Rejecting Rotational Disturbances on Small Disk Drives Using Rotational Accelerometers

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HPL Disk Mechanics

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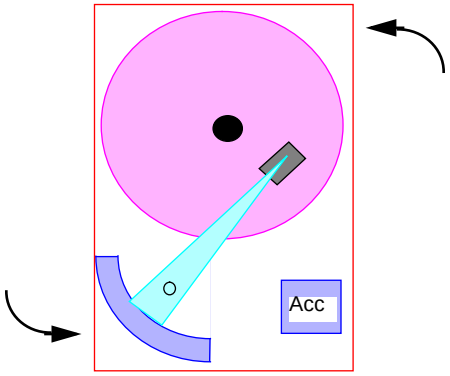
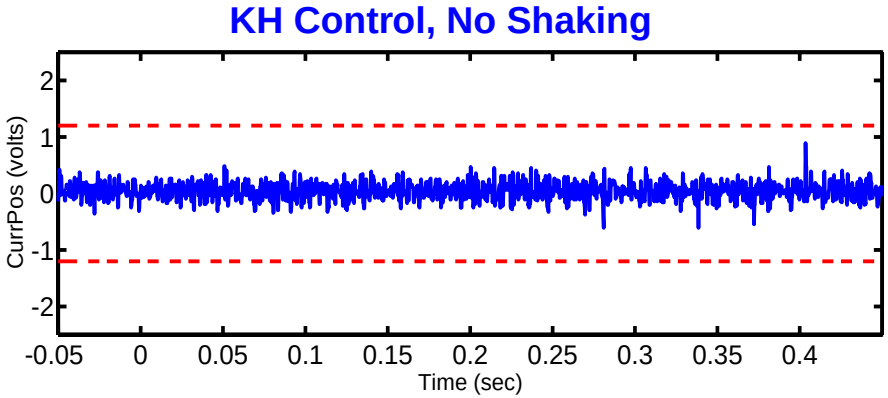
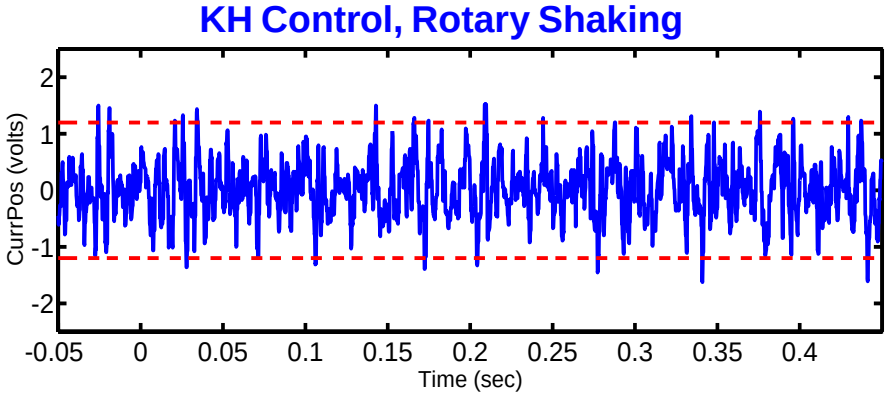
Problem: External shock and vibration a significant portion of offtrack budget.







- **50-500 Hz vibration**
- **86.5 rad/s^2 rms**
- **Accel. write protect trips between 100-200 rad/s^2**
- **1.2 volts = 12% of track**

Goal: Use KittyHawk rotational accelerometer to substantially diminish effects of rotary shock and vibration.

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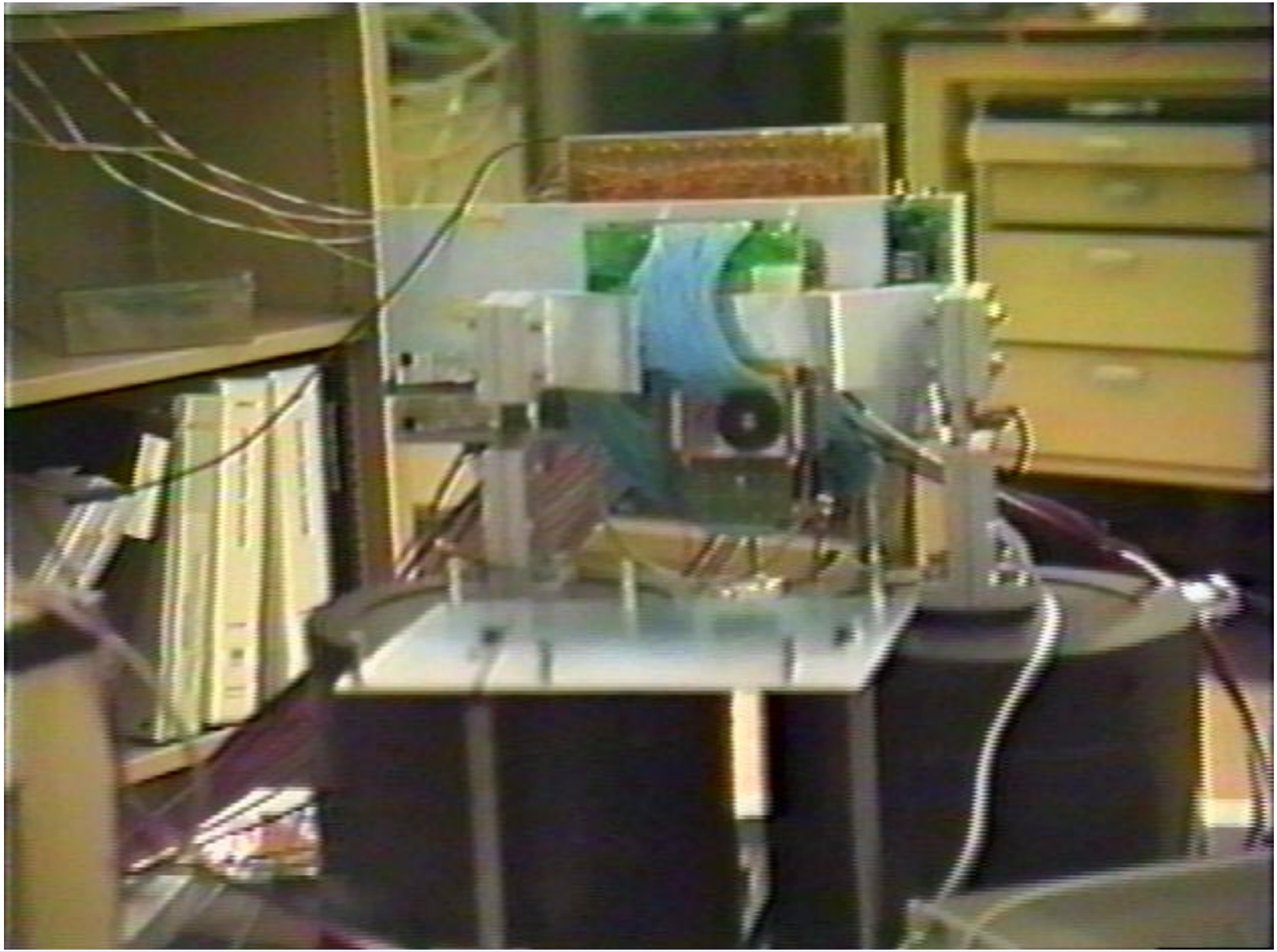

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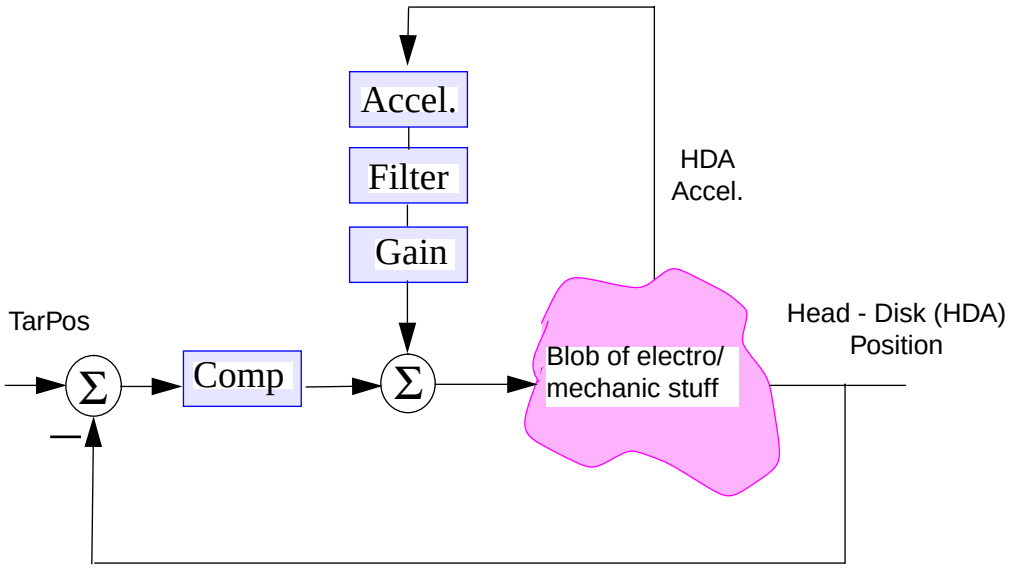
Technical issues:



Why not "Just do it?"

1) Accelerometer beam resonances
2) Low sample rate of KittyHawk servo
3) Large gain variation of KittyHawk accelerometer

"Zer are technical zolutions." -- Edward Teller, 1983

1) Filters to compensate accelerometer frequency characteristics
2) Multirate sampling
3) Adapting filter gain

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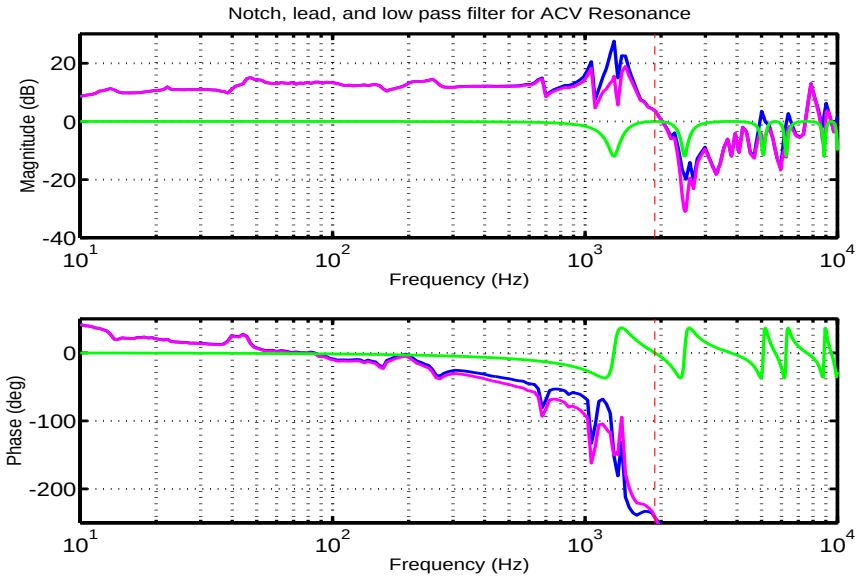
Accelerometer Beam Resonances and Other Nonidealities



- **Resonance puts limit on the frequency that can be followed.**
- **Can be filtered.**
- **Filters give phase hit.**
- **Matching phase is as critical as matching gains.**

Basic assumption (from sampling of product accelerometers):

- **Shape of accelerometer response is approximately constant.**
- **Only the gain is highly variable.**

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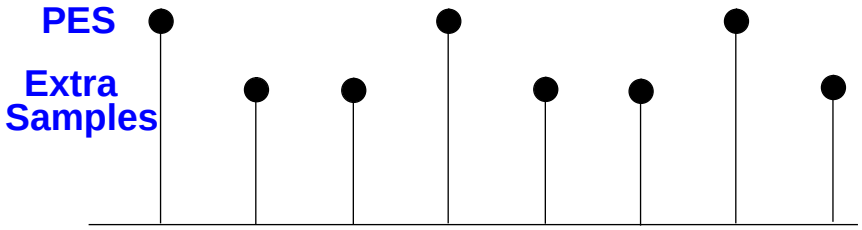
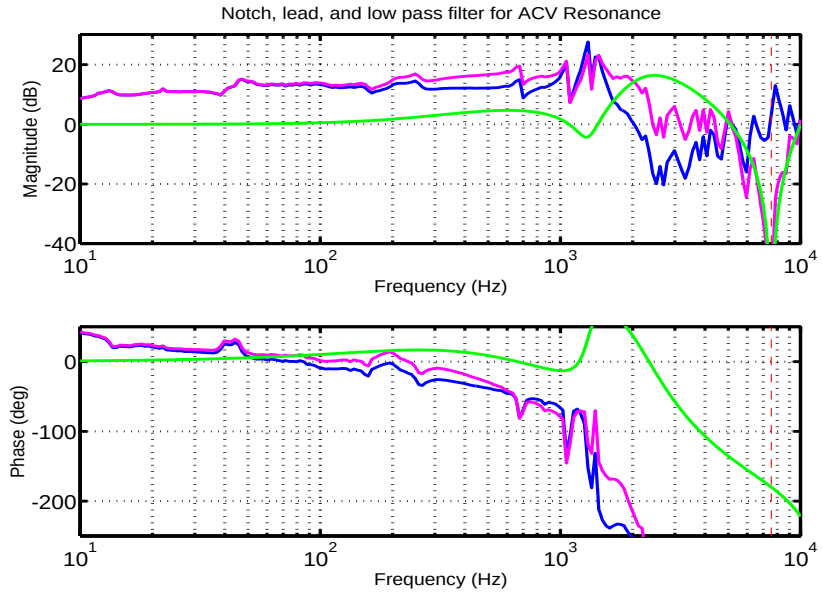
Multirate Sampling





- **PES is limited by # of sectors.**
- **Accelerometer signal is not.**
- **Extra samples on accelerometer**
  - ***broaden bandwidth***
  - ***reduce phase hit of filters***
  - ***give more freedom in filter design (e.g. lead filters)***

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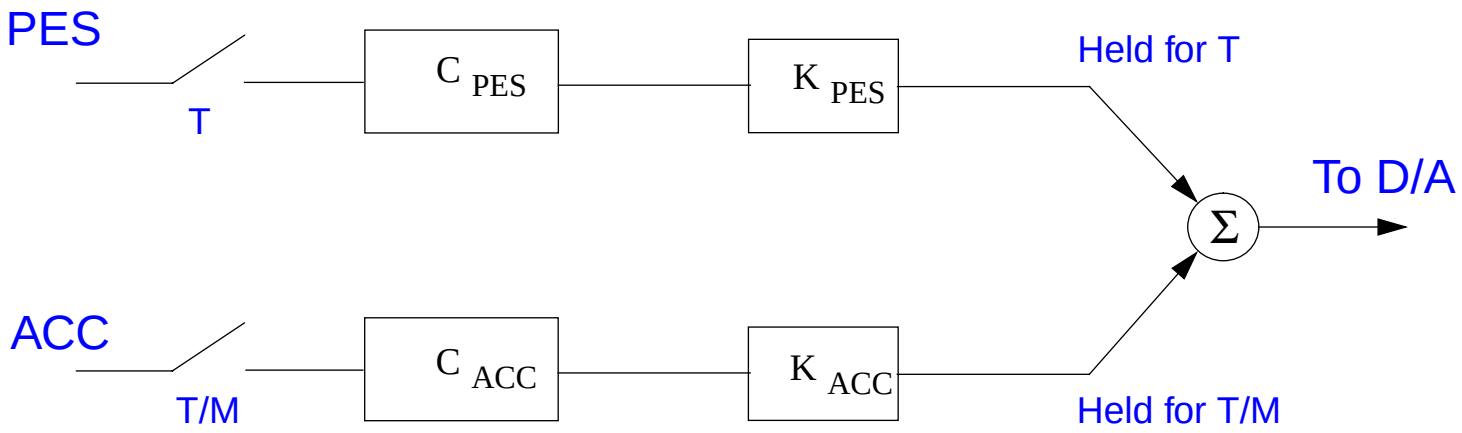
Implementing Multirate



- **PES loop clocked by disk sector.**
- **ACC loop clocked by disk sector and by extra clock for inter-sector samples.**
- **M = oversample multiplier**
- **Basic assumption means that can keep C_{ACC} constant and adapt only K_{ACC}.**

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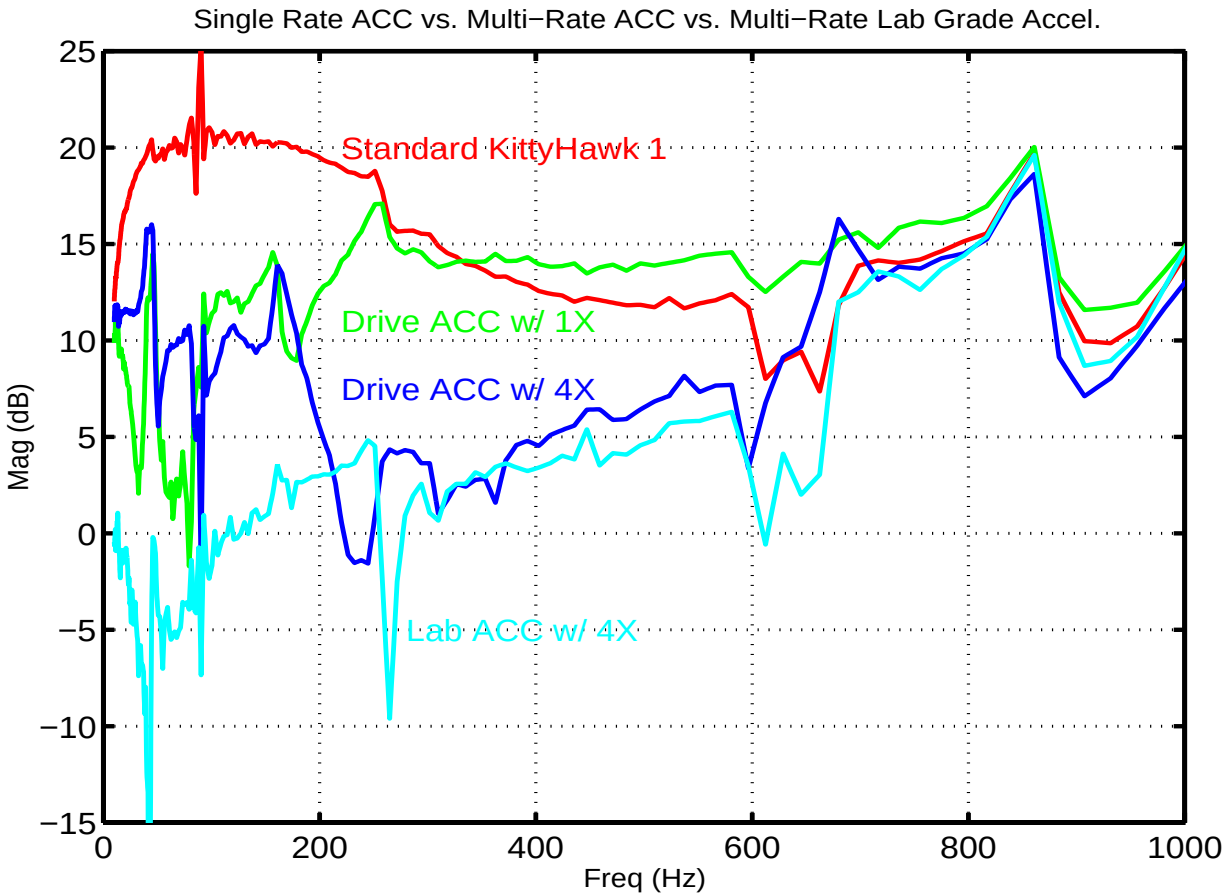
Disturbance Rejection Frequency Response



Area below red curve indicates increased disturbance rejection.

Input is voltage to shaker table.

Output is PES.

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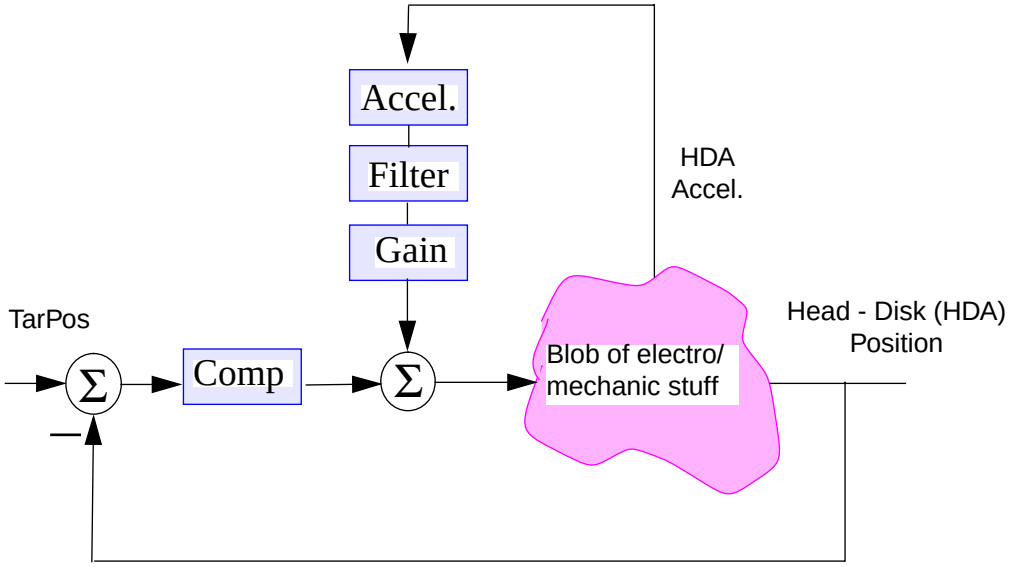
Two Choices for Adaptation



Identify Accel. response:

- **Complete, "right" way.**
- **Requires estimating HDA accel. from head position and compensator output.**
- **Requires estimating 2nd derivatives.**

Forget that. Pray to gods of LMS. (Chant, "Widrow-Hoff...")

- **Really want to remove effects of HDA accel. from PES.**
- **LMS decorrelates signals i.e. it removes effects of one from another.**
- **Sometimes, if you've thought about it enough, you do get to "Just do it."**

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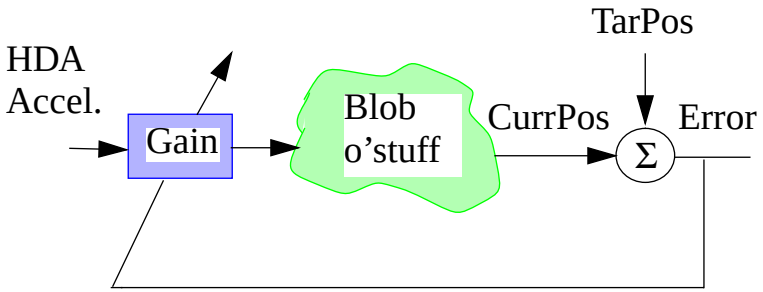
Gain Adaptation

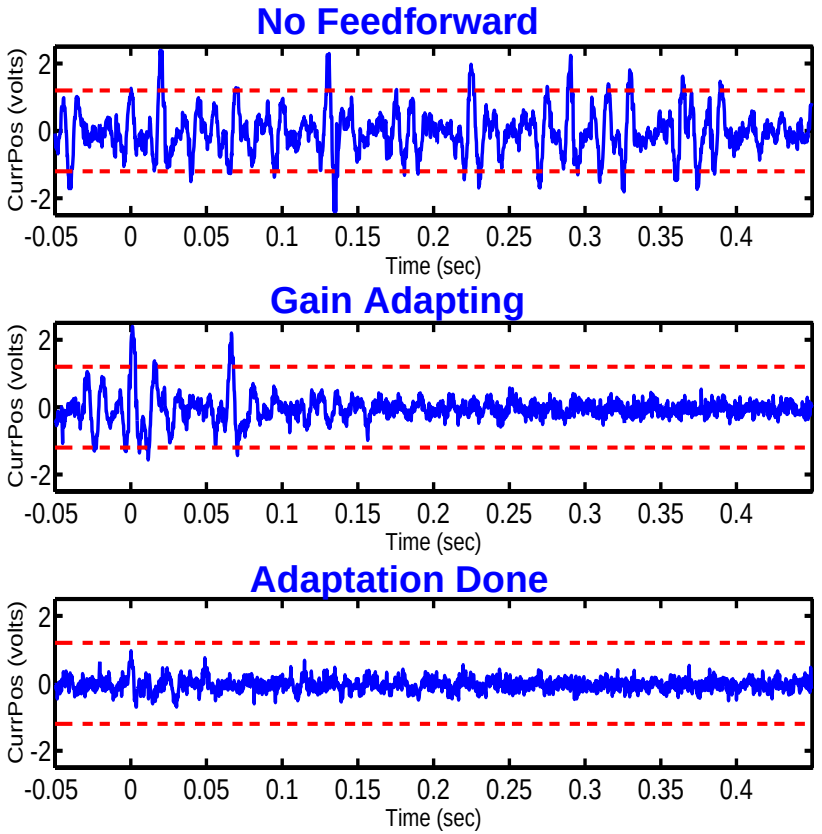


LMS:

- $w_{k+1} = w_k + 2\mu\varepsilon_k x_k$
- $\text{Gain}_{k+1} = \text{Gain}_k + 2\mu(\text{Error})_k(\text{HDA Accel.})_k$

In DSP:

- **6 instructions for LMS**
- **4 instructions for gain limit**
- **6 instructions for threshold**



- **50-150 Hz random rotary vibration**
- **57.7 rad/s^2 rms**

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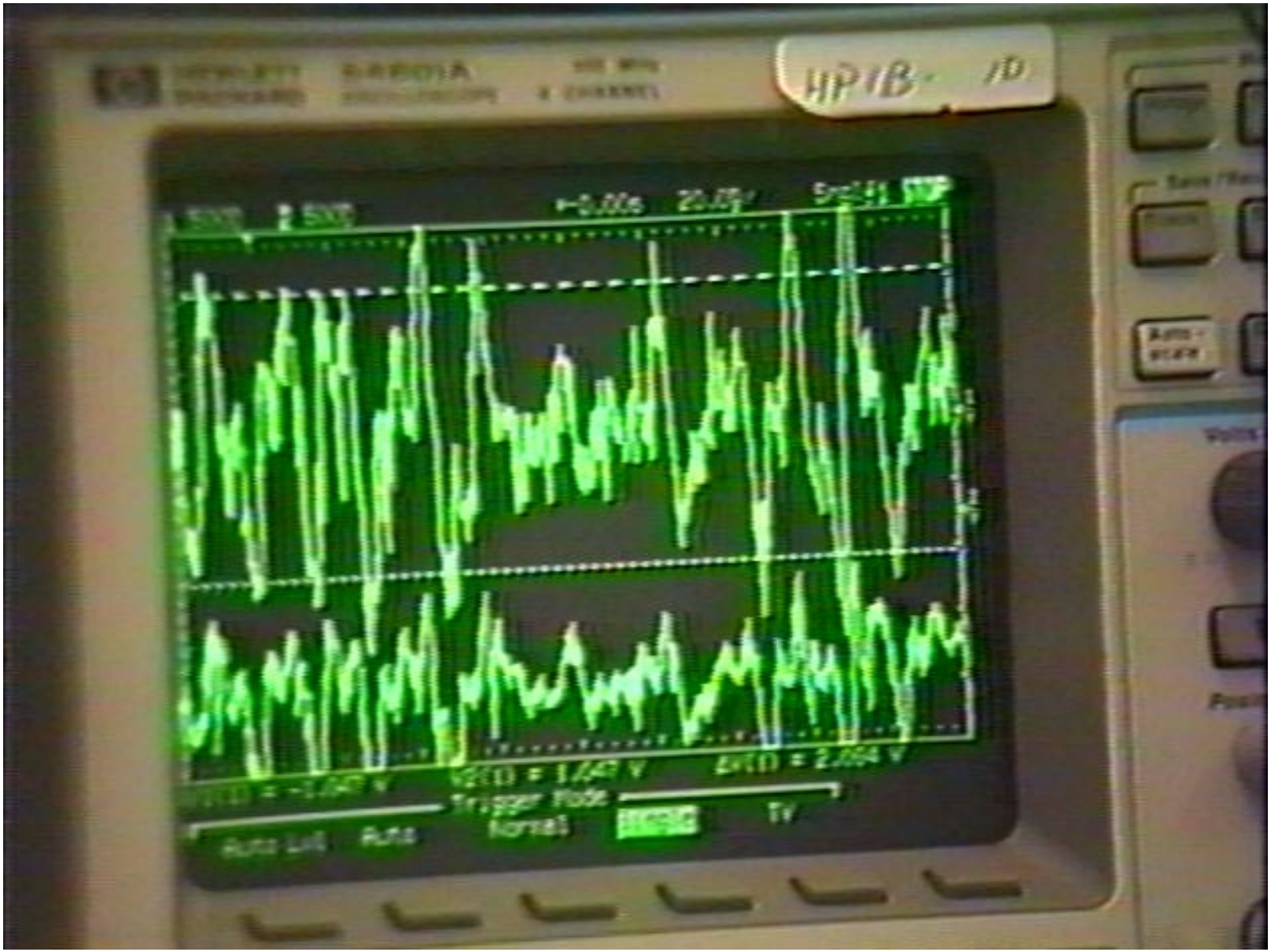

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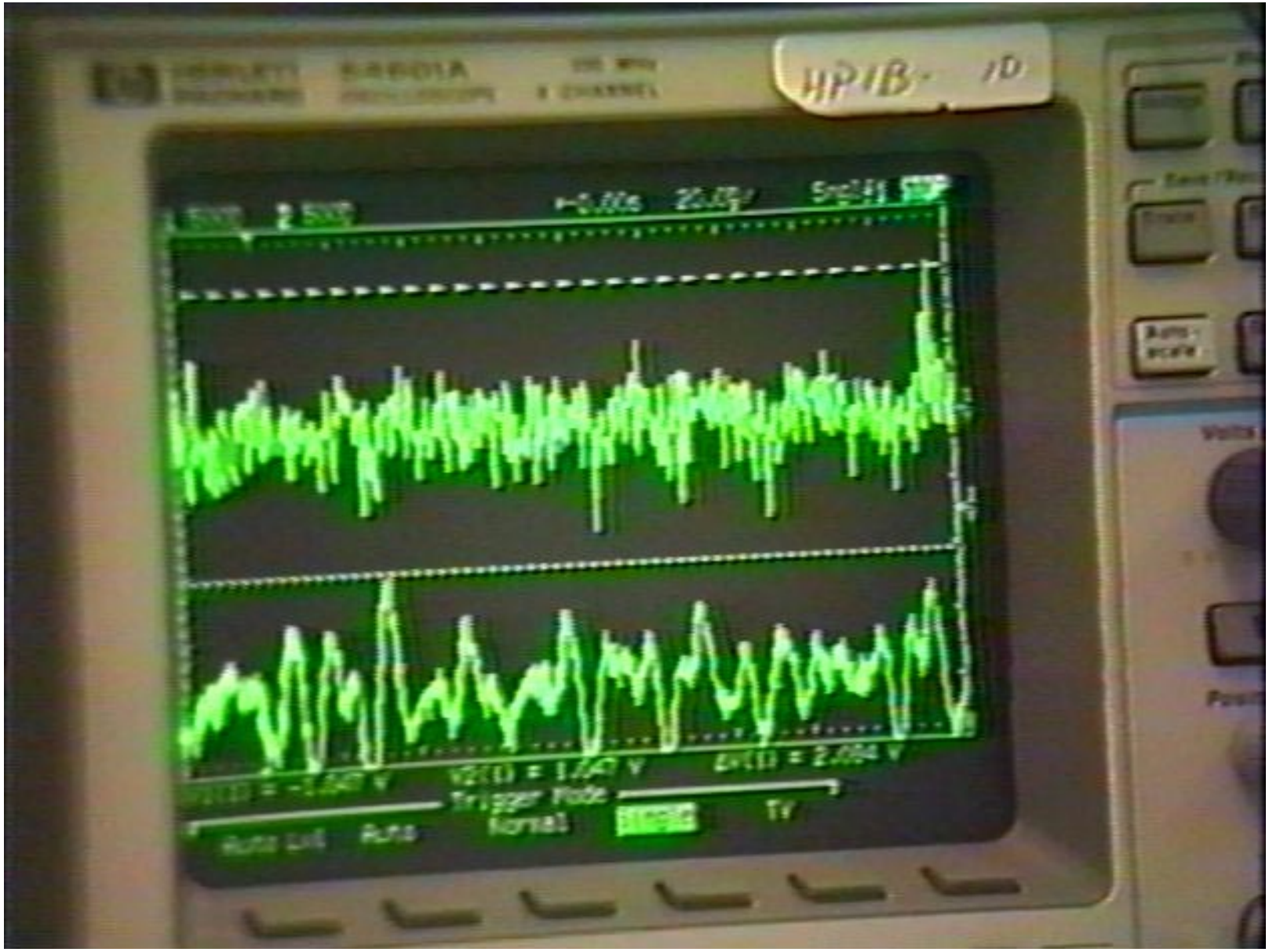
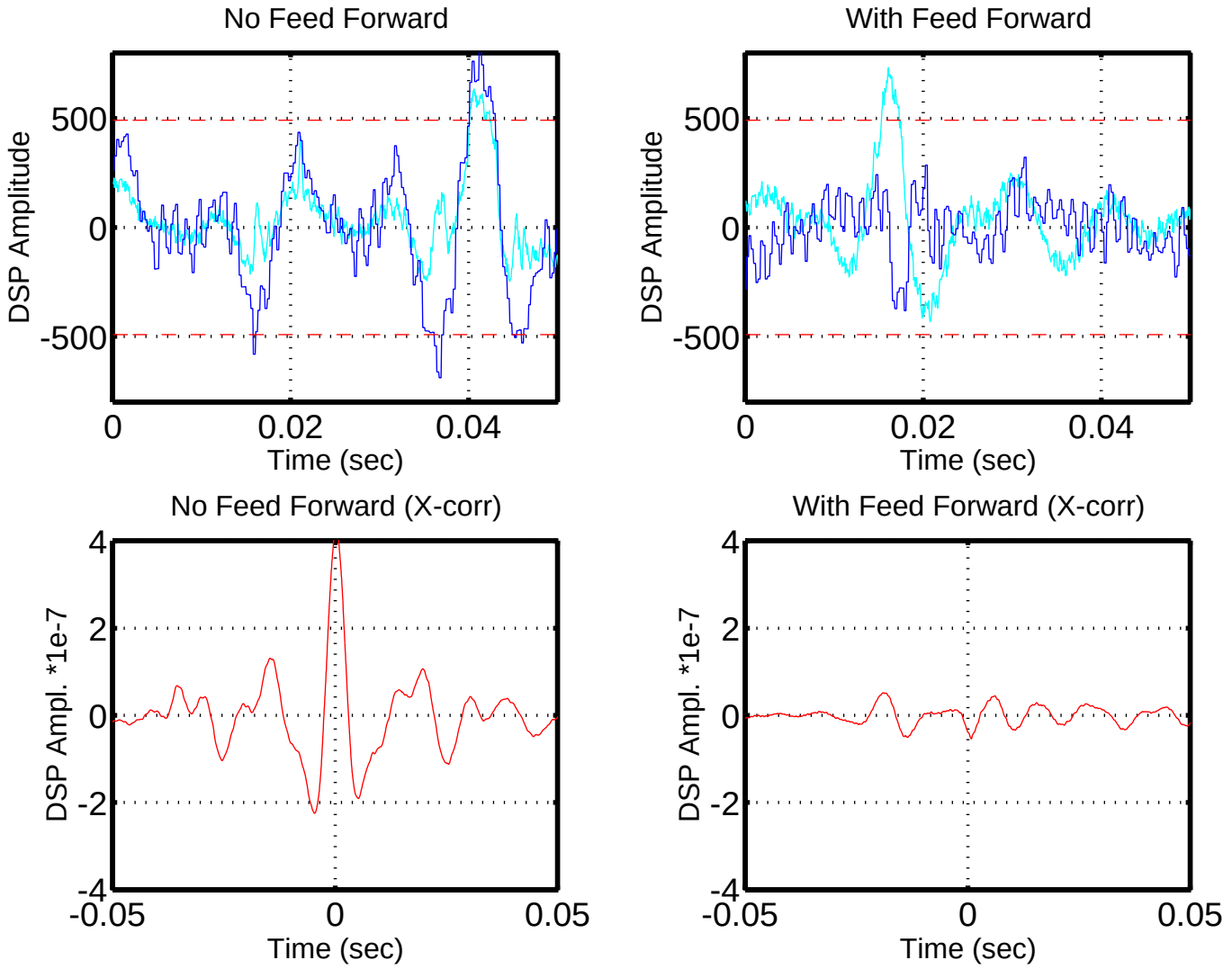


Results from adaptation: Rotational Shaking



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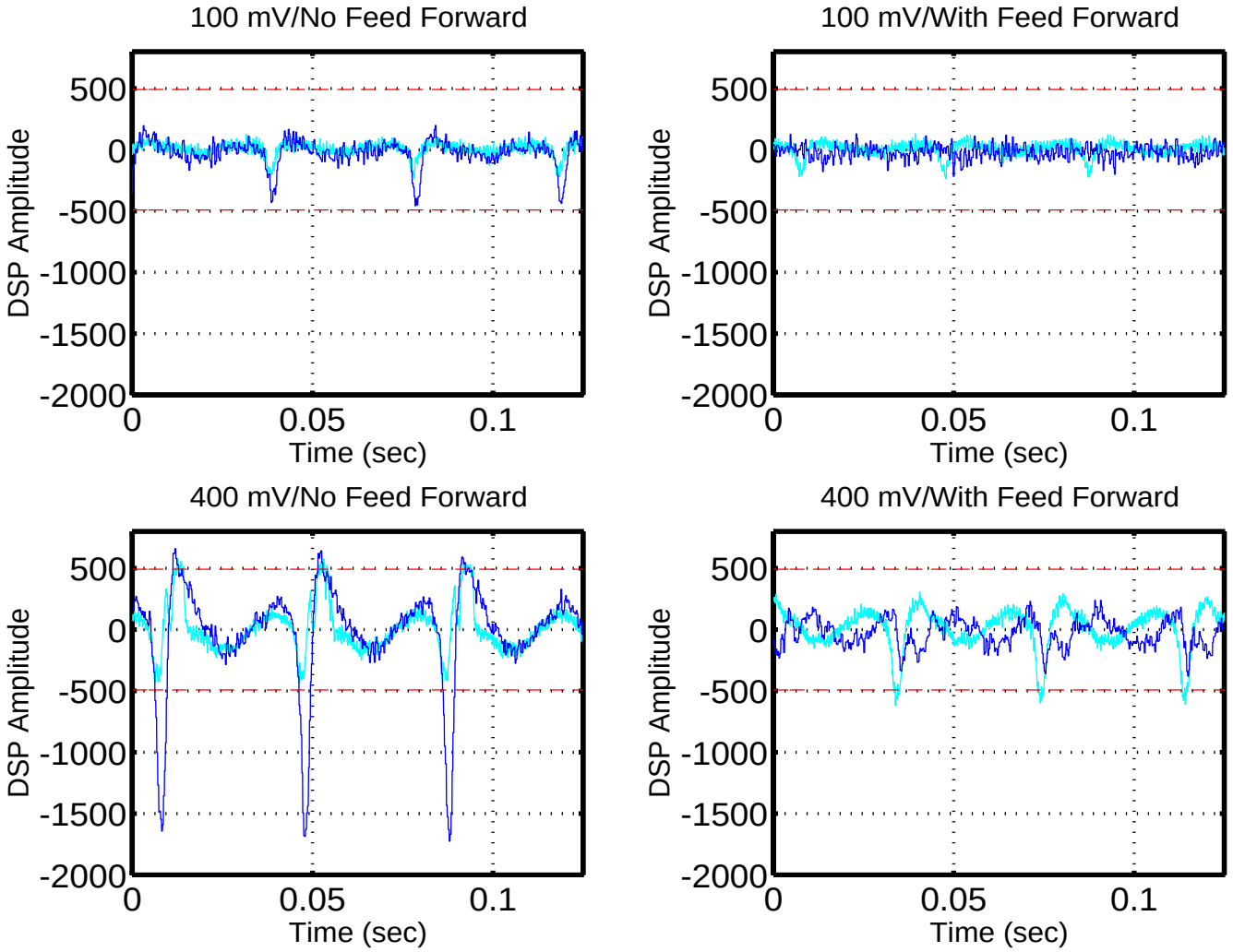
Results from adaptation: Rotational Shocking



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What Does It Cost?

Accelerometer feedforward:

- a rotational accelerometer

Multi-rate:

- 1 clock
- direct DSP access to A/D & D/A
- CPU bandwidth

Adaptation:

- 16 instructions (CPU bandwidth)
- shaking

The same method can be applied to other sensors, e.g. velocity sensing.