Advanced LIGO Preliminary Design Review of the BSC ISI system - Overview Presentation

LIGO-G0900676-v3

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1. Introduction

BSC Internal Seismic Isolation (BSC-ISI) system

- ✓ A support structure (Stage 0) and Two suspended active stages (Stage 1 & 2).
- ✓ Will be installed for Advanced LIGO into the BSC chambers.
- ✓ A BSC-ISI system in each of the 15 BSC chambers.
- ✓ Optic table supports the test masses and beam splitters.
- ✓ Stage 0 will support the baffles
- ✓ Optical table is higher than I-LIGO (above the support tubes).

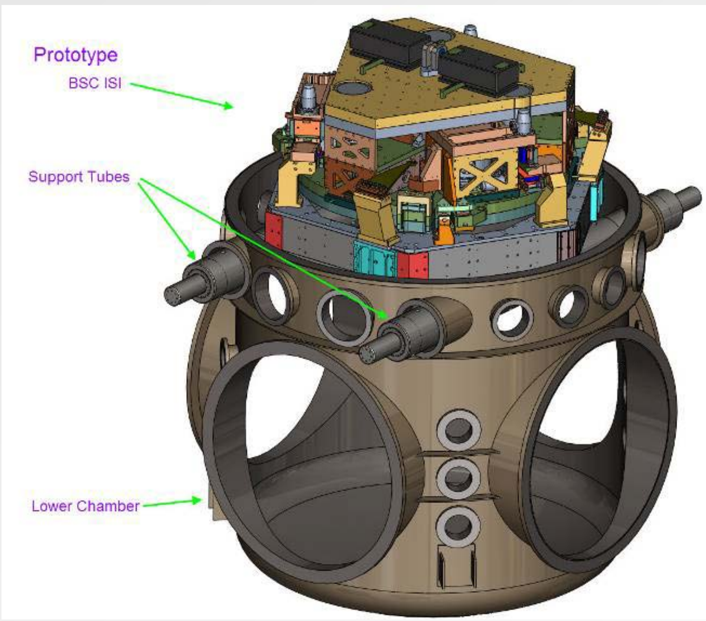


Fig.1: The BSC-ISI system installed on the support tubes of the HEPI-BSC.

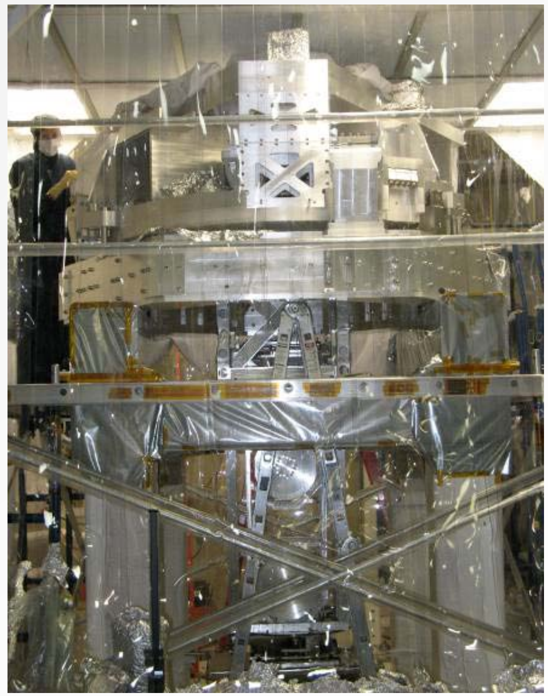


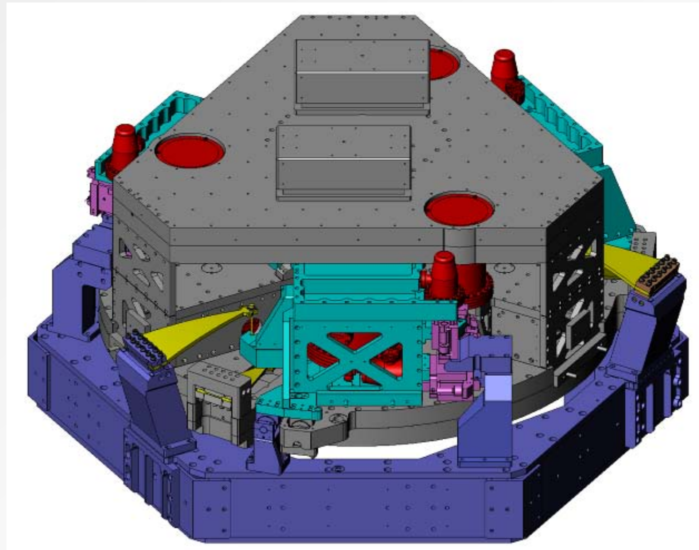
Fig.2: BSC-ISI on its assembly stand at LASTI.

1. Introduction

Both suspended stages and have 6 degrees of freedom:

- ✓ Blades provide the vertical flexibility
- ✓ Rods provide the horizontal one
- ✓ Suspension frequencies in the 1Hz-7Hz range
- ✓ Passive isolation from few Hz to ~ 100Hz
- ✓ Active isolation in the 0.1Hz-20Hz range.
- ✓ Active control positioning

BSC-ISI as built for the prototype installed at LASTI



- Stage 0 in violet
- Stage 1 in cyan
- Stage 2 in grey
- Blades and flexure in yellow
- Sensors in Red
- Actuators in Pink

Historic

- ✓ Design requirements: May 2004 , LIGO-E030179-A, Design Requirements for the In-Vacuum Mechanical Elements of the Advanced LIGO Seismic Isolation System for the BSC Chamber.

- ✓ Initial design done by ASI. Presented in the document “Advanced LIGO BSC Prototype Critical Design Review, June 18 2004”.

- ✓ Technical memorandum delivered on October 15, 2004 and a transition meeting was held on January 18-19, 2005. A critical review has been presented by the SEI team on January 2005, document G050007-00-R.

- ✓ Analysis showed that this design should meet most of the design requirements as described on "Design requirements summary", page 4-10 of “Advanced LIGO BSC Prototype Critical Design Review". The initial design is described in part 2 of this document.

- ✓ Requirements which were not met were waived by the SEI team.

- ✓ A prototype of the BSC-ISI was then manufactured by Arland and Limerick.

- ✓ Assembled at MIT in 2006.

2. Initial design

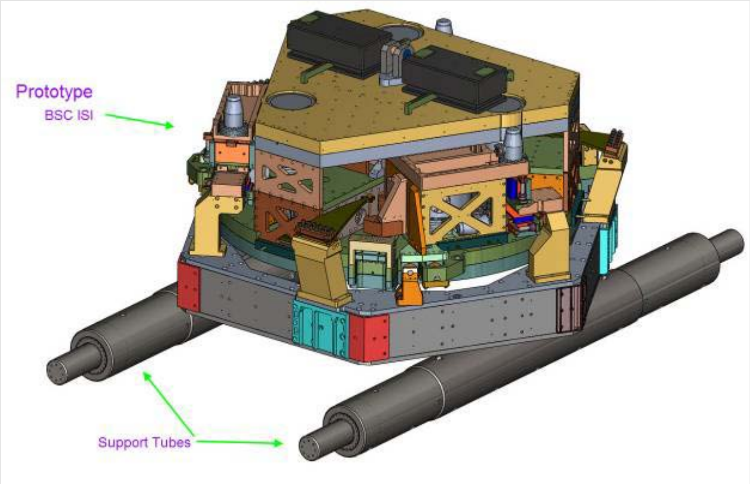


Fig.1: as built for the prototype installed at LASTI.

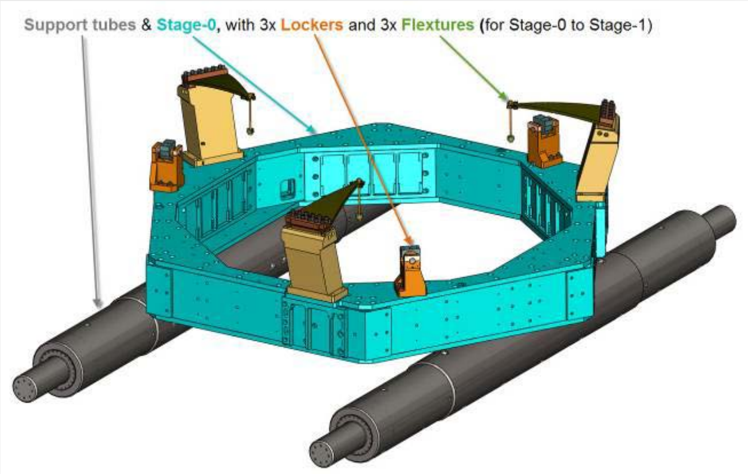


Fig.2: Stage 0 with the Stage0-to-Stage1 lockers and the Blade posts for Stage 1.

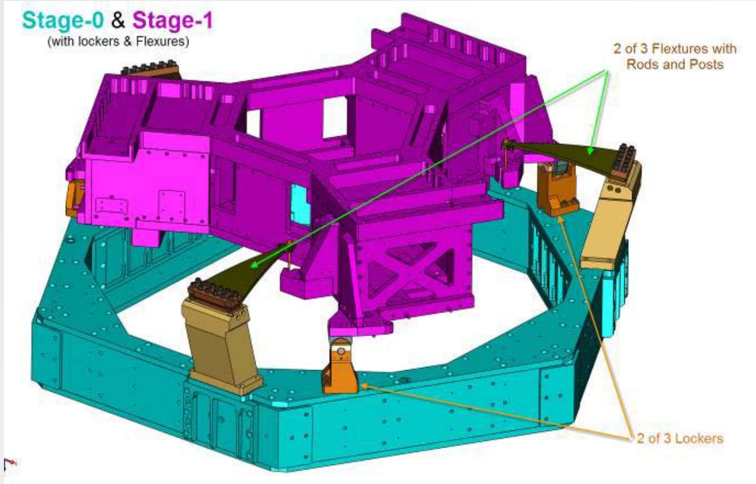


Fig.3: Stage1 is suspended to the flexure rods.

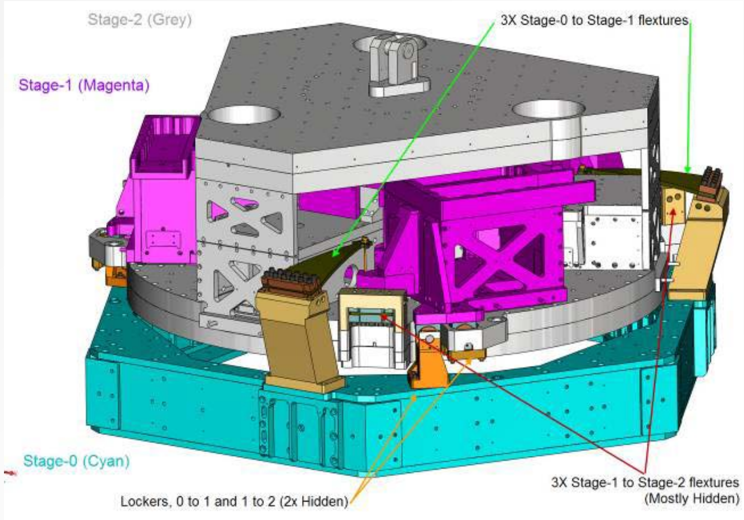


Fig.4: Stage 1 and Stage 2 fit together. Optical table on Stage2.

2. Initial design

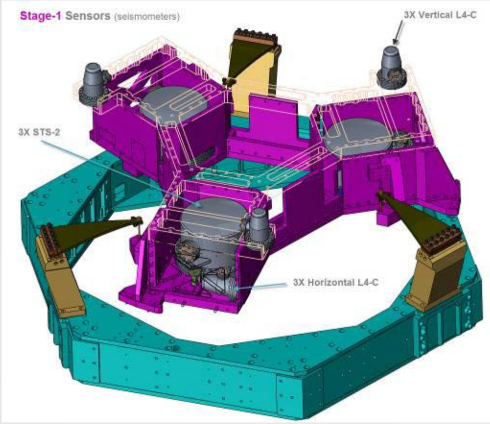


Fig.1: position of the instruments on stage 1.

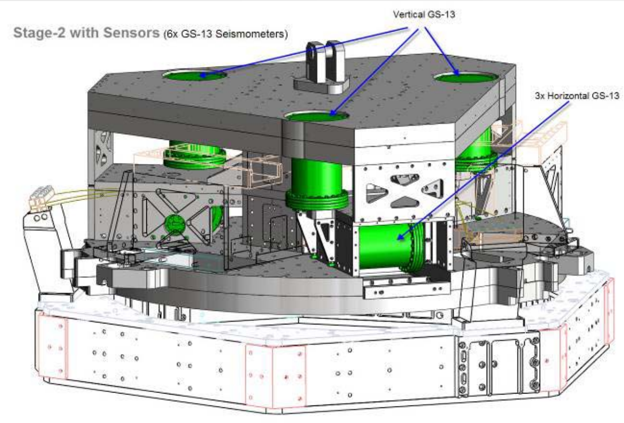


Fig.2: position of the instruments on stage 2.

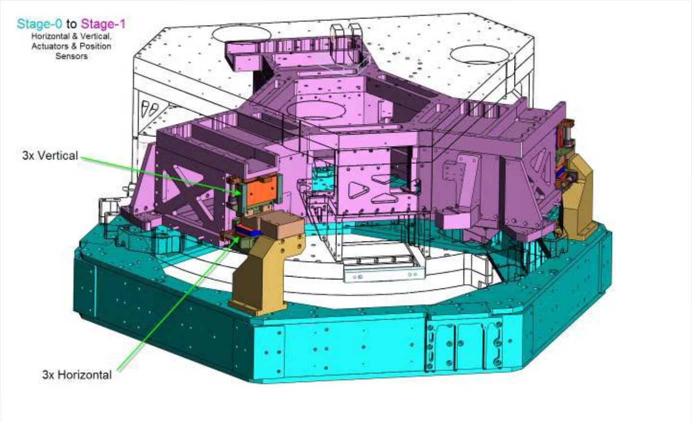


Fig.3: position of the actuators on stage 1.

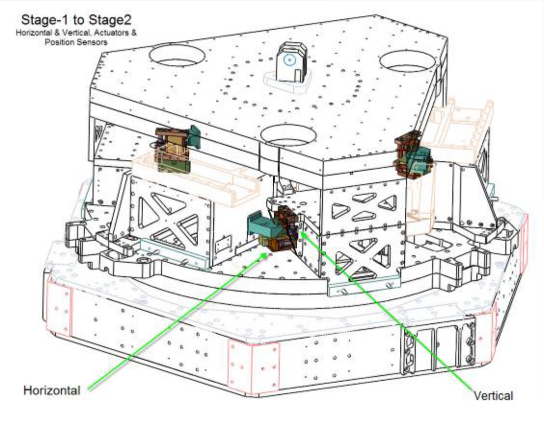
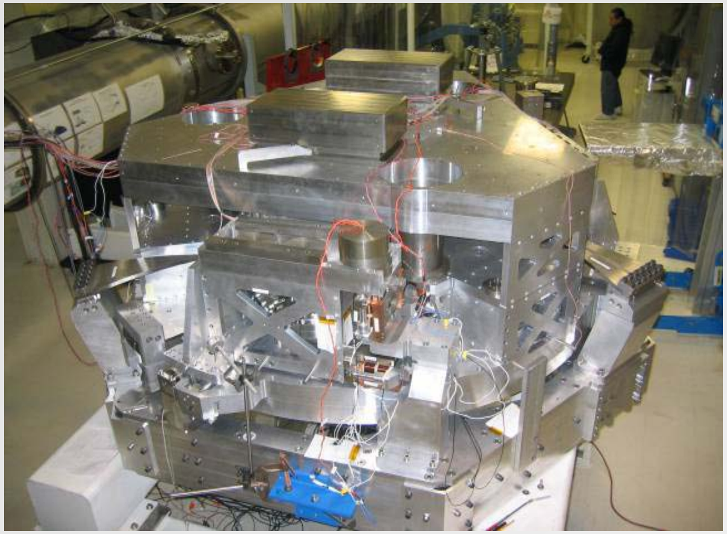


Fig.4: position of the actuators on stage 2.

3.1 Dirty assembly and Testing (2006-2007)



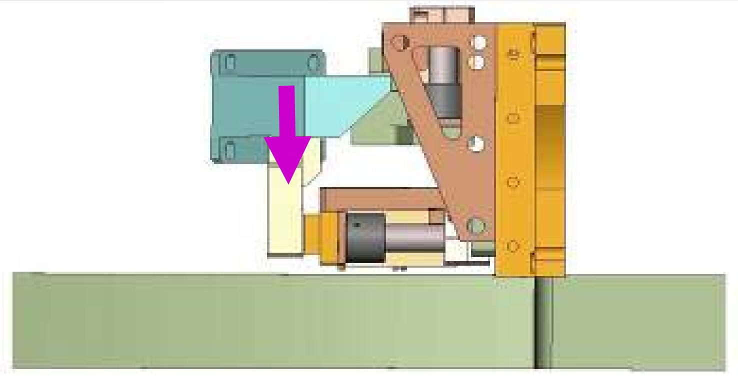
Dirty assembly at LASTI

Objectives

- ✓ Parts fit
- ✓ Measure the cross couplings
- ✓ Shimming process

Conclusion

- ✓ Fit but referencing was unsatisfactory
- ✓ Actuators mis-positioned
- ✓ Adequate performance



Small actuators re-positioning

→

"X to Ry" : from
190mHZ to 60mHz

"Y to Rx" :from
190mHZ to 90mHz

3.2 Cleaning (2007)

Cleaning period permitted us to:

✓ Adjust the Cleaning space requirements and facilities : in-house chemical cleaning and oven space limitations determined. Large plate baking capability moved to LIGO.

✓ Adjust the cleaning process: Cleaning/baking procedures evolved.

✓ Solve some cleaning issues.

✓ Modifications, i.e., Mounting holes of the optical table become through holes.

Machining scraps

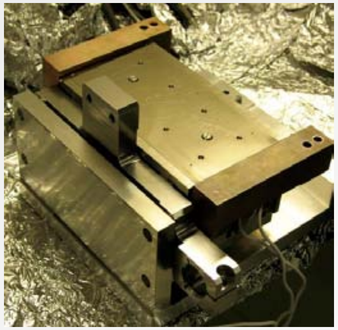
Holes in the large plate

Residual chemicals

3.3 Clean assembly (Late 2007- 2008)

- ✓ Careful attention was given to assembly issues.
- ✓ Wrote the assembly procedure
- ✓ Main problems identified and addressed
- ✓ A change design list established


Friction




Actuators

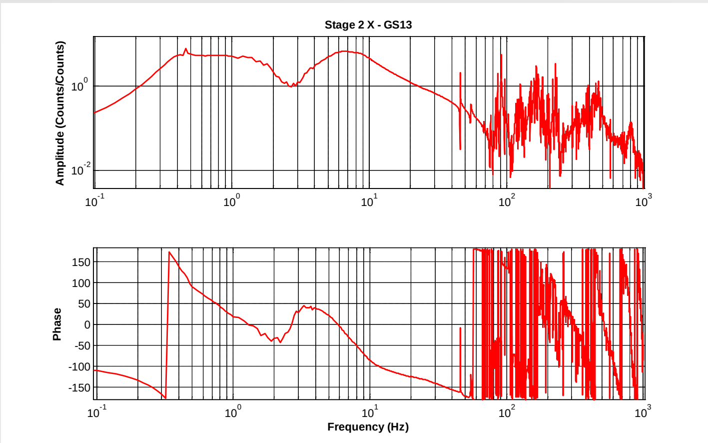
Tooling

Rods attachment

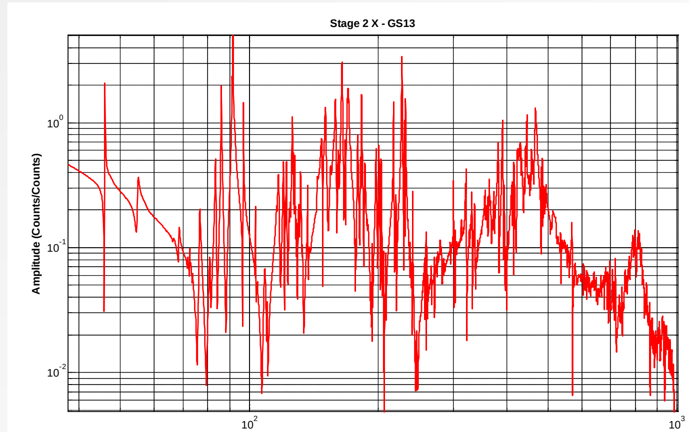
3.4 First commissioning (June 2008- December 2008)

Three major problems identified:

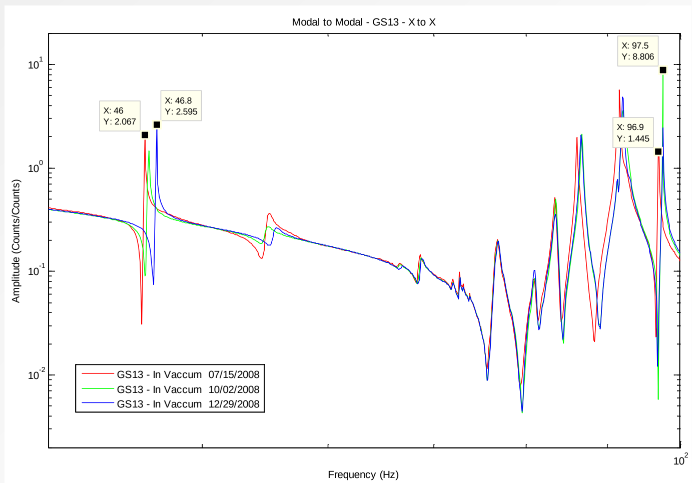
- ✓ **The first deformation resonances were much lower in frequencies than required.**
- ✓ **The modal density at high frequencies was higher than expected.**
- ✓ **The plant was variant in time.**



Low frequency modes



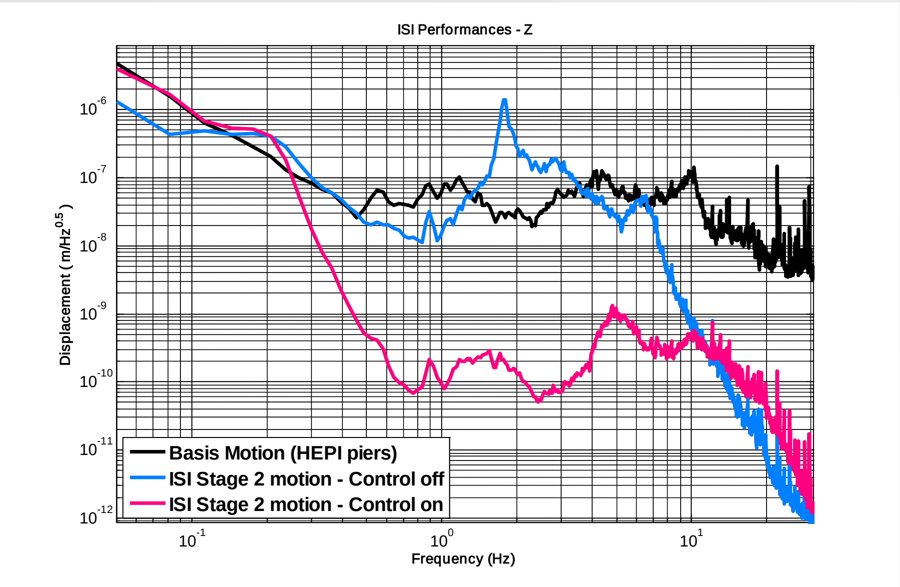
High modal density



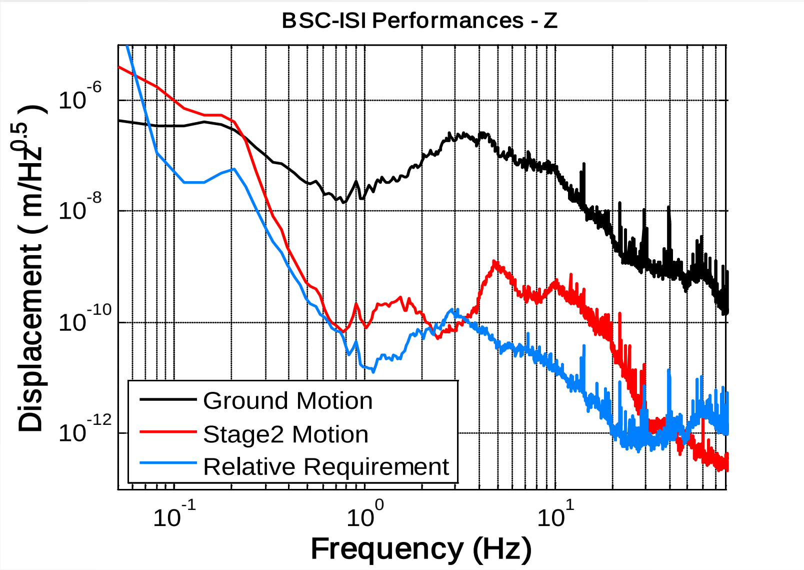
Plant variation

3. Prototype assembly and testing

- ✓ **Plant variability was the main limit of the control performance.**
- ✓ **The control adjusted iteratively according to the plant changes**
- ✓ **Fully controlled the 12 degrees of freedom of the system.**



ISI System Performance 11/2008



BSC Global Performance 11/2008

- ✓ **Decided to stop the control development to investigate the sources of resonances and the plant variability.**
- ✓ **Necessary in order to make the control more robust and to improve the performance.**

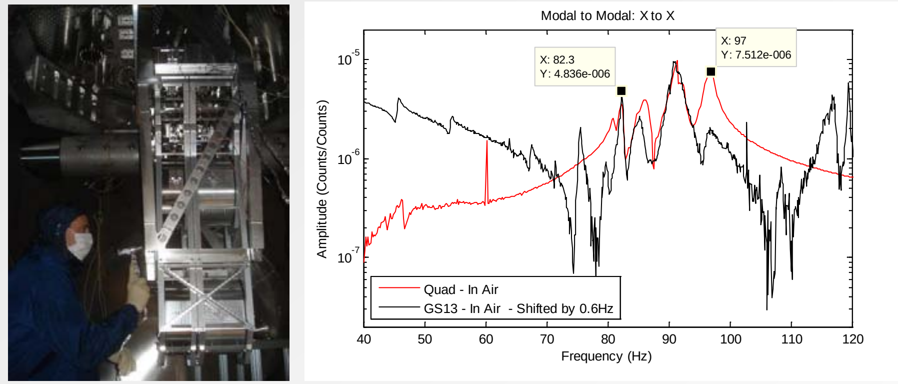
3.5 In Situ Testing

- ✓ **Correlate some modes in the quad with some modes in the BSC-ISI transfer function**

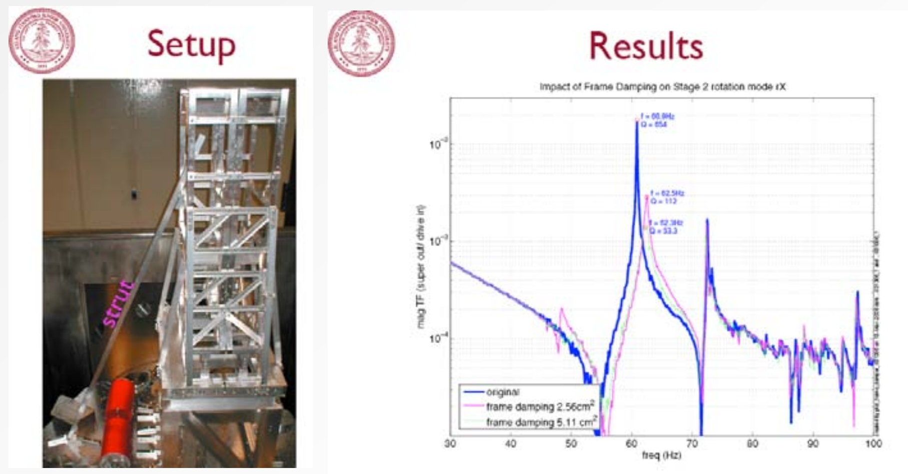
- ✓ **Concluded we should continue the investigation on the use of damping.**

- ✓ **Showed that the quad was neither the source of the high number of resonances nor the cause of the shifting modes.**

- ✓ **Continued the investigation by studying the other stages.**



Quad-ISI modal testing



Damping strut setup & Result on the Tech Demo at Stanford

3.5 Testing and hardware modifications

GS13 pods

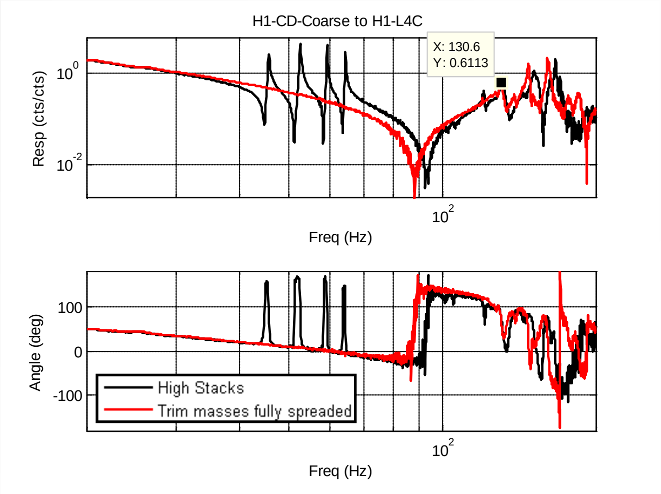
- ✓ GS13 pods mounted cantilevered.
- ✓ Brackets have been machined and installed to lock the free end of the pods.
- ✓ Great improvement on the transfer functions for both the horizontal and vertical seismometers.
- ✓ Permanent solution to clamp the pods on both sides under development.

Trim masses (counter weights)

- ✓ One of the biggest sources of resonances. Stacks to high, poor attachment.
- ✓ Brackets machined and trim masses have been re-machined in order to split these columns and attach them stiffely in various locations.
- ✓ Significant improvements obtained on both stages.
- ✓ Trim masses location and their attachment to the stages are being revised for AdL.

GS13 Attachment

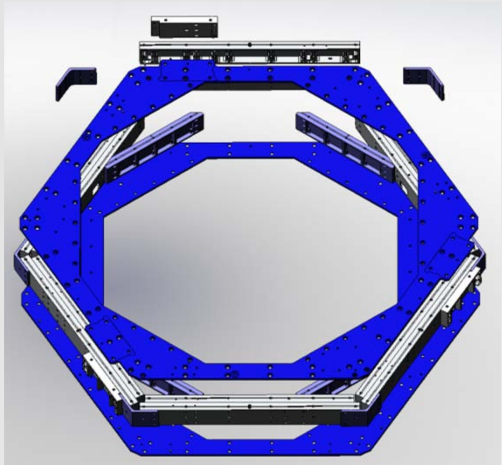
Counter weights



Transfer function

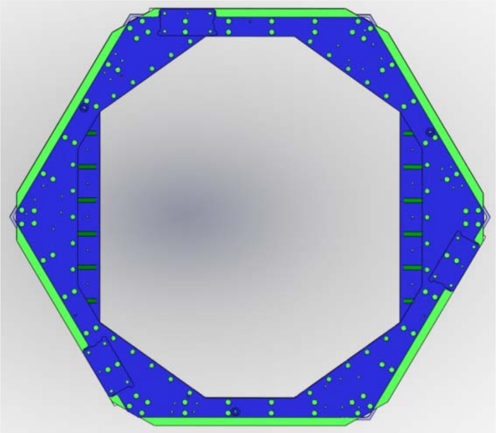
Stage 0

LASTI Prototype

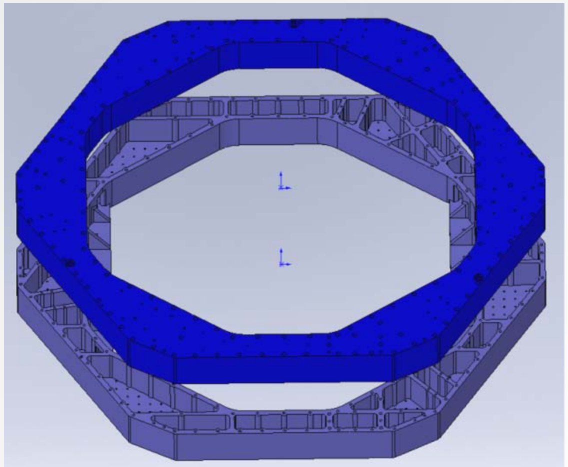


- ✓ 29 parts
- ✓ 967 lbs + hardware
- ✓ 330 screws
- ✓ ~38,000 USD

LASTI prototype
Re-designed



Advanced LIGO



- ✓ 2 parts
- ✓ 1186 lbs + hardware
- ✓ 106 screws
- ✓ ~42,000 USD (Qty 15)

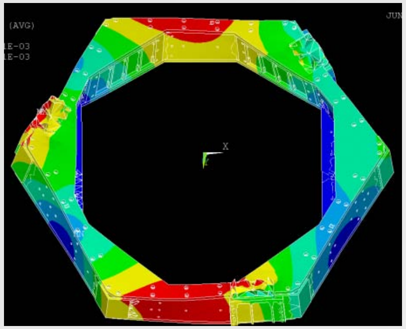
4. Advanced LIGO Design

LASTI Prototype

- ✓ **Modal Analysis**

  1st natural frequency 77 Hz

- ✓ **Static Analysis**



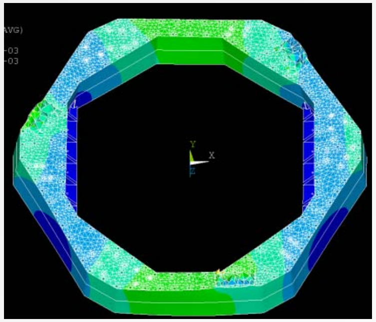
Nodal displacement contours plotted at the same scale (from 0 to 0.225 mm)

Re-designed

- ✓ **Modal Analysis**

  1st natural frequency 133 Hz

- ✓ **Static Analysis**



Bottom flexure rod displacement

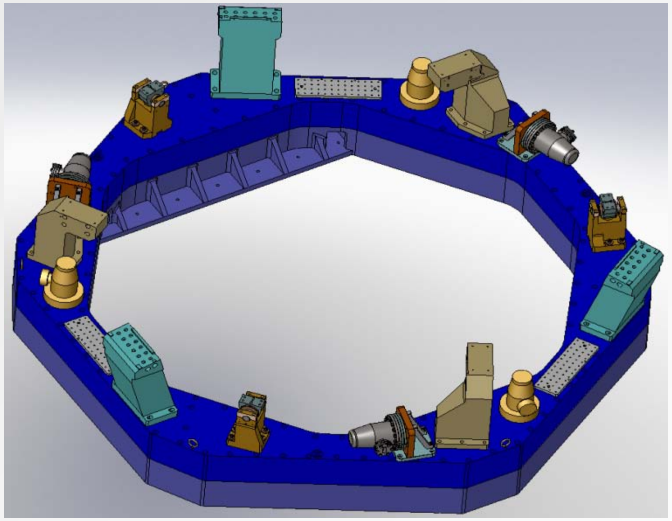
	Post #	x displacement	y displacement	displacement in the x-y plane	z displacement	% between z displacement
		mil	mil	mil	mil	
LASTI Prototype	1	-2.3	-4.6	5.2	30.3	7.85
	2	-9.0	1.4	9.1	29.8	
	3	10.9	2.9	11.3	27.9	
Re-designed	1	-1.3	-4.1	4.3	28.3	6.60
	2	-6.6	1.4	6.7	28.0	
	3	7.0	2.2	7.4	26.5	

LASTI Prototype

- ✓ 3 Stage 0-1 Blade posts
- ✓ 3 Stage 0-1 Actuator posts
- ✓ 3 Stage 0-1 Lock down posts
- ✓ 3 eyebolts for lifting

Re-designed

- ✓ Posts position maintained.
- ✓ Possible feed-forward from Stage 0 to Stage 1
- ✓ 6 breadboards on the top
- ✓ Beam dumps attachment
- ✓ 6 eyebolts (on both parts)

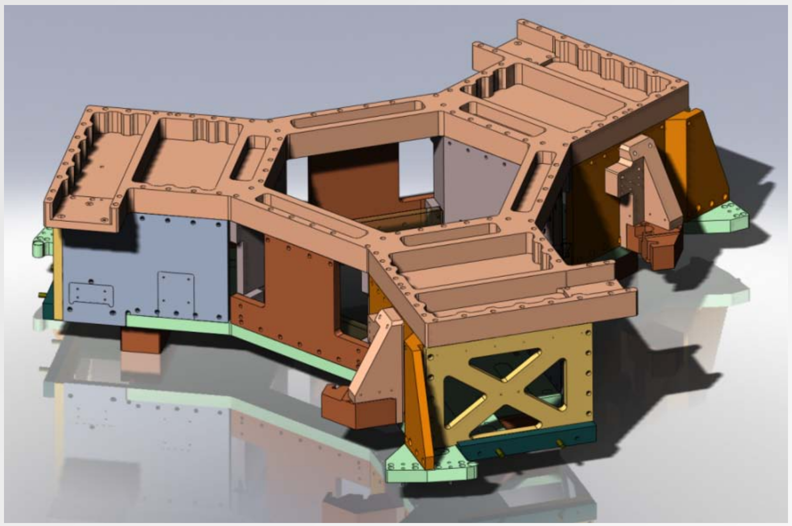


Components on Stage 0
(only half of the breadboards are represented)

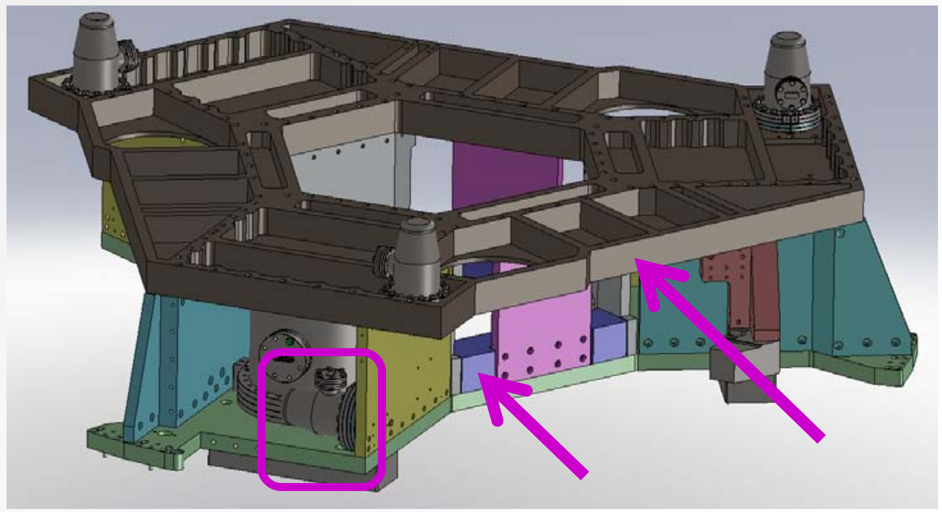
4.1 Stage 1

3 main objectives in the Stage1 re-design:

- ✓ **Re-designing the positioning of the parts. Cut outs are replaced by pins.**
- ✓ **Implementing the changes of the “design changes list”.**
- ✓ **Improving the stiffness where it can easily be made.**



Prototype

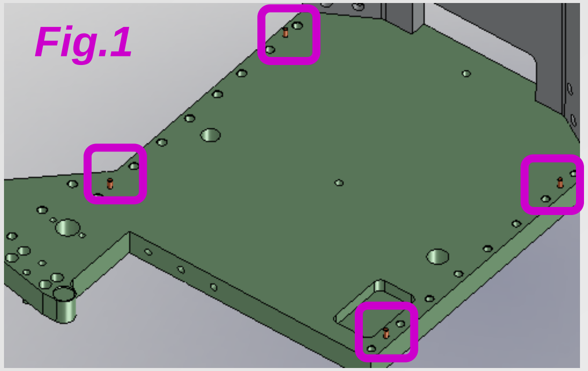


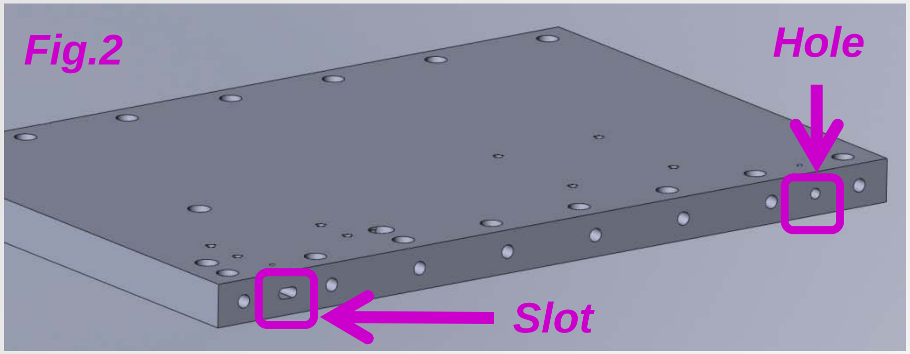
AdL Design

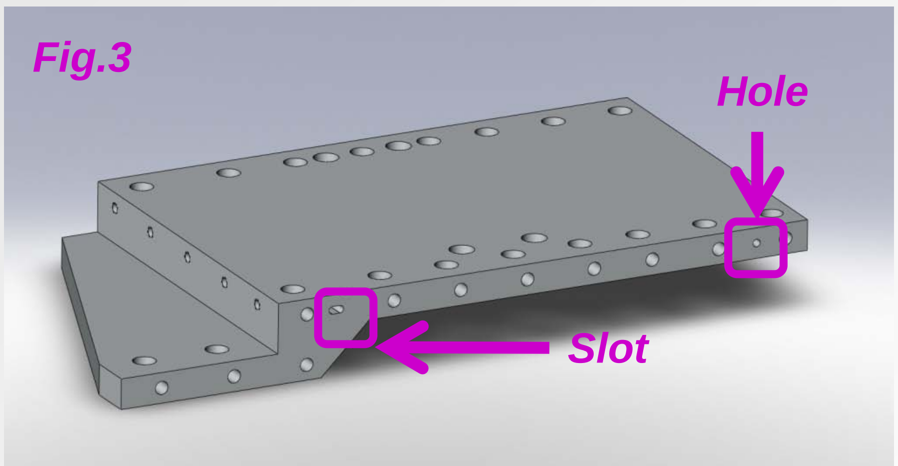
***G0900461-v1, Stage1 design review presentation*.**

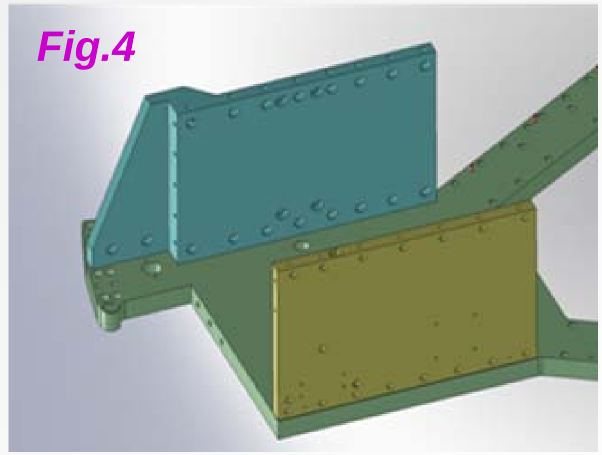
4. Advanced LIGO Design

Stage 1 – Parts positioning





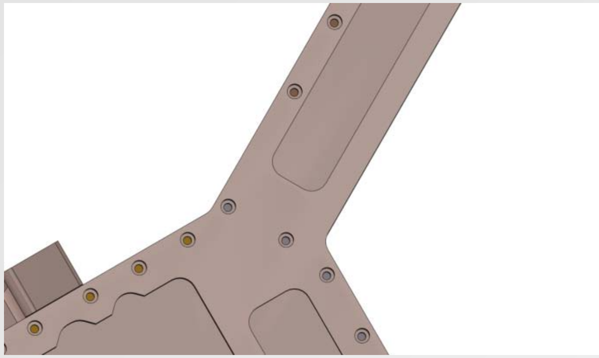




***G0900461-v1, Stage1 design review presentation*.**

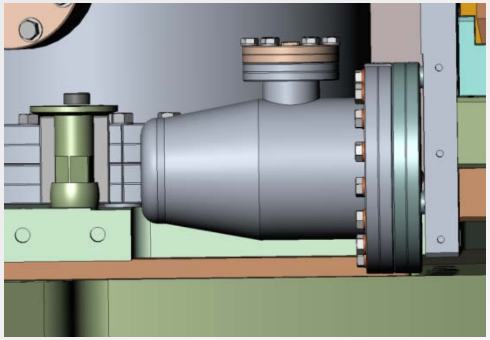
Stage 1- Items on the Change design list

Item #5 – Part 2007825
Holes too small

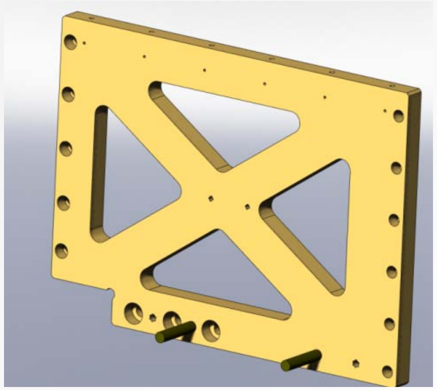


Item #6 – Part 2007827
Barrel Nut access

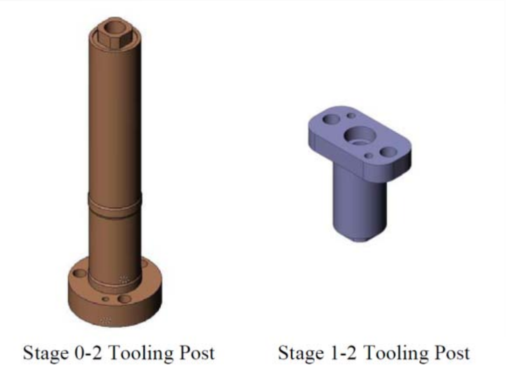
Item #18 – Horizontal L4C Placement



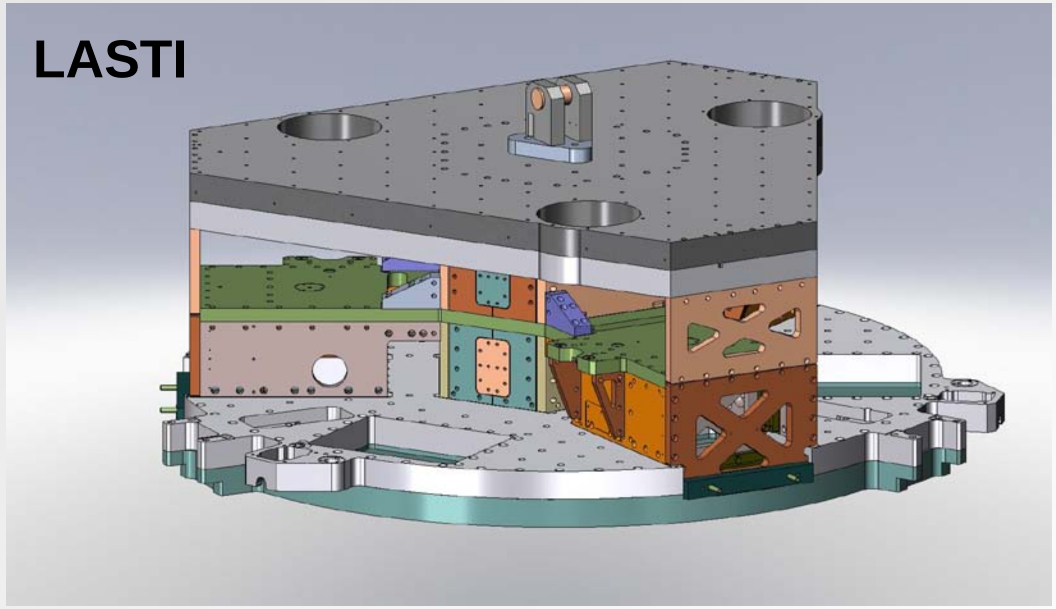
Item # 32 – 20007831
Holes alignment

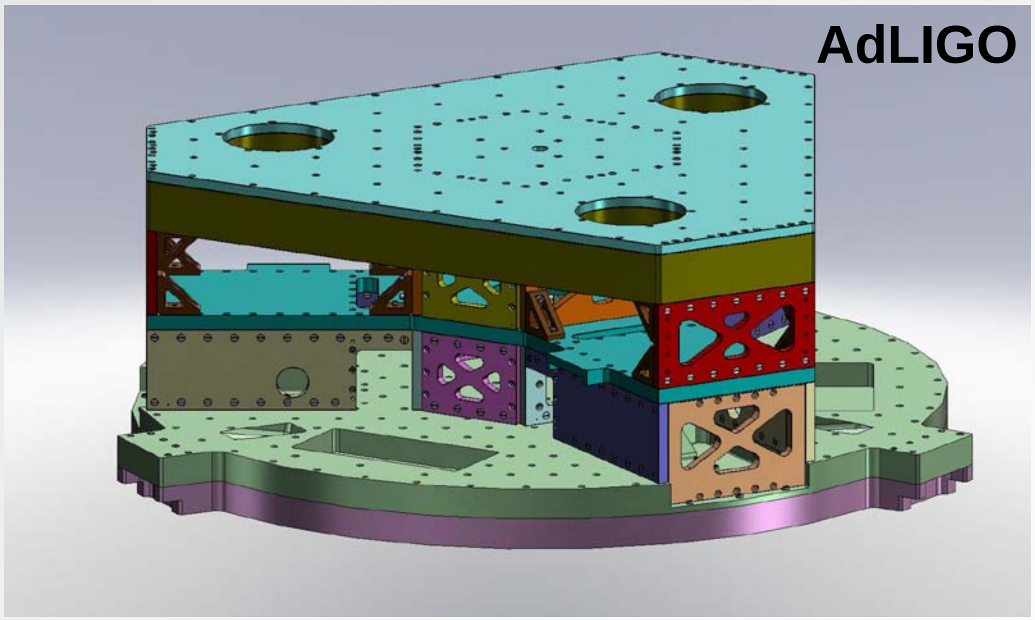


Item # 42
Tooling posts



4.3 Stage 2

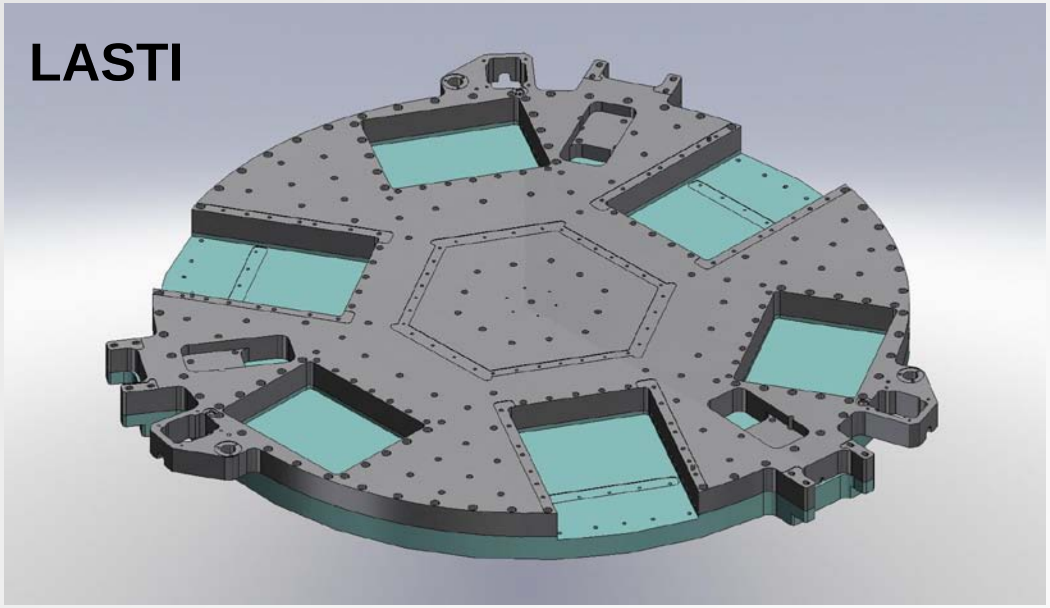


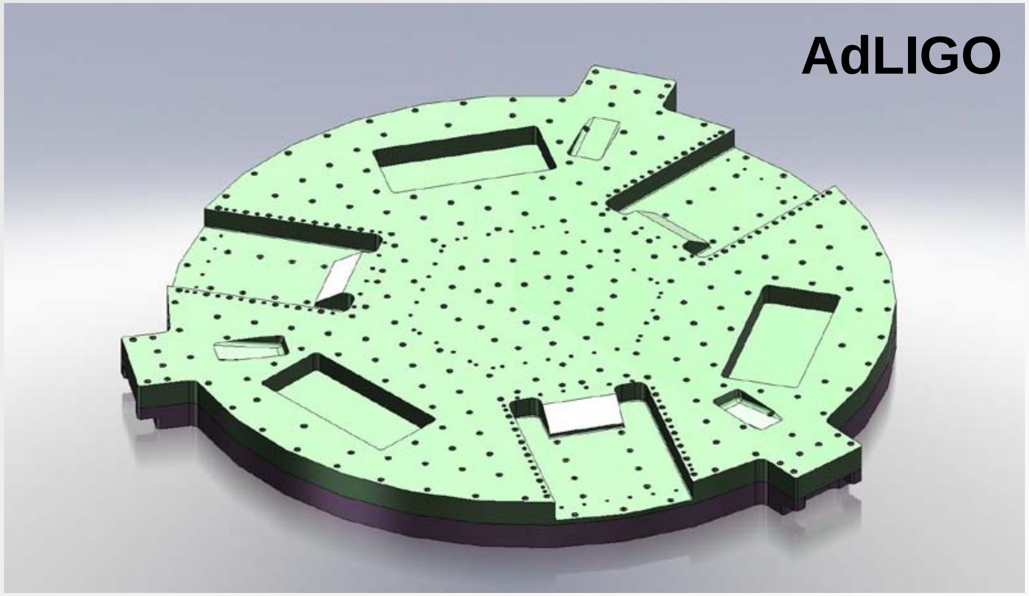


Changes for Advanced LIGO:

- ✓ Simpler Assembly
- ✓ Dowel Pins to Align
- ✓ Redistributed Mass for Better Stiffness

Stage 2- Optical Table

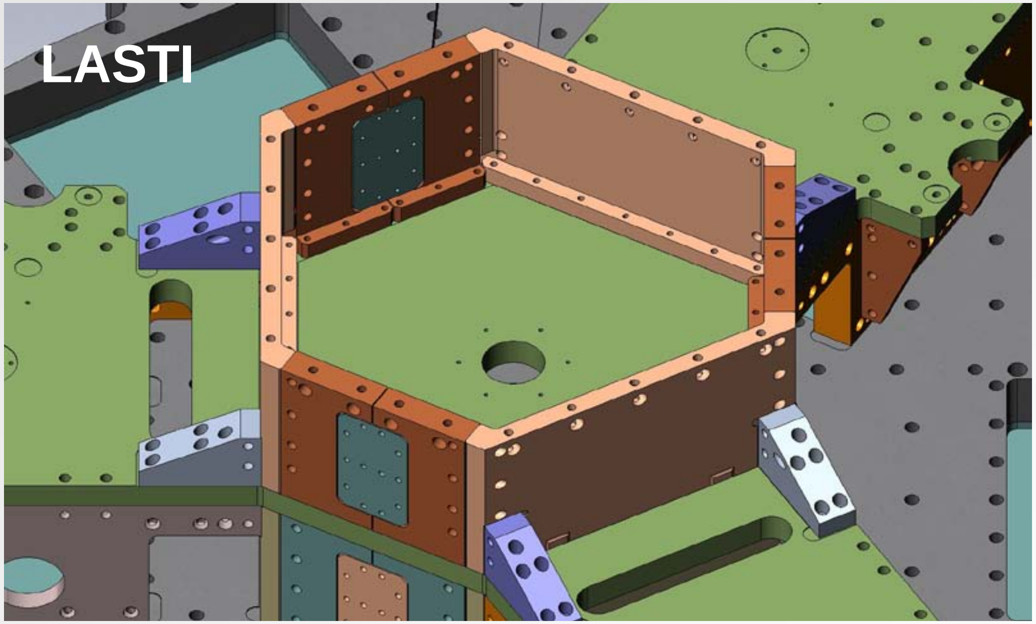


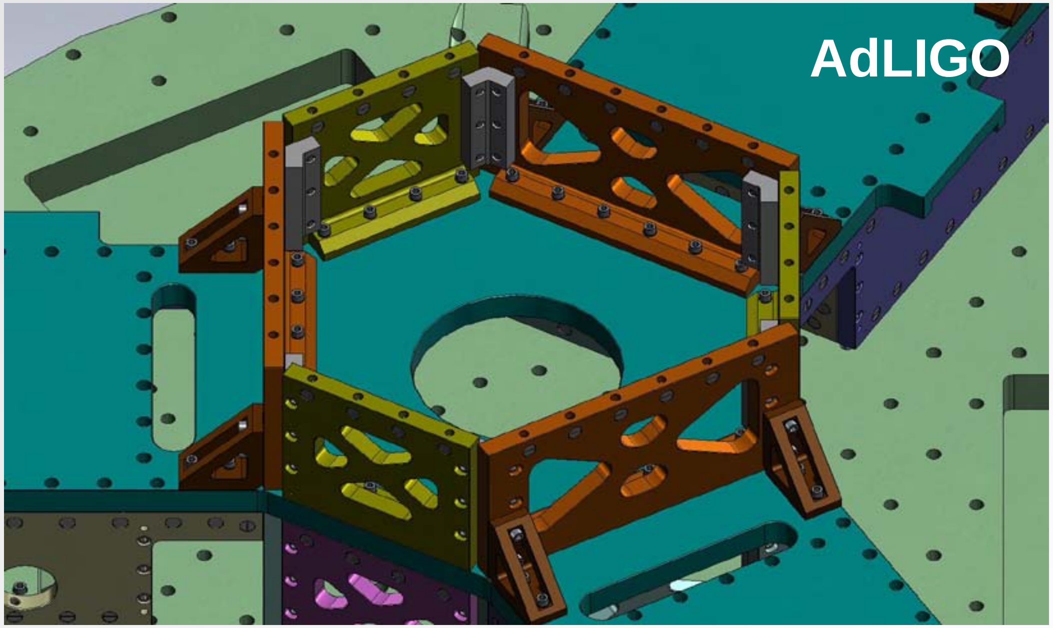


Changes for Advanced LIGO:

- ✓ New Webbing
- ✓ Eliminate Blind Holes
- ✓ Add Vent Grooves
- ✓ Eliminate “Cut-outs”

Stage 2- Hex Walls

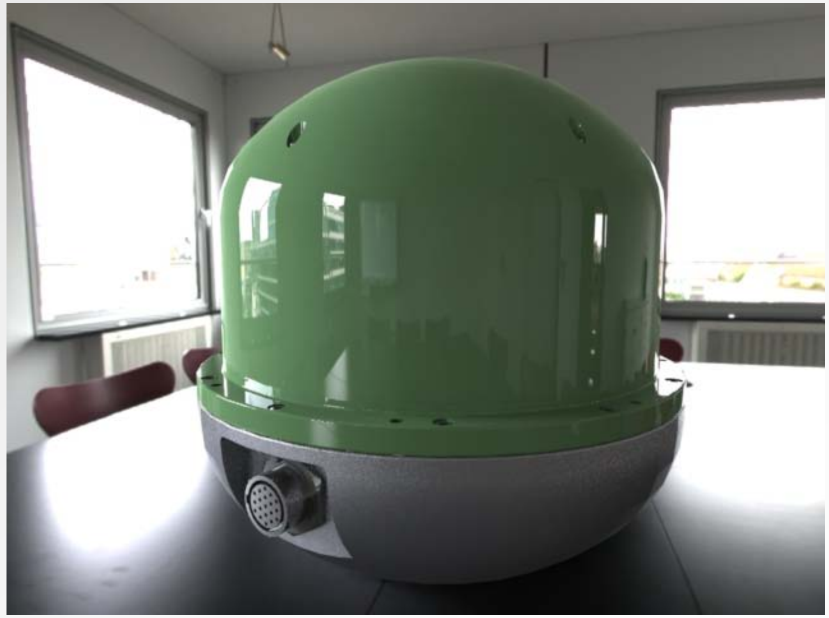




Changes for Advanced LIGO:

- ✓ Fewer Plates
- ✓ Dowel Pins to Align
- ✓ Floating Brackets Couple Plates together

STS-2 vs. Trillium 240 OBS



STS-2 Diameter: 9.5 in
Dia. with lockerMtrs: 13.5in
Height: 9.5 in
Weight: 21 lb

Trillium Diameter: 9.5 in
Height: 8.9 in
Weight: 21 lb
(No Locker needed)

STS-2 vs. Trillium 240 OBS Pods

STS-2 Pod
- **Base OD: 16.0 in**
- **Top Hat OD: 14in**
- **Height: ~11 in**
- **Weight: ~115 lb**
- **FeedThru OD: 4.47in**

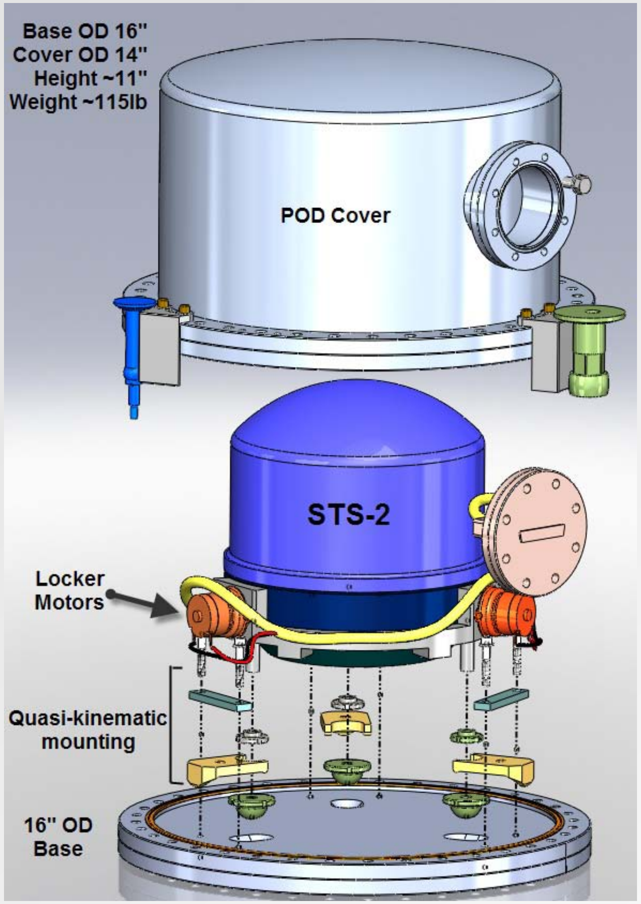
→

Trillium Pod
- **Base OD: 12 in**
- **Top Hat OD: 10in**
- **Height: ~11.5 in**
- **Weight: ~75 lb**
- **FeedThru OD: 4.47in**

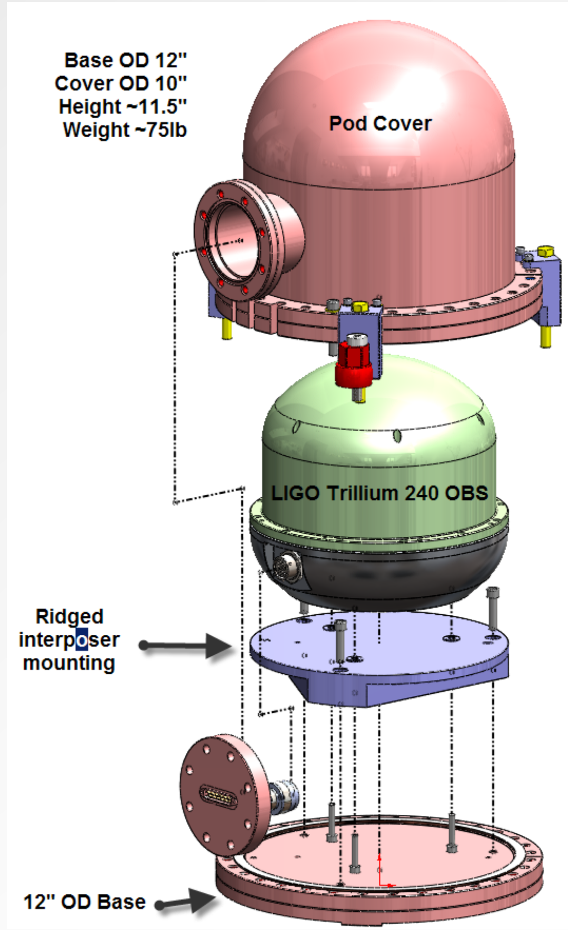
→

STS-2 vs. Trillium 240 OBS Pods

Trillium Pod Diameter: 12 in
Height: ~11.5 in
Weight: ~75 lb



STS-2

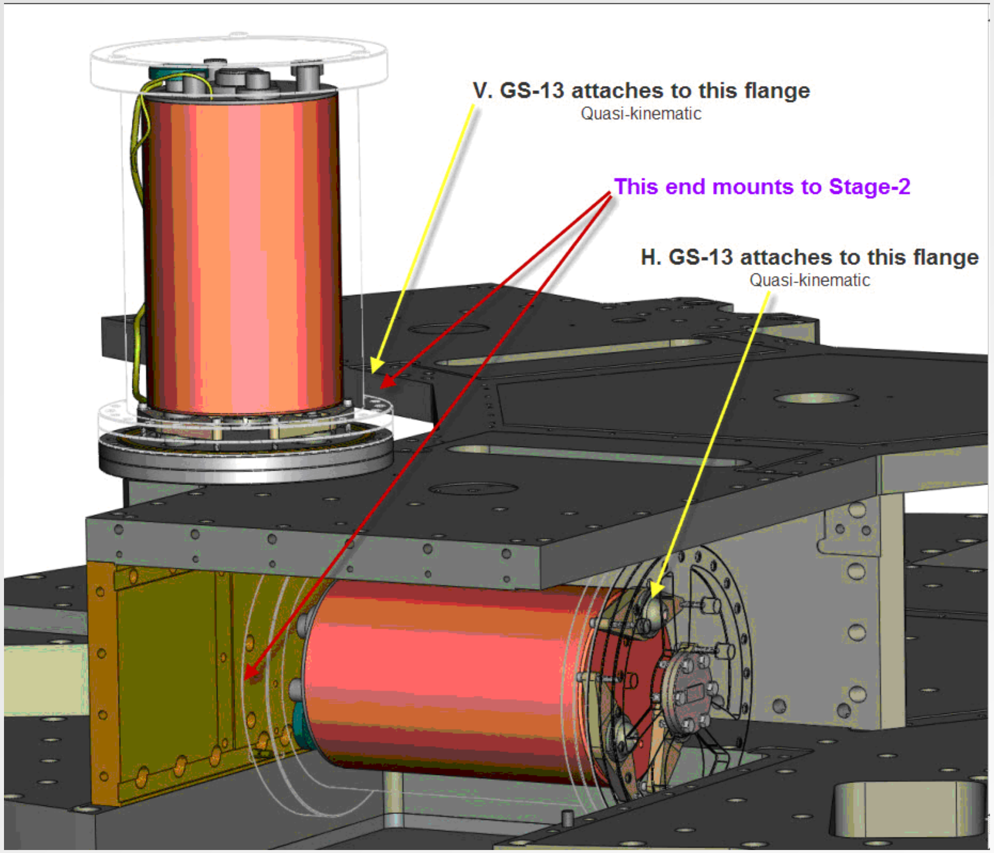


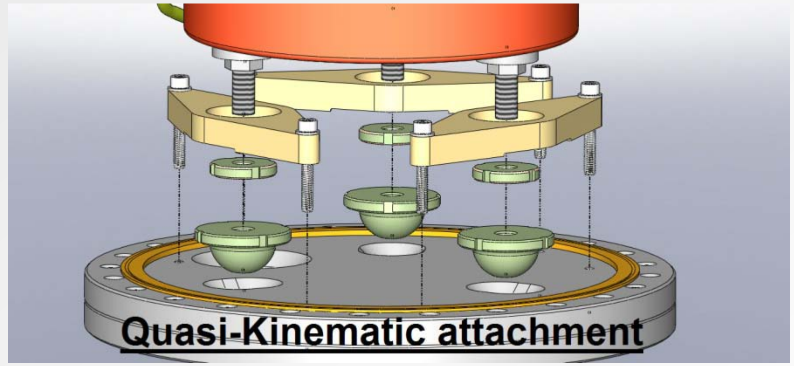
Trillium

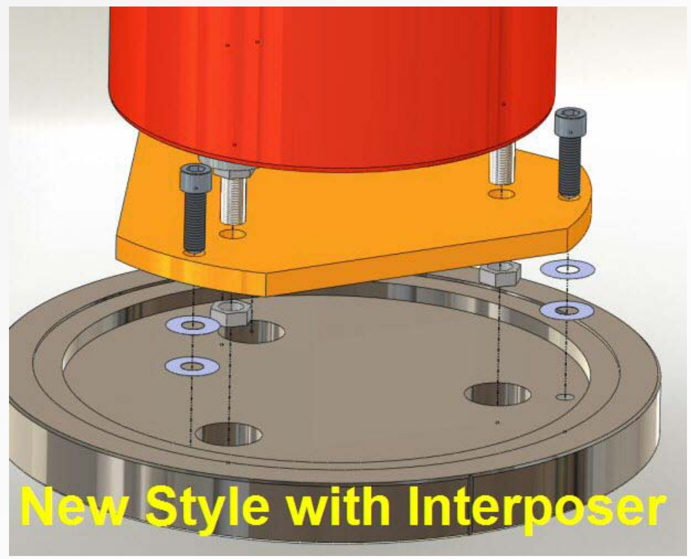
GS-13 Pod Original

GS-13 Pod Diameter: 10.0 in
Height: ~15 in
Weight: ~75 lb

2 Configurations Horizontal and Vertical



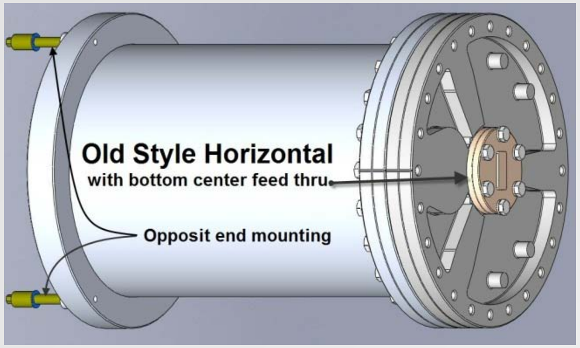


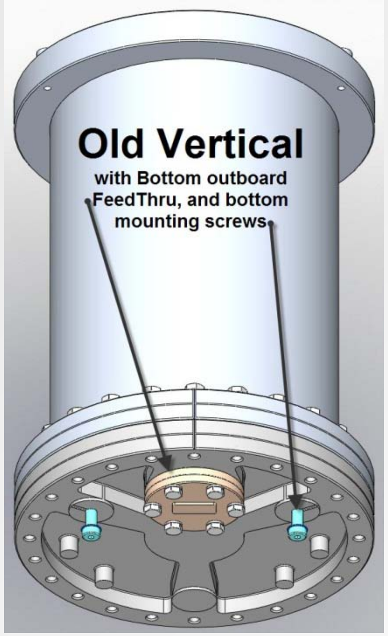


GS-13 Pod Original vs. New

GS-13 Pod Original Diameter: 10.0 in
Height: ~15 in
Weight: ~72 lb

New, 1 Configuration Horizontal and Vertical





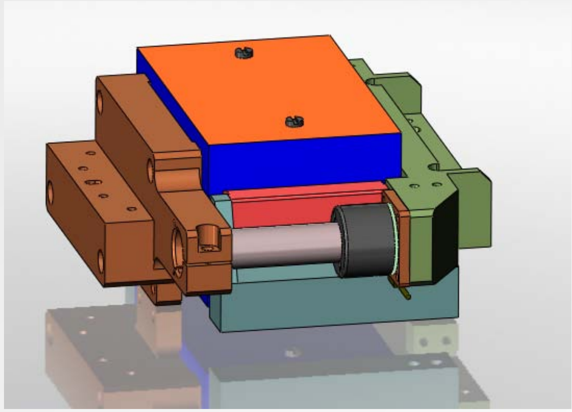
4. Final Design

Actuators bracketing

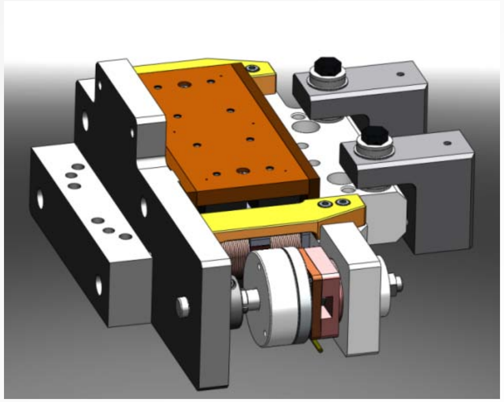
1. sub-assembly over constrained with locking bar attached
2. gaps in all actuators are difficult to set once actuators are installed
3. Assembly order puzzle
4. For testing purposes the actuators need to be more easily isolated
5. Position sensor targets are not easily adjustable
6. Bracket connecting the horizontal fine actuator may not be a stiff connection
7. Access to the screws to install the fine actuators is very tight

New Actuators and New Brackets

- Both large (stage 0-1) and small (stage 1-2) have been re-designed
- They have larger gaps between the coil and magnet.
- External dimensions changed necessitating the design of new attachment brackets
- The actuator assembly re-design encompasses the new size of the actuators
- It addresses the concerns discovered during the assembly of the LASTI prototype.
- An intermediary design was done to test the new large actuators at LASTI.
- The performance and stiffness of the new actuators and brackets were satisfactory.



Prtototype



Advanced LIGO

4. AdL Design

Remaining Steps

- ✓ Finish the individual sub-projects
- ✓ Flexure rods attachment
- ✓ Blades tooling
- ✓ Cabling routing
- ✓ Special tooling, Dial indicators
- ✓ Top assembly
- ✓ Drawings, tolerancing
- ✓ Documentation

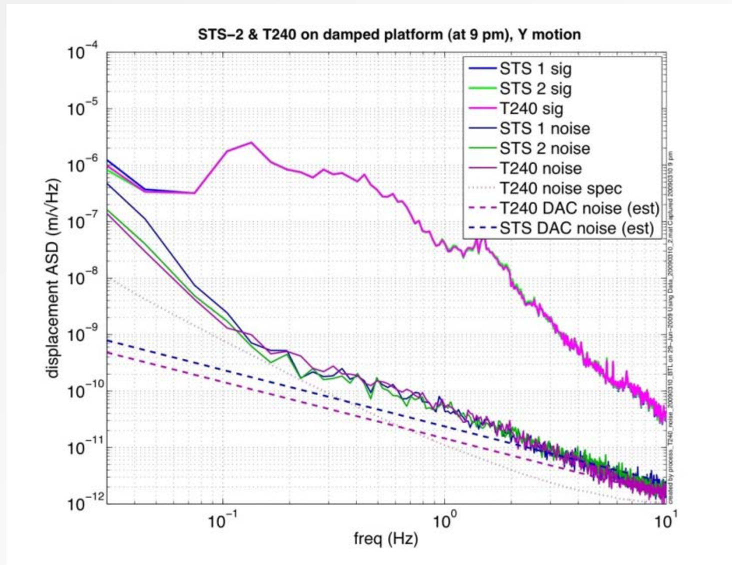
Schedule

- ✓ August 15, Sub-projects, tooling and top assembly ready.
- ✓ August 17-19, internal review with the SEI team.
- ✓ August 19-31, final adjustments after the internal review.
- ✓ September 1st, start working on the drawings and documentation.
- ✓ October 1st, we start to put together the documentation for the FDR.
- ✓ October 15, the documentation is posted for the FDR.

Nanometrics Trillium 240 (T240)

- ✓ **Low-frequency inertial sensors**
- ✓ **Used On stage 1, where more of the low frequency control is done**
- ✓ **Intended to replace the Streckeisen STS-2 originally specified**
- ✓ **The T240 and the STS-2 have similar size, weight, cost and performance.**
- ✓ **The T240 can be purchased. STS-2 are on 18 month delivery schedules**
- ✓ **The T240 has no locking motors.**
- ✓ **New pod smaller, weigh smaller (from 115 to 70 lbs)**
- ✓ **We recently measured and compared T240 with STS-2s. No significant noise difference.**

Testing sensors at the ETF

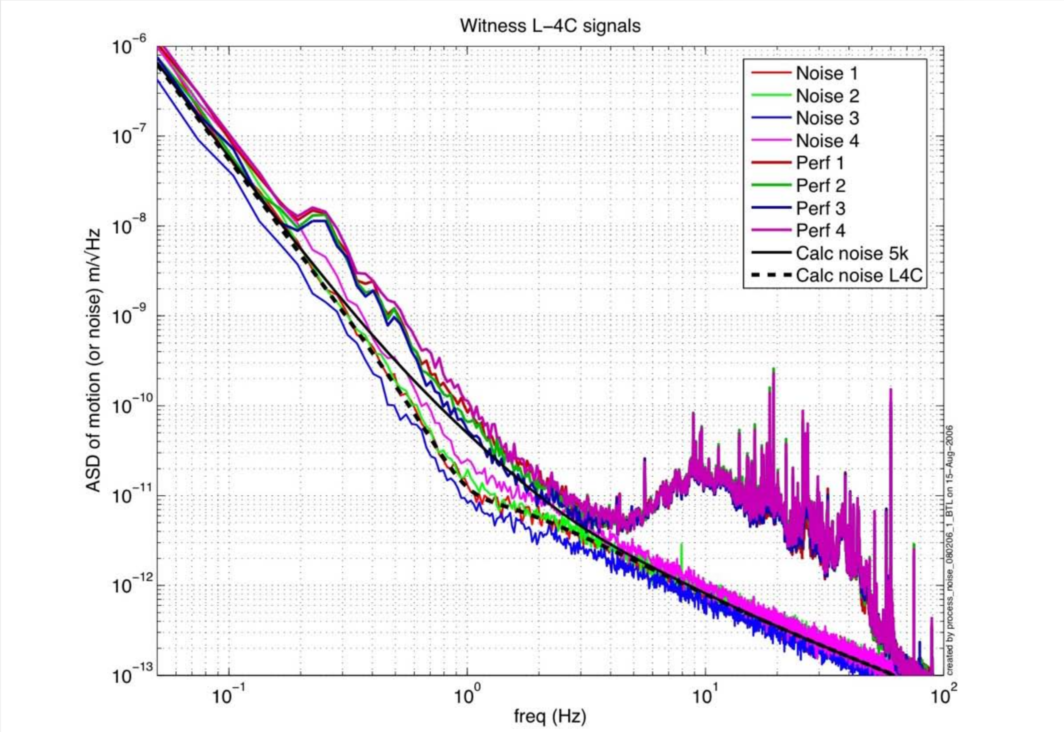


Noise estimates of the T240 mounted on the ETF Tech Demo, and compared with 2 STS-2s

See T0900318, 'Noise testing of the Nanometrics Trillium 240 on the Tech Demo'

Sercel L-4C Inertial Sensors

- ✓ **High frequency inertial sensors used on Stage 1.**
- ✓ **Passive geophone with a 1 Hz natural frequency.**
- ✓ **We equip it with a local preamplifier placed into a vacuum pod.**
- ✓ **Have been in use on the 'Rapid Prototype', Tech Demo and HEPI.**

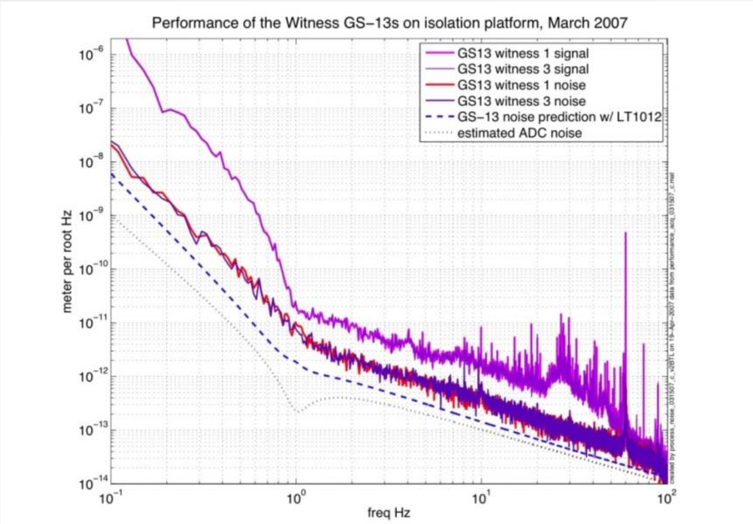


L-4C Noise performance measured with witness L-4Cs on the second stage of the Tech Demo.

A discussion of the noise measured from a set of witness L-4Cs on the table of the Tech Demo is described at http://ligo.phys.lsu.edu:8080/SEI/679.

GS-13 Inertial Sensors

- ✓ Used On stage 2, the stage closest to the optic.
- ✓ Moving coil seismometer with a 1 Hz natural frequency.
- ✓ We replace the internal electronics board with one of our own design [D050358-01].
- ✓ It makes this device the lowest noise 10 Hz commercial seismometer available today.
- ✓ A vacuum ‘pod’ has been designed to contain the instrument.
- ✓ In use on the prototype and in the observatories on the HAM6-ISI platforms.
- ✓ New units will have custom flexures so the locking motors are not needed.
- ✓ All units will be tested according to our specifications at the manufacturer before shipping and then again at LLO after the new flexures are installed.



Noise performance of the GS-13s. This measured noise will allow us to reach the BSC requirements.

✓*Instrument modifications, testing, and pod assembly for the HAM6-ISI are described in the ‘GS-13 Seismometer Assembly Procedure’ [E080086].*

✓*The flexures and testing are described in LIGO-T0900089, ‘GS-13 Seismometer Flexure Report’.*

Capacitive Sensors

- ✓The capacitive displacement sensors are sold by ADE.
- ✓They include a UHV compatible head, designed for LIGO, and a readout board.
- ✓The sensor range for the stage 0-1 sensors is +/- 1 mm, noise floor around 6e-10 m/rtHz.
- ✓The sensor range for the stage 1-2 sensors is only +/- 0.25 mm, noise about 1.5 e-10 m/rtHz
- ✓All the hardware for both stages is identical
- ✓The only difference is the calibration and the matching capacitors in the readouts.
- ✓The heads are cleaned and baked at low temperature, require a special strain relief for the cable.
- ✓Heads are provided with special protective stops.

Actuators

- ✓ Custom actuators designed and fabricated for the ISI platforms by a commercial design firm, PSI.
- ✓ Coil actuators maximize the drive linearity and minimize generation of external magnetic fields.
- ✓ Set of the stage 0-1 actuators have been built and installed for the HAM6-ISI system. The stage 1-2 actuators are of a similar design, but are a bit smaller.
- ✓ A set of these actuators has been delivered to MIT.
- ✓ Since these actuators have potted coils, special cleaning procedures have been developed [E080497] to clean some parts of the actuators before they are fully assembled. The final actuators are cleaned and baked.

Actuator issues:

- ✓ Wire connectors made of PEEK terminal block on the actuator will probably be modified by adding a crimp pin to the wire, and replacing the slotted bolt on the terminal block with a hex-head bolt.
- ✓ Kapton-based potting compound used for the HAM6 installations has been discontinued by the manufacturer and replaced with an upgraded material (PI-2525 resin). The new material is currently being investigated by the LIGO Lab.

6. Electronics

Entire system made up of a set of

- **Electronics chassis**
- **Some timing chassis**
- **The “Blue Box”**
- **Computer system.**
- **Interconnection of all of the electronics chassis in schematic LIGO-D0901301-v1.**

ISI Interface Chassis

- **Gathers all of the signals from GS-13, the L4C and Capacitive Position Sensors**
- **Interfaces them with the computer via an Anti-Alias filter chassis.**
- **Installed in the LASTI ISI system**
- **Some modification is needed for use in Advanced LIGO (*See details in LIGO-L0900118).***

ISI Coil Driver

- **High-current driver receives signals from the computer via an Anti-Image filter chassis.**
- **Provides high current signals to the ISI actuators.**
- **The design works well.**
- **Minor changes are being done to make the chassis easier to put into production.**

6. Electronics

Binary I/O Chassis

- Essentially a patch-panel that takes one connector that goes to the Binary I/O card
- Binary Out signals go to the ISI Interface chassis to control gain and filter settings
- Binary In signals come from fault monitors in the Coil Driver chassis.
- Simple board but it will have to be redesigned to interface with the newer style of Binary I/O.

Anti-Alias Chassis

- A low-pass filter for all incoming signals
- Cutoff frequency set so that signal higher than the Nyquist frequency don't alias down into the passband.
- Boards have 32 channels corresponding to the 32-channel Analog to Digital Converters to which they connect.
- More details on revisions in LIGO-L0900118.

Trillium T240 Interface Chassis

- Needs to be designed. Should resemble the STS-2 Interface chassis in use in the HEPI system.
- Will interface with the Trillium T240 and send signals to computer via Anti-Alias filter, and ADC board.
- Will also receive binary output signals that switch some of the seismometer's functionality.

6. Electronics

Manufacture and Production

- All chassis will be manufactured at a turn-key external company.

- They will order the parts, stuff the boards, assemble the chassis, and deliver the whole thing ready for testing

- We are currently examining several of these companies for the manufacture of HEPI electronics, and will select one at the end of a bidding cycle.

Setup and Testing of the Electronics

- Boxes and several small boards have been made to help with the task.

- The STS-2/GS-13 Tester boxes.

- Emulator box connected in the place of an in-vacuum seismometer. Allows testing all of the wiring, and computer system without endangering an expensive seismometer.

- A switch board that emulates the functionality of the binary I/O modules, so gains and whitening can be set right at the rack,

- Several inline breakout boards that go inline with the cables, and allow you to clip onto any wire inside, and check the health of the signal there.

- Documentation on system test procedure. A set of “quick start guides” for quick overview of functionalities and “care and feeding”. A sample system test procedure listed LIGO-L0900118.

7. Cleaning, Leak check, Assembly, Storage, and Installation.

Cleaning

- Parts will be cleaned to LIGO specifications according to LIGO-E960022.
- Cleaning and baking of parts except the large plates will take place at LHO, LLO and CIT.
- Large plates will be chemically cleaned by an outside vendor and air baked at LHO and LLO.
- Special procedures, for the actuators and the capacitive position sensors (used for the E-LIGO)
- Vacuum pods for the Trillium, GS-13 and L4-C seismometers will be cleaned and baked.
- Vacuum pods are then filled with a neon tracer gas for leak detection.

Unclear if:

- If the tracking of the clean and bake of parts will be done using cleaning travelers as in the past
- Or whether this will be replaced by the new JIRA inventory control system.
- This is a systems level decision rather than an SEI level decision.

7. Cleaning, Leak check, Assembly, Storage, and Installation.

Leak checking

- Sensors enclosed in vacuum sealed pods
- Concerns with contamination of the vacuum due to a leak
- Concerned outline in T0900192. We have to adopt a zero-tolerance approach.
- Mainly driven by the GS-13 instrument which uses several substances.
- Each sensor will be tested prior to being installed in a vacuum pod.
- During assembly the pod is filled with at least 0.1 atmospheres of Neon gas.
- This gas is used to identify leaks after assembly.
- We leak test the pods in vacuum oven.
- All pods will be assembled at the Livingston site.
- Pods which are shipped to Hanford will be leak-tested at Hanford prior to installation
- We are also investigating the use of a more robust vacuum feed-through.
- Assembly documents exist for the L4-C (T080261) and the GS-13 (T080086)
- Based on our experience (BSC-ISI prototype at LASTI and HAM-ISI).
- Another assembly procedure will be done for the Trillium T-240.

7. Cleaning, Leak check, Assembly, Storage, and Installation.

Assembly

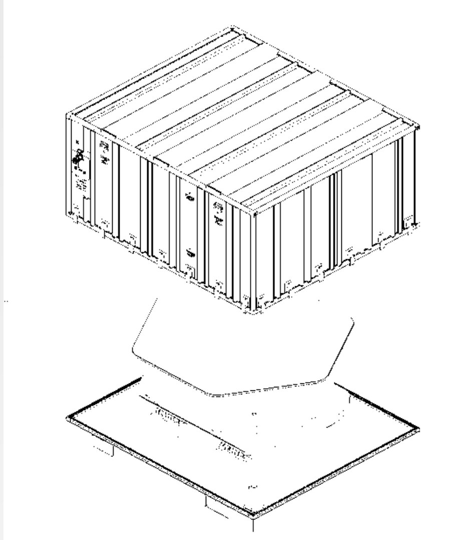
- ✓ Assembly procedure of the prototype0
- ✓ Will be fully updated along with the final design.

Storage

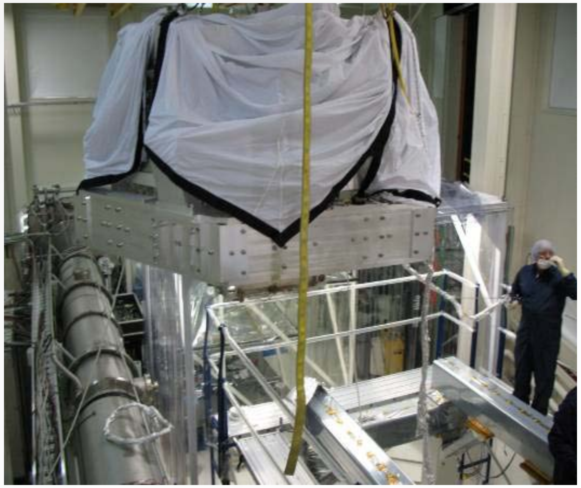
- ✓ Once assembly and testing is complete the BSC ISI will be prepared per LIGO document E960022-B
- ✓ Will be placed in a modular container similar to the container designed for the HAM ISI.

Installation

- ✓ Described in LIGO-L0900118
- ✓ Done at LASTI
- ✓ Installation procedure and hazard analysis will be written before the FDR



HAM ISI Storage Container



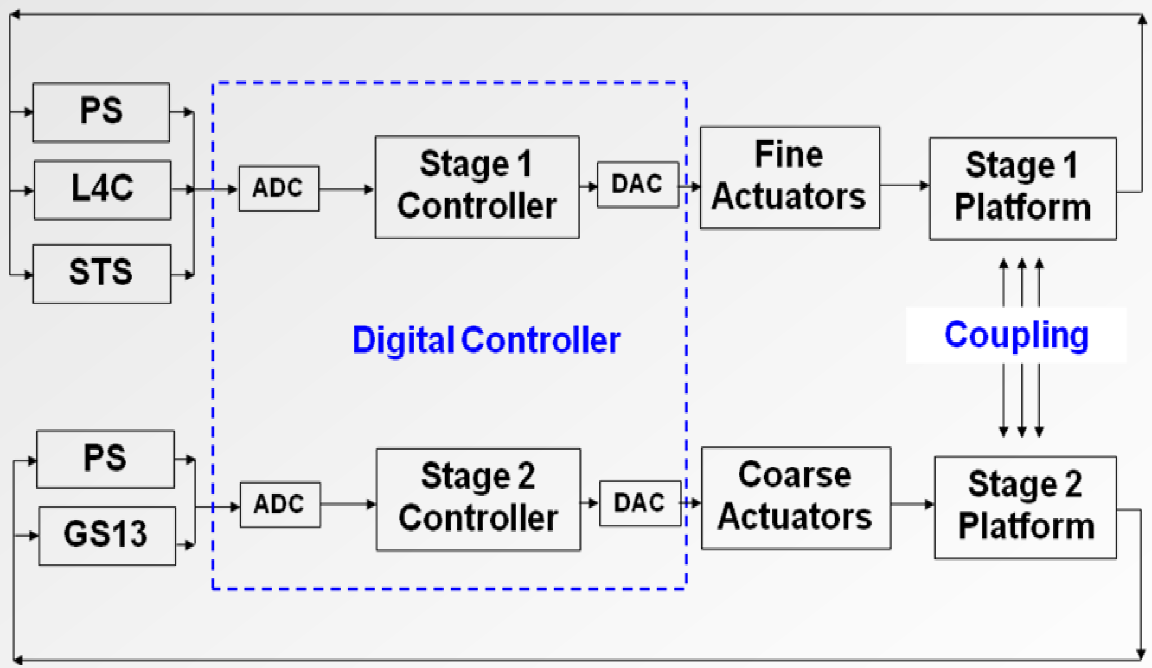
BSC ISI Instalation at LASTI

Control Strategy

✓ Feedback control approach is described on the diagram below.

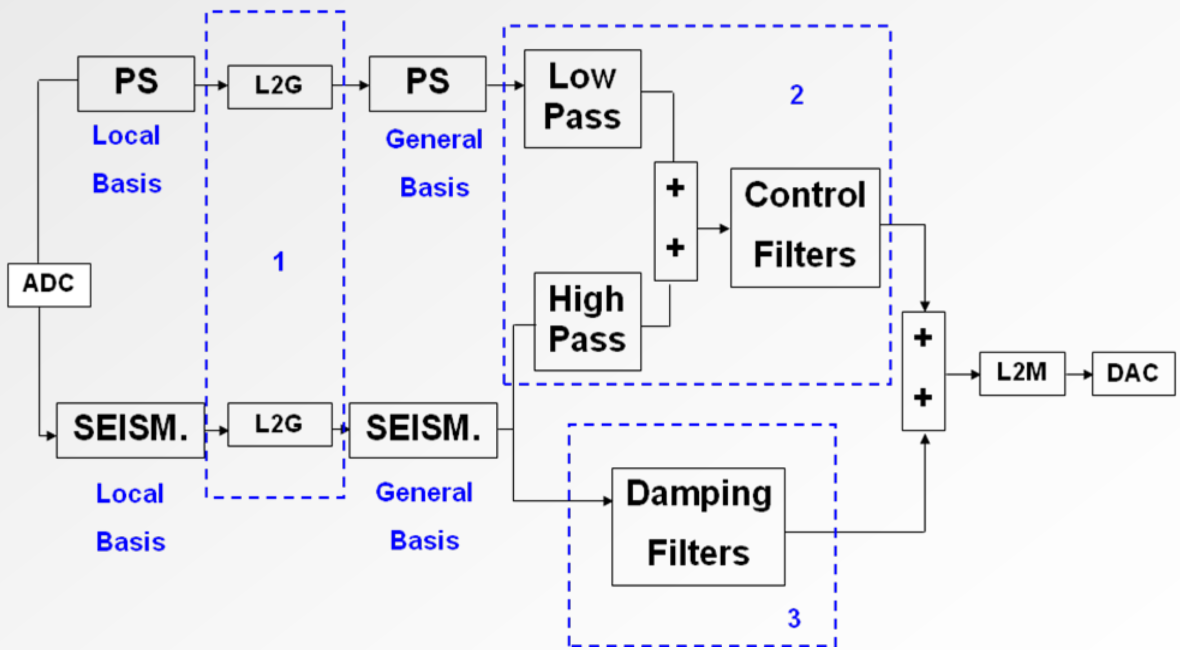
✓ The motion of the stages are coupled to each other

✓ The stages can be controlled independently



8. BSC-ISI Control

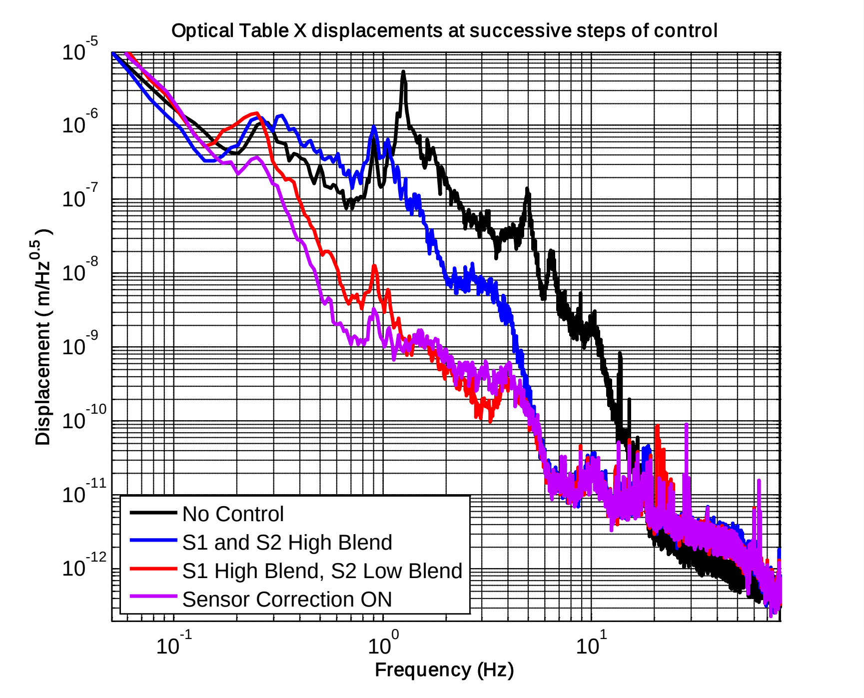
- ✓ For each stage, the control is based on the use of 6 independent SISO loops.
- ✓ The control is done in the basis of the general coordinate system: X, Y, RZ, Z, RX, RY.
- ✓ X and Y are aligned with the arms of the interferometer.
- ✓ Position sensors are used to measure the relative position of the stage
- ✓ A Local to General coordinate change of basis matrix
- ✓ Seismometer to measure the inertial motion
- ✓ Seismometer signal sensors are first used to damp the suspension resonances
- ✓ Complementary filters are then used to blend the position sensors and the seismometers.
- ✓ The position sensors signal is filtered by the low pass and
- ✓ The seismometer is filtered by the high pass.
- ✓ The two signals are summed resulting in a super sensor (block 2 on the diagram above).
- ✓ Finally a control filter is applied to the super-sensor to provide loop gain.
- ✓ Unity gain frequency goal is 30Hz, the phase margin to 30 degrees.
- ✓ Control steps are detailed in document LIGO-T0900250.



8. BSC-ISI Performance

Active control isolation

- ✓ Motion of the optical table measured in the X direction with the GS13.
- ✓ The black curve shows the motion of the table when the control is off.
- ✓ The Blue curve shows the motion of the table with a high frequency blend on both stages(0.7Hz).
- ✓ "X to Ry" and "Y to Rx" motions are decoupled using a tilt decoupling matrix.
- ✓ Red curve: the blend frequency has been lowered to 0.2Hz on stage 2.
- ✓ Purple curve, the sensor correction has been turned on.

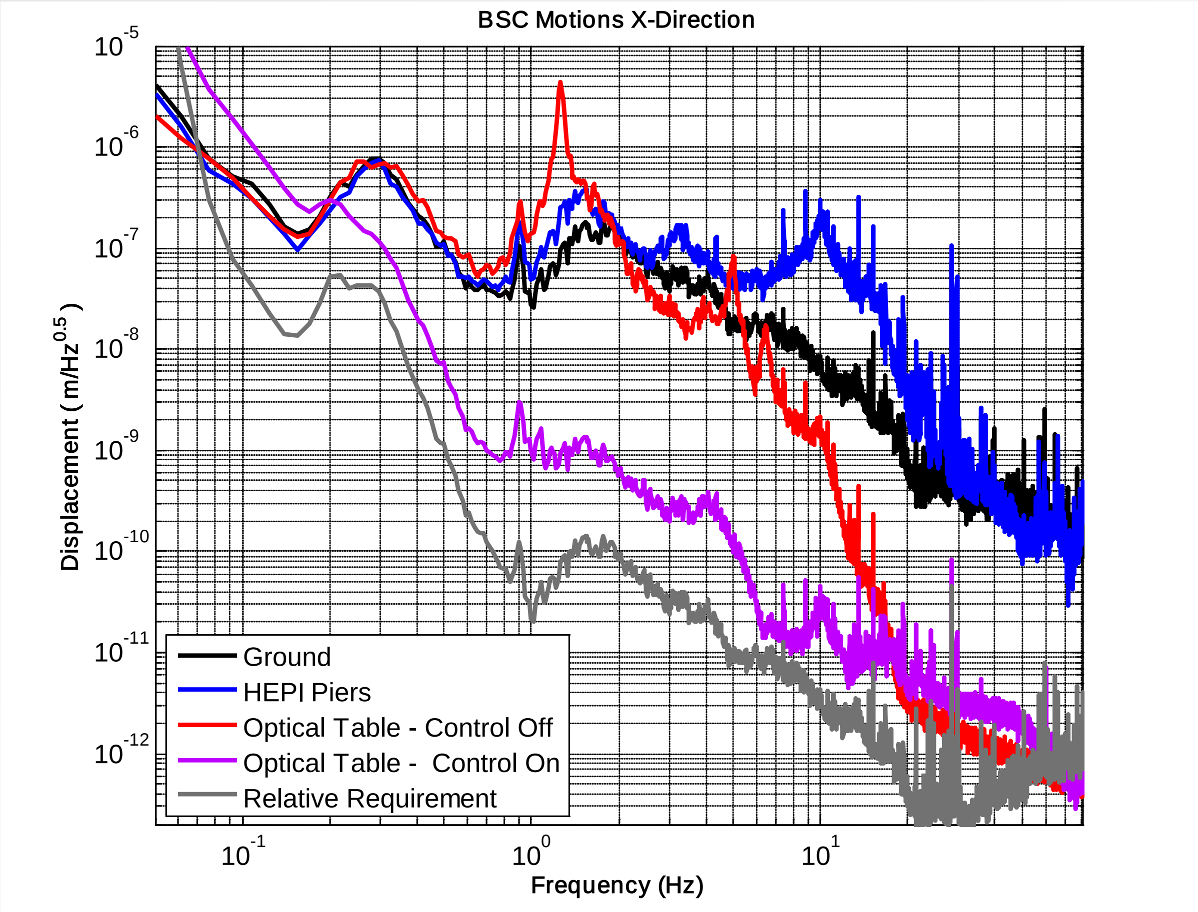


- ✓ At low frequencies (around 0.1Hz) there is very little motion amplification.
- ✓ The isolation starts as low as 0.1Hz which is good.
- ✓ The isolation at 1Hz is close to a factor of 100.
- ✓ The control provides isolation up to 20Hz, which is good.

8. BSC-ISI Performance

Global isolation (Active & Passive)

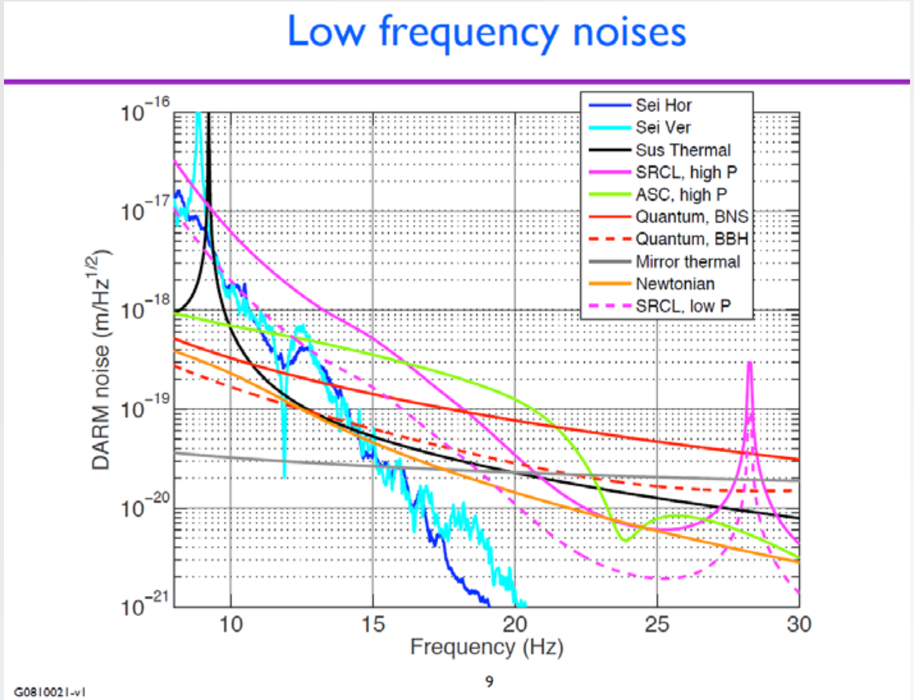
- The ground motion is shown in Black. It is measured with a STS.
- The HEPI motion is shown in Blue. It is measured with HEPI L4Cs.
- The motion of stage2 when the control is off is presented in Red
- The motion of stage2 when the control is on is presented in Purple
- The relative requirements are presented in Grey

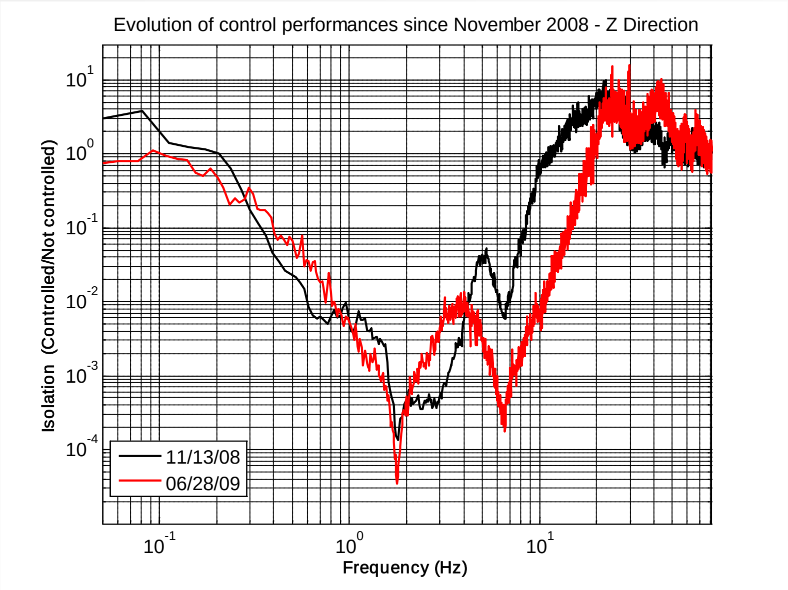


8. BSC-ISI Performance

- ✓ **Predictive noise budget for Advanced LIGO, the document G0810021-v1**
- ✓ **At 17Hz the seismic noise was below the other sources of noise.**

- ✓ **Estimation based on the BSC-ISI performances as of November 2008.**
- ✓ **Performance improved since**





8. BSC-ISI Performance

Control commissioning at LASTI:

- Stage 1 blend frequency will be lowered

- HEPI feedback control will be restored

- Sensor correction from the Ground to HEPI will be implemented

Those steps have already been done in the past and have proven to significantly improve the performance.

Some other steps not tried before will also be tested:

- ✓ **Sensor correction from HEPI L4C to Stage1**
- ✓ **Feedforward from HEPI to Stage1 at high frequencies (10Hz-20Hz)**
- ✓ **Feedforward from Stage1 to Stage2 at high frequencies (10Hz-20Hz)**

Ideas for improving performance < 0.1 and 10-15 Hz

#1 Increase of the sampling frequency

- ✓ Time delay reduction, smaller loss of phase from anti aliasing and anti image
- ✓ Low or no extra cost

#2 Feedforward using L4C on stage 0

- ✓ Advantages:

- path more direct than from HEPI to Stage1. Less local deformations, better performance.
- source of feedforward well decoupled from the action (not true for a feedforward from stage 1 to stage2).

- ✓ Will be tested at LASTI : L4Cs will be mounted on Stage 0 of the prototype
- ✓ Cost : $6700/unit (L4C, preamp, feed through, pod, cable, flange) + Interface chassis ~ $30k/per chamber

Or

#3 Sensor Correction & Feedforward using low frequency 3 axis instruments on cross beams

- ✓ Guralps, Trilium Compact ($7060/unit)
- ✓ Advantages:

- Out of vacuum
- Low frequency instruments permitting sensor correction (micro seismic improvements).
- Could be combined for tilt subtraction in the horizontal instruments

- ✓ Will be tested at LASTI
- ✓ Cost

9. Procurement

Order placed or ready for procurement: $3.9M of $17.43M Total (22.4%)

Description	Proc,. ID	Status
GS-13 Seismometers	SI-165	Order Placed
L4-C Seismometers	SI-175	Ready for procurement
L4-C Pods	SI-193	Ready for Procurement
ADE Position Sensors	SI-162	Ready for Procurement
Large Electromagnetic Actuators	SI-170	Order Placed
In-vac Cabling	SI-164	Ready for Procurement
Actuator Coil Drivers	SI-300	Ready for Procurement
In pod wire harnesses	SI-165	Ready for Procurement

Ready between the PDR and the FDR : $2.03M (11.7%)

Description	Proc,. ID	Status
GS-13 Pods	SI-193	Design inc. as part of this PDR – 7/30/09
Trillium 240 OB Seismometer	SI-107b	Specs inc. as part of this review – 7/15/09
Trillium 240 OB Pods	SI-193	Design inc. as part of this PDR – 7/30/09
Small Electromagnetic Actuators	SI-170	Design inc. as part of this PDR - 8/30/09
Springs Material		8/30/09

10. Remaining Steps to the FDR

List of things we are concerned with and working on:

Testing

- ✓ **Balancing of stage1, Shimming**
- ✓ **Tilt on vertical seismometers**
- ✓ **High frequency performance**
- ✓ **Ground to HEPI sensor correction**

Design

- ✓ **Schedule**
- ✓ **Late projects (Rods attachment, Blade loading)**
- ✓ **Actuators, GS13 & Trim masses attachment**

10. Remaining Steps to the FDR

Design

- The Stage0, Stage1, Stage2, Actuators Brackets and Seismometers sub-projects are on time according to the re-design schedule M0900175-v1.

- We are going to start the detailing phase for those project. Our objective is to have the drawings ready for the FDR.

- We are behind schedule on the Flexure Rods sub-project. More manpower will be affected to this project to bring it back on time. As for the other subprojects, our objective is to have the drawings ready for the FDR.

- We start working on the tooling re-design like it was schedule in M0900175-v1.

Testing

- The shims on the prototype at LASTI will be adjusted to lower the amount of trim masses used on stage1. 500pds are currently use which results in concentrated masses creating local deformations.

Control

- The control commissioning continues as described previously.

Documentation

The following documents must be prepared before the FDR:

- Assembly procedure and hazard analysis.

- Installation procedure and Hazard analysis.

- First article testing plan

10. Remaining Steps to the FDR

1	System Design Requirements, especially any changes or refinements from DRR	**Mechanical: E030179-A** **Performances: E990303-03-D**
2	Subsystem and hardware requirements, and design approach	**BSC-CDR-ASI20008644-A** **Technical Memorandum: 20009033-A**
3	Justification that the design can satisfy the functional and performance requirements	**Section 8 of this document**
4	Subsystem block and functional diagrams	**p.48 of this document**
5	Equipment layouts	**Section 2 of this document for the initial design.** **Section 4 for the new design.**
6	Document tree and preliminary drawings (information issued)	**LIGO E050065-C for the drawings of the initial design.** **A new tree will be created for the drawings of the final design.** **Links to the rest of the documentation are posted on the Advanced LIGO wiki page**
7	Modeling, test, and simulation data	**Technical Memorandum: 20009033-A for the modeling and simulations.** **Section 3 & 8 of this document for testing.**
8	Thermal and/or mechanical stress aspects	**BSC-CDR-ASI 20008644-A** **Technical Memorandum: 20009033-A**
9	Vacuum aspects	**Actuators and ADE capacitive sensors passed RGA.** **Section 7 of this document for the seismometers pods leak test.**
10	Material considerations and selection	**All 7075 parts used in the initial design have been replaced by 2024-T4 in the final design.** **All other materials used are on the vacuum approved list.**
11	Environmental controls and thermal design aspects	**Thermal dissipation of the actuators T060076.**

10. Remaining Steps to the FDR

12	Software and computational design aspects	In the process of designing the control topology and the operator interface at LASTI
13	Power distribution and grounding	Electronics overview: D0901301-V1
14	Electromagnetic compatibility considerations	It will be measured at the next opening of the chamber in September 2009.
15	Fault Detection, Isolation, & Recovery strategy	The watch dog approach used for the HAM will be adjusted to the BSC
16	Resolution to action items from DRR	Section 4 of this document
17	Interface control documents	Per SEI requirements E990363-03
18	Instrumentation, control, diagnostics design approach	Instrumentation, control: Section 8 of this document. Diagnostics: TBD
19	Fabrication and manufacturing considerations	- Stage 0 design review - Stage 1 design review - Stage 2 design review
20	Preliminary reliability/availability issues	- Redundant mechanical protections for actuators and position sensors - Software watchdogs - L4C designed to be shipped unlocked - GS13 retrofitted with the new flexure rods. See section on sensors. - Moved from STS to Trilium which is 1.5 million hours mean time between failure. Expected to be better in our environment. - Working with the CDS on the reliability of the computer.
21	Installation and integration plan	Section 7.5 of this document.
22	Environment, safety, and health issues	Hazard analysis will be done for the FDR
23	Mitigation of personnel and equipment safety hazards Reflected in equipment design and procedures for use	Hazard analysis will be done for the FDR
24	Human resource needs, cost and schedule	Section 9 of this document

10. Remaining Steps to the FDR

25	Any long-lead procurements	**Section 9 of this document**
26	Technical, cost & schedule risks and planned mitigation	**AdL Risk register**
27	Test plan overview	**Schedule M0900175-v1**
28	Planned tests or identification of data to be analyzed to verify performance in prototyping phase	**Section 3 of this document**
30	In production/installation/integration phase	**Section 9 of this document**
31	Identification of testing resources	**TBD**
32	The test equipment required for each test adequately identified	**TBD**
33	Organizations/individuals to perform each test identified	**TBD**
34	QA involvement	**Mick Flanigan involved in procurement, inspection and testing**
35	Test and evaluation schedule, prototype and production	**Section 3 of this document. Production schedule**
36	Lessons learned documented, circulated	**Section 3 of this document.**
37	Problems and concerns	**Control and design issues addressed and under correction as described in this document.**