Active Vibration Isolation by Hexapod For TOsion-Bar Antenna

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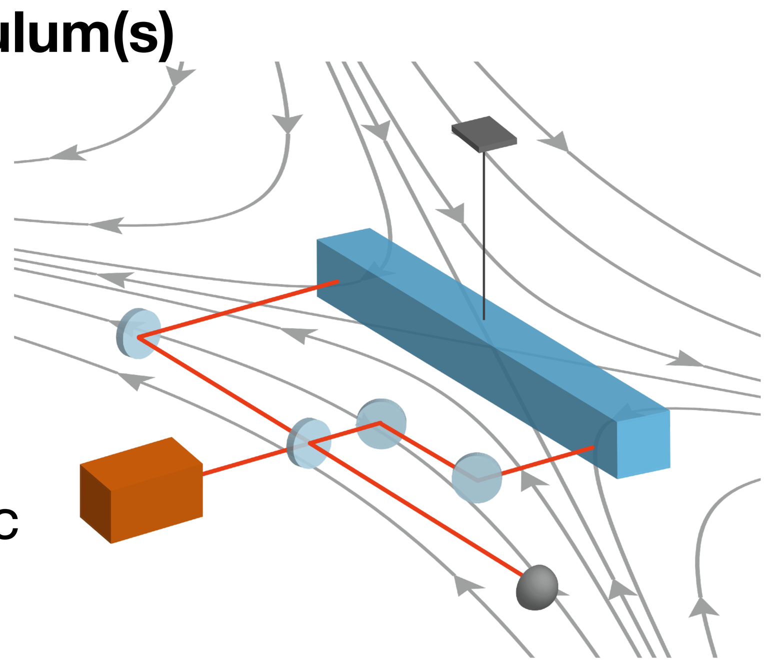
Abstract

TOBA (TOrsion-Bar Antenna) is a gravitational wave detector using a torsion pendulum. The resonant frequency of torsional motion is ~1mHz, therefore it can be a ground-based GW detector which is sensitive to low frequency GWs (0.1-10Hz). Our target sensitivity is ~ 10^{-19} /√Hz @ 0.1Hz, which will enable us to detect IMBH(intermediate mass black hole) binary mergers and NN (Newtonian Noise), etc. One of the dominant noise is seismic cross-coupling noise, which comes from asymmetry of the system. To reduce it we developed an active vibration isolation system using hexapod stage. Here we show the current result of active vibration isolation.

1. Introduction | What is TOBA?

TOBA = "TOrsion-Bar Antenna" [1]

- GW detector using (a) **torsion pendulum(s)**
- Low resonant frequency (~ mHz)
  - Target range: **0.1Hz ~ 10 Hz**
- Ground-based
  - Inexpensive, Easy to maintenance
- Our goal: **10^{-19}/√Hz @ 0.1 Hz**
- Scientific targets:
  - IMBH merger, Newtonian Noise, etc

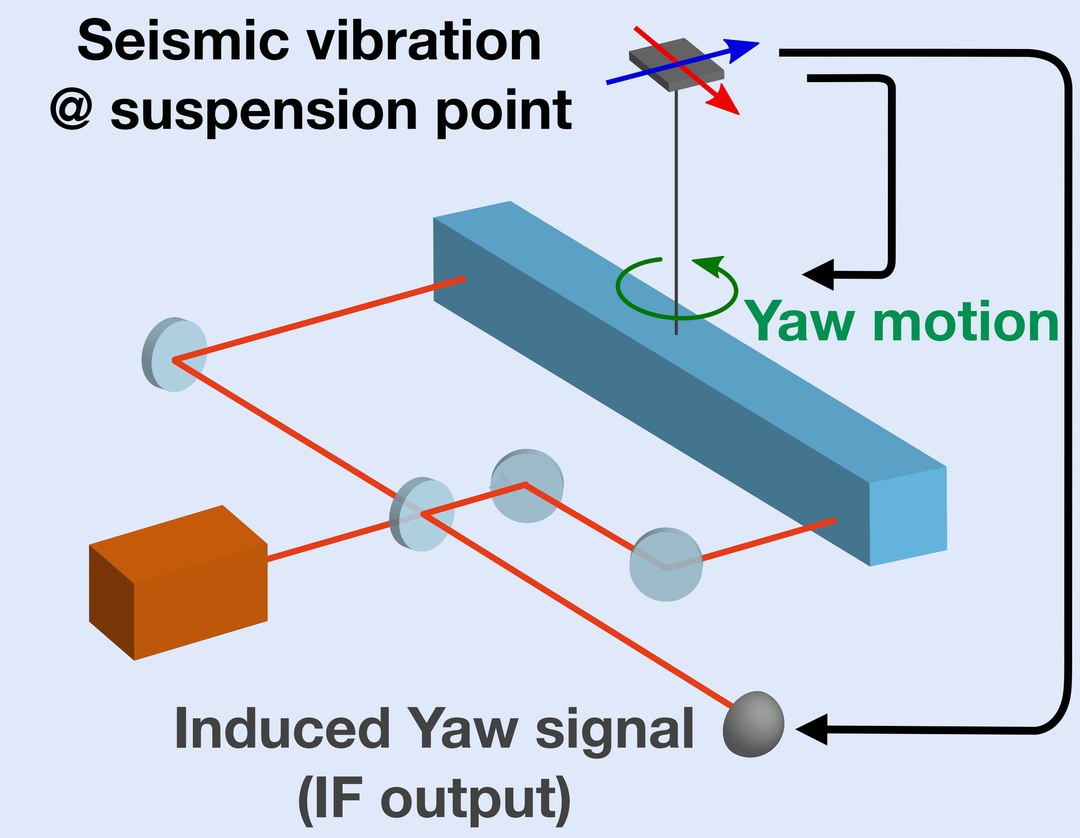


R&D Plan

Phase-I (2009)	Phase-II (2015)	**Phase-III (Now)**	Final (Future)
Principle Test		Cryogenic Test	Goal
10^{-8}/√Hz @ 0.1 Hz (Established)		10^{-15}/√Hz @ 0.1 Hz (Design)	10^{-19}/√Hz @ 0.1 Hz (Target)
- Room Temp. - 25cm TM(s)		- **Cryo. Temp. (4K)** - 35cm TMs	- **Cryo. Temp. (4K)** - **10m TMs**

[1] Ando +, Phys. Rev. Lett. **105**, 161101(2010)

2. Seismic Cross-Coupling | Main Noise



Through asymmetry of the system:
- Tilt of TM
- Tilt of mirrors
- Position of beamspot

Seismic Cross-Coupling Noise = **Seismic vibration** × **Coupling Constant**

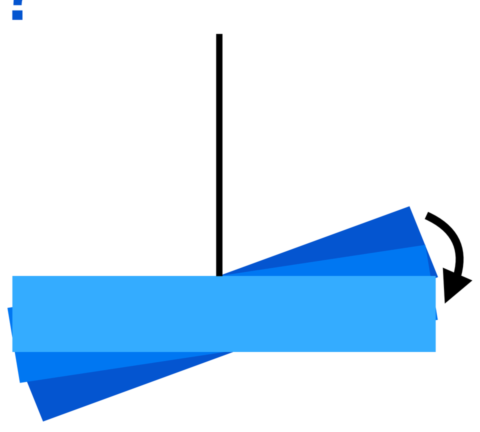
Requirement: 10^{-16} rad/√Hz @ 0.1 Hz | 10^{-7} m/√Hz@ 0.1 Hz, 10^{-10} m/√Hz@ 1 Hz | 10^{-9} rad/m

How to Reduce Cross-Coupling Noise?

2 ways:

- **Reduce coupling constant**
  - Adjust position of COM, tilt, etc…
  - Well understood, reduction is demonstrated [2]

▸Requirement: **10^{-9} rad/m** → feasible value



- **Reduce seismic vibration**
  - Passive vibration isolation (such as a pendulum)
  - Active vibration isolation

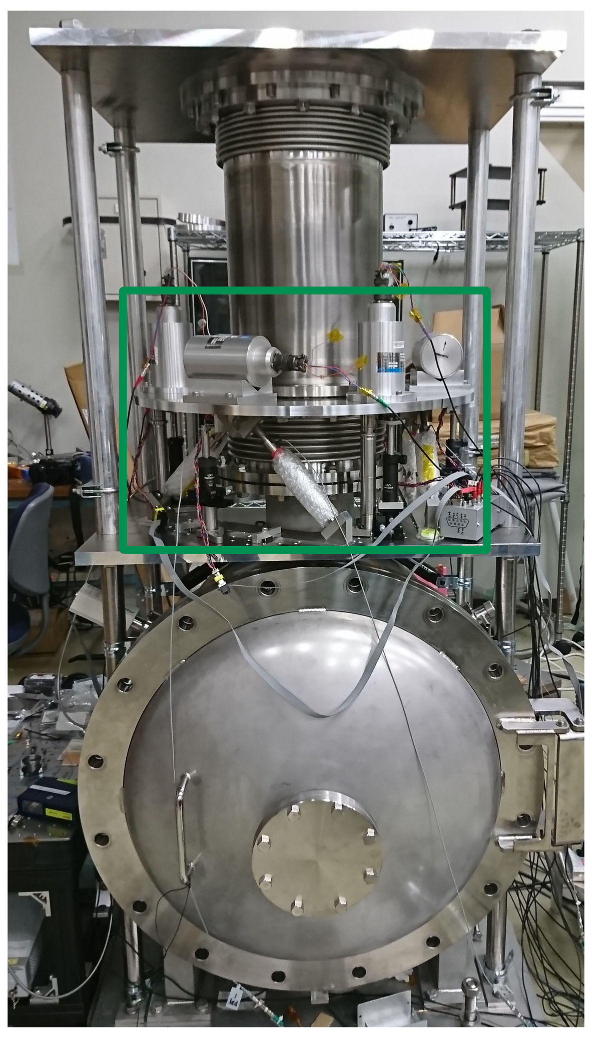
▸Requirement: **10^{-7} m/√Hz @ 0.1 Hz, 10^{-10} m/√Hz @ 1Hz**

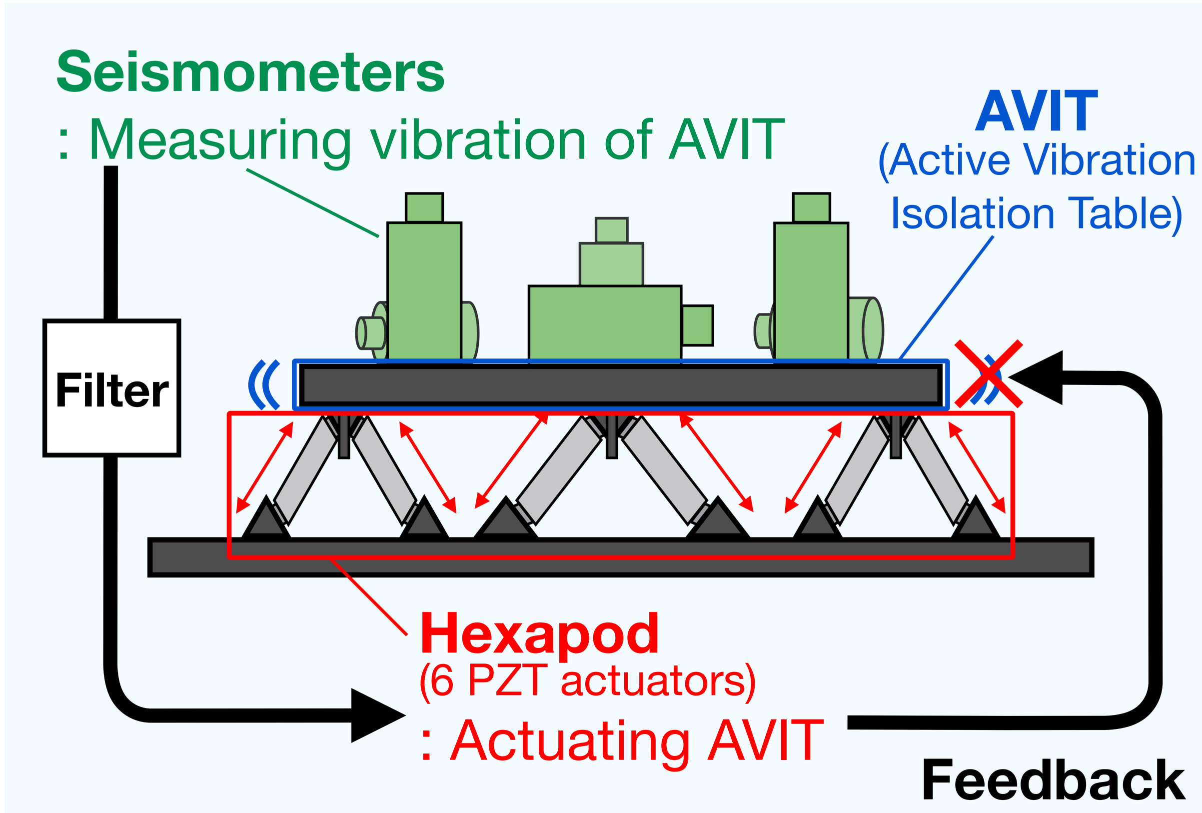
At 0.1 Hz, passive vibration isolation is difficult

▶ **Active vibration isolation**

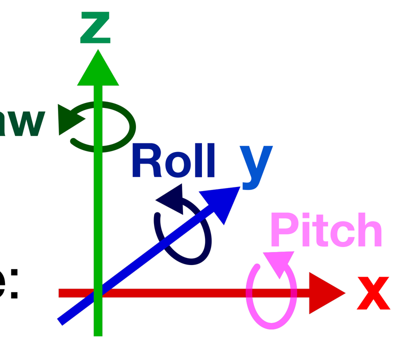
[2] Shimoda +, Phys. Rev. D **97**, 104003 (2018)

3. Experiment | Hexapod Table

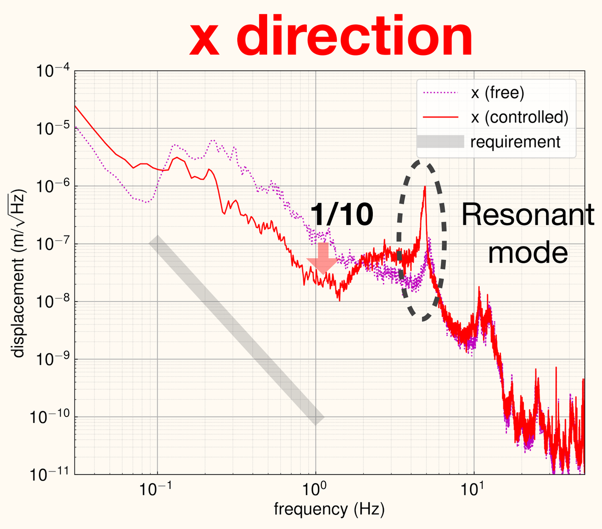




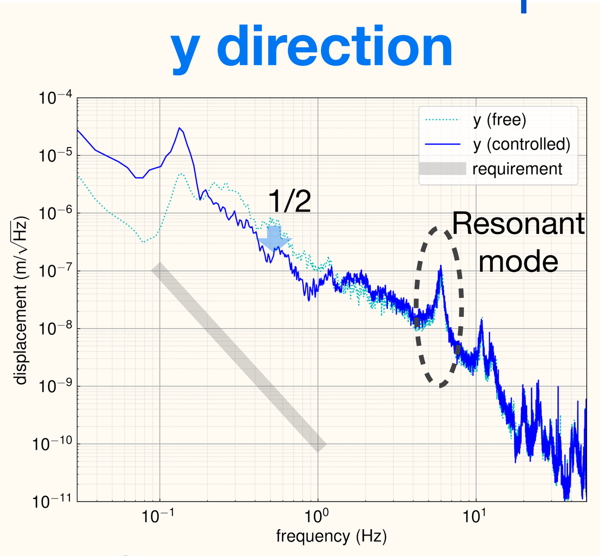
Coordinate:



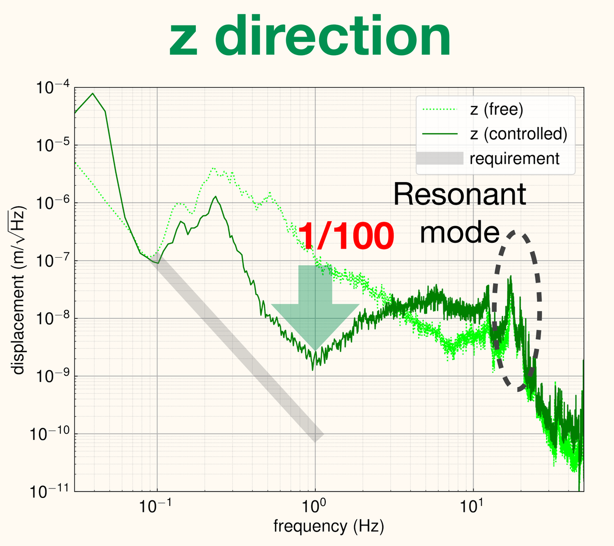
4. Result & Discussion | Performance



- Control band: **0.2~2 Hz**
- **1/10** reduction @ 1 Hz



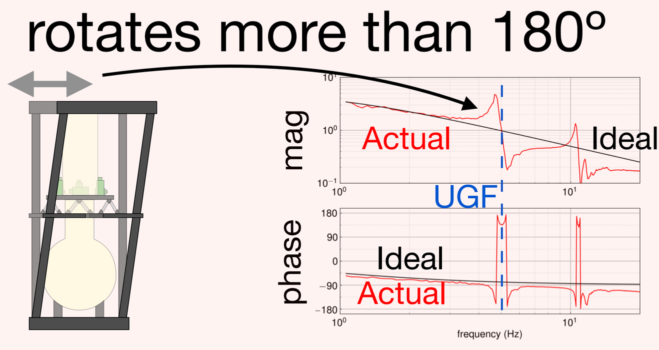
- Control band: **0.2~1 Hz**
- 1/2 reduction @ 1 Hz
- Control is unstable



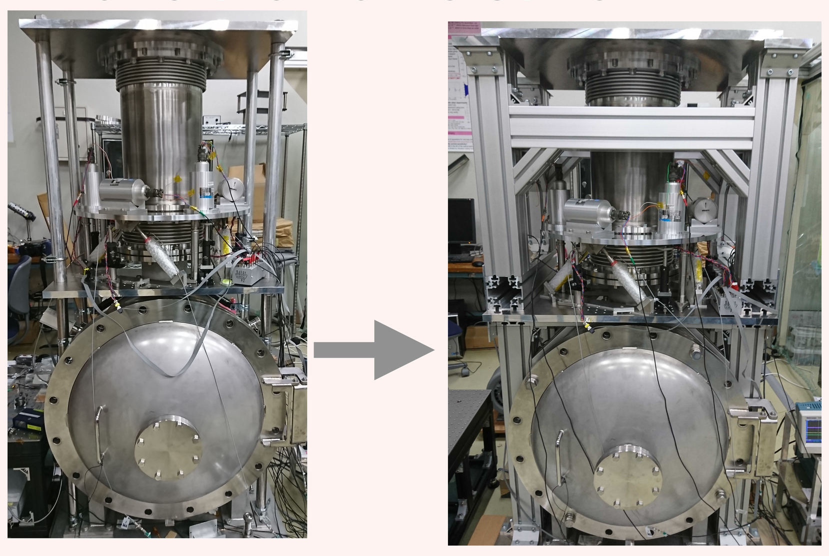
- Control band: **0.1~3 Hz**
- **1/100** reduction @ 1 Hz

Problems and solutions

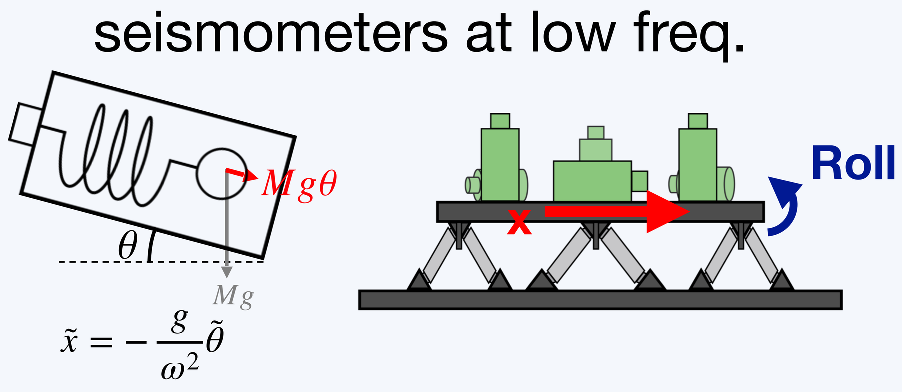
- High frequency:
  Resonant modes of the frame
  - Phase of open loop TF rotates more than 180°



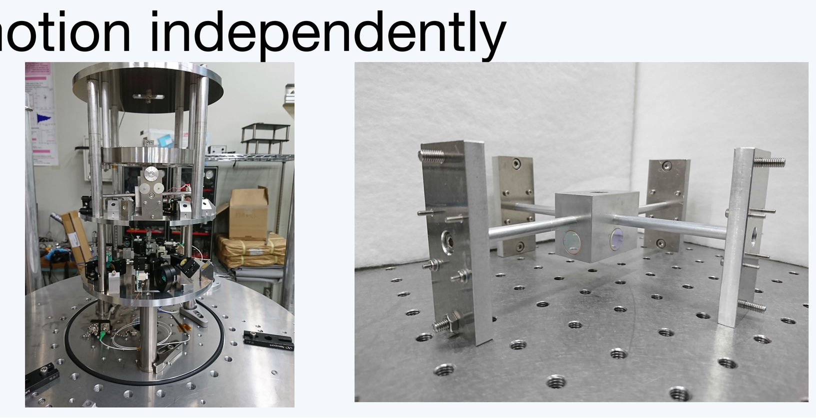
▶ **Make the frame stiffer**



- Low frequency:
  Tilt-Horizontal coupling
  - When actuating in **x**, also shaking **Roll** simultaneously
  - **Irregular response** of seismometers at low freq.



▶ Install a **tilmeter** and **control tilt** motion independently



5. Summary

We designed an active vibration isolation system and tested it . We succeeded in reducing vibration 100 smaller @ 1 Hz at best. Current performance is limited because of resonant modes of the frame and tilt-horizontal coupling. For future we will solve these problem and achieve the requirement.