LIGO Laboratory / LIGO Scientific Collaboration

LIGO- E1000326 *LIGO* July 12th, 2011

aLIGO HAM-ISI, Pre-integration Test report, Phase I, LLO Unit # 2

E1000326 – V5

Adrien Le Roux, Joe Hanson, Celine Ramet, Michael Vargas

Distribution of this document:
Advanced LIGO Project

This is an internal working note
of the LIGO Laboratory

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

Table of contents:

Introduction

This unit was first assembled in the early fall of 2010, and tested until October 2010. Following the discovery of un-autorized repairs while building this unit, the testing was interrupted. Testing done until interruption can be seen under v1 of this document. The unit was subsequently disassembled in Spring 2011 and immediately re-assembled.

The procedure document used to perform this test is:

- E1000309 –V9 - aLIGO HAM-ISI, Pre-Integration Testing Procedure, Phase I (post assembly, before storage)

Other useful information can be found in:

- E1000300 - HAM-ISI LLO test stand: software and electronic check

I. Pre-Assembly Testing

- ***Step 1: Position Sensors***

Note: The back panel reads 0.508V/0.001"

S/N sensor	S/N board	ADE Gap Standoff(mm)	Location on the Jig	Gap Standoff on Jig(mm/in)	Voltage before zeroing	Voltage after zeroing. Prebake	Voltage after zeroing. Post bake
12081	NR	NR	NR	NR	NR	NR	NR
12078	NR	NR	NR	NR	NR	NR	NR
12079	NR	NR	NR	NR	NR	NR	NR
12080	NR	NR	NR	NR	NR	NR	NR
12071	NR	NR	NR	NR	NR	NR	NR
12069	NR	NR	NR	NR	NR	NR	NR

NR: not recorded

Sensors noise spectra measured before baking:

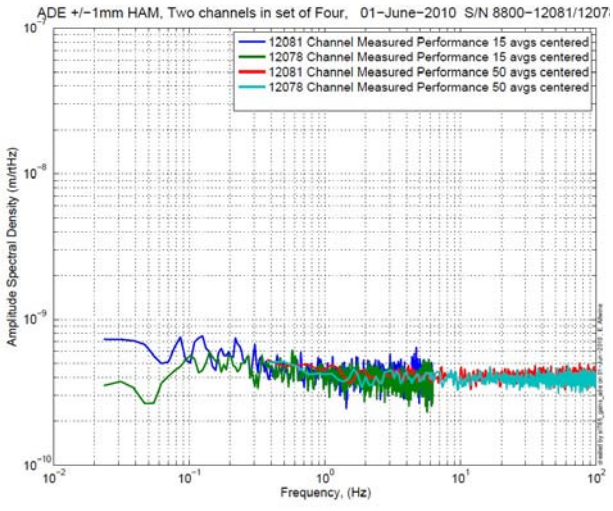


Figure - H1 and V1 sensor noise

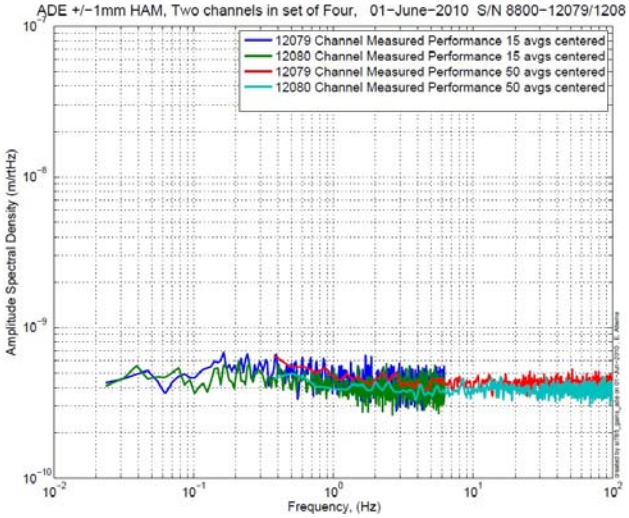


Figure - H2 and V2 sensor noise

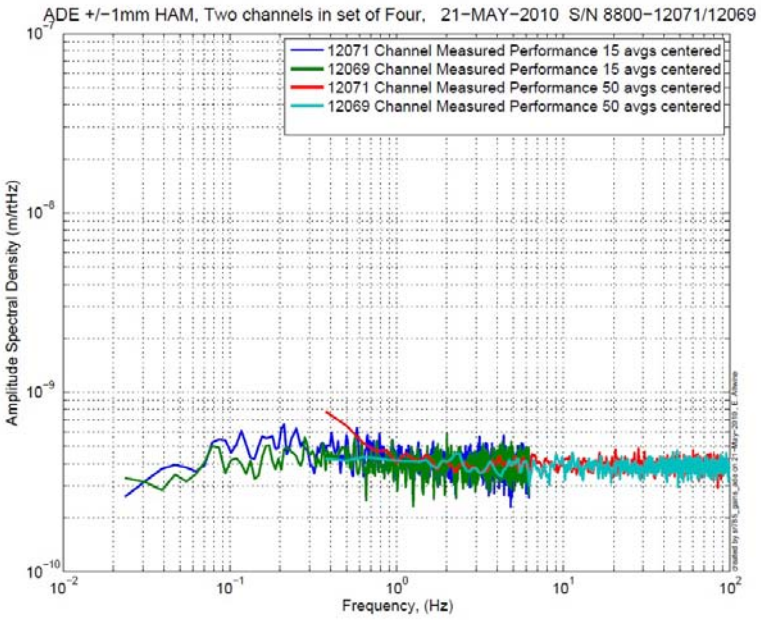


Figure - H3 and V3 sensor noise

Acceptance Criteria:

- Power spectrum magnitudes must be lower than:
  - 9.e-10 m/√Hz at 0.1Hz
  - 6.e-10 m/√Hz at 1Hz

Issues/difficulties/comments regarding this test: Values of sensor gaps and zeroing were not recorded. Waived for this unit.

Test result: **Passed: X** **Failed: ___**

- ***Step 2: GS13***

All the data related to GS-13 post podding testing can be found in the SVN at : SeismicSVN\seismic\Common\Data\aLIGO_GS13_TestData\PostMod_TestResults_PDFs. E1000058 spreadsheet provides the status of each individual GS-13 at LLO site during aLIGO HAM assembly

Data files in SVN at:
/opt/svncommon/seisvn/seismic/Common/Data/aLIGO_GS13_TestData/PostMod_TestResults_Raw ASCII

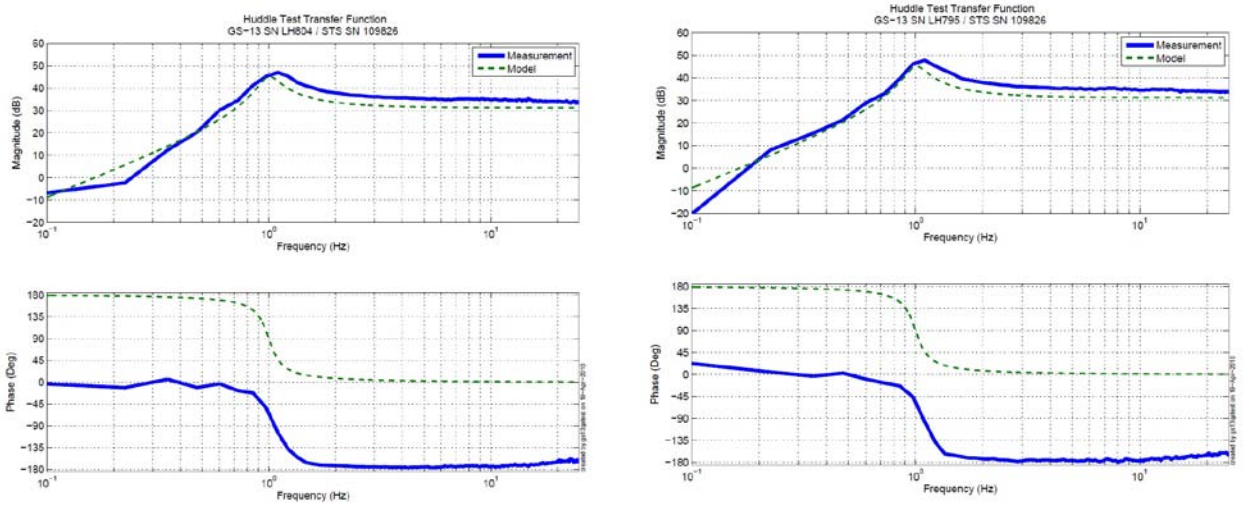
Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/Common/MatlabTools

- gs13qatest.m

Figures in SVN at:
/opt/svncommon/seisvn/seismic/Common/Data/aLIGO_GS13_TestData/PostMod_TestResults_PDFs

- ***Step 2.1 – Horizontal GS-13s***

Huddle testing



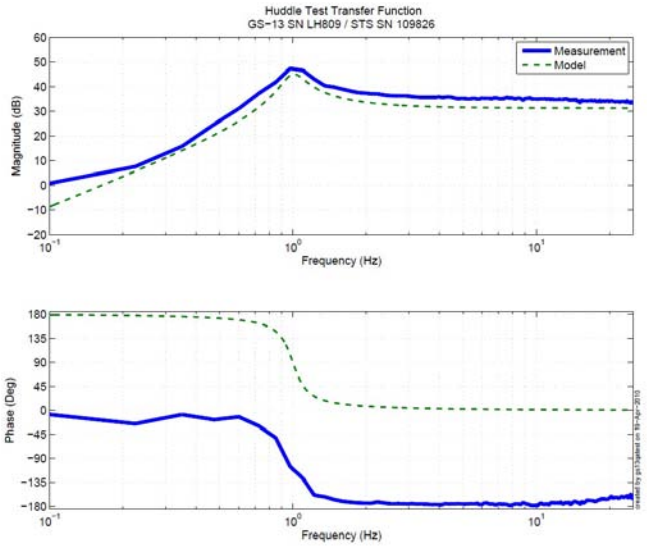


Figure - Huddle testing of Horiz GS-13 804, 795, and 809 after aLIGO modifications

- ***Step 2.2 – Vertical GS-13s***

Huddle testing

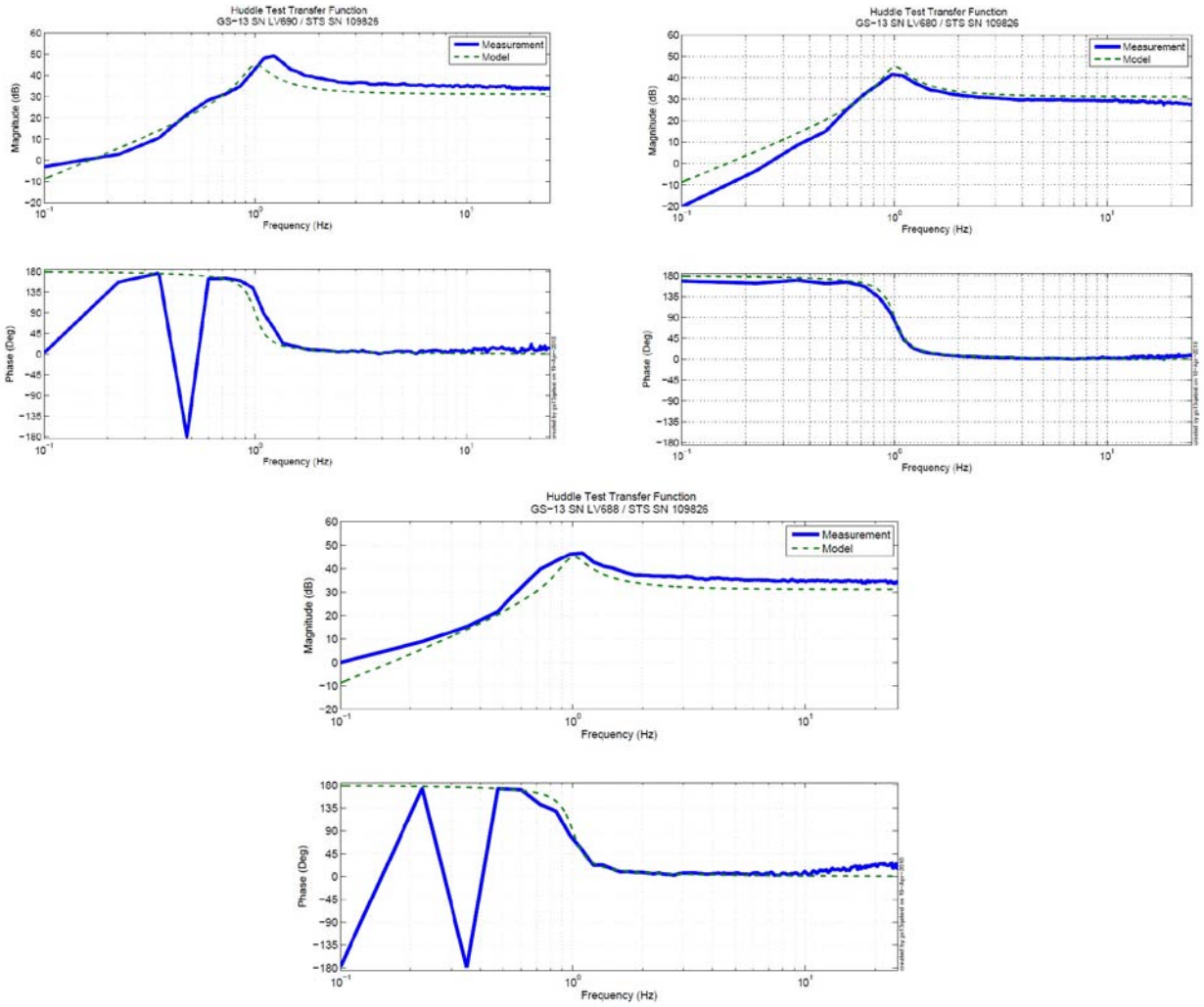


Figure - Huddle testing of Vert GS-13 690, 680 and 688 after aLIGO modifications

Driven testing

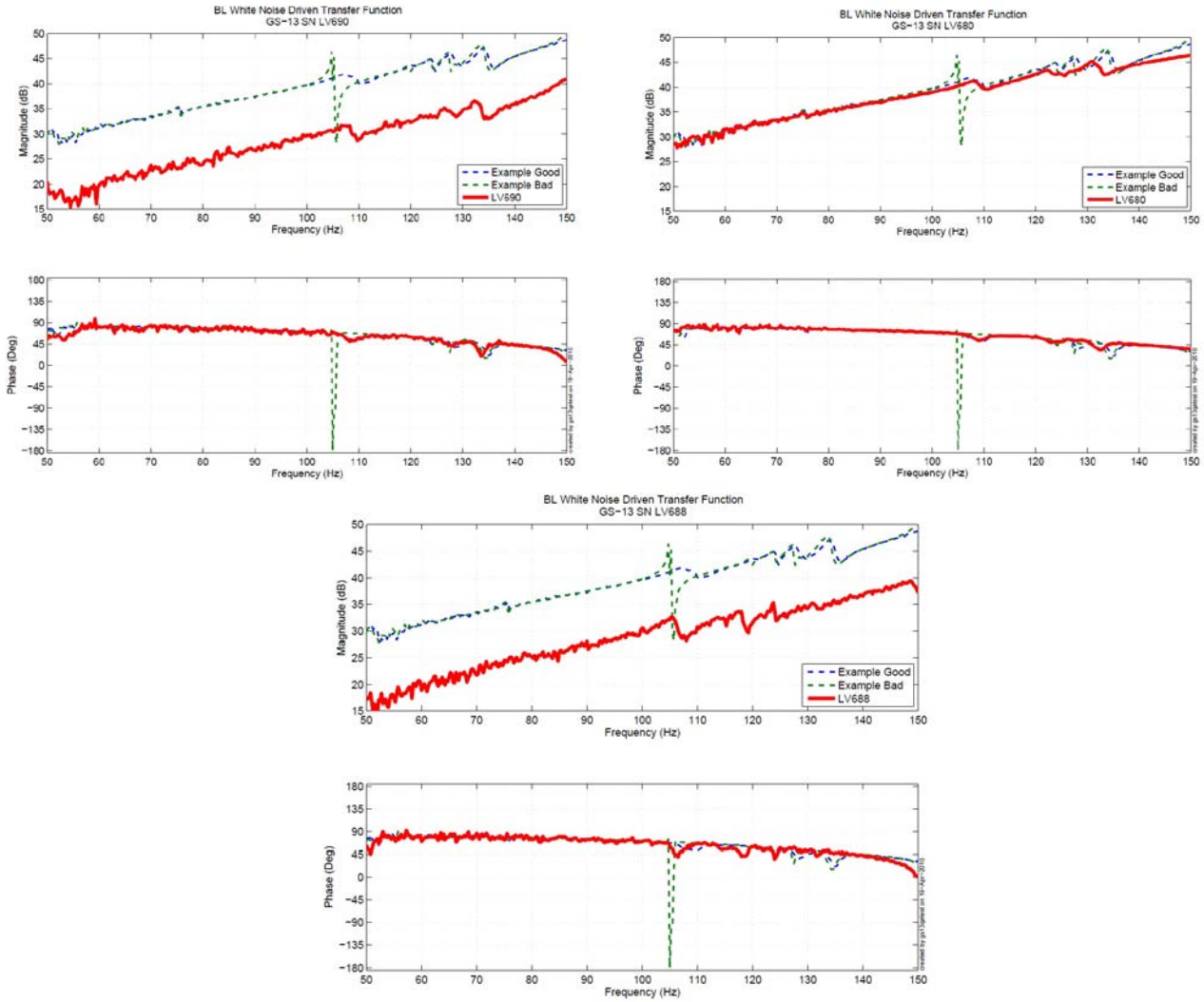


Figure - Driven Transfer Function of Vert GS-13 690, 680 and 688 after aLIGO modifications

Issues/difficulties/comments regarding this test:
The difference in magnitude between model and the measurement in the driven test does not matter here, these measurements are made to ensure that we have no more 104 Hz resonances (resonance due to the springs inside the instrument).

Acceptance Criteria:

- GS13 should have been already modified and tested. GS-13 Inspection/Pod Assembly (D047810). Checklist is defined in F090070-v6
- Resonant frequency at 1 Hz (huddle testing)
- No spring resonance on vertical driven tests

Test result: **Passed: _X_** **Failed: ___**

- ***Step 3: Actuators***

Actuator data can be found at: T0900564. Actuator inventory is made at Section II – Step 1.

Actuator Serial #: L081 Operator Name: Gordon, Matt Date: 11/22/2009 Time: 10:52 AM Actuator Coil Resistance: 6.30 Ohms, PASS Ambient Temperature: 70.4 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.528 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.505	Actuator Serial #: L084 Operator Name: Gordon, Matt Date: 11/22/2009 Time: 10:15 AM Actuator Coil Resistance: 6.35 Ohms, PASS Ambient Temperature: 69.7 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.523 Y Travel Limit (inches): 0.204 Z Travel Limit (inches): 0.507
Actuator Serial #: L086 Operator Name: Gordon, Matt Date: 11/21/2009 Time: 4:28 PM Actuator Coil Resistance: 6.26 Ohms, PASS Ambient Temperature: 70.0 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.534 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.507	Actuator Serial #: L089 Operator Name: Gordon, Matt Date: 11/21/2009 Time: 5:14 PM Actuator Coil Resistance: 6.24 Ohms, PASS Ambient Temperature: 70.0 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.530 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.507
Actuator Serial #: L092 Operator Name: Gordon, Matt Date: 11/19/2009 Time: 9:41 AM Actuator Coil Resistance: 6.28 Ohms, PASS Ambient Temperature: 67.9 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.539 Y Travel Limit (inches): 0.206 Z Travel Limit (inches): 0.507	Actuator Serial #: L139 Operator Name: Gordon, Matt Date: 4/13/2010 Time: 8:42 AM Actuator Coil Resistance: 6.44 Ohms, PASS Ambient Temperature: 73.3 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.528 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.505

Acceptance Criteria:

- Actuators were previously tested and results are reported in T0900564.

The tests report must contain:

1- Test results (Passed: _X_ Failed: ___)

II. Tests to be performed during assembly

- ***Step 1: Inventory (E1000052)***

DCC/Vendor number	Part name	Configuration	S/N	S/N	S/N
D071001	Stage 0 base		002		
D071050	Stage 1 base		001		
D071051	Optical table		002		
D071002	Spring Post		007	005	015
D071100	Spring		34	17	39
D071102	Flexure		42	21	45
ADE	Position sensor	Horizontal	11981	12079	12071
		Vertical	12078	12080	12069
D047812	GS-13 pod	Horizontal	92	26	46
		Vertical	32	19	51
D047823	L4C pod	Horizontal	N/A	N/A	N/A
		Vertical	N/A	N/A	N/A
D0902749	Actuator	Horizontal	L139	L081	L086
		Vertical	L084	L089	L092

- ***Step 2: Check torques on all bolts***

Acceptance Criteria:

- All bolts should trip the wrench, and start moving immediately after. If any bolts in a pattern move before torque is reached, recheck after all bolts are brought to spec.

Test result: **Passed: X** **Failed: ___**

- ***Step 3: Check gaps under Support Posts***

Acceptance Criteria:

- A 0.001 inch shim cannot be passed freely through any connection to Stage 0 or between post and gussets. If shim can pass through, loosen all constraining bolts, and then retighten iteratively from the center of the part to the edges. Retest.

Test result: **Passed: X** **Failed: ___**

- ***Step 4: Pitchfork/Boxwork flatness before Optical Table install***

Acceptance Criteria:

- Shim inserted won't pass between parts.

Test result: **Passed: X** **Failed: ___**

- ***Step 5: Blade spring profile***

Blade #	Base (")	Tip(")	Flatness (mils)
1	.486	.472	+14
2	.483	.469	+14
3	.484	.472	+12

Table 1 - Blade profile

Acceptance Criteria:

- Blades must be flat within 0.015" inches.

Test result: **Passed: X** **Failed: ___**

- ***Step 6: Gap checks on actuators-after installation on Stage 1***

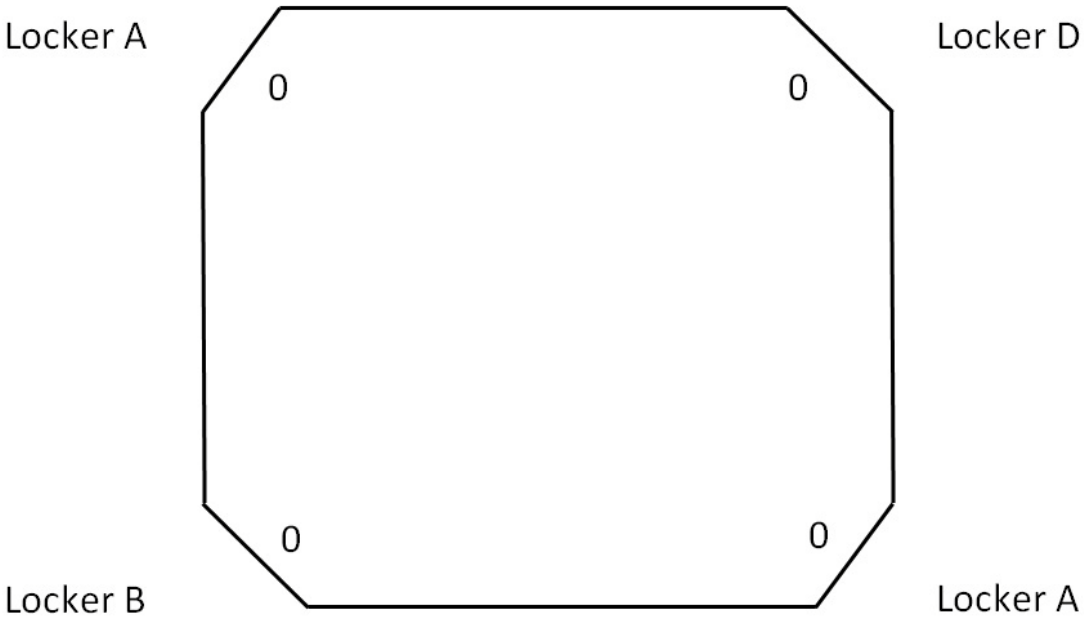
Actuator	Front Gap (1/1000")	Back Gap (1/1000")
V1	85	80
V2	80/85	85/80
V3	85	80
H1	85/80	75/80
H2	80	80
H3	80	85/80

Acceptance Criteria

- Gaps must be within 0.010” of design value (0.080”)

Test result: **Passed: X** **Failed: ___**

- ***Step 7: Check level of Stage 0***

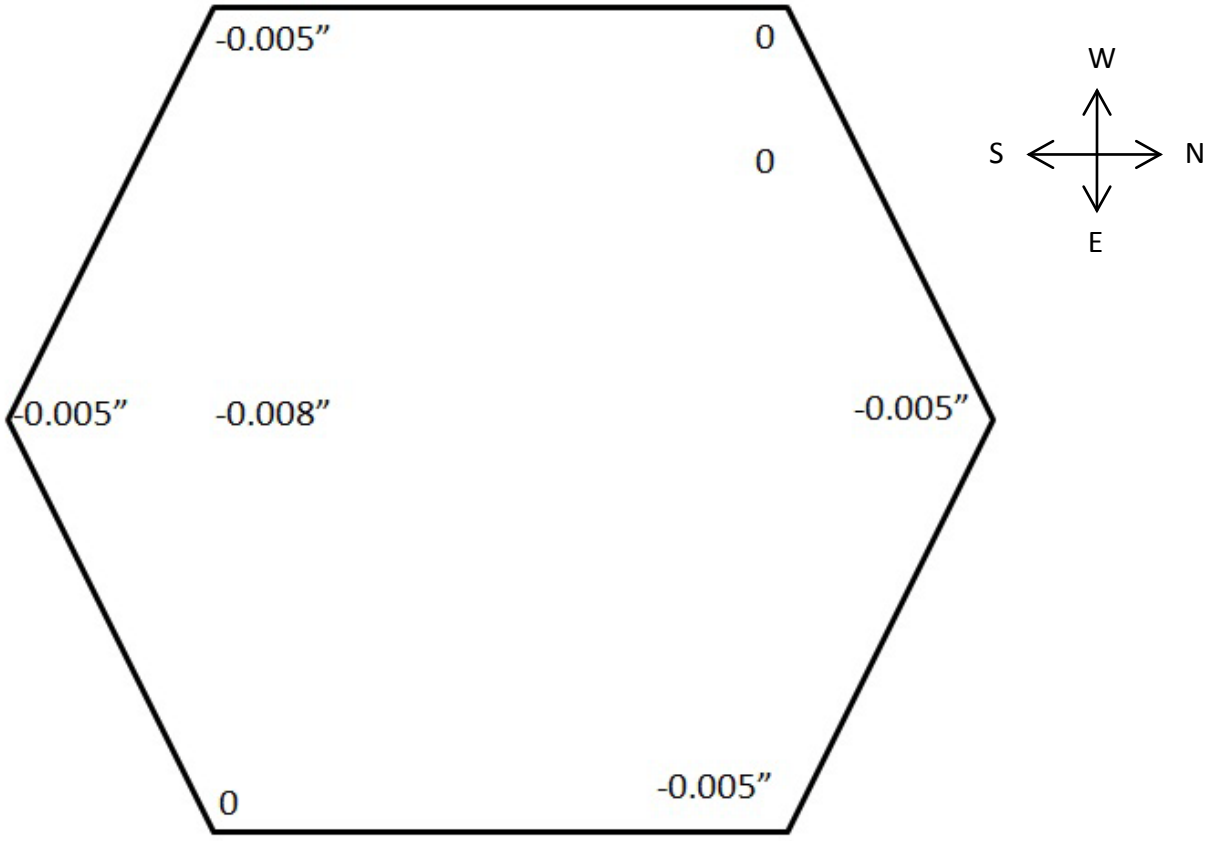


Acceptance Criteria

- The maximum angle of the table with the horizontal mustn’t exceed ~100µrad

Test result: **Passed: X** **Failed: ___**

- ***Step 8: Check level of Stage 1 Optical Table***



Acceptance Criteria

- The maximum angle of the table with the horizontal mustn’t exceed ~100µrad

This table appears to have local deformation but no tilt since opposite corners are always at the same level.

Test result: **Passed: _X_** **Failed: ___**

- ***Step 9: Mass budget***

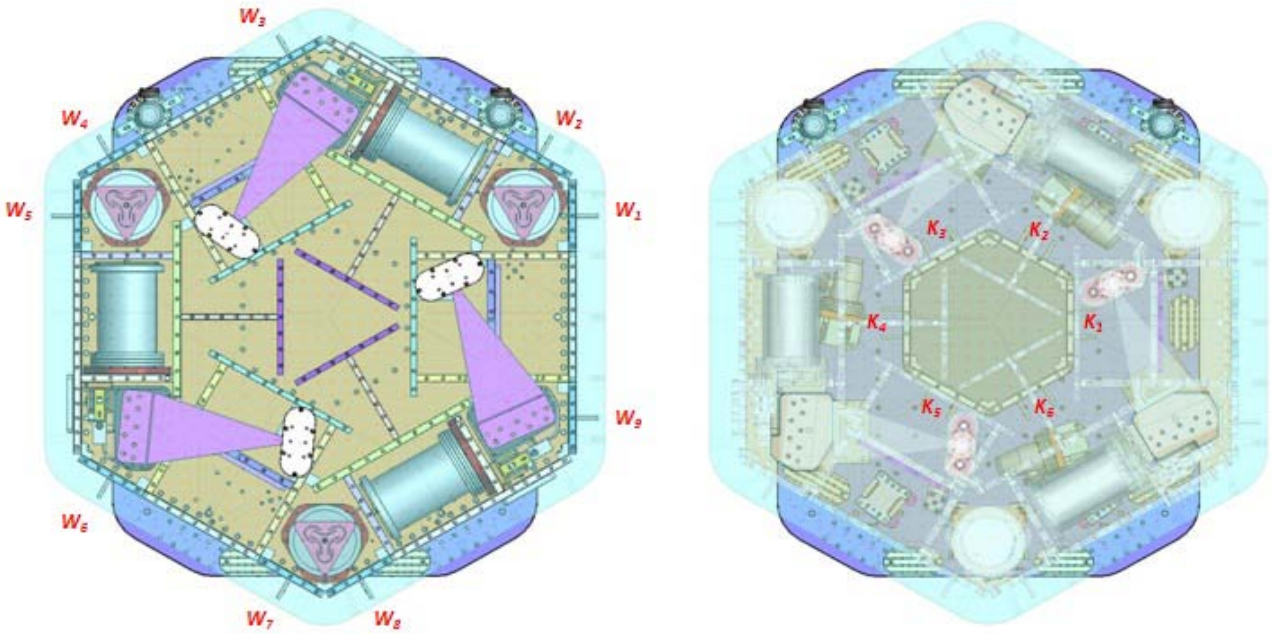


Figure – Keel Masses and Wall masses location

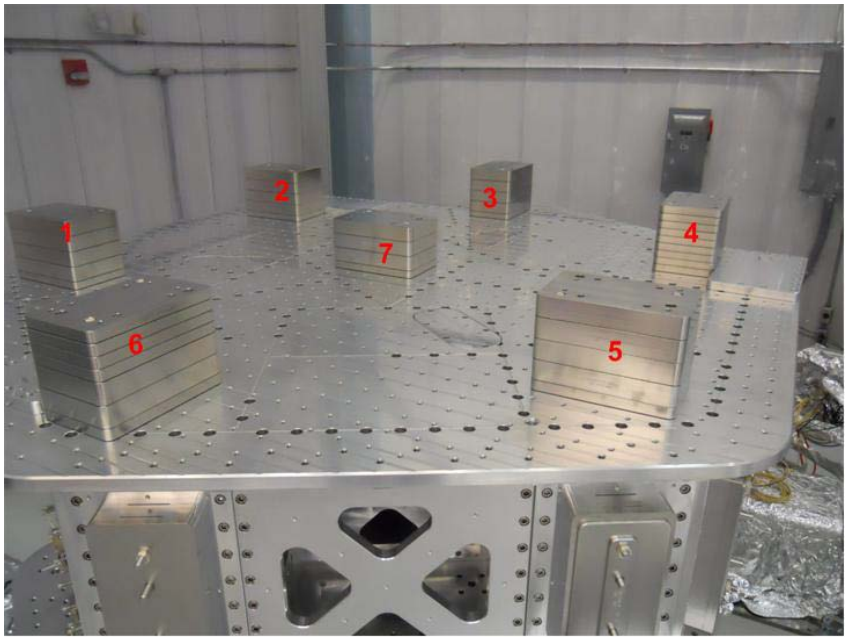


Figure - Optical table masses distribution

	Mass (kg)
t1	55.00
t2	55.00
t3	55.00
t4	55.00
t5	55.00
t6	55.00
t7	50.00
total	380.00

	00	01	02	03	04	05	06		
	0.6	1.1	2.2	4.5	7.9	15.6	27.2	lbs	kgs
w9			1	1		1		22.3	10.12
w1	1			1		1		20.7	9.39
w2	1		2	1		1		25.1	11.39
w3	5		1	1		1		25.3	11.48
w4			3	1		1		26.7	12.11
w5			1	1		1		22.3	10.12
w6		1	1	1		1		23.4	10.61
w7	1			1		1		20.7	9.39
w8	3		2	1		1		26.3	11.93
Side Masses Total	11	1	11	9	0	9	0	212.8	96.52

	Side	Keel	Top	Total
Weigh (kg)	96.52	90.08	380.00	566.61
Torque x at O (N.m)	-15.41	0.00	-12.46	-27.87
Torque y at O (N.m)	-13.60	5.26	13.70	5.36

Table - Masses distribution (computed using T1100261)

Acceptance Criteria

The Mass budget must be

- 579.1 Kg (cf E1100427)+/-25Kg (5%)

Test result: **Passed: _X_** **Failed: ___**

- ***Step 10: Shim thickness***

Lockers	Shim thickness (mil)
A	130
B	120
C	121
D	120

Table – Shims Thickness

Test result: **Passed: X** **Failed: ___**

- ***Step 11: Lockers adjustment***

D.I at Lockers	Dial indicators V	Dial indicators H
A	-0.5	-2
B	0	1
C	0	1.5
D	1	0

Table – Dial indicators read-out (table locked-unlocked)

Acceptance Criteria

- Vertical and horizontal displacement near the lockers must be lower than 2 mils (0.002")

Test result: **Passed: X** **Failed: ___**

III. Tests to be performed after assembly

- ***Step 1 - Electronics Inventory***

Write down serial number of coil driver, Anti aliasing chassis, Anti image chassis and interface chassis used for this test are listed below:

Hardware	LIGO reference	S/N
Coil driver	D0902744	S1000317
		S1000316
Anti Image filter	D070081	S1000251
Anti aliasing filter	D1000269	S1000244
		S1000245
Interface chassis	D1000067	S1000311
		S1000312
		S1000314

Table - Inventory electronics

Acceptance Criteria

- Inventory is complete

Test result: **Passed: X** **Failed: ___**

- ***Step 2 - Set up sensors gap***

	10 Kg masses at each corners		No mass		No mass	
Table locked	**ADE boxes on**		**ADE boxes on**		**ADE boxes off**	
Sensors	**Offset (Mean)**	**Std deviation**	**Offset (Mean)**	**Std deviation**	**Offset (Mean)**	**Std deviation**
H1	-112.87	1.1246	182.51	1.8798	41.24	3.70
H2	-162.84	1.4504	-540.41	2.0247	-620.43	2.87
H3	118.09	1.2993	-153.12	1.7698	*51.685*	*0.26*
V1	211.66	1.9934	-102.92	3.234	-181.66	3.93
V2	-279.05	3.1611	735.28	3.4404	590.21	7.81
V3	-118.9	1.208	-111.92	1.6334	*51.136*	*0.23*

Table – Capacitive position sensor readout after gap set-up

Acceptance criteria:

- All mean values must be lower than 400 cts (a bit less than .0005”).
- All standard deviations below 5 counts.
- No cross talk

Test result: **Passed: X** **Failed: __**

- ***Step 3 - Measure the Sensor gap***

Sensors	Gap measured on the Jig	Gap measured on the table
H1	NR	0.085"
H2	NR	0.085"
H3	NR	0.085"
V1	NR	0.082"
V2	NR	0.085"
V3	NR	0.082"

Acceptance criteria:

Sensors gap measured on the jig and on the optic table must be:
- 0.080" +/-0.005"

Test result: **Passed: X** **Failed: __**

- ***Step 4 - Check Sensor gaps after the platform release***

	Table locked		Table unlocked	
Sensors	**Offset (Mean)**	**Std deviation**	**Offset (Mean)**	**Difference**
H1	-12.51	1.47	862.86	875.374
H2	-664.81	1.47	-1592.00	927.19
H3	132.22	1.87	914.53	782.31
V1	65.02	1.46	-1569.80	1634.821
V2	455.35	1.76	169.56	285.79
`V3	44.88	1.81	505.96	461.084

Table – Sensor gaps after platform release

Acceptance criteria:

- Absolute values of the difference between the unlocked and the locked table must be below:
  - 1600 cts for horizontal sensors (~0.002")
  - 1600 cts for vertical sensors (~0.002")
- Considering the acceptance criteria of step 4, all mean values must be lower than
  - 2000 cts for horizontal sensors (~0.0025")
  - 2000 cts for vertical sensors (~0.0025")

Test result: **Passed: X** **Failed: __**

- ***Step 5 – Performance of the limiter***

- ***Step 5.1 - Test Nº1 - Push "in the general coordinates"***

	CPS read out		Calculated after calibration	
Sensors	**UP (Counts)**	**Down (Counts)**	**UP (mil)**	**Down (mil)**
V1	19912	-20765	23.7	-24.7
V2	20457	-16374	24.3	-19.5
V3	19315	-19069	23.0	-22.7
	CPS read out		**Calculated after calibration**	
Sensors	**CW(-RZ)**	**CCW (+RZ)**	**CW (mil)**	**CCW (mil)**
H1	22442	-21520	26.7	-25.6
H2	21206	-20014	25.2	-23.8
H3	19684	-23038	23.4	-27.4

Table - Optic table range of motion

- ***Step 5.2 - Test Nº2 – Push "locally"***

	CPS read out		Calculated after calibration	
Sensors	**UP (Counts)**	**Down (Counts)**	**UP (mil)**	**Down (mil)**
V1	19912	-20765	23.7	-24.7
V2	20457	-16374	24.3	-19.5
V3	19315	-19069	23.0	-22.7
	CPS read out		**Calculated after calibration**	
Sensors	**CW(-RZ)**	**CCW (+RZ)**	**CW (mil)**	**CCW (mil)**
H1	22442	-21520	26.7	-25.6
H2	21206	-20014	25.2	-23.8
H3	19684	-23038	23.4	-27.4

Table - Optic table range of motion

Acceptance criteria:

- The vertical sensor readout be positive when the optic table is pushed in the +Z direction
- The horizontal sensor readout be negative when the optic table is pushed in the +RZ direction
- **Step 7.1**
  - Absolutes value of all estimated motions must be higher than 16000counts (~0.020")
- **Step 7.2**
  - No contact point on sensors
  - Absolute value of sensor read out must be higher than 16000counts (~0.020")
  - No contact point on actuators

Test result: **Passed: X** **Failed: ___ .**

- ***Step 6 - Position Sensors unlocked/locked Power Spectrum***

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Powerspectra/Undamped
LLO_HAM_ISI_Unit_2_Calibrated_PSD_CPS_GS13_Unlocked_Locked_2011_06_09.mat
Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Powerspectra/Undamped
- Powerspectra_Measurement_HAM_ISI_Locked_Unlocked.m

Figures in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/Powerspectra/Undamped
LLO_HAM_Unit_2_Calibrated_PSD_CPS_Unlocked_Locked_2011_06_09.pdf

CPS calibration:
The CPS power spectrums are calibrated by using a sensitivity of 30.2 nm/count.

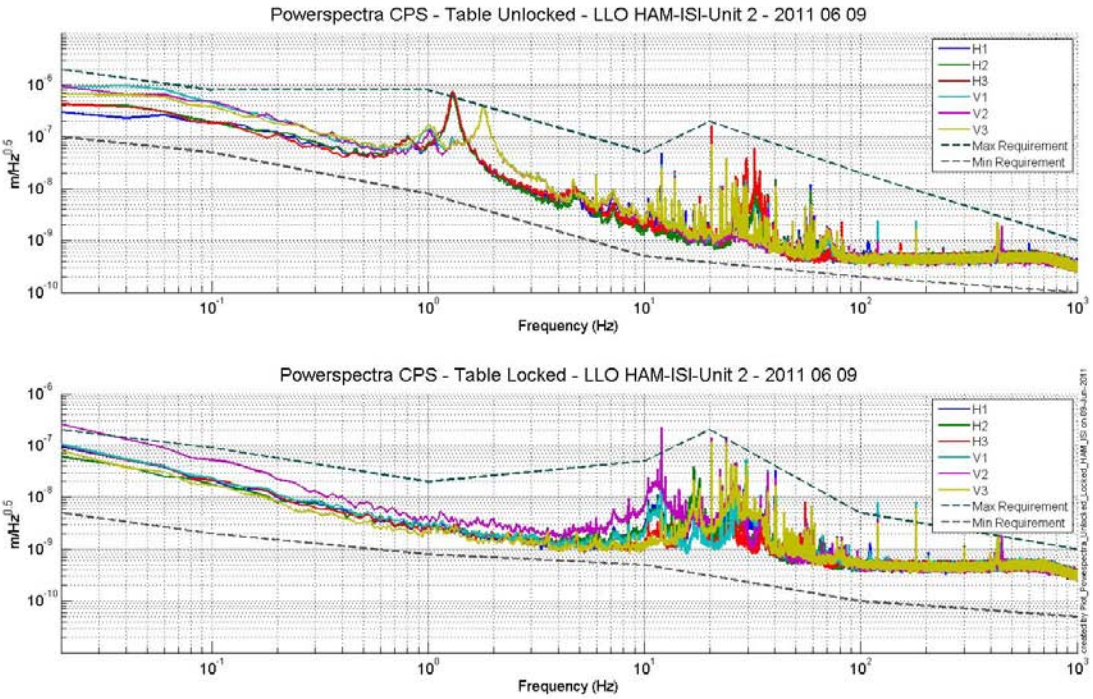


Figure - Calibrated CPS power spectrum
(+ signs are Horizontal requirements, x signs are Vertical requirements)

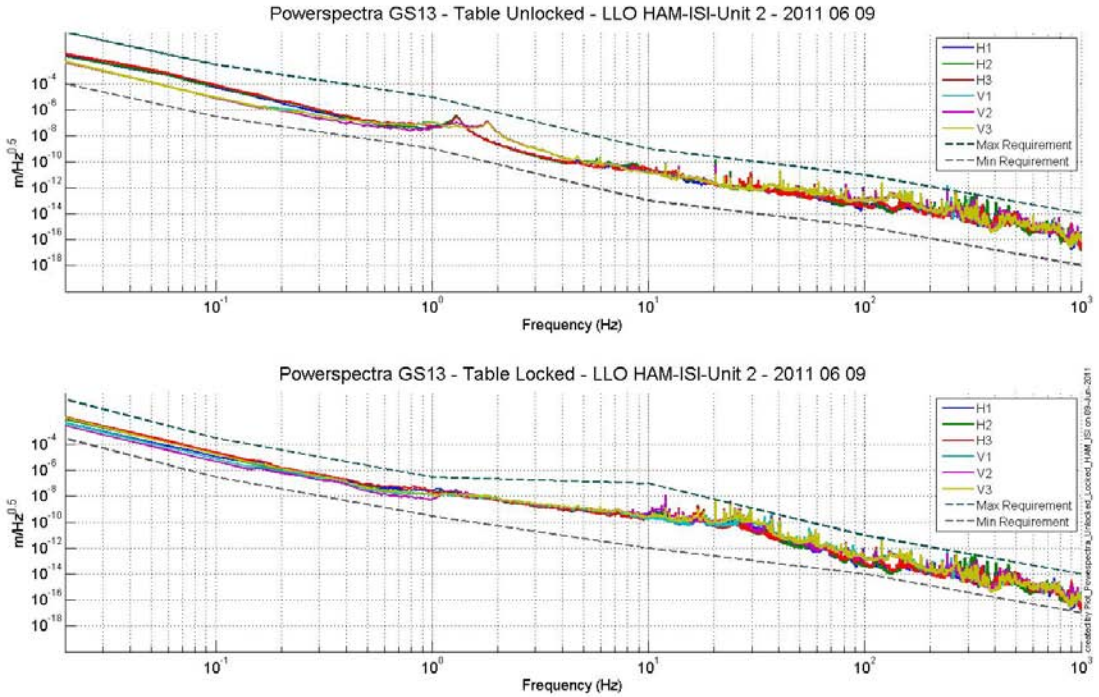


Figure – Power spectrum Calibrated GS13

Acceptance criteria:

- No cross talk (peaks at low frequencies + harmonics on measurements)
- Magnitudes of power spectra must be between requirement curves such as in the following figures (dashed lines)

Sensors	ISI state	Frequency (Hz)	$2x10^{-2}$	$1x10^{-1}$	1	10	20	100	1000
GS-13	Table locked	Max	$3x10^{-1}$	$3x10^{-4}$	$3x10^{-7}$	10^{-7}		10^{-11}	10^{-14}
		Min	$3x10^{-4}$	$3x10^{-7}$	$3x10^{-10}$	10^{-12}		10^{-14}	10^{-17}
	Table unlocked	Max	1	$3x10^{-3}$	10^{-5}	10^{-9}		10^{-11}	10^{-14}
		Min	10^{-4}	$3x10^{-7}$	10^{-9}	10^{-13}		10^{-15}	10^{-18}
CPS	Table locked	Max	$2*10^{-7}$	$2x10^{-8}$	10^{-8}	$5x10^{-8}$	$2x10^{-7}$	$5x10^{-9}$	10^{-9}
		Min	$5x10^{-9}$	$2x10^{-9}$	$8x10^{-10}$	$5x10^{-10}$		10^{-10}	$5x10^{-11}$
	Table unlocked	Max	$2x10^{-6}$	$8x10^{-7}$	$8x10^{-7}$	$5x10^{-8}$	$2x10^{-7}$	$2x10^{-8}$	10^{-9}
		Min	10^{-7}	$5x10^{-8}$	$8x10^{-9}$	$5x10^{-10}$		$2x10^{-10}$	10^{-10}

Table - Step 6 -Normal conditions-Sensors powerspectra requirements

Test result: **Passed: _X_** **Failed: ___**

- ***Step 7 - GS13 power spectrum -tabled tilted***

The figure below presents the GS13 power spectrum when the table is unlocked and loaded with a 20Kg mass at one of its corner.

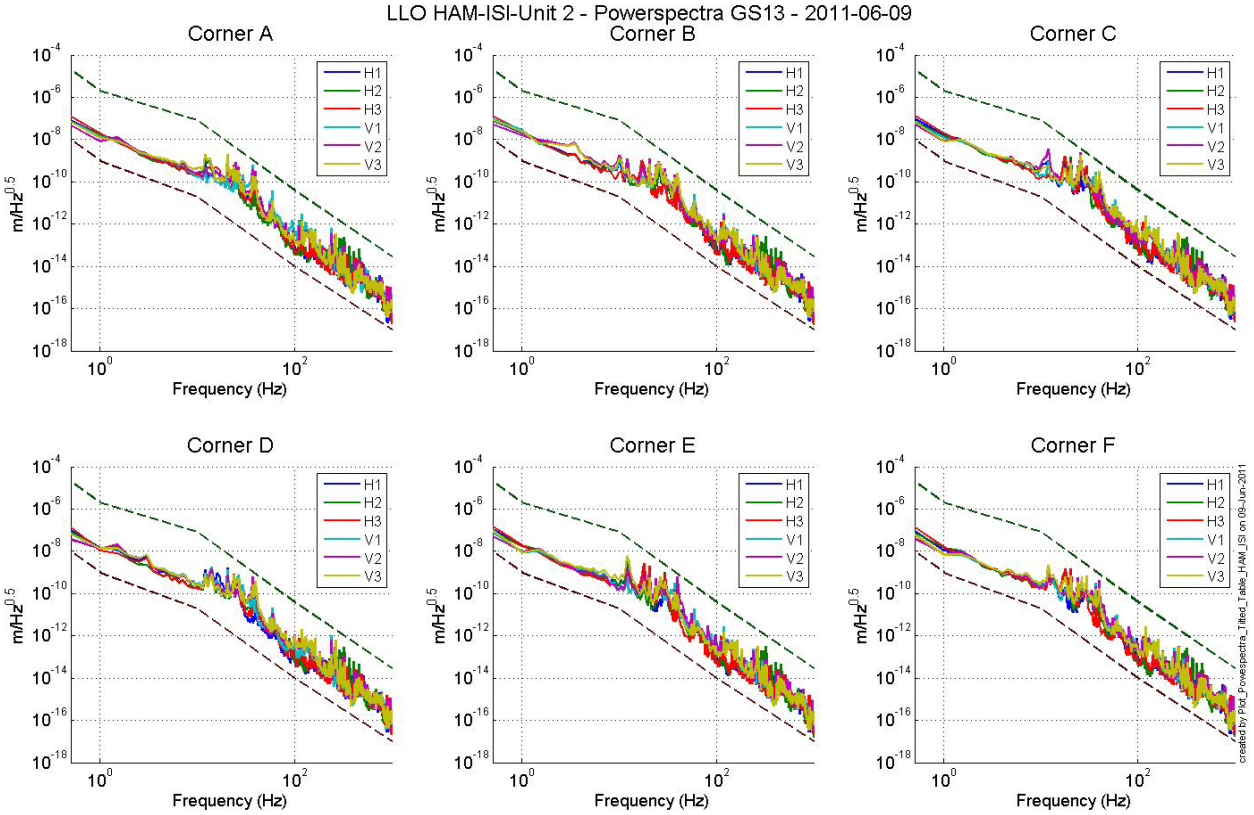


Figure – Power spectrum Calibrated GS13 with mass at corner

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/ Powerspectra/Undamped

- LLO_HAM_ISI_Unit_2_Calibrated_PSD_CPS_GS13_Unlocked_Locked_2011_06_09.mat
- LLO_HAM_ISI_Unit_2_Calibrated_PSD_GS13_Table_Tilted_2011_06_09.mat

Scripts files for taking and processing the data, and plotting it in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_collection/Old_Scripts

- Powerspectra_Measurement_HAM_ISI_Locked_Unlocked.m

/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_collection/

- Powerspectra_Measurements_Tilted_HAM_ISI.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/ Powerspectra/Undamped

- LLO_HAM_Unit_2_Calibrated_PSD_GS13_Unlocked_Locked_2011_06_09.pdf
- LLO_HAM_ISI_Unit_2_Calibrated_PSD_GS13_Table_Tilted_2011_06_09.pdf

Acceptance criteria:

- With table unlocked and tilted, magnitudes of power spectra must be lower than:

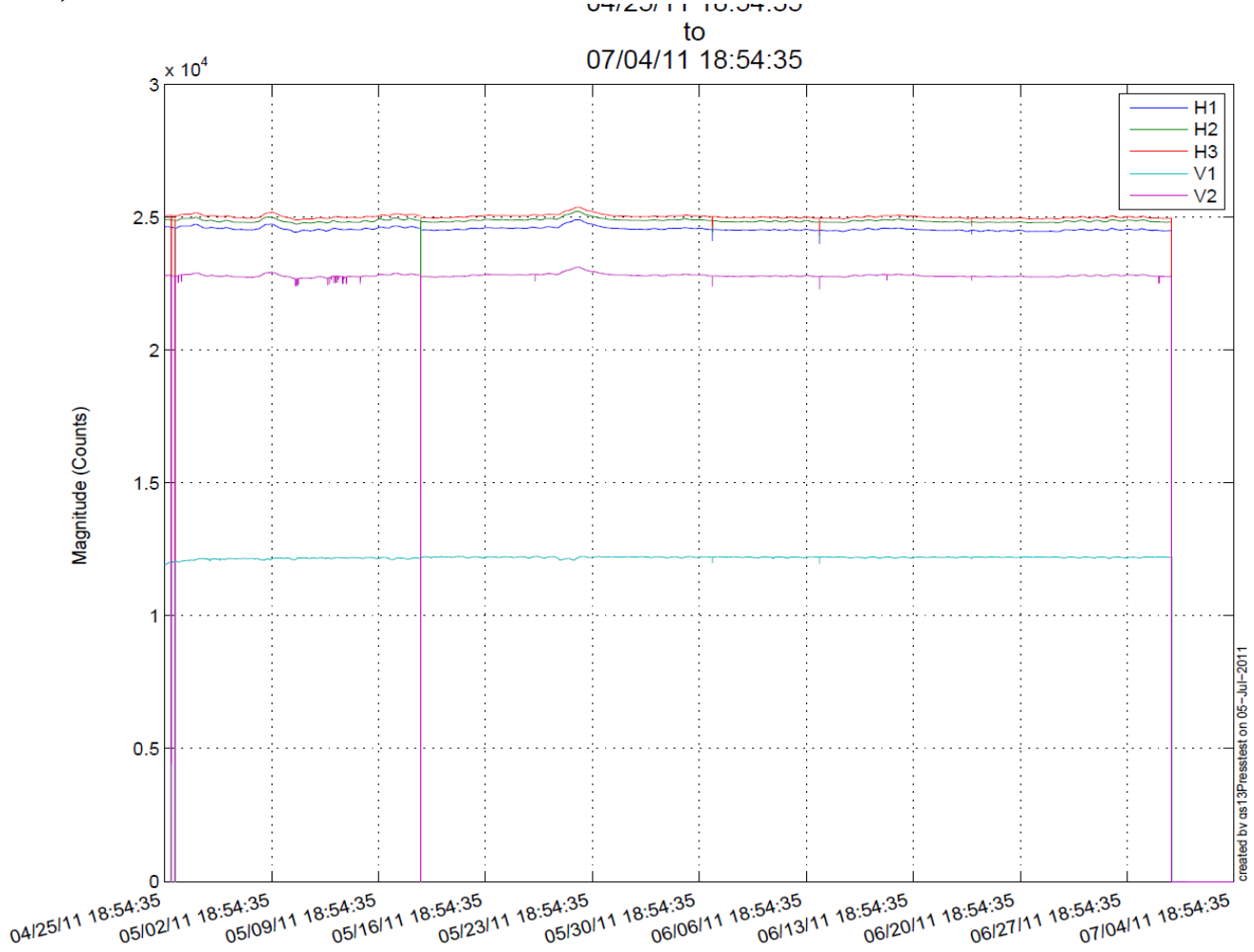
Sensor	ISI State	Frequency	$5x10^{-1}$ Hz	1	10	100	1000
GS-13	Table Tilted	Max	$2x10^{-5}$	$2x10^{-6}$	$8x10^{-8}$	$4x10^{-11}$	$3x10^{-14}$
		Min	10^{-8}	10^{-9}	$2x10^{-11}$	10^{-14}	10^{-17}

Table - Table Tilted- Sensors powerspectra requirements

Test result: **Passed: X** **Failed: ___**

- ***Step 8- GS13 pressure readout***

During this test, the pressure sensors of the 6 GS13s is checked using a Matlab function gs13PressTest. These plots should be as long as possible (i.e. as long as the ISI is connected to the test stand)



Issues/difficulties/comments regarding this test

We know that the drop to 0 at the end of the plot is due to issues with getdata.
We can notice issues with V2 dropping a few hundreds of counts now and then, but since it happened with the precedent unit, it is probably due to the read-out electronics.
We could not measure V3, due to an issue with the read-out electronics. (constantly reading ~32,000 cts)
V1 is obviously not reading properly.
By switching out cables and directly visualizing signals, we figured out that the problems were in the readout chains, both V1 and V3 pressure sensors are working properly.

Acceptance criteria:

- The pressure on all channels must be 25000 counts +/- 3000 counts
- All channels must follow comparable trend

Test result: **Passed:** ___ **Failed:** _X___

- ***Step 9 - Coil Driver, cabling and resistance check***

Actuator	V1		H1		V2	
Coil driver	S1000317 - Coarse 1		S1000317 - Fine 1		S1000317 - Fine 2	
Anti image pin #						
Cable #	28		25		30	
Resistance (Ohm)	P1 - P2	P2 - P3	P1 - P2	P2 - P3	P1 - P2	P2 - P3
	O.L (infinity)	6.4	O.L (infinity)	6.5	O.L (infinity)	6.3
MEDM offset (1000 counts)	Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)	
	300		301		300	

Actuator	H2		V3		H3	
Coil driver	S1000317 - Coarse 2		S1000316 - Coarse 1		S1000316 - Fine 1	
Anti image pin #						
Cable #	29		26		27	
Resistance (Ohm)	P1 - P2	P2 - P3	P1 - P2	P2 - P3	P1 - P2	P2 - P3
	O.L (infinity)	6.3	O.L (infinity)	6.5	O.L (infinity)	6.4
MEDM offset (1000 counts)	Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)	
	303		296		298	

Table - Actuators resistance check

Acceptance criteria:

- The measured resistance between the middle pin and one side pin must be 6.5 +/-1 ohms
- Actuator neutral pins must be connected on pin #1 (left side pin of the plug)
- Actuator drive pins must be connected on pin #2 (middle pin of the plug)
- Actuator ground shield pins must be connected on pin #3 (right pin of the plug)
- All LEDs on the coil driver front panel must be green

Test result: **Passed: X** **Failed: ___**

- ***Step 10 - Actuators Sign and range of motion (Local drive)***

	Negative drive	Positive drive
H1 readout (count)	-23488	24172
H2 readout (count)	-24360	23816
H3 readout (count)	-25346	24644
V1 readout (count)	-19560	19643
V2 readout (count)	-26054	26371
V3 readout (count)	-22176	22095

Table - Range of motion - Local drive

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Static_Tests
- LLO_HAM-ISI_Unit_2_Range_Of_Motion_20110609.mat

Scripts files for taking and processing the data, and plotting it in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_collection
- Range_Motion_HAM_ISI.m

Acceptance criteria:
- Main couplings sensors readout must be at least 16000 counts (~0.02")
- A positive offset drive on one actuator must give positive sensor readout on the collocated sensor. Signs will also be tested when measuring local to local transfer functions.

Test result: **Passed: _X_** **Failed: ___**

- ***Step 11 - Vertical Sensor Calibration***

Lockers	D.I readout for a negative drive	D.I readout without any drive	D.I readout for positive drive	
A	20	0	-19	
B	19	0	-19	
C	19	0	-20	
D	19.5	0	-19.5	
Average	19.375	0	-19.375	**-38.8**
Sensors	**Counts**	**Counts**	**Counts**	**Difference (Counts)**
V1	-17007	-955.08	15339	-32346
V2	-15842	482.06	17131	-32973
V3	-15224	726.9	16888	-32112
			Average	**-32477**

Table - Calibration of capacitive position sensors

Vertical sensitivity: 32477/38.8 = **837.0361 count/mil**

or 837.0361 count/mil * 1/ 1638V/count = 0.5110 V/mil

or 25400nm/mil * 1/837.0361 mil/count = 30.3452 nm/count

Nominal Calibration

CPS Sensitivity: 20V/0.039" = 20V/39mils = 0.513V/mil

Calibration in counts: 2^{15} / 20 * 20/39 = 840 count/mil

or 25400 nm/mil * 1/840 mil/count = 30.2nm/count

Change = (837.0361 **-840)/840= -0.3528%**

Acceptance criteria:

- Deviation from nominal value < 2%. Nominal value is 840 count/mil.

Test result: **Passed: _X_** **Failed: ___**

- ***Step 12 - Vertical Spring Constant***

Results presented below are obtained after the initial sensors calibration.

Sensors	Mean diff counts	Mean diff m	K (N/m)	Error with average
V1	7837	2.37E-04	8.29E+04	0.381%
V2	7835	2.37E-04	8.29E+04	0.414%
V3	7930	2.39E-04	8.19E+04	-0.794%
		Average (N/m)	8.26E+04	
		Total Stiffness (N/m)	2.477E+05	

Table - Vertical spring constant

Acceptance criteria:

- +/-2 % of 2.4704e5 N/m (i.e. between 2.421e5 and 2.520e5 N/m)
- +/- 5% of variation between each spring and the average

The measured error on the vertical stiffness is 0.27%.

Test result: **Passed: X** **Failed: ___**

- ***Step 13 - Static Testing (Tests in the local basis)***

		H1	H2	H3	V1	V2	V3
Actuators (1000 counts)	H1	2072.5	1291.2	1322.9	-15.22	25.398	19.299
	H2	1299.4	2070.1	1319.8	5.18	5.253	9.745
	H3	1308.8	1308.5	2129.8	-23.62	15.581	2.146
	V1	188.8	191.74	-389.03	1512.6	-29.942	-648.16
	V2	-397.82	192.34	199.52	-668.82	1533.6	-29.541
	V3	187.69	-404.86	193.81	-50.42	-650.6	1519.9

Table - Main and cross coupling

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Static_Tests
- LLO_HAM_ISI_Unit_2_Sensor_Readout_Local_20110609.mat

Scripts files for taking data in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_Collection
- Sensor_Readout_Local_Drive_MEDM_HAM_ISI.m
-

Issues/difficulties/comments regarding this test:

Acceptance criteria:

- **Vertical**
  For a +1000 count offset drive on vertical actuators
  - Collocated sensors must be 1400 counts +/- 10%

- **Horizontal**
  For a +1000 count offset drive on horizontal actuators
  - Collocated sensors must be 2000 counts +/- 10%
  - Non-collocated horizontal sensors must be 1250 counts +/-10%

Test result: **Passed: X** **Failed: ___**

- ***Step 14 - Linearity test***

	Slope	Offset	Average slope	Variation from average(%)
H1	2.089	951	2.0977	-0.41
H2	2.088	-1491		-0.46
H3	2.116	1021		0.87
V1	1.522	-1578	1.5163	0.37
V2	1.522	215		0.37
V3	1.505	518		-0.75

Table - Slopes and offset of the triplet Actuators - HAM-ISI - Sensors

Scripts files for taking data in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_Collection

- Linearity_Test_Awgstream_HAM_ISI.m

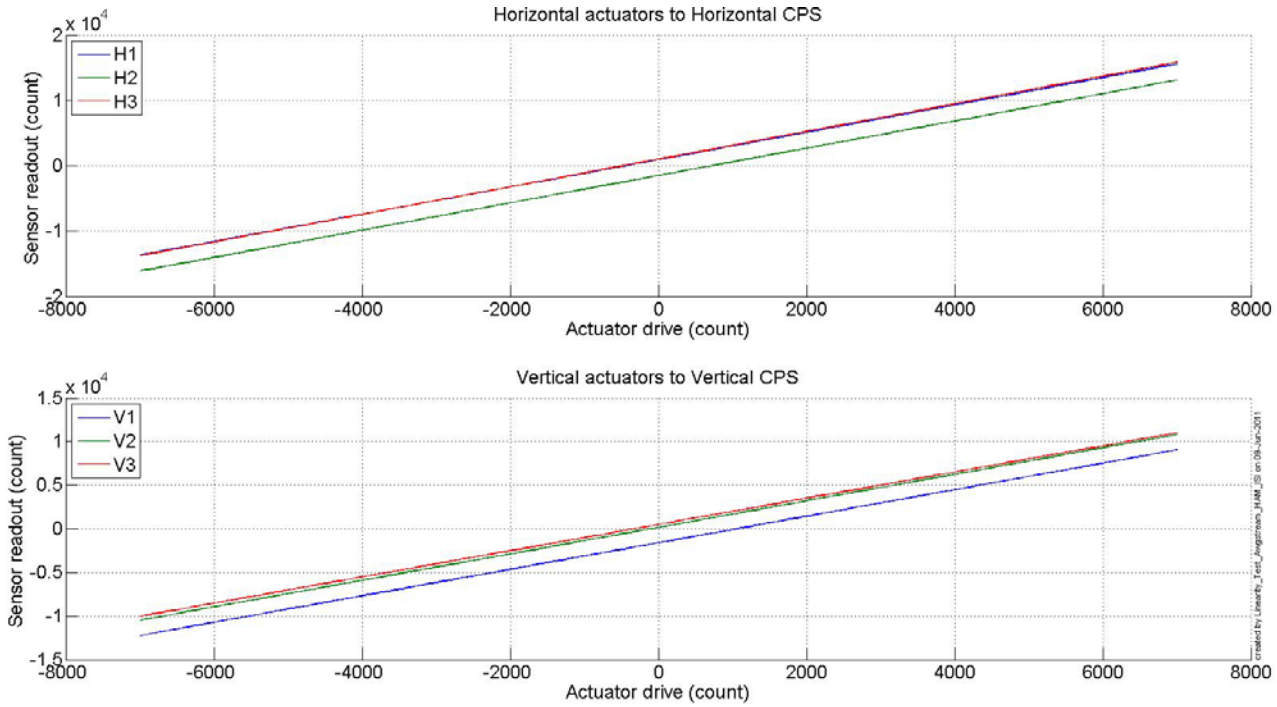


Figure - Horizontal and vertical actuators x HAM-ISI x sensors

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Linearity_test

- LLO_HAM_ISI_Unit_2_Linearity_test_20110609.mat

Figures in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/Linearity_test

- LLO_HAM_ISI_Unit_2_Linearity_test_20110609.fig
  LLO_HAM_ISI_Unit_2_Linearity_test_20110609.pdf

Acceptance criteria:

- Horizontal and vertical slopes of the triplet actuators x HAM-ISI x sensors: Average slope +/- 1%

Test result: **Passed: X** **Failed: ___**

- ***Step 15 - Cartesian Basis Static Testing***

Sensors readout (count)	1000 counts drive	X Drive	Y Drive	Z Drive	Rx Drive	Ry Drive	Rz Drive
	H1	263.528	-390.4432	39.232	-351.599	-234.314	-1870.593
	H2	232.73	510.05	51.46	511.84	-214.09	-1926.44
	H3	-492.32	23.53	10.56	70.06	532.44	-1901.82
	V1	-5.871	6.292	248.899	-510.236	-1619.426	11.019
	V2	-21.28	-33.566	239.421	1633.514	398.43	-57.855
	V3	2.8	-18.2	270.36	-1169.8	1208.911	29.8
	Direction read out	492.38	524.71	256.965	2516.66	2506.73	2404.763

Table - Tests in the general coordinate basis

Issues/difficulties/comments regarding this test:

Acceptance criteria:

Sensors readout (count)	X Drive	Y Drive	Z Drive	Rx Drive	Ry Drive	Rz Drive
H1	+	-				-
H2	+	+				-
H3	-	0				-
V1			+	-	-	
V2			+	+	+	
V3			+	-	+	
Direction read out	+	+	+	+	+	+

Table – Reference table

For a positive drive in the Cartesian basis:

- Local sensor readout must have the same sign that the reference table (**CONT2ACT check**)
- Cartesian sensors read out must be positive (**DISP2CEN check**) in the drive direction

Test result: **Passed: X** **Failed: ___**

- ***Step 16- Frequency response***

Compensation filters of the new GS13 interface chassis are located in the geophone pre-filters bank. Powerspectra were measured with masses on the optic table not bolted.

- ***Step 16.1 - Local to local measurements***

Local to local transfer functions have been measured with 90 repetitions.

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_2_Data_TF_L2L_50mHz_500mHz_20110610-001759.mat
- LLO_HAM_ISI_Unit_2_Data_TF_L2L_500mHz_5Hz_20110609-201238.mat
- LLO_HAM_ISI_Unit_2_Data_TF_L2L_200Hz_800Hz_20110609-170556.mat
- LLO_HAM_ISI_Unit_2_Data_TF_L2L_5Hz_200Hz_20110609-183917.mat

Data collection script files:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_Collection

- Run_TF_L2L_50mHz_500mHz.m
- Run_TF_L2L_500mHz_5Hz.m
- Run_TF_L2L_5mHz_200Hz.m
- Run_TF_L2L_200Hz_800Hz.m

Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_2_TF_L2L_2011_05_03.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAMISI/X2/Data/Unit_2/Figures/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_2_TF_L2L_H_CPS_50mHz_800Hz_2011_06_10.fig
- LLO_HAM_ISI_Unit_2_TF_L2L_V_CPS_50mHz_800Hz_2011_06_10.fig
- LLO_HAM_ISI_Unit_2_TF_L2L_H_GS13_50mHz_800Hz_2011_06_10.fig
- LLO_HAM_ISI_Unit_2_TF_L2L_V_GS13_50mHz_800Hz_2011_06_10.fig

Storage of measured transfer functions in the SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_functions/ Measurements/Undamped/

- LLO_HAM_ISI_Unit_2_Data_TF_L2L_2011_06_10.mat

The local to local transfer functions are presented below.

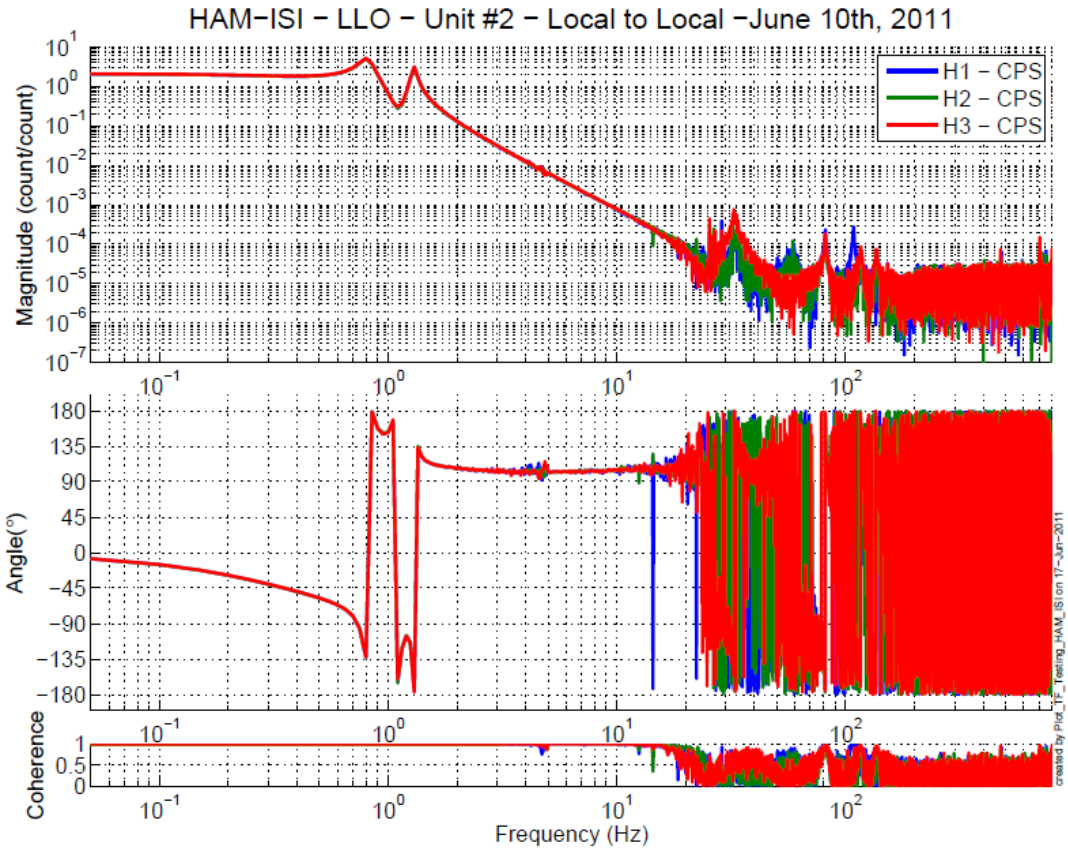


Figure - Local to Local Measurements – Horizontal capacitive sensors

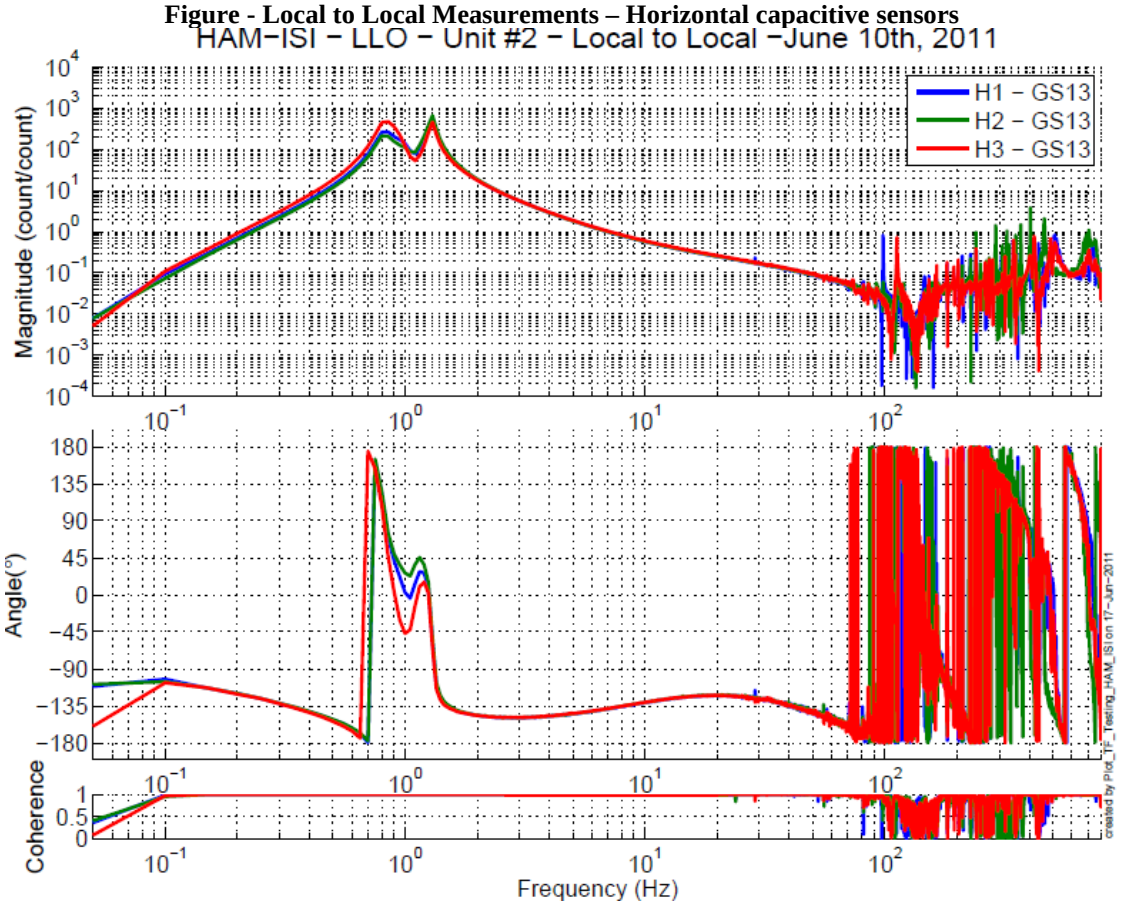


Figure - Local to Local Measurements – Horizontal inertial sensors

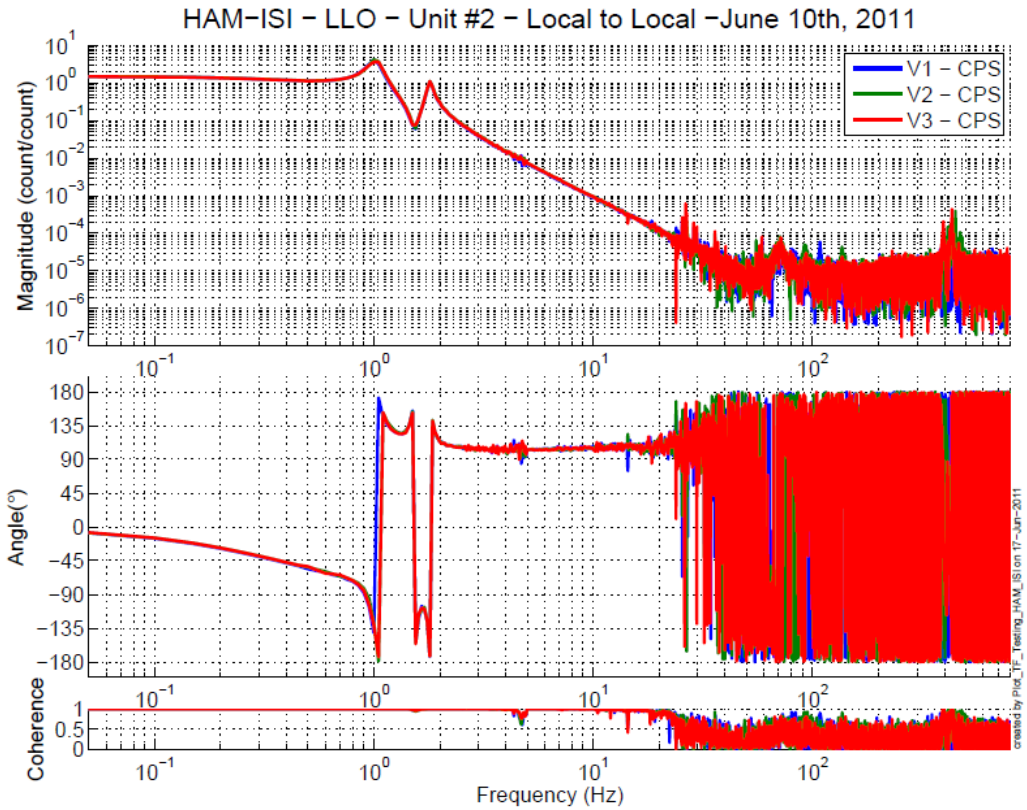


Figure - Local to Local Measurements – Vertical capacitive sensors

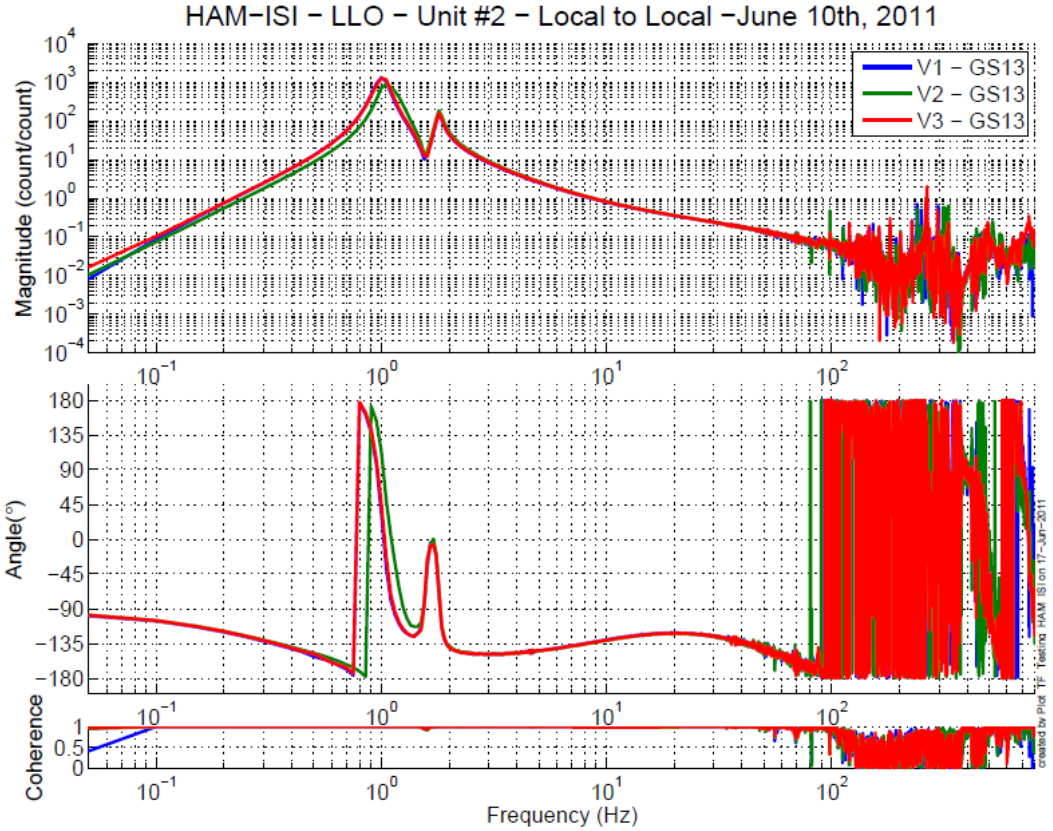


Figure - Local to Local Measurements – Vertical inertial sensors

Issues/difficulties/comments regarding this test:
Around 1 Hz, the inertial sensors seem to indicate different behaviors of each corner.

▪ *Step 16.2 - Cartesian to Cartesian measurements*

Cartesian to Cartesian transfer functions have been measured with 90 repetitions.

Data files in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_2_Data_TF_C2C_50mHz_500mHz_20110610-233216.mat
- LLO_HAM_ISI_Unit_2_Data_TF_C2C_500mHz_5Hz_20110610-202655.mat
- LLO_HAM_ISI_Unit_2_Data_TF_C2C_5Hz_200Hz_20110610-185334.mat
- LLO_HAM_ISI_Unit_2_Data_TF_C2C_200Hz_800Hz_20110610-172013.mat

Scripts files for processing and plotting in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_2_TF_C2C_2011_05_03.m.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_2_TF_C2C_X_Y_RZ_CPS_50mHz_800Hz_2011_06_13.fig
- LLO_HAM_ISI_Unit_2_TF_C2C_X_Y_RZ_GS13_50mHz_800Hz_2011_06_13.fig
- LLO_HAM_ISI_Unit_2_TF_C2C_Z_RX_RY_CPS_50mHz_800Hz_2011_06_13.fig
- LLO_HAM_ISI_Unit_2_TF_C2C_Z_RX_RY_GS13_50mHz_800Hz_2011_06_13.fig

Storage of measured transfer functions in the SVN at:
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_functions/Cartesian_to_Cartesian

- LLO_HAM_ISI_Unit_2_Data_TF_C2C_2011_06_13

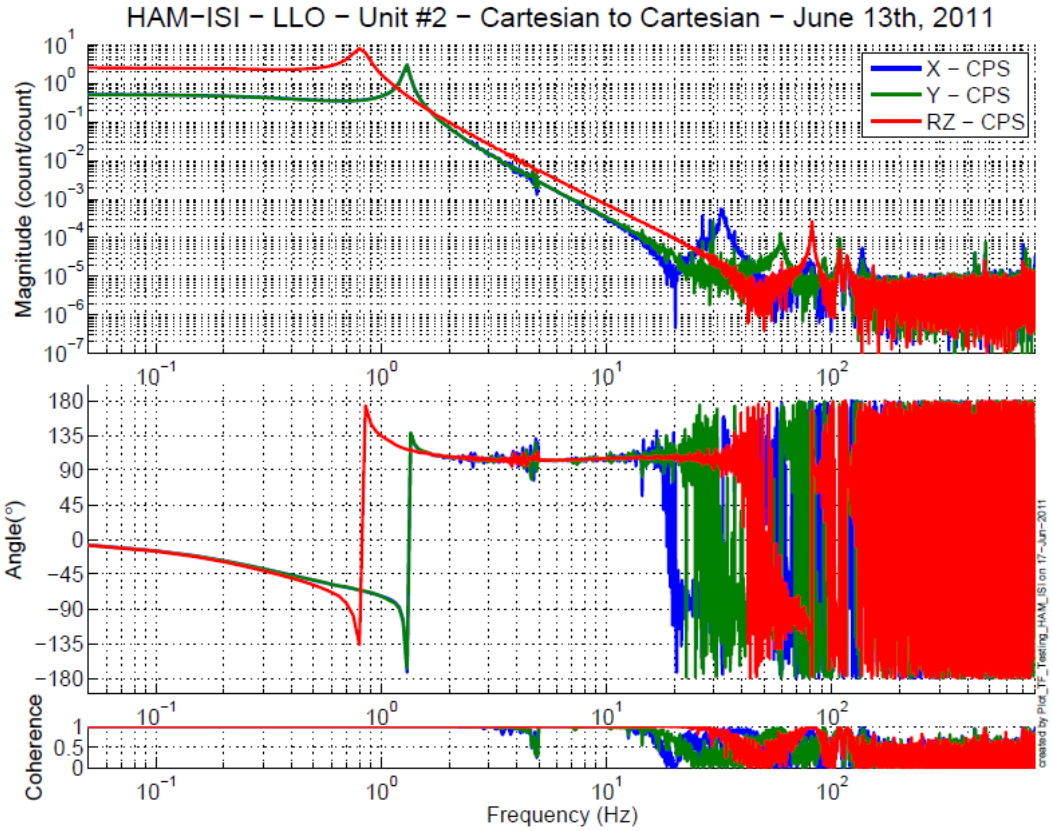


Figure - Cartesian to Cartesian CPS measurements – X, Y, RZ directions

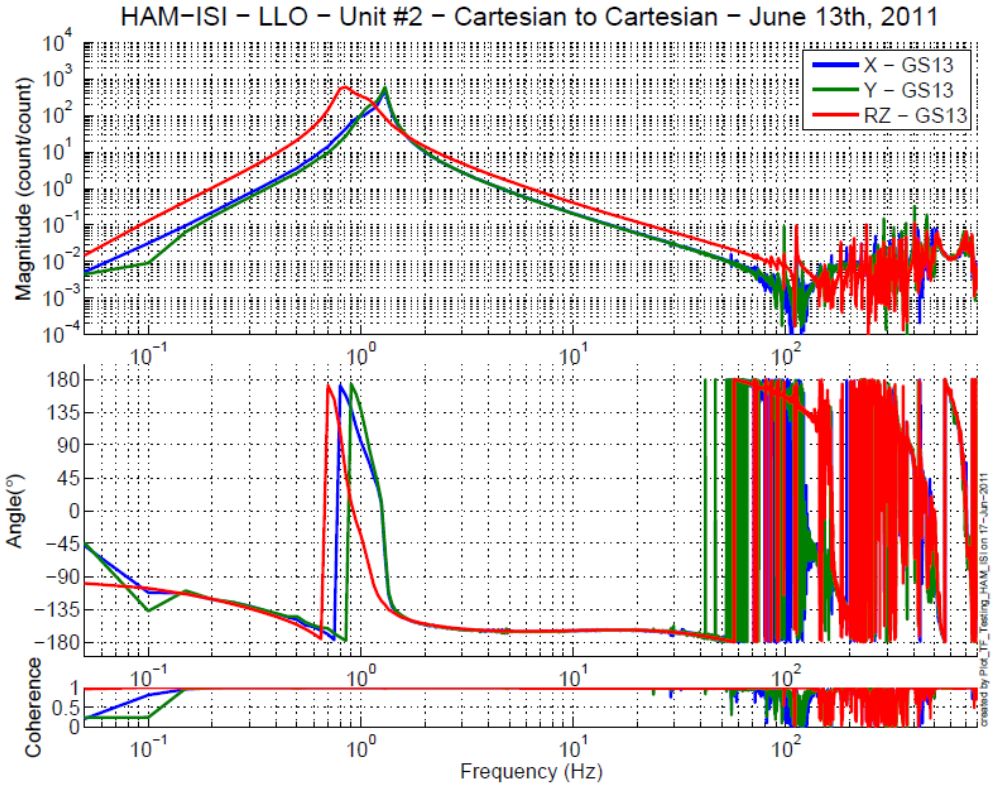


Figure - Cartesian to Cartesian GS-13 measurements – X, Y, RZ directions

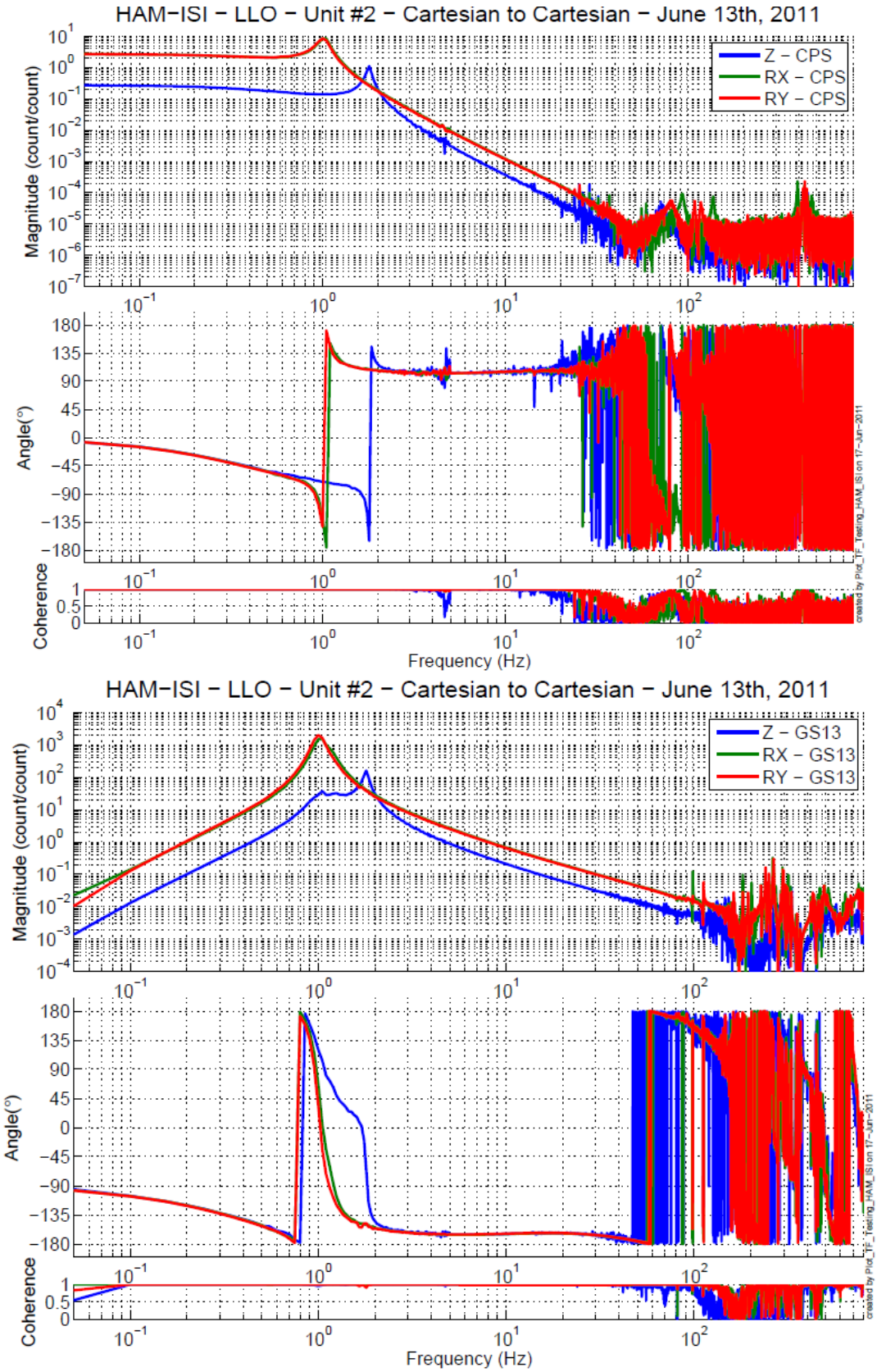


Figure - Cartesian to Cartesian measurements – Z, RX, RY directions

Issues/difficulties/comments regarding this test:
There seems to be a slight asymmetry between the X and Y direction on the inertial sensors TF around 1 Hz.
The Z direction GS-13 TF also presents some somewhat unexpected features around 1.2 Hz.

Acceptance criteria:

- Local to local measurements
  - On CPS, the phase must be 0º at DC
  - On Geophones, the phase must be -90º at DC
  - Identical shape in each corner
- Cartesian to Cartesian measurements
  - On CPS, the phase must be 0º at DC
  - On Geophones, the phase must be -90º at DC
  - Identical shape X/Y and RX/RY

Test result: **Passed: X** **Failed: ___**

- ***Step 17 - Transfer function comparison with Reference***
  - ***Step 17.1 - Local to local - Comparison with Reference***

Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_2_TF_L2L_2011_04_06.m

Local to local figures in SVN at:
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_2_TF_L2L_H_CPS_50mHz_800Hz_wRef_2011_06_10.fig
- LLO_HAM_ISI_Unit_2_TF_L2L_V_CPS_50mHz_800Hz_wRef_2011_06_10.fig
- LLO_HAM_ISI_Unit_2_TF_L2L_H_GS13_50mHz_800Hz_wRef_2011_06_10.fig
- LLO_HAM_ISI_Unit_2_TF_L2L_V_GS13_50mHz_800Hz_wRef_2011_06_10.fig

GS13, Local to local measurement

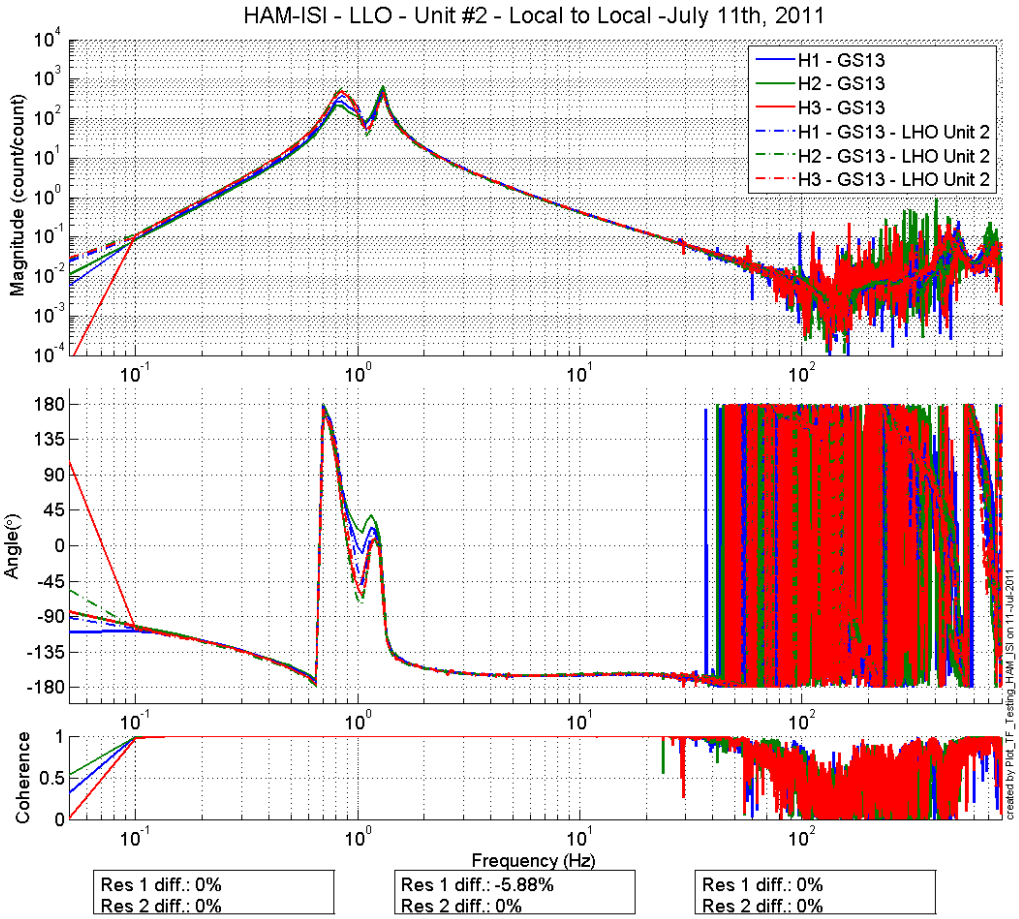


Figure - Local to local measurements comparison with LHO HAM Unit 2 – Horizontal GS-13

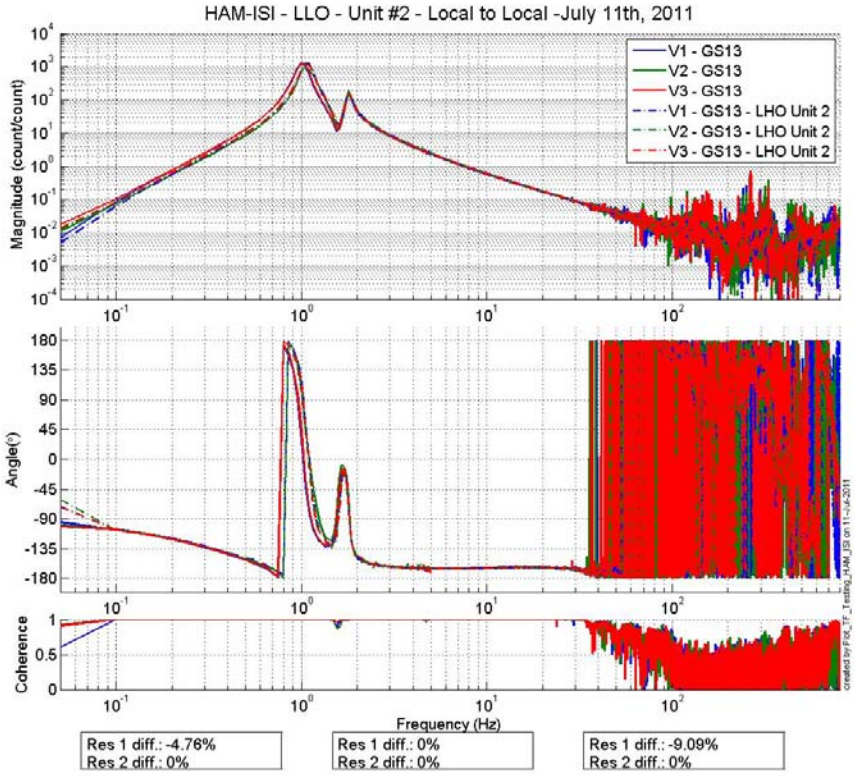


Figure - Local to local measurements comparison with LHO HAM Unit 2 – Vertical GS13

CPS, Local to local measurement, Undamped

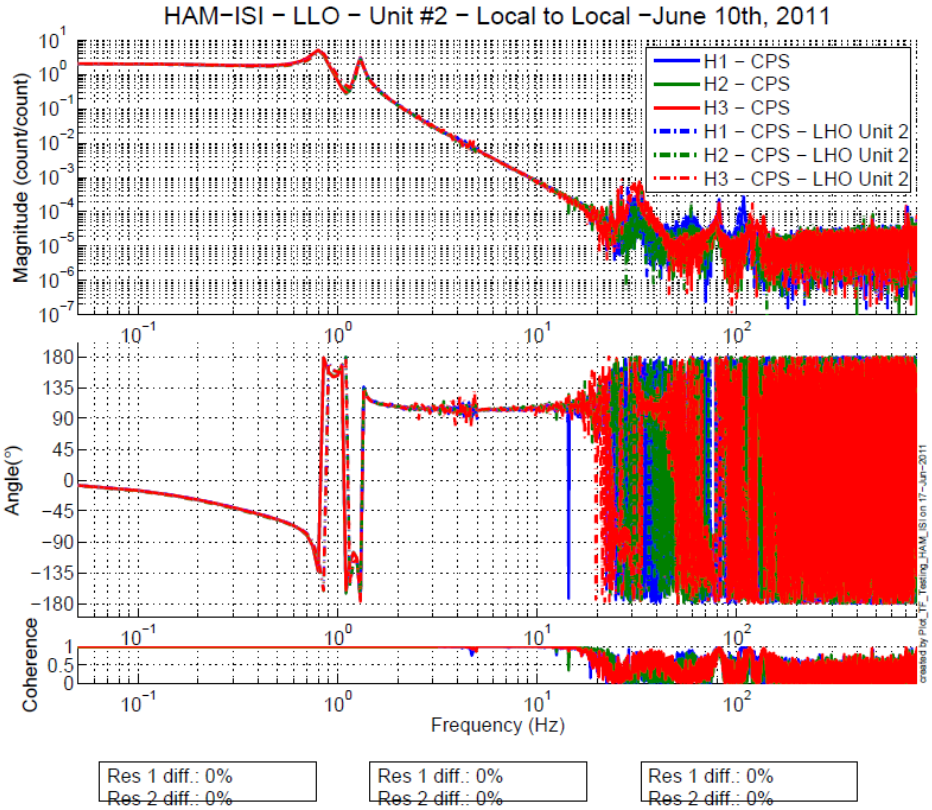


Figure - Local to local measurements comparison – Horizontal Position sensors

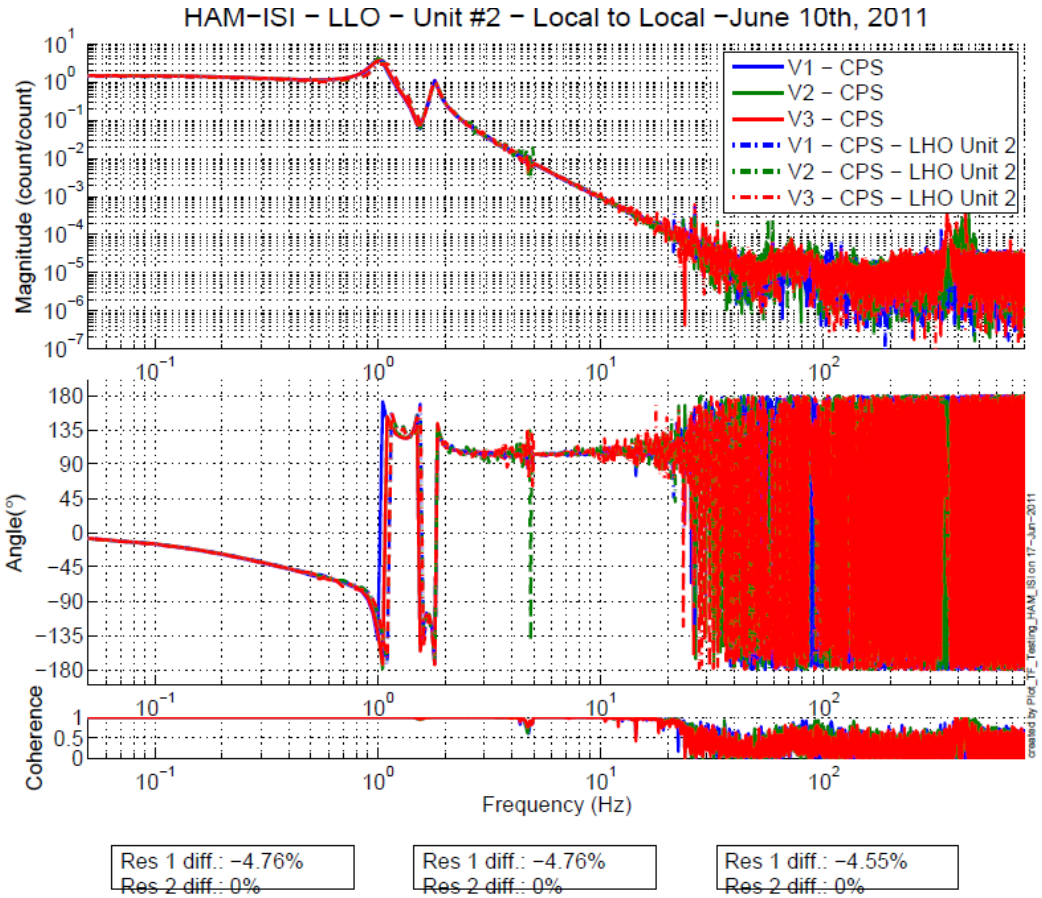


Figure - Local to local measurements comparison – Vertical Position sensors

- ***Step 17.2 - Cartesian to Cartesian - Comparison with Reference***

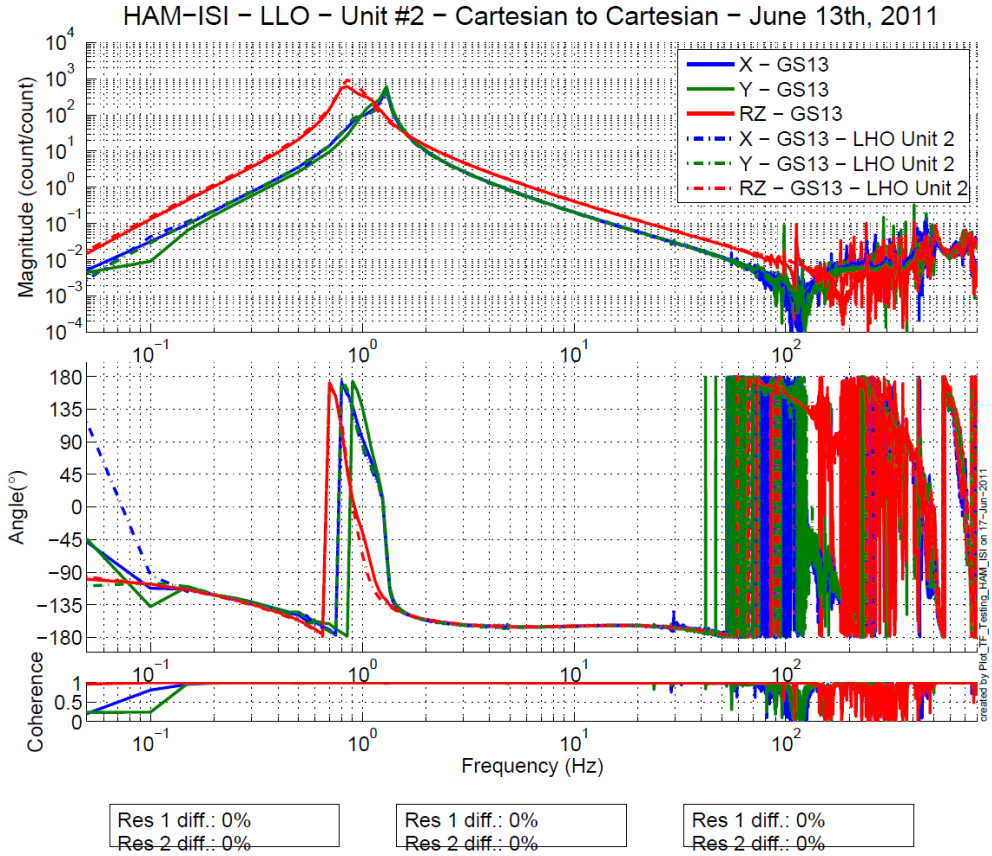


Figure - Cartesian to Cartesian GS-13 measurements- Comparison w/ LHO Unit 2 - X, Y, RZ directions

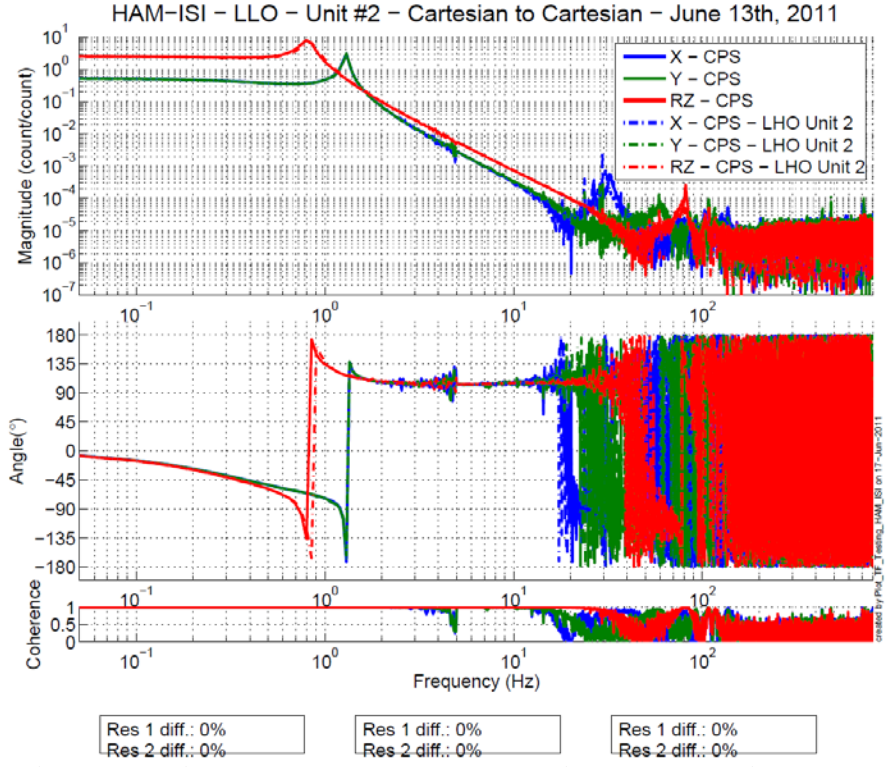


Figure - Cartesian to Cartesian CPS measurements - Comparison w/ LHO Unit 2 - X, Y, RZ directions

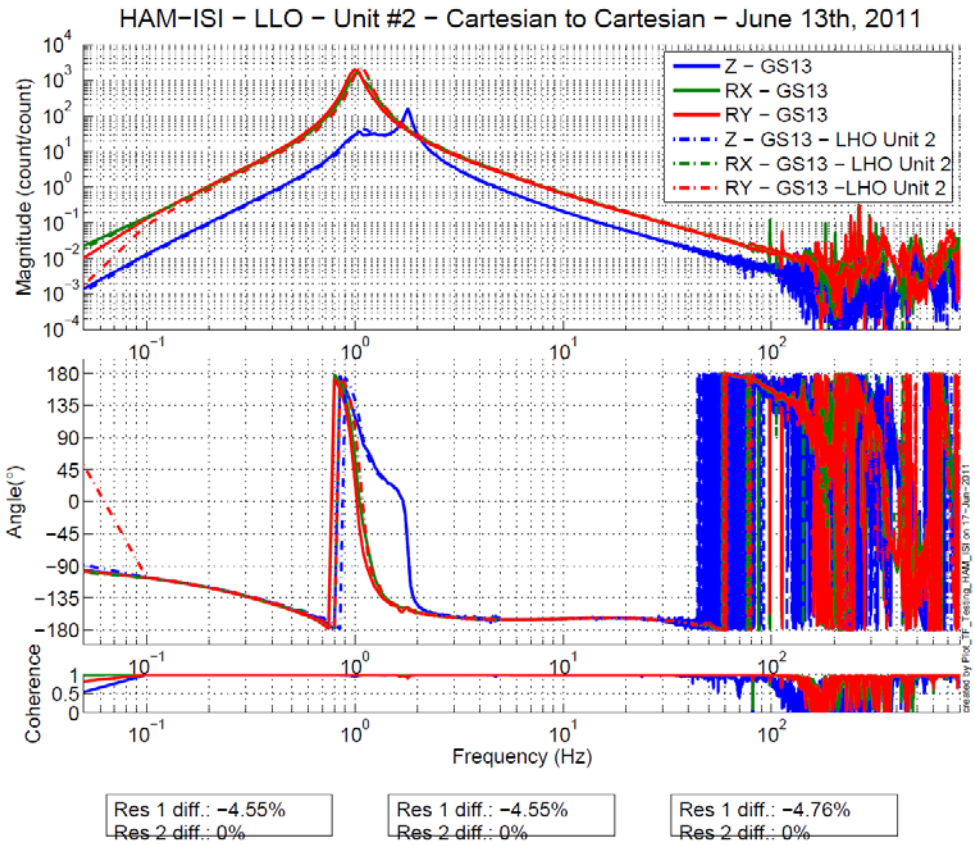


Figure - Cartesian to Cartesian GS-13 measurements - Comparison w/ LHO Unit 2 - Z, RX, RY directions

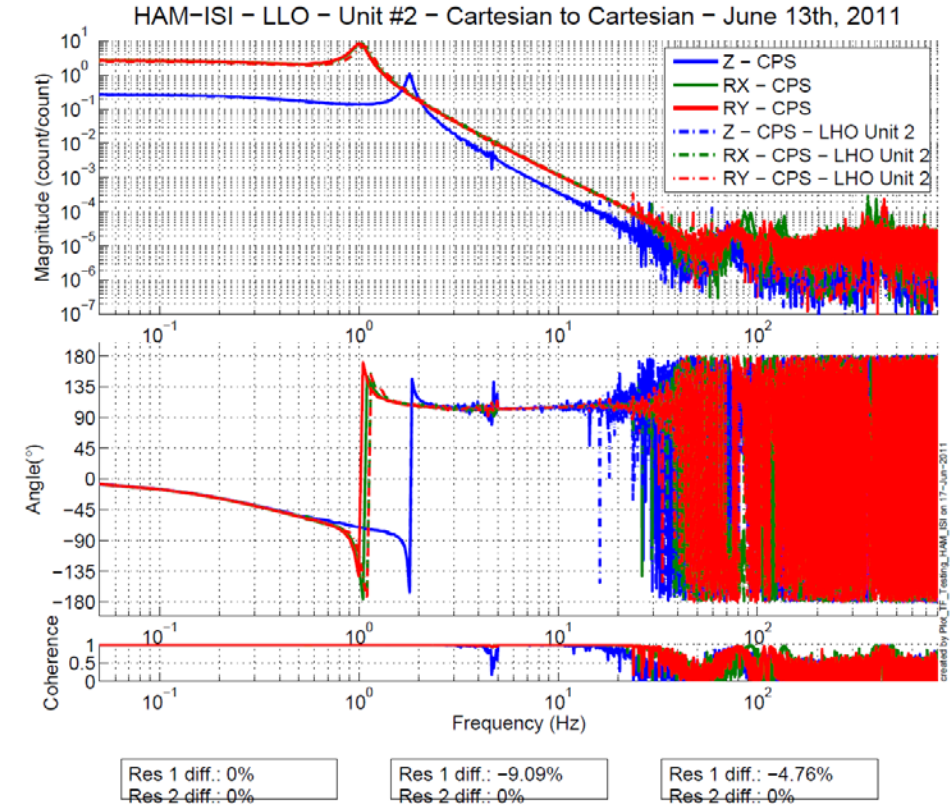


Figure - Cartesian to Cartesian CPS measurements - Comparison w/ LHO Unit 2 - Z, RX, RY directions

Acceptance criteria:

- No difference with the reference transfer functions (SVN)
  - Phase – less than 10º - In Phase – Out of Phase
  - Damping (fit by eye with Reference transfer functions)
  - DC gain
  - Eigen frequencies shift less than 10%

Test result: **Passed: X** **Failed: ___**

- ***Step 18 - Lower Zero Moment Plane***

Data collection script files:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_Collection

- Run_Cart2Cart_10mHz_100mHz.m

Data files in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- LZMP_LLO_HAM-ISI-Unit_2_2011_06_13.mat

Scripts files for processing and plotting in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Measurements/Undamped/

- LZMP_2011_05_03.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/Transfer_Functions/Measurements/Undamped/

- LZMP.fig

X & Y offsets:

X offset (mm)	**0.704**
Y offset (mm)	**2.273**

Table – Offset of the Lower Zero Moment Plane

The results from two measurements are presented on the figure below:

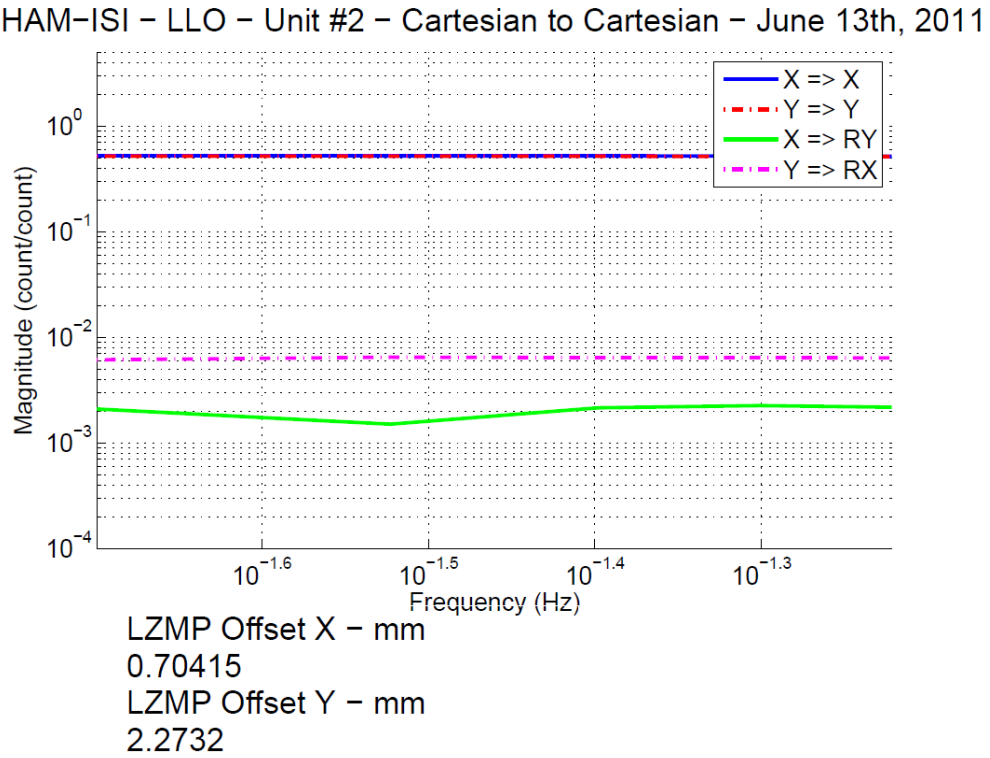


Figure - Lower Zero moment plane – Main and cross couplings at low frequency

Issues/difficulties/comments regarding this test:
Because of the unexpectedly high results, we took this measurement numerous times. The final results are presented above, but the sum of all results are summarized in the following table.

Notes	Date Measurement	x (mm)	y (mm)
	Sept 25th	0.7884	1.7566
	Sept 27th	0.1278	1.7536
	Oct 3rd	0.7218	1.1414
After re-assembly	May 3rd	0.9677	2.4428
	May 4th	0.9374	2.4645
	May 5th	0.9003	2.4807
After mass change	June 10th	0.7042	2.2732
	June 28th	0.7794	2.2084
	June 29th	0.7896	2.1932
	June 30th	0.7607	2.1791
Mass imbalance 1	June 30th	0.7901	2.2222
Mass imbalance 2	July 5th	0.7585	2.2205
	July 7th	0.7422	2.2147
	July 9th	0.77513	2.1915

We tried to find any geometrical discrepancies on Stage 1 that could explain this measurement, but nothing of any significance was found.

Acceptance criteria:
- X offset must be less than 2 mm
- Y offset must be less than 2 mm

Test result: **Passed: ___** **Failed: _X__**

- ***Step 19 - Damping loops***

In this step, HAM6 damping loops are implemented. First, damping performances are evaluated in simulation. Second, Damping loops are implemented and performance is experimentally measured.

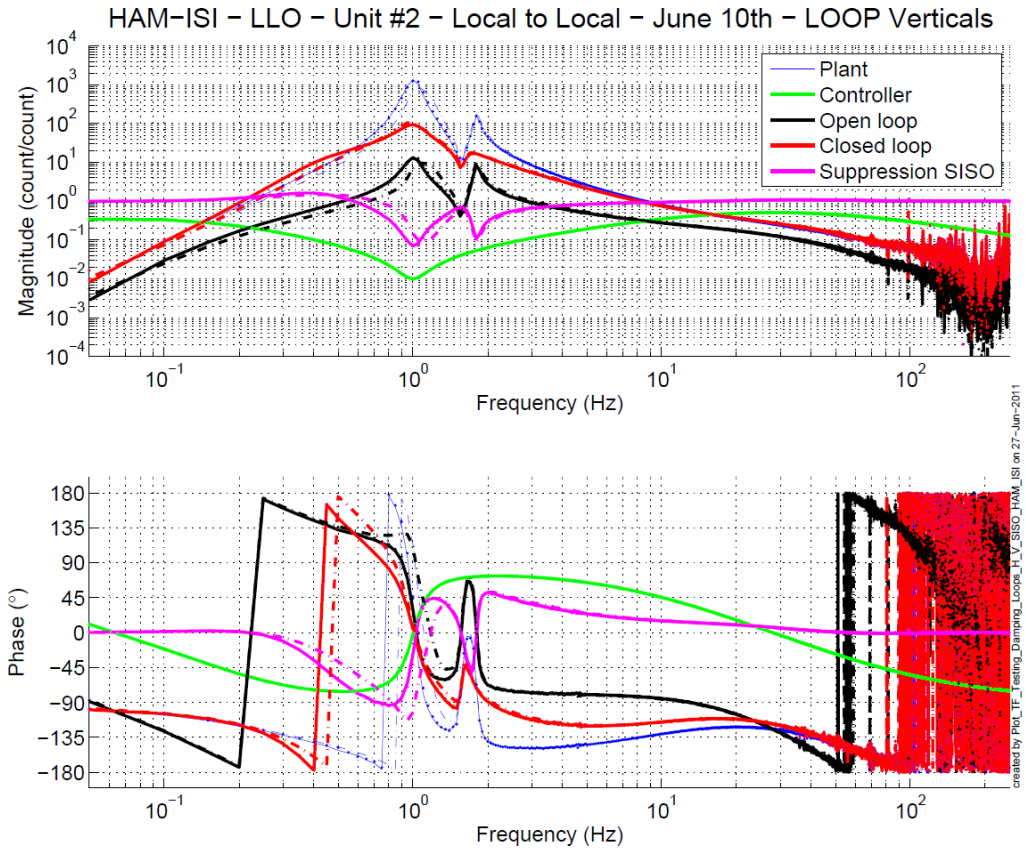
- ***Step 19.1 - Transfer functions - Simulation***

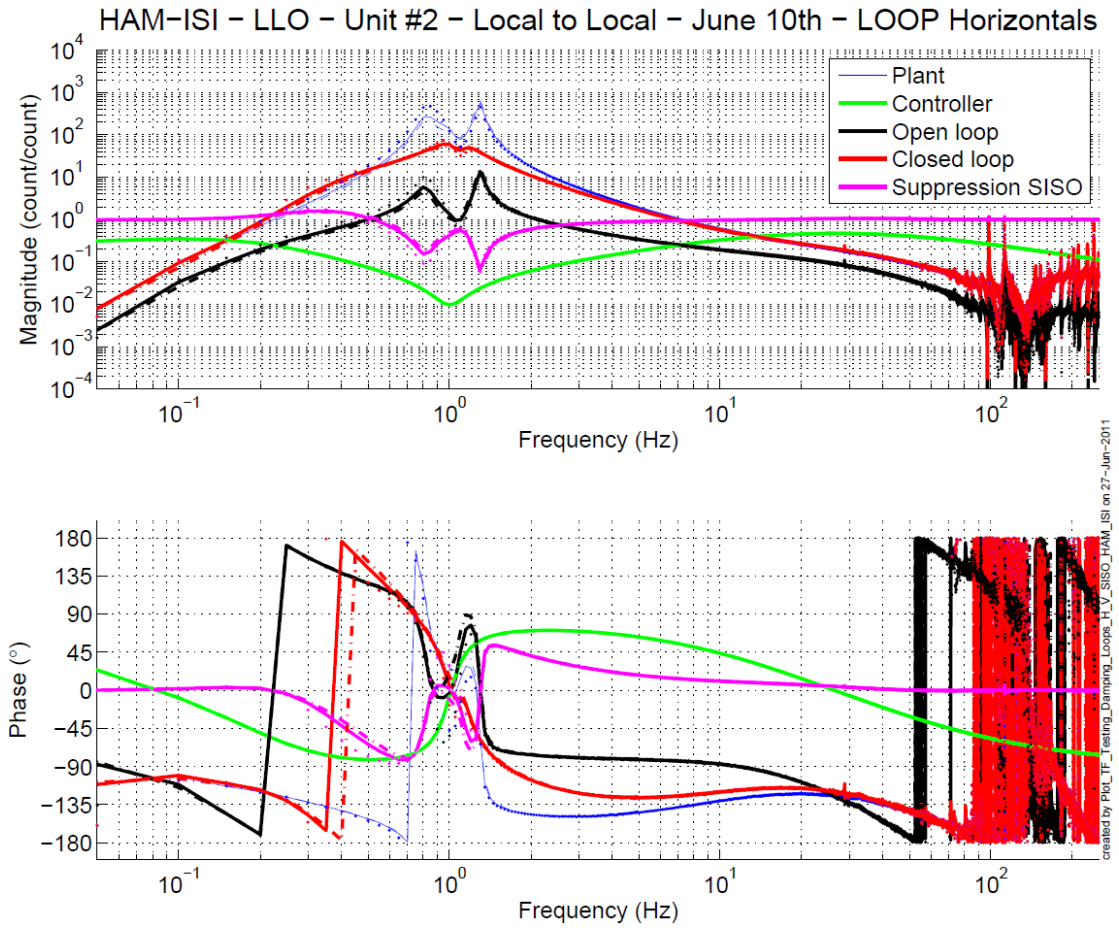
Continuous HAM6 filters are located in the SVN at:
/optseisvn/seismic/HAM-ISI/Common/HAM6_Main_Results
- HAM6_LLO_Damping_Filters.mat

Scripts files used to evaluate damping loops performance from measurementsare located in SVN at:
/ seismic/HAM-ISI/X1/Data/Unit_2/Transfer_Functions/Simulations/Damping/
HAM_ISI_LLO_Unit_2_Damping_TF_2011_06_21.m

Save file is located in the SVN at:
/seismic/HAM-ISI/X2/Data/Unit_2/Transfer_Functions/Simulations/Damping/
- LLO_HAM_ISI_Unit_2_Damping_TF_2011_06_21.mat

Figures in SVN at:
seismic/HAM-ISI/X2/Data/Unit_2/Figures/Transfer_Functions/Simulations/Damping/
- LLO_HAM_ISI_Unit_2_Damping_TF Horizontals_2011_06_21.fig
- LLO_HAM_ISI_Unit_2_Damping_TF Verticals_2011_06_21.fig





Acceptance criteria:

- HAM6 damping loops must implemented and stable with
  - Phase margin must be at least 45º
  - Gain margin must be at least 20dB

Test result: **Passed: _X_** **Failed: ___**

- ***Step 19.2 - Powerspectra – Experimental***

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Powerspectra/Damping/

Scripts files for taking data and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Scripts/Data_Collection/

- Powerspectra_Measurements_Undamped_Damped_HAM_ISI.m
-

Figures in SVN at:
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_2/Figures/Powerspectra/Damping/
- LLO_HAM_ISI_Unit_2_Calibrated_PSD_CPS_Undamped_Damped_2011_06_28.fig
- Simulation_vs_experimental_Suppression.fig

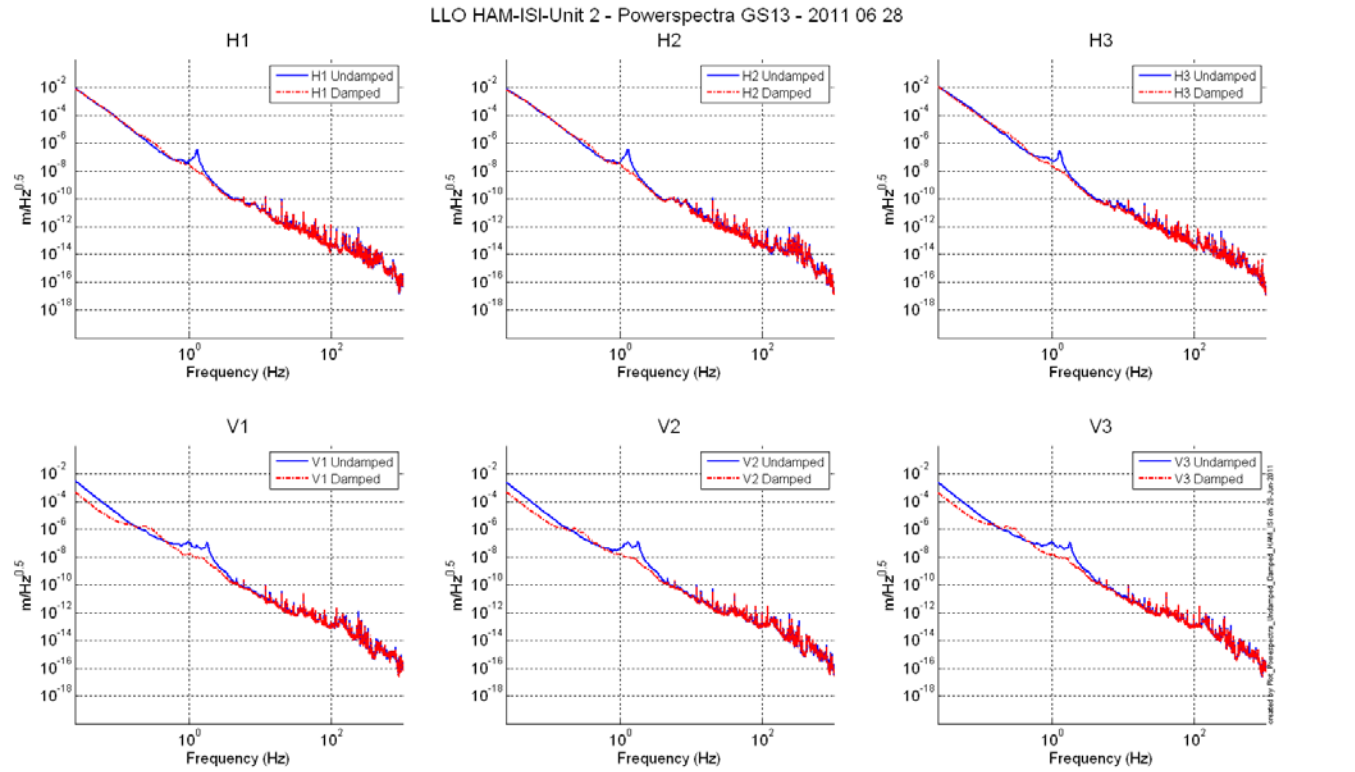


Figure - Damped/Undamped GS-13 Power Spectra comparison

Sensitivity:
The figure below compare the sensitivity ('Undamped/Damped') of LLO HAM (Aug 2008) and LHO Unit 2. Performances are very similar, which confirms that we can use the damping loop as they are (modulo electronics change compensation). The plot also shows that the measured performance matches with the prediction

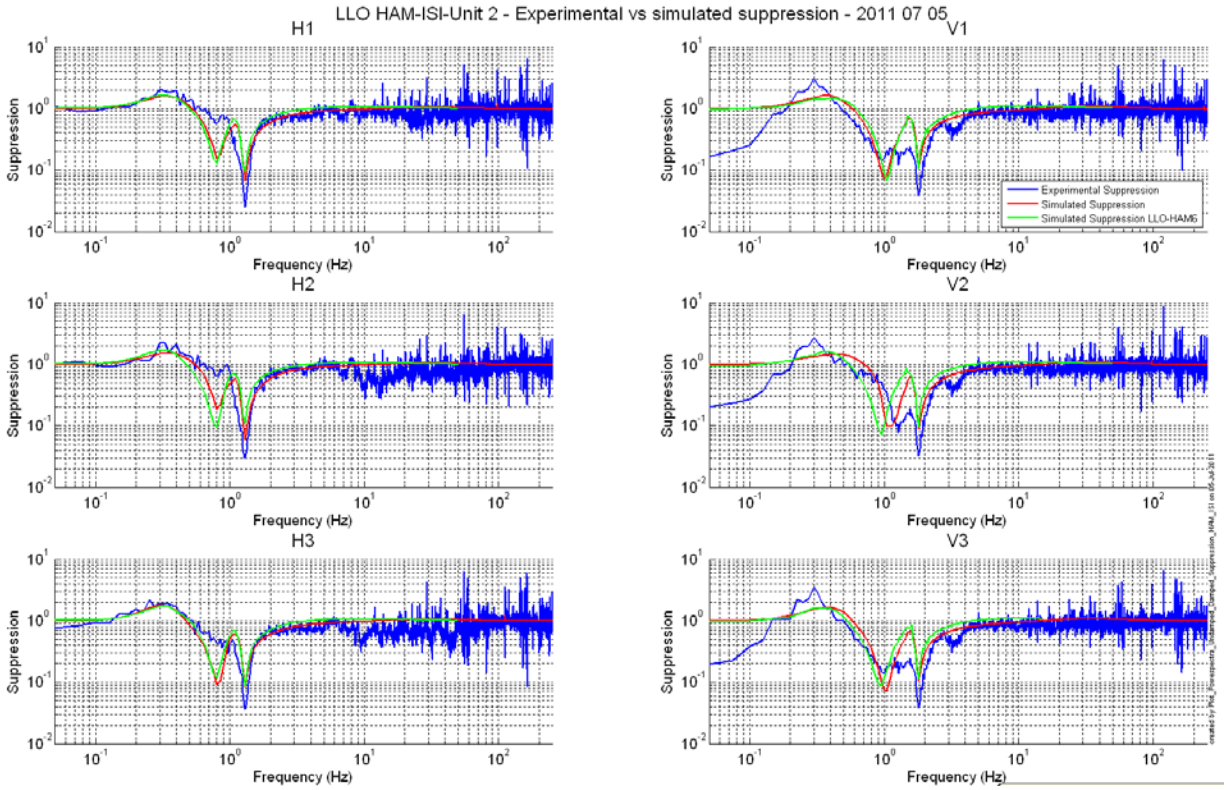


Figure - Experimental vs Simulated suppression

Acceptance criteria:

- HAM6 damping loop must stable when all damping loops are engaged
- Similar damping effect than in simulated plots

Test result: **Passed: _X_** **Failed: ___**

Conclusion

Only a few issues were found during the testing of this unit, which are summed up here:

- Sensor gaps not measured on jig
- Local 2 local transfer functions displays a slightly different behavior around 1 Hz in corner 3 than in the others
- Y LZMP measurements do not meet requirements and all LZMP measurements seem to have a fairly high uncertainty