LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

*LIGO Laboratory / LIGO Scientific Collaboration*

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# HAM SAS Test Plan at LASTI

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# 1 Introduction

The HAM SAS testing at LASTI will aim to answer the following questions:

1. Vacuum compatibility of the HAM SAS system
2. Fit Check of the HAM SAS system in a LIGO vacuum envelope
3. Effectiveness of the HAM SAS installation tooling
4. Seismic attenuation factor of the HAM SAS
5. DC pointing stability of the HAM SAS
6. Compatibility of the HAM SAS and triple installation.

With these goals in mind the following testing plan will be followed

# 2 HAM SAS Payload for these tests

The HAM SAS GAS springs have been designed to hold a total payload of 1.1 tonnes which includes the optics table. The optics table is 378.5 kg, therefore it will be necessary to provided an additional 722 kg of payload for it to operate. A static instability has been observed in soft systems that have appreciable mass mounted well above the optical table surface. Ideally to test for this effect we would mount on the optics table the entire Advanced LIGO HAM 2 payload (See Figure 2-1), unfortunately this would involve at least 5 suspensions that we do not currently do not have. For this reason we will have to mount masses on the table that simulate the correct mass properties of the suspensions. Brian Lantz has demonstrated that when calculating the height that mass needs to be mounted above the optics table to correctly simulate a suspension the following must be rules must be used:

1. The mass of suspension simulator must be the same as the suspension including its cage.
2. The fraction of this mass that is equal to the non-suspended mass must have its center of gravity at the same location as the non suspended part of the suspension.
3. The fraction of this mass that is equal to the suspended mass must have its center of mass located at the height of the attachment point to the cage.

The HAM table that is expected to be worst from this point of view is HAM 2 with a stable recycling cavity. An expected layout of this is shown in Figure 2-1

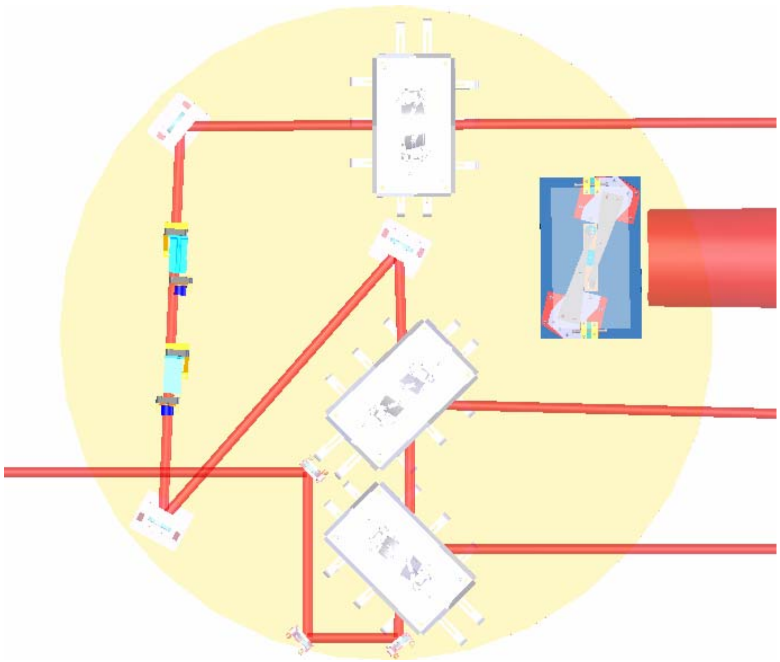

**Figure 2-1 The anticipated layout of HAM 2 with a stable recycling cavity geometry. The suspensions required are three modecleaner triples (MC1, MC3 and RM), a single RM style triple (MMT3) and 2 Initial LIGO SOS style suspensions (MMT1 and SM)**

In Figure 2-2 the mass and effective height of the significant contributions is shown. This leads to a total payload mass of 213 kg with an effective height of 0.54m which produces a vertical moment of 115 m kg. We have used these numbers to develop the HAM SAS payload that will be used to test this system.

| Mass Element | Suspended Mass | Suspended Height | Non Suspended Mass | Non Suspended Mass Height | Total Mass |
|---|---|---|---|---|---|
| MC1 | 9 Kg | 0.826 m | 36 kg | 0.388 m | 45 kg |
| MC2 | 9 Kg | 0.826 m | 36 kg | 0.388 m | 45 kg |
| MMT3 | 38.3 Kg | 0.796 m | 40.4 kg | 0.537 m | 78.7 kg |
| RM | 9 Kg | 0.826 m | 36 kg | 0.388 m | 45 kg |

**Figure 2-2 Suspension Mass Contributions**

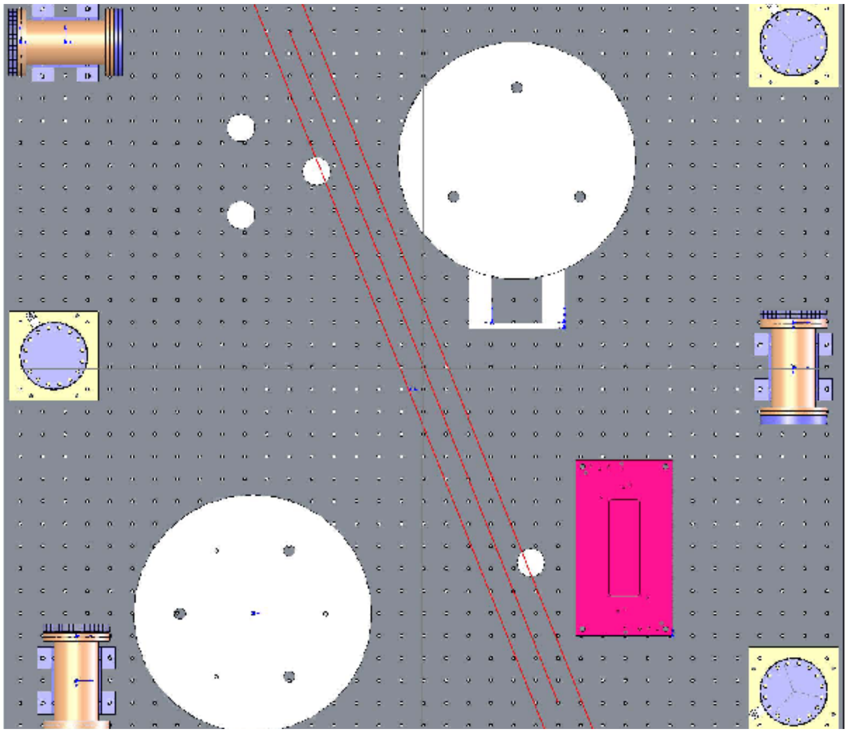

**Figure 2-3 Proposed table load for HAM SAS Test at LASTI (Top View)**

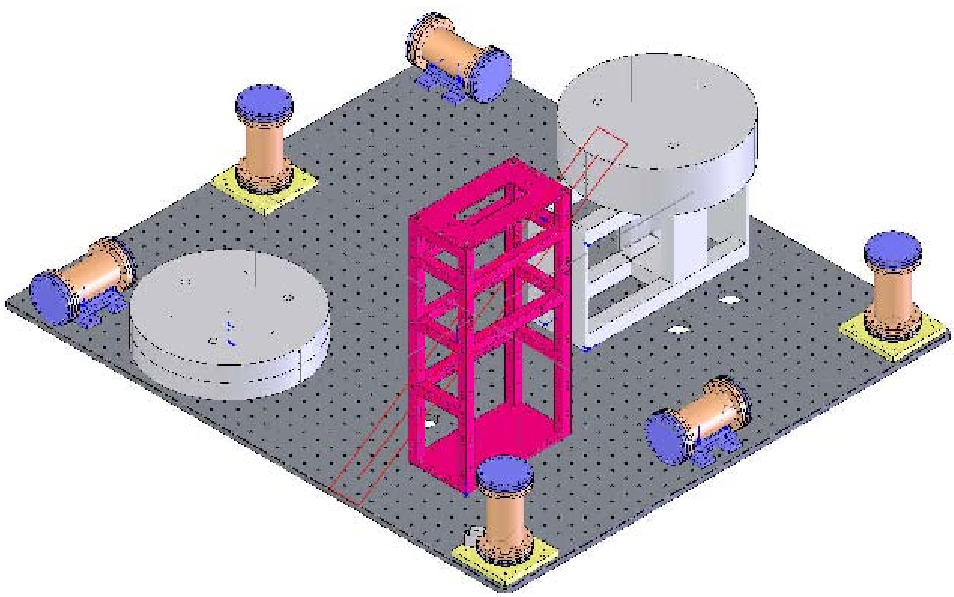

**Figure 2-4 Proposed table load for HAM SAS Test at LASTI (Isometric View). The table load includes 3 Horizontal Geophones, 3 Vertical Geophones, A complete MC triple pendulum (Frame only shown) and three mass simulators. The elevated mass is a number 1 leg element from a BSC mounted on an Initial LIGO LOS frame. The other mass simulators are Initial LIGO BSC Seismic number 3 leg elements. The mass properties of this set up are included below.**

| Element | Mass (Kg) | Height(m) | Vertical Moment |
|---|---|---|---|
| Optical Table | 378.450 | | |
| H1 Geophone | 11.250 | 0.102 | 1.143 |
| H2 Geophone | 11.250 | 0.102 | 1.143 |
| H3 Geophone | 11.250 | 0.102 | 1.143 |
| V1 Geophone | 11.250 | 0.127 | 1.429 |
| V2 Geophone | 11.250 | 0.127 | 1.429 |
| V3 Geophone | 11.250 | 0.127 | 1.429 |
| Triple_Suspended | 9.000 | 0.826 | 7.434 |
| Triple_Non_Suspended | 36.000 | 0.388 | 13.968 |
| BSC Leg Element 1 | 274.500 | 0.470 | 128.988 |
| LOS Cage | 22.000 | 0.197 | 4.331 |
| BSC Leg Element 3 | 105.075 | 0.069 | 7.206 |
| BSC Leg Element 3 | 105.075 | 0.069 | 7.206 |
| | | SUM | 176.85 |

**Figure 2-5 Summary of the proposed table load for the HAM SAS experiments at LASTI .**

I have deliberately increased the vertical moment of this test because a tilt stability of this type will be very debilitating to the future performance, hence I wanted to ensure that we have significant margin against this issue. In addition to this the GAS springs may be chosen to be softer in the future which will cause the effective load height to increase which may lead to instabilities. A fifty percent margin in this should cover this possibility. In addition to the components illustrated here approximately 100 Kg of trim mass will be required for the GAS springs to reach their optimal operating point.

# 3 In Air Test Plan

## 3.1 Pre Venting Plan

1. Install cleanroom and scissor tables
2. Install all electronics
3. RGA LASTI Vacuum system in high sensitivity mode

## 3.2 Installation Plan and in air testing

The HAM SAS platform with an initial payload consisting of:

1. A full triple suspension prototype
2. 6 L4-C geophones installed in vacuum cans (Currently estimated at 25 pound each)
3. A mass simulator to represent the effective payload of HAM 2 in a stable recycling cavity design which is the worst case scenario for HAM payloads.

The following tests will be performed before sealing up the vacuum system:

### 3.2.1 Installation and alignment of MC Triple to an external reference

One of the expressed concerns about the operational effectiveness of HAM SAS expressed by many people is the ease in which a triple pendulum can be installed and mounted on a soft seismic isolation system. I think the main fear is that whilst a triple can easily be installed on a HAM SAS platform when it is locked down, it is important that a triple can be installed to an external reference..

To explore this issue we will install a triple on the HAM SAS platform in its locked and leveled state, it position will be monitored by the LVDTs. The triple will then be installed and aligned to an external reference in its free swinging state (ie all stops will be released). Then we will release the stops on the HAM SAS and use the LVDTs to return the HAM SAS to its nominal operating point. We will then confirm that the bottom mirror of the triple can be aligned to the external reference without using more than a third of its angular bias. The set-up that will be used to do this is shown in Figure 3-1. The triple will be installed at the side of the optics table. In addition to this if the triple and the HAM SAS are likely to react in an adverse manner, this location is probably most likely to reveal this. The end door of Yend HAM will need to be removed to conduct this test.

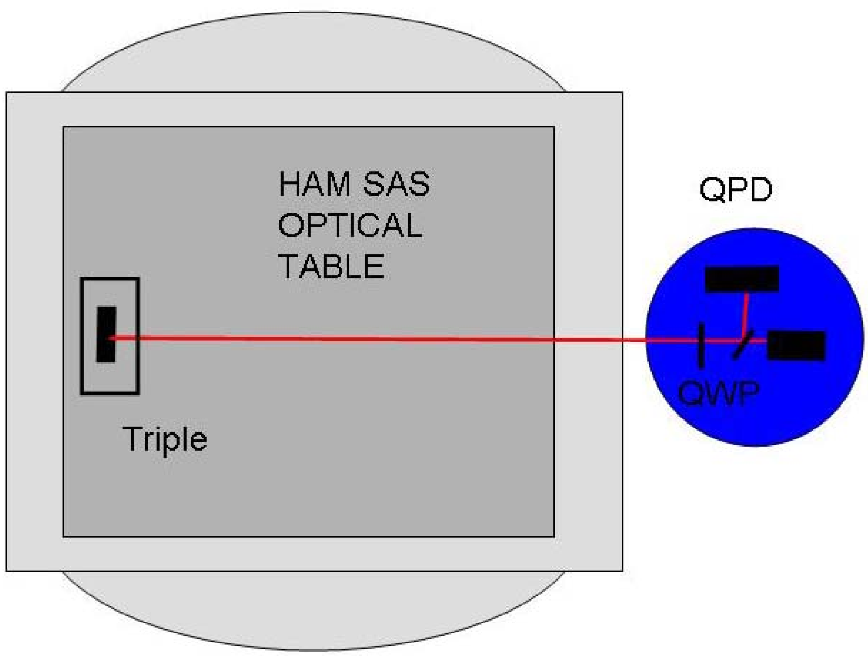


**Figure 3-1 Triple Installation**

### 3.2.2 Transitioning to Vacuum

There a couple of issues that we need to be concerned with in the transition to vacuum.

1. The frequency tuning and the position of the HAM SAS are heavily load dependent. The HAM SAS probably displaces approximately 0.3 cubic meters which will mean the

effective buoyancy effects due to air will reduce by approximately 300g. This will change the height appreciably when transitioning to vacuum.

2. The Yend HAM will tilt when the placed under vacuum. This is due to the unbalanced atmospheric pressure on the Yend HAM bending the floor when the system is under vacuum. Experience gained from monitoring the Xend HAM suggests that this tilt will be about 0.5 mRad. The stiffer floor at the observatories reduces this effect by a factor of 2.

# 4 In Vacuum Testing

## 4.1 Long Term Drift Measurement

The requirement on long term drift on a HAM seismic isolation chamber is 0.1 mm in translation and 100 µRad as stated in LIGO Document E990303-03-D. The long term tilt stability about the z and y axes will be monitored using an optical lever. The harder measurement is the measurement of translational stability. This is because most long range (~ 1m in this case) displacement sensors tend to have either excellent displacement resolution and poor range (eg. interferometers) or greater range and only mm accuracy (Optical levers or time of flight measurements). To circumvent this problem we will make a relative measurement inside the vacuum using short range position measurements techniques such as LVDTs or OSEMs.

This will be a relative measurement between the base plate and optical table of HAM SAS. This will be done by mounting a 3 axis position sensor on a column placed at the center of the baseplate that reaches up towards the optical table. A non-contact method will be used to continuously monitor the relative distance between the optical table and the top of this column.

I think that we should pursue the use of LVDTs for sensing the relative position between the baseplate and the optical table. This is because LVDTs are the only sensor that I know of that has a large working range and hence will not become the limiting earthquake stop for HAM SAS.

The motion of the HAM SAS on large time scales is likely to be totally dominated by drift in the LVDTs. This is because a low frequency servo will effectively lock the optical table to position reference of the LVDTs. This is because the anti-drift servo relies on LVDTs and as its sensor and as a result the long term drift of HAM SAS is likely to be limited to the stability of the LVDTs. Some people have expressed concern that the out of loop reference LVDTs may drift at the same rate as the in loop ones. I propose that we arrange the LVDTs in anti-parallel configuration to minimize this potential error.

In addition to this I propose to add an optical sensor as illustrated in Figure 4-1. Given the location of X end HAM LASTI the piers that will mount the optics will need to be relatively compact. Once the scissor tables (Early September) are installed it will be possible to determine whether it is feasible to mount the optics on the support piers of the cross beams. The rotational stability of the table will be determined by the reflected beam and the translation stability will be determined by the lens mounted on the optical table.

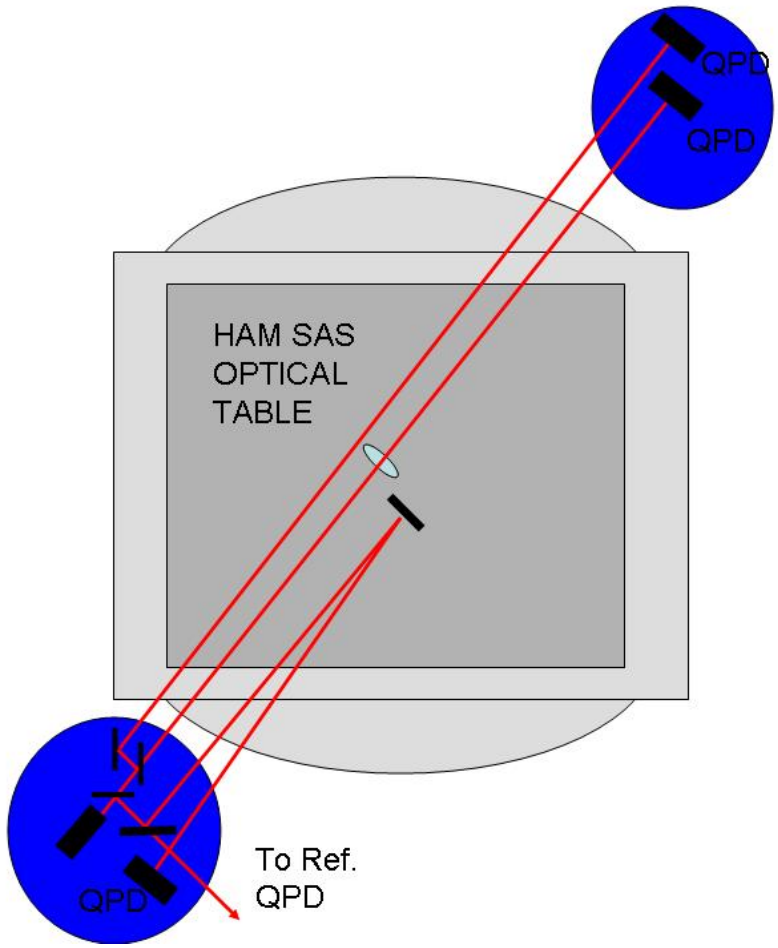


**Figure 4-1 Proposed External Monitoring of Drift of HAM SAS**

If possible this method will be assembled ahead of time to get a gauge on its performance.

## 4.2 Seismic Isolation Performance of the HAM SAS

The Advanced LIGO seismic isolation performance requirements have recently been relaxed [3, 4]. The most optimistic isolation performance of the HAM SAS is given in Figure 4-2 . This assumes both vertical and horizontal directions have 30 mHz natural resonances and isolation plateaus of -60dB (Vertical) and -80dB (Horizontal).

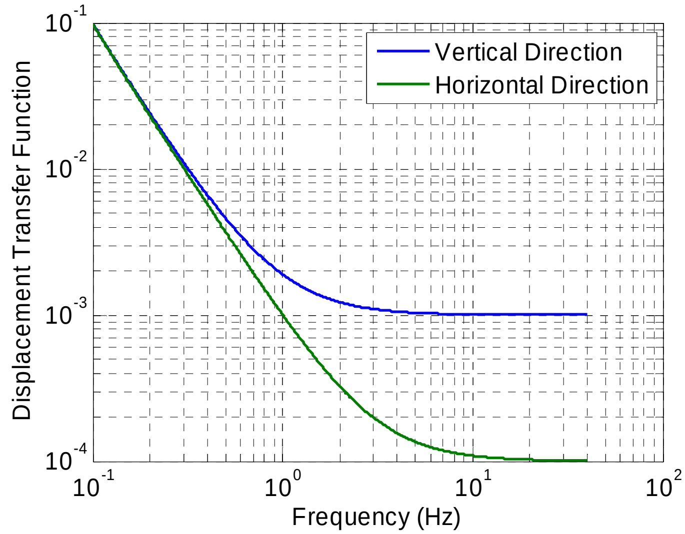


**Figure 4-2 Optimistic Performance Curves for HAM SAS**

These performance estimations are used in the estimate of performance that the HAM SAS will achieve in the LASTI environment. To estimate the performance we will use an estimate of the typical LASTI seismic environment. This was taken in the middle of the night. The seismic environment at LASTI is highly variable and this should only be taken as a guide. The reference used is plotted against the reference spectra of the two observatories in Figure 4-3

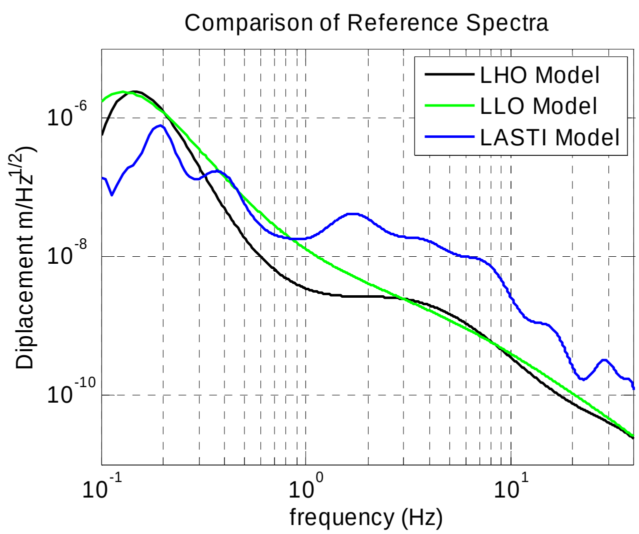


**Figure 4-3 Seismic Reference Spectra**

When results shown in Figure 4-2 and Figure 4-3 are combined an optimistic estimate of the displacement sensitivity that can be achieved at LASTI can be obtained. The results are shown in

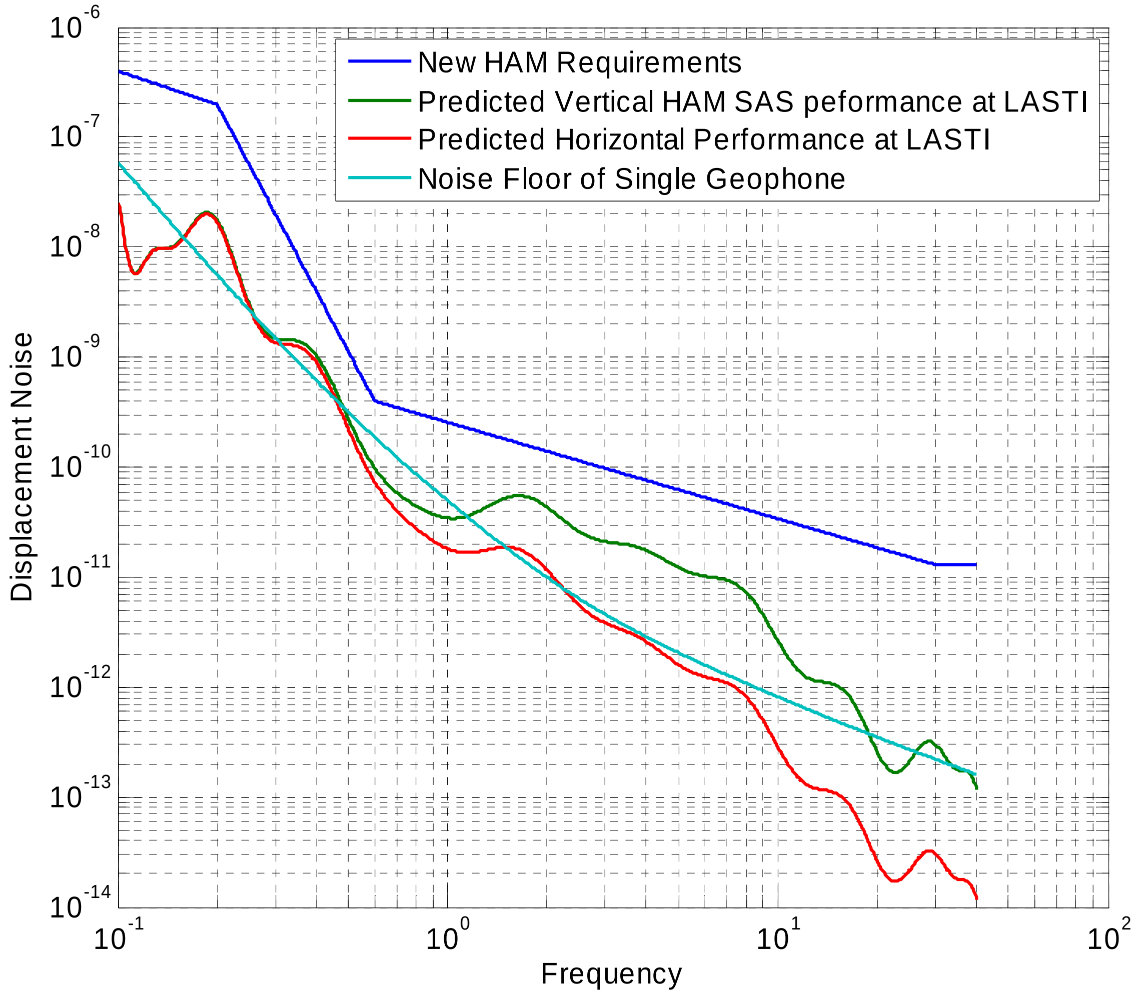


**Figure 4-4 Optimistic performance projections of HAM SAS in the LASTI environment**

A complete suite of Guralp seismometers (CMG-40T) will be provided to completely instrument the floor under Yend HAM. This will enable transfer functions to be taken from the floor to the HAM table top in all 6 dofs. This will enable us to extrapolate our results to observatory conditions. However Figure 4-4 shows that there is a chance that HAM SAS will be able to demonstrate the required sensitivity even in the elevated noise of the LASTI environment

## 4.3 Test for Interaction between horizontal and vertical directions

It has been theorized that because the GAS springs dynamically de-couple mass from the inverted pendulum legs that a very low vertical resonance may degrade the performance of the isolation in the vertical direction. For this reason the horizontal isolation will be checked for different vertical spring resonances set by the electro-magnetic anti-spring.

## 4.4 Triple Characterization

A complete system ID on a triple platform will be performed to determine whether any significant changes in the mode structure have occurred as a result of mounting to HAM SAS platform.

## 4.5 Fabry Perot Test

Given the tight time schedule involved with the testing of this of system it is probably unlikely that we will get to this test as it will be the lowest priority. However if time allows will lock the cavity to a fixed mirror located on the HAM SAS optical table.

## 4.6 Blind Mass Addition Test

Doug Cook will arrange to have two pieces of counterweight manufactured and cleaned to class A standards. He will also supply the clamps and the Class A hardware required to bolt them to a standard Initial LIGO HAM optical table. One of the pieces of counterweight will have a mass in the range of (0.5-2 kg) and the second piece will have a mass of (5-10 Kg). Doug will be provided with a table layout for current Yend HAM table layout. He will then specify any location that he wants to have both pieces of counterweight installed. The only requirement is that they cannot be located at the same location as either the table geophones or the triple pendulum. Doug will inform the HAM SAS team of the mass and the desired location of each mass on the optics table two weeks before a vent will occur to install them. A vent will occur and the length of the vent required to resume the HAM SAS to full functioning performance will be noted.

## 4.7 Test of Instability Susceptibility to Support Table Twisting

The HAM SAS stability depends critically on the load distribution on the 4 IP legs. Any twisting of the HAM SAS support table may alter the load distribution amongst the 4 IP legs. Hopefully the HAM SAS support table will be stiff enough to prevent this effect being significant. We will test this effect by introducing an error in the height of one of support piers via the scissor tables. The error that will be introduced will not exceed 0.25 mm or 10 thousandths of an inch. We will also monitor the twist of the ground under the table during a pump down cycle using an optical lever.

# 5 References

1. *LIGO-T050063-00-R*, “Triple Pendulum at LASTI Installation and Characterization”, L. Ruet, R. Mittleman and N. Robertson

2. *LIGO-E990303-03-D*, “Seismic Isolation Subsystem Design Requirements Document”, P Fritschel, D Coyne, J Giaime, B Lantz, D Shoemaker

3. *LIGO-T060075-00-D HAM* “Seismic Isolation Requirements”, Peter Fritschel, 14 March 2006

4. *LIGO-G060379*, Talk by Brian Lantz see p 9

# Appendix 1. Additional Equipment Required

## Lasers and Optics

1. 1 of Fiber coupled 635nm wavelength laser
2. Numerous misc 635 nm optics
3. One DLC mirror mount and one DLC Lens mount plus lens and mirror for vacuum use

## Mechanical Structures

1. Need to solid platforms on which to mount the lasers and optical receiver. One of these mounts could be a pedestal like structure made of 3 old HAM bases. This is the same as what the optics table for the triple experiment is mounted on. Given the space constraints the tower on the narrow corridor side will need to be purpose built.
2. A stiff column to go up the center of the HAM SAS table to mount the sensors that will monitor the position of the HAM SAS Optical table.

## Sensors

1. 4 additional quad PDs (The same modules as LIGO uses for wavefront sensors) and means to get them read into LIGO controls
2. 3 additional LVDTs to monitor the position of the HAM SAS optical table relative to the support structure.

## CDS Extras

1. Interface electronics for the 6 L4C In-vacuum geophones
2. Interface electronics for the 3 Guralp floor mounted seismometers
3. Interface electronics for 4 Quad PDs
4. Interface electronics for 3 additional LVDTs
5. Complete set of LIGO controls for a triple pendulum
6. There remains a chance that an STS-2 will be required to be installed on the top of the optics platform in vacuum. If this is required we will borrow electronics from the ISI for this test

## Whitening for the Guralps Interface Board

A typical LASTI seismic spectra was used to calculate the typical voltage out from the Guralp. The Guralps that will be used is a CMG-40T. This has a sensitivity of 800 V/m/s. The combination of this and the typical LASTI spectra is displayed in Figure 5-1

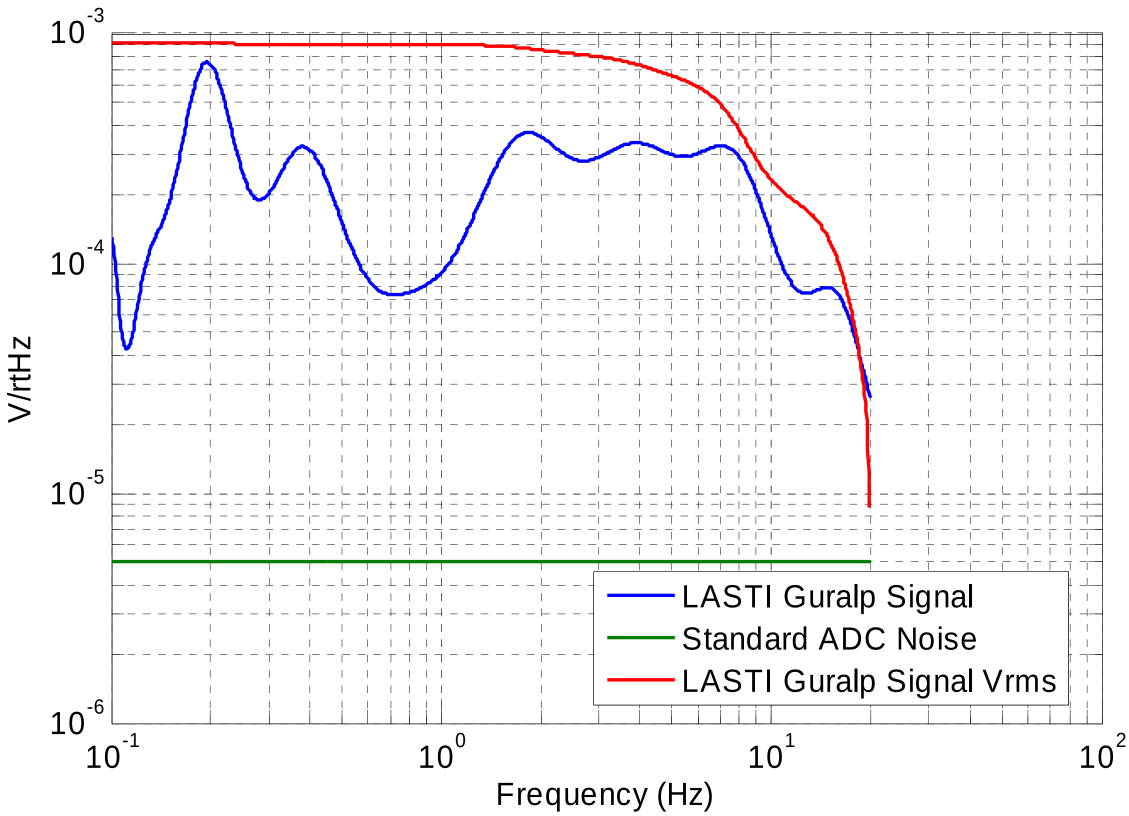


**Figure 5-1Expected Signal from the LASTI Guralps**

Using this as a guide it would be appropriate to have a gain of 200 from DC to 200 Hz plus a zero at 10 Hz and pole at 50 Hz.