Advanced LIGO Seismic Isolation System Development Test Plan

LIGO-G010136-00-R

By the Advanced LIGO Seismic Isolation Team members* at JILA, LLO, LSU, MIT, and Stanford

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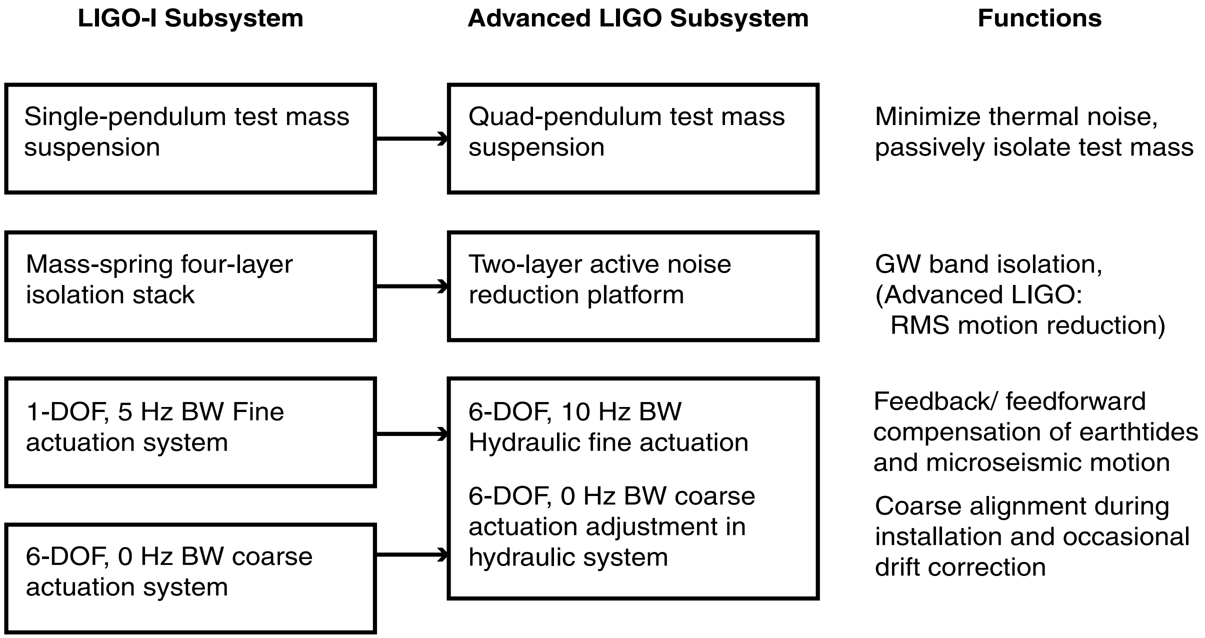
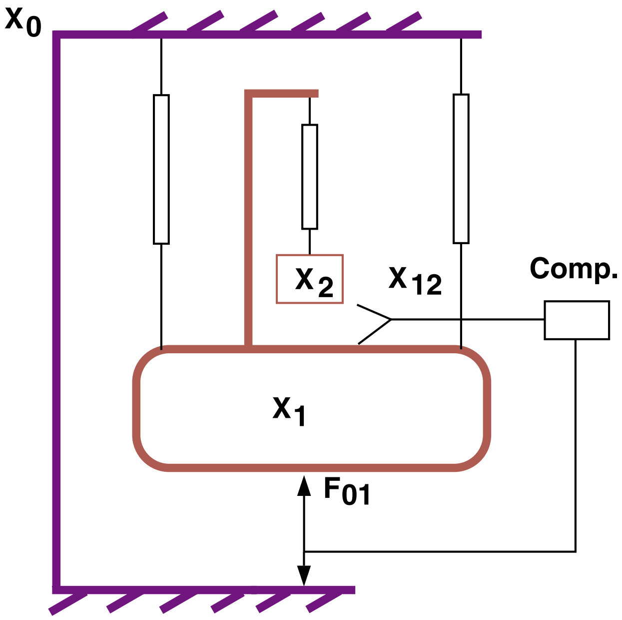
Functional Breakdown

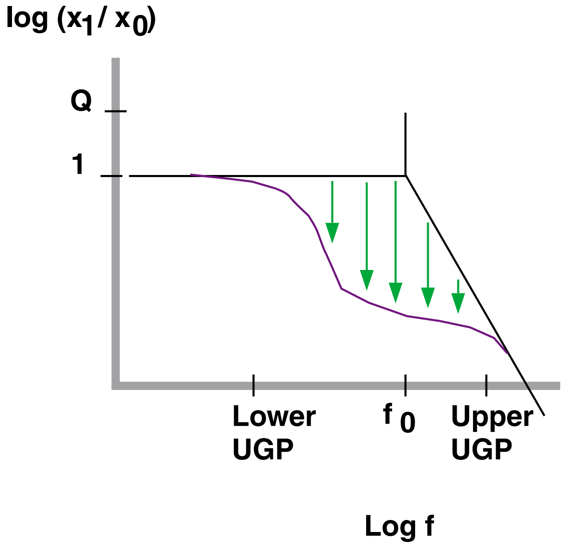


LIGO-I Subsystem	**Advanced LIGO Subsystem**	**Functions**
Single-pendulum test mass suspension	Quad-pendulum test mass suspension	Minimize thermal noise, passively isolate test mass
Mass-spring four-layer isolation stack	Two-layer active noise reduction platform	GW band isolation, (Advanced LIGO: RMS motion reduction)
1-DOF, 5 Hz BW Fine actuation system	6-DOF, 10 Hz BW Hydraulic fine actuation	Feedback/ feedforward compensation of earthtides and microseismic motion
6-DOF, 0 Hz BW coarse actuation system	6-DOF, 0 Hz BW coarse actuation adjustment in hydraulic system	Coarse alignment during installation and occasional drift correction

Seismic isolation functions in LIGO-I and Advanced LIGO. (The pendulum suspension, though not part of SEI, is shown because it contributes significant seismic isolation.)

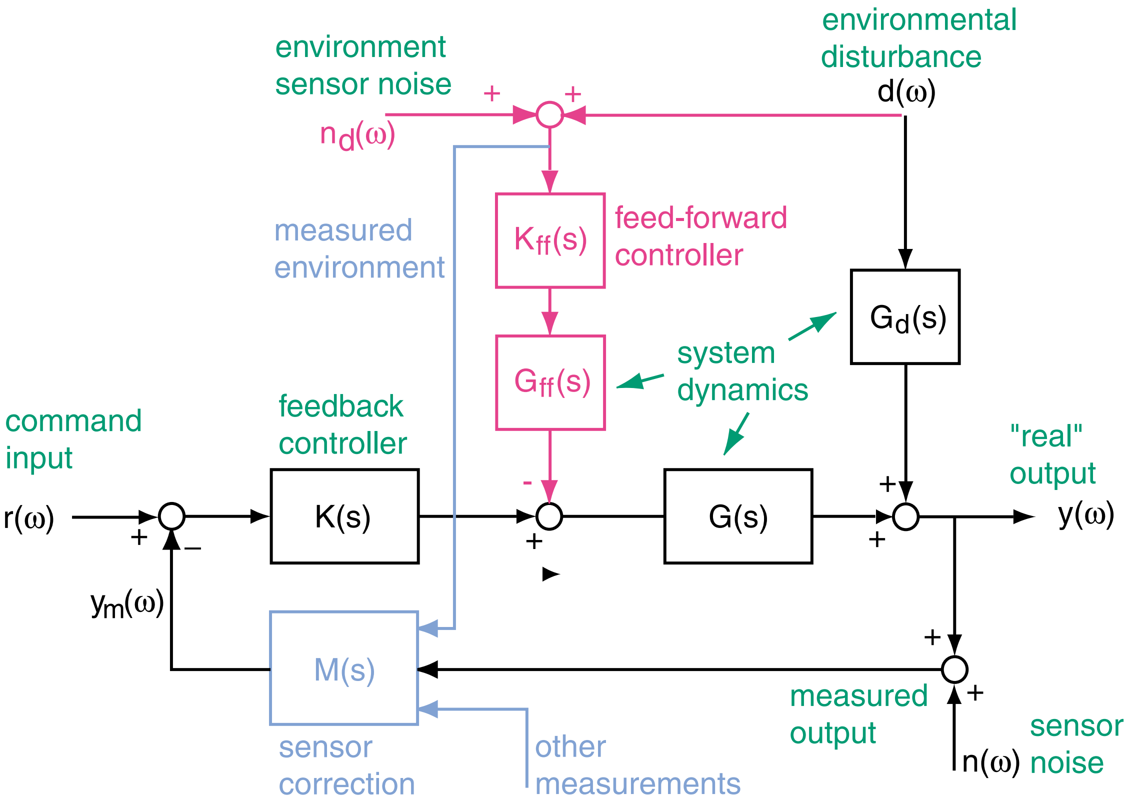
Active Seismic Isolation





Active seismic isolation.

Feedback, feed-forward, sensor correction

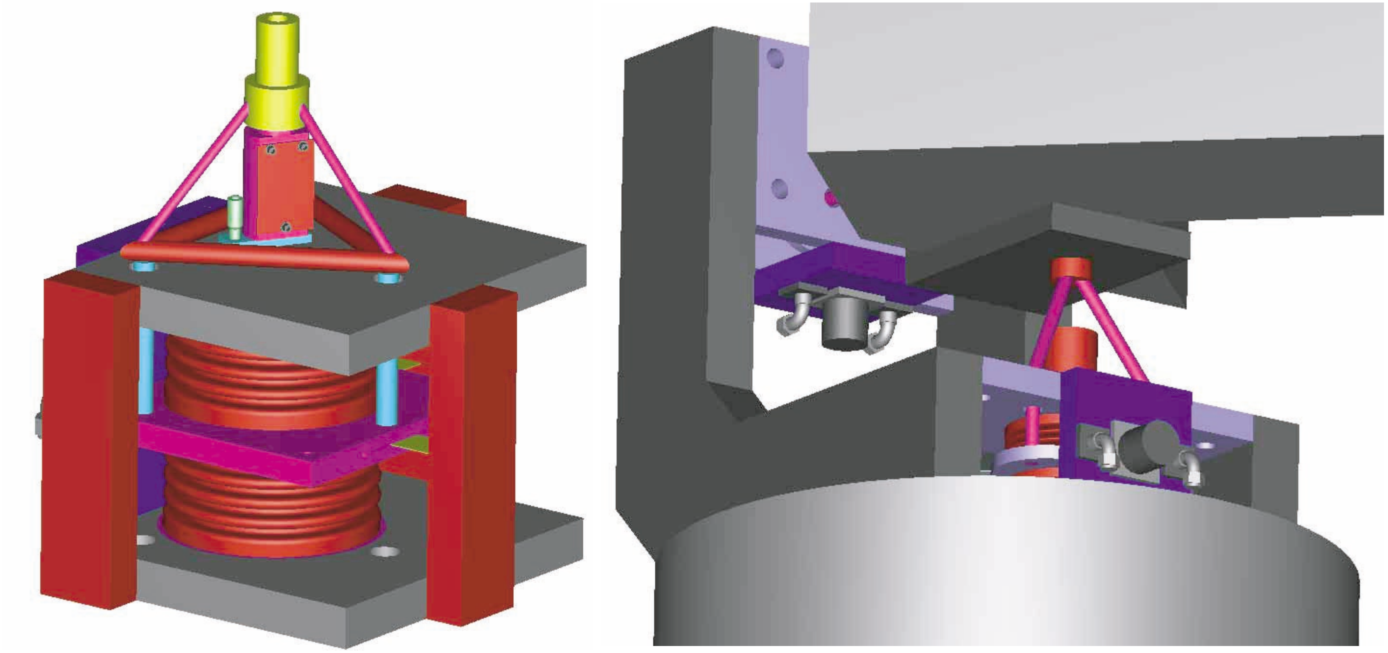


Feedback:

$$
\begin{aligned}
y \;=\; & (I+GK)^{-1}GK\,r && \text{command tracking}\\
& +(I+GK)^{-1}G_d\,d && \text{disturbance suppression}\\
& -(I+GK)^{-1}GK\,n. && \text{noise}
\end{aligned}
$$

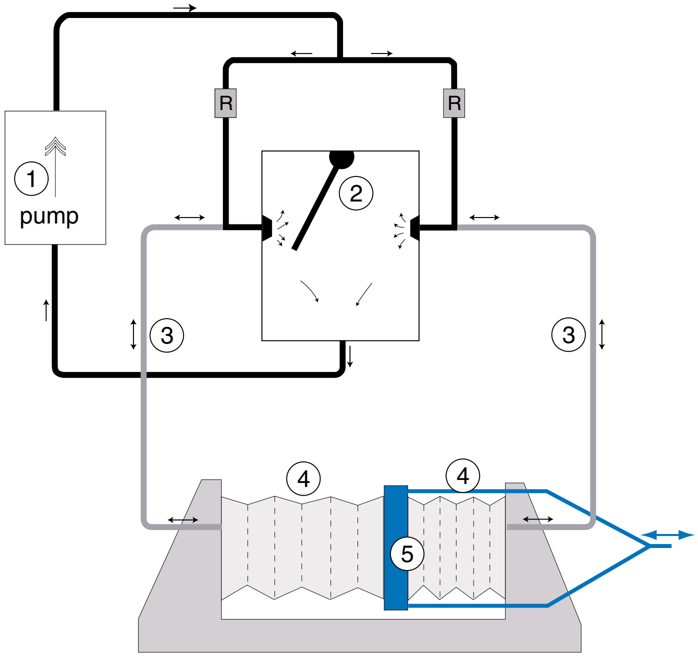
Feedforward: If $K_{ff}G_{ff}G = G_d$, environmental noise cancelled.

The Quiet Hydraulic Actuator.



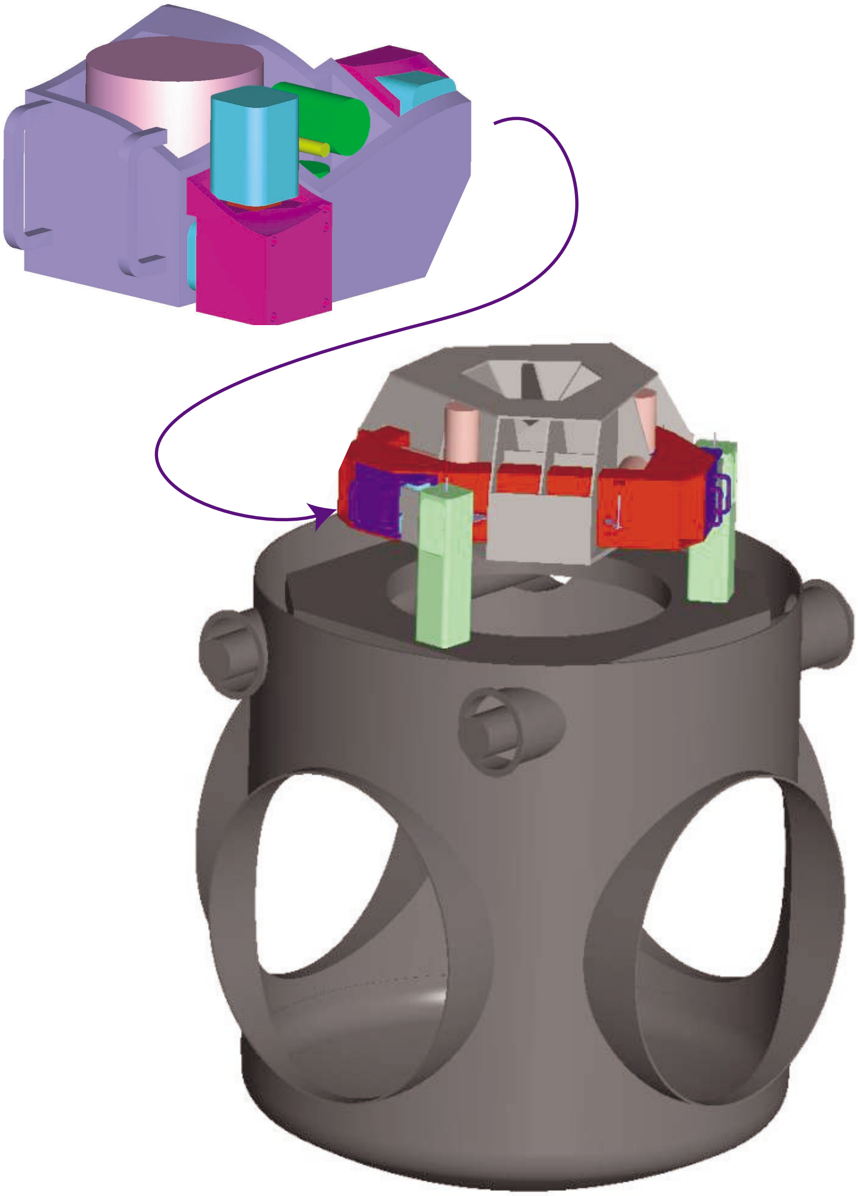
Hydraulic actuator will provide ±1 mm, 2 Hz BW continuous actuation in 6 DOF. Each bellows assembly acts in 1 DOF; two DOF at each corner. Viscous fluid and remote pump assure quiet operation.

Differential bellows:



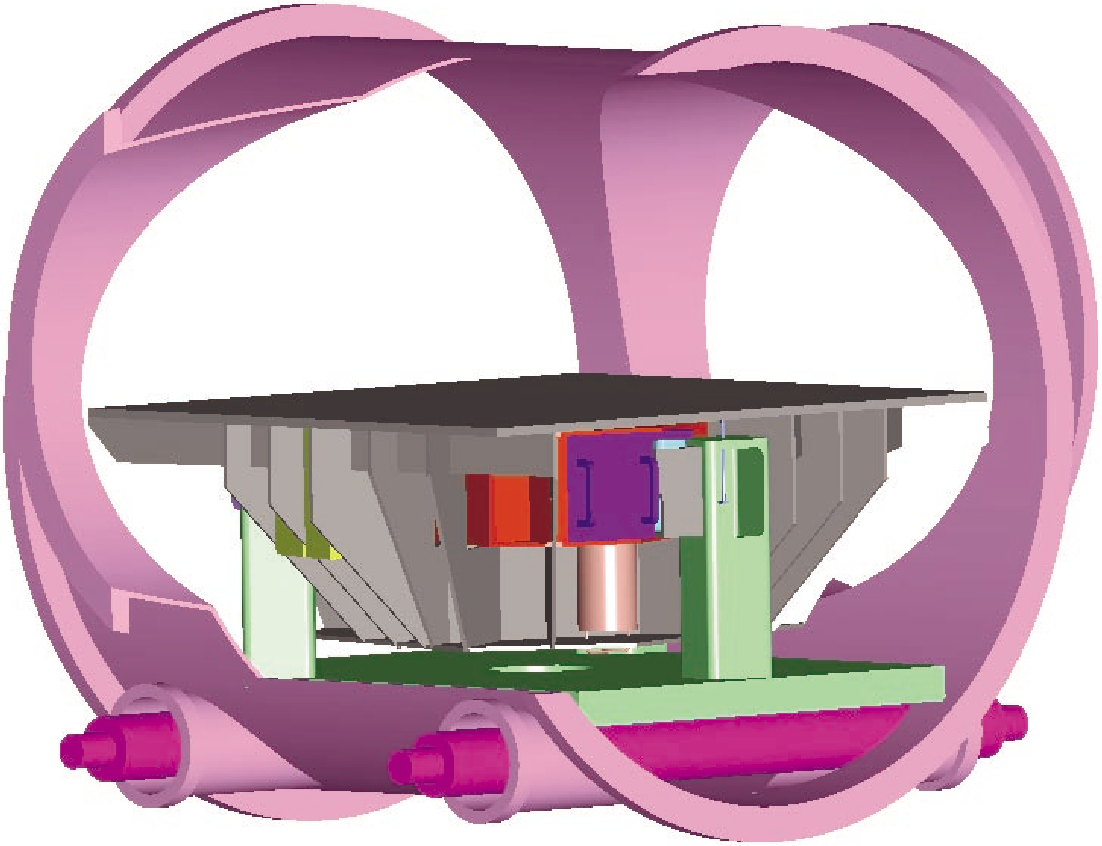
The control valve creates a pressure differential on the bellows. The middle plate is attached with flexures to both the base and the payload, only constraining motion in 1 DOF.

BSC Design



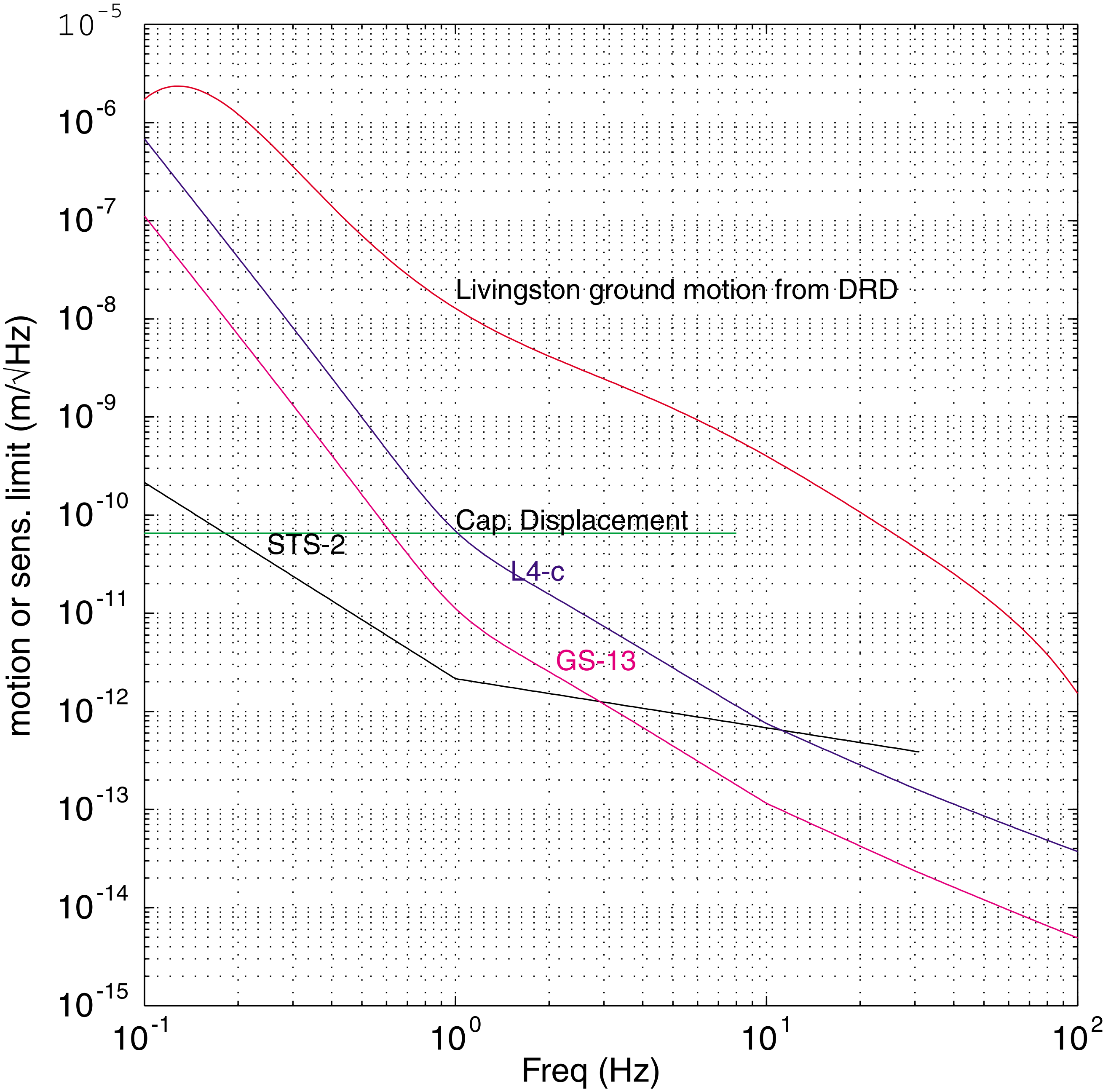
Rendering of BSC design of the two-stage active platform.

HAM Design



Rendering of the HAM design.

Sensor noise



Development plan

- Electronics/DSP dSpace → LIGO-brand?
- Prototype HAM two-stage active isolation platform to be tested in ETF at Stanford, with preliminary results in 4Q01.
- UHV prep research: Pod seals, wiring, structure fab methods.
- Pathfinder HAM and BSC to be installed/tested in MIT LASTI, 3/4Q02.
- Hydraulic stage to provide extra attenuation for noisy MIT site. Full prototype to be built at MIT, then replicated.
- Final design. . .

ETF test plan

- verify design viability:
    - structural stability/ modal structure/ stiffness.
    - plant ID versus model.
    - Controller workability and robustness.
    - Sensor & actuator pod design; fit and adjustability with structure.
    - Spring and flexure design.

- verify basic performance:
    - seismic transmission T(f)
    - some noise studies.

ETF test plan, continued

- Design OK'd for LASTI, then Continued development:
  - Optimal controller design - step response versus noise perf.
  - Supervisory control system design – use LIGO-brand electonics or not?
  - Dynamic range / noise compromises.

- Facility requirements:
  - basic test equipment
  - witness seismometers and accelerometers
  - dSpace system
  - optical levers - use 2-stage system as base?
  - michelson interferometer? - ditto?

LASTI test plan: HAM

- Initial Goals:
  - fit and assembly test with UHV provisions.
  - plant ID versus dynamic model.
  - UHV wiring install and test.
  - verify basic performance as in ETF.

- Detailed tests:
  - joint SEI/SUS assembly test with UHV provisions
  - transmission and noise performance
  - controller tweaking
  - implementation of supervisory control in LIGO data environment

LASTI test plan: HAM, BSC

- facility requirements: same as ETF, plus:
  - hydraulic stage with noise reduction in 1 - 10 Hz region, if noise studies are to be meaningful.
  - RGA and vacuum measurements
  - “cartridge installation” facility
- BSC testing:
  - compare plant against model
  - test performance

Reliability estimates for SEI

The design has been configured in a way that reduces sensitivity to component failures:

- Most in-vacuum components in pods, which can be tested before installation, catching infant mortality.
- Entire SEI can be tested when installed, in air, and defects corrected.
- Two or three sensors per DOF allows some fail-operate options. Alternate controller designs for systems with missing sensors or actuators can be devised, with reduced performance.
- Pod replacement should require of order 1 day interruption of operation.

Reliability estimates for SEI, cont'd

Most in-vacuum components known to be high reliability:

- Streckeisen STS-2 manufacturer lists 300,000 hour MTBF, in field use. 90 in-vacuum units implies 1 failure per 140 days. Our sensors should last longer than those in field use, however.
- GS-13 Geophone is a variant of S-13, which has 3000 units in field. Vender says "a few" return for repair per year.
- Capacitive bridge has only passive electrode heads and wires in vacuum.
- Non-contacting voicecoil/permanent magnet actuator, if operated within power capacity, is expected to be robust. (MTBF unknown, since it is a custom design.)