

*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO- E1000330 V2

*LIGO*

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**aLIGO HAM-ISI, Pre-integration Test Report, Phase I, LLO  
India #1 (post-assembly, before storage)**

E1000330 – V2

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Distribution of this document:  
Advanced LIGO Project

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## *Introduction*

This first Unit for LIGO India was built in fall 2013, and was tested in October/November 2013, 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
11982	NR	NR	NR	NR	NR	NR	NR
11995	NR	NR	NR	NR	NR	NR	NR
12010	NR	NR	NR	NR	NR	NR	NR
12003	NR	NR	NR	NR	NR	NR	NR
11993	NR	NR	NR	NR	NR	NR	NR
12037 → 12058	NR	NR	NR	NR	NR	NR	NR

NR: not recorded

**Note:** CPS V3 12037 was replaced by 12058 because its behavior was different than the other verticals in the TFs.

### Sensors noise spectra measured before baking:

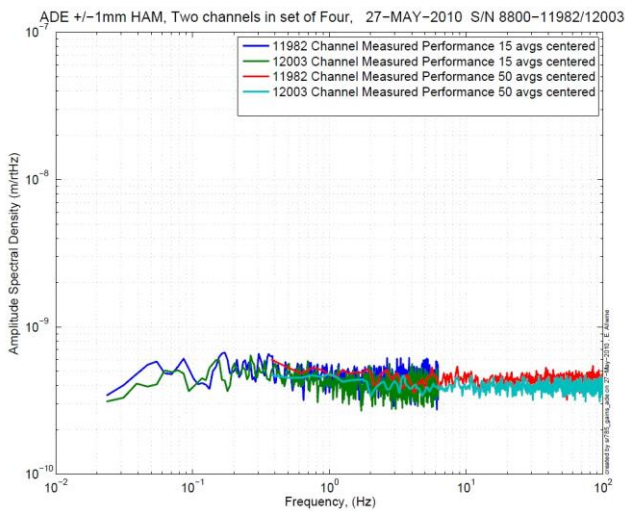


Figure 1: H1 and V1 sensor noise

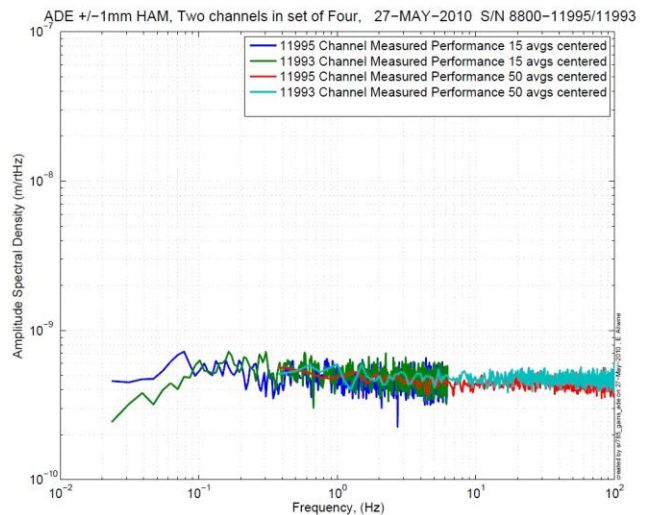


Figure 2: H2 and V2 sensor noise

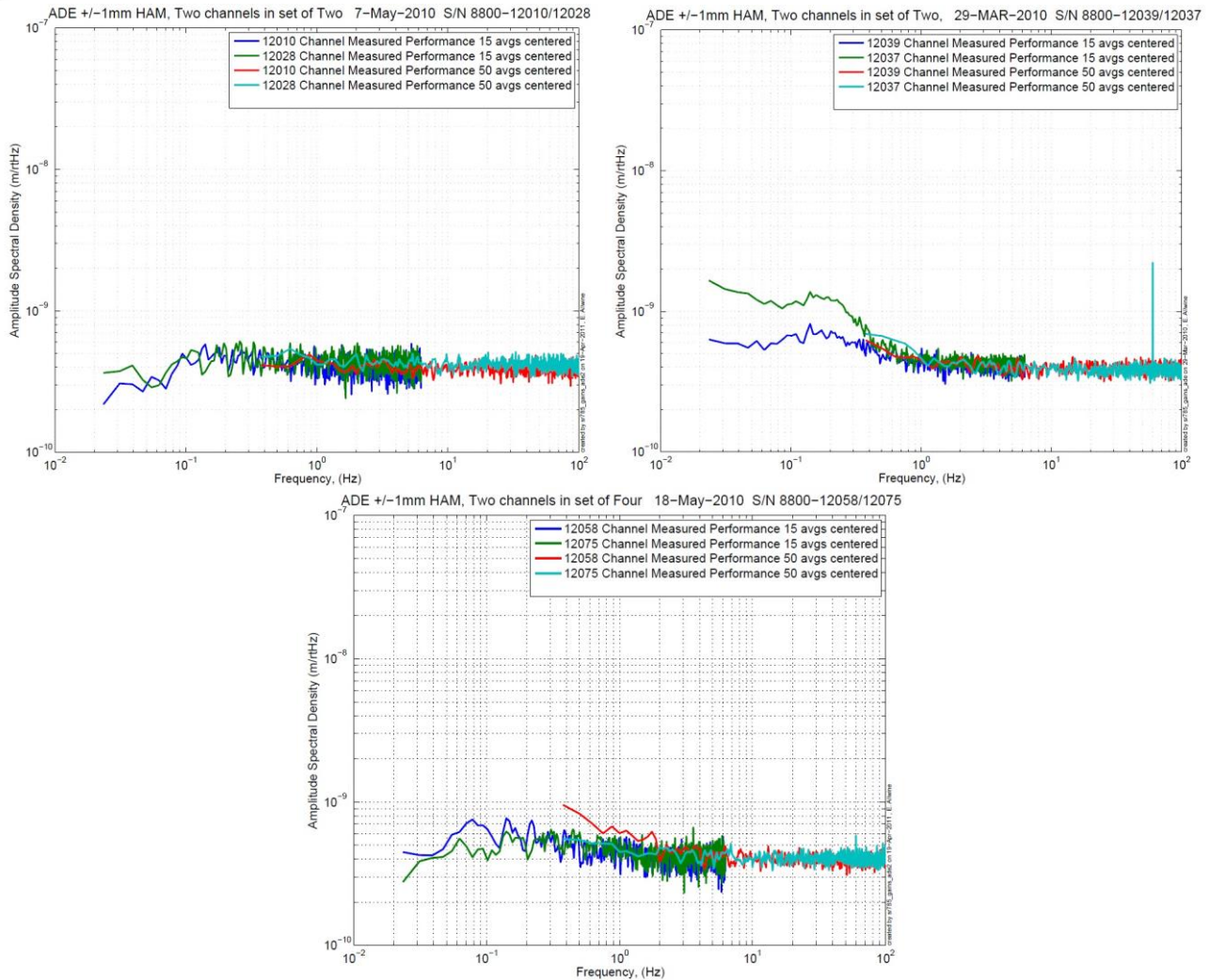


Figure 3: H3 (12010) and V3 (12037 & 12058) sensor noise

**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\_Raw ASCII*

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

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

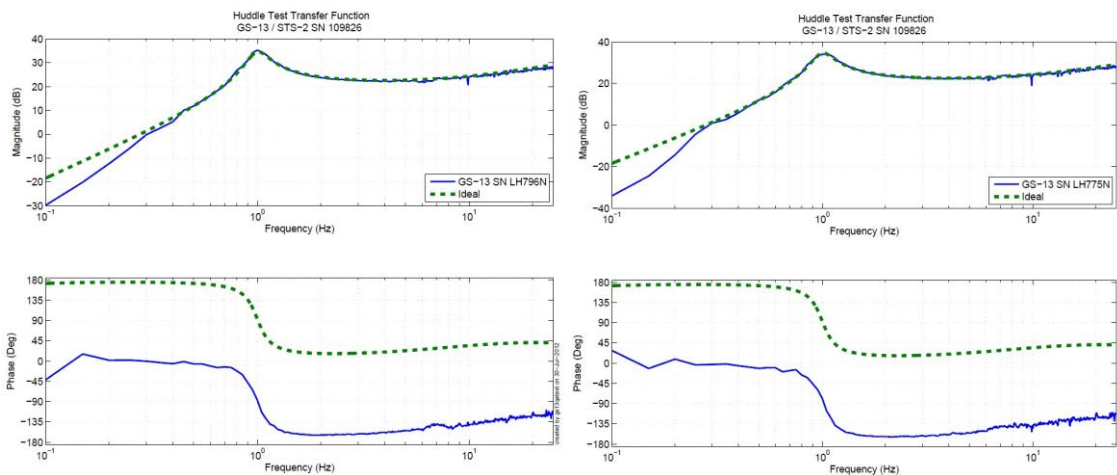
- gs13qatest.m

**Figures in SVN at:**

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

▪ **Step 2.1 – Horizontal GS-13s**

**Huddle testing**



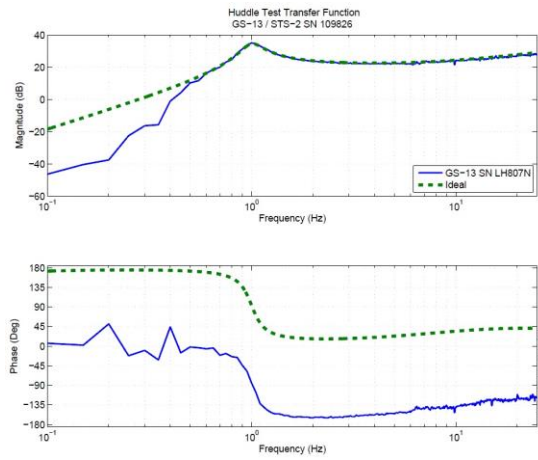


Figure 4: Huddle testing of Horiz GS-13 796, 775, and 807 after aLIGO modifications



## Step 2.2 – Vertical GS-13s

### Huddle testing

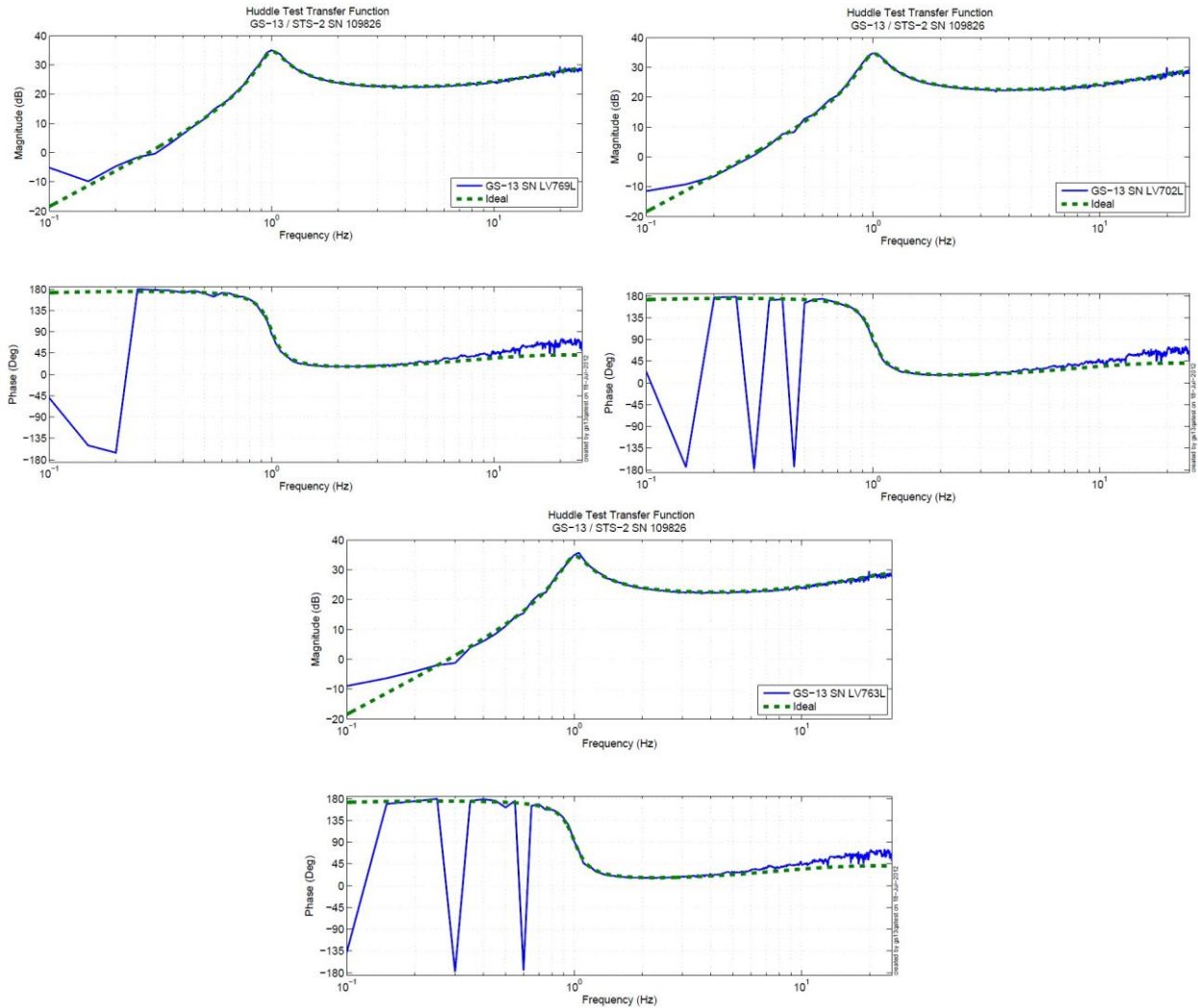


Figure 5: Huddle testing of Vert GS-13 769, 702 and 763 after aLIGO modifications

Driven testing

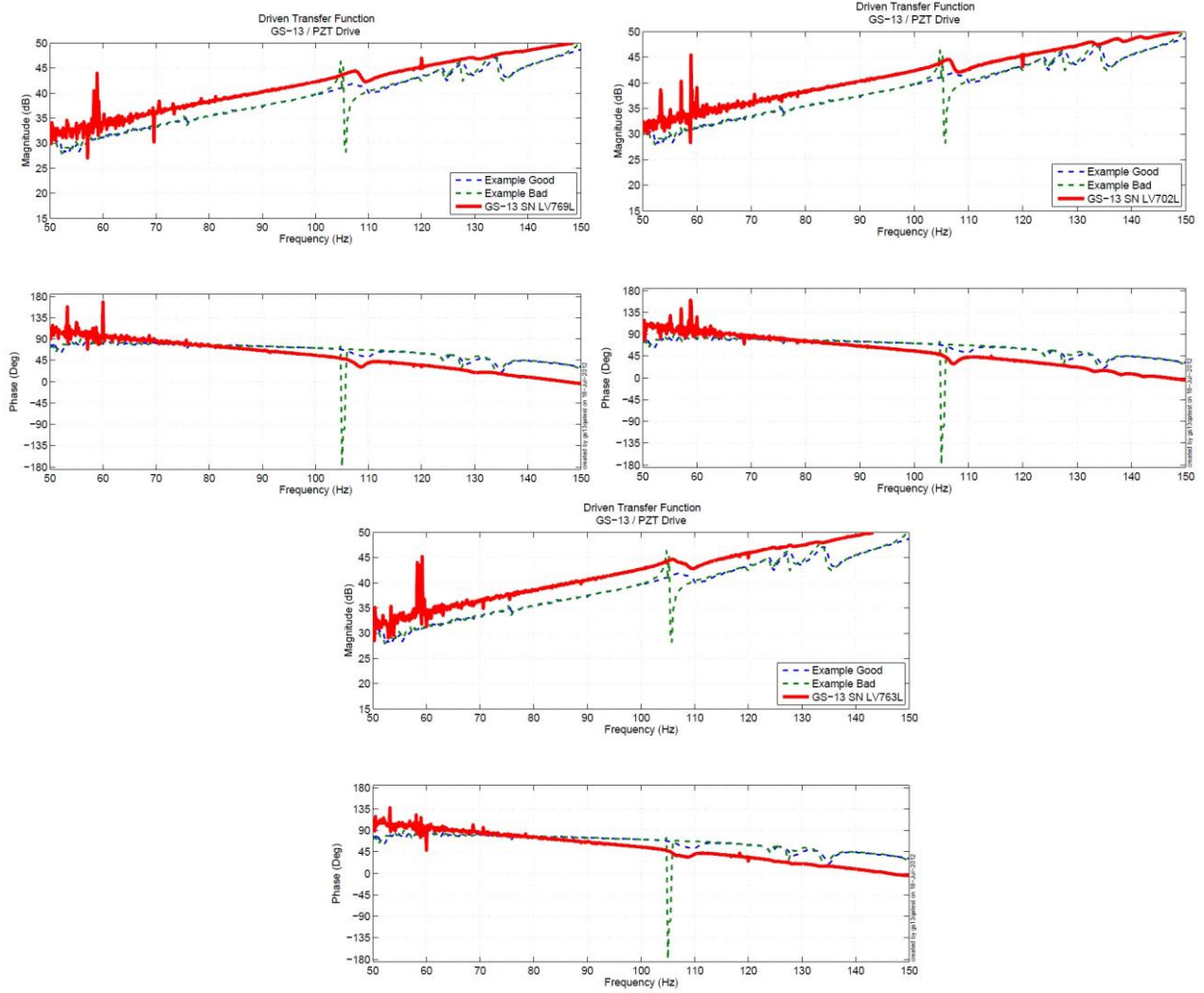


Figure 6: Driven Transfer Function of Vert GS-13 769, 702 and 763 after aLIGO modifications

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.

<p>Actuator Serial #: L133          Operator Name: Gordon, Matt          Date: 4/12/2010 Time: 2:51 PM          Actuator Coil Resistance: 6.43 Ohms, PASS          Ambient Temperature: 73.3 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.529          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.505</p>	<p>Actuator Serial #: L069          Operator Name: Gordon, Matt          Date: 11/23/2009 Time: 9:41 AM          Actuator Coil Resistance: 6.29 Ohms, PASS          Ambient Temperature: 69.8 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.537          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.507</p>
<p>Actuator Serial #: L157          Operator Name: Gordon, Matt          Date: 4/13/2010 Time: 6:24 PM          Actuator Coil Resistance: 6.45 Ohms, PASS          Ambient Temperature: 73.3 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.525          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.503</p>	<p>Actuator Serial #: L083          Operator Name: Gordon, Matt          Date: 11/21/2009 Time: 5:52 PM          Actuator Coil Resistance: 6.27 Ohms, PASS          Ambient Temperature: 69.7 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.527          Y Travel Limit (inches): 0.205          Z Travel Limit (inches): 0.508</p>
<p>Actuator Serial #: L144          Operator Name: Gordon, Matt          Date: 4/13/2010 Time: 9:52 AM          Actuator Coil Resistance: 6.39 Ohms, PASS          Ambient Temperature: 73.31 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</p>	<p>Actuator Serial #: L130          Operator Name: Gordon, Matt          Date: 4/12/2010 Time: 1:52 PM          Actuator Coil Resistance: 6.41 Ohms, PASS          Ambient Temperature: 73.3 F          Hi Pot Test Results: 1000 MOhms, PASS          X Travel Limit (inches): 0.540          Y Travel Limit (inches): 0.208          Z Travel Limit (inches): 0.506</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		029	045	003
D071100	Spring		037	043	048
D071102	Flexure		003	012	020
ADE	Position sensor	Horizontal	11982	11995	12010
		Vertical	12003	11993	12037
D047812	GS-13 pod	Horizontal	29	85	90
		Vertical	25	33	51
D047823	L4C pod	Horizontal			
		Vertical			
D0902749	Actuator	Horizontal	L133	L157	L144
		Vertical	L069	L083	L130

- *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	0.487	0.485	+ 2
2	0.503	0.494	+ 9
3	0.496	0.4875	+ 8.5

**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")
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**

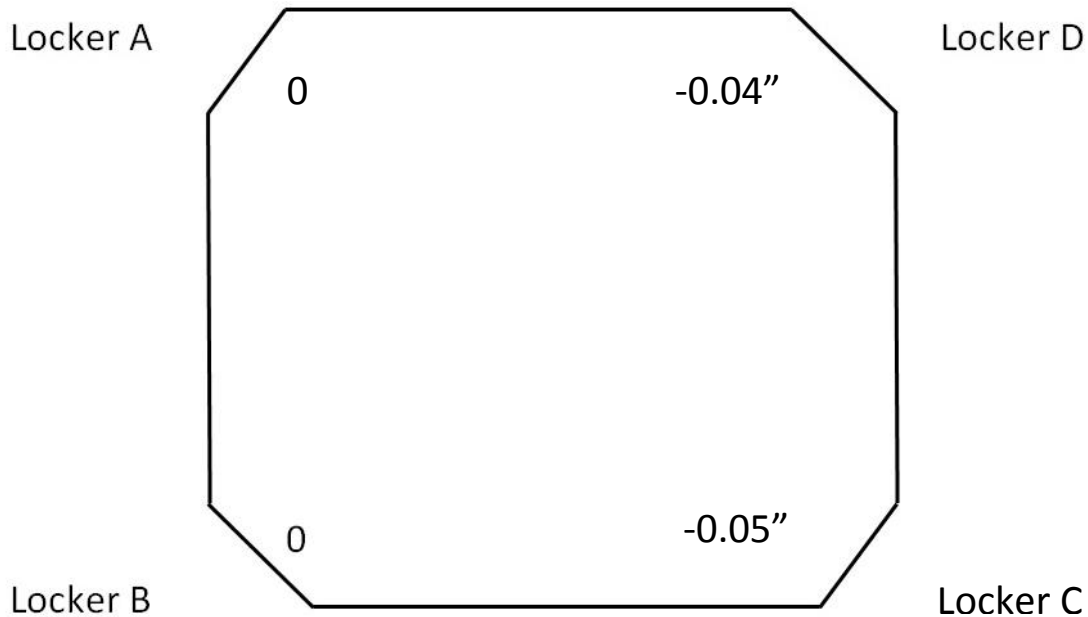
- Gaps must be within 0.010" of design (i.e. 0.090" and .070" pass, but 0.095" and 0.065" doesn't).

Test result:

Passed:   X  

Failed:   \_\_\_  

▪ *Step 7: Check level of Stage 0*



Max angle = (0.05)/72=

**Note:** These results were the ones before we leveled the test stand. We didn't record the results after leveling it (but it was within specs). We will try to re-shoot Stage 0 and the Optical Table and record the numbers this time.

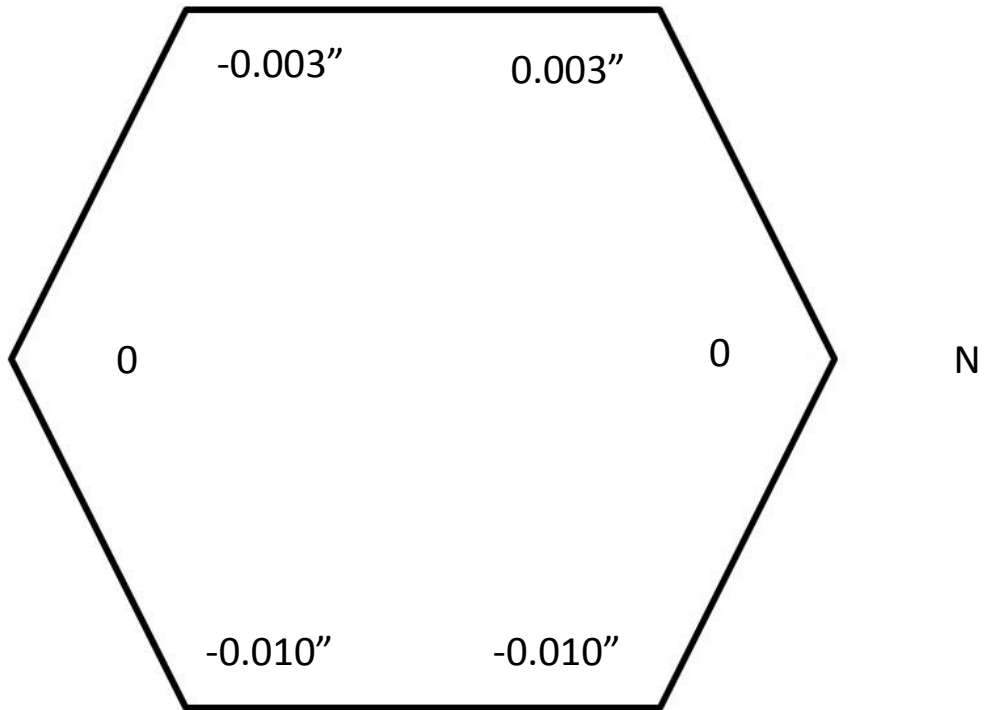
**Acceptance Criteria**

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

**Test result:** Passed: \_\_\_ Failed: \_\_\_ Waived: 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 = (0.013)/85.59= 152 urad**

**Note:** These results were the ones before we leveled the test stand. We didn't record the results after leveling it (but it was within specs). We will try to re-shoot Stage 0 and the Optical Table and record the numbers this time.

**Acceptance Criteria**

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

**Test result:** Passed: \_\_\_ Failed: \_\_\_ Waived: X

▪ *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	1	47.9	21.73
w1							2	54.4	24.68
w2		1			1	1	1	51.8	23.50
w3						1	1	42.8	19.41
w4						2	1	58.4	26.49
w5			1				2	56.6	25.67
w6	1					1	1	43.4	19.69
w7		1	1				2	57.7	26.17
w8						2	1	58.4	26.49
Side Masses Total	2	2	2	1	1	8	12	471.4	213.82

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	15.92
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)	213.82	90.08	277	580.9
Torque x at O (N.m)		0.00	-69.02	
Torque y at O (N.m)		5.26	0	

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)
A	129
B	130
C	127
D	125

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
A	-0.5	-1
B	0	0
C	-1	0
D	1	-1.25

Table 5: 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	S1103354
		S1000316
Anti Image filter	D070081	S1000249
Anti aliasing filter	D1000269	S1106137
		S1106138
Interface chassis	D1000067	S1102219
		S1106356
		S1106358

Table 6: Inventory electronics

#### Acceptance Criteria

- Inventory is complete

Test result:

Passed:  X

Failed:    

- *Step 2 - Set up sensors gap*

#### Capacitive position sensor readout after gap set-up

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
H1	587.62	18.728	436.5	35.03	482.56	37.98
H2	-239.97	11.364	-246.13	20.126	-209.3	24.27
H3	109.61	14.577	109.6	17.622		
V1	129.91	25.659	228.61	33.354	263.14	37.30
V2	957.49	34.115	1019	43.678	1063	50.19
V3	553.89	51.034	759.89	22.382		

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:**     

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

Sensors	Table locked		Table unlocked	
	Offset (Mean)	Std deviation	Offset (Mean)	Difference
H1	193.64	25.681	1151	957.36
H2	-236.13	26.746	154.17	390.3
H3	151.94	25.349	-201.41	-353.35
V1	163.02	17.694	-103.31	-266.33
V2	28.829	35.983	1630.9	1602.071
V3	170.9	26.131	918.5	747.6

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”*

Sensors	CPS read out		Calculated after calibration	
	UP (Counts)	Down (Counts)	UP (mil)	Down (mil)
V1	20024	-18943	23.8	-22.6
V2	20666	-17876	24.6	-21.3
V3	20925	-19376	24.9	-23.1
Sensors	CPS read out		Calculated after calibration	
	CW(-RZ)	CCW (+RZ)	CW (mil)	CCW (mil)
H1	21643	-20224	25.8	-24.1
H2	22291	-22916	26.5	-27.3
H3	22194	-19112	26.4	-22.8

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	-23492	24456		X
H2	-23879	23441		X
H3	-24668	25008		X
V1	-18884	20369		X
V2	-24970	27250		X
V3	-22098	22561		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 Absolute 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**

We swapped V3 CPS 12037 with 12058 and retook this test.

**Data files in SVN at:**

/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/ Powerspectra/Undamped  
 - LLO\_HAM\_ISI\_India\_1\_Calibrated\_PSD\_CPS\_GS13\_Unlocked\_Locked\_2013\_12\_23.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\_1/Figures/Powerspectra/Undamped  
 - LLO\_HAM\_ISI\_India\_1\_Calibrated\_PSD\_CPS\_Unlocked\_Locked\_2013\_12\_23.fig  
 - LLO\_HAM\_ISI\_India\_1\_Calibrated\_PSD\_GS13\_Unlocked\_Locked\_2013\_12\_23.fig

**CPS calibration:**

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

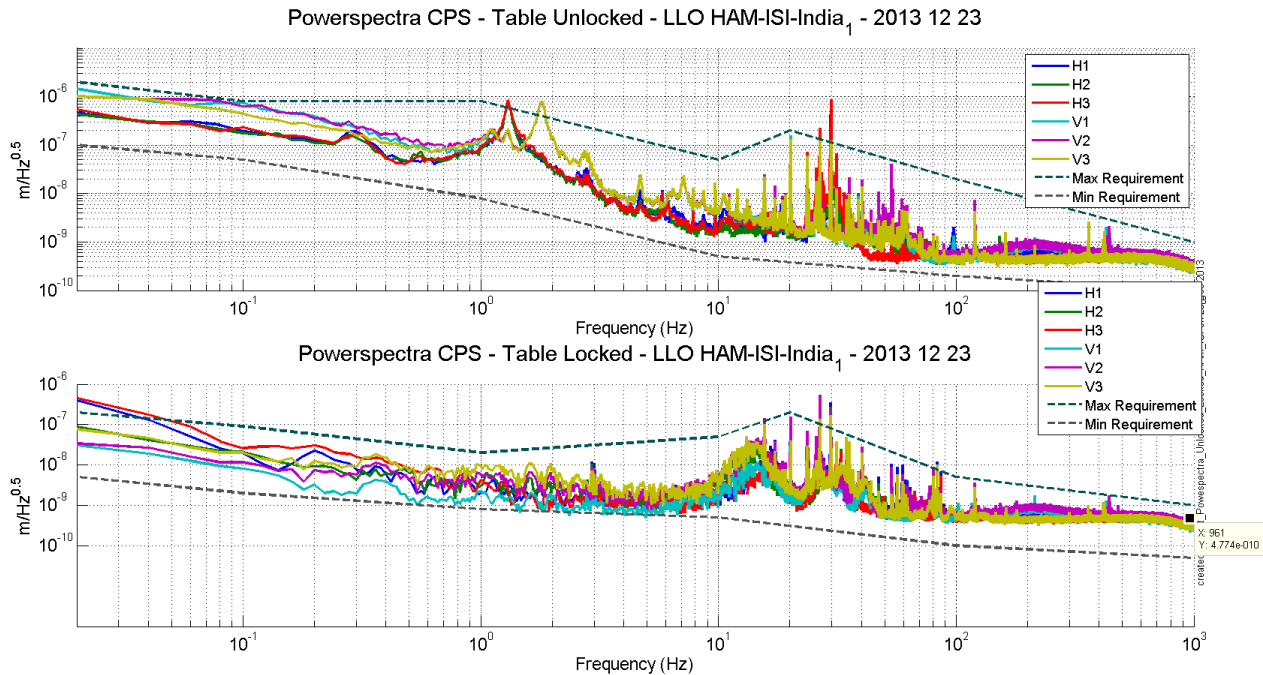


Figure 8: Calibrated CPS power spectrum

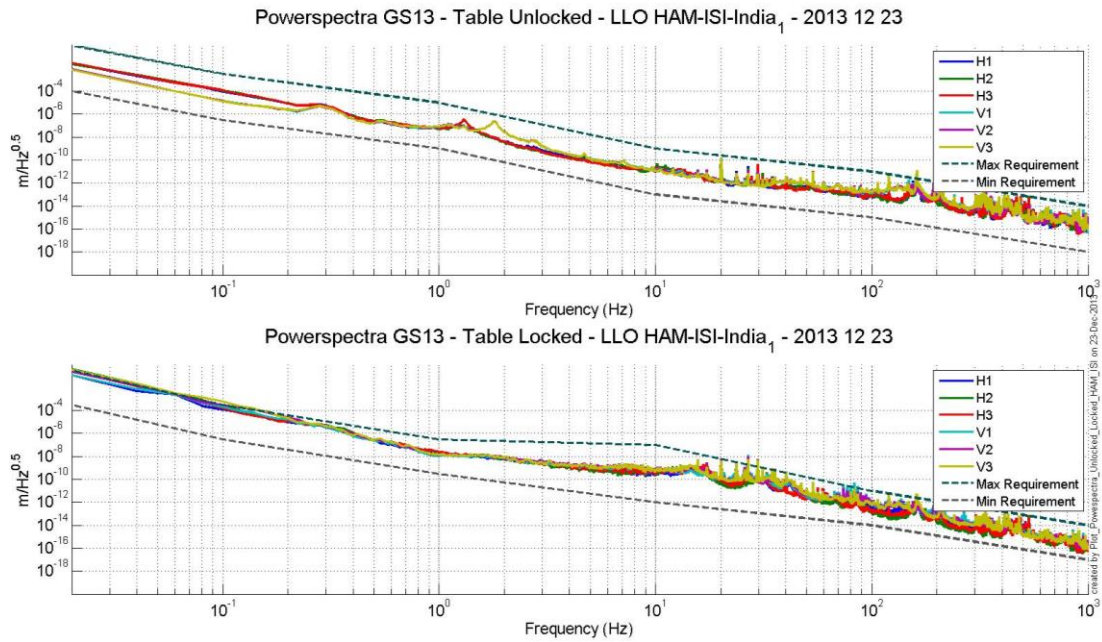


Figure 9: Power spectrum Calibrated GS13

**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 unlocked	Max	$2 \times 10^{-6}$	$8 \times 10^{-7}$	$8 \times 10^{-7}$	$5 \times 10^{-8}$	$2 \times 10^{-7}$	$2 \times 10^{-8}$	$10^{-9}$
		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

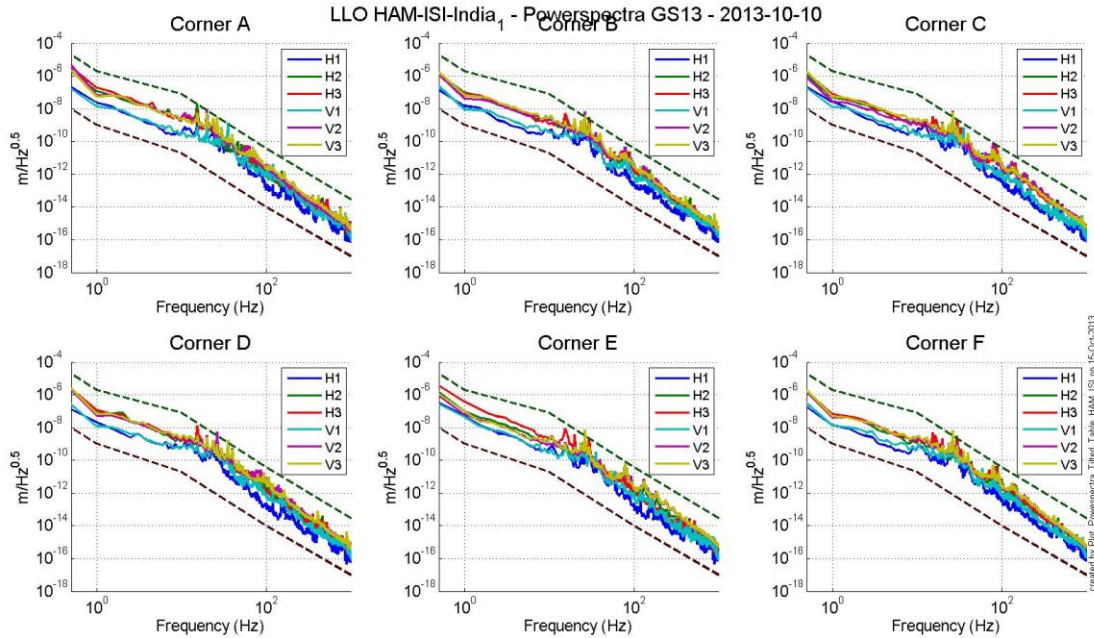
Test result:

Passed:  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 10: Power spectrum Calibrated GS13 with mass at corner**

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/ Powerspectra/Undamped*  
 - LLO\_HAM\_ISI\_India\_1\_Calibrated\_PSD\_GS13\_Table\_Tilted\_2013\_10\_10.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\_1/Figures/ Powerspectra/Undamped*  
 - LLO\_HAM\_ISI\_India\_1\_Calibrated\_PSD\_GS13\_Table\_Tilted\_2013\_10\_10.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	Max	$2 \times 10^{-5}$	$2 \times 10^{-6}$	$8 \times 10^{-8}$	$4 \times 10^{-11}$	$3 \times 10^{-14}$
	Tilted	Min	$10^{-8}$	$10^{-9}$	$2 \times 10^{-11}$	$10^{-14}$	$10^{-17}$

**Table 11: Table Tilted- Sensors power spectra requirements**

**Test result:**

**Passed:**   

**Failed:**   X



- **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 (+)	
	0.310		0.309		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		0.314		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>	-23492	24456
<b>H2 readout (count)</b>	-23879	23441
<b>H3 readout (count)</b>	-24668	25008
<b>V1 readout (count)</b>	-18884	20369
<b>V2 readout (count)</b>	-24970	27250
<b>V3 readout (count)</b>	-22098	22561

Table 13: Range of motion - Local drive

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Static\_Tests*  
 - LLO\_HAM-ISI\_India\_1\_Range\_Of\_Motion\_1016201320131016.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	20	0	-19	
B	21	0	-20	
C	18	0	-19	
D	18	0	-19	
<b>Average</b>	19.25	0	-19.25	<b>38.5</b>

Sensors	Counts	Counts	Counts	Difference (Counts)
V1	-16108	-459.64	16397	32505
V2	-15132	1218.9	17635	32767
V3	-16104	390.69	15764	31868
	-15781.33	383.32	Average	32380.00

Table 14: Calibration of capacitive position sensors

**Vertical sensitivity:**  $32380/38.5 = 841$  count/mil

or  $841$  count/mil /  $1638$  V/count =  $0.513$ V/mil

or  $25400$ nm/mil /  $841$  mil/count =  $30.20$  nm/count

**Nominal Calibration**

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

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

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

**Difference with Nominal sensitivity =  $(840-841)/840=-0.12\%$**

**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	-783.96	-8618.7	-8550.5	-8544.7	-7787.34	-2.35E-04	8.34E+04
V2	790.7	-7009.4	-7047.6	-7053.3	-7827.47	-2.36E-04	8.30E+04
V3	273.08	-7911.7	-7905.9	-7899	-8178.61	-2.47E-04	7.94E+04
<b>Average (N/m)</b>							<b>2.46E+05</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 **1.47%**

Test result:

Passed: X

Failed:

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

		H1	H2	H3	V1	V2	V3
Actuators (1000 counts)	H1	-2121.57	-1321.94	-1267.80	103.79	85.01	-18.71
	H2	-1340.91	-2063.54	-1322.60	47.19	-4.63	30.95
	H3	-1368.23	-1303.04	-2084.10	49.69	14.17	7.25
	V1	-239.44	-129.64	324.40	-1558.91	-36.13	671.36
	V2	311.89	-44.67	-354.28	594.29	-1579.93	15.16
	V3	-276.18	465.20	-209.53	90.59	726.53	-1526.31

Table 16: Main and cross coupling

**Data files in SVN at:**

/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Static\_Tests

- LLO\_HAM\_ISI\_India\_1\_Sensor\_Readout\_Local\_20111126.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

- 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:**     

**Failed:**   X

▪ *Step 14 - Linearity test*

	Slope	Offset	Average slope	Variation from average (%)
H1	2.094	1963	2.0873	0.32
H2	2.064	813		-1.12
H3	2.104	383		0.80
V1	1.514	-732	1.5050	0.60
V2	1.499	826		-0.40
V3	1.502	161		-0.20

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

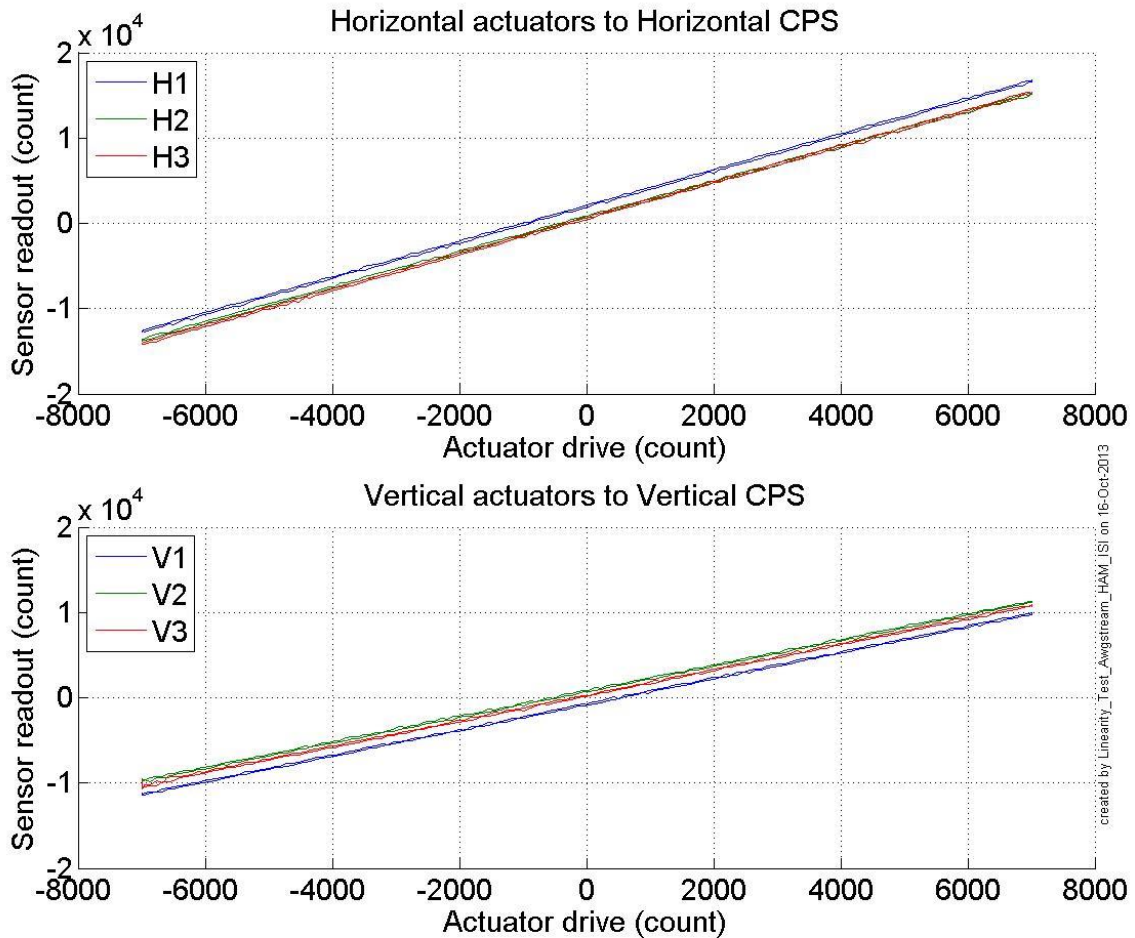


Figure 11: Horizontal and vertical actuators x HAM-ISI x sensors

**Data files in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Linearity\_test*  
- LLO\_HAM\_ISI\_India\_1\_Linearity\_test\_20131016.mat

**Figures in SVN at:**

*/ligo/svncommon/SeiSVN/seismic/HAM-ISI/X2/Data/India\_1/Figures/Linearity\_test*  
- LLO\_HAM\_ISI\_India\_1\_Linearity\_test\_20131016.fig  
- LLO\_HAM\_ISI\_India\_1\_Linearity\_test\_20131016.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*

1000 counts drive		X Drive	Y Drive	Z Drive	Rx Drive	Ry Drive	Rz Drive
Sensors readout (count)	H1	-245.489	509.831	48.381	564.031	357.551	1935.331
	H2	-211.228	-340.528	55.6723	-417.728	423.5823	2131.572
	H3	539.79	20.41	-67.07	59.49	-626.37	1946.03
	V1	-22.3	14.7	-203.3	529.7	1730.29	-54.3
	V2	12.9	48.6	-352.1	-1820.1	-398.1	-20.1
	V3	-32.79	4.31	-350.79	1261.41	-1307.39	17.81
	Direction read out	-15807.1	-15804	-8314	-81975	-81878	-78984

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:

		X Drive	Y Drive	Z Drive	Rx Drive	Ry Drive	Rz Drive
Sensors readout (count)	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:**

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

- LLO\_HAM\_ISI\_India\_1\_Data\_TF\_L2L\_50mHz\_500mHz\_20131125-191024.mat
- LLO\_HAM\_ISI\_India\_1\_Data\_TF\_L2L\_500mHz\_5Hz\_20131125-160450.mat
- LLO\_HAM\_ISI\_India\_1\_Data\_TF\_L2L\_5Hz\_200Hz\_20131121-144422.mat
- LLO\_HAM\_ISI\_India\_1\_Data\_TF\_L2L\_200Hz\_800Hz\_20131121-131047.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\_1/Transfer\_Functions/Measurements/Undamped/*

- Plot\_LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_2013\_10\_25.m

**Figures in SVN at:**

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

- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_V\_CPS\_50mHz\_800Hz\_2013\_11\_21.fig
- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_H\_GS13\_50mHz\_800Hz\_2013\_11\_21.fig
- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_H\_CPS\_50mHz\_800Hz\_2013\_11\_21.fig
- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_V\_GS13\_50mHz\_800Hz\_2013\_11\_21.fig

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

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

- LLO\_HAM\_ISI\_India\_1\_Data\_TF\_L2L\_2013\_11\_21.mat

The local to local transfer functions are presented below.

HAM-ISI - LLO - India 1 - Local to Local - November 21st, 2013

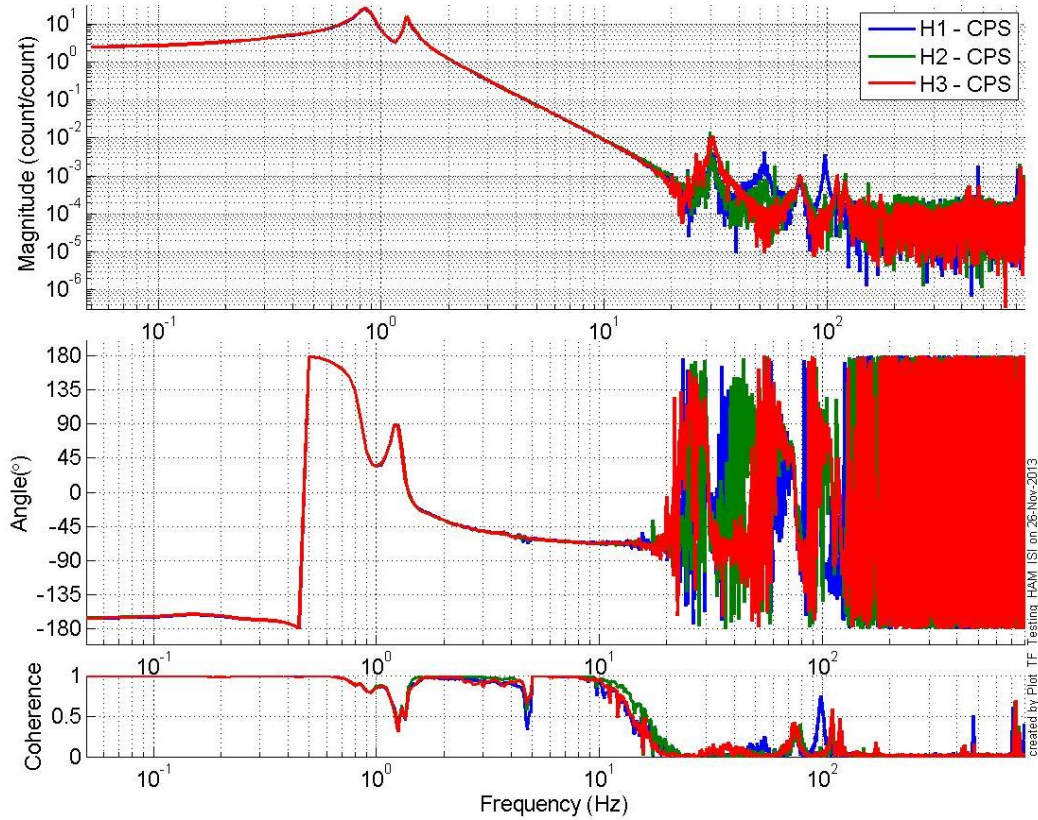


Table 19: Local to Local Measurements – Horizontal capacitive sensors

HAM-ISI - LLO - India 1 - Local to Local - November 21st, 2013

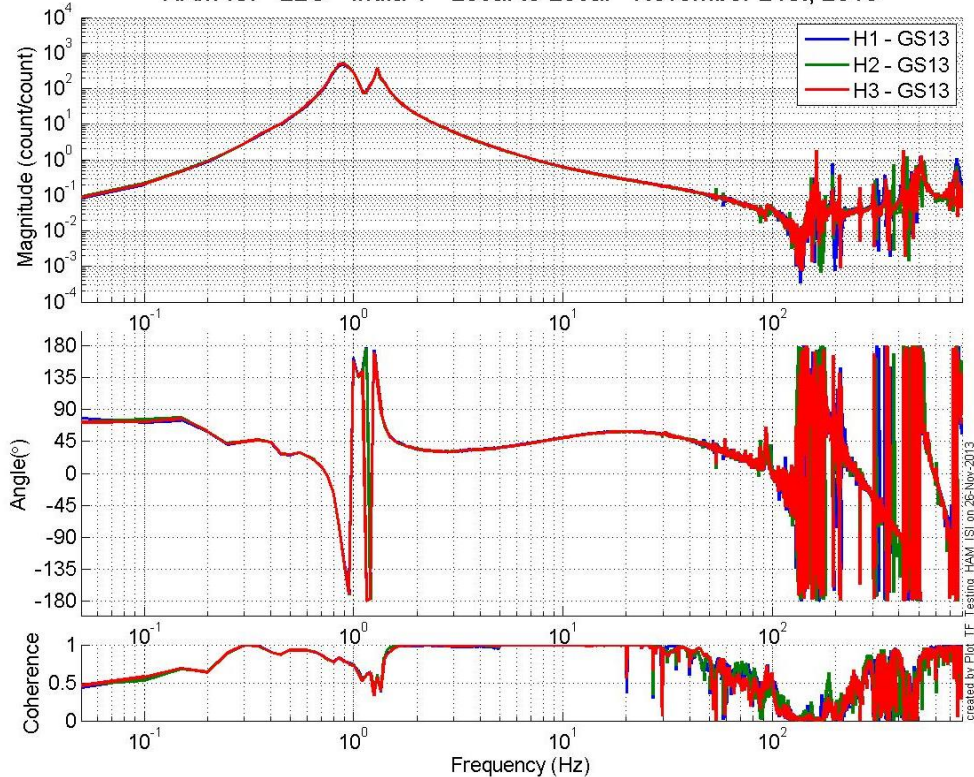
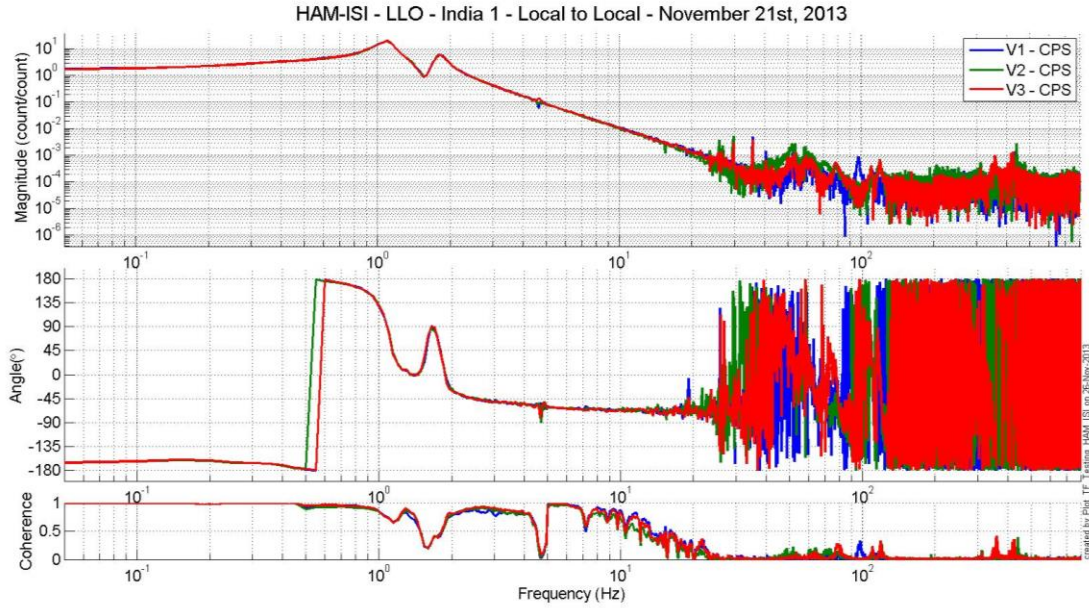
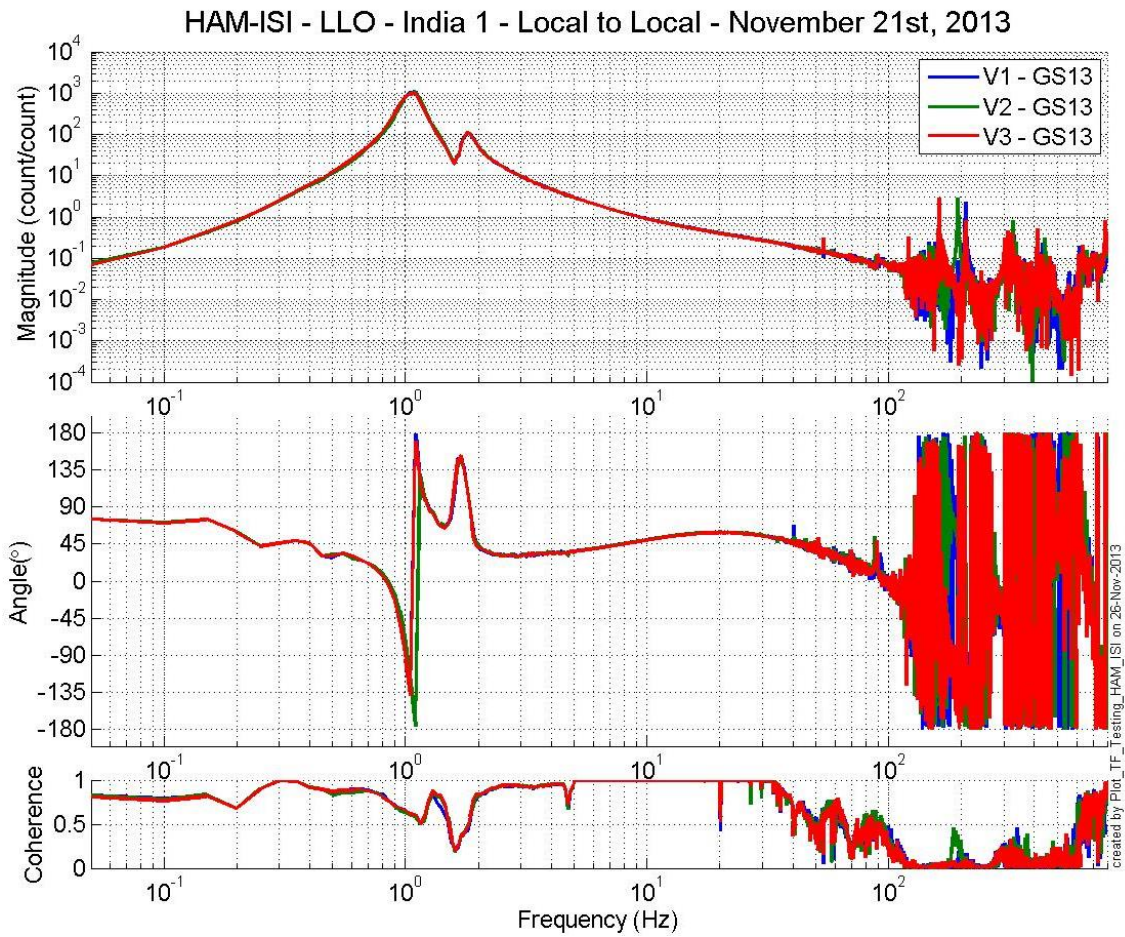


Table 20: Local to Local Measurements – Horizontal inertial sensors



**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
  - On CPS, the phase must be  $0^\circ$  at DC
  - On Geophones, the phase must be  $-90^\circ$  at DC
  - Identical shape in each corner
- Cartesian to Cartesian measurements
  - On CPS, the phase must be  $0^\circ$  at DC
  - On Geophones, the phase must be  $-90^\circ$  at DC
  - 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\_1/Transfer\_Functions/Measurements/Undamped/*

- Plot\_LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_2011\_08\_02

**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\_1\_TF\_L2L\_H\_CPS\_50mHz\_800Hz\_wRef\_2011\_08\_02.fig
- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_V\_CPS\_50mHz\_800Hz\_wRef\_2011\_08\_02.fig
- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_H\_GS13\_50mHz\_800Hz\_wRef\_2011\_08\_02.fig
- LLO\_HAM\_ISI\_India\_1\_TF\_L2L\_V\_GS13\_50mHz\_800Hz\_wRef\_2011\_08\_02.fig

**GS13, Local to local measurement**

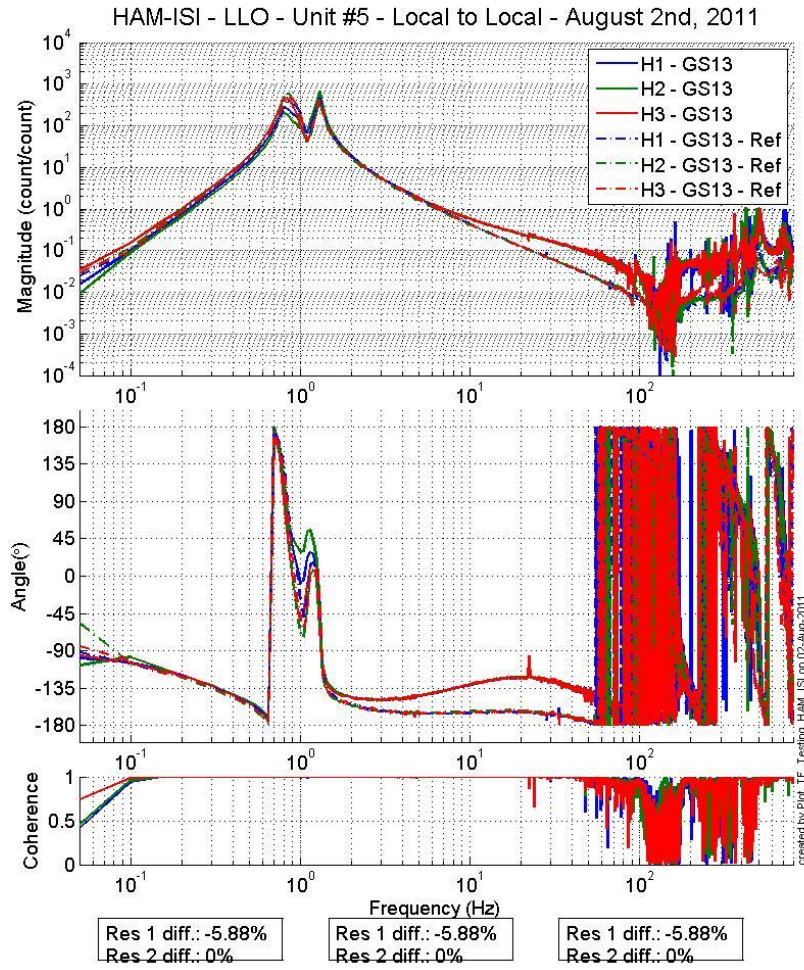


Figure - Local to local measurements comparison with LHO UNIT 2 – Horizontal GS-13

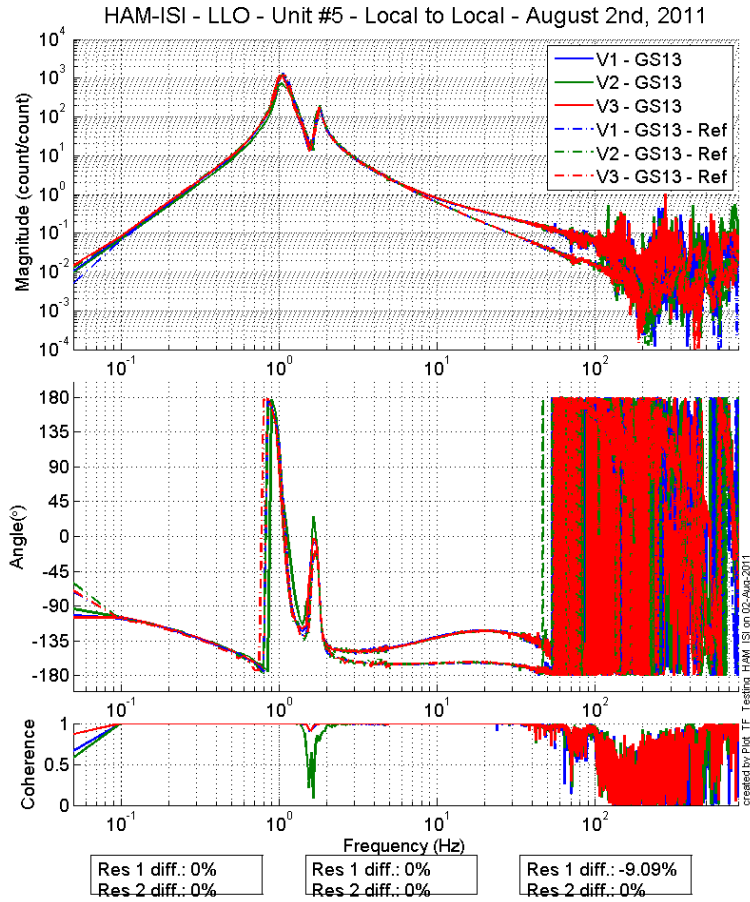


Figure - Local to local measurements comparison with LHO UNIT 2 – Vertical GS13



CPS, Local to local measurement, Undamped

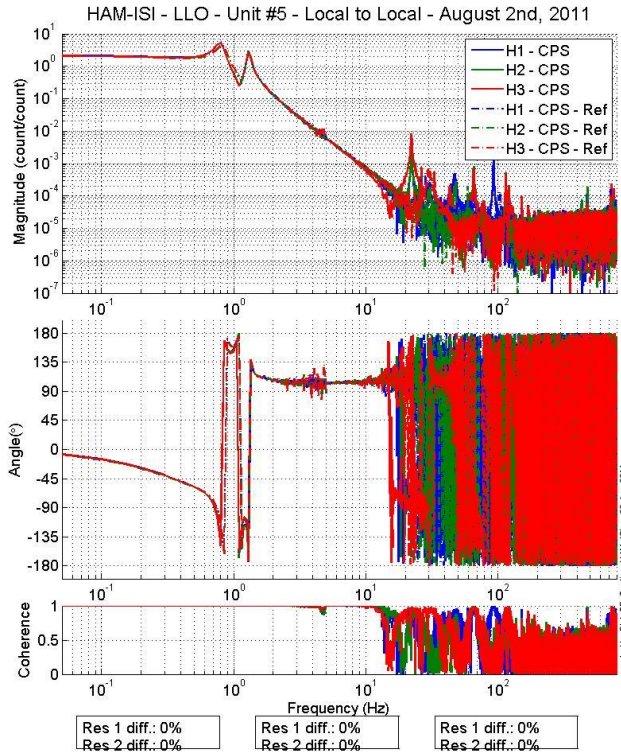


Figure - Local to local measurements comparison – Horizontal Position sensors

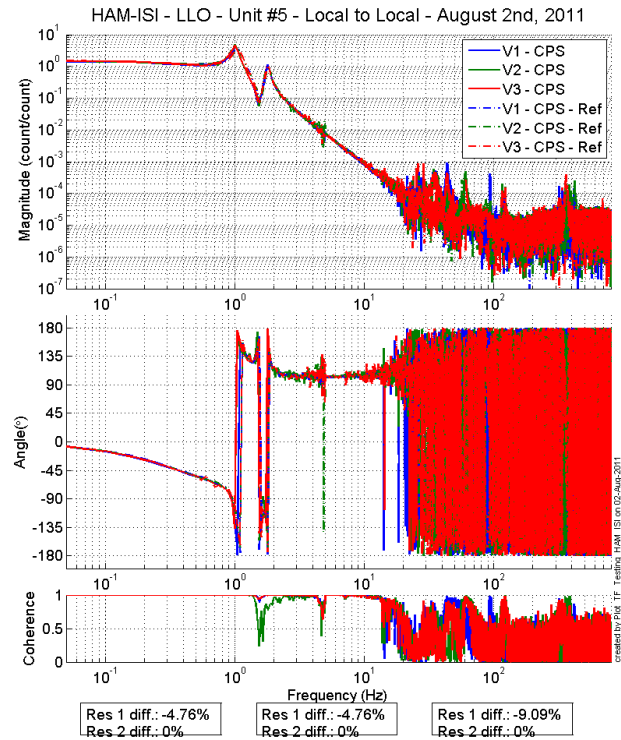


Figure - Local to local measurements comparison – Vertical Position sensors

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

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

*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)
  - Phase – less than  $10^\circ$  - In Phase – Out of Phase
  - Damping (fit by eye with Reference transfer functions)
  - DC gain
  - Eigen frequencies shift less than 10%

**Test result:**

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

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

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

**Data collection script files:**

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

- Run\_Cart2Cart\_10mHz\_100mHz.m

**Data files in SVN at:**

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

- LZMP\_LLO\_HAM-ISI-India\_1\_2011\_08\_02.mat

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

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

- LZMP\_2011\_08\_02.m

**Figures in SVN at:**

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

- LZMP.fig

**Acceptance criteria:**

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

**Test result:**

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

**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\_1/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\_1/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 1. The known issues are summed up here:

- Sensor gaps not recorded on the jig (III Step 2 & 3)
- Level of Stage 0 and Optical Table (II Step 7 & 8) are within range but the numbers haven't been recorded. It will have to be done.
- The Cartesian Basis Static Testing (III Step 15) direction readout is in nm instead of counts (issue with the script that needs to be fixed).
- The Static Testing Local Basis & Cartesian Basis (III Step 13 & 15) has been done with the compensation filters off because they were tripping the watchdogs. This explains why all the results in the table have been multiplied by (-1).

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