

*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO- E1000331 V2

*LIGO*

Oct 26th, 2014

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**aLIGO HAM-ISI, Pre-integration Test Report, Phase I, LLO  
India #2 (post-assembly, before storage)**

E1000331 – V2

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Advanced LIGO Project

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### Introduction

This second Unit for LIGO India was built in fall 2013 and spring of 2014, and was tested in the spring of 2014, just after we got done building BSC-ISI at LLO.

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

S/N sensor	S/N board	ADE Gap Standoff(m m)	Location on the Jig	Gap Standoff on Jig(mm/in)	Voltage before zeroing	Voltage after zeroing. Prebake	Voltage after zeroing. Post bake
12011	NR	NR	NR	NR	NR	NR	NR
12019	NR	NR	NR	NR	NR	NR	NR
12075	NR	NR	NR	NR	NR	NR	NR
12020	NR	NR	NR	NR	NR	NR	NR
12008	NR	NR	NR	NR	NR	NR	NR
12014	NR	NR	NR	NR	NR	NR	NR

NR: not recorded

### Sensors noise spectra measured before baking:

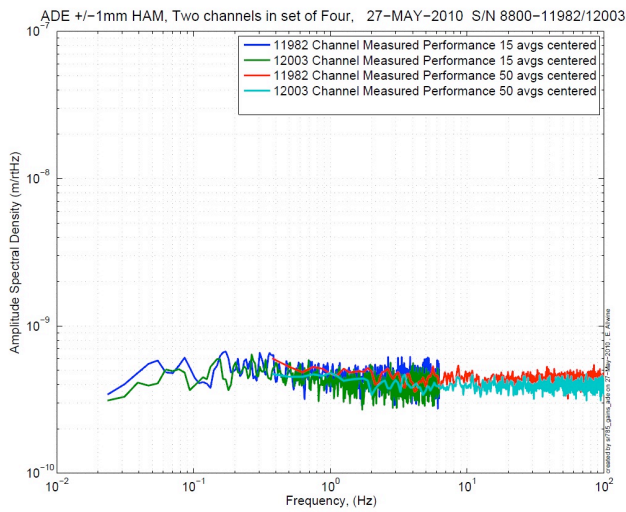


Figure 1: H1 and V1 sensor noise

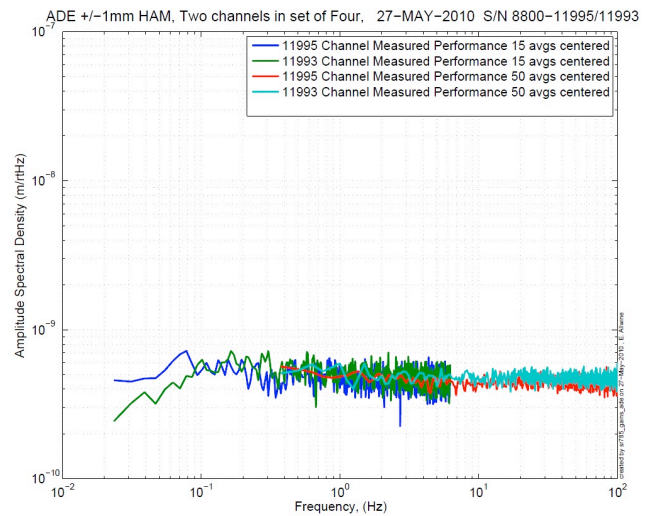


Figure 2: H2 and V2 sensor noise

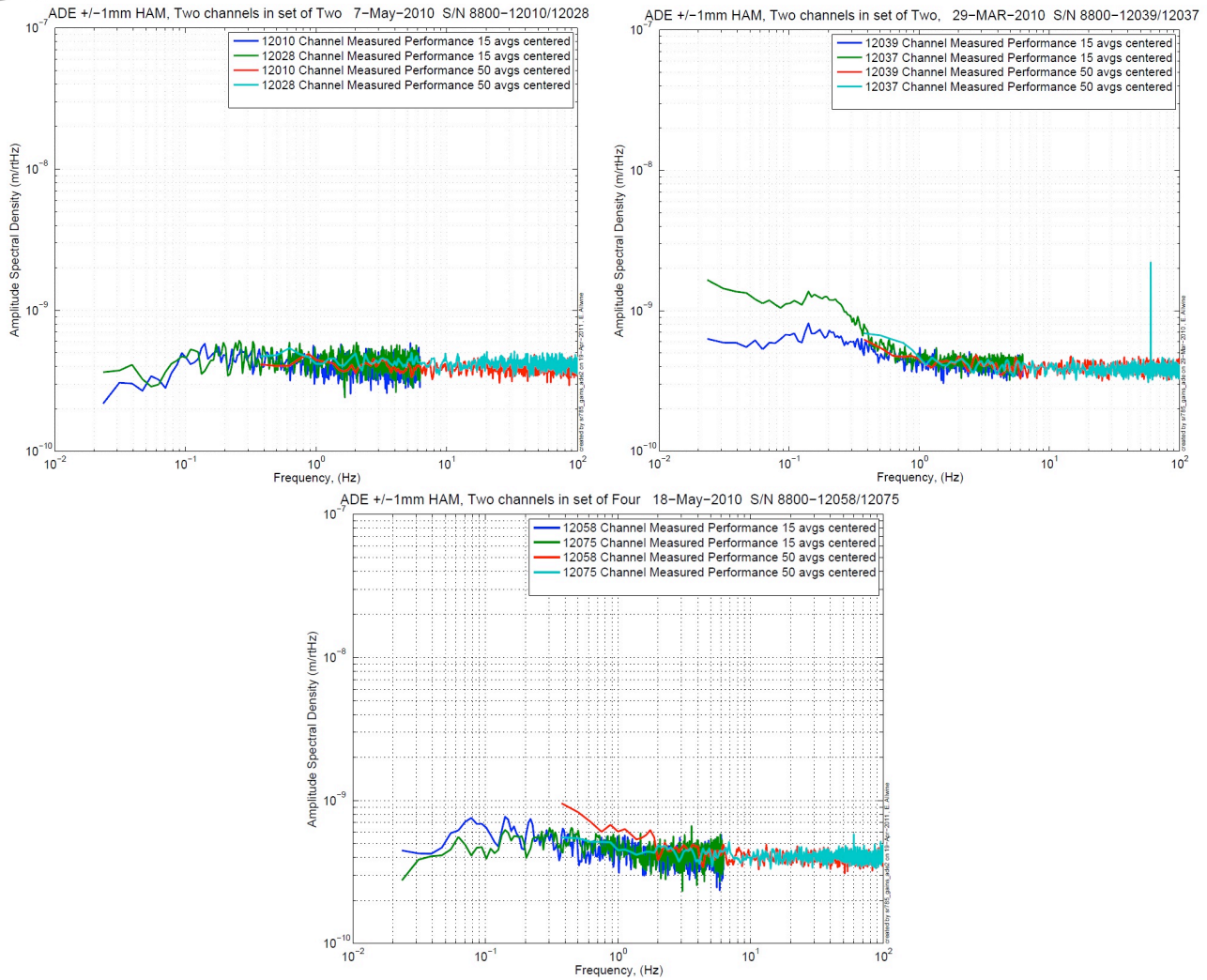


Figure 3: H3 (12010) and V3 (12037 & 12058) sensor noise

**Acceptance Criteria:**

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

Issues/difficulties/comments regarding this test:

**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:**

*/ligo/svncommon/SeiSVN/seismic/Common/Data/alIGO\_GS13\_TestData\PostMod\_TestResults\_RawASCII*

**Scripts files for processing and plotting in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/Common/MatlabTools*

- gs13qatest.m

**Figures in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/Common/Data/alIGO\_GS13\_TestData\PostMod\_TestResults\_PDFs*

▪ **Step 2.1 – Horizontal GS-13s**

**Huddle testing**

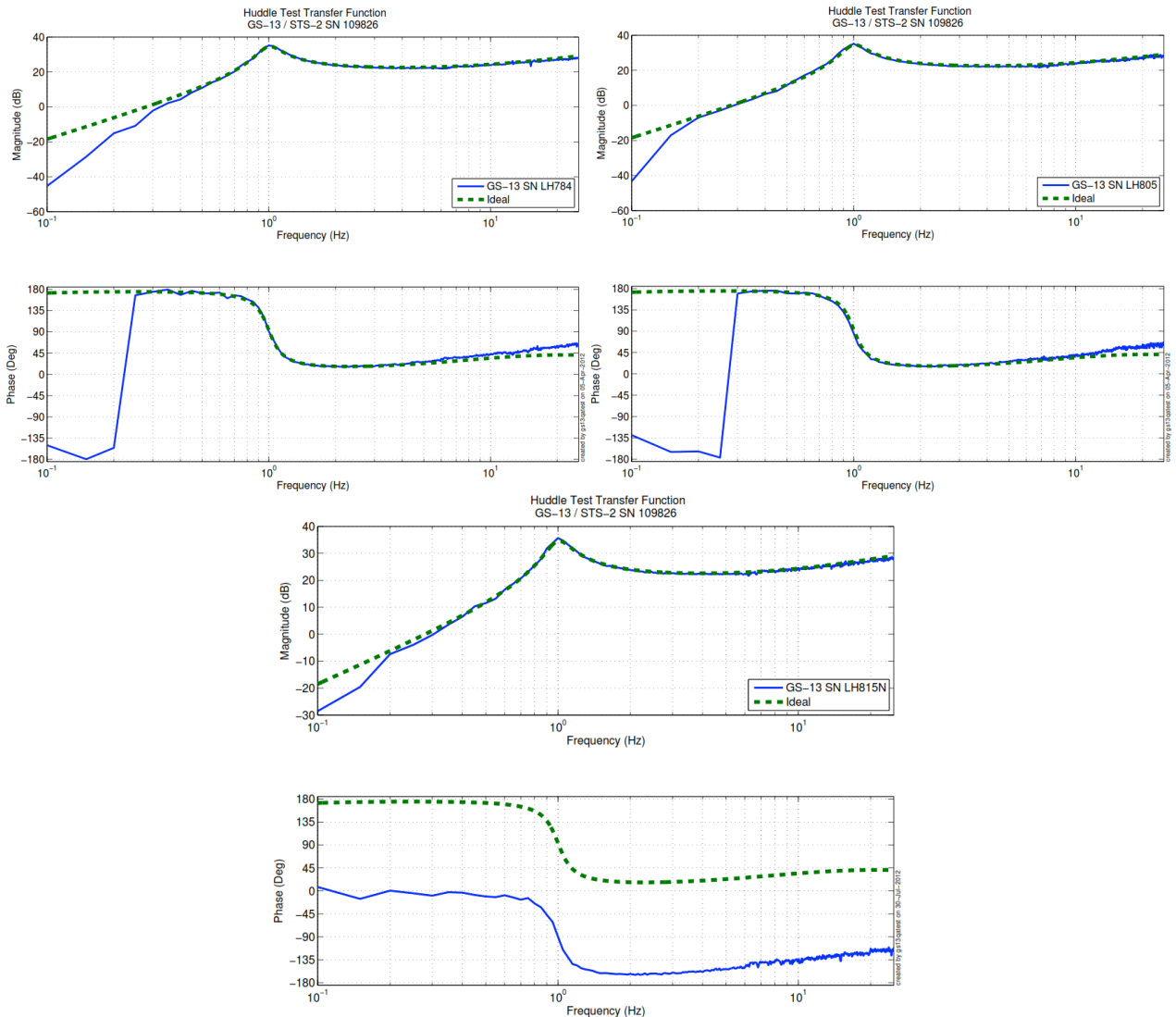


Figure 4: Huddle testing of Horiz GS-13 784, 805, and 815 after aLIGO modifications

## Step 2.2 – Vertical GS-13s

### Huddle testing

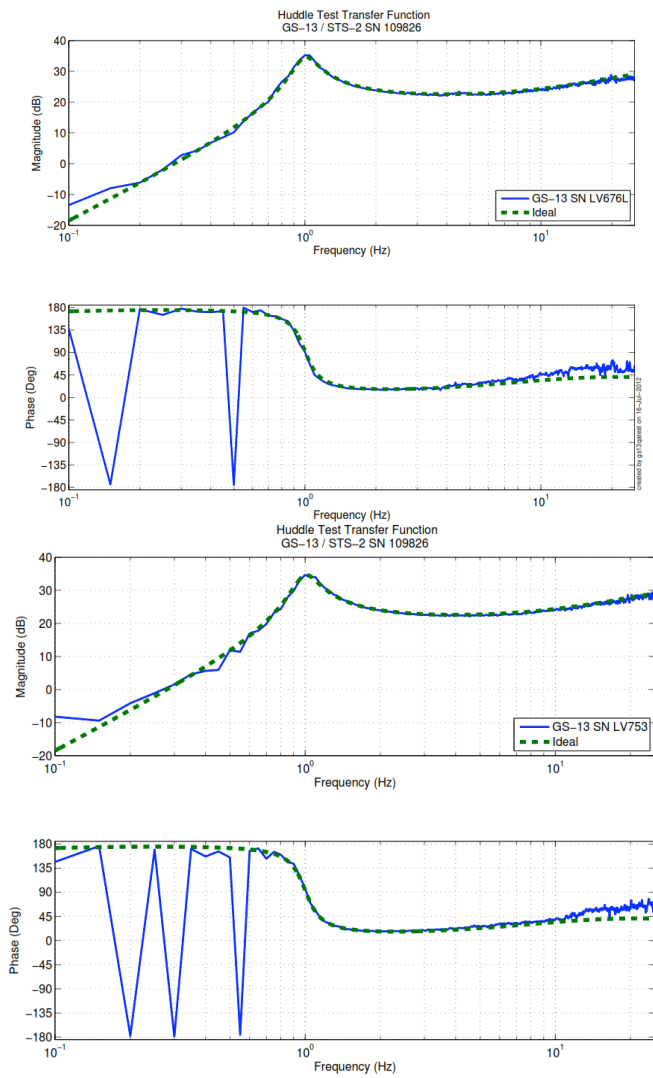


Figure 5: Huddle testing of Vert GS-13 676 and 753 after aLIGO modifications

**Driven testing**

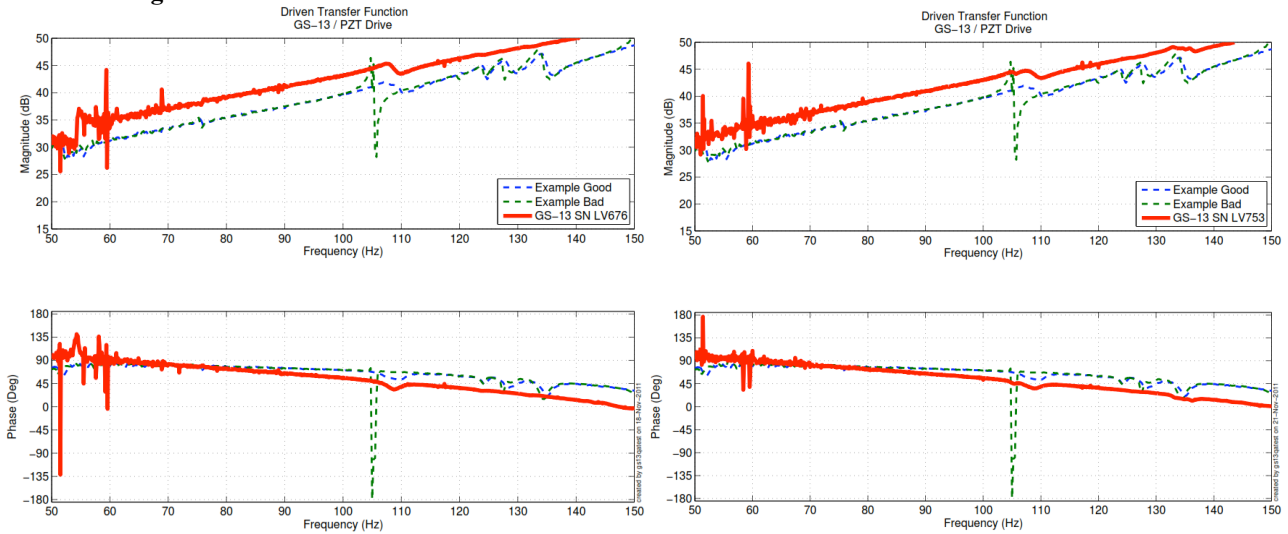


Figure 6: Driven Transfer Function of Vert GS-13 676, 704 and 753 after aLIGO modifications.

**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

**Notes:**

- GS-13 V704 has incomplete Post-Modification testing data. Documentation shows that this seismometer was accepted after modification and testing, but no successful test data exists.
- Referencing Step 6, Figure 9 and Step 16.1, Table 22, it can be seen that there is no disparity between vertical inertial sensors. For these reasons, this seismometer is accepted for this unit.

**Test result:**

**Passed:**   X  

**Failed:**



▪ **Step 3: Actuators**

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

<p>Actuator Serial #: L011          Operator Name: Smith, Lane          Date: 8/12/2009          Time: 8:36 AM          Actuator Coil Resistance: 6.39 Ohms, PASS          Ambient Temperature: 68.9 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.517          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.475</p>	<p>Actuator Serial #: L008          Operator Name: Smith, Lane          Date: 8/12/2009 Time: 10:03 AM          Actuator Coil Resistance: 6.33 Ohms, PASS          Ambient Temperature: 69.8 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.522          Y Travel Limit (inches): 0.206          Z Travel Limit (inches): 0.481</p>
<p>Actuator Serial #: L071          Operator Name: Gordon, Matt          Date: 11/19/2009 Time: 11:12 AM          Actuator Coil Resistance: 6.37 Ohms, PASS          Ambient Temperature: 72.0 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.527          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.507</p>	<p>Actuator Serial #: L076          Operator Name: Gordon, Matt          Date: 11/19/2009 Time: 1:03 PM          Actuator Coil Resistance: 6.31 Ohms, PASS          Ambient Temperature: 71.3 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.534          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.508</p>
<p>Actuator Serial #: L077          Operator Name: Gordon, Matt          Date: 11/19/2009 Time: 10:40 AM          Actuator Coil Resistance: 6.34 Ohms, PASS          Ambient Temperature: 70.7 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.529          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.503</p>	<p>Actuator Serial #: L156          Operator Name: Gordon, Matt          Date: 4/13/2010 Time: 5:13 PM          Actuator Coil Resistance: 6.37 Ohms, PASS          Ambient Temperature: 73.3 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.548          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.505</p>

**Acceptance Criteria:**

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

**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		013		
D071051	Stage 1 base		014		
D071050	Optical table		014		
D071002	Spring Post		009	012	023
D071100	Spring		021	035	040
D071102	Flexure		027	028	043
ADE	Position sensor	Horizontal	12011	12019	12075
		Vertical	12020	12008	12014
D047812	GS-13 pod	Horizontal	97	83	43
		Vertical	41	75	96
D047823	L4C pod	Horizontal			
		Vertical			
D0902749	Actuator	Horizontal	L008	L071	L076
		Vertical	L011	L077	L156

Notes:

- CPS 12037 replaced with 12014 due to large fluctuations in signal. This CPS was previously removed from India\_1 ISI.

### ▪ 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	0.482	0.471	+ 11
2	0.479	0.468	+ 11
3	0.490	0.472	+ 18

Table 1 - Blade profile

**Acceptance Criteria:**

- Blades must be flat within 0.015" inches.

**Test result:**

**Passed:**    

**Failed:**  X

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

Actuator	Front Gap (1/1000")	Back Gap (1/1000")
H1	0.085	0.080
H2	0.085	0.085
H3	0.080	0.080
V1	0.085	0.085
V2	0.080	0.080
V3	0.085	0.085

**Acceptance Criteria**

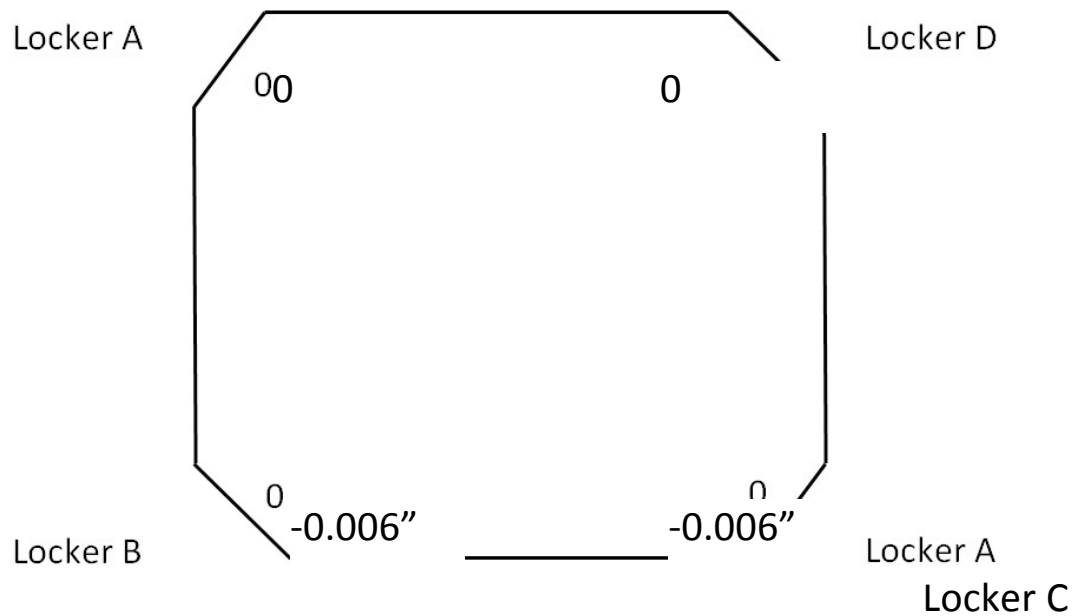
- Gaps must be within 0.010" of design (i.e. 0.090" and .070" pass, but 0.095" and 0.065" doesn't).

Test result:

Passed:  X

Failed:  \_\_\_

▪ **Step 7: Check level of Stage 0**



Max angle =  $(0.006)/72 = 83 \mu\text{rad}$

**Acceptance Criteria**

- The maximum angle of the table with the horizontal mustn't exceed  $\sim 100 \mu\text{rad}$

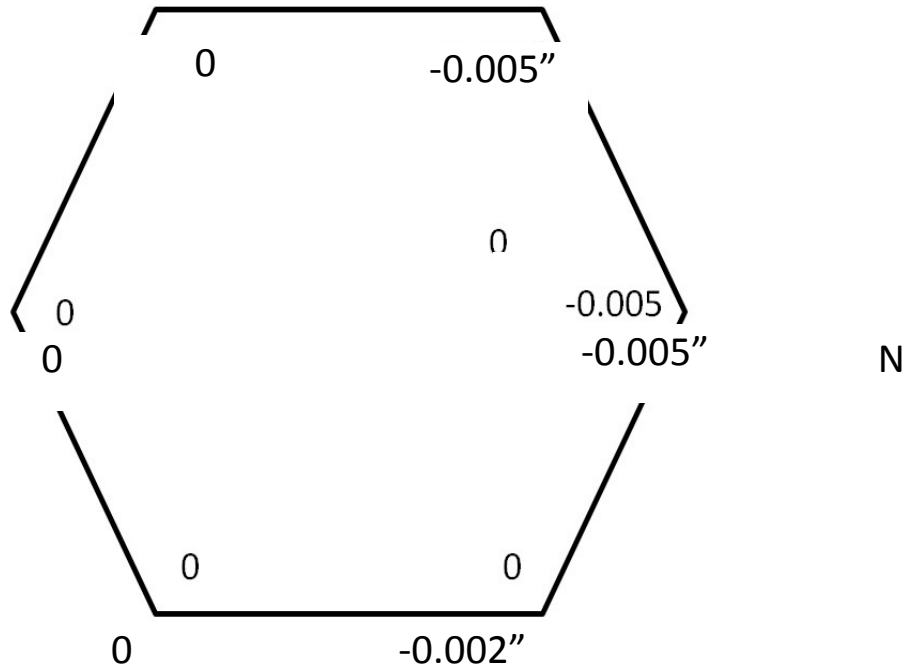
Test result:

Passed:  X

Failed:  \_\_\_

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

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



Max angle =  $(0.005)/85.59 = 58 \text{ urad}$

**Acceptance Criteria**

- The maximum angle of the table with the horizontal mustn't exceed  $\sim 100 \mu\text{rad}$

Test result:    Passed:  X     Failed:         Waived:

▪ Step 9: Mass budget

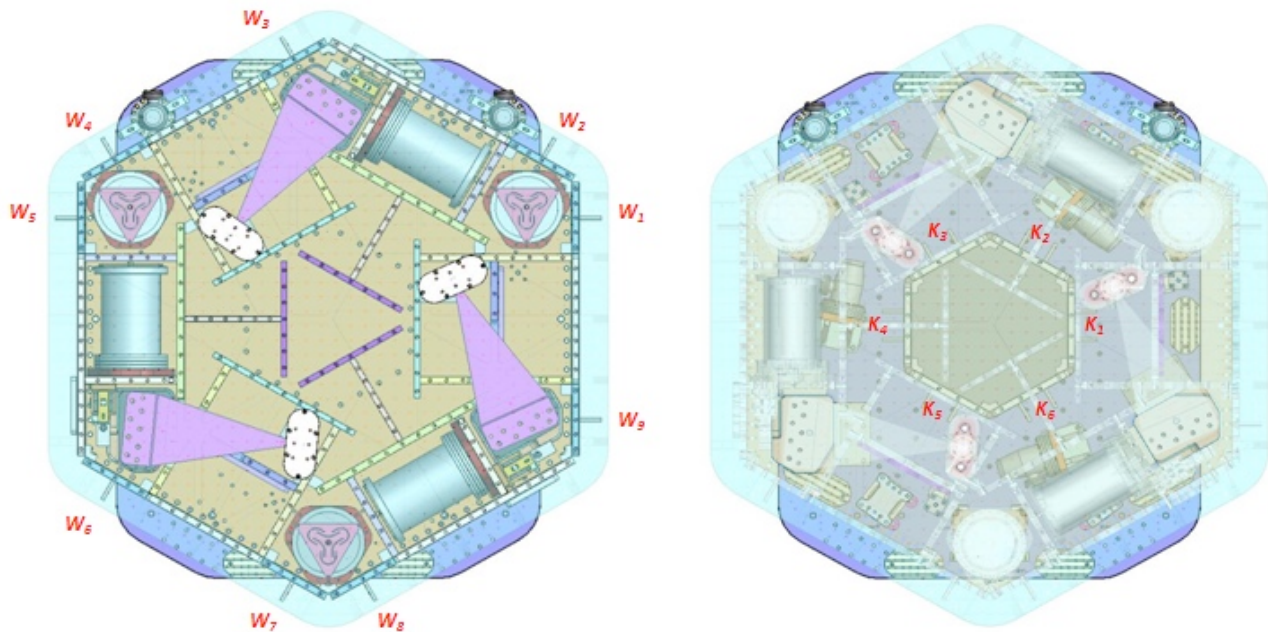


Figure 7: Keel Masses and Wall masses location

	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	50.7	23.00
w1						1	1	42.8	19.41
w2					1	1	1	50.7	23.00
w3						2	1	58.4	26.49
w4					1	1	1	50.7	23.00
w5	1					2	1	59.0	26.76
w6						1	1	42.8	19.41
w7	3	1				1	1	45.7	20.73
w8	1					2	1	59.0	26.76
Side Masses Total	5	1	0	0	3	12	9	459.8	208.56

Table 2: 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	15.95
k2	1	1	1				1	31.1	14.14
k3					1		1	35.1	15.95
k4	1	1	1				1	31.1	14.14
k5					1		1	35.1	15.95
k6	3		1				1	31.2	14.18
	5	2	3	0	3	0	6	198.7	90.32

	Side	Keel	Top	Total
Weigh (kg)	208.56	90.32	277	575.88

Torque x at O (N.m)	-38.79	0.00	0	-38.79
Torque y at O (N.m)	-33.16	5.26	0	-27.91

Table 3: 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 (mils)
<b>A</b>	120
<b>B</b>	120
<b>C</b>	120
<b>D</b>	122

Table 4: 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
<b>A</b>	0.5	1
<b>B</b>	0.5	1.5
<b>C</b>	-1.5	0
<b>D</b>	0.5	0

Table 5: Dial indicators read-out (in thousandths 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
<b>Coil driver</b>	D0902744	S1103354
		S1000316

<b>Anti Image filter</b>	D070081	S1000249
<b>Anti aliasing filter</b>	D1000269	S1106137
		S1106138
<b>Interface chassis</b>	D1000067	S1102219
		S1106356
		S1106358

Table 6: Inventory electronics

**Acceptance Criteria**

- Inventory is complete

**Test result:**

**Passed:**  X

**Failed:**    

▪ **Step 2 - Set up sensors gap**

Table locked	10 Kg masses at each corners		No mass		No mass	
	ADE boxes on		ADE boxes on		ADE boxes off	
Sensors	Offset (Mean)	Std deviation	Offset (Mean)	Std deviation	Offset (Mean)	Std deviation
<b>H1</b>	-7.1812	9.1566	476.19	30.281	-0.062243	0.25114
<b>H2</b>	320.09	8.4585	422.99	36.762	-0.2749	0.20577
<b>H3</b>	-108.04	12.858	-415.97	22.491	1.3305	0.23885
<b>V1</b>	-111.39	16.755	75.356	51.32	-2.7923	0.20891
<b>V2</b>	-78.931	19.949	195.8	60.894	-0.2679	0.23267
<b>V3</b>	-95.993	77.577	106.75	357.73	-0.7577	0.26977

Capacitive position sensor readout after gap set-up

Issues/difficulties/comments regarding this test:

**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:**    

**Failed:**  X



▪ **Step 3 - Measure the Sensor gap**

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

**Acceptance criteria:**

Sensors gap measured on the jig and on the optic table must be:

- 0.080” +/-0.002”

**Test result:**

Passed:     

Failed:      Waived: X

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

Sensors	Table locked		Table unlocked	
	Offset (Mean)	Std deviation	Offset (Mean)	Difference
H1	-7.1812	9.1566	-255.27	36.947
H2	320.09	8.4585	353.52	36.345
H3	-108.04	12.858	-978.25	69.47
V1	-111.39	16.755	-260.99	89.457
V2	-78.931	19.949	-186.44	76.184
V3	-95.993	77.577	-1491.2	79.125

Table 7: Sensor gaps after platform release

**Acceptance criteria:**

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

**Comments:**

**Test result:**

Passed: X

Failed:

- Step 5 – Performance of the limiter
- Step 5.1 - Test N°1 - Push “in the general coordinates”

		CPS read out		Calculated after calibration	
Sensors	UP (Counts)	Down (Counts)	UP (mil)	Down (mil)	
V1	18721	-20251	22.0	-23.8	
V2	19946	-20165	23.4	-23.7	
V3	19799	-20540	23.3	-24.1	
		CPS read out		Calculated after calibration	
Sensors	CW(-RZ)	CCW (+RZ)	CW (mil)	CCW (mil)	
H1	24514	-16809	28.8	-19.8	
H2	19831	-21939	23.3	-25.8	
H3	20625	-22704	24.2	-26.7	

Table 8: Optic table range of motion

- Step 5.2 - Test N°2 – Push “locally”

	Push in positive direction	Push in negative direction	Railing	Actuator Gap Check
H1	-22774	27815		X
H2	-24330	23542		X
H3	-24757	23959		X
V1	-19990	20504		X
V2	-32768	30676		X
V3	-24216	22532		X

Table 9: Optic table range of motion

**Acceptance criteria:**

- The vertical sensor readout must be positive when the optic table is pushed in the +Z direction
- The horizontal sensor readout must be negative when the optic table is pushed in the +RZ direction
- **Step 5.1**
  - o Absolutes value of all estimated motions must be higher than 16000counts (~0.020”)
- **Step 5.2**
  - o No contact point on sensors
  - o Absolute value of sensor read out must be higher than 16000counts (~0.020”)
  - o No contact point on actuators

Test result:

Passed:  X

Failed:      .

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

**Data files in SVN at:**

/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/ Powerspectra/Undamped  
 - LLO\_HAM\_ISI\_India\_2\_Calibrated\_PSD\_CPS\_GS13\_Unlocked\_Locked\_20140516.mat

**Scripts files for processing and plotting in SVN at:**

/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Scripts/Data\_collection/  
 - Powerspectra\_Measurements\_Locked\_Unlocked\_HAM\_ISI.m  
 - Powerspectra\_Measurements\_Tilted\_HAM\_ISI.m

**Figures in SVN at:**

/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Figures/Powerspectra/Undamped  
 - LLO\_HAM\_ISI\_India\_2\_Calibrated\_PSD\_CPS\_Unlocked\_Locked\_2014\_05\_16.fig  
 - LLO\_HAM\_ISI\_India\_2\_Calibrated\_PSD\_GS13\_Unlocked\_Locked\_2014\_05\_16.fig

**CPS calibration:**

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

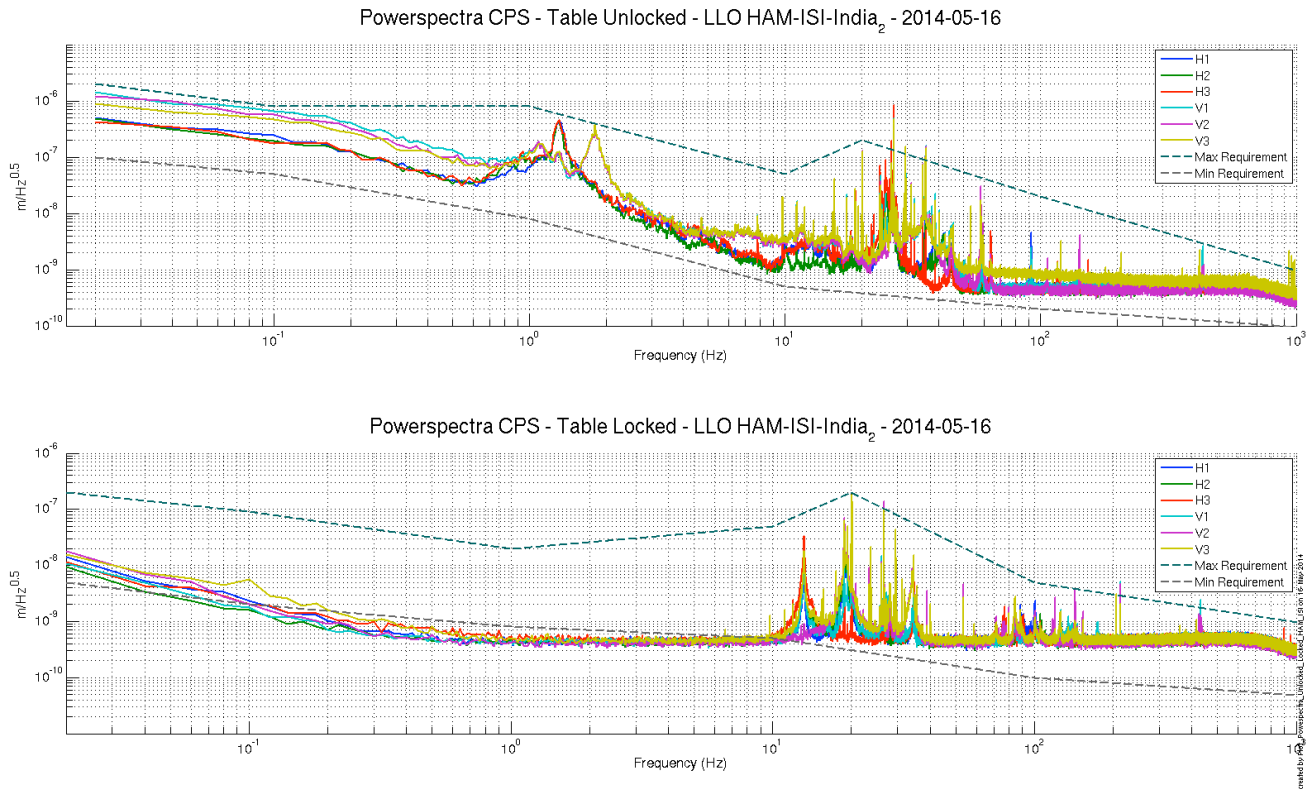
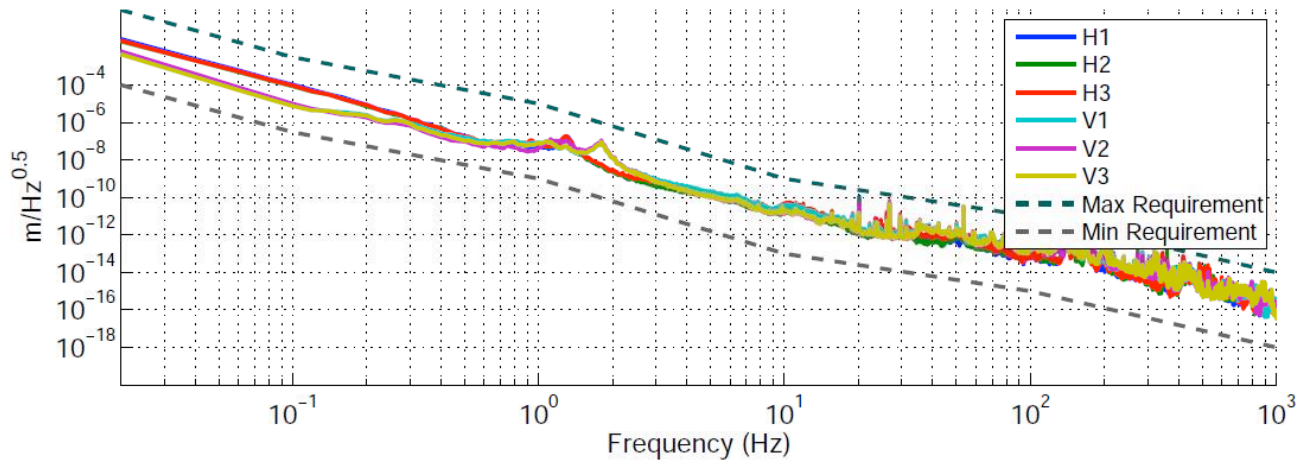
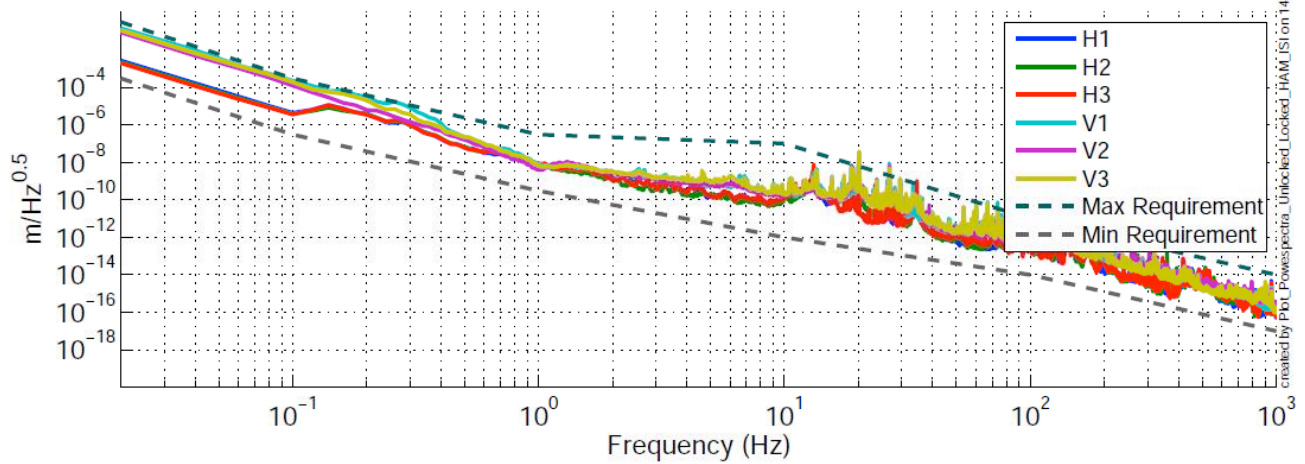


Figure 8: Calibrated CPS power spectrum

Powerspectra GS13 – Table Unlocked – LLO HAM-ISI-India<sub>2</sub> – 2014-05-13



Powerspectra GS13 – Table Locked – LLO HAM-ISI-India<sub>2</sub> – 2014-05-13



created by PPO, Powerspectra\_Unlocked\_Locked\_HAM\_ISI on 14-May-2014

Figure 9: 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)	$2 \times 10^{-2}$	$1 \times 10^{-1}$	1	10	20	100	1000
GS-13	Table locked	Max	$3 \times 10^{-1}$	$3 \times 10^{-4}$	$3 \times 10^{-7}$	$10^{-7}$		$10^{-11}$	$10^{-14}$
		Min	$3 \times 10^{-4}$	$3 \times 10^{-7}$	$3 \times 10^{-10}$	$10^{-12}$		$10^{-14}$	$10^{-17}$
	Table unlocked	Max	1	$3 \times 10^{-3}$	$10^{-5}$	$10^{-9}$		$10^{-11}$	$10^{-14}$
		Min	$10^{-4}$	$3 \times 10^{-7}$	$10^{-9}$	$10^{-13}$		$10^{-15}$	$10^{-18}$
CPS	Table locked	Max	$2 \times 10^{-7}$	$2 \times 10^{-8}$	$10^{-8}$	$5 \times 10^{-8}$	$2 \times 10^{-7}$	$5 \times 10^{-9}$	$10^{-9}$
		Min	$5 \times 10^{-9}$	$2 \times 10^{-9}$	$8 \times 10^{-10}$	$5 \times 10^{-10}$		$10^{-10}$	$5 \times 10^{-11}$
	Table	Max	$2 \times 10^{-6}$	$8 \times 10^{-7}$	$8 \times 10^{-7}$	$5 \times 10^{-8}$	$2 \times 10^{-7}$	$2 \times 10^{-8}$	$10^{-9}$

	unlocked								
		Min	$10^{-7}$	$5 \times 10^{-8}$	$8 \times 10^{-9}$	$5 \times 10^{-10}$		$2 \times 10^{-10}$	$10^{-10}$

Table 10: Step 6 -Normal conditions-Sensors power spectra requirements

Test result:

Passed:     

Failed:   X

▪ **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.

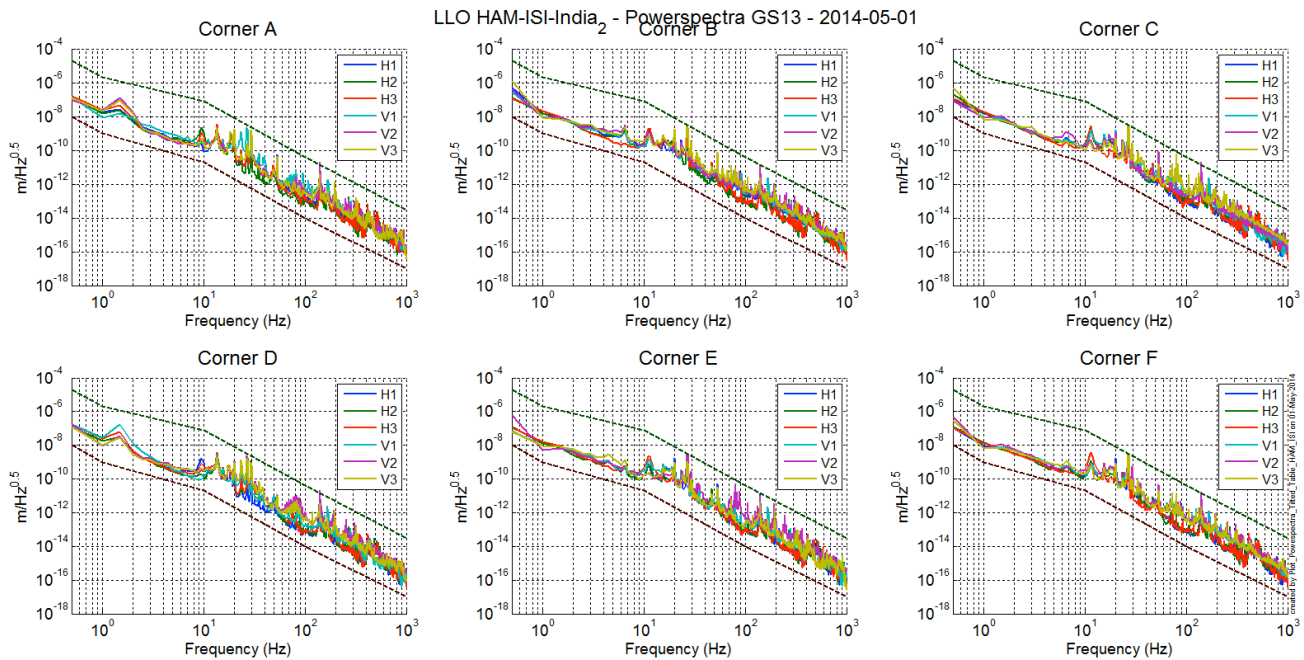


Figure 10: Power spectrum Calibrated GS13 with mass at corner

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/ Powerspectra/Undamped - LLO\_HAM\_ISI\_India\_2\_Calibrated\_PSD\_GS13\_Table\_Tilted\_2014\_05\_01.mat*

**Scripts files for taking and processing the data, and plotting it in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Scripts/Data\_collection/ - Powerspectra\_Measurements\_Tilted\_HAM\_ISI.m*

**Figures in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Figures/ Powerspectra/Undamped - LLO\_HAM\_ISI\_India\_2\_Calibrated\_PSD\_GS13\_Table\_Tilted\_2014\_05\_01.fig*

**Acceptance criteria:**

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

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

Table 11: 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: *seismic/SeiSVN/Common/MatlabTools*

- gs13Presstest.m

**Note:** the figure hasn't been plotted because of a bug in the script but the pressure sensors are all working fine and the pressure readouts are within requirements.

Issues/difficulties/comments regarding this test

**Acceptance criteria:**

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

**Test result:**

▪

**Passed:**  X

**Failed:**  \_\_\_\_



▪ Step 9 - Coil Driver, cabling and resistance check

Actuator	V1		H1		V2	
Coil driver	S1103354 – Fine 1		S1103354 – Coarse 1		S1103354 – Coarse 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)	6.5	O.L (infinity)	6.6	O.L (infinity)	6.6
MEDM offset (1000 counts)	Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)	
	0.309		0.310		0.309	

Actuator	H2		V3		H3	
Coil driver	S1000317 - Coarse 2		S1000316 - Coarse 1		S1000316 - Fine 1	
Anti image pin #						
Cable #	29					
Resistance (Ohm)	P1 - P2	P2 - P3	P1 - P2	P2 - P3	P1 - P2	P2 - P3
	O.L (infinity)	6.6	O.L (infinity)	6.6	O.L (infinity)	6.6
MEDM offset (1000 counts)	Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)		Measurement P2 (-) ; P1&P3 (+)	
	0.307		0.313		0.313	

Table 12: 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:  X  Failed:      )

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

	Negative drive	Positive drive
<b>H1 readout (count)</b>	-22140	26430
<b>H2 readout (count)</b>	-24069	24185
<b>H3 readout (count)</b>	-25004	23917
<b>V1 readout (count)</b>	-19381	19711
<b>V2 readout (count)</b>	-26106	25475
<b>V3 readout (count)</b>	-20547	21753

Table 13: Range of motion - Local drive

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Static\_Tests*  
 - LLO\_HAM-ISI\_India\_2\_Range\_Of\_Motion\_20140513.mat

**Scripts files for taking and processing the data, and plotting it in SVN at:**

*/ligo/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 with for a negative drive	D.I readout without any drive	D.I readout with for a positive drive	
A	19	0	-19	
B	19	0	-19.5	
C	20	0	-20	
D	19.5	0	-19.5	
<b>Average</b>	19.375	0	-19.5	<b>38.875</b>

Sensors	Counts	Counts	Counts	Difference (Counts)
V1	-16964	-260.99	16451	33415
V2	-16036	-186.44	15852	31888
V3	-18760	-1491.2	15224	33984
	-17253.33	-646.21	15842.33	33095.66

Table 14: Calibration of capacitive position sensors

**Vertical sensitivity:**  $33095/38.875 = 851 \text{ count/mil}$   
 or  $851 \text{ count/mil} / 1638 \text{ V/count} = 0.52\text{V/mil}$   
 or  $25400\text{nm/mil} / 851 \text{ mil/count} = 29.84 \text{ nm/count}$

**Nominal Calibration**

CPS Sensitivity:  $20\text{V}/0.039" = 20\text{V}/39\text{mils} = 0.513\text{V/mil}$

Calibration in counts:  $2^{15} / 20 * 20/39 = 840 \text{ count/mil}$   
 or  $25400 \text{ nm/mil} * 1/840 \text{ mil/count} = 30.2\text{nm/count}$

**Difference with Nominal sensitivity =  $(840-851)/840=-1.3\%$**

**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	Initial position	Measurement 1	Measurement 2	Measurement 3	Mean diff counts	Mean diff m	K (N/m)
V1	-658.05	-4611.2	-4628	-4626	-3968.95	-1.18E-04	8.28E+04
V2	-986.86	-4898.7	-4921.5	-4900.6	-3924.19	-1.17E-04	8.37E+04
V3	-1689	-5413.5	-5351.4	-5415.3	-3694.35	-1.10E-04	8.89E+04
						<b>Average (N/m)</b>	<b>2.54E+04</b>

Table 15: 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 **2.8%**

**Test result:**

**Passed:** \_\_\_

**Failed:** X

Note on this test: 1Kg masses were used, not the 2Kg recommended in the procedure.

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

		H1	H2	H3	V1	V2	V3
<b>Actuator s (1000 counts)</b>	<b>H1</b>	2076.97	1363.32	1347.99	75.28	29.85	-556.61
	<b>H2</b>	1146.47	2045.46	1018.31	-154.52	-98.44	-379.43
	<b>H3</b>	1116.37	1395.30	2077.51	152.68	136.05	-571.07
	<b>V1</b>	74.27	205.18	-403.39	1548.72	-150.51	-1215.66
	<b>V2</b>	-504.93	43.99	60.73	-834.82	1427.89	-530.47
	<b>V3</b>	216.47	-565.26	33.67	19.78	-460.09	2153.36

Table 16: Main and cross coupling

**Data files in SVN at:**

- /ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Static\_Tests
- LLO\_HAM\_ISI\_India\_2\_Sensor\_Readout\_Local\_20140411.mat

**Scripts files for taking data in SVN at:**

- /ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Scripts/Data\_Collection
- Sensor\_Readout\_Local\_Drive\_MEDM\_HAM\_ISI.m

**Note:** the compensation filters were not on while taking this test because they were tripping the watchdogs. This explains why all the results in the table have been multiplied by (-1).

Issues/difficulties/comments regarding this test:

**Acceptance criteria:**

- **Vertical**  
For a +1000 count offset drive on vertical actuators
  - o Collocated sensors must be 1400 counts +/- 10%
  
- **Horizontal**  
For a +1000 count offset drive on horizontal actuators
  - o Collocated sensors must be 2000 counts +/- 10%
  - o Non-collocated horizontal sensors must be 1250 counts +/-10%

**Test result:**

**Passed:** \_\_\_\_

**Failed:**  X

▪ Step 14 - Linearity test

	Slope	Offset	Average slope	Variation from average (%)
H1	2.165	-3087	2.142	1.1
H2	2.107	-1091		
H3	2.153	2553		
V1	1.521	-1482	1.517	0.20
V2	1.492	744		
V3	1.5381	950		

Table 17: Slopes and offset of the triplet Actuators - HAM-ISI - Sensors

Scripts files for taking data in SVN at:

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Scripts/Data\_Collection*

- Linearity\_Test\_Awgstream\_HAM\_ISI.m

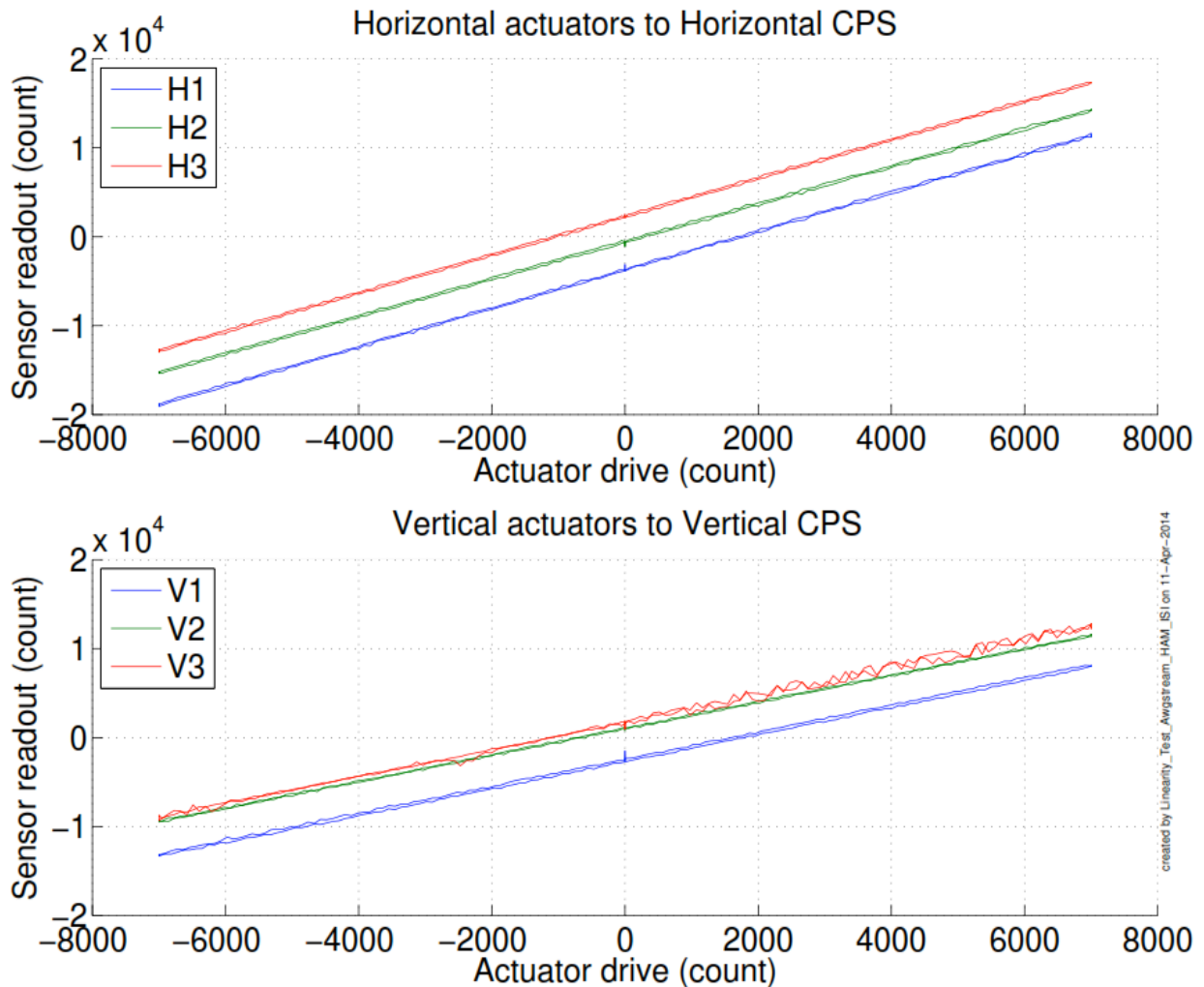


Figure 11: Horizontal and vertical actuators x HAM-ISI x sensors

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Linearity\_test*  
- LLO\_HAM\_ISI\_India\_2\_Linearity\_test\_20140411.mat

**Figures in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Figures/Linearity\_test*  
- LLO\_HAM\_ISI\_India\_2\_Linearity\_test\_20140411.fig  
- LLO\_HAM\_ISI\_India\_2\_Linearity\_test\_20140411.pdf

**Acceptance criteria:**

- Horizontal and vertical slopes of the triplet actuators x HAM-ISI x sensors: Average slope +/- 2%

**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						
H2							
H3							
V1							
V2							
V3							
Direction read out							

Table 18: Tests in the general coordinate basis

Issues/difficulties/comments regarding this test: the compensation filters were not on while taking this test because they were tripping the watchdogs. This explains why all the results in the table have been multiplied by (-1).

The results in the table are very consistent with what we had for the previous units. The only issue we have on this test is the direction read out which is with the direction read out values, the calibration filters were on so these values are in nm instead of counts, explaining the high numbers.

**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:**     

**Failed:**   X



## ▪ 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:

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Transfer\_Functions/Measurements/Undamped/*

- LLO\_HAM\_ISI\_India\_2\_Data\_TF\_L2L\_50mHz\_500mHz\_20140507-224208.mat
- LLO\_HAM\_ISI\_India\_2\_Data\_TF\_L2L\_500mHz\_5Hz\_20140507-193635.mat
- LLO\_HAM\_ISI\_India\_2\_Data\_TF\_L2L\_5Hz\_200Hz\_20140507-180302.mat
- LLO\_HAM\_ISI\_India\_2\_Data\_TF\_L2L\_200Hz\_800Hz\_20140507-162928.mat

#### Data collection script files:

*/ligo/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:

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Transfer\_Functions/Measurements/Undamped/*

- Plot\_LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_2014\_05\_07.m

#### Figures in SVN at:

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Figures/Transfer\_Functions/Measurements/Undamped/*

- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_V\_CPS\_50mHz\_800Hz\_2014\_05\_07.fig
- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_H\_GS13\_50mHz\_800Hz\_2014\_05\_07.fig
- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_H\_CPS\_50mHz\_800Hz\_2014\_05\_07.fig
- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_V\_GS13\_50mHz\_800Hz\_2014\_05\_07.fig

#### Storage of measured transfer functions in the SVN at:

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Transfer\_functions/Measurements/Undamped/*

- LLO\_HAM\_ISI\_India\_2\_Data\_TF\_L2L\_2014\_05\_07.mat

The local to local transfer functions are presented below.

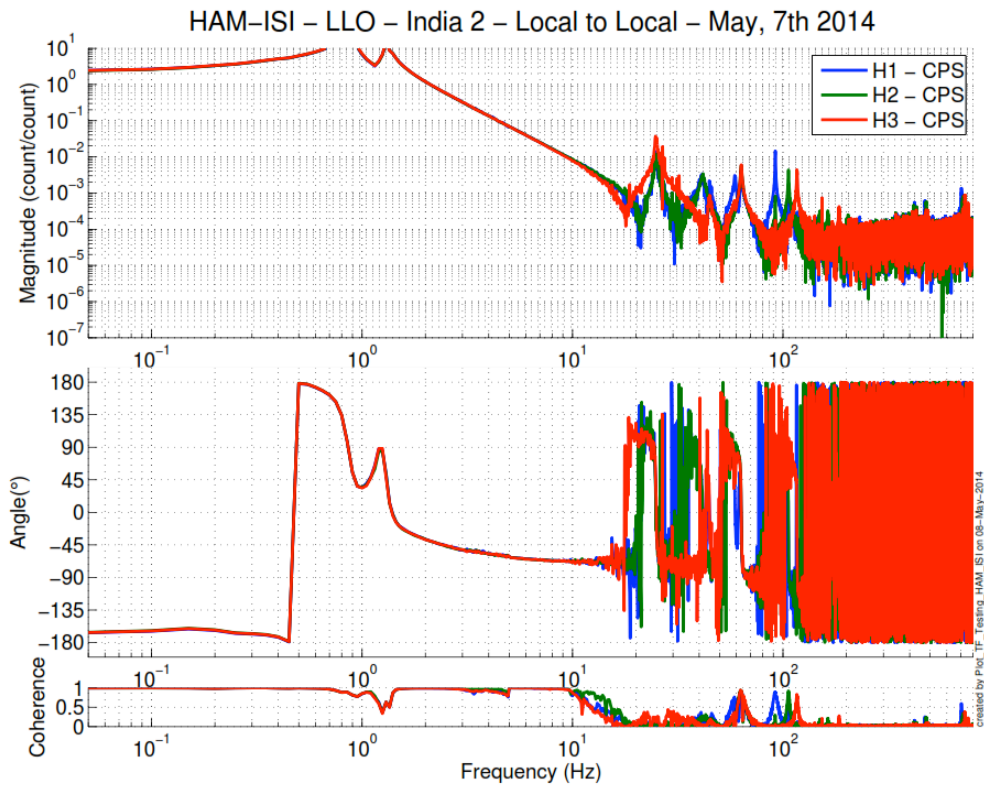


Figure 19: Local to Local Measurements – Horizontal capacitive sensors  
HAM-ISI – LLO – India 2 – Local to Local – May, 7th 2014

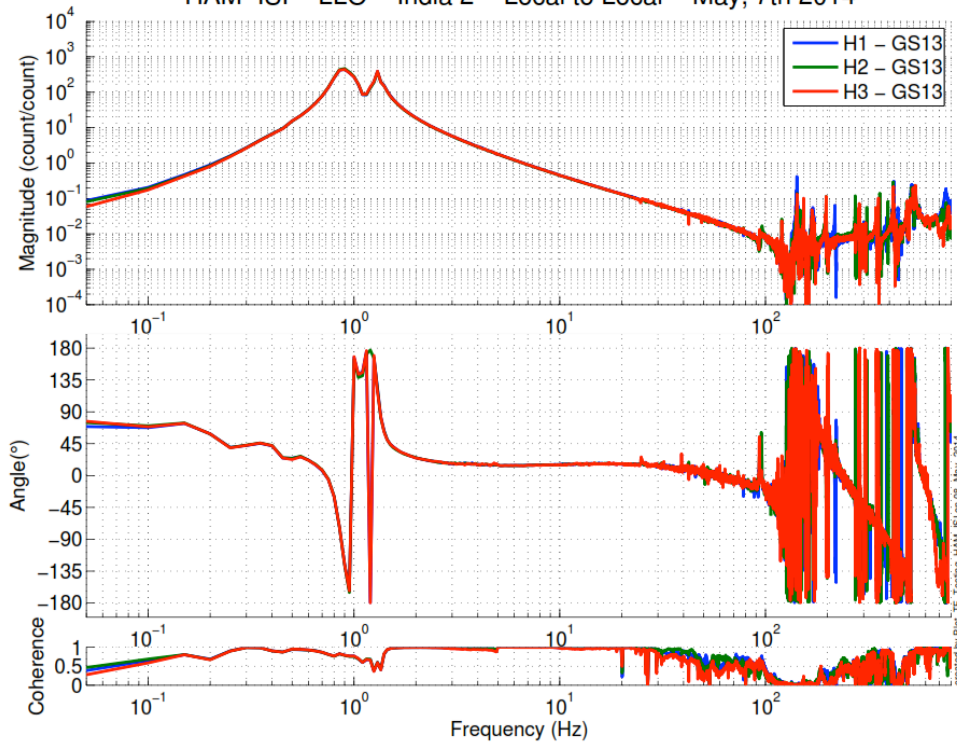


Table 20: Local to Local Measurements – Horizontal inertial sensors

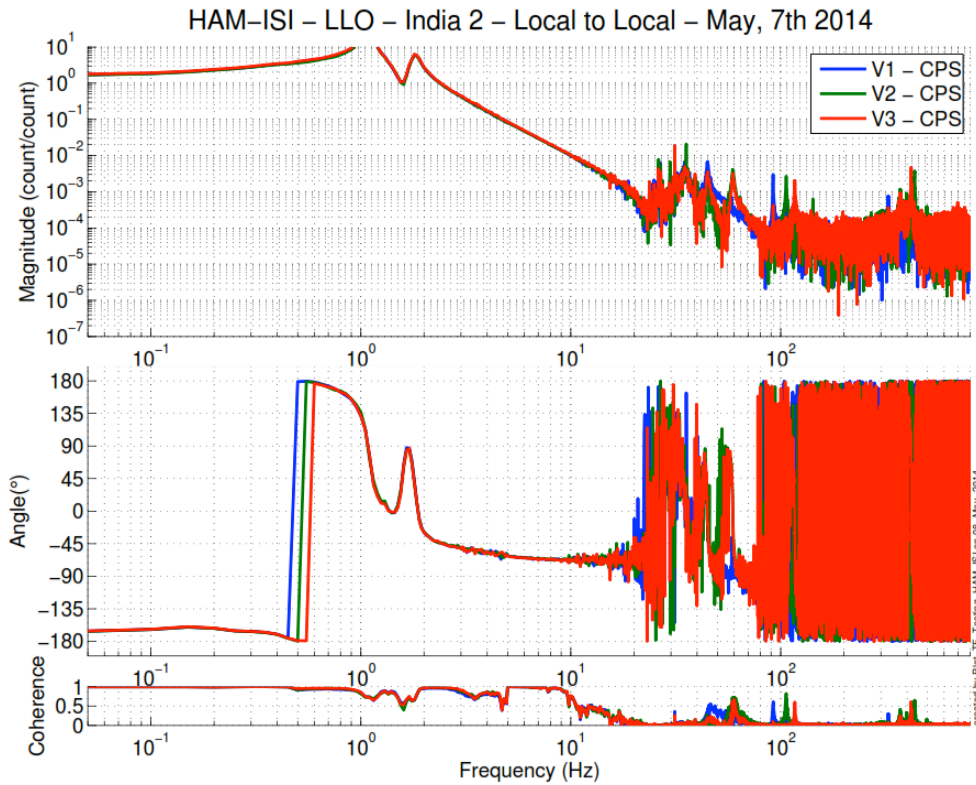


Table 21: Local to Local Measurements – Vertical capacitive sensors

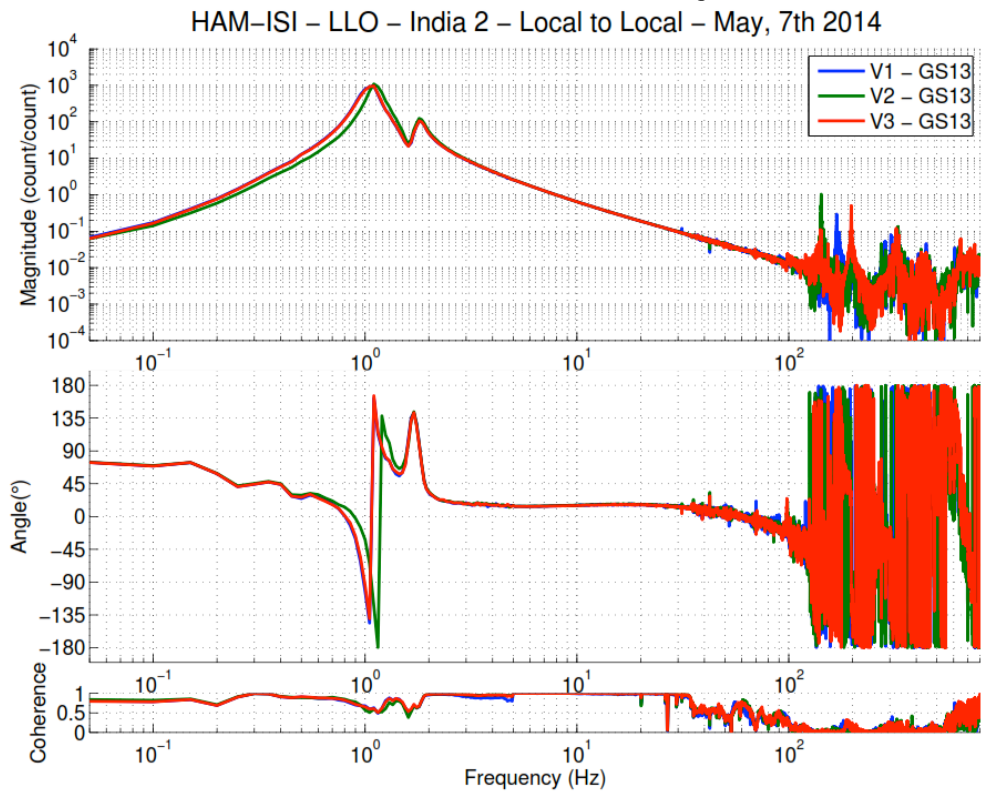


Table 22: Local to Local Measurements – Vertical inertial sensors

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

Issues/difficulties/comments regarding this test:

**Acceptance criteria:**

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

**Test result:**

**Passed:** \_\_\_\_

**Failed:** \_\_\_\_

**Waived:** X

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

This is the 2nd unit which is 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:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_2/Transfer\_Functions/Measurements/Undamped/*

- Plot\_LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_2014\_05\_07.m

**Local to local figures in SVN at:**

*/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Figures/Transfer\_Functions/Measurements/Undamped*

- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_H\_CPS\_50mHz\_800Hz\_wRef\_2014\_05\_07.fig
- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_V\_CPS\_50mHz\_800Hz\_wRef\_2014\_05\_07.fig
- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_H\_GS13\_50mHz\_800Hz\_wRef\_2014\_05\_07.fig
- LLO\_HAM\_ISI\_India\_2\_TF\_L2L\_V\_GS13\_50mHz\_800Hz\_wRef\_2014\_05\_07fig

**GS13, Local to local measurement**

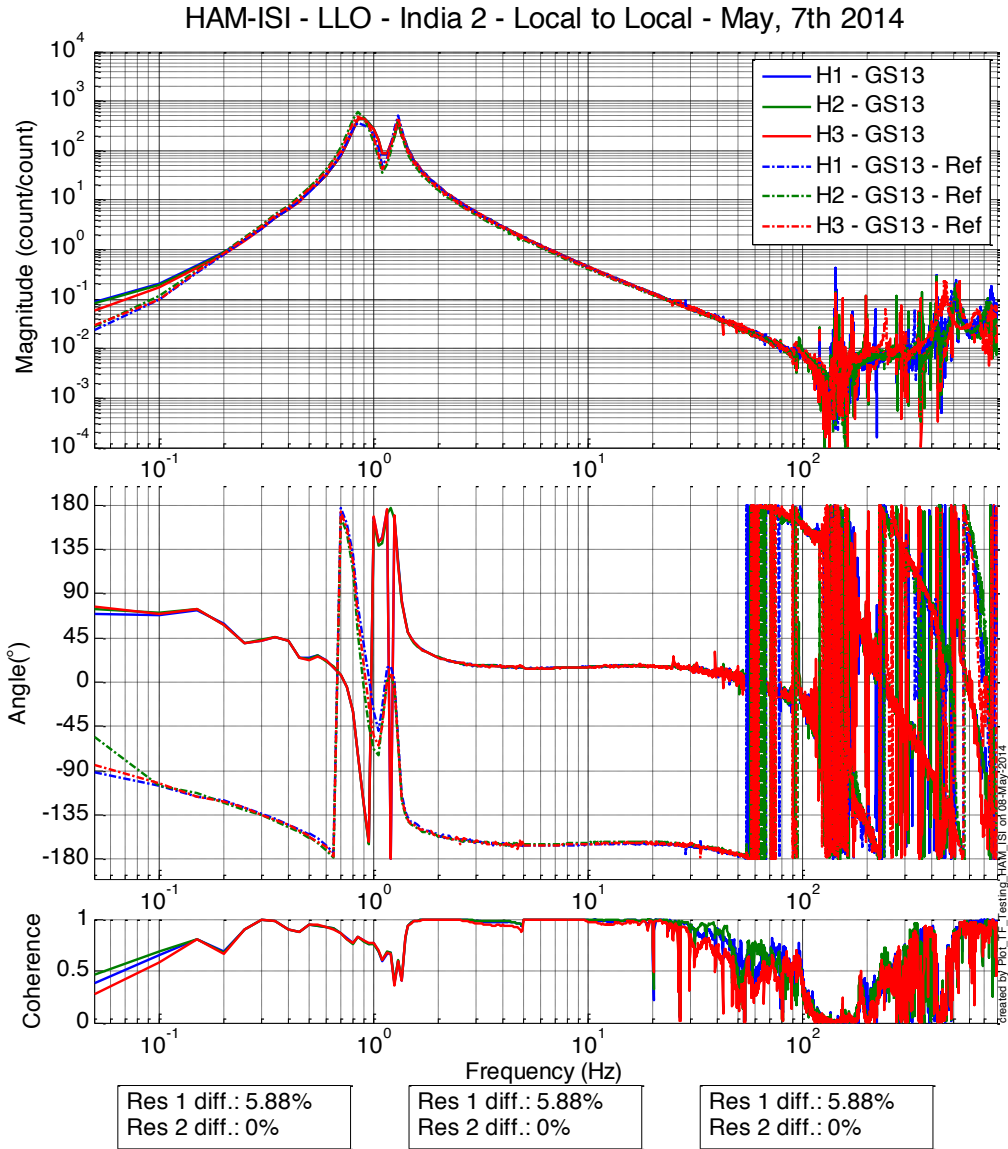


Figure - Local to local measurements comparison with LHO UNIT 2 – Horizontal GS-13

HAM-ISI - LLO - India 2 - Local to Local - May, 7th 2014

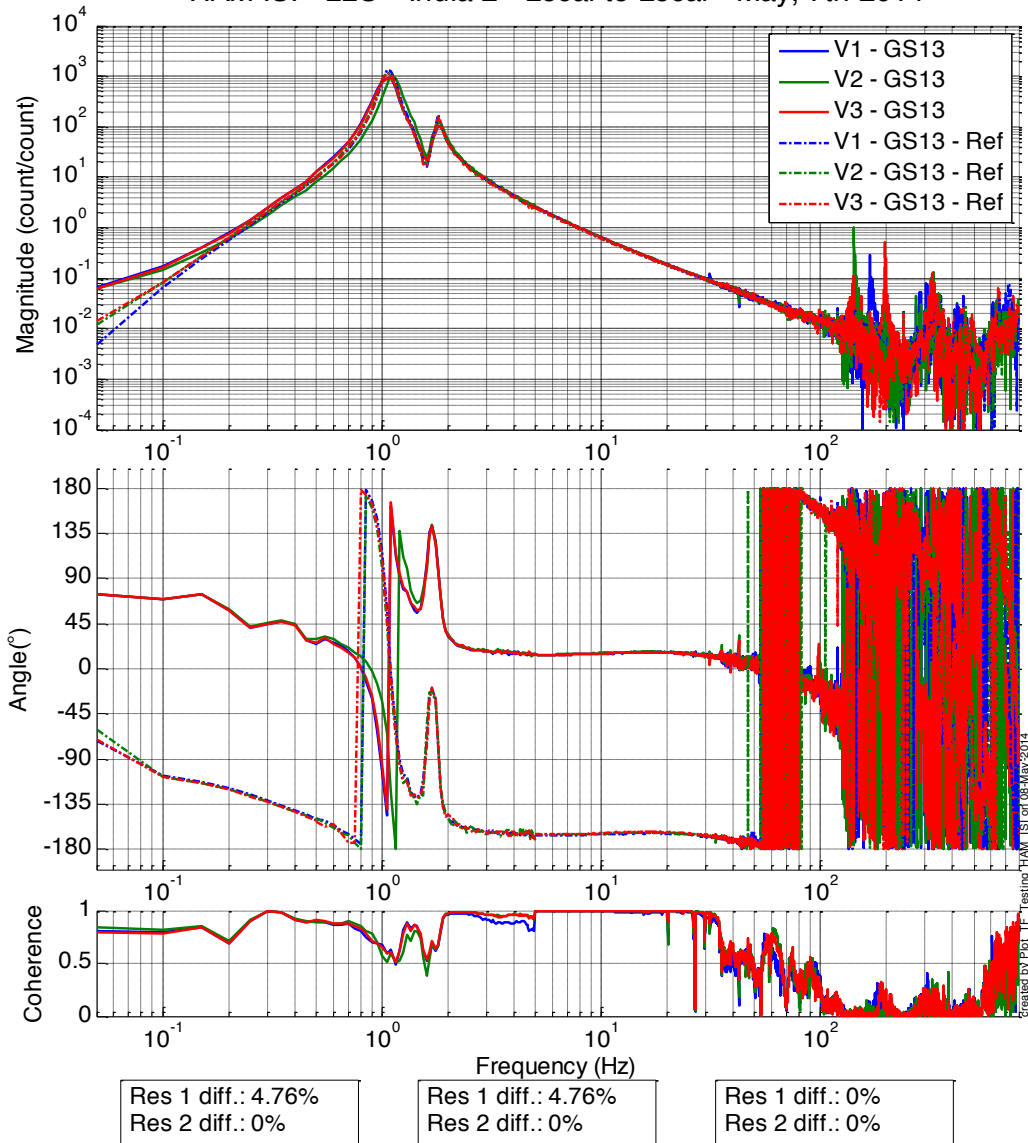


Figure - Local to local measurements comparison with LHO UNIT 2 – Vertical GS13

CPS, Local to local measurement, Undamped

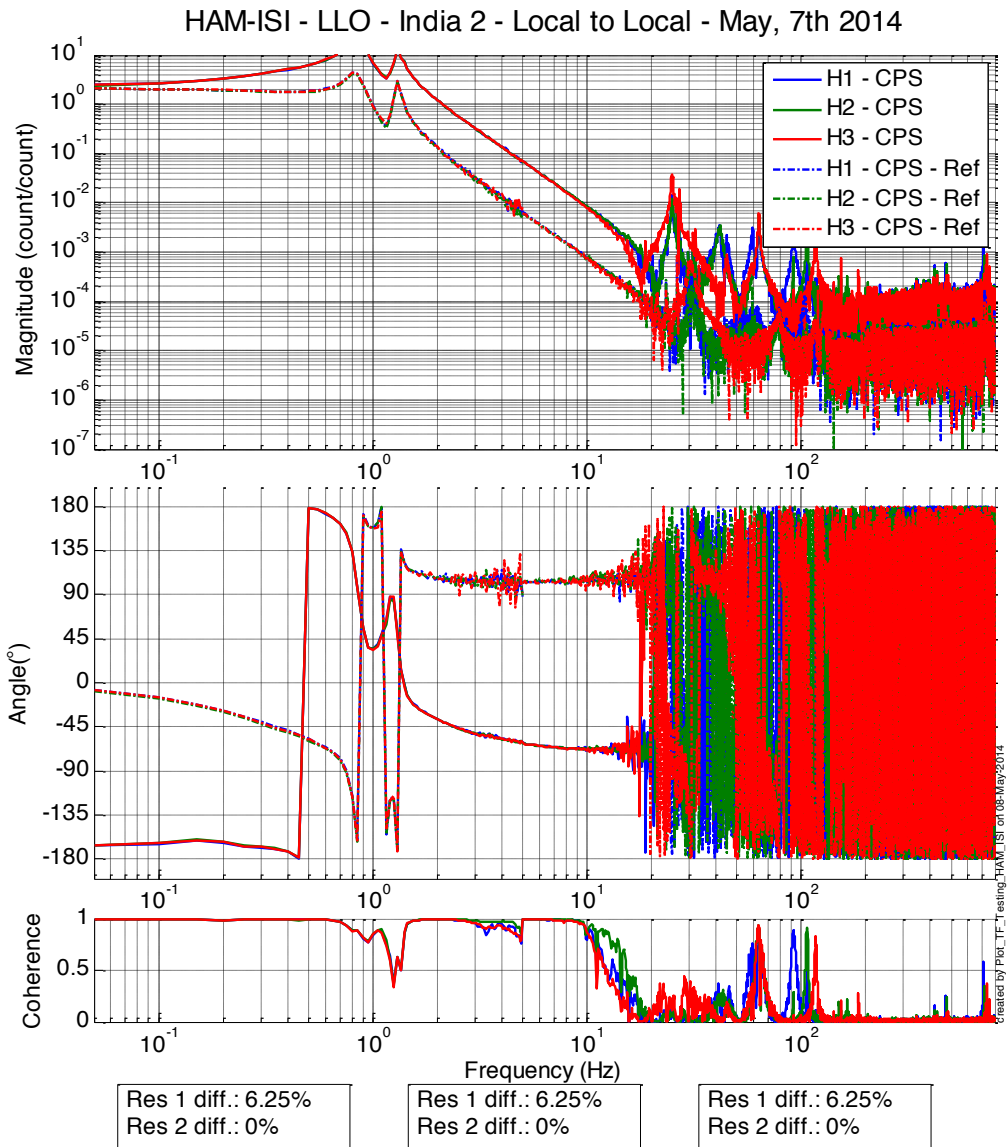


Figure - Local to local measurements comparison – Horizontal Position sensors



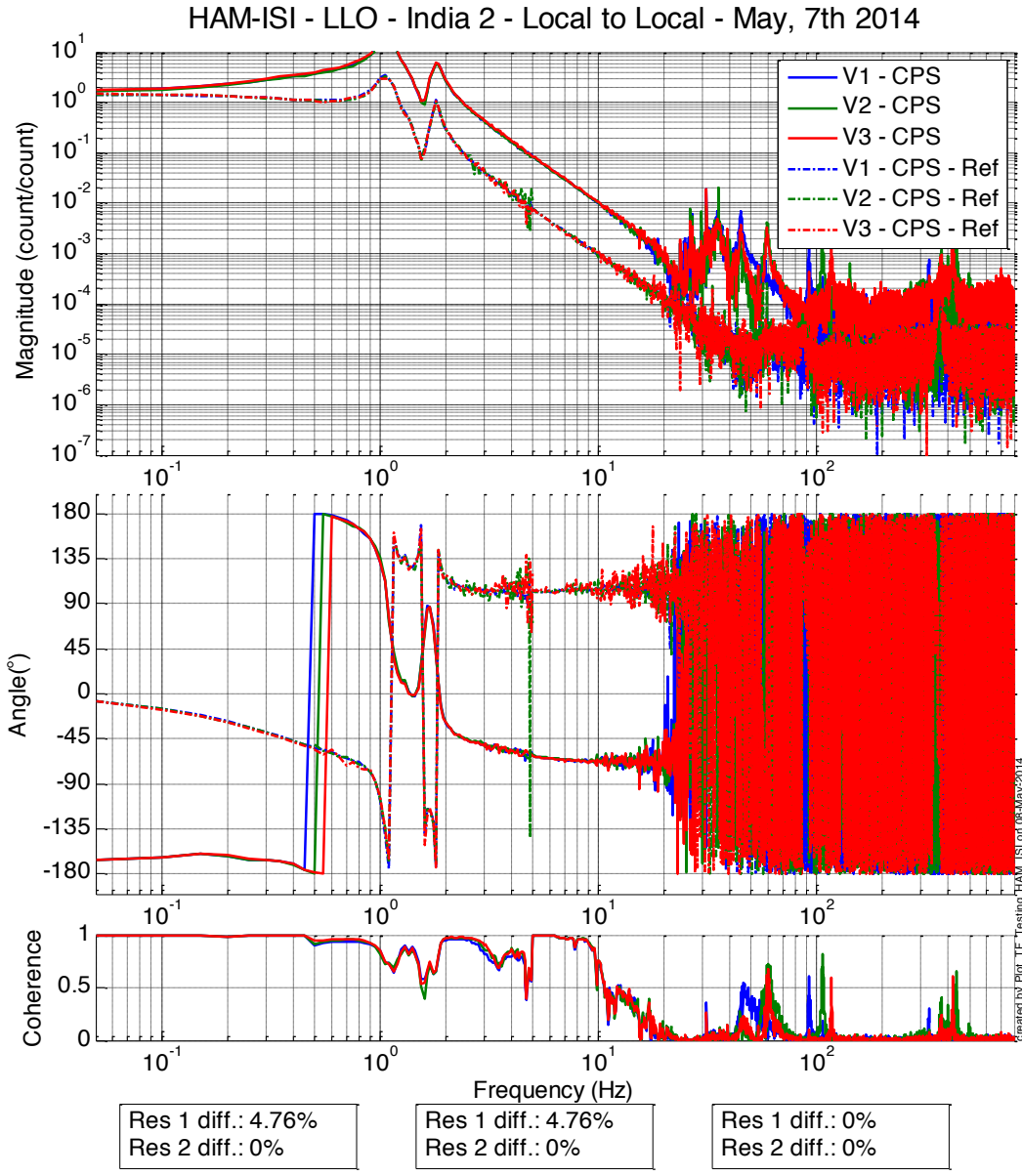


Figure - Local to local measurements comparison – Vertical Position sensors

- Step 17.2 - Cartesian to Cartesian - Comparison with Reference

**Scripts files for processing and plotting in SVN at:**

*ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Transfer\_Functions/Measurements/Undamped/*

- Plot\_LLO\_HAM\_ISI\_India\_1\_TF\_C2C\_2011\_08\_02.m

**Cartesian to Cartesian figures in SVN at :**

*/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Figures/Transfer\_functions/Measurements/Undamped*

**Acceptance criteria:**

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



**Test result:**

**Passed:** \_\_\_

**Failed:** \_\_\_

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

**Scripts files for processing and plotting in SVN at:**

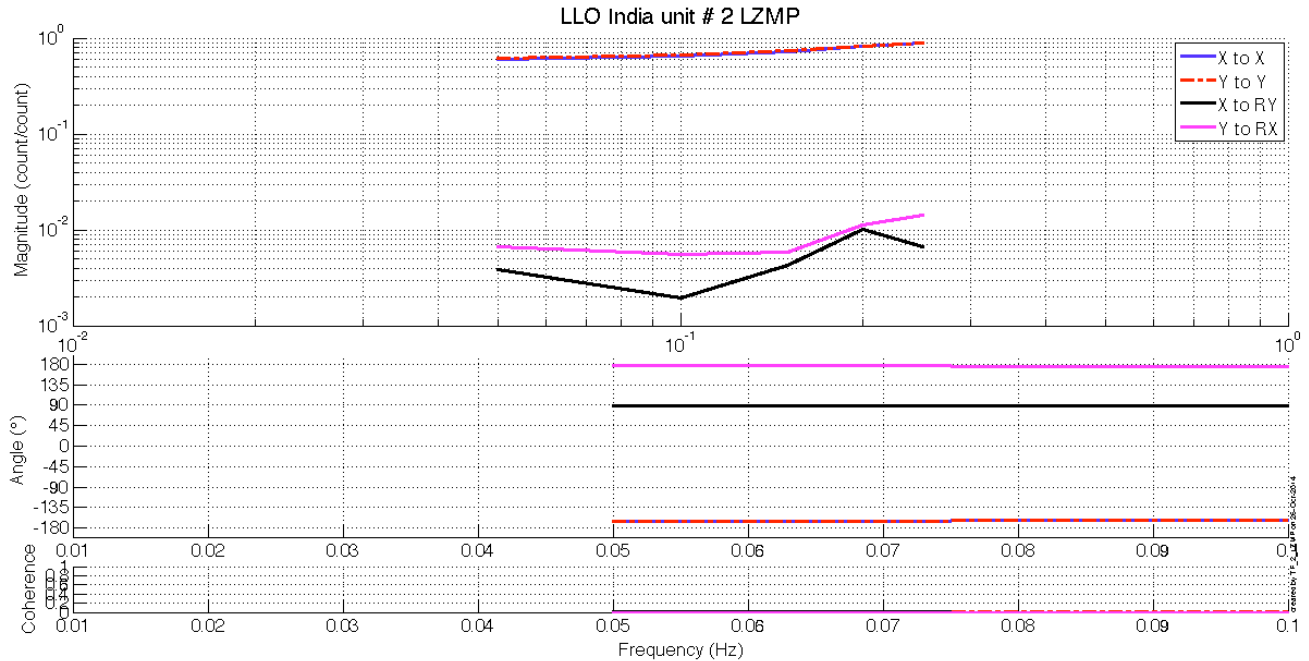
*ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Misc/*

- TF\_2\_LZMP.m

**Figures in SVN at:**

*ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Misc/*

- LLO\_India\_Unit\_2\_LZMP\_26-Oct-2014.fig
- LLO\_India\_Unit\_2\_LZMP\_26-Oct-2014.pdf



LMZP Offset X - mm

1.0643

LMZP Offset Y - mm

1.9712

Issues/difficulties/comments regarding this test:

LZMP data was missing. It was processed using the low frequency part of the existing L2L Transfer functions, applying the input/output filters to that, and pushing it into the Cartesian basis before doing the regular LZMP computation

LZMP plotting functions displays phase and coherence in a non-ideal way. This is very minor, and not worth updating for now.

**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:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Transfer\_Functions/Simulation/Damping*

**Figures in SVN at:**

*/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Figures/Transfer\_Functions/Simulations/Damping/*

**Results are saved in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Transfer\_Functions/Simulations/Damping/*

**Acceptance criteria:**

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

**Test result:**

**Passed:** \_\_\_\_

**Failed:** \_\_\_\_

▪ **Step 19.2 - Powerspectra – Experimental**

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_#/Powerspectra/Damping/*

**Scripts files for taking data and plotting in SVN at:**

*/ligo/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/India\_#/Figures/Powerspectra/Damping/*

**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 HAM India 2. The known issues are summed up here:

- Sensor gaps not recorded on the jig (III Step 2 & 3).
- III Step 2 Setup Sensors Gap, the standard deviations are higher than the spec.
- The Vertical GS13 Post Modification Huddle and Driven Tests for SN V704 are not acceptable, although the seismometer passed QA. An acceptable test may have been run, but not saved. All further tests show no sign of incorrect modification.
- Step 5 Blade Profile, one blade is out of spec by 3 mil.
- III Step 12 Vertical Spring Constant, the average spring constant is out of spec by 0.8%.
- III Step 13 Static Testing in the Local Basis, H3-H1 & H2-H3 non-collocated sensors are out of spec by 9 and 107 counts, respectively.
- The Cartesian Basis Static Testing (III Step 15) script is not running correctly.

When this Unit is approved, it will be put in a shipping container and stored to be shipped to India later.