Active Vibration Isolation and Some More Things

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Ando Lab Midterm Seminar 2019

Active Vibration Isolation and Some More Thing~~s~~

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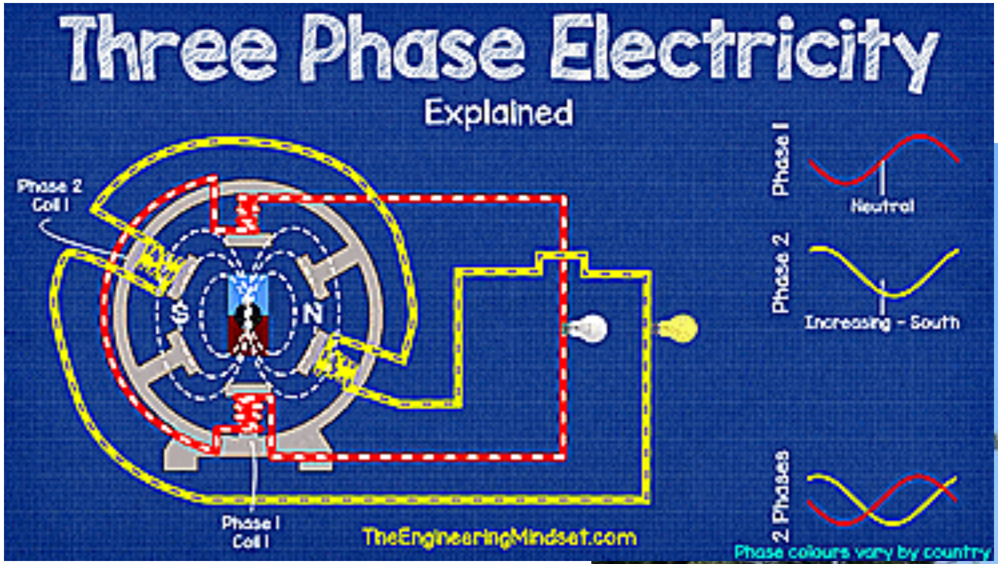
Contents

- Active Vibration Isolation
  - Current Status
  - Next Task
    - New Frame
    - Tiltmeter
- Other Ideas
  - Broader-Bandwidth Inertial Sensor
  - Thermal Noise Measurement of Coil-Coil Actuators
  - Measurement of Non-Equilibrium Suspension Thermal Noise
  - Frequency Stabilization Using OMIT
  - etc…

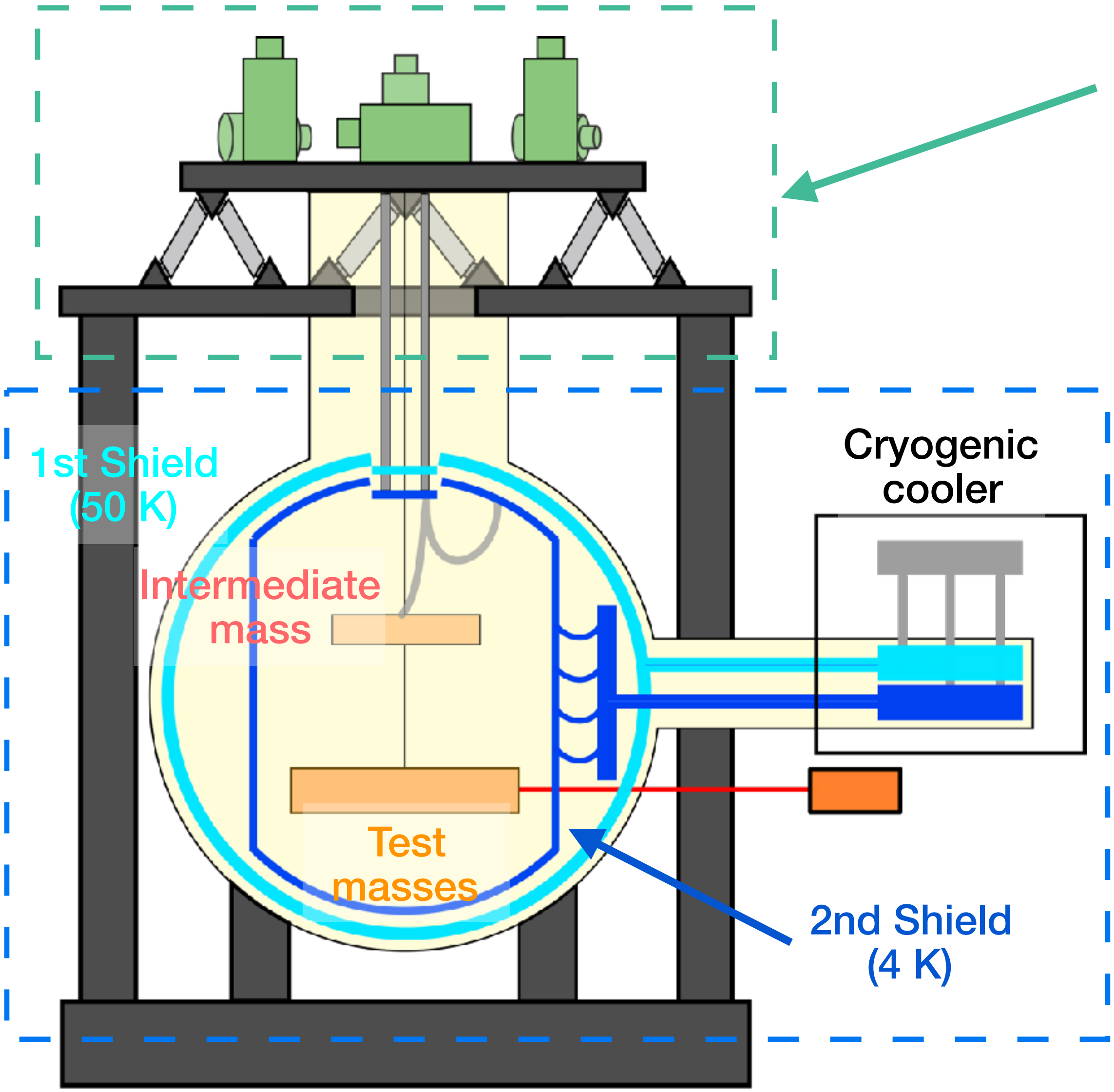
Active Vibration Isolation for Phase-III TOBA

What is TOBA

- … was told many times
- I focus on Phase-III TOBA

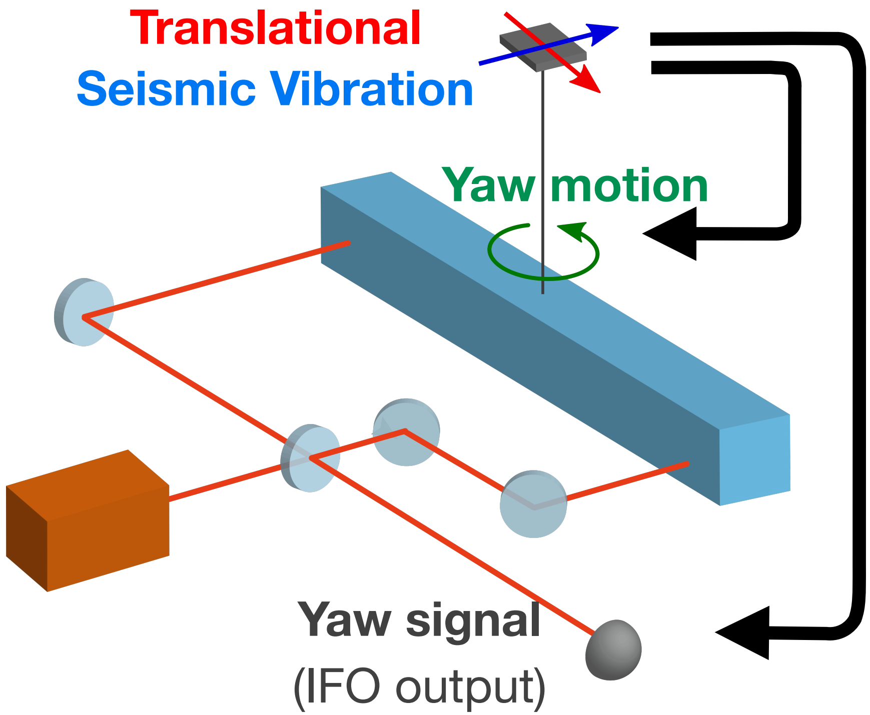


Phase-III TOBA



- Active vibration isolation
  - isolation ratio ~ 10^2 @ 0.1 - 1 Hz
  - reducing vibration caused by the cooler via heatlinks
- Cryogenic
  - cooled down to 4 K (Shimoda)
  - Silicon wire with High Q ($Q \sim 10^8$) (Ching Pin)

Seismic Cross-Coupling Noise



induced by asymmetry
of the system
(mirror tilt, TM tilt, etc.)

Cross-coupling noise = **Coupling Coefficient** × **Translational Seismic Vibration**

Requirement:

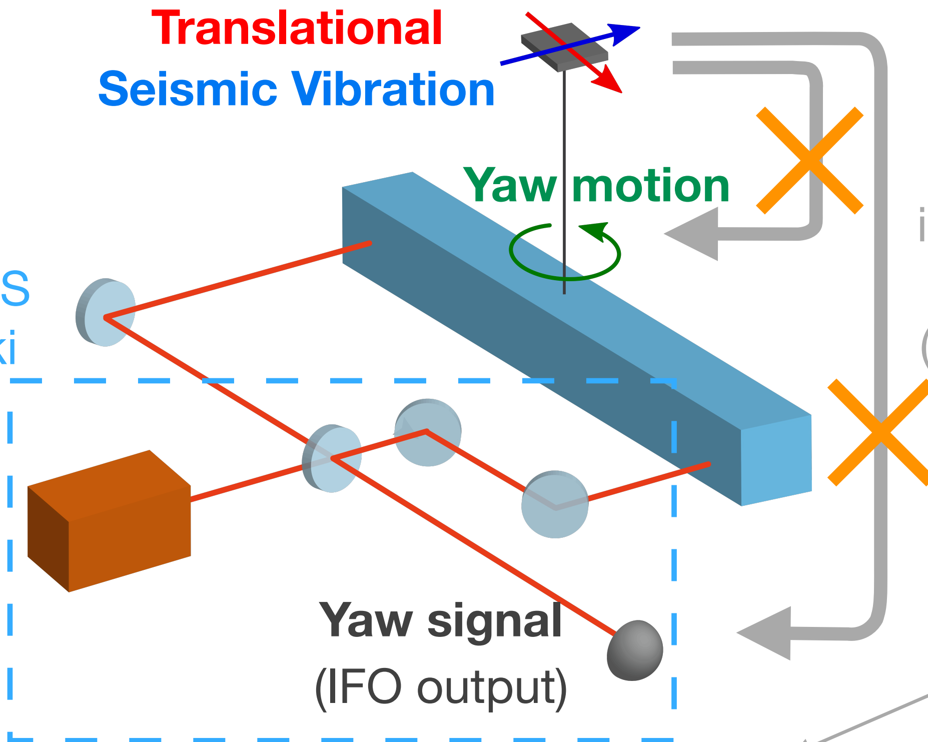
10^{-16} rad/√Hz @ 0.1 Hz

10^{-9} m/rad

10^{-7} m/√Hz @ 0.1 Hz

10^{-10} m/√Hz @ 1Hz

Seismic Cross-Coupling Noise



NewWFS
Miyazaki

induced by asymmetry
of the system
(mirror tilt, TM tilt, etc.)

Phase-2.5 (2017)
Shimoda

Cross-coupling noise = **Coupling Coefficient** × **Translational Seismic Vibration**

Requirement:
10^{-16} rad/√Hz
@ 0.1 Hz

10^{-9} m/rad

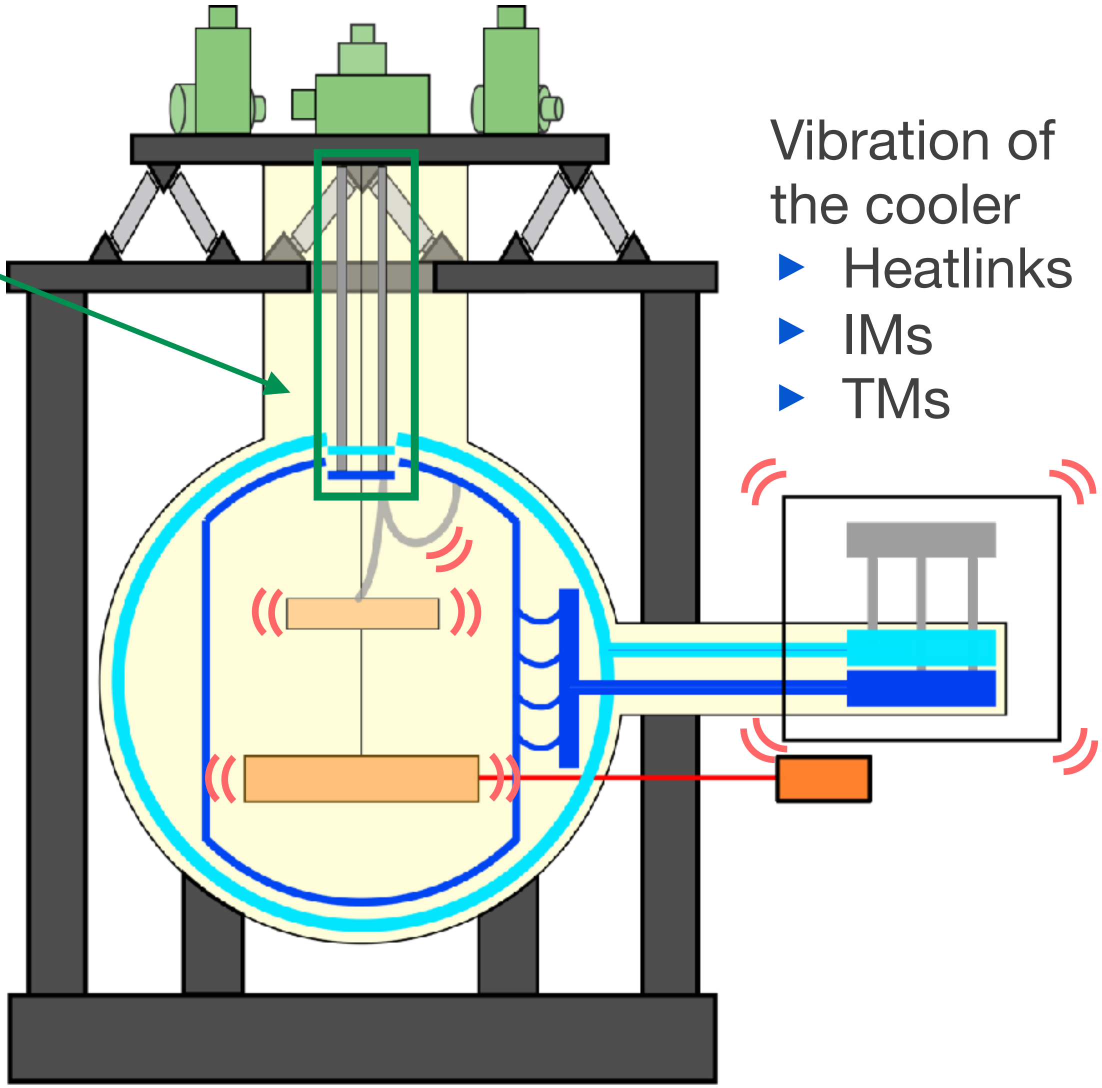
AVIT
Takano

10^{-7} m/√Hz @ 0.1 Hz
10^{-10} m/√Hz @ 1Hz

Vibration from the Cooler via Heatlinks

Adiabatic rods:
Connect heatlinks and
AVIT adiabatically

- Reduce vibration of the heatlinks by AVIT before they shake IMs and TMs



Vibration of the cooler
- Heatlinks
- IMs
- TMs

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- Active Vibration Isolation
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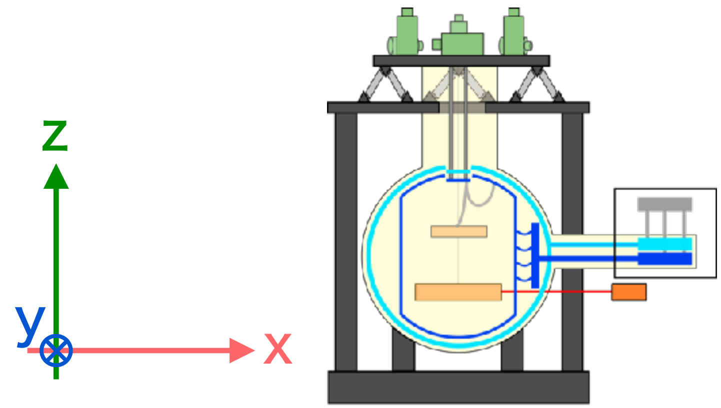
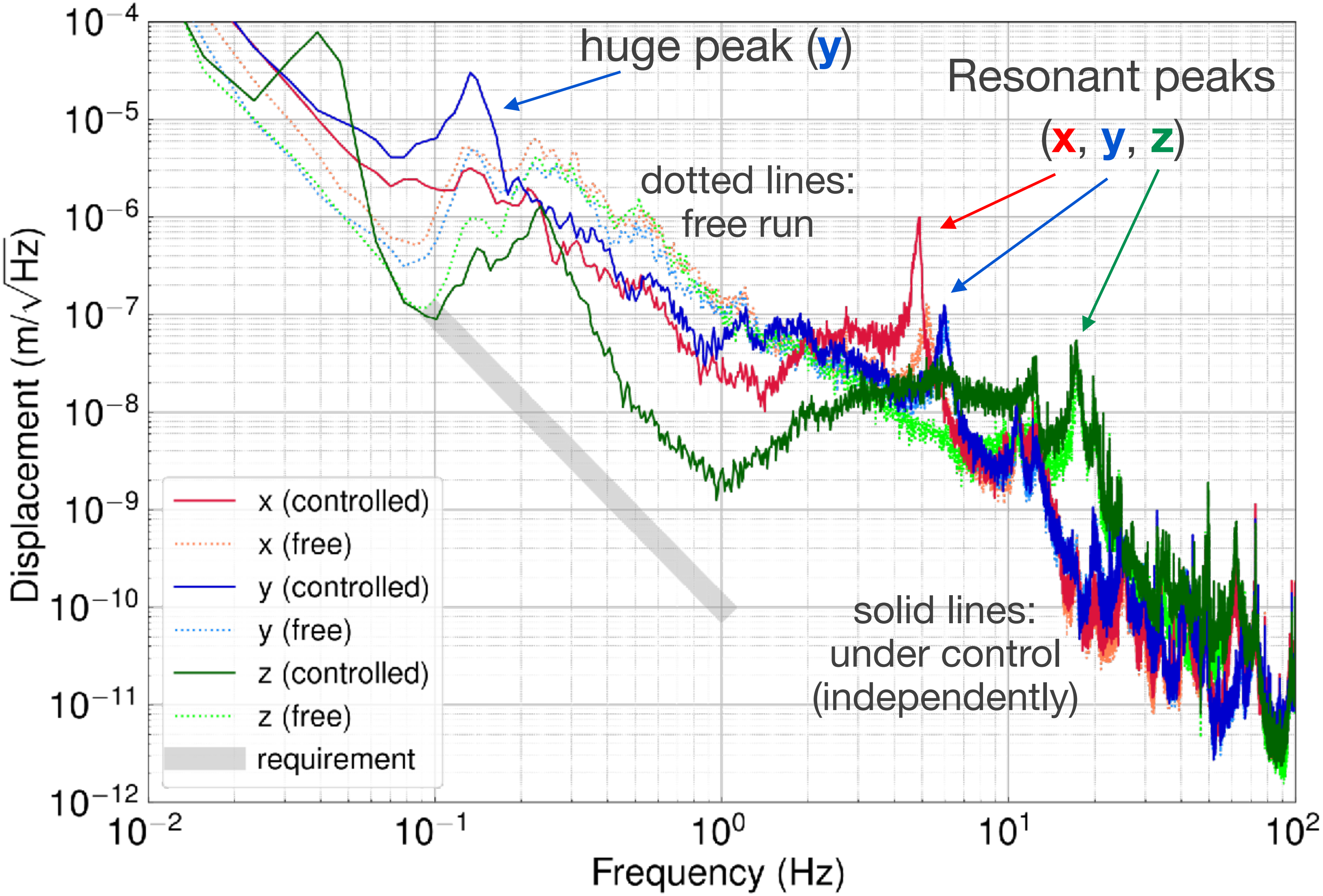
Summary of Performance at Thesis

	x	y	z
Stability	○	△	○
Max. reduction ratio	1/10	1/2	1/100
control band	0.2 - 2 Hz	0.2 - 1 Hz	0.1 - 3 Hz

- Control each DoF independently
- I failed in simultaneous control



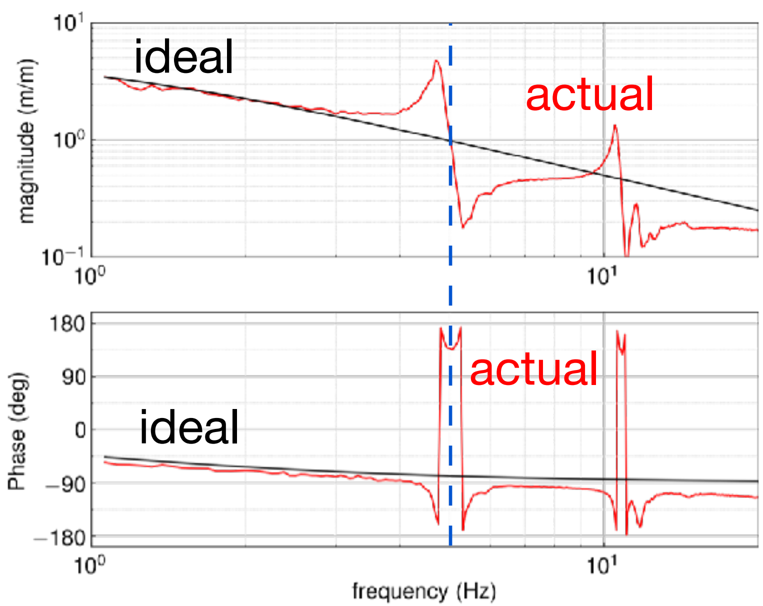
Performance at Thesis



Problems

High Frequency

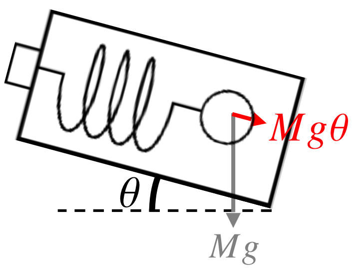
- Control Gain was small
  - UGF was limited by frame resonance modes
  - OLTF rotates > 180°



  - Make the frame stiffer

Low Frequency

- Cross-over frequency was higher than 0.1 Hz
- Servo was unstable (especially in y)
  - Tilt-horizontal coupling of Geophones



$$M\ddot{x} = Mg\theta$$

$$\downarrow$$

$$\tilde{x} = -\frac{g}{\omega^2}\tilde{\theta}$$

  - Geophones are insensitive below 0.1 Hz
  - Need another tilt sensor

Contents

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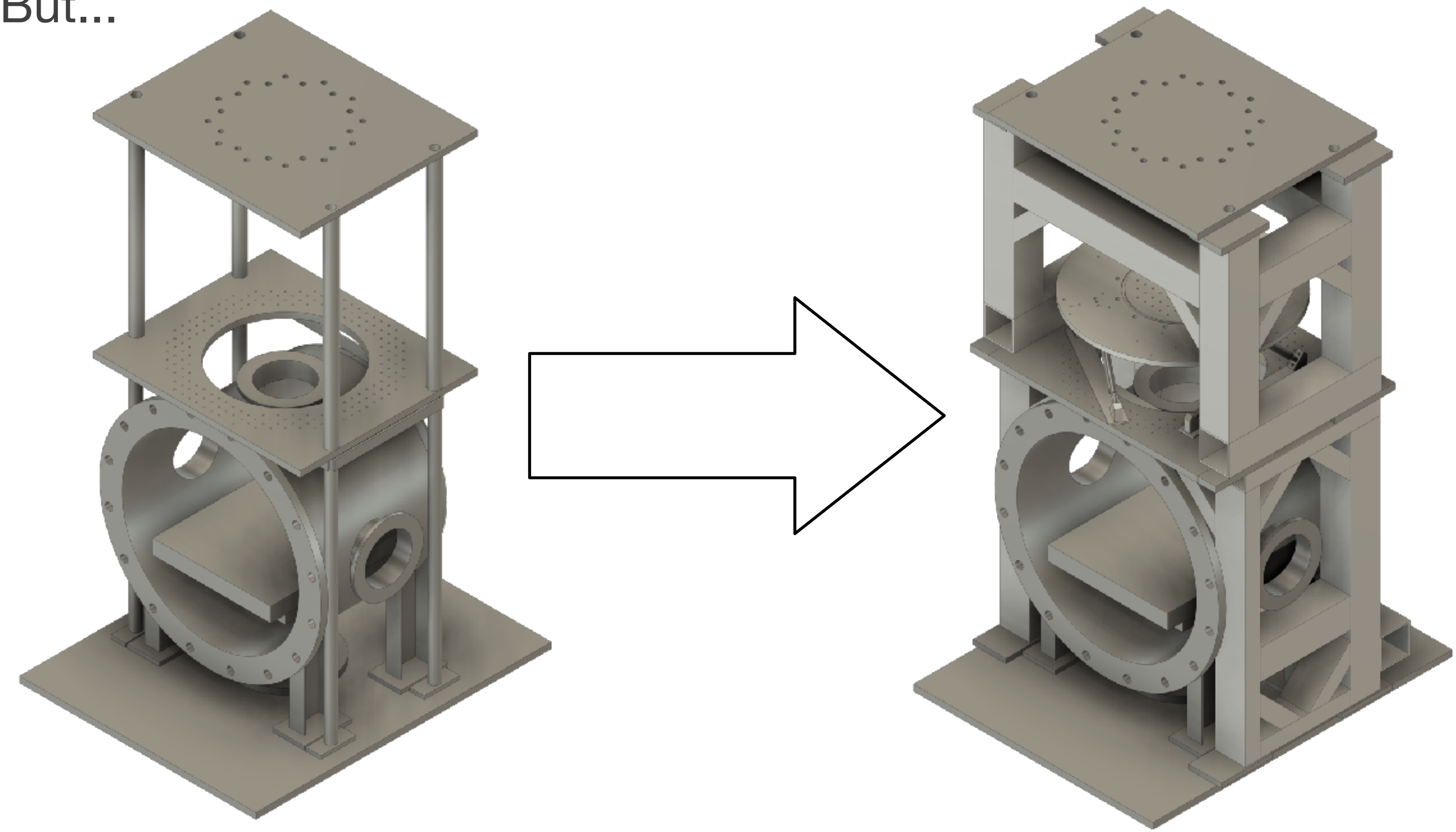
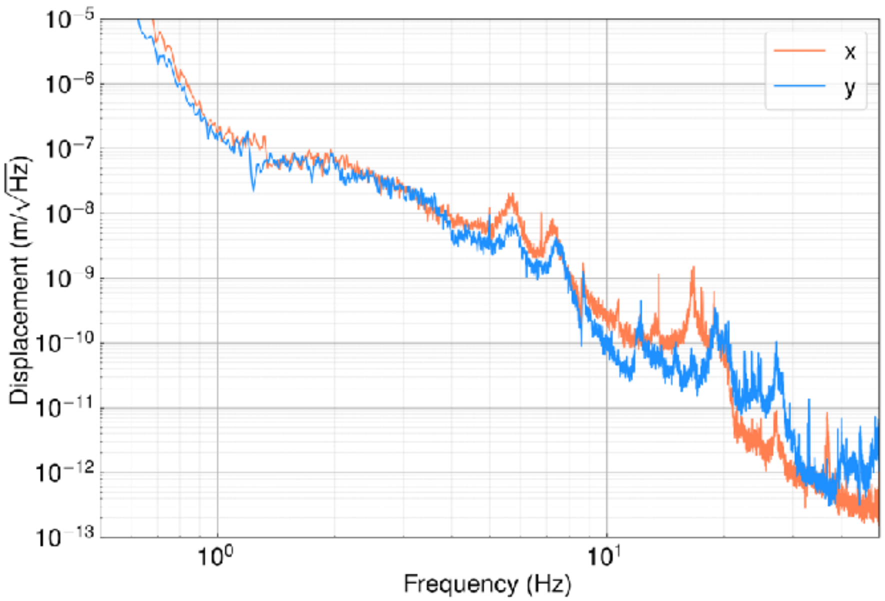
New Frame Design

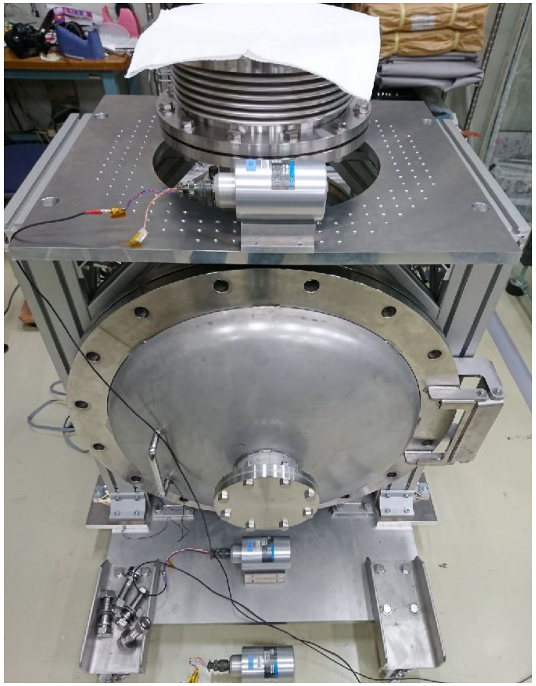
- Made by aluminum frames bought from MISUMI
- From simulation, resonant frequency of the first mode is ~ 40 Hz
- But...



Nightmare

- After construction of the 1st floor, I measured the vibration spectra.

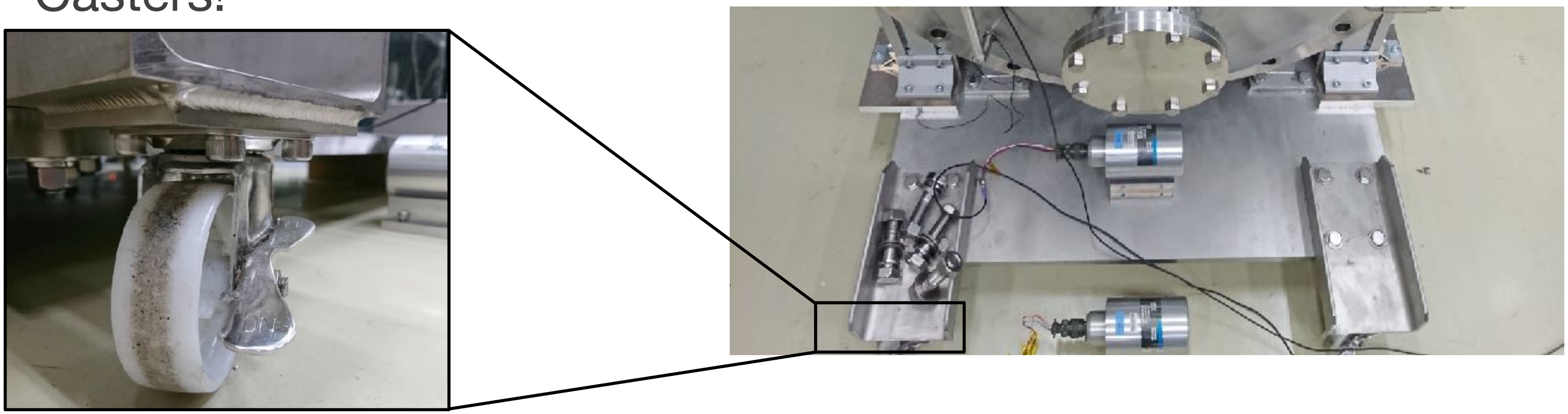




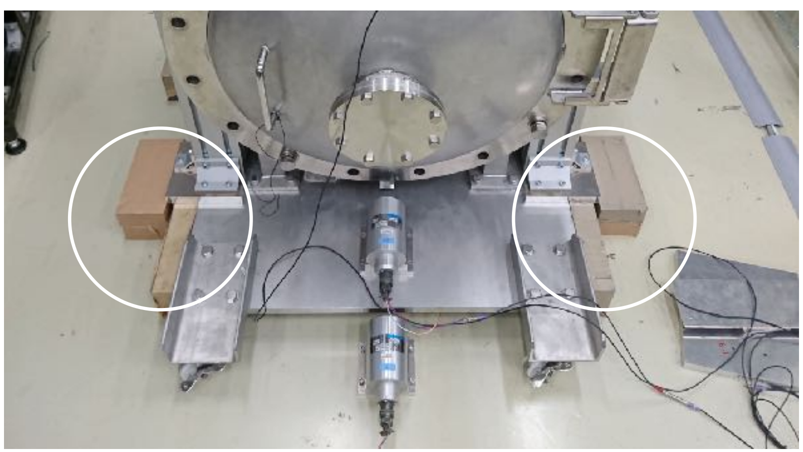
- Peaks are at 5.5 Hz (x) and 7 Hz (y).
- Almost the same as before.
- It seed that these peaks was not due to the frame resonance.

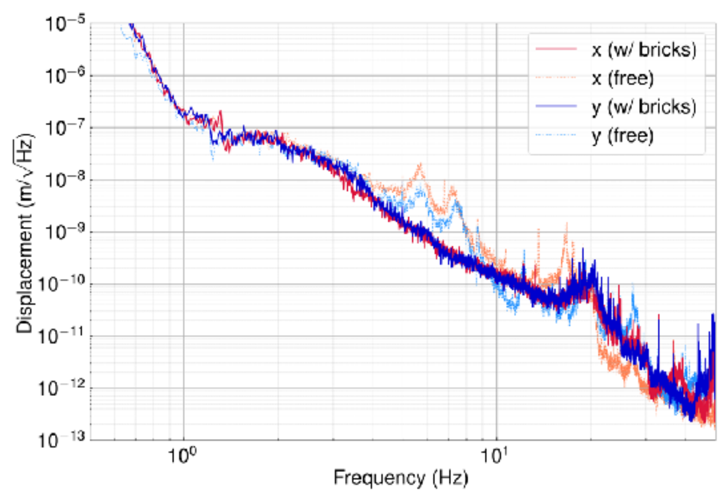
The Original Sin

- Casters!



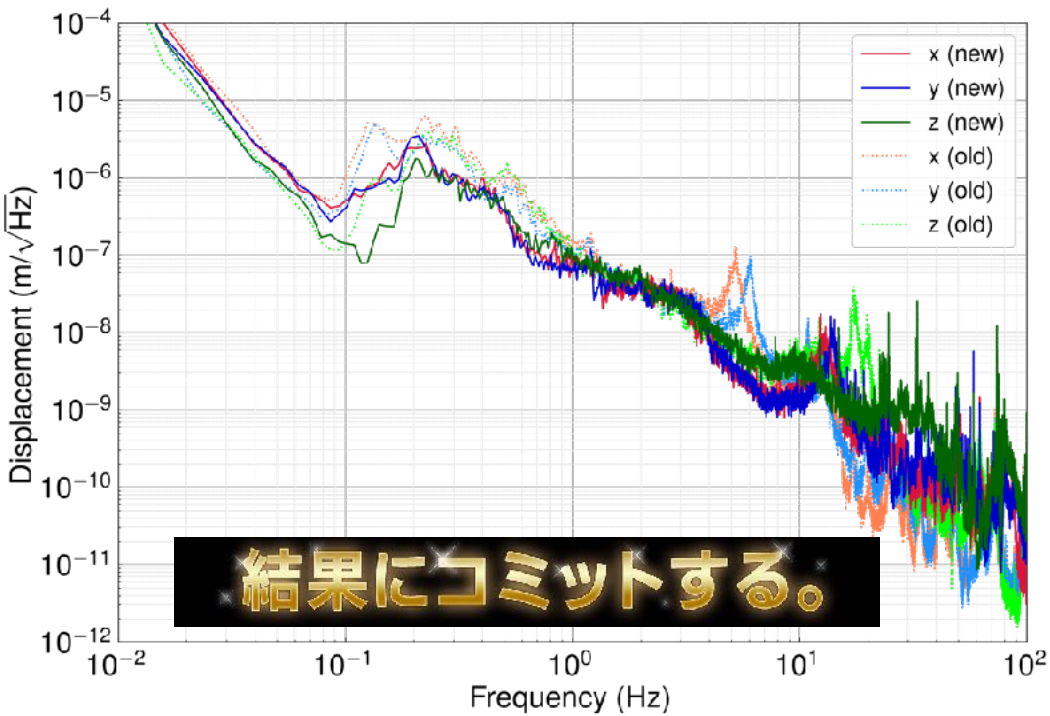
- I put lead bricks next to the base plate, then the peaks went to much higher frequency.

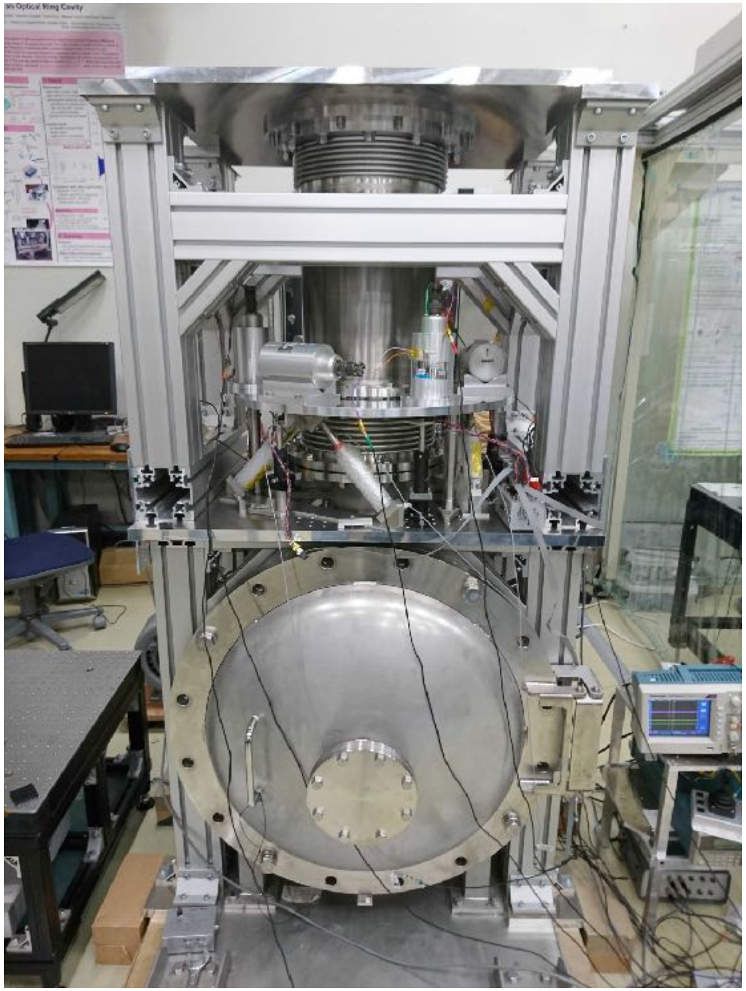




New Frame

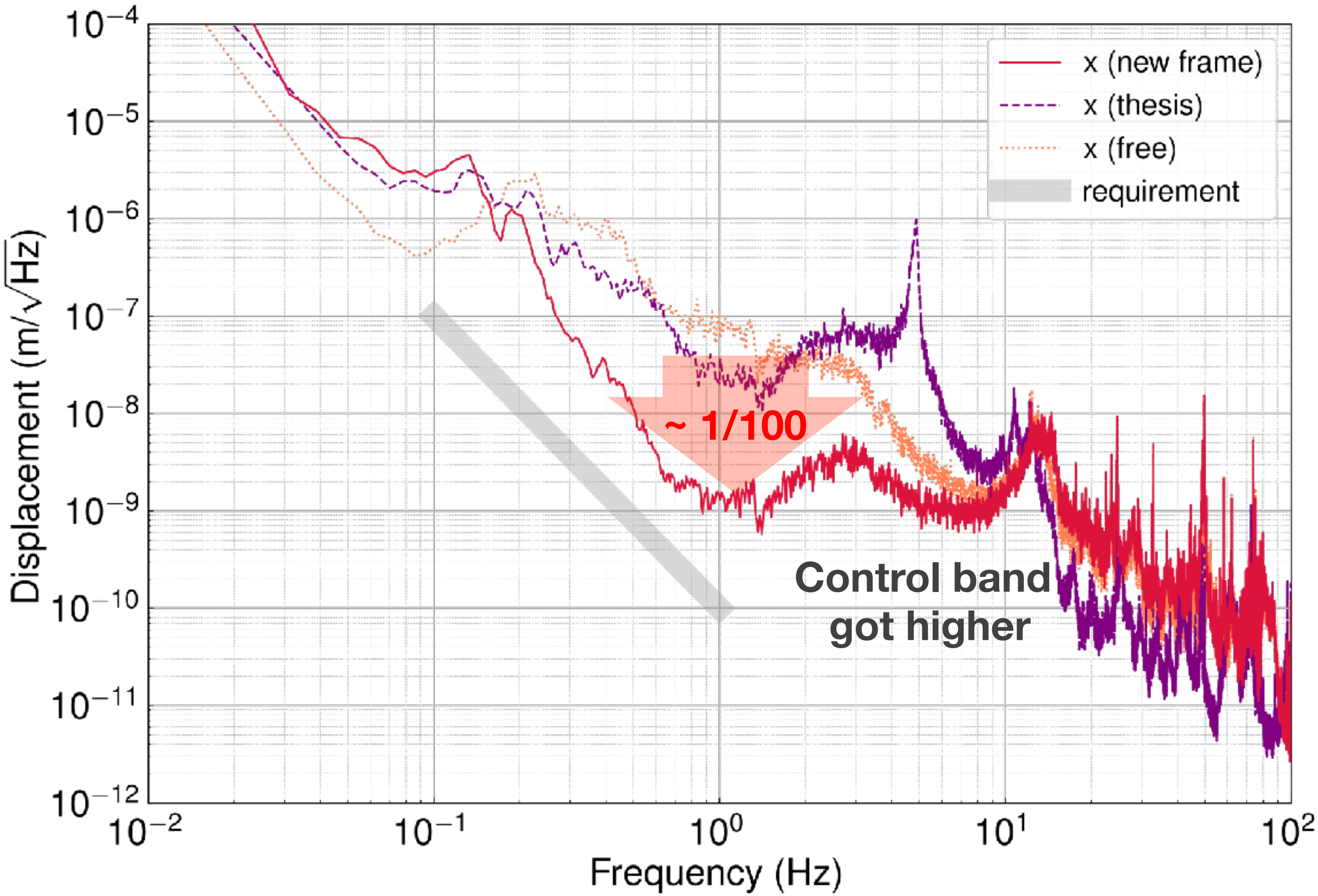
- Finally I finished to construct the new frame
- Resonant frequency of each DoF:
  - x: 5 Hz → **12.7 Hz**
  - y: 6 Hz → **14 Hz**
  - z: 17 Hz → **32 Hz**





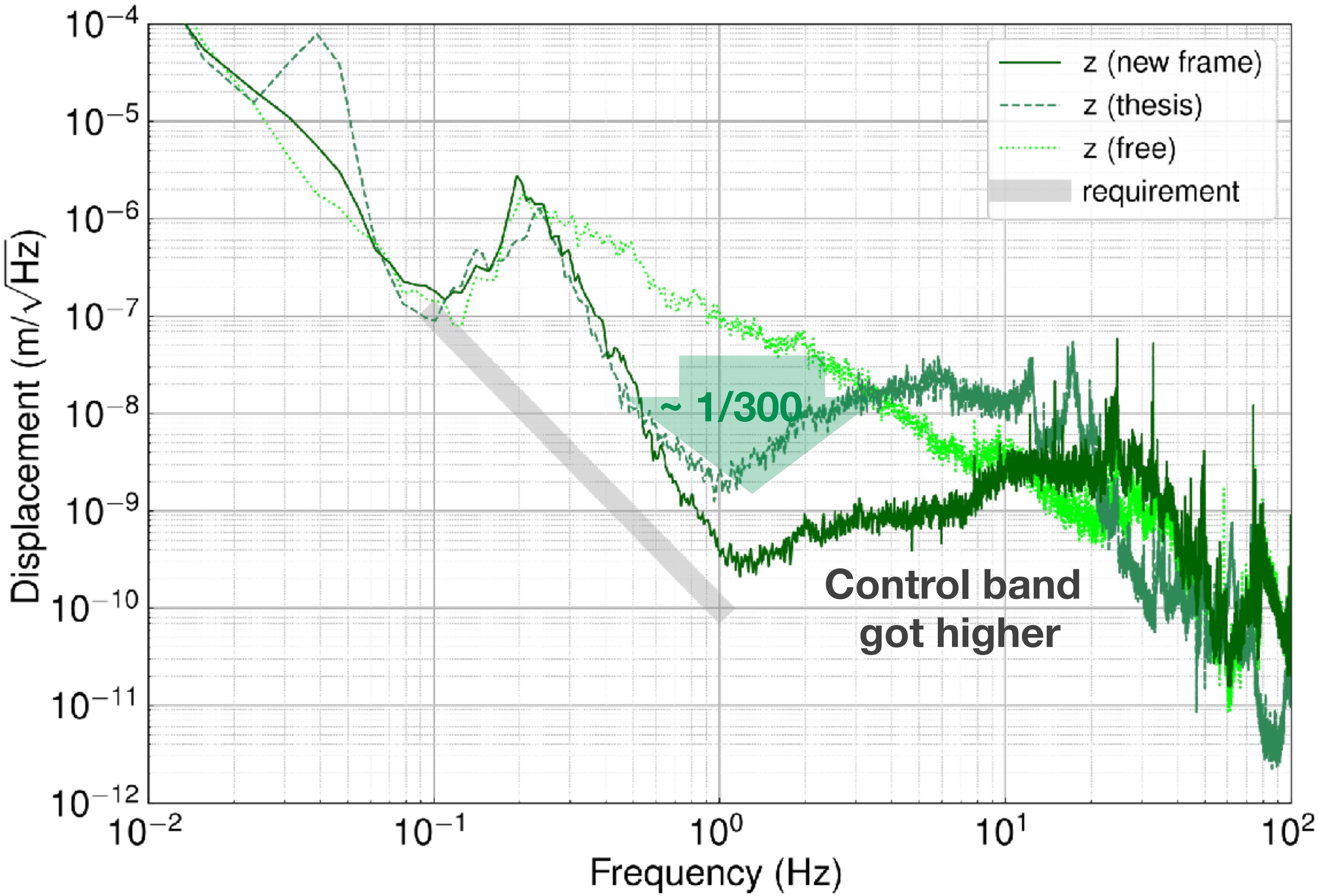
Performance on April (x)

- Performance got improved



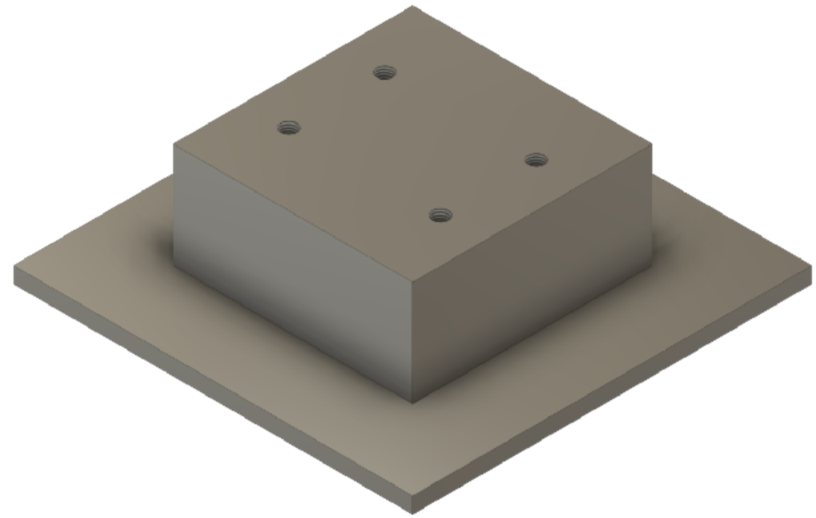
Performance on April (z)

- Performance got improved



Next Task

- Change the casters to rigider foots



- Combine the frame and AVIT to the main vacuum chamber

Contents

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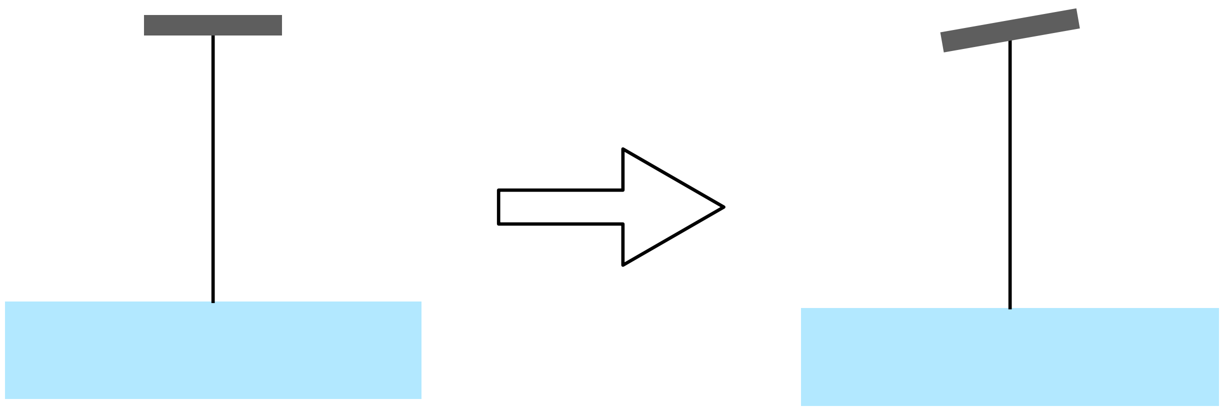
Tiltmeter

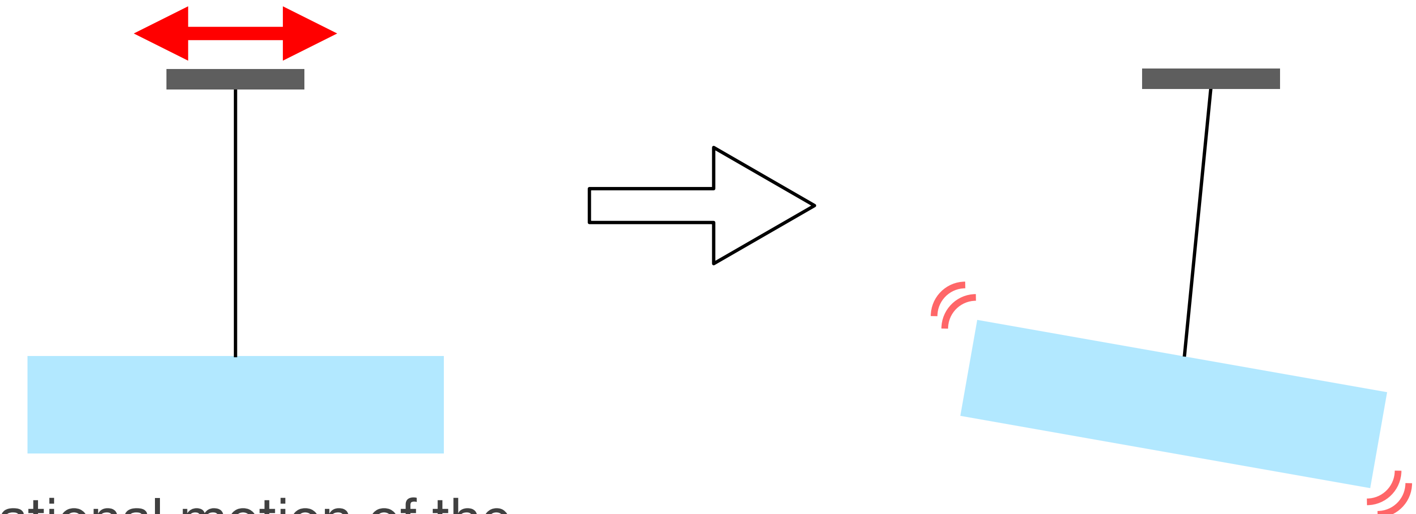


- Even though the suspension point tilts, suspended mass does not tilt
  - Relative tilt between the mass and the ground is the tilt of ground itself
- For AVIT, there are 2 functions:

◉ **Measure the actuator efficiency** of tilt to decouple 6 DoF of Hexapod

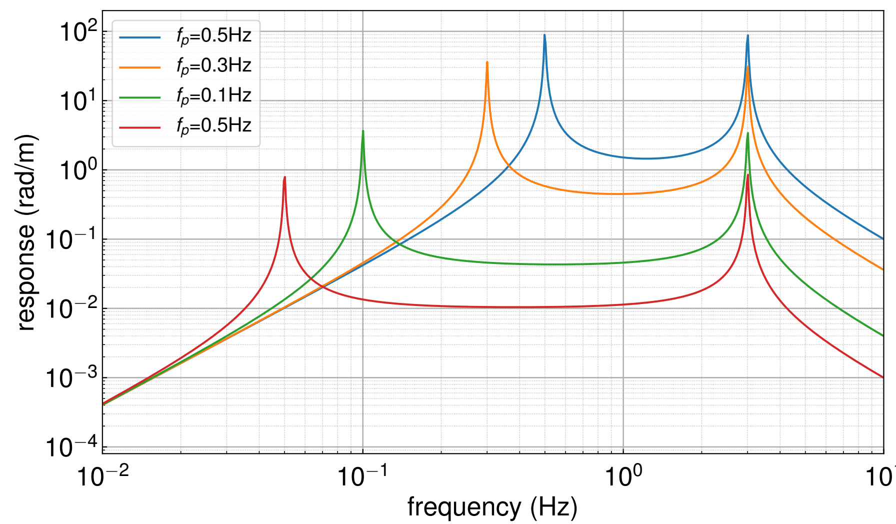
◉ **Measure the ground tilt** and control to reduce tilt-horizontal coupling

Horizontal coupling



- Translational motion of the suspension point induces tilt motion of the suspended mass
- The lower the res. freq., the lower the coupling efficiency

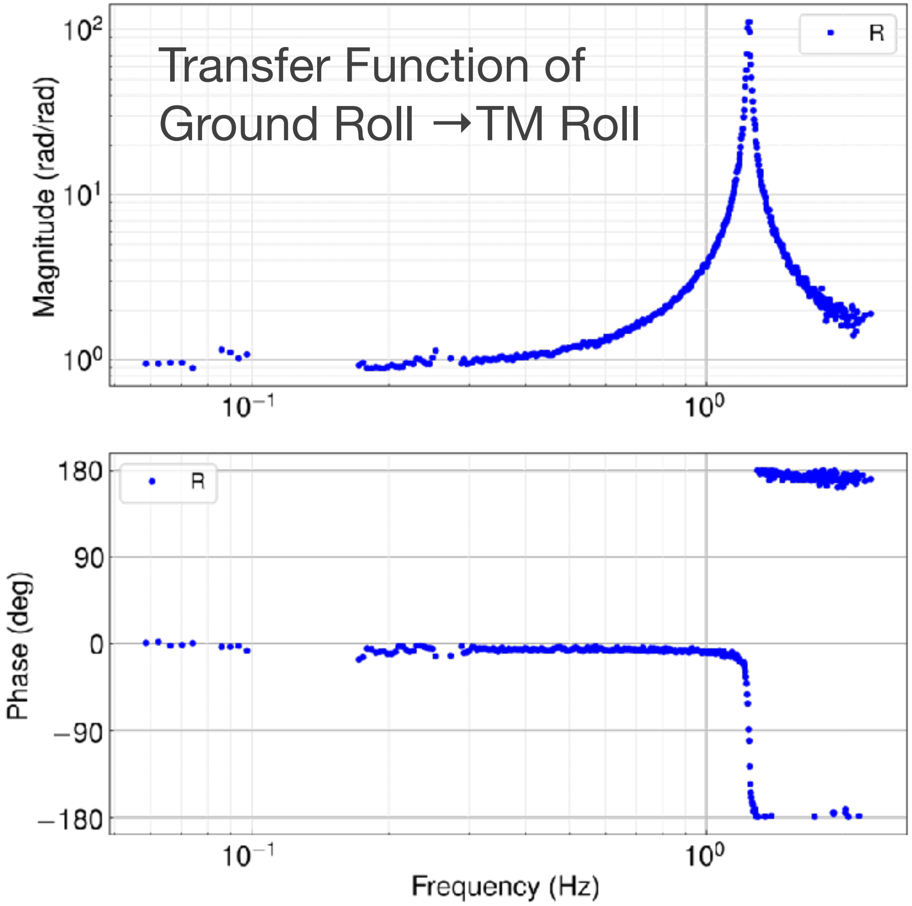
$$C_{x\theta} = \frac{\omega_t^2}{g} = \frac{(2\pi f_t)^2}{g}$$



Current Status of Tiltmeter

- Suspended successfully

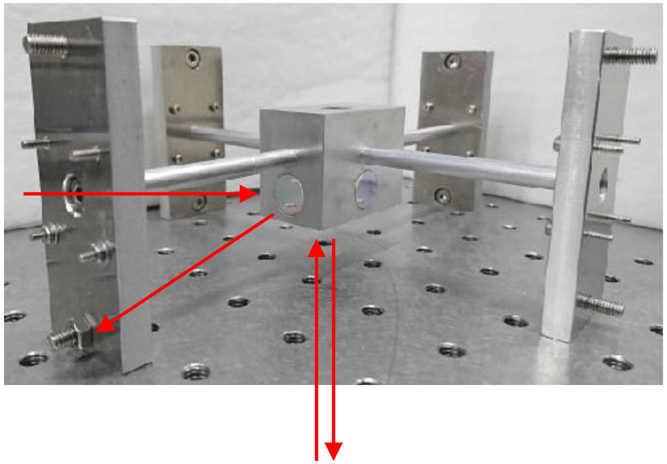
- Mechanical response were measured



Next Tasks

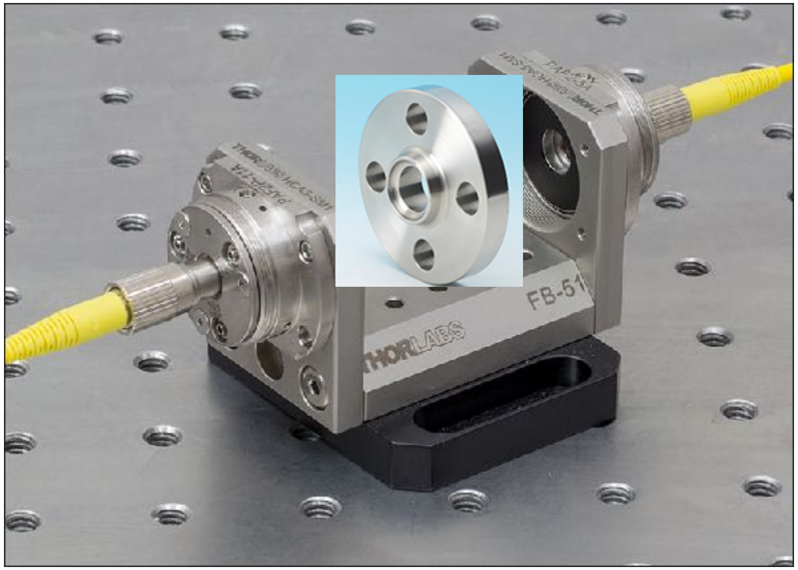
Optics

- Construct 2 optical levers
  - ◉ Pitch and Roll (from bottom of TM)
  - ◉ Yaw (from front of TM)
- Make a fiber feedthrough
  - ◉ Commercial or Handmade



Lower resonant frequency

- Target: **0.03 Hz**
- Current: **0.13 Hz**
  - ◉ Fine tuning of COM is necessary
  - ◉ Balancing is a big problem

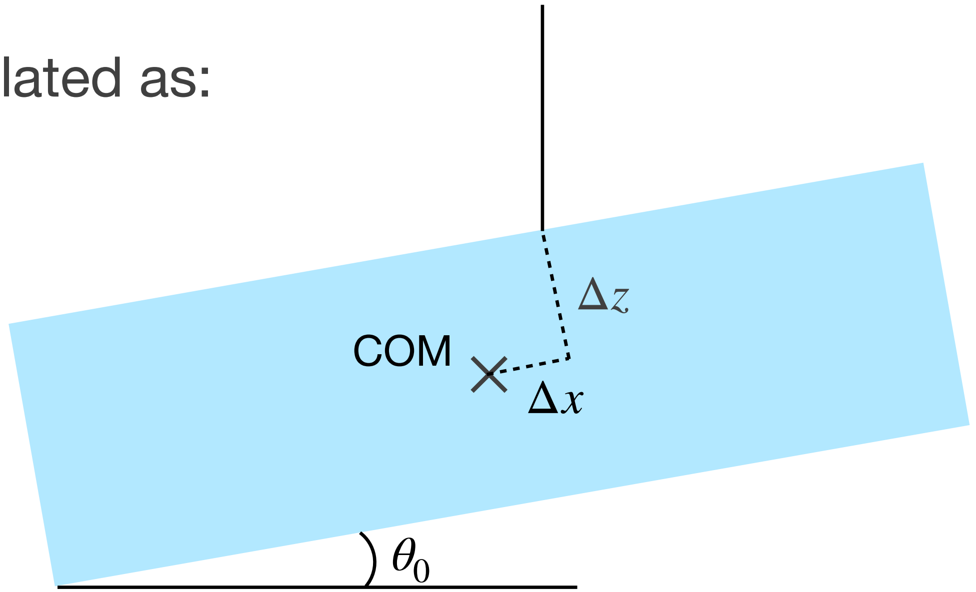


Balancing Problems

The lower the resonant frequency goes, the harder to balance TM horizontally

- Equilibrium tilt angle is calculated as:

$$\theta_0 = \frac{mg\Delta x}{mg\Delta z + \kappa}$$



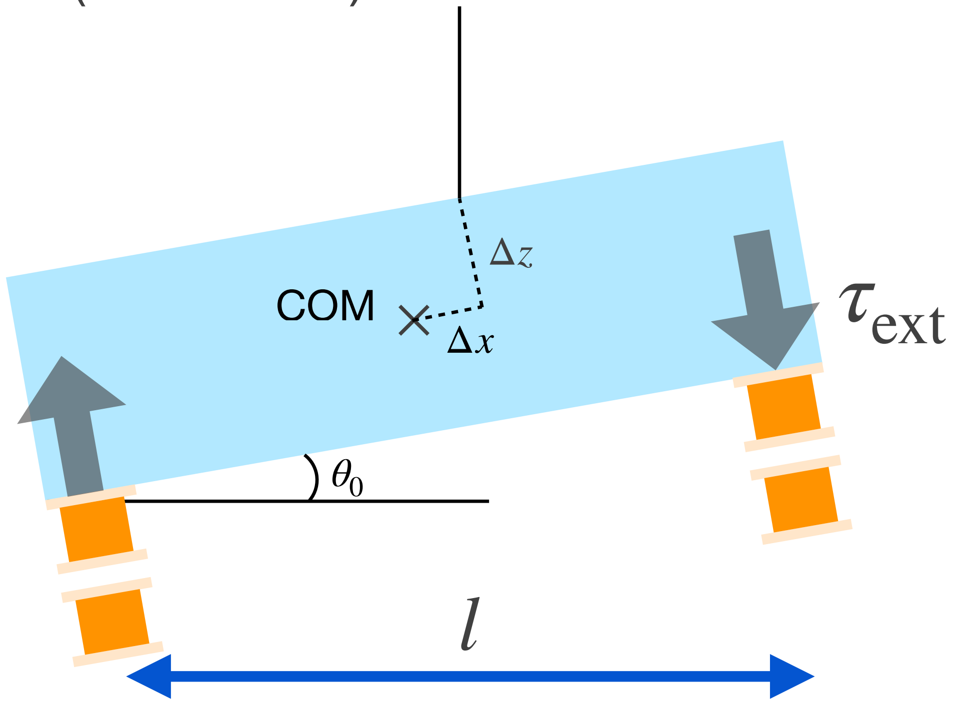
- Resonant frequency of tilt:

$$f_t = \frac{1}{2\pi}\sqrt{\frac{mg\Delta z + \kappa}{I}}$$

  - If f_t is close to 0, θ_0 is big even Δx is close to 0

Tiltmeter with Coil-Coil Actuators

- To solve this, I plan to use coil-coil actuators to balance TM precisely (DC offset)
- Resonant frequency can be also adjusted by coil-coil actuators (AC control)



$$\theta_0 = \frac{mg\Delta x + \tau_{ext}}{mg\Delta z + \kappa}$$

Parameters:

- $m = 300$ g
- $l = 80$ mm
- $\Delta x \sim 10$ μm

▸ $F_{ext} \sim \mathbf{4 \times 10^{-4}}$ **N**

▸ Feasible value for coil-coil actuators

Future Plan

- Construct 2 optical levers
- Make or buy (or both) a fiber feedthrough
- Attach coil-coil actuators to TM
- Adjust position of COM to lower resonant frequency
- Install the whole setup on AVIT
- …

So many things to do

Some Ideas
What I’m considering

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- Active Vibration Isolation
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- Other Ideas
  - Broader-Bandwidth Inertial Sensor
  - Thermal Noise Measurement of Coil-Coil Actuators
  - Measurement of Non-Equilibrium Suspension Thermal Noise
  - Frequency Stabilization Using OMIT
  - etc…

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  - etc…

Broader-Bandwidth Inertial Sensor

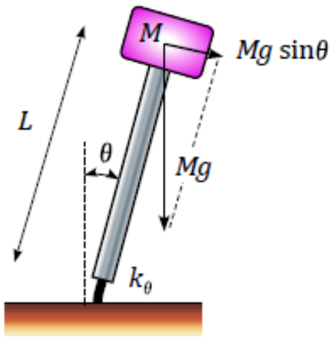
- Bad points of geophones
  - ◉ Resonant frequency (~ 1Hz) is relatively high for our purpose
  - ◉ In principle, a geophone is speedometer
    - ▶ below its res. freq. sensitivity gets worse ($\propto f^3$)
  - ◉ Tilt-horizontal coupling is inevitable

- Some ideas for better inertial sensor
  - ◉ Lower resonant frequency (~ 0.1 Hz?)
    - ▶ IP, GAS, some kind of linkage, etc. could realize it
  - ◉ Measuring displacement (not velocity)
    - ▶ MI, cavity, etc
  - ◉ Using (a) pendulum(s)
    - ▶ Avoidable tilt-horizontal coupling (as I explained)

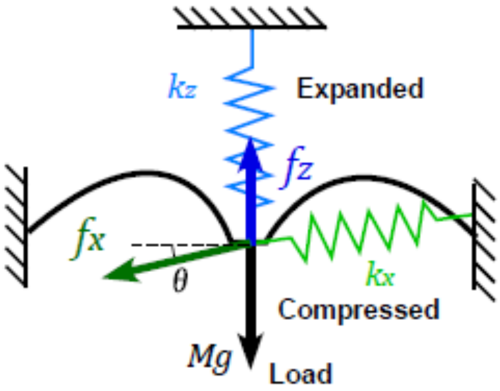
How to Realize Low Resonant Frequency

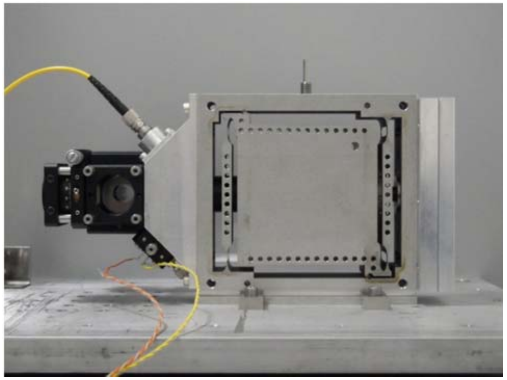
- Inverted Pendulum
  - ◉ Horizontal translation
  - ◉ good: well-used in our neighbors
  - ◉ bad: difficult to use (?)
    - ▶ I heard from Akutsu-san that Fujii-san said:

      "I don't recommend to use IP for VIS of TMS because its characteristics doesn't fit our calculation and difficult to handle it."



- GAS Filter
  - ◉ Vertical translation





- Some other linkage:
  - ◉ Folded pendulum
  - ◉ Roberts linkage

Roberts Linkage

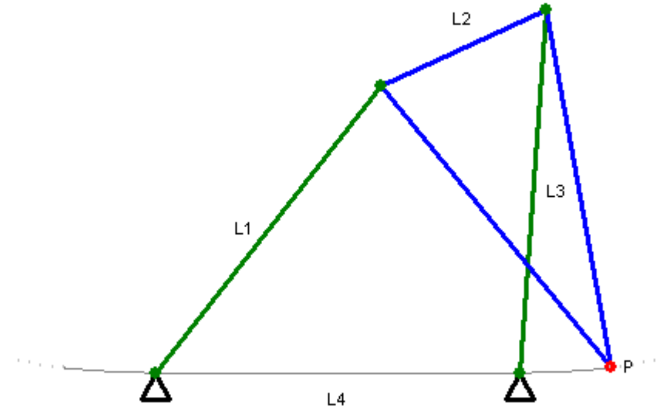
Roberts linkage: a kind of linkage of which motion is approx. linear

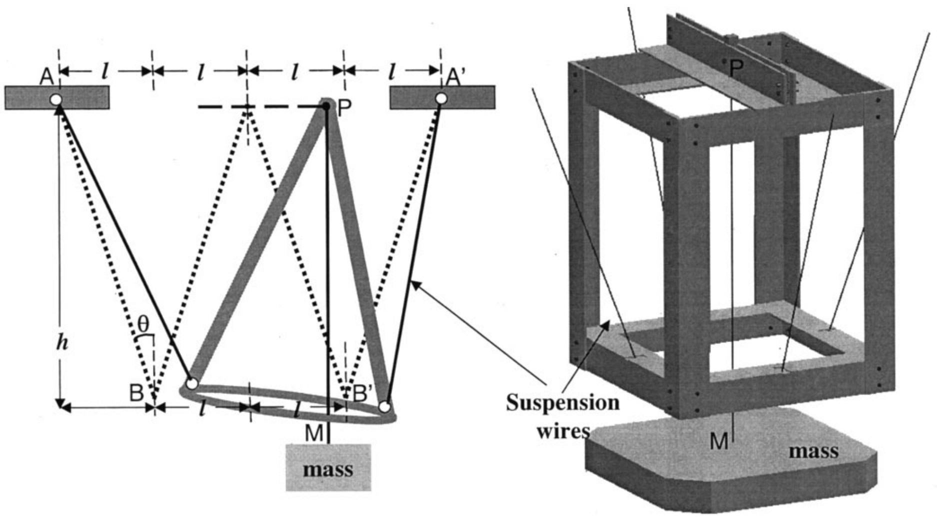
- Once developed for VIS of AIGO
  in Univ. of Western Australia

  Garoi +, Rev. Sci. Instr. **74**, 3487(2003)

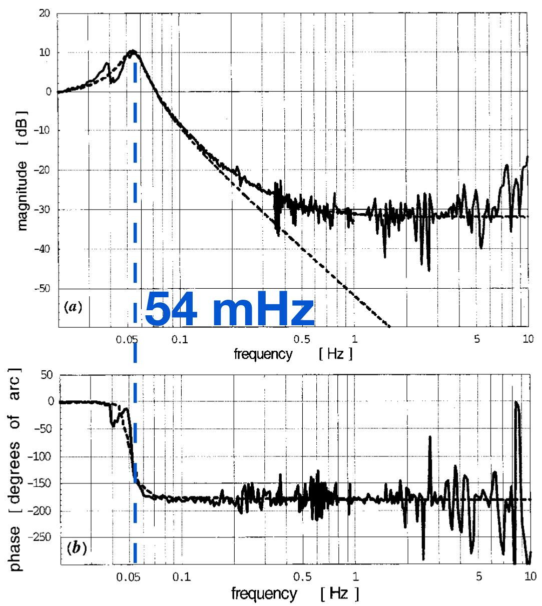
◉ Suspended by 4 wires

◉ Resonant frequency: 54 mHz





(a) (b)



Read out

- A geophone reads relative velocity between the internal mass and housing by EMF
- The sensitivity is good at frequency above f_0, but gets worse drastically below f_0
  - ▶ Let's measure its displacement directly
  - ▶ MI or FP Cavity

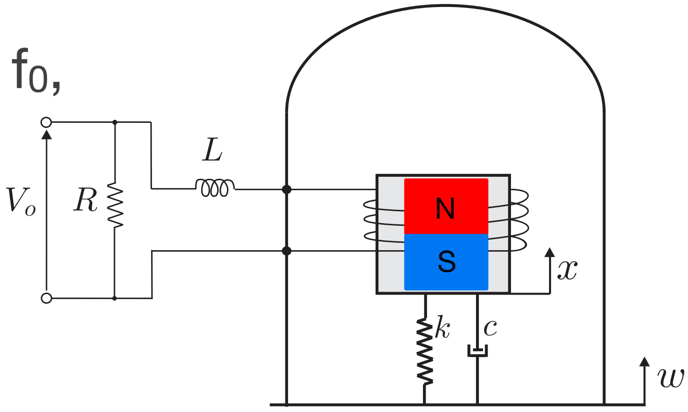
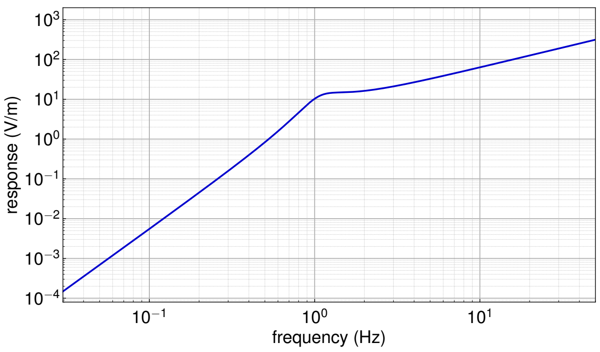


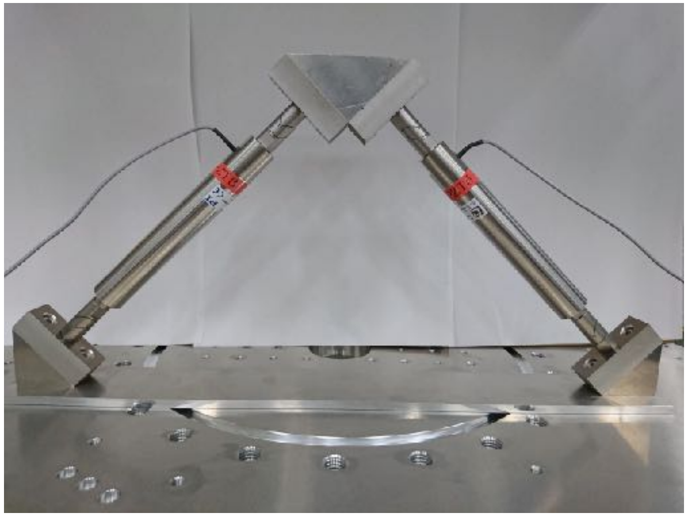
Figure 4: Working principle of a geophone.



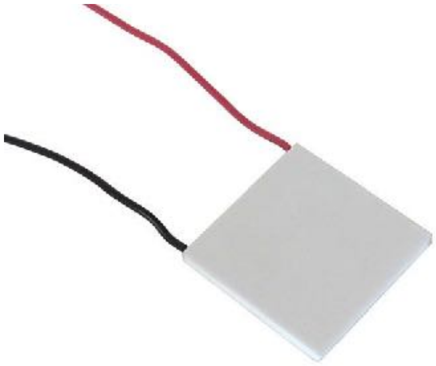
- How to control the IFO in its linear range ?
  - ◉ RMS of seismic vibration: ~ 10 μm
  - ◉ Typical wavelength of laser: ~ 1 μm
- Solution
  - ◉ Use actuators which have very large range
  - ◉ Use IFO with broader linear range -> Quadrature phase MI

Long Range Actuator

- Piezoelectric actuator
  - ◉ Already used for AVIT
  - ◉ Range is enough



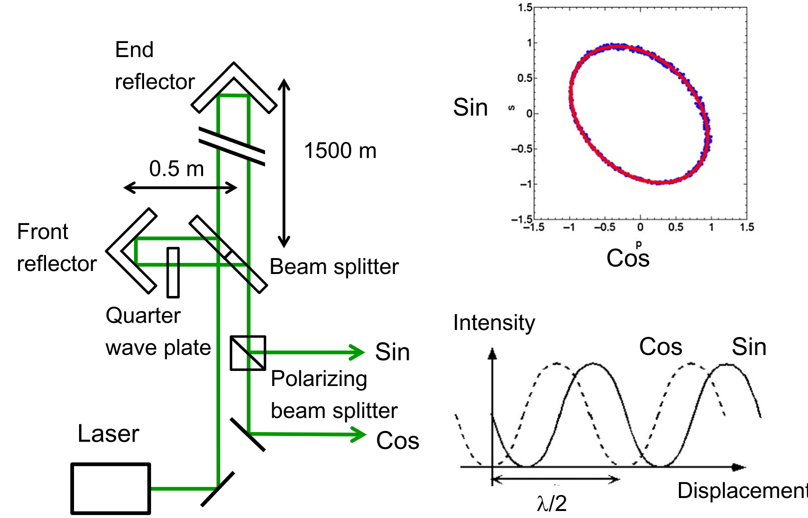
- Temperature-driven actuator
  - ◉ make use of thermal expansion
  - ◉ A metal bar with Peltier device
  - ◉ example: an aluminum bar with 10 cm long
    - ▶ Coefficient of thermal expansion: 23 × 10-6 / K
    - ▶ Max. temp. difference: 70 K
    - ▶ Max. expansion range: ~ **160 μm** → sufficient

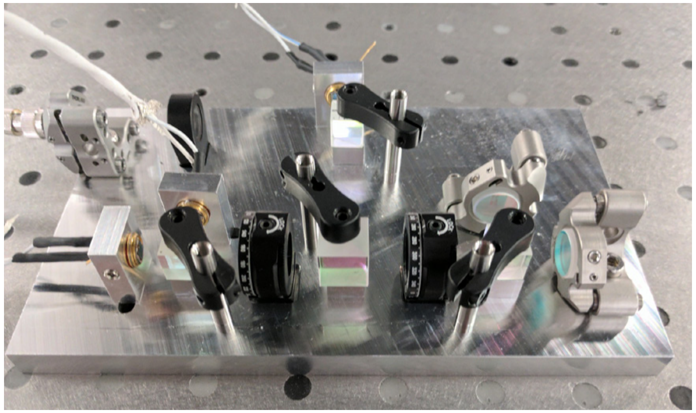


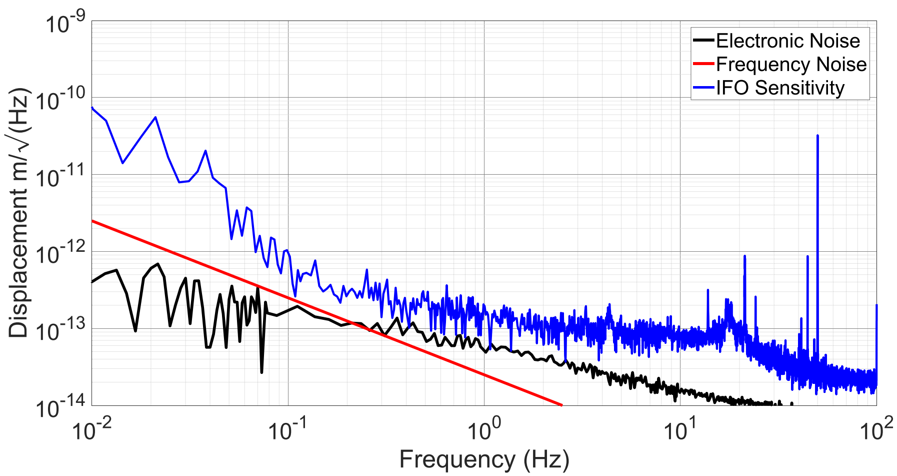
Quadrature Phase Interferometer

Quadrature phase interferometer:

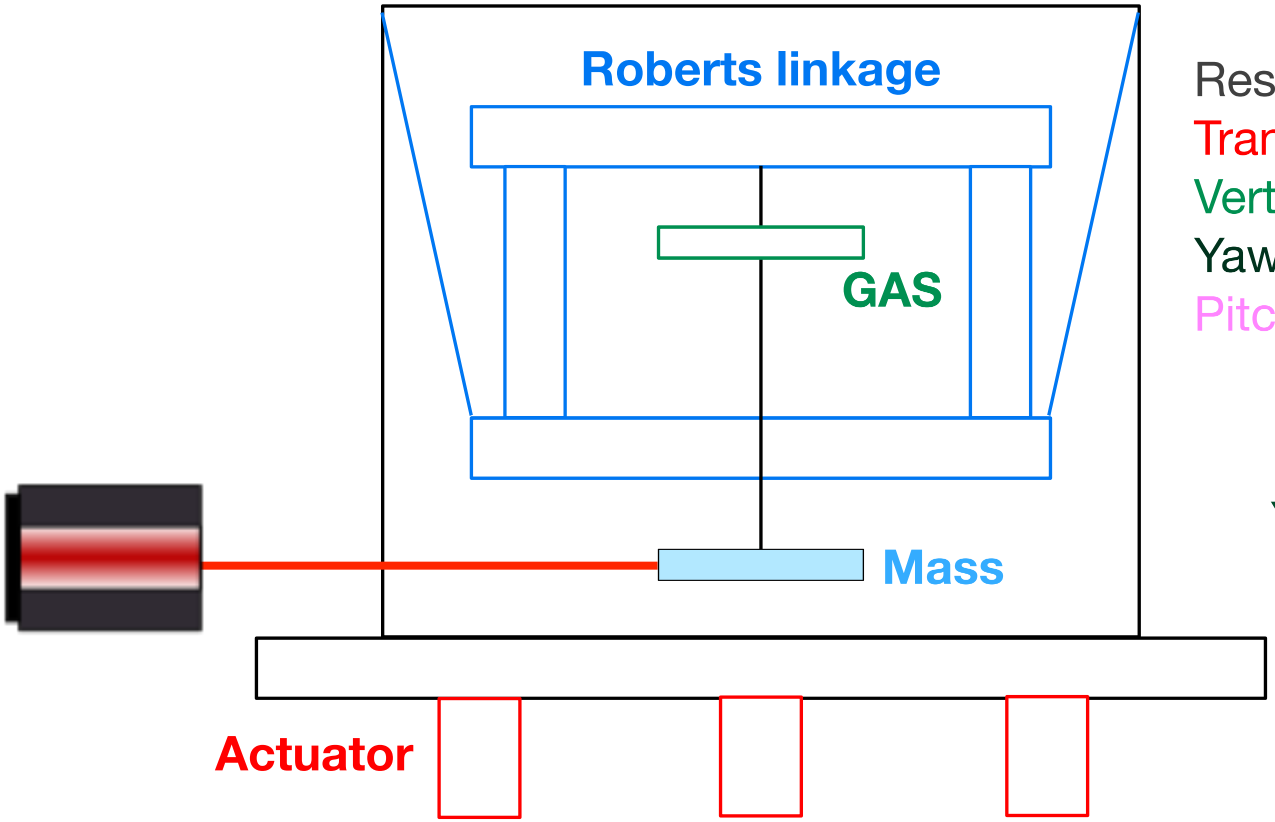
- Using of polarization of the light
- Have infinite range theoretically
- Used in many field:
  - Phase-I TOBA (by Okada-san)
  - GIF (the longest QPI, probably)
  - [Miyazaki-kun almost tried it (but finally gave up)]
  - A group in Univ. of Birmingham



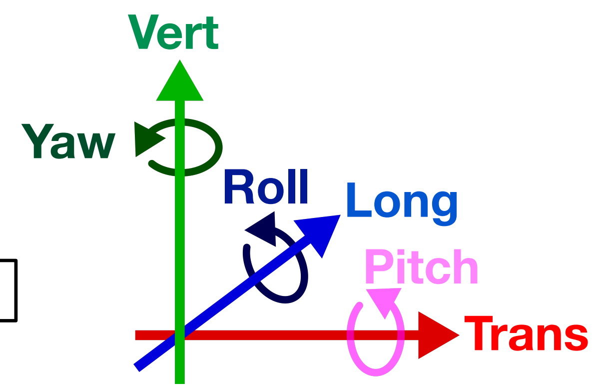




Examples of Setup (1)

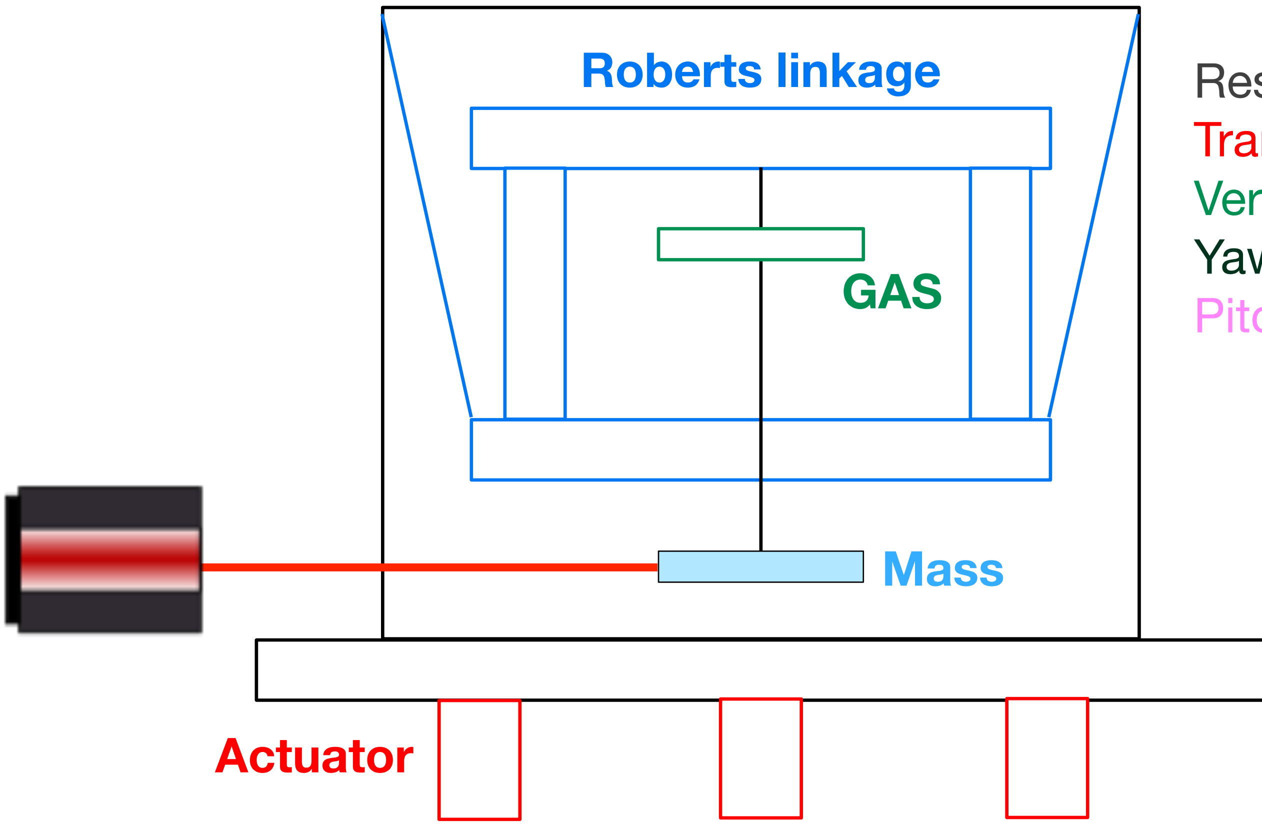


Resonant frequency
Trans, Long: Roberts linkage
Vert: GAS or blade springs
Yaw: Torsion pendulum
Pitch, Roll: Adjusting COM

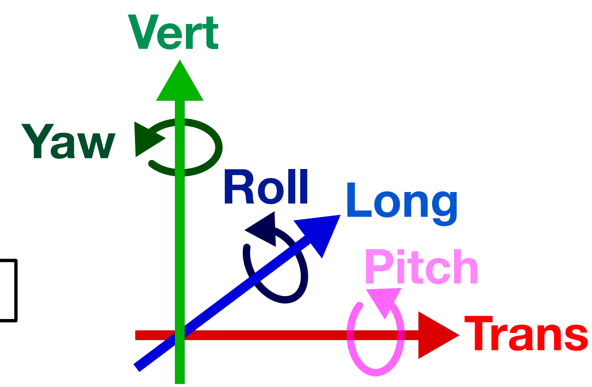


Readout
Trans, Long, Vert: QPI (without control)
Pitch, Roll, Yaw: MI (controlled by Actuators)

Examples of Setup (2)



Resonant frequency
Trans, Long: Roberts linkage
Vert: GAS or blade springs
Yaw: Torsion pendulum
Pitch, Roll: Adjusting COM



Readout
Trans, Long, Vert: Cavity (controlled by Actuators)
Pitch, Roll, Yaw: WFS (controlled by Actuators)
or MI (controlled by Actuators)

Summary

- Active Vibration Isolation
  - New frame: almost done, seems good
  - Replacement of caster: planning
  - Tiltmeter: a lot of things to do
- Broader-Bandwidth Inertial Sensor
  - Just considering some basic concept
  - Will anyone make it?


END