SM1.4/GI1.6
EGU2013-4532
B53

Instrument Self-Noise and Sensor Misalignment

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Summary

In this study we investigate self-noise of RefTek™ 151-60A "Observer" broadband seismometers (T_0=60 s, f_0 ≈17 mHz) using the coherency analysis method from Sleeman et al. (2006).

We present a self-noise model for this type of sensor and compare it to the self-noise models of the standard observatory sensor STS-2 (Streckeisen) and RefTek's 151-120 seismometer, which both have natural periods T_0 of 120 s, and are of higher quality and price.

We further report on the sensitivity of this technique to sensor misalignment and our success of eliminating leakage of the omnipresent microseism noise into self-noise estimates by numerically rotating seismic traces in order to find real self-noise.

Instrument Self-Noise

With ever-improving seismic instruments, processing methods and computational capabilities it becomes important to distinguish between the various sources of noise that are recorded in seismic data (Ringler et al., 2011).

One of these sources of noise is the seismograph itself, which is why for an assessment of its suitability for a given purpose and for reasons of quality control it is necessary to have a means of estimating its self-noise.

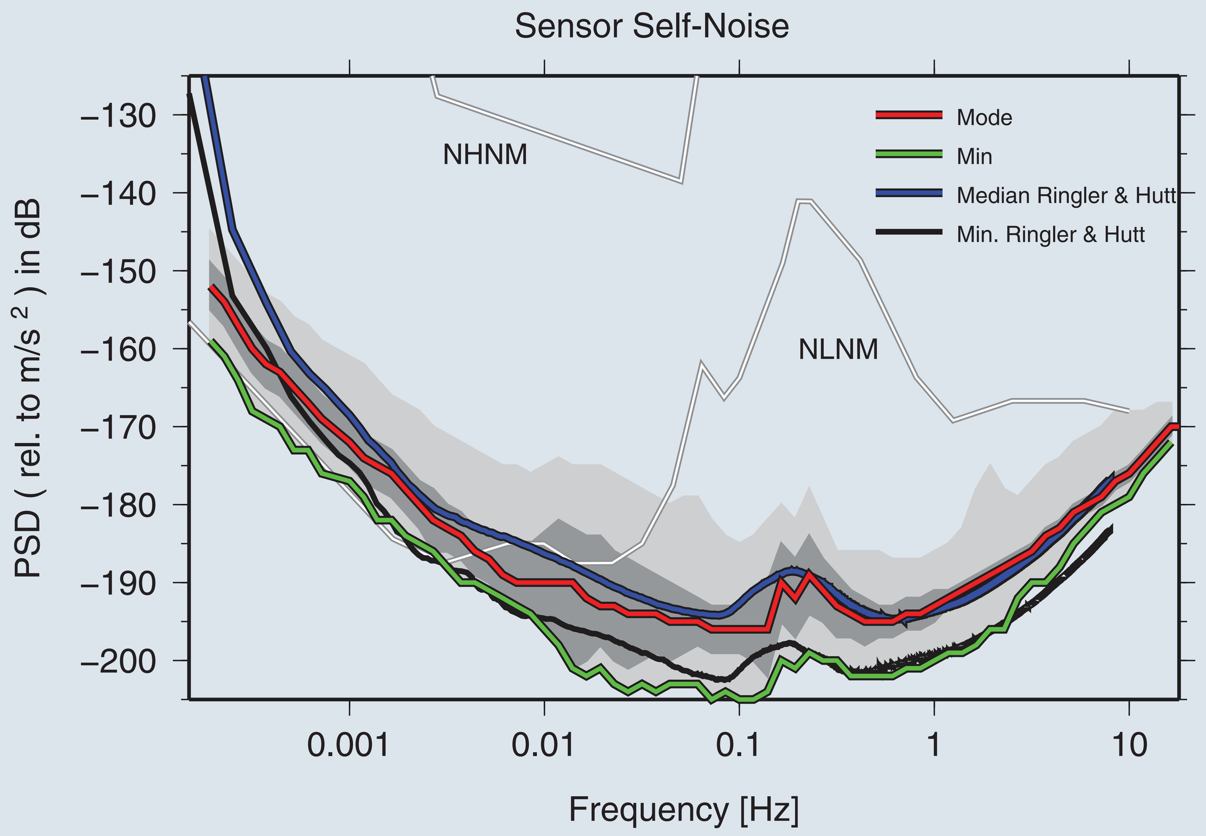


Fig.1: Self-Noise model of the STS-2 as published by Sleeman & Melichar (2012). In all of the self-noise curves the signature of Earth's microseisms, which are the dominant source of natural seismic background noise in the pictured frequency range (Peterson, 1993), can clearly be recognized (also see Ringler & Hutt, 2010).

Sleeman et al. (2006) propose a method of measuring the self-noise of seismographs using coherency analysis. Assuming the seismic background noise recorded by three collocated, co-aligned sensors to be identical, they compute autopower spectra (P_{ii}) and cross-power spectra (P_{ij}) of the recorded data in order to eliminate coherent background noise, and thus isolate and identify the incoherent portion, which can be attributed to the instrument.

Sensors, Alignment & Finding True Self-Noise

While aforementioned method is intriguingly simple and robust in ideal cases, the computed self-noise estimates strongly depend upon the exact alignment of the collocated instruments.

Non-aligned sensors will record background-noise incoherently, and thus this noise will not cancel out completely for three sensors i,j,k (Eq. 1).

Incoherently recorded background-noise will instead "leak" into self-noise estimates N of each of the sensors:

$$N_{ii} = P_{ii} - P_{ji} \cdot \frac{P_{ik}}{P_{jk}}. \qquad (1)$$

Sleeman & Melichar (2012) show that a misalignment of two stations on the order of 0.2° may cause a significant portion (≈10 dB) of the background noise to remain in the self-noise spectrum.

This value of 0.2° is in the range of the max. guaranteeable error in orthogonality of the STS-2's sensing axes (Sleeman & Melichar, 2012).

For the 151-60A this error in orthogonality is <0.5° (pers. comm. RefTek, see Fig.2).

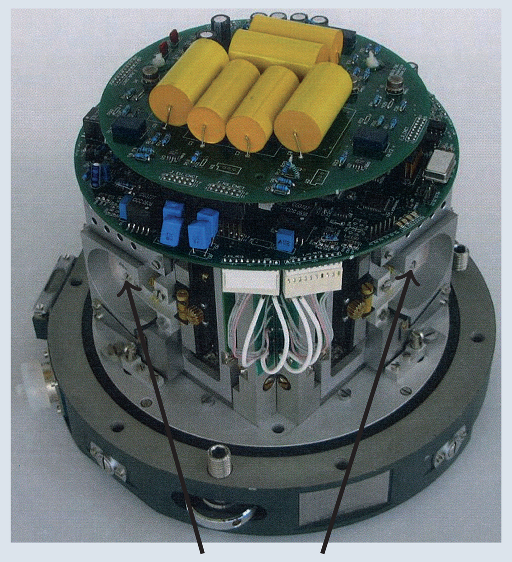


Fig.2: Inside view of a RefTek 151-series broadband sensor.

An exact alignment of the horizontal components of three collocated sensors is hard to realize by setup alone. Optimal alignment can subsequently be achieved by numerically rotating the horizontal traces of two sensors about their z-axis, searching for the angles of rotation that minimize their self-noise level in the microseisms band.

We installed 15 151-60A sensors at the Conrad-Observatory and selected the quietest period of nine hours of continuous recordings for our self-noise computations.

For the best recordings of 11 sensors we performed a grid-search for optimal angles of rotation with minimum self-noise in the microseisms band for both horizontal components separately (ϱ_N & ϱ_E, $\Delta\varrho = 0.02°$) and all possible permutations of triples of sensors (Fig. 3).

An example is shown in Fig.4, results for all sensors are listed in Tab.1.

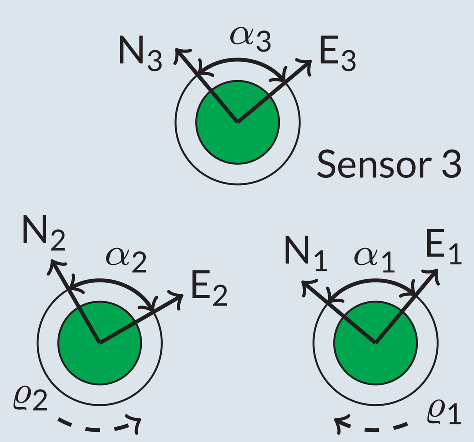


Fig.3: Schematic view of the experiment setup illustrating the misalignment between the three sensors' horizontal components and the rotation performed in this study to align two sensors with the third.

Given a reasonable vertical alignment of sensors, we were able to completely remove leakage of microseisms-noise into self-noise estimates. Further, the applied method is so sensitive to misalignment (Fig. 5) as to provide a means of verification of the manufacturer's information on max. error in orthogonality of the sensing axes (see Tab. 1).

Results

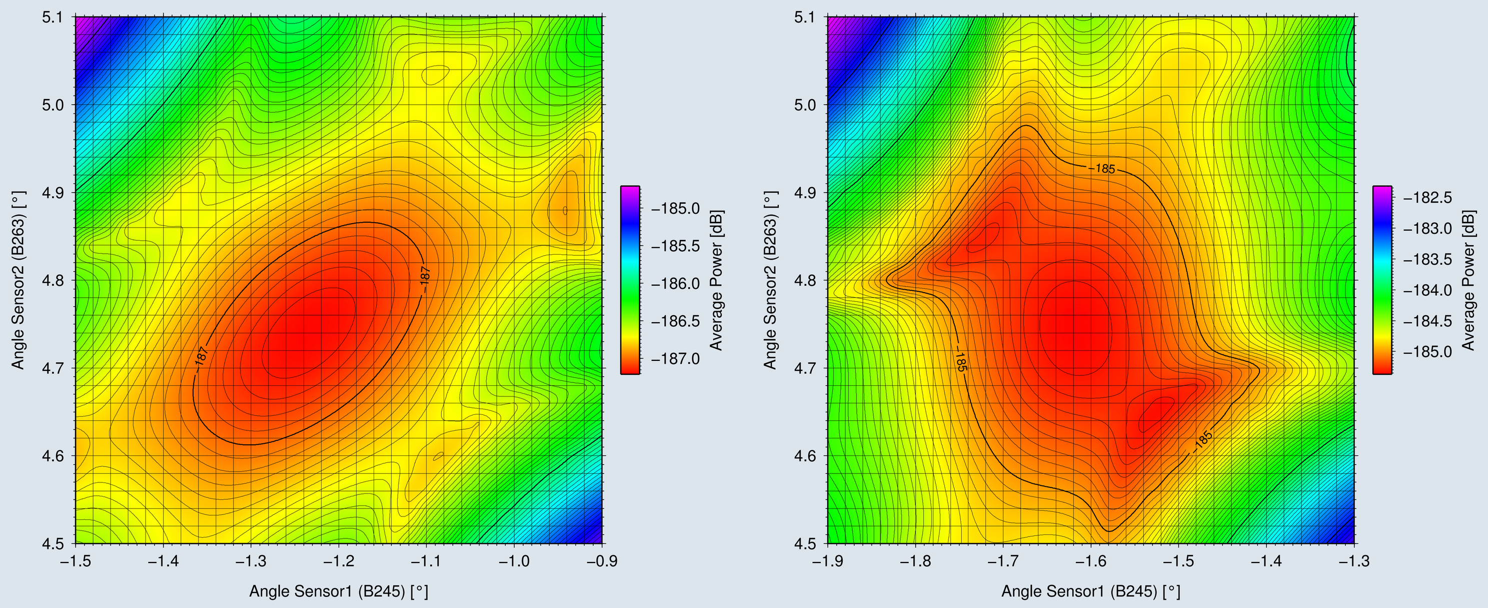


Fig.4: Mean self-noise from numerically rotating two sensors' horizontal components to achieve exact alignment with the third (B267).
Left: N/S-comp., Right: E/W-comp.

Tab.1: Table listing the optimal angles of rotation (ϱ_N/ϱ_E) to align the horizontal components of 11 RefTek 151-60A sensors. Differences of the angles of rotations ($\varrho_E - \varrho_N$) are listed boldfaced below them.

Sensor 3 ⟹ / Sensor 1/2 ⇓	B209	B220	B221	B224	B225	B226	B234	B245	B263	B267	B32C
B209	0.00	0.30/0.70 **0.40**	-5.31/-5.46 **-0.15**	0.02/0.27 **0.25**	3.27/3.66 **0.39**	0.57/1.03 **0.46**	-0.59/-0.04 **0.55**	2.15/2.83 **0.68**	-3.82/-3.55 **0.27**	0.90/1.23 **0.33**	-0.32/-0.04 **0.28**
B220	-0.30/-0.70 **-0.40**	0.00	-5.61/-6.16 **-0.55**	-0.28/-0.43 **-0.15**	2.97/2.96 **-0.01**	0.27/0.33 **0.06**	-0.89/-0.74 **0.15**	1.85/2.13 **0.28**	-4.12/-4.25 **-0.13**	0.60/0.53 **-0.07**	-0.62/-0.74 **-0.12**
B221	5.31/5.46 **0.15**	5.61/6.16 **0.55**	0.00	5.33/5.73 **0.40**	8.58/9.12 **0.54**	5.90/6.47 **0.57**	4.72/5.42 **0.70**	7.46/8.29 **0.83**	1.49/1.91 **0.42**	6.21/6.69 **0.48**	4.99/5.52 **0.53**
B224	-0.02/-0.27 **-0.25**	0.28/0.43 **0.15**	-5.33/-5.73 **-0.40**	0.00	3.25/3.39 **0.14**	0.55/0.76 **0.21**	-0.63/-0.28 **0.35**	2.13/2.56 **0.43**	-3.84/-3.82 **0.02**	0.88/0.96 **0.08**	-0.34/-0.21 **0.13**
B225	-3.27/-3.66 **-0.39**	-2.97/-2.96 **0.01**	-8.58/-9.12 **-0.54**	-3.25/-3.39 **-0.14**	0.00	-2.68/-2.65 **0.03**	-3.86/-3.70 **0.16**	-1.12/-0.83 **0.29**	-7.09/-7.21 **-0.12**	-2.37/-2.43 **-0.06**	-3.59/-3.60 **-0.01**
B226	-0.57/-1.03 **-0.46**	-0.27/-0.33 **-0.06**	-5.90/-6.47 **-0.57**	-0.55/-0.76 **-0.21**	2.68/2.65 **-0.03**	0.00	-1.18/-1.04 **0.14**	1.57/1.82 **0.25**	-4.40/-4.56 **-0.16**	0.32/0.23 **-0.09**	-0.90/-0.95 **-0.05**
B234	0.59/0.04 **-0.55**	0.89/0.74 **-0.15**	-4.72/-5.42 **-0.70**	0.63/0.28 **-0.35**	3.86/3.70 **-0.16**	1.18/1.04 **-0.14**	0.00	2.75/2.87 **0.12**	-3.23/-3.51 **-0.28**	1.50/1.28 **-0.22**	0.28/0.10 **-0.18**
B245	-2.15/-2.83 **-0.68**	-1.85/-2.13 **-0.28**	-7.46/-8.29 **-0.83**	-2.13/-2.56 **-0.43**	1.12/0.83 **-0.29**	-1.57/-1.82 **-0.25**	-2.75/-2.87 **-0.12**	0.00	-5.97/-6.37 **-0.40**	-1.23/-1.62 **-0.39**	-2.46/-2.77 **-0.31**
B263	3.82/3.55 **-0.27**	4.12/4.25 **0.13**	-1.49/1.91 **-0.42**	3.84/3.82 **-0.02**	7.09/7.21 **0.12**	4.40/4.56 **0.16**	3.23/3.51 **0.28**	5.97/6.37 **0.40**	0.00	4.74/4.75 **0.01**	3.50/3.51 **0.01**
B267	-0.90/-1.23 **-0.33**	-0.60/-0.53 **0.07**	-6.21/-6.69 **-0.48**	-0.88/-0.96 **-0.08**	2.37/2.43 **0.06**	-0.32/-0.23 **0.09**	-1.50/-1.28 **0.22**	1.23/1.62 **0.39**	-4.74/-4.75 **-0.01**	0.00	-1.23/-1.25 **-0.02**
B32C	0.32/0.04 **-0.28**	0.62/0.74 **0.12**	-4.99/-5.52 **-0.53**	0.34/0.21 **-0.13**	3.59/3.60 **0.01**	0.90/0.95 **0.05**	-0.28/-0.10 **0.18**	2.46/2.77 **0.31**	-3.50/-3.51 **-0.01**	1.23/1.25 **0.02**	0.00

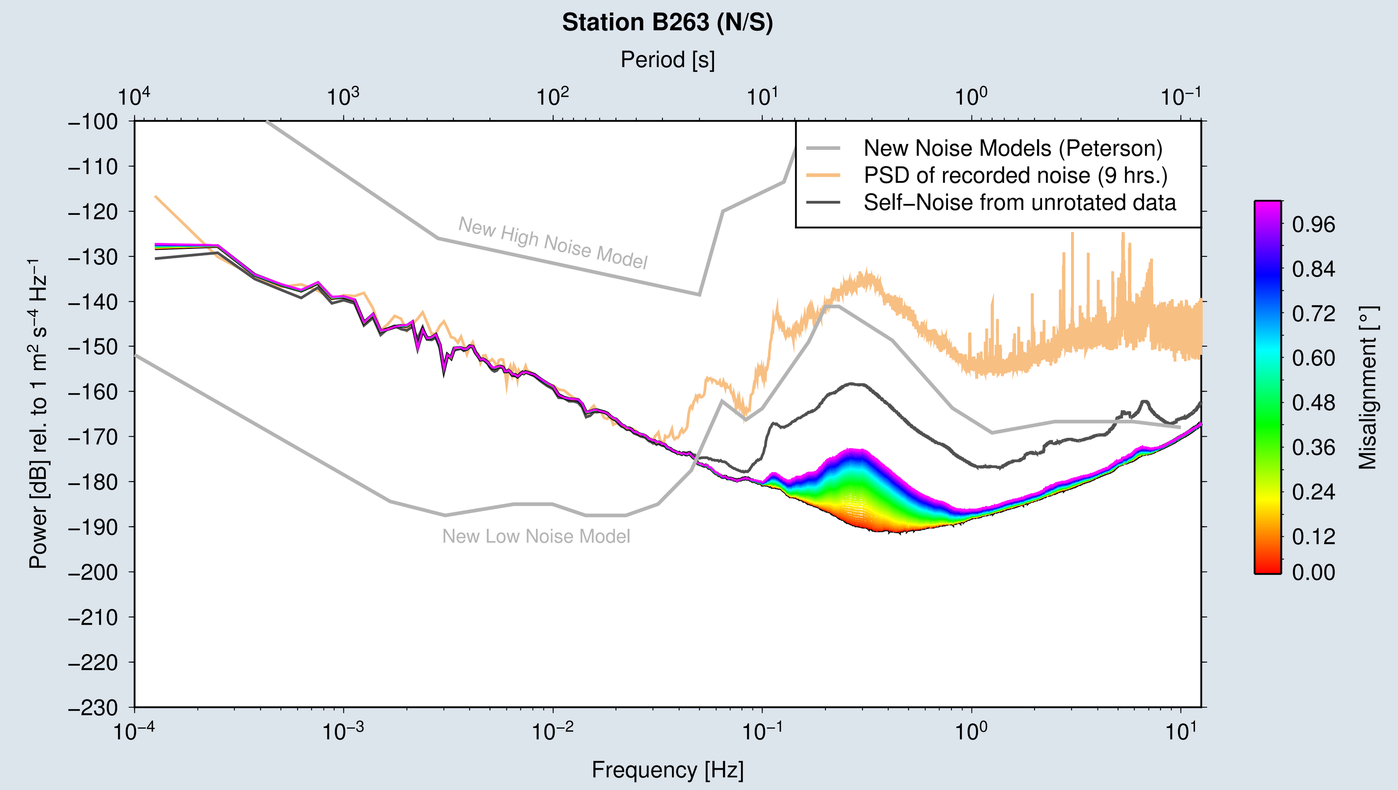


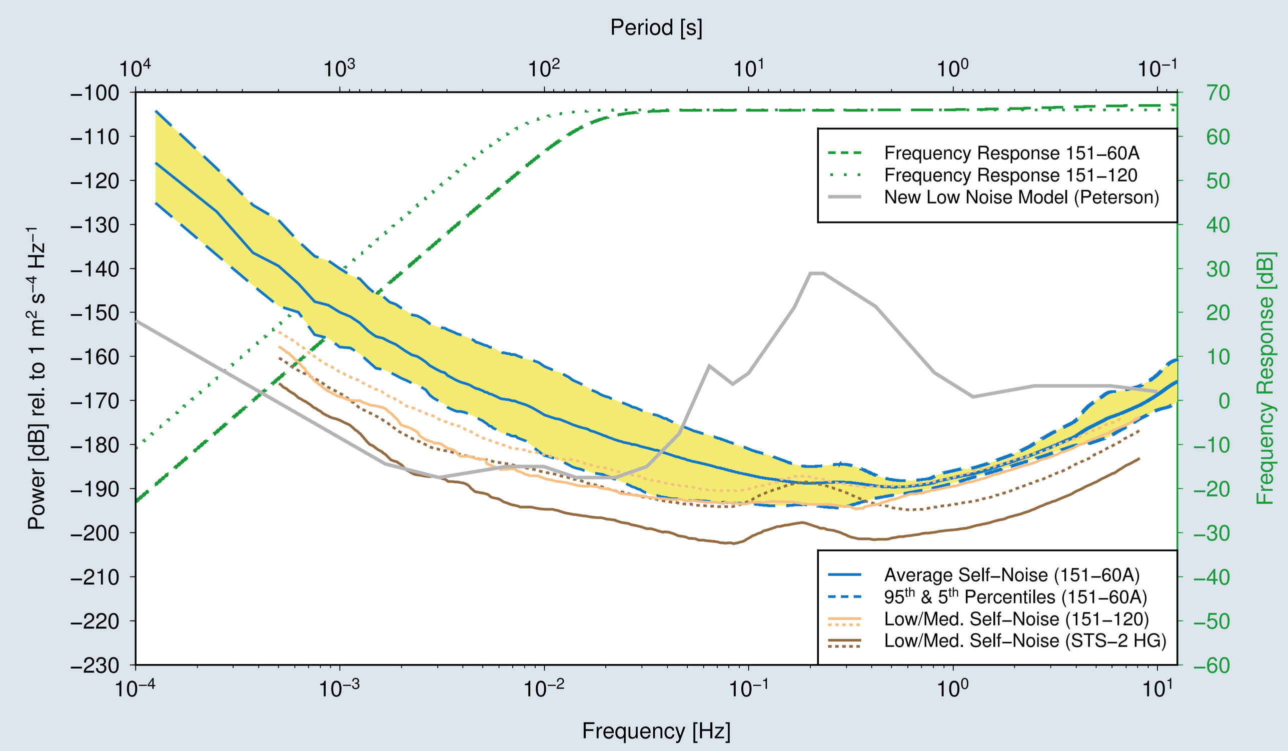
Fig.5: Misalignment of only one single station (B263) primarily manifests itself through leakage of microseism noise into the self-noise estimate of that station (colored lines). This leakage is quite significant, reaching more than 10 dB at 0.3 Hz for 0.5° of misorientation.

Self-noise estimates of the other two stations (not shown here) exhibit only very small variations since they are still well aligned.

Self-Noise Model for the RefTek 151-60A

Fig.6: Self-noise model for the RefTek 151-60A calculated from data (9 hrs.) recorded at the Conrad Observatory by 15 collocated sensors. Self-noise was computed for all possible permutations of triples of sensors (vertical components only). From the results, 306 self-noise curves of 13 sensors were selected for derivation of this model. To best estimate the true self-noise, curves of clearly misaligned triples of sensors were excluded.

Taking into account the intermediate price of the 151-60A in relation to RefTek's 151-120 or Streckeisen's STS-2, our results compare fairly well with their self-noise models, which have been included in the figure as digitized from the work published by Ringler & Hutt (2010).



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