Low-Frequency Operation of Interferometers - Potential for LIGO and First Tests with Coupled Suspensions

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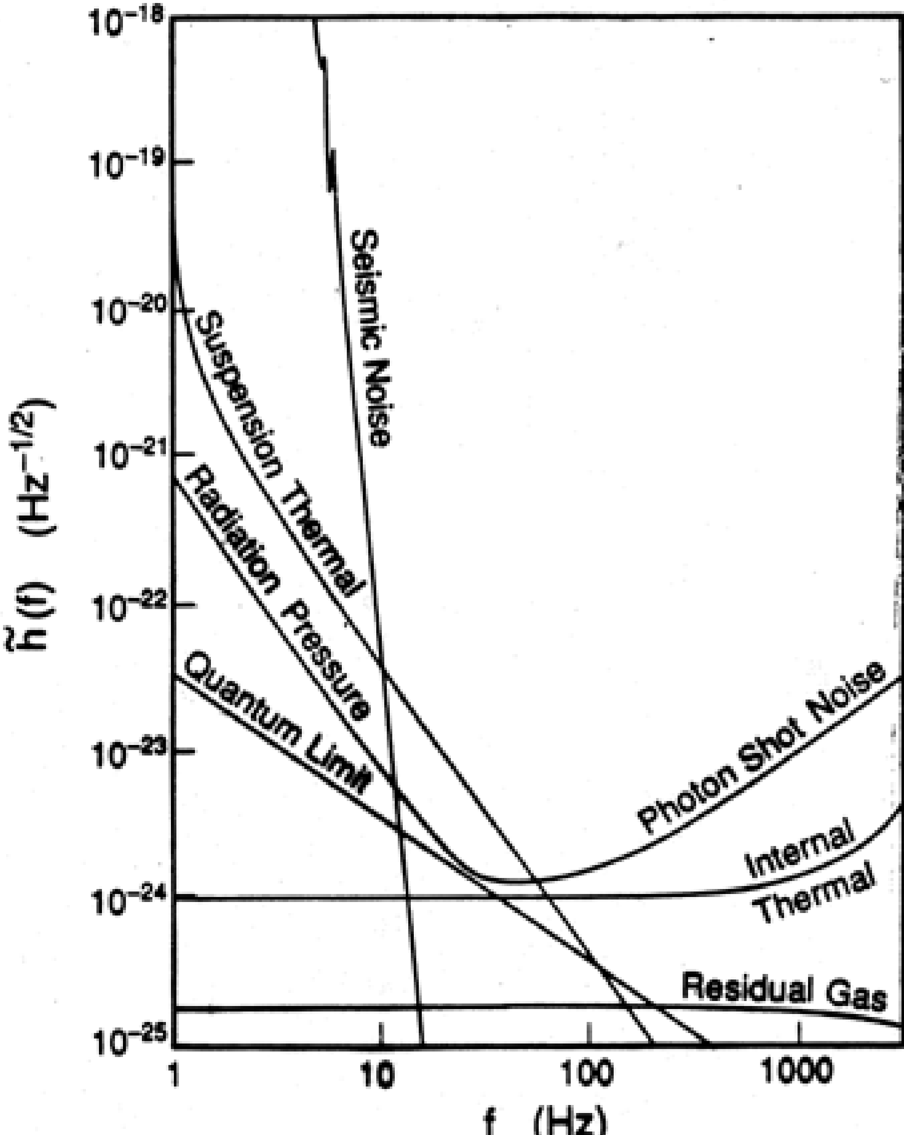
With Valuable Assistance from Steve Vass

Aspen, February 23, 2000

LIGO-G000423-00-I



10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
$\tilde{h}(f)$ $(Hz^{-1/2})$
Seismic Noise
Suspension Thermal
Radiation Pressure
Quantum Limit
Photon Shot Noise
Internal Thermal
Residual Gas
1
10
100
1000
f (Hz)

Objectives in extending operation to lower frequencies include:

1. We can track chirp signals (NS-NS etc.) over a longer time and frequency range;
   - improve sensitivity for detection;
   - get better data on sources and relativistic effects on chirp waveforms, etc.;
   - possibility of more signals within frequency range;
2. many more pulsars within frequency range (including known ones).

3. Stochastic background searches are improved (particularly with separated sites).

4. In general - much wider searches are possible.

In addition:

-- If could operate at ~1 Hz and lower, new possibilities for gravity gradient measurements can open - relevant to geophysics as well as gravitational waves.

Wire of fiber suspensions - coupled by a suspension-point interferometer

Can operate down to well below 1 Hz - with force feedback to remove the pendulum resonance.

> An old idea - but now see it as a key part of new concepts to extend seismic isolation - and opening new areas for LIGO.

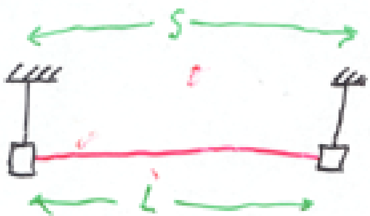
May be the first of a new family of frequency-independent seismic isolation techniques.

POSSIBILITY OF EXTENDING OPERATING RANGE DOWN TO "D.C." (~ 1 cycle / day ?)

– INTO REGION WHERE GRAVITY GRADIENTS ARE MORE IMPORTANT THAN GRAVITATIONAL WAVES.

"SUSPENSION-POINT INTERFEROMETER"

NORMAL SUSPENSION



IF $\delta S > \delta L$ CAN'T MEASURE FORCES CAUSING δL.

BUT – IF MEASURE δS ALSO COULD DO IT

IDEA PROPOSED – USE 2nd INTERFEROMETER FOR THIS.

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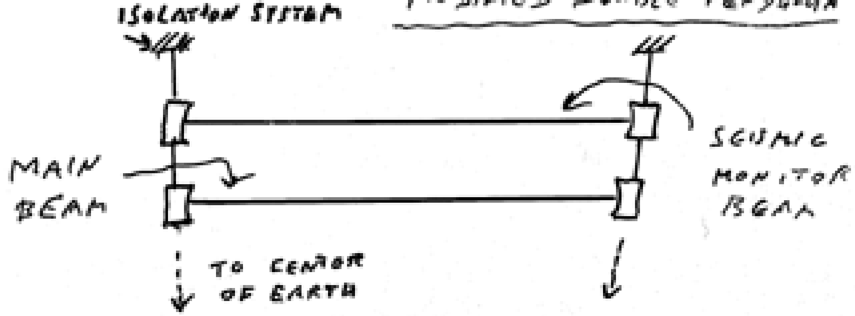
MODIFIED DOUBLE PENDULUM



CLOSED-LOOP OPERATION – LOCK UPPER BEAM TO FIXED LENGTH BY FEEDBACK FORCES

OR/ OPEN-LOOP RECORD UPPER SIGNAL AND CORRECT FOR EFFECT ON LOWER MASSES.

FREQUENCY RANGE: > 10 HZ – SEISMIC NOISE REDUCED $(\sim \frac{1}{100})$

NO LOSS OF SENSITIVITY FOR GRAVITATIONAL WAVES

$\ll 1$ HZ → DOWN

GRAVITY GRADIENT MEASUREMENT (TO THERMAL NOISE LIMIT)

GEOPHYSICS APPLICATIONS ?

MOTION OF EARTH CORE .... ?

GROUND AND ATMOSPHERIC MOTIONS AND DENSITY CHANGES OF VARIOUS KINDS, ETC.

APPLICATION TO DOUBLE (OR TRIPLE) PENDULUM SYSTEM

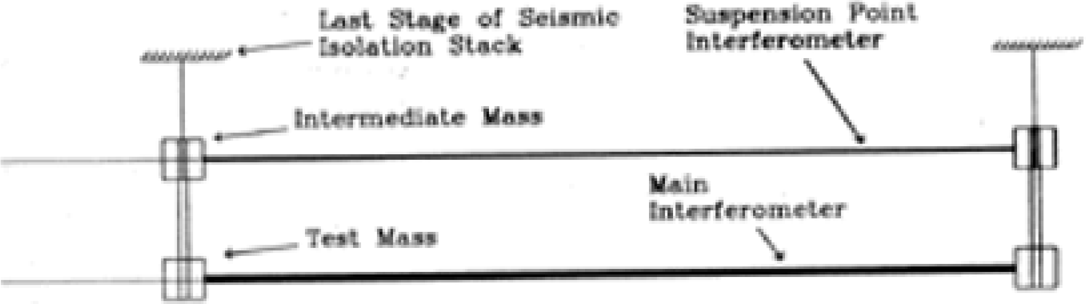
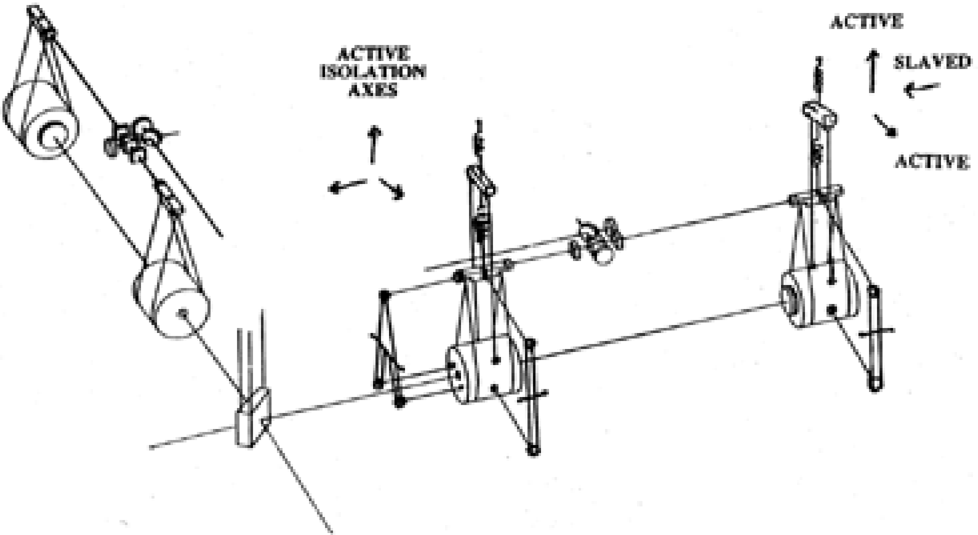


FIGURE 5. Upgrade 2 - Use of an active antiseismic guard system to supplement the slaved seismic isolation system of the Base Model.

(REDUCING 2ND ORDER EFFECTS)



Note: This sketch only illustrates the principle, and the way the various degrees of freedom are controlled in one arm by a combination of the slave and the guard systems. The other arm is arranged in the same way, but is not drawn in here, for simplicity.

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FROM SEPTEMBER 1987 DESIGN FOR A LIGO INTERFEROMETER (LIGO T870001-00-R)

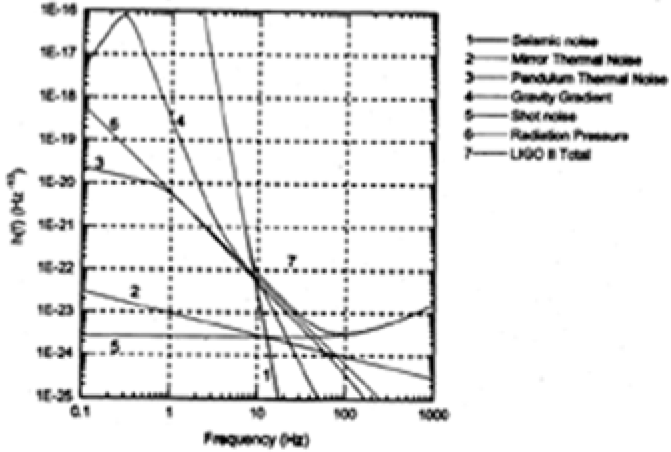


Fig. 4a Predicted contributions to the LIGO II noise spectrum plotted as strain (h).

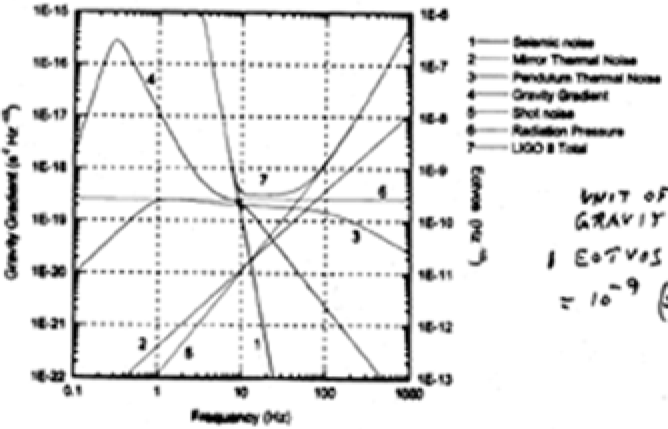


Fig. 5a Predicted contributions to the LIGO II noise spectrum plotted as gravity gradient.

UNIT OF GRAVITY GRADIENT
1 EOTVOS
= 10^{-9} (SEC^{-1})^2

AS

(18)

Plan to test some of this in test interferometers

- Measure gravity gradient background to check estimates of limits for gravitational wave observation (at nighttime - when little traffic);
- run to measure and understand the gravity gradient background - and possibly ways to discriminate against it;
- find what the real problems are.

Preliminary tests with simplest possible interferometer:

-- one long arm -
laser stabilized to atomic line (He-Ne laser);

-- one-bounce unequal-arm Michelson interferometer for upper and lower beams;

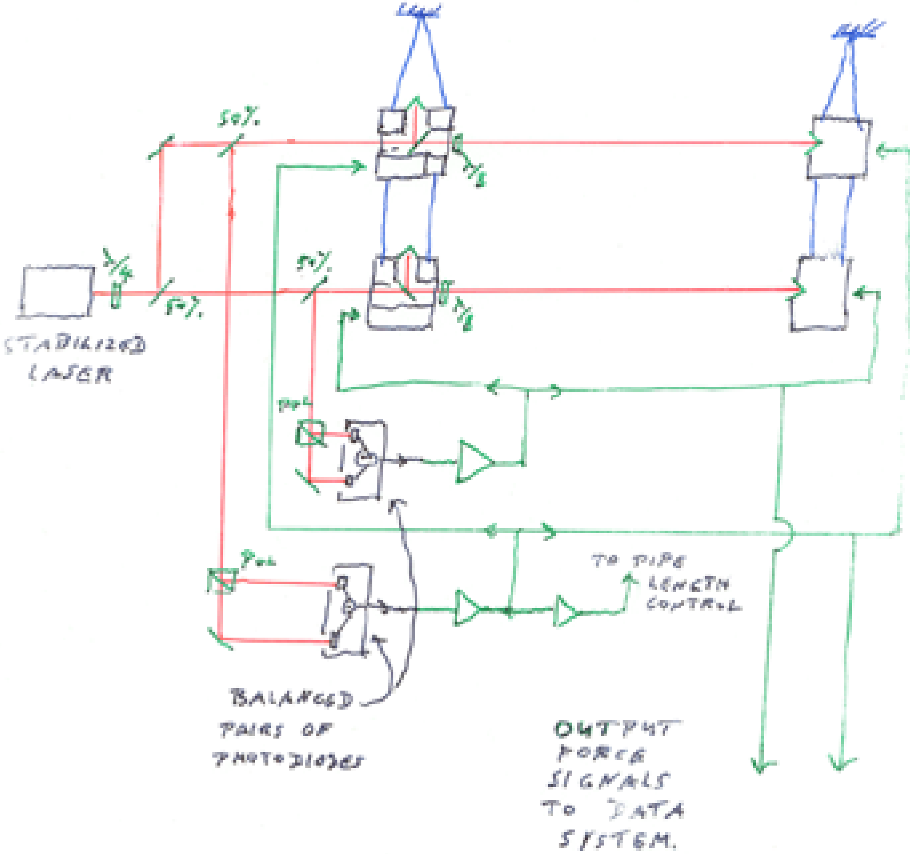
-- initial feedback with coil-magnet systems.

Present Conclusions

- Initial tests are encouraging (no major problems)

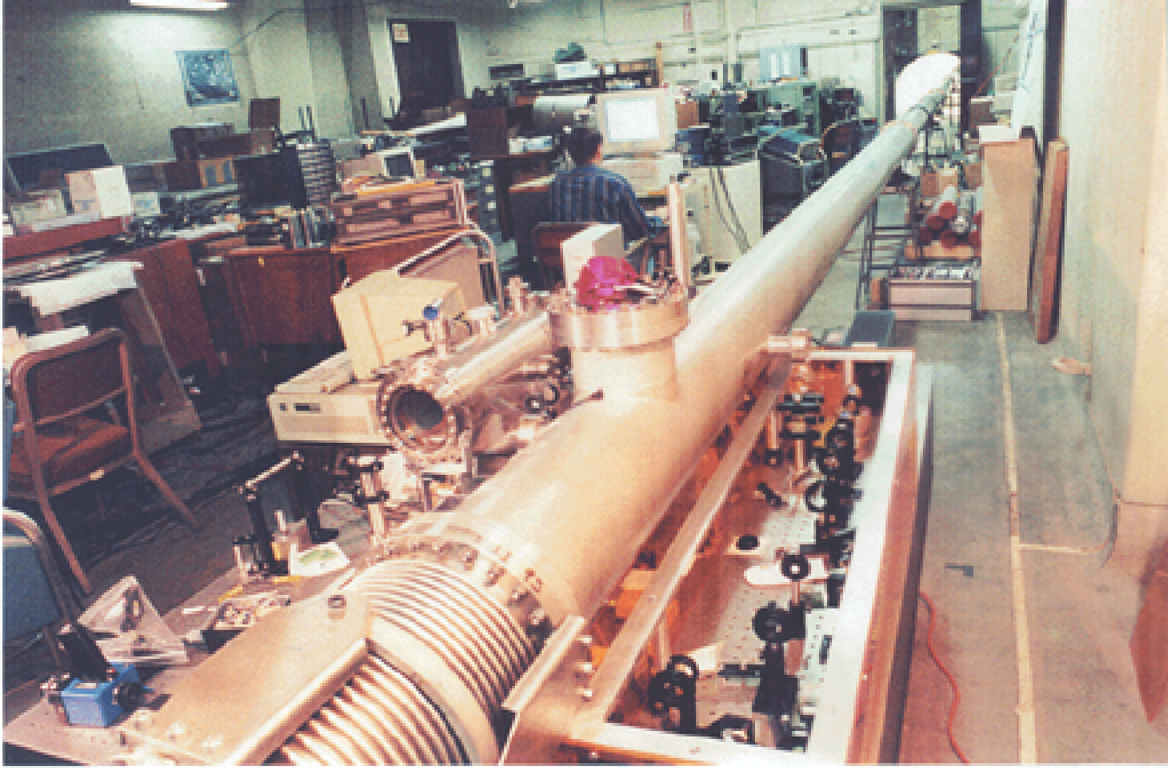
Looks a relatively simple addition to LIGO - with much potential benefit.

SIMPLIFIED SCHEMATIC FOR FIRST PRELIMINARY TESTS



AH

412 ↖ PRESENT LEVITATED SYSTEMS IN SOUTH TANK



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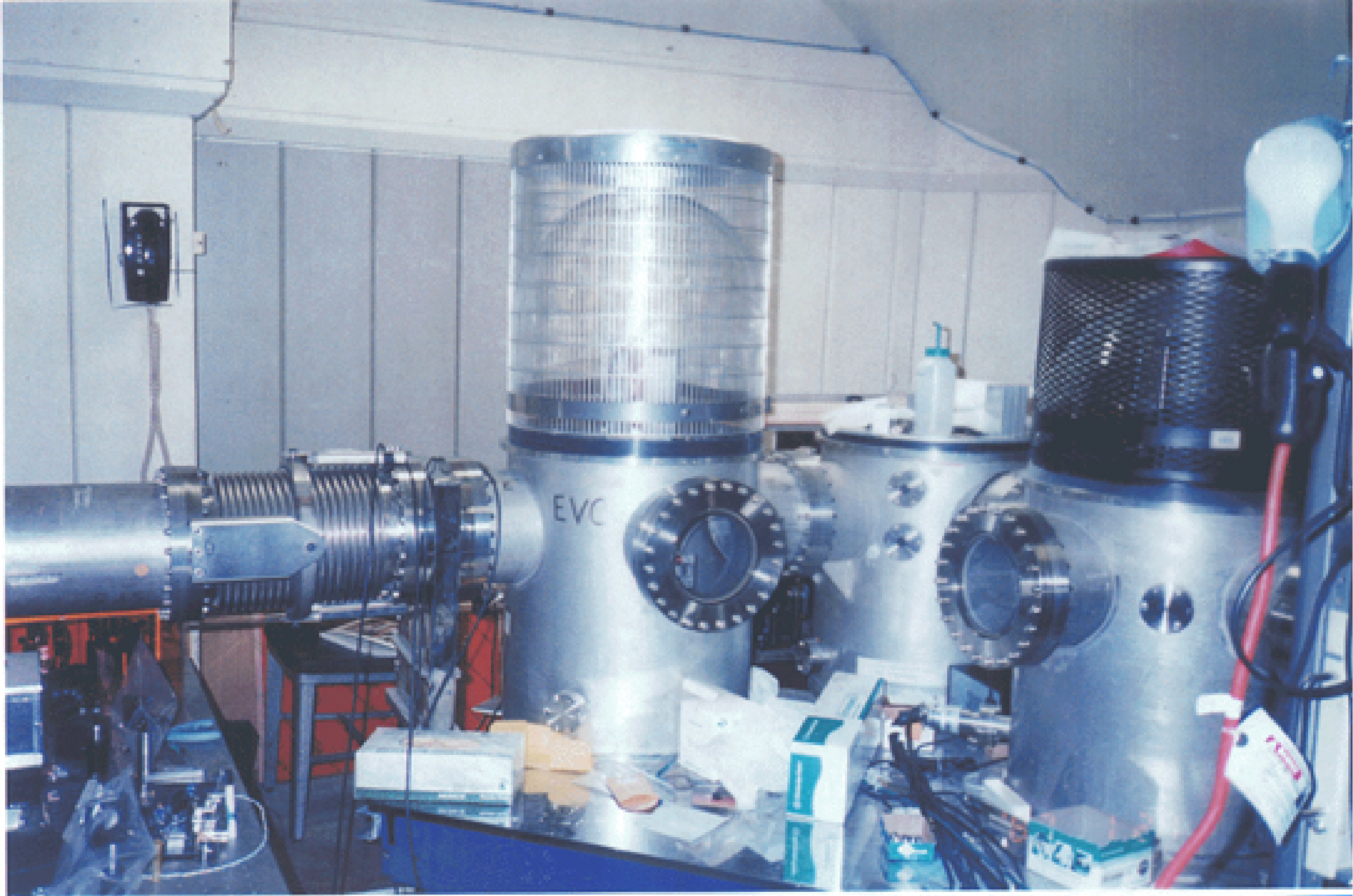
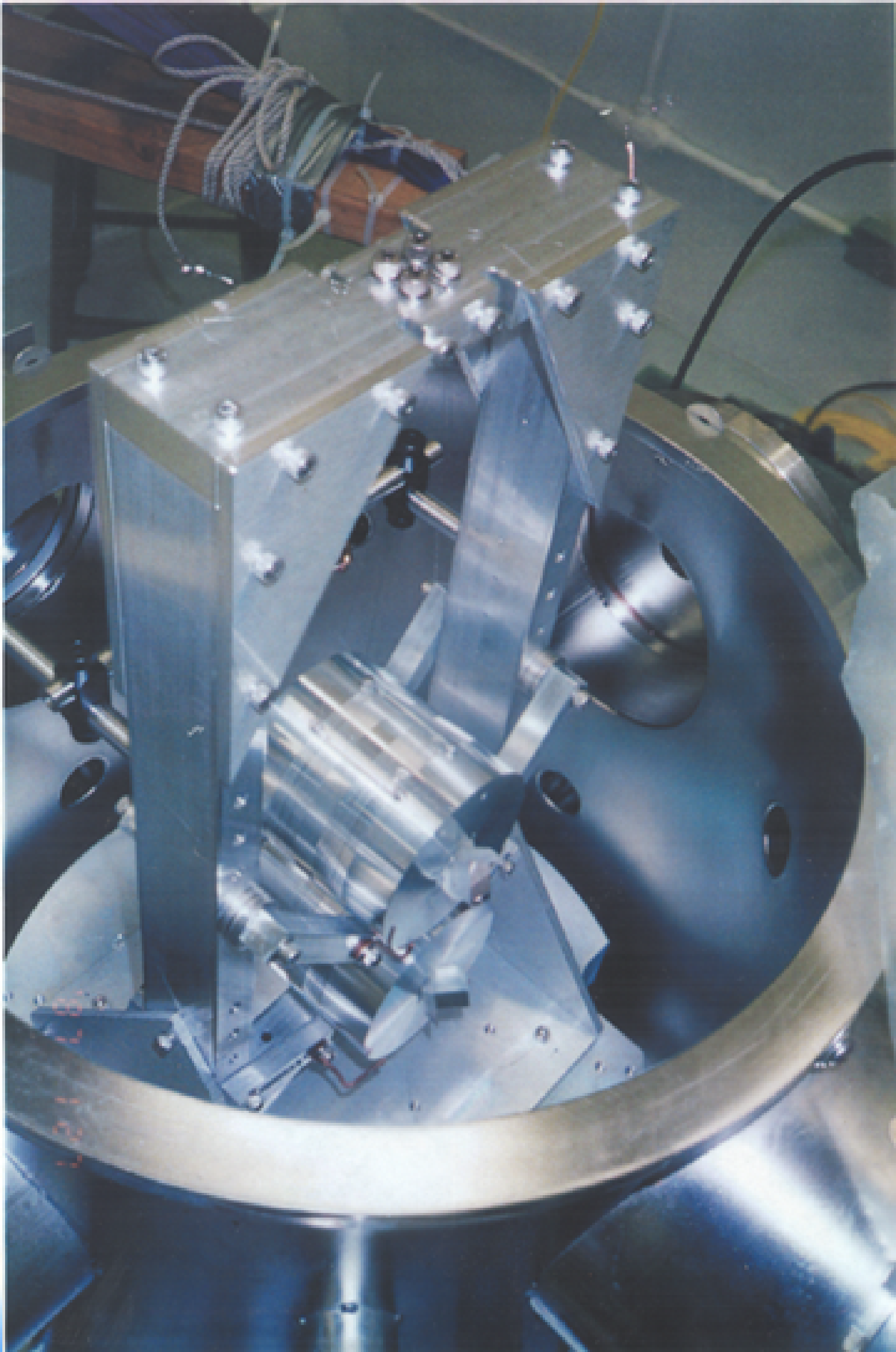
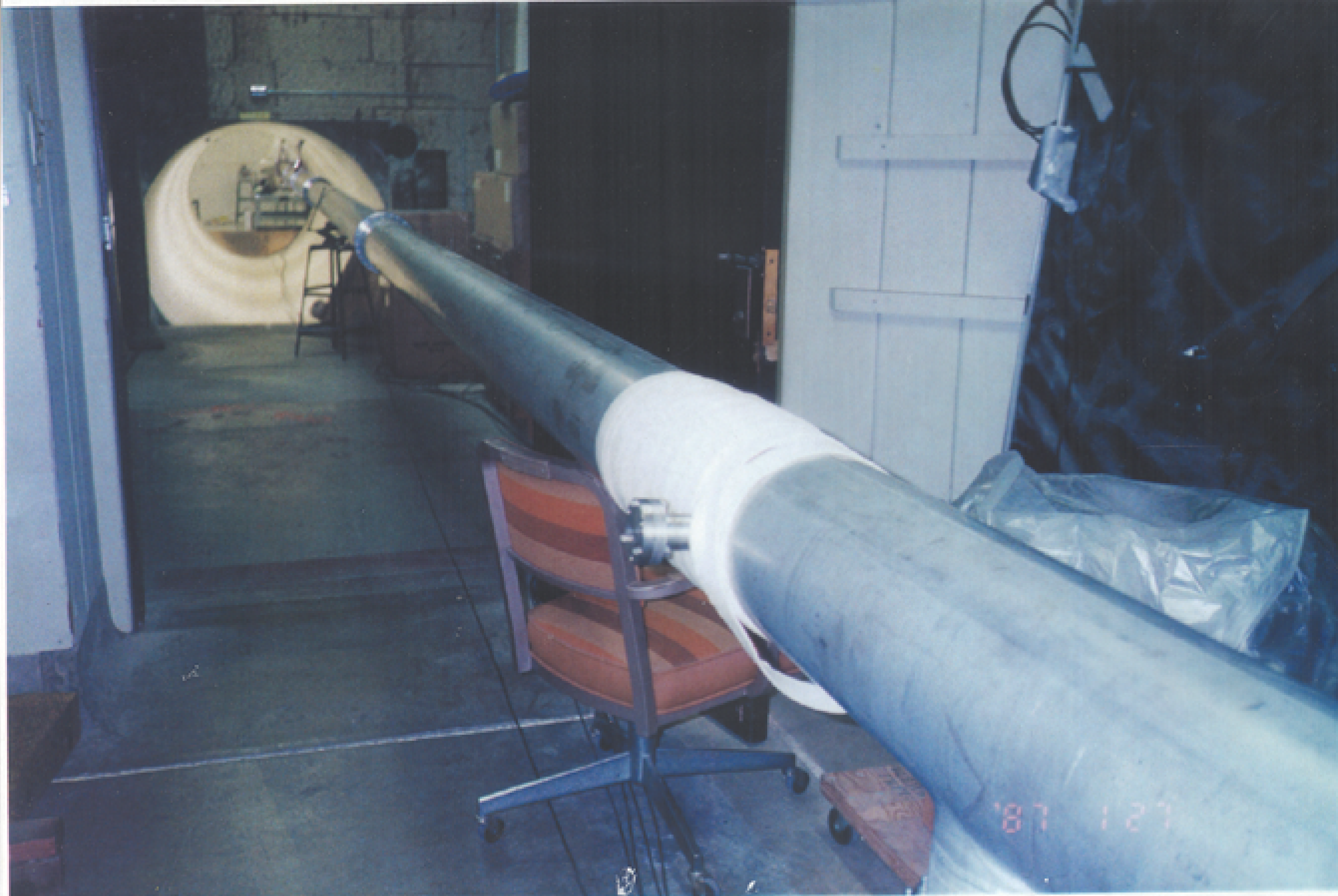

EVC





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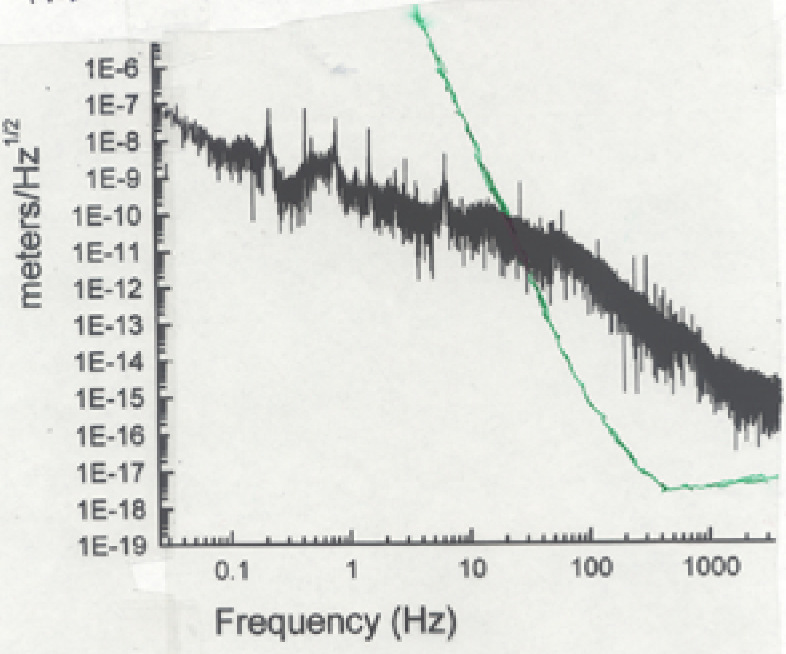
CALCULATED EQUIVALENT DIFFERENTIAL MOTION OF FREE TEST MASSES CORRESPONDING TO THE FEEDBACK FORCES MEASURED IN SYSTEM.



DATA FROM FEBRUARY 16, 2000.
NOW BETTER BY FACTOR ~ 6
(MARCH 14, 2000)

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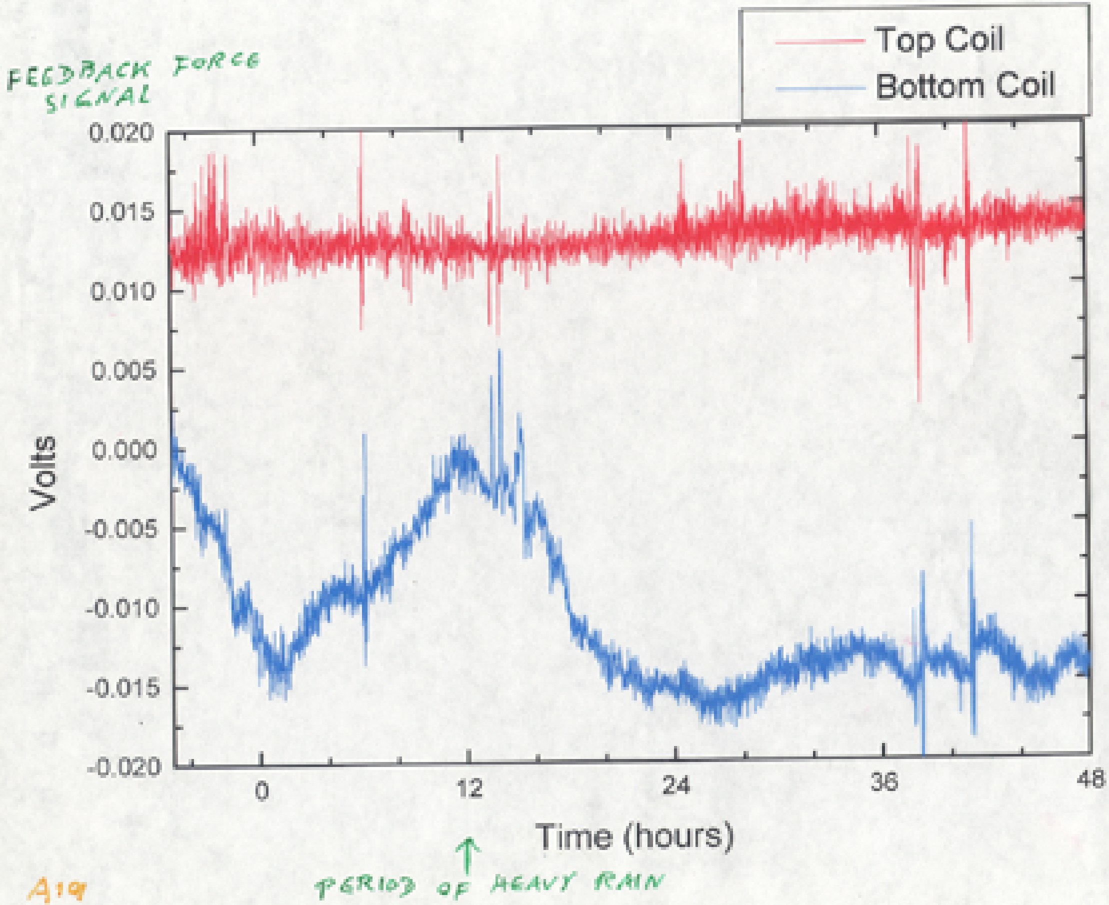
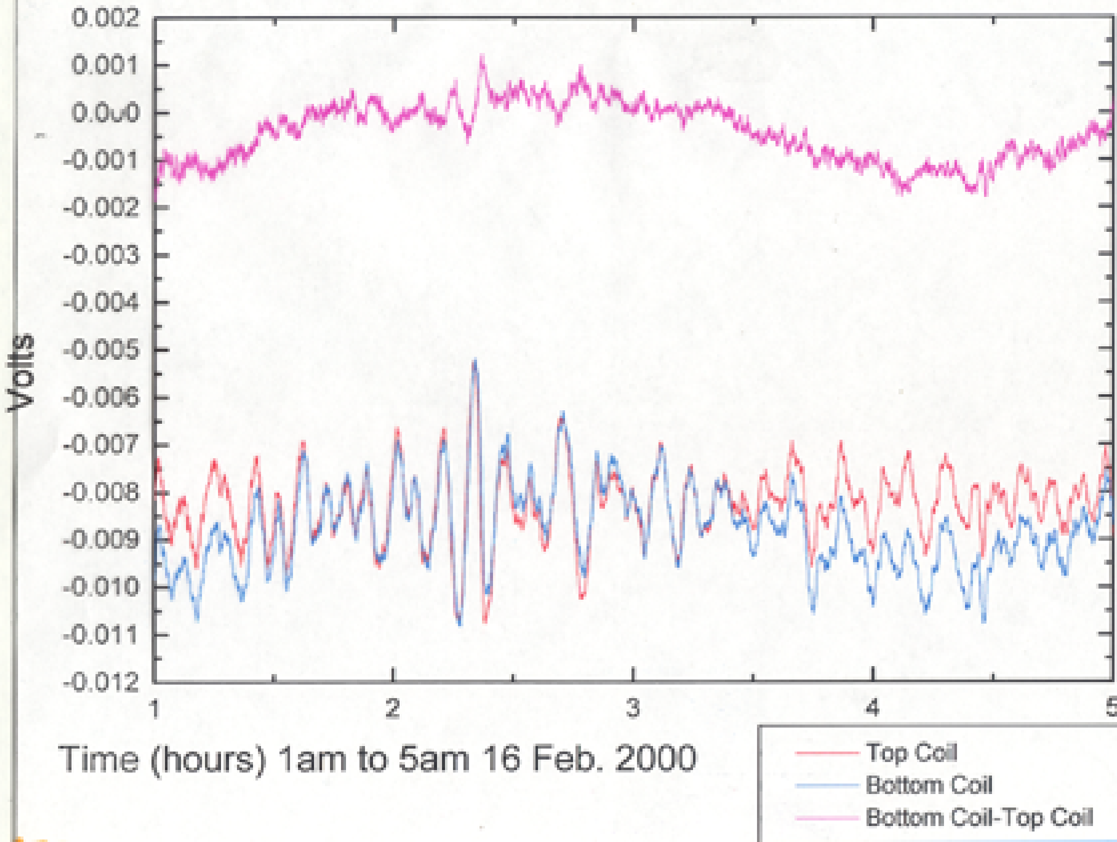

FEEDBACK FORCE SIGNAL
Top Coil
Bottom Coil
Volts
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
0
12
24
36
48
Time (hours)
PERIOD OF HEAVY RAIN
A19



Volts
0.002
0.001
0.000
-0.001
-0.002
-0.003
-0.004
-0.005
-0.006
-0.007
-0.008
-0.009
-0.010
-0.011
-0.012
1
2
3
4
Time (hours) 1am to 5am 16 Feb. 2000
Top Coil
Bottom Coil
Bottom Coil-Top Coil

Update:

Experimental Q Values for Magnetically Levitated Crystals

TGG	(60/40 polish on all surfaces)	Q = 6.0×10^6 at 222.84 kHz
GGG	(unpolished circumference)	Q = 6.7×10^5 at 221.50 kHz
New	(60/40 polish on all surfaces)	Q = 9.7×10^6 at 222.46 kHz

TGG and GGG cylinders: 15 mm diameter × 8 mm long.