Implementing In-House Piggy-Back Shock Accelerometer Calibration

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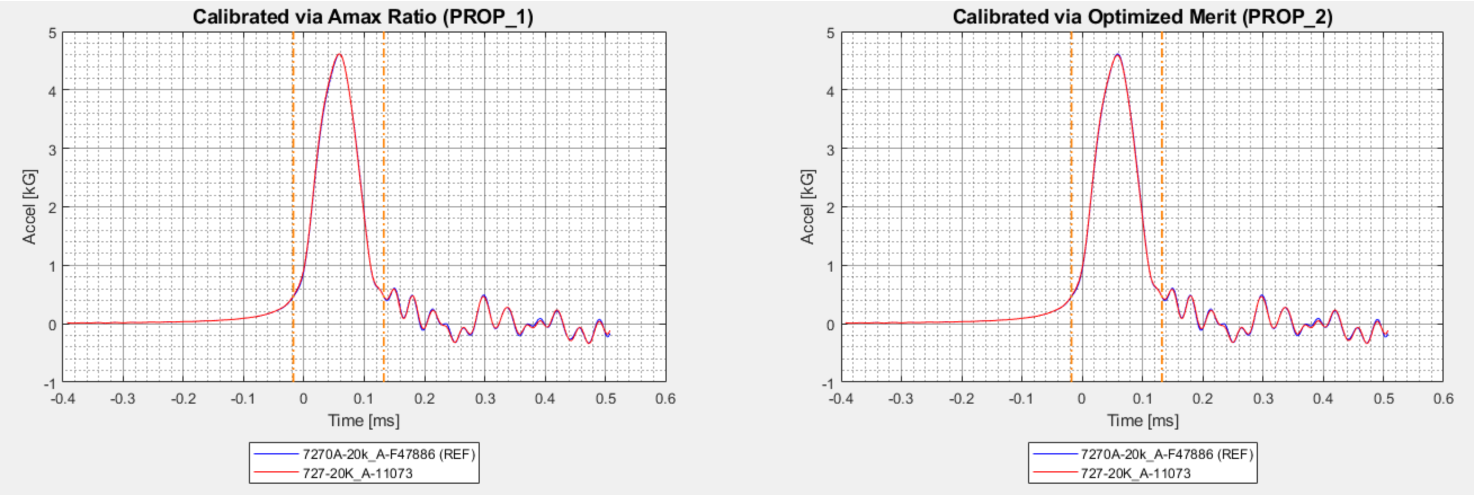


Overview

- Need for in-house shock accelerometer calibration
- Importance of broadband signal fidelity and data system accuracy / traceability
- Identifying accelerometer resonance and applying appropriate lowpass filtering
- Suggested piggy-back calibration approach
- Picking a “golden” reference accel to avoid bias
- Proposed piggy-back calibration technique with multiple shocks and multiple amplitudes
- Conclusions

Need for In-House Shock Accelerometer Calibration

- Shock measurements, especially severe shock, are difficult measurements to make accurately.
  - Such measurements are:
    - often made on very expensive test articles.
    - often time consuming and expensive tests to perform.
  - Bottom line, we want to get the measurements right!
- Typical calibration period of shock accelerometers is once/year.
- Reasons to desire “sanity check” calibration of shock accelerometer during the 1-year period:
  - Unexpected or strange shock results measured in a test.
  - Damage to an integral cable of a shock accelerometer.
  - New accelerometer, you want to double-check it’s claimed performance and sensitivity factor.
- Sending shock accelerometers to outside lab to “sanity check” is time consuming and expensive.
- In-house “sanity check” calibration is very quick and can sometimes be viewed as “free”.
  - ***If it helps you avoid making a misleading measurement, you actually save a lot of $$$.***

Importance of Broadband Signal Fidelity and Data System Accuracy

- Severe shock, including pyro-shock, can easily have significant energy content above 100*kHz.

- When calibrating an accelerometer for severe shock, you want to accurately measure the shock “pulse”.
  - The output of the accelerometers in the calibration test will consist of:
    measured signal **=** **actual environment** + **sensor distortion**.
    - For high-frequency shocks, sensor resonance can be a significant distortion.
  - It is important to measure the accelerometer’s resonance so that you can properly filter the data for BOTH calibration and general accelerometer use.
  - Some of the toughest high-G, high-frequency accelerometers have mounted resonance in the range of 200*kHz to 1.2*MHz, or slightly higher.
  - It is important that the entire measurement system (amplifiers and data sampling) has a flat passband with sufficient bandwidth (also no slew-rate limiting within the desired bandwidth).

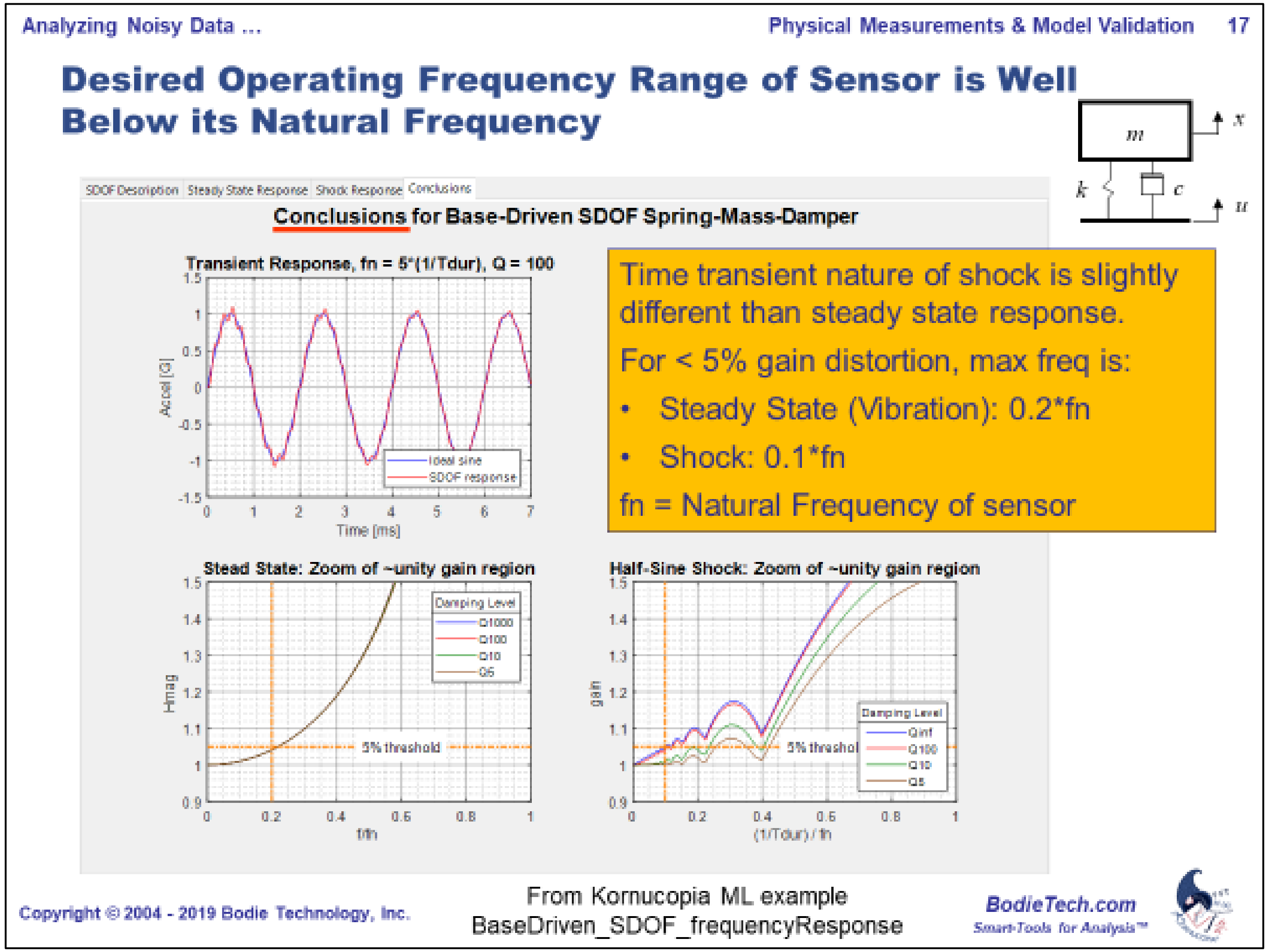
- The ***Spectral Dynamics VIDAS®*** system is capable of accurately capturing severe shock data. It is a 5MSa/s/ch, 16-bit, high-speed broadband DAS (Data Acquisition System).

Importance of Identifying Accelerometer Resonance and Applying Proper Lowpass Filtering

- Many, but not all, severe shock accelerometers are undamped MEMS devices with very high Q values (100 or greater, barely any damping!).

- Often stated rule of thumb from **steady-state vibrations** is that you filter the measured signal at **1/5** or lower than resonance of sensor to avoid sensor distortion from resonance.
  - For **pulse-like shocks**, the criterion is tighter, **1/10**.

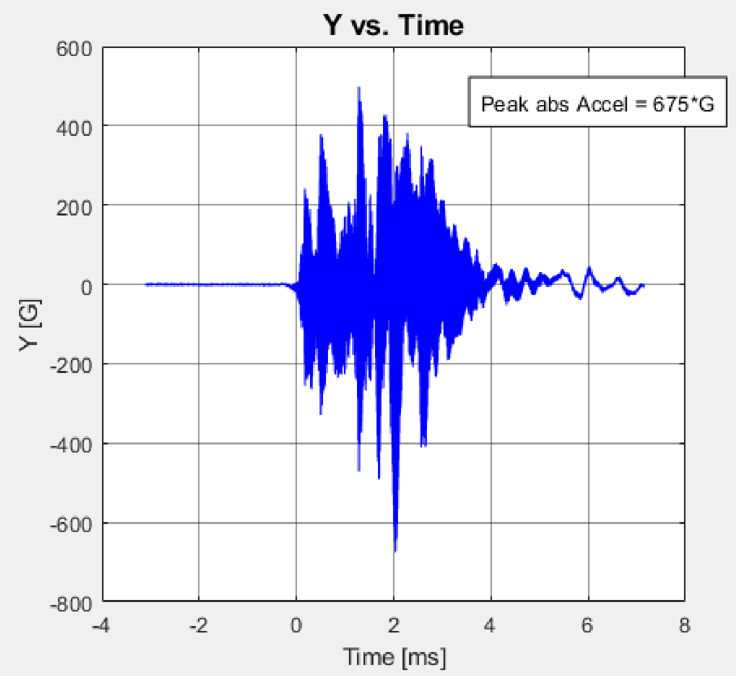
- If you want to push your measurements to their limits, you must know the sensor's mounted resonance!



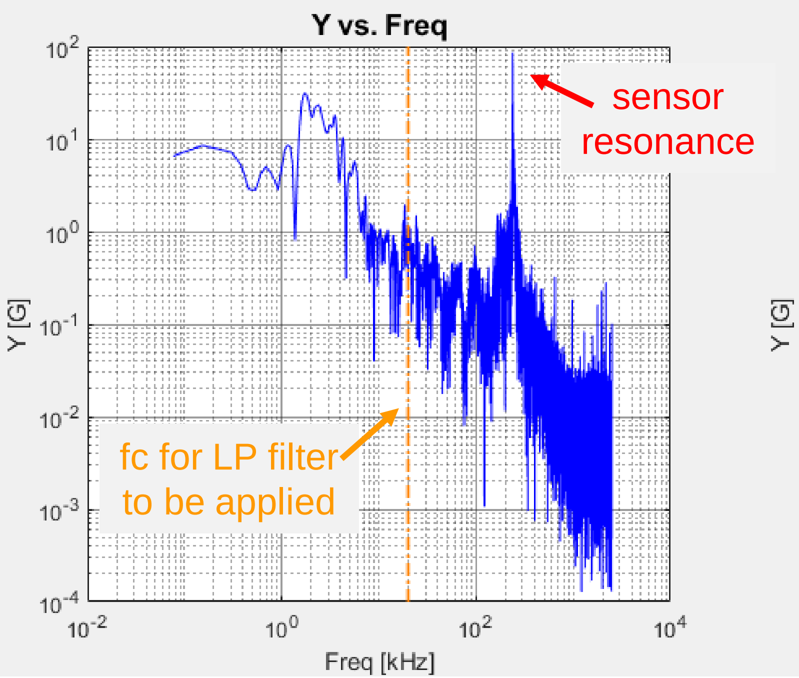
What is the True Acceleration Signal?

- The raw data would claim a very noisy signal with peak absolute acceleration of **675*G**.
- DFS (Discrete Fourier Series) analysis shows resonance of sensor dominating response!
- LP filtering at 0.1 times sensor resonance shows what the sensor is capable to accurately measure (peak abs Accel = **219*G**).

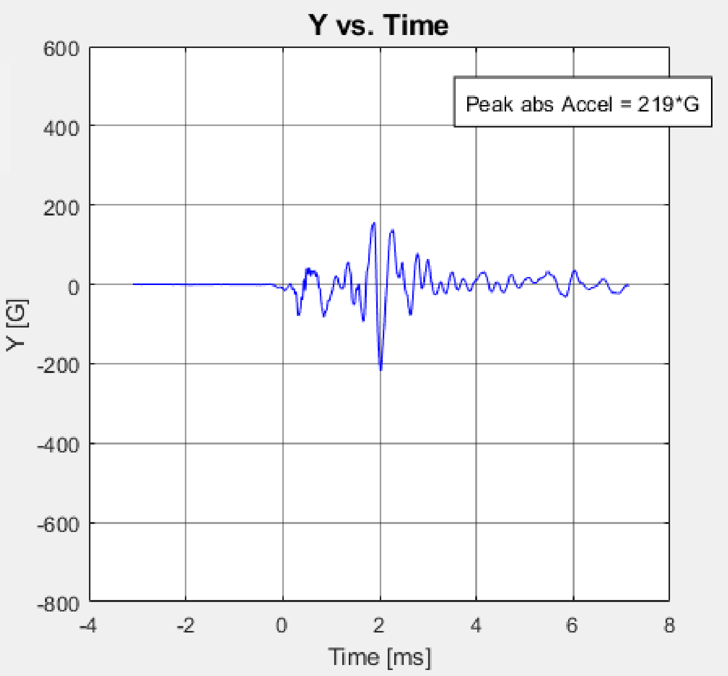
Raw output, fs = 5*MHz



DFS of raw output



LP filtered output
fc = 0.1*fn_sensor



Shock Accelerometer Calibration

- Typical shock accelerometer calibrations are performed using a device that can deliver a sharp and severe shock pulse to the accelerometer.
  - Along with specialized equipment, a shock table is a viable candidate for generating this pulse in many cases.

- There are a few methods to measure the acceleration imposed on the Accelerometer Under Test (AUT). Common reference acceleration measurement methods include:
  - Laser vibrometer.
  - Piggy-back mounting of AUT “in-line” with a reference accelerometer (REF).
    - It is NOT recommended to mount the AUT next to the REF as there is often noticeable difference in the shock input to the two devices.

- For Piggy-back mounting you can:
  - Use a *special shock calibration accelerometer* that has an in-line stud mount to allow AUT mounting.

  OR

  - Use a stiff block and mount the reference accel (REF) on one side, and the AUT on the opposite side, directly in-line with the REF and the imposed shock-pulse direction.

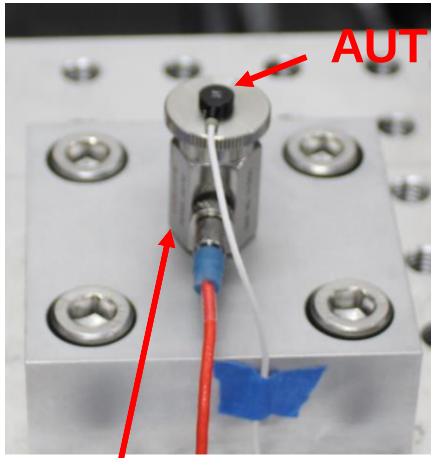
Suggested Piggy-Back Calibration Approach

- For both examples, the AUT is an Endevco 727 adhesive mount shock accel.

1. **Disc-on-Stud**
   - REF is sold as a primary comparison calibration accel, NIST traceable.
   - Charge-based PE accel.
   - Difficult to precisely mount accel to disc, resulting in mount offsets and signal distortion (see next slide).

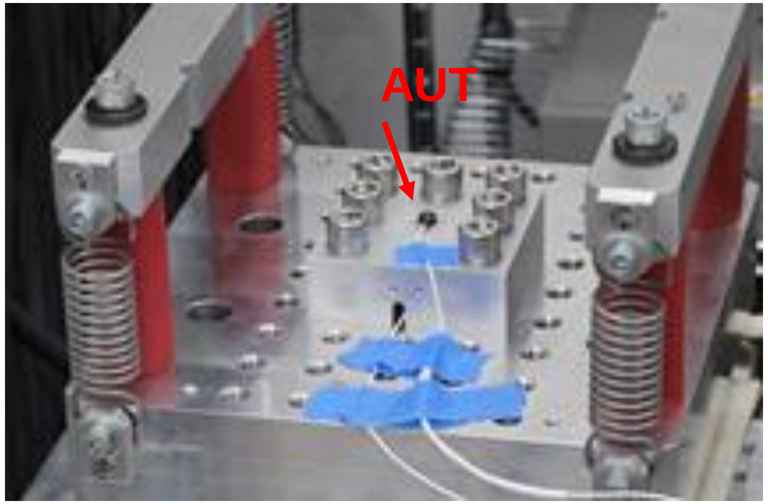
2. **Piggy-Back Block** ✓
   - Flexible choice of REF and AUT accels.
   - Validated with reciprocity checks.
   - More repeatable in-line shock response compared to disc-on-stud for 2270.
     - Fairly good 1st mode 43*kHz. Does not cause issues with in-line response between both accels.

Disc-on-Stud

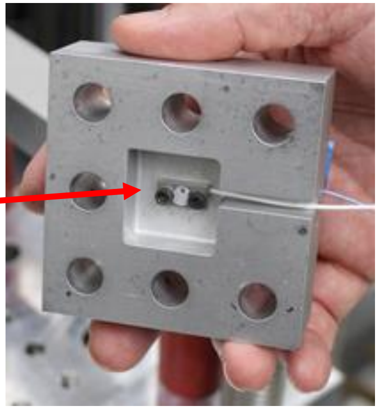


REF
Endevco
2270

Piggy-Back Block

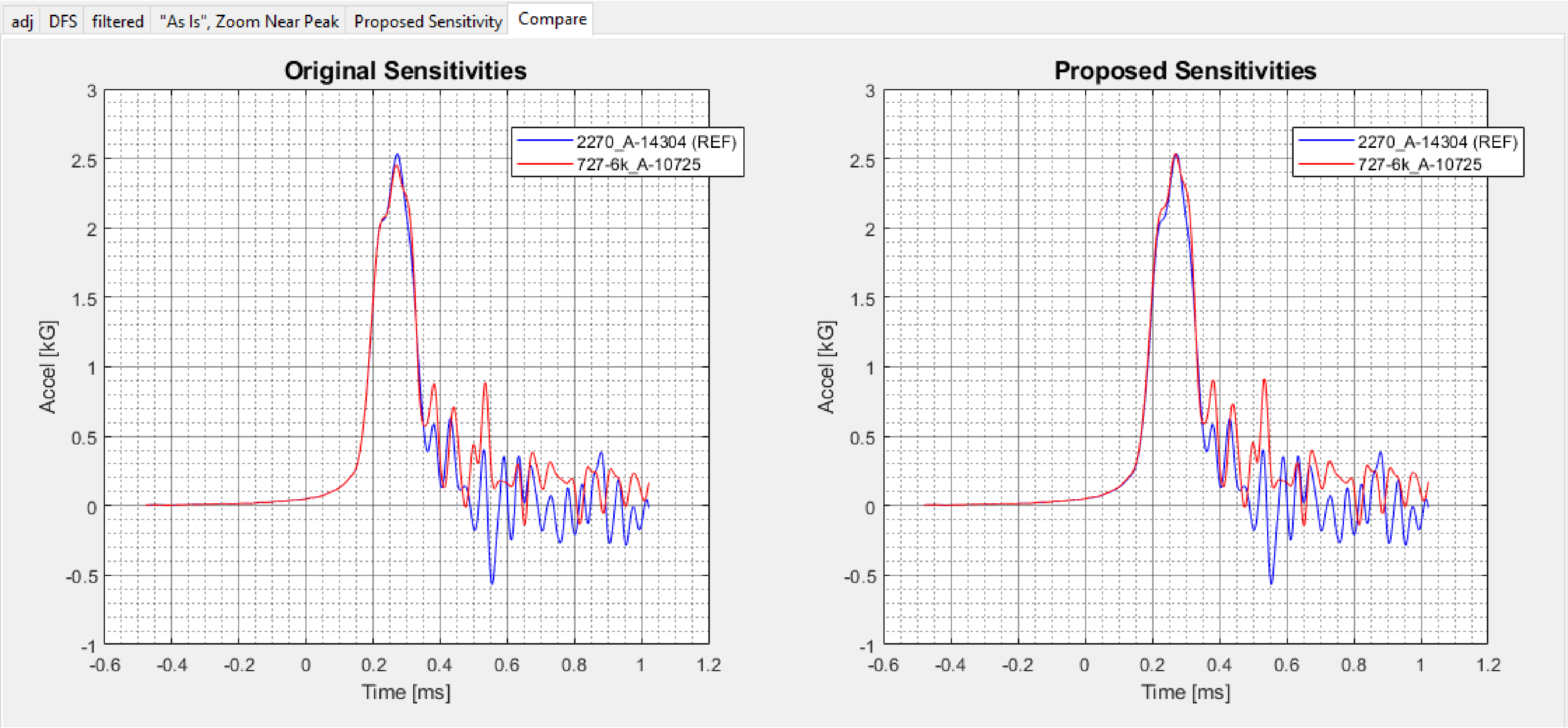


REF
Endevco
7270A



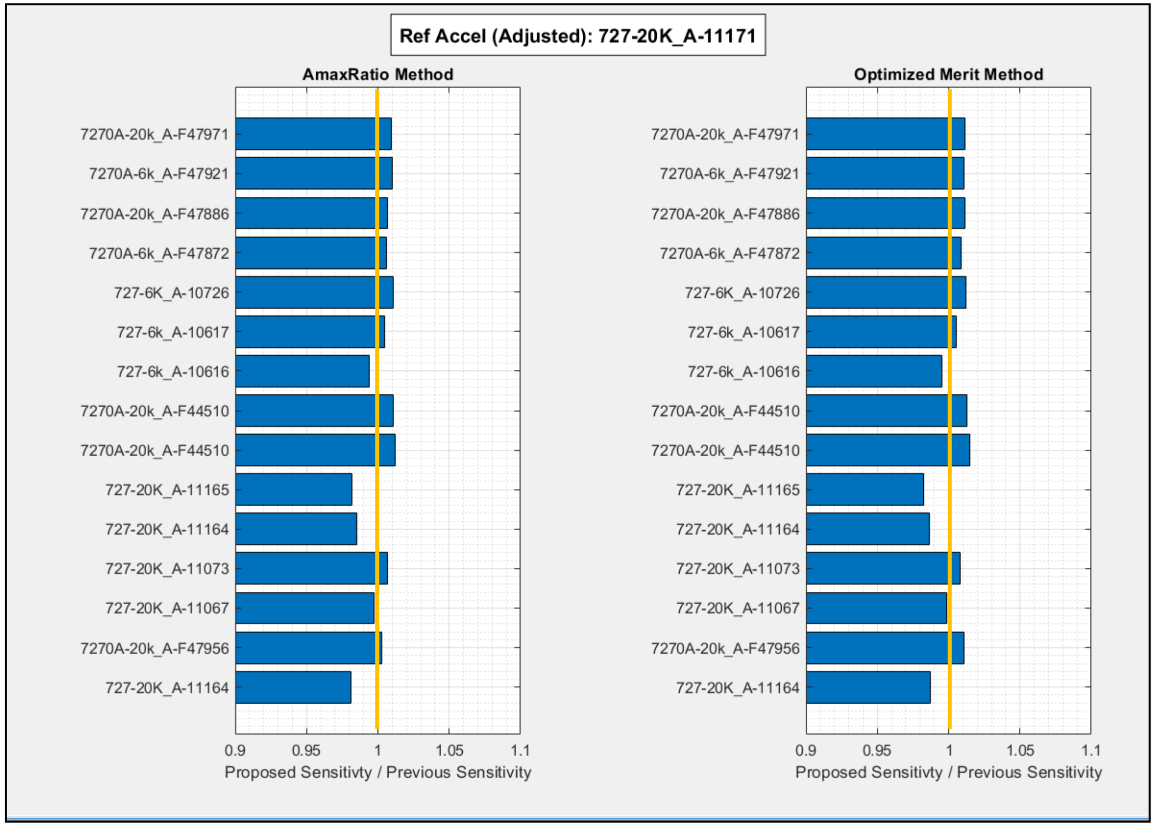
Difficulties of *Disc-On-Stud* Piggy-Back Calibration Set-up

- The 2 plots show a piggy-back calibration test with original AUT sensitivity and after proposed AUT sensitivity. The curves have very noticeable differences caused by the fact that the 2 accels (REF and AUT) did not experience the same shock exactly due to small misalignment of AUT on disc causing moments and other content.



Picking a "Golden" Reference Accel to Avoid Bias

- Consider the case of purchasing 15 new shock accelerometers from one or more vendors.
  - Each accelerometer has a unique sensitivity factor computed by NIST traceable calibration at the vendor's factory.
- To the right is a Piggy-Back-Block assessment of the 15 accels to a single common REF accel.
  - If everything was perfect, all the blue bars would be at 1 (normalized sensitivity).
  - The total variation is +/- 2%.
- When picking a "Golden" REF accel, it is best to select one that is in the middle (if you have a large group).
  - Use this "Golden" Accel only for your internal calibration efforts. Send back to vendor or other calibration lab once/year.

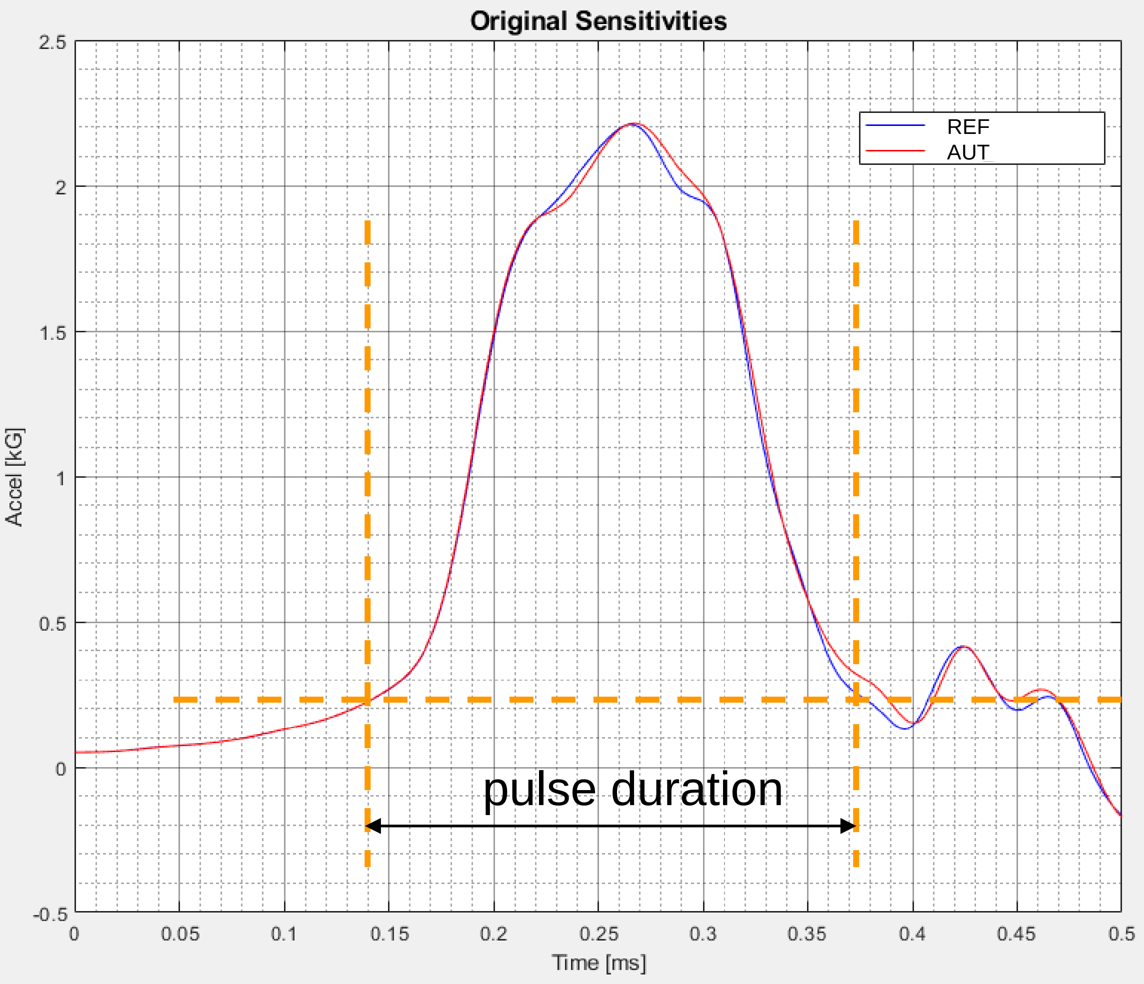


Proposed Piggy-Back Calibration Protocol

- Use Piggy-Back Block mounting on a shock table. For higher G shocks, use DMSA (Dual Mass Shock Amplifier) if needed. Other approaches include Hopkins bar or dedicated pulse generation devices.
- Apply multiple levels of shock, typically 3 or 4, with half-sine or haversine pulse shape. Use 3 replicates per level.
  - Typical range of shock levels: [500*G, 1.0*ms] to [5,000*G, 0.14*ms], or higher.
- Collect data with appropriate wide bandwidth DAS.
- For each shock event perform the following on both the REF and AUT:
  - Remove DC offset using mean of pre-trigger data.
  - Compute DFS (Discrete Fourier Series) or other Fourier Spectra to clearly identify sensor natural frequency.
  - Apply appropriate bi-directional LP filter. By default, use fc = 0.1*fn_sensor (determined from DFS above).
  - Isolate initial impact pulse region & then compute pulse duration.
  - Compute Sensitivity via two approaches:
    1. **Amax Ratio** method
    2. **Optimized Merit** method
- After all shock levels are analyzed, summarize to yield “best” sensitivity value for sensor.

Sensitivity Calculation Approaches for Non-Ideal Data

- Consider the two accel signals (REF & AUT).
- The data shows that there is some extra frequency content in the REF that is not quite the same as the AUT.
- Classical method of sensitivity determination is to scale AUT until AUTmax equals REFmax.
- Perhaps a better algorithm is to compute a *measure of merit* between the 2 curves within the pulse duration bounds.
    - Includes all the points, not just the peak.
    - Possible merits are Rsq, NRMSE, …
        - NRMSE = Normalized Root Mean Square Error.
    - Scale the AUT to optimize the merit.

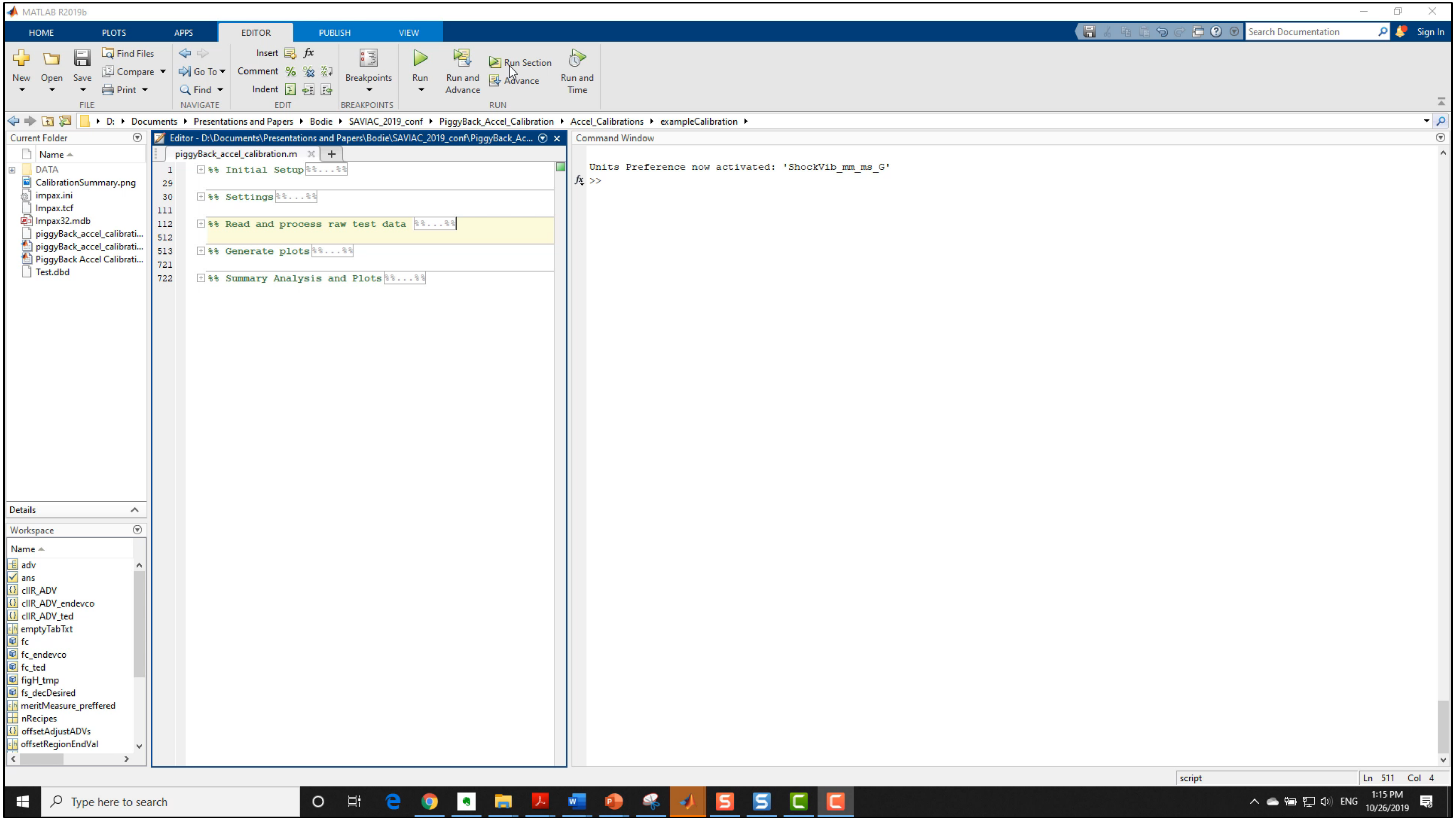


Automating Calibration Calculations and Documenting Results

- For a calibration procedure to be useful it must be automated, easy to use, and self documenting. The calibration results should also be retrievable in the future (if needed).

- The following example was created using ***Kornucopia® ML™***, for use with MATLAB®.
  - Key features
    - Script is simple to use, and fully customizable.
    - Kornucopia imports the data directly from the IMPAX SD hybrid data files, including all the meta information stored on these files.
    - Kornucopia handles all units-related calculations.
    - The results are stored and presented in a *Kornucopia Results Notebook* via a tabbed MATLAB figure.
      - You can easily look at all the events and their various plots.
      - Any data can easily be retrieved from the figure at a future date.
    - The script creates a single-page PNG image summarizing the calibration results. This PNG is then printed and place with the accelerometer.

Example Video of Calibration Session



Example: Final Calibration Summary

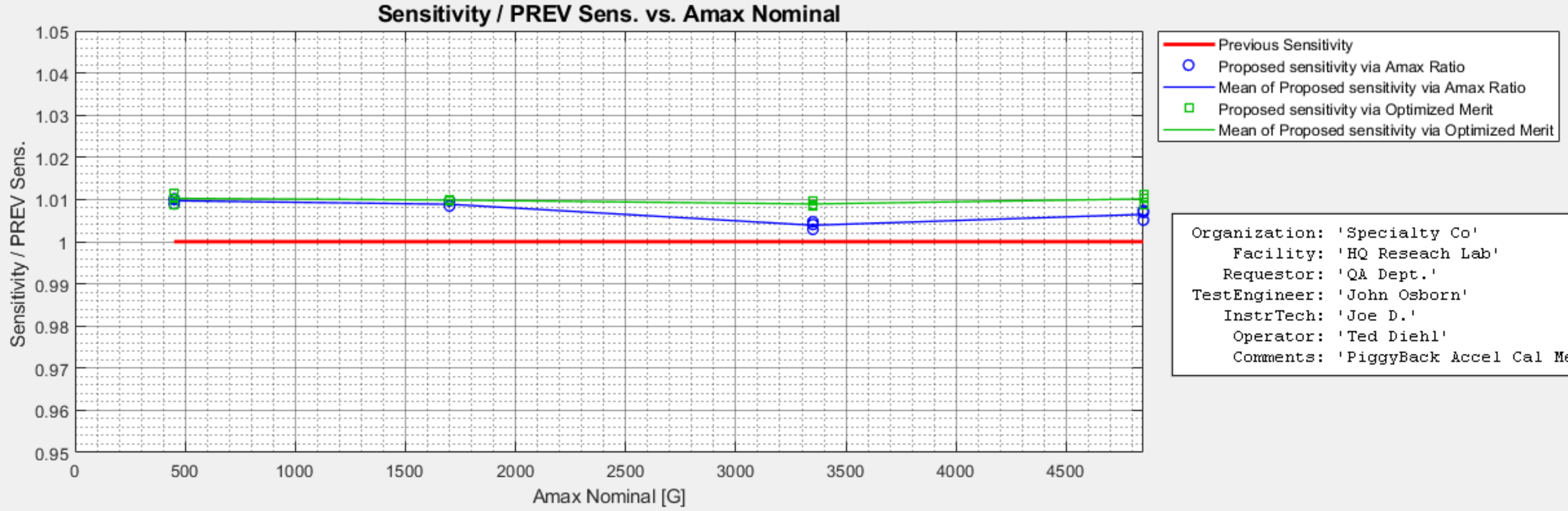
Summary of Sensitivity values vs nominal shock severity

Summary of final choices for Sensitivity

Final Calibration Sensitivity

Pics | Event 1 | Event 2 | Event 3 | Event 4 | Event 5 | Event 6 | Event 7 | Event 8 | Event 9 | Event 10 | Event 11 | Event 12 | Calibration Summary (All Events)

D:\Documents\Presentations and Papers\Bodie\SAVIAC_2019_conf\PiggyBack_Accel_Calibration\Accel_Calibrations\exampleCalibration




```
Organization: 'Specialty Co'
    Facility: 'HQ Reseach Lab'
   Requestor: 'QA Dept.'
TestEngineer: 'John Osborn'
   InstrTech: 'Joe D.'
    Operator: 'Ted Diehl'
    Comments: 'PiggyBack Accel Cal Method'
```

```
Calibration Summary (PROP_1 = Cal via Amax Ratio, PROP_2 = Cal via Optimized Merit)
fc=40*kHz, Bi-dir LP Butter Order 6
===================================================================================
                            Sensitivity    Proposed / PREV
                               [V/G]
                            ___________    _______________
727-20K_A-11073 (PREV)      9.22e-06        NaN
727-20K_A-11073 (PROP_1)    9.28e-06       1.01
727-20K_A-11073 (PROP_2)    9.31e-06       1.01
```

```
Calibration Date: 09-May-2019 10:59
REF sensor: 7270A-20k_A-F47886
Sensor being calibrated: 727-20K_A-11073
Calibrated sensitivity via previous cal value.
Sensitvity: 9.215e-06*V/G,  Excitation: 10.0*V
```

Conclusions

- Accelerometers should be calibrated at least once/yr.
- In-house “sanity check” calibration should be done when accelerometers produce unexpected results or have undergone cable repairs. This in-house check is a fast and inexpensive approach to improve confidence in your sensors.
- For severe shock, it is important to be able to accurately measure broadband content, avoid aliasing, and capture the accelerometer data accurately.
  - ***Spectral Dynamics VIDAS®*** is a 5MSa/s/ch 16-bit high-speed broadband DAS demonstrated here.
- If you have a shock table, we propose using a **Piggy-Back Block** technique for in-house calibration checks.
  - This technique was found to be more robust than traditional disc-on-accel piggy-back techniques.
- For accuracy and traceability, it is important to calibrate using multiple shock levels and replicates, and then to have all the data (raw, DFS, filtered, and sensitivity calculations) stored and plotted in an easily accessed and retrievable manner.
  - ***Kornucopia® ML™***, for use with MATLAB® was demonstrated as an efficient tool to perform, present and archive the various transient dynamic data.