Active Isolation and Alignment in 6 DOF for LIGO 2

JILA, LSU, MIT, Stanford

LIGO Science Collaboration

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Detection of Gravitational Waves

Detection of Gravitational Waves

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Time $0 = T_0$

- $T = \frac{P}{4}$
- $T = \frac{P}{2}$
- $T = \frac{3P}{4}$
- $T = 1$ Period

Input light

Output light, containing gravitational wave signal

4km arm cavity
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/$\sqrt{\text{Hz}}$ & ground motion of $10^{-9}$ meters/$\sqrt{\text{Hz}}$
You are going to hear me describe:

- How we arrange our systems to make isolation tables.
- How LIGO 2 plans to control its optics.
- A few results from the prototype work at Stanford and MIT.
  - Feedback control of a 6-DOF isolation system.
  - Pendulum interactions.
  - Two useful control results.
  - Pictures of the next 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 $\geq 70$dB 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
A Variety of Requirements for a Variety of Optics

Test Masses (4)
1*10^{-19} meters/\sqrt{Hz} at 10 Hz
1*10^{-14} meters RMS
1*10^{-9} radians RMS

Suspended mode cleaner
3*10^{-17} meters/\sqrt{Hz} at 10 Hz
View of the Tanks
Functional Description of the System

LIGO-I Subsystem
- Single-pendulum test mass suspension
- Mass-spring four-layer isolation stack
- 1-DOF, 5 Hz BW Fine actuation system
- 6-DOF, 0 Hz BW coarse actuation system
- Feedback/ feedforward compensation of earthtides and microseismic motion

LIGO-II Subsystem
- Quad-pendulum test mass suspension
- Two-layer active noise reduction platform
- 6-DOF, 2 Hz BW Hydraulic fine actuation system
- 6-DOF, 0 Hz BW coarse actuation adjustment in hydraulic system
- Coarse alignment during installation and occasional drift correction

Minimize thermal noise, passively isolate test mass
GW band isolation, (LIGO-II: RMS motion reduction)

~10^{-7} m rms,
~10^{-9} m/√Hz

10^{-8} m rms,
10^{-13} m/√Hz

10^{-14} m rms,
10^{-19} m/√Hz

~10^{-6} m rms,
~10^{-9} m/√Hz at 10 Hz
Two stage active platform in the BSC

Blade spring supporting inner stage (1 of 3)
Blade spring supporting outer stage (1 of 3)
Inner stage pod (1 of 3, contains 2 GS-13s)
Outer stage pod (1 of 3)
Pod holster for outer stage pod
Two Stage Active Platform in the HAM

blade spring supporting inner stage (1 of 3)
blade spring supporting outer stage (1 of 3)
inner stage pod
outer stage pod
support structure
inner stage (optics table)
Predicted Motion of the Optics Table

Predicted motion of the optical table, in the horizontal and vertical directions. The contributions from ground motion (LSM) and second stage sensor motion are shown.
Prediction of Test Mass Motion in the BSC

Amplitude Spectral Density of the Horizontal Motion of the Test Mass

- **total motion**
- **horz coupling**
- **1e-3*vert**
Sensor Noise, and the LIGO ground motion model

![Noise Level of Various Sensors in the Reference Design](chart.png)
Some Results from our Prototypes

6 Degree-of-Freedom active platform testbed for ideas on active isolation

12 Degree-of-Freedom active platform to demonstrate robust performance at low frequencies

Design of a new two-stage active platform, in vacuum, controlled in 12 DOF.
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 feedforward reduction of ground motion.
- Demonstrate reliable operation of stiff platform and pendulum working together.
The Single Layer Platform
Isolation Performance

System Transmission

Data from Oct 24
Generated by oct_performance2.m
Horizontal performance
Pendulum Interactions

Closed loop transfer function of channel 1 (5/30/00)
Feedforward of Ground Motion

System Transmission

Data from Nov 5
Generated by nov_performance1.m
Correction of flexible modes
Preliminary Two Stage Performance

Horizontal Motion

Vertical Motion
Build a new Double Active Stage

- Prototype for the HAM chamber system, to be installed in vacuum at Stanford.
- Same sensors, similar actuators as the LIGO 2 system.
- Same dynamics as planned for LIGO 2 system.
- Centers of mass of two stages at the same location.
- Sensors and actuators well aligned.
- How well does it work?
Views of the Prototype

inner stage (table top removed)

inner stage with outer stage and supports

assembled system with table top
Next Stop, the ETF