Sensor Noise Estimates for Advanced LIGO Seismic Isolation Systems

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Sept. 28, 2009

1 Summary

This document, and the associated matlab file, SEI_sensor_noise.m, are intend to simplify the distribution of noise estimates and sensor response for the self-noise (including LIGO-added preamps, if any) of sensors used for the LIGO SEI system. A summary plot of the estimated noise of the various sensors in shown in figure 1.

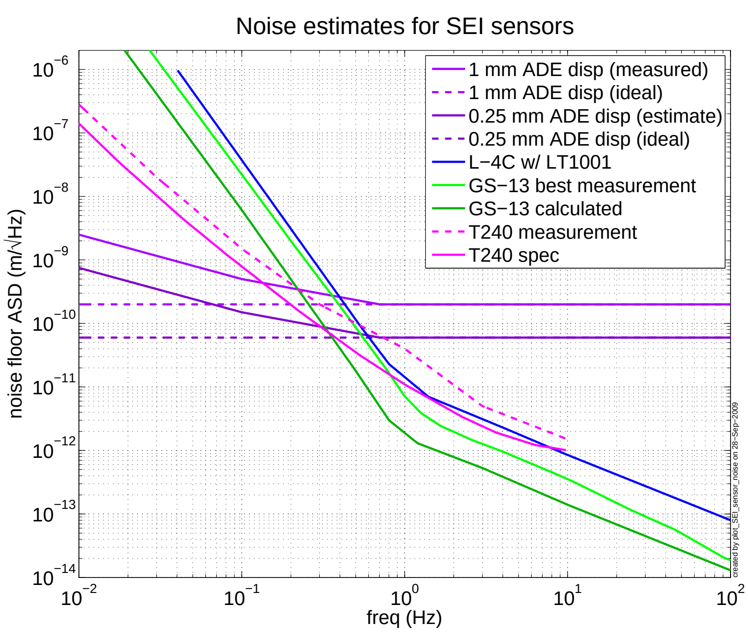

Figure 1: Noise estimates for the various SEI sensors.

The sensors include: ADE capacitive displacement sensors with +/- 1 mm and +/- 0.25 mm ranges (the **ADE_1mm** and **ADE_p25mm**), the GS-13 seismometer with on-board preamp, both calculated and measured (the **GS13calc** and **GS13meas**), the L-4C seismometer with its on-board preamp (the **L4C**), the Nanometrics Trillium 240 low-frequency seismometer, both specified and measured (the **T240spec** and **T240meas**), the Streckeisen STS-2 low-frequency seismometer (the **STS2**), and the Kaman DIT-5200 eddy current displacement sensor (the **Kaman_1mm**). Descriptions of origins of the various estimates follows.

2 Matlab code

There is a stand-alone matlab function 'SEI_sensor_noise.m' which can be used to return both the sensor noise ASD in meters/$\sqrt{\text{Hz}}$, and the sensor's (including preamp, if any) response function in volts/meter, as a function of frequency. The script plot_SEI_sensor_noise.m makes a summary plot of the various instruments, as shown in figure 1.

3 ADE capacitive sensors

There are two different versions of the ADE capacitive sensor now in use. They are nearly indistinguishable, as they use the same active head and readout box. The difference is that one is set to have a +/- 1 mm range, and the other is set to use a +/- 0.25 mm range.

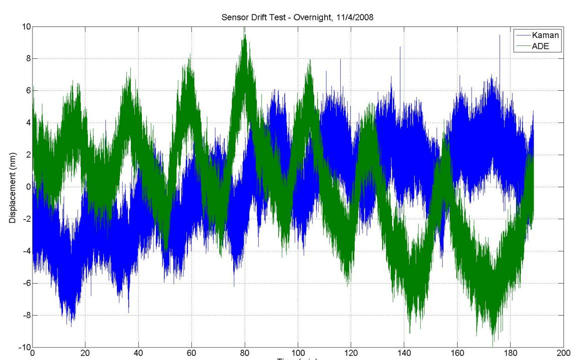

Figure 2: Time history signal from the 1 mm ADE and Kaman sensors, locked down. The drift is caused, at least in part, by temperature variations from the air conditioning.

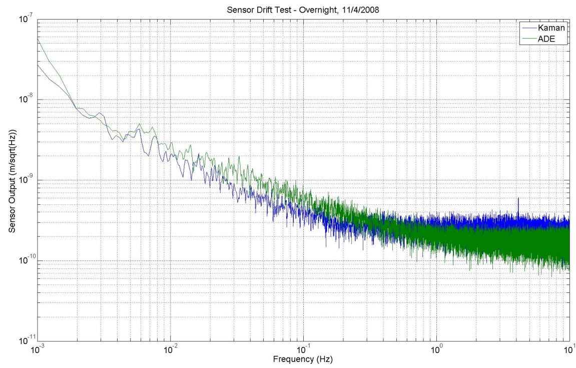

Figure 3: ASD of the signal from the 1 mm ADE and Kaman sensors, locked down. The low frequency noise is caused, at least in part, by temperature variations from the air conditioning.

3.1 +/- 1 mm ADE sensor

Per measurements by Andy Stein and email from the manufacturer (see SEI log entries http://ligo.phys.lsu.edu:8080/SEI/1311 and http://ligo.phys.lsu.edu:8080/SEI/1219), the noise of the sensors with the +/- 1 mm range ought to be flat with frequency (it's a modulated sensor) with a noise of about 2×10^{-10} meters/$\sqrt{\text{Hz}}$. The data from Andy show increased noise at low frequency, and show that this is clearly the result of room temperature variations. For our estimate, we use the increased low frequency noise. For sensors in the vacuum system, the noise at low frequencies ought to be much better than this. For sensors outside the chamber, like the Kaman sensor, this is a serious cause for concern.

3.2 +/- 0.25 mm ADE sensor

Data from Jay Heefner (XXX put in SEI log ref from 2XXX) put the measured noise of this device at about 6×10^{-11} meters/$\sqrt{\text{Hz}}$. Since we are told that the noise and full-scale range should scale together for these devices, this is about what one would expect for a sensor with 1/4 of the range of the +/- 1 mm device. What we do is to scale the noise for the 1 mm sensor so that the high frequency noise is 6×10^{-11} meters/$\sqrt{\text{Hz}}$. This results in noise estimates shown below

4 Kaman displacement sensor

get Rich's curve for this.

Frequency (Hz)	+/- 1 mm sensor noise ASD (m$\sqrt{\text{Hz}}$)	+/- 0.25 mm sensor noise ASD (m$\sqrt{\text{Hz}}$)
1e-3	5e-8	1.5e-8
2e-3	9e-9	2.7e-9
1e-2	2.5e-9	7.5e-10
0.1	5e-10	1.5e-10
0.7	2e-10	6e-11
100	2e-10	6e-11

Table 1: Noise estimates for ADE sensors

5 GS-13 Seismometer

The GS-13 seismometer has a LIGO preamp using the LT1012 mounted in the instrument (see T0900457-v1). The best noise performance we have measured with this instrument still does not match the predictions. The prediction for the LT1012 is calculated by the matlab function GS13_noise_calc_2007(freq,'lt1012'). A quick fit to that is shown in the table below. This calculations is a bit involved, so a quick fit to the predicted noise floor is given below in table 2. In figure 4 we see that the fit is quite good. However, the best measured noise is not as good as the prediction. The best measured noise is shown in figure 5. To design the readout electronics (ADC levels, etc) we use the calculated noise performance, but to estimate ultimate platform motion, we use the measured data. This is the conservative approach.

Frequency (Hz)	GS-13 calculated noise ASD (m$\sqrt{\text{Hz}}$)
0.01	1.9e-5
0.1	6.1e-9
0.5	1.8e-11
0.8	3.0e-12
1.2	1.3e-12
3	5.3e-13
10	1.4e-13
100	1.3e-14

Table 2: Calculated noise estimate for the GS-13 with LT1012 preamp

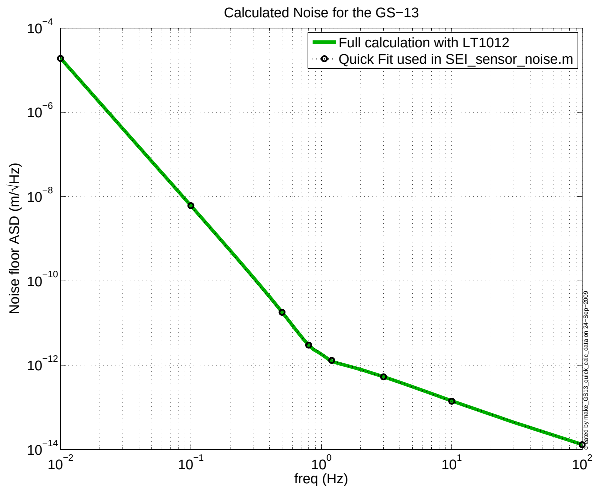

Figure 4: Full calculation and quick fit for the GS-13 with the LIGO LT1012 preamp.

6 L-4C Seismometer

The noise for the L4C has been both measured on the Tech Demo table, and calculated based on the given noise for the L-4C and the LT1001 used for the preamp. The calculations for the LT1001 are described in T0900449 'Changing the op-amp for the L-4C seismometer preamp'.

Frequency (Hz)	L-4C w LT1001 noise ASD (m$\sqrt{\text{Hz}}$)
0.04	1.0e-6
0.52	1.0e-10
0.8	2.3e-11
1.4	7.0e-12
4	2.3e-12
10	8.5e-13
100	8.0e-14

Table 3: Noise estimates for L-4C sensor

In 2006, we measured the noise floor of 4 witness L-4Cs mounted on the stage 2 optical table of the Tech Demo, with all the isolation loops running, and compared the noise of the sensors (using the multi-channel coherent subtraction method) against the

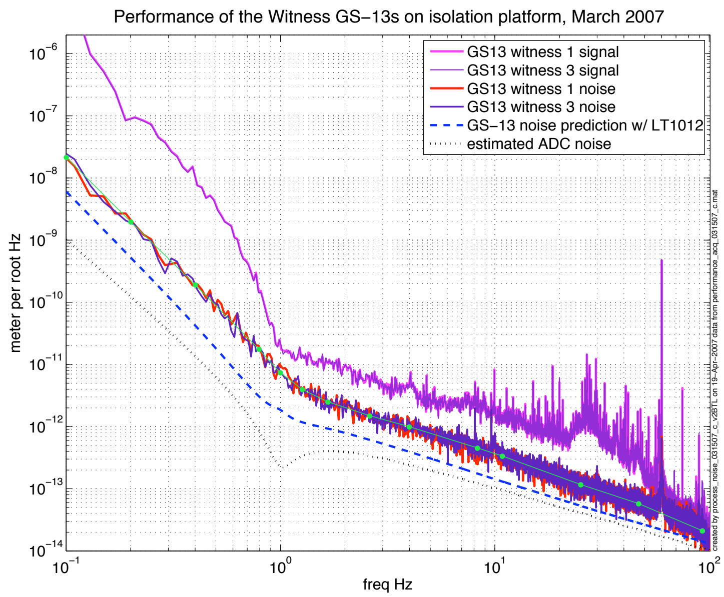

Figure 5: Best measured noise performance of the GS-13, with fit. Data from Tech Demo in March 2007.

predicted noise floor from the LT1001, and showed that they match pretty well. See http://ligo.phys.lsu.edu:8080/SEI/679.

7 Nanometrics Trillium 240

The noise estimate use for the T240 is just the specification given by the manufacture. We have some data for the noise floor, but have not been able to reach this specification. The cause of the discrepancy is not known. The manufacture's noise curve is shown below in figure 8.

The data we measured was done with at Trillium 240 and 2 STS-2s on the optics table of the Tech Demo at Stanford. The measurements were done with stage 1 locked to stage 0, and stage 2 floating with the damping loops on. The doors were closed but the systems were at air (check this).

We assume that the instrument noise floor is not a function of direction, since the the actual device comprises 3 identical umbrella angle sensors which are then electronically

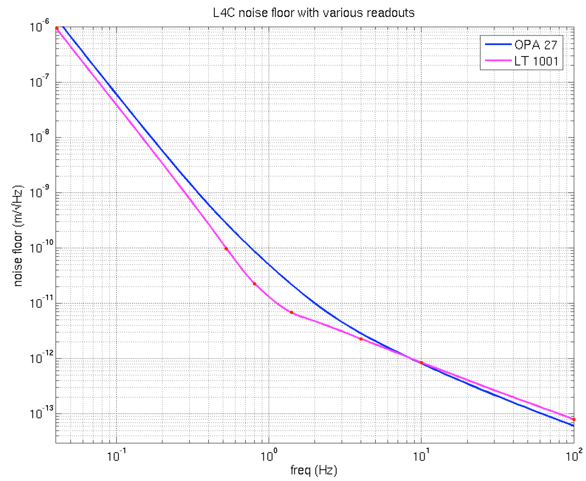

Figure 6: Predicted (magenta curve) and fitted (red dots) noise of the L-4C with the LIGO LT1001 preamp.

combined to make the x-y-z outputs. Certainly this is not fair for certain environmental effects. For example, at low frequency X and Y will be affected by thermal case distortions (which cause the instrument to tilt) much more severely than Z, and Z is much more sensitive to overall temperature changes (which cause the suspension springs to sag). We include all 3 data sets here, and hope that we will get this right in the pod design. This said, we can make the 'best measured' table shown below. It is not surprising that the best data above 0.1 Hz is from X, since the 3 sensors were all aligned along the X axis, so the subtraction should be the best, there. The data at 10 mHz are not very good, so we estimate the noise there at twice the manufacture's spec, which is the same ratio as the data at 30 mHz. These estimates should be taken with skepticism.

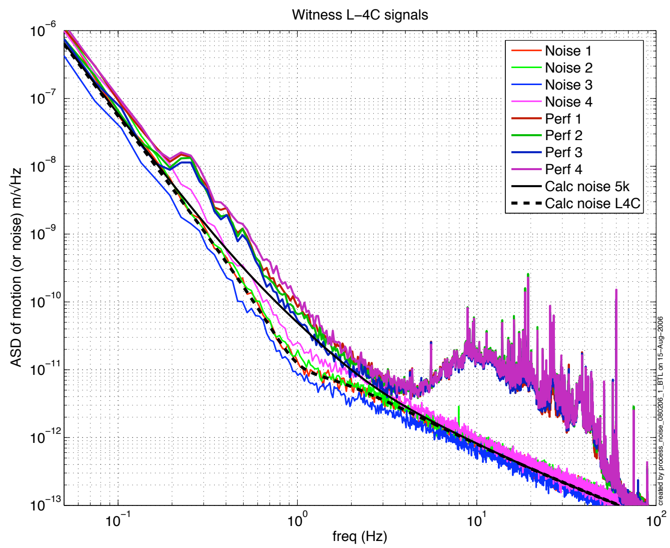

Figure 7: Measured noise of the L-4C with the LIGO LT1001 preamp. Note that the measured noise matches the predicted noise of the preamp pretty well.

Frequency (Hz)	T240 measured noise ASD (m$\sqrt{\text{Hz}}$)	DOF used
0.01	2.8 e-7	guess from Z
0.03	2e-8	Z
0.1	1.5e-9	all
0.3	2e-10	X
1.0	4e-11	X
3.0	5e-12	X
10	1.5e-12	X

Table 4: Noise estimates for T-240 sensor

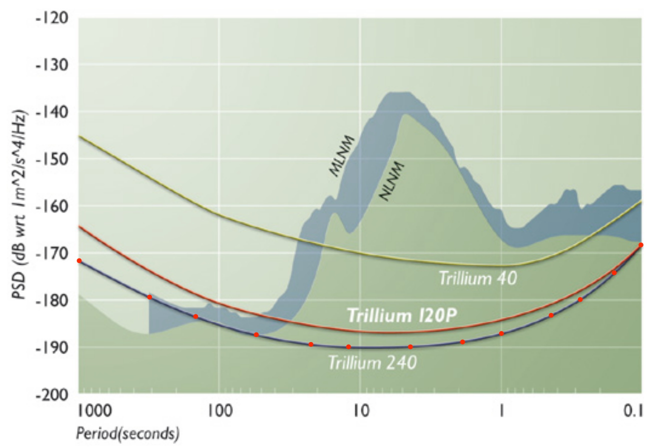

Figure 8: Manufacturer's noise specification from the Trillium 240, with red dots indicating the points used for our fit.

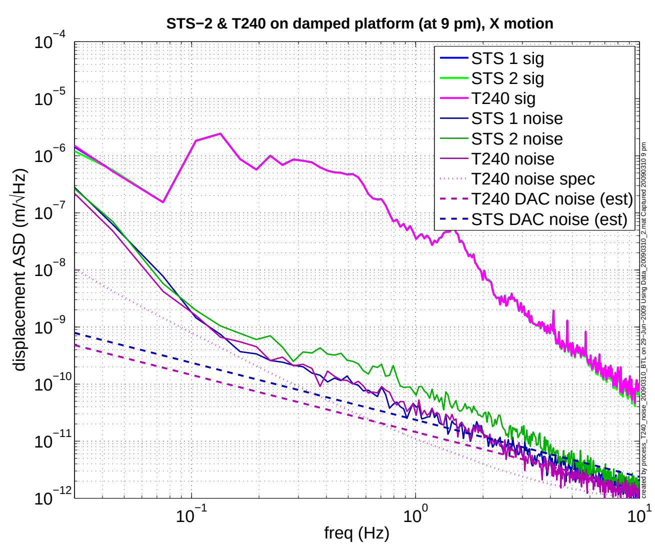

Figure 9: Best measured noise performance of the T240 in X. Data from Tech Demo in March 2009.

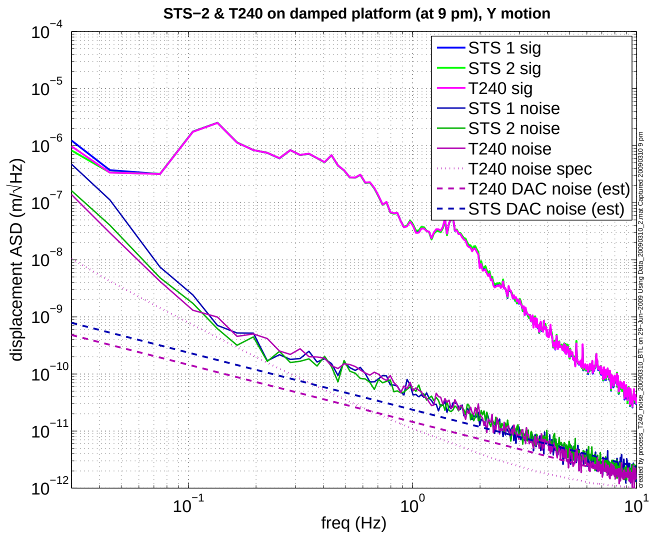

Figure 10: Best measured noise performance of the T240 in Y. Data from Tech Demo in March 2009.

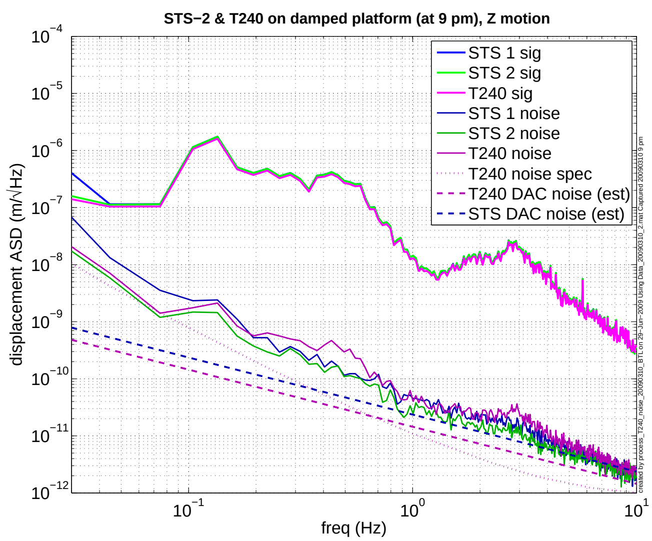

Figure 11: Best measured noise performance of the T240 in Z. Data from Tech Demo in March 2009.