LIGO Laboratory / LIGO Scientific Collaboration

LIGO- E1000327 *LIGO* July 20th, 2011

aLIGO HAM-ISI,

LLO Assembly Unit# 3 (HAM3 Chamber) Testing Report,

Phase I: Assembly validation

E1000327 – V7

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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.

Following that testing, the testing procedure was modified (going to v7), that latest version of the test report (v5)was created afterwards, some data being re-processed. In other words, v4 was still using the older requirements.

The procedure document used to perform this test is:

- E1000309 –V7 - 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
12057	NR	NR	NR	NR	NR	NR	NR
12026	NR	NR	NR	NR	NR	NR	NR
12013	NR	NR	NR	NR	NR	NR	NR
12059	NR	NR	NR	NR	NR	NR	NR
12056	NR	NR	NR	NR	NR	NR	NR
12083	NR	NR	NR	NR	NR	NR	NR

NR: not recorded

Will be measured for the next units.

Sensors noise spectra measured before baking:

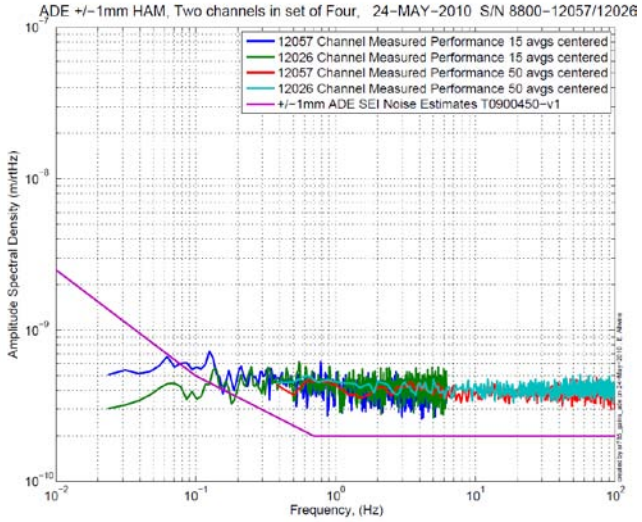


Figure - H1 and V1 sensor noise

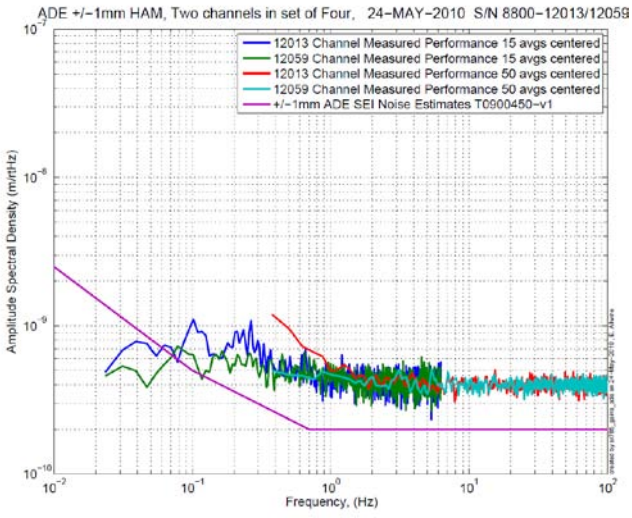


Figure - H2 and V2 sensor noise

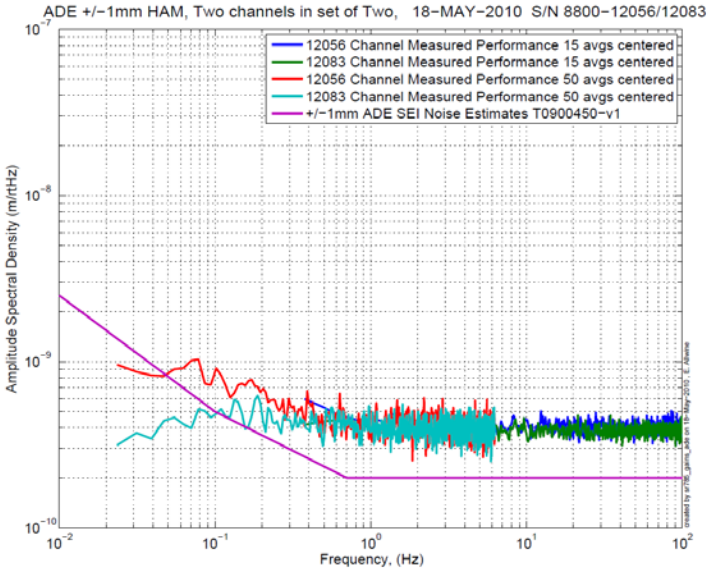


Figure - H3 and V3 sensor noise

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.
12013 (used for H2) is noisier than other sensors, still passes.

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

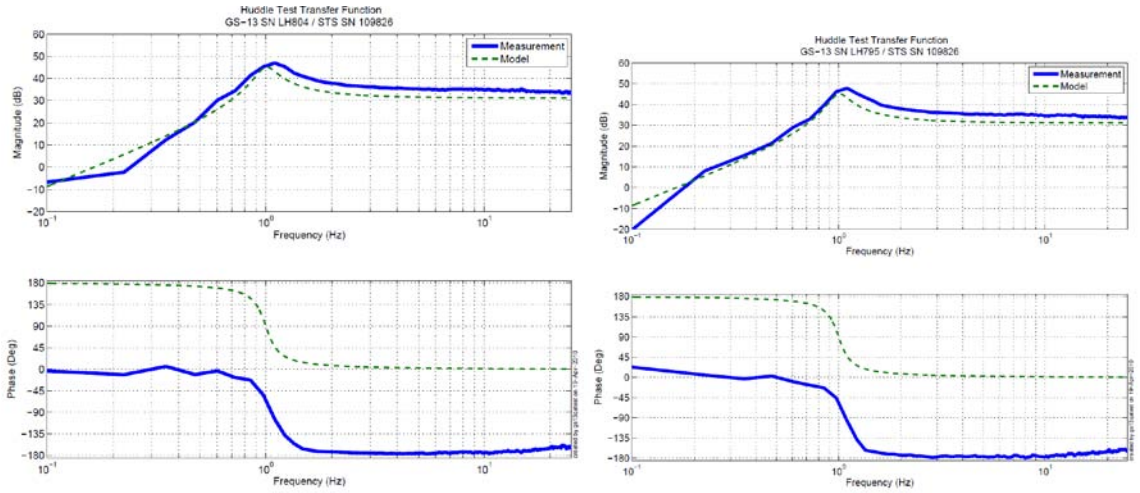
Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/Common/MatlabTools

- 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



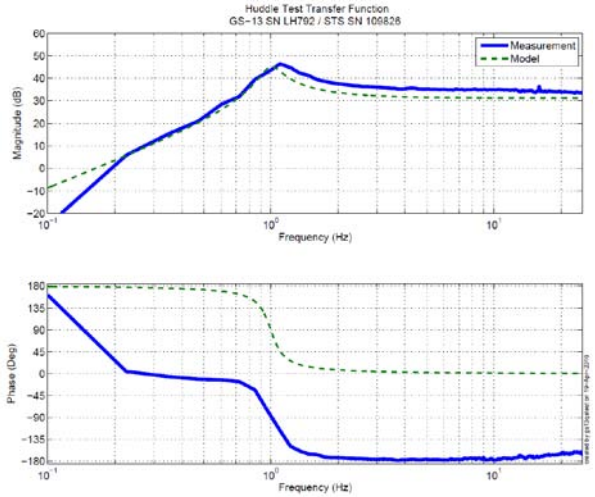


Figure - Huddle testing of Horiz GS-13 804,795, and 792 after aLIGO modifications

- ***Step 2.2 – Vertical GS-13s***

Huddle testing

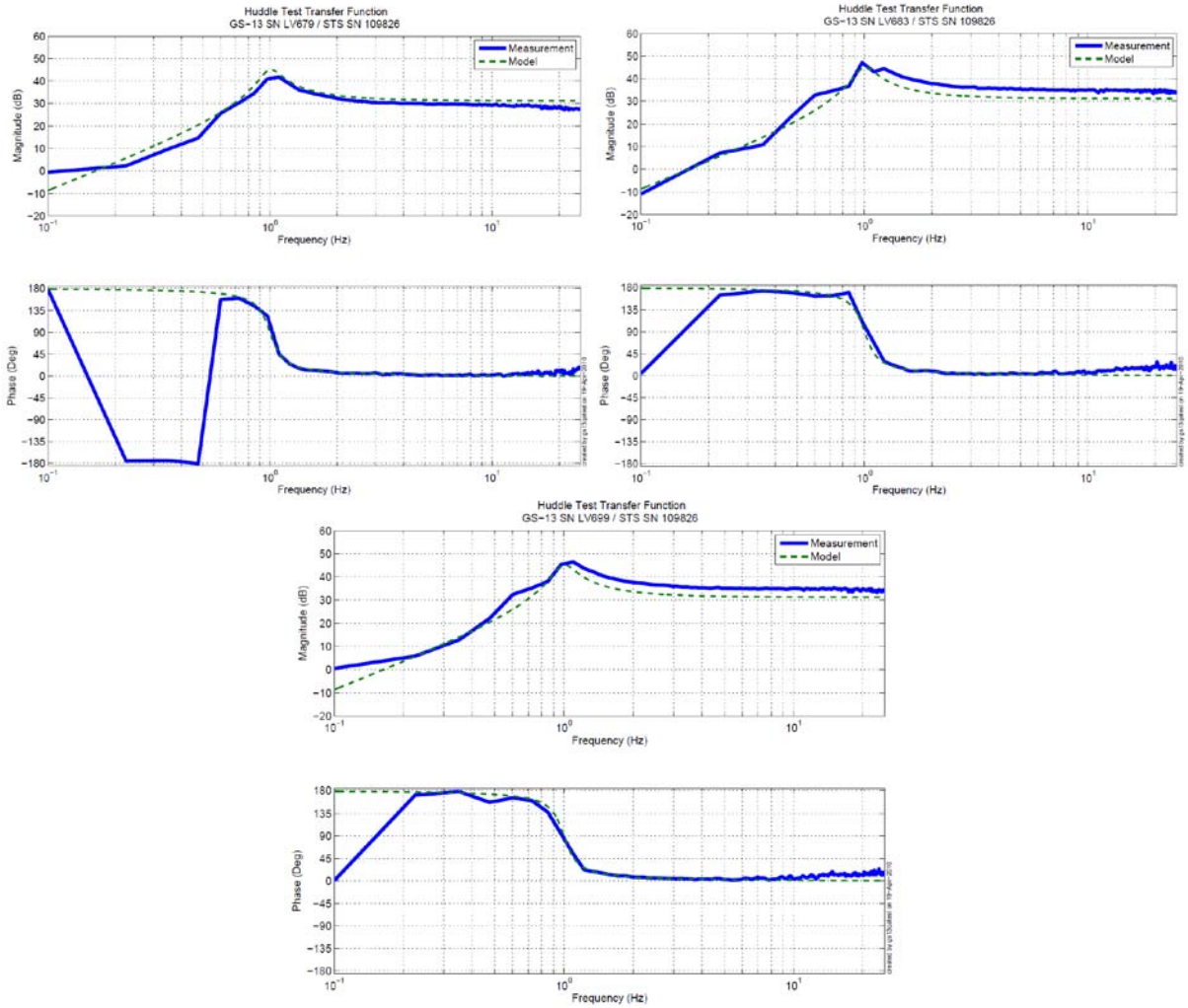


Figure - Huddle testing of Vert GS-13 679,683 and 699 after aLIGO modifications

Driven testing

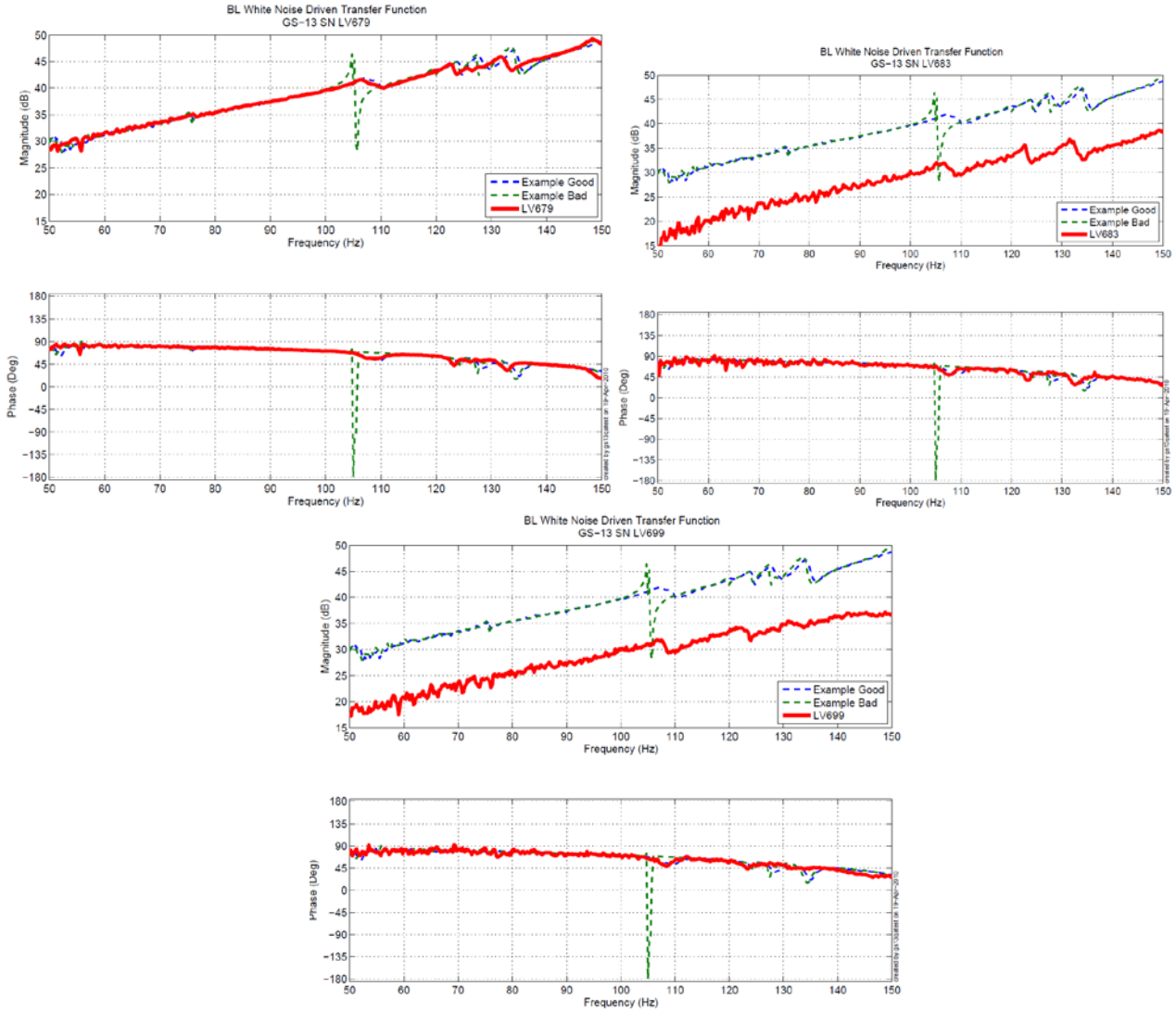


Figure - Driven Transfer Function of Vert GS-13 679,683 and 699 after aLIGO modifications

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 #: L087 Operator Name: Gordon, Matt Date: 11/22/2009 Time: 11:48 AM Actuator Coil Resistance: 6.28 Ohms, PASS Ambient Temperature: 71.1 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.526 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.508	Actuator Serial #: L088 Operator Name: Gordon, Matt Date: 11/21/2009 Time: 4:48 PM Actuator Coil Resistance: 6.31 Ohms, PASS Ambient Temperature: 70.0 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.530 Y Travel Limit (inches): 0.206 Z Travel Limit (inches): 0.506
Actuator Serial #: L096 Operator Name: Gordon, Matt Date: 11/23/2009 Time: 3:50 PM Actuator Coil Resistance: 6.26 Ohms, PASS Ambient Temperature: 71.1 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.530 Y Travel Limit (inches): 0.206 Z Travel Limit (inches): 0.509	Actuator Serial #: L134 Operator Name: Gordon, Matt Date: 4/12/2010 Time: 3:25 PM Actuator Coil Resistance: 6.34 Ohms, PASS Ambient Temperature: 73.3 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.536 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.506
Actuator Serial #: L137 Operator Name: Gordon, Matt Date: 4/12/2010 Time: 4:19 PM Actuator Coil Resistance: 6.42 Ohms, PASS Ambient Temperature: 73.3 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.530 Y Travel Limit (inches): 0.206 Z Travel Limit (inches): 0.501	Actuator Serial #: L145 Operator Name: Gordon, Matt Date: 4/13/2010 Time: 11:44 AM Actuator Coil Resistance: 6.45 Ohms, PASS Ambient Temperature: 73.1 F Hi Pot Test Results: 1000 MOhms, PASS X Travel Limit (inches): 0.526 Y Travel Limit (inches): 0.205 Z Travel Limit (inches): 0.506

Acceptance Criteria:

- Actuators were previously tested and results are reported in T900564.

The tests report must contain:

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

II. Tests to be performed during assembly

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

aLIGO HAM-ISI Serial Number Registration					
Assembly Site	LLO	Assembly S/N	003	Destination	L1-H3
DCC/Vendor number	**Part name**	**Configuration**	**S/N**	**S/N**	**S/N**
D071001	Stage 0 base		6		
D071051	Stage 1 base		5		
D071050	Optical table		6		
D071002	Spring Post		42	28	34
D071100	Spring		42	15	14
D071102	Flexure		14	26	15
ADE	Position sensor	Horizontal	12057	12013	12056
		Vertical	12026	12059	12083
D047812	GS-13 pod	Horizontal	66/46	26	92
		Vertical	56	2	60
D047823	L4C pod	Horizontal	N/A	N/A	N/A
		Vertical	N/A	N/A	N/A
D0902749	Actuator	Horizontal	145	088	134
		Vertical	096	137	087

- ***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	.495	.491	+4
2	.501	.489	+12
3	.498	.490	+8

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	80	90
V2	90	75
V3	95/85	65/80
H1	85	
H2	80	
H3	80	

Acceptance Criteria

- Gaps must be within 0.010" of design (i.e. 0.090" and .070" pass, but 0.095" and 0.065" doesn't).

Test result: **Passed: ___** **Failed: __X__**

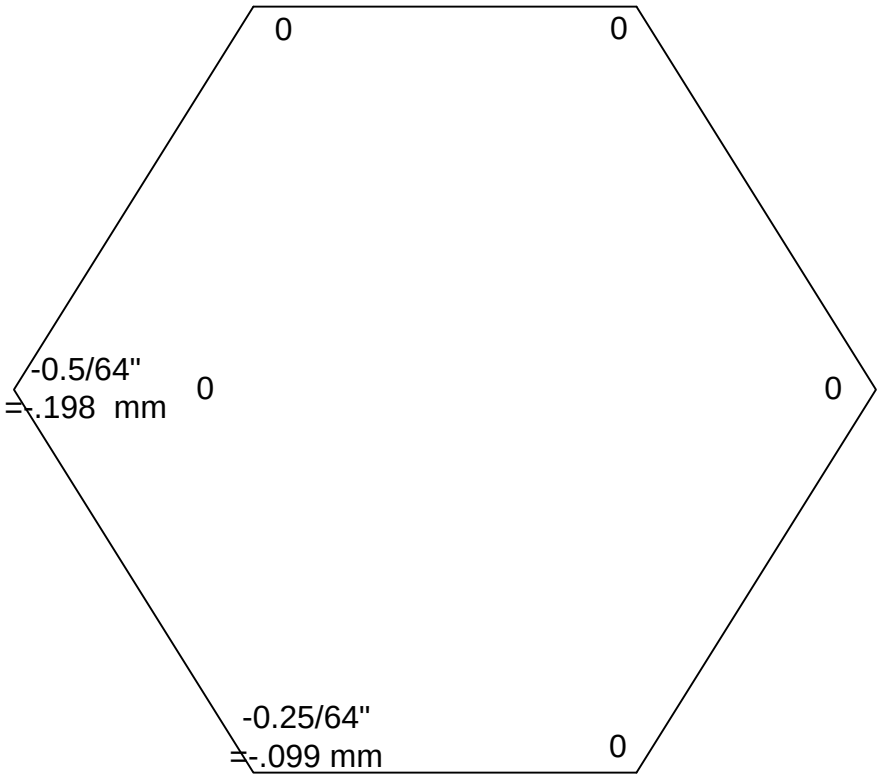
- ***Step 7: Check level of Stage 0***

Not recorded.

Test result: **Passed: ___** **Failed: __X__**

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

Optical Level measurement of Stage 1 at large (12 - 15) number of points.



Max angle=(.5/64)/85.59= 91 urad

Acceptance Criteria

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

Test result: Passed: _X_ Failed: ___

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

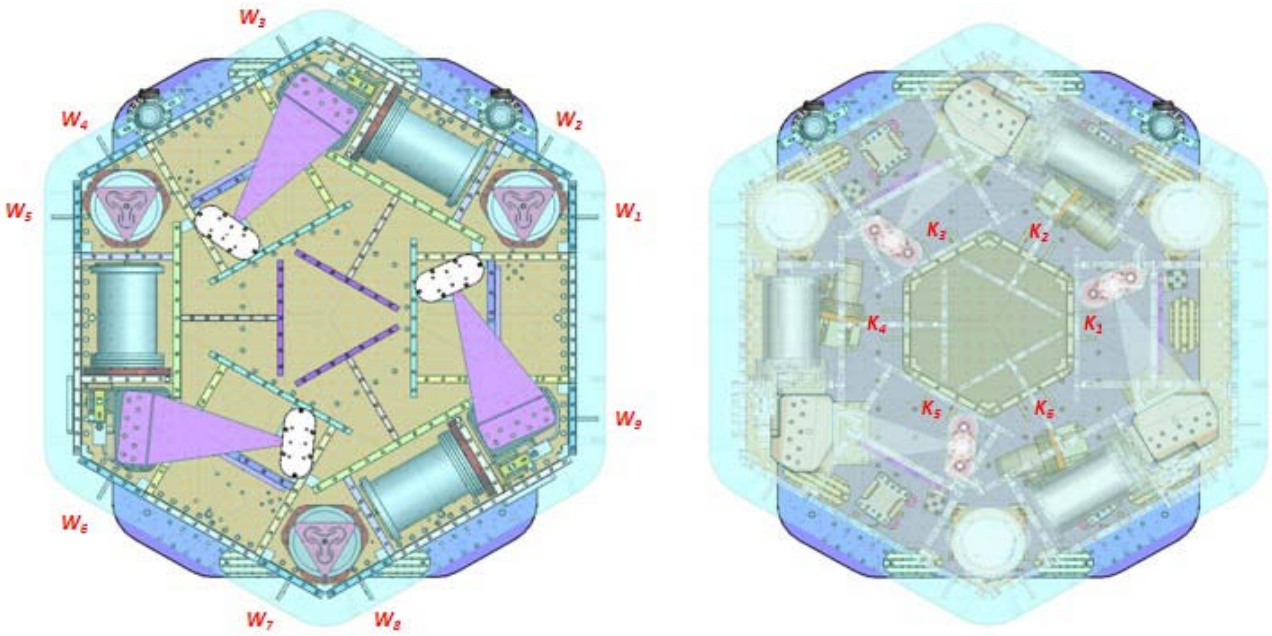


Figure – Keel Masses and Wall masses location

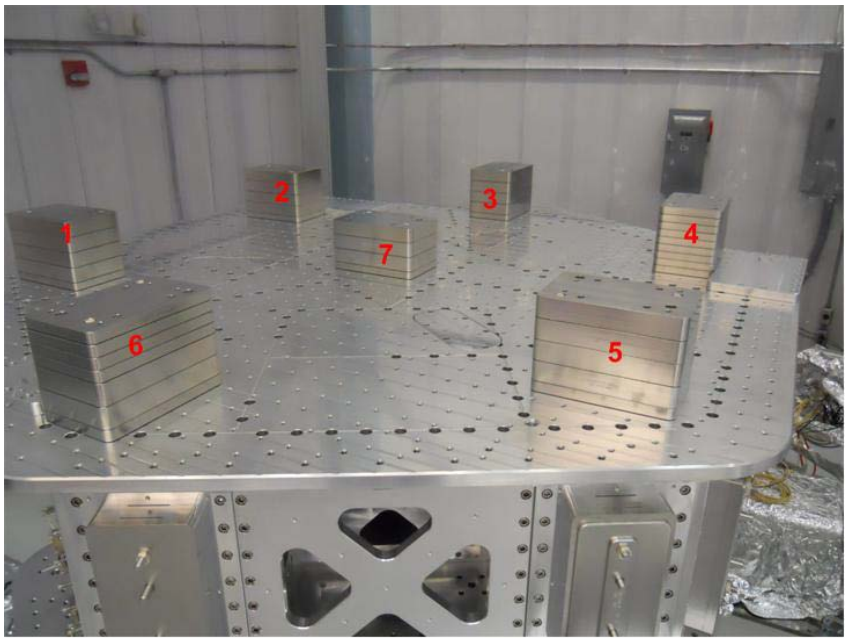


Figure - Optical table masses distribution

	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	42.8	19.41
w1	1					1	1	43.4	19.69
w2						1	1	42.8	19.41
w3						1	1	42.8	19.41
w4		1		1		1	1	48.4	21.95
w5		1				1	1	43.9	19.91
w6	2					1	1	44	19.96
w7						1	1	42.8	19.41
w8						1	1	42.8	19.41
Side Masses Total	3	2	0	1	0	9	9	393.7	178.58

Table – Wall masses distribution

	00	01	02	03	04	05	06		
	0.6	1.1	2.2	4.5	7.9	15.6	27.2	lbs	kgs
k1					1		1	35.1	15.92
k2	1	1	1				1	31.1	14.11
k3					1		1	35.1	15.92
k4	1	1	1				1	31.1	14.11
k5					1		1	35.1	15.92
k6	1	1	1				1	31.1	14.11
	3	3	3	0	3	0	6	198.6	90.08

	Side	Keel	Top	Total
Weigh (kg)	178.58	90.08	305.00	573.66
Torque x at O (N.m)	-13.85	0.00	-8.72	-22.57
Torque y at O (N.m)	-24.30	5.26	11.21	-7.83

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	125
B	125
C	125
D	125

Table – Shims Thickness

Acceptance Criteria

- Inventory is complete

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

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

D.I at Lockers	Dial indicators V	Dial indicators H
A	0.5	-1
B	2	0
C	.25	0
D	-1.5	-1.5

Table – Dial indicators read-out (in thousands of an inch)

Issues/difficulties encountered during this test : N/A

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***

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	
Table locked	**ADE boxes on**		**ADE boxes on**	
Sensors	**Offset (Mean)**	**Std deviation**	**Offset (Mean)**	**Std deviation**
H1	-36.967	1.2	-109.44	1.5
H2	254.8	1.1	243.71	0.8
H3	-23.343	0.7	-91.761	1.1
V1	-264.62	0.6	-52.461	1.6
V2	-148.73	1.8	24.719	1.5
V3	196.35	1.4	296.66	1.2

Table – Capacitive position sensor readout after gap set-up

Issues/difficulties/comments regarding this test: HAM-ISI – LLO unit#3 uses synchronized satellite boxes

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" +/-0.002"

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	-274.44	0.83234	664.2	938.64
H2	-43.197	0.75333	-327.25	-284.053
H3	159.76	0.74358	-561.14	-720.9
V1	-296.64	1.0669	583.93	880.57
V2	245.48	1.4453	495.1	249.62
`V3	-362.15	1.627	-1144.2	-782.05

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	20269	-20331	24.0	-24.1
V2	20234	-20363	23.9	-24.1
V3	19885	-19746	23.5	-23.4
	CPS read out		**Calculated after calibration**	
Sensors	**CW(-RZ)**	**CCW (+RZ)**	**CW (mil)**	**CCW (mil)**
H1	18281	-22331	21.6	-26.4
H2	24413	-19937	28.9	-23.6
H3	18099	-22126	21.4	-26.2

Table - Optic table range of motion

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

	Push in positive direction	Push in negative direction	Railing	Actuator Gap Check
H1	20691	-26431		**X**
H2	24701	-24100		**X**
H3	25028	-22929		**X**
V1	19785	-20422		**X**
V2	31629	-32519		**X**
V3	19762	-21787		**X**

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_3/ Powerspectra/Undamped
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_CPS_GS13_Unlocked_Locked_2011-03-25.mat
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_GS13_Table_Tilted_2011-03-29.mat

Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Powerspectra/Undamped
- 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_3/ Powerspectra/Undamped
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_CPS_GS13_Unlocked_Locked_2011-03-25.mat
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_GS13_Table_Tilted_2011-03-29.mat

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

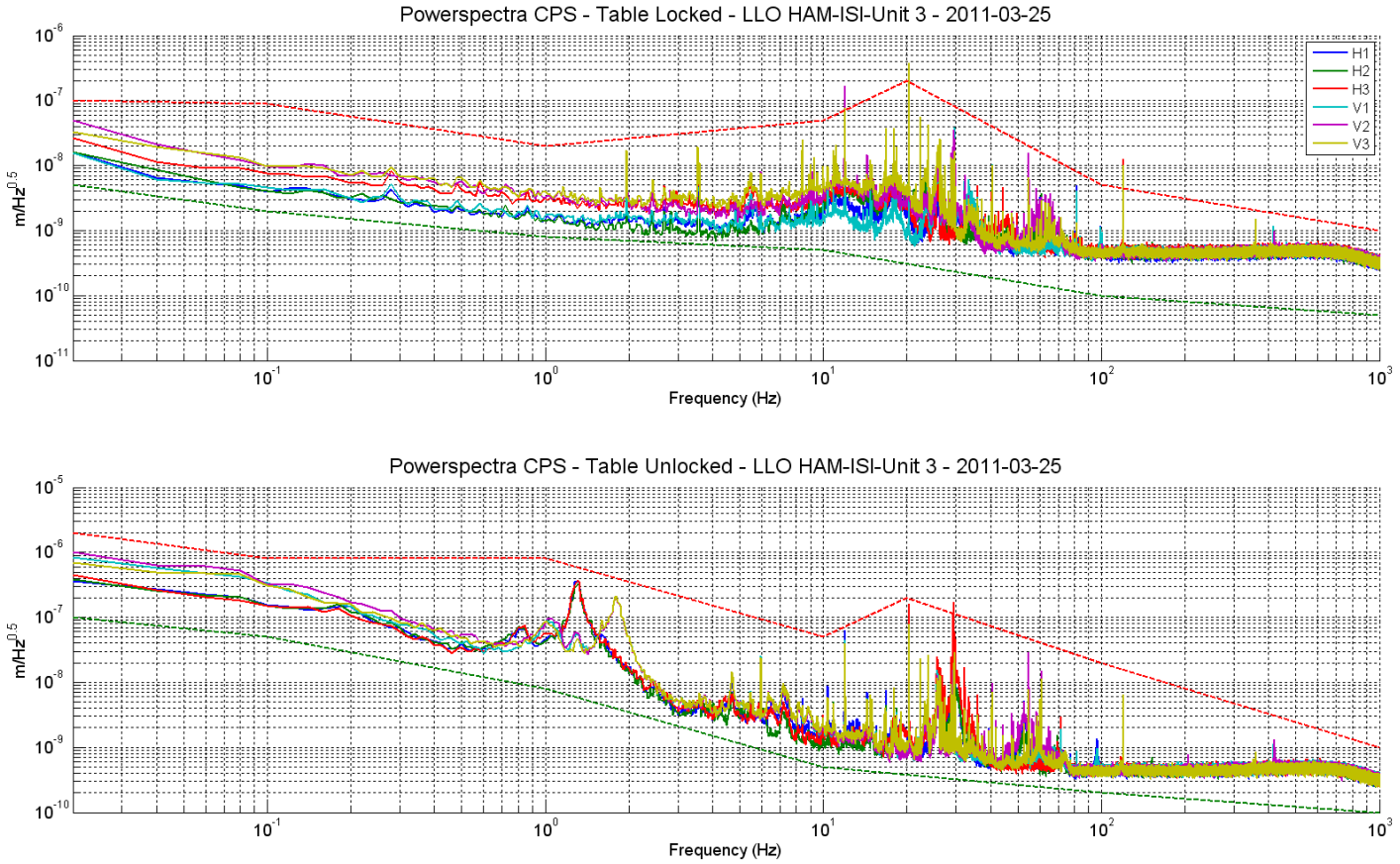


Figure - Calibrated CPS power spectrum

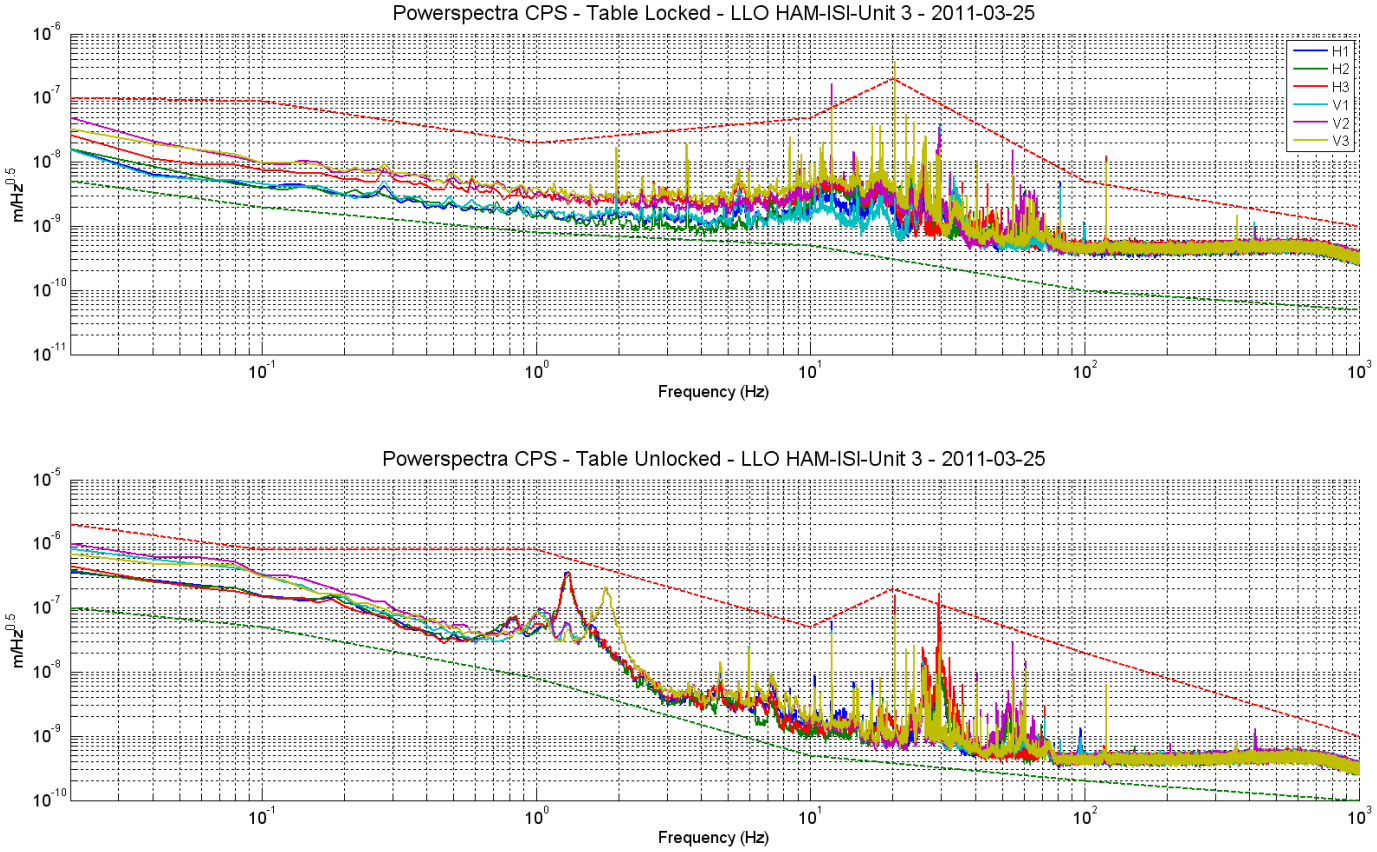


Figure – Power spectrum Calibrated GS13

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 power spectra 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.

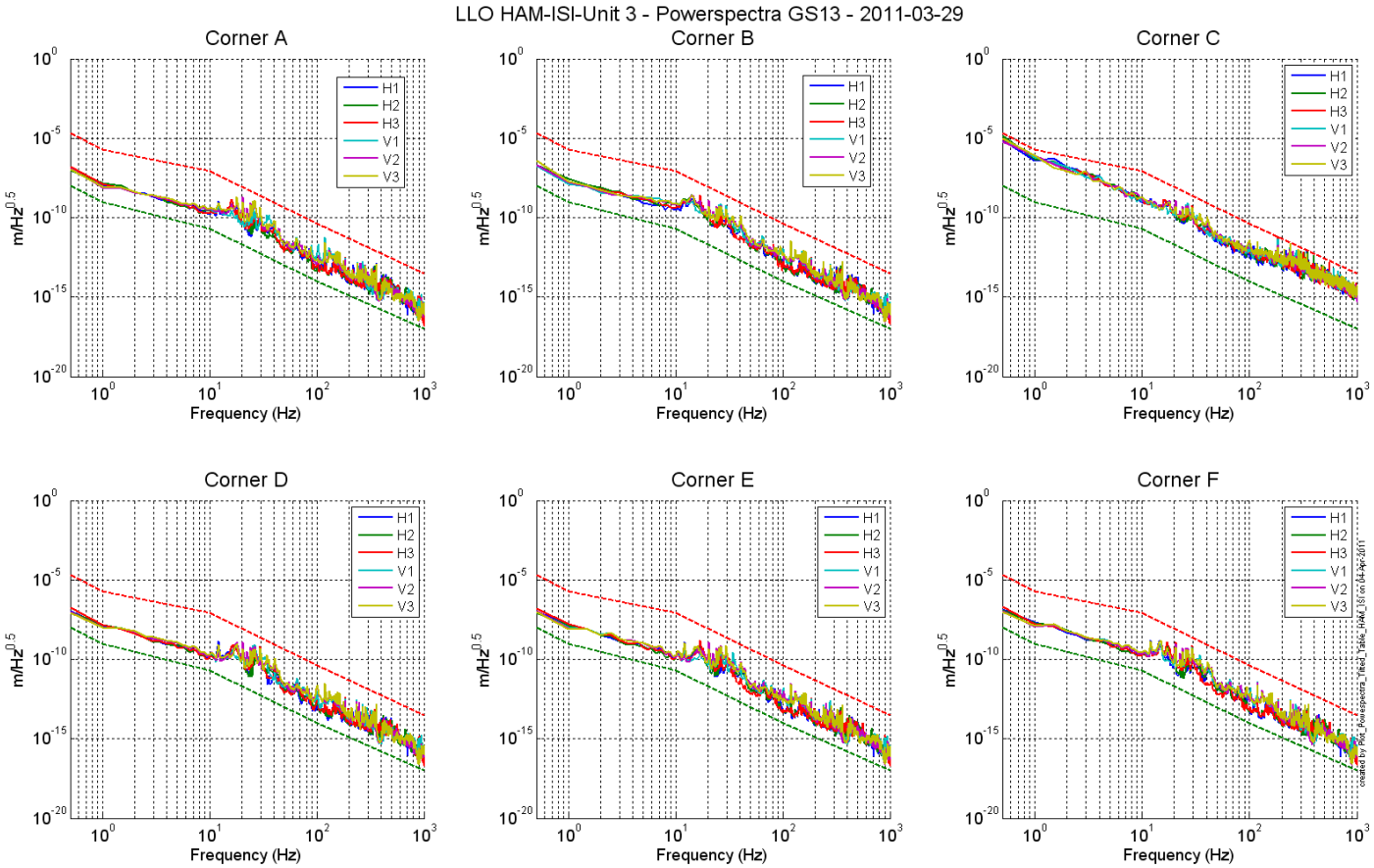


Figure – Power spectrum Calibrated GS13 with mass at corner

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/ Powerspectra/Undamped
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_CPS_GS13_Unlocked_Locked_2011-03-25.mat
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_GS13_Table_Tilted_2011-03-29.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/
- Powerspectra_Measurements_Tilted_HAM_ISI.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Figures/ Powerspectra/Undamped
- LLO_HAM_Unit_3_Calibrated_PSD_GS13_Unlocked_Locked_2011-03-25.pdf
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_GS13_Table_Tilted_2011-03-29.pdf

Acceptance criteria:
- With table unlocked and tilted, magnitudes of power spectra must be fully included within:

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 power spectra requirements

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

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

Scripts files for taking and processing the data, and plotting it in SVN at:
seismicSVN/Common/MatlabTools

- gs13Presstest.m

Figures in SVN at:

- seismicSVN/Common/Data/Pressure_Plots

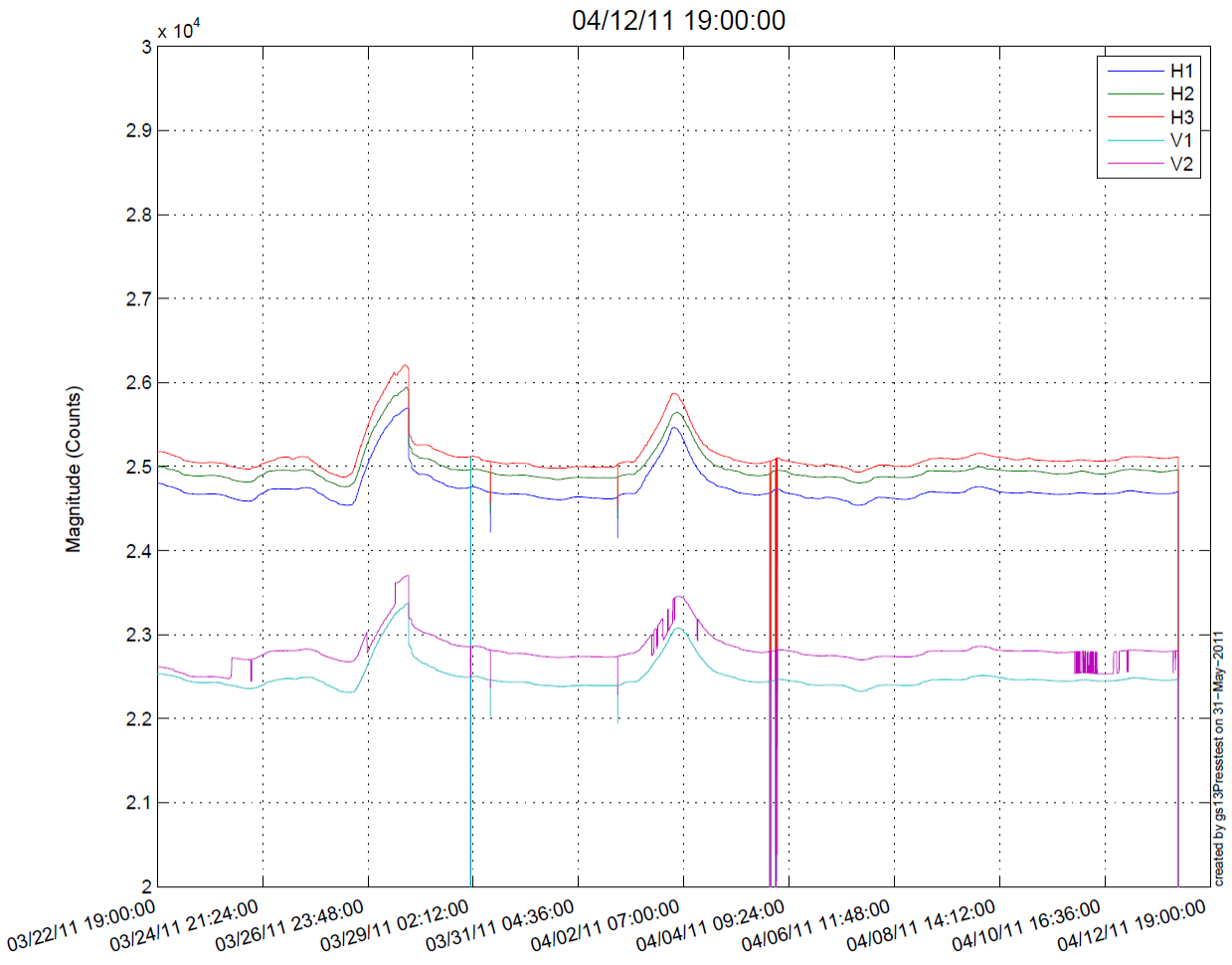


Figure – Pressure Plots

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.
We could not measure V3, due to an issue with the read-out electronics.

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
	6.3	O.L (infinity)	6.5	O.L (infinity)	6.4	O.L (infinity)
MEDM offset (1000 counts)	Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)	
	0.3		0.303		0.3	

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
	6.4	O.L (infinity)	6.4	O.L (infinity)	6.3	O.L (infinity)
MEDM offset (1000 counts)	Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)	
	0.303		0.296		0.298	

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

The tests report must contain:

1- **The table "Actuators resistance check"**
2- **Issues/difficulties/comments regarding this test**
3- **Test result (Passed: ___ Failed: ___)**

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

	Negative drive	Positive drive
H1 readout (count)	-24840	23704
H2 readout (count)	-23504	24473
H3 readout (count)	-25079	24232
V1 readout (count)	-19988	19535
V2 readout (count)	-25296	27191
V3 readout (count)	-22424	21599

Table - Range of motion - Local drive

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Static_Tests
- LLO_HAM-ISI_Unit_3_Range_Of_Motion_20110329.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	19	0	-19	
B	19.25	0	-19	
C	18.5	0	-19	
D	19	0	-19	
Average	18.9375	0	-19	**-37.9**
Sensors	**Counts**	**Counts**	**Counts**	**Difference (Counts)**
V1	-15407	703	16730	-32137
V2	-15595	551	16437	-32032
V3	-17675	-1772	14357	-32032
			Average	**-32067**

Table - Calibration of capacitive position sensors

Vertical sensitivity: 32067/37.91 = 845.3 count/mil

or 845.3 count/mil * 1/1638 V/count = 0.516V/mil

or 25400nm/mil * 1/845.3 mil/count = 30.05 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

Difference with Nominal sensitivity = (845.3-840)/840=-0.63%

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	7370	2.23E-04	8.81E+04	**5.59 %**
V2	7538	2.28E-04	8.62E+04	3.32 %
V3	8553	2.58E-04	7.60E+04	**-8.91 %**
		Average (N/m)	8.34E+04	
		Total Stiffness (N/m)	2.50E+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 **1.32%**.

Test result: **Passed: __** **Failed: _X__**

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

		H1	H2	H3	V1	V2	V3
Actuators (1000 counts)	H1	1967.669	1210.834	1224.792	-3.392	12.744	-33.92
	H2	1207.9290	2017.293	1256.419	11.939	21.785	-21.05
	H3	1224.299	1259.544	2015.90	37.030	16.072	-30.849
	V1	201.7530	172.320	-313.735	1415.569	-43.636	-546.33
	V2	-276.287	261.940	230.952	-554.369	1437.609	-44.9600
	V3	159.632	-385.887	142.389	44.354	-612.036	1403.714

Table - Main and cross coupling

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Static_Tests
- LLO_HAM_ISI_Unit_3_Sensor_Readout_Local_20110331.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	2.077	127.6	2.0845	-0.37
H2	2.102	-763		0.83
H3	2.075	-711		-0.46
V1	1.498	-282	1.4872	0.74
V2	1.479	368.3		-0.53
V3	1.484	-1024		-0.20

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

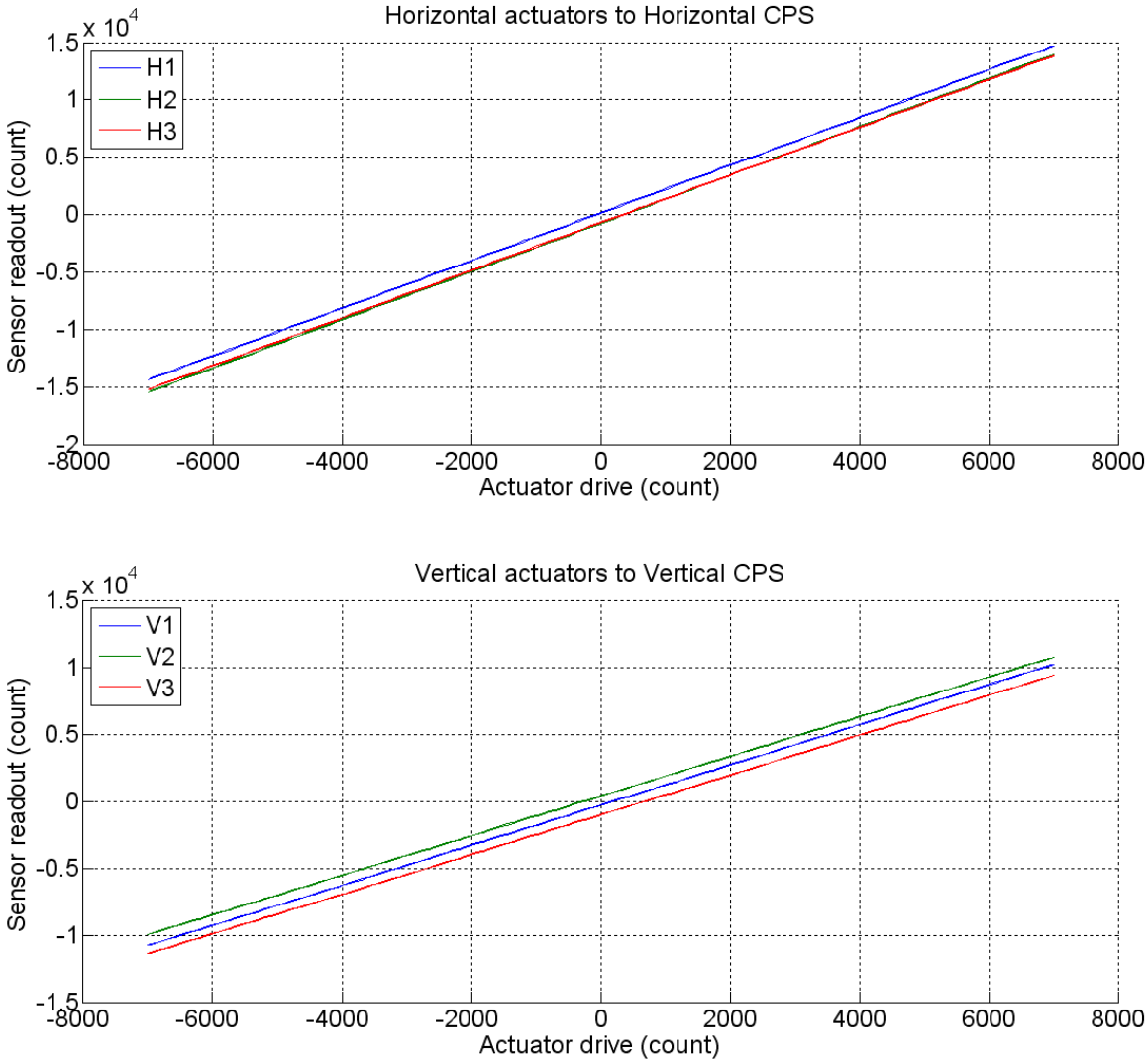


Figure - Horizontal and vertical actuators x HAM-ISI x sensors

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Linearity_test
- LLO_HAM_ISI_Unit_3_Linearity_test_20110407.mat

Figures in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Figures/Linearity_test
- LLO_HAM_ISI_Unit_3_Linearity_test_20110407.fig
- LLO_HAM_ISI_Unit_3_Linearity_test_20110407.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_3/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_3_Data_TF_L2L_50mHz_500mHz_20110406-181629.mat
- LLO_HAM_ISI_Unit_3_Data_TF_L2L_500mHz_5Hz_20110406-151108.mat
- LLO_HAM_ISI_Unit_3_Data_TF_L2L_200Hz_800Hz_20110406-120426.mat
- LLO_HAM_ISI_Unit_3_Data_TF_L2L_5Hz_200Hz_20110406-133747.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_3/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_3_TF_L2L_2011_04_06.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAMISI/X2/Data/Unit_3/Figures/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_3_TF_L2L_H_CPS_50mHz_800Hz_2011_04_06.fig
- LLO_HAM_ISI_Unit_3_TF_L2L_V_CPS_50mHz_800Hz_2011_04_06.fig
- LLO_HAM_ISI_Unit_3_TF_L2L_H_GS13_50mHz_800Hz_2011_04_06.fig
- LLO_HAM_ISI_Unit_3_TF_L2L_V_GS13_50mHz_800Hz_2011_04_06.fig

Storage of measured transfer functions in the SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_functions/ Measurements/Undamped/

- LLO_HAM_ISI_Unit_3_Data_TF_L2L_2011_04_06.mat

The local to local transfer functions are presented below.

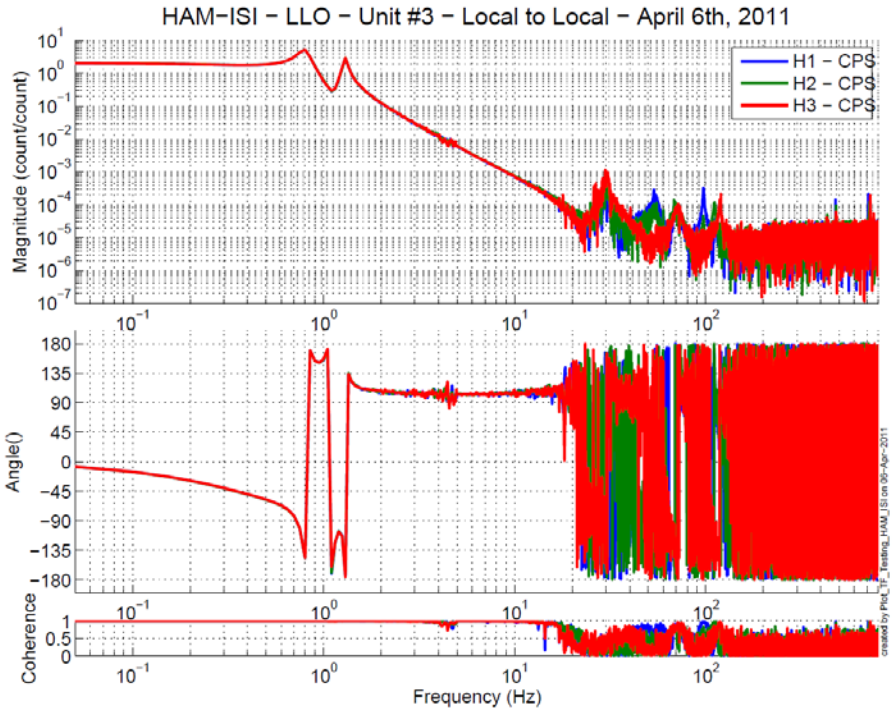


Figure - Local to Local Measurements – Horizontal capacitive sensors

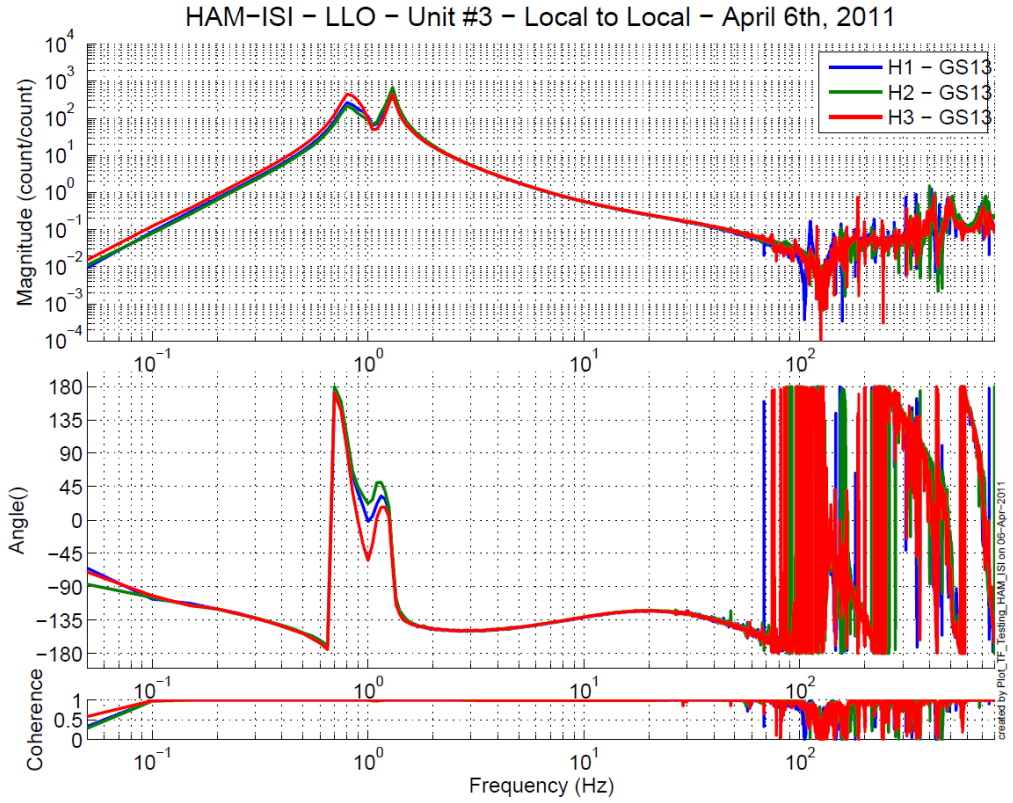


Figure - Local to Local Measurements – Horizontal inertial sensors

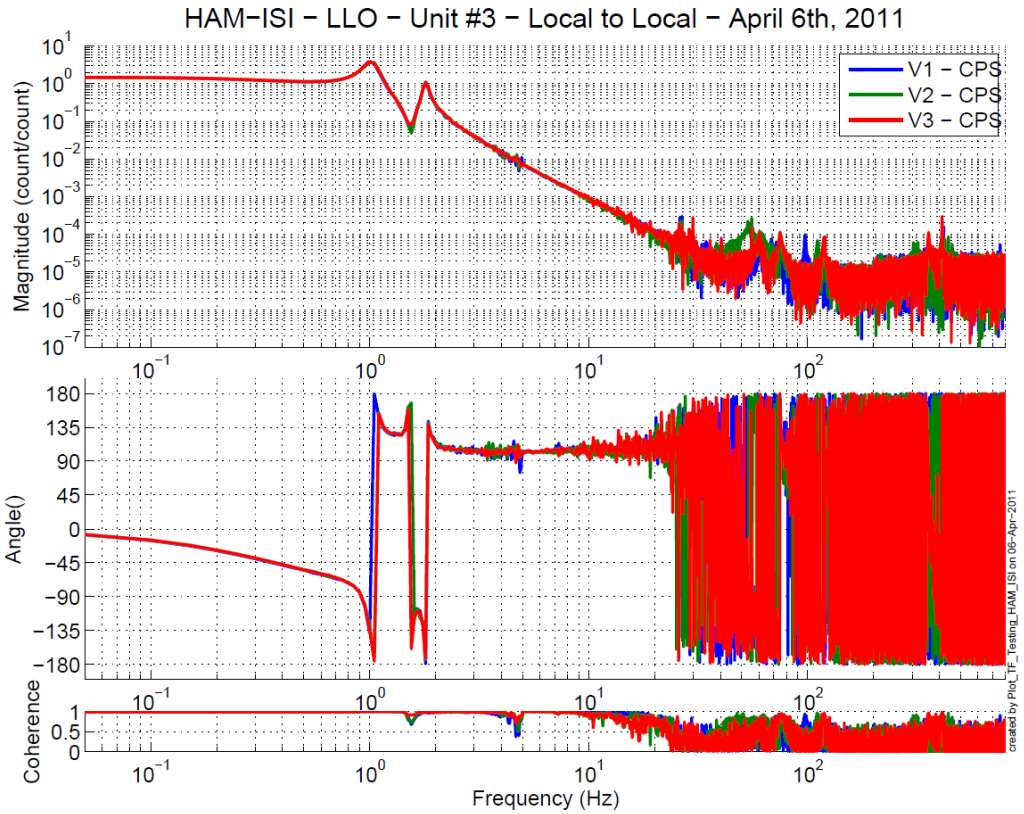


Figure - Local to Local Measurements – Vertical capacitive sensors

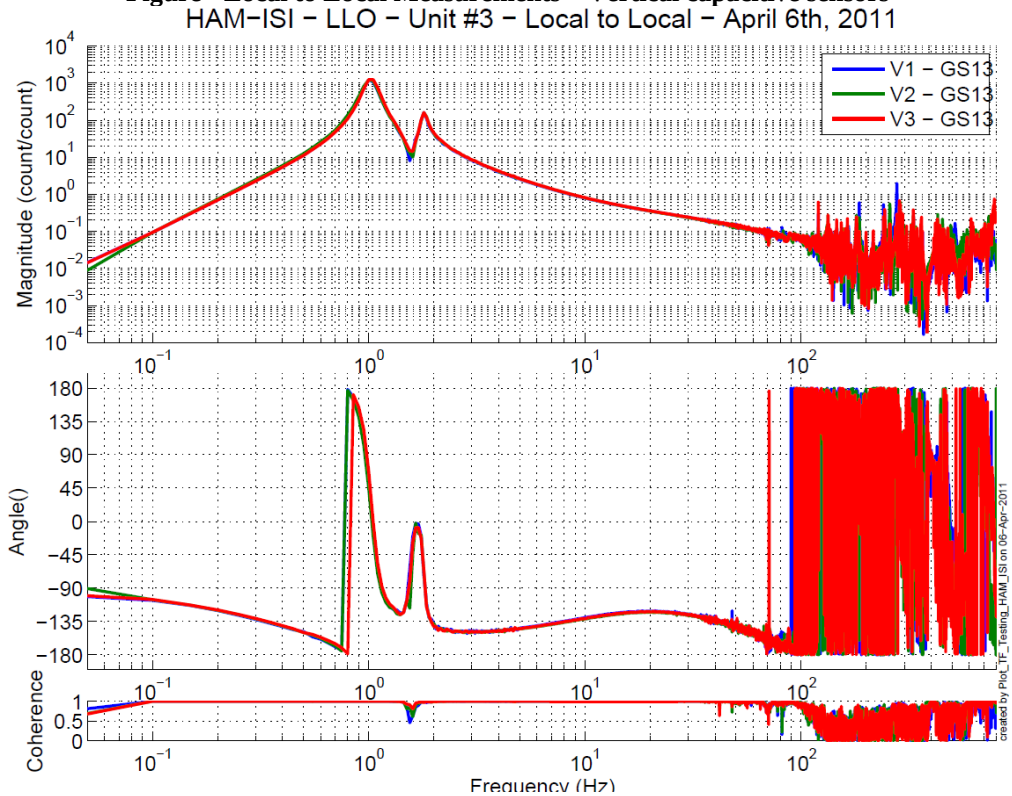


Figure - Local to Local Measurements – Vertical inertial sensors

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_3/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_3_Data_TF_C2C_50mHz_500mHz_20110405-215335.mat
- LLO_HAM_ISI_Unit_3_Data_TF_C2C_500mHz_5Hz_20110405-184814.mat
- LLO_HAM_ISI_Unit_3_Data_TF_C2C_5Hz_200Hz_20110405-171453.mat
- LLO_HAM_ISI_Unit_3_Data_TF_C2C_200Hz_800Hz_20110405-154132.mat

Scripts files for processing and plotting in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_3_TF_C2C_2011_04_06.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Figures/Transfer_Functions/Measurements/Undamped/

- LLO_HAM_ISI_Unit_3_TF_C2C_X_Y_RZ_CPS_50mHz_800Hz_2011_04_05.fig
- LLO_HAM_ISI_Unit_3_TF_C2C_X_Y_RZ_GS13_50mHz_800Hz_2011_04_05.fig
- LLO_HAM_ISI_Unit_3_TF_C2C_Z_RX_RY_CPS_50mHz_800Hz_2011_04_05.fig
- LLO_HAM_ISI_Unit_3_TF_C2C_Z_RX_RY_GS13_50mHz_800Hz_2011_04_05.fig

Storage of measured transfer functions in the SVN at:
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_functions/Cartesian_to_Cartesian

- LLO_HAM_ISI_Unit_3_Data_TF_C2C_2011_04_05

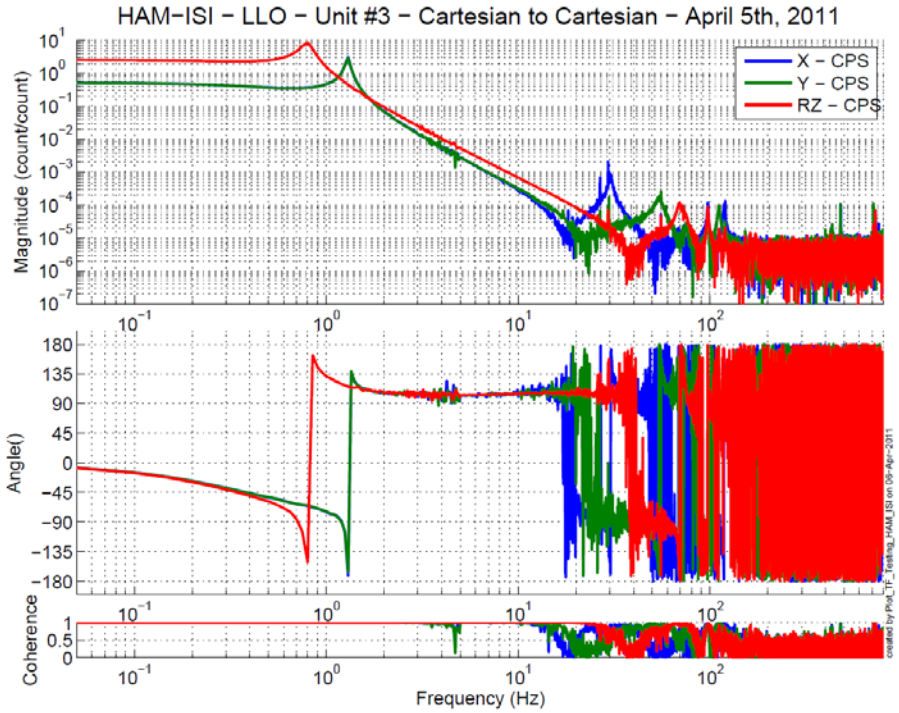


Figure - Cartesian to Cartesian CPS measurements – X, Y, RZ directions

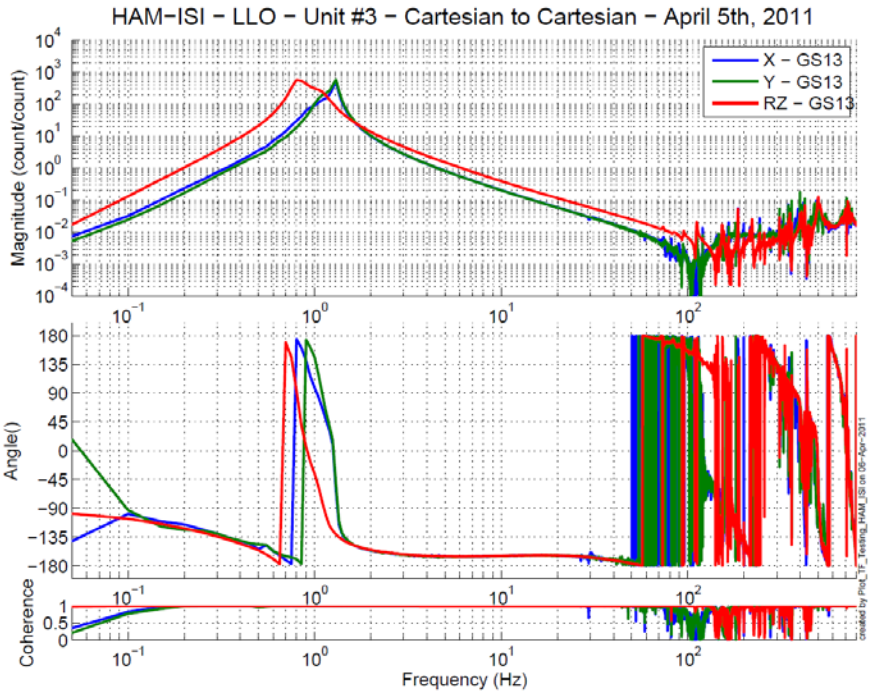
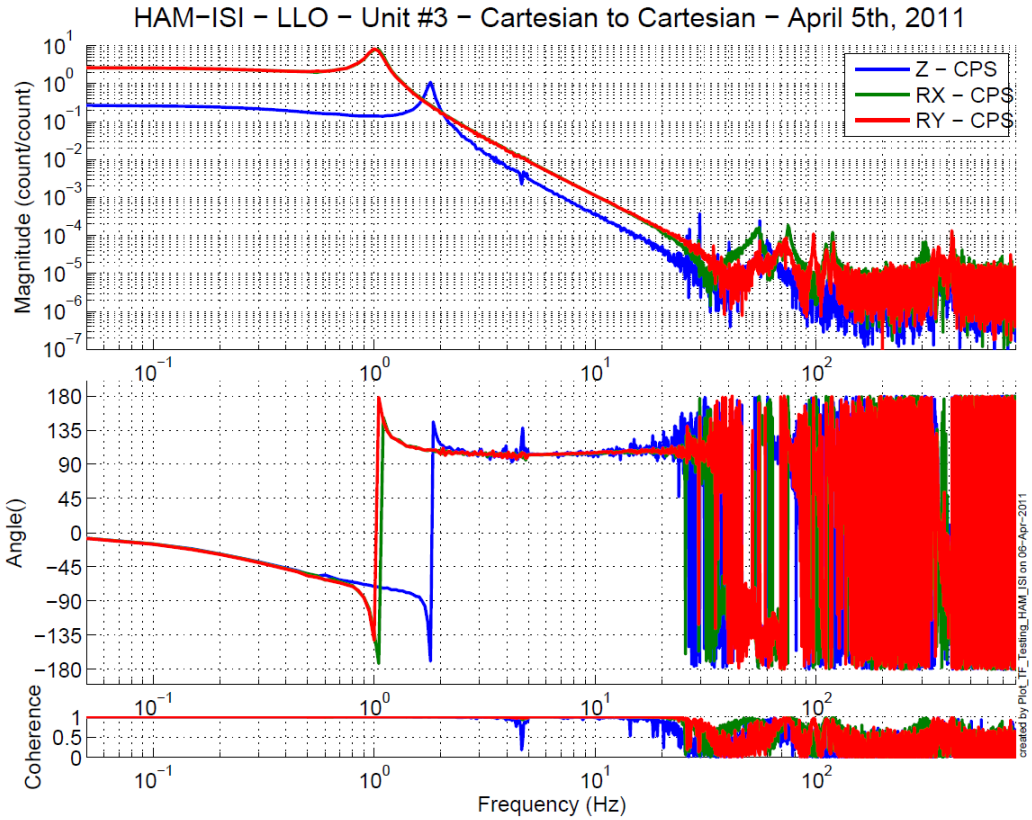


Figure - Cartesian to Cartesian GS-13 measurements – X, Y, RZ directions



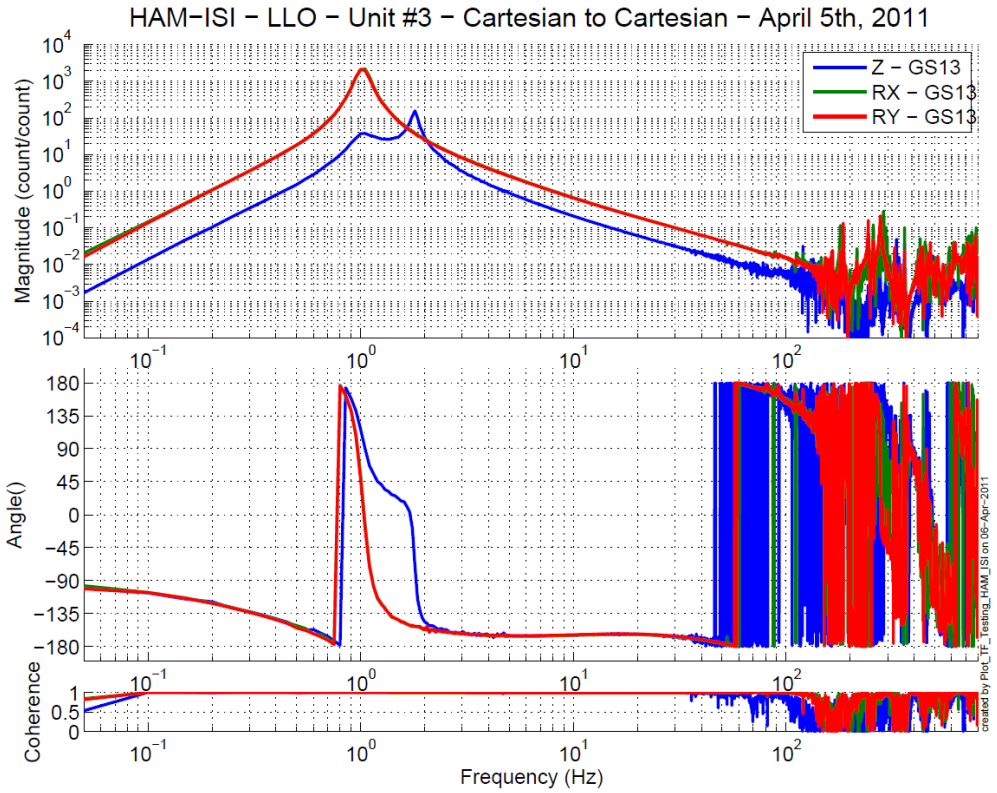


Figure - Cartesian to Cartesian measurements – Z, RX, RY directions

Issues/difficulties/comments regarding this test:

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***

This is the 1st unit compared to LHO Unit #2 instead of LLO HAM 6 (v4 was comparing to LLO HAM 6 and both data can be found on the SVN).

Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_3_TF_L2L_2011_04_06.m

Local to local figures in SVN at:
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Figures/Transfer_Functions/Measurements/

- LLO_HAM_ISI_Unit_3_TF_L2L_H_CPS_50mHz_800Hz_wRef_2011_04_06.fig
- LLO_HAM_ISI_Unit_3_TF_L2L_V_CPS_50mHz_800Hz_wRef_2011_04_06.fig
- LLO_HAM_ISI_Unit_3_TF_L2L_H_GS13_50mHz_800Hz_wRef_2011_04_06.fig
- LLO_HAM_ISI_Unit_3_TF_L2L_V_GS13_50mHz_800Hz_wRef_2011_04_06.fig

GS13, Local to local measurement

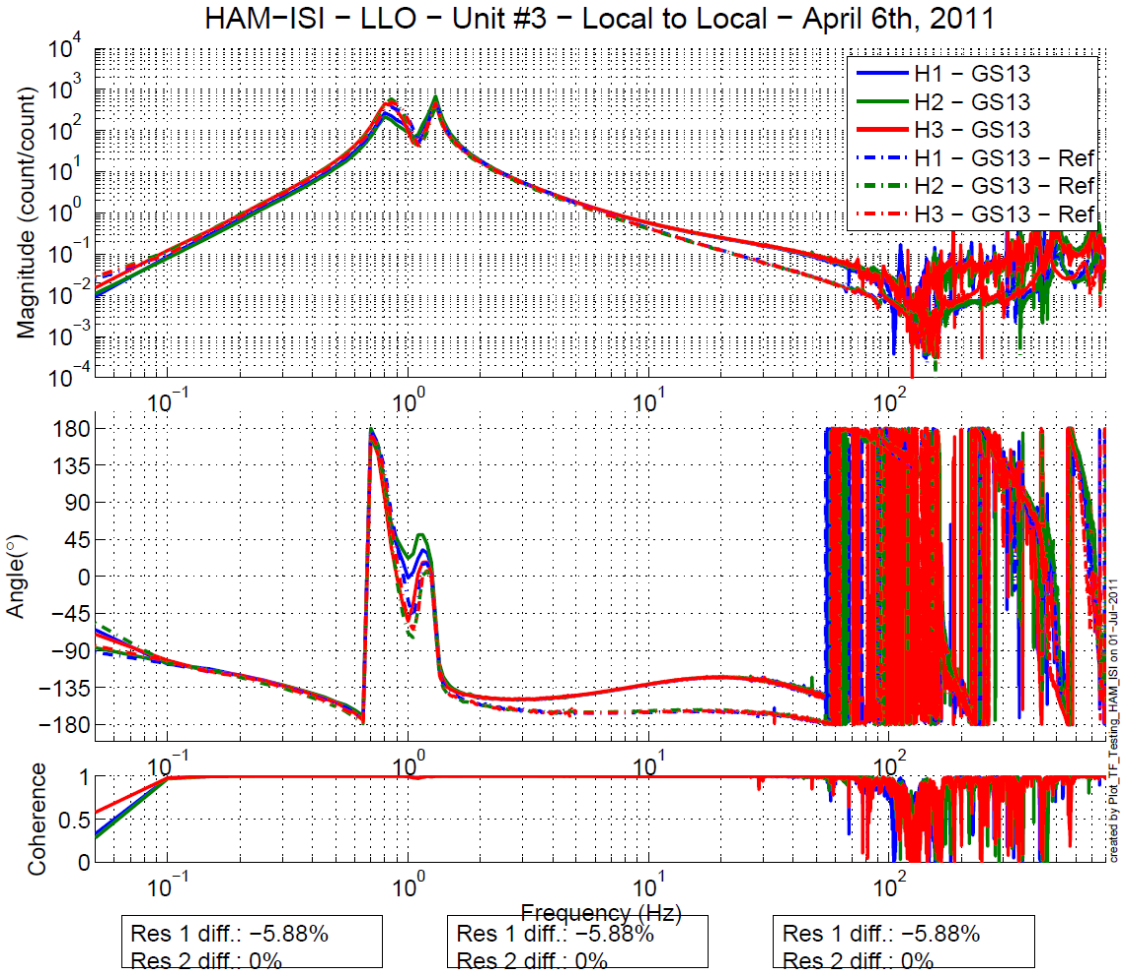


Figure - Local to local measurements comparison with LHO UNIT 2 – Horizontal GS-13

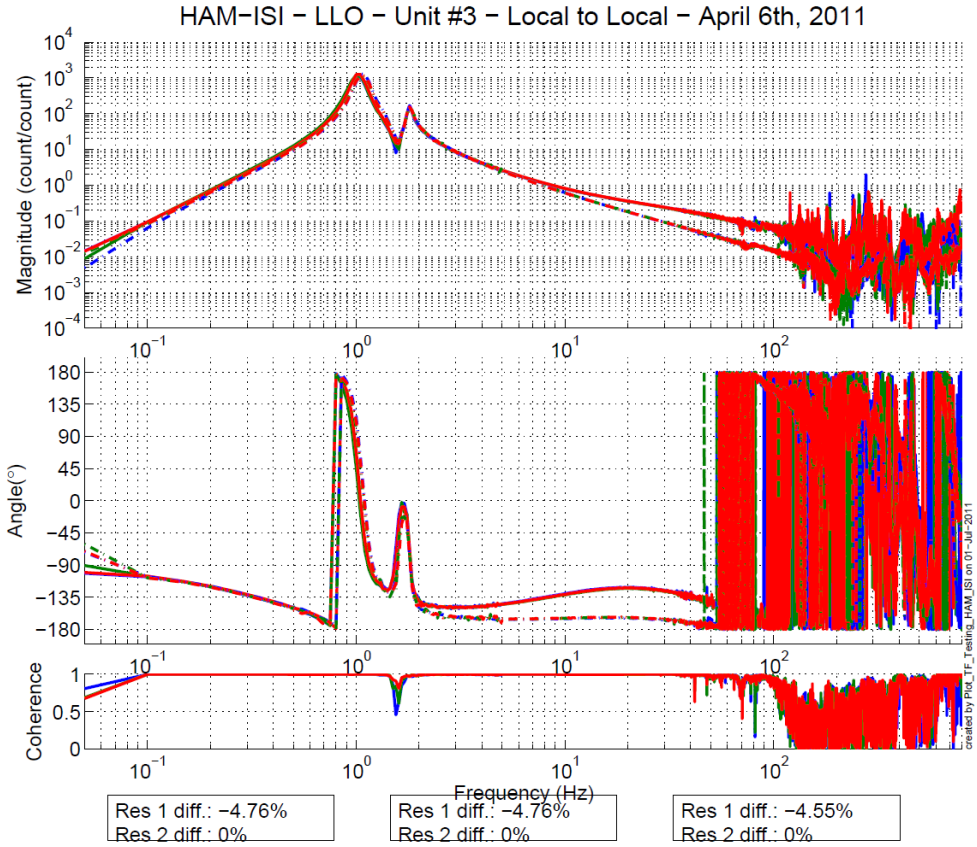


Figure - Local to local measurements comparison with LHO UNIT 2 – Vertical GS13

CPS, Local to local measurement, Undamped

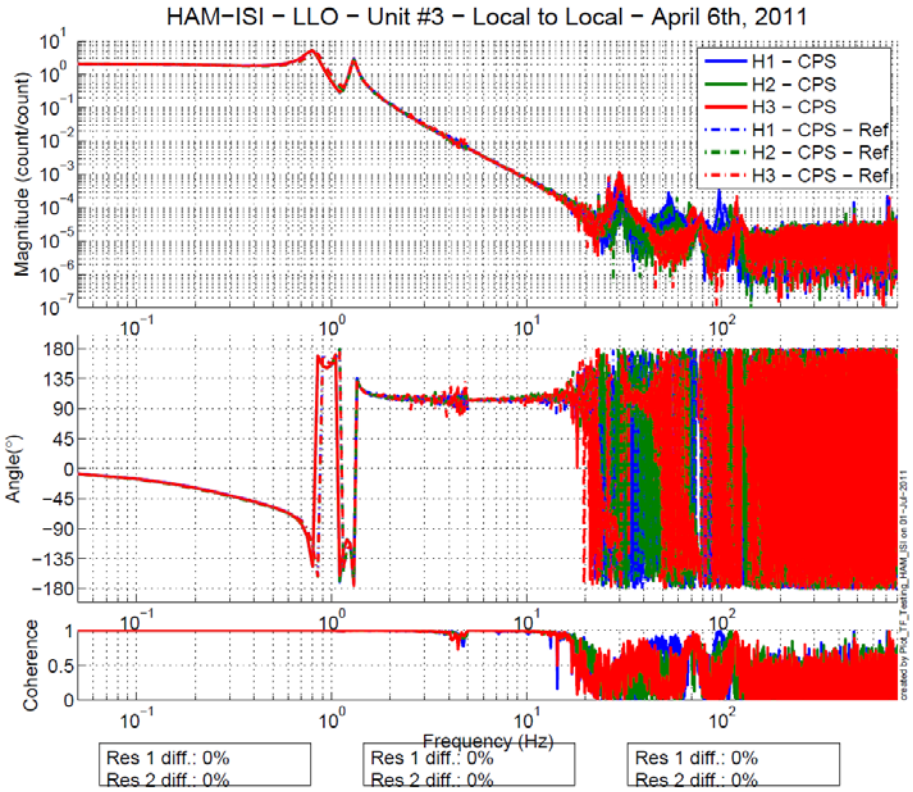


Figure - Local to local measurements comparison – Horizontal Position sensors

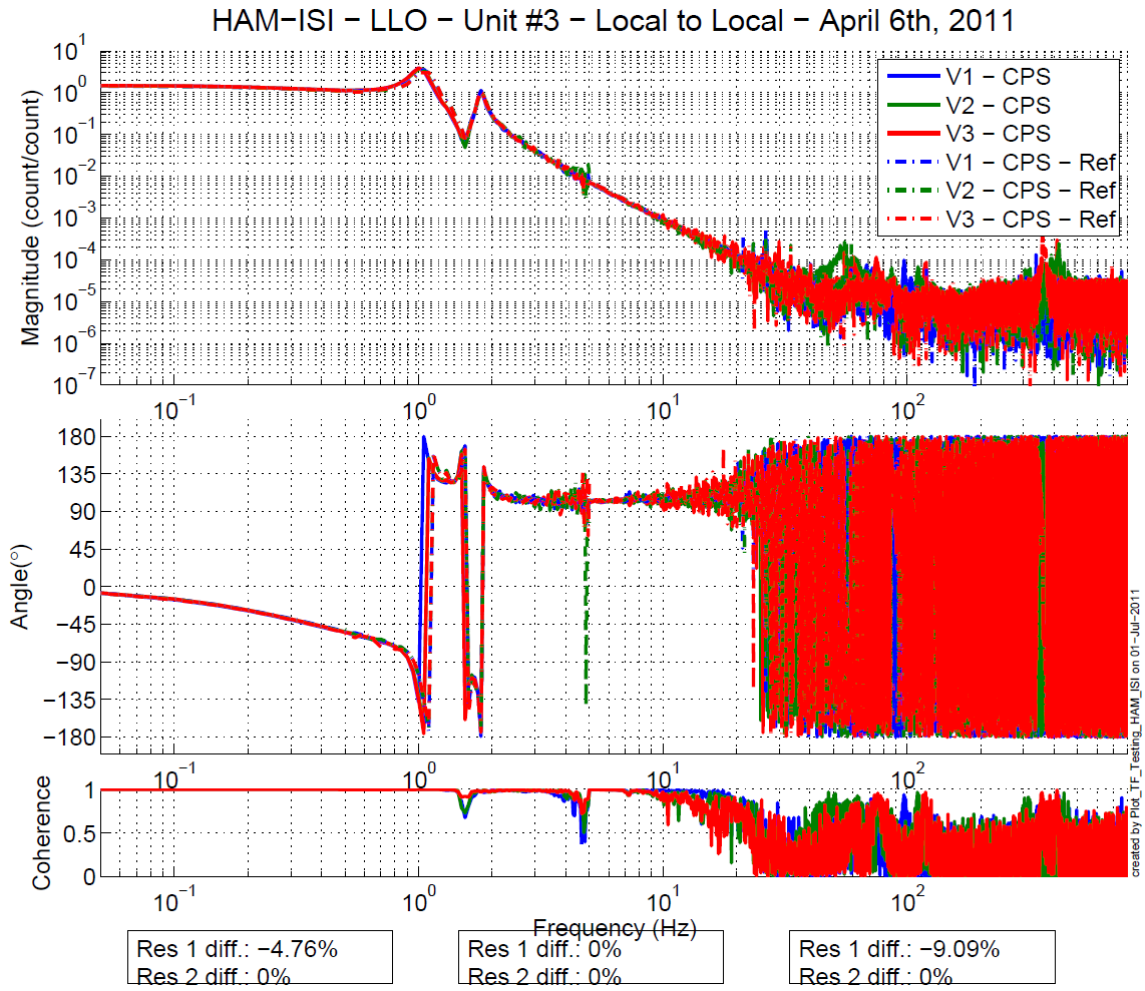


Figure - Local to local measurements comparison – Vertical Position sensors

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

Scripts files for processing and plotting in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Measurements/Undamped/

- Plot_LLO_HAM_ISI_Unit_3_TF_C2C_2011_04_06.m

Cartesian to Cartesian figures in SVN at :
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_functions/Cartesian_to_Cartesian

- LLO_HAM_ISI_Unit_3_TF_C2C_X_Y_RZ_CPS_50mHz_800Hz_wRef_2011_04_05.fig
- LLO_HAM_ISI_Unit_3_TF_C2C_Z_RX_RY_CPS_50mHz_800Hz_wRef_2011_04_05.fig
- LLO_HAM_ISI_Unit_3_TF_C2C_X_Y_RZ_GS13_50mHz_800Hz_wRef_2011_04_05.fig
- LLO_HAM_ISI_Unit_3_TF_C2C_Z_RX_RY_GS13_50mHz_800Hz_wRef_2011_04_05.fig

GS13, Cartesian to Cartesian measurement, Undamped

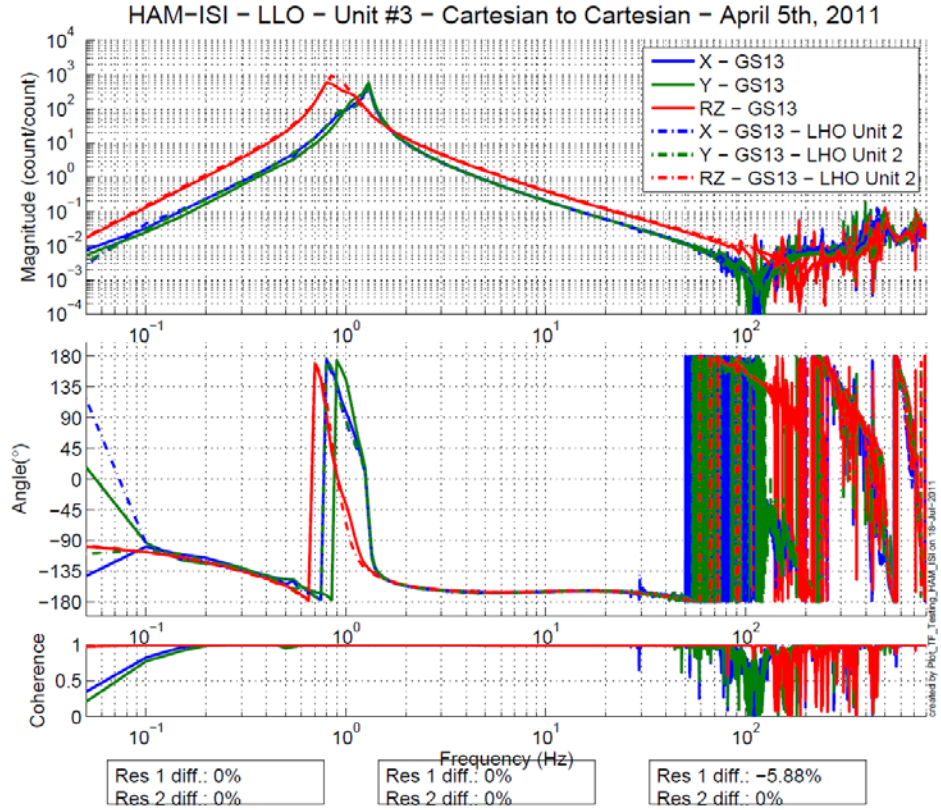


Figure - Cartesian to Cartesian measurements comparison with LHO Unit2 – Horiz GS13

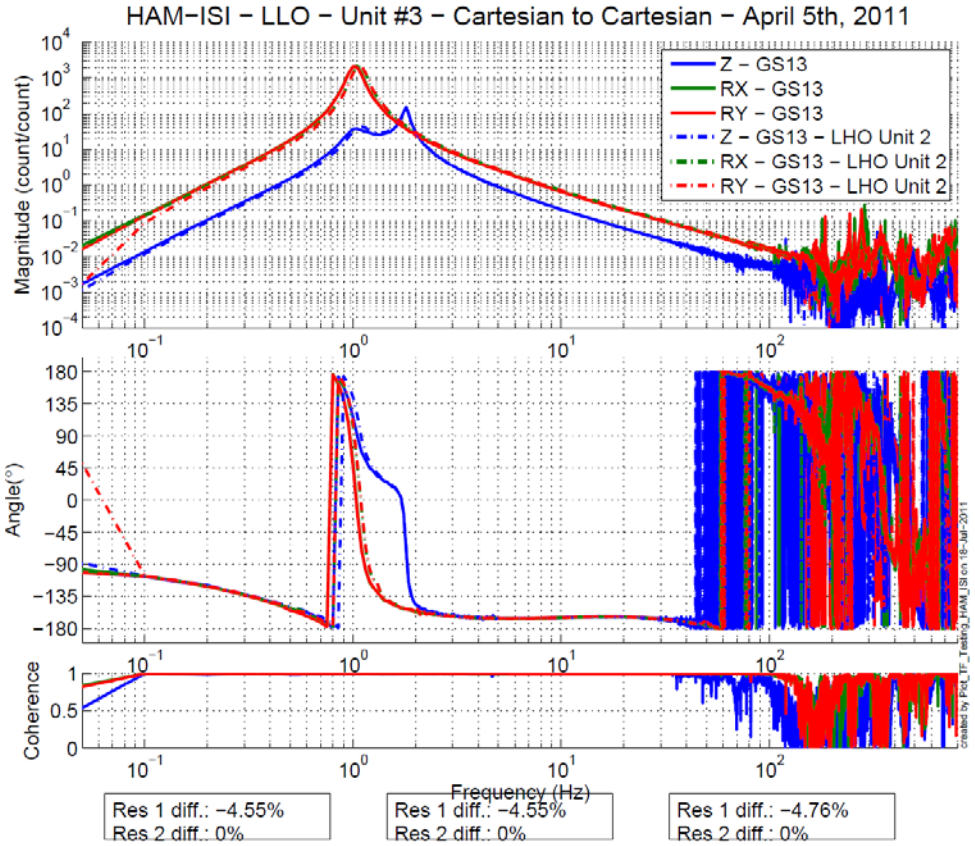


Figure - Cartesian to Cartesian measurements comparison with LHO Unit2 – Vertical GS13

CPS, Cartesian to Cartesian measurement, Undamped

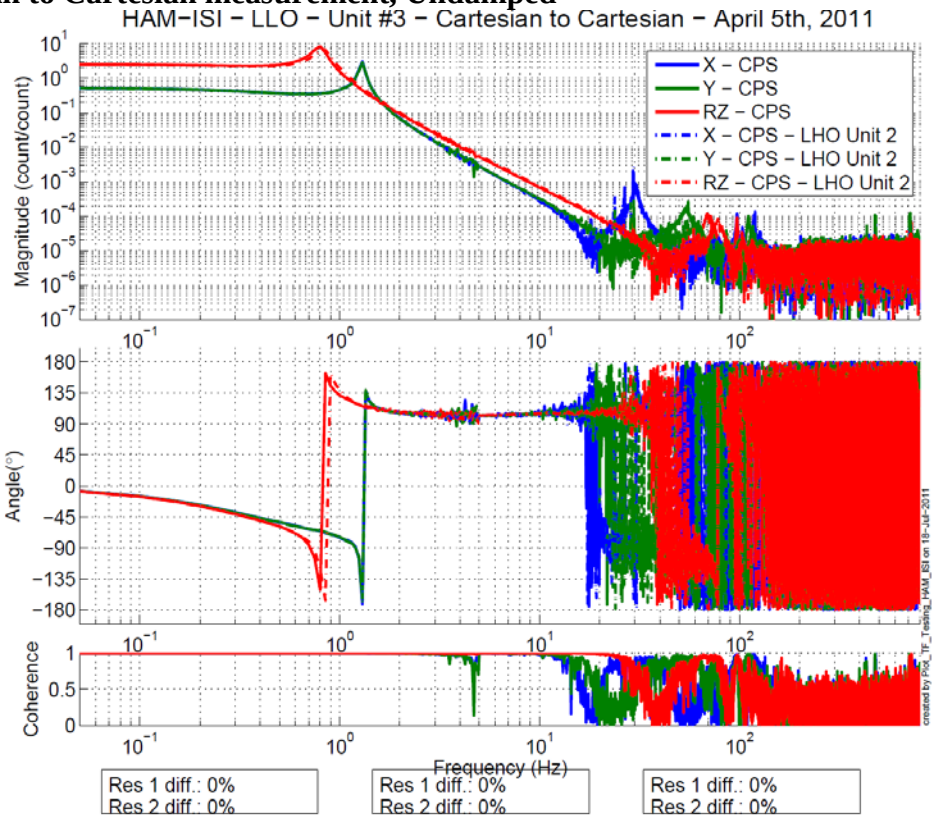


Figure - Cartesian to Cartesian measurements comparison with LHO Unit2 – Horizontal Position sensors

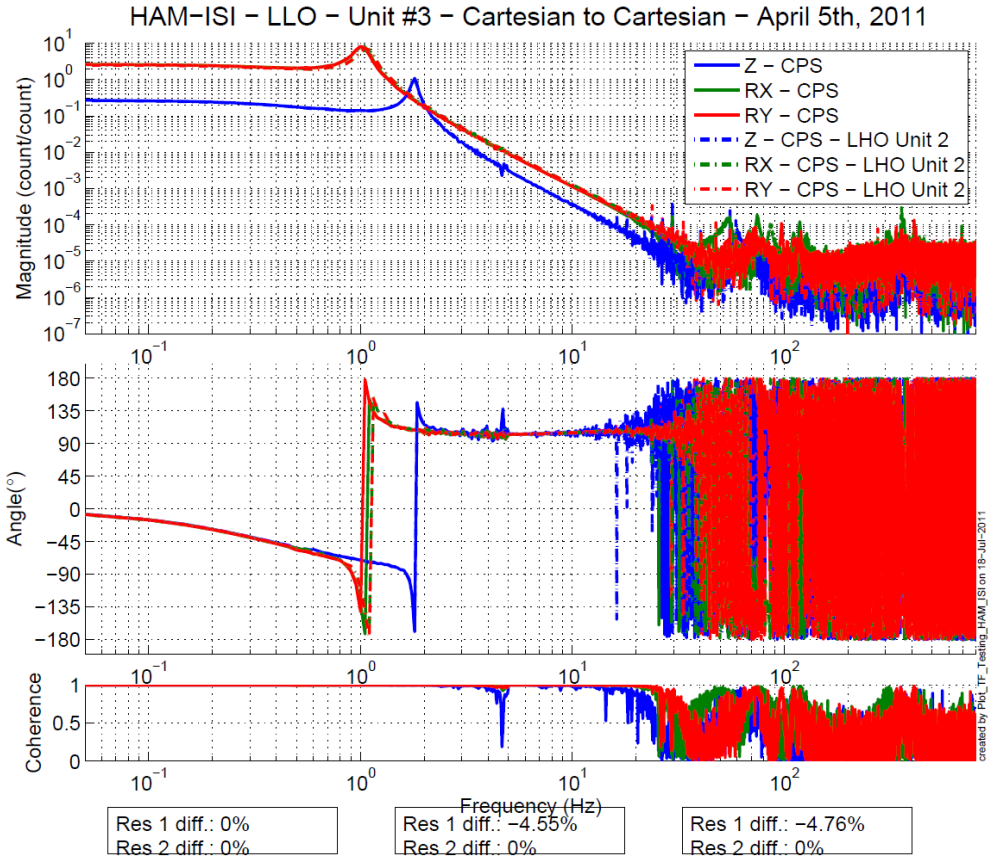


Figure - Cartesian to Cartesian measurements comparison with LHO Unit2 – Vertical Position sensors

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_3/Transfer_Functions/Measurements/Undamped/

- LZMP_LLO_HAM-ISI-Unit_3_2011_04_06.mat

Scripts files for processing and plotting in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Measurements/Undamped/

- LZMP_2011_04_06.m

Figures in SVN at:
opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Figures/Transfer_Functions/Measurements/Undamped/

- LZMP.fig

X & Y offsets:

X offset (mm)	**0.399**
Y offset (mm)	**0.738**

Table – Offset of the Lower Zero Moment Plane

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

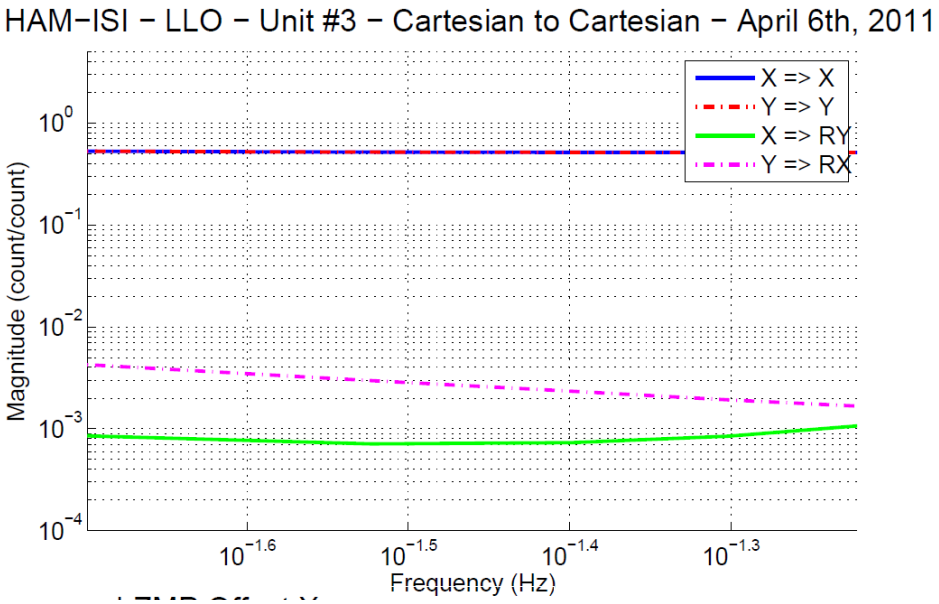


Figure - Lower Zero moment plane – Main and cross couplings at low frequency

Issues/difficulties/comments regarding this test

It was discovered after the testing was complete and the unit stored away, that this measurement was done with an insufficient amount of averages. This measurement should be redone during Phase #2 of the testing.

Acceptance criteria:

- X offset must be less than 2 mm
- Y offset must be less than 2 mm

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

- ***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***

Scripts files for processing and plotting in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Simulation/Damping

- HAM_ISI_LLO_Unit_3_Damping_TF_2011_04_18.m

Figures in SVN at:
/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Simulations/Damping/

- Damping_LOOP_H1_H2_H3.fig
- Damping_LOOP_V1_V2_V3.fig

Results are saved in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/Transfer_Functions/Simulations/Damping/

The following figures present the plant, controller, open loop, closed loop and sensitivity of vertical and horizontal damping loops. H1 (respectively V1) are plotted in solid line, H2 (respectively V2) are plotted in dash line, H3 (respectively V3) are plotted in dash-dot line.

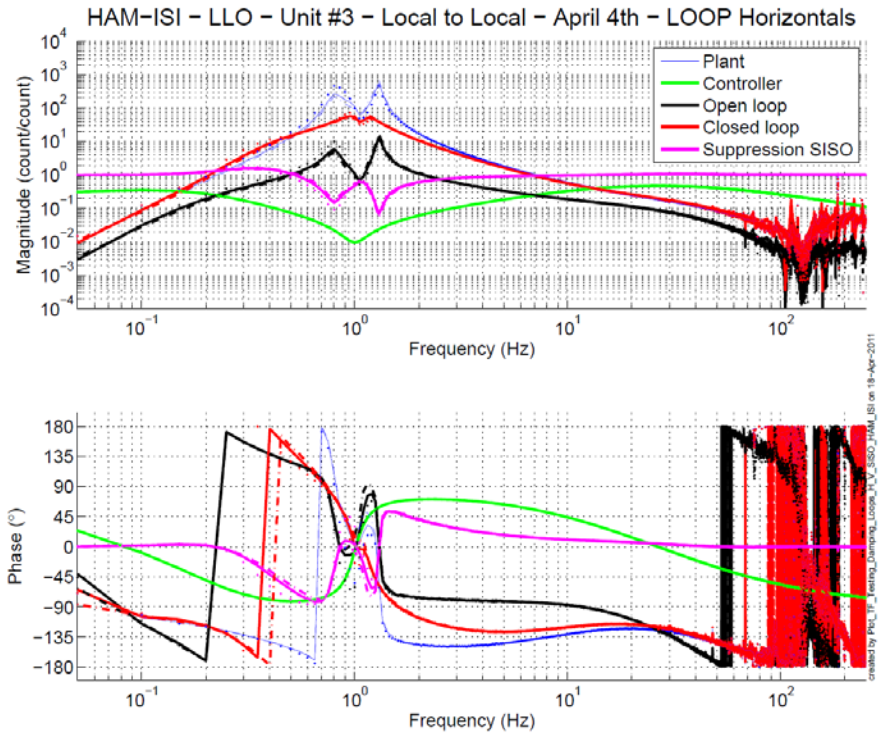


Figure - Horizontal damping loops - Simulation

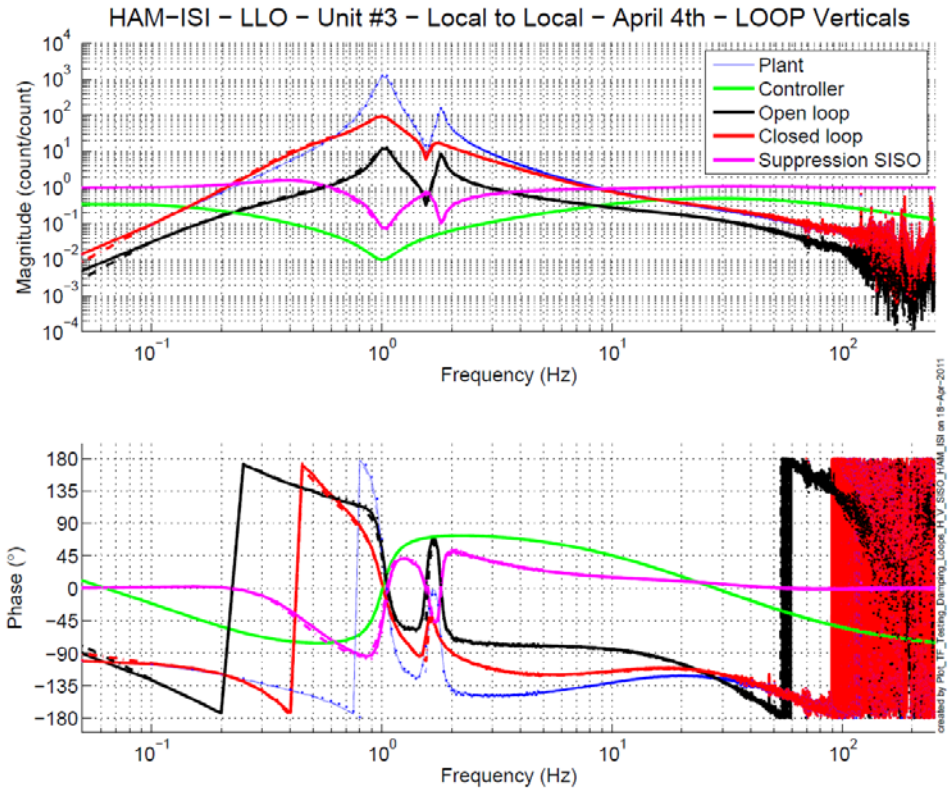


Figure - Vertical damping loops - Simulation

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: ___**

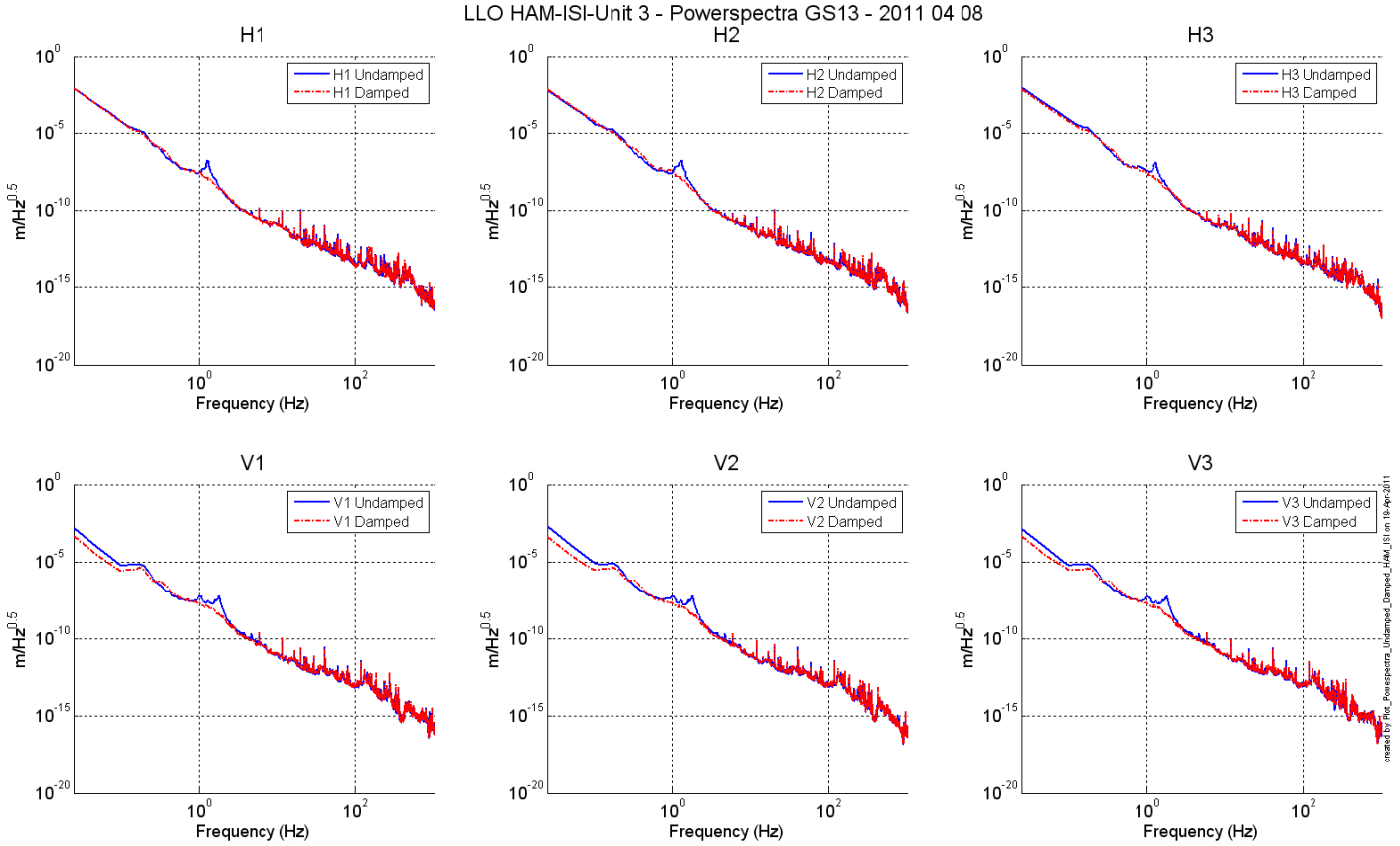
- ***Step 19.2 - Powerspectra – Experimental***

Data files in SVN at:
/opt/svncommon/seisvn/seismic/HAM-ISI/X2/Data/Unit_3/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_3/Figures/Powerspectra/Damping/
- LLO_HAM_ISI_Unit_3_Calibrated_PSD_CPS_Undamped_Damped_2011_04_08.fig
- Simulation_vs_experimental_Suppression.fig



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.

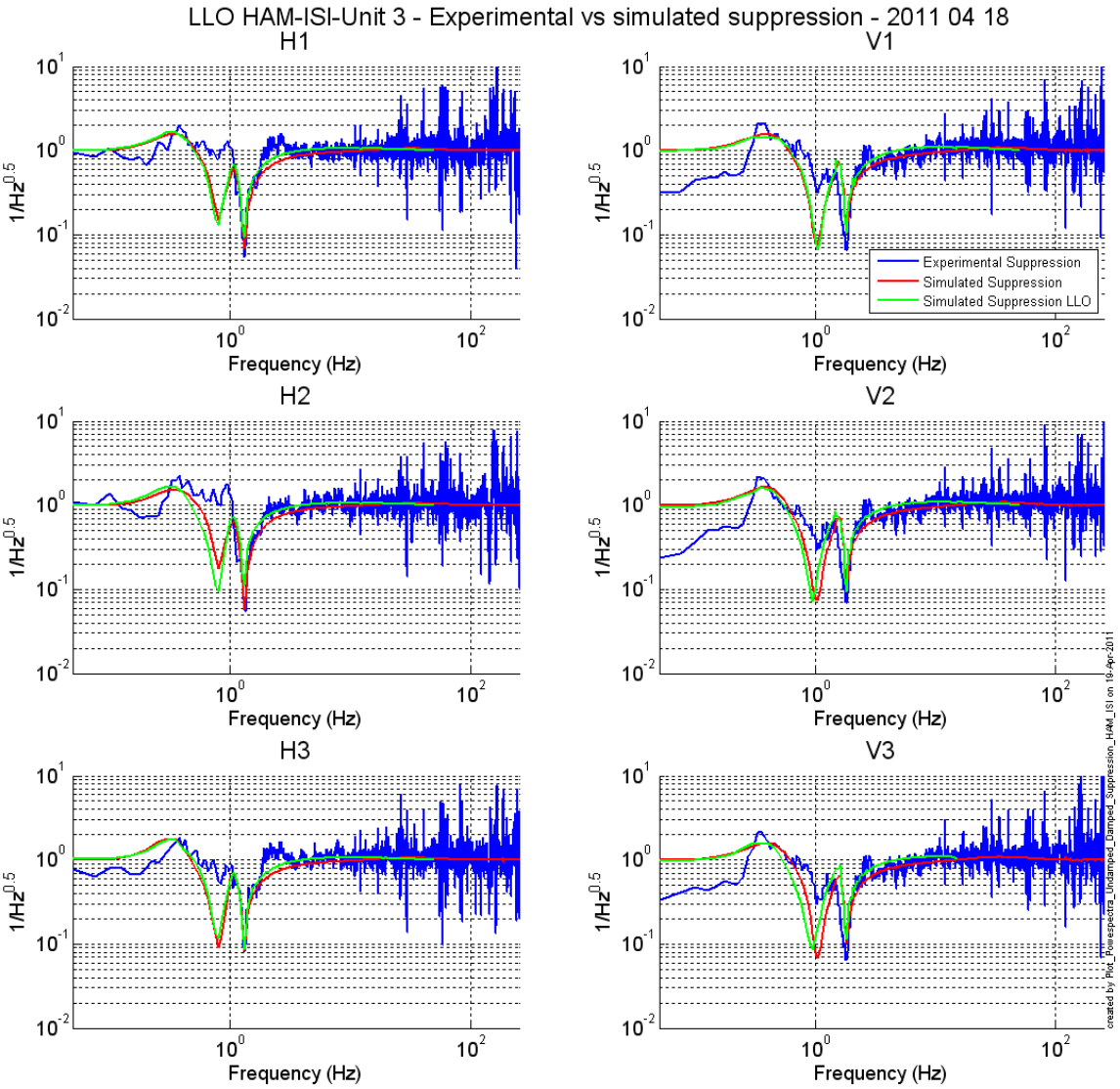


Figure – Horizontal (left) and vertical (right) damping loops - Experimental

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

A few issues were found during the testing of this unit. Some were only discovered after reprocessing of the data following the requirements update. This unit was approved based on the precedent version of this document (v4). The known issues are summed up here:

- sensor gaps not recorded on the jig
- actuator gaps do not meet requirements, it was decided during the approval meeting to
- LZMP measurements were done with only 1 average (high uncertainty), they should be redone on the side of the chamber
- Vertical spring constant: one spring appears to have a much lower constant than the others (-8.91% than the average of the 3). Because no significant difference can be seen between the 3 corners in the vertical local to local transfer functions, it's likely that it's due
- Could not check pressure on V3 GS-13 and V2 GS-13 gives some weird results.