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A Technique to Determine the Self-Noise of Seismic Sensors for Performance Screening

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Introduction

One of the factors which determines the quality of a seismic broadband sensor is its *self noise*. This value describes how much of an output signal a sensor generates under the ideal condition, that there is no movement of the ground at all. In reality, of course, this condition is never met, as the ground is always in some form of motion due to seismic noise. This noise is generated - among others - by ocean swell and waves, by wind or by various human activities. Nevertheless, under seismically very quiet conditions, the self noise of a seismic sensors can limit its ability to detect extremely small seismic signals. It is therefore the goal of any designer of sensitive seismic instruments, to keep the sensor's self noise to a minimum. However, it cannot be completely eliminated. Some of the sources of self noise are, that

- the electronic components of the feedback loop always generate some electronic noise, and that
- depending on the ambient temperature the Brownian motion of the air molecules within the sensor's housing affect the boom, causing it to vibrate ever so slightly.

The self noise is difficult to measure, as it is usually drowned out by the ever present movement of the Earth due to its seismic noise. There are however various methods to estimate the self noise. One was first described by *Sleeman et al. (2006)* and later by *Hart et al. (2007)*. The prerequisite for using this Sleeman-Method is to concurrently operate three identical sensors under exactly the same conditions in order to expose each of them to the "same" coherent noise. Their respective signals are recorded and the coherency of their signals is then analysed.

Sensor package

We used three identical vertical CMG-3 components. However, they were not mounted onto a base plate as in a regular orthogonally oriented sensor or into a stack as in a borehole sensor. Instead, we kept them separate by mounting each of them in its own standard borehole housing without stacking them together. This arrangement allows us to place them side by side on a seismic pier. Although the sensors in each triplet are physically identical, they are connected to each other following the same logic used in a regular three component borehole sensor. Hence, when the triplet is connected to a digitizer, one sensor will be recorded as the Z-component, one as N/S and the third as E/W. This is, of course, only a logical nomenclature, because the three sensors shall record the same waveforms when placed next to each other.All three sensors have a flat response to velocity between 120s and 50Hz and the very large sensitivity of 2*30,000 V/[m/s]. The triplet of vertical sensors (from now on called **VVV**) has serial numbers T34501 A,B,C, s Sensor A carries the power conditioning and the lock/unlock/centering logic, similar to the Z-comp in a regular borehole stack.

Summary

Seismic noise affects the performance of a seismic sensor and is thereby a limiting factor for the detection threshold of monitoring networks. Among the various sources of noise, the intrinsic self-noise of a seismic sensor is most diffcult to determine, because it is mostly masked by natural and anthropogenic ground noise and is also affected by the noise characteristic of the digitizer. Here we present a new technique to determine the self-noise of a seismic system (digitizer + sensors). It is based on a method introduced by Sleeman et al. (2005) to test the noise performance of digitizers. We infer the self-noise of a triplet of identical sensors by comparing coherent waveforms over a wide spectral band across the set-up. We will show first results from a proof-of-concept study done in a vault near Albuquerque, New Mexico. We will show, how various methods of shielding the sensors affect the results of this technique. This method can also be used as a means of quality control during sensor production, because poorly performing sensors can easily be identified.

Modeling Seismometer Misalignment

Our question to answer is how different alignment configurations between three 3c seismometer systems affect the noise estimated provided by three channel coherence technique developed by Sleeman.

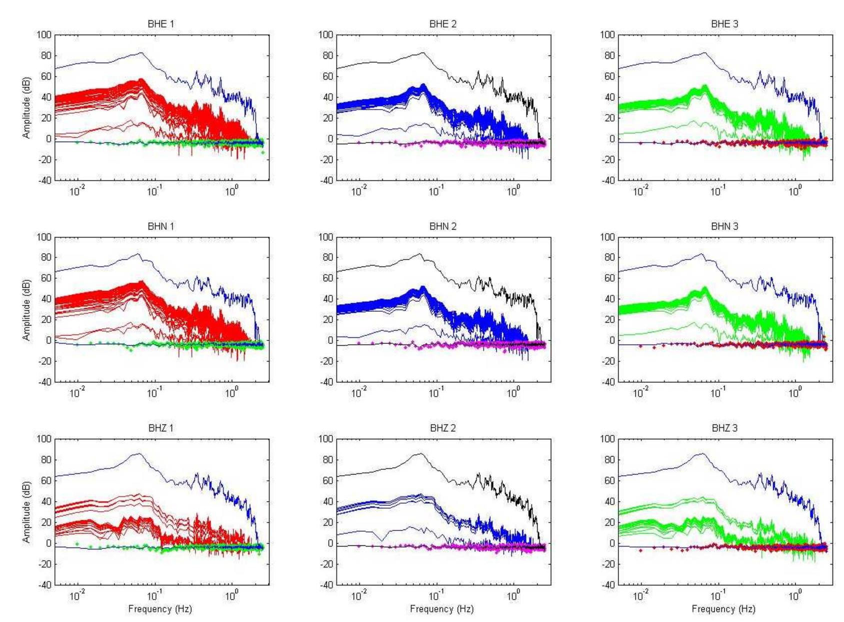
Define the three Euler rotation matrices:

$$Z\_rot = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad X\_rot = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\varphi) & -\sin(\varphi) \\ 0 & \sin(\varphi) & \cos(\varphi) \end{bmatrix} \quad Y\_rot = \begin{bmatrix} \cos(\psi) & 0 & \sin(\psi) \\ 0 & 1 & 0 \\ -\sin(\psi) & 0 & \cos(\psi) \end{bmatrix}$$

We assume the rotation product of: Z_rot * X_rot * Y_rot, which represents a rotation whose Euler angles are θ, φ, and ψ.

Using a grid search methodology for the expected ranges of θ (-4° to +4°), φ (90° to 87°), and ψ (-4° to +4°), we apply a rotation to the reference seismometer (sensor 1). Then apply the 3-component coherence to the common components among the three seismometers (i.e. group one BHZ1, BHZ2 and BHZ3, group one BHN1, BHN2 and BHN3, and group one BHE1, BHE2 and BHE3) and record the incoherent noise estimates given through this analysis. We use the RMS of the estimated incoherent noise to identify when sensor 2 and sensor 3 are aligned with the reference seismometer.

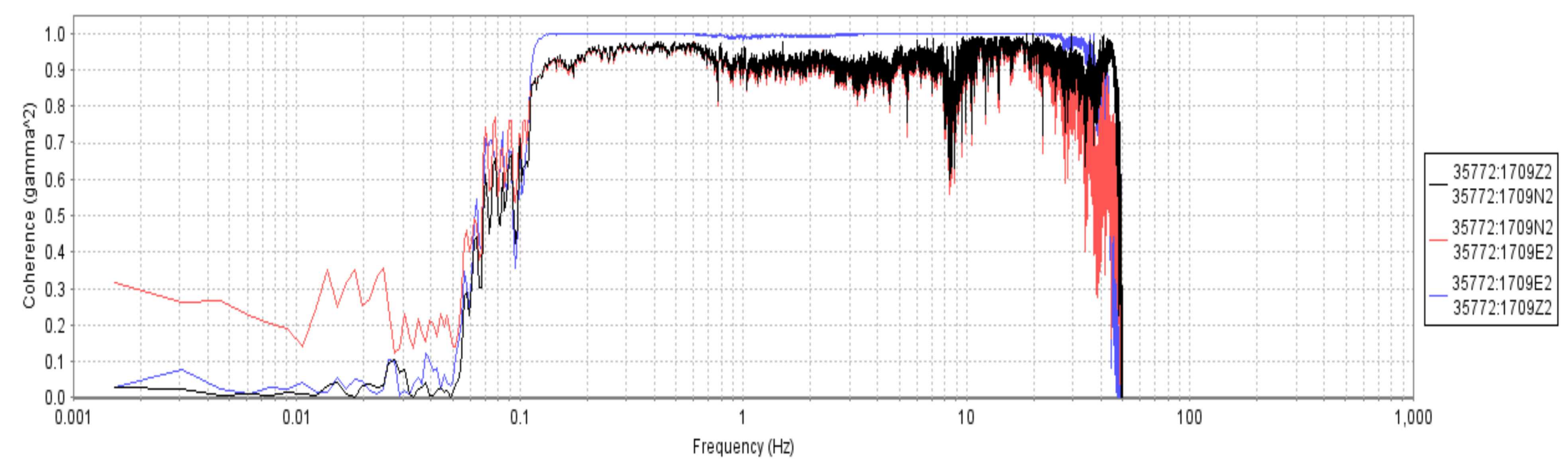
Below we present results of a modeling run where sensor 2 was rotated by [0 90 -1] and sensor 3 was rotated by [-1 89 0].



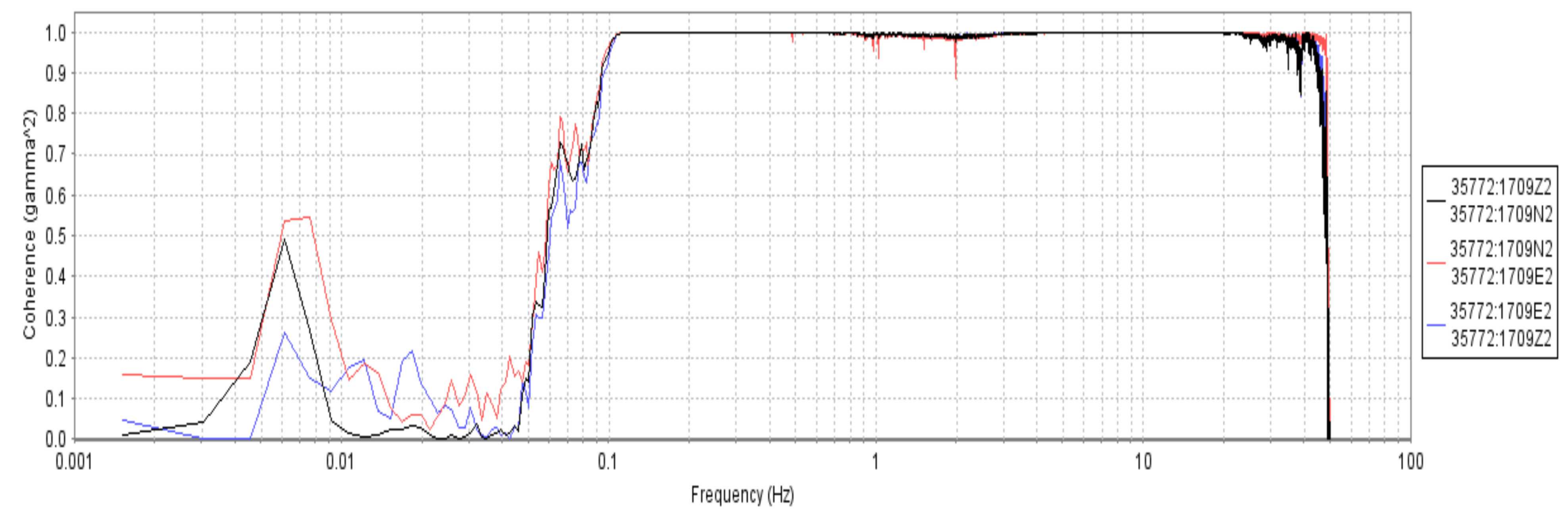
Main observation was that across rows one and two the reference has two minimum noise estimates and the two seismometers under evaluation (SUE) have one minimum noise estimate. It turns out that the minimum estimates are given when the reference is aligned with either of the SUE. We can use this to identify the misalignments, and correct for them (under the assumption that each seismometer 3-axis system is orthogonal).

Column 1 color definitions:
Blue lines: coherent signal common to each component and unique incoherent noise
Red lines: 3-component noise estimates for this one component of the nine element system.
Green dots: Noise estimate given by 3-component coherence after seismometers 2 and 3 have been realigned to reference (rotation angles were provided through this analysis by observing that the minimum noise estimates for 2 and 3 were when the reference was aligned with each one at different steps in the grid search process).

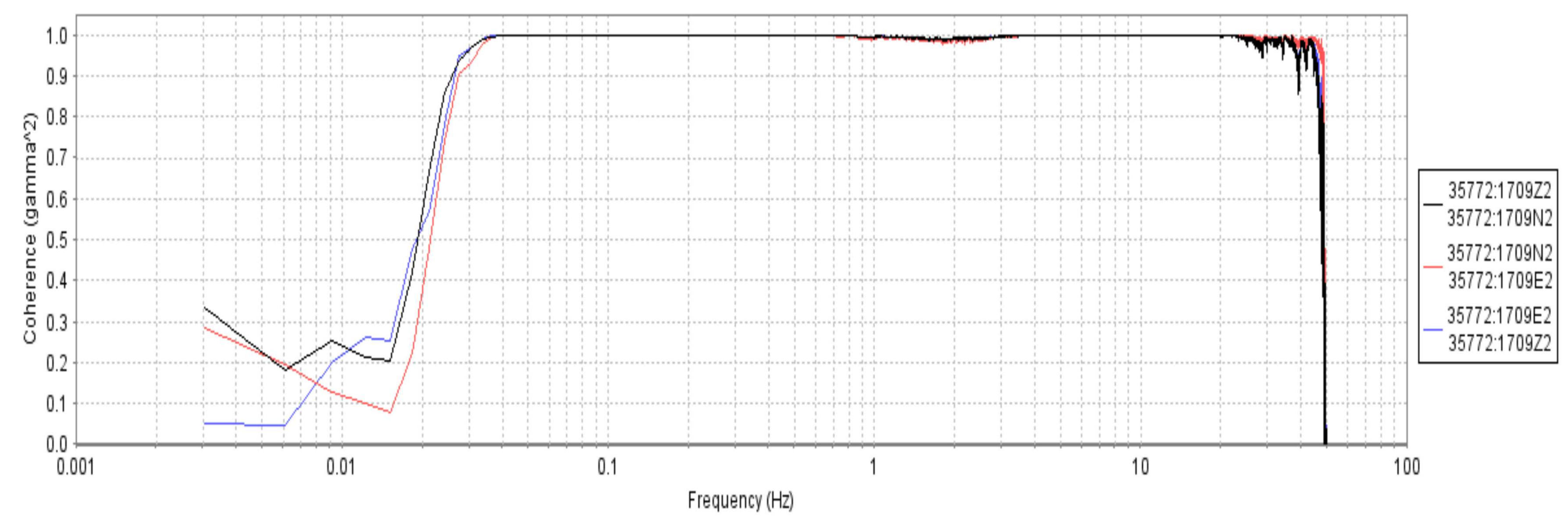
Initial Results for Sensor Coherence



A rough alignment of the three sensors within a few degrees leads to poor coherence over the whole frequency band.



The coherence improves significantly after the three sensors are fine aligned with a deviation from the N-direction of less then one degree.



The coherence improves even more when all three sensors are thermally insulated. The coherent band widens from 0.04 to 30 Hz.

Next Steps:

- Thermally insulate each sensor individually
- Magnetic shielding
- Comparison with air pressure fluctuations
- Move to seismically quieter test vault
- Modify alignment code for real test case

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