Analysis of STS1-E300 Measurements at Albuquerque Seismic Lab

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May 5, 2007

On April 4, 2007 Metrozet's STS1-E300 Electronics Module was installed on to a triaxial set of STS-1 sensors (2 Horizontal and 1 Vertical) at the USGS Albuquerque Seismological Laboratory (USGS/ASL, where GSN station ANMO is located). These sensors were co-located and co-aligned with ASL's permanent set of triaxial, STS-1 reference sensors. The reference sensors were operating using the original Streckeisen "Feedback Electronics" boxes. Signals from the six axes are being recorded using a Quanterra Q680 digitizer.

This experimental setup is being used by ASL personnel as part of an independent test of the Metrozet STS1-E300 electronics. The ASL team has been exercising the many operating modes of the STS1-E300 module (including its comprehensive sensor control, motor control, calibration, and diagnostic modes; see www.metrozet.com for details of the STS1-E300 module). One important test is to determine instrumental noise performance at a relatively quiet test site, such as ANMO. As is widely agreed, analysis of Z-axis (vertical) data is preferred in order to understand the noise contribution from the sensor electronics. This is because of the ability to measure background ambient seismic, as well as incoherent sensor noise, to much lower levels, using vertical sensors.

This analysis has been performed by Metrozet. However, careful attention has been paid ensuring that the spectral amplitudes agree closely with those calculated by Bob Hutt at ASL.

The data presented here are from a quiescent 16,000 second period (beginning on UTC day 105, at UTC time 08:49:49). 1 Hz (0.4 Hz Nyquist) data are used. The two raw data files used are available for download at www.metrozet.com.

The first:
"DATA_XX_NHYX_00_LHZ_2007_105_08_49"
is for the ASL reference STS-1 Z-channel (with factory electronics).

The second:
"DATA_XX_NHYX_20_LHZ_2007_105_08_49"
is for the test STS-1 Z-channel (with Metrozet STS1-E300 electronics)

The data are analyzed according to the following algorithm:

1. Raw data (counts) are multiplied by the digitizer scale factor. For the LH data, this value is 9.536E-7 Volts per count (including the standard 2.384uV/count weight of the digitizer, and a 4X factor introduced by the Q680's LH, 1 Hz, decimation filter). Following this scaling, the data are in Volts.

2. The voltage data are divided by the scalar responsivity (2452 V-sec/m for the reference sensor, and 3336 V-sec/m for the test sensor). Note that the test sensor responsivity (using the STS1-E300) was calculated from the original factory calibration sheet, using “Metrozet STS-1 Scale Factor Calculator V1.0” software applet. As is shown below, this provides a nearly exact value for the scalar responsivity. Following this scaling, the data are in units of velocity (m/sec).
3. The data set is divided into 16 contiguous, non-overlapping segments, each of 1000 second length. There are two such sets of data: one for the reference sensor and one for the test sensor.
4. This data are windowed, using a Hanning window.
5. The power spectral density (PSD), and the inter-sensor coherence is calculated for each of the 1000 second records.
6. The PSD values are scaled to correct for the noise bandwidth factor of the Hanning window.
7. The PSDs and coherence records are stacked and averaged. The PSDs use RMS averaging and the coherence uses vector averaging. The result of this are two PSD spectra (SIGNAL spectra; one for each sensor), and a single coherence spectrum.
8. The SIGNAL PSD plots indicate that the long period response of the two sensors is nearly identical. As such, we apply a ***nominal*** long period de-convolution to the data (using a conjugate pole pair at $0.01234 \pm 0.01234i$ radians per second). This converts the PSD plots to “exact” velocity, over the band of 2.5 seconds to 1000 seconds. Note that at periods shorter than 2.5 seconds, the indicated velocity is affected by the Q680 decimation filter.
9. Using a standard algorithm for incoherent noise calculation (e.g., Barzilai, et. al., *Review of Scientific Instruments*, **69**, 2767 (1998)), we calculate the incoherent noise, that is attributable equally to each of the sensors. As is obvious from the data, this “identical” sensor treatment is quite justified: the signal PSD’s are identical, even within the frequency range exhibiting the lowest signal PSD values (50 to 1000 seconds).
10. All of the spectral data (SIGNAL PSD and INCOHERENT NOISE PSD) are converted to acceleration units, as is customary for this community. This is accomplished through spectral differentiation (multiplication by $2\pi f$ at each point). The resulting data are plotted in db units (re 1 $mRMS^2/sec^4$-Hz)
11. The resulting spectral plots do exhibit a degree of statistical variation (“noise”) in their values that is consistent with using only 16 averages. We do not perform any smoothing of these curves.

The resulting plots are shown below. The top plot shows the SIGNAL PSD. This is simply the background signal at ANMO. The overlap of the curves from the two sensors is nearly exact (typically to within 0.1 dB) over the entire band. The largest deviation occurs at periods at which the PSD values are the smallest (300 to 700 seconds). This is consistent with the fact that we are observing signal levels that are within 6 to 10 dB of the incoherent noise floor of the sensors. We expect, and observe, fluctuations between the recorded PSDs, due to the contribution of this incoherent noise. Note that with some data sets, the test data may have lower PSD values than the reference in this band. In others, the situation may be reversed (according to ASL analyses). For reference, the New Low Noise Model (NLNM) is plotted (green curve).

The second plot shows the INCOHERENT NOISE PSD for each sensor (using the other as a reference within the coherence calculation). Again, the noise plots overlap very closely. They are well below the NLNM at all periods within this band. Note that the rise in calculated INCOHERENT NOISE within the microseismic noise band (2.5 to 10 seconds in this case) is not illustrative of the actual noise of either sensor. It is simply a consequence of the limitation of a coherence analysis to measure noise in the presence of large backgrounds. The practical limit to coherence is observed to be 0.999998 in this band. Given that the SIGNAL PSD levels approach -120 dB, coherence techniques can only be expected to resolve incoherent noise down to a level of -180 dB. ***We are quite certain that the actual INCOHERENT NOISE level of either sensor is at or below -200 dB within the microseismic band.***

The third plot shows the inter-sensor coherence. As discussed above, it is nearly 1.00000 within the microseismic band. As expected, it drops somewhat between 300-700 seconds. This is the point at which the ANMO background signal is dropping to a level that is close to the self-noise of each sensor.

In conclusion:

1. The STS1-E300 provides analog performance that is nearly identical to that of the original Factory Electronics box.
2. The calculated self noise of an STS1-E300-equipped sensor is well below the NLNM over the entire band used within this analysis (2.5 seconds to 1000 seconds).
3. The long period frequency response of a sensor using the STS1-E300 is indistinguishable to that of the original sensor.
4. The exact scalar responsivity of any STS-1 sensor using the STS1-E300 module can be calculated accurately, using a Metrozet-supplied software applet.

For Further Information

To discuss any details of this analysis, or of the STS1-E300 module, contact:
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Comparative Plots from ASL Data
Vertical STS-1 Sensors:

ASL Reference STS-1 with Factory Electronics (BLUE)

STS-1 with Metrozet STS1-E300 Electronics (RED)

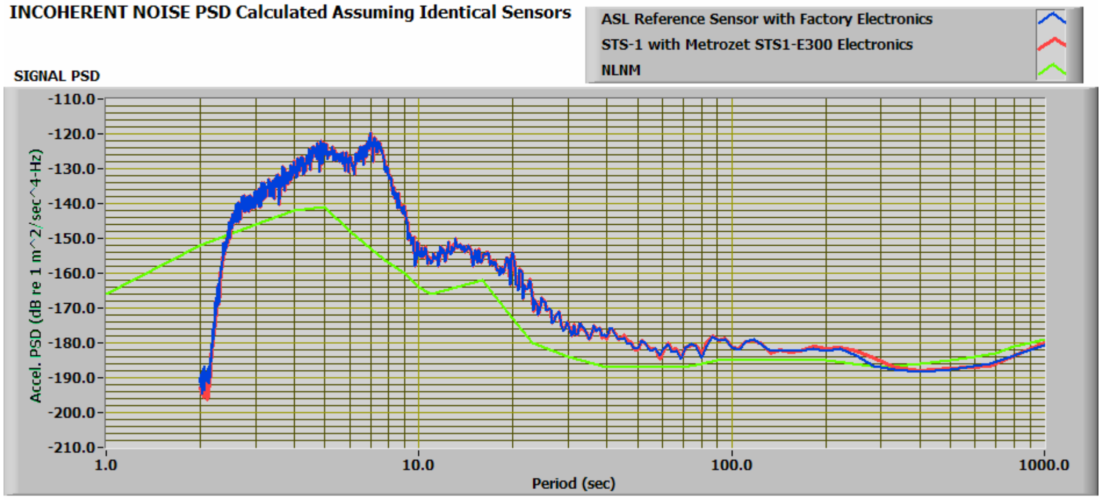
NLNM (GREEN)

Using Q680 Digitzer LH data (1 Hz Output; 0.4 Hz Nyquist)

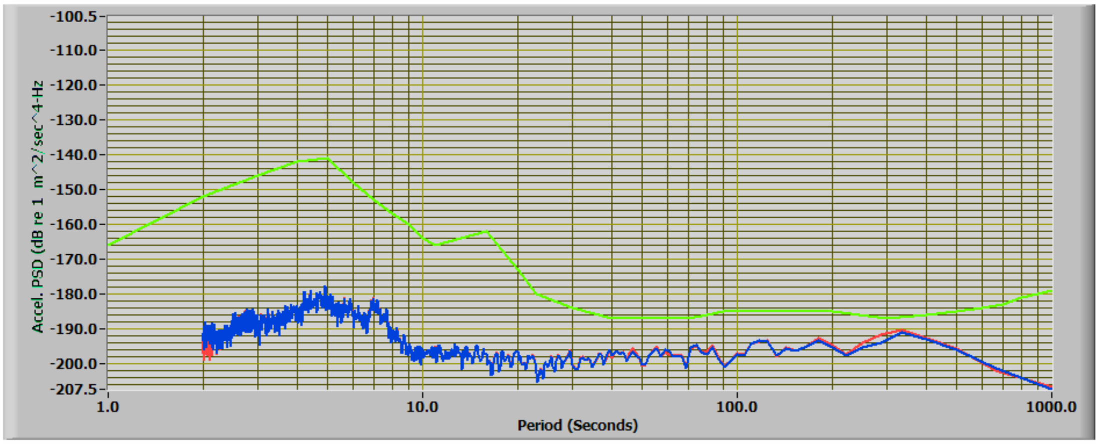
SIGNAL PSD
INCOHERENT NOISE PSD
COHERENCE

INCOHERENT NOISE PSD Calculated Assuming Identical Sensors

SIGNAL PSD



INCOHERENT NOISE PSD



COHERENCE