Test Results and Alternate Packaging of a Damped Piezoresistive MEMS Accelerometer

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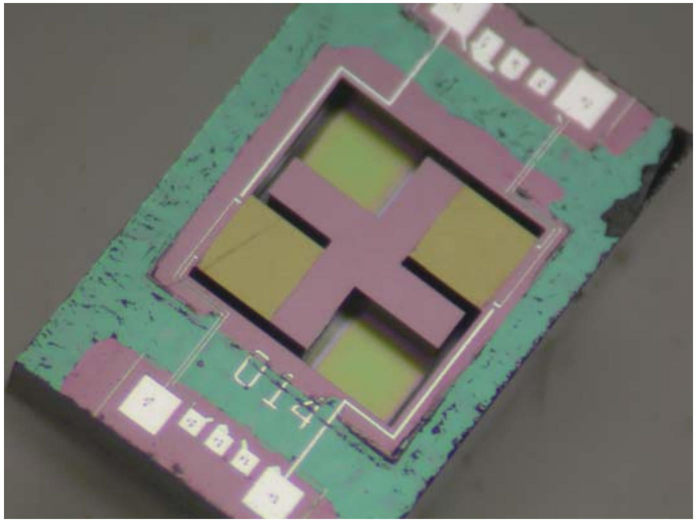
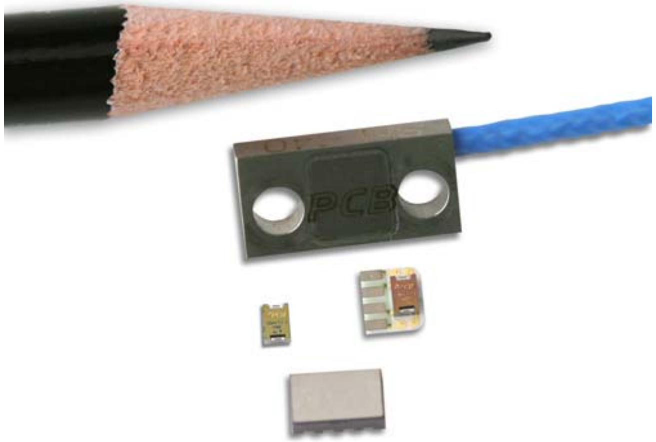
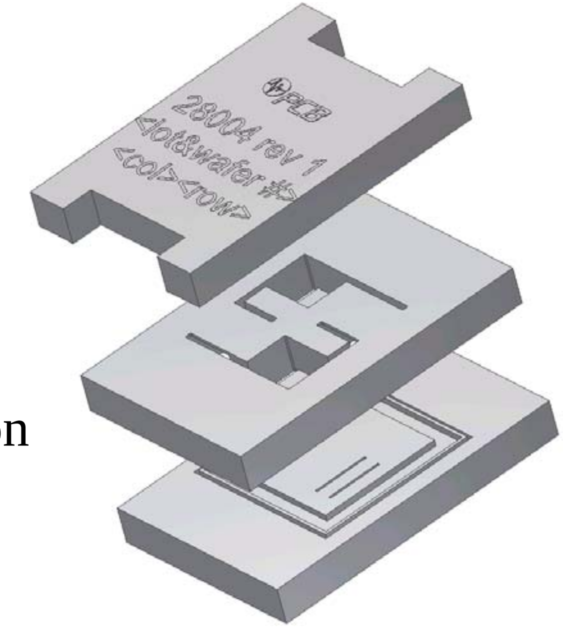
Introduction



- Description of new 20kG MEMS piezoresistive sensor
- Test data, side-by-side with legacy sensor:
  - Hopkinson bar to >40kG
  - Penetration through 2 ft concrete >850 ft/s
  - Penetration into concrete >1400 ft/s
  - Metal-on-metal hammer test >10kG
  - VHG shock >90kG
- Failure analyses / improvements
- Alternate packages

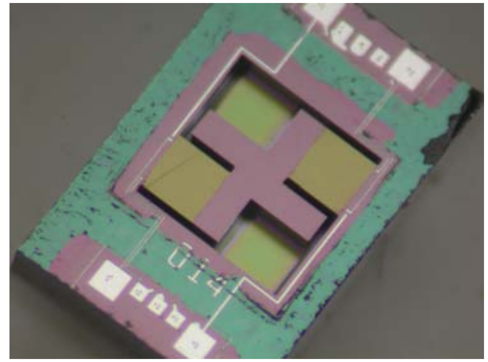


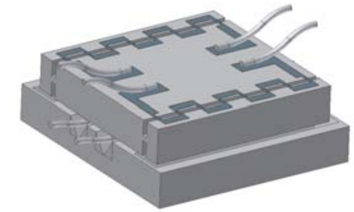
New Sensor Description



- Diced from a hermetic sandwich of three wafers
- Bandwidth matched to requirements of application
- Intentionally low resonance, which enables:
  - Slight damping to reduce resonant amplification
  - Mechanical stops for Over Range protection
- Ion implantation on one side only, for low
  ZMO, Thermal Zero Shift, and warm up drift
- >5000 Ohm Input Resistance for low power consumption
- Utilizes new semiconductor processing
  techniques for good control of parameters
- Packaged to be drop-in replaceable with legacy sensor, but the
  new sensor can be solder-bumped for “flip chip” version

Sensor Comparison





	New Sensor	Legacy Sensor
Sensitivity	1uV/V/G	1uV/V/G
Full Scale	20kG	20kG
Resonance	~65kHz	~350kHz
Resonant amplification "Q"	~10	~1000
Mechanical stops	+/- 40kG	none
Input Resistance	~5000 Ohm	~500 Ohms
ZMO	<40mV	<100mV
Hermetic	yes	no
"Flip chip" capable?	yes	no
Saw cuts at stressed structures	no	yes
Individually manual assembled	no	yes

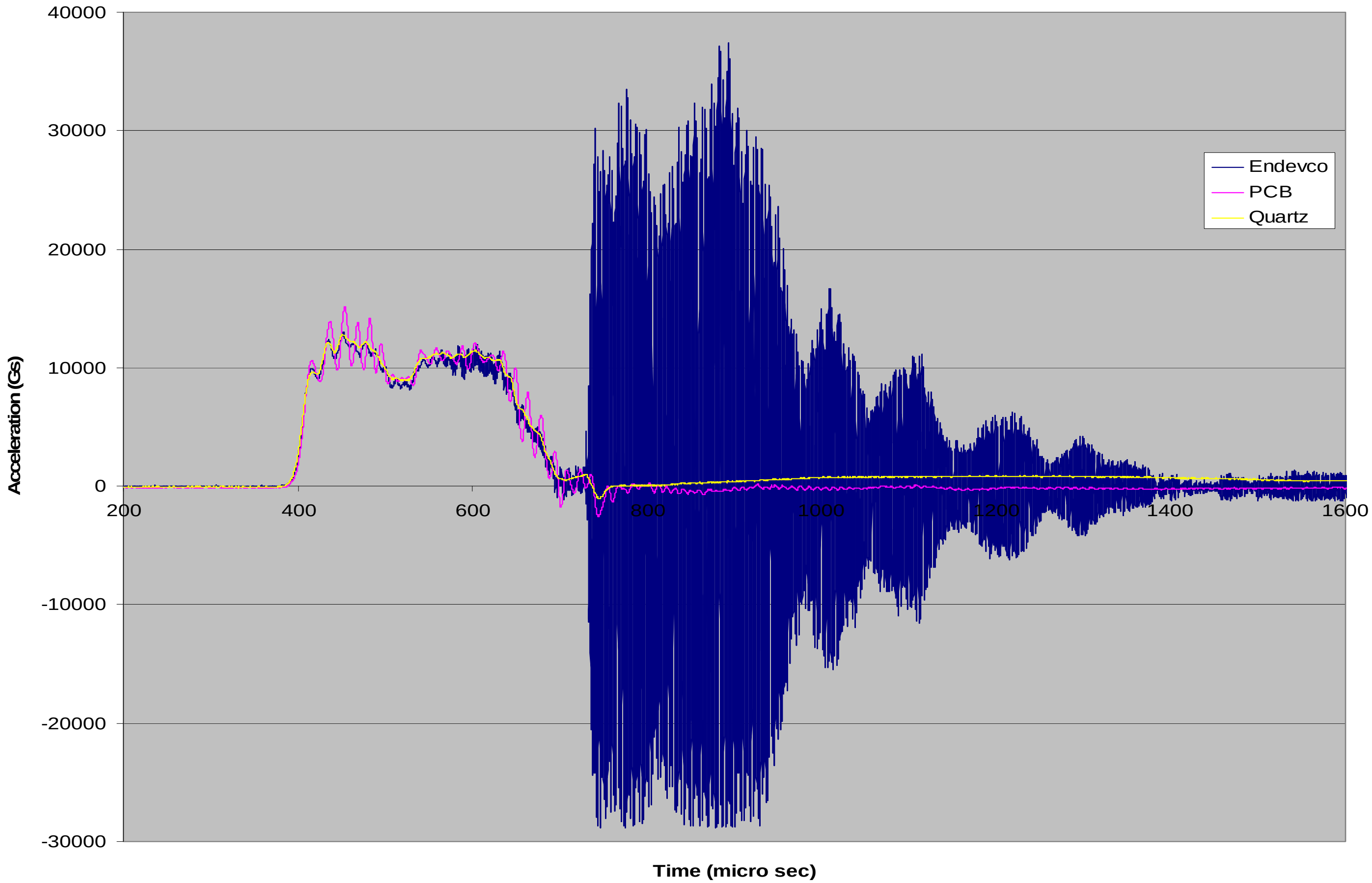
Test Results – Hopkinson Bar

Side-by-side comparison with legacy sensors and quartz disk under a tungsten flyaway

Test were conducted at 10kG, 40kG, and higher levels

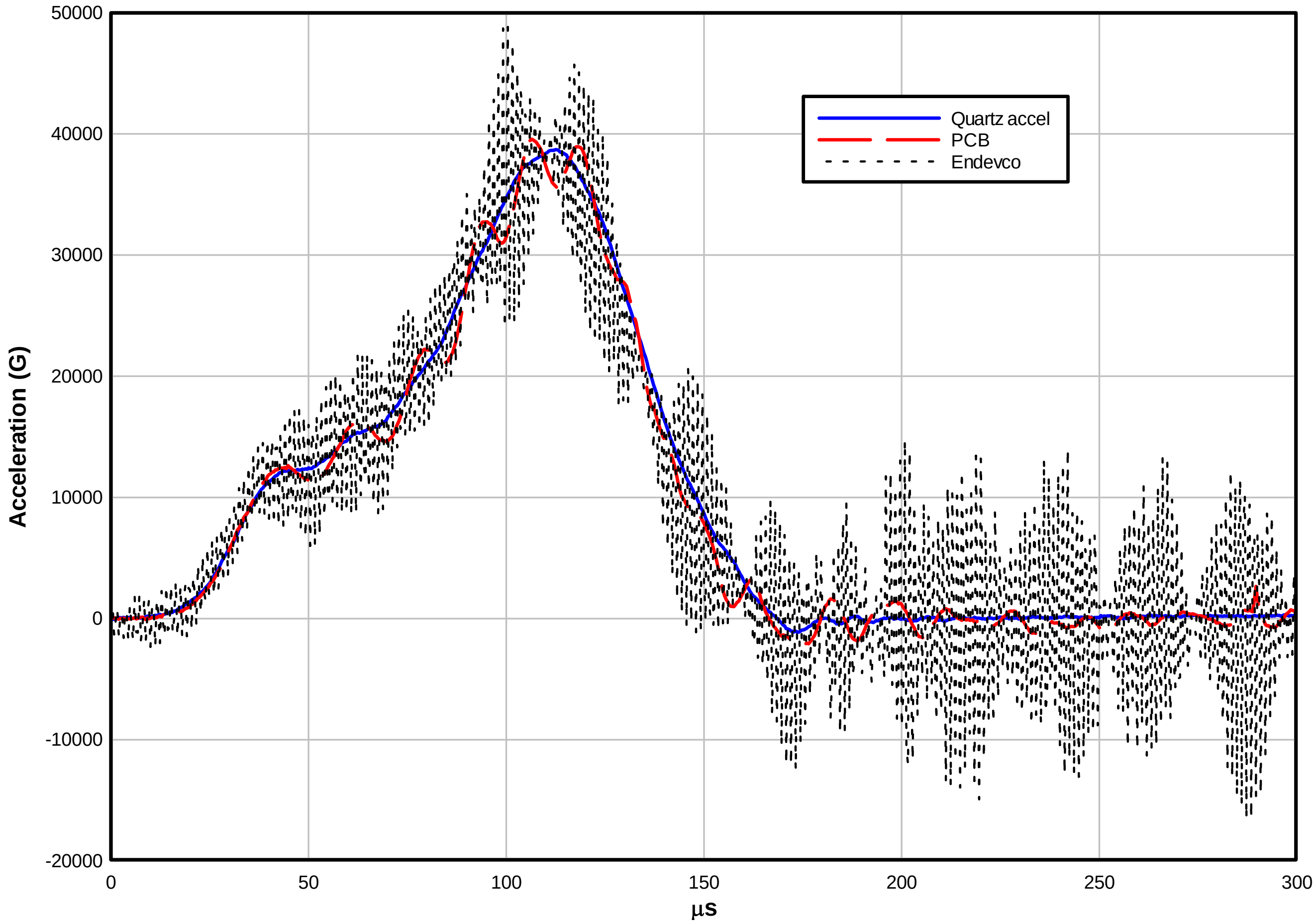
Credit: D. Frew and H. Duong of Sandia National Laboratory

Test Results – Hopkinson Bar



In low level tests the new sensor showed some low Q resonant amplification during the initial pulse, and the legacy sensor (20kG) showed extremely high Q response after the fixture broke away from the bar. The quartz output shifted (cable noise?)

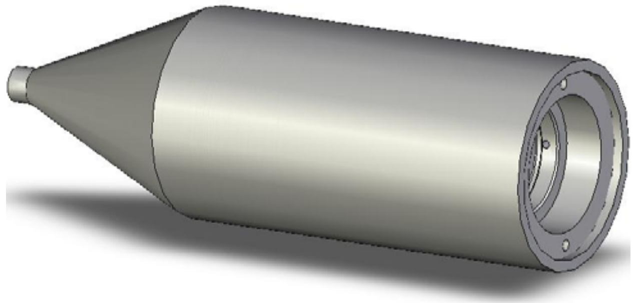
Test Results – Hopkinson Bar



Wideband data shows ~40kG amplitude was still below stop levels of the new sensor.

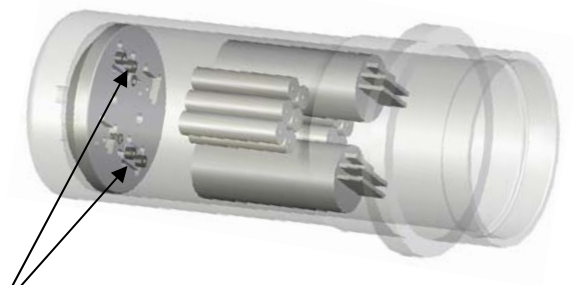
High Q response of legacy sensor (60kG) is visible throughout the pulse.

Test Results – Penetration



STUBBI penetrator

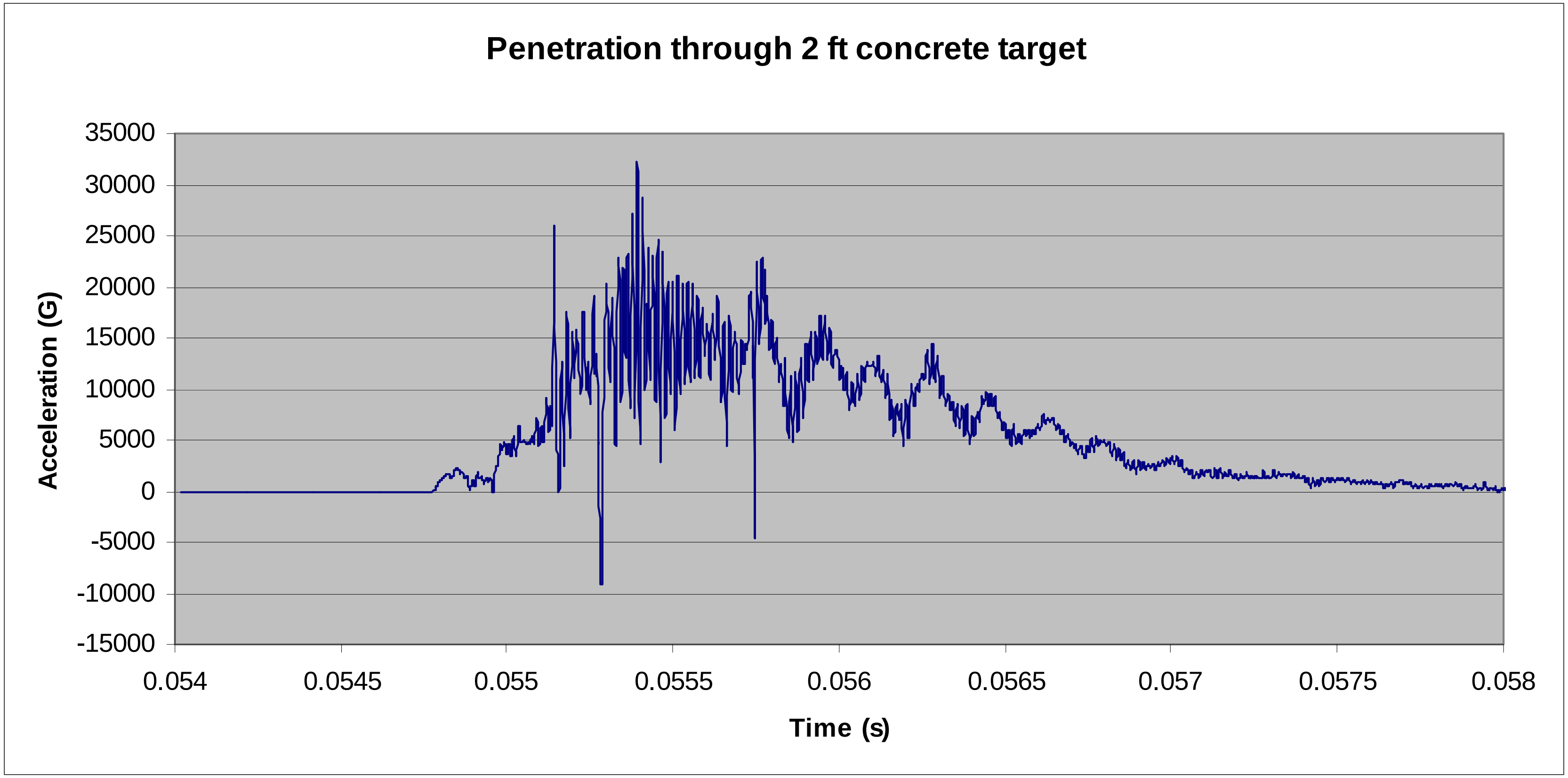
instrumentation
canister



Two sensors mounted in instrumentation canister, along with batteries and recorders set to 1MHz sample rate and 125kHz filter.
Fired from gun at 850 ft/s

Credit: J. Foley and A. Beliveau of Eglin AFB AFRL

Test Results – Penetration



The new sensor's ~65kHz resonance damped quickly to show rigid body deceleration of ~750 ft/s ΔV of impact and structural modes of the ~100 pound STUBBI penetrator and instrumentation canister. A wire failure prevented the recording of data on accompanying legacy sensor.

Test Results – Penetration

3” diameter 30 lb penetrator fired at 1440 ft/s into unreinforced unconfined 6000 psi concrete. Two back-to-back recorder/triax sensor canisters, with 6 channels at 75kHz sample rate and 10kHz filters.

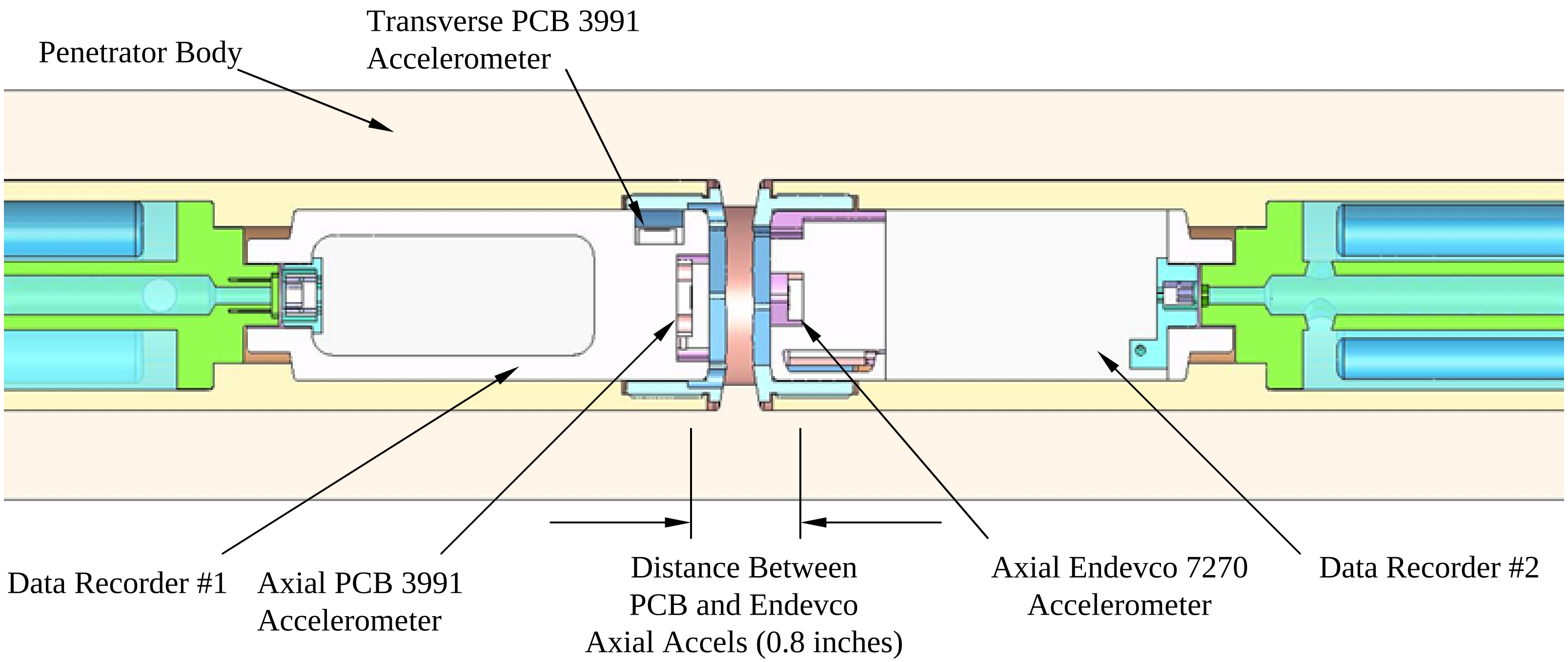
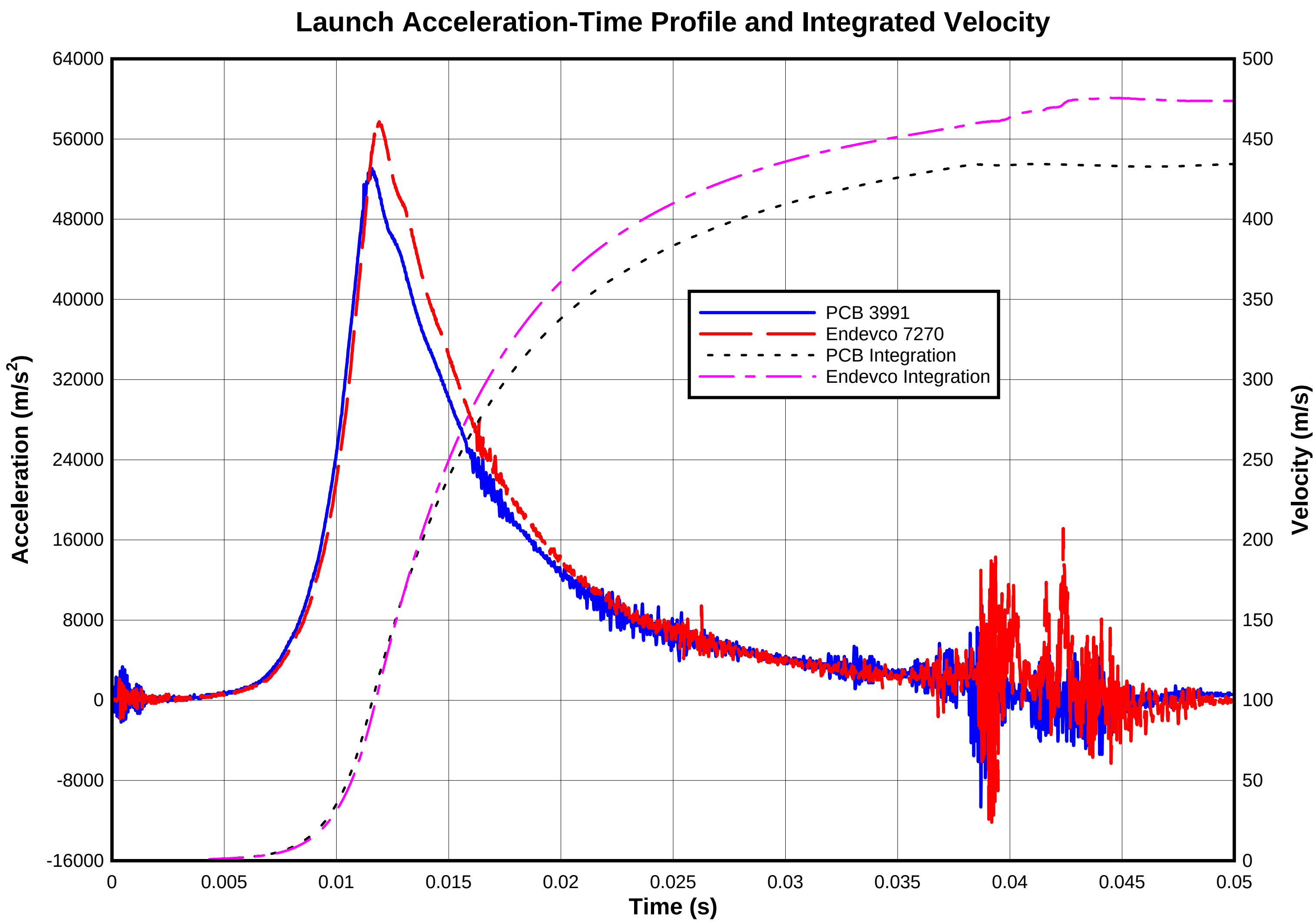


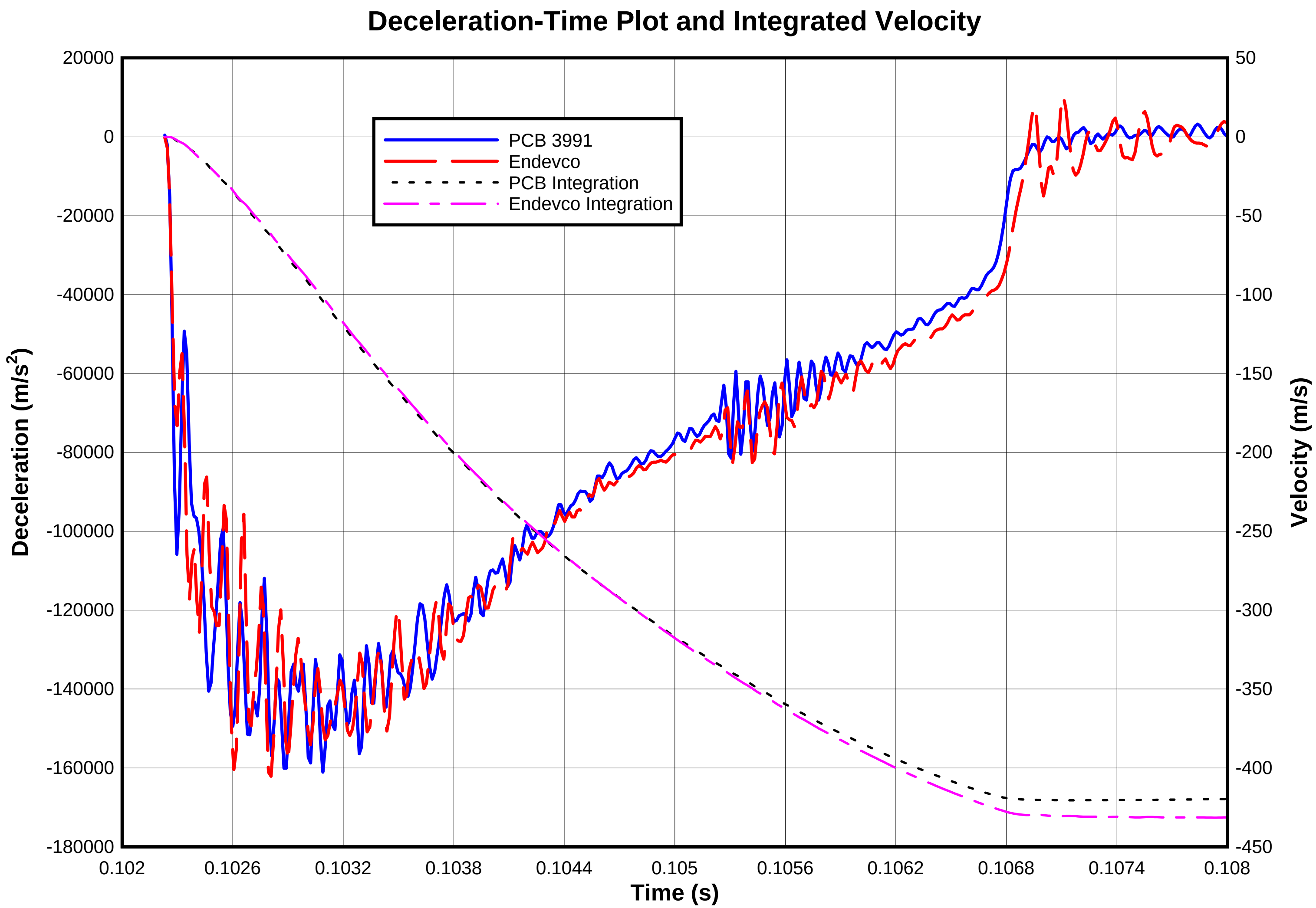
Illustration credit: D. Frew, Sandia National Laboratory

Test Results – Penetration



Credit: R. Hastie, DTRA, Vicksburg MS

Test Results – Penetration



Credit: R. Hastie, DTRA, Vicksburg MS

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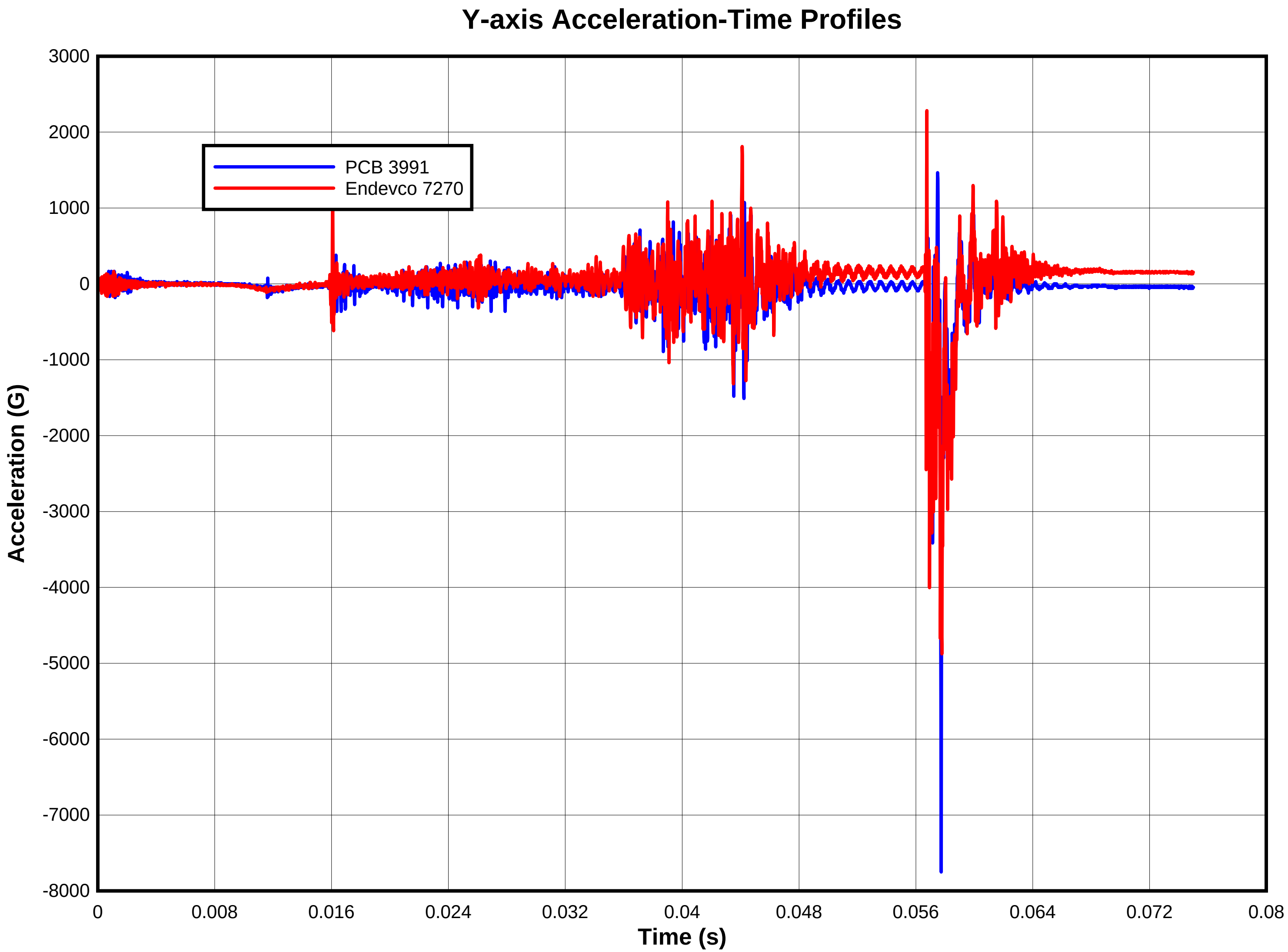
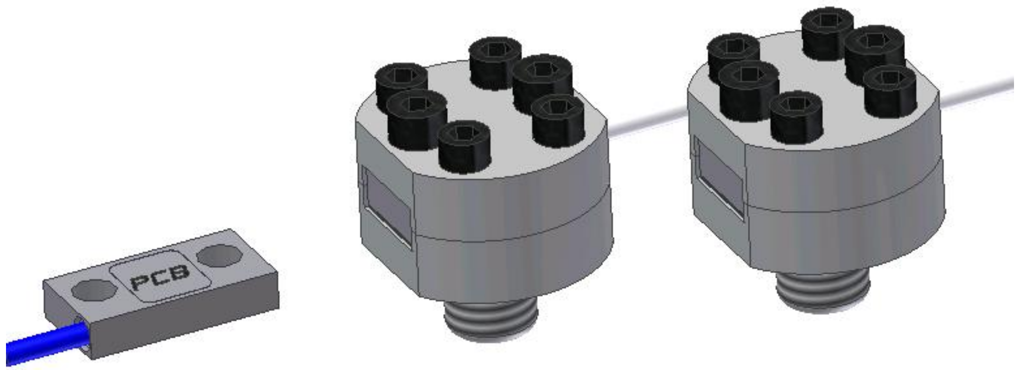
Test Results – Penetration



Credit: R. Hastie, DTRA, Vicksburg MS

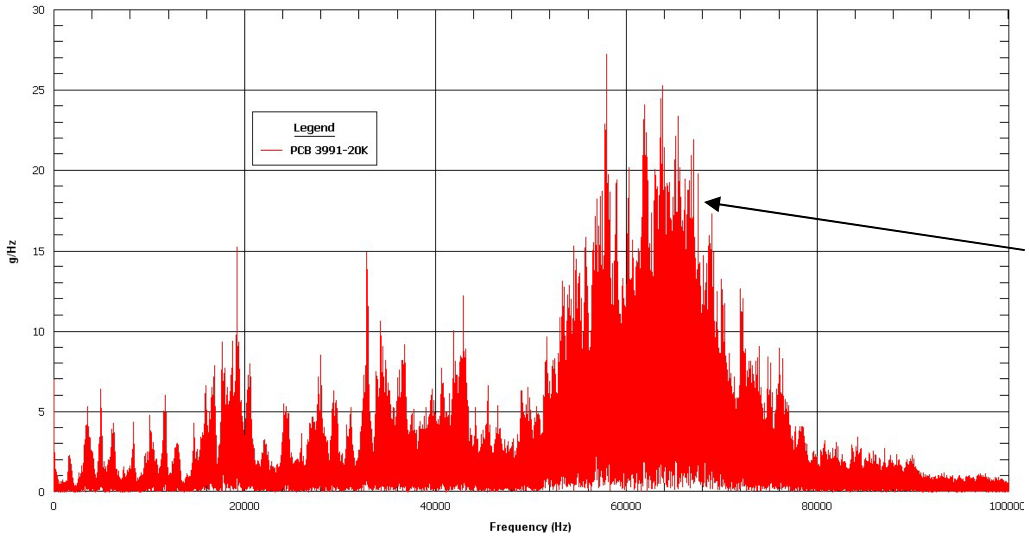
Test Results – Metal-to-Metal Hammer



New sensor was mounted alongside mechanically-filtered legacy sensors (one each of 20kG and 60kG versions). All registered ~10kG peaks from pneumatic hammer blows in direction of sensitive axes. Data sample rate was 5MHz with 2.5MHz anti-alias filter.

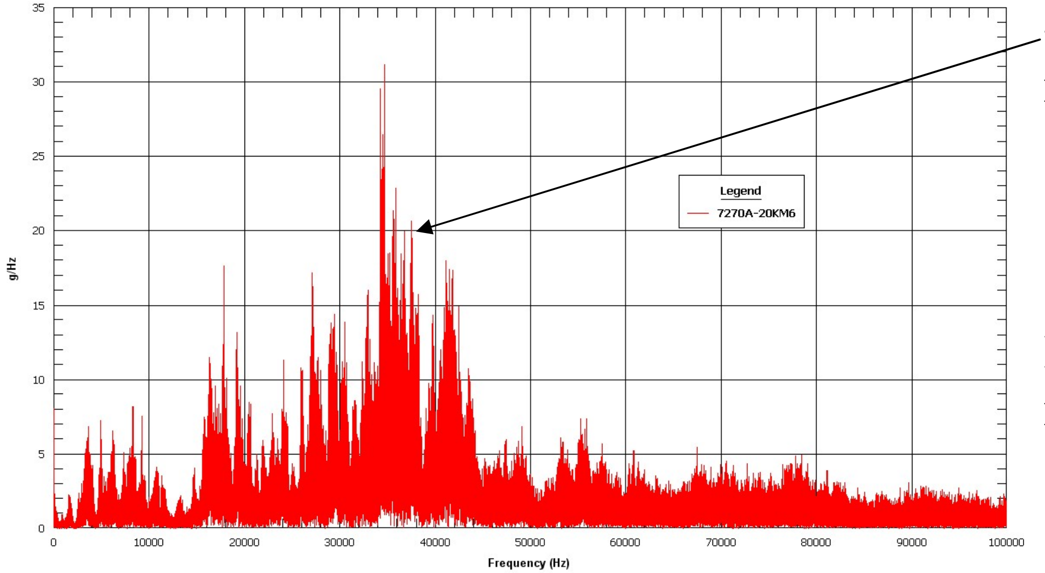
Mechanically-filtered package was designed to prevent failure due to Over Range from resonant amplification of high Q legacy sensor during explosive events and metal-to-metal impacts.

Test Results – Metal-to-Metal Hammer



FFT to 100kHz

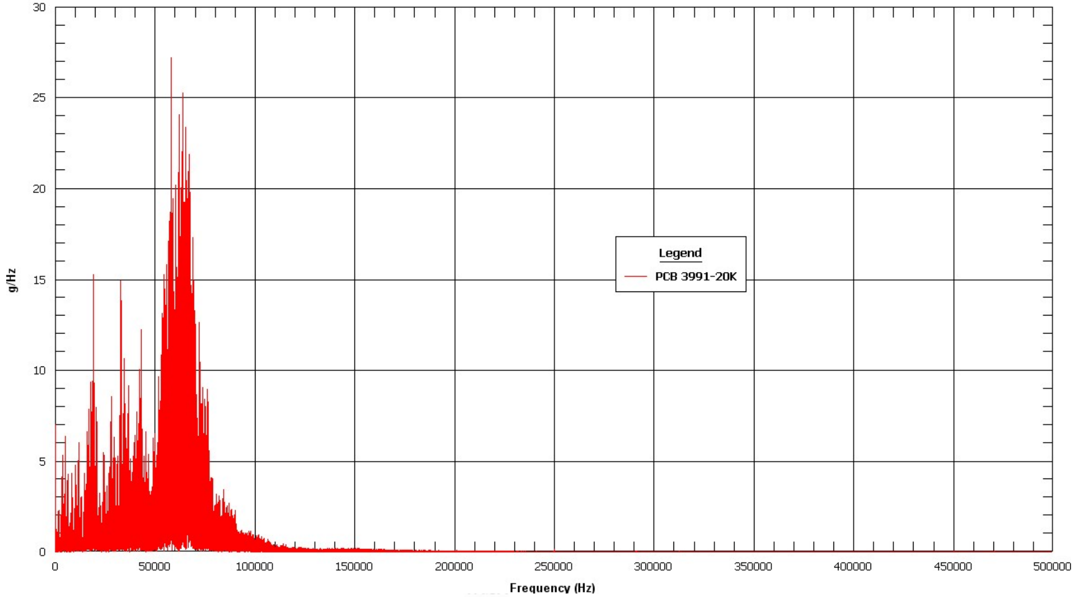
~65kHz low Q resonance of new sensor



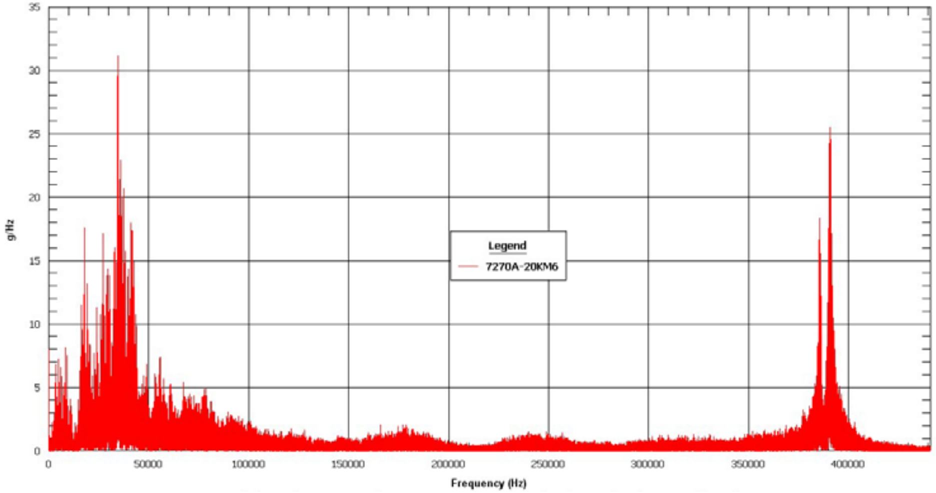
~30-40kHz low Q resonance in the housing of the mechanical filter

Data below ~25kHz matches fairly well

Test Results – Metal-to-Metal Hammer



This is the same FFT results as in previous slide, but a wider view (to ~500kHz) shows that the new sensor's low resonance and squeeze film damping effectively filtered higher frequency components…

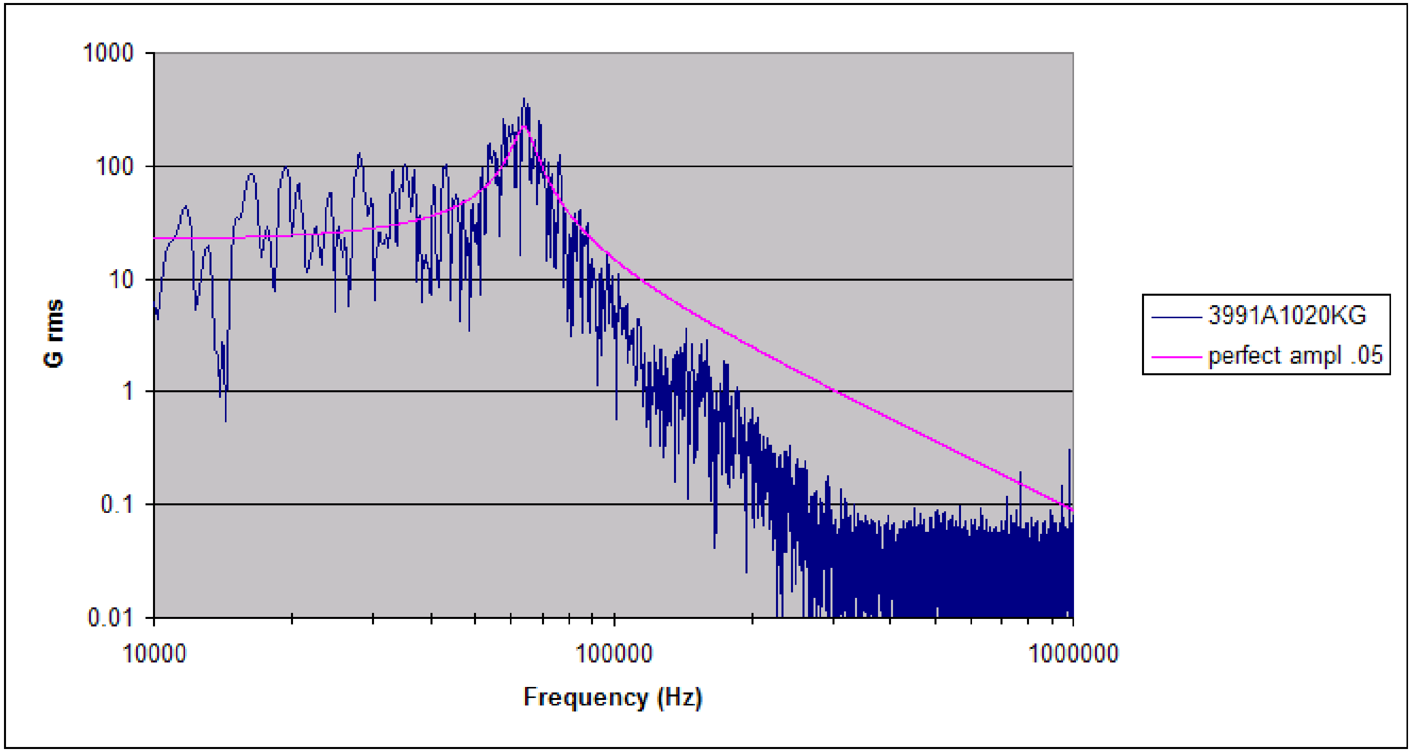


…whereas the high Q 380kHz resonance of the 20kG legacy sensor comes through despite mechanical isolation

Test Results – Damping

Shaker tests indicate the sensitivity frequency response matches a single DOF system with 65kHz resonance and 0.05 damping. Overlaying a perfect sensitivity curve on the hammer test FFT shows the damping may be more effective than expected at frequencies higher than the primary resonance.

Associated with the damping was a phase delay of ~4 microseconds.



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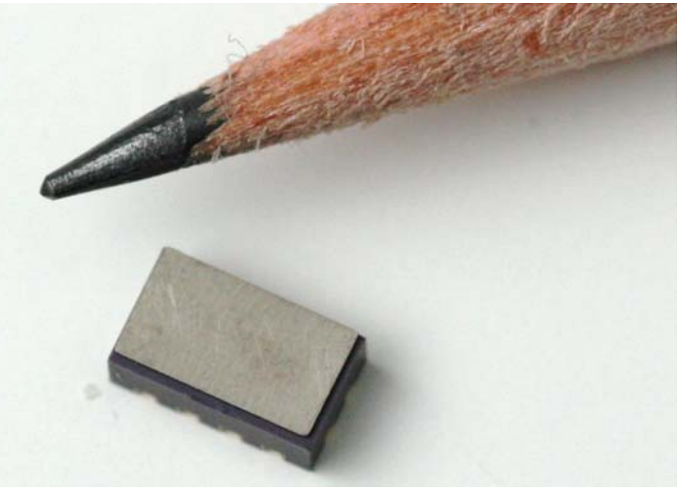
Test Results – Metal-to-Metal

A test at another facility was recently conducted using an alternate package: ceramic surface mount Leadless Chip Carrier. Powered operation and survival of both the new sensor and the legacy sensor was reported in side-by-side tests on a “VHG” shock machine. The level was “as hard as we could go”: ~90kG.

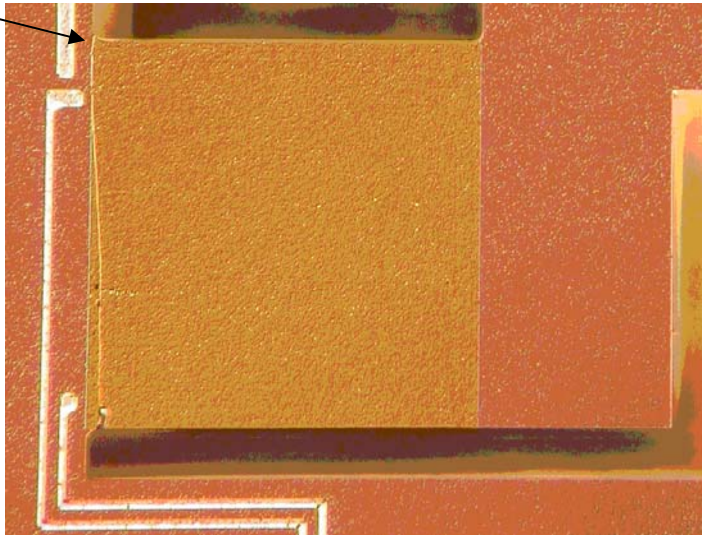
Also tested was warmup drift over 10 minutes
@ 5V excitation, epoxied to circuit board
New sensor: ~8 Gs equivalent
Legacy sensor: ~33-46 G equivalent



Failure Analyses / Improvements

•**ESD**: Failures occurred during extremely low humidity conditions. In normal handling, ESD had not been a problem. The reason was found. Additional ESD protection has been built in to the next batch of sensors, but until then modest ESD precautions are advised.

•**Stress fracture**: a 20kG device failed at >10 times Over Range on the Hopkinson bar, despite the presence of 40kG stops. Only one of 4 cantilevers cracked, indicating a low-probability local condition rather than general failure. Internal stress concentrators have been identified and minimized on the next design revision.



•Until the new units are available, stops will be set to ~30000G to avoid failure in extreme Over Range. Each of the devices currently shipping is fully tested at Over Range to 3 times Full Scale.

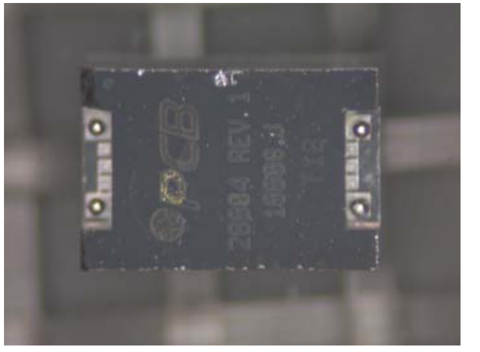
Higher Range Sensor

Although the 20kG sensor has been shown to handle most applications described, future applications may need unrestricted travel to above 30kG. With a simple modification, the sensor family will soon include a 60kG version.

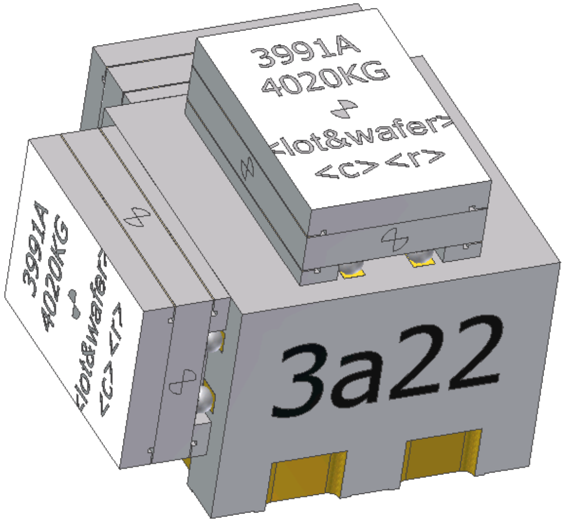
- Sensor footprint is identical, so it will fit in all packages
- Same 200mV output (10V excitation) at 60kG Full Scale
- Mechanical stops at ~100kG
- Resonance frequency ~100kHz
- Frequency response 5% to ~20kHz
- Smaller phase delay
- Q will be slightly higher than the 20kG version (~30), but still significantly smaller than all versions of the legacy sensor (~1000)

Other Packaging Alternatives

- Flip chip proof-of-concept prototype is shown here with solder bumps (prior to application of solder balls). With this slight modification, the sensor could be directly mounted to a circuit board.

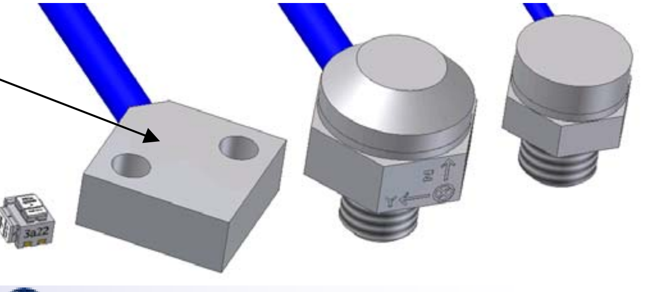


- Surface mount triaxial block for flip chip sensors, with internal pad connections, would enable significant miniaturization.



- The surface mount triax would allow a package small enough to use the same mounting hole pattern as the legacy single axis package.

- ¼-28 stud packages for extreme environments could hold single or triaxial versions. (Controlling cable and/or triax orientation would be a challenge…)



Conclusions

The new sensor allows miniaturized simplified mounting

- Squeeze film damping eliminates need for mechanical filtering
- Surface mount / flip chip options put the sensor on circuit board

Resolution is improved, less headroom needed

- Gain of conditioning and data acquisition can be scaled to measurement rather than the Q of the undamped legacy sensor
- 20kG new sensor can often be used in place of the 60kG range of the legacy sensor. (Future 60kG new sensor will allow measurement to 100kG, in the rare instances that is necessary.)

Data acquisition can be simpler

- Sample rate and electrical filter requirements to avoid aliasing of new sensor are much less severe than legacy sensor