LOW-FREQUENCY OPERATION OF INTERFEROMETERS - RECENT DEVELOPMENTS AND EXPERIMENTS WITH COUPLED SUSPENSIONS

CEGG

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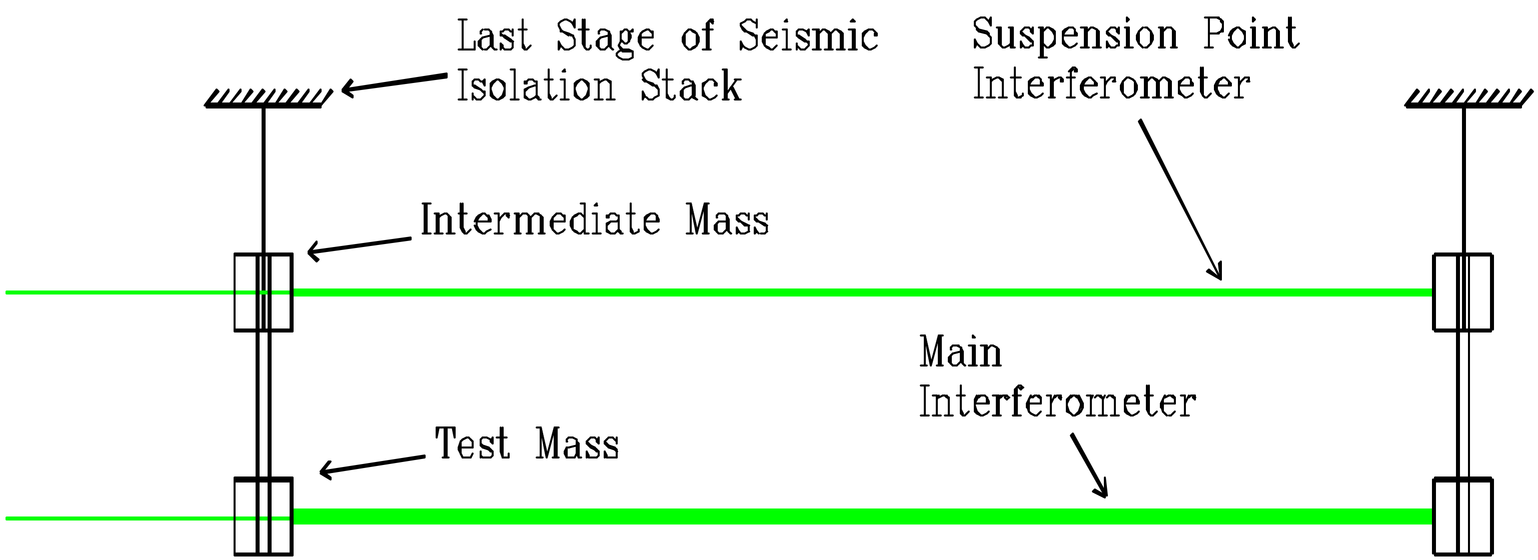
The Coupled – Suspension Technique

APPLICATION TO DOUBLE (OR TRIPLE) PENDULUM SYSTEM

Principle: Feedback forces applied to upper and lower masses keep distances constant. Forces induced by gravity waves and/or gravity gradients may be measured down to zero frequency, in principle.



Aims.

1. Develop and test techniques for extending gravity-wave experiments to lower frequencies.

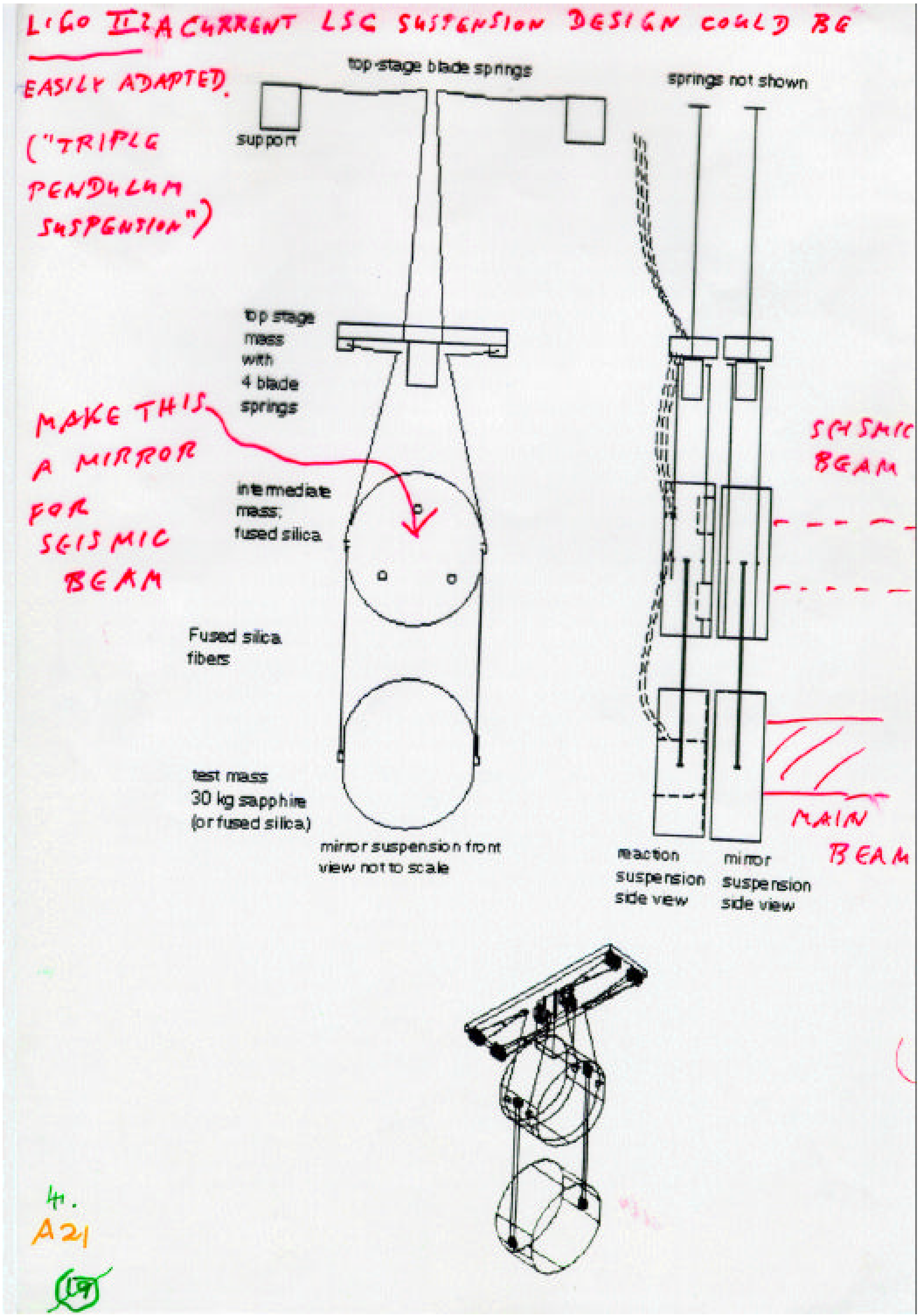
2. Help assess usefulness and feasibility as add-on to a future LIGO.

3. Make measurements of gravity-gradient background to find real limits to G.W. observations and open future possibilities to beat these limits.

4. Explore possible other applications of the techniques (e.g. geophysics, ground motions in earthquakes….)

An effort to push back a frontier limiting terrestrial gravity experiments.

In part Short-term aims (LIGO upgrades)
In part Longer-term aims (will be even more important when thermal noise is smaller, such as in future cryogenic interferometers).



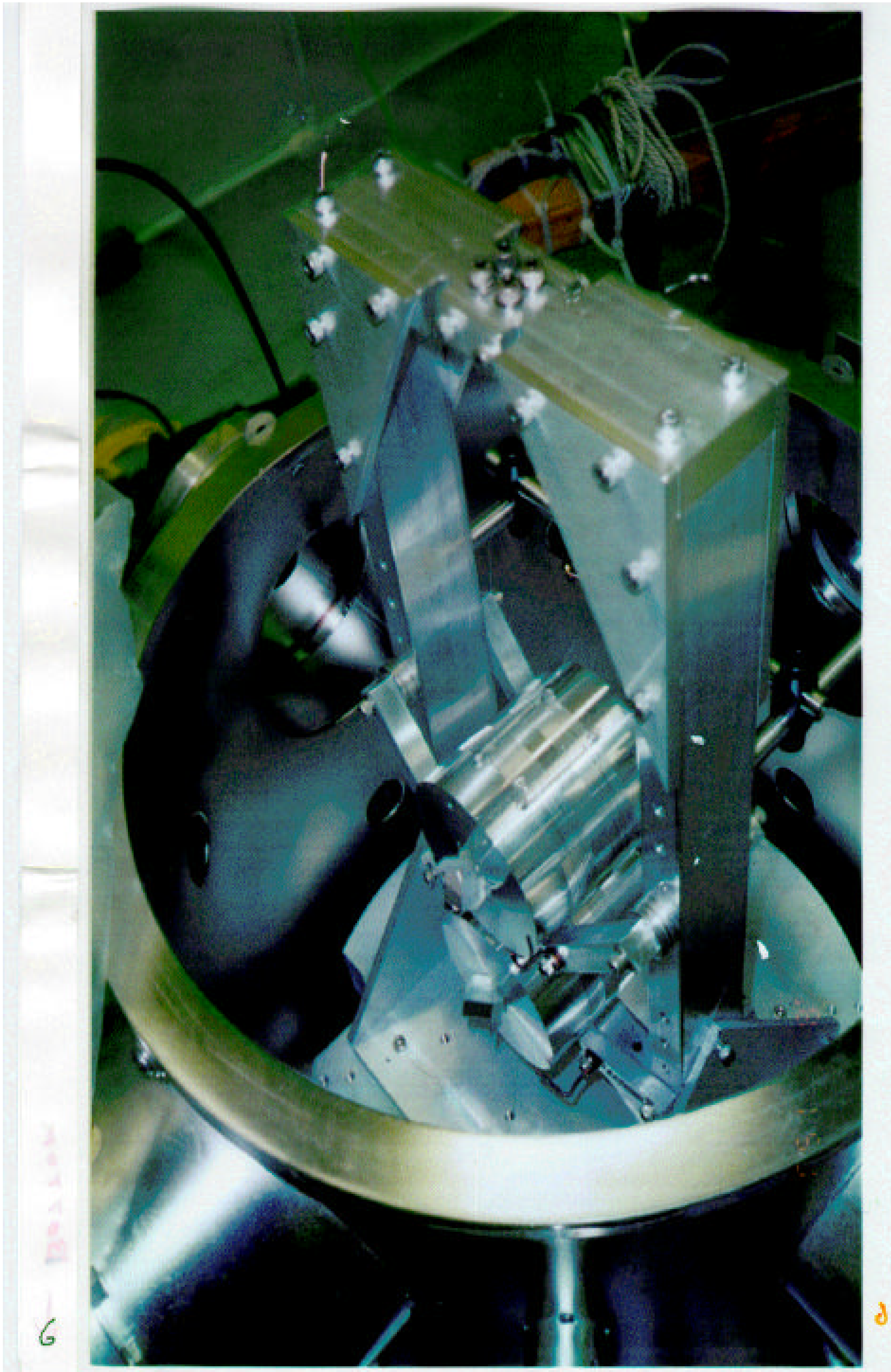
Based on Fig. 2 of the LIGO Report "Strawman LIGO II Design" by D.Shoemaker, K. Strain, and E. Gustafson, (July 9, 1999), with hand-written additions in red.)

Initial Tests: Simplest possible setup:
1 arm. 1 Bounce Michelsons. (o.k.< 0.1 Hz) corner cube reflectors – no angular control installed so far, laser stabilized to atomic line.

Findings: First order as expected. See several signals from small nearby earthquakes, magnitudes 2 to 3), probably from the local ground disturbance.

Puzzles: Observe a 24 hour signal – partly correlated with temperature. Also variations in background noise at frequencies around 0.01 Hz.

First Addition: Pipe length control by interferometrically controlled heating of part of pipe (using upper beam). Operation was improved, but the puzzles persisted.

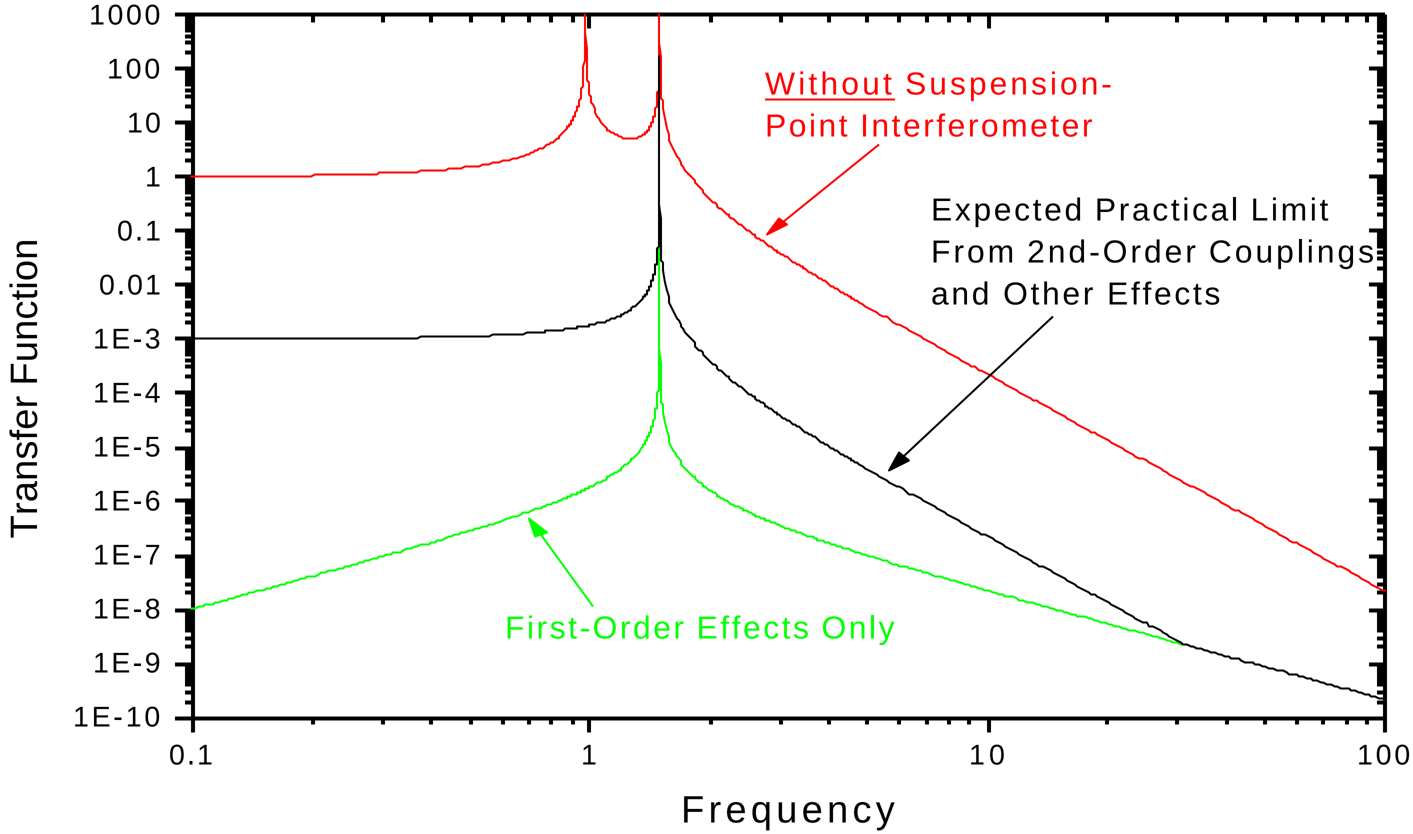


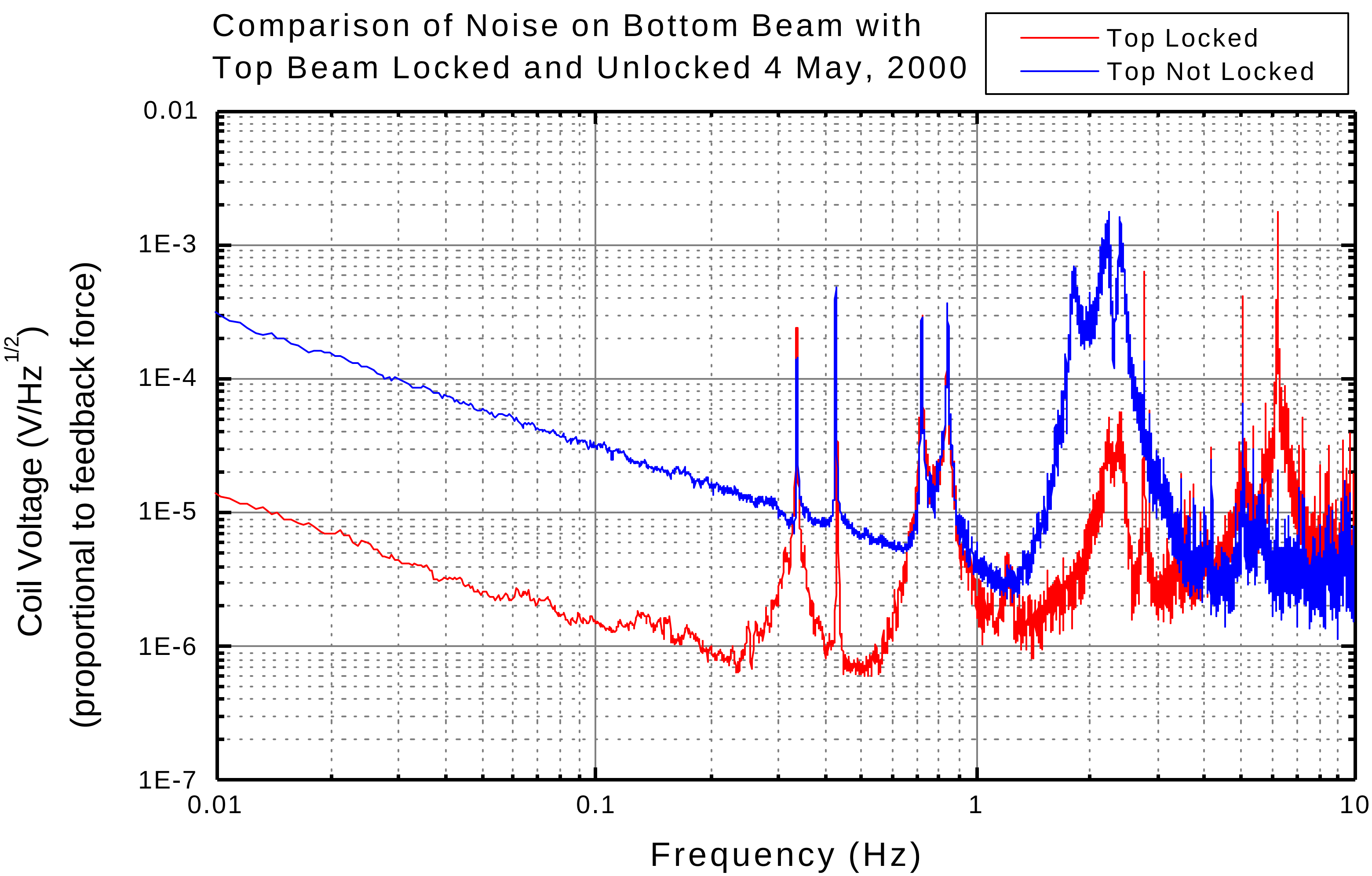
A12 ↖ PRESENT LEVITATED SYSTEMS IN SOUTH TANK

Coupled – suspension tests in west arm.
(at right side of photo)

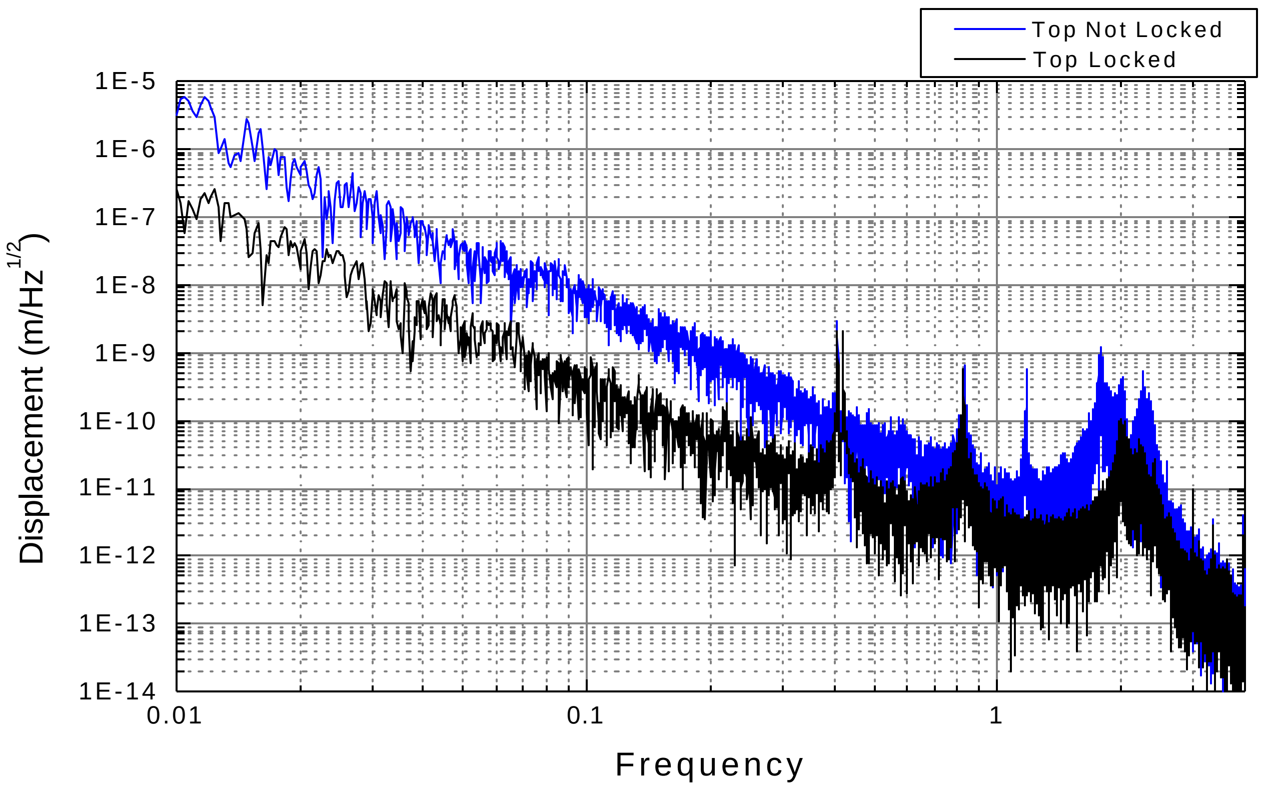
Estimated differential transfer function from suspension-points of second-last pendulums to final test masses

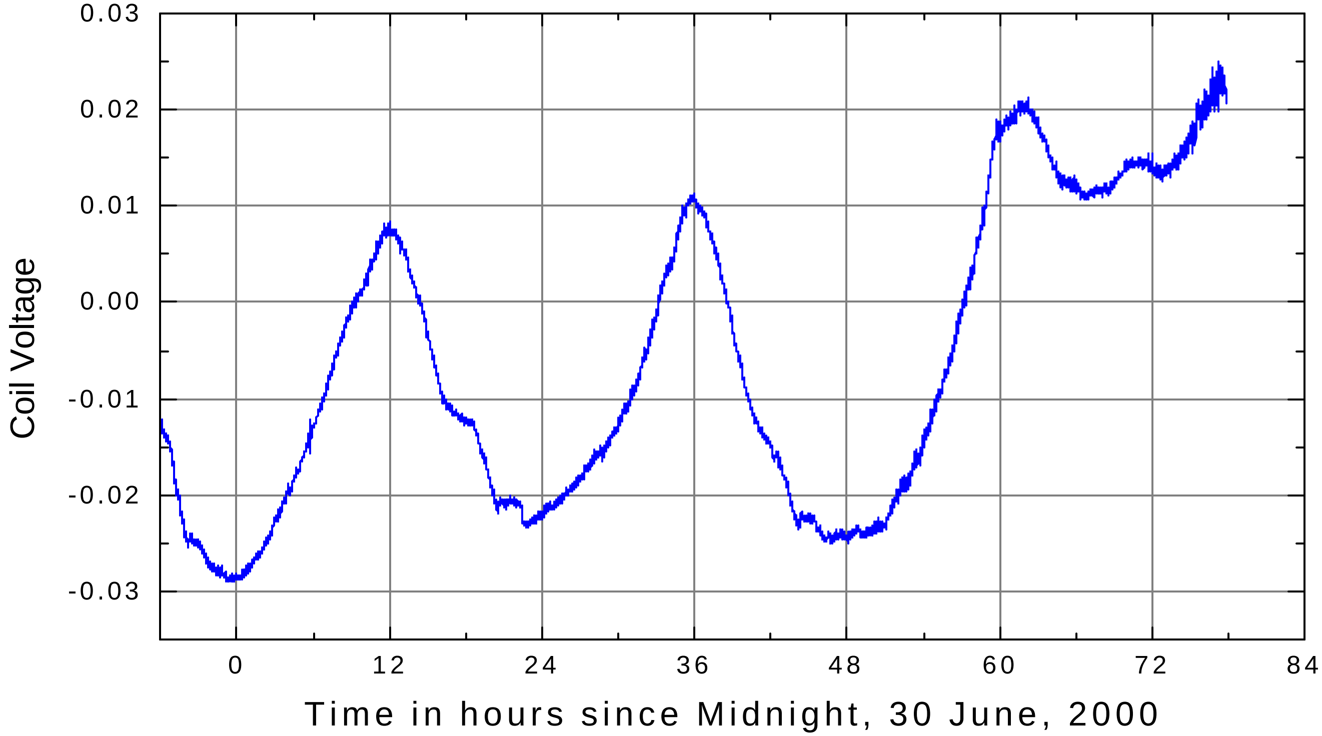
(test mass feedback turned off)



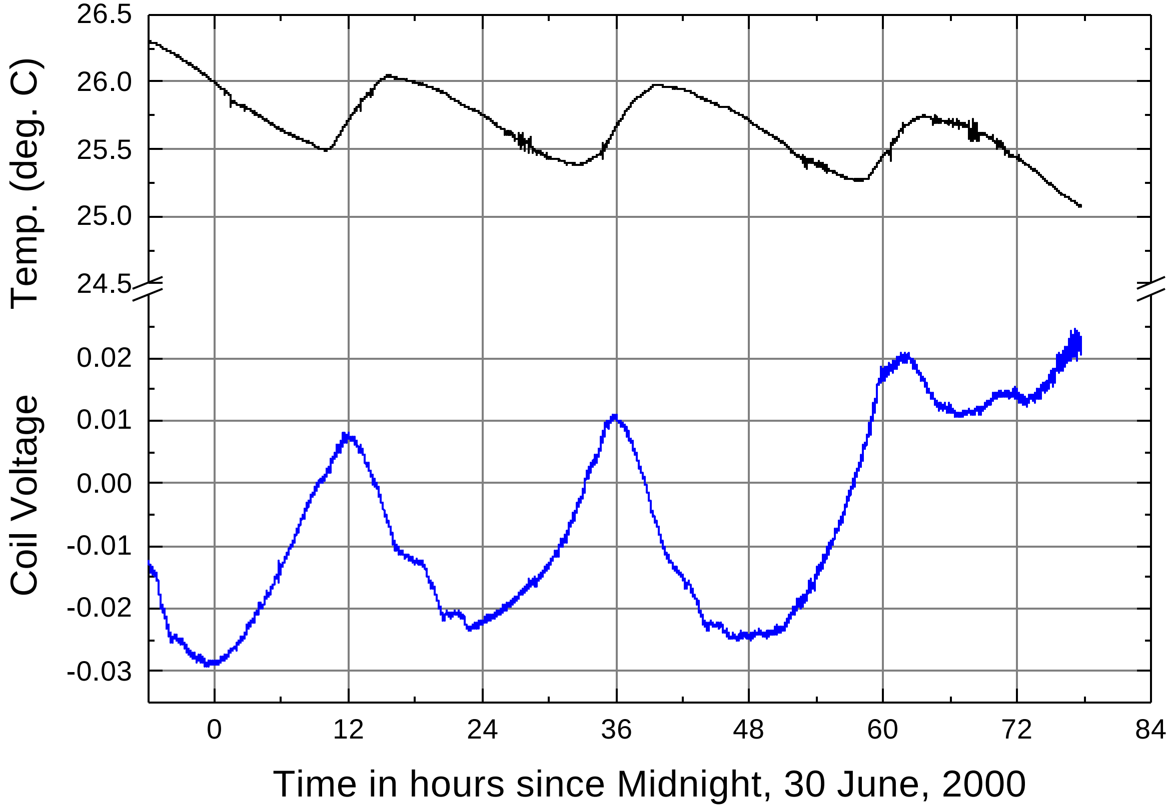

Comparison of Noise on Bottom Beam with
Top Beam Locked and Unlocked 4 May, 2000
Top Locked
Top Not Locked
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
0.01
0.1
1
10
Coil Voltage (V/Hz^1/2)
(proportional to feedback force)
Frequency (Hz)

Calculated equivalent differential motion of free test masses corresponding to the feedback forces measured in one set of test runs.
July 17, 2000





(A long holiday weekend – for 4th of July)
(Unusually quiet period)


26.5
26.0
25.5
25.0
24.5
Temp. (deg. C)
0.02
0.01
0.00
-0.01
-0.02
-0.03
Coil Voltage
0
12
24
36
48
60
72
84
Time in hours since Midnight, 30 June, 2000

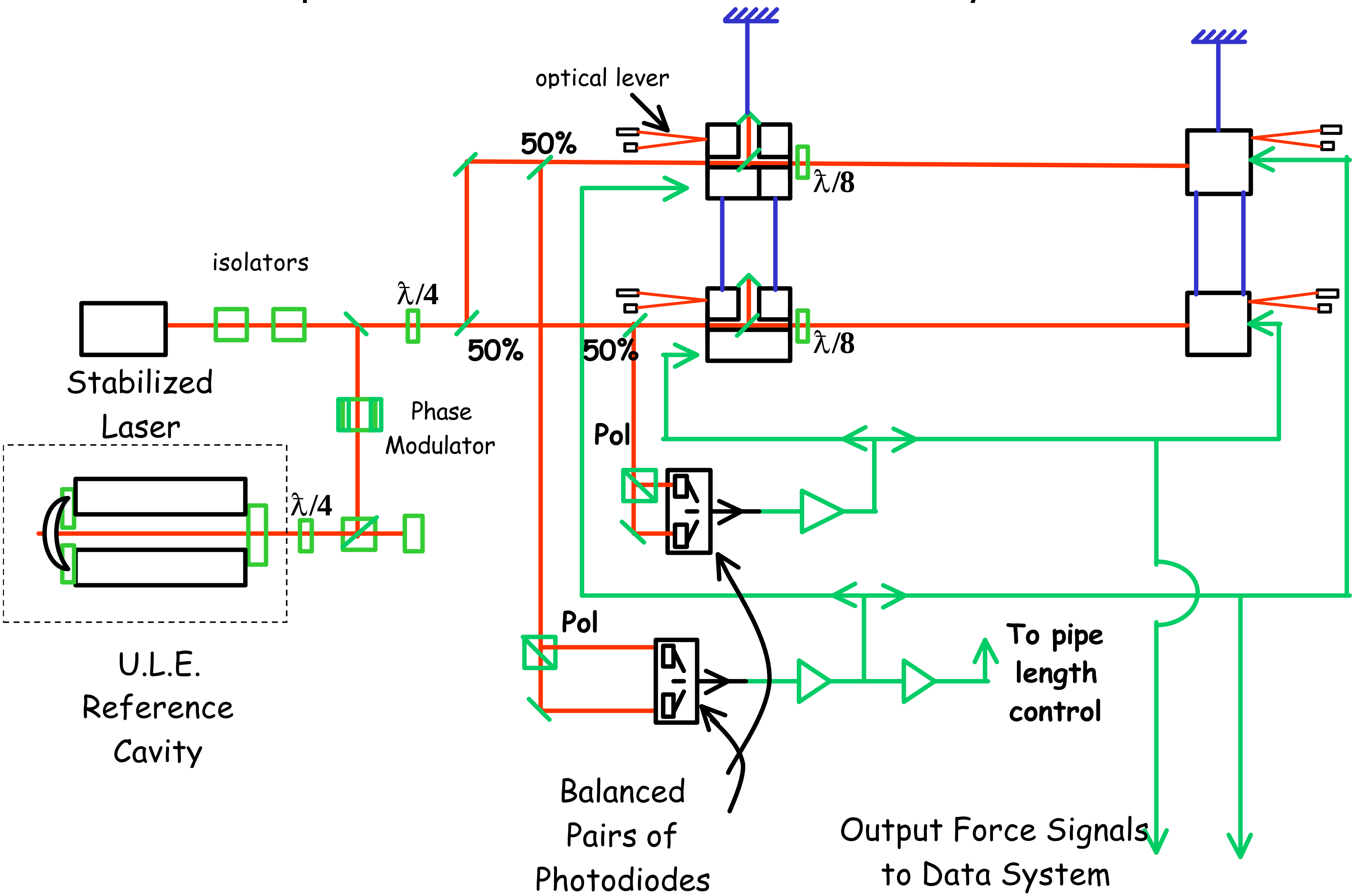
RECENT ADDITIONS To help understand these preliminary findings.

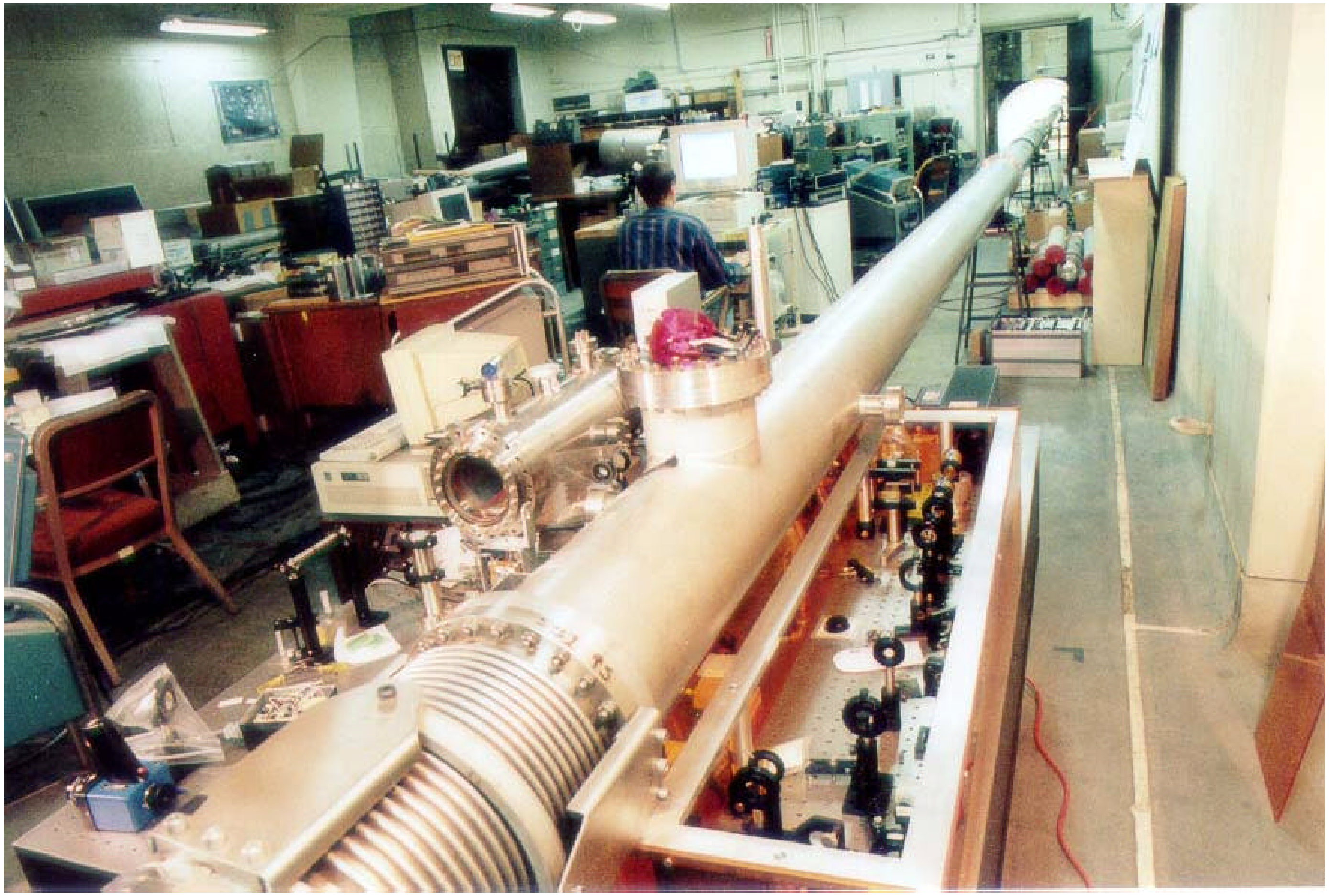
1. Add ULE reference cavity to check laser frequency changes.

2. Add optical levers to lower masses and use 4 magnet/coil pushers for each mass.
(Found that feedback forces cause rotations)

Add (last week) feedback rotation and tilt control to lower masses.

Simplified Schematic of Current Test System





Recent photograph showing chamber for ULE reference cavity being set up.

NOTES:

1. Below ~ 100Hz – The record of feedback forces is generally more useful than residual mass motions.

2. Factors which make interferometer operation more difficult at low frequencies include:

   Test mass angular controls must operate in the signal frequency region, so their forces form part of the signal, and low noise is important;

   Temperature effects are important;

   Seismic noise, including tilts, is large.

3. Planned steps:

   Replace corner cubes by cavities, with the required orientation controls, to bring higher frequencies within range;

   Replace the stabilized HeNe laser by a doubled-frequency Nd:YAG laser.

Use as a Testbed for Proposed GGG Actuators

As reported earlier, GGG is a high-Q paramagnetic crystal and potentially useful for quiet actuators in advanced interferometers. This low-frequency system may be a useful testbed for this technique.

OVERALL CONCLUSIONS SO FAR

This initial test system does operate down to <1mHz.

Further development – for angular controls and other missing features – is in progress.

It seems too early yet to propose for LIGO – but looks promising.