

Vibration Suppression R&D at SLAC

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Project Requirements

We are concentrating on the Final Doublet stabilization (most difficult problem).

Beam spot sizes at the IP $\sim 1\text{nm}$ -> Some feedback (at least slow) is required

Note: Electron beam (beam / beam deflection) is the only long term reference

Electron beam can provide information at 120Hz (for NLC), can provide feedback at $f > \sim 20\text{Hz}$.

Ground motion varies with site, and nearby equipment. We are considering what to do IF active vibration damping is required.

Basic R+D Goal: Stabilize a test “magnet” to $< 1\text{nm}$ for frequencies above $\sim 5\text{Hz}$ in the SLC collider hall.

Additional Goal: Construct a test bed for vibration suppression technology.

Linear Collider Final Focus Magnet Requirements

If LIGO can do it, why can't we?

For LIGO, stabilizing and measuring the position of the test mass is the primary technical challenge: the entire system can be designed around this requirement.

For the Linear Collider, other considerations constrain the problem:

“Test mass” must actually be a magnet - at best a permanent magnet, but may have flowing Helium or even water. This magnet is an extended object with important internal degrees of freedom.

A Linear Collider involves the use of large amounts of power (hundreds of megawatts). This implies pumps, compressors, air blowers, cooling water, etc. The local environment is likely to be much more noisy than for LIGO.

Detector: Constrained space. High magnetic fields, Possible vibration source.
(LC would be much easier without a detector;-)

Stabilization Subsystems

Alignment (<<1Hz): Slow movers, using beam for feedback. Note that macroscopic mechanical objects are not stable to nanometers, so the beam is the only reference.

Considerable work at SLAC, FNAL, etc., etc.

Magnet movers with sufficient resolution have been demonstrated

Low Frequencies (<<10Hz): Can use beam / corrector magnet feedback.

Work at SLAC (SLC/SLD), and others. Problem believed to be understood through simulations.

High Frequencies (5Hz > 1 KHz): Acoustic frequency range. Use Accelerometers / interferometers or other non-beam based sensors. **This is the topic of the rest of this talk.**

Ultra Fast Feedback (intra-train): This is straightforward for TESLA. Difficult for room temperature machines. NLC plan is to add this to other systems, but not rely on it until demonstrated.

Simulation work done at DESY, CERN, SLAC, etc., etc.

Vibration Damping: Accelerometers vs. Interferometers

Both types of sensors are “almost” commercial with sub-nanometer noise in the frequency range of interest.

Both are inconvenient for the detector:

Accelerometers require bulky sensors located on the Quads in the detector

Interferometers require penetrations through the detector.

Fundamentally different operation:

Accelerometers lock to the “fixed stars”. Unfortunately the rest of the accelerator is moving relative to the fixed stars.

Interferometers lock to a point on the ground. Unfortunately the ground is moving differently at different locations.

This talk will concentrate on Accelerometer based systems, the next talk will describe the Interferometer work being done at UBC.

R+D Plan Overview

- 1: Construct a simple system with a rigid block. Measure and control all degrees of freedom. Use this to develop feedback data acquisition system, and self calibrating feedback loop. A software simulator is also being developed for this system.
- 2: Construct a system consisting of 2 blocks. Control each with accelerometers, then use a laser interferometer (or capacitive sensor) between the blocks to simulate the 120 Hz beam data. Develop dual data rate feedback system.

Note that the accelerometers can sense all 6 degrees of freedom (or more for an extended system), but only work at frequencies above $\sim 5\text{Hz}$. The electron beam senses a single combination of modes, at frequencies from DC to 120 Hz.
- 3: Constructed an extended system (rigid beam), with accelerometers to measure the internal (and solid body) modes. Control internal modes of the structure with feedback.
- 4: Construct a pair of final focus magnets and support (mock up). Control the motions with feedback, using an interferometer to simulate beam data.

Technology - Sensors

Geophones measure above the device resonance. Provide good low frequency sensitivity, but are bulky due to large low frequency test mass support. High frequency performance usually limited by higher frequency internal resonances.

Accelerometers measure below the device resonance. Are compact, but have high noise at low frequencies due to small displacements of the test mass.

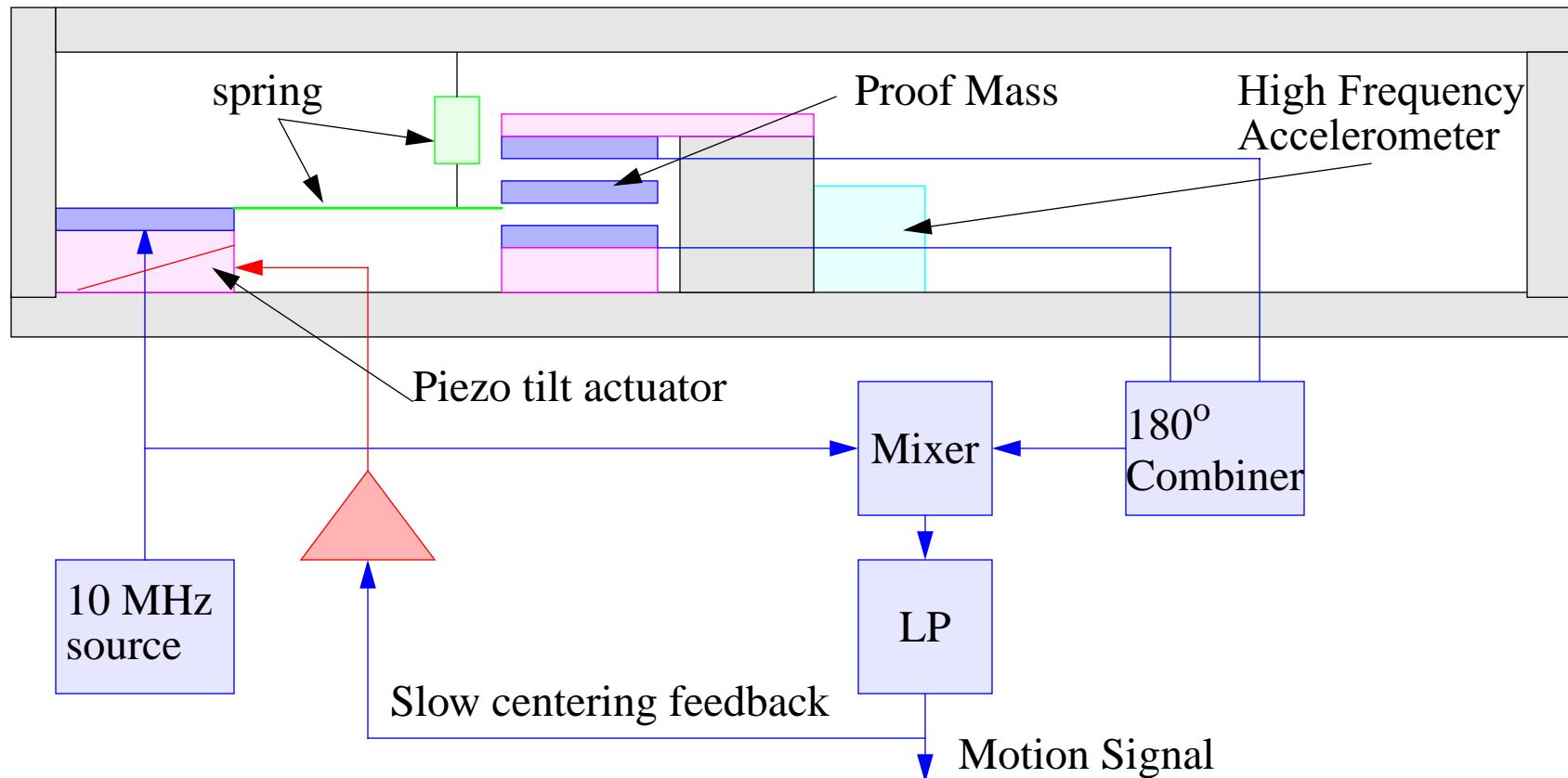
Commercial Geophones have sufficient sensitivity at low frequencies, but are bulky and will not work in a high magnetic field.

Piezo-electric accelerometers are available with a specified noise of $0.6(\mu\text{m}/\text{s})^2/\text{sqrt(Hz)}$ at 1 Hz. This is sufficient for noise $< 1\text{nm}$ for frequencies from 4Hz to $>500\text{Hz}$.

Initial tests indicate that noise is $\sim 10X$ spec, which would only allow sub-nanometer noise for frequencies below 20Hz.

We can do initial testing with our accelerometers, but will need to construct a compact, non-magnetic geophone for later testing.

Sensors - electrostatic geophone design concept:



Would design with fundamental resonance $\sim 5\text{Hz}$. First higher order resonance $>100\text{Hz}$, would allow use of compact piezoelectric accelerometer for high frequency measurement.

Electronics test (proof mass position locked) gave $<0.1\text{nm Hz}^{1/2}$ noise (OK).

Actuator Issues

Piezo-electric elements are generally considered for the short range / high frequency actuators for the quads. They have the advantage of smooth motion at the sub-nanometer level, and of simplicity.

Piezo-electric actuators are stiff ($\sim 10^7$ N/m): will couple ground motion to the quads.

The required forces are very small

Assumed quad mass = 200Kg.

Assumed resonant frequency = 10Hz.

Support stiffness = $\sim 10^6$ N/m.

Required force for a 100 nanometer (worst case) motion = 0.1 Newton.

Can use an electro-static pusher. With 4 10x10cm plates, 1mm separation, need about 1 kV drive voltage. This system will have very low stiffness. (~ 1000 N/m).

Electrostatic pushers are nonlinear $F \sim V^2$, but this is predictable: correct in software.

Can use RF capacitance meter (see above) to provide gap measurement to <1nm.

Support System - Test Block

Define, control, and measure all 6 solid body modes.

Easily change resonance frequencies for R+D testing.

Real quad support may not be orthogonal, so test system is not orthogonal.

Test system will use a 30Kg test mass, supported on 6 springs. Initially vertical resonant frequency will be $\sim 5\text{Hz}$ (can be changed later)

Alignment will be done with manual actuators (with upgrade path to remote control).

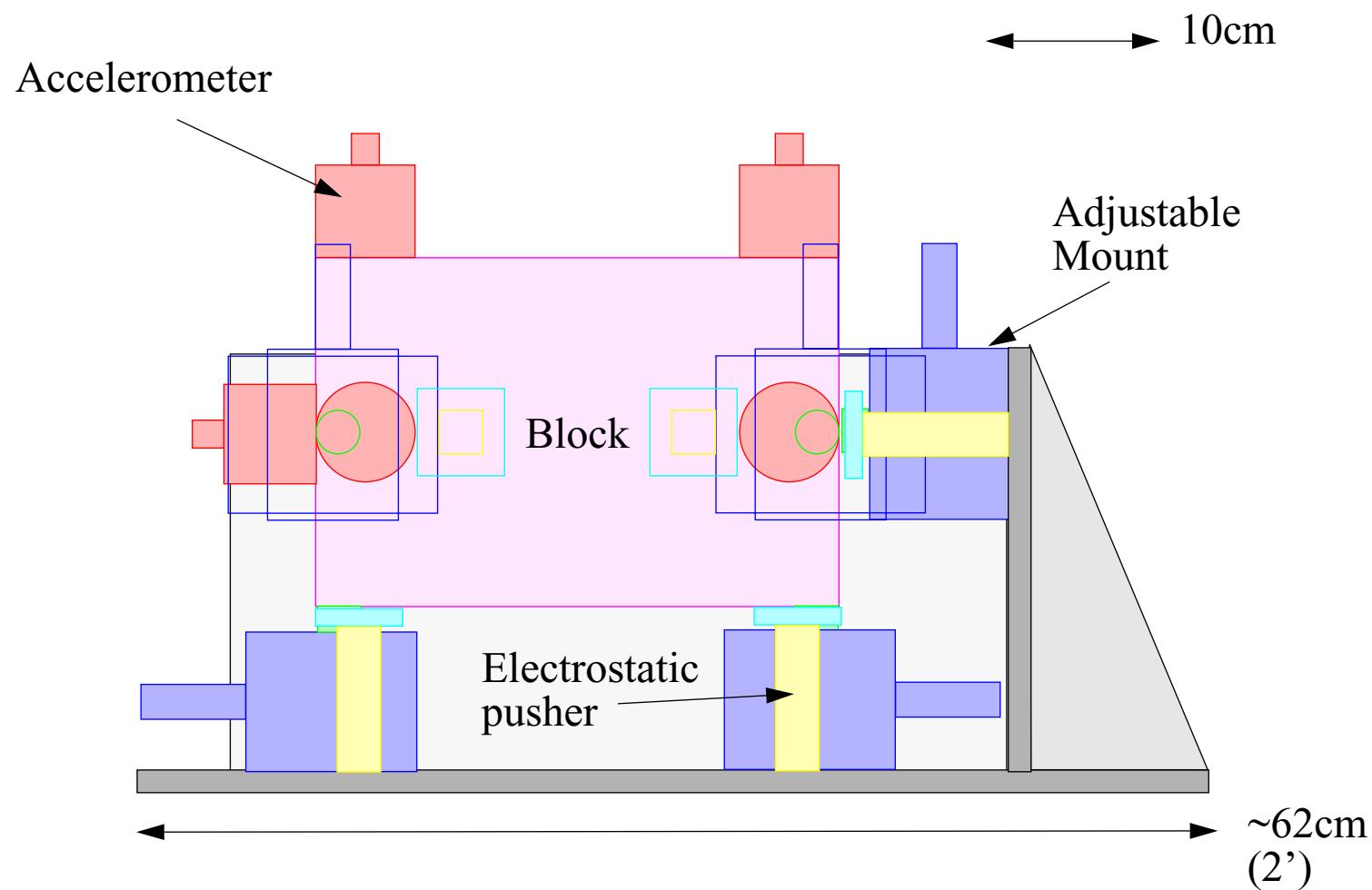
Vibration measurement using piezoelectric accelerometers (upgrade to electrostatic geophones later).

Actuators will be electrostatic pushers (but keep open options of voice coils of piezoelectric actuators).

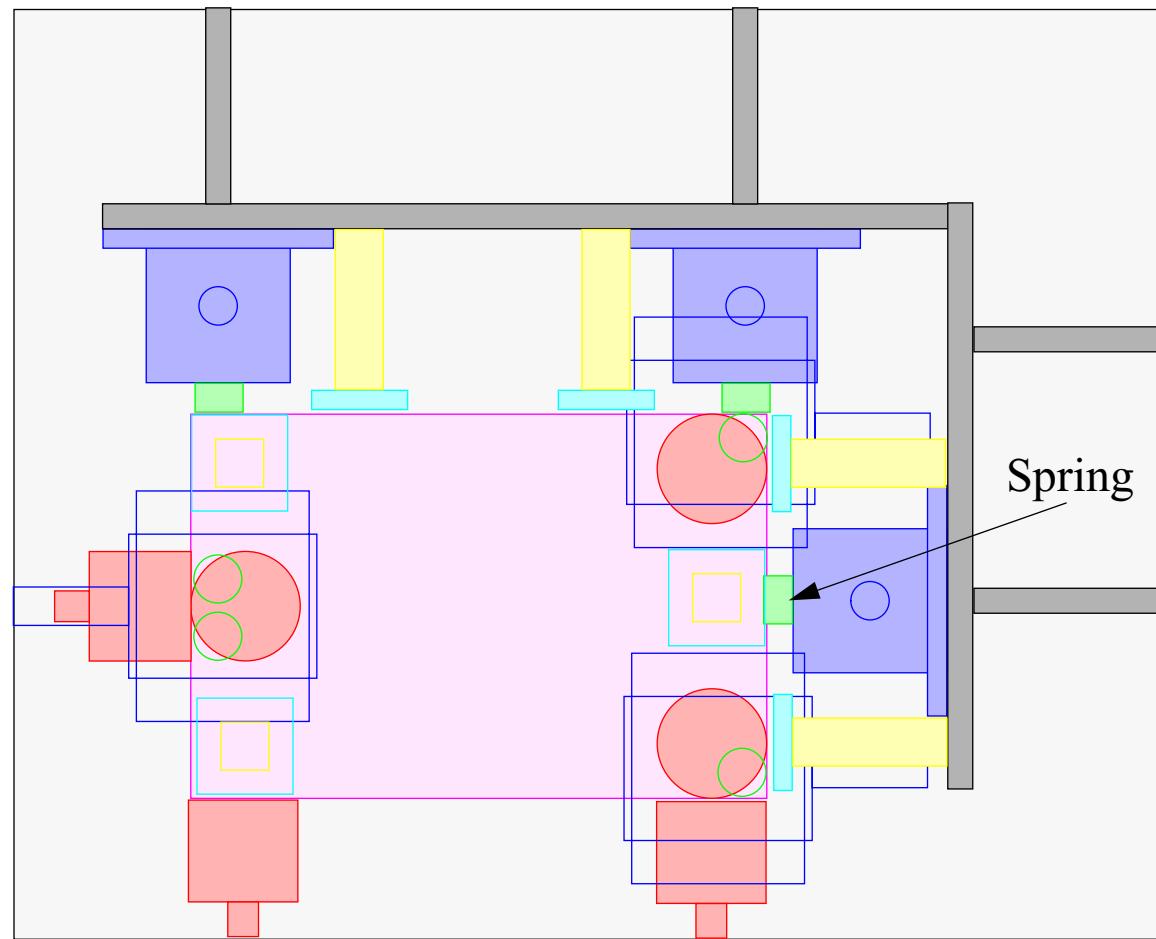
No hardware damping - all damping to be done in software.

Status: Hardware on order / parts being machined.

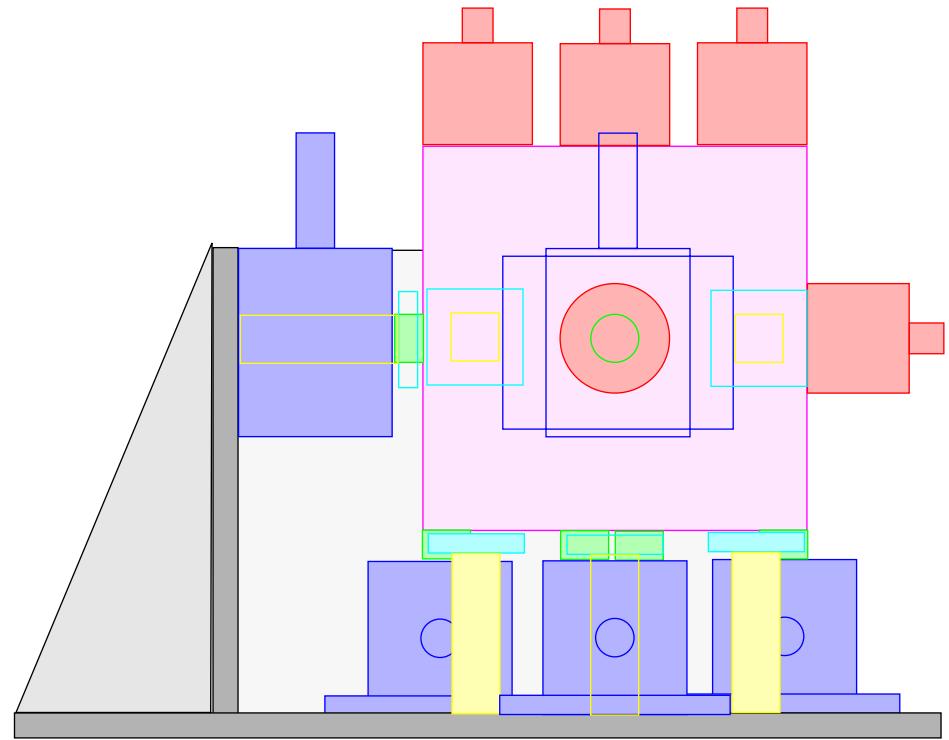
Side



Top



End



Simulation Code

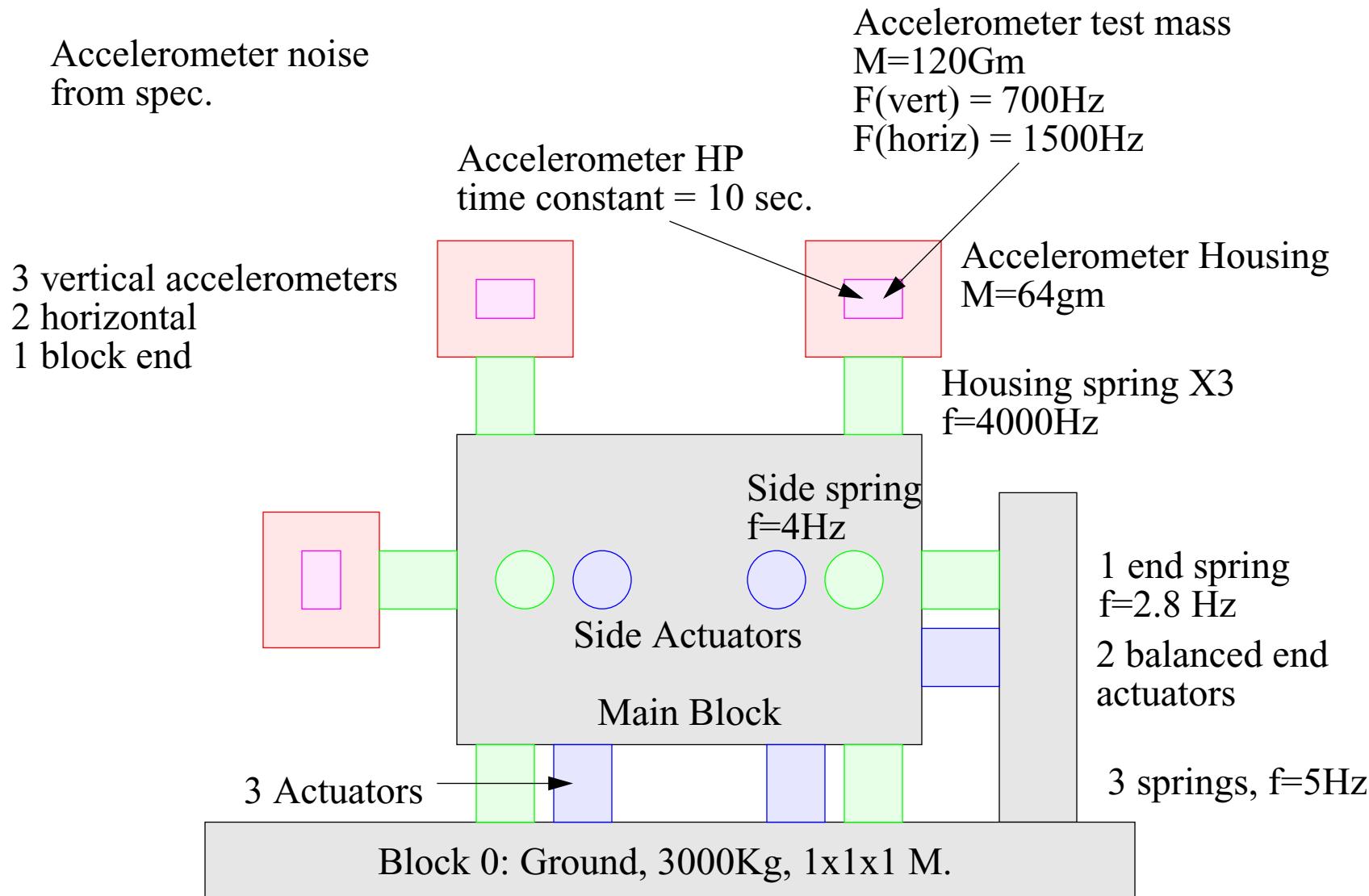
Simulates combinations of blocks and springs (including angular momentum).

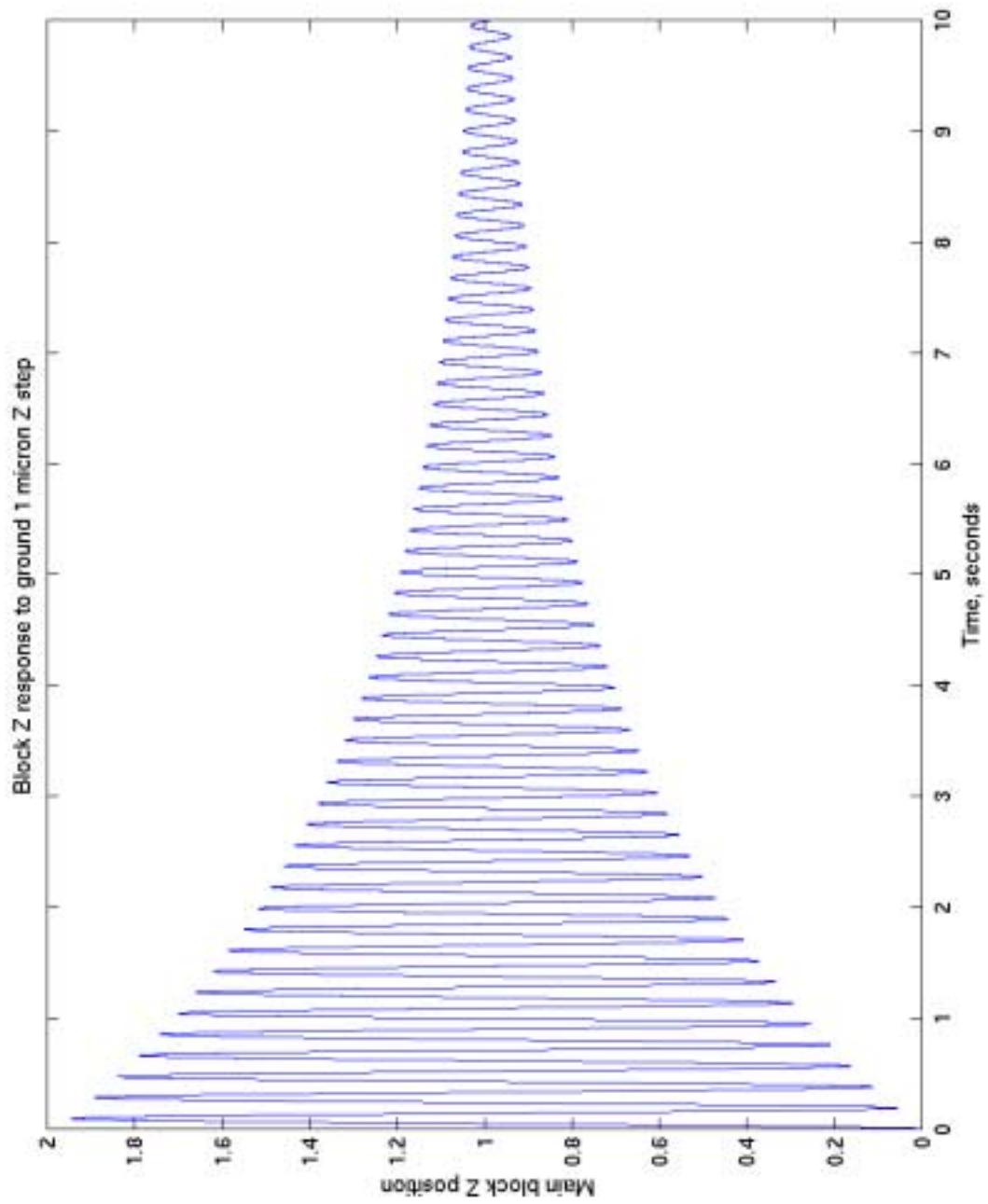
Sensors modeled as distance measurements between blocks, with noise.

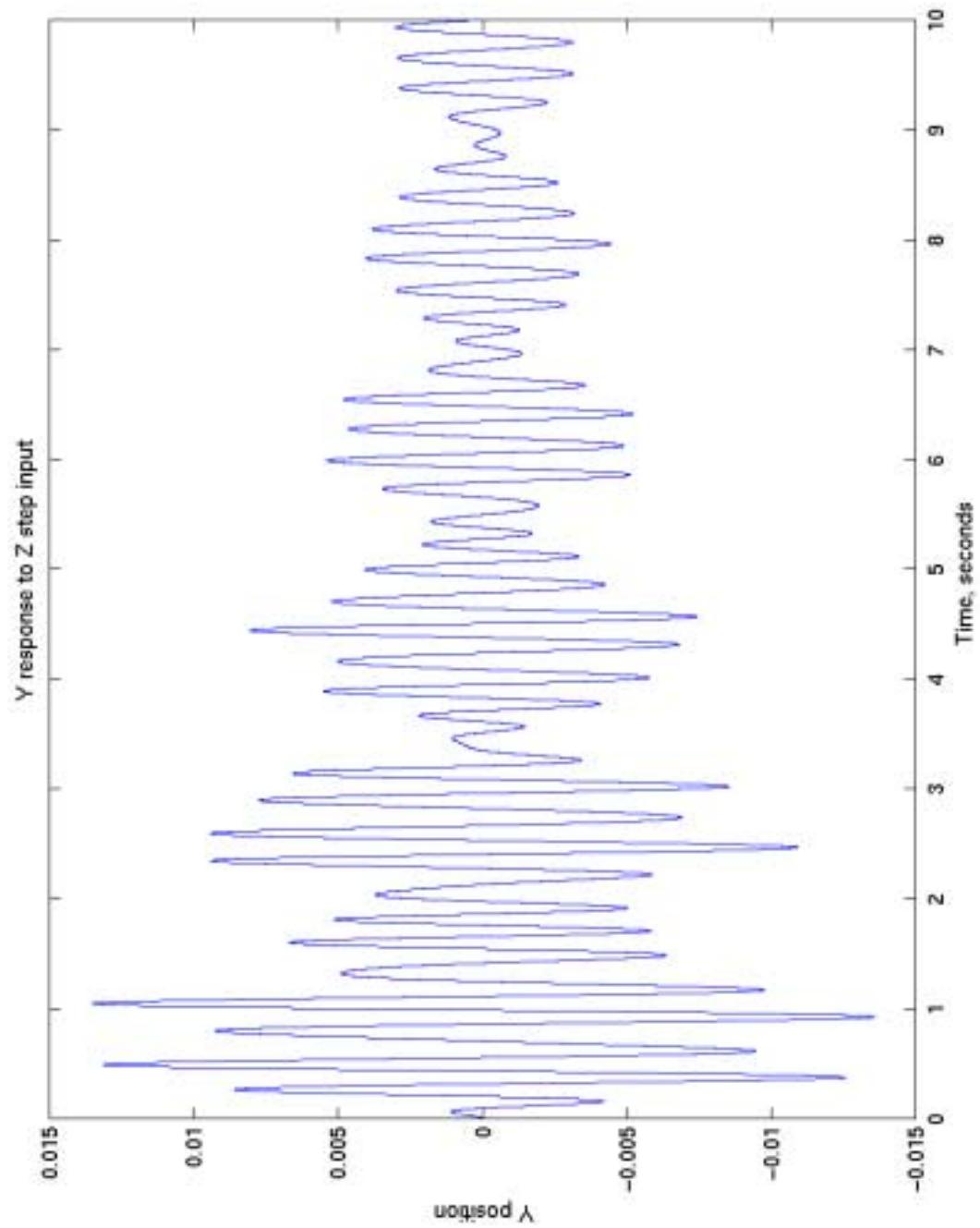
Actuators modeled as producing force between selected points on blocks.

Simulator feedback code designed to port directly to the real system.

Simulator runs at ~1/10 real speed.







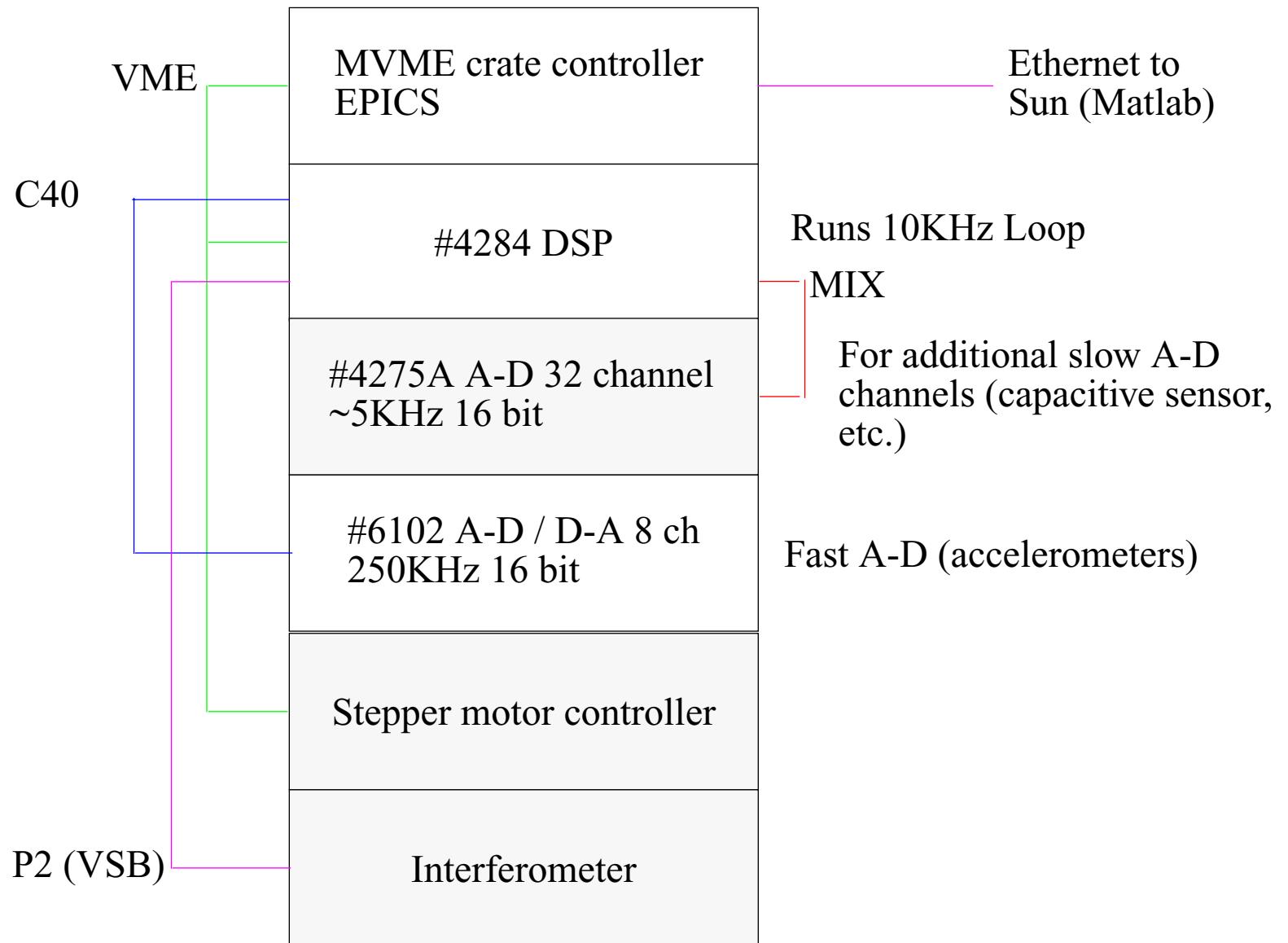
Simulator Results - Very Preliminary

Goal: Orthogonalize system - separate into 6 harmonic oscillator problems)

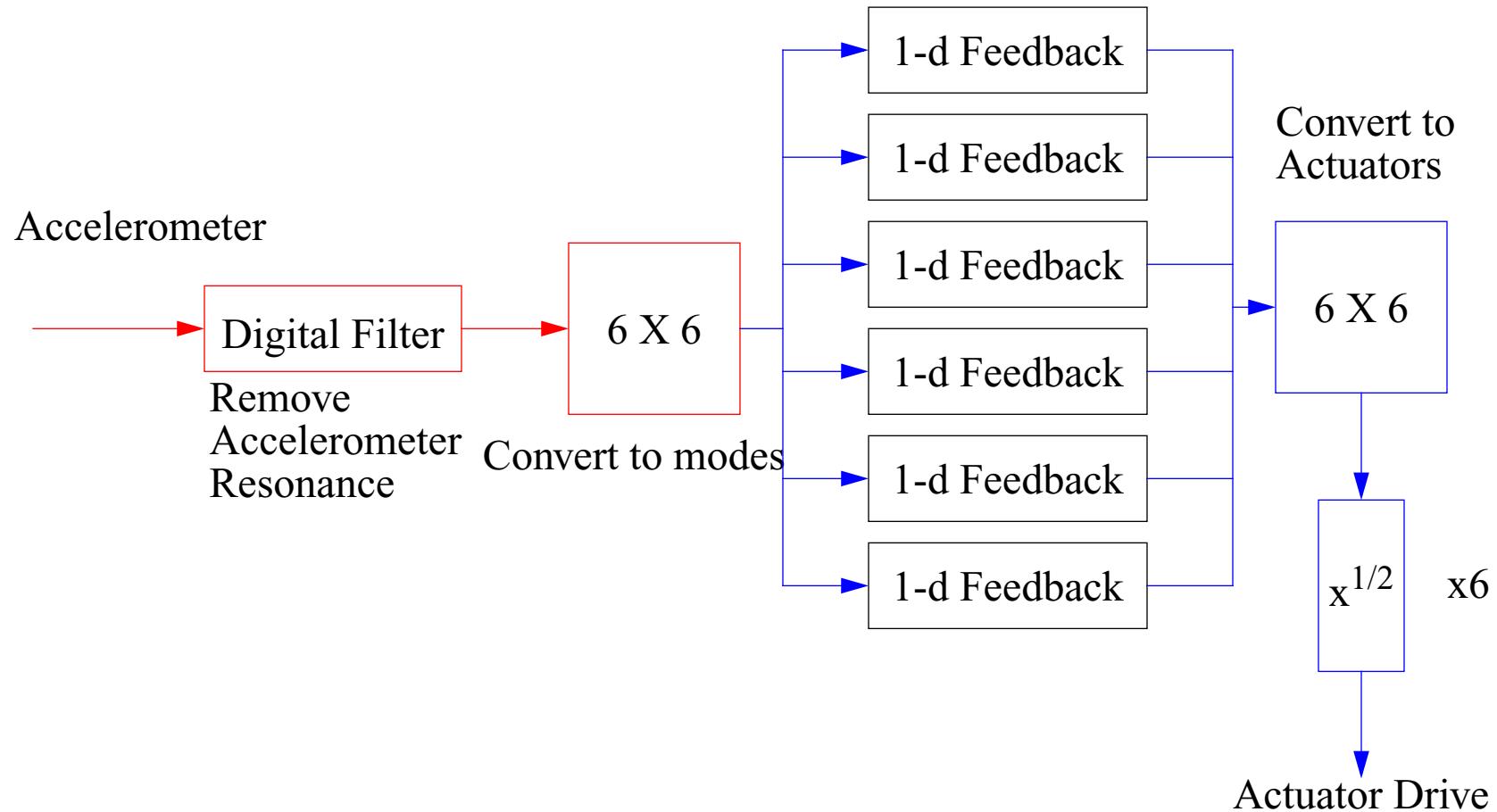
1. Drive actuators with noise. Measure first 6 resonance peaks (mode frequencies).
2. For each frequency, For each Actuator, drive at mode frequency. Measure the response of each sensor. Least squares fit to Actuators -> Modes, and Modes -> Sensor matrices.
3. Check results by driving Actuator combination with step function, measure modes and frequencies with sensors. (Works fairly well).

This procedure should work for internal modes of an extended object.

Feedback System Hardware:



Feedback System Software



Reduce problem to 6, 1-d harmonic oscillators.

Feedback can be PID, or state space.

Status / Plans

Simulator work underway to develop self orthogonalizing and self tuning feedback.

Mechanical tests system under design / fabrication (expected ~January 2001).

Feedback data acquisition / control hardware on order. Expect operational ~February 2001

Expect to close the feedback loop ~ March 2001.

In parallel, are developing electrostatic geophones.

Try for single block stabilization demonstration ~June 2001

Later:

Two - Block system with interferometer to simulate beam effects.

Stabilize an extended object.

Stabilize a realistic final focus magnet mock up.

