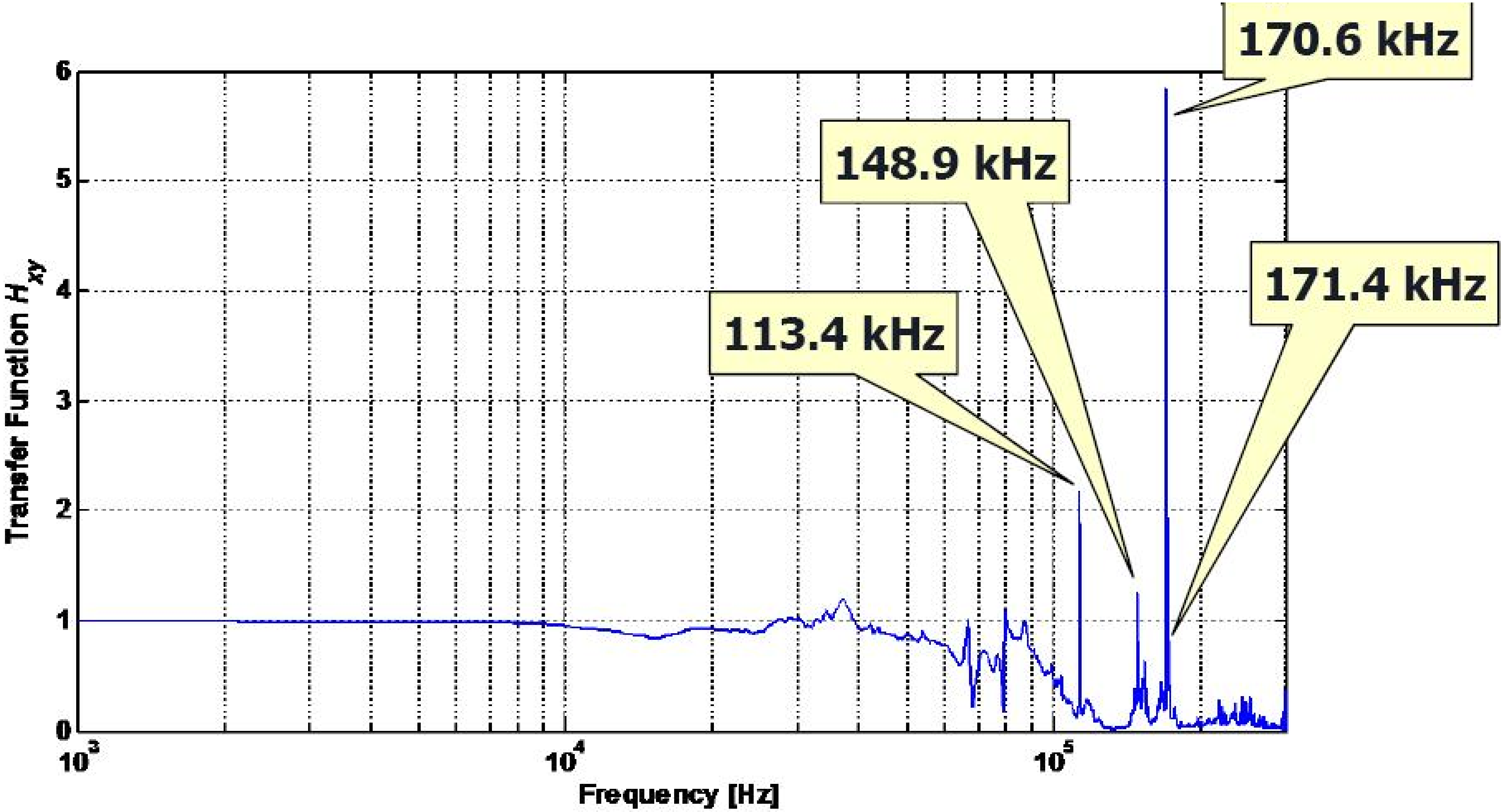
Frequency response

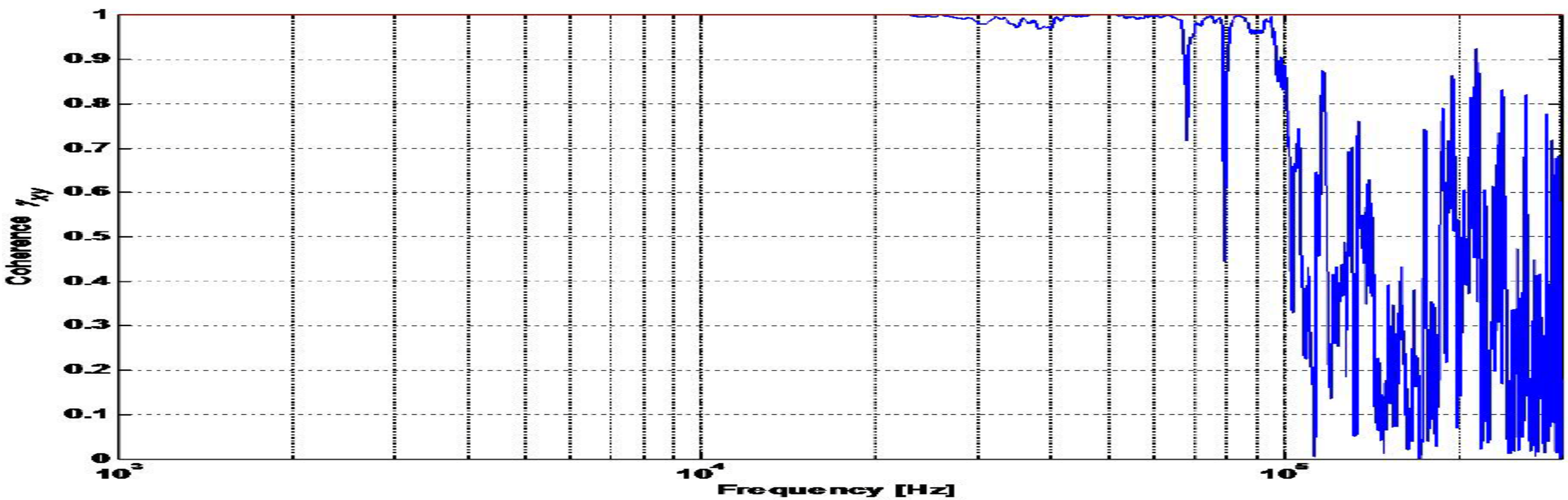
- Frequency response is measured by graphing the transfer function between the test accelerometer and the laser vibrometer.
- The “flat” bandwidth is close to 10 kHz, with reasonable bandwidth to 40 kHz.
- The resonances noted at 150 kHz and 170 kHz are above the natural frequency at 113 kHz and are thought to be caused by higher frequency modes of the seismic system.

FREQUENCY RESPONSE



Coherence

- Coherence plot generated from multiple data sets and is confirmation of both the performance of the accelerometer and the test equipment.
- Coherence out to 80 kHz indicates the accelerometer output is only a function of the shock input. Dips near 68 and 80 kHz are likely due to resonant modes in the flyaway test fixture.



Summary

- Further characterization of a damped/stopped MEMS accelerometer was conducted at the AFRL shock laboratory of Eglin AFB. The testing confirms the new damped/stopped accelerometer has:
  - **High shock survivability of 4x full range**
  - **Minimum ZMO shift following shocks**
  - **Damping between 2 and 10%**
  - **Linearity through full scale range**
  - **“Soft” stops**
  - **Frequency response flat to 10 kHz**

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- The authors would like to thank the team at the Dynamic Shock Facility of AFRL at Eglin AFB for their high quality, thorough evaluation of our next generation damped accelerometer.

- Note: The data from testing conducted at Eglin AFB presented in this paper was cleared for public release by Eglin AFB Public Affairs liaison officials (ref: case number 96ABW-2010-0288).

Distribution Statement: Approved for Public Release

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