LIGO Laboratory / LIGO Scientific Collaboration

LIGO- E1100296 *LIGO* October 20th, 2012

aLIGO BSC-ISI, Pre-integration Testing report,

Phase I (post-assembly)

E1100296 – V1

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Distribution of this document:
Advanced LIGO Project

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Introduction

The BSC-ISI testing is performed in three phases:
1) BSC-ISI, Pre-integration Testing, Phase I (post-assembly)
2) BSC-ISI, Pre-integration Testing, Phase II: Tests done after Transport (and possible storage), during mating phase with Suspensions, before insertion.
3) BSC-ISI, Integration Phase Testing: Procedure and results related to the commissioning in the chamber.

This document presents the series of tests (Phase I) performed on the ISI-BSC2 in the LVEA.

The testing procedure document E1000486-v5 was used.

All results are posted on the SVN at:
https://svn.ligo.caltech.edu/svn/seismic/BSC-ISI/H2/Data/BSC2/

The following type of document can be found in the SVN:
- Excel spreadsheet (.xls)
- Data location
- Figures location
- Masses distribution scheme (ppt)

I. Pre-Assembly Testing

- ***Step 1 - CPS Test and calibration – E1100369***

CPS sensors are tested (calibration and noise test) at MIT before being cleaned and baked at LLO. The list of installed sensors used for testing (phase I) are reported in step II.3.

All data related to the CPS testing can be found in the SVN at
/svn/seismic/Common/Data/aLIGO_BSC_ISI_CPS/

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

- ***Step 2 - GS13 – Inspection/Assembly – E1000058 – E1100740***

GS13 are tested and podded at LLO. We had to replace one GS-13 on this Unit due to a bad feed thru, the cable screw wouldn't go all the way, leaving the cable the possibility to wobble. The feed thru is going to be inspected and tested again.
The list of installed sensors used for testing (phase I) are reported in step II.3.

All the data related to GS-13 post podding testing can be found in the SVN at :
/svn/seismic/Common/Data/aLIGO_GS13_TestData/PostMod_TestResults_PDFs

E1000058 and E1100740 spreadsheets provide the status of each individual GS-13 at LLO site for HAM-ISI and BSC-ISI and the installation location of the geophones.

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

- ***Step 3 - L4C – Inspection/Assembly – E1000136 – E1100740***

L4C are tested and podded at LLO. The list of installed sensors used for testing (phase I) are reported in step II.3.

All the data related to L4C post podding testing can be found in the SVN at :
/svn/seismic/Common/Data/aLIGO_L4C_TestData/TestResults_PDFs/

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

- ***Step 4 - T240 – Inspection/Assembly - E1100326 – E1100740***

T240 are tested and podded at LLO. We haven't had to replace the T240s on this Unit, and these are the ones with the new Voltage Regulator, it seems that they are working fine and keep the pressure sensor from dying. The list of installed sensors used for testing (phase I) are reported in step II.3.

All the data related to T240 post podding testing can be found in the SVN at : seismic/Common/Data/aLIGO_T240_TestData/AsReceived_TestResults_PDFs.

E1100326 and E1100740 spreadsheets provide the status of each individual T240 at LLO site for BSC-ISI and the installation location of the geophones.

Test result: Passed: _X_ Failed: ___ Waived : __

- ***Step 5 - Actuators - T0900564 - T1100234 – E1100741***

The list of installed sensors used for testing (phase I) are reported in step II.2
Large actuators data can be found at: T0900564. Actuator inventory is made at Section II – Step 2.
Small actuators data can be found at: T1100234. Actuator inventory is made at Section II – Step 2.

Test result: Passed: _X_ Failed: ___ Waived : __

II. Tests to be performed during assembly

- ***Step 1 - Test stand level***

The Test Stand was transformed and re-leveled to dock a BSC-ISI.

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

- ***Step 2 - Actuators Inventory***

The actuators S/N are reported in the table below. Further information can be found in T0900564 and T1100234.

Stage 1		Stage 2	
Actuator	**Actuator S/N**	**Actuator**	**Actuator S/N**
ST1 - H1	L120	**ST2 - H1**	S039
ST1 - H2	L119	**ST2 - H2**	S040
ST1 - H3	L106	**ST2 - H3**	S050
ST1 - V1	L103	**ST2 - V1**	S043
ST1 - V2	L104	**ST2 - V2**	S047
ST1 - V3	L101	**ST2 - V3**	S049

Table 1 - Actuators' inventory

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

- ***Step 3 - Sensors Inventory***

The sensors S/N are reported in the table below.

CPS Stage 1	CPS S/N	ADE board serial #
H1	12429	13201
H2	12533	13419
H3	12828	13454
V1	13084	13183
V2	13081	13528
V3	12580	12953

Table 2 - Capacitive position sensors' inventory – Stage 1

CPS Stage 2	CPS S/N	ADE board serial #
H1	12520	13230
H2	12541	13418
H3	12448	13450
V1	12569	13238
V2	12577	13439
V3	12561	13452

Table 3 - Capacitive position sensors' inventory – Stage 2

Geophones GS13	Serial Number	POD
H1	852	54
H2	834	70
H3	540	50
V1	770	64
V2	725	55
V3	762	12

Table 4 - GS13 inventory

Geophones L4C	Serial Number	POD
H1	1092	92
H2	811	36
H3	804	53
V1	918	115
V2	1093	18
V3	809	43

Table 5 - L4C inventory

Geophones T240	Serial Number	POD
1	117	15
2	121	501
3	123	3

Table 6 - T240 inventory

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

- ***Step 4 - Electronics Inventory***

Write down in the table below all serial numbers all the electronic equipment:

Hardware	Ligo reference	S/N
Interface Chassis Pod 1	D1002432	S1102228
Interface Chassis Pod 2	D1002433	S1102230
Interface Chassis Pod 3	D1002434	S1102229
Anti-alliasing Chassis	D1002693	S1103404
Anti-alliasing Chassis	D1002693	S1103405
Anti-image Chassis	D1002693	S1103402
Binary Input Chassis	D1001726	S1101284
	D1001726	S1101280
Binary Output Chassis	D1001728	S1101319
T240 Interface Pod 1	D1002694	S1103177
T240 Interface Pod 2	D1002694	S1103181
T240 Interface Pod 3	D1002694	S1103180
Anti-image Chassis	D1000305	S1103502
Coil driver Pod 1	D0902744	S1103564
Coil driver Pod 2	D0902744	S1103563
Coil driver Pod 3	D0902744	S1103356

Table 7 - Electronic equipment

Note: The electronic rack used to test BSC2 (unit #3) is the BSC8 electronic rack.

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

- ***Step 5 - Check level of Stage 0 after top-bottom plate assembly***

Note: This test has not been performed

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

- ***Step 6 - Check gaps under the blade posts***

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

- ***Step 7 - Blade post shim thickness***

This table shows the shims thickness installed under the lockers.

Stage 0-1		Stage 1-2	
Lockers	**Shim thickness (mil)**	**Lockers**	**Shim thickness (mil)**
Corner 1	121	**Corner 1**	121
Corner 2	114	**Corner 2**	133
Corner 3	117	**Corner 3**	125

Table 8 - Shims thickness

Acceptance criteria: Both D0901805 Stage 0-1 Locker Shims & D0902551 Stage 1-2 Locker Shims goes from .110” up to .130” with an increment of .001”.

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

- ***Step 8 - Blade 0-1 post launch angle***

This test has not been performed on LLO Unit 2.

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

- ***Step 9 - Gap checks on actuators***

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

- ***Step 10 - Mass budget***

Note: The initial version (V1) of the blade spacers was used. Consequently, the additional payload is expected to be lower than design due to the "relative overall softness" of the ISI.

The figure below presents the location of the masses on both stages. Two vibration absorbers were installed in corner 1 and 2 vibration absorbers were installed in corner 3. Masses on stage 2 are resting on Viton pads.

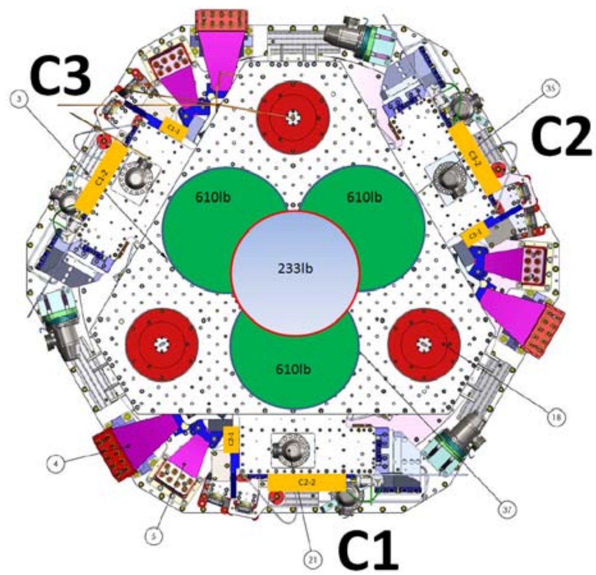

Figure 1: Masses distribution

Stage 1:

The stage 1 payload is reported in the table below:

Stage 1		
Location	**Weight (lb)**	**Weight (Kg)**
C1-1		0.0
C1-2	30	13.6
C2-1		0.0
C2-2	7.5	3.4
C3-1		0.0
C3-2	30	13.6
Total	67.5	30.6

Table 9 - Payload Stage 1

Nominal payload on stage 1: 109Kg – 240lb
Additional payload on stage 1 is 70.9 kg (172lb) less than expected.
Nominal mass of stage 1=916Kg - 2019lb

Stage 2:

The stage 2 payload is reported in the table below:

Mass Type	Quantity	Weight	Unit	Weight (lb)
D972213	3	610	lb	1830
D0972215	1	233	lb	233
D071200 - type 1	3	1.1	lb	3.3
D071200 - type 2	6	2.2	lb	13.2
D071200 - type 3	8	4.5	lb	36
D071200 - type 4	9	7.9	lb	71.1
D071200 - type 5	0	15.6	lb	0
D071200 - type 6	6	27.2	lb	163.2
				2349.8

Table 10 - Payload Stage 2

Nominal payload: 1183.4Kg – 2609lb
Total nominal mass of Stage 2: 2913.9Kg – 6424lb
Additional stage 2 payload is 260lb lighter than the design.

Stage 2 additional payload 10% lighter than nominal => Stage 2 is 9% lighter than nominal.
Payload on stage 0-1 blades is 432lb lighter than design (5%).

Test failure Mitigation: The blade stiffness is lower than design but in good agreements with the mass budget (see section III.7.2). The rigid body mode frequencies should be close from nominal.

Test result: **Passed: __** **Failed: _X_** **Waived : __**

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

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

- ***Step 12 – Cables inventory – E1100822***

The final Class A cables have been used for the testing of this Unit.

DCC Number	Description	Length (in)	Serial Number	Location
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106933	ST1 - V2 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106935	ST1 - V3 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106937	ST1 - H3 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106941	ST1 - H2 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106943	ST2 - H2 - ext
D1100150	2-wire, 14awg 2 pins to 3-pin F	40	S1107086	ST1 - V2
D1100150	2-wire, 14awg 2 pins to 3-pin F	40	S1107092	ST1 - H1
D1100150	2-wire, 14awg 2 pins to 3-pin F	40	S1107094	ST1 - H2
D1100150	2-wire, 14awg 2 pins to 3-pin F	40	S1107097	ST1 - V3
D1100150	2-wire, 14awg 2 pins to 3-pin F	40	S1107109	ST1 - V1
D1100150	2-wire, 14awg 2 pins to 3-pin F	40	S1107113	ST1 - H3
D1100151	2-wire, 14awg 2 pins to 3-pin F	60	S1107161	ST2 - V1
D1100151	2-wire, 14awg 2 pins to 3-pin F	60	S1107168	ST2 - V3
D1100151	2-wire, 14awg 2 pins to 3-pin F	60	S1107175	ST2 - V2
D1100151	2-wire, 14awg 2 pins to 3-pin F	60	S1107179	ST2- H1
D1100151	2-wire, 14awg 2 pins to 3-pin F	60	S1107181	ST2 - H3
D1100151	2-wire, 14awg 2 pins to 3-pin F	60	S1107196	ST2 - H2
D1100152	25-pin F-to-25-pin F	110	S1107242	ST1 - T240 - C1
D1100152	25-pin F-to-25-pin F	110	S1107250	ST1 - T240 - C3
D1100152	25-pin F-to-25-pin F	110	S1107262	ST1 - T240 - C2
D1100153	25-pin F-to-25-pin F	80	S1107300	ST1 - L4C - C1 - ext
D1100153	25-pin F-to-25-pin F	80	S1107301	ST1 - L4C - C2 - ext
D1100153	25-pin F-to-25-pin F	80	S1107302	ST1 - L4C - C3 - ext
D1100153	25-pin F-to-25-pin F	80	S1107303	ST2 - GS13 - C3 - ext
D1100153	25-pin F-to-25-pin F	80	S1107304	ST2 - GS13 - C1 - ext
D1100153	25-pin F-to-25-pin F	80	S1107306	ST2 - GS13 - C2 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1107019	ST2 - V2 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1107011	ST2- V1 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1107003	ST2 - H3 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106991	ST2 - H1 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106988	ST1 - V1 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1106987	ST2 - V3 - ext
D1100148	2-wire, 14awg 3-pin M to 3-pin F	80	S1107010	ST1 - H1 - ext
D1100154	25-pin M-to-two 9-pin F straight	48	S1107375	ST1 - L4C - C2
D1100154	25-pin M-to-two 9-pin F straight	48	S1107339	ST1 - L4C - C1
D1100154	25-pin M-to-two 9-pin F straight	48	S1107377	ST1 - L4C - C3
D1100155	25-pin M-to-two 9-pin F straight	120	S1107417	ST2 - GS13 - C2
D1100155	25-pin M-to-two 9-pin F straight	120	S1107401	ST2 - GS13 - C3
D1100155	25-pin M-to-two 9-pin F straight	120	S1107396	ST2 - GS13 - C1

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

- ***Step 13 - Cable routing***

The final Class A cables have been used for the testing of this Unit.
The cabling has been done following E1101027 aLIGO BSC-ISI Cable Routing Manual.

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

III. Tests to perform after assembly

- ***Step 1- Geophones pressure readout***

Calibrated pressure measured by the geophones is reported in the table below:

	Pressure (counts)		
Sensors	**Corner 1**	**Corner 2**	**Corner 3**
ST1-L4C-P	102.58	102.50	102.59
ST1-L4C-D	0.11	0.08	-0.34
ST1-GS13-P	102.77	102.42	102.45
ST1-GS13-D	0.40	0.23	-0.60
ST1-T240-P	101.86	99.80	100.41

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

- ***Step 2- Set up sensors gap – Locked vs unlocked position***

During this step, sensors gap are adjusted. This step considers that the lockers have been finely setup during assembly.

15-Oct-11

	Table locked		Table unlocked		Difference locked - unlocked	
Sensors	**Offset (Mean)**	**Std deviation**	**Offset (Mean)**	**Std deviation**	**Offset (Mean)**	**mil**
ST1 - H1	-65.3	4.0	-380.6	24.4	315	0.38
ST1 - H2	-447.0	4.5	-736.2	19.2	289	0.34
ST1 - H3	-2320.9	4.2	-1694.1	29.6	-627	-0.75
ST1 - V1	416.8	6.6	-1302.2	30.5	1719	2.05
ST1 - V2	676.9	5.2	-175.4	38.5	852	1.01
ST1 - V3	772.7	8.1	-731.3	45.6	1504	1.79
ST2 - H1	617.7	21.3	1026.3	40.2	-409	-0.12
ST2 - H2	-355.3	20.7	-1966.4	33.0	1611	0.48
ST2 - H3	-509.9	18.7	-412.9	28.5	-97	-0.03
ST2 - V1	133.0	21.5	1424.3	80.3	-1291	-0.38
ST2 - V2	1653.5	33.9	226.0	93.7	1427	0.42
ST2 - V3	-691.1	15.1	398.8	119.7	-1090	-0.32

Table 11 - Capacitive position sensors readout after gap set-up

Acceptance criteria:

- In the locked position, all mean values must be lower than 400 counts for stage 1 CPS and 1600 counts for stage 2 CPS on Dataviewer (a bit less than .0005”).
- In the locked position, all standard deviations below 25 counts for stage 1, 100 counts for stage 2
- Absolute values of the difference between the unlocked and the locked table must be below:

  Stage 1
  - 1600 cts for horizontal sensors (~0.002”)
  - 1600 cts for vertical sensors (~0.002”)

  Stage 2
  - 6500 cts for horizontal sensors (~0.002”)
  - 6500 cts for vertical sensors (~0.002”)
- Considering the acceptance criteria of step 2, all mean values must be lower than

  Stage 1
  - 2000 cts for horizontal sensors (~0.0025”)
  - 2000 cts for vertical sensors (~0.0025”)

  Stage 2
  - 8000 cts for horizontal sensors (~0.0025”)
  - 8000 cts for vertical sensors (~0.0025”)

Note: The CPS will be readjusted once SUS will installed

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

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

Test Failure mitigation:

This test was not performed. The sensor gaps have not been measured. These sensors have already been tested at LASTI. Moreover, risks of scratching the target are so high that we preferred not performing this test. In the future, this test will be removed from the testing procedure.

Test result: Passed: __ Failed: ___ Waived : _X_

Step 4- Performance of the limiters

- ***Step 4.1 - Test Nº1 - Push "in the general coordinates Z/RZ"***

Test result: Passed: __ Failed: ___ Waived : _X_

- ***Step 4.2 - Test Nº2 – Push "locally"***

Sensors	Push in positive direction	Push in negative direction	Mil	Mil	Actuator Gap Check
ST1 - H1	-16000	18500	-19	22	X
ST1 - H2	-16500	17500	-20	21	X
ST1 - H3	-19000	16800	-23	20	X
ST1 - V1	-20000	21000	-24	25	X
ST1 - V2	-28400	18600	-34	22	X
ST1 - V3	-24700	20700	-29	25	X
ST2 - H1	rail	rail			X
ST2 - H2	rail	rail			X
ST2 - H3	rail	rail			X
ST2 - V1	rail	rail			X
ST2 - V2	rail	rail			X
ST2 - V3	rail	rail			X

Table 12 - Stages range of motion – "Push locally"

Acceptance criteria:

- The vertical sensor readout must be positive when the optical table is pushed in the +Z direction
- The horizontal sensor readout on Stage 2 must be positive when the optic table is pushed in the +RZ direction
- **Step 4.2**
  - Absolutes value of all estimated motions must be higher than 15000counts for stage 1 (~0.018")
  - Absolutes value of all estimated motions must be higher than 32000counts for stage 2 (~0.010")

Test result: Passed: _X_ Failed: ___ Waived : __

- ***Step 5 - Sensors Powespectra***

The geophones powerspectra have been measured and can be found in the SVN:

/seismic/BSC-ISI/H2/BSC2/Data/Figures/Spectra/Undamped/

-

/seismic/BSC-ISI/H2/BSC2/Data/Spectra/Undamped

- LLO_ISI_BSC3_ASD_m_LOC_CPS_T240_L4C_GS13_2012_09_24_205825.mat
- LLO_ISI_BSC3_ASD_m_L4C_GS13_Stage_Tilted_2012_10_01.mat

Stage locked – unlocked

The powerspectra are measured in two different configurations:

- Stage 1 locked – Stage 2 locked
- Stage 1 unlocked – Stage 2 unlocked

seismic/BSC-ISI/H2/BSC2/Data/Spectra/Undamped/

- LHO_ISI_BSC2_ASD_m_LOC_CPS_T240_L4C_GS13_2012_10_16_153749.mat
- LHO_ISI_BSC2_ASD_m_LOC_CPS_T240_L4C_GS13_2012_10_18_155138.mat

seismic/BSC-ISI/H2/BSC2/Data/Figures/Spectra/Undamped/

- LHO_ISI_BSC2_ASD_CT_LOC_CPS_T240_L4C_GS13_2012_10_16_153749.fig
- LHO_ISI_BSC2_ASD_CT_LOC_CPS_T240_L4C_GS13_2012_10_18_155138.fig
- LHO_ISI_BSC2_ASD_m_LOC_CPS_T240_L4C_GS13_2012_10_16_153749.fig
- LHO_ISI_BSC2_ASD_m_LOC_CPS_T240_L4C_GS13_2012_10_18_155138.fig

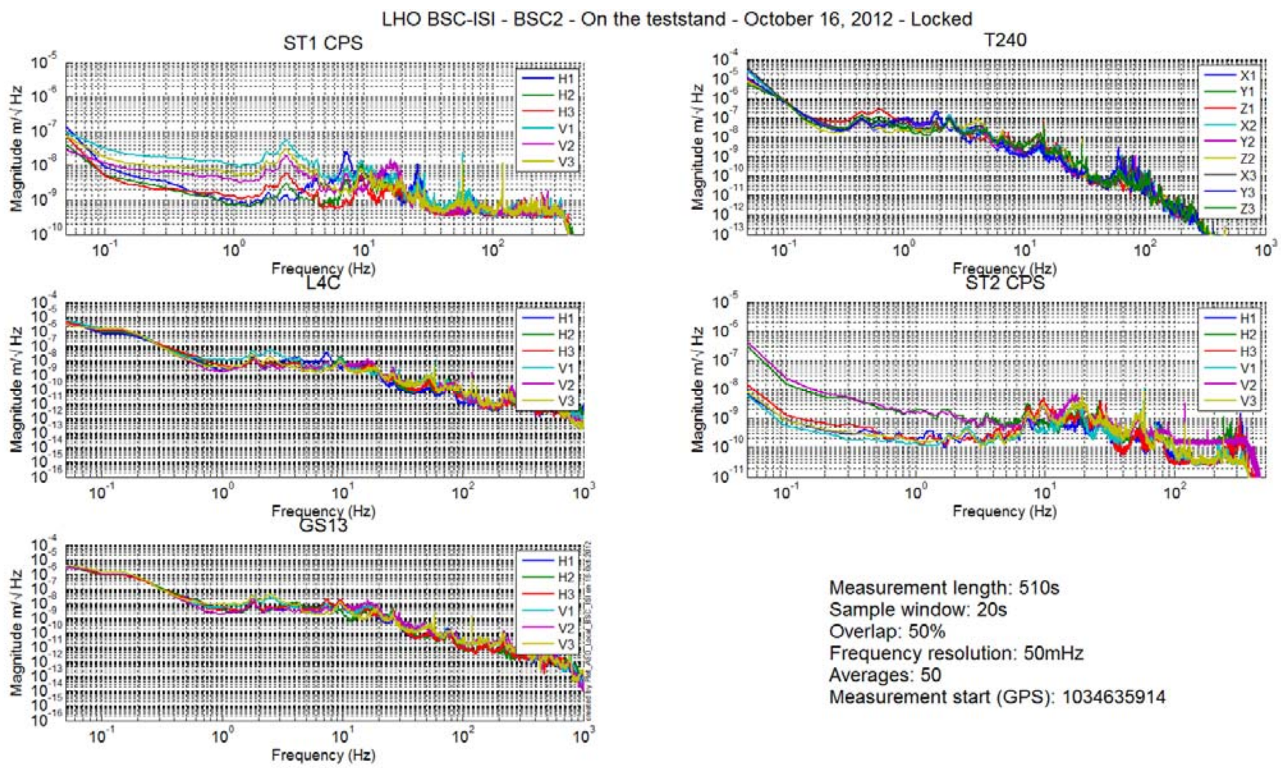

Figure 2: Spectra Stage 1 Locked Stage 2 Locked

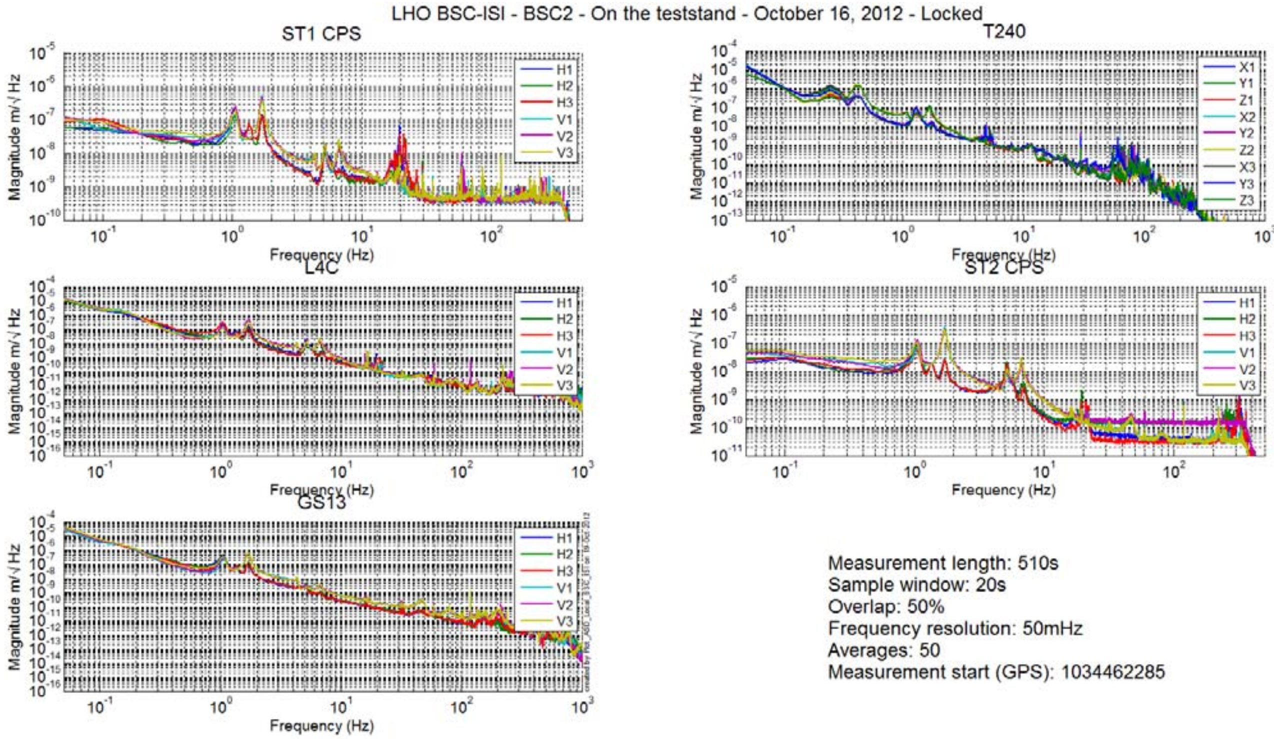

Figure 3: Spectra Stage 1 Unlocked Stage 2 Unlocked

Note: All sensors are working properly. However, the noise floor of the stage CPS in corner 2 is pretty high above 10Hz. It is probably a grounding issue. Consequently, the problem will be assessed once the ISI will in the chamber.

Stage Tilted

The powerspectra are measured when the ISI is unlocked a mass is placed on stage 2 to tilt Stage 1 and Stage 2.

The six configurations are the following in six different configurations:

- Mass placed in the actuator pocket at corner 1
- Mass placed in the pocket under the blade 0-1 at corner 1
- Mass placed in the actuator pocket at corner 2
- Mass placed in the pocket under the blade 0-1 at corner 2
- Mass placed in the actuator pocket at corner 3
- Mass placed in the pocket under the blade 0-1 at corner 3

/seismic/BSC-ISI/H2/BSC2/Data/Spectra/Undamped/

- LHO_ISI_BSC2_ASD_m_L4C_GS13_Stage_Tilted_2012_10_18.mat

seismic/BSC-ISI/H2/BSC2/Data/Figures/Spectra/Undamped/

- LHO_ISI_BSC2_Tilted_ASD_CT_LOC_ST1_L4C_2012_10_18.fig
- LHO_ISI_BSC2_Tilted_ASD_CT_LOC_ST2_GS13_2012_10_18.fig
- LHO_ISI_BSC2_Tilted_ASD_m_LOC_ST1_L4C_2012_10_18.fig
- LHO_ISI_BSC2_Tilted_ASD_m_LOC_ST2_GS13_2012_10_18.fig

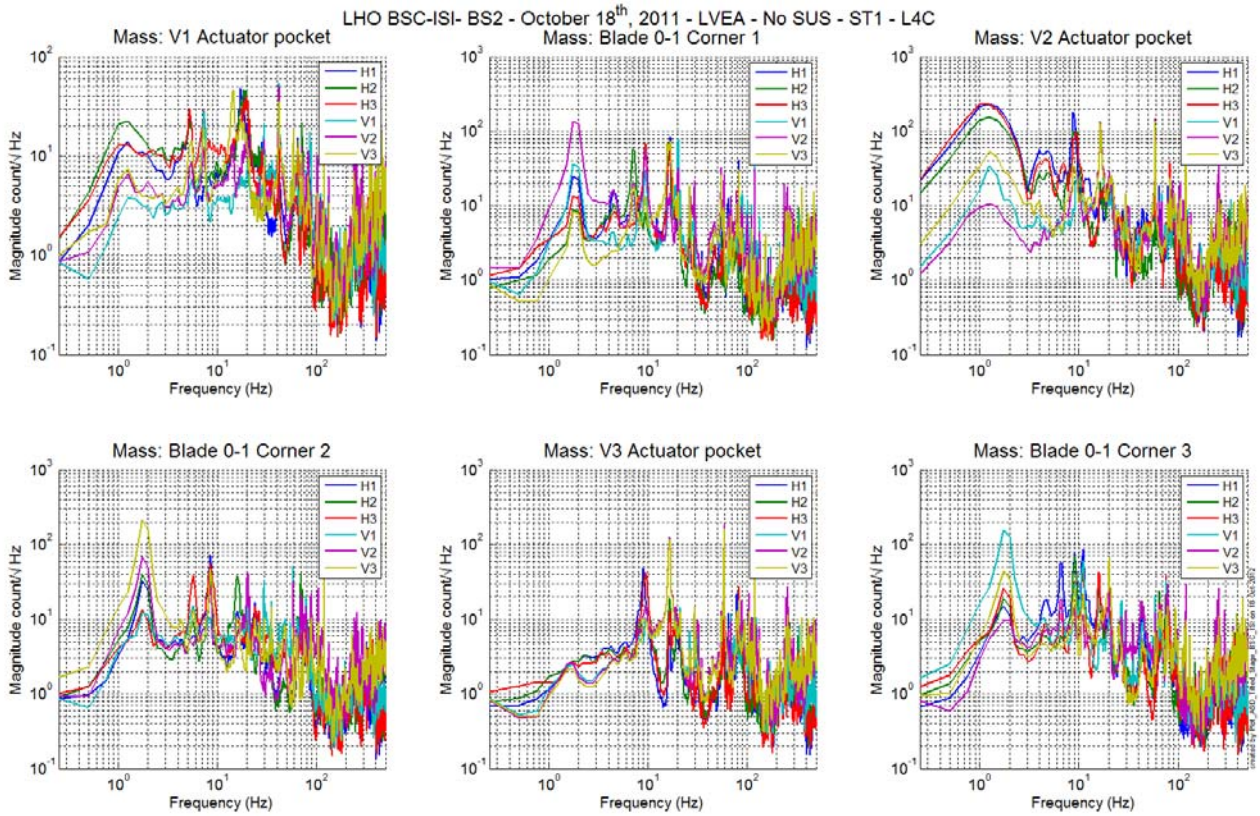

Figure 4 - ST1 L4C – Tilted

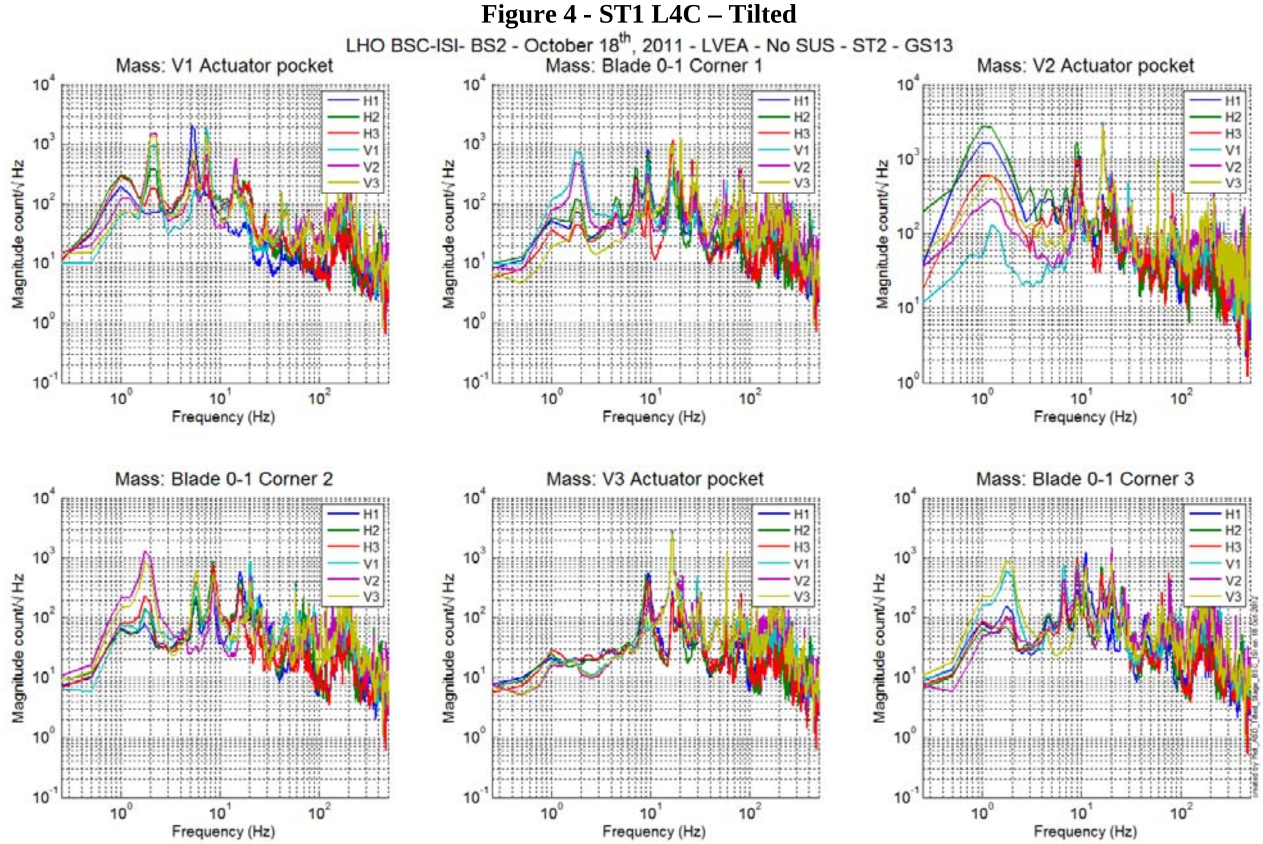

Figure 5 - ST1 GS13 – Tilted

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

- ***Step 6 - Coil Driver, cabling and resistance check***

Resistances of the couple (actuators + cables) were measured using the voltage and current the coil drivers read back. Resistances of the couple actuator + cables are reported in the table below:

seismic/BSC-ISI/H2/BSC2/Data/Static_Tests/
LHO_ISI_BSC2_Actuators_Resistance_20121015T161350.mat

Actuator	Resistance (Ω)
ST1 H1	7.3
ST1 H2	7.3
ST1 H3	7.4
ST1 V1	7.4
ST1 V2	7.3
ST1 V3	7.3
ST2 H1	11.1
ST2 H2	10.9
ST2 H3	10.8
ST2 V1	11.2
ST2 V2	11.2
ST2 V3	10.9

Note : All resistance are within 0.3ohmsand the cable resistance is about 1 ohm. The test is passed.

Acceptance criteria:
- For the actuators of stage 1, the measured resistance between the middle pin and one side pin must be 6.3 +/-0.5 ohms
- For the actuators of stage 2, the measured resistance between the middle pin and one side pin must be 10.3 +/-0.5 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 binary input bit must be in the upper state.

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

- ***Step 7- Actuators Sign and range of motion (Local drive)***
  - ***Step 7.1 - Actuators sign***

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

  - ***Step 7.2 - Range of motion - Local drive***

In this step, range of motion of the two stages is checked when applying a local drive (30000 counts) on actuators.

seismic/BSC-ISI/H2/BSC2/Data/Static_Tests/
- LHO_ISI_BSC2_Range_Of_Motion_20121011.mat

Sensor readout (counts)	Negative drive	no drive	Positive drive	Amplitude count	mil
ST1 - H1	-16167	-389	15518	31684	38
ST1 - H2	-15692	-734	15253	30945	37
ST1 - H3	-17844	-1689	13649	31492	37
ST1 - V1	-14068	-1292	11449	25517	30
ST1 - V2	-13099	-202	12701	25800	31
ST1 - V3	-13212	-369	12483	25695	31
ST2 - H1	-8375	1025	10426	18801	5.6
ST2 - H2	-10696	-1723	7202	17898	5.3
ST2 - H3	-9803	-428	8915	18718	5.6
ST2 - V1	-10006	1400	12807	22813	6.8
ST2 - V2	-10874	224	11291	22165	6.6
ST2 - V3	-11120	385	11854	22974	6.8

Table 13 - Range of motion - Local drive

Acceptance criteria:
- Amplitude p-p must be at least 30000 counts (0.035”) for Stage 1 CPS H
- Amplitude p-p must be at least 25000 counts (0.03”) for Stage 1 CPS V
- Amplitude p-p must be at least 18000 counts (0.005”) for Stage 2 CPS H
- Amplitude p-p must be at least 22000 counts (0.006”) for Stage 2 CPS V
- Signs of actuators drive and sensors read out have to be the same

Note: The motion of the platform can be computed. For a 30000 counts drive in the +Z direction, the platform should move by 12.6 mil on Stage 1 and 3.6mil on Stage 2.

In the Cartesian basis, the platform should move (calculation) by:

Stage 1 - Platform move for 32K counts drive:	12.63	mil
Stage 2 - Platform move for 32K counts drive:	3.59	mil

Note: The range of motion in the case of a “local drive” is in agreements with the measurements done on the previous units.

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

- ***Step 8 - Vertical Sensor Calibration***

This test is inaccurate due to the important hysteresis introduced by the dial indicators. Moreover, the sensors calibrations have been checked at LASTI. This test has not been performed on LLO Unit 2.

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

- ***Step 9 - Vertical Spring Constant***

This test is realized by loading the ISI when one stage is locked and using the capacitive position sensors as reference.

The stiffness measurements of the spring are reported in the tables below. The nominal blade stiffness are:

- Stage 1: 1241lb/in
- Stage 2: 1465lb/in

Blade Stage 0-1

Stage 2 Locked & Stage 1 Unlocked. Stage 1 is loaded with 3 x 10Kg masses and the measurements are repeated three times (by rotating the masses).

	No load	Mean load	Diff 1	
V1	-1243	-8894.5	-7651.5	
V2	-187	-7813	-7626	
V3	-398	-8193	-7795	
			-7690.83	count
			-9.24	mil
			1191	lb/in
			-4	%

The blades from stage 0 to stage 1 are too soft by 4%.

Blade Stage 1-2

Stage 1 Locked & Stage 2 Unlocked. Stage 2 is loaded with 3 x 5Kg masses and the measurements are repeated three times (by rotating the masses).

	Mean No load	Mean Load	Diff	
V1	1415.5	-25258.75	-26674.25	
V2	1455.5	-24681.75	-26137.25	
V3	357.5	-26905.5	-27263	
			-26692	count
			-8.02	mil
			-1361	lb/in
			-7	%

In section II.10, it is shown that:
- Payload on stage 0-1 blades is 432 lighter than design (-5%)
- Payload on stage 1-2 blades is 260lb lighter than design (-8%)

In this section we measured the blade stiffness:
- Stage 0-1 blades are softer by 4% than design
- Stage 1-2 blades are softer by 7% than design

Test mitigation: Blades are softer than design. The low stiffness measurement is in good agreements with the mass budget. The rigid body modes frequencies should be close from design.

Test result: **Passed: __** **Failed: _X_** **Waived : __**

▪ *Step 10 - Static Testing (Tests in the local basis)*

The static tests results are reported in the SVN at :
seismic/BSC-ISI/H2/BSC2/Data/Static_Tests/
LHO_ISI_BSC2_Offset_Local_Drive_20121018.mat
The table below shows the main and the cross-coupling when the actuators are driven in the local basis:

		Sensors					
		ST1 - H1	ST1 - H2	ST1 - H3	ST1 - V1	ST1 - V2	ST1 - V3
Actuators	ST1 - H1	3786	1522	1522	-22	8	-6
	ST1 - H2	1521	3754	1515	-11	22	-9
	ST1 - H3	1534	1521	3781	-16	-14	23
	ST1 - V1	55	-128	88	3012	-561	-544
	ST1 - V2	94	20	-145	-522	3013	-560
	ST1 - V3	-151	86	49	-545	-534	3000

Table 14 - Static test - Local to local - Stage 1

		Sensors					
		ST2 - H1	ST2 - H2	ST2 - H3	ST2 - V1	ST2 - V2	ST2 - V3
Actuators	ST2 - H1	2211	320	344	1	8	9
	ST2 - H2	337	2112	330	1	47	-5
	ST2 - H3	346	324	2202	-25	17	-2
	ST2 - V1	88	124	-185	2663	287	-36
	ST2 - V2	-182	88	117	-61	2615	274
	ST2 - V3	119	-198	77	286	-23	2702

Table 15 - Static test - Local to local - Stage 2

Acceptance criteria:
- Main couplings readout must be positive
- Comparison with the reference tables:
  - o Main coupling differences mustn't exceed 200 counts
  - o Cross coupling differences mustn't exceed 50 counts

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

- ***Step 11- Static Testing - In the general coordinate basis (Static test - CPS)***
  - ***Step 11.1 – Change of basis matrices from Cartesian to Local***

The static tests results are reported in the SVN at :
/seismic/BSC-ISI/H2/BSC2/Data/Static_Tests/
LHO_ISI_BSC2_Offset_Cartesian_Drive_20121018.mat

Actuators	Sensors					
	ST1 - H1	**ST1 - H2**	**ST1 - H3**	**ST1 - V1**	**ST1 - V2**	**ST1 - V3**
ST1 - X	-1503	746	745	14	-7	11
ST1 - Y	5	-1294	1310	-1	-12	12
ST1 - Z	0	-11	-8	637	631	633
ST1 - RX	7	113	-148	-2489	2124	370
ST1 - RY	-166	94	80	-991	-1656	2643
ST1 - RZ	-2753	-2754	-2762	14	-25	-6

Actuators	Sensors					
	ST2 - H1	**ST2 - H2**	**ST2 - H3**	**ST2 - V1**	**ST2 - V2**	**ST2 - V3**
ST2 - X	626	-1211	620	-24	-42	1
ST2 - Y	1073	1	-1068	-19	-36	8
ST2 - Z	6	7	3	966	938	986
ST2 - RX	-258	14	254	-2295	2265	-54
ST2 - RY	136	-291	146	-1373	-1275	2680
ST2 - RZ	1642	1568	1639	-12	11	-14

Table 16 - Static test - Local to local - Stage 1 – Stage 2

Acceptance criteria:

- Comparison with the reference tables:
  - Differences mustn't exceed 100 counts

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

- *Step 11.2 – Base change matrices from Cartesian to Cartesian*

The static tests results are reported in the SVN at :
/seismic/BSC-ISI/H2/BSC2/Data/Static_Tests/
LHO_ISI_BSC2_Offset_Cartesian_Drive_20121018.mat

Actuators \ Sensors	ST1 - X	ST1 - Y	ST1 - Z	ST1 - RY	ST1 - RY	ST1 - RZ
ST1 - X	1501	5	5	-4	2	5
ST1 - Y	-3	1500	2	-6	21	-8
ST1 - Z	-4	7	641	5	-9	9
ST1 - RX	27	415	8	2645	-174	9
ST1 - RY	-386	29	2	164	2641	-3
ST1 - RZ	4	-5	-2	-21	-2	2870

Table 17 - Static test Cartesian drive – Cartesian to local – Stage 1

Actuators \ Sensors	ST2 - X	ST2 - Y	ST2 - Z	ST2 - RY	ST2 - RY	ST2 - RZ
ST2 - X	1218	-5	-4	3	15	28
ST2 - Y	0	1242	6	-17	5	3
ST2 - Z	-4	1	966	-19	11	6
ST2 - RX	-57	263	-22	3459	292	7
ST2 - RY	-263	-46	3	-282	3488	-7
ST2 - RZ	57	16	-8	32	-17	2249

Table 18 - Static test Cartesian drive – Cartesian to local – Stage 2

Acceptance criteria:

- Main couplings readout must be positive
- Comparison with the reference tables:
  - Main coupling differences mustn't exceed 200 counts
  - Cross coupling differences mustn't exceed 50 counts

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

- ***Step 12 - Linearity test***

The "Linearity test" was performed twice (rearranging the cables). The second time, all corners seemed to respond similarly.

The linearity test data can be found in the SVN at:
/seismic/BSC-ISI/H2/BSC2/Data/Linearity_Test/
- LHO_ISI_BSC2_Linearity_Test_2012_10_11.mat
- LHO_ISI_BSC2_Linearity_test_20121018.mat

The linearity test figures can be found in the SVN at:
/seismic/BSC-ISI/H2/BSC2/Data/Figures/Linearity_Test/
- LHO_ISI_BSC2_Linearity_test_20121011.fig
- LHO_ISI_BSC2_Linearity_test_20121018.fig

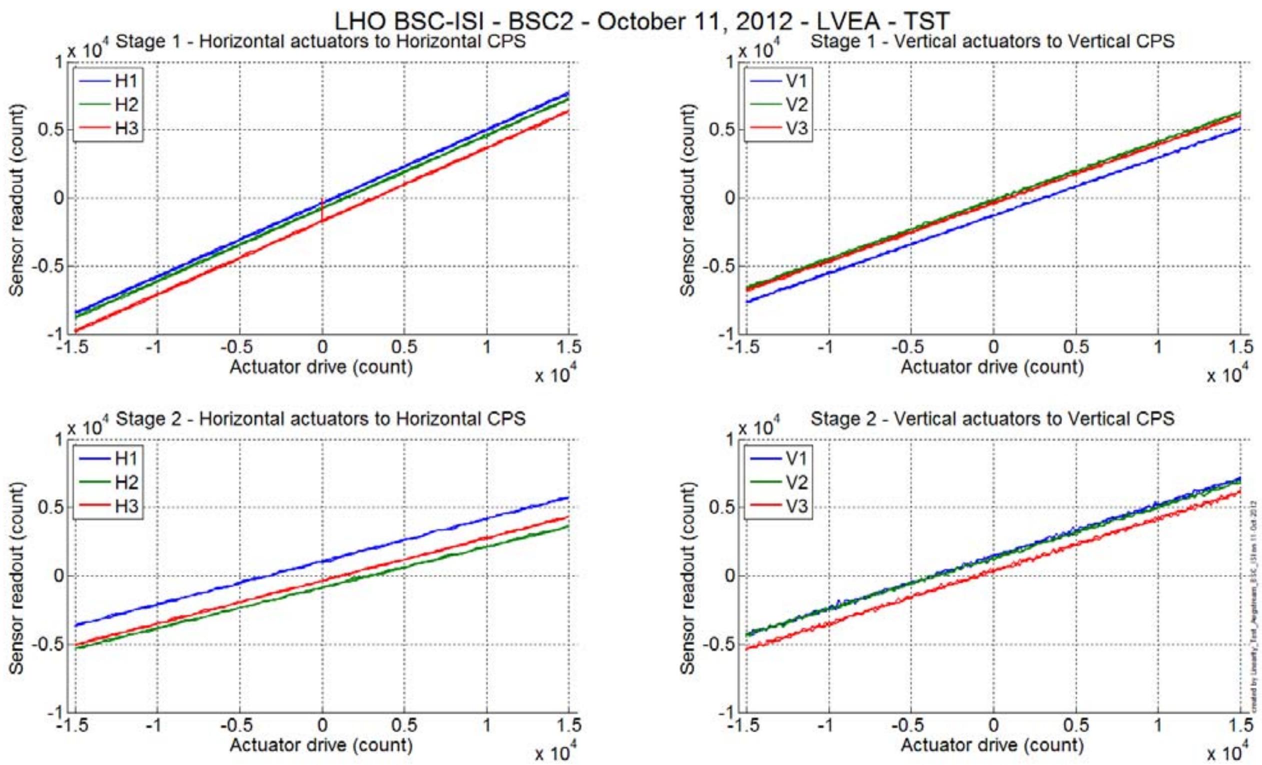

Figure 6 - Linearity Test

Slope – Offset:

		Slope	Offset	Average slope	Variation from average(%)
Stage 1	ST1 - H1	0.538	-374	0.5370	0.19
	ST1 - H2	0.535	-752		-0.37
	ST1 - H3	0.538	-1695		0.19
	ST1 - V1	0.425	-1281	0.4277	-0.62
	ST1 - V2	0.430	-160		0.55
	ST1 - V3	0.428	-374		0.08
Stage 2	ST2 - H1	0.313	1048	0.3080	1.62
	ST2 - H2	0.298	-862		-3.25
	ST2 - H3	0.313	-366		1.62
	ST2 - V1	0.382	1416	0.3797	0.61
	ST2 - V2	0.373	1303		-1.76
	ST2 - V3	0.384	370		1.14

Table 19 - Slopes and offset of the triplet Actuators - BSC-ISI – Sensors

		Slope	Offset	Average slope	Variation from average(%)
Stage 1	ST1 - H1	0.539	-177	0.5380	0.44
	ST1 - H2	0.536	-856		-0.24
	ST1 - H3	0.539	-1667		0.37
	ST1 - V1	0.428	1225	0.4289	0.17
	ST1 - V2	0.430	-595		0.56
	ST1 - V3	0.428	-2601		0.11
Stage 2	ST2 - H1	0.315	1230	0.3095	2.25
	ST2 - H2	0.301	942		-2.29
	ST2 - H3	0.313	-1643		1.51
	ST2 - V1	0.382	11842	0.3797	0.71
	ST2 - V2	0.373	4597		-1.65
	ST2 - V3	0.383	-6160		0.98

Table 20 - Slopes and offset of the triplet Actuators - BSC-ISI – Sensors

Acceptance criteria:

- Horizontal and vertical slopes of the triplet actuators x BSC-ISI x sensors: Average slope +/- 2.5%

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

- ***Step 13 – Transfer functions – Local to Local***

Note: two vibration absorbers were installed in corner 1 and 2 vibration absorbers were installed in corner 3. No TMDs were installed on the stage 0-1 blades.

Data files measurement of local to local transfer functions in SVN at:
seismic/BSC-ISI/H2/BSC2/Data/Transfer_Functions/Measurements/Undamped/

- LHO_ISI_BSC2_Data_L2L_10mHz_100mHz_ST1_ST2_20121016-203156.mat
- LHO_ISI_BSC2_Data_L2L_100mHz_700mHz_ST1_ST2_20121015-233530.mat
- LHO_ISI_BSC2_Data_L2L_700mHz_10Hz_ST1_ST2_20121016-045827.mat
- LHO_ISI_BSC2_Data_L2L_10Hz_100Hz_ST1_ST2_20121015-200821.mat
- LHO_ISI_BSC2_Data_L2L_100Hz_500Hz_ST1_ST2_20121016-184636.mat
- LHO_ISI_BSC2_Data_L2L_500Hz_1000Hz_ST1_ST2_20121016-172146.mat

Script file for processing and plotting local to local transfer functions in SVN at:
/seisvn/seismic/BSC-ISI/H2/BSC2/Scripts/Control_Scripts

- Step_1_TF_L2L_10mHz_1000Hz_LLO_ISI_BSC2.m

Figures of local to local transfer functions (Main couplings) in SVN at:
/seismic/BSC-ISI/H2/BSC2/Data/Figures/Transfer_Functions/Measurements/Undamped/

- LHO_ISI_BSC2_TF_L2L_Raw_from_ST1_ACT_to_ST1_CPS_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST1_ACT_to_ST1_L4C_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST1_ACT_to_ST1_T240_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST1_ACT_to_ST2_CPS_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST1_ACT_to_ST2_GS13_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST2_ACT_to_ST1_L4C_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST2_ACT_to_ST1_T240_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST2_ACT_to_ST2_CPS_2012_10_16.fig
- LHO_ISI_BSC2_TF_L2L_Raw_from_ST2_ACT_to_ST2_GS13_2012_10_16.fig

Measured of local to local transfer functions in the SVN at:
/svncommon/seisvn/seismic/BSC-ISI/H2/BSC2/Data/Transfer_Functions/Simulations/Undamped
LHO_ISI_BSC2_TF_L2L_Raw_2012_10_16.mat

Note 1: The transfer functions are measured from the Output filter bank (excitation variable) to the input (IN1) of the input filter bank. The transfer functions presented below are raw transfer functions without any electronic compensation of the sensor electronic. The actuator and the coil driver electronic compensation are introduced in these transfer functions.

Note 2: The L4Cs are out of phase (should be -90 before 1Hz). A minus sign is added in the calibration filters that convert count to nm/s.

Note 3: The first resonance of the test stand can be seen at 19.6Hz on Stage 1 CPS.

Note 4: The first resonance of the structure observed on stage 1 by the L4C is around 220Hz.

Note 5: There is a poor coherence on the GS13 transfer functions. It can be explained by the weak drive of the fine actuators. Moreover, the stage 2 of the ISI is strongly excited by the fans of the clean rooms. These two factors strongly affect the quality of the measurements.

Note 6: Some saturation of the T240s during the measurements explains the “wobbles” in the transfer function in the [700mHz; 10Hz] frequency band.

Note 7: On the ST1 CPS transfer functions, resonances seen by V1 and V3 seem to be slightly higher than resonances in the V2 direction ([100Hz; 200Hz] frequency band).

Note 8: On the ST1 L4C transfer functions, resonances seen by V2 seem to be slightly higher than resonances in the other vertical directions.

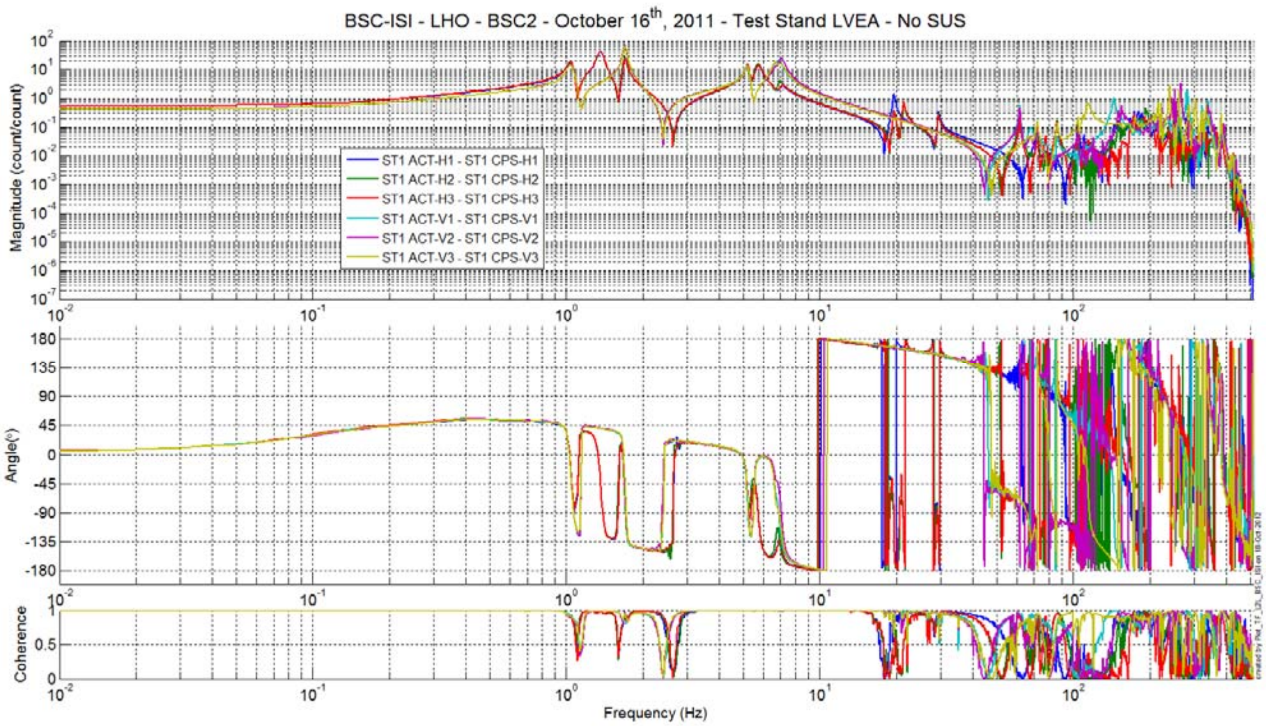

Figure 7: TF L2L Raw - ST1 Act to ST1 CPS

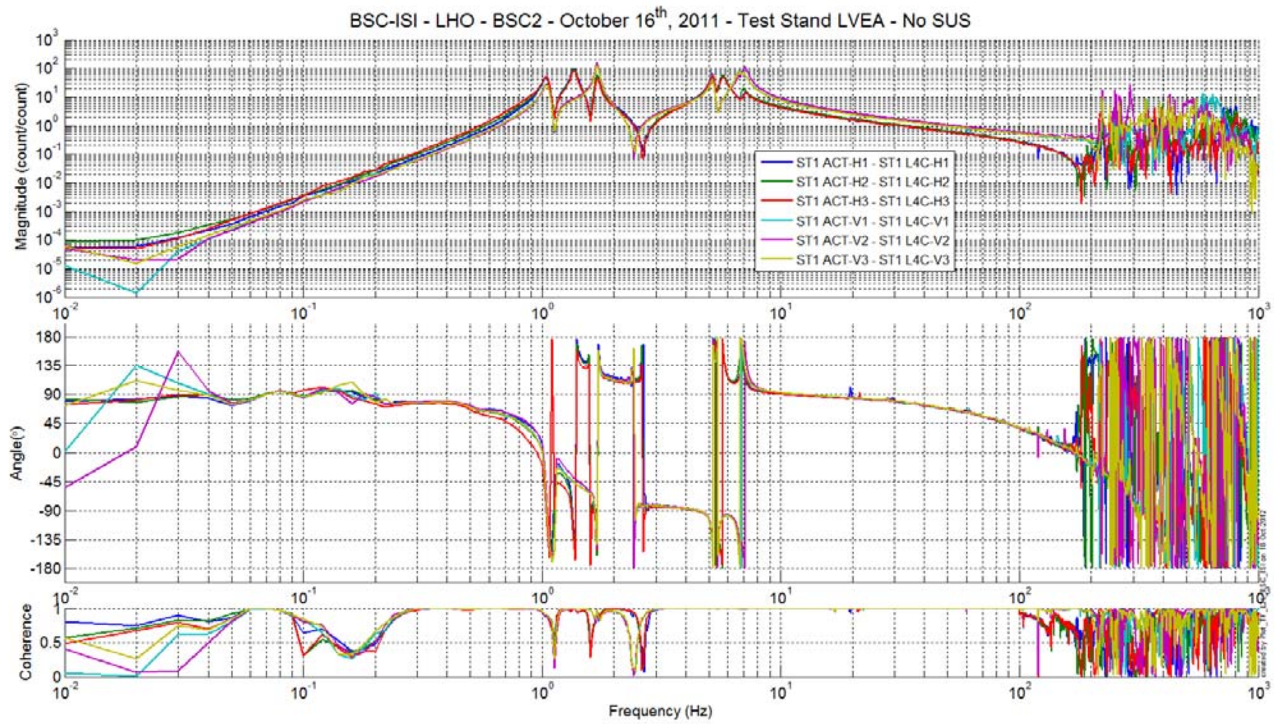

Figure 8: TF L2L Raw - ST1 Act to ST1 L4C

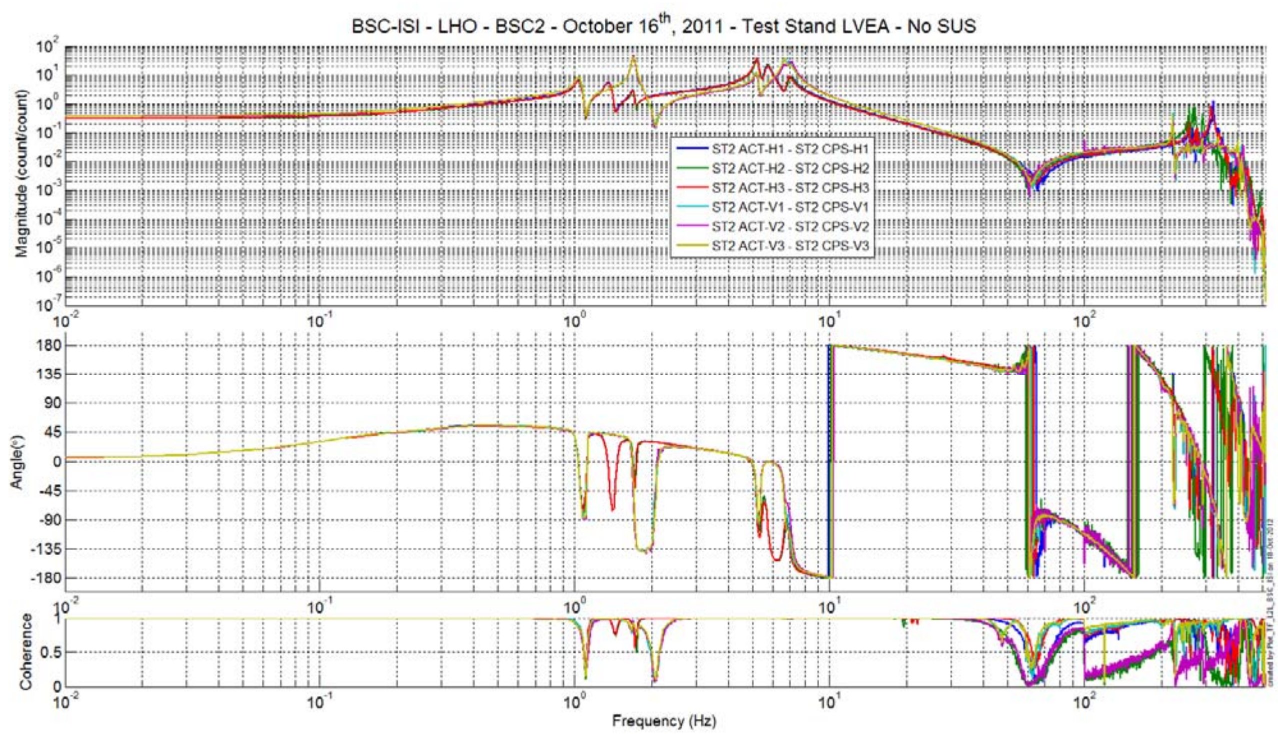

Figure 9: TF L2L Raw - ST2 Act to ST2 CPS

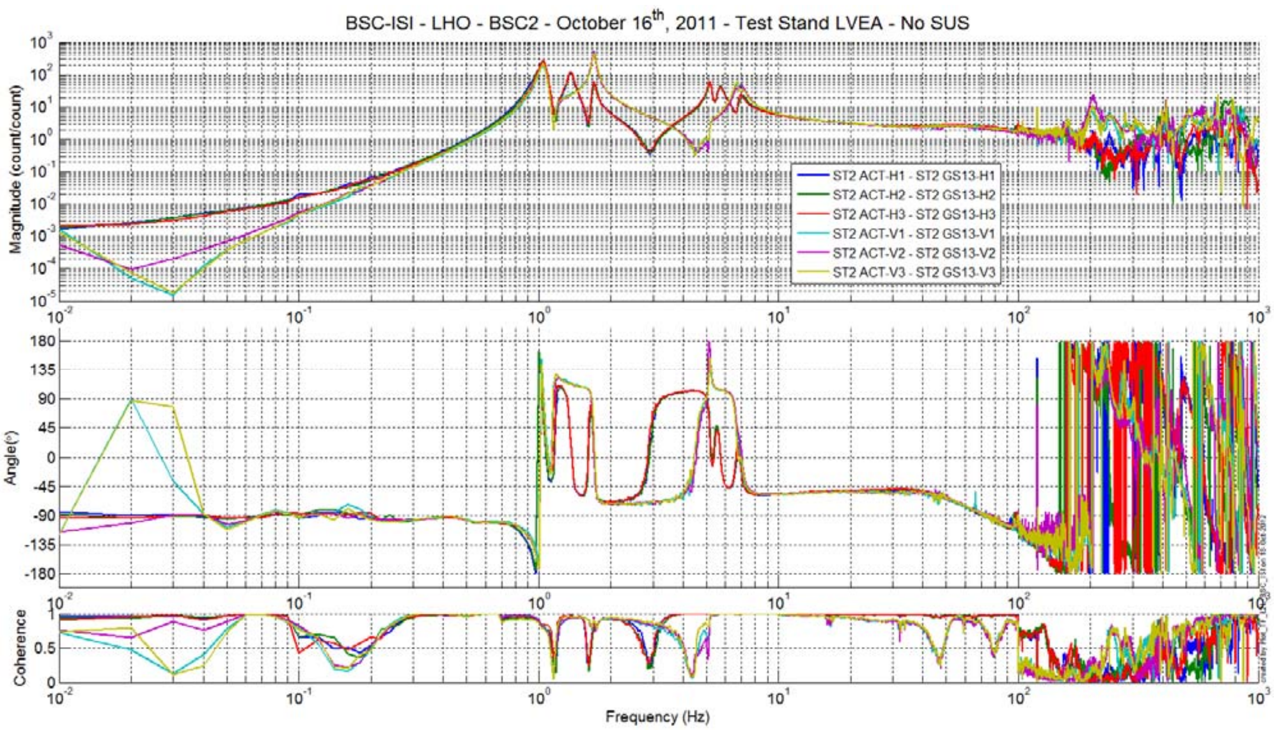

Figure 10: TF L2L Raw - ST2 Act to ST2 GS13

Comparison between the BSC2 and BSC8

BSC2 and BSC8 transfer functions are compared in similar conditions.

- BSC2: High test stand – 4 Vibration absorbers on stage 1 – No TMDs – Stage 2 dummy payload resting on Viton pads
- BSC8: High test stand – No Vibration absorbers on stage 1 – No TMDs – Stage 2 dummy payload not resting on Viton pads

Comparison between the transfer functions of BSC8 and BSC2 can be found in the SVN at:
seismic/BSC-ISI/H2/BSC2/Data/Figures/Transfer_Functions/Comparisons/L2L/

- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST1_ACT_H_to_ST1_CPS_H_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST1_ACT_H_to_ST1_L4C_H_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST1_ACT_V_to_ST1_CPS_V_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST1_ACT_V_to_ST1_L4C_V_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST2_ACT_H_to_ST2_CPS_H_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST2_ACT_H_to_ST2_GS13_H_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST2_ACT_V_to_ST2_CPS_V_20110722_vs_20121016.fig
- LHO_ISI_BSC8_vs_BSC2_Comparison_TF_L2L_ST2_ACT_V_to_ST2_GS13_V_20110722_vs_20121016.fig

Note 1: The rigid body mode of BSC2 and BSC8 are at the same frequencies

Note 2: BSC2 and BSC8 transfer functions were measured with two different sample rates

Note 3:

- Stage 1 L4C TF Horizontal are similar
- Difference in the Stage 1 L4C TF Vertical are visible in the [200;300]Hz frequency band

- Most of the stage 2 resonances are reduced by the addition of Viton pads under the keel masses
- Stage 2 GS12 Horizontal TFs are similar except for H2. The resonances seen between [700;800]Hz will be less visible in the Cartesian basis

Note 4: The phase difference in the ST2-GS13 transfer functions is probably coming from the masses installed on Viton on the top of stage 2.

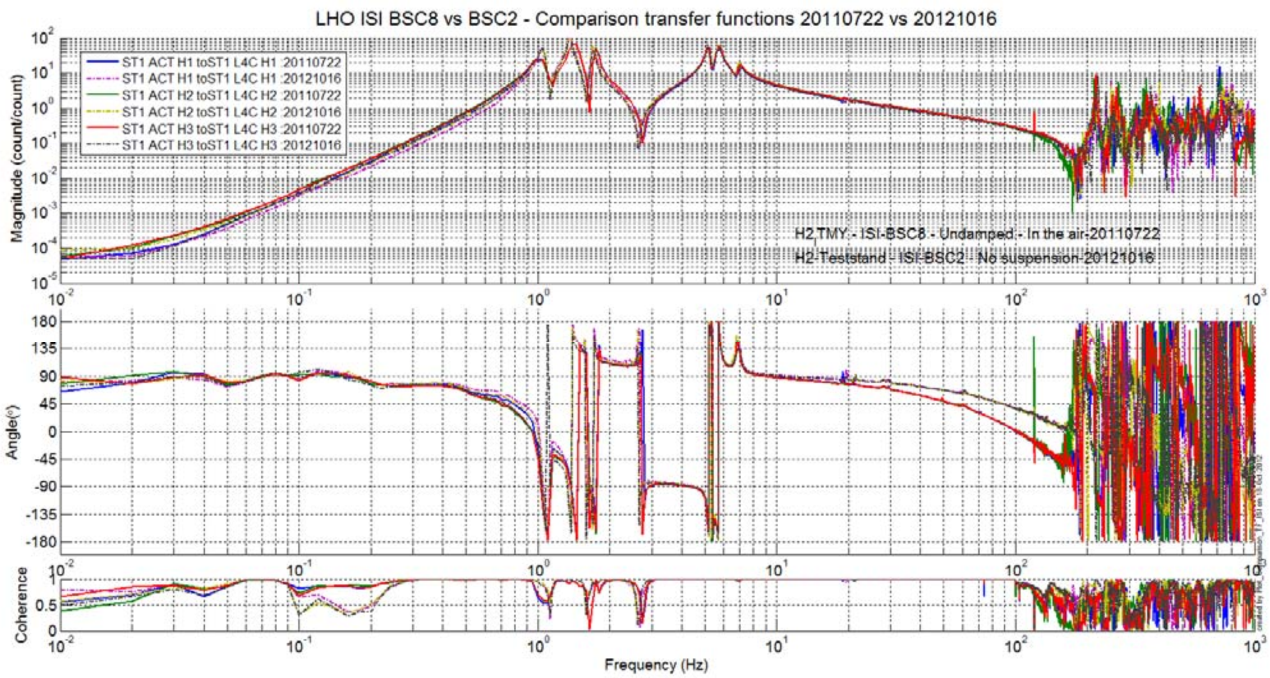

Figure 11 – Comparison BSC6 vs BSC2 – ST1 ACT Horizontal – ST1 L4C Horizontal

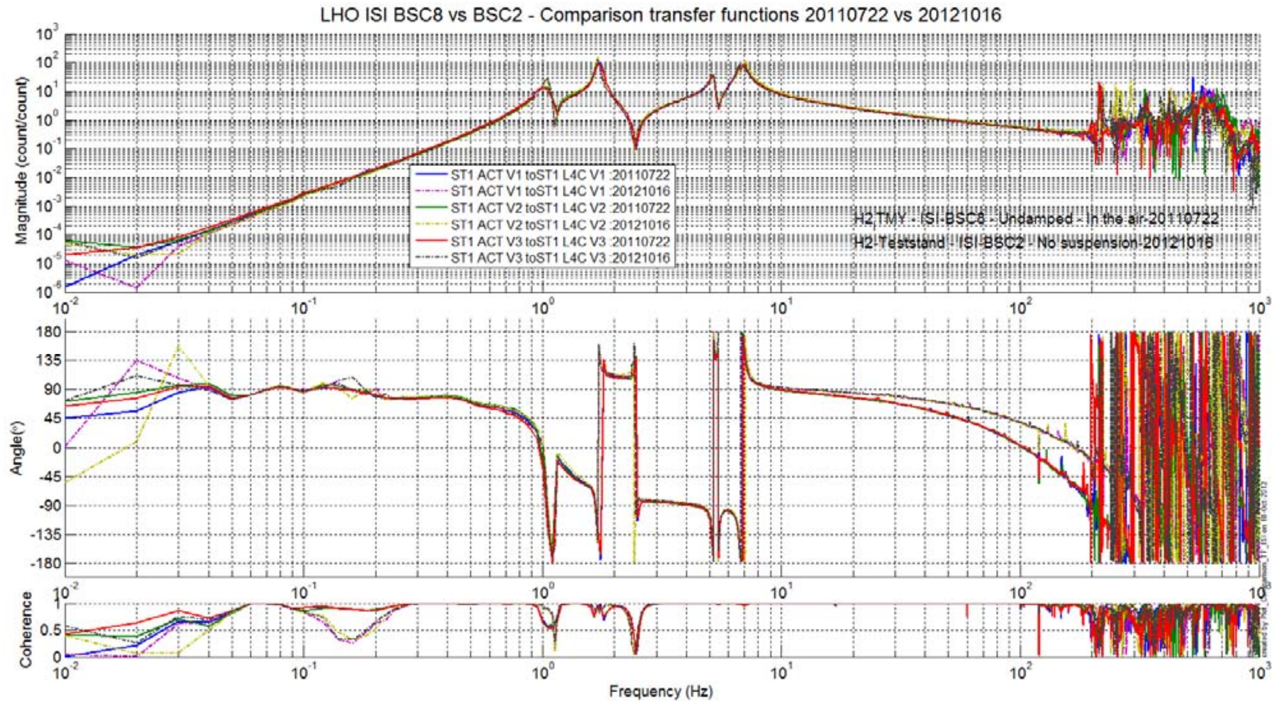

Figure 12 - Comparison BSC6 vs BSC2 – ST1 ACT Vertical – ST1 L4C Vertical

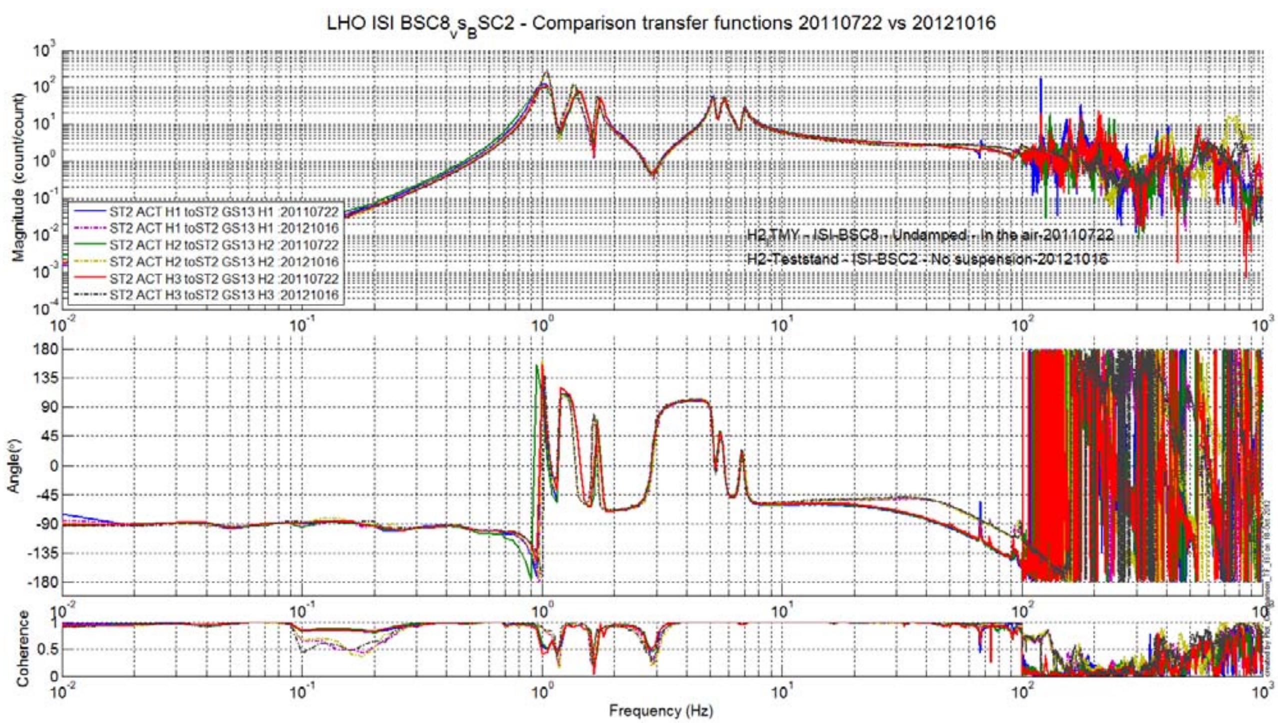

Figure 13 -- Comparison BSC6 vs BSC2 – ST2 ACT Horizontal – ST2 GS13 Horizontal

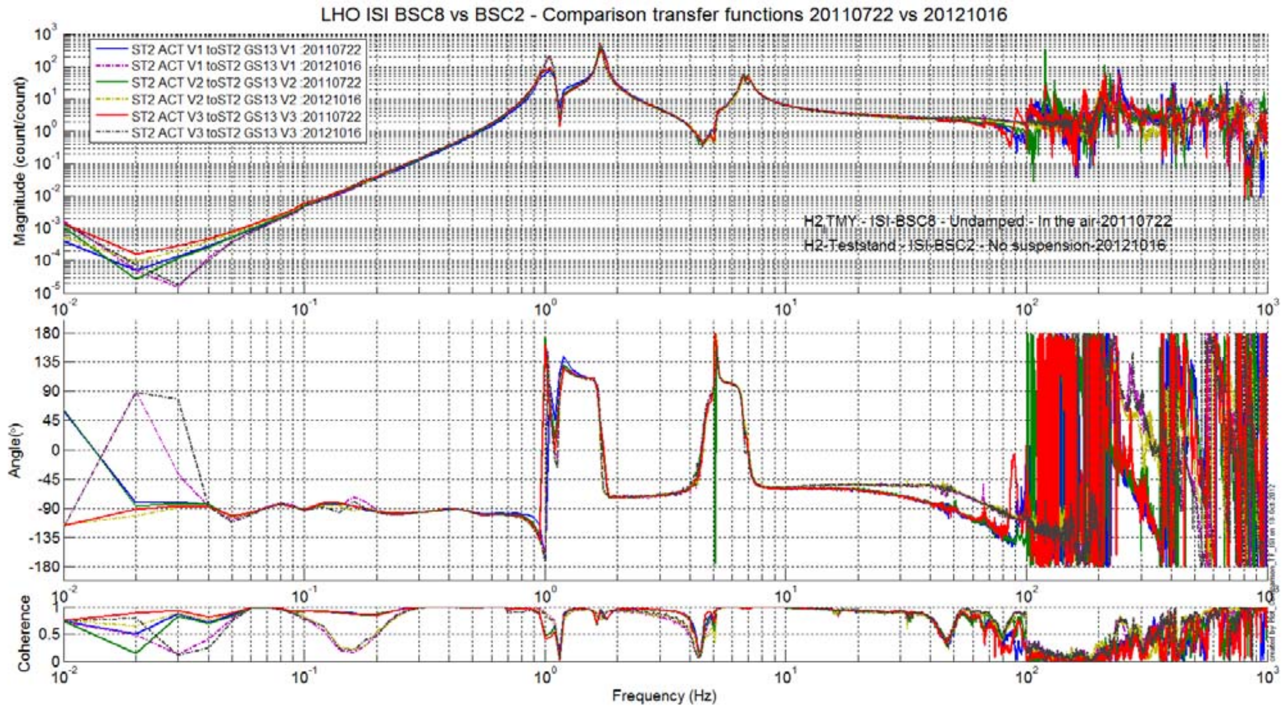

Figure 14 - Comparison BSC6 vs BSC2 – ST2 ACT Vertical – ST2 GS13 Vertical

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

- ***Step 14 - Symmetrization – Calibration***

Not performed

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

- ***Step 15 – Change of base – Cartesian to Cartesian - Simulations***

The transfer functions in the Cartesian basis can be found in the SVN at:
seismic/BSC-ISI/H2/BSC2/Data/Figures/Transfer_Functions/Simulations/Undamped/

- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST1_ACT_to_ST1_CPS_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST1_ACT_to_ST1_L4C_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST1_ACT_to_ST1_T240_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST1_ACT_to_ST2_CPS_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST1_ACT_to_ST2_GS13_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST2_ACT_to_ST1_L4C_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST2_ACT_to_ST2_CPS_2012_10_16.fig
- LHO_ISI_BSC2_TF_C2C_Reconstructed_Sym_from_ST2_ACT_to_ST2_GS13_2012_10_16.fig

Note: The resonances of the structure seen at high frequencies are less visible in the Cartesian

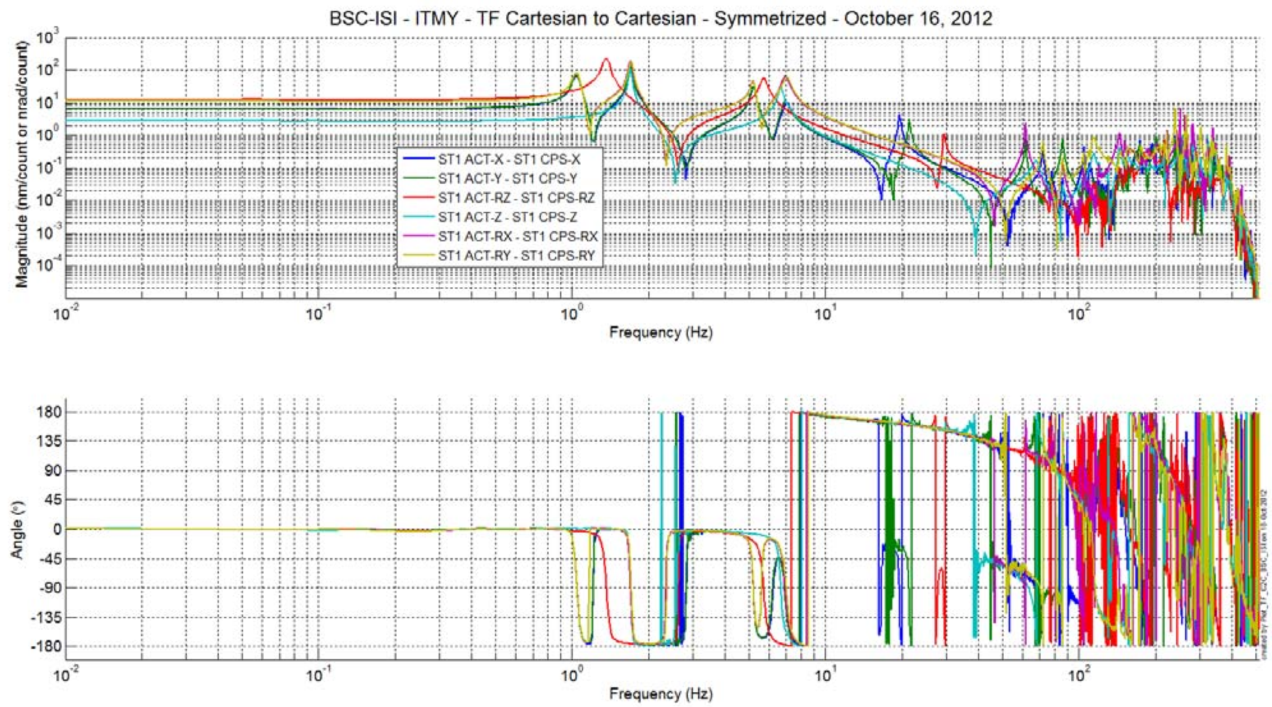

Figure 15 – Transfer functions in the Cartesian basis – ST1 CPS

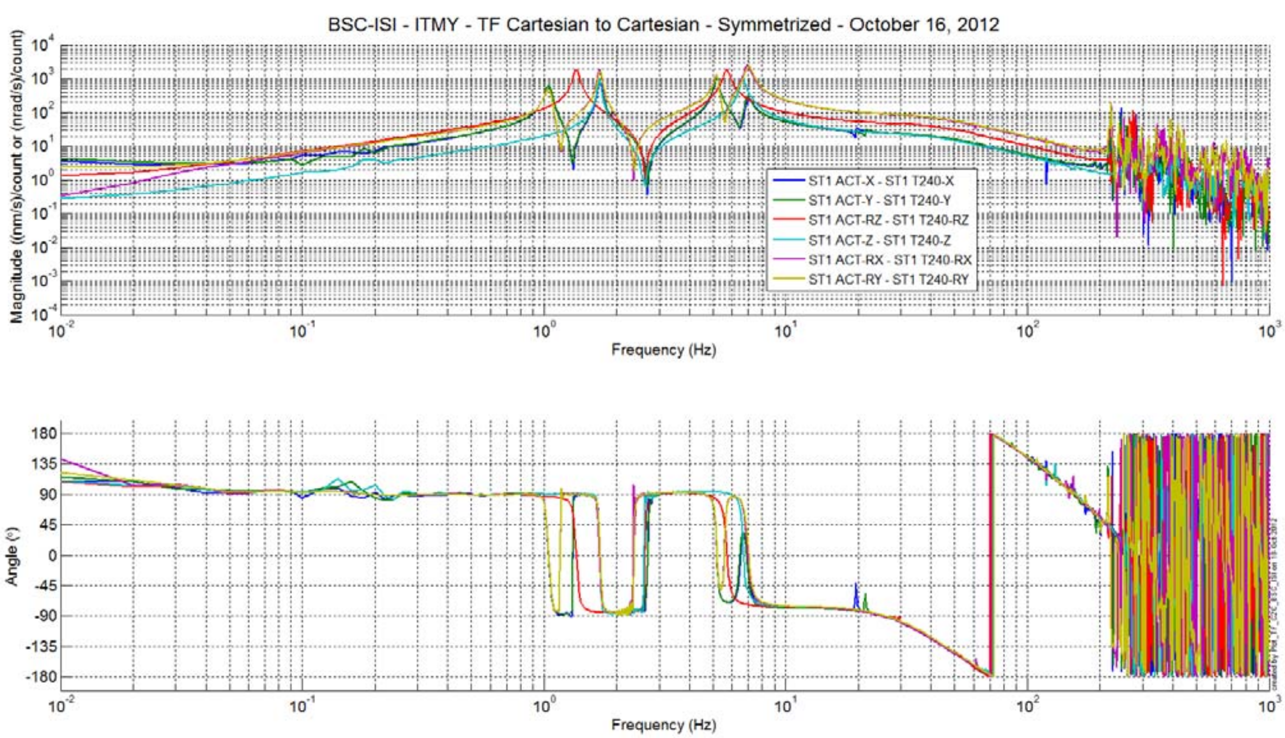

Figure 16 - Transfer functions in the Cartesian basis – ST1 T240

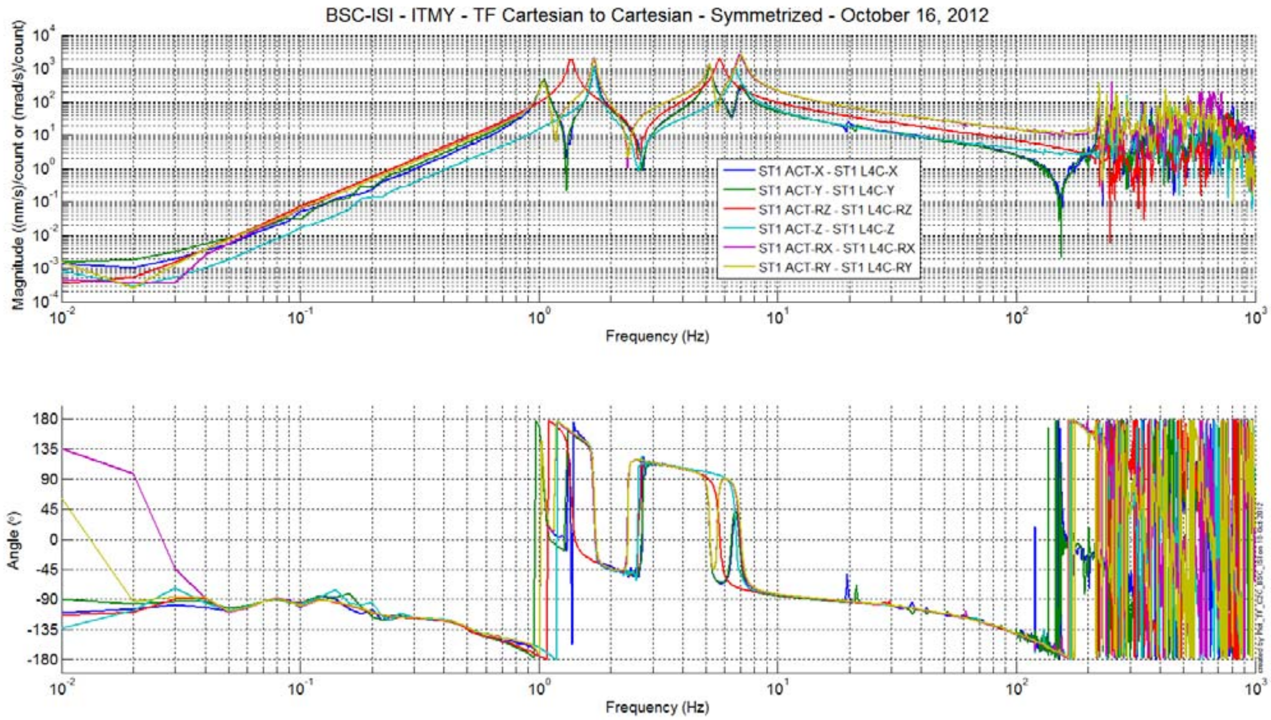

Figure 17 - Transfer functions in the Cartesian basis – ST1 L4C

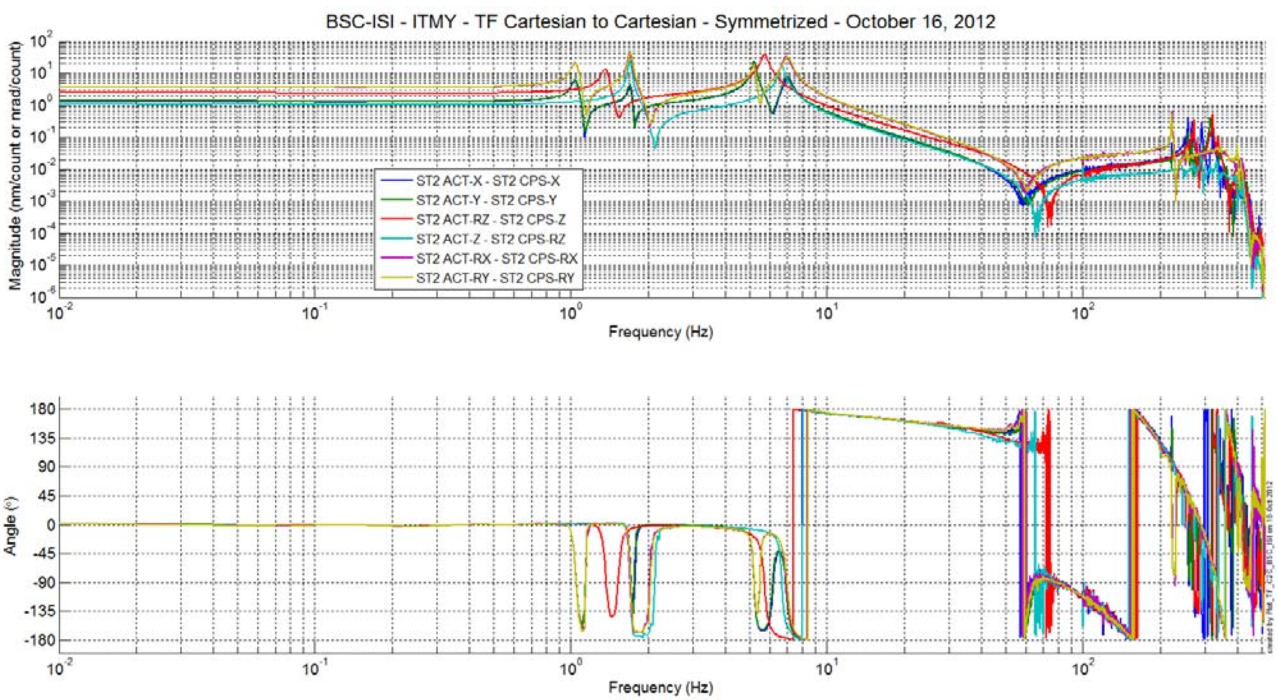

Figure 18 - Transfer functions in the Cartesian basis – ST1 T240

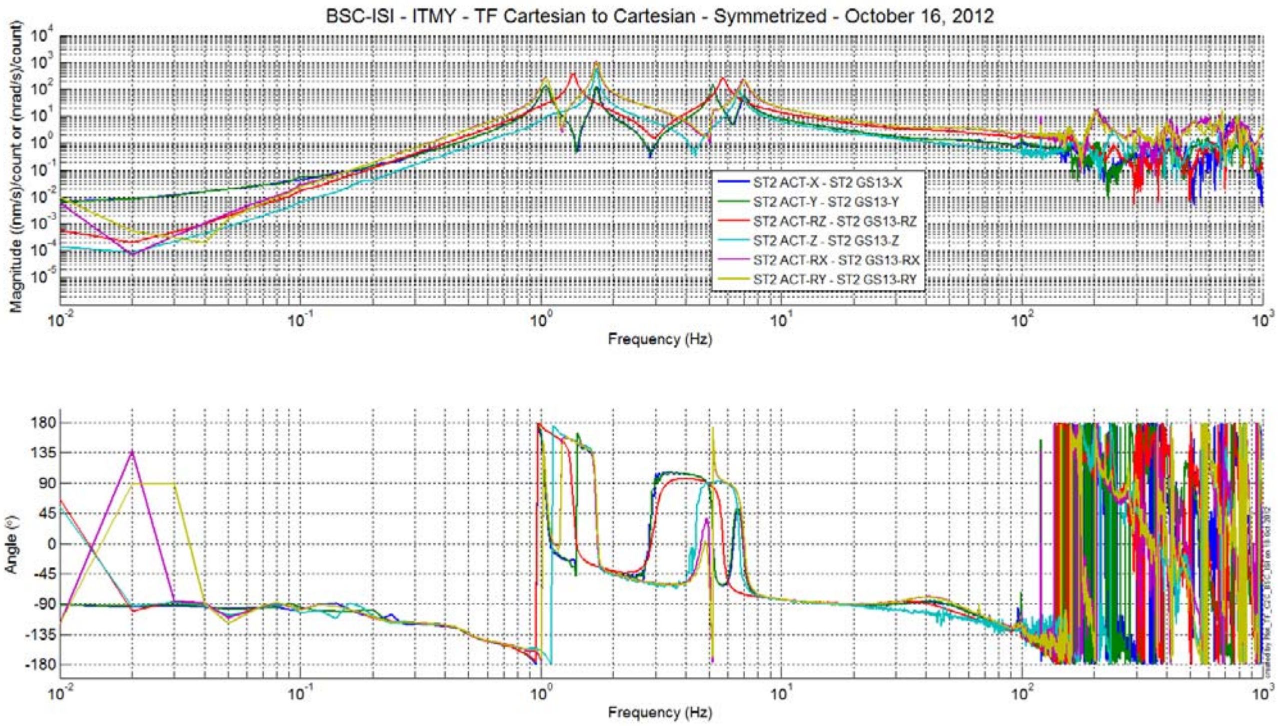

Figure 19 - Transfer functions in the Cartesian basis – ST2 GS13

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

- ***Step 16- Transfer functions - Cartesian to Cartesian - Measurements***

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

- ***Step 17 - Lower Zero Moment Plan***
  - ***Step 17.1 - Stage 1 - LZMP***

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

  - ***Step 17.2 - Stage 2 - LZMP***

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

- ***Step 18- Damping Loops – Transfer function – Simulations***
  - ***Step 18.1 - Damping Loops – Stage 2***

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

  - ***Step 18.2 - Damping Loops – Stage 1***

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

- ***Step 19- Damping Loops – Powerspectra***

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

- ***Step 20- Isolation Loops – for one unit per site***

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

IV. BSC-ISI testing Summary

This is the third “aLigo BSC-ISI” tested at LHO. The testing procedure document E1000483-v5 was used. Tests were done during in October 2012.

The LHO ISI-BSC2 is validated per the tests presented in this report. All results are posted on the SVN at:
https://svn.ligo.caltech.edu/svn/seismic/BSC-ISI/H2/BSC2/Data

FAILED AND WAIVED TESTS

1- List of tests that failed/waived and won’t be redone

- **Step II.10 – Mass budget –** The mass of the payload is slightly lower than the design
- **Step III.9 – Spring constant –** The blades are slightly softer than the design. However, the blade softness and the payload are in good agreements. It doesn’t have any effect on the rigid body modes of the ISI.

2- List of tests that failed/waived, that need to be re-done during phase 2

3- List of tests skipped that won't be performed because not feasible during phase II (i.e. stage 0 leveling)

- **Step II.5 –** Check level of Stage 0 after top-bottom plate assembly
- **Step II.8** – Blade 0-1 Post Launch Angle – No need for this test, the budget mass looks good and we already reposition the Blades after noticing a gap between the Blade and its Spacer on Stage 0-1 (see comment on Step 9 – Vertical Spring Constant).

4- List of tests skipped that we won't do because they are not essential (i.e. redundant with another test)

- **Step III.3 – Measure the Sensor gap -** This test was not performed. The sensor gaps have not been measured. These sensors have already been checked at LASTI. Moreover, risks of scratching the target are so high that we preferred not performing this test. In the future, this test will be removed from the testing procedure.
- **Step III.8 – Vertical sensor calibration -** The test is not realized in a proper way to evaluate accurately the calibration of the vertical CPS.

5- Lists of tests skipped that needs to be done during phase II.

- **Step III.14 – Symmetrization – Calibration**
- **Step III.16 – Transfer functions – Cartesian to Cartesian - Simulations**
- **Step III.17 – Lower Zero Moment Plan**
- **Step III.18.1 – Damping Loops – Stage 2**
- **Step III.18.2 – Damping Loops – Stage 1**
- **Step III.20 – Isolation loops**