Development of An Active Seismic Isolation Prototype for Gravitational Wave Interferometers

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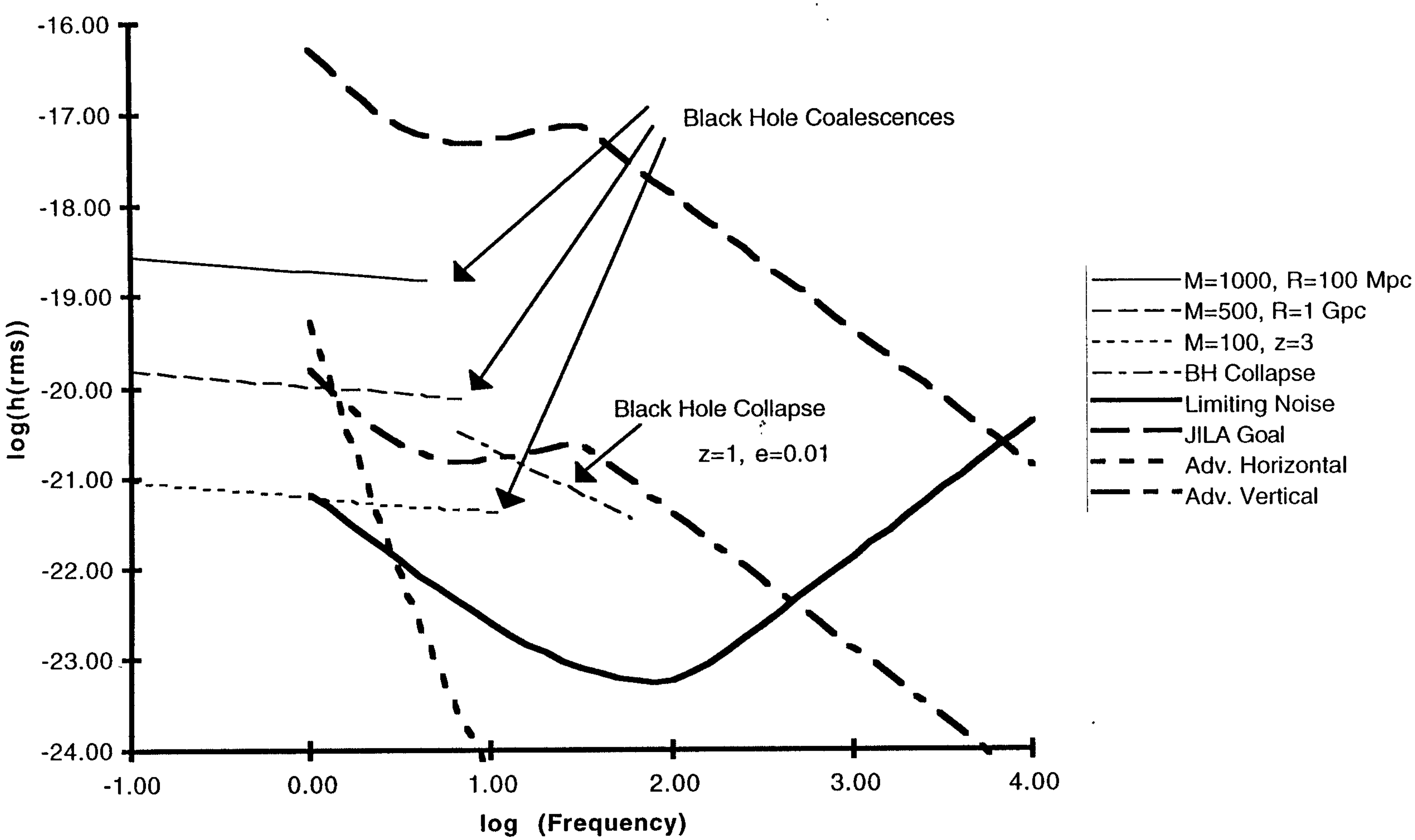
The JILA Gravity Group

- Started in 1986
- Early NIST and NSF support
- Sustained NSF support since 7/91
- Current roster: Peter Bender, Jim Faller, Robin Stebbins, Joe Giaime, Sam Richman
- Past members: Clive Speake, Peter Saulson, Peter Nelson, James Mason, David Newell, 9 REU students
- Active projects: seismic isolation, G, g, LISA
- Visit our web page at http://onehertz.colorado.edu, username: JILA, password: JILA

Goals

- To embark on the development of advanced detectors
  - Long and complex project (target date: 2007)
  - Collaboration with many groups (interferometry, suspensions, control systems)
- In this proposal: design a prototype of an active seismic isolation system
  - Scaled for a payload of 50 kg
  - Compatible with all potential testbed interferometers
  - Adopt the lessons of our "technology demonstrator" to a practical design for application in an advanced interferometer
  - Suitable for estimating the cost of construction

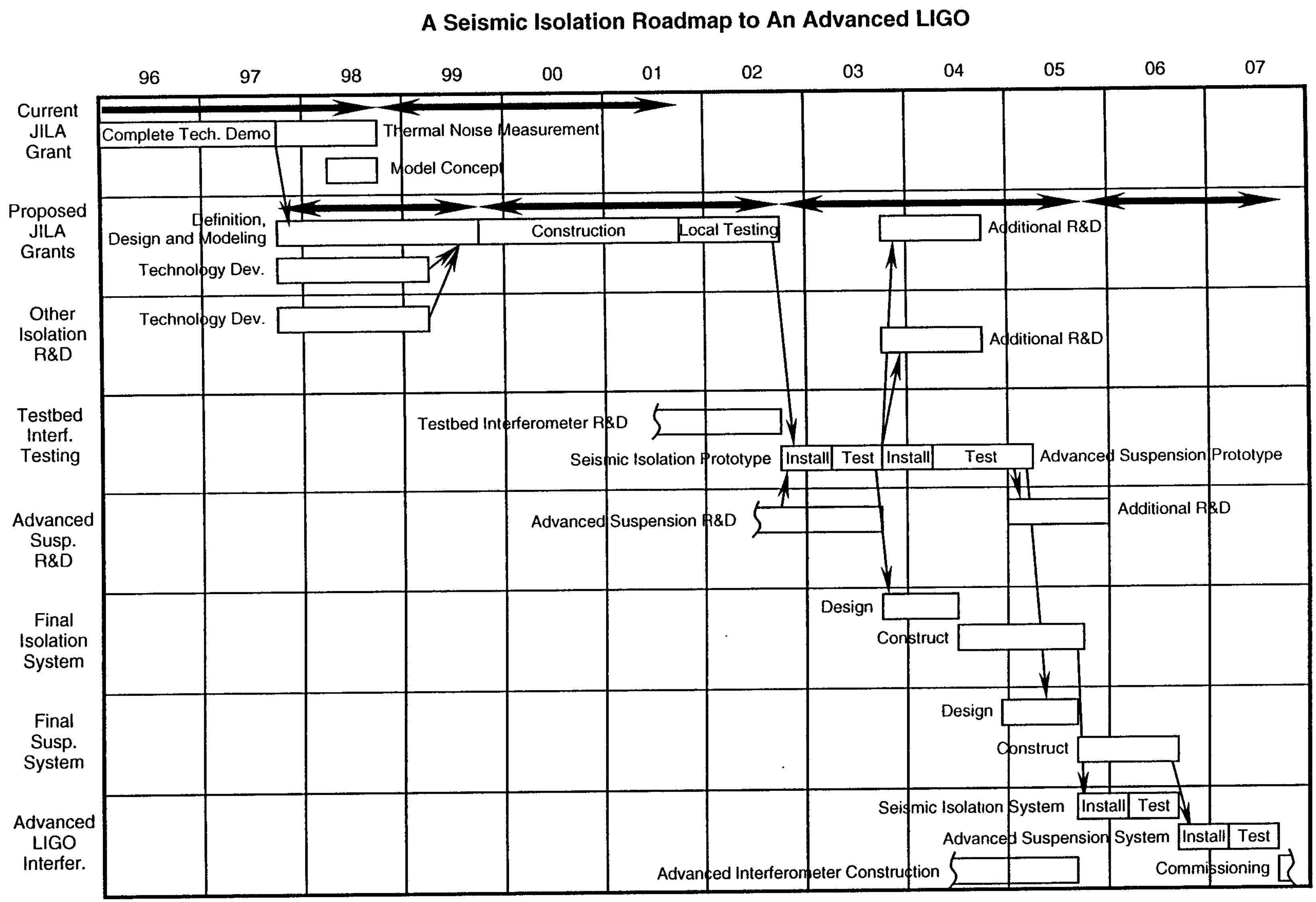
Signal Sources, Detector Sensitivity and Noise



Seismic Isolation Technology Roadmap

- N.B. - This is only a strawman. It isn't endorsed by any collaborators.
- Presumption: A commissioning start date of 2007
- Current grant and follow-on
  - Technology demonstrator is complete before starting prototype design
  - A follow-on grant to investigate noise in pendulums on our technology demonstrator.
- Proposed grant and follow-ons
  - Design and construction of scaled prototype isolation systems
  - Testing of prototype isolation systems with advanced suspensions
  - Design, construction, installation and testing of final isolation systems in an advanced LIGO interferomter

Seismic Isolation Roadmap

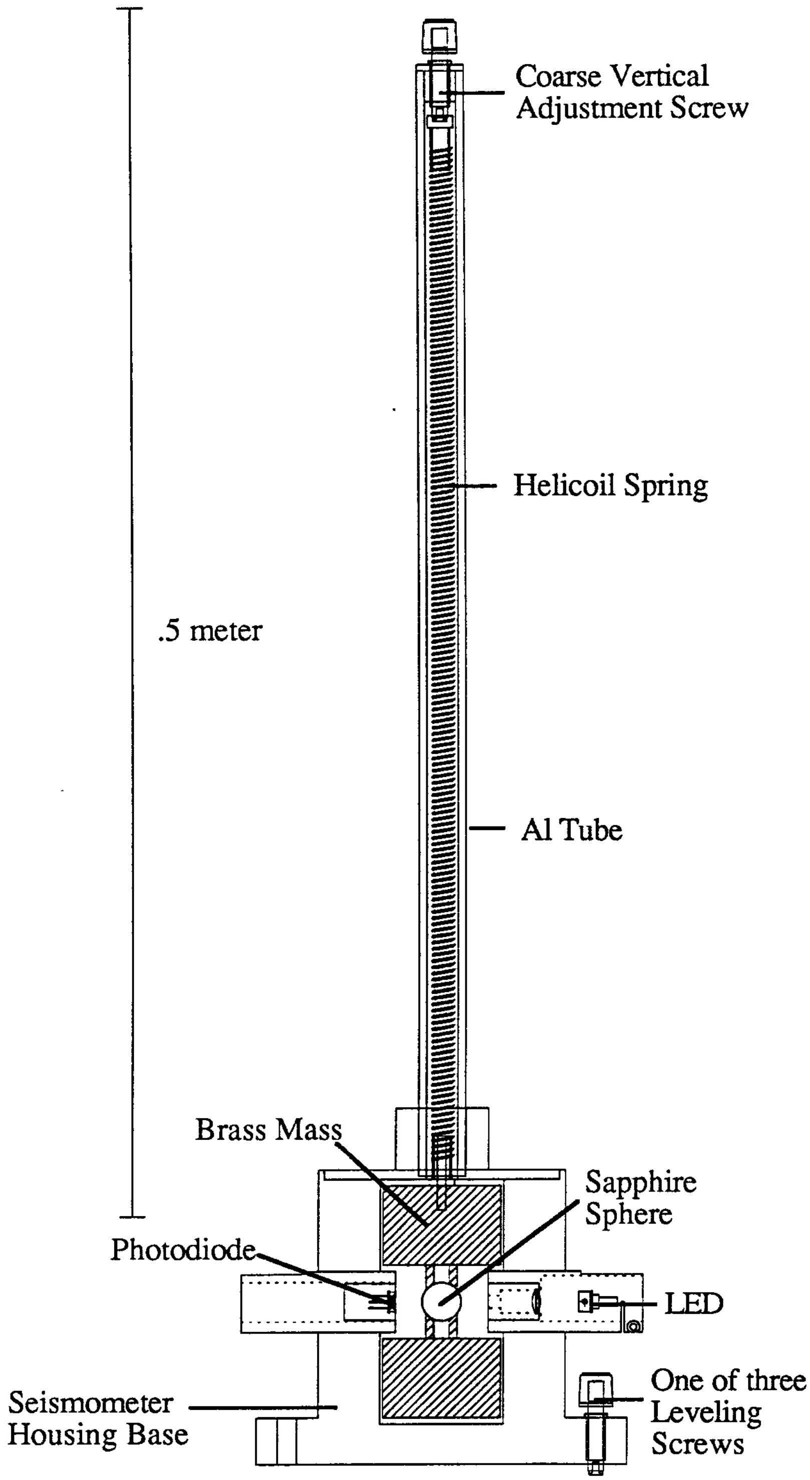


Important Questions for the Road Ahead

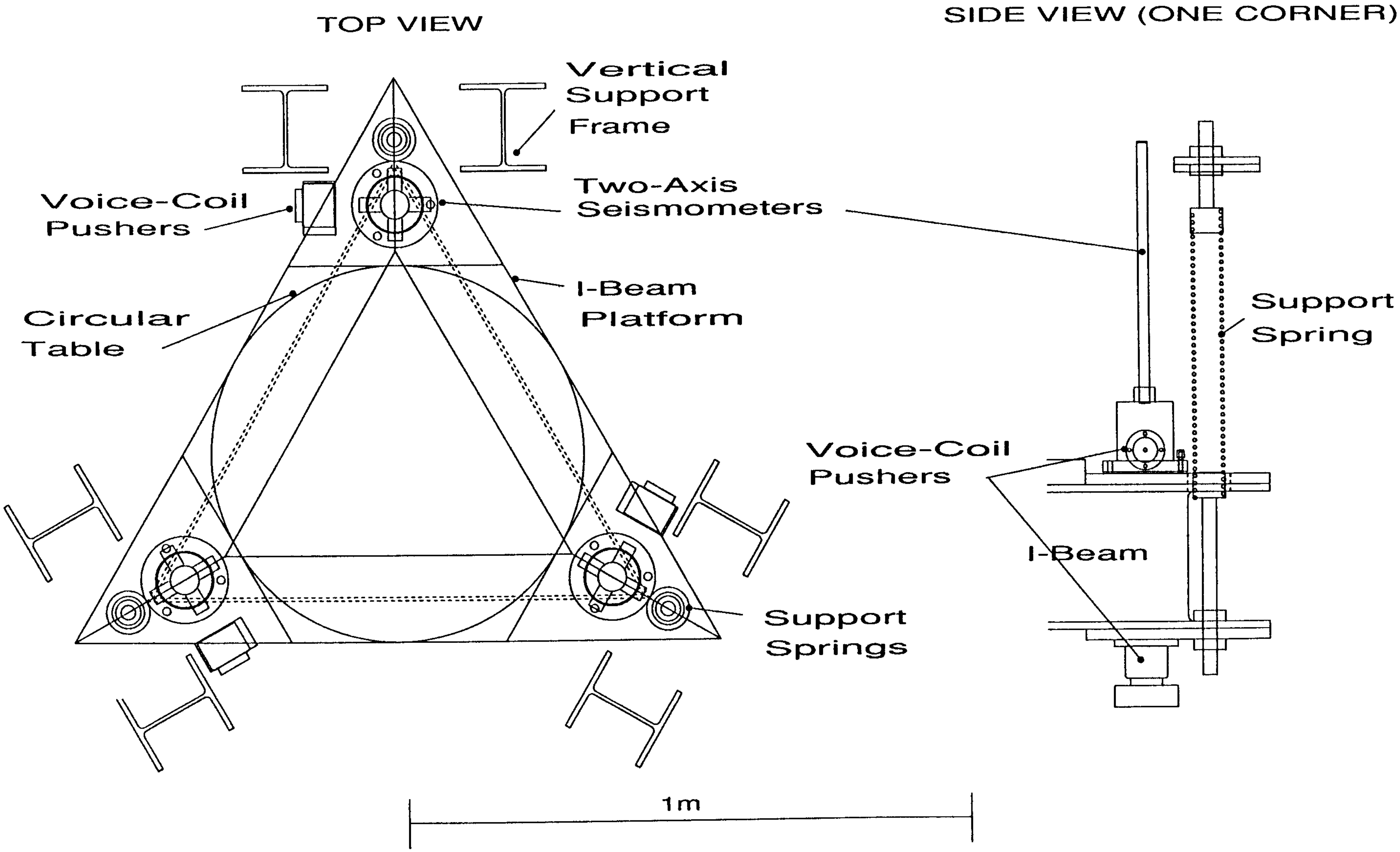
- Target date for start of advanced interferometer commissioning
- Will there be a testbed(s), like the 40 m, for advanced LIGO interferometers? What are its parameters?
- How many isolation systems need to be tested? How many does the testbed need?
- What level of isolation performance is needed, and by what date?

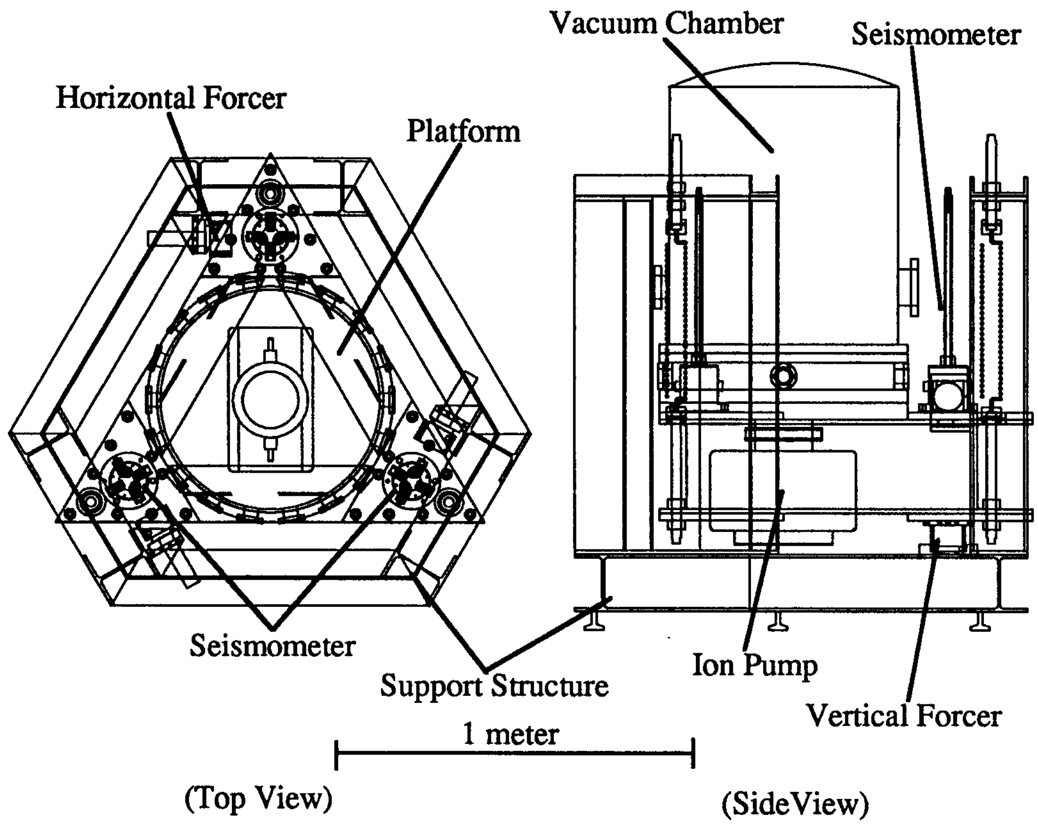
Important Concepts in Our Design

- Active and passive seismic isolation (1-30 Hz)
- Multiple stages with modest gain (100) per stage
- Full isolation in all 6 degrees-of-freedom (DOFs)
- A preliminary stage
  - Intended to bring laboratory noise down to the level of a quiet site
  - In air, having a draft shield
  - Optical imaging readouts (1×10^{-11} m/$\sqrt{\text{Hz}}$, 1-30 Hz)
  - 2 DOF seismometers
- Two main stages
  - In vacuum, ~10^{-6} torr
  - Dual imaging and interferometric readouts ($1 \times 10^{-13} f^{-2.5} + 3 \times 10^{-15}$ m/$\sqrt{\text{Hz}}$, 1-30 Hz)
  - Single DOF seismometers

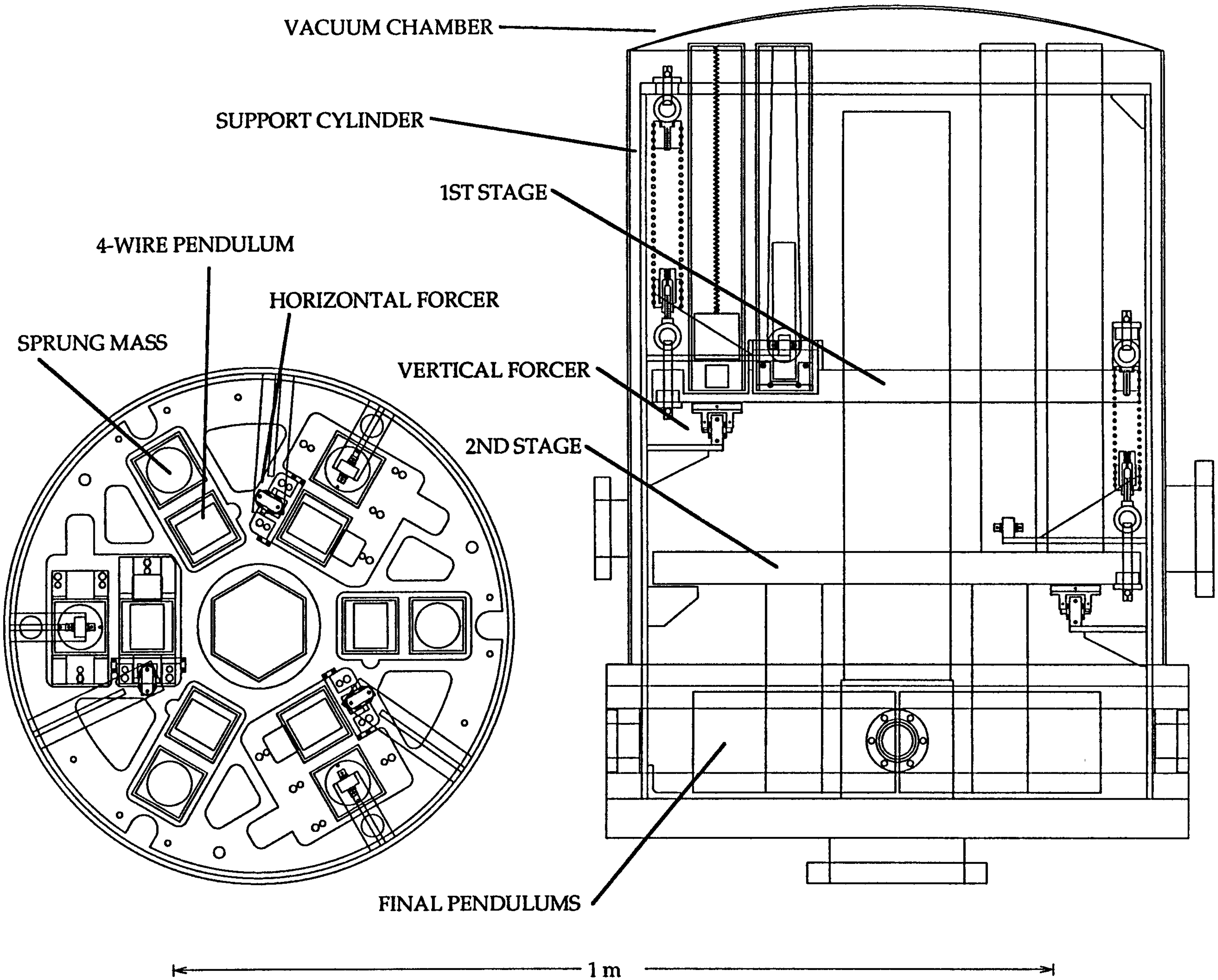


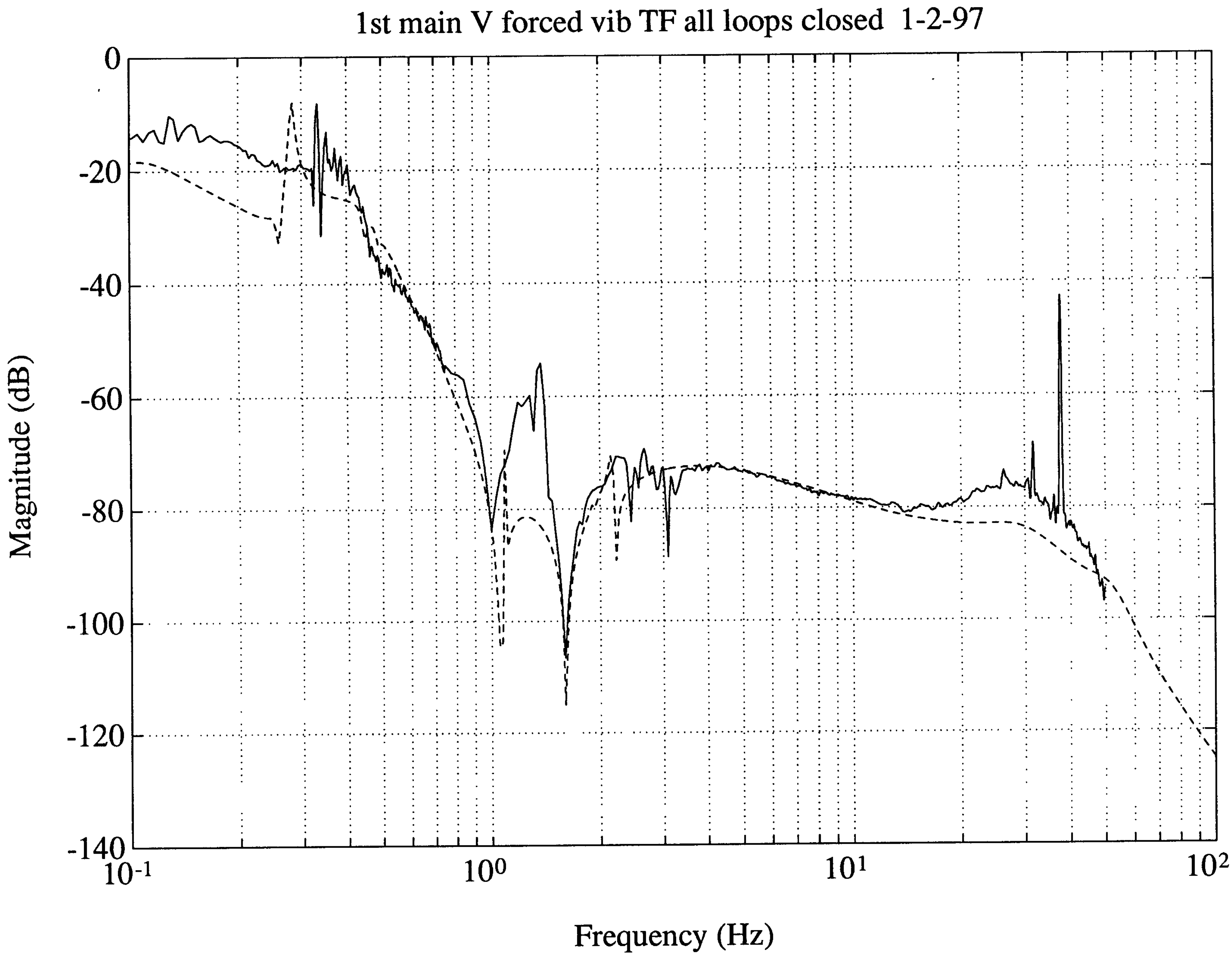
Two axis seismometer with displacement detection.


TOP VIEW
SIDE VIEW (ONE CORNER)
Vertical Support Frame
Two-Axis Seismometers
Voice-Coil Pushers
I-Beam Platform
Circular Table
Support Spring
Voice-Coil Pushers
I-Beam
Support Springs
1m

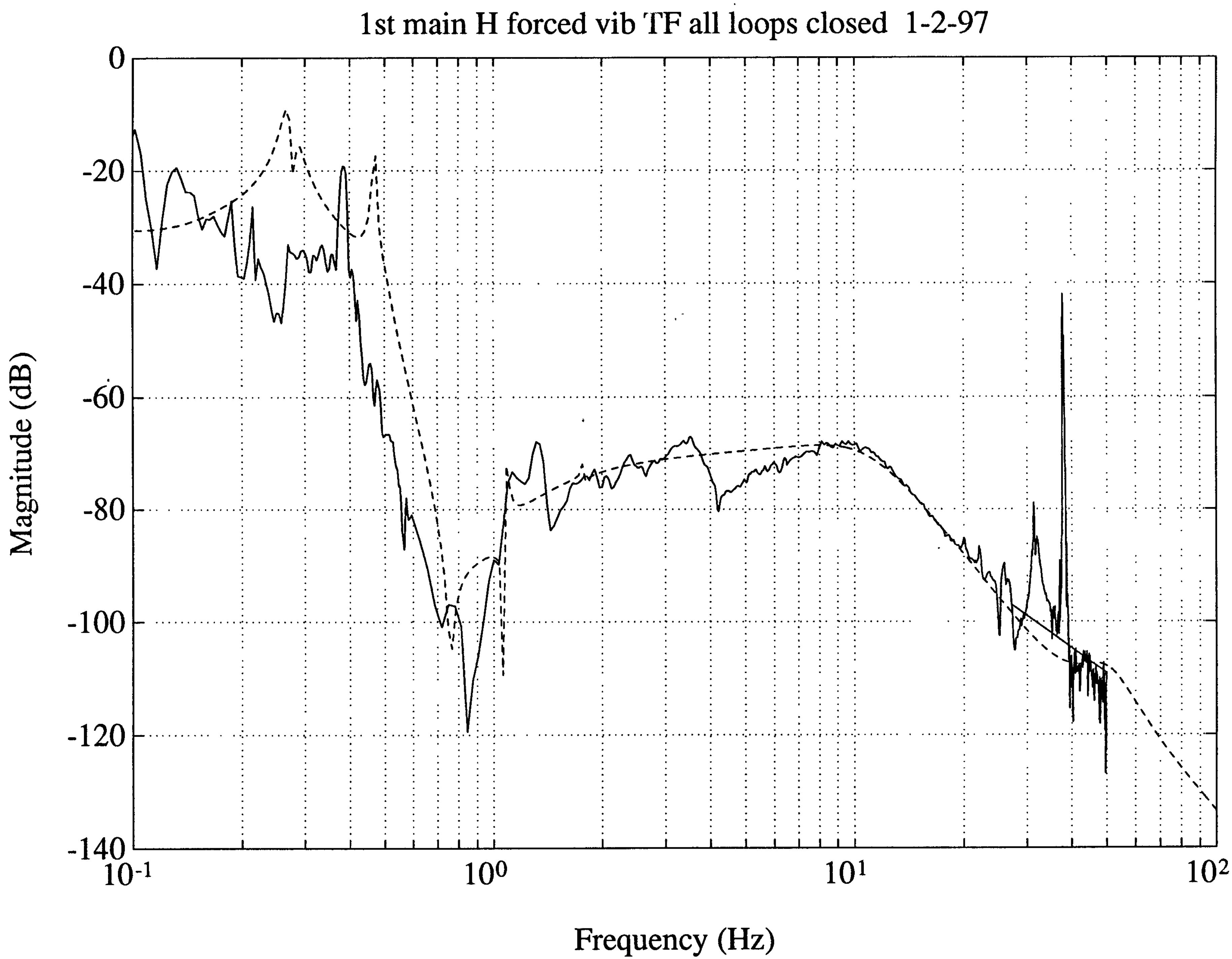


The mechanical layout of the preliminary stage is shown in two views.


VACUUM CHAMBER
SUPPORT CYLINDER
1ST STAGE
4-WIRE PENDULUM
HORIZONTAL FORCER
SPRUNG MASS
VERTICAL FORCER
2ND STAGE
FINAL PENDULUMS
1 m



1st main V forced vib TF all loops closed 1-2-97
Magnitude (dB)
Frequency (Hz)
0
-20
-40
-60
-80
-100
-120
-140
10^{-1}
10^{0}
10^{1}
10^{2}



1st main H forced vib TF all loops closed 1-2-97
Magnitude (dB)
Frequency (Hz)
0
-20
-40
-60
-80
-100
-120
-140
10-1
10^0
10^1
10^2

Overview of Proposed Work

- Definition of requirements
- Conceptual design
- Numerical modeling
- Development of technological improvements
- Detailed design
- Final product: design with sufficient detail to generate accurate estimates of construction cost
- Active partners: LIGO, GEO, Stanford

Definition of Requirements (LIGO, GEO and Stanford)

- Goals of the testing campaign
- Mechanical requirements of testbed(s), for testbed(s), payloads
- Vacuum requirements: contamination, optical and electrical feedthroughs
- Control system compatibility, simulator merge
- Interaction with advanced suspension development and advanced interferometry

Conceptual Design

- Geometry
- Adaptability to testbeds
- Input parameters (e.g., masses and dimensions) to numerical model

Modeling of Scaled Prototype Design

- Adapt current model with dimensions and masses
- Design control loop compensation
- Examine performance
- Iterate with interferometer models
- Relation to full-scale isolation system model to be developed under the current proposal.

Technology Development

- What the technology demonstrator lacks: robustness, automation, practical design for gravitational wave interferometer.
- Vacuum requirements: eliminate brass, plastic parts in fiber optic assembly, coil in forcers, revise cleaning techniques.
- Reduction of manual alignment: position sensor/ seismometer servo loops, modified seismometer suspensions, remote alignment.
- Digital control
- MIMO servos
- Other servo improvements: feed-forward, system ID [new]

Detailed Design

- Mechanical components of platforms and suspensions
- Electronic, mechanical and optical components of the control systems.
- Materials and fabrication methods
- Construction drawings and parts lists for costing

Summary

- Design a scaled prototype
- Roadmap for development of advanced isolation technology
- Initial phase of a program leading to advanced detectors