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# Calibration of Mark Products L4C and L4-3D Short Period Sensors Utilized at the Nevada National Security Site

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## Abstract

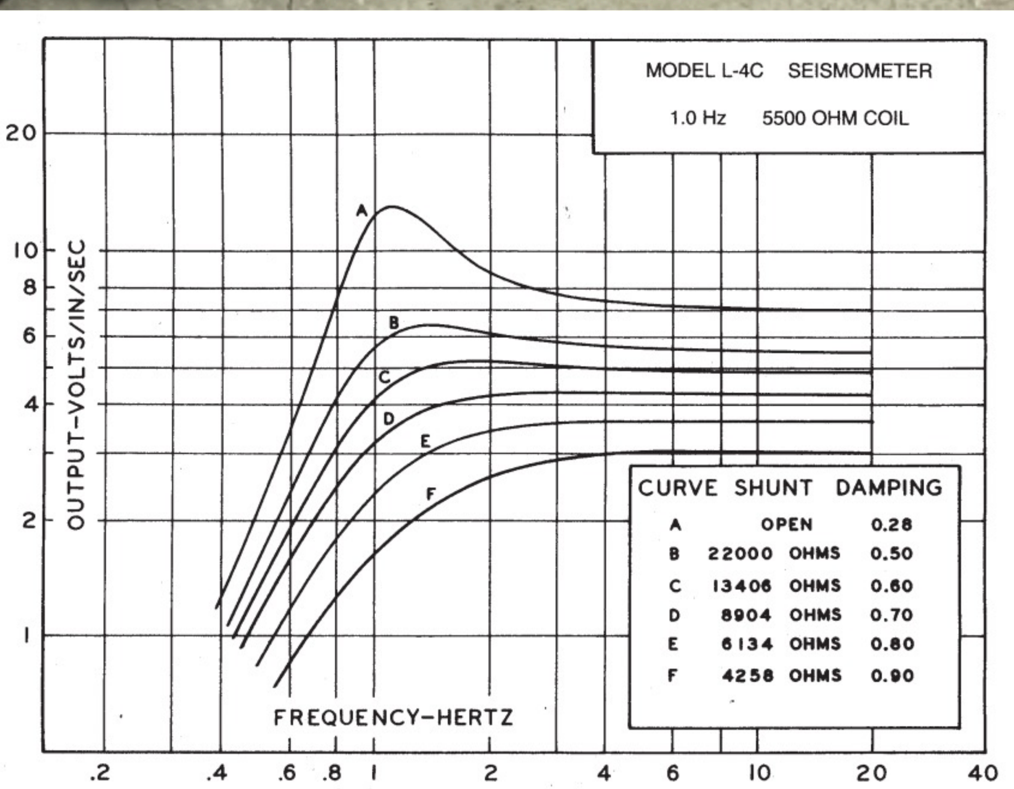
We accepted for calibration 44 vintage Mark Products L4C and L4C-3D, vertical and three-component short-period seismic sensors, which had served on a number of temporary deployments at the Nevada National Security Site (NNSS). Considering the age of these sensors, and their cycling through several temporary deployments and exposure to harsh desert conditions, characterizing their performance prior to their use on future experiments will bring higher confidence in measurements made with these sensors.

Calibration of these sensors took place at the Facility for Acceptance, Calibration and Testing (FACT), operated by Sandia National Laboratories in Albuquerque, New Mexico, USA. FACT consists of hardware testbeds as well as remote field sites that allow us to evaluate both individual geophysical components as well as integrated monitoring systems. The NNSS sensors were calibrated utilizing our Spektra CS-18P Seismic Calibration System, which utilizes a laser vibrometer to provide SI-traceable amplitude and phase response for the sensor under test. Sensors were calibrated with 1% tolerance, 8,888 ohm damping resistors installed to provide a reasonably flat response curve. Calibrations were conducted at discrete frequencies, with 1/3 octave spacing, from 0.5 Hz to 160 Hz. Here we discuss the results of calibrating this group of sensors.


## Seismic Sensors

Two models of Mark Products short-period sensors, 25 L-4C (single component) sensors and 19 L-4C-3D (three component) sensors, were accepted for calibration using the Spektra CS-18P Primary Calibration System.

These sensors (below) have been utilized on multiple field deployments, at the Nevada National Security Site (NNSS), since the 1990s.




The manufacturer-published figure above illustrates nominal amplitude response curves for the sensors.

- We calibrated the sensors with the aim of a critically damped sensor, working on the premise dataloggers leveraged would have sufficiently high impedance as to not affect sensor response.
- In order to achieve a sensitivity curve approximating curve D, an 8,888 ohm shunt resistor was implemented during the calibration.

## System Components

**Laser Isolation Platform**

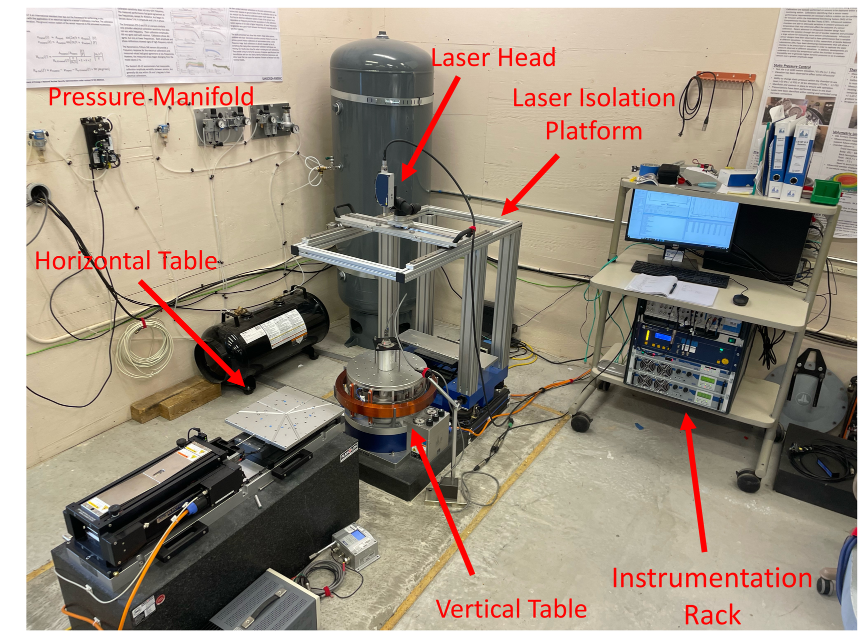
- Attenuates the impact of ground vibrations on the motion measured by the laser. In the photo to the right, the laser head is positioned for vertical calibrations.

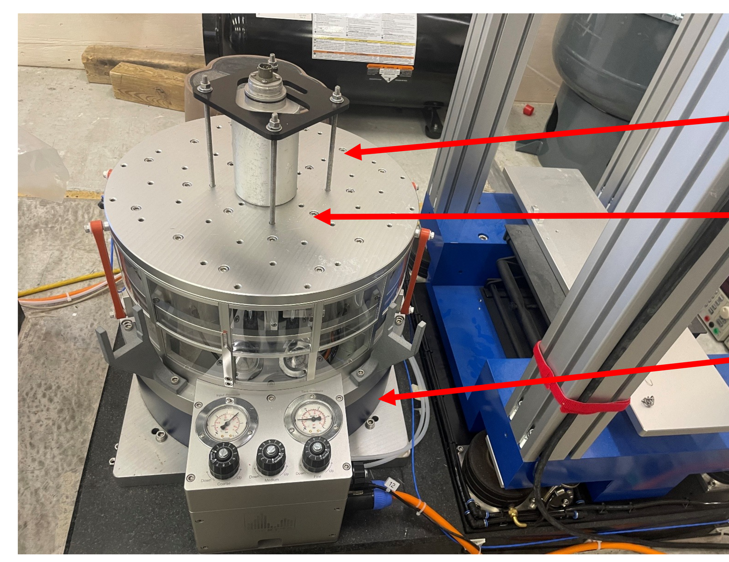
**Instrumentation Rack**

- The rack houses the digitizer, laser vibrometer, vertical and horizontal amplifiers and horizontal table centering system.

**Pressure Manifold**

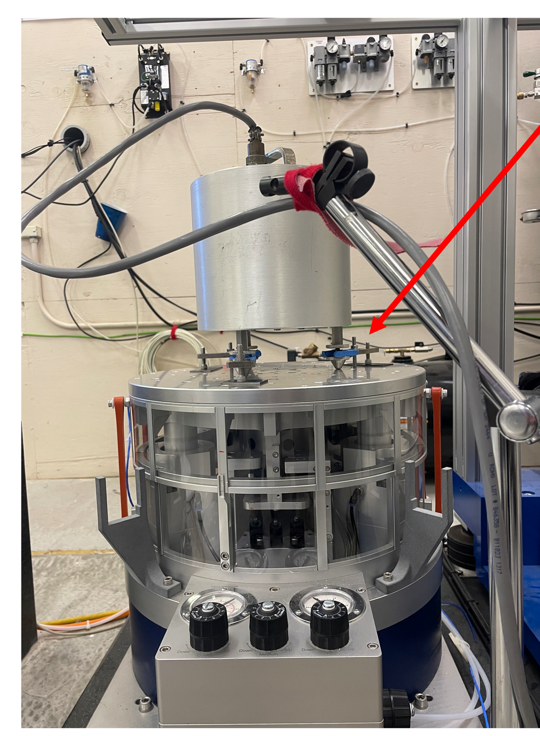
- The air bearings utilized in the shake tables require dry, filtered, compressed air.

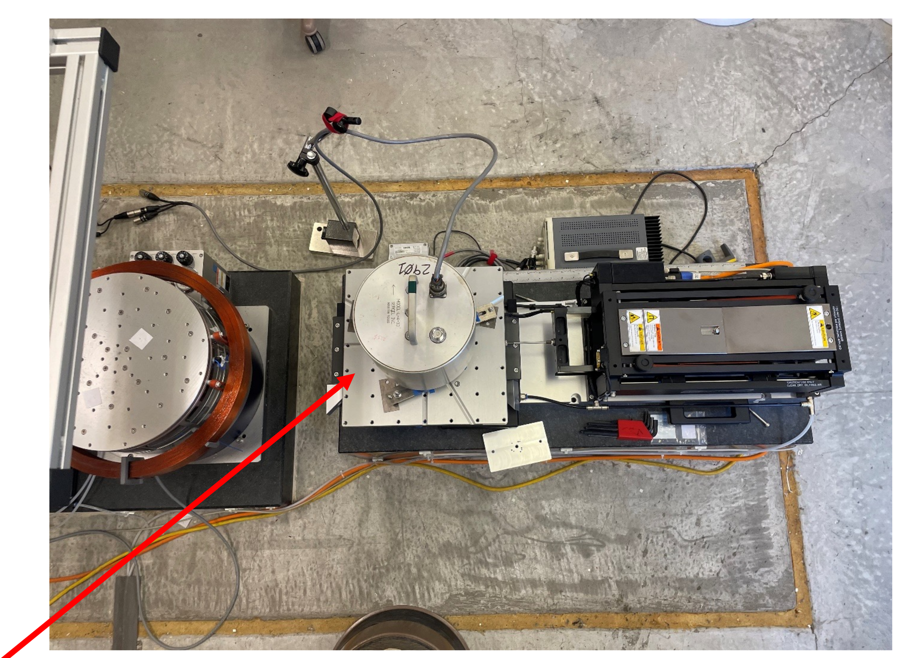


**Vertical Table**

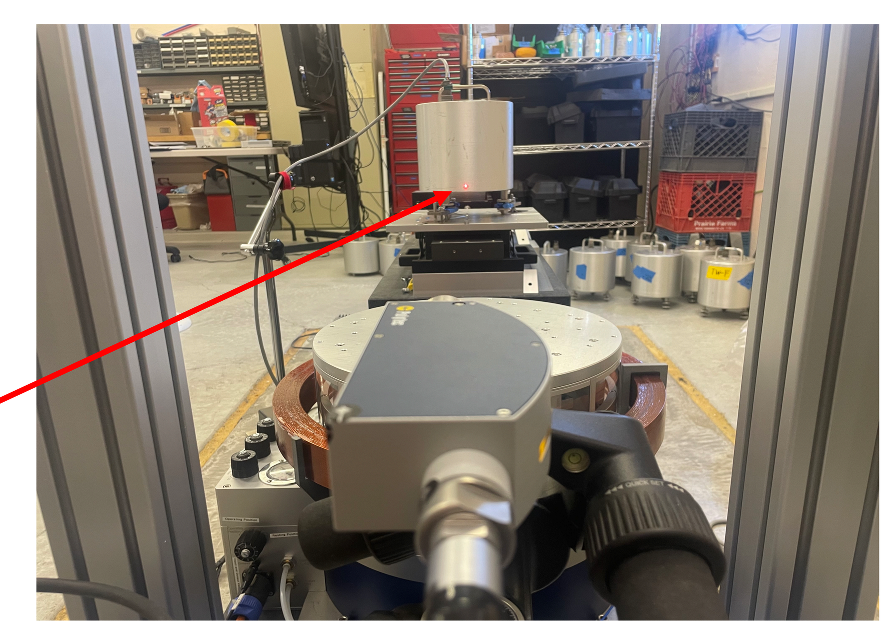
- The L-4C sensor is mounted on the vertical table using an aluminum plate and threaded rod stock.
- The sensor is positioned approximately in the center of the table and the laser (not visible in photo) is aimed near the center of the sensor case.
- Precision air pressure regulators are utilized to manually raise the table to a neutral point, allowing for maximum, un-inhibited travel of the table, once calibrations are commanded.
- L-4C-3D mounted using anchors for each of the 3 feet.





**Horizontal Table**

- L-4C-3D mounting utilizes foot anchors similar to vertical table mounting. Machined groves in the horizontal table are available for aligning sensors, provided positioning the sensor feet places the sensor in a north/south or east/west alignment.
- The laser positioned for horizontal measurements and aimed near the bottom of the sensor. Our standard procedure is to aim the laser at the base of sensors and then determine if aim elsewhere is prudent.



## Calibration Snapshot

**Side bar (far left):**

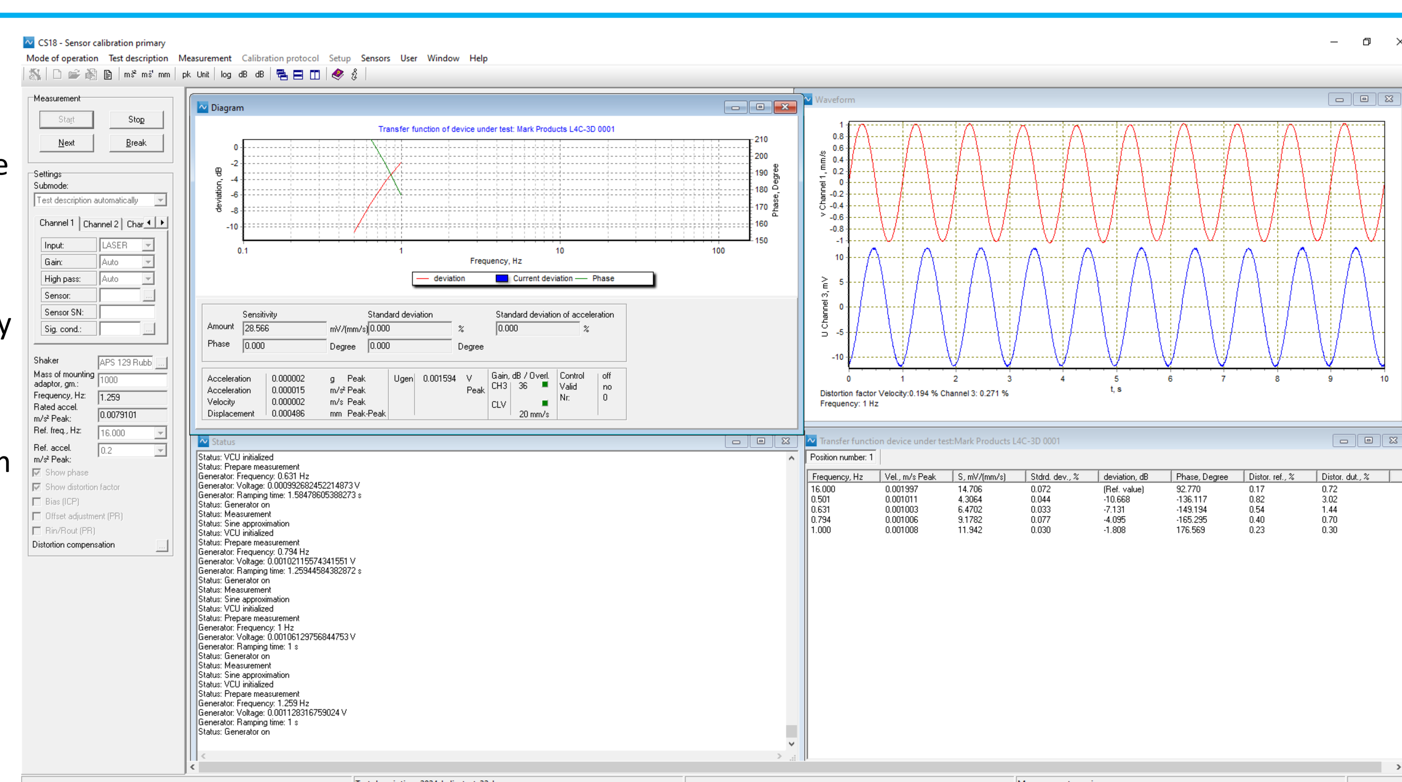
- System settings and parameters, e.g. frequency and acceleration, to which the device-under-test (DUT) is exposed during current operation.

**Bottom left window:**

- This calibration status window informs the user, in real-tme, of the active step during the actual calibration process.

**Top left window:**

- The response plot updates as the system completes the sequence at given frequency. The red line represents DUT deviation (normalized amplitude sensitivity in dB) and green line denotes phase sensitivity (in degrees)
- In this example, calibrations from 0.5 Hz through 1 Hz have completed.
- The values below the plots update in real-time during the calibration, allowing the user to view the results as sensitivities are determined.



**Top right window:**

- Time-series plots of sensor velocity as measured by the laser vibrometer (red) and velocity output from the DUT (blue).
- The plots allow the operator to make visual comparisons of waveform quality, and raw amplitude and relative phase during the calibration sequence.
- Beneath the plots are total harmonic distortion for the laser-based measurement and the DUT output.

**Bottom right window:**

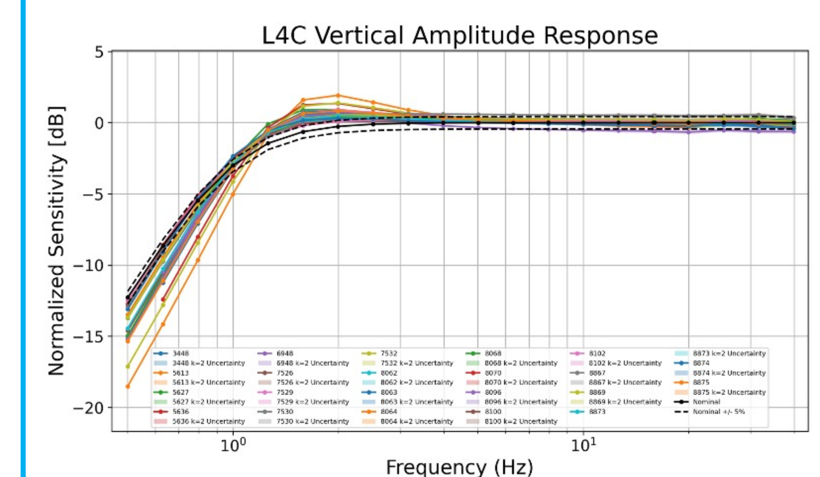
The calibration table updates, in real-time, and documents at each calibration frequency:

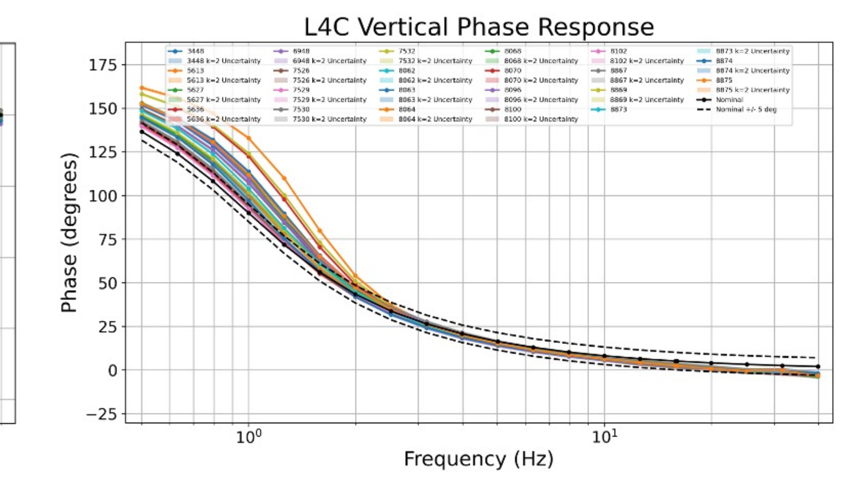
- Frequency
- Peak velocity
- Sensitivity of DUT
- Standard deviation of the measurements
- Deviation (normalized amplitude sensitivity of DUT)
- Phase sensitivity of the DUT
- Reference distortion (THD)
- DUT distortion (THD).

## Results

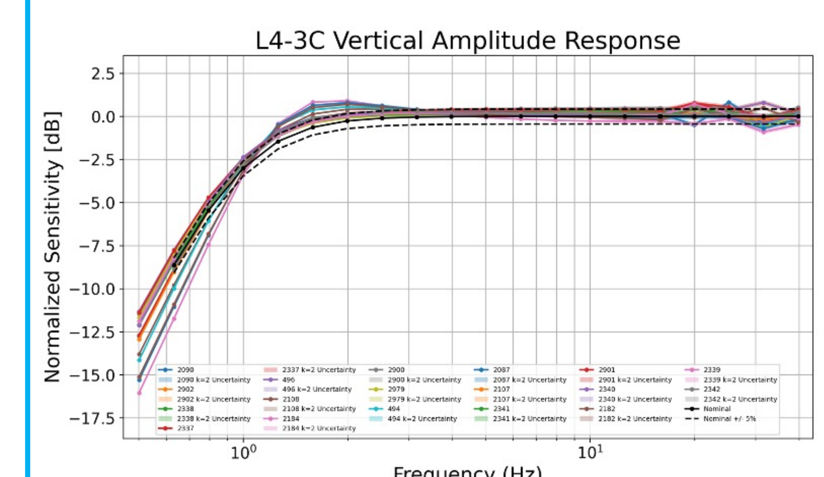
Below are plots of normalized amplitude and phase sensitivity results from the calibration effort, grouped by instrument model and sensor axis.

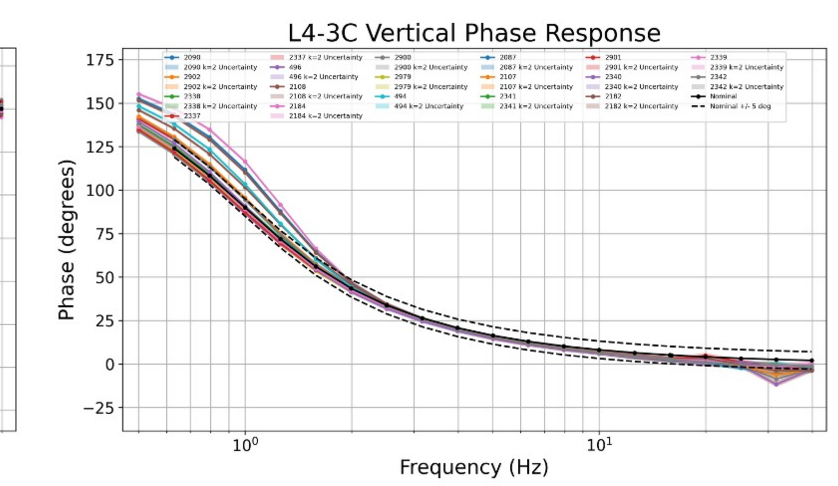
The solid and dashed black lines in each amplitude plot are the nominal amplitude response (critically damped) and +/-5% of nominal, respectively. Similarly, the solid and dashed black lines in the phase response plots illustrate the nominal phase response (critically damped) and +/-5 degrees of nominal, respectively.

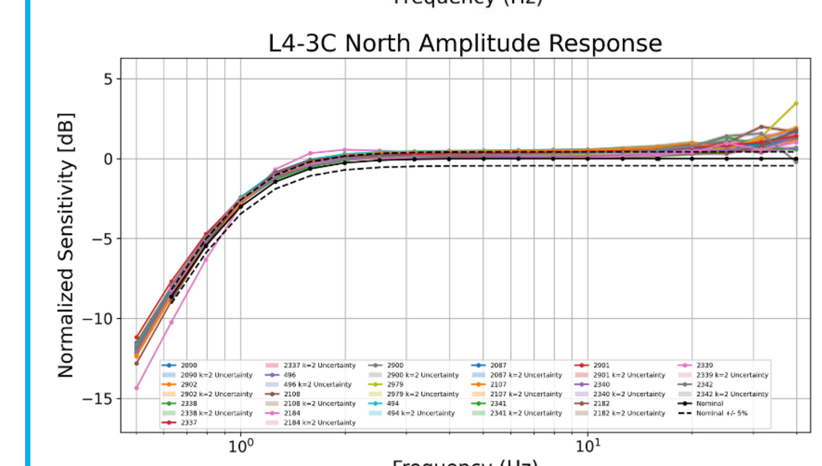


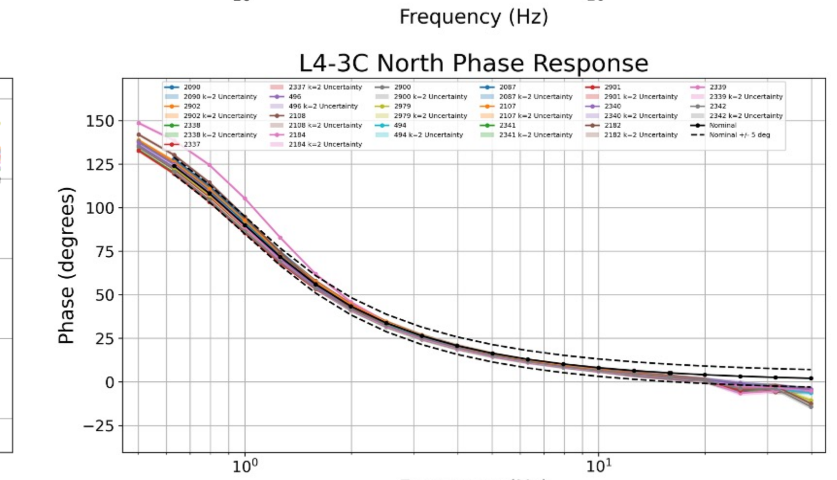



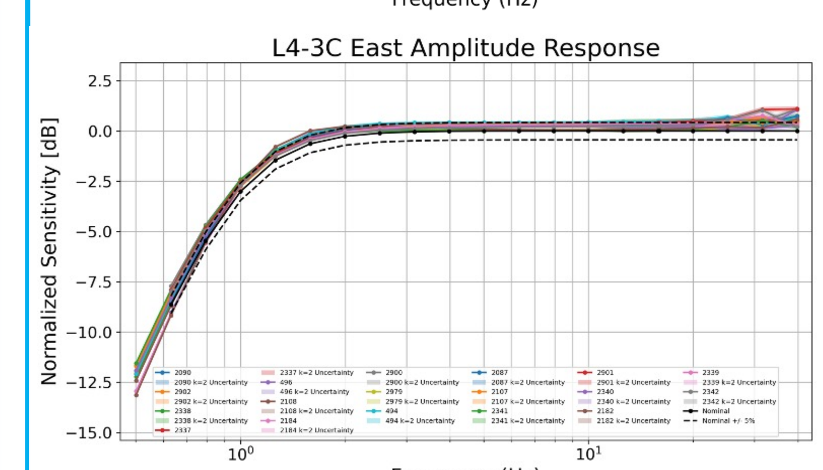

- Overall, the single component sensors amplitude responses match nominal +/- 5%, above 3Hz, though 3 sensors where found to be inoperative and not calibrated.
- These sensors appear to be slightly under-damped, as evident from the rise in amplitude sensitivity below ~3 Hz and above the response roll-off.
- The phase response of all single component sensors fall within +/-5 degrees of the nominal response above approximately 2.3 Hz.

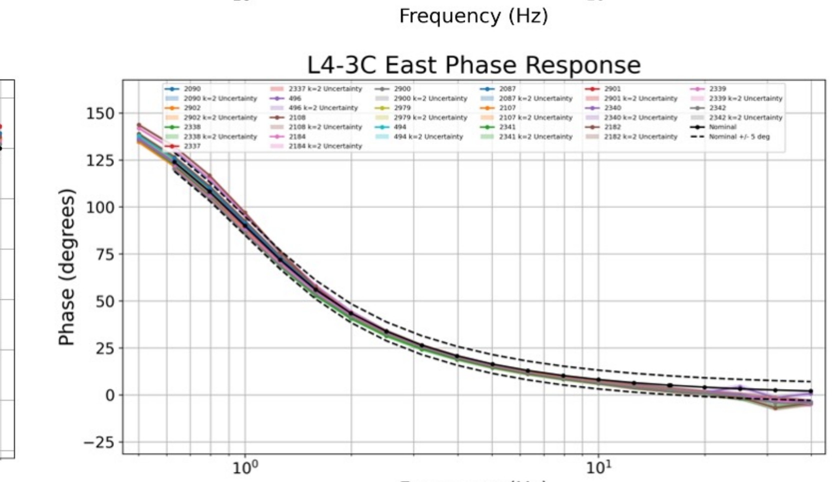



- Several L-4C-3D vertical component responses amplitudes show deviations from a flat response at, and above, approximately 20 hz. We infer these deviations are a result of resonances of the sensor, as total harmonic distortion of measurements increased at some frequencies above 20 Hz.
- The north and east component amplitude responses generally appear critically damped and fall slightly above nominal, with few sensors exceeding 5% of nominal below 10 Hz.
- Similarly, phase response of most sensors fall within +/-5 degrees of nominal.

## Conclusions

- By calibrating the sensors under controlled conditions, we were able to determine their general state of health, and their amplitude and phase response, after decades of rough service on field deployments at the NNSS.
- The L-4C sensors appear to be slightly underdamped, with majority of amplitude responses rising above the +5% curve between 1 Hz and 3Hz.
- The L-4C-3D sensors, particularly the vertical component, show some underdamping between 1 Hz and 3 Hz, while the horizontal components generally match nominal below 10 Hz, to within +/-5% or +/-5 degrees of nominal amplitude or phase response, respectively.
- Periodic, traceable calibrations of sensors increase researchers' confidence in measurements made with such sensors.

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