Keeping Nanometer Beams Colliding

Vibration Stabilization of the Final Doublet

Tom Himel
SLAC

LCD meeting

November 6, 2001

Contents

- Overview
- Vibration stabilization test system progress
- Motion sensor development
- Future plans

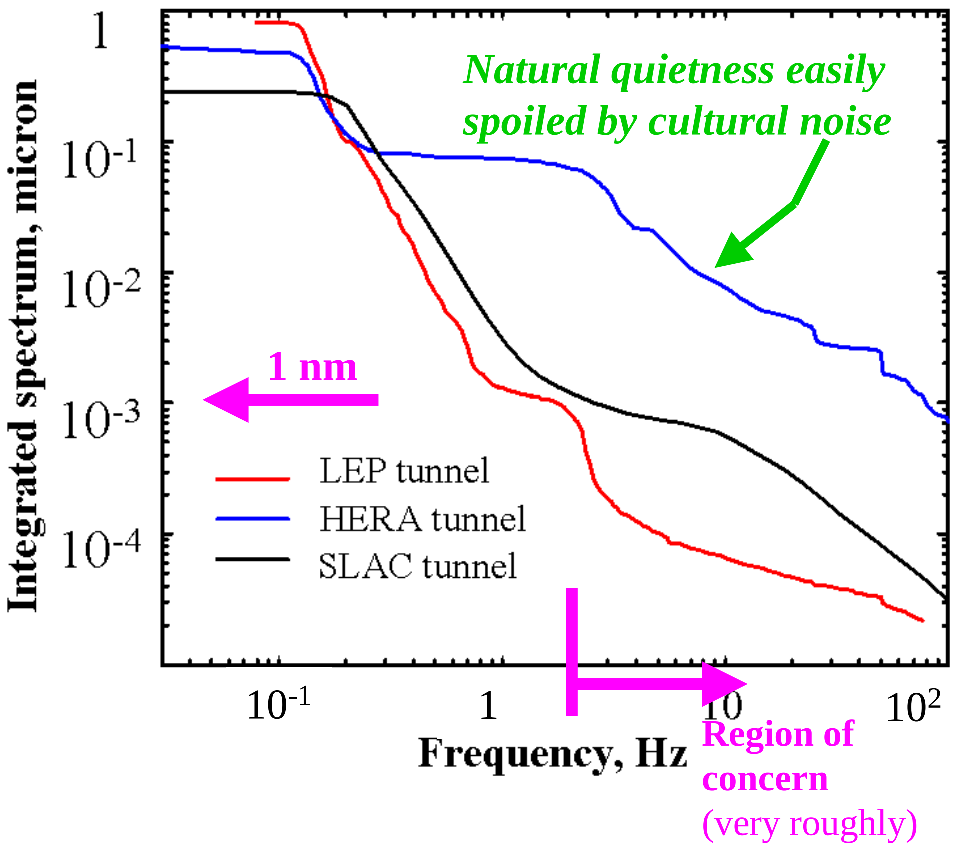
Major Contributors

- Carlos Damien
- Eric Doyle
- Linda Hendrickson
- Tom Himel
- Joe Frisch
- Andrei Seryi
- Steve Smith

Effect of fast motion on the beam
= *produce beam offset at IP*

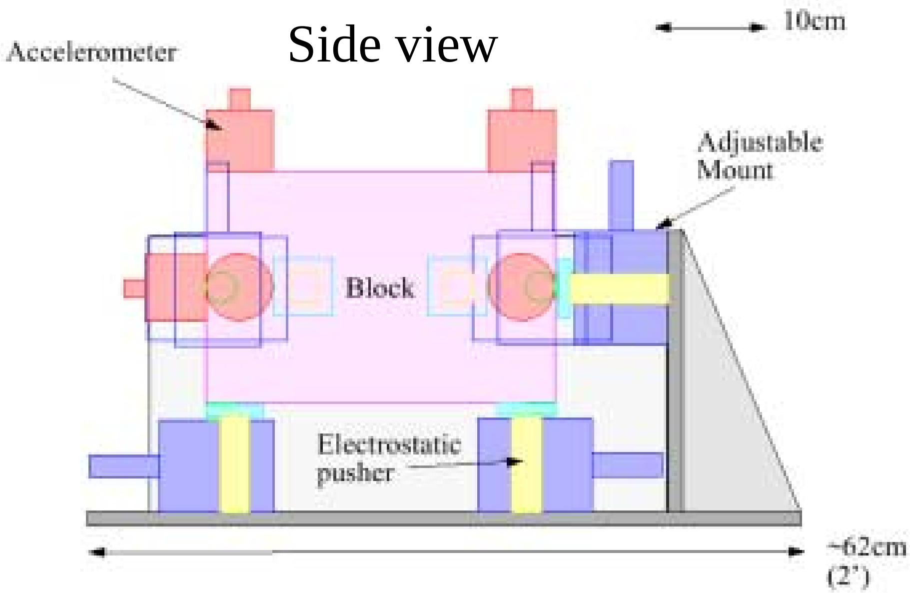
Rough scale of ***jitter*** *tolerances:*

- **Linac quads** (many of them!): tolerance ~ 10nm
  - natural quietness, good girders.
- Some quads in **beam delivery**: tolerance ~ 5-10 nm
  - natural quietness, maybe some active method
- **Final quads**: tolerance ~1/3 IP beam size ~ 1 nm
  - rely on active methods to keep beams colliding

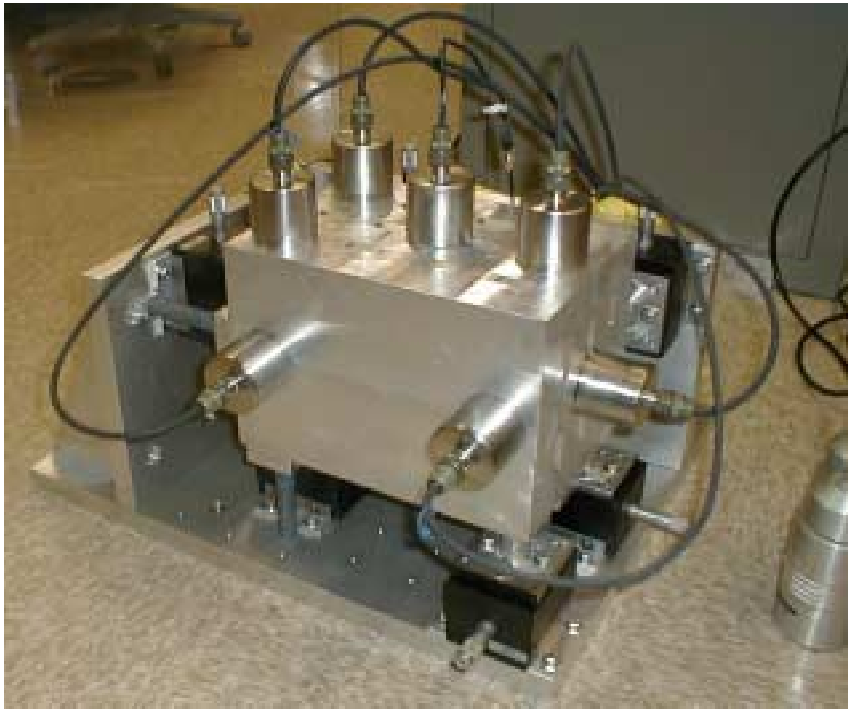


- **Frequency of concern**: above significant beam-based feedback gain ~1Hz

Inertial stabilization R&D at SLAC
one object, 6D, digital feedback

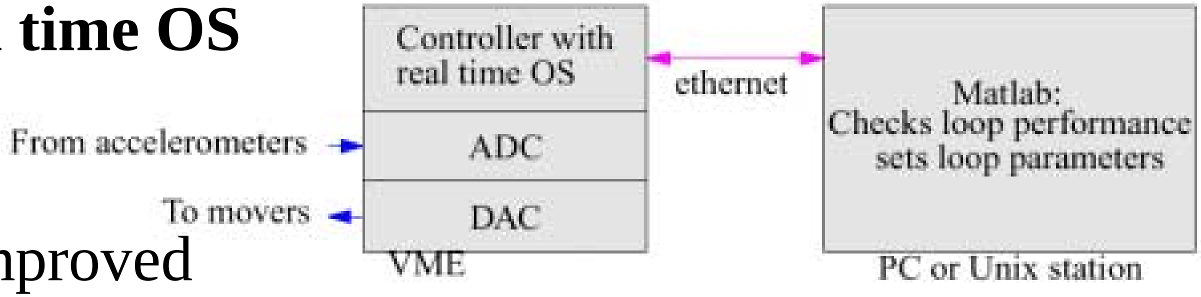


Schematic of the object to be stabilized



Inertial sensors

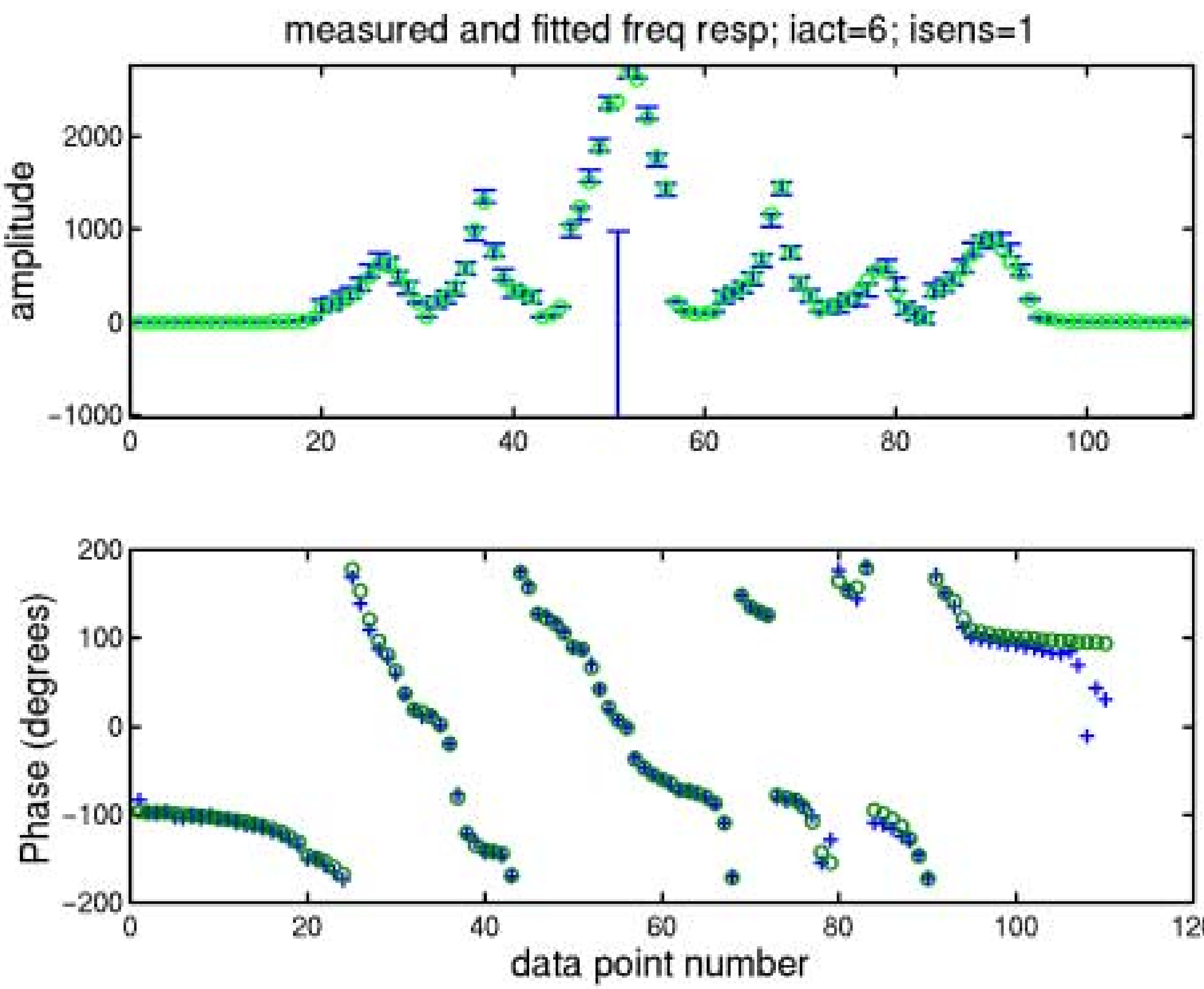
Digital feedback @ real time OS



Hardware and software
are working and being improved

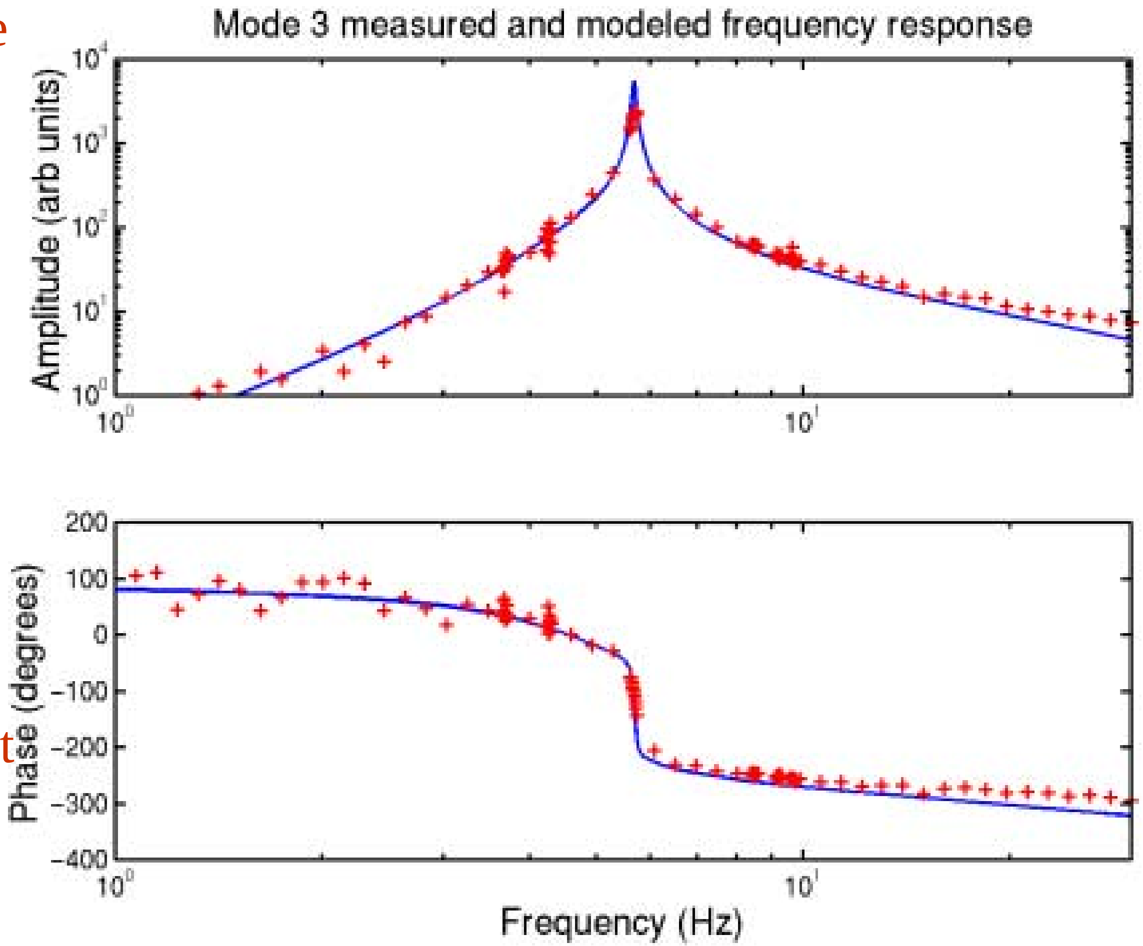
Calibration/Orthogonalization

- Excite each of 6 actuators with sine wave at 110 frequencies.
- Record amplitude and phase at each of 6 sensors.
- Result is 6x6 = 36 plots like these.
- Do 96 parameter (resonant freqs and Q’s, sensor freqs and Q’s, 2 6x6 coupling matrices) nonlinear least squares fit.



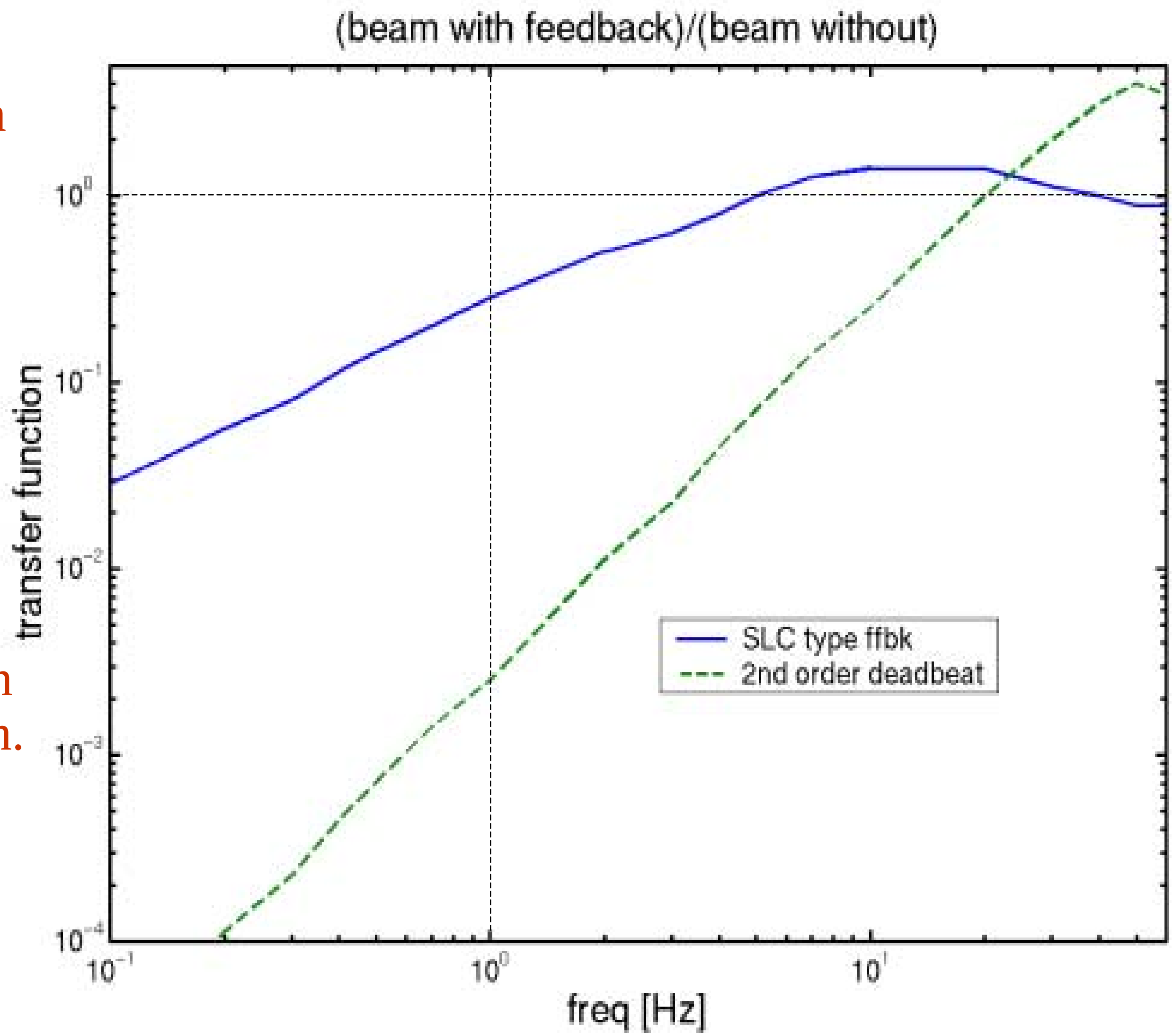
Check of calibration/orthogonalization

- Excite mode 3 (mostly vertical motion) with sine waves at 110 different frequencies.
- Plot the amplitude and phase of the mode 3 sensor combination (red “+”)
- Compare to model of harmonic oscillator and sensor (blue line)
- Note there are no peaks at other resonant frequencies so the calibration is good.



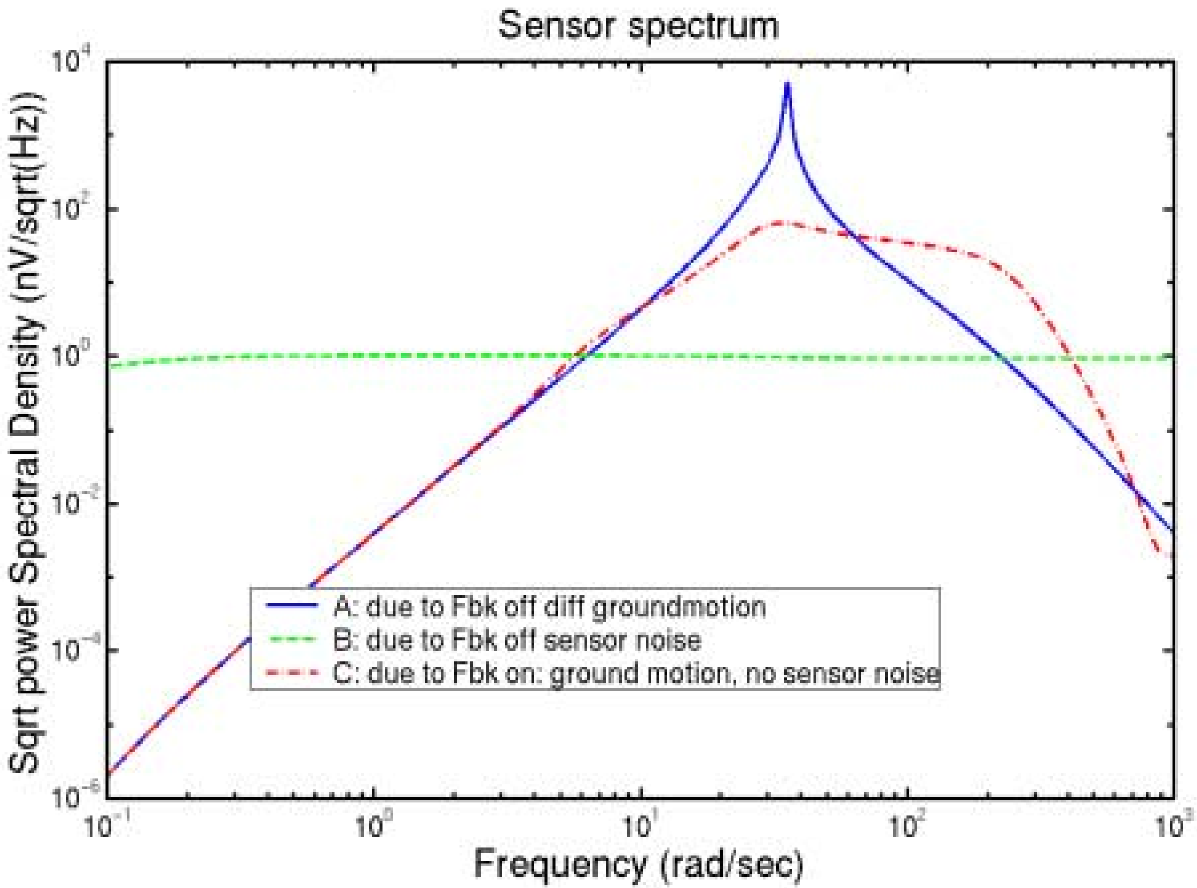
Effect of beam-beam deflection feedback must be folded in to get beam/beam separation

- Solid curve is modeled suppression of beam-beam separation by beam-beam deflection feedback.
- Measurements at SLC corroborate it.
- Note trade-off between good low frequency rejection and high frequency amplification.
- Solid curve folded in when evaluating FD stabilization. Without this, low freq. motion is very large.



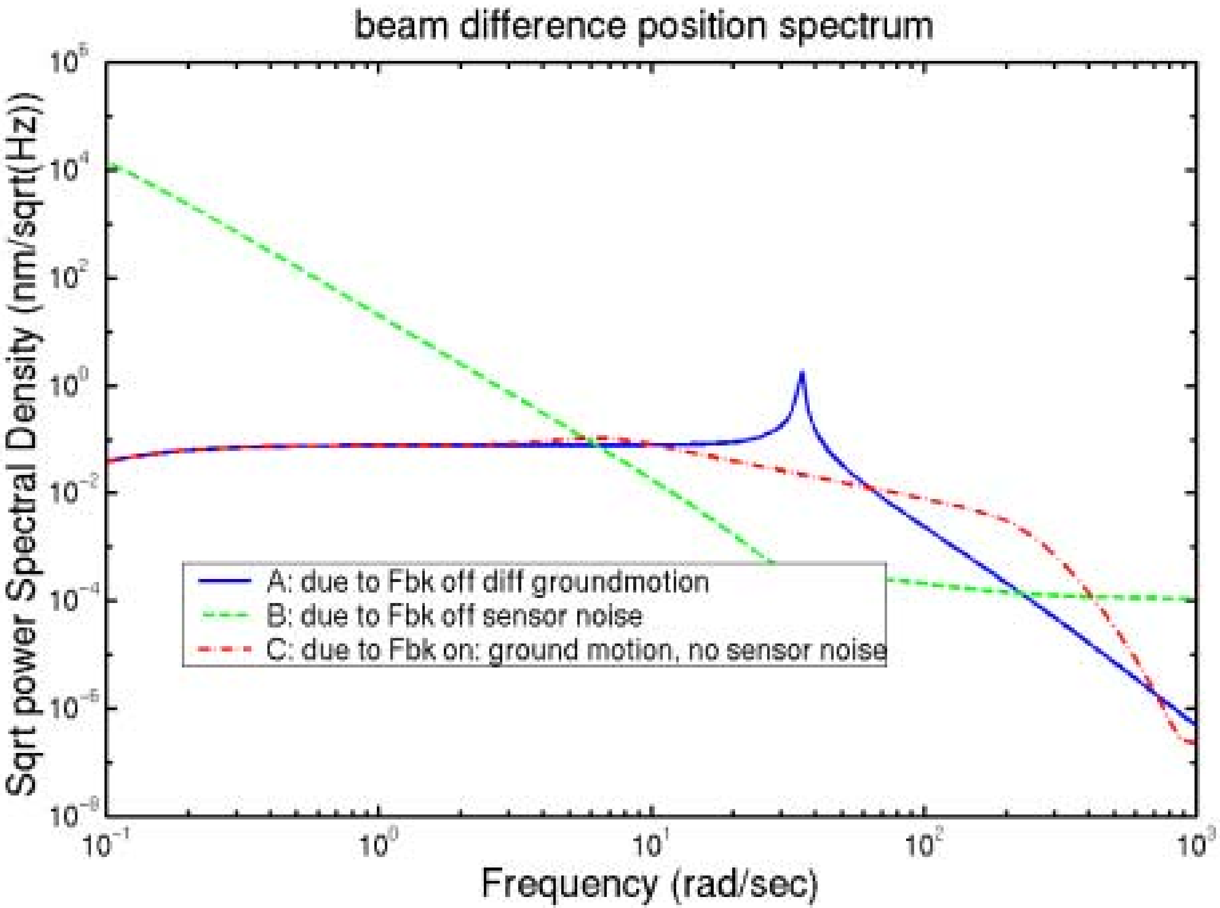
Signal to Noise – HS1 sensor

- The signal to noise ratio determines how well a feedback can work.
- The loop gain needs to be large where the signal is large and small where the sensor noise is large.
- This plot is for a commercial geophone (HS1) which measures velocity.



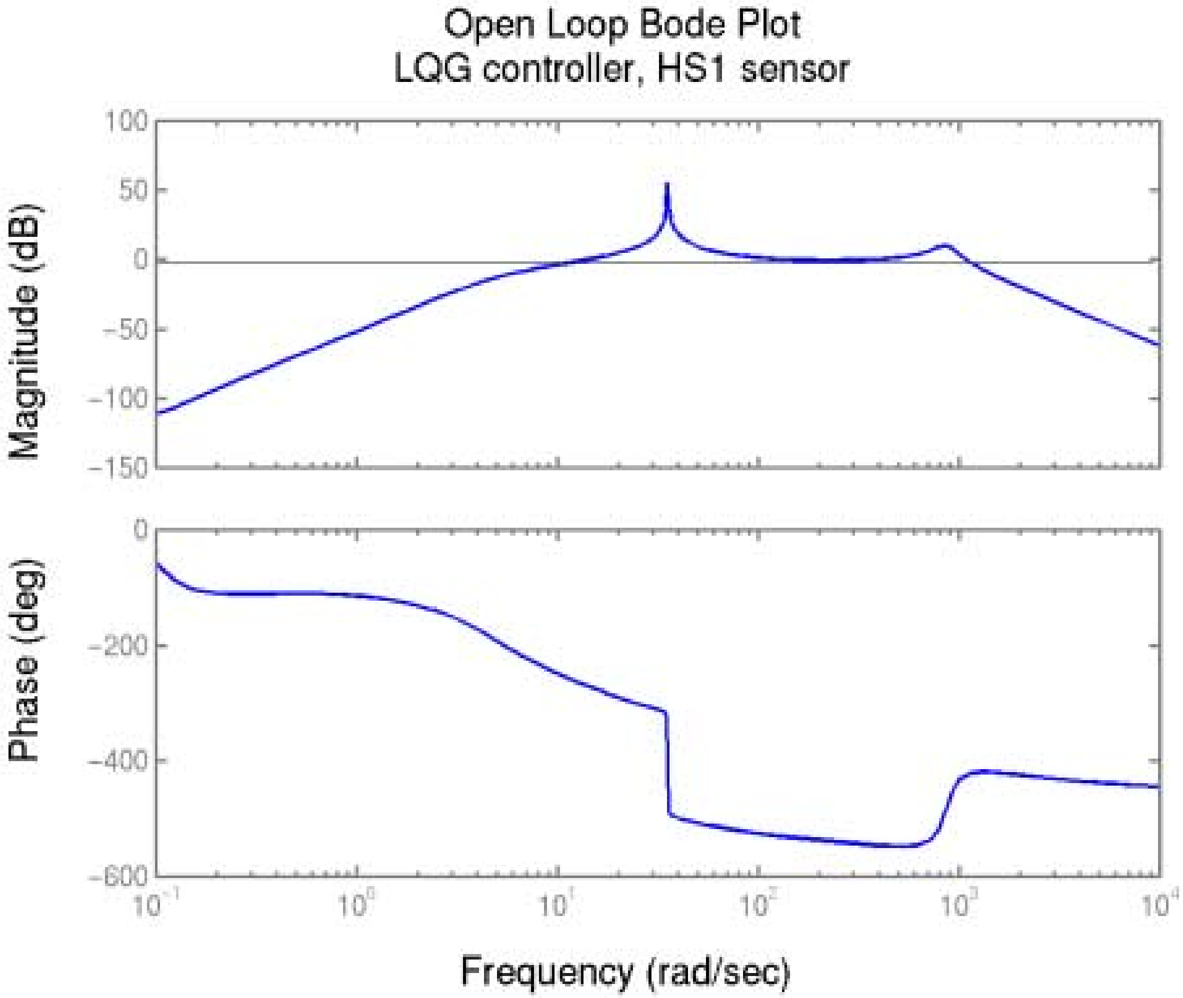
Signal to Noise as a position

- Here the detector sensitivity (it falls off rapidly below 4.5 Hz) is taken into account and the velocity is integrated to get a position.
- Note that all these spectra factor in the effect of beam beam deflection feedback and the differential motion for 2 doublets.
- Note very poor S/N at low freqs



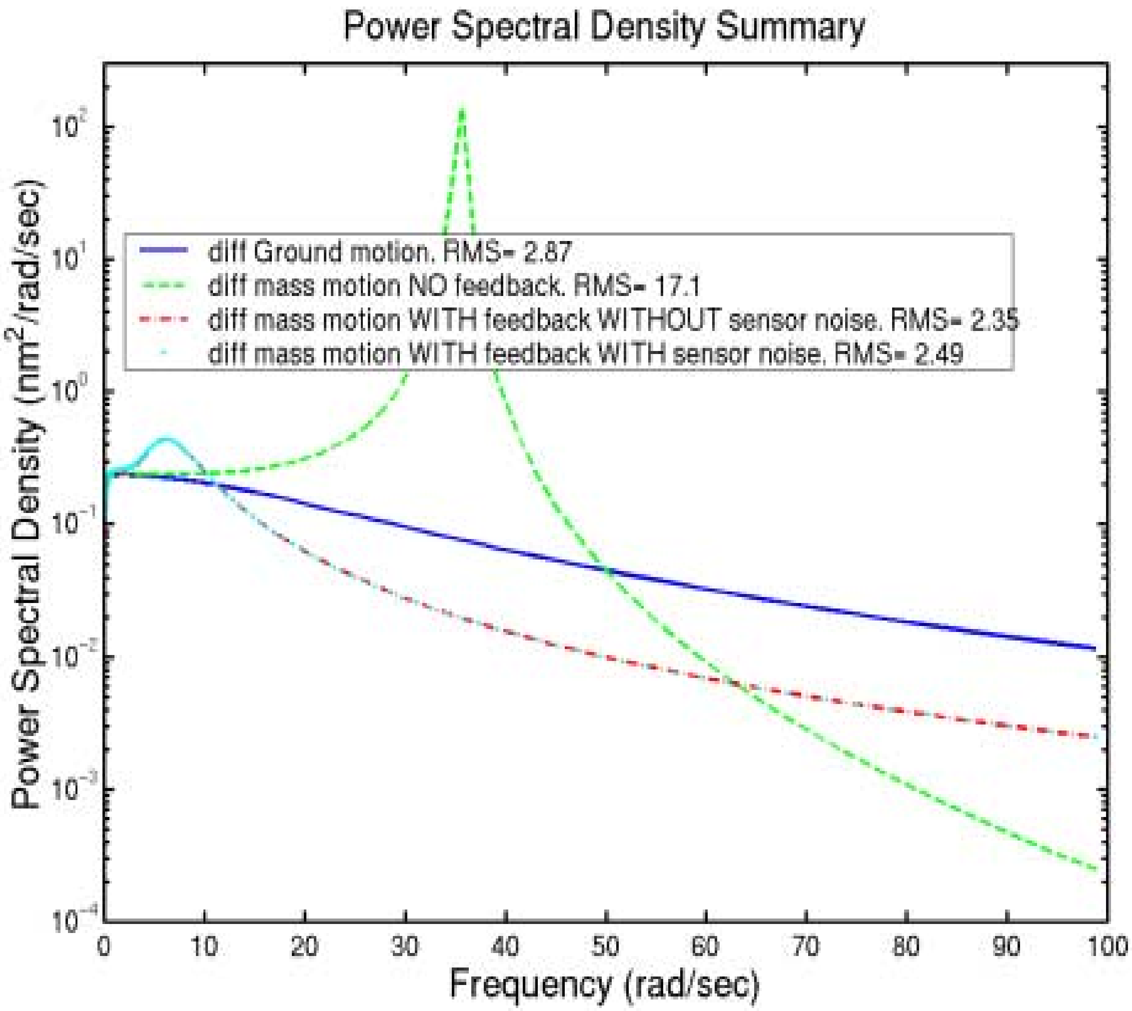
Open Loop Transfer Function
HS1 Sensor

- Goal: Large gain where S/N >1; small gain where S/N<1
- Slope can't be too steep where gain crosses zero to keep the phase from being too large and the loop from being unstable.
- This is an LQG controller designed to minimize the RMS motion. It uses a Kalman filter.



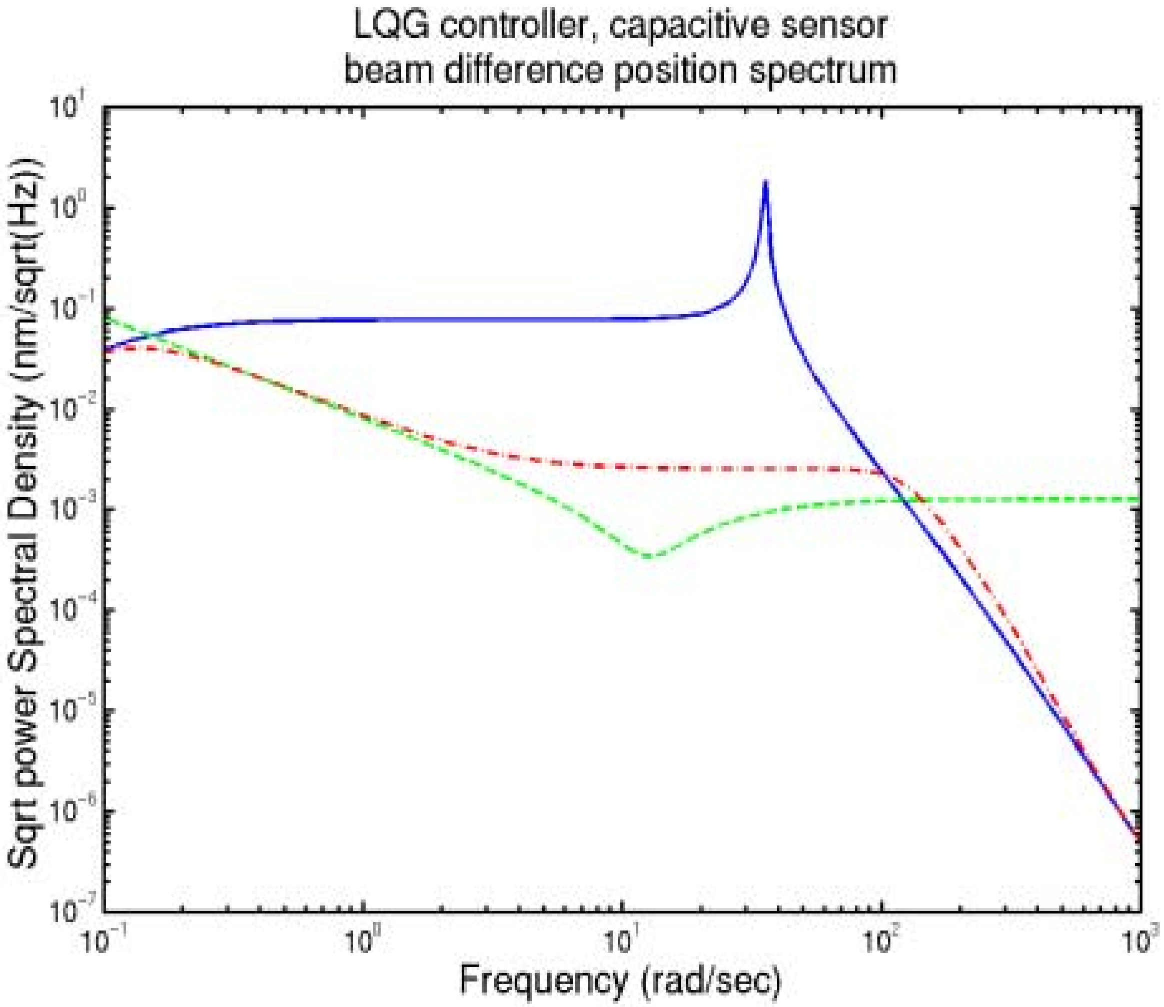
Simulated Power Spectrum HS1 sensor

- RMS is the sqrt of the integral under a curve
- Note that major contribution for the closed loop case comes from near 1 Hz.
- Note feedback improves on the sprung mass motion by a factor of 6, but does not improve on the ground motion.



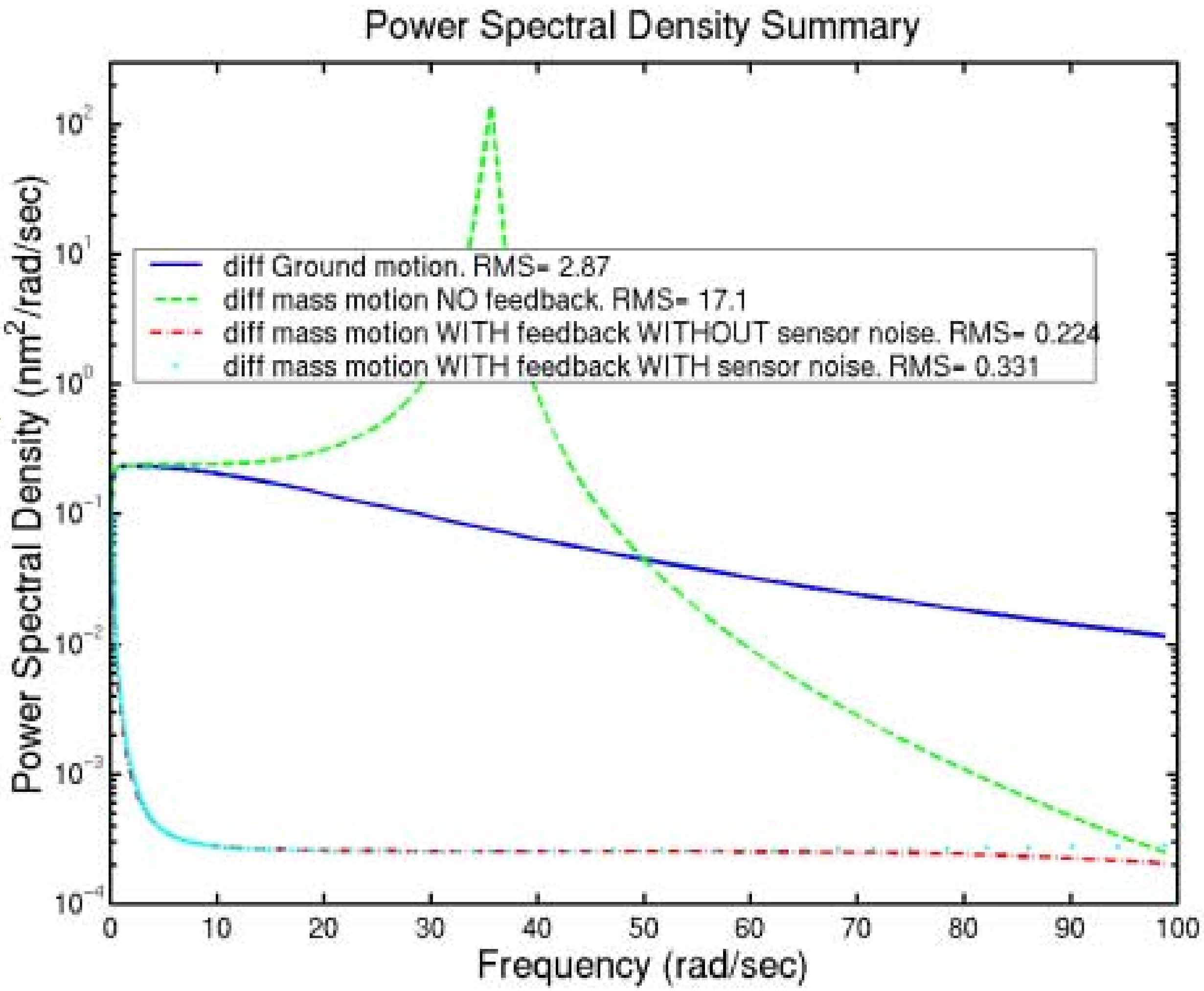
Position Signal to Noise for a Planned Capacitive Sensor

- Capacitive sensor measures position instead of velocity. Hence sensitivity falls of less rapidly at low freq
- Capacitive sensor readout is very low noise and has no 1/f noise.
- S/N crossover freq down a factor of 50



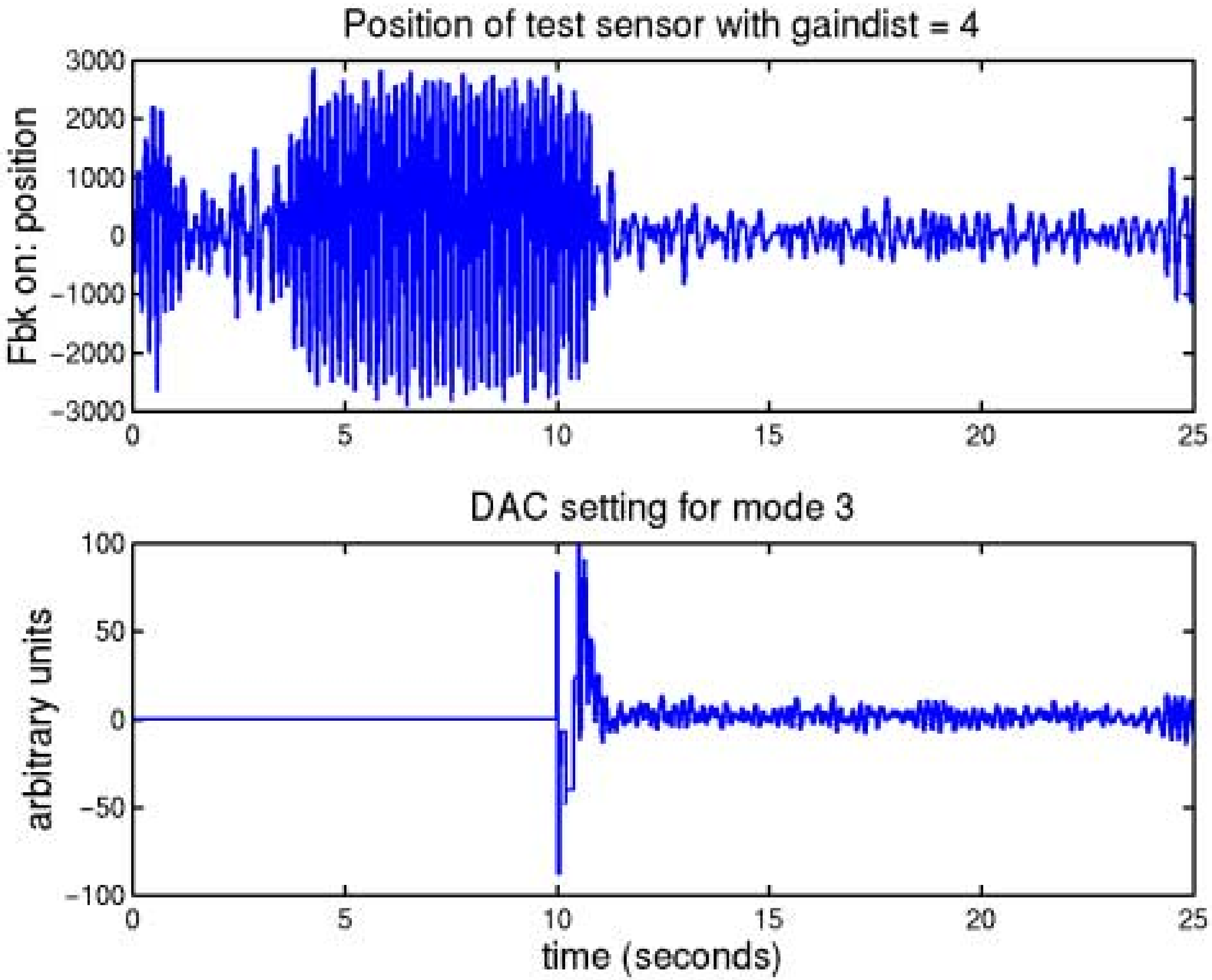
Simulated Power Spectrum – Capacitive sensor

- RMS now down to 0.33 nm.
- Note there is a commercial capacitive sensor (the STS2 made by Streckeisen) which works still better than this.
- We are building our own which is smaller and non-magnetic



Real Data from Test System

- Feedback was turned on after 10 seconds.
- RMS improved dramatically
- Still doesn't work as well as simulation. Investigating it.



Capacitive Sensor Development

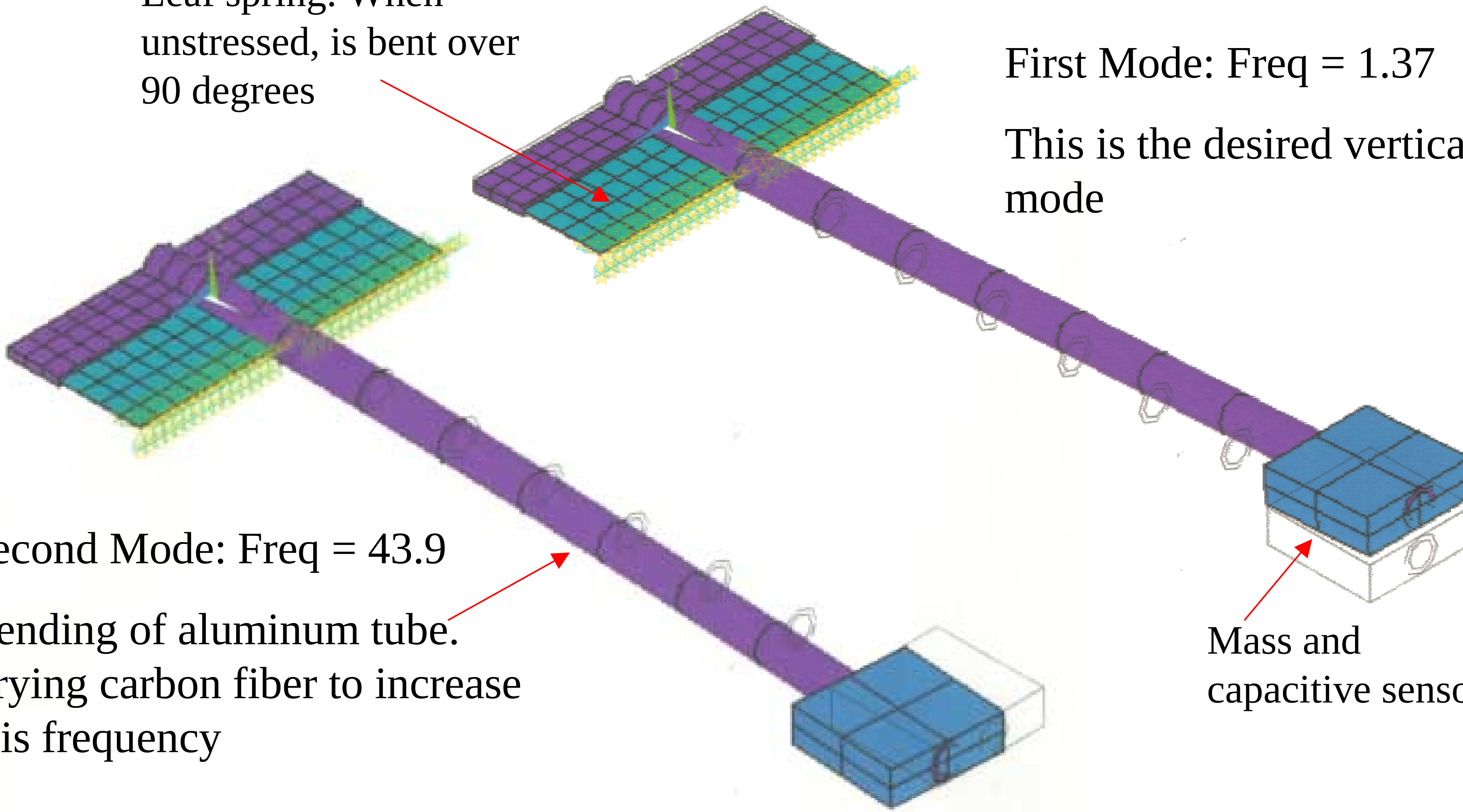
- We are developing our own capacitive sensor that will be low noise, small, and non-magnetic. Unfortunately we have not found any commercial sensors that meet our requirements.
- Carlos Damien built a few mechanical prototypes to gain an understanding of the problems.
- Eric Doyle is now using ANSYS to refine the design.
- Electronics have been developed.
- Custom leaf springs have been purchased.

Capacitive Sensor Modeling

Leaf spring. When unstressed, is bent over 90 degrees

First Mode: Freq = 1.37

This is the desired vertical mode



Second Mode: Freq = 43.9

Bending of aluminum tube. Trying carbon fiber to increase this frequency

Mass and capacitive sensor

FD Stabilization Status and Plans

Prototype with one mass and 6 degrees of freedom:

- System works and has been extensively used.
- DSP can read ADCs and write to DACs and do feedback calculations.
- DSP is slower and has less floating point precision than desired so we are planning to go to a much faster PowerPC CPU.
- Commercial geophones with 4.5 Hz resonant frequency are in use.
- Calibration/orthogonalization works spectacularly well.
- Have tested several feedback controllers including an optimal LQG controller.
- Starting investigations of robust controllers that are not as close to instability as the LQG controller.

- A lower resonant frequency (and hence more sensitive there), capacitive geophone is under design.

- Later stages will include 2 coupled masses and an extended mass.