Active Isolation and Alignment at Stanford and Advanced LIGO

JILA, LSU, MIT, Stanford

LIGO Science Collaboration

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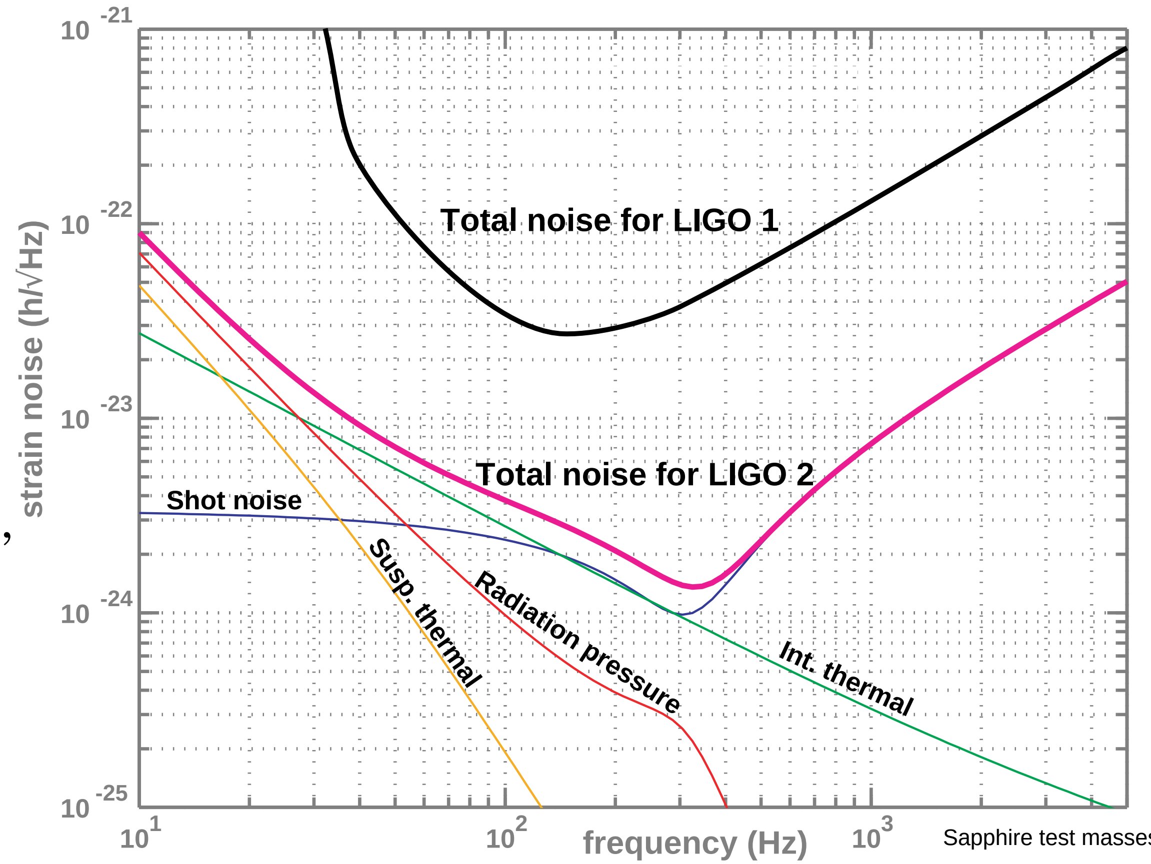
LIGO-G010164-00-D

Sensitivity Goal for LIGO 2

Extend the range by 10
for NS-NS inspirals
improve event rate by 1000.



Open up the bandwidth
to 10 Hz to see new events,
such as merger of 10 - 30
solar mass black holes.

As a result,
at 10 Hz we demand that the test mass motion
have equal contributions from

"intrinsic" thermal noise of 10^{-19} meters/√Hz &
ground motion of 10^{-9} meters/√Hz

Functional Description of the System

LIGO-I Subsystem	LIGO-II Subsystem
Single-pendulum test mass suspension	Quad-pendulum test mass suspension

Minimize thermal noise, passively isolate test mass

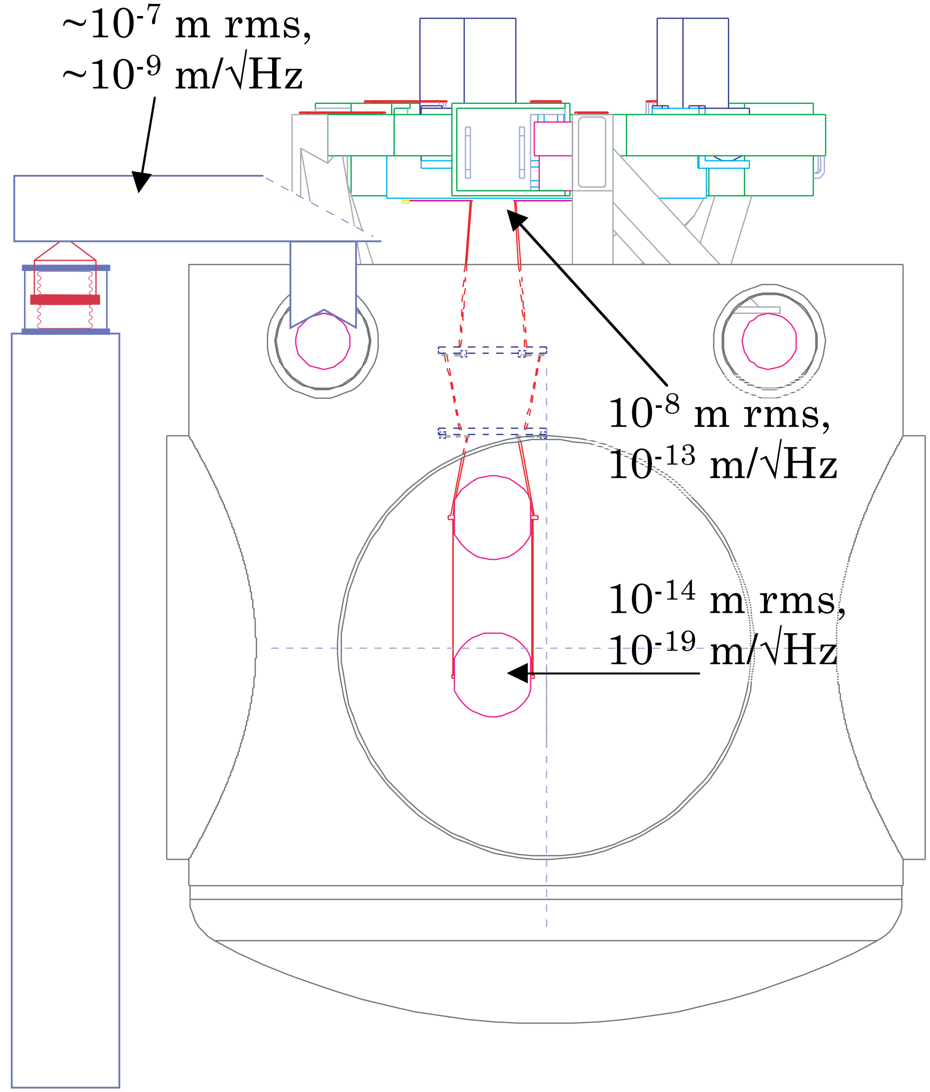
LIGO-I Subsystem	LIGO-II Subsystem
Mass-spring four-layer isolation stack	Two-layer active noise reduction platform

GW band isolation, (LIGO-II: RMS motion reduction)

LIGO-I Subsystem	LIGO-II Subsystem
1-DOF, 5 Hz BW Fine actuation system	6-DOF, 2 Hz BW Hydraulic fine actuation system
6-DOF, 0 Hz BW coarse actuation system	6-DOF, 0 Hz BW coarse actuation adjustment in hydraulic system

Feedback/ feedforward compensation of earthtides and microseismic motion

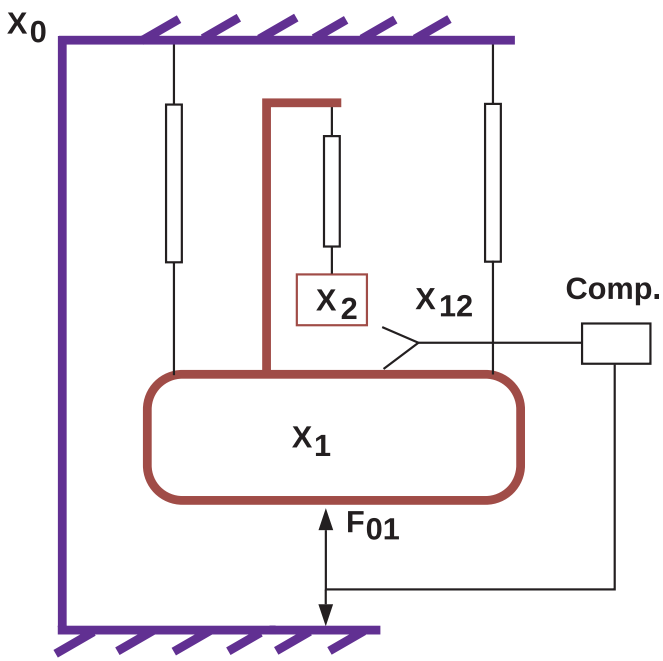
Coarse alignment during installation and occasional drift correction

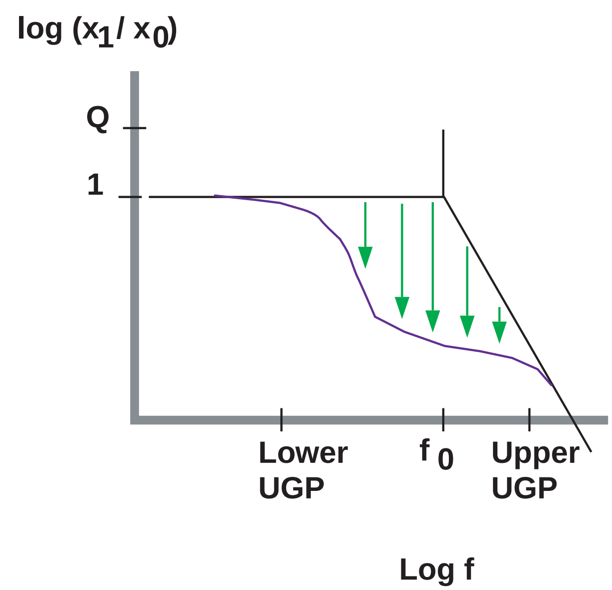


Stanford is Addressing Four Parts of Isolation and Alignment System

- External Hydraulics - Corwin
- Design questions for active platforms
- Modeling of active platforms
- Design of Advanced LIGO isolation and alignment system

Active Isolation



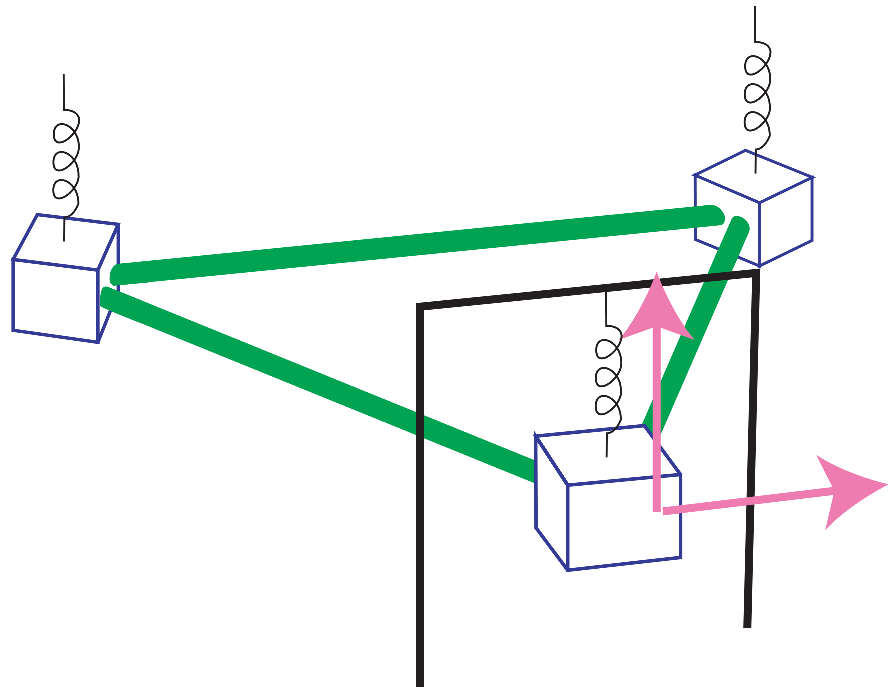


Suspended platform with inertial sensor
Feedback loop is used to add active isolation based on sensor
Decouples low frequency sensor from stiff platform
Used at JILA to achieve >=70dB isolation above 1Hz

Geometry of our 6 DOF platforms

Consider,

- Triangular platform.
- Compliant attachment to support structure.
- Instrument each corner with 2 DOF controls for vertical and tangential directions.



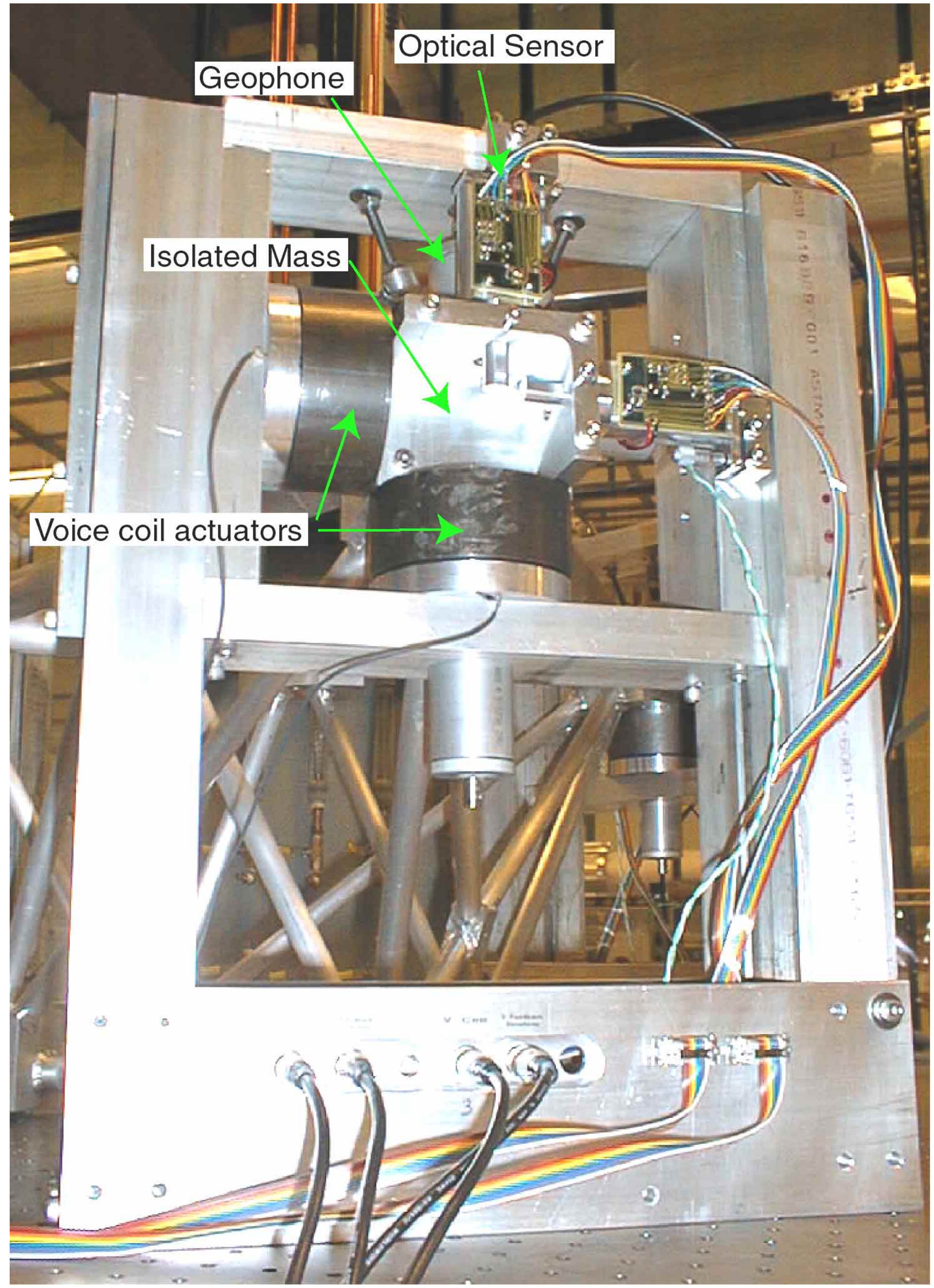
View of a 2 DOF corner

Hung with springs at 7 Hz from support structure

Each corner has vertical and tangential control

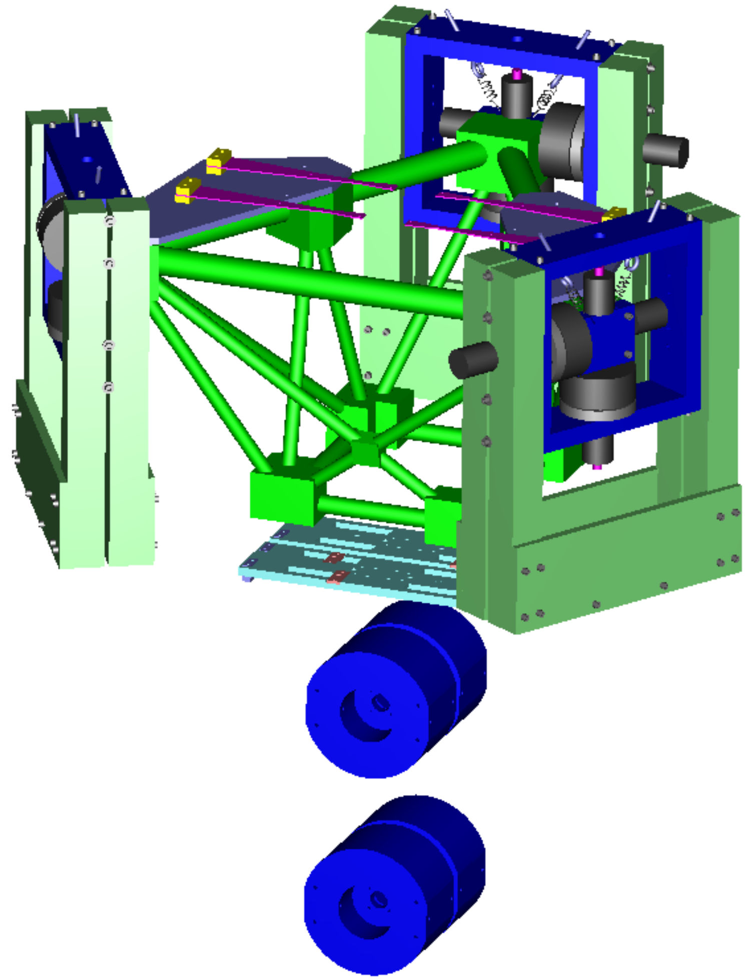
Sensors for both
inertial motion and
relative displacement

Collocated actuators

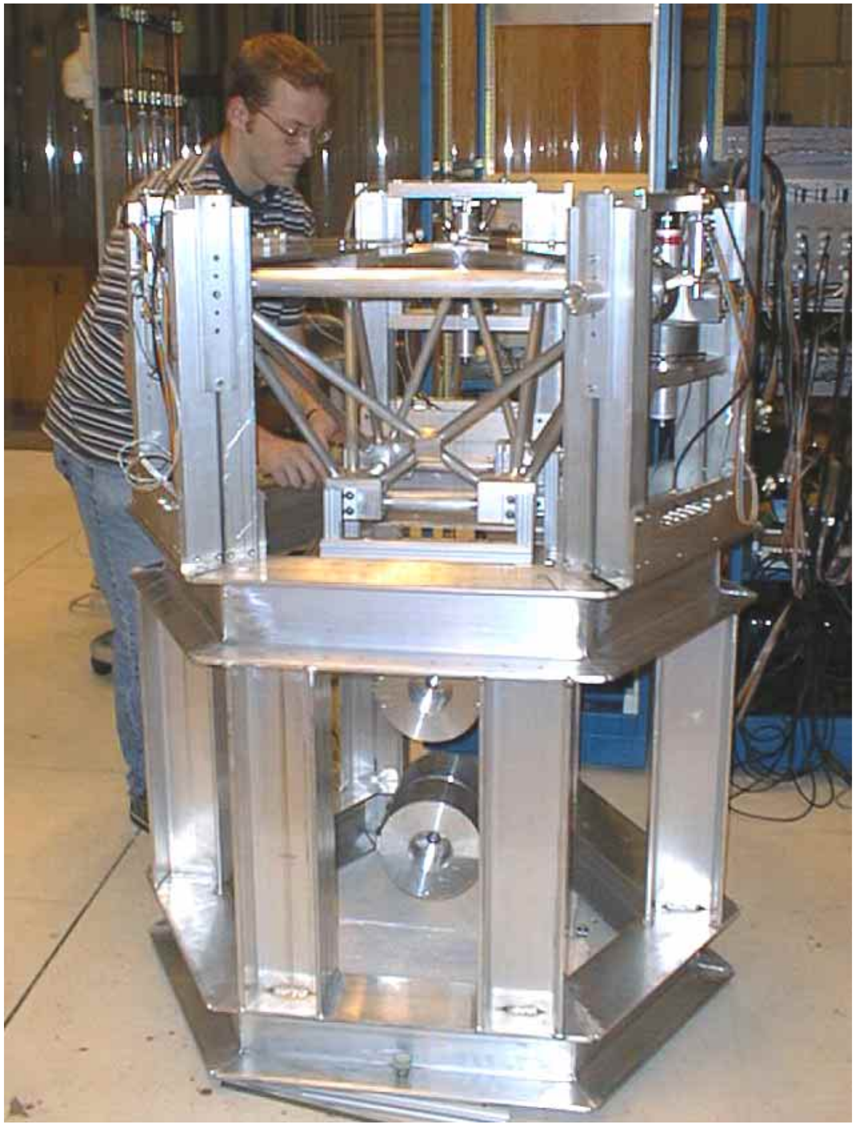


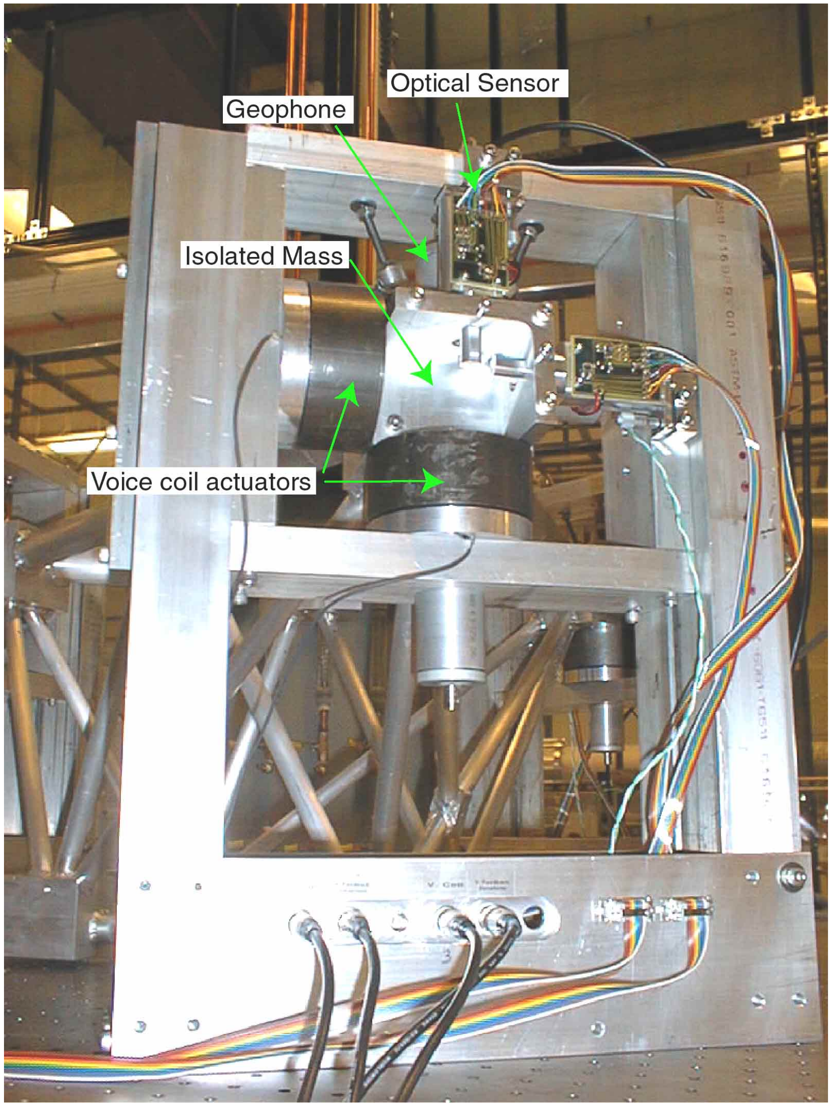
Single Layer Platform with Pendulums

- Demonstrate 6 DOF active platform with collocated sensors and actuators.
- Demonstrate sensor blending.
- Validate computer model used to design LIGO system.
- Demonstrate sensor correction to reduce ground motion.
- Demonstrate reliable operation of stiff platform and pendulum working together.

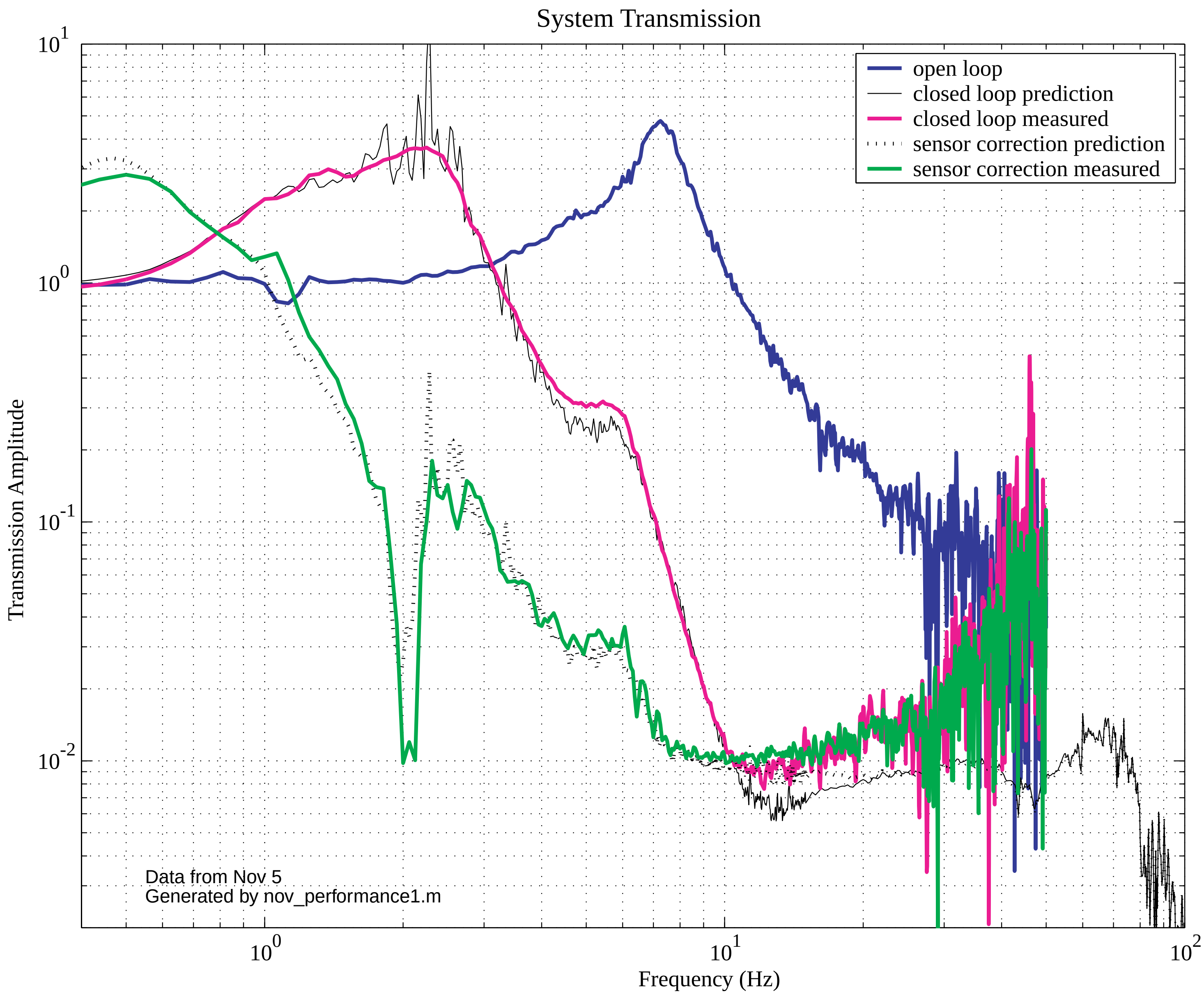


The Single Layer Platform

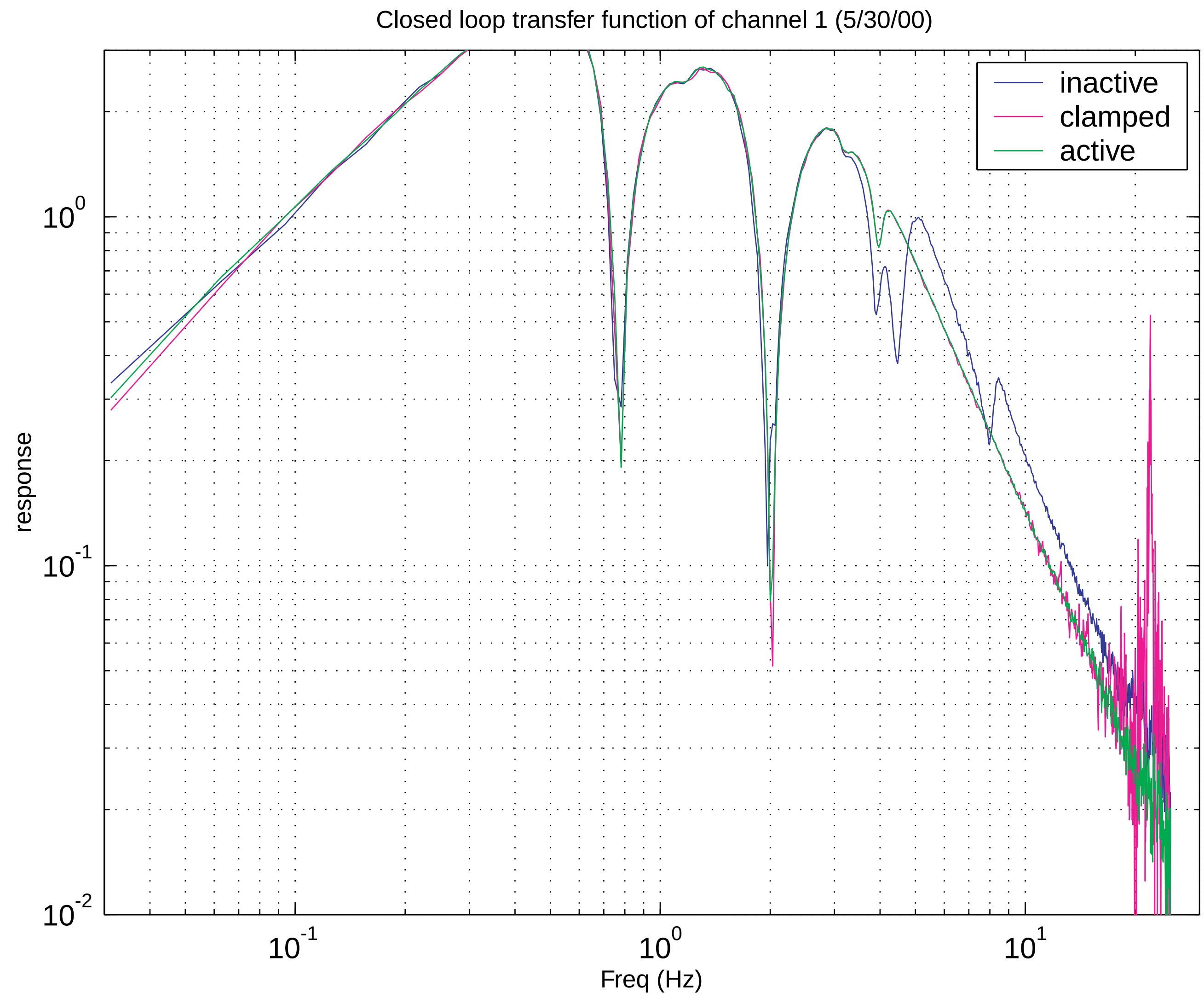




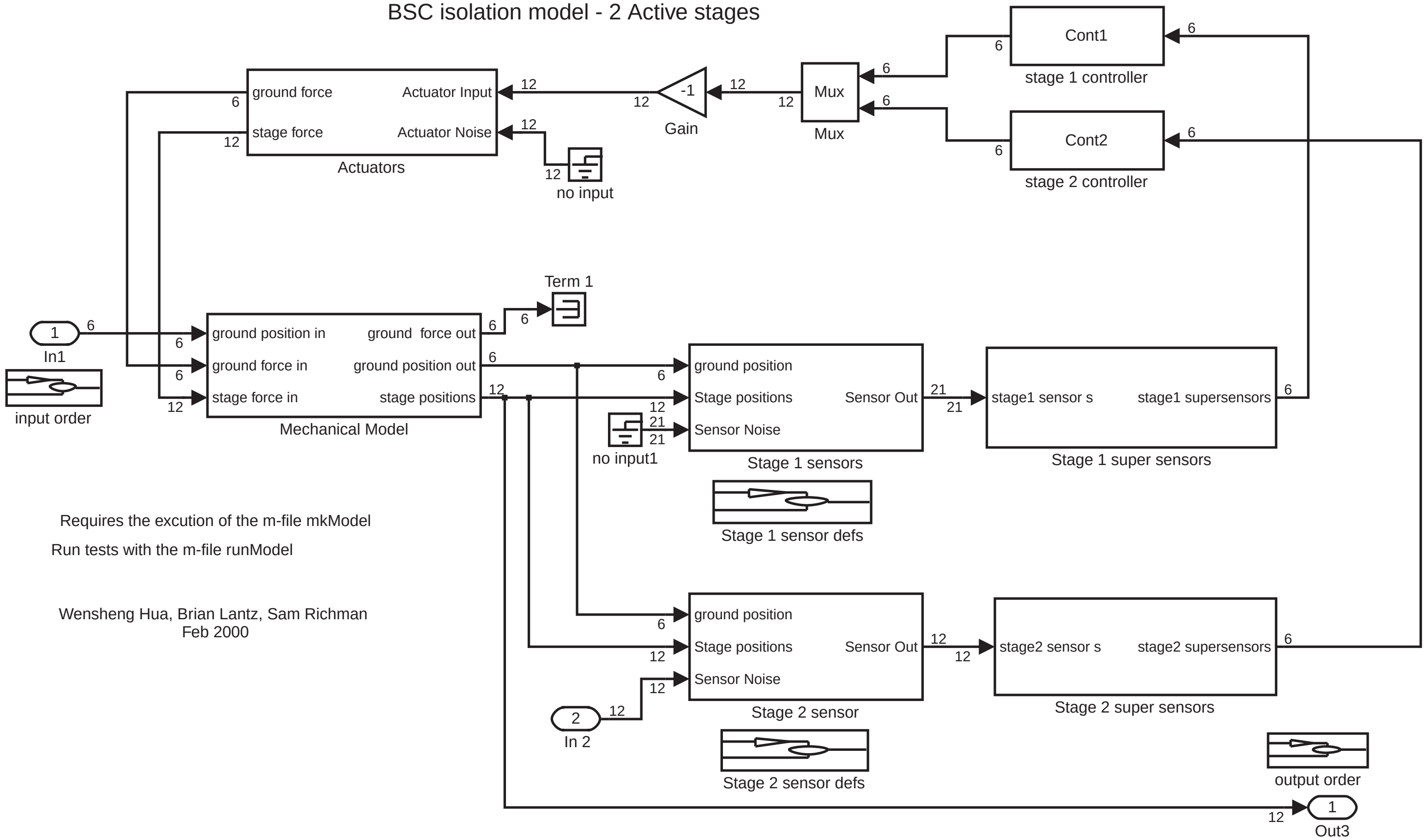
Results from Single Layer Platform



Pendulum Interactions



Simulink Model Diagram



Model used to simulate the dynamics of the reference design.

The controller can be cross-compiled onto dSPACE hardware and used on the real system.

Model Construction

1) A set of test inputs and outputs.

2) A mechanical model of the two stage system

3) A set of sensors which are distributed on the outer stage

4) Filters which blend the outer stage sensors into six “super-sensors”

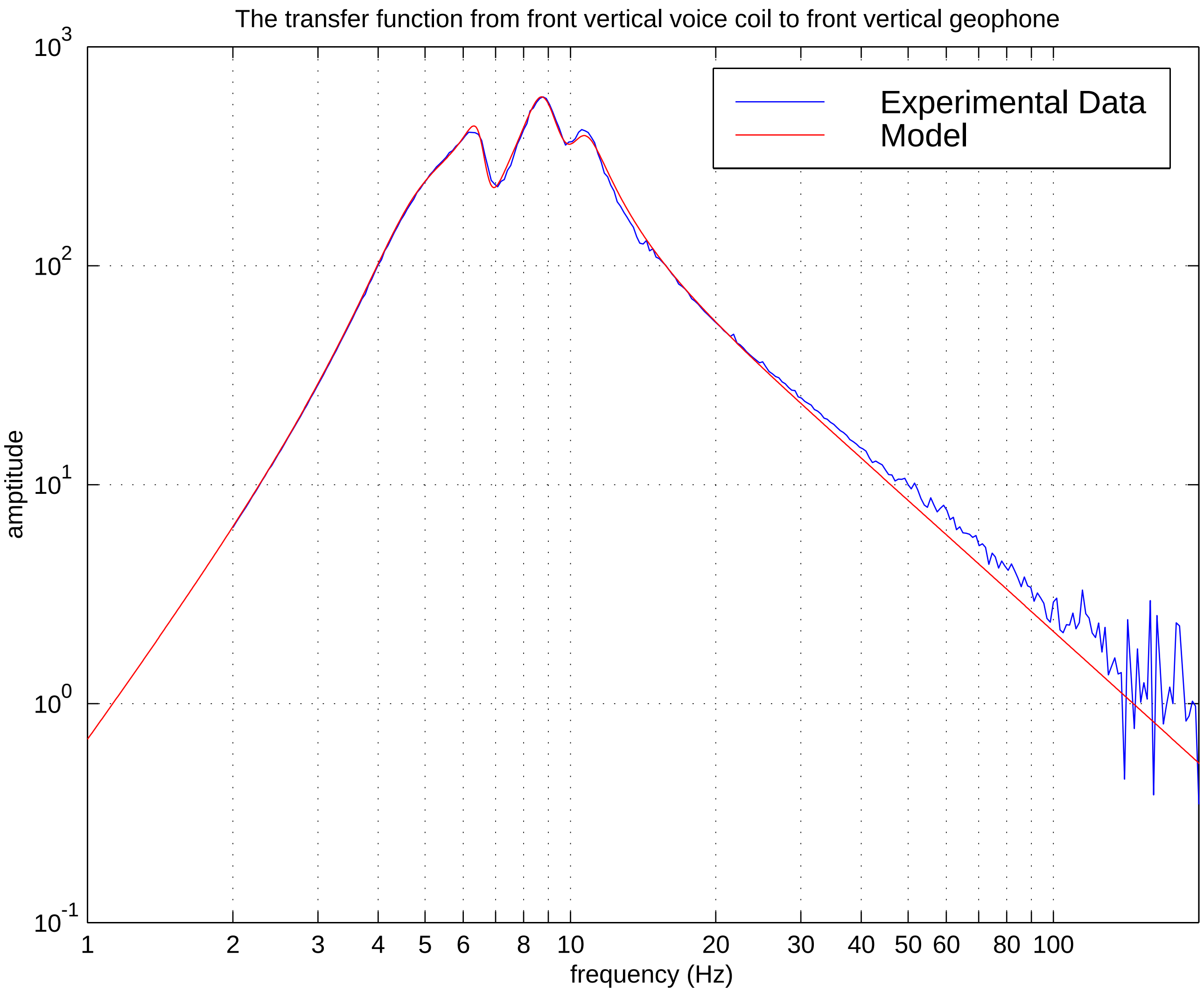
5) A set of sensors which are distributed on the inner stage

6) Filters which blend the inner stage sensors into six “super-sensors”

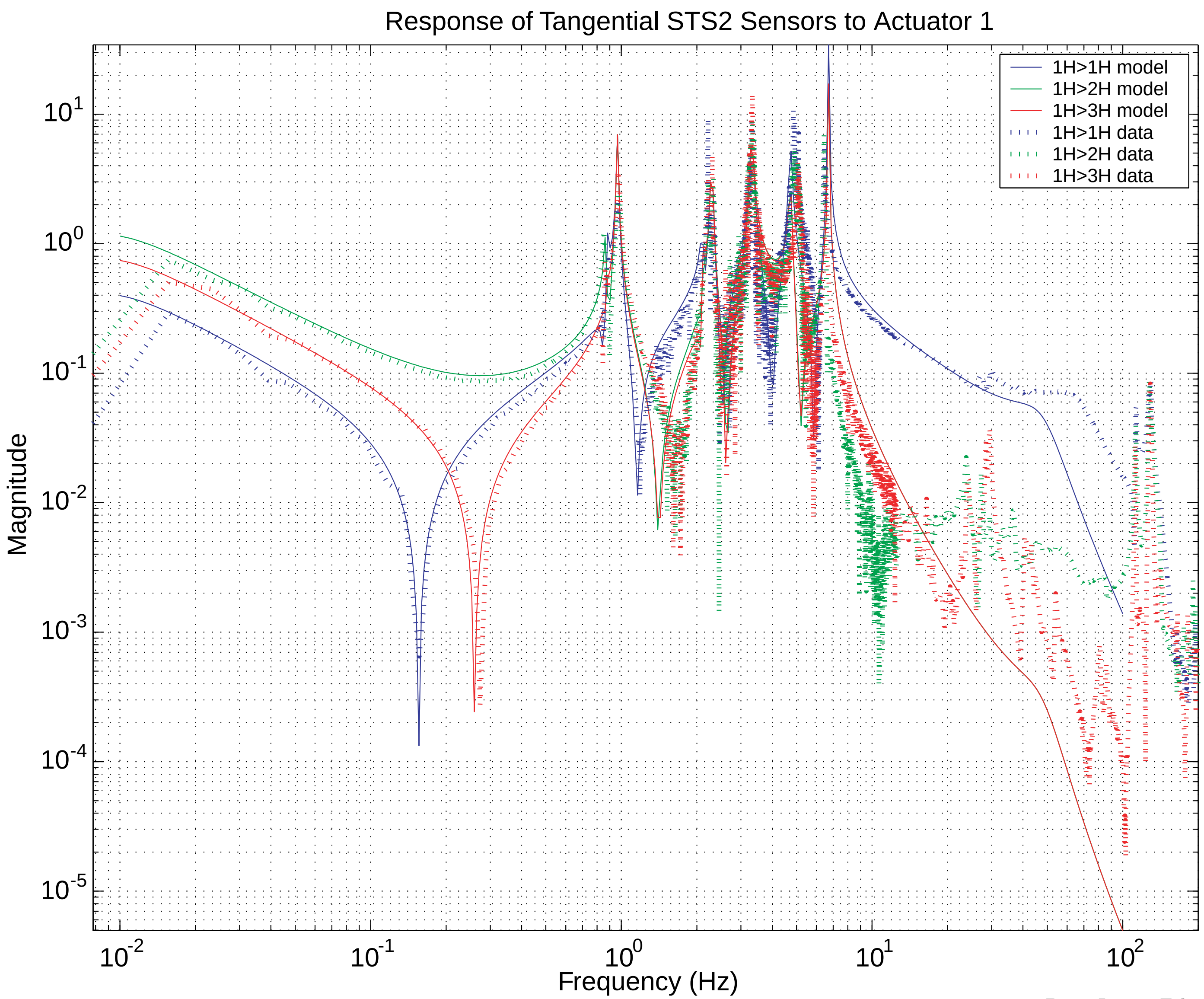
7) A set of actuators between the outer stage and the ground

8) A set of actuators between the inner stage and the outer stage

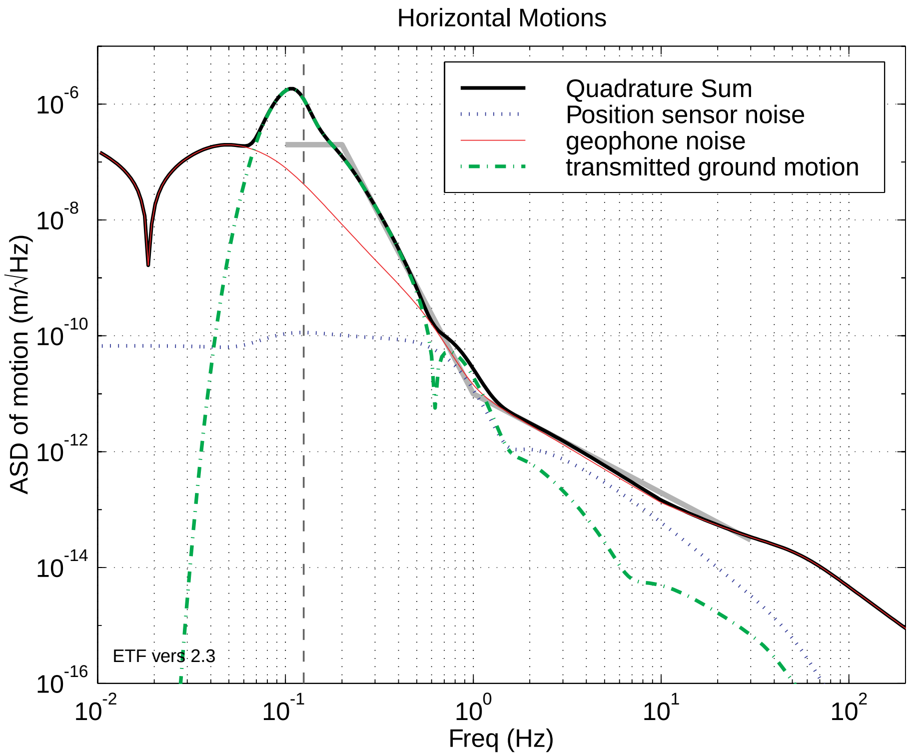
9) A set of 12 SISO control laws which connect the 12 actuators to the 12 super-sensors

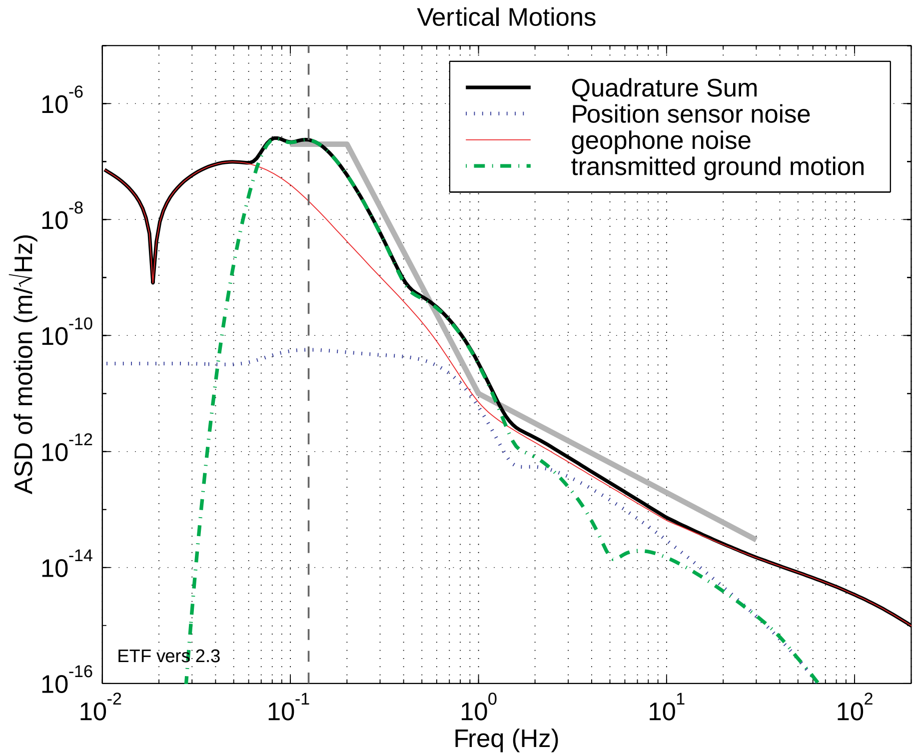

The transfer function from front vertical voice coil to front vertical geophone
Experimental Data
Model
amptitude
frequency (Hz)
10^3
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6
8
10
20
30
40
50
60
80
100

Model of Rapid Prototype



Predicted Motion of Optics Table

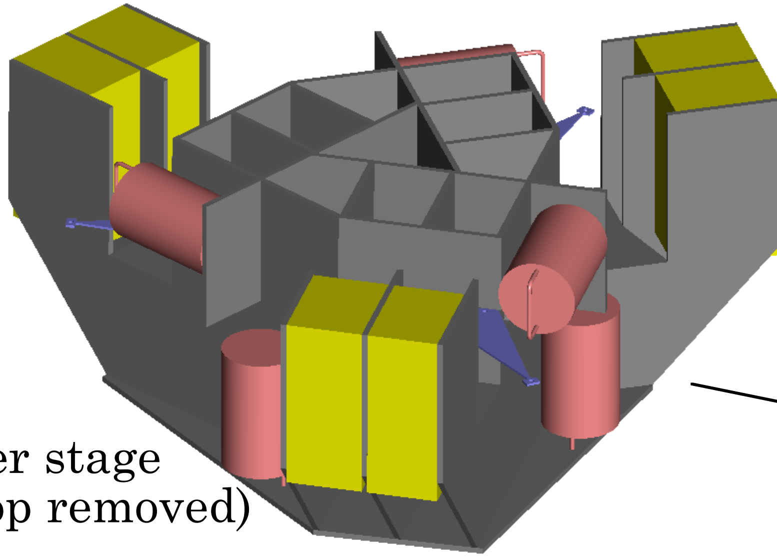




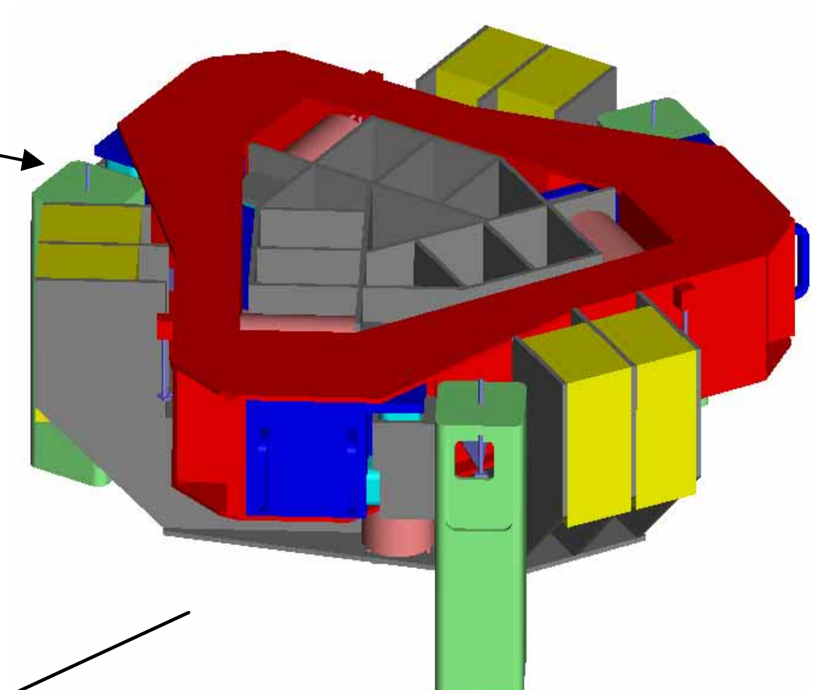
Next Step: Two Stage Prototype for Advanced LIGO

- Prototype for the HAM chamber system,
  to be installed in vacuum at the Stanford ETF.
- Same sensors, similar actuators as the Advanced LIGO system.
- Same dynamics as the Advanced LIGO system.
- Centers of mass of two stages at the same location.
- Sensors and actuators well aligned.
- How well does it work? Feed design information to the Pathfinder design at LASTI.

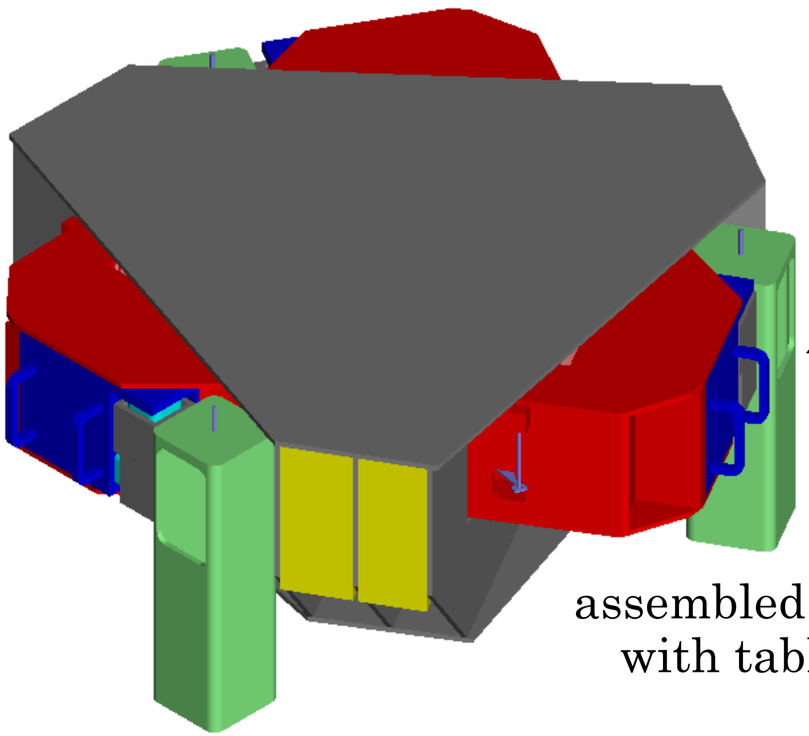
Views of the Prototype



inner stage
(table top removed)

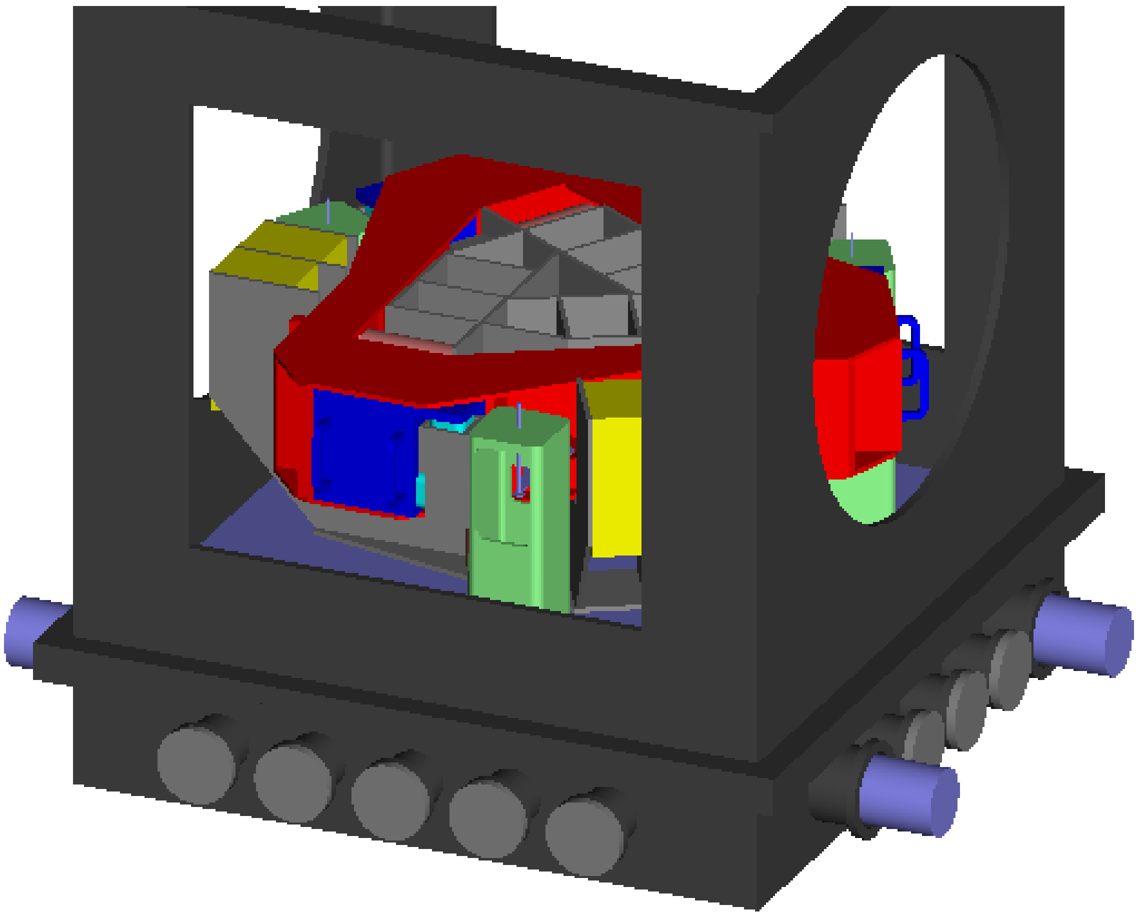


inner stage with outer stage
and supports



assembled system
with table top

Prototype installed in the ETF vacuum system



Ideal Facility for
Engineering Prototype

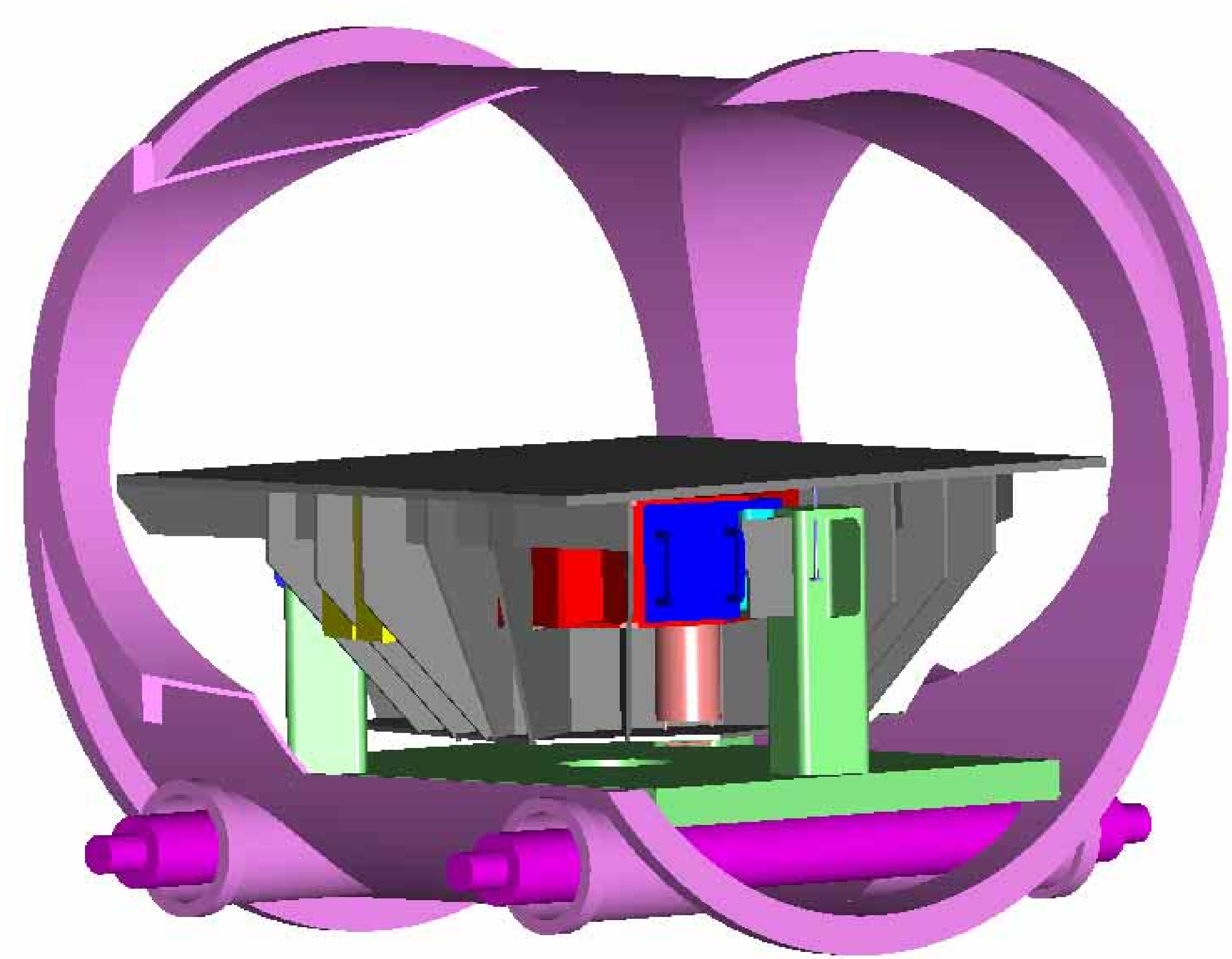
- Easy access to system
- Modest requirements for vacuum components

RFQ on the way to contractors

Install in ~4 months

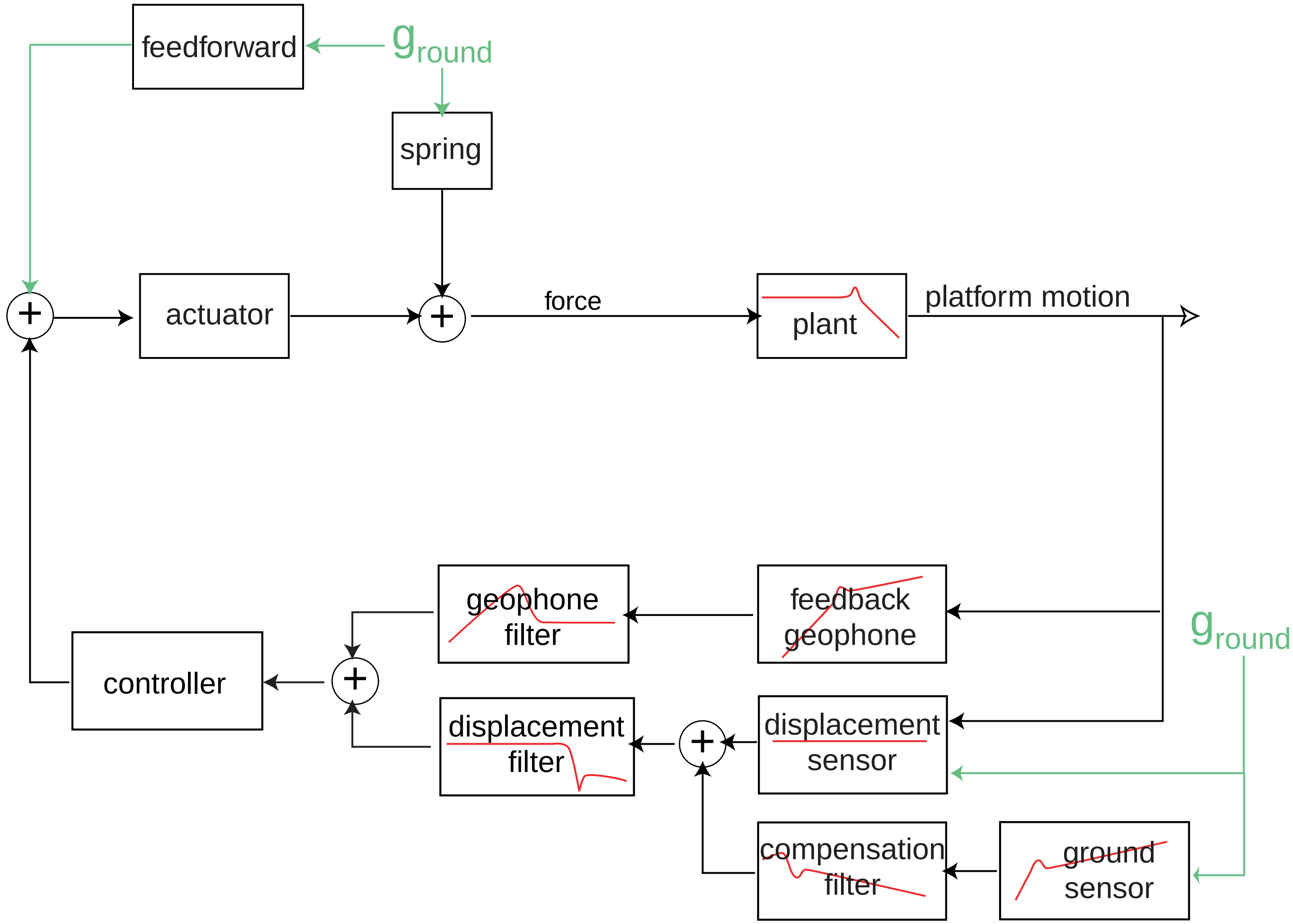
2 sets of data to the LASTI Pathfinder

Sketch of Active System in HAM Tank



View of the Tanks

1 DOF Model



feedforward
ground
spring
actuator
force
plant
platform motion
geophone
filter
feedback
geophone
ground
controller
displacement
filter
displacement
sensor
compensation
filter
ground
sensor