Optimizing a Rotating Tilt Sensor for the LISA Torsion Pendulum

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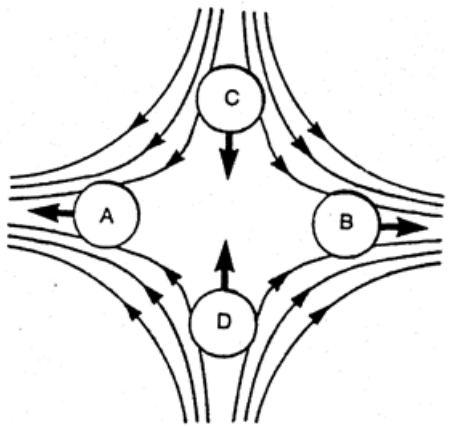
Overview

- Background
  - Gravitational Wave Detection
  - Eöt-Wash LISA Pendulum
- Rotating Tilt Sensor
- Improvements
  - Hardware
  - Software
- Results

Gravitational Waves

- Produced by asymmetrically accelerating quadrupole mass moments
- Propagating “ripples” that stretch/compress spacetime
- Why search for gravitational waves?
  - Another verification of general relativity
  - New “window” on the universe for observational astronomy
  - Could potentially observe gravitational cosmic background radiation

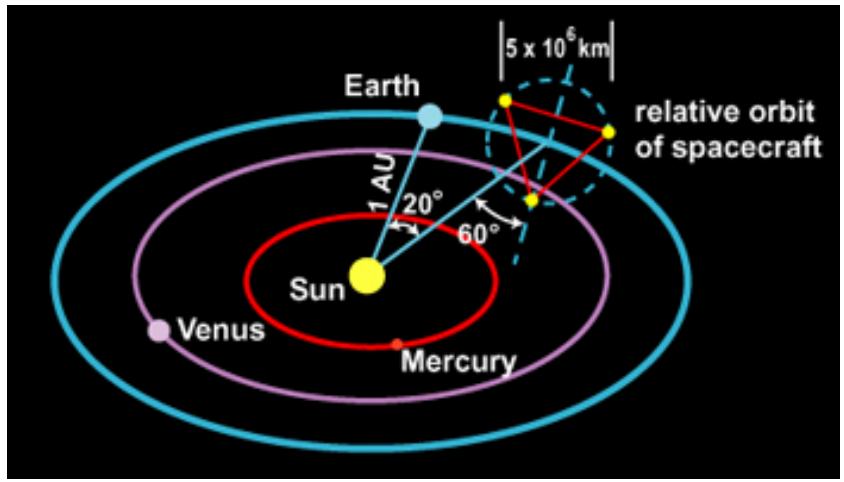
nmp.jpl.nasa.gov

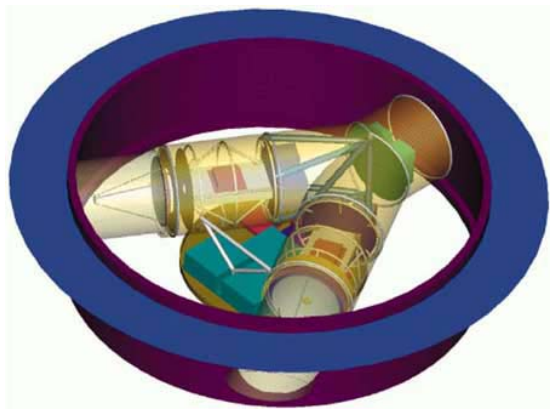


http://www.astro.utu.fi/~cflynn/astroII/l11.html

Laser Interferometer Space Antenna (LISA)

- Currently in development, launch planned for 2015.
- Three spacecraft, each operating as an independent interferometer
- Will be able to detect waves in the "low frequency" band ($10^{-4} \leq f \leq 1$ Hz), including…
  - Short period binary stars
  - Black Hole/Black Hole mergers
  - Low frequency stochastic background





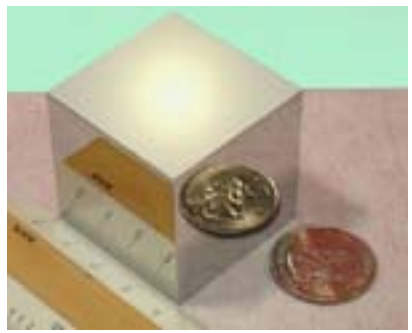
lisa.jpl.nasa.gov

LISA Test Masses

• Sensitive to displacements as small as 10 pm.

• Must be shielded from all forces except those due to gravitational waves, such as:

- Radiation pressure
- Solar wind
- Solar magnetic field
- Outgassing
- Patch Effects
- Gravitational forces within spacecraft



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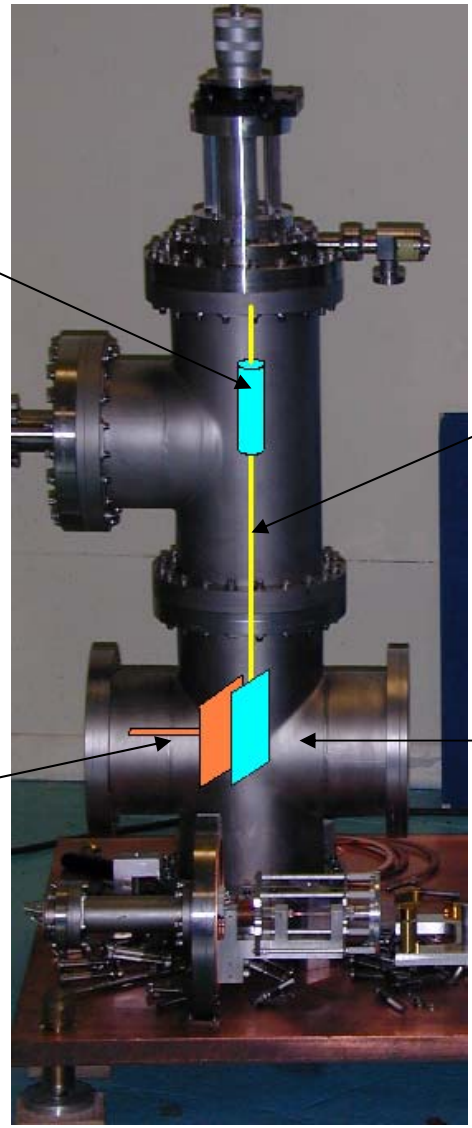
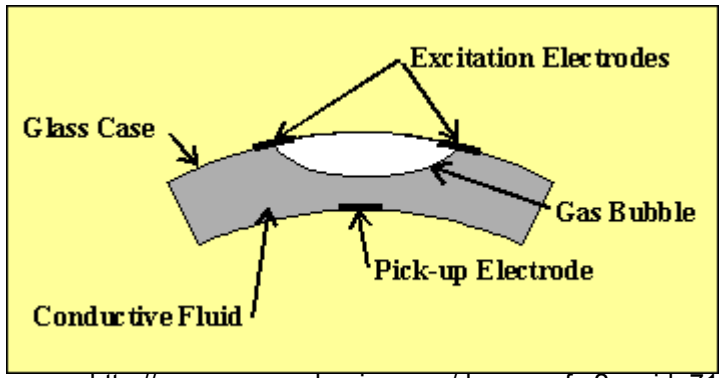
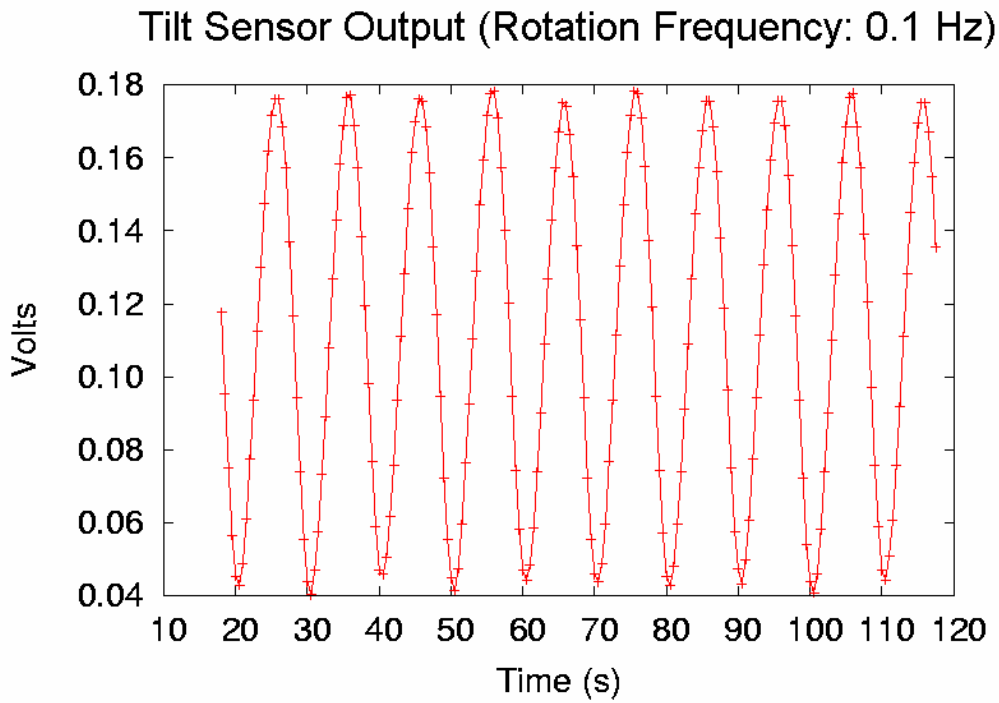
Eöt-Wash LISA Torsion Pendulum



Rotating Tilt Sensor



http://www.geomechanics.com/dspapp.cfm?appid=71



Why Rotating?

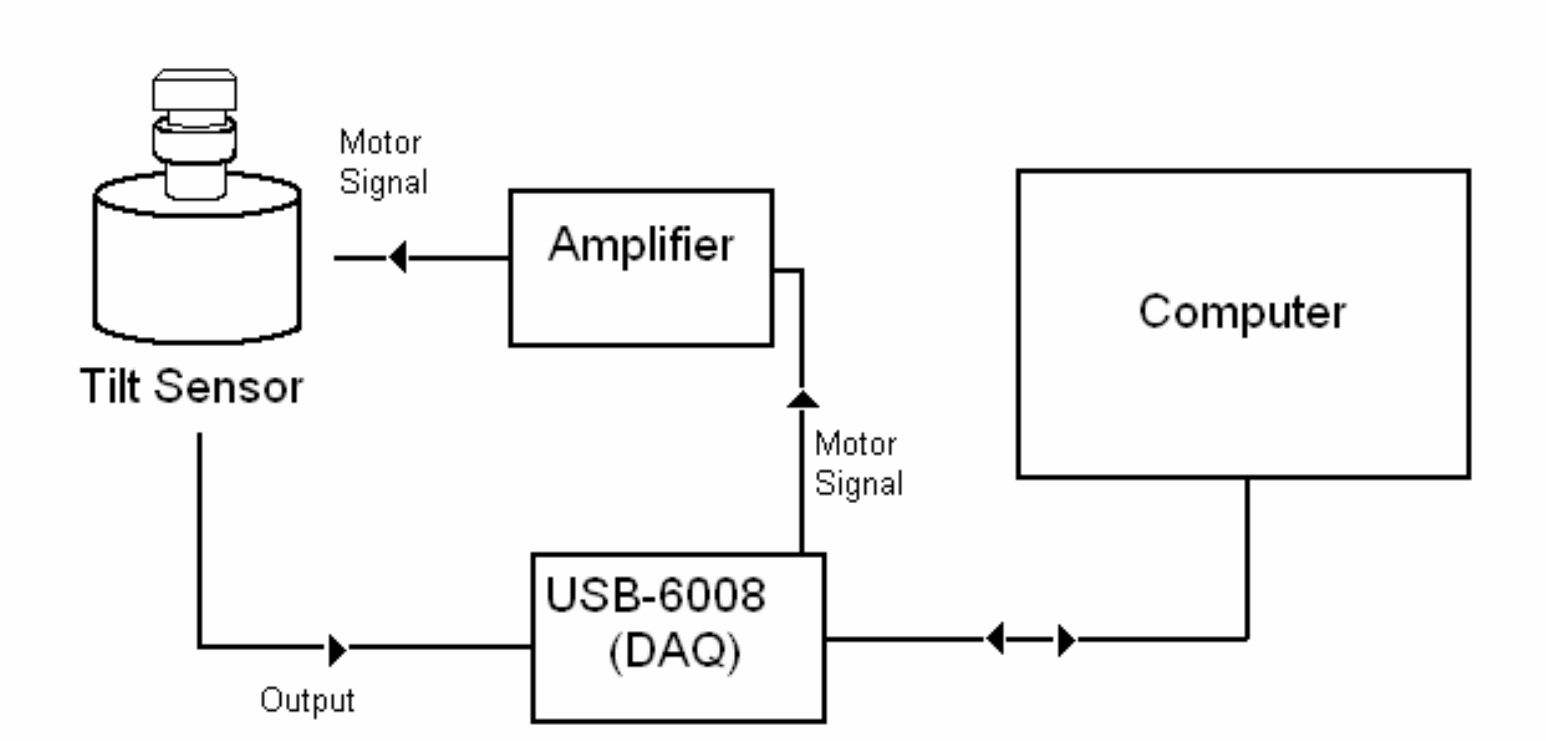
- Zero-point drift
  - Time varying signal about zero
- Rotating the tilt sensor gives an oscillating signal
- Fitting this to a sinusoidal function allows us to extract the actual tilt

$$o(t)=z(t) + A(t)\ sin(2\pi ft+\phi)$$

Zero-point drift

Tilt

Original System

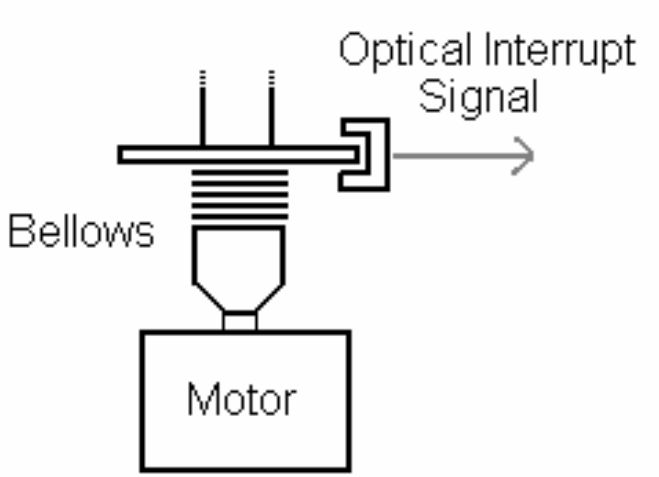


- Both motor signal and data collection handled by computer

- Rotation frequencies very low

Hardware Improvements

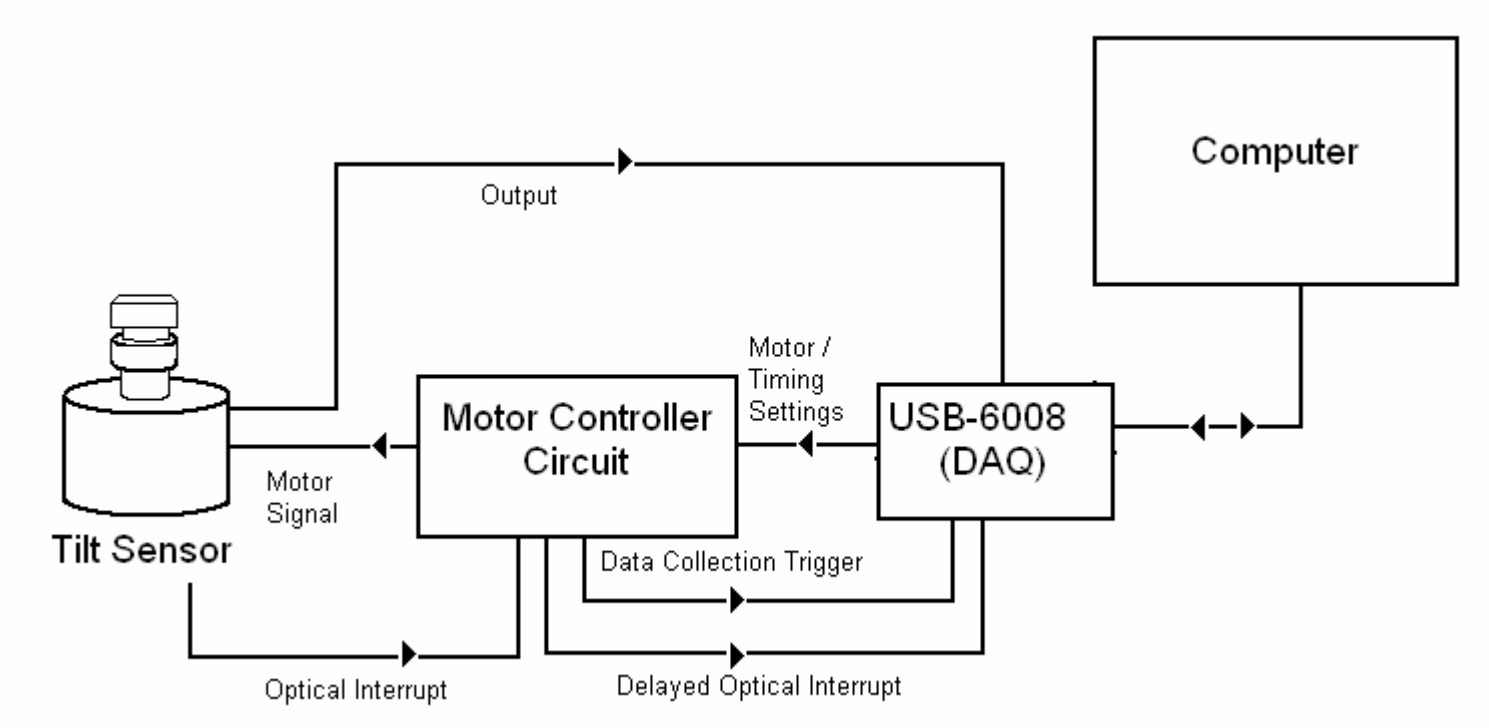
- New Stepper Motor
  – Capable of higher rotation frequencies
- L297/L298 Motor Controller
  – Hardware based method of signal generation for stepper motor
- Crystal Oscillator
  – Hardware based clock signal for stepper motor
- Optical Interrupt
  - Used to mark when the motor has completed one revolution
  - Useful in data analysis routines
- Data Collection Trigger
  – TTL signal (from crystal oscillator) used to time data collection



Software Improvements

- "Machinery" behind user interface controls updated
- Data Analysis code added
  - Fits the raw data to a sinusoidal function:
    - $f(t) = o + \sum_n a_n \cos(\omega_n t) + b_n \sin(\omega_n t)$
  - The coefficients give the offset, x-tilt, and y-tilt

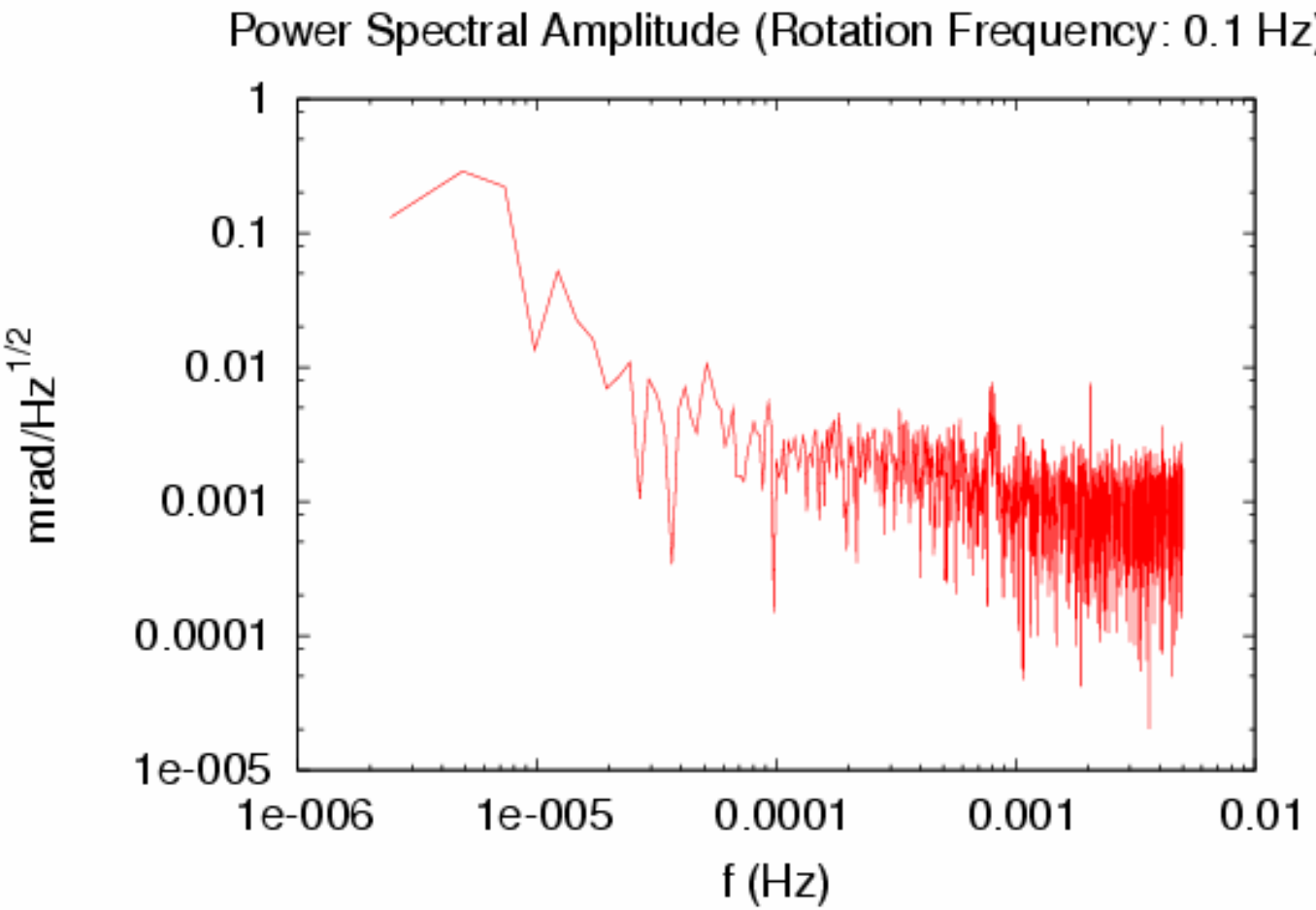
New System



- The repetitive work is done by the *hardware*

- The software is now free to handle other less demanding tasks

Results


Power Spectral Amplitude (Rotation Frequency: 0.1 Hz)
mrad/Hz^1/2
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
1e-005
0.0001
0.001
0.01
f (Hz)

Conclusions

- We have developed a system that is primarily hardware based
- Higher rotation frequencies can be achieved

  (greater than 0.1 Hz)
- *However…*
  - Current noise levels when rotating exceed those of stationary runs

Acknowledgements

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- The Eöt-Wash group - in particular:
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  - Stephan Schlamminger
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