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PISE: A test and calibration facility dedicated to seismological instrumentation. Feedback on a batch of 110 stations

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1. Abstract

Seismological projects are increasingly based on a subsequent instrumentation. The trend is clearly toward a network densification and the growth of seismometers parks. This occurs at the international, national and local levels, and concerns both temporary research experiments and permanent observatories. Despite technical constraints specific to each project, they all require detailed monitoring of the status and characteristics of the instrumentation, and an efficient maintenance.

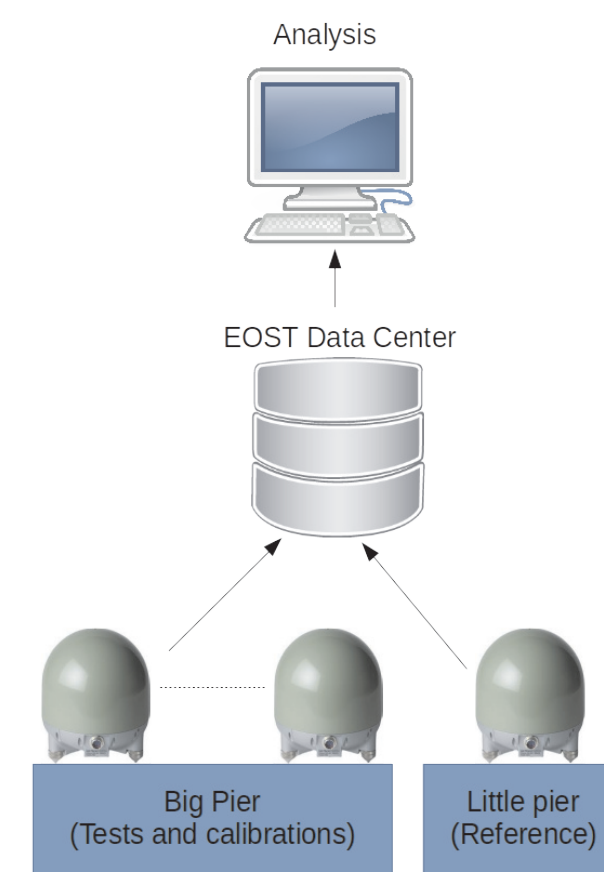
We set up a technical platform at the EOST (Ecole et Observatoire des Sciences de la Terre (Univ. Strasbourg)); the Seismological Instrumental Platform of EOST (PISE). Using dedicated seismological pillars, we test, validate, calibrate, maintain and monitor over time seismometers and dataloggers characteristics.

We use several calibration methods, both relative and absolute. In order to increase the signal to noise ratio, we remotely perform them, while instruments are in quiet conditions on their pillar. For this purpose, we present here our operating mode and some specially developed network devices able to control instrument calibration.

As PISE has been chosen as the instrumentation facility of the broad-band French network RESIF (REseau Sismologique et géodésique Français), currently under construction, we already tested and calibrated 110 stations acquired in early 2017. We present here a feed-back on those instruments performances, and their expected dispersions on the whole batch, before field deployment, but also on our calibration procedures, roughly tried out with several operators and a not negligible number of units.

2. Principle

PISE works around two measurements rooms in the basement of EOST building. One hosts an official broad-band station (code FR.STR). This station is integrated in RESIF network and provides reference data to the facility. Its lies on a dedicated pier, decoupled from the building. Its room is closed, and movements around are limited. A second room hosts a "big pier", decoupled from the building too, and is used for testing and calibrating instruments, up to 8 stations each time...



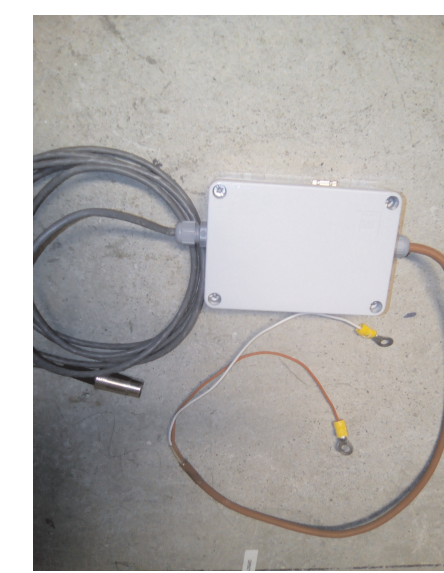
Once the stations under verification are deployed, they are running at least 12 hours, and all calibration procedures are performed remotely after that time. No one enter anymore in the room during that time. All tests and calibration are performed remotely from an "analysis room". For this purpose, we developed network modules, based on Arduino, allowing the operator to launch calibration procedure.



Signal injector module:

It injects external custom signal in calibration coils. The seismometer is fully controllable (short-period mode, output in UVW, ...) with simple console commands sent through network.

It is plugged between sensor and digitizer and uses digitizer supply.



Calibration table module:

It fully handles all movement of the calibration table sold by Lennartz Electronic GmbH (see paragraph 4).

A little GUI allows controlling the module from the analysis room.

In early 2017, PISE was chosen to test and calibrate 110 stations acquired by RESIF network. The instruments chosen are Nanometrics Trillium-120QA and Trillium-120PH as sensors, and Nanometrics 24 bits Centaur3 (3 or 6 channels) as digitizers. PISE has been delivered in march 2017 and performed tests and calibrations since that period. We validated 80 complete stations for now, and the work is still on progress.



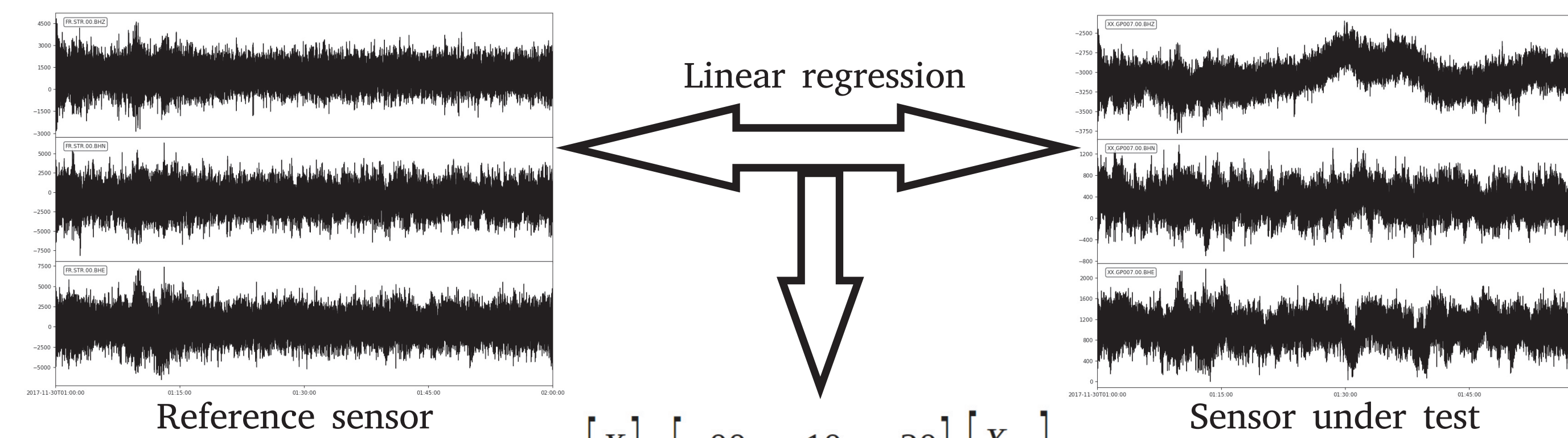
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- Lennartz Electronic: CT-EW1, available at: <http://www.lennartz-electronic.de/index.php/accessories/ct-ew1>, last access: 2017-12-07
- Nanometrics (2017): Trillium-120Q/QA User Guide (v 171751R3)
- Nanometrics (2017): Trillium Posthole User Guide (v 17217R7)
- Wiedlandt, E. (2002): Seismic Sensors and their Calibration, New Manual of Seismological Observatory Practice, Ch. 5

3. Sensitivity (relative to reference)

Method:

A simple linear regression is made between test data and reference data. It gives the rotation matrix between the 2 streams from which the orientation error and sensitivities can be calculated. As the reference data comes from a sensor on an other pier, we don't really know its uncertainty.



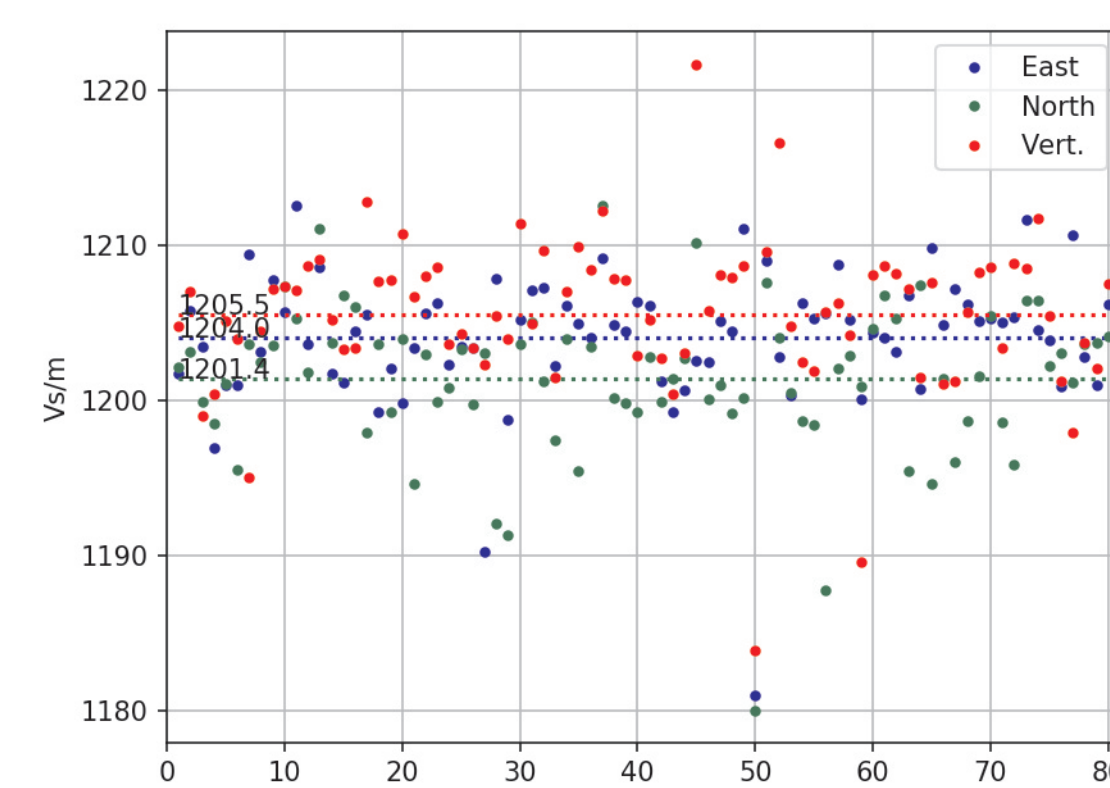
Orientation Error:
 $\alpha = \arctan(a_{01}/a_{00})$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} a_{00} & a_{10} & a_{20} \\ a_{01} & a_{11} & a_{21} \\ a_{02} & a_{12} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} X_{ref} \\ Y_{ref} \\ Z_{ref} \end{bmatrix}$$

Rotation matrix

Sensitivities:
 $G_x = a_{00}/\cos(\alpha)$
 $G_y = a_{11}/\cos(\alpha)$
 $G_z = a_{22}$

Results (on 80 sensors):



Average orientation: 2.004 degrees
 Standard deviation of azimuths: 0.814 degrees
 Orientation max error: 4.37 degrees
 Average sensitivity of East comp.: 1204.0 Vs/m
 Deviation of East sensitivities: 4.3 Vs/m
 Max error of East sensitivities: 1.750 percent
 Average sensitivity of North comp.: 1201.4 Vs/m
 Deviation of North sensitivities: 4.9 Vs/m
 Max error of North sensitivities: 1.827 percent
 Average sensitivity of Vert. comp.: 1205.5 Vs/m
 Deviation of Vert. sensitivities: 5.0 Vs/m
 Max error of Vert. sensitivities: 1.635 percent

Theory from manufacturer:
 Within $\pm 0.5\%$ of nominal at 1Hz

5. Impulse response (High-pass filter)

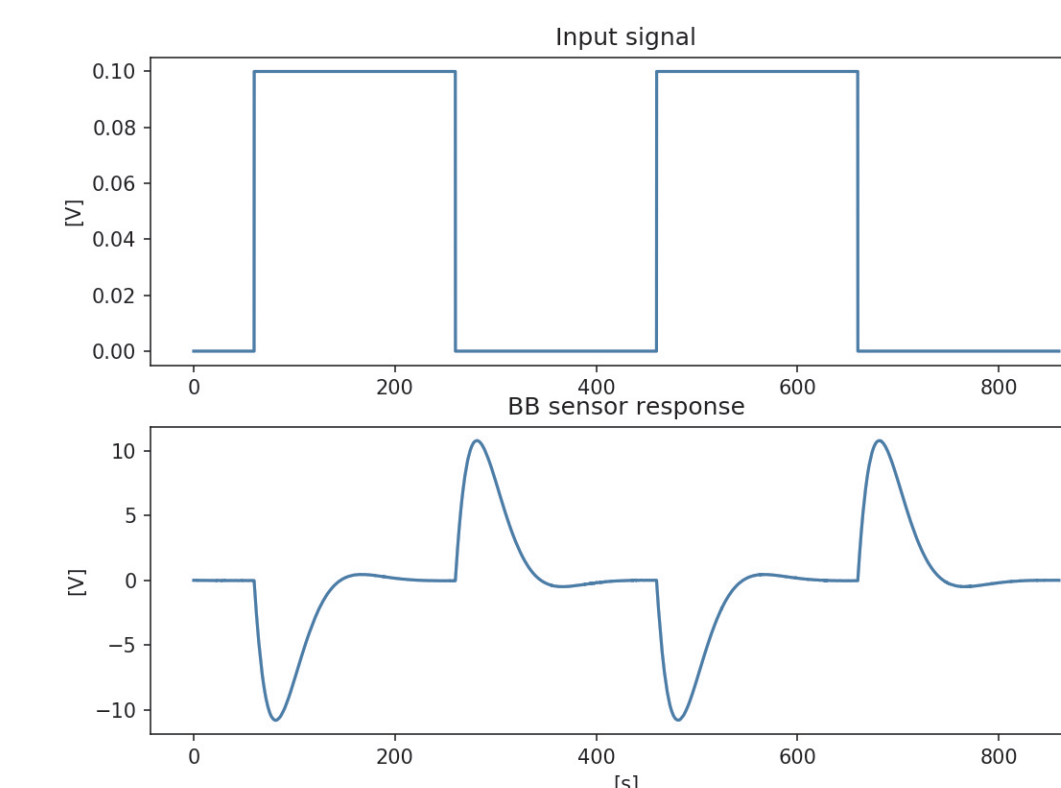
Method:

A step signal with a period of 400s is injected within the calibration coil, using the signal injector. Centaur have an embedded signal generator which can be used as well.

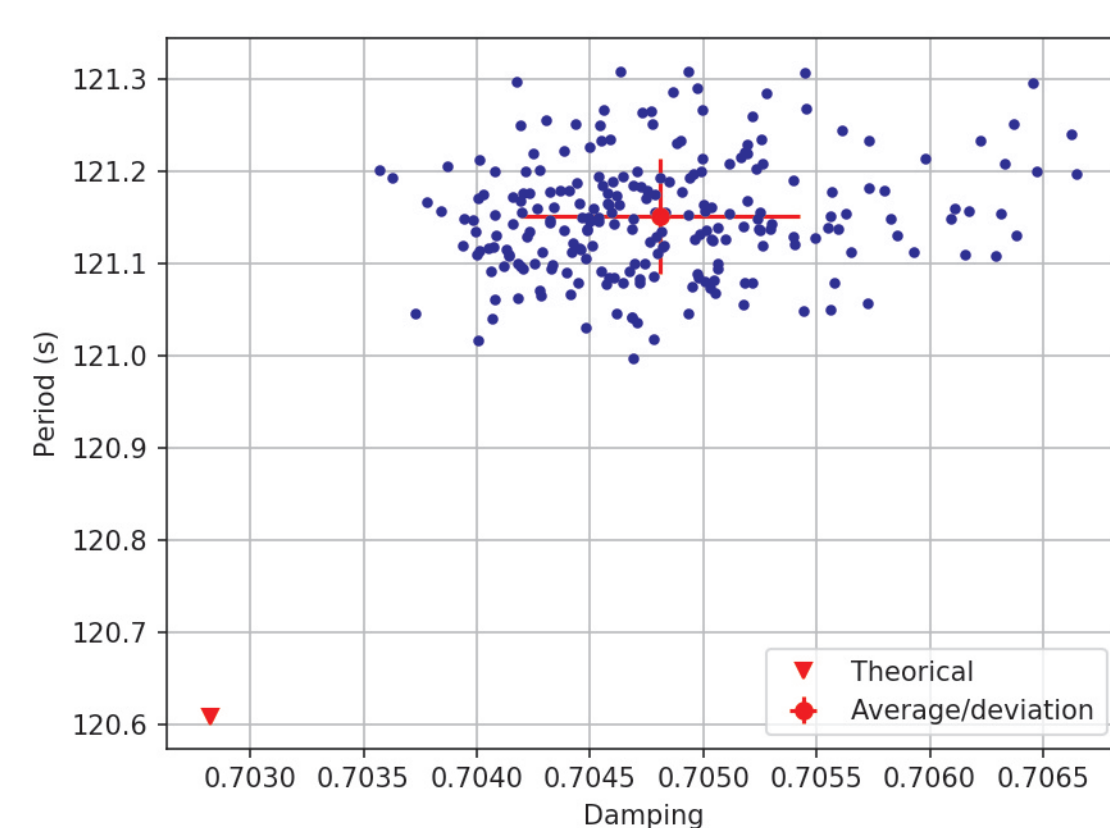
The corresponding time signal in velocity is:

$$\tilde{f}(t) = e^{-h \cdot w_0 \cdot t} \cdot \sin(w_0 \cdot t \cdot \sqrt{1-h^2})$$

The response depends only of cut-off period and damping constant. It is fitted at best according to theory, and the best fit gives period and damping for each pulse.



Results (on 80 sensors):



Average period: 121.152 seconds
 St. deviation of periods: 0.063 seconds
 Average damping: 0.704810
 St. deviation of dampings: 0.000618
 Max error from average period: 0.130 percent
 Max error from theoretical damping: 0.544 percent
 Max error from average damping: 0.261 percent

Theory from manufacturer:
 Lower corner poles within $\pm 0.5\%$ of nominal provided

4. Sensitivity (absolute)

Method:

PISE owns a calibration table sold by Lennartz Electronic GmbH. It applies a known vertical movement, measured by displacement gauges.

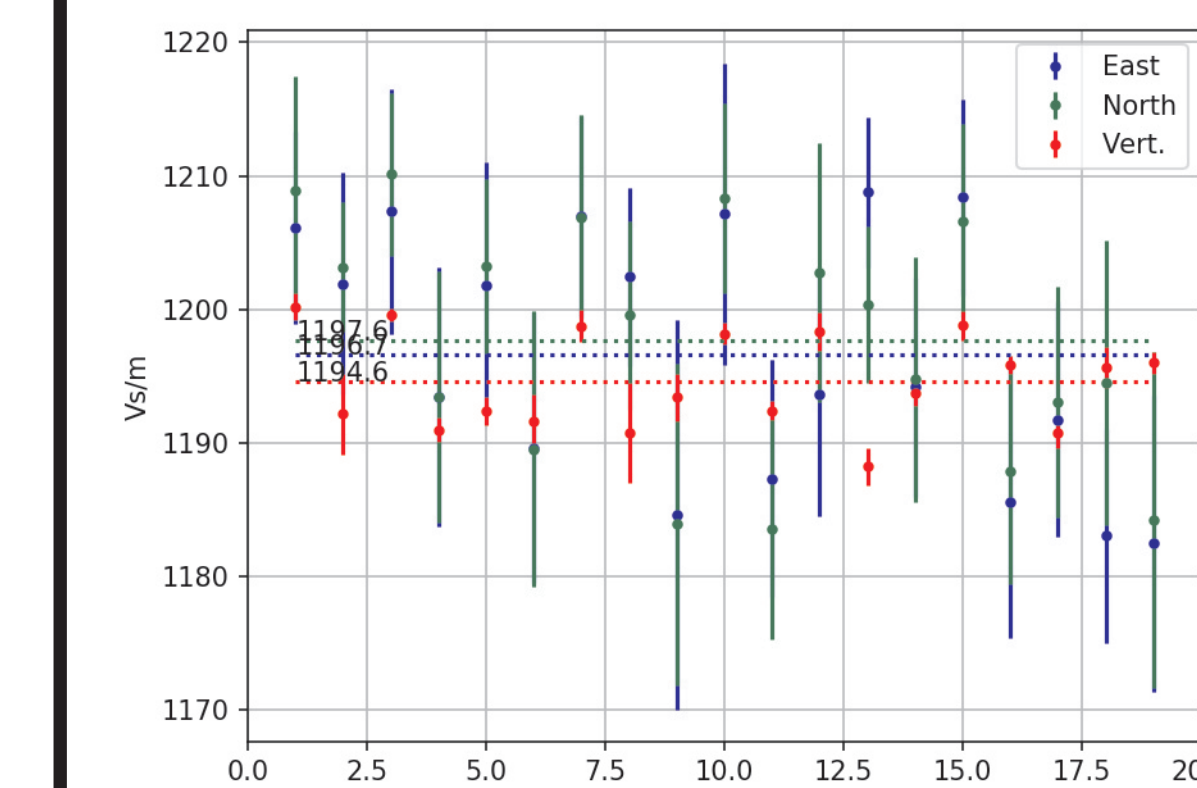
By simply installing a seismometer on top, one can restore the vertical displacement from velocity data and deduct sensitivity.

Adding a plate on the table on one side and on a fixed feet on the other, the vertical movement creates a tilt applying a gravity projection on the horizontal component. It depends on the vertical displacement and the plate length, and therefore one can deduct horizontal sensitivity.

As a high quality record is required for each component, it is very time-consuming. We therefore applied this method on only 16 sensors.

Furthermore, due to its mechanical design, this method has probably an uncertainty not better than 10%.

Results (on 16 sensors):



East component statistics:
 Average sensitivity: 1196.7 Vs/m
 Standard deviation of sensitivities: 9.3 Vs/m
 Max error from theoretical sensitivity: 1.625 percent
 Max error from average sensitivity: 1.186 percent
 North component statistics:
 Average sensitivity: 1197.6 Vs/m
 Standard deviation of sensitivities: 8.7 Vs/m
 Max error from theoretical sensitivity: 1.532 percent
 Max error from average sensitivity: 1.172 percent
 Vertical component statistics:
 Average sensitivity: 1194.6 Vs/m
 Standard deviation of sensitivities: 3.5 Vs/m
 Max error from theoretical sensitivity: 1.146 percent
 Max error from average sensitivity: 0.536 percent

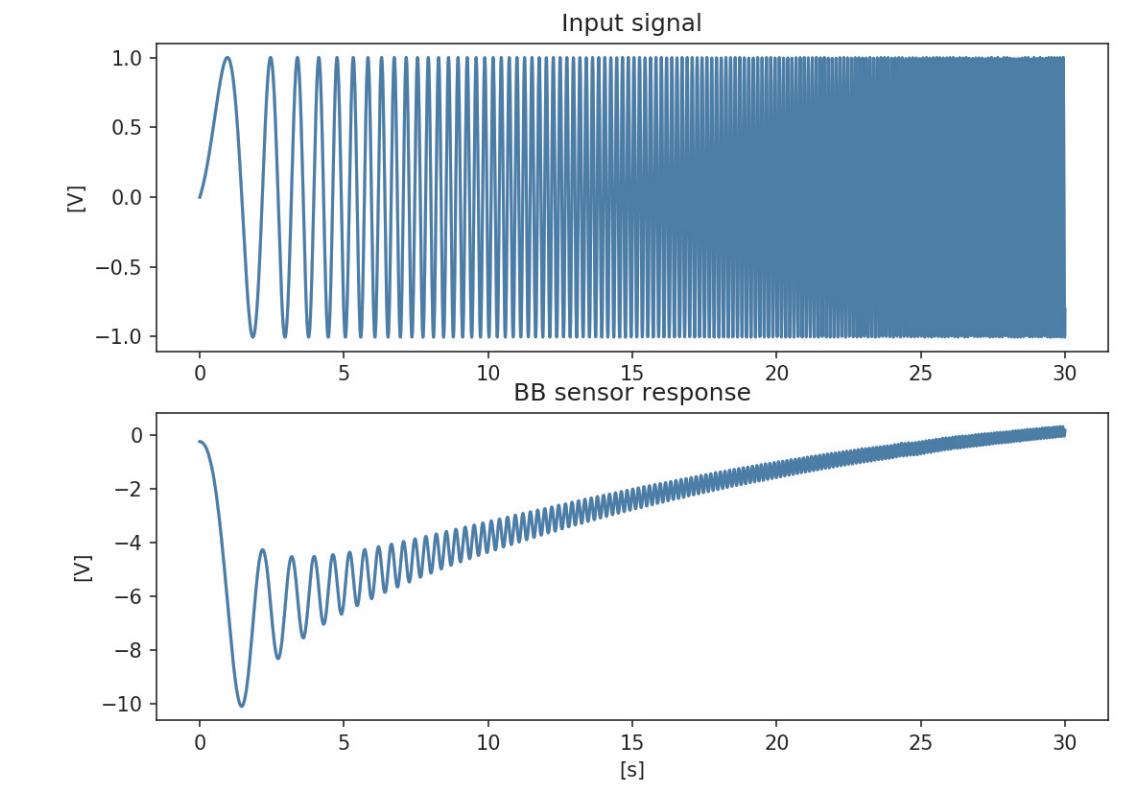
Theory from manufacturer:
 Within $\pm 0.5\%$ of nominal at 1Hz

6. Sweep signal (Low-pass filter)

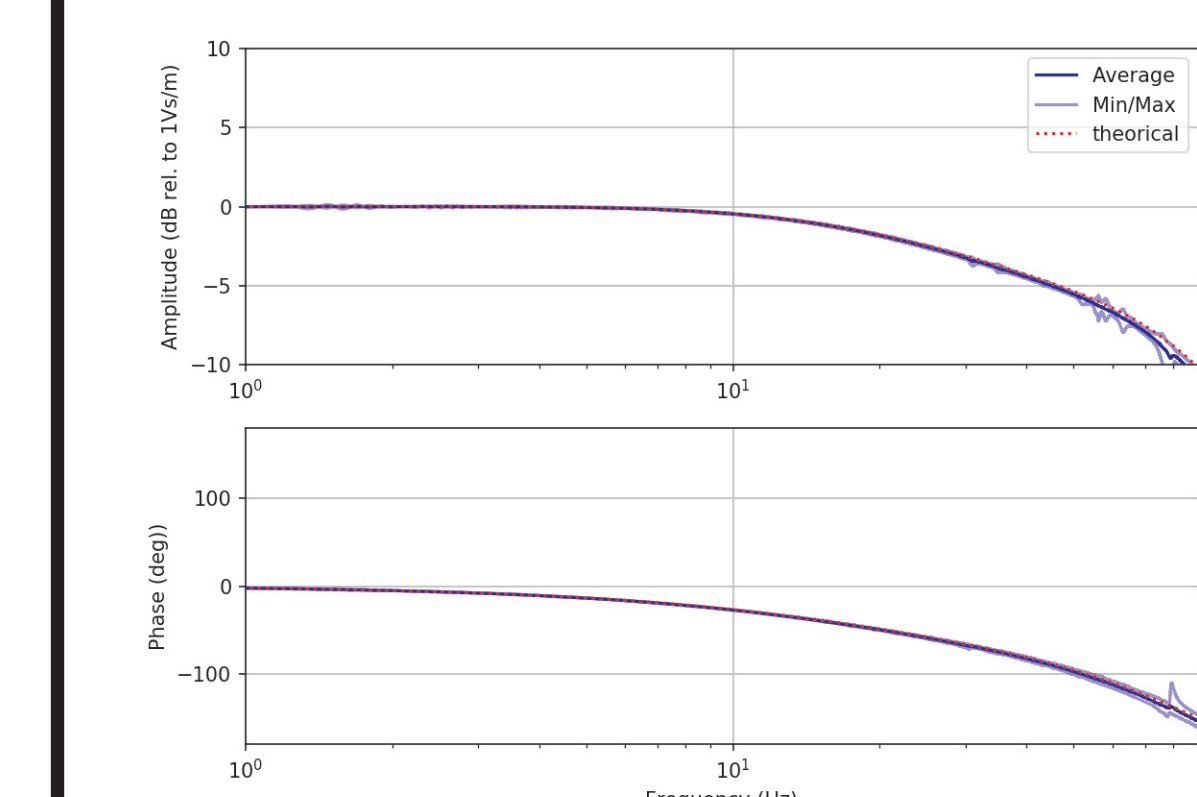
Method:

A sinusoidal signal with sweeping frequency between 0.1 and 100 Hz is injected within the calibration coil, using the signal injector module. A simple spectral division between input signal (recorded on an other digitizer and converted in velocity) and the response gives a raw image of the "low-pass part" of the transfer function.

Due to the pier spurious resonance, and the high-frequencies noise level, it is difficult to draw a thin curve. We therefore bought a passive mechanical vibration isolator from Minus-k, allowing us to filter the disturbing frequencies and raise the signal to noise ratio.

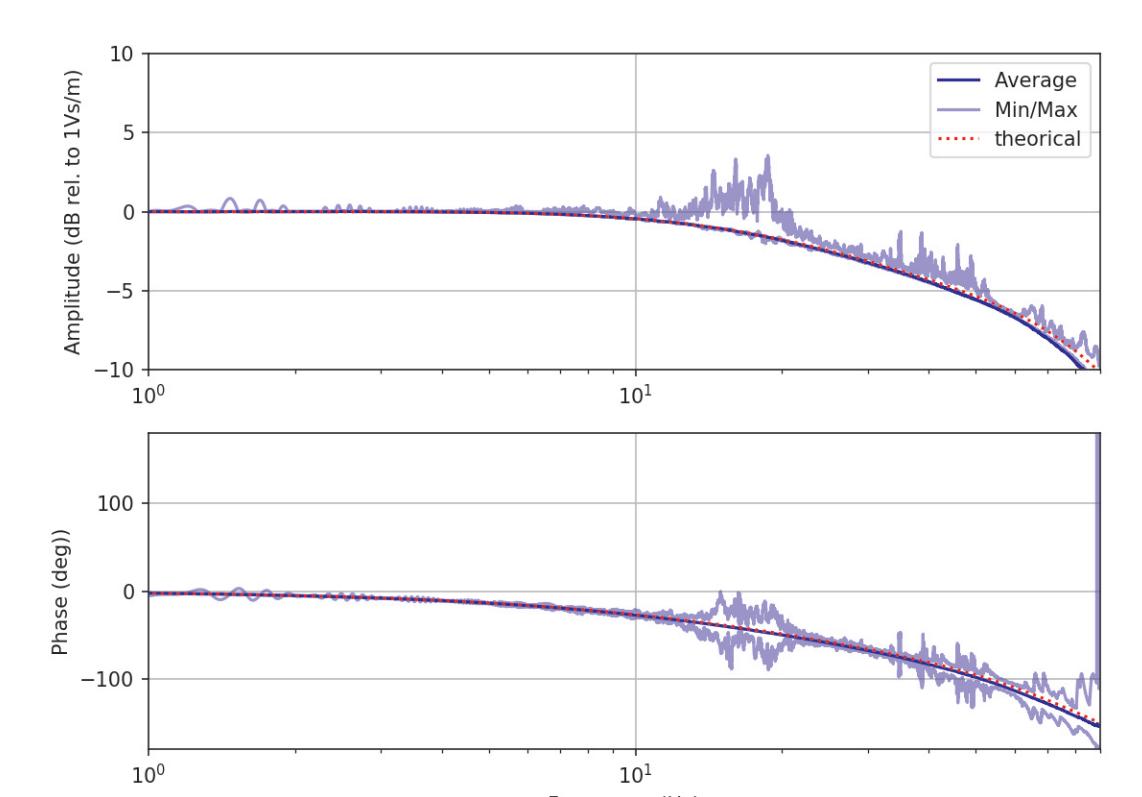


Results with vibration isolator (on 8 sensors):



Max error from theoretical response: 0.51 dB
 Avg. error from theoretical response: 0.28 dB ($1 < f < 40$ Hz)

Results without vibration isolator (on 72 sensors):



Max error from theoretical response: 16.76 dB
 Avg. error from theoretical response: 1.10 dB ($1 < f < 40$ Hz)

Theory from manufacturer:
 High-frequency response within ± 1 dB of nominal up to 40 Hz