LIGO Laboratory / LIGO Scientific Collaboration

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aLIGO HAM-ISI, Phase III Testing report

(Control Commissioning)

LLO HAM 3

E13000155-V6

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Distribution of this document:
Advanced LIGO Project

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Introduction

This document presents the tests performed to characterize and validate the "HAM-ISI LLO Unit #3". This unit was the 3rd unit assembled for aLIGO at LLO. This unit was partially assembled in Fall 2010, but following the discovery of unauthorized repairs in the parts, the assembly was interrupted. All parts in questions were disassembled. This unit was the 1st to be re-assembled when the assembly started back in Spring 2011.

This was the first unit pulled out from storage for installation at Livingston in January 2012, to be installed in HAM 3 chamber. Horizontal seismometers, springs tuned mass dampers, and final cables were installed. Also, the Capacitive Position Sensors cables were shielded.

Phase 1 Report validates the assembly:

LIGO-E1000327: aLIGO HAM-ISI, Test Report, Phase I: Assembly Validation, LLO Unit #3 (HAM3)

Phase 2 report validates the integration with HEPI and the suspensions:

LIGO-E1200104: aLIGO HAM-ISI, Pre-Installation Test Report, Phase II, LLO HAM 3

This document (Pphase 3) validates the controls commissioning. It is made of two parts:

- Part I: Transfer Functions and Control Loops
- Part II: Noise and Noise measurements

I. Transfer Functions and Control Loops

1. Local to local Transfer Functions

Measurements taken after the fall 2012 vent used to install HEPI, before closing the chamber (90 repetitions). This set of measurements (from 12/17/12) is the one used for all the following simulation plots of this section.

Data files in SVN at:
seismic/HAM-ISI/L1/HAM3/Data/Transfer_Functions/Measurements/Undamped/
- LLO_ISI_HAM3_Data_TF_L2L_50mHz_500mHz_20121218-021643.mat
- LLO_ISI_HAM3_Data_TF_L2L_500mHz_5Hz_20121217-200710.mat
- LLO_ISI_HAM3_Data_TF_L2L_5Hz_200Hz_20121217-183337.mat
- LLO_ISI_HAM3_Data_TF_L2L_200Hz_800Hz_20121218-052216.mat

Data collection script files:
seismic/HAM-ISI/L1/HAM3/Scripts/Data_Collection/
- Run_Exc_Batch_L1ISIHAM3.m

Scripts files for processing and plotting in SVN at:
seismic/HAM-ISI/L1/HAM3/Scripts/Control_Scripts/Version_2/
- Step_1_TF_L2L_L1_ISI_HAM3.m

Figures in SVN at:
/seismic/HAM-ISI/L1/HAM3/Data/Figures/Transfer_Functions/Measurements/Undamped/
- LLO_ISI_HAM3_TF_L2L_Raw_from_ACT_to_CPS_2012_10_17.fig
- LLO_ISI_HAM3_TF_L2L_Raw_from_ACT_to_GS13_2012_10_17.fig

Storage of measured transfer functions in the SVN at:
seismic/HAM-ISI/L1/HAM3/Data/Transfer_Functions/Simulations/Undamped/
- L1_HAM_ISI_Unit_3_Data_TF_L2L_2012_12_17.mat

The local to local transfer functions are presented below.

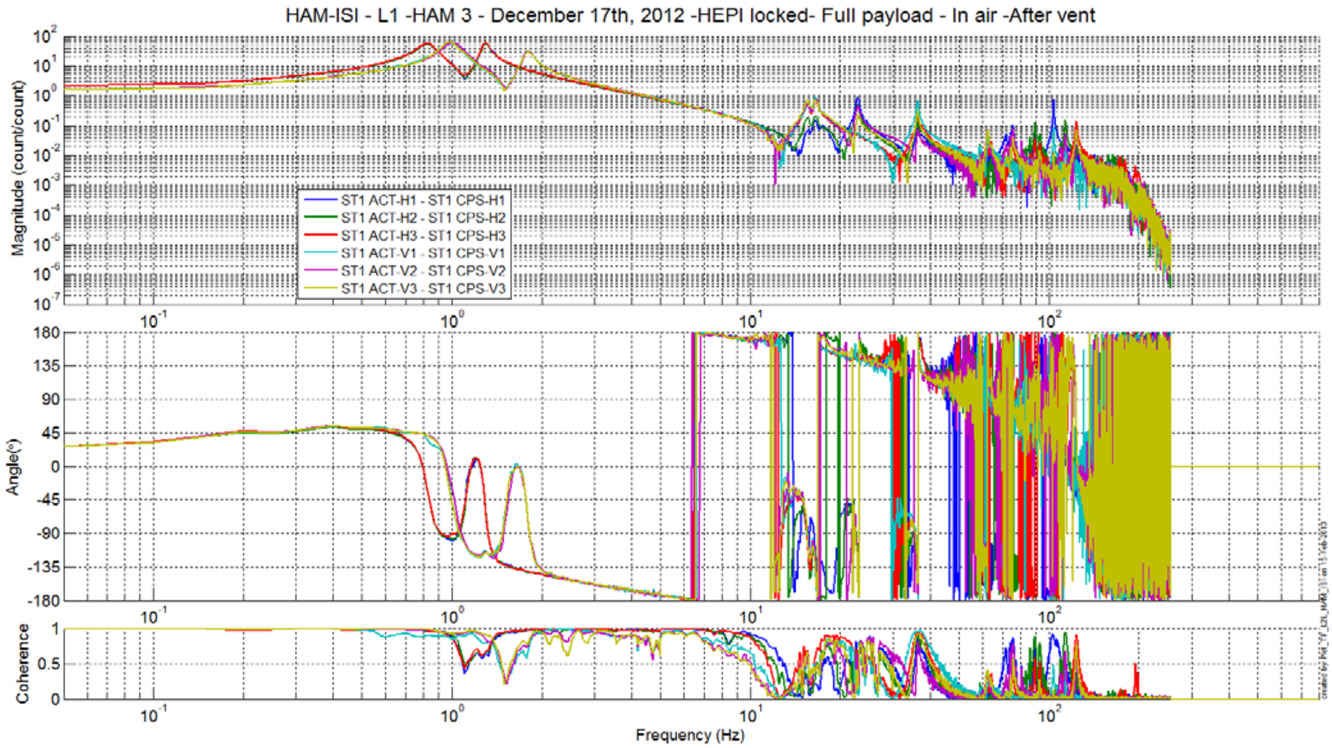


Figure - Local to Local Measurements –Capacitive Position Sensors

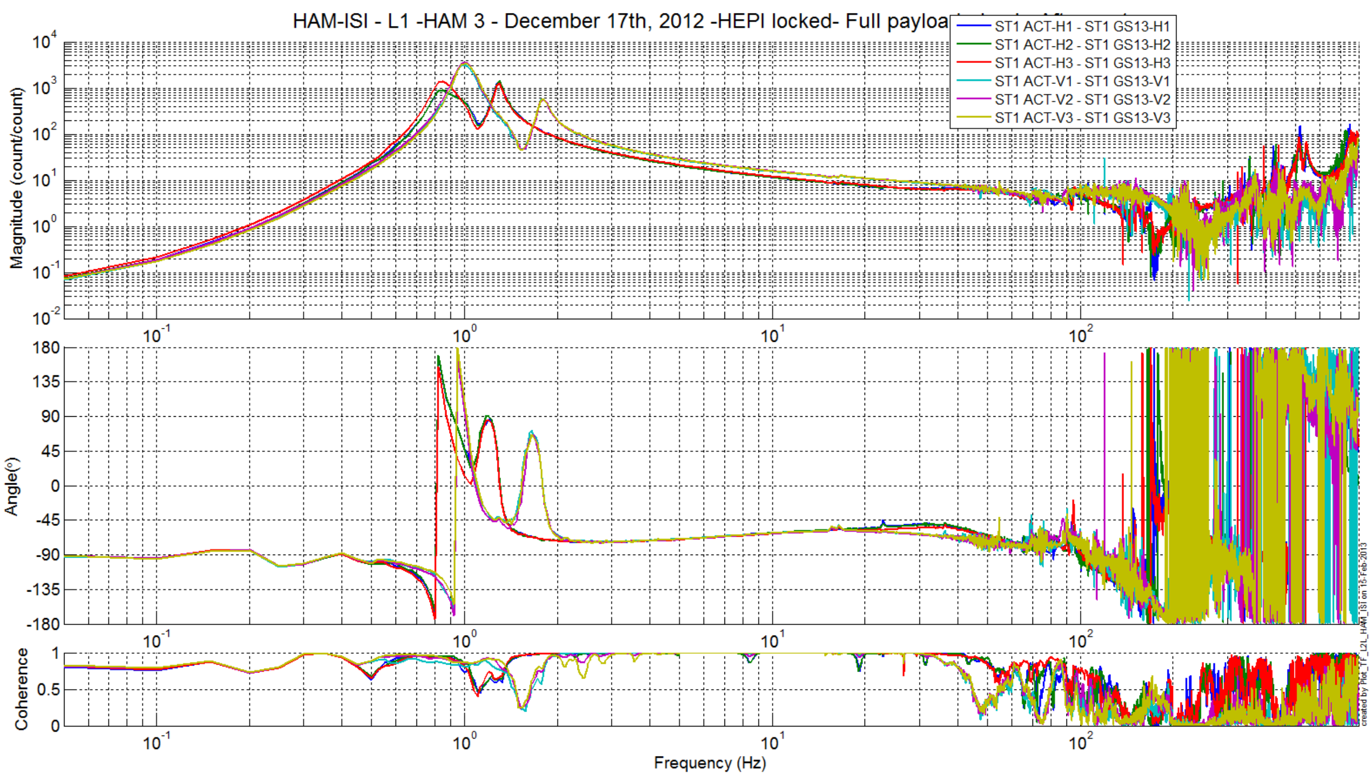
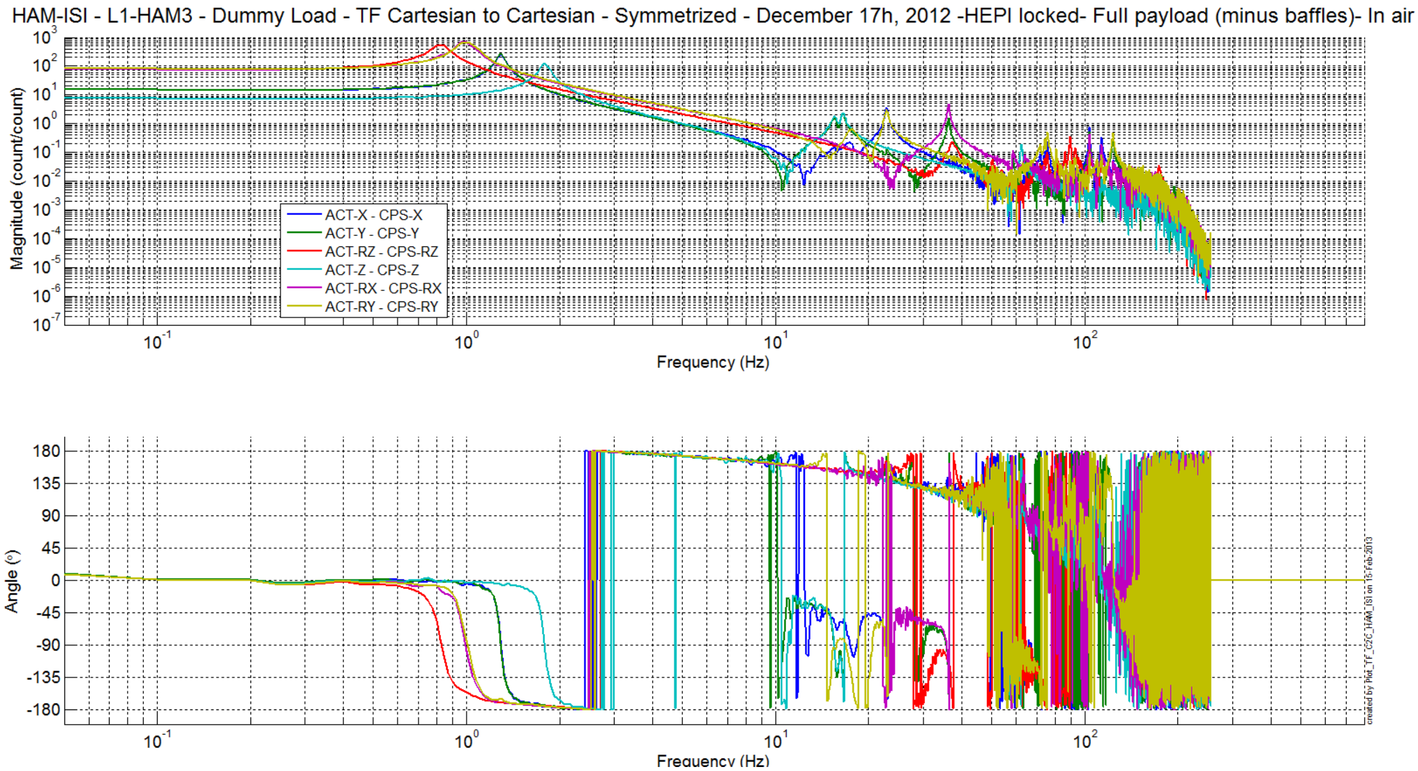


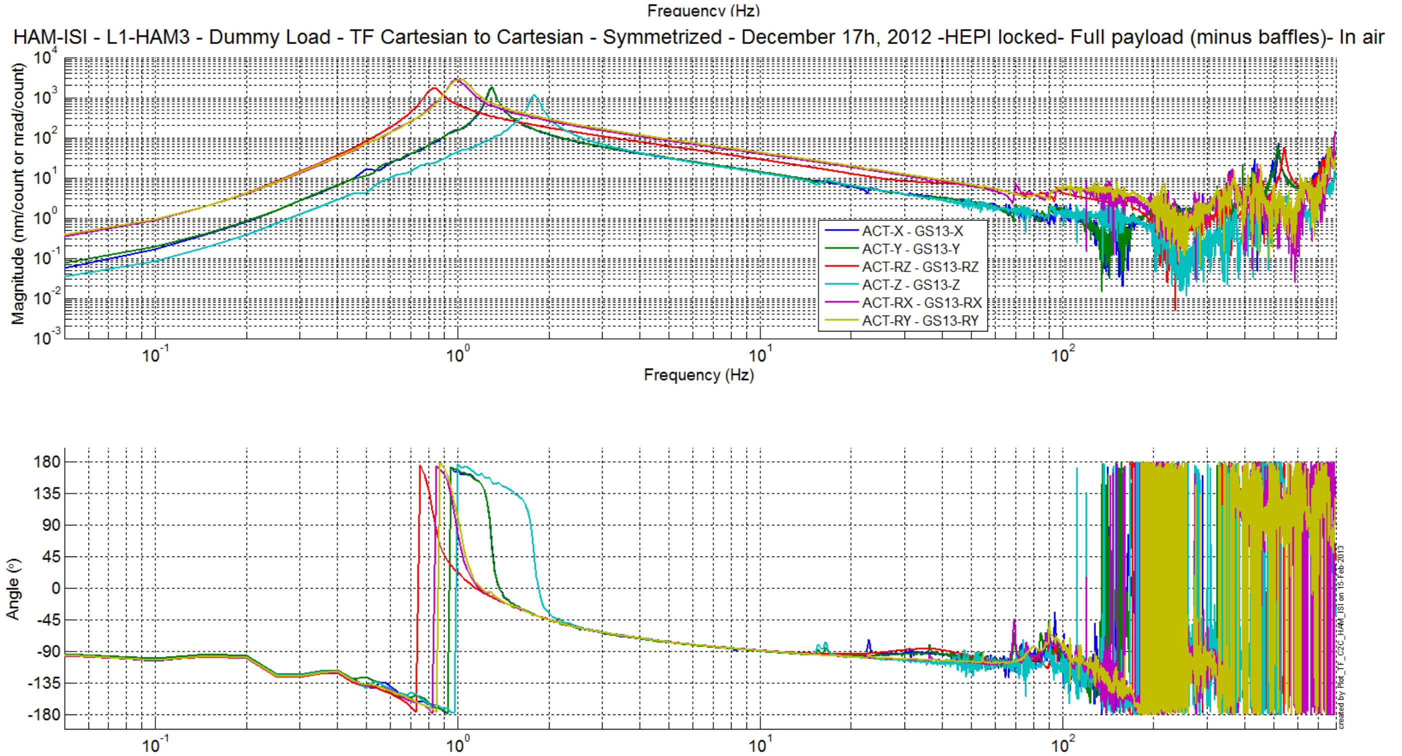
Figure - Local to Local Measurements – Inertial sensors

2. *Step 3 Cartesian to Cartesian transfer functions*

Step 3 recombines those transfer functions in Cartesian to Cartesian coordinates, after the sensor/actuators responses have been normalized in Step 2.

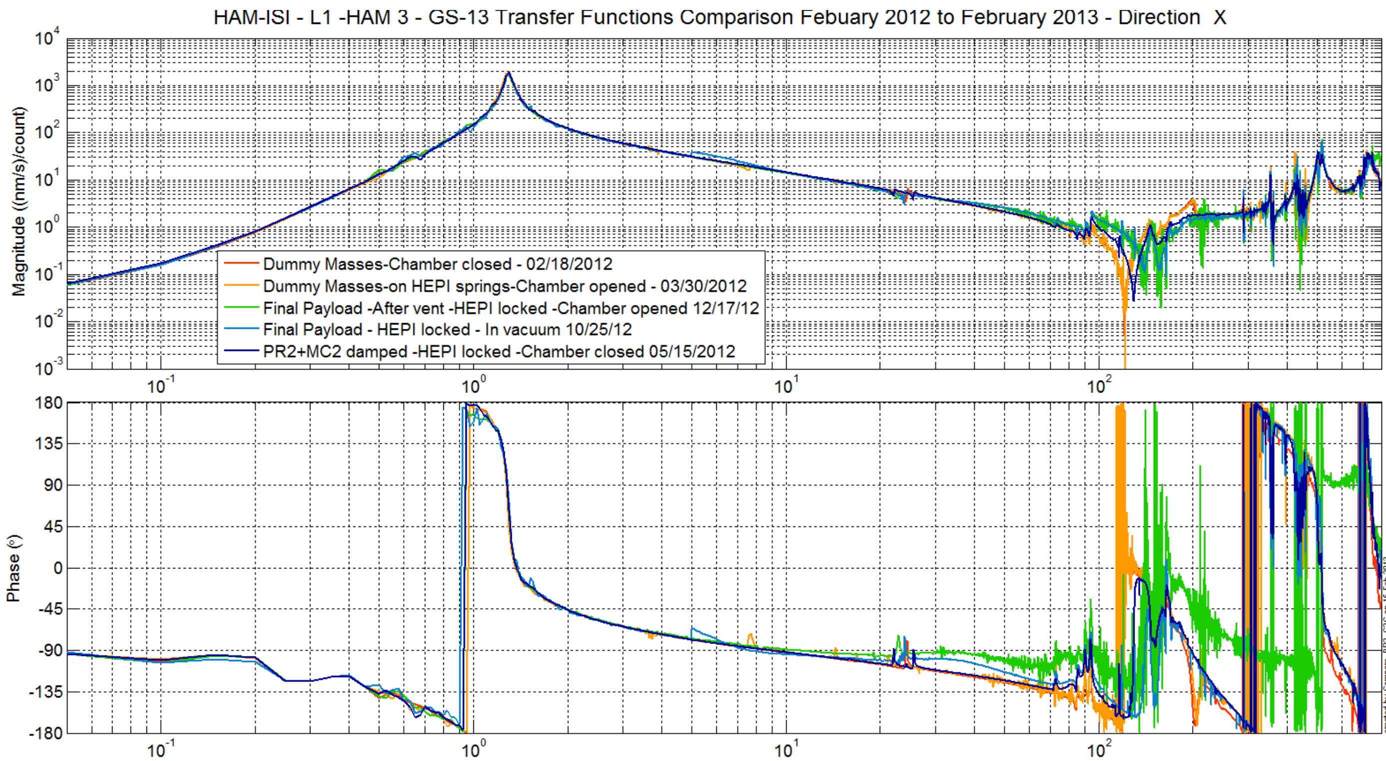
Note that the title of those figures is wrong, the payload was final at the time of those measurements.

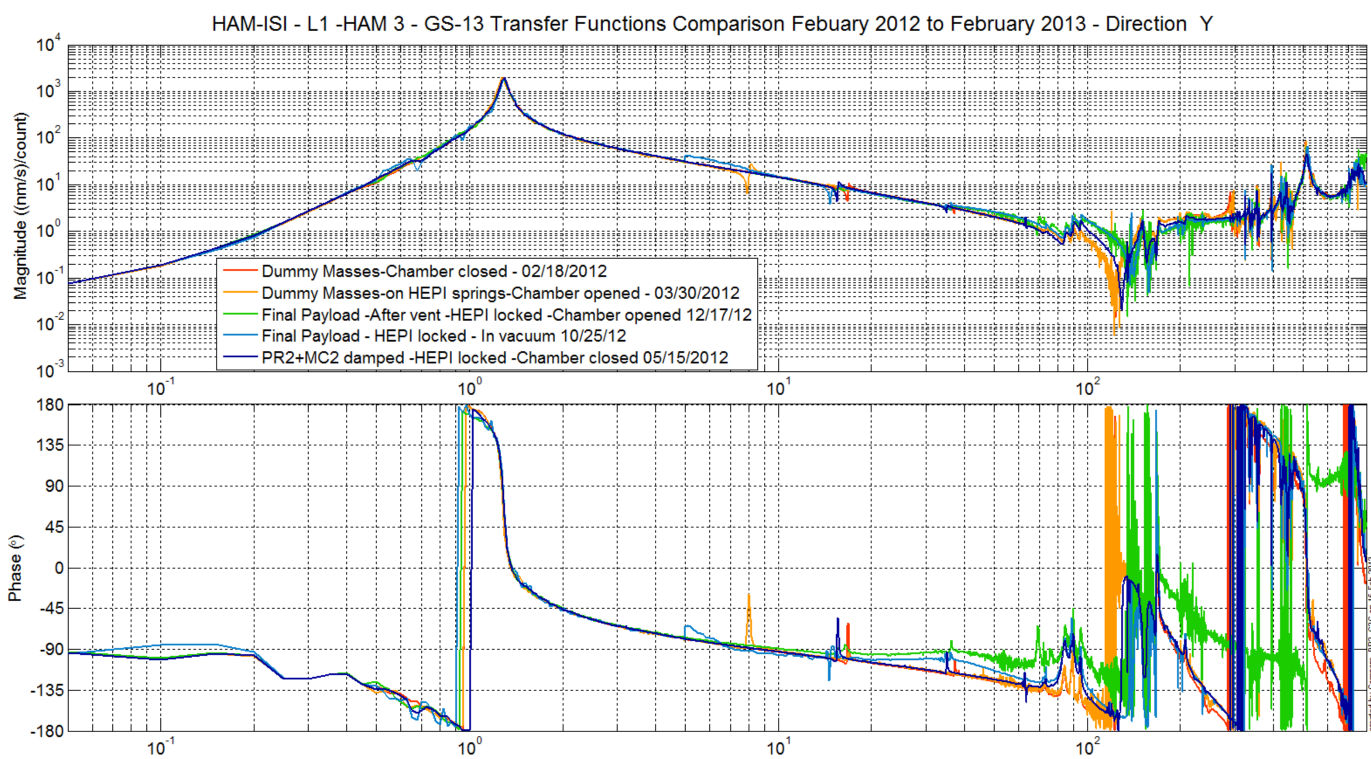


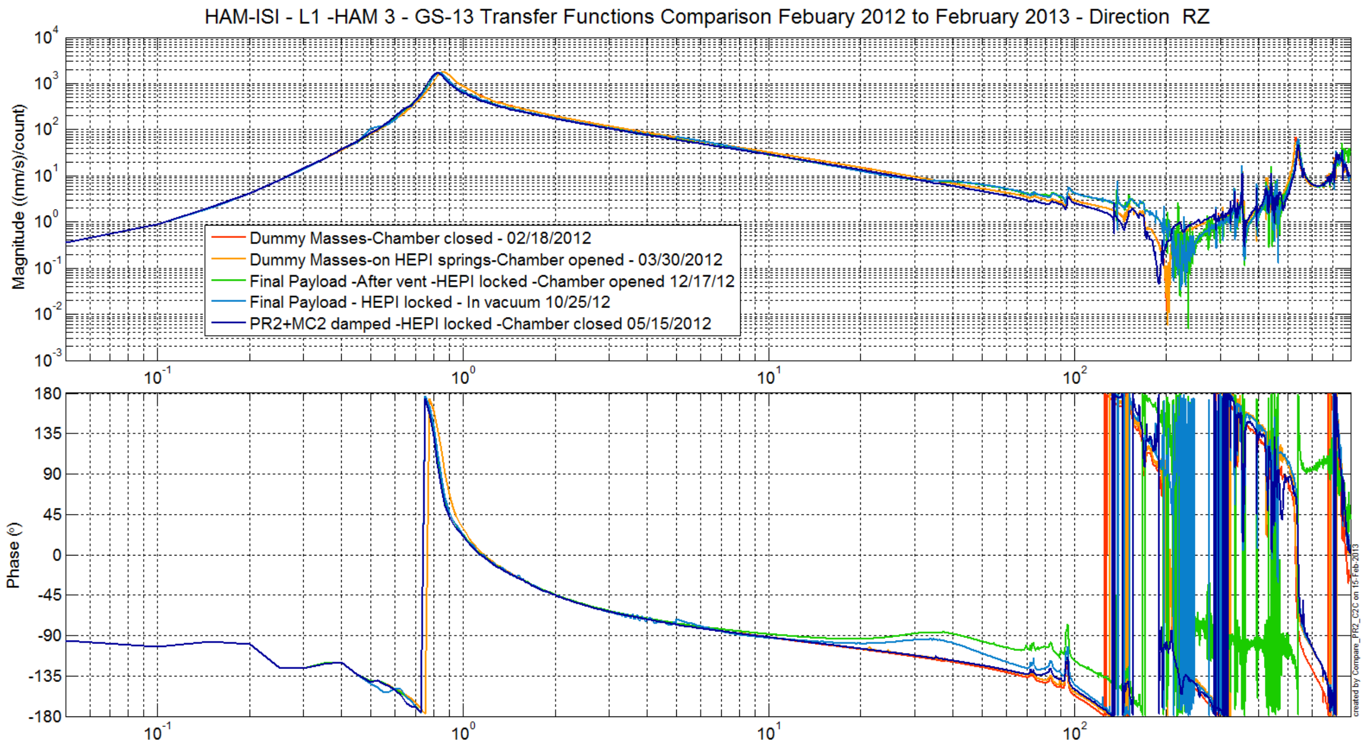


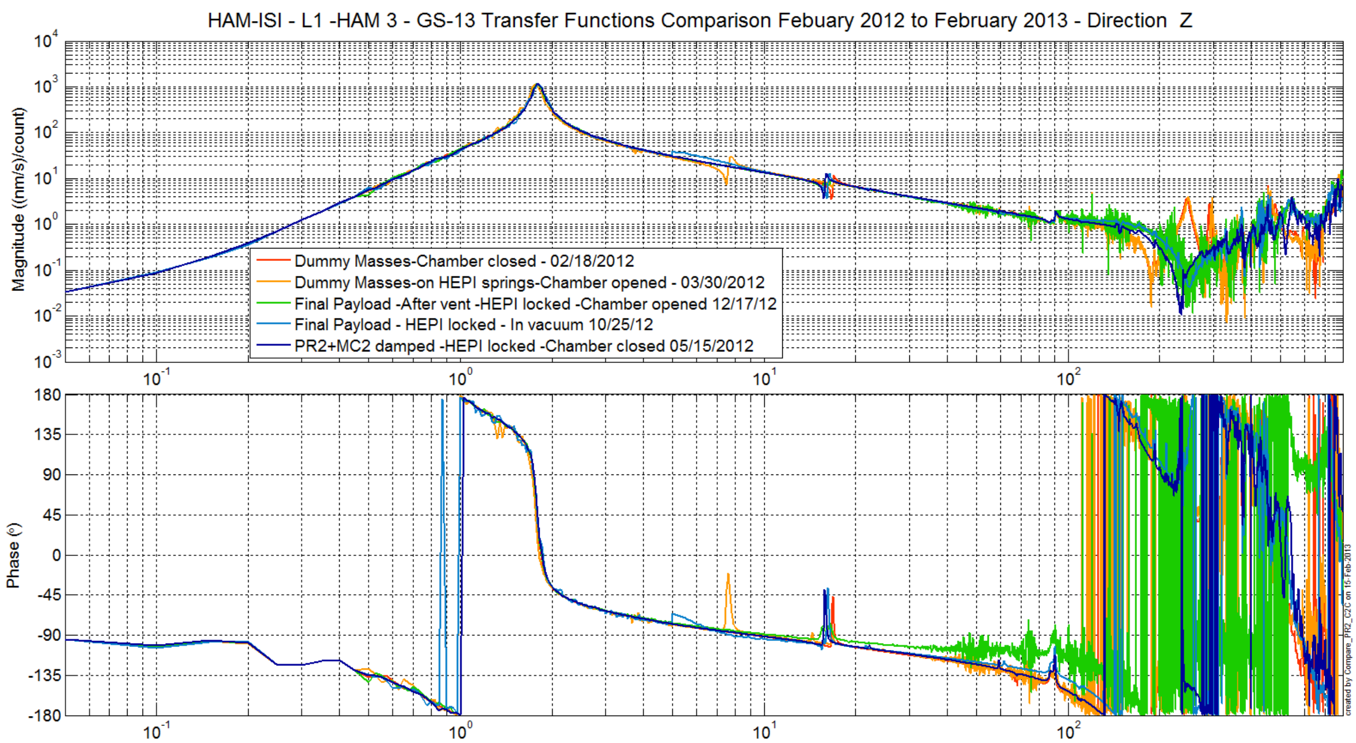
Transfer Function Evolution

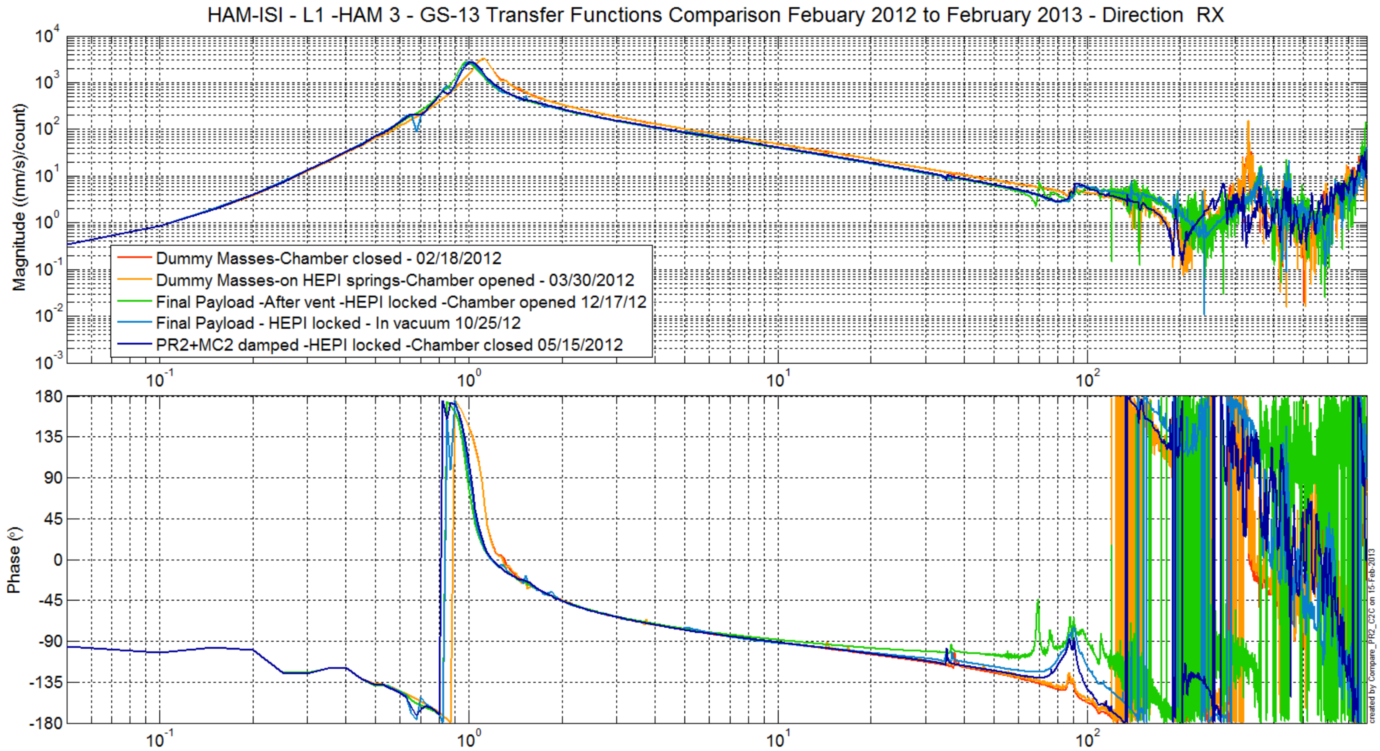
Those same data were used to look at the evolution of the GS-13 transfer functions (in cartesian coordinates) over the year 2012 and the installation of the real payload:

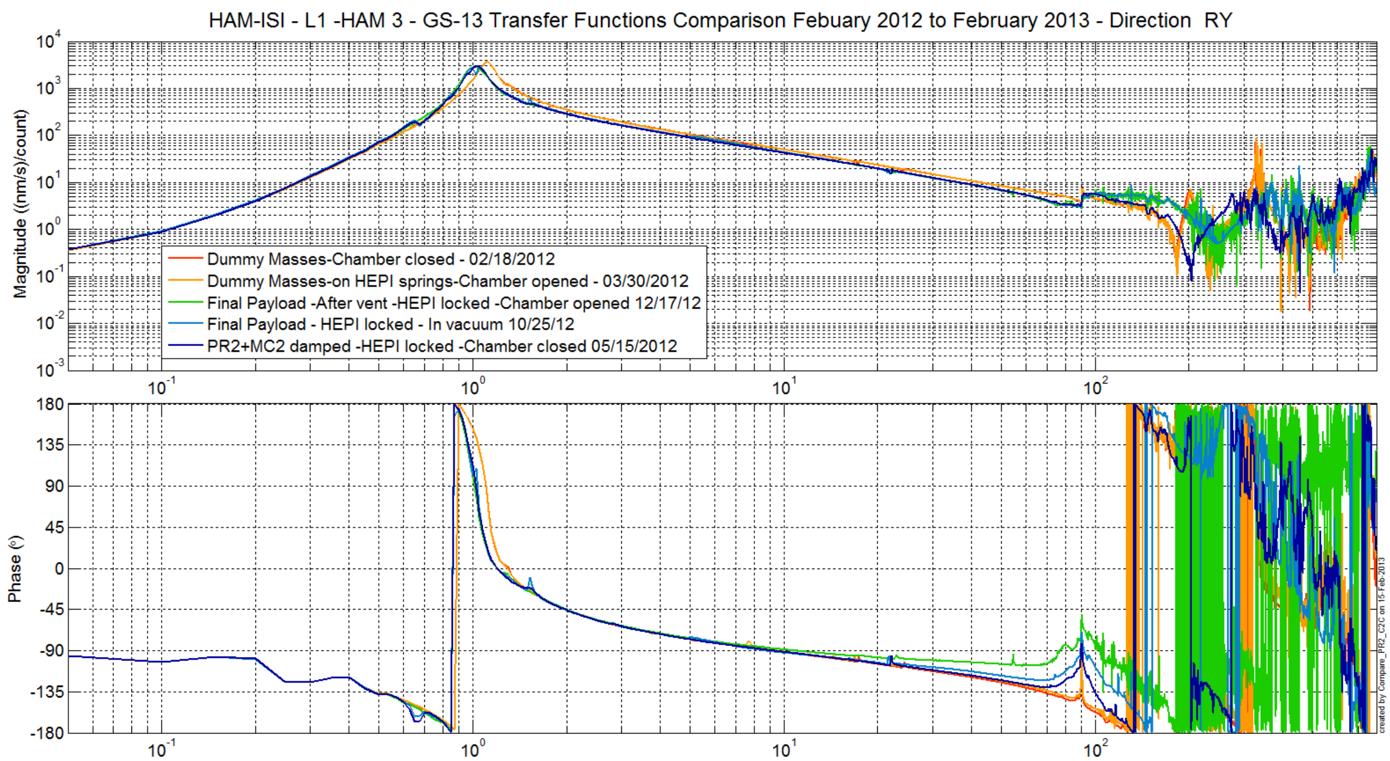





HAM-ISI - L1 -HAM 3 - GS-13 Transfer Functions Comparison Febuary 2012 to February 2013 - Direction RZ
Magnitude ((nm/s)/count)
Phase (°)
Dummy Masses-Chamber closed - 02/18/2012
Dummy Masses-on HEPI springs-Chamber opened - 03/30/2012
Final Payload -After vent -HEPI locked -Chamber opened 12/17/12
Final Payload - HEPI locked - In vacuum 10/25/12
PR2+MC2 damped -HEPI locked -Chamber closed 05/15/2012


HAM-ISI - L1 -HAM 3 - GS-13 Transfer Functions Comparison Febuary 2012 to February 2013 - Direction Z
Magnitude ((nm/s)/count)
Phase (°)
Dummy Masses-Chamber closed - 02/18/2012
Dummy Masses-on HEPI springs-Chamber opened - 03/30/2012
Final Payload -After vent -HEPI locked -Chamber opened 12/17/12
Final Payload - HEPI locked - In vacuum 10/25/12
PR2+MC2 damped -HEPI locked -Chamber closed 05/15/2012

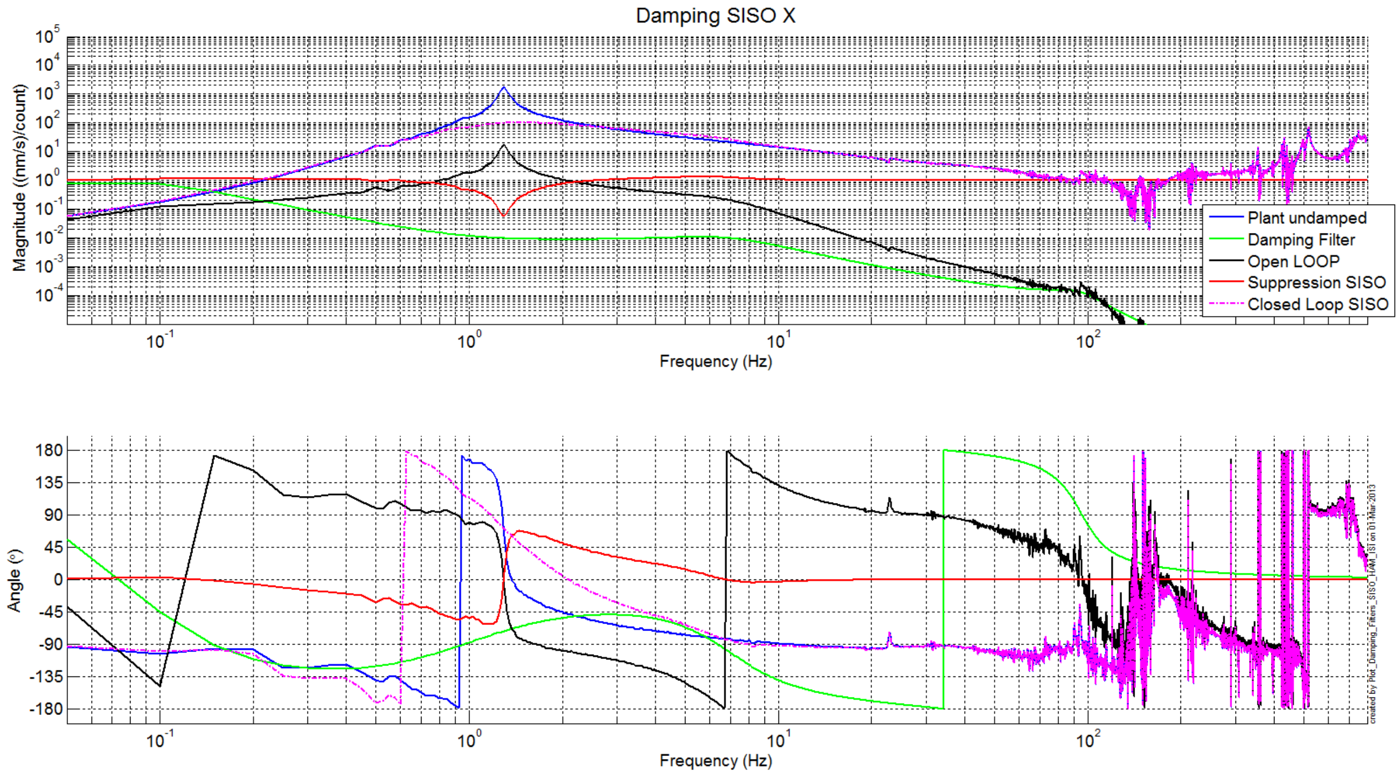

HAM-ISI - L1 -HAM 3 - GS-13 Transfer Functions Comparison Febuary 2012 to February 2013 - Direction RX
Magnitude ((nm/s)/count)
Dummy Masses-Chamber closed - 02/18/2012
Dummy Masses-on HEPI springs-Chamber opened - 03/30/2012
Final Payload -After vent -HEPI locked -Chamber opened 12/17/12
Final Payload - HEPI locked - In vacuum 10/25/12
PR2+MC2 damped -HEPI locked -Chamber closed 05/15/2012
Phase (°)

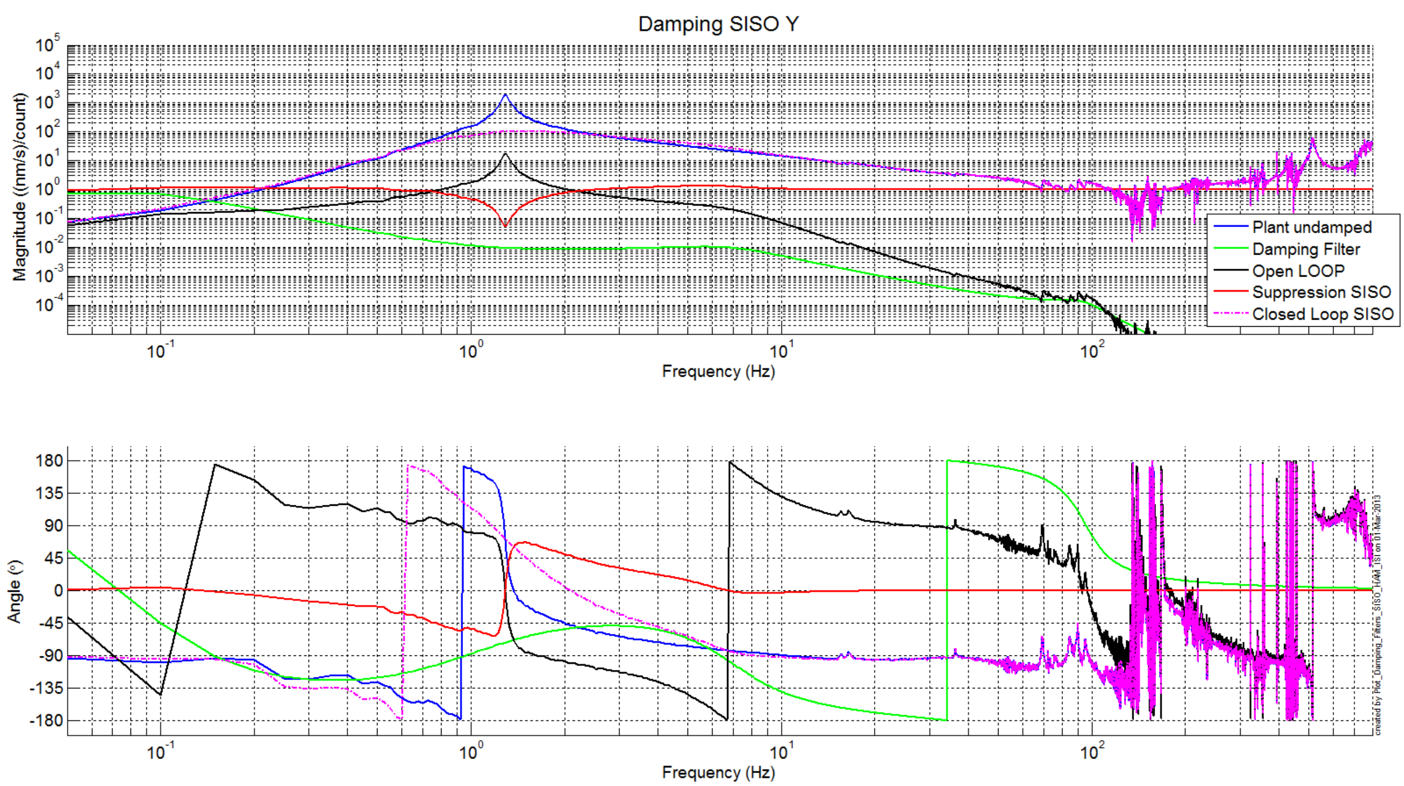

HAM-ISI - L1 -HAM 3 - GS-13 Transfer Functions Comparison Febuary 2012 to February 2013 - Direction RY
Magnitude ((nm/s)/count)
Dummy Masses-Chamber closed - 02/18/2012
Dummy Masses-on HEPI springs-Chamber opened - 03/30/2012
Final Payload -After vent -HEPI locked -Chamber opened 12/17/12
Final Payload - HEPI locked - In vacuum 10/25/12
PR2+MC2 damped -HEPI locked -Chamber closed 05/15/2012
Phase (°)

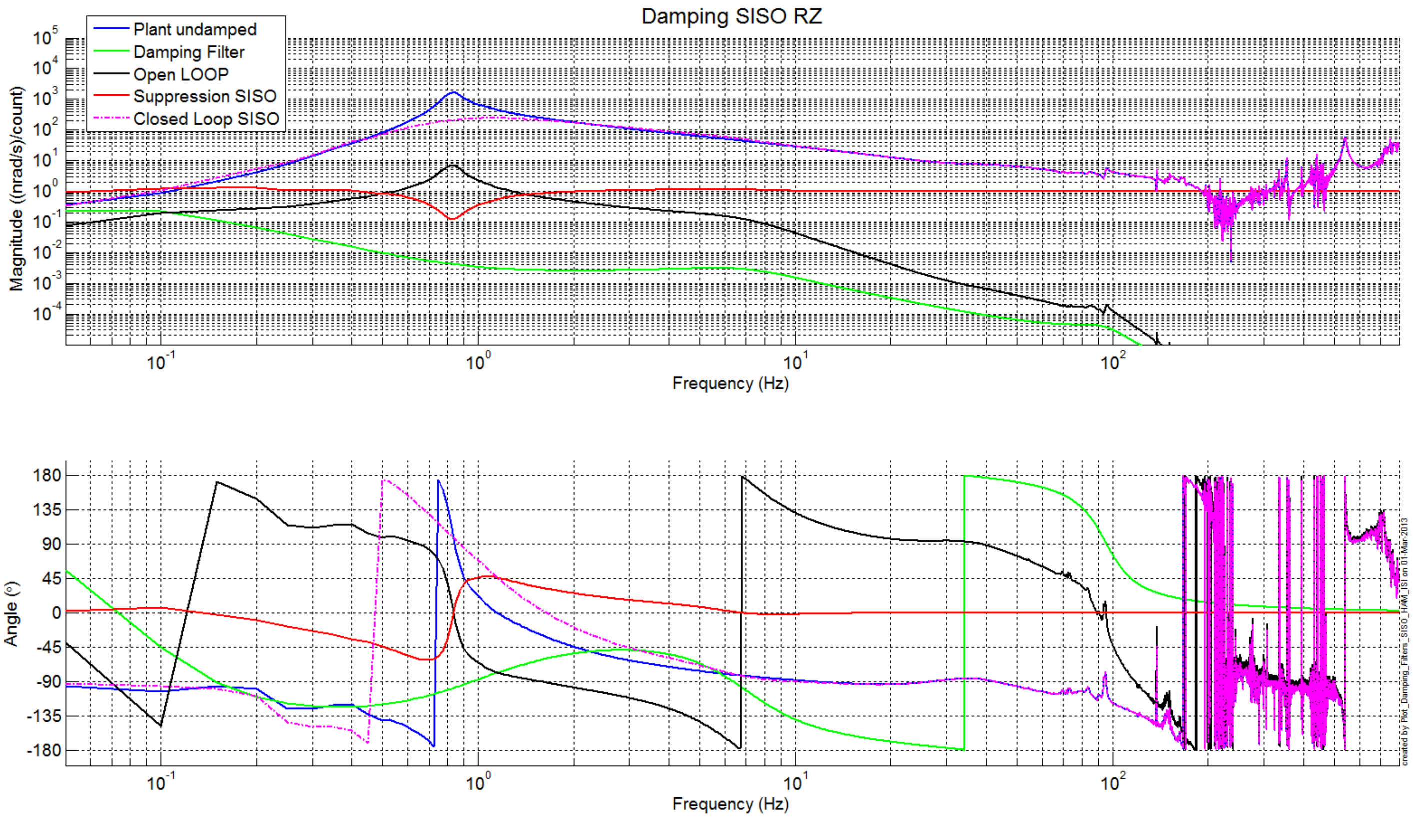
3. *Step 4 Damping Loops*

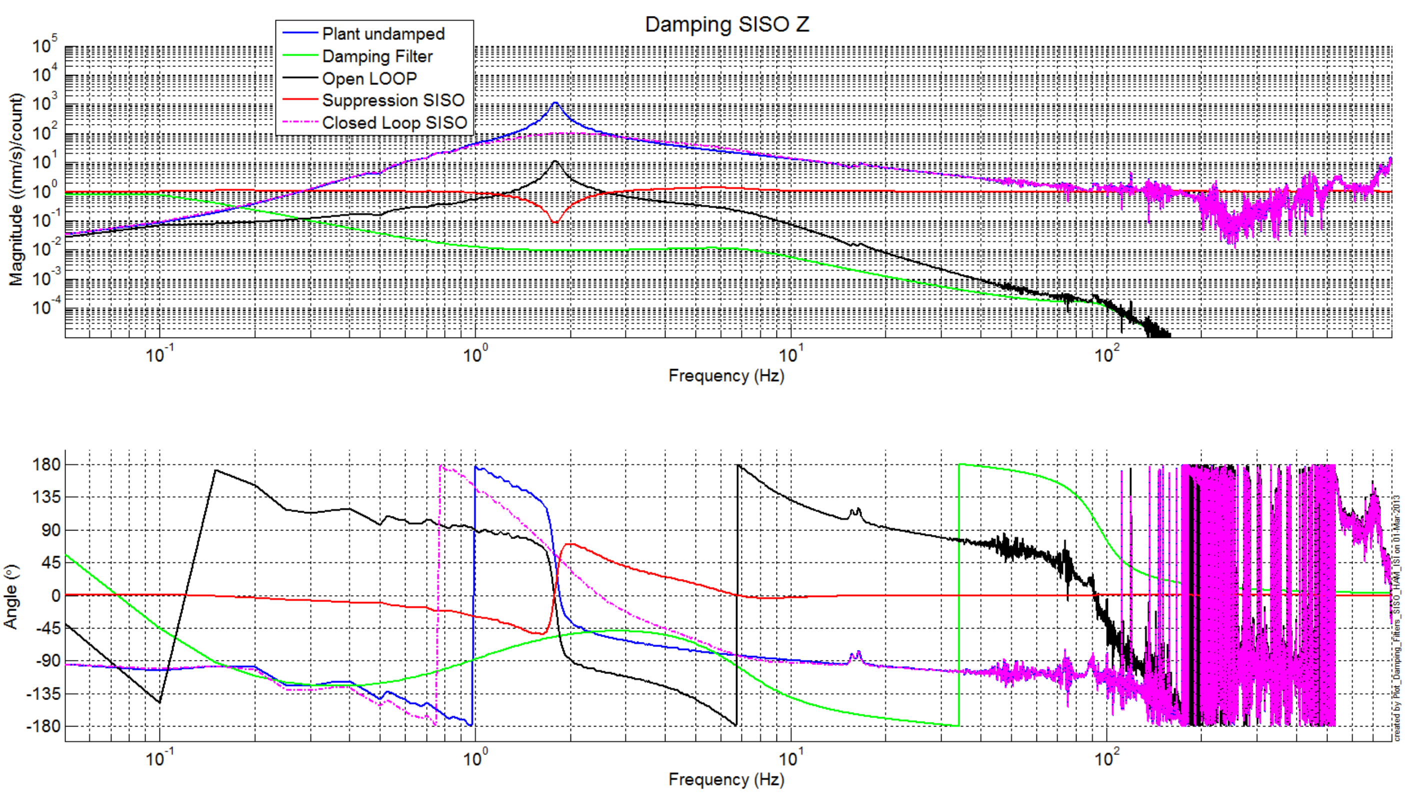
Those damping loops are the same used on all sites, and on all ISIs.

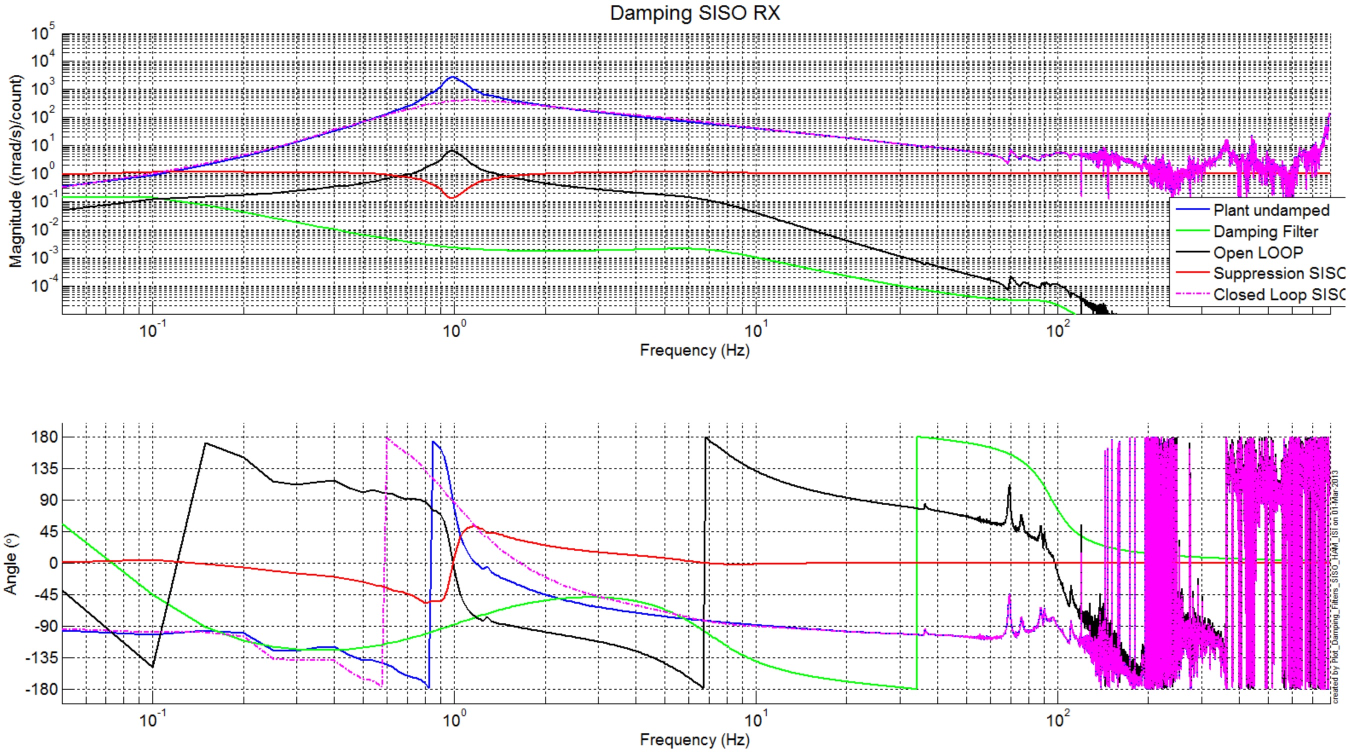
All figures can be found there:
HAM-ISI/L1/HAM3/Data/Figures/Transfer_Functions/Simulations/Damped/

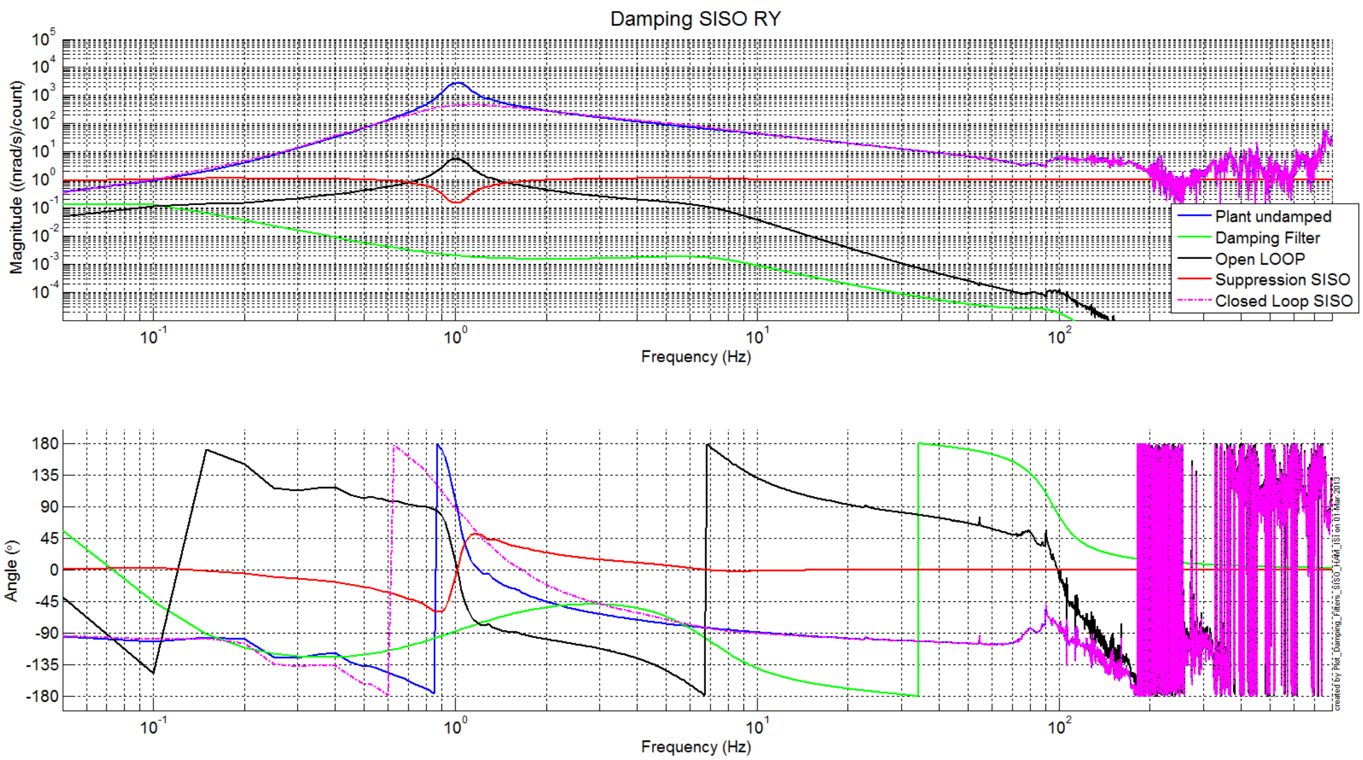




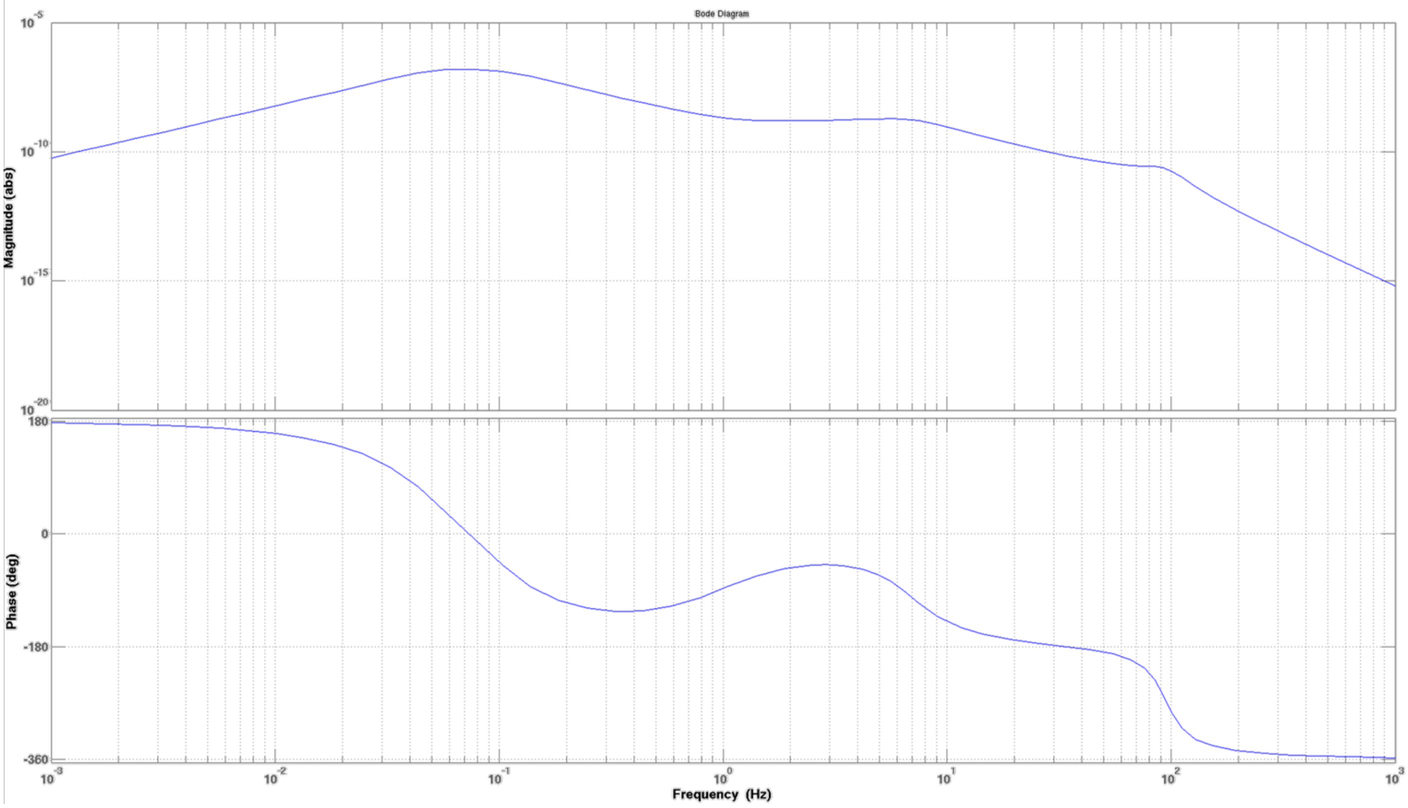

Damping SISO RZ
Plant undamped
Damping Filter
Open LOOP
Suppression SISO
Closed Loop SISO
Magnitude ((nrad/s)/count)
Frequency (Hz)
Angle (°)
Frequency (Hz)


Damping SISO Z
Plant undamped
Damping Filter
Open LOOP
Suppression SISO
Closed Loop SISO
Magnitude ((nm/s)/count)
Frequency (Hz)
Angle (°)
Frequency (Hz)





Please note that even though it's not visible here on the 6 previous plots (because the measurements did not go any lower than 50 mHz), all damping filters are AC coupled. Below is the example of the bode plot of the X damping filter (all filters have the same low frequency behavior).


Bode Diagram
Magnitude (abs)
Phase (deg)
Frequency (Hz)

4. *Step 5 Blend Filters:*

The blend filters presented below were designed by Ryan De Rosa during the IMC test to obtain a good compromise between noise injection and common rejection at low frequencies.

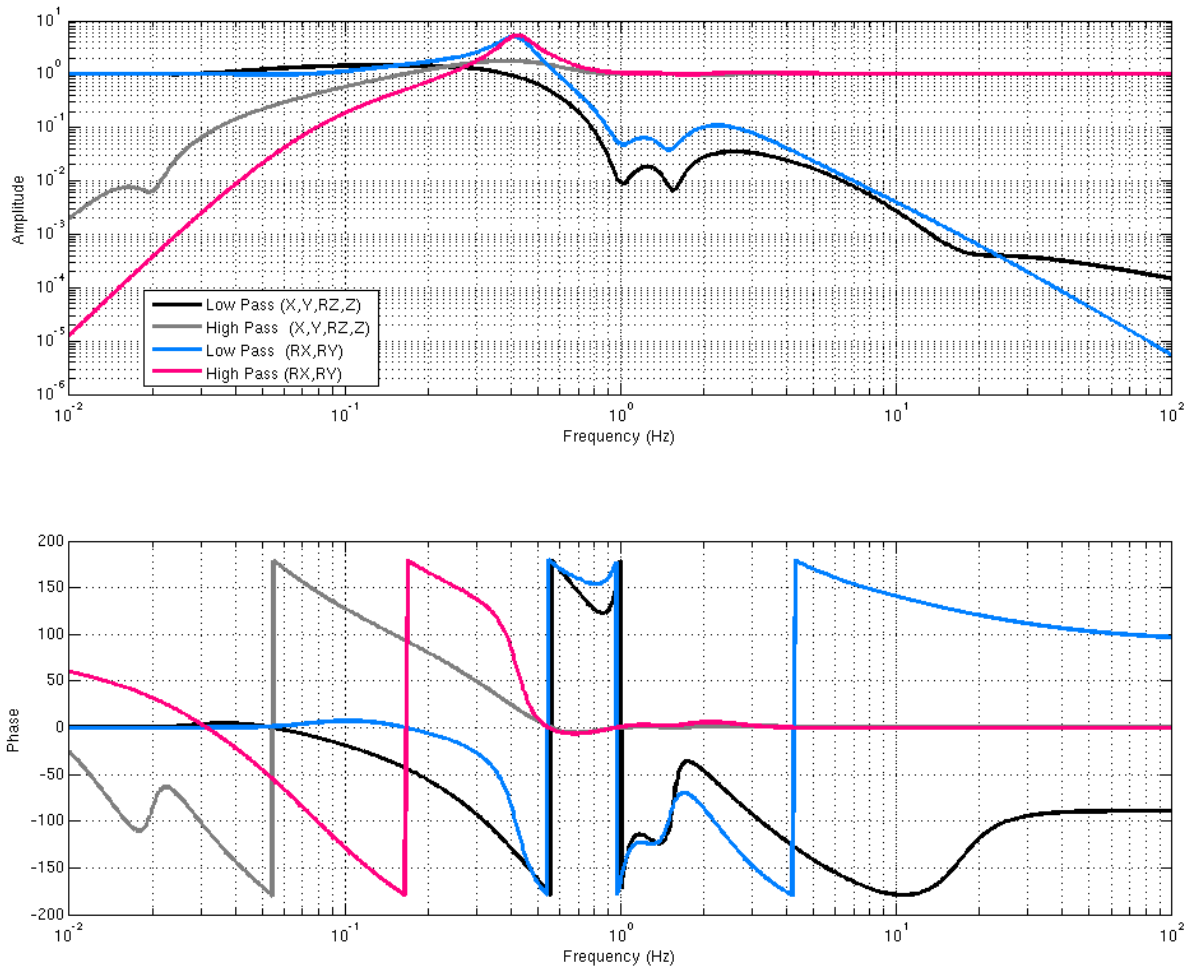
There is a set of filters for RX and RY (0.425 Hz Blend, suppression of 20 at 1Hz), and one set for X, Y, RZ, Z (0.250 Hz Blend, suppression of 100 at 1Hz). The suppression at 1 Hz was adjusted so that ISI X and RY table motion contributes about equally to the suspension point's translation motion. RY Blend has a slightly high "peaking" at the blend frequency which is necessary to high pass sufficiently the sensor noise, and low pass enough the RY motion. The amplification at the blend frequency doesn't impact significantly the cavity motion.

More information can be found in Ryan’s alog 6148 (https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=6148) : “Between 0.1 and 0.7 Hz the estimate of the cavity motion agrees well, with ISI sensor noise dominating at low frequency and some other noise source contributing from 1+ Hz. Below 0.1 Hz the sensor noise estimate is a good match for the cavity motion.”

The filters are committed in the svn in:

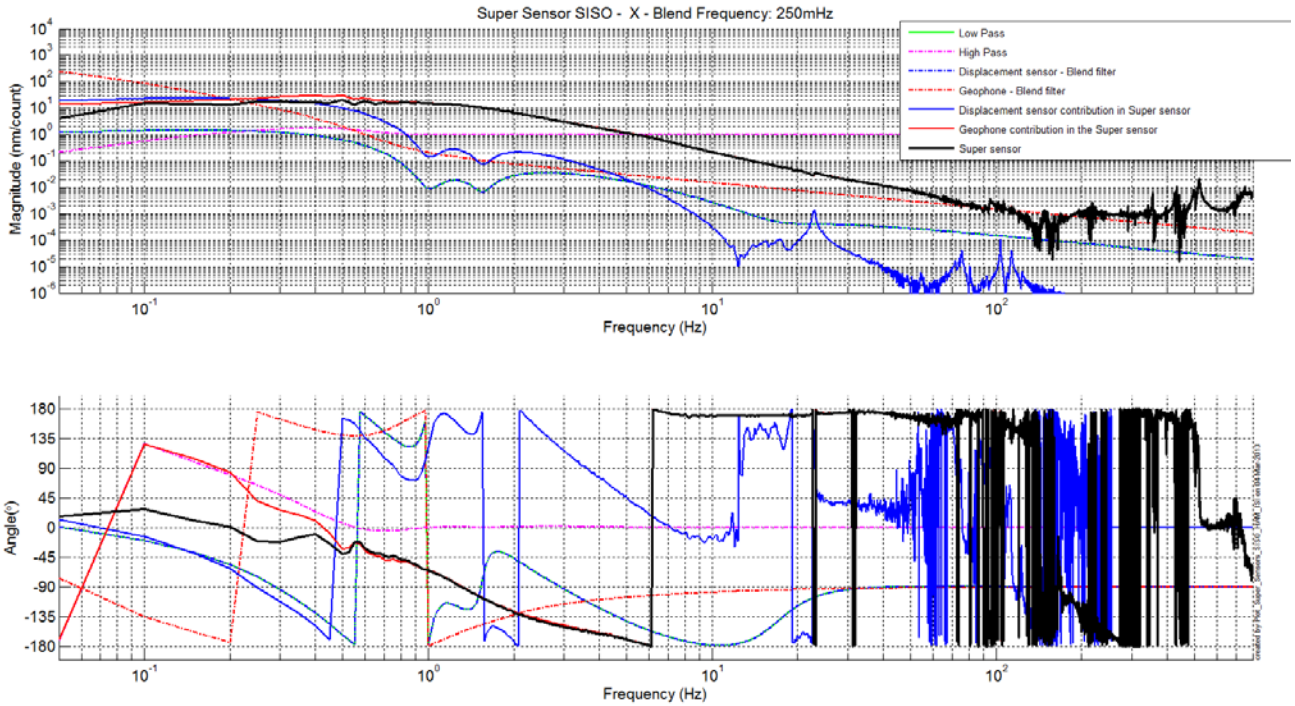
ligo/svncommon/SeiSVN/seismic/HAM-ISI/Common/Complementary_Filters_HAM_ISI/

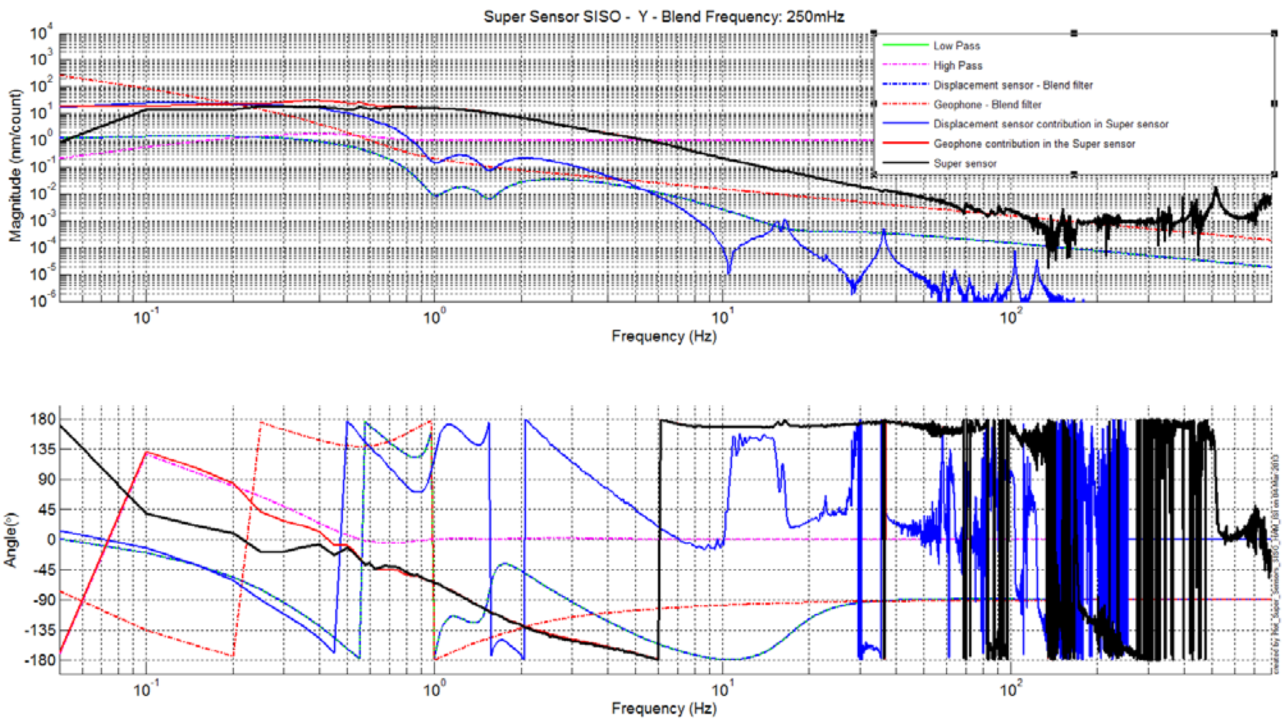
They are saved in: **HAM-ISI_Generic_Comp_Filters.mat**

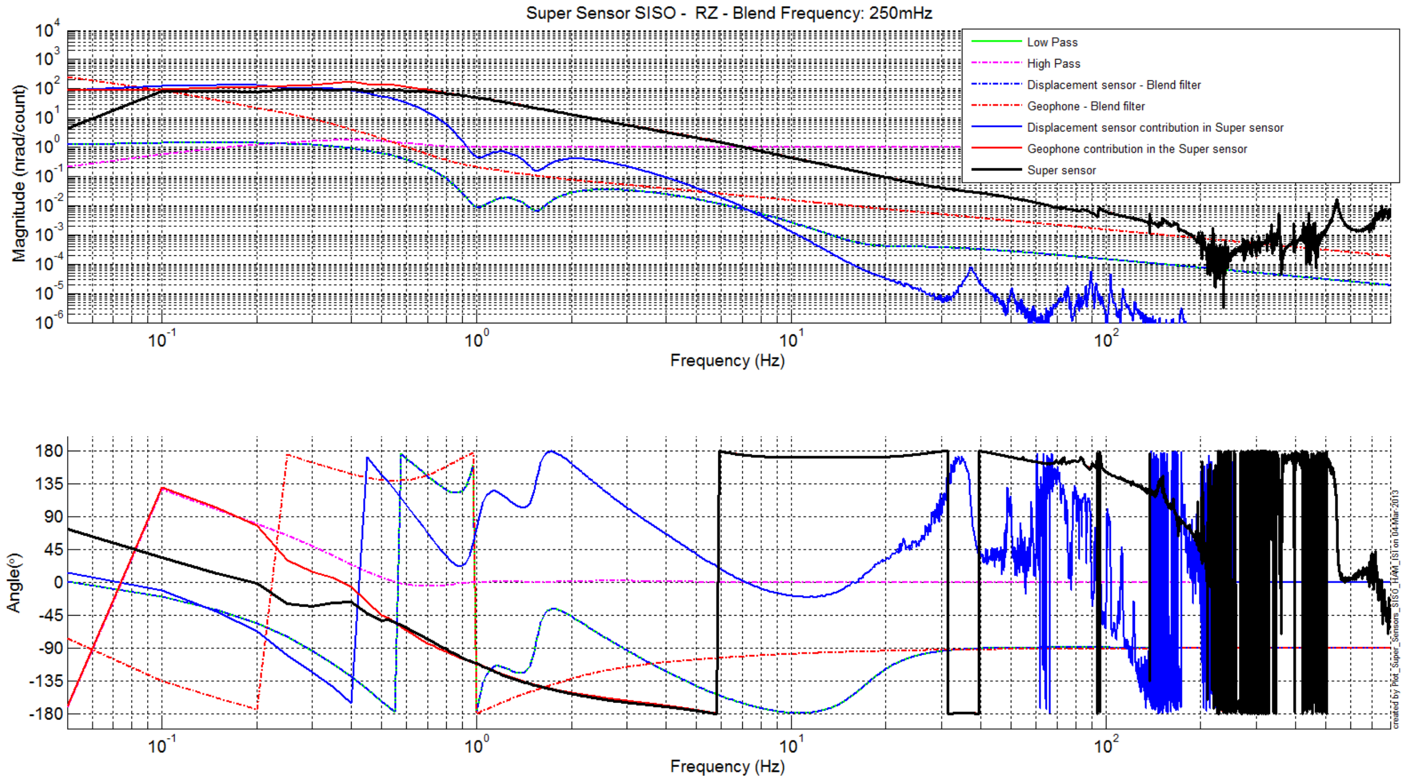


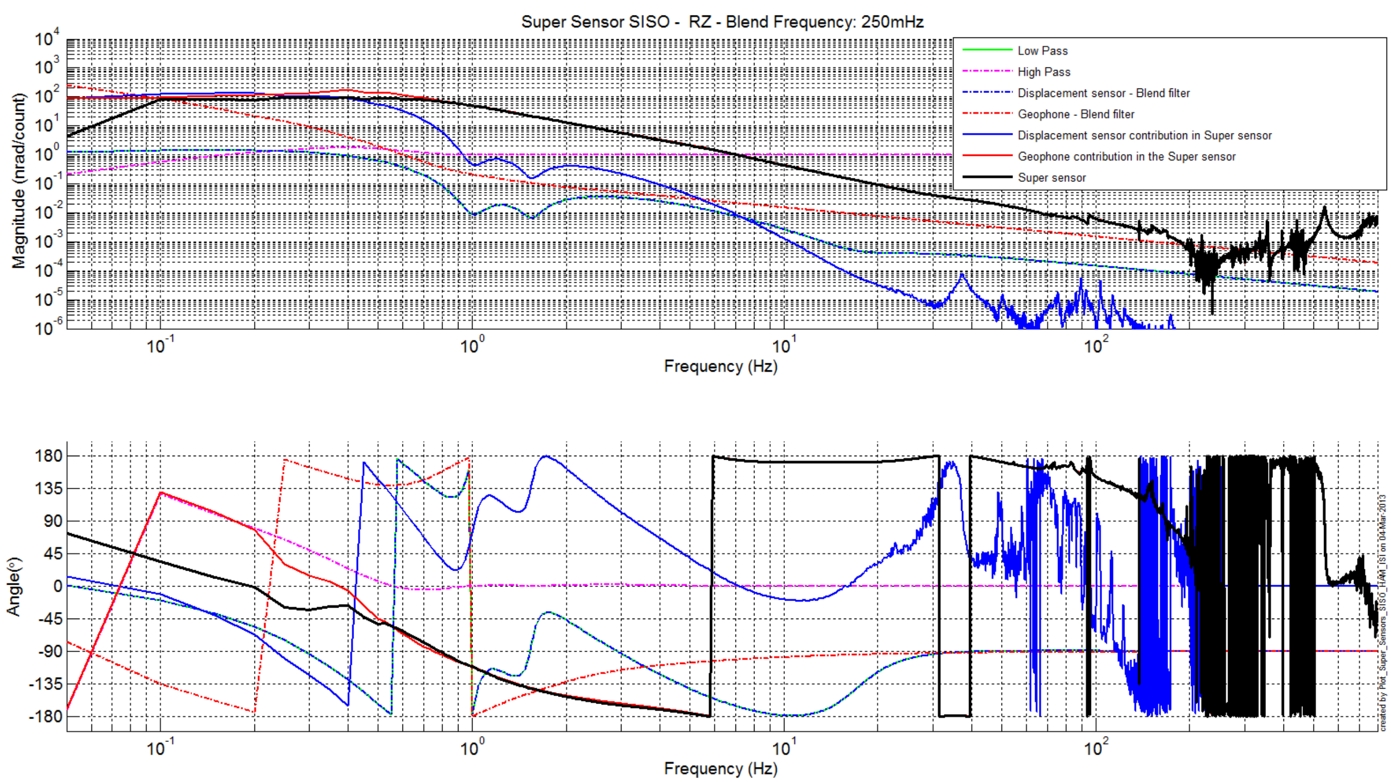
The Figures presented below can be found in:

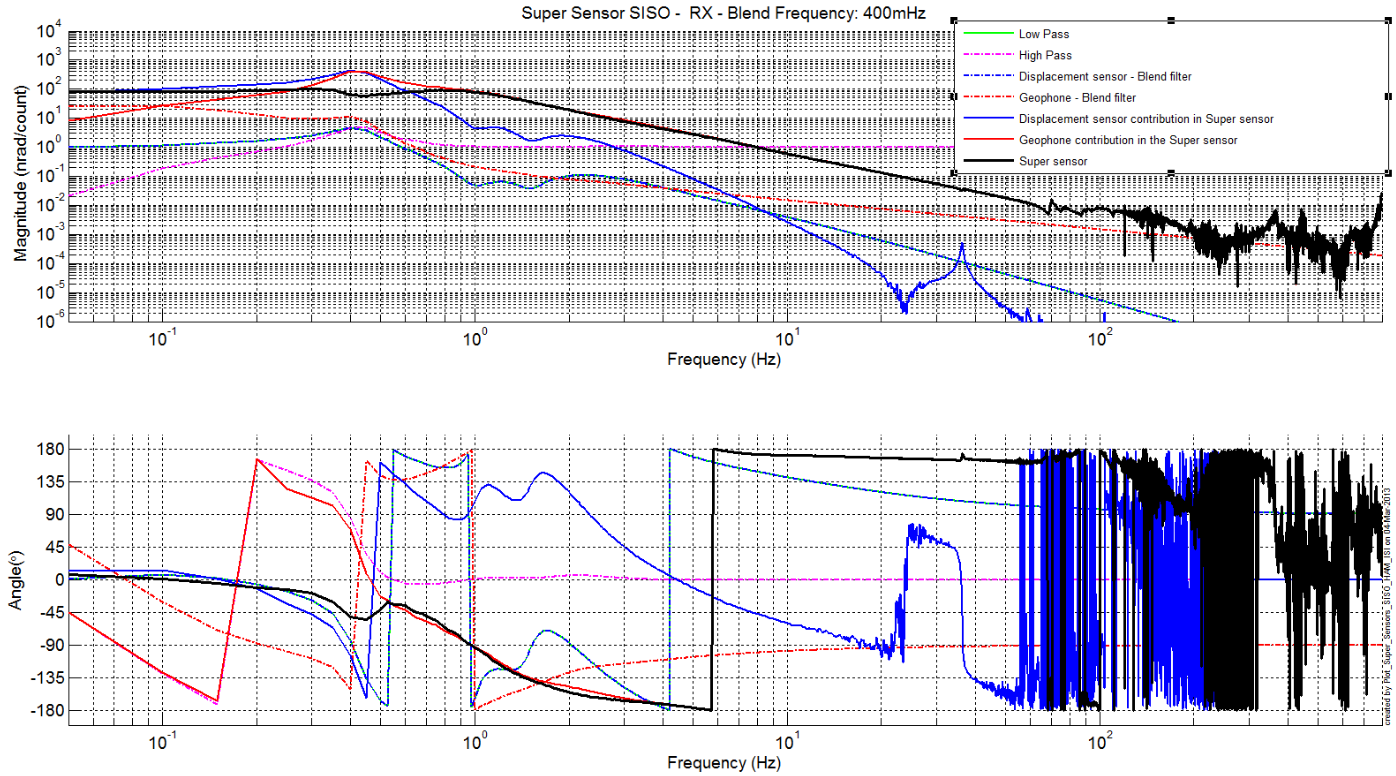
seismic/HAM-ISI/L1/HAM3/Data/Figures/Transfer_Functions/Simulations/Super_Sensors

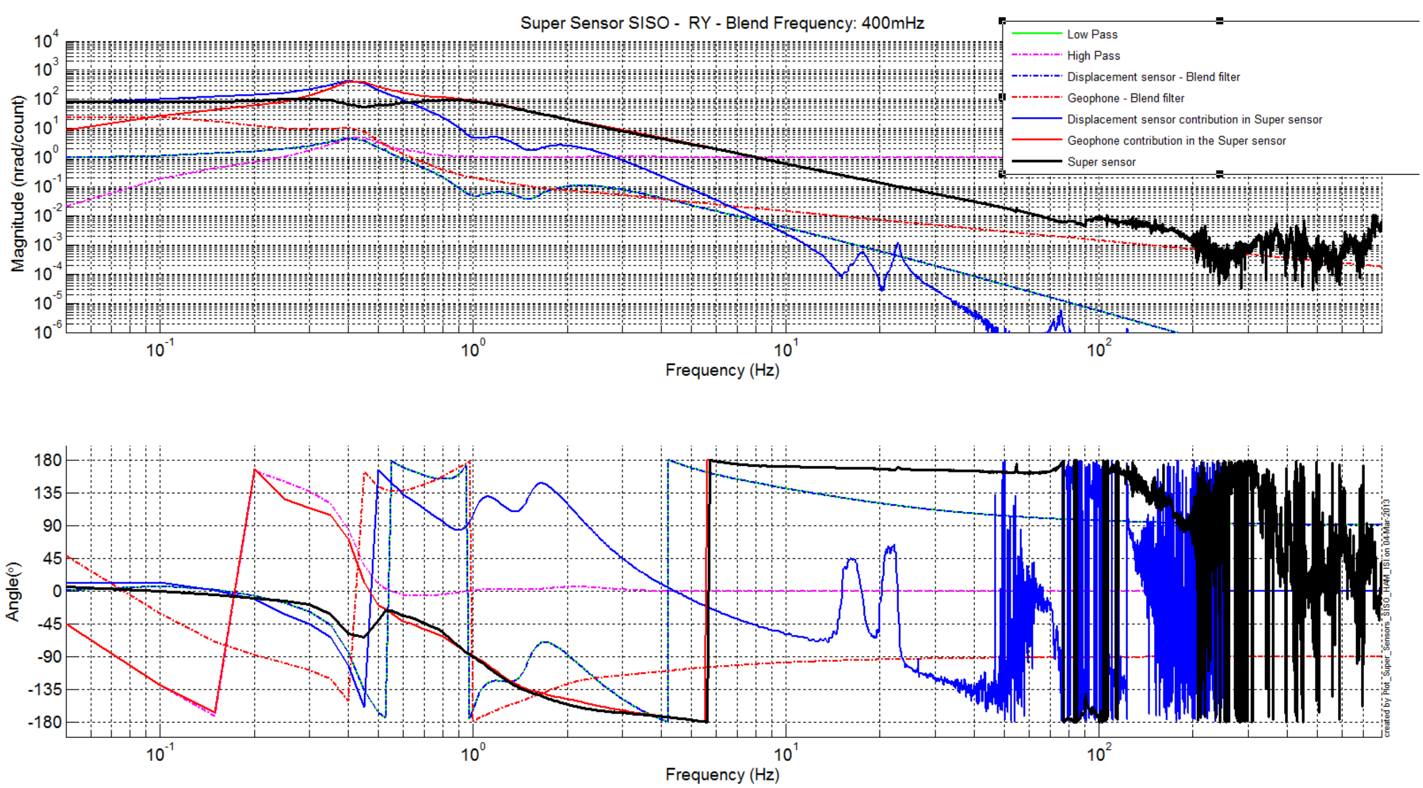





Super Sensor SISO - RZ - Blend Frequency: 250mHz
Low Pass
High Pass
Displacement sensor - Blend filter
Geophone - Blend filter
Displacement sensor contribution in Super sensor
Geophone contribution in the Super sensor
Super sensor
Magnitude (nrad/count)
Frequency (Hz)
Angle(°)
Frequency (Hz)


Super Sensor SISO - RZ - Blend Frequency: 250mHz
Low Pass
High Pass
Displacement sensor - Blend filter
Geophone - Blend filter
Displacement sensor contribution in Super sensor
Geophone contribution in the Super sensor
Super sensor
Magnitude (nrad/count)
Frequency (Hz)
Angle(°)
Frequency (Hz)


Super Sensor SISO - RX - Blend Frequency: 400mHz
Low Pass
High Pass
Displacement sensor - Blend filter
Geophone - Blend filter
Displacement sensor contribution in Super sensor
Geophone contribution in the Super sensor
Super sensor
Magnitude (nrad/count)
Frequency (Hz)
Angle(°)
Frequency (Hz)

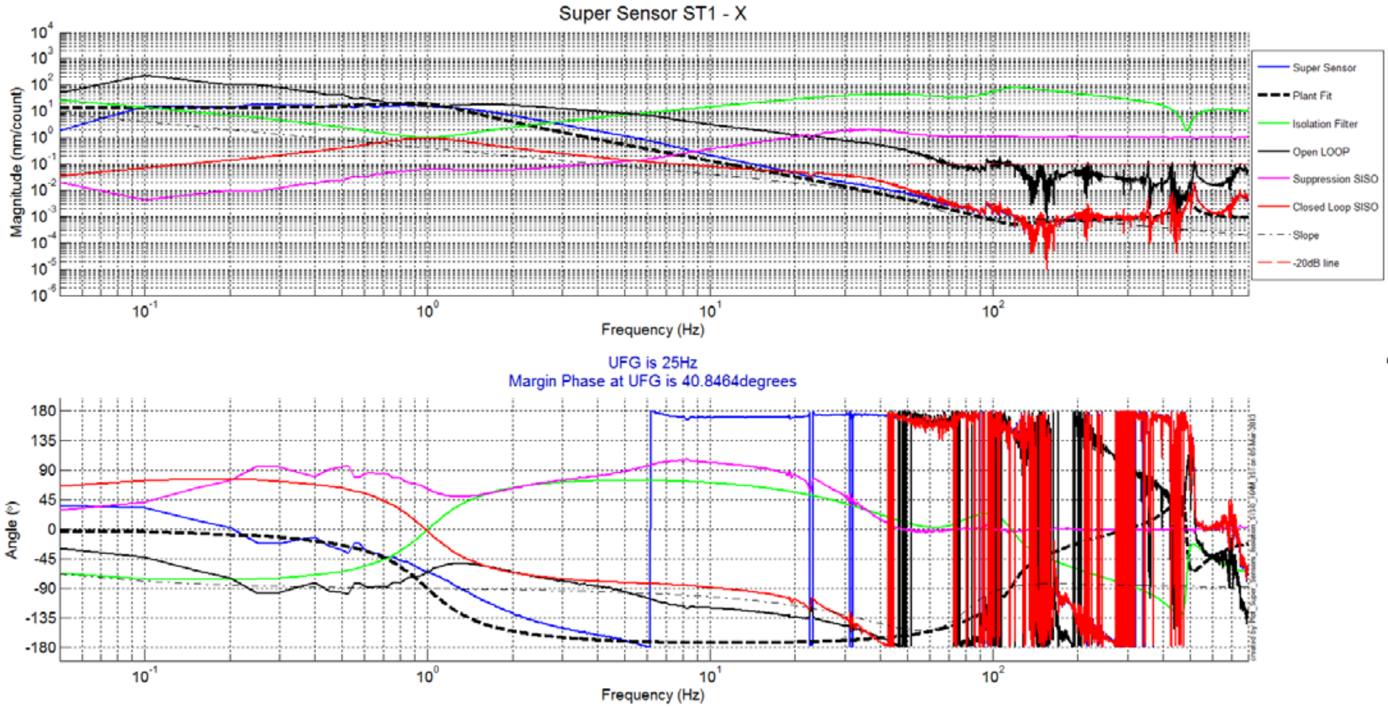

Super Sensor SISO - RY - Blend Frequency: 400mHz
Low Pass
High Pass
Displacement sensor - Blend filter
Geophone - Blend filter
Displacement sensor contribution in Super sensor
Geophone contribution in the Super sensor
Super sensor
Magnitude (nrad/count)
Frequency (Hz)
Angle(°)
Frequency (Hz)

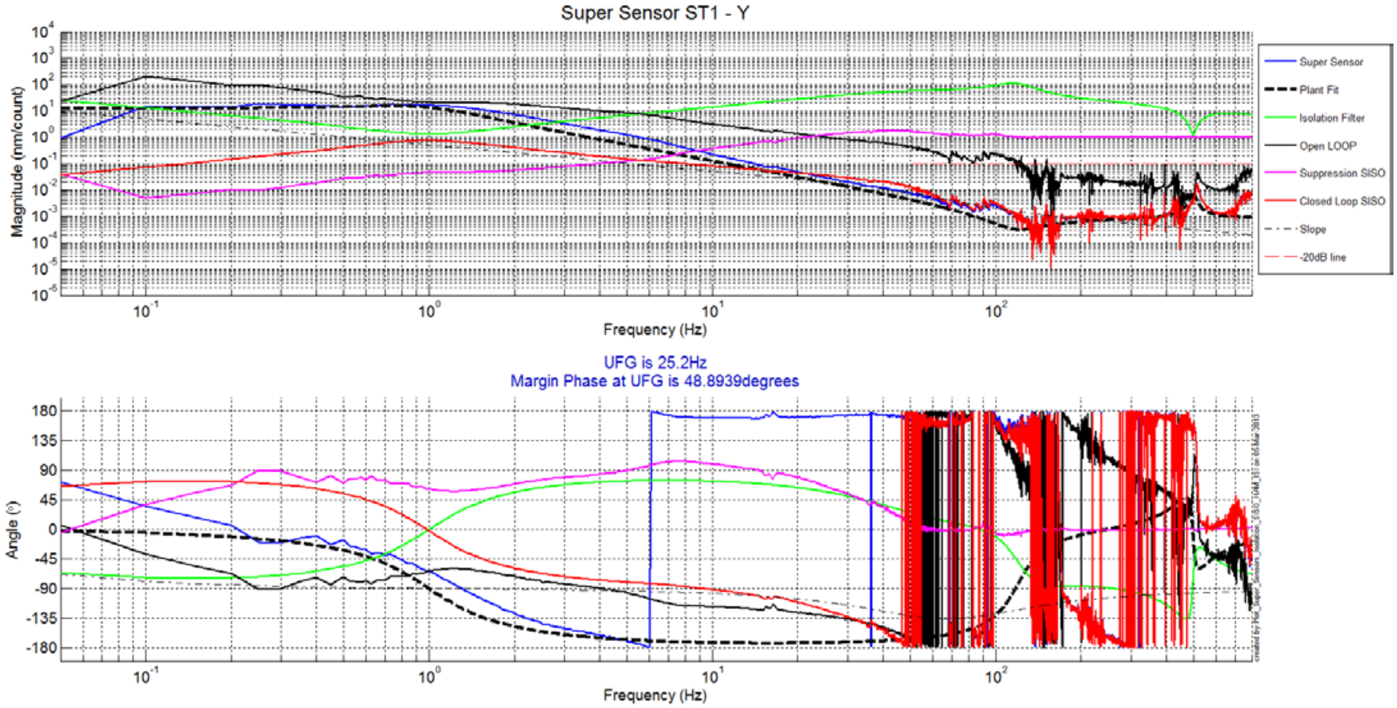
5. *Step 6 & 7 Isolation Filters*

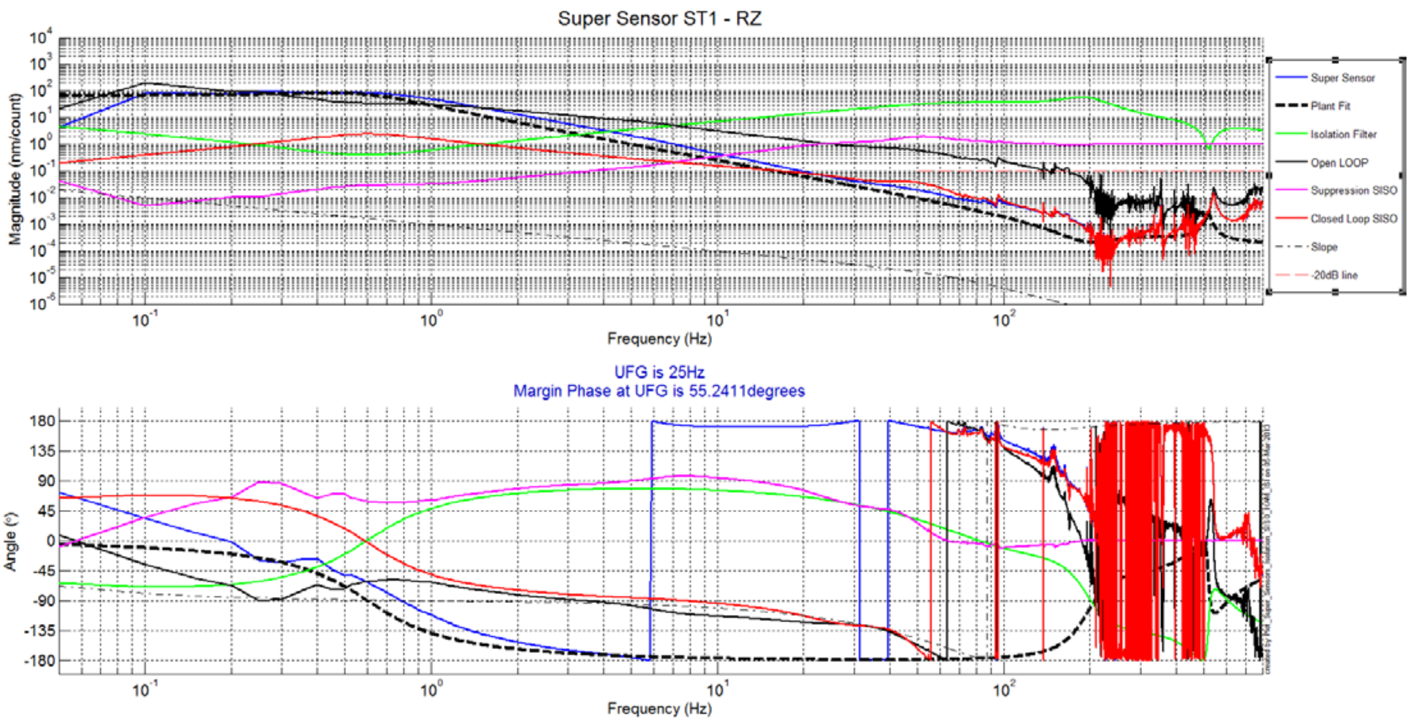
Those isolation filters (level 2 UGF ~25 Hz) were designed by Sebastien Biscans in August 2012, and have been used for the most part of the Input Mode Cleaner commissioning.

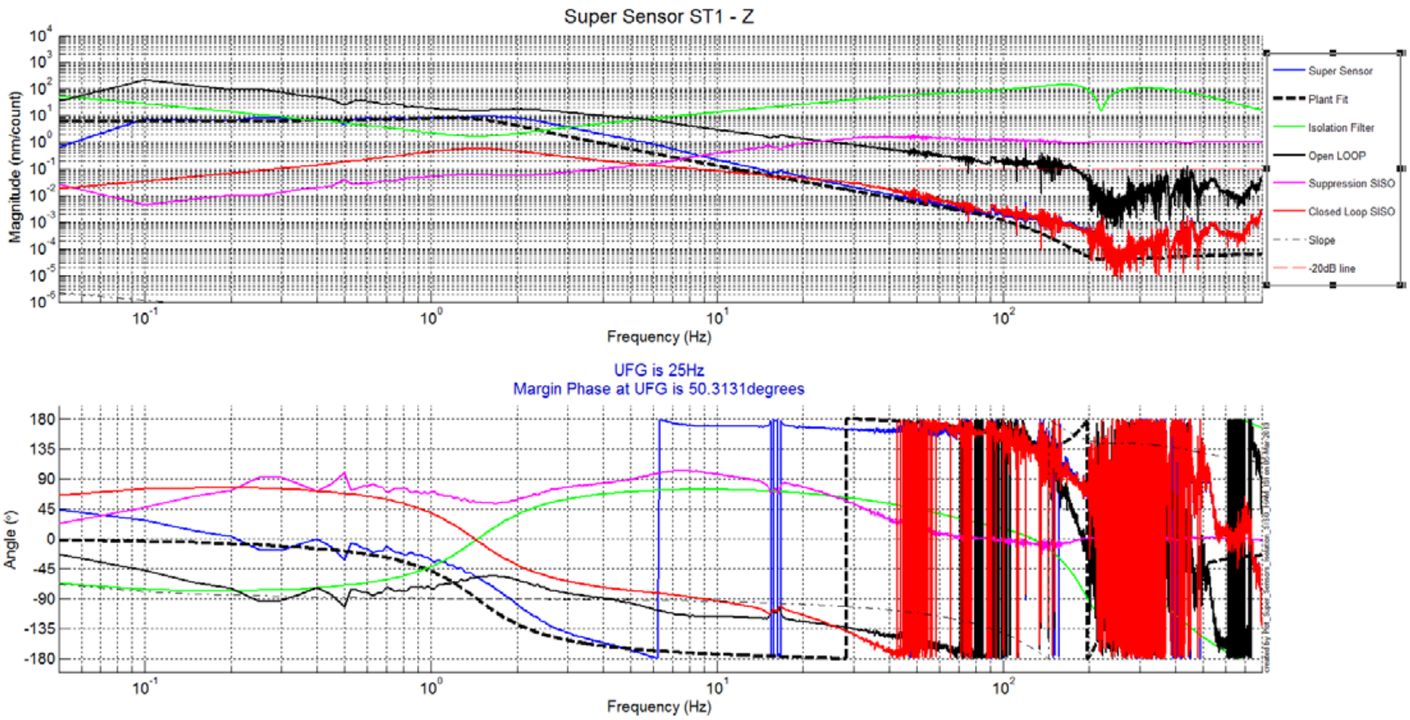
Design parameters can be found there:
HAM-ISI/L1/HAM3/Scripts/Control_Scripts/Version_2/Isolation_Filters_Design/

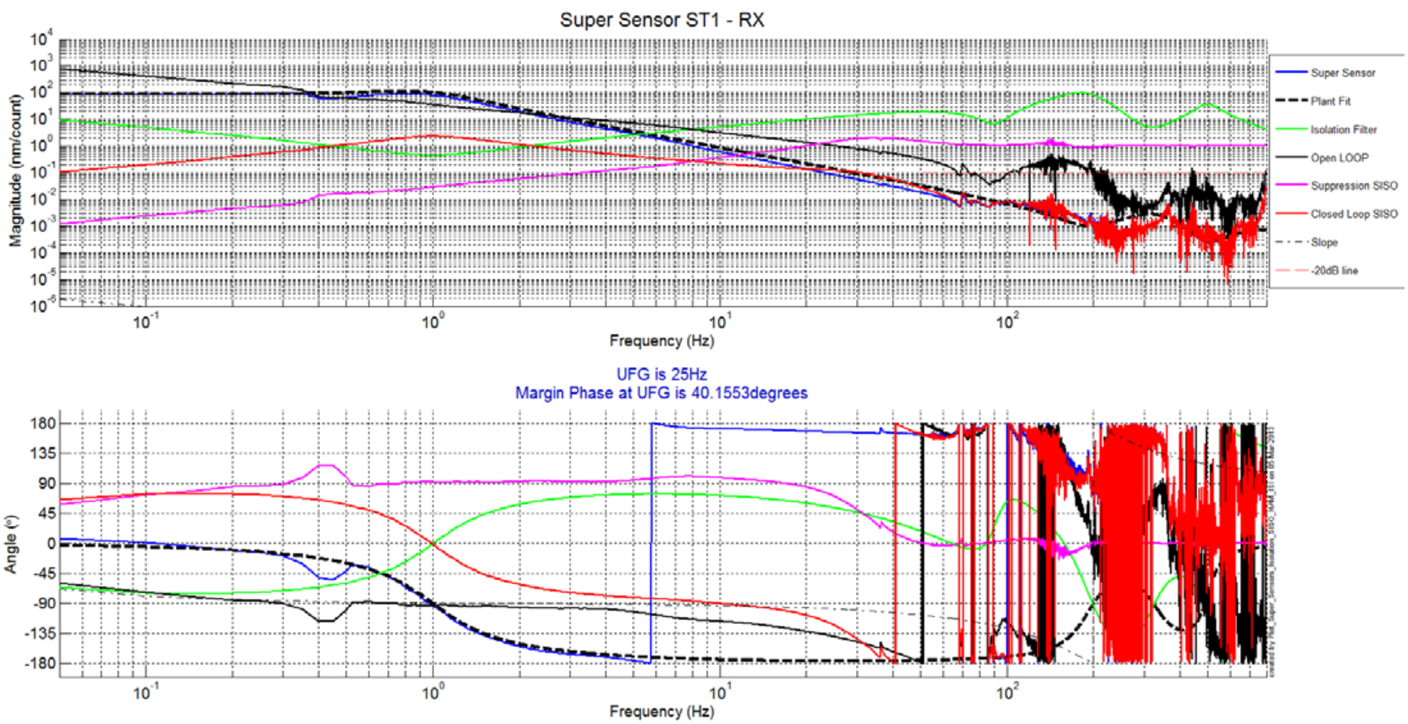
- Vert_Isolation_L1_ISI_HAM3_Level2_SB_20120808.m
- Horiz_Isolation_L1_ISI_HAM3_Level2_SB_20120808.m

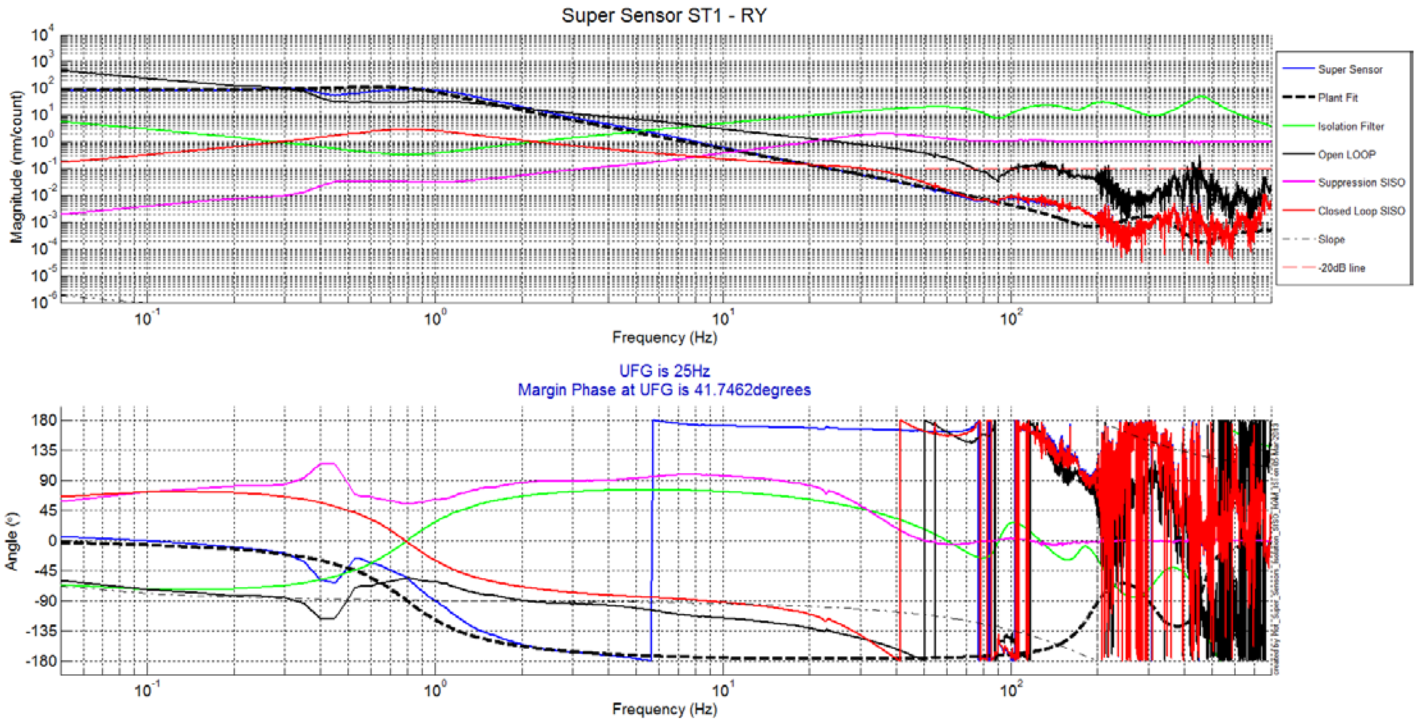



Super Sensor ST1 - Y
Magnitude (nm/count)
Frequency (Hz)
Super Sensor
Plant Fit
Isolation Filter
Open LOOP
Suppression SISO
Closed Loop SISO
Slope
-20dB line
UFG is 25.2Hz
Margin Phase at UFG is 48.8939degrees
Angle (°)


Super Sensor ST1 - RZ
Magnitude (nm/count)
Frequency (Hz)
Super Sensor
Plant Fit
Isolation Filter
Open LOOP
Suppression SISO
Closed Loop SISO
Slope
-20dB line
UFG is 25Hz
Margin Phase at UFG is 55.2411degrees
Angle (°)


Super Sensor ST1 - Z
Magnitude (nm/count)
Frequency (Hz)
Super Sensor
Plant Fit
Isolation Filter
Open LOOP
Suppression SISO
Closed Loop SISO
Slope
-20dB line
UFG is 25Hz
Margin Phase at UFG is 50.3131degrees
Angle (°)
Frequency (Hz)


Super Sensor ST1 - RX
Magnitude (nm/count)
Frequency (Hz)
Super Sensor
Plant Fit
Isolation Filter
Open LOOP
Suppression SISO
Closed Loop SISO
Slope
-20dB line
UFG is 25Hz
Margin Phase at UFG is 40.1553degrees
Angle (°)
Frequency (Hz)



All figures can be found there:
seismic/HAM-ISI/L1/HAM3/Data/Figures/Transfer_Functions/Simulations/Isolated/

II. Noise and Motion Measurements

1. Check sensor noise and platform transmissibility

In this section:

- We compare the local sensors ASDs taken during quite time and compare them 3 by 3 for the Horizontal CPSs, Vertical CPSs, Horizontal GS13s and Vertical GS13s. We check the symmetry between the corners and check the ASDs against ground motion and sensor noise.
- We check the platform's translation transmissibility in the Cartesian basis (DC transmission, resonance Q, passive isolation)

The measurement and processing is done using:

"Performance_Test_1_Damping_OFF_Low_Gain.m".

This script gets 900 seconds of data, decimates, computes and calibrates ASDs.

The data is saved in

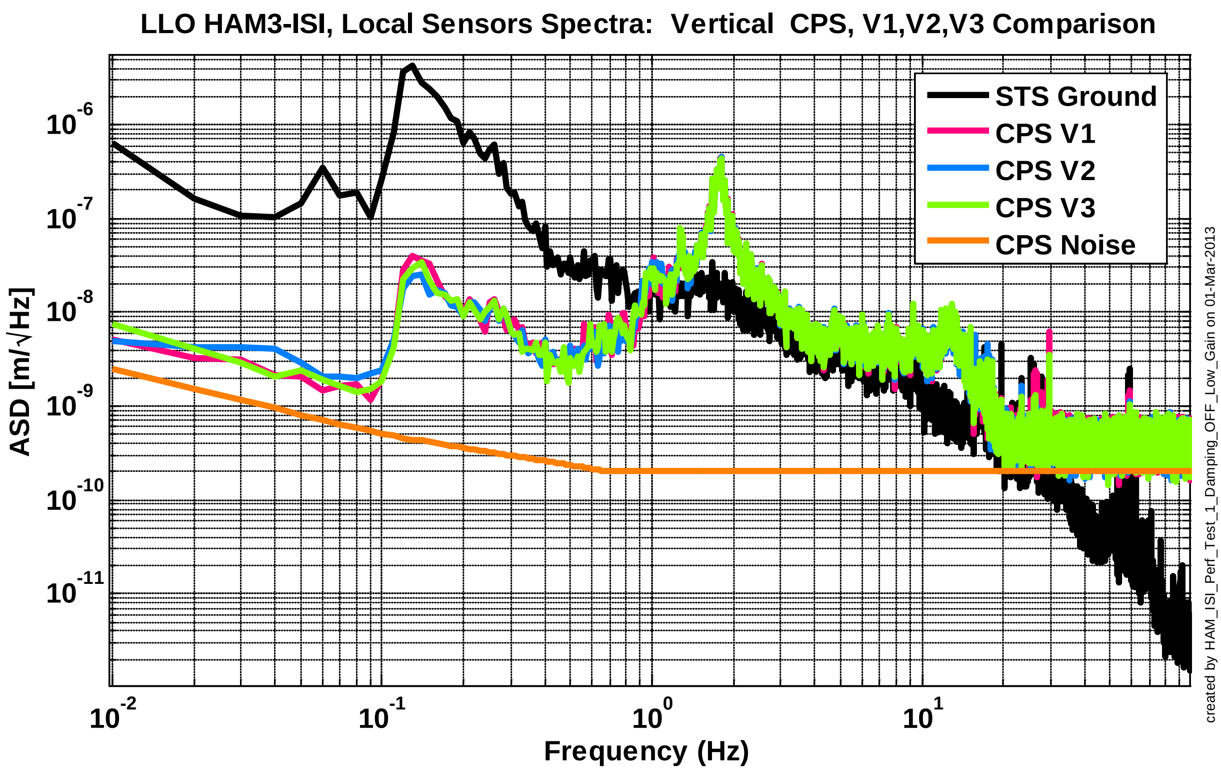
/ HAM-ISI/L1/HAM2/Data/Perf_Analysis/**2013-01-24-a/**

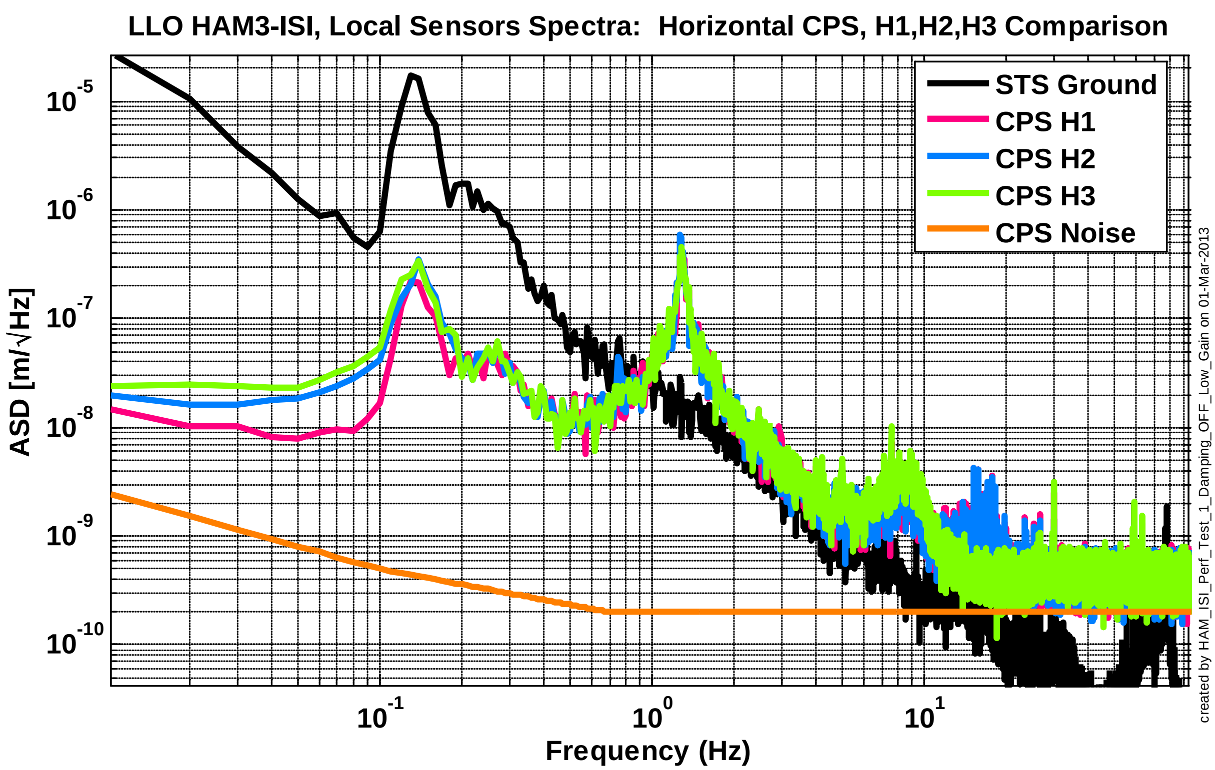
and the figures are saved in

/Data/Figures/Perf_Analysis//**2013-01-24-a/fig**

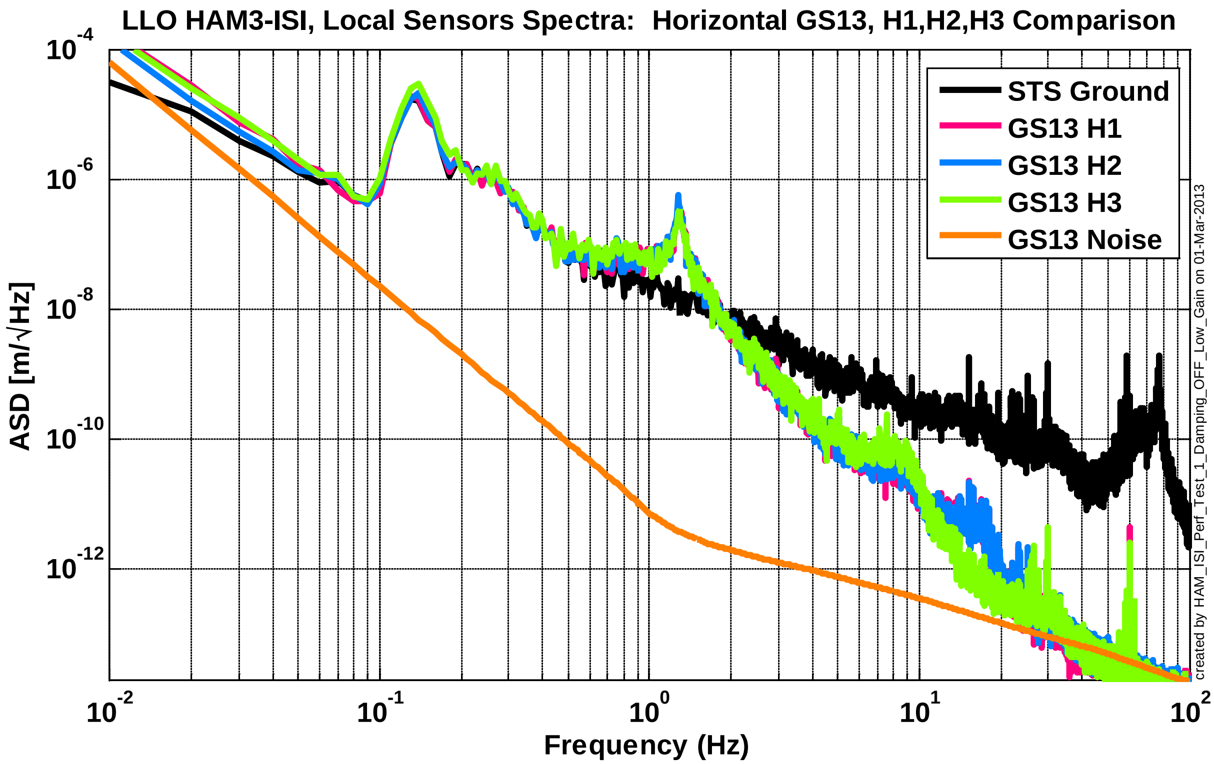
/Data/Figures/Perf_Analysis//**2013-01-24-a/pdf**

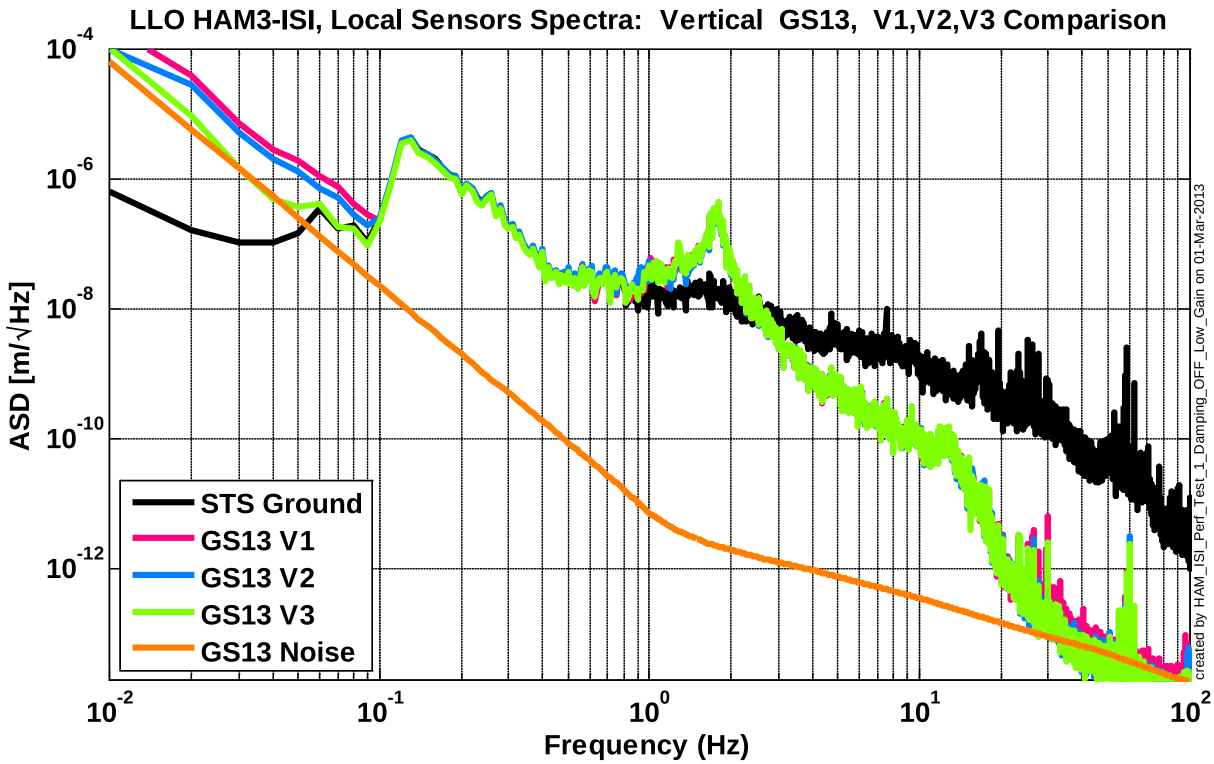
/Data/Figures/Perf_Analysis//**2013-01-24-a/png**



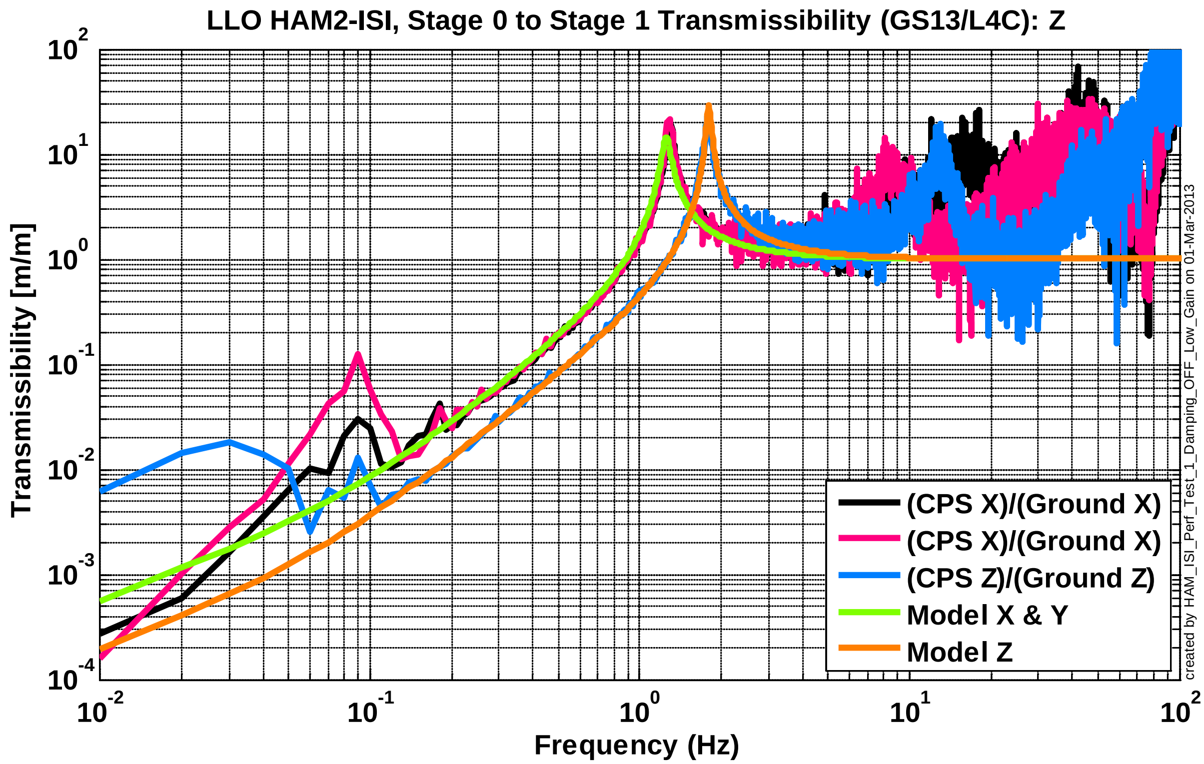


CPSs Comparison Comments: vertical sensors spectra are very symmetric. H2 and H3 are slightly higher than H1. We'll repeat this test to check if we get the same results.

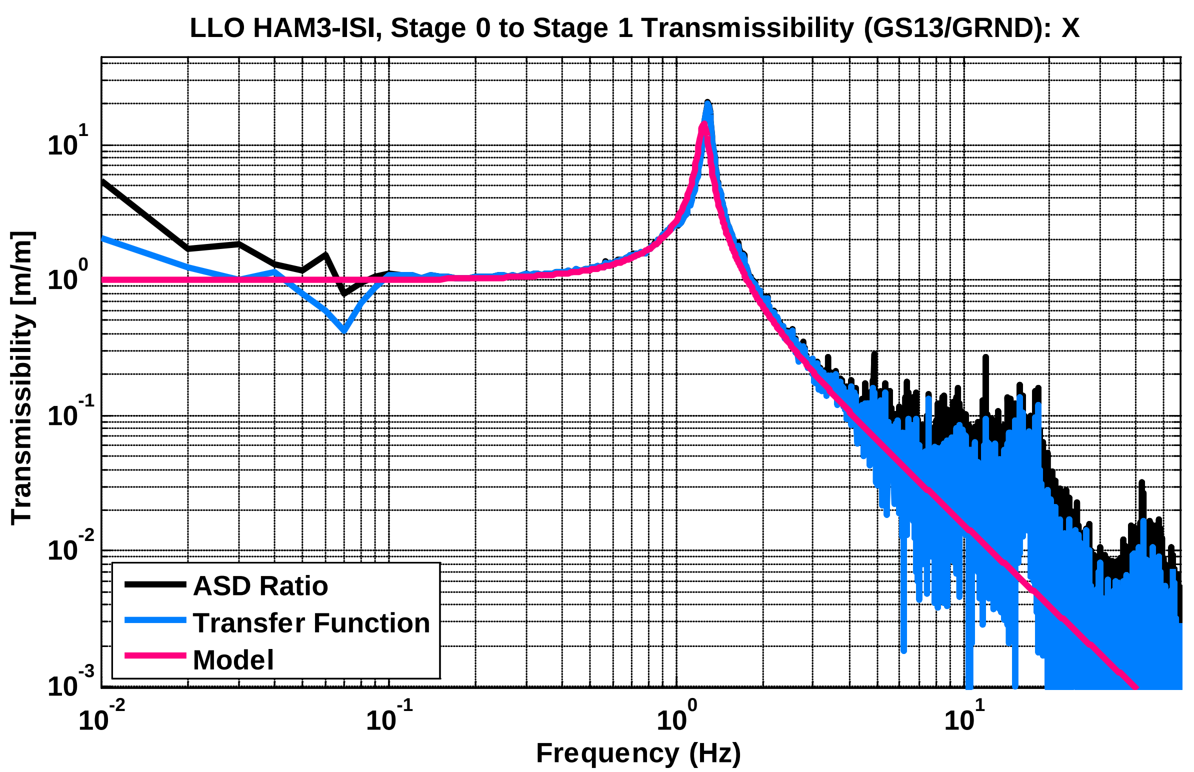


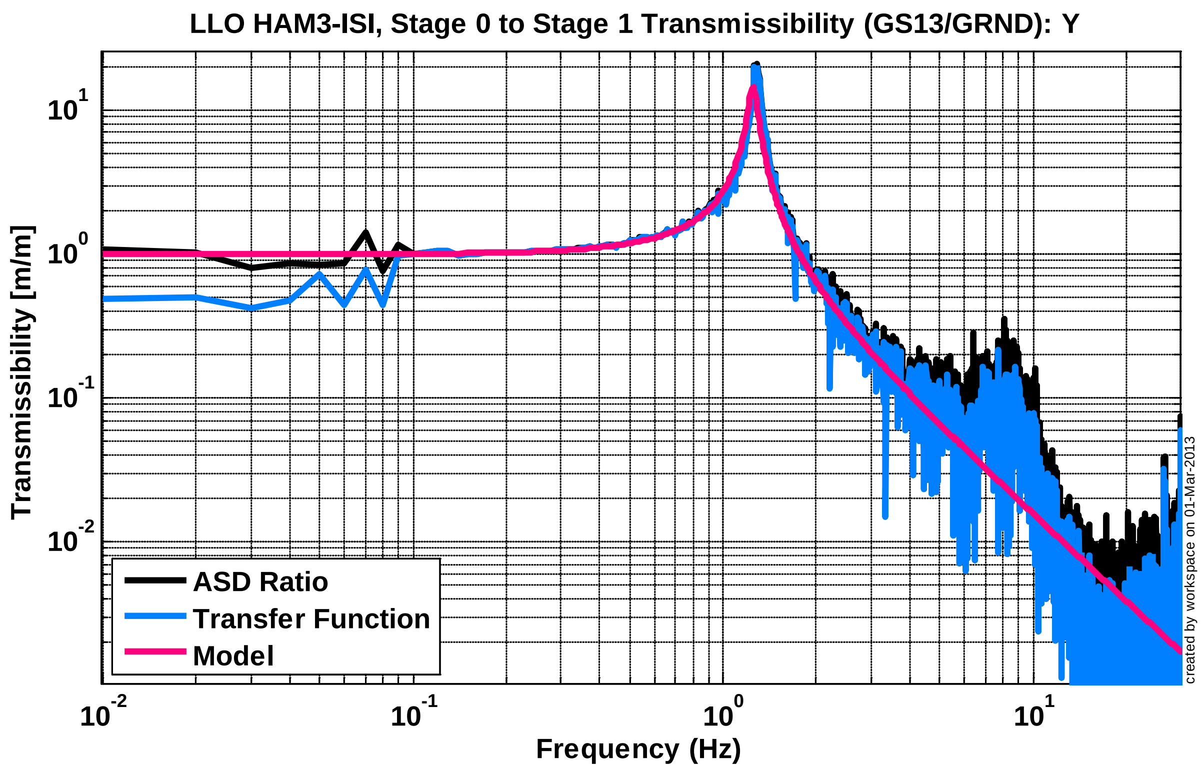


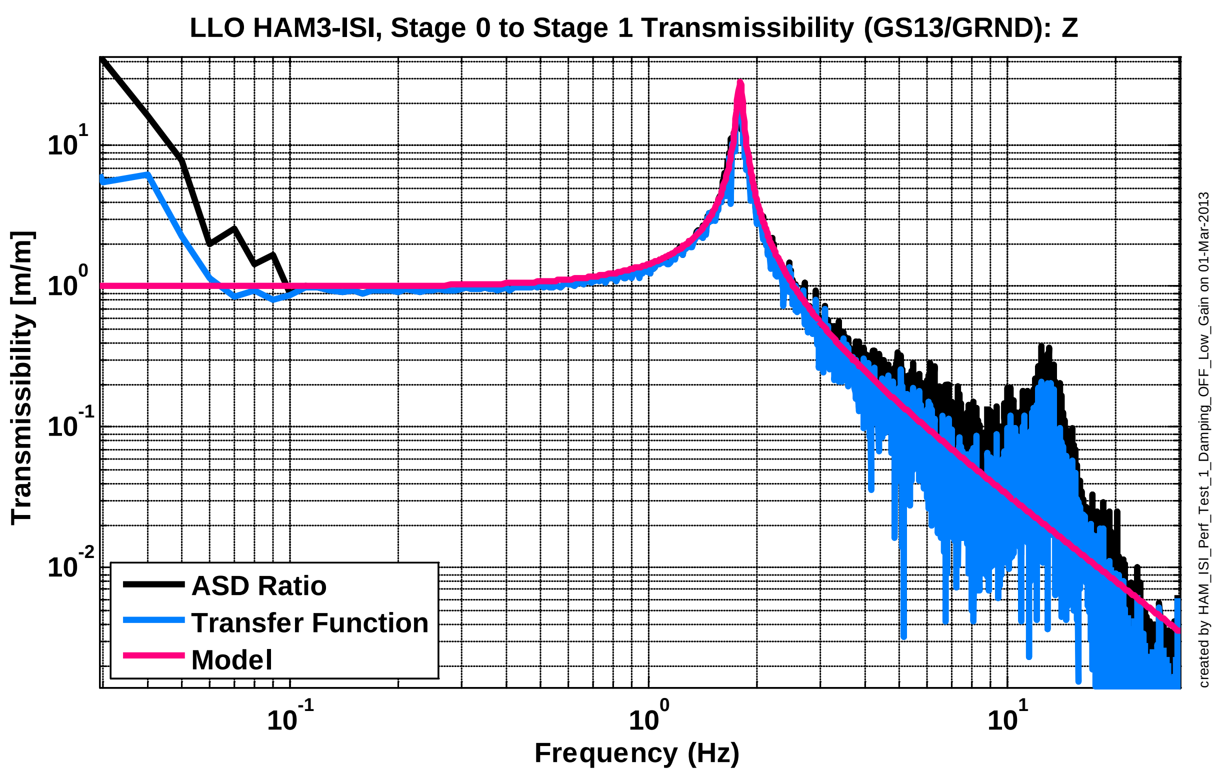
GS13s Comparison Comments: Only V3 gets close to the sensor noise at low frequency.



CPS Transmissibility Comments: there is an excellent agreement between models and measured transfer functions.







GS13 Transmissibility Comments: there is an excellent agreement between models and measured response, both for ASD ratios and transfer functions

2. Check the damping loops

In this section:

- We compare the Cartesian ASDs with damping ON and OFF. We check the damping loops don’t increase the motion outside of the control bandwidth.

- We compare the measured and calculated sensitivity.

The measurement and processing is done using:

“Performance_Test_2”.

This script gets 900 seconds of data, decimates, computes and calibrates ASDs.

The data is saved in

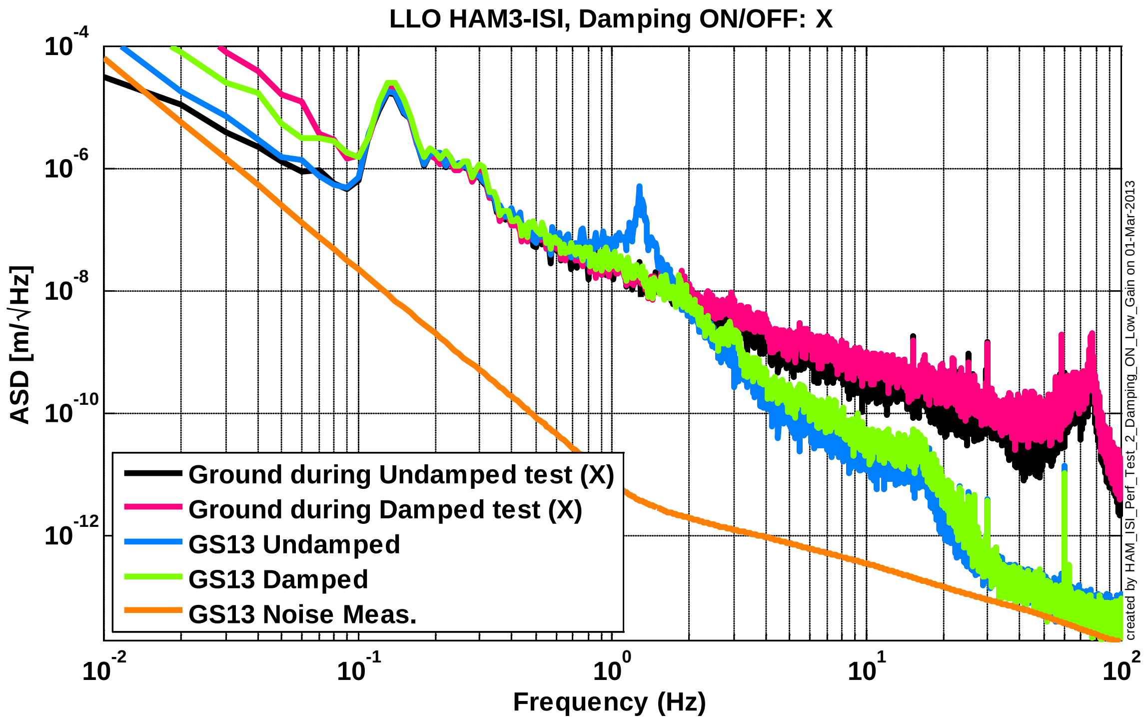
/ HAM-ISI/L1/HAM2/Data/Perf_Analysis/**2013-01-24-a/**

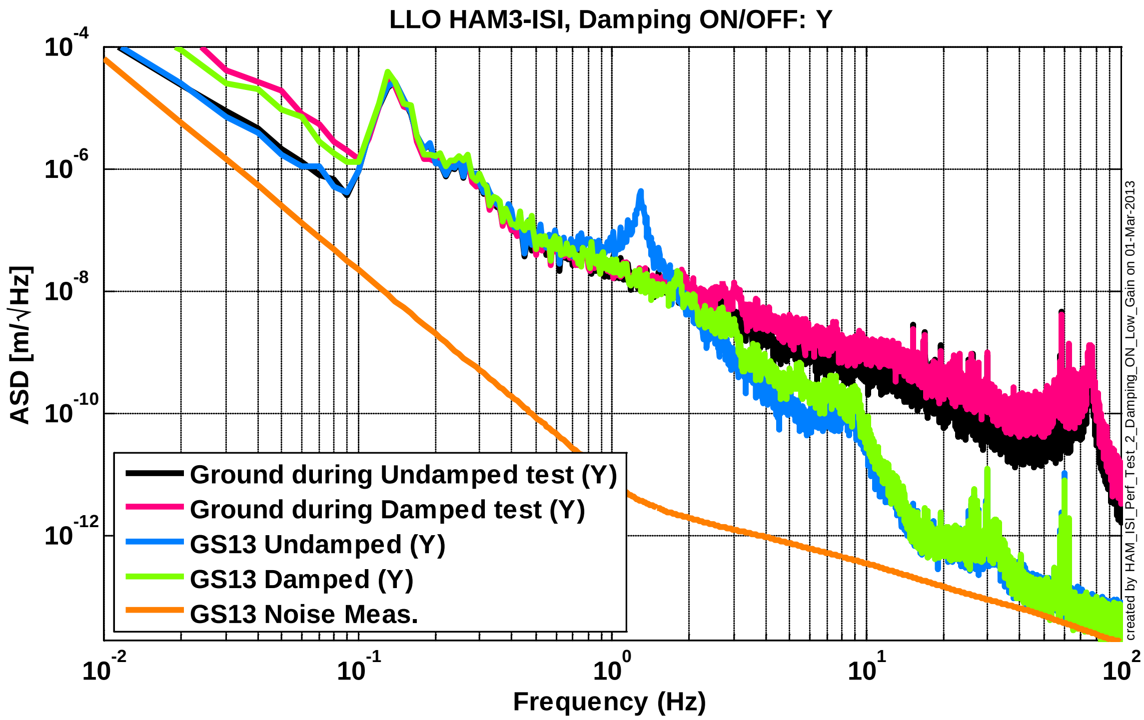
and the figures are saved in

/Data/Figures/Perf_Analysis//**2013-01-24-a/fig**

/Data/Figures/Perf_Analysis//**2013-01-24-a/pdf**

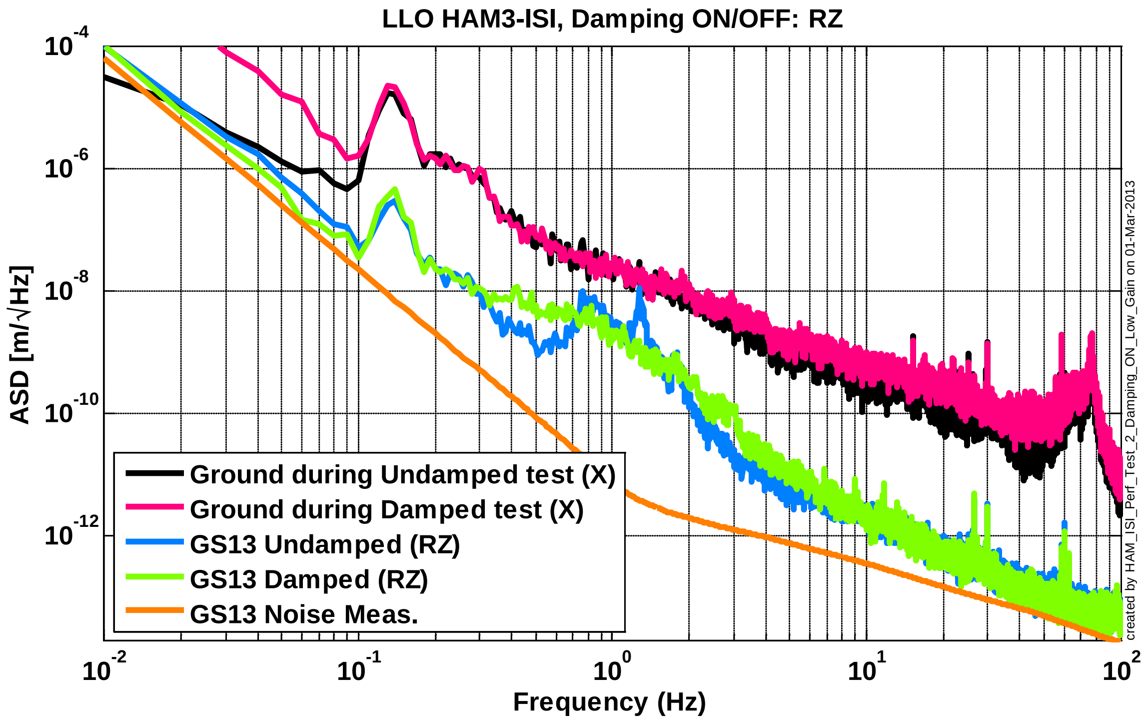
/Data/Figures/Perf_Analysis//**2013-01-24-a/png**



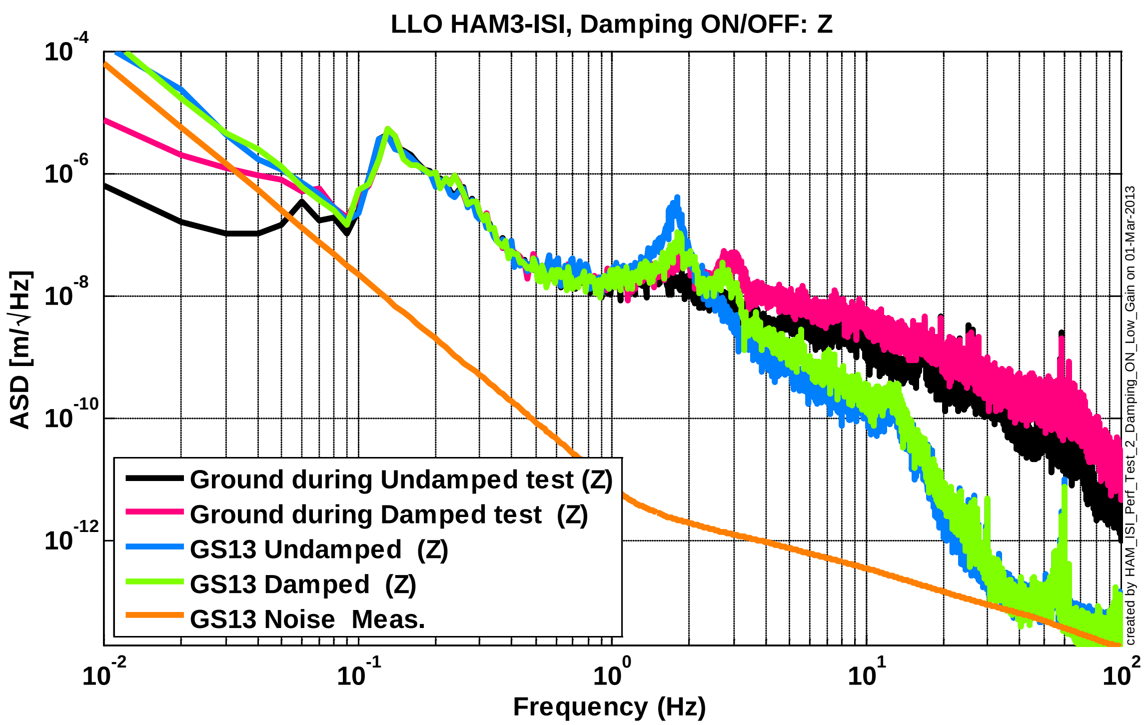


X,Y damping loops Comments:

- Good attenuation at the resonance
- No amplification at low frequency (higher input ground)
- No excess amplification above the unity gain frequency

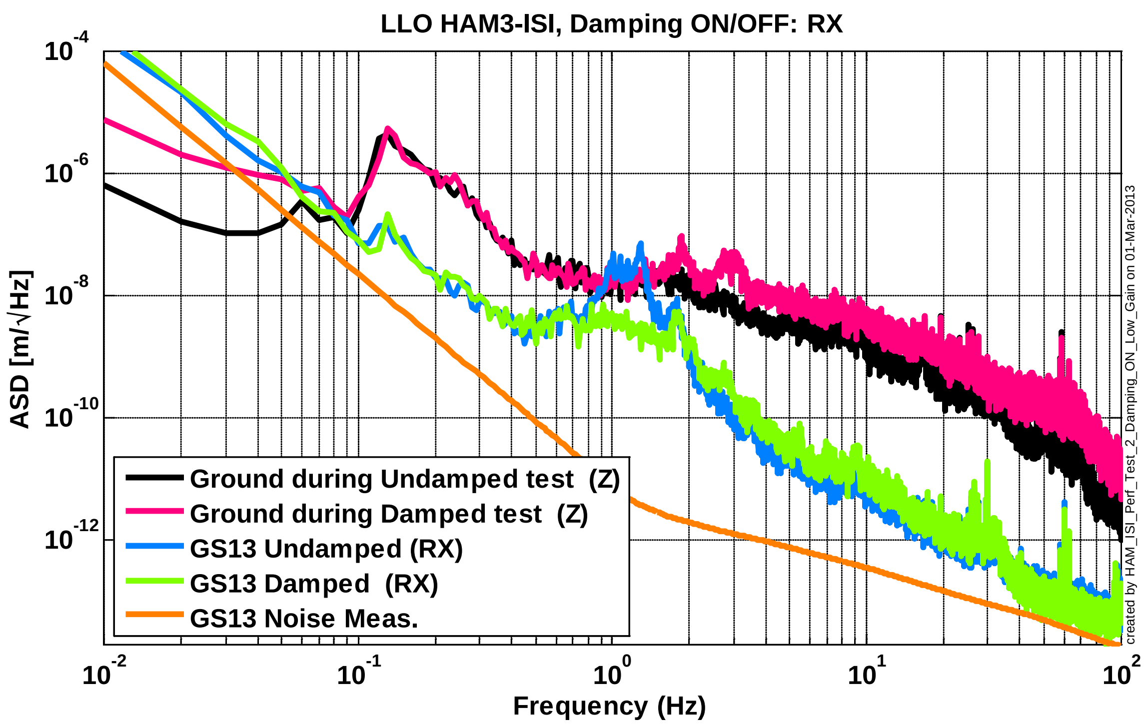


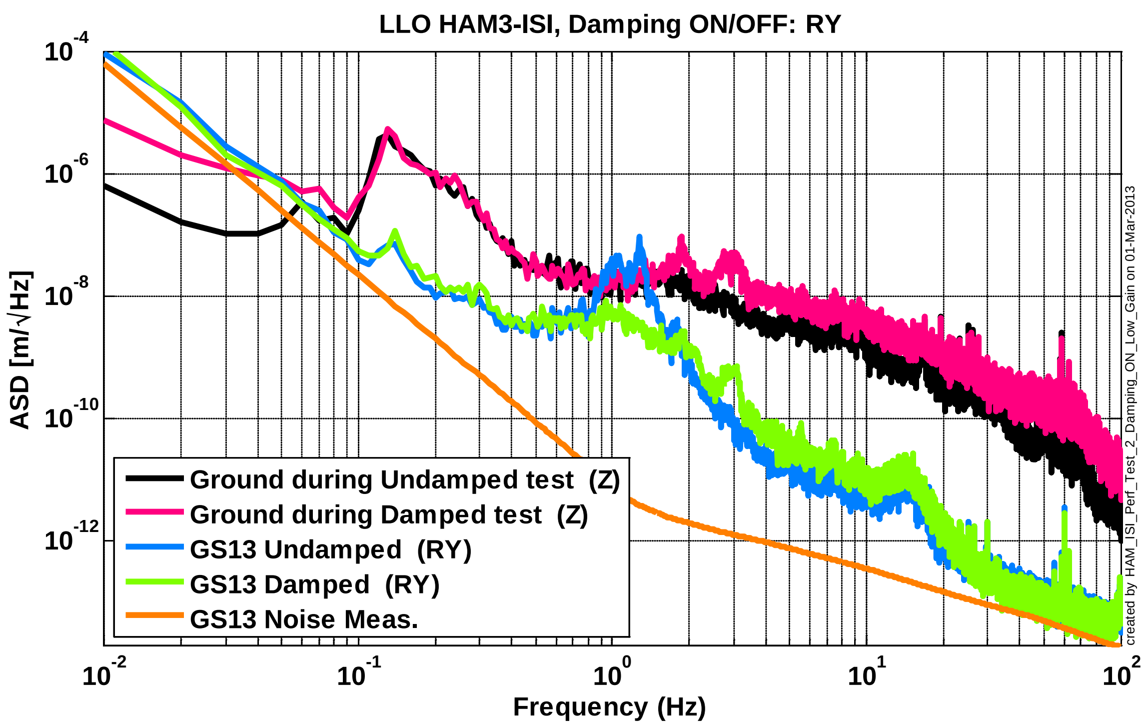
RZ damping loops Comments: The ASD is in the sensor noise below 0.1Hz . There is visible amplification near the lower and higher unity gain frequency.



Z damping loops Comments:

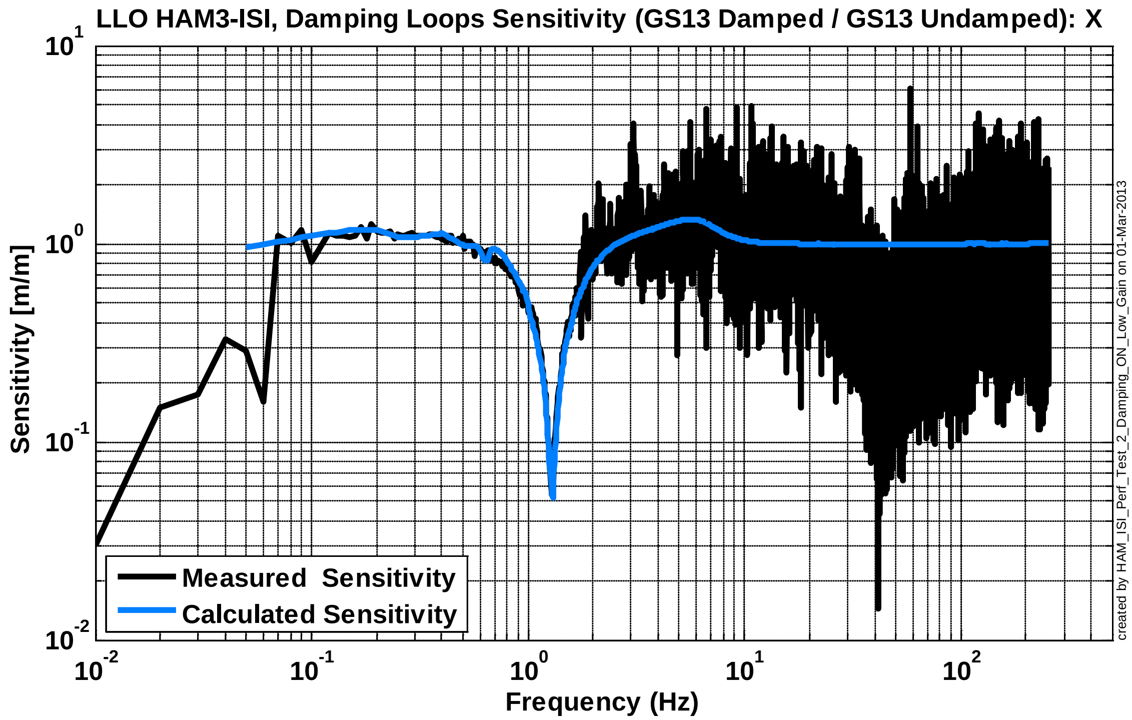
- Good attenuation at the resonance
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency

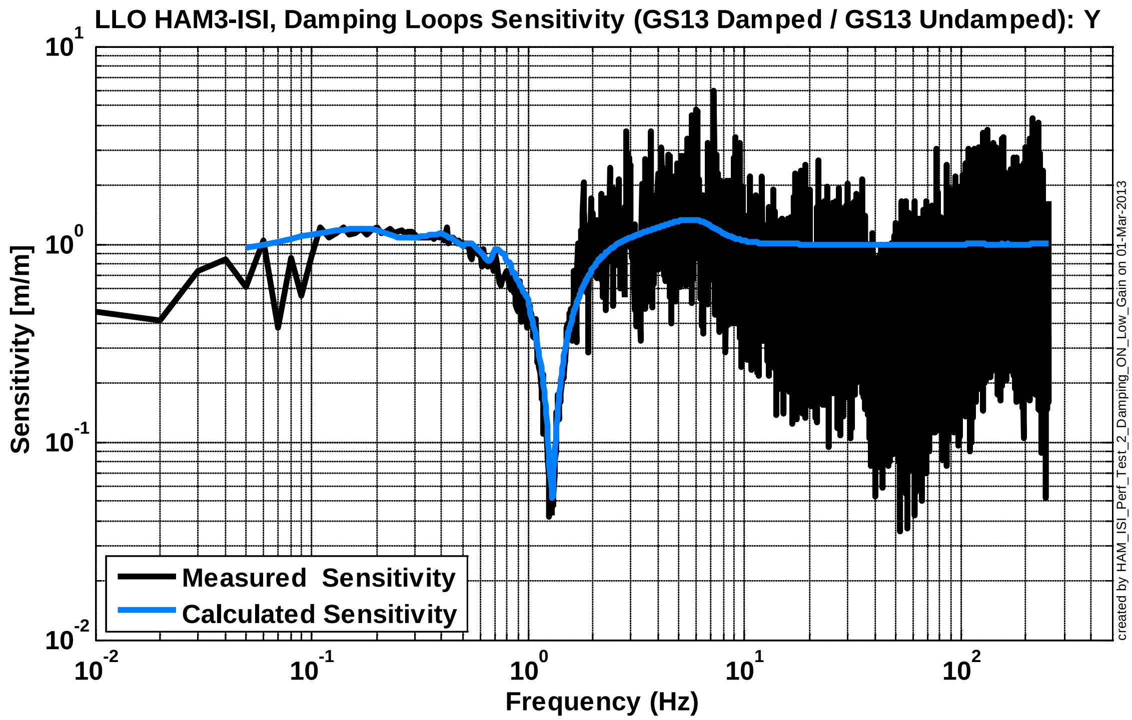




RX and RY damping loops Comments:

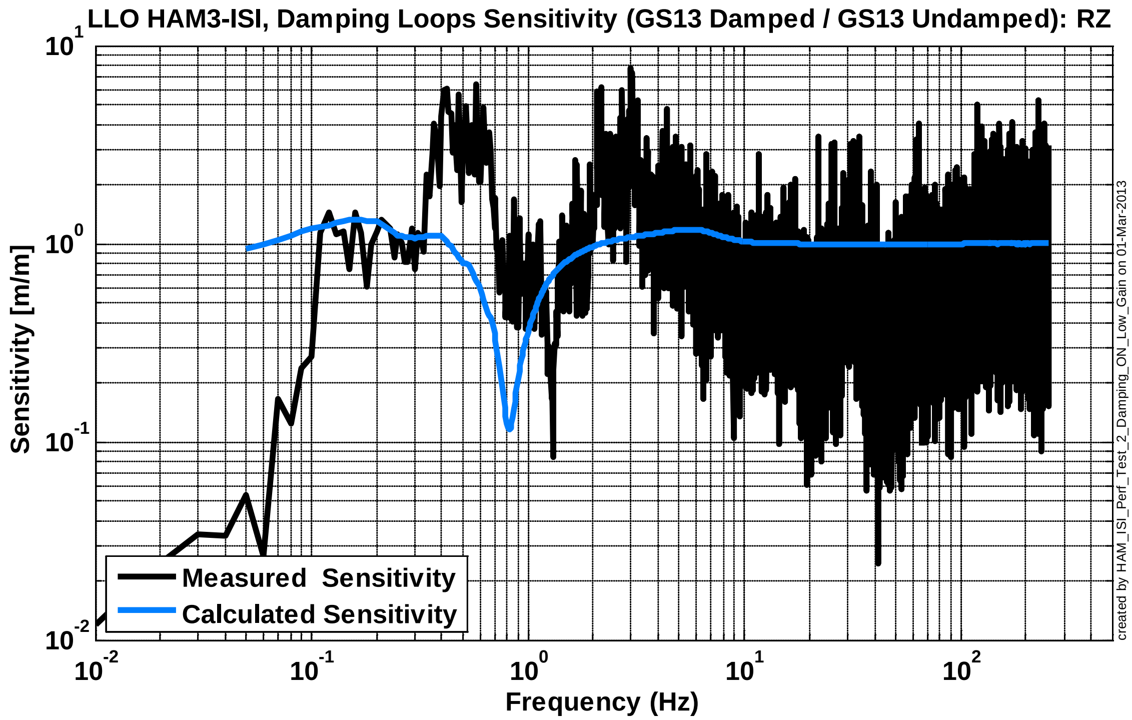
- Good attenuation at the resonance
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency



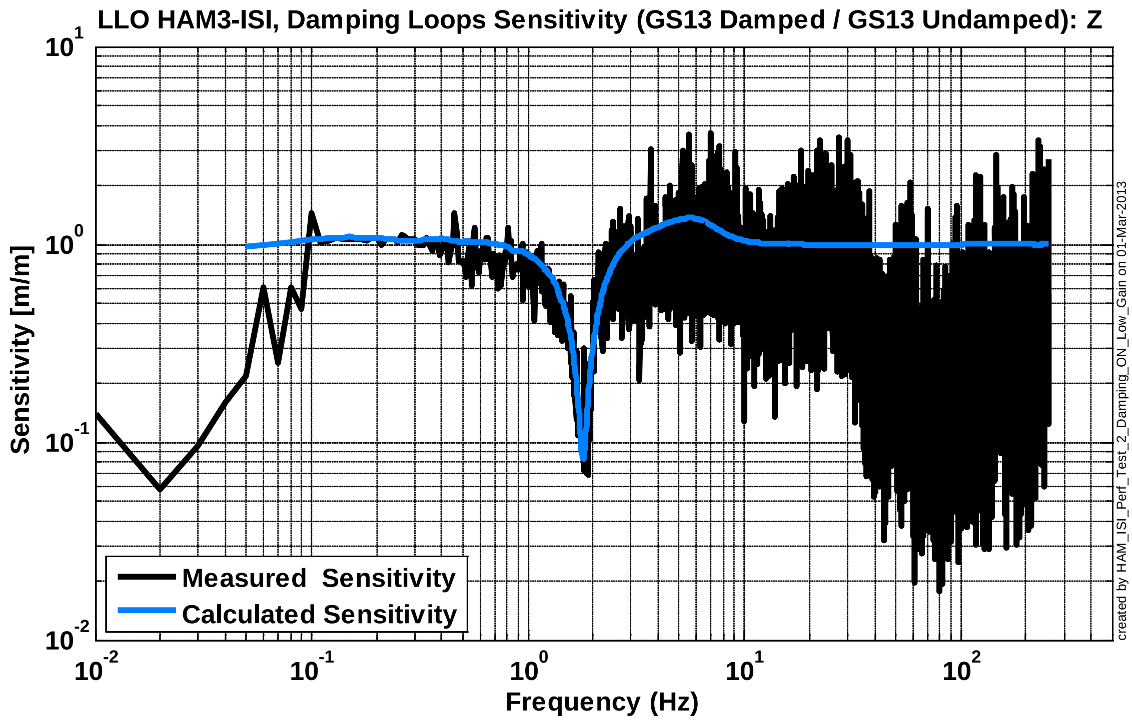


X and Y damping loops sensitivity Comments:

- There is excellent agreement between the measured and calculated sensitivity from 0.1Hz to 2Hz
- Above 2 Hz we need to increase the averaging over the frequency bin in order to more closely check the actual amplification

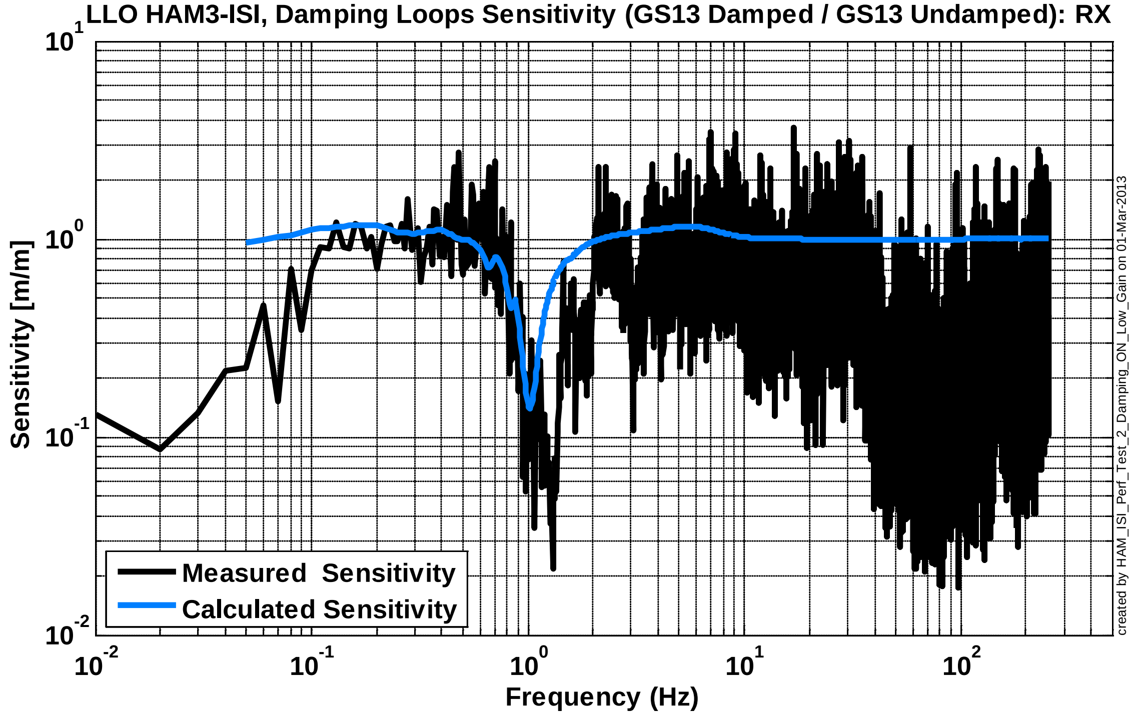


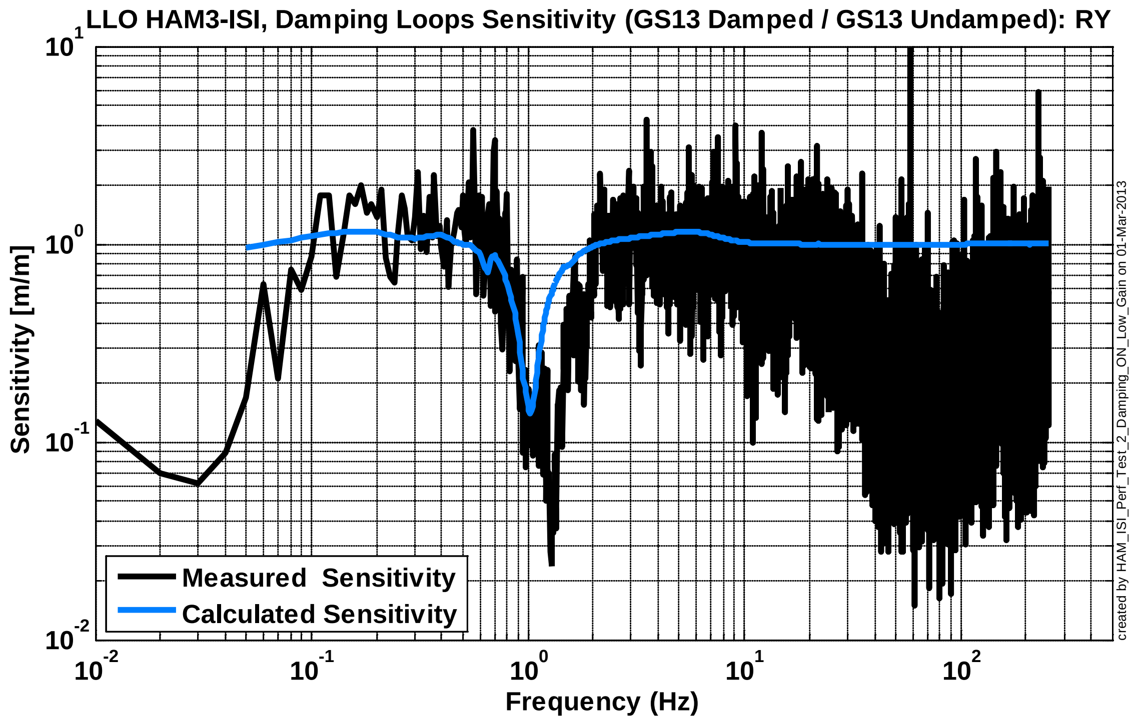
RZ damping loops sensitivity Comments: Measurement shows amplification in the control bandwidth.



Z damping loops sensitivity Comments:

- There is excellent agreement between the measured and calculated sensitivity from 0.1Hz to 2Hz
- Above 2 Hz we need to increase the averaging over the frequency bin in order to more closely check the actual amplification





RX and RY damping loops sensitivity Comments:

- Measured and calculated sensitivity show the same tendency
- Cross couplings from horizontal loop seem to contribute to RX, RY damping.

3. Check analog/digital switchable filter

In this section, we leave the damping ON, and turn both the analog gain and whitening filters to high gain mode. This also engages their digital counterpart. In the figures below:

- We check that the digital filters engaged invert well their analog counterpart.
- The analog filtering doesn't induce low frequency noise and that it does bring the signal above the ADC noise at high frequencies

The measurement and processing is done using:

"Performance_Test_3_Damping_ON_High_Gain.m".

This script gets 900 seconds of data, decimates, computes and calibrates ASDs.

The data is saved in

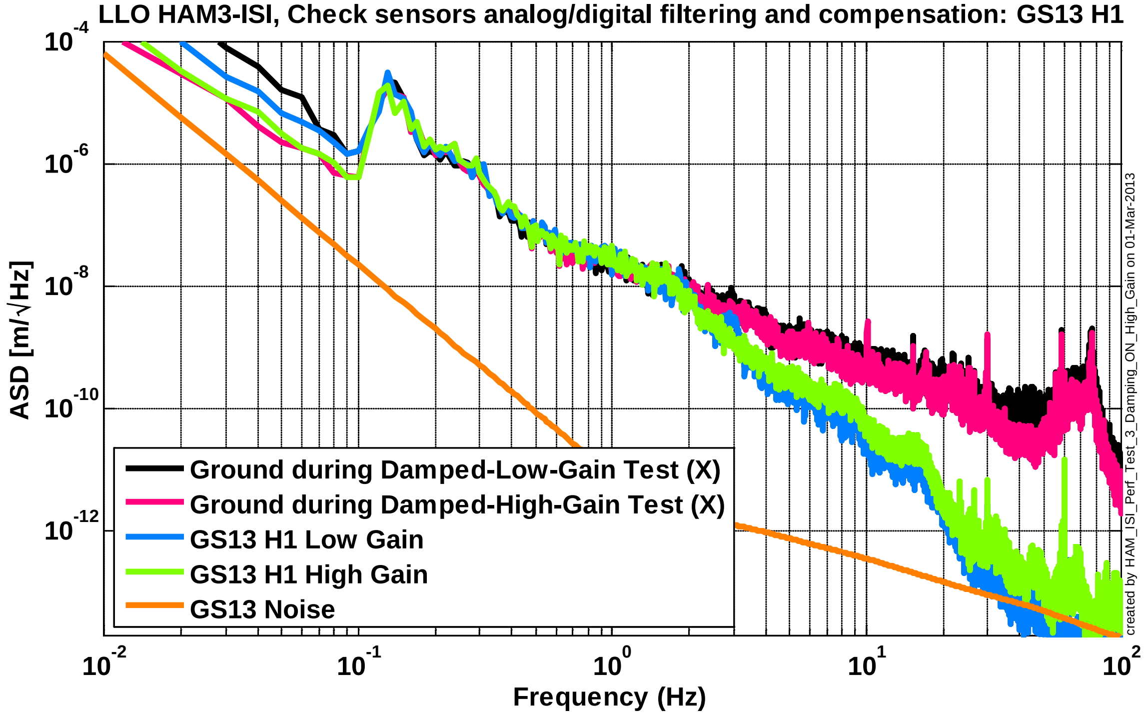
/ HAM-ISI/L1/HAM2/Data/Perf_Analysis/**2013-01-24-a/**

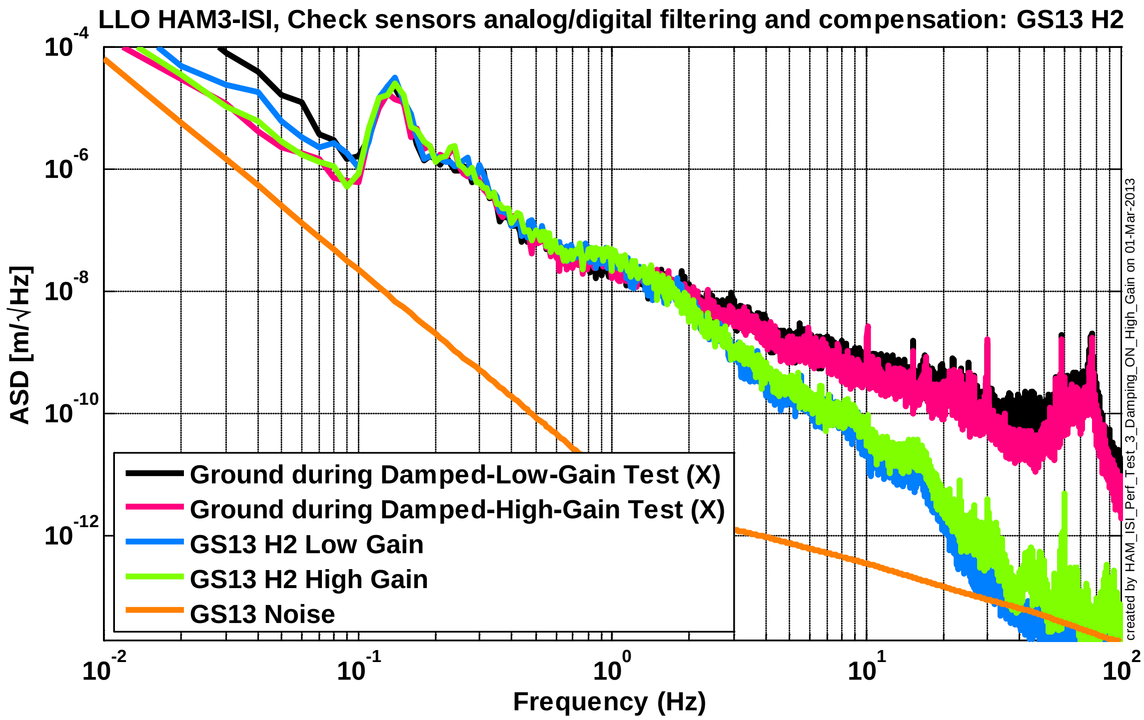
and the figures are saved in

/Data/Figures/Perf_Analysis//**2013-01-24-a/fig**

/Data/Figures/Perf_Analysis//**2013-01-24-a/pdf**

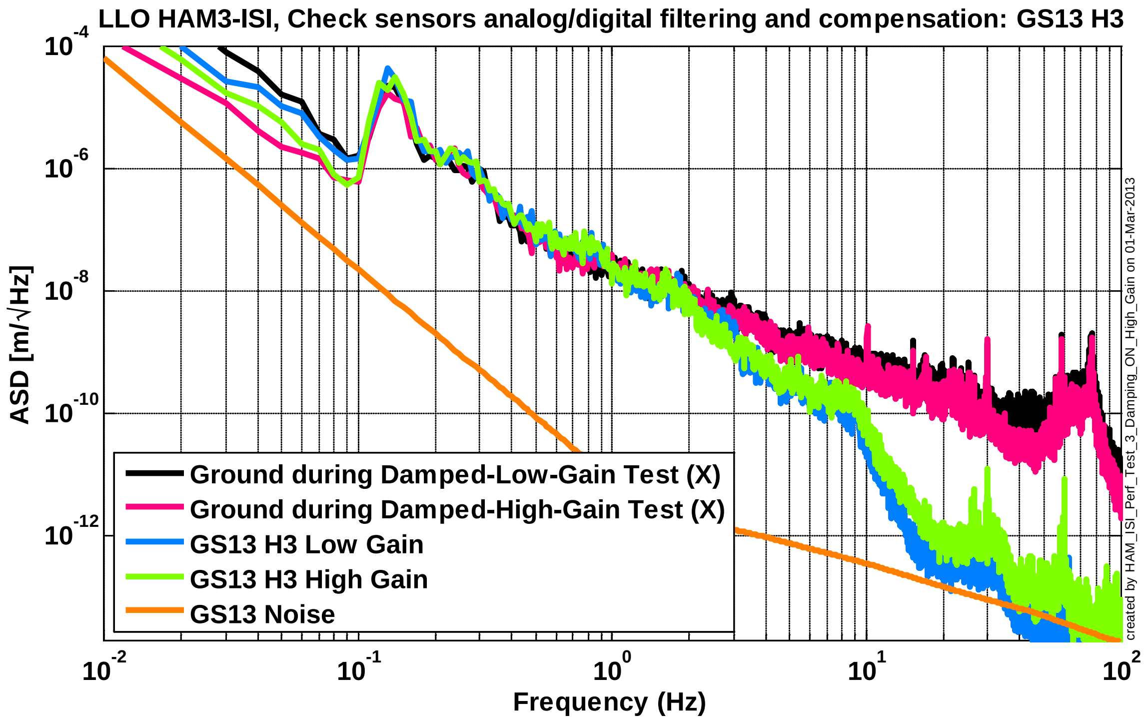
/Data/Figures/Perf_Analysis//**2013-01-24-a/png**



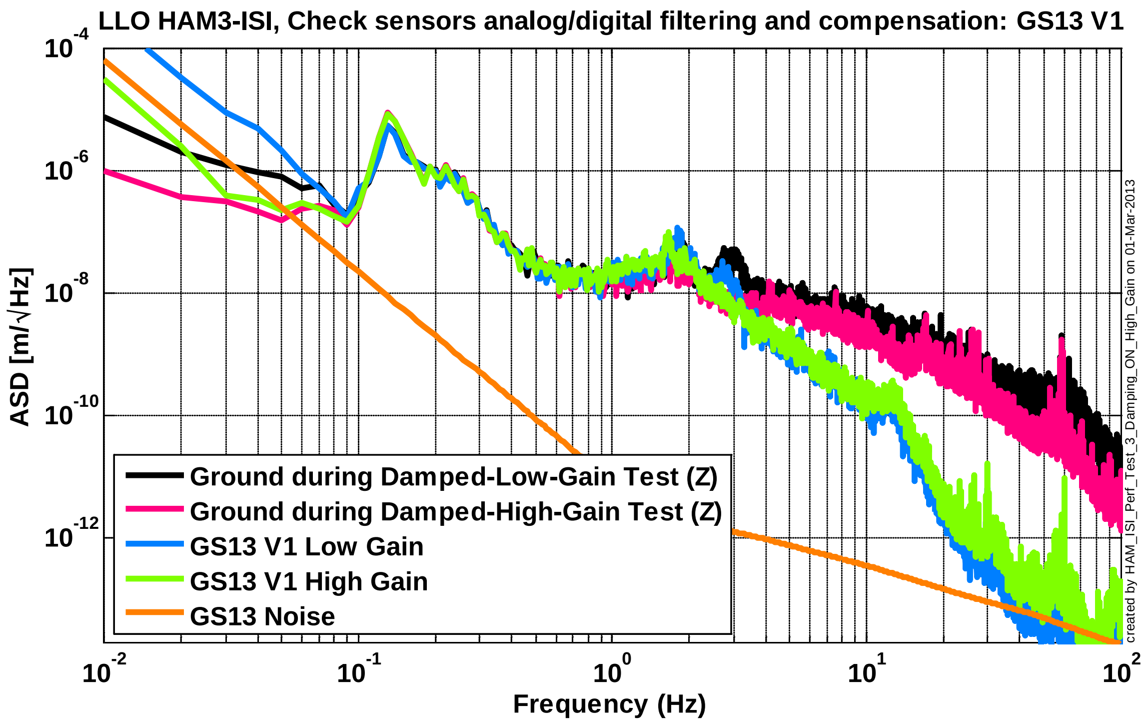


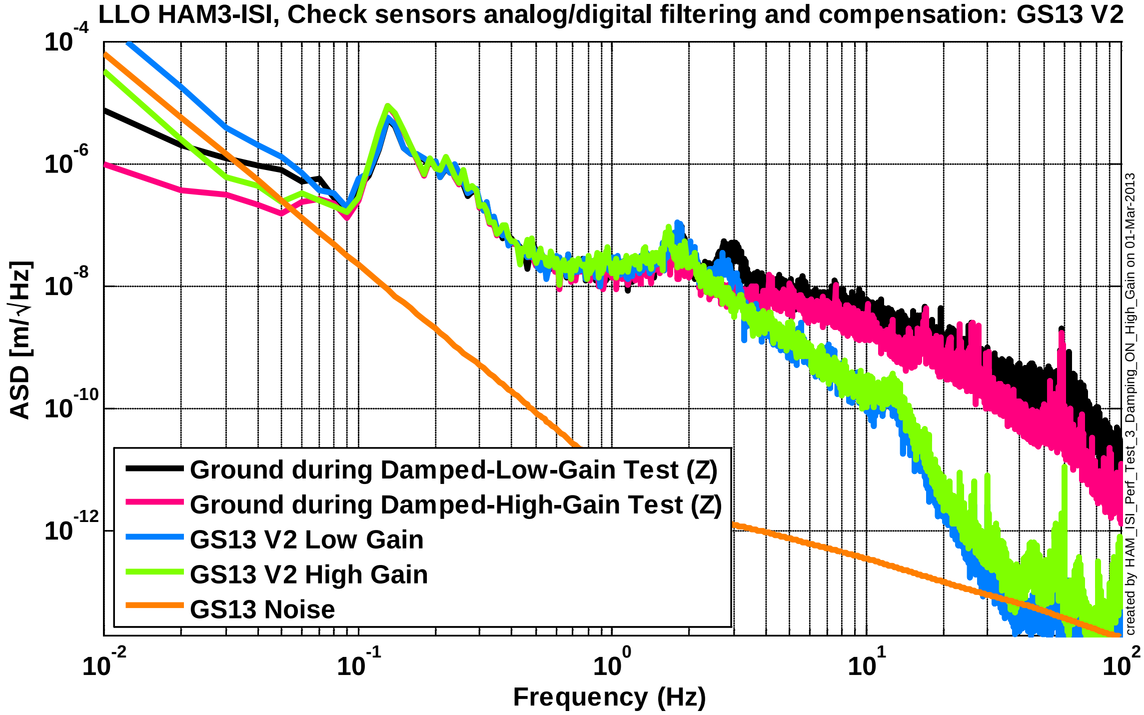
H1, H2 GS13 Gains and Whitening Comments:

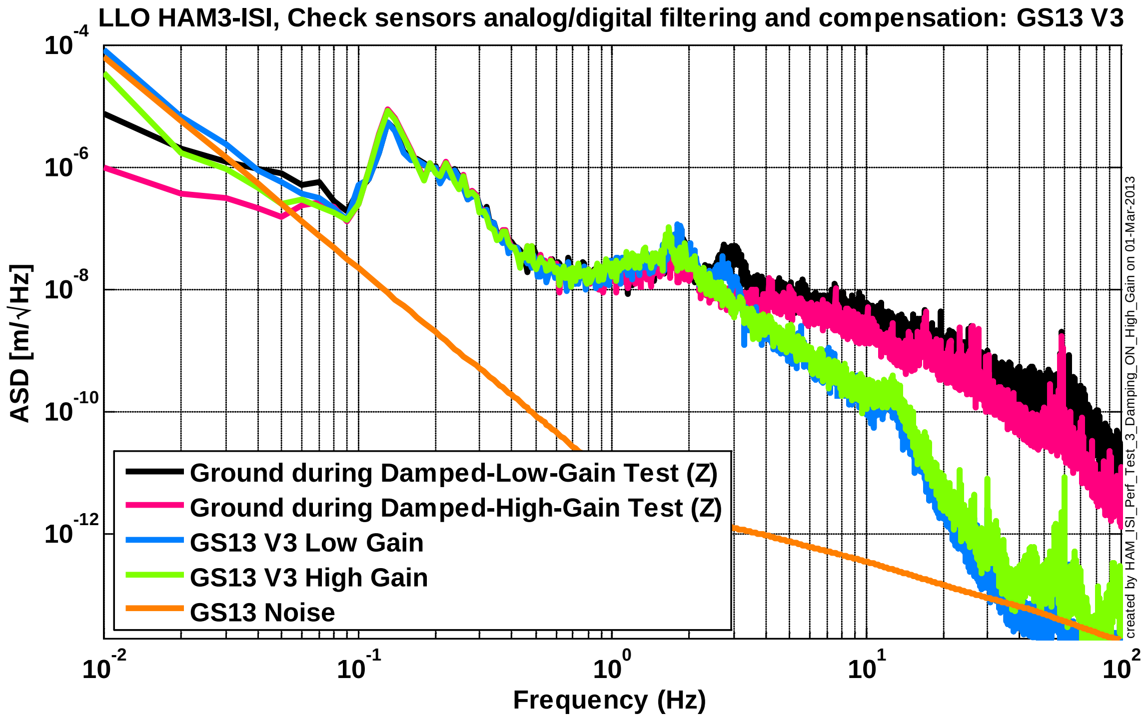
- Digital filters invert well the analog filters
- Analog filters does not alter the low frequency (ground went done)
- Signal raises above ADC noise at higher frequency



H3 GS13 Gains and Whitening Comments: same comments as for H1 and H2.







V1, V2, V3 GS13 Gains and Whitening Comments:

- Digital filters invert well the analog filters
- Analog filtering does not seem alter the low frequency (ground went done). Could be double-checked.
- Signal raises above ADC noise at higher frequency

4. Check Vertical control loop performance

In this section, we leave the damping, the analog gain and whitening filters ON. We engage the vertical control loops (Standard Blend, Level 2).

For the vertical degrees of freedom:

- We compare the GS13 spectras, with control ON and off.
- We compare the measured sensitivity with the low pass complementary filter

Then we check that the vertical loops don't amplify the horizontal motion/tilt coupling. We check it not only in the horizontal GS13s, but also in the horizontal CPSs.

The measurement and processing is done using:

"Performance_Test_4_Vertical_Isolation_ON_High_Gain.m"

This script gets 900 seconds of data, decimates, computes and calibrates ASDs.

The data is saved in

/ HAM-ISI/L1/HAM2/Data/Perf_Analysis/**2013-01-24-a/**

and the figures are saved in

/Data/Figures/Perf_Analysis//**2013-01-24-a/fig**

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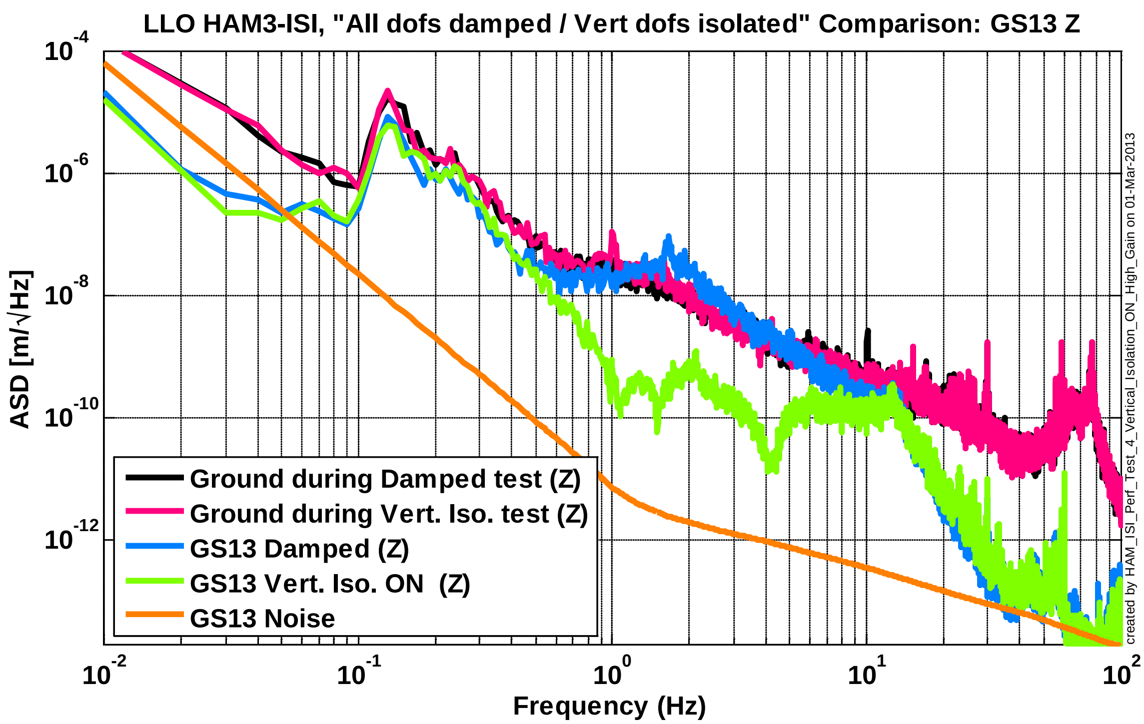
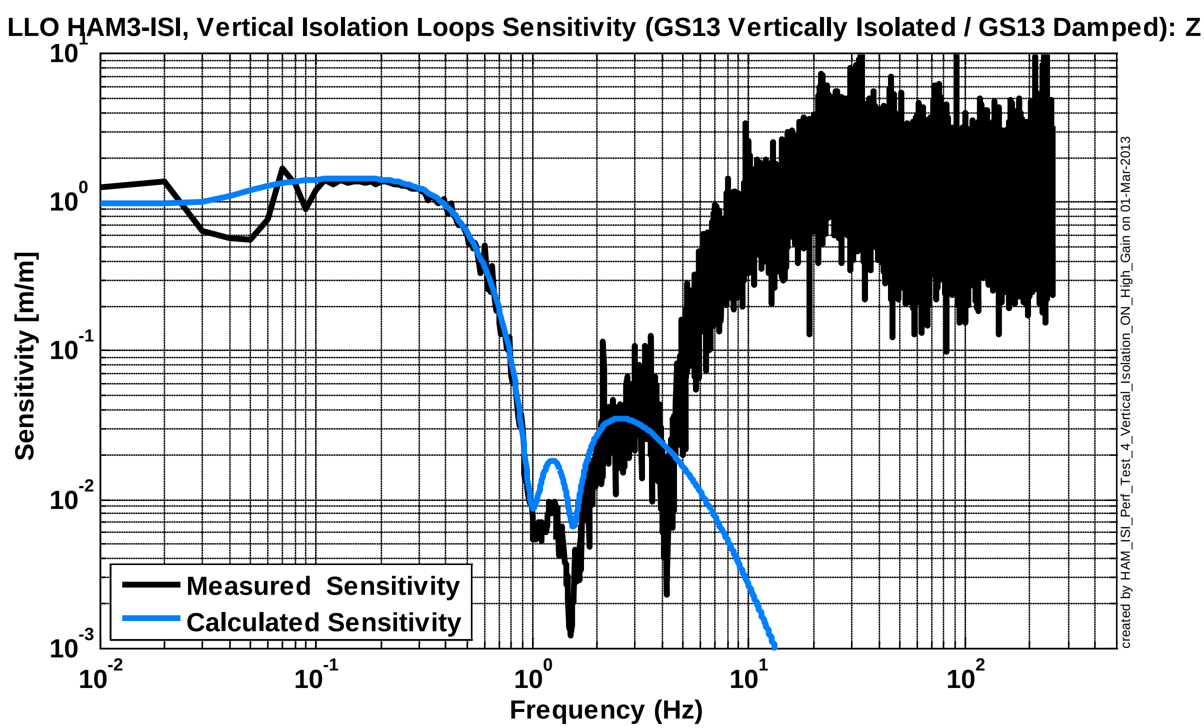
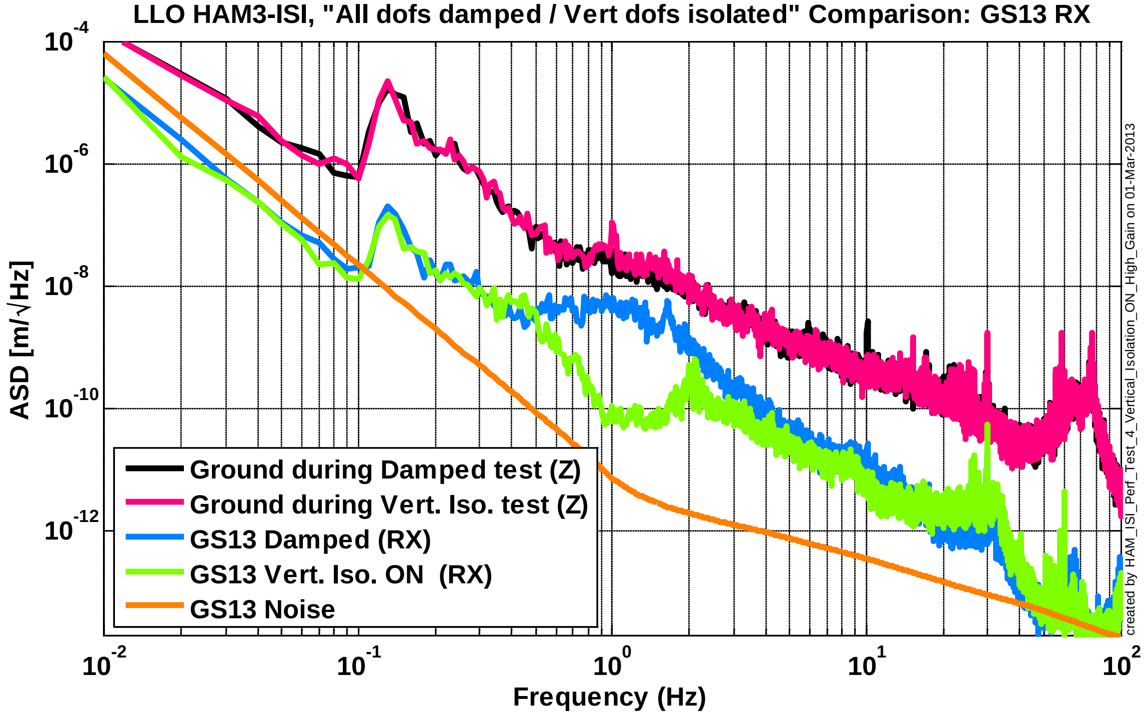
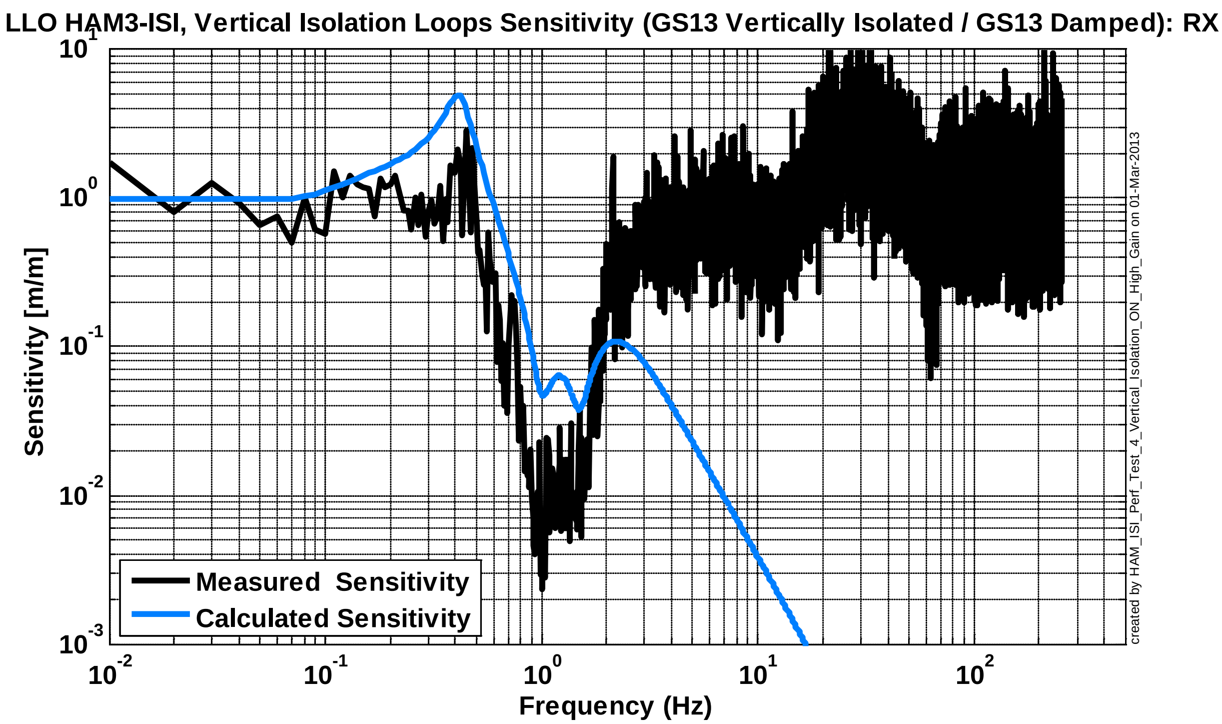




Z isolation loops Comments:

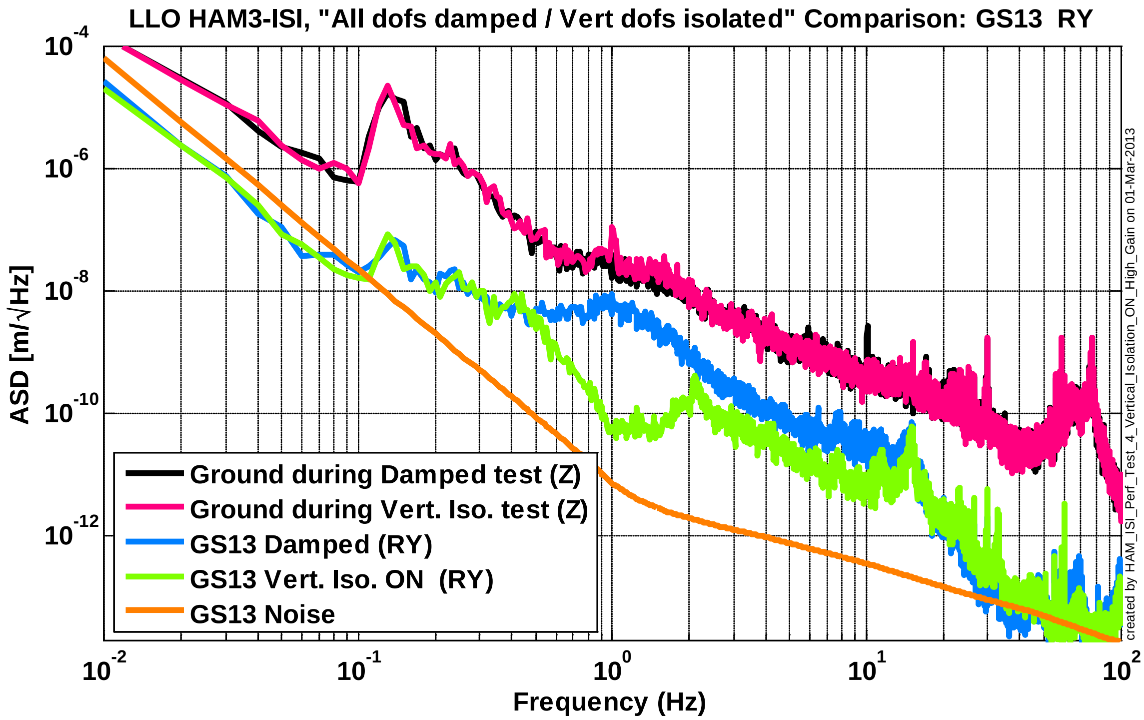
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Very agreement between the measured sensitivity and the low pass filter

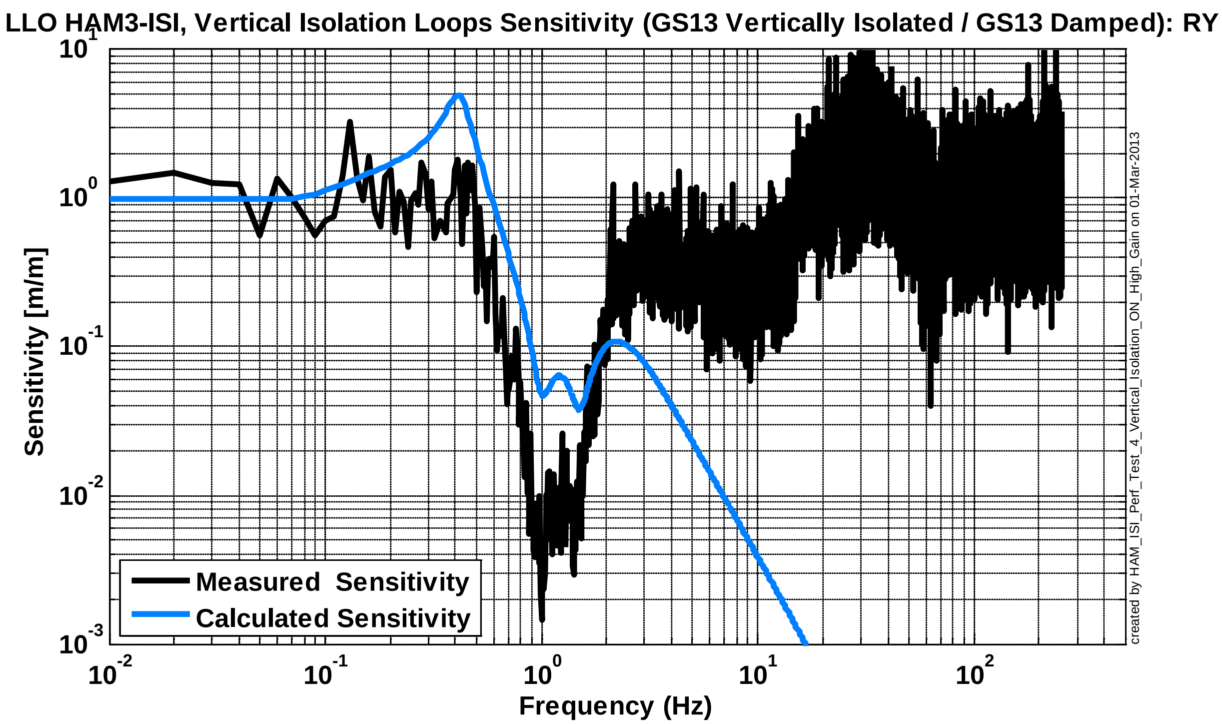




RX isolation loops Comments:

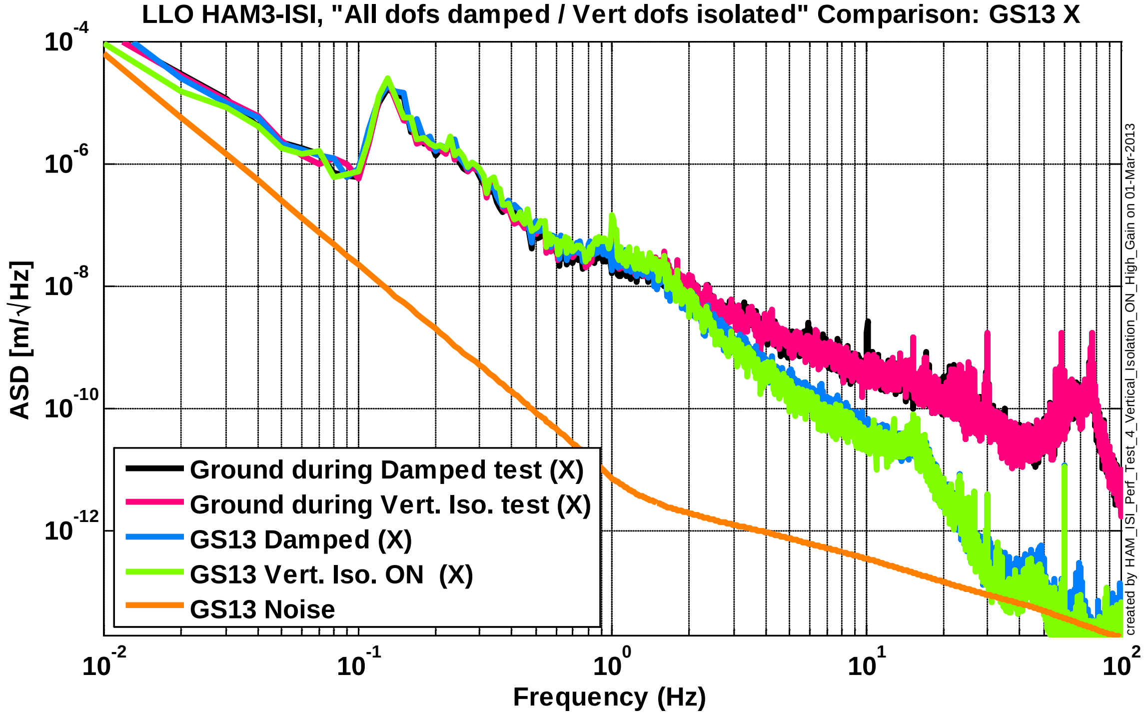
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Measured sensitivity show less amplification than low pass filter

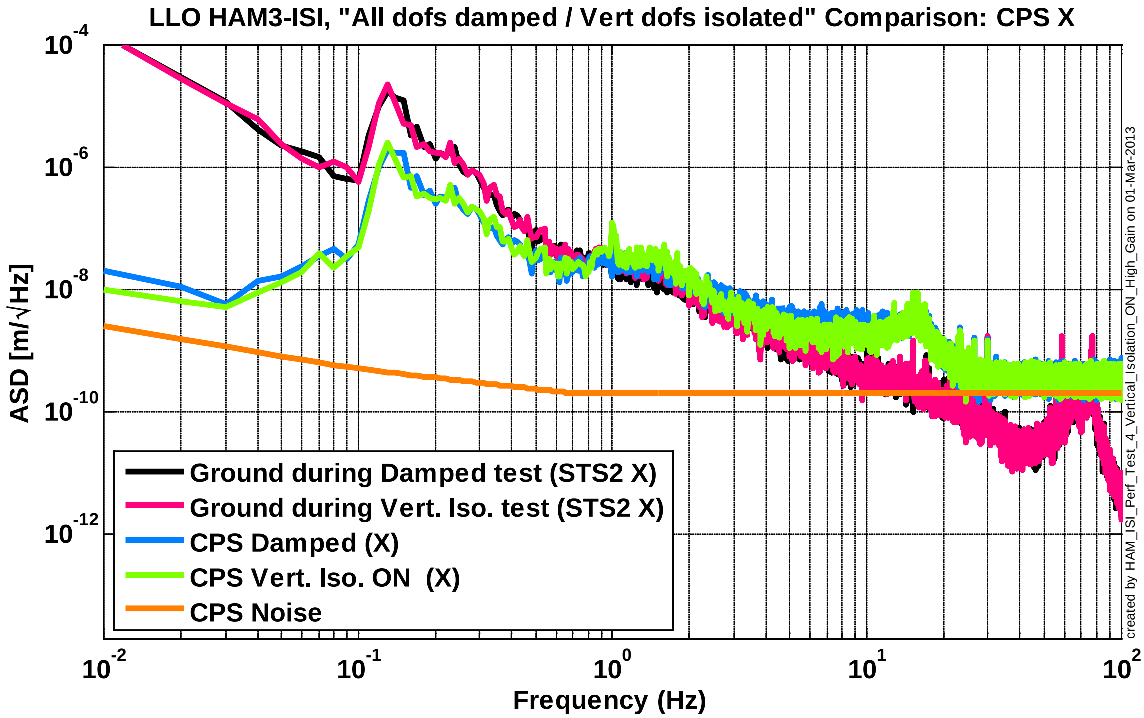




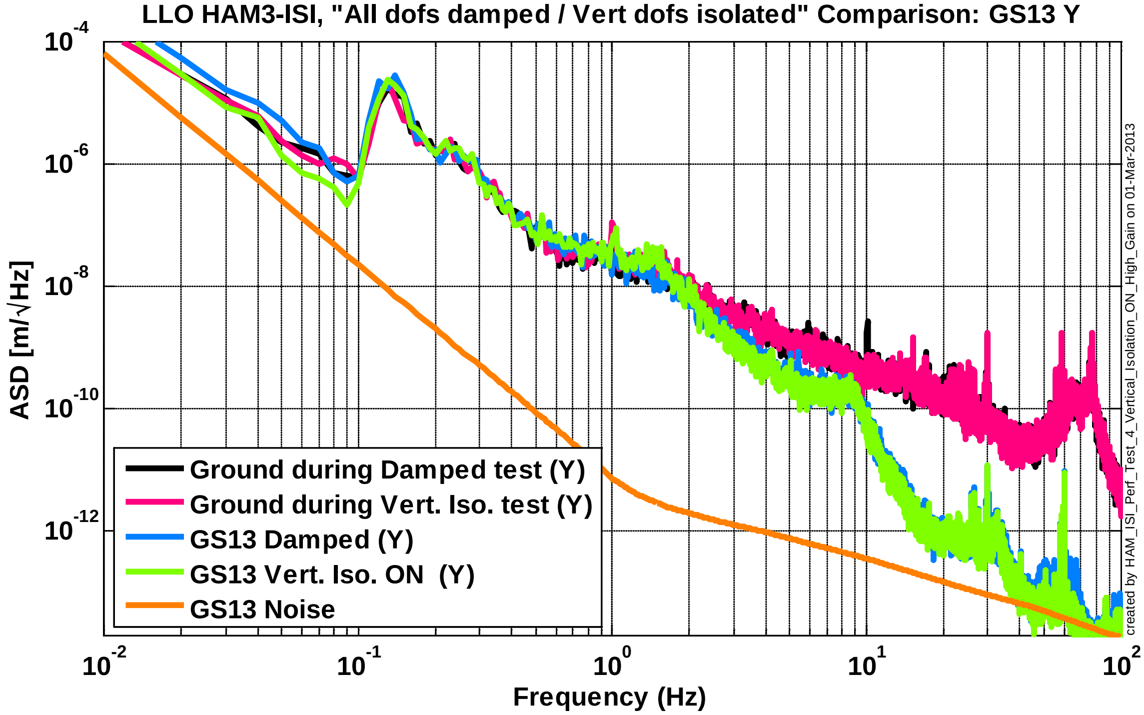
RY isolation loops Comments:

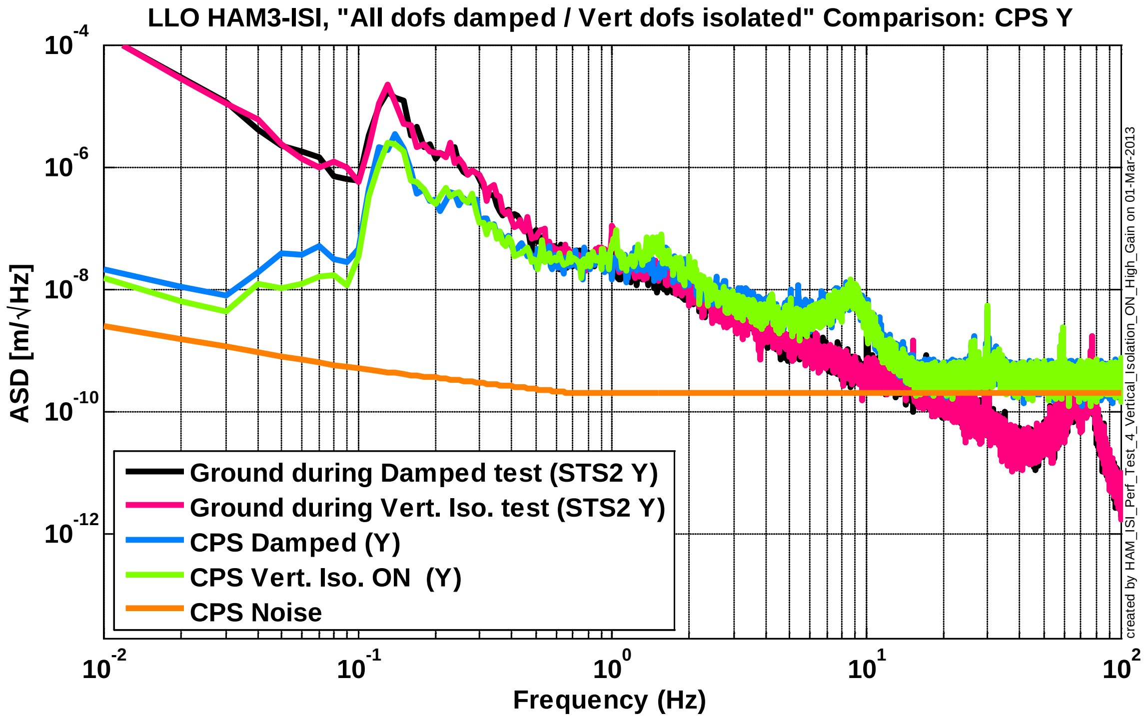
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Measured sensitivity show less amplification than low pass filter





Impact of vertical loops on X sensors: no visible effect.





Impact of vertical loops on Y sensors: no visible effect.

5. Check Horizontal control loops performance

In this section, we leave the damping, the analog gain and whitening filters, and the Vertical Loops ON. We engage horizontal loops (Standard Blend, Level 2).

For all the degrees of freedom:

- We compare the GS13 spectra, with control ON and OFF.
- We check the CPS motion and compare with typical cavity motion
- We compare measured sensitivity and low pass complementary filter

The measurement and processing is done using:

"Performance_Test_5_Vertical_Isolation_ON_High_Gain.m"

This script gets 900 seconds of data, decimates, computes and calibrates ASDs.

The data is saved in

/ HAM-ISI/L1/HAM2/Data/Perf_Analysis/**2013-01-24-a/**

and the figures are saved in

/Data/Figures/Perf_Analysis//**2013-01-24-a/fig**

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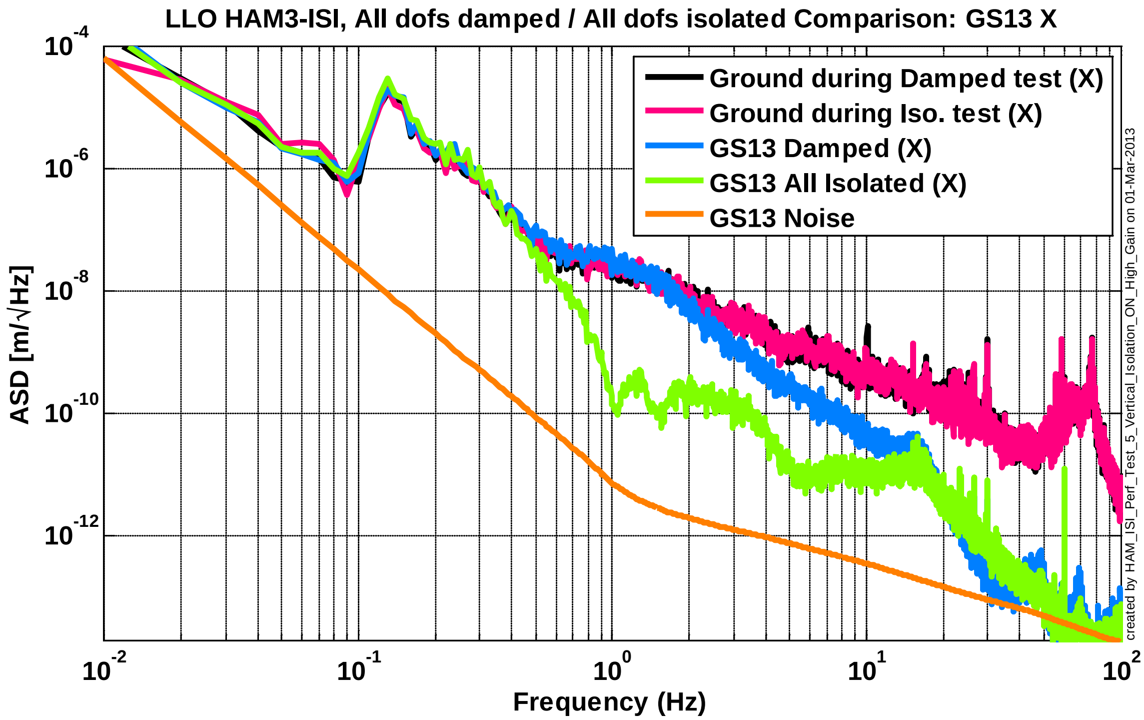
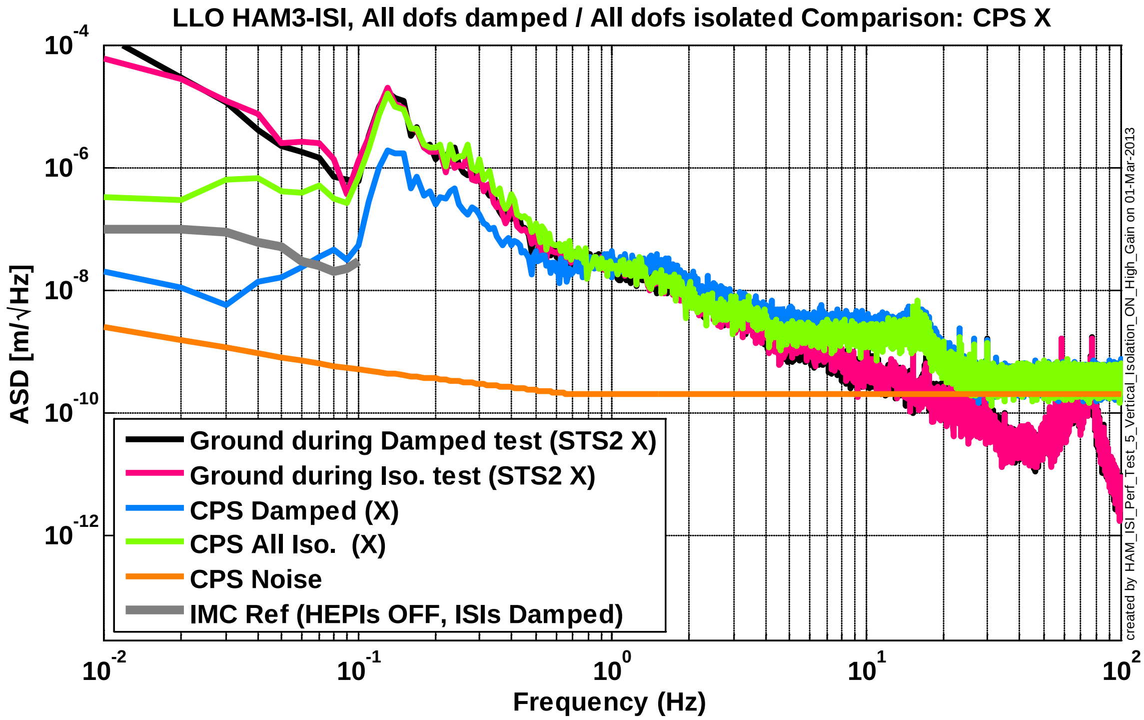
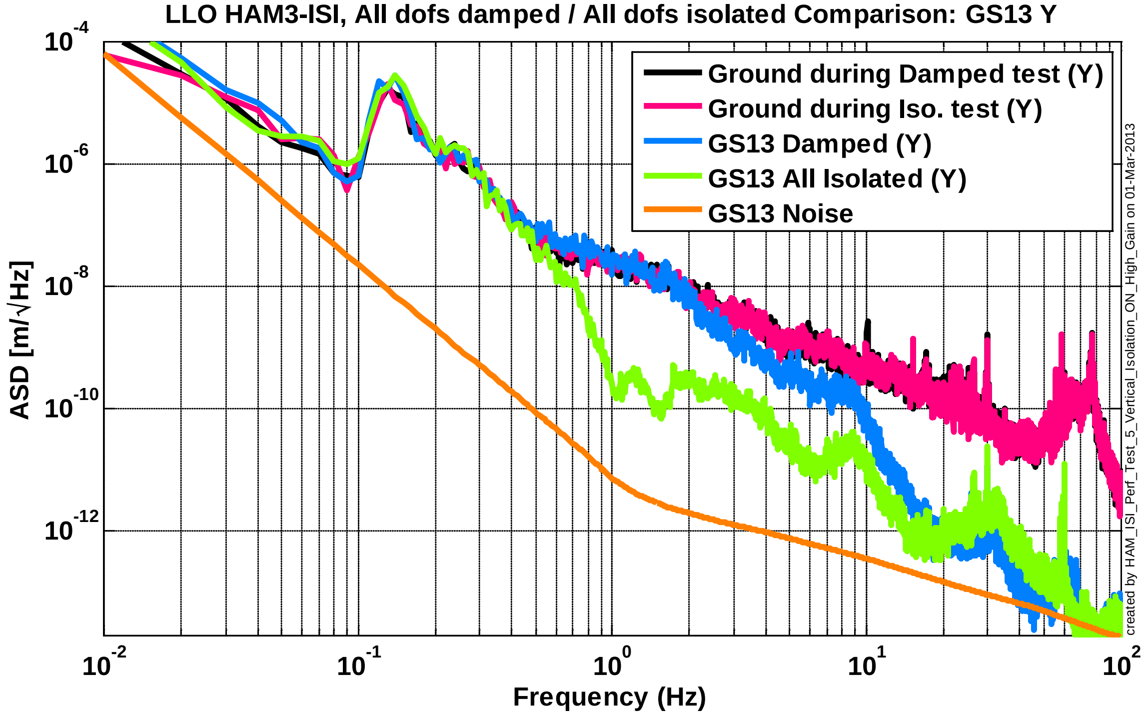
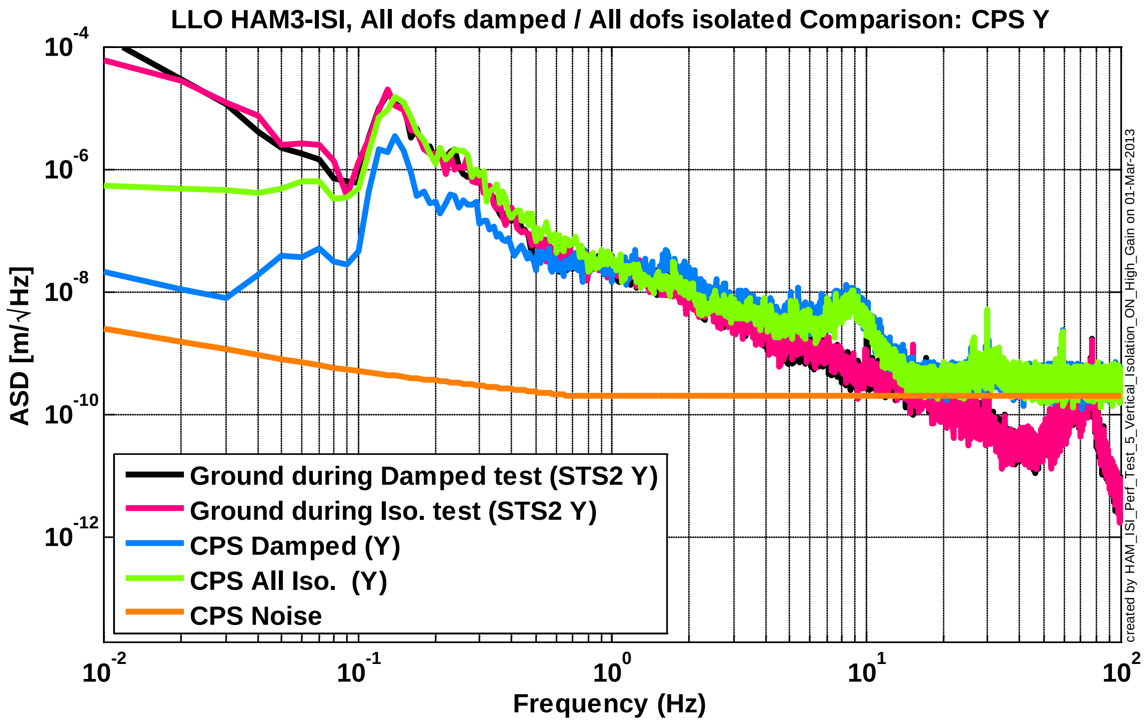




X isolation loops Comments:

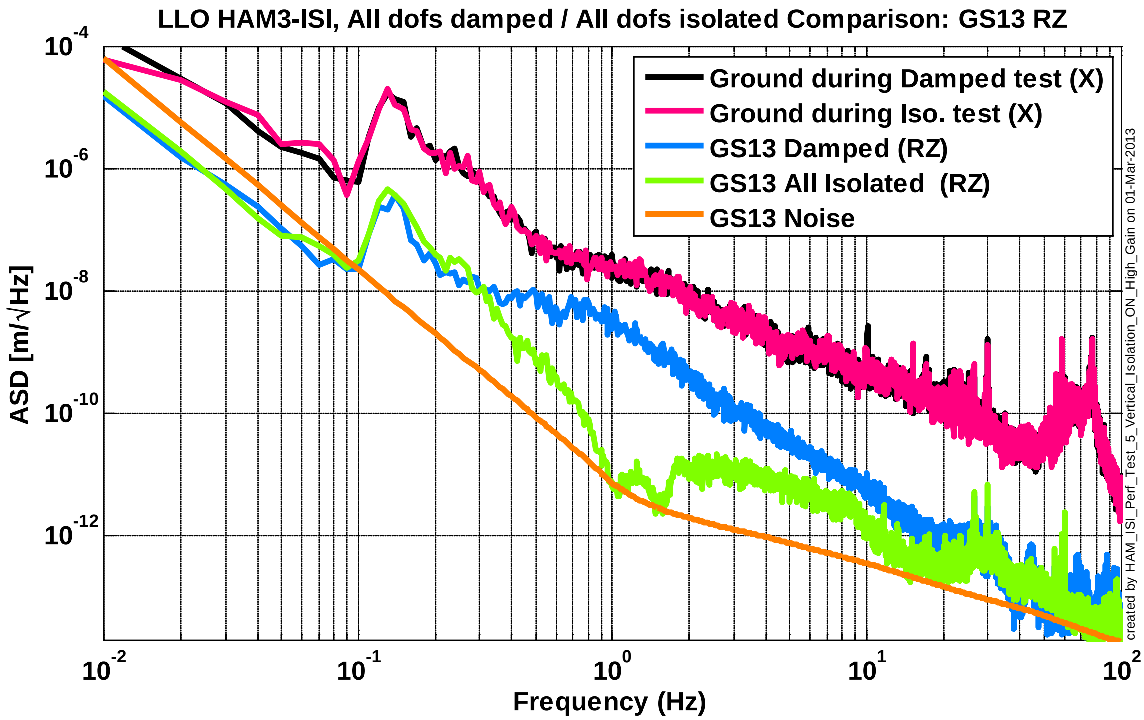
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Amplification as expected in the CPS (Ground to High Pass?)

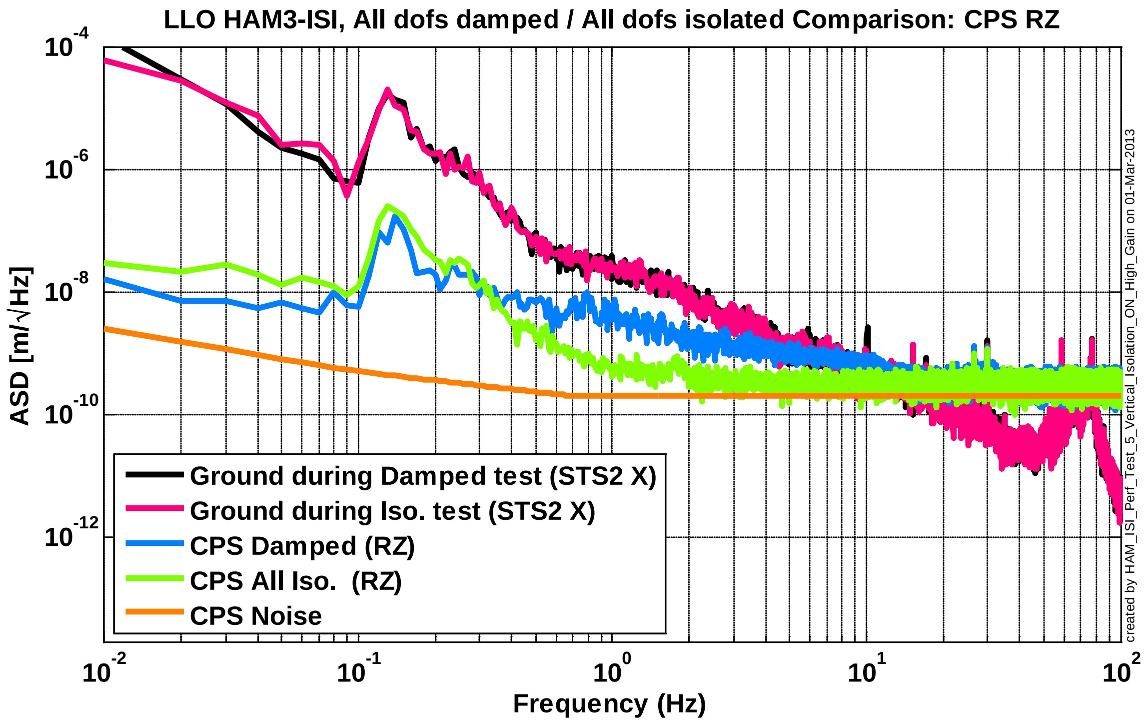




Y isolation loops Comments:

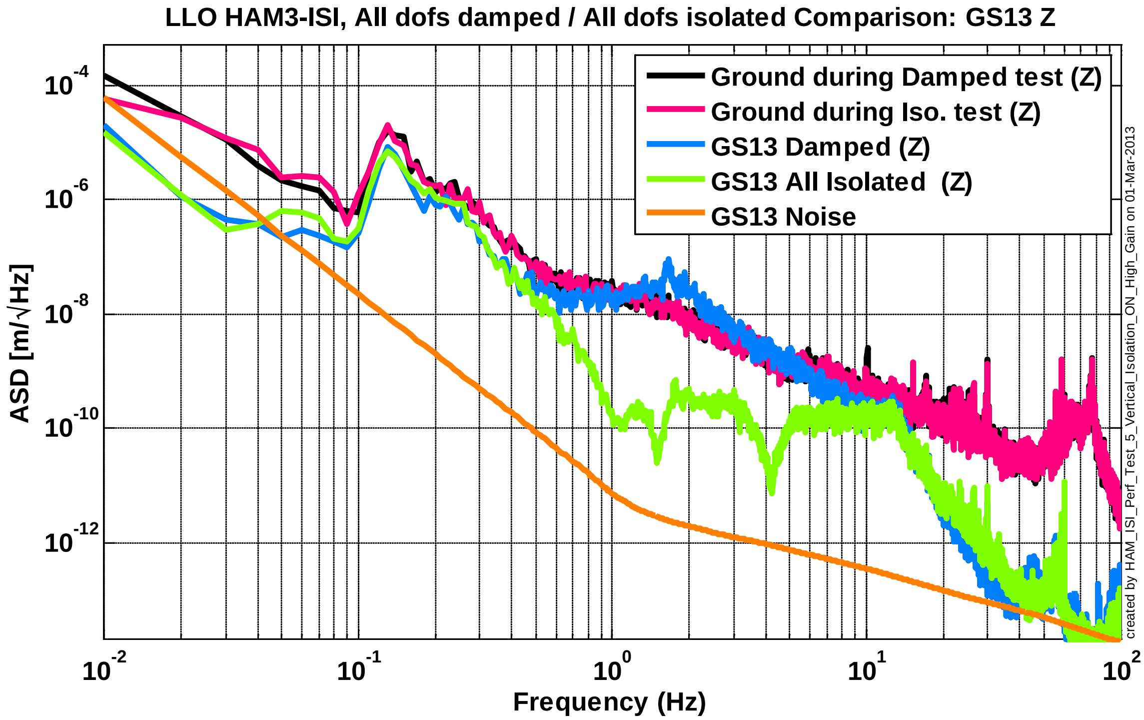
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Amplification as expected in the CPS

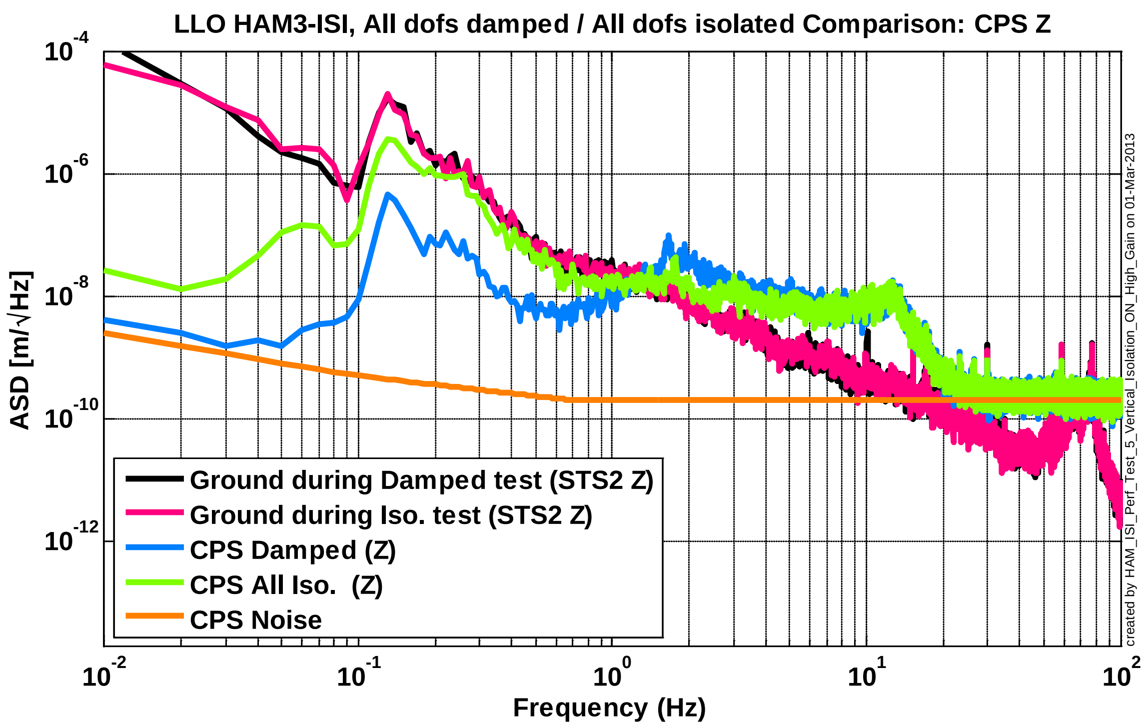




RZ isolation loops Comments:

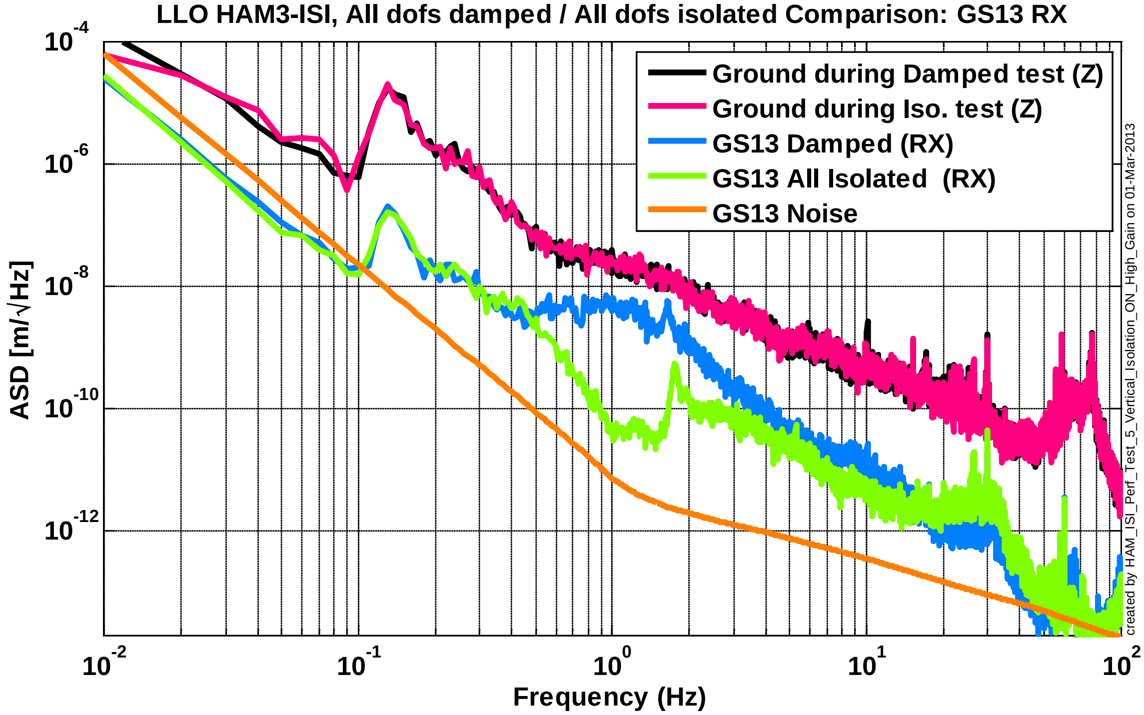
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Amplification as expected in the CPS

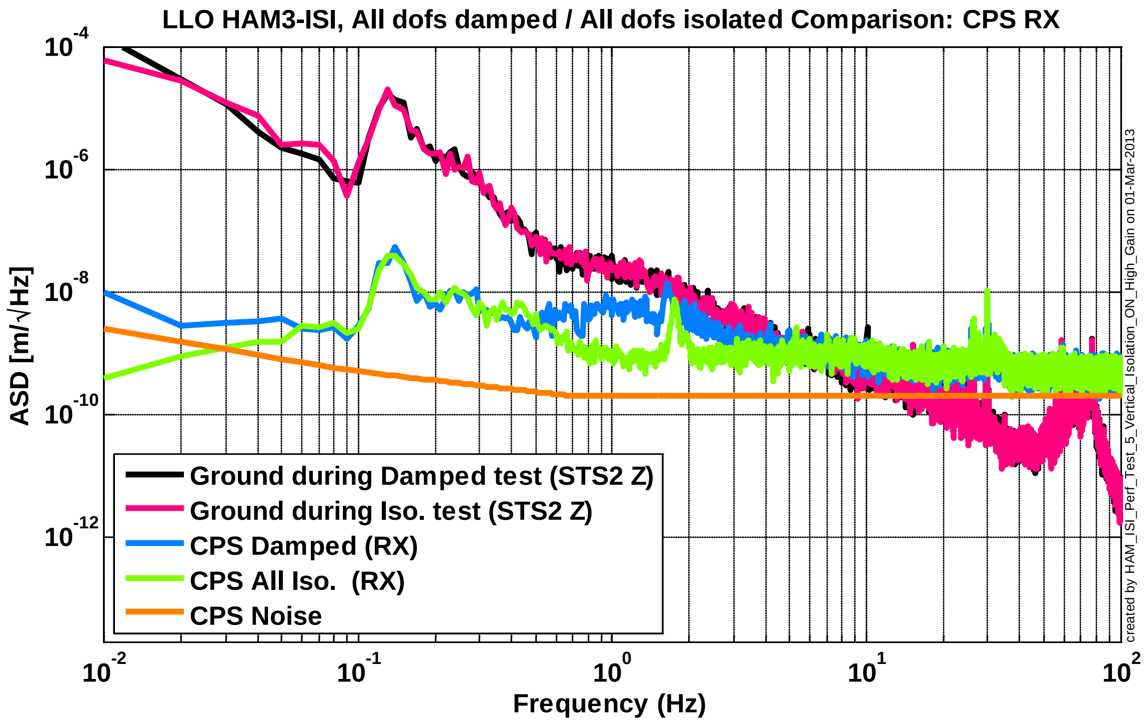




Z isolation loops Comments:

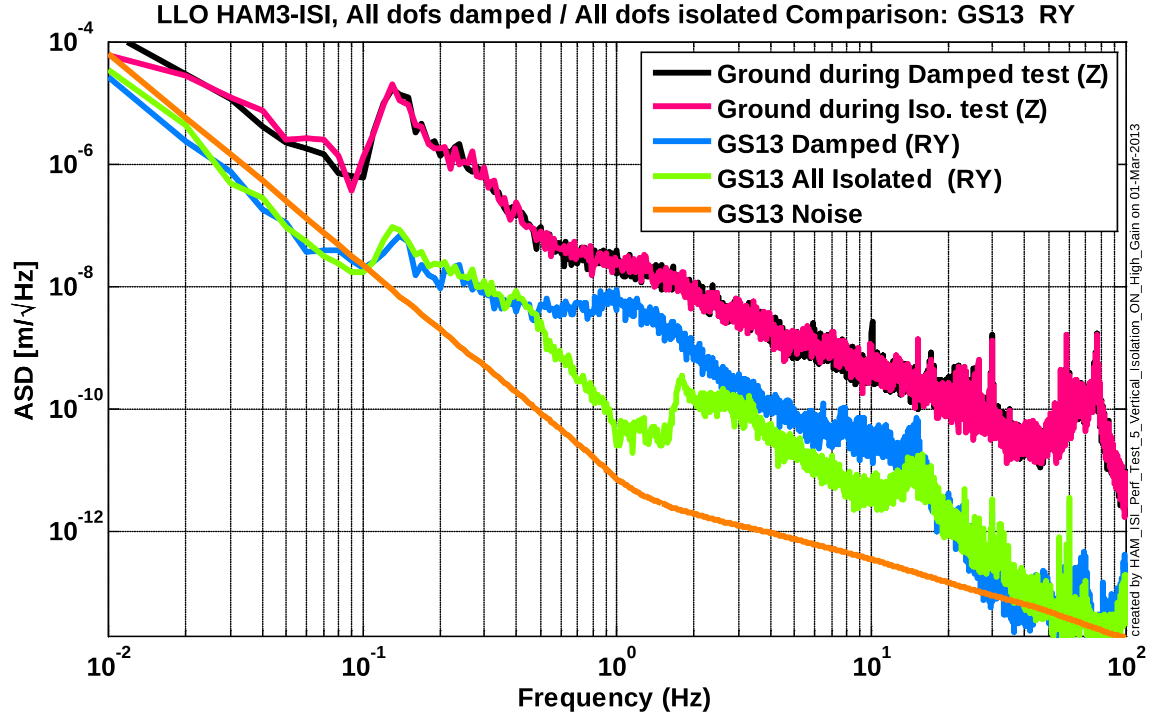
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Amplification as expected in the CPS

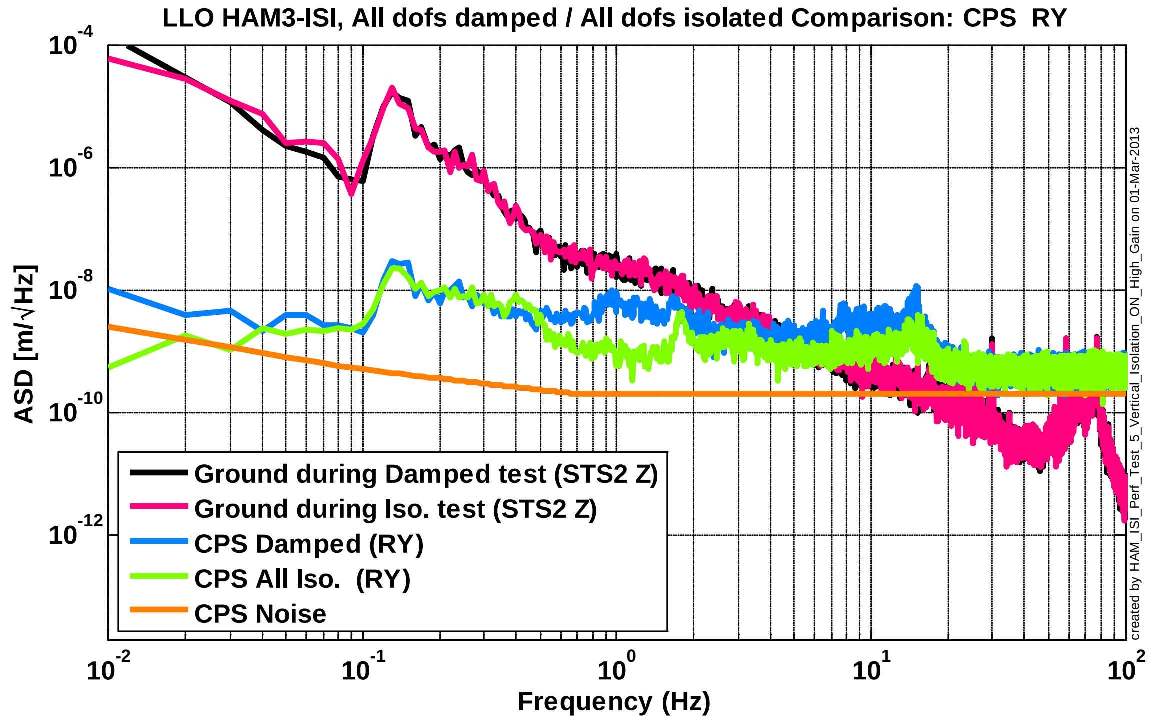




RX isolation loops Comments:

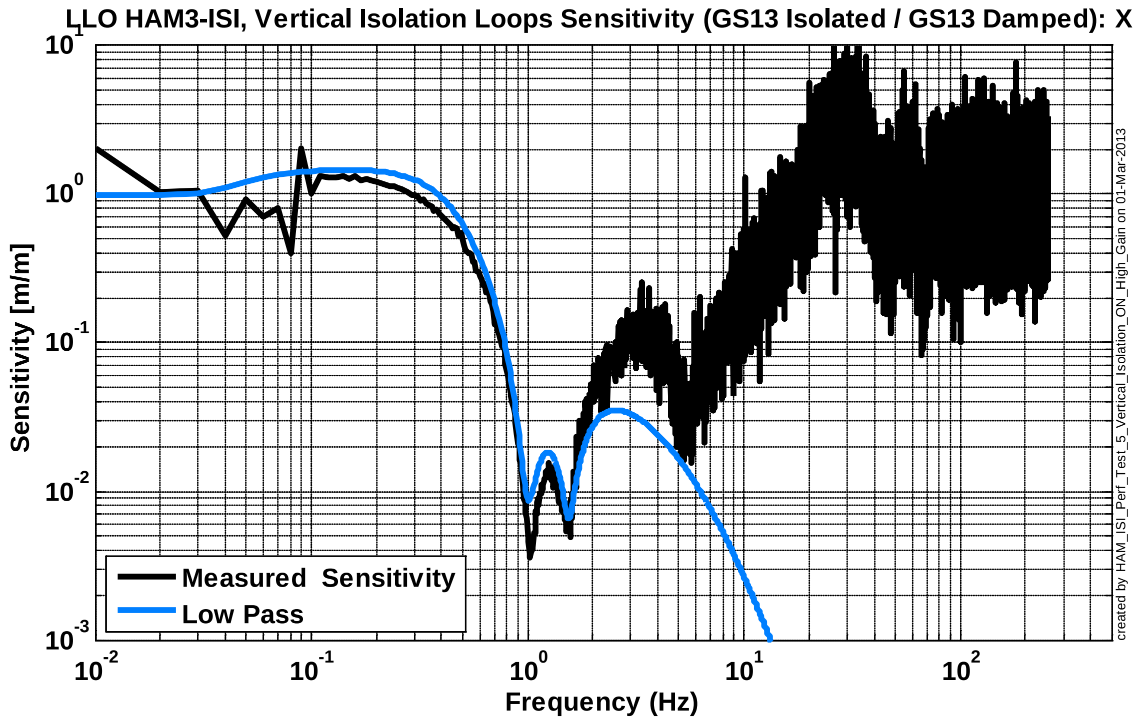
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Very little amplification in the CPS

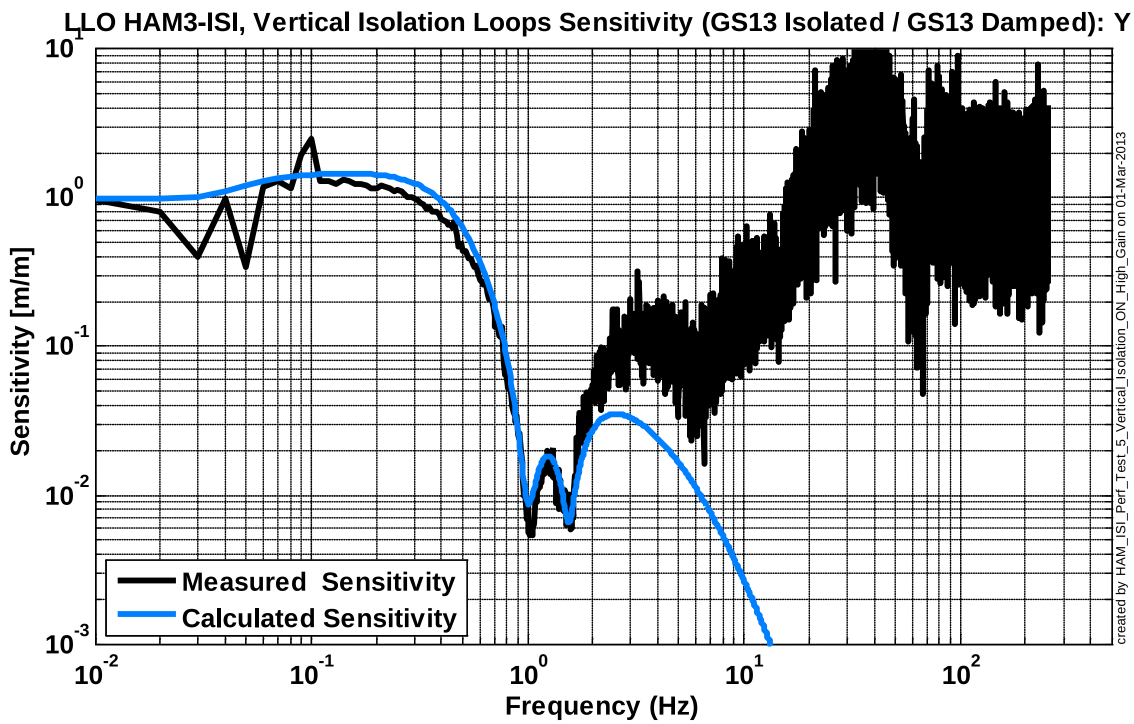




RY isolation loops Comments:

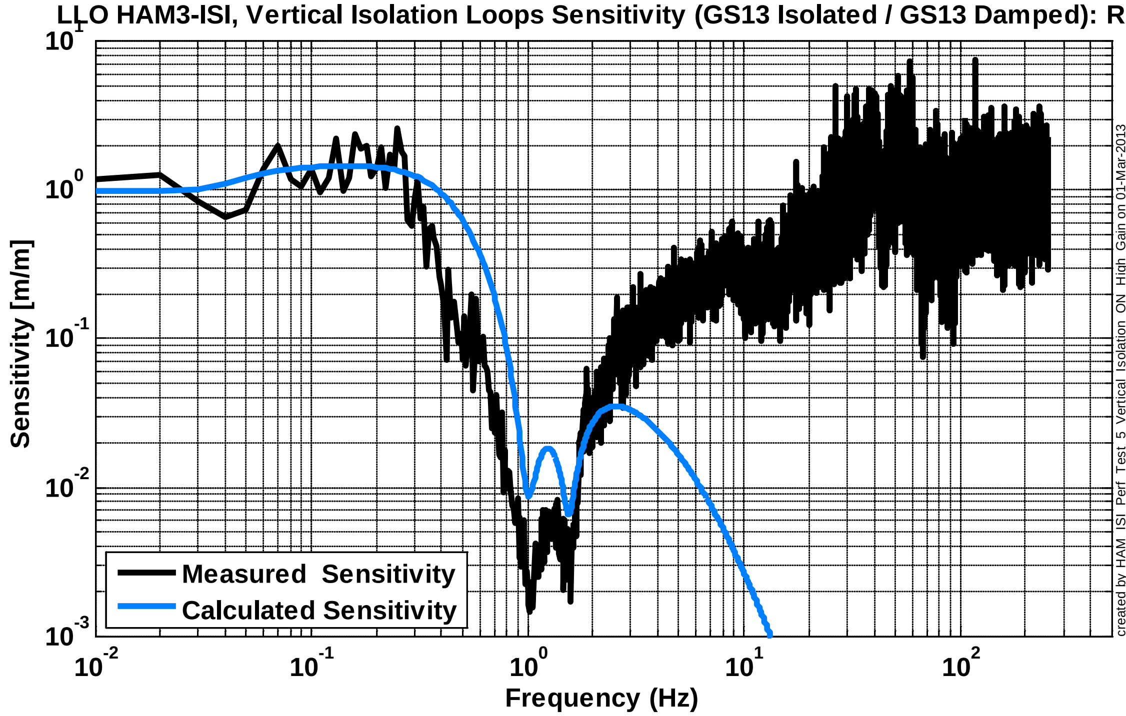
- No amplification at low frequency (GS13 in sensor noise)
- No excess amplification above the unity gain frequency
- Very little amplification in the CPS

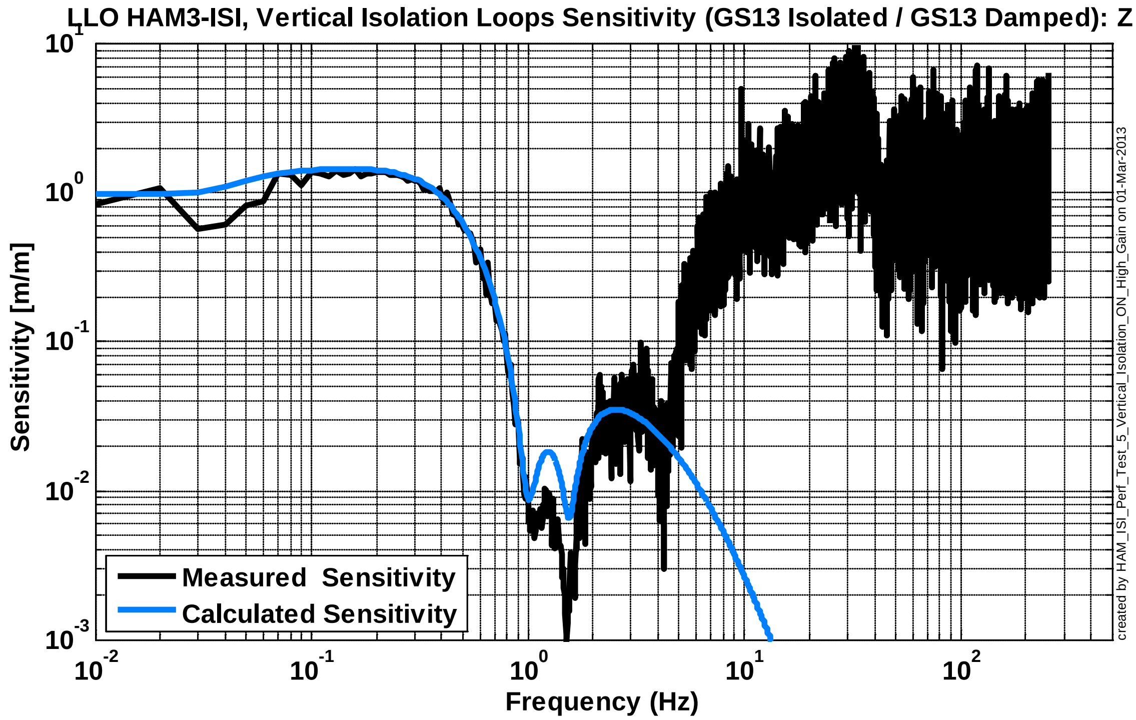




X and Y isolation loops Comments:

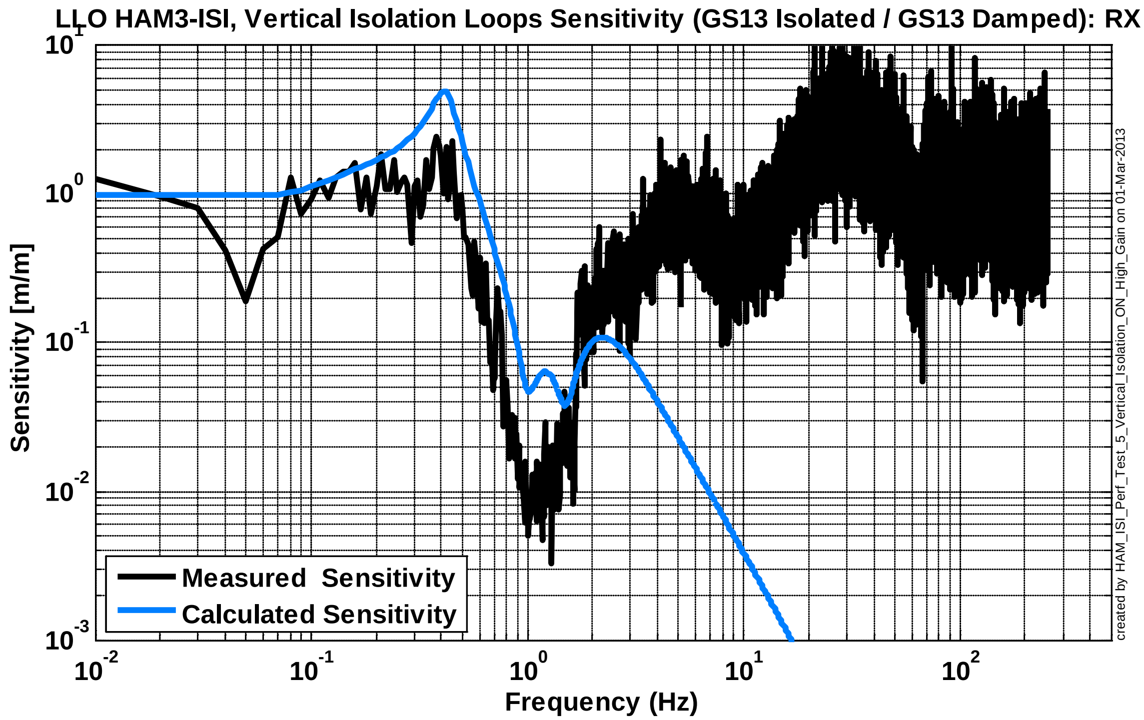
- No amplification at low frequency (GS13 in sensor noise)
- Very good agreement between measured sensitivity and low pass complementary filter.

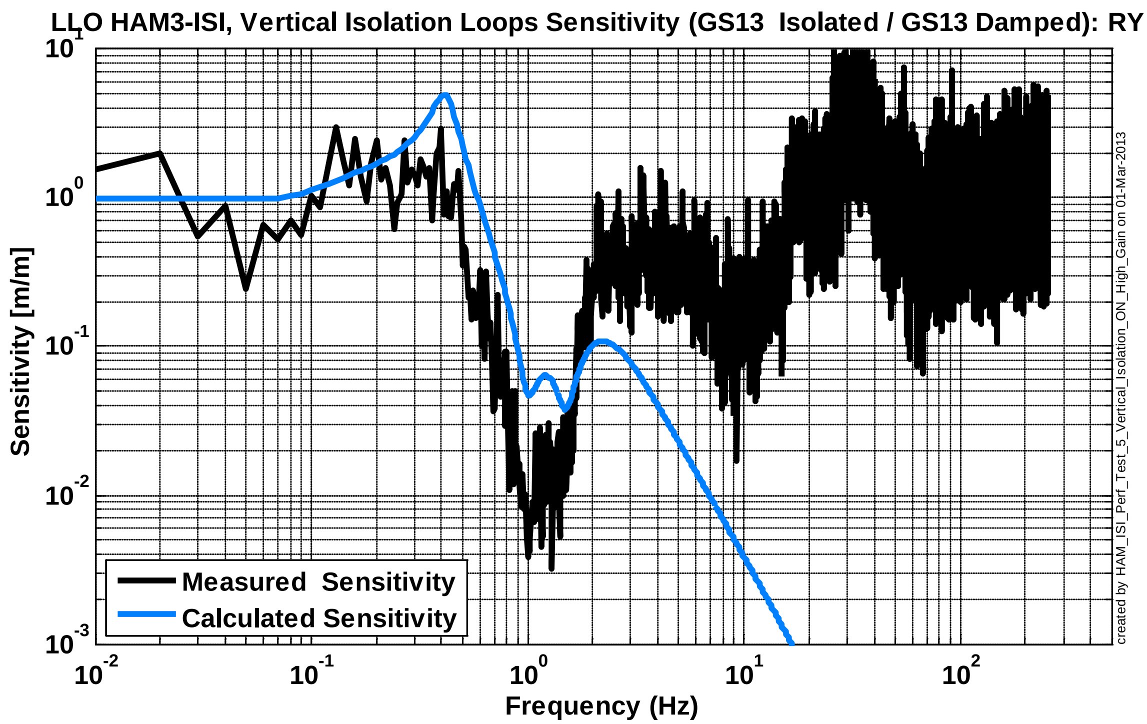




RZ and Z isolation loops Comments:

- No amplification at low frequency (GS13 in sensor noise)
- Quite good (RZ) and very good (Z) agreement between measured sensitivity and low pass complementary filter.





RX and RY isolation loops Comments:

- No amplification at low frequency (GS13 in sensor noise)
- Measured sensitivity show less amplification than low pass filter

Conclusion

- We will check that CPS H2 and H3 are not noisier than they should.
- RZ damping loops motion amplification can be further discussed. It is not a problem for the overall performance.
- RX, RY isolation loops don't match with low blend. We'll do cross couplings calculations, but for now we won't complain that measured sensitivity show less amplification than calculated.
- We'll do a complete sensitivity calculation for isolation loops: (P+GL)/(1+CG)
- Comment on figures: the rotation plot's legends indicate meters instead of radians. The plots are indeed in radians. This typo will be corrected for the validation of all other units.

We (SEI) validate the testing and commissioning results, and submit the report to the review committee for acceptance of this HAM-ISI unit.