The assessment of DPFP cavity experiment

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Midterm report meeting 2023

Abstract

- I will introduce the current situation of noise budget
- For my research purpose, I was not really pursuing sensitivity. However, It was better than I expected, so I hope to get better sensitivity with this set up
- We designed a suspension last year. I would like to discuss how to make it better
- To save the time to create circuits (soldering, making boxes), I would like to package and design highly versatile circuits。

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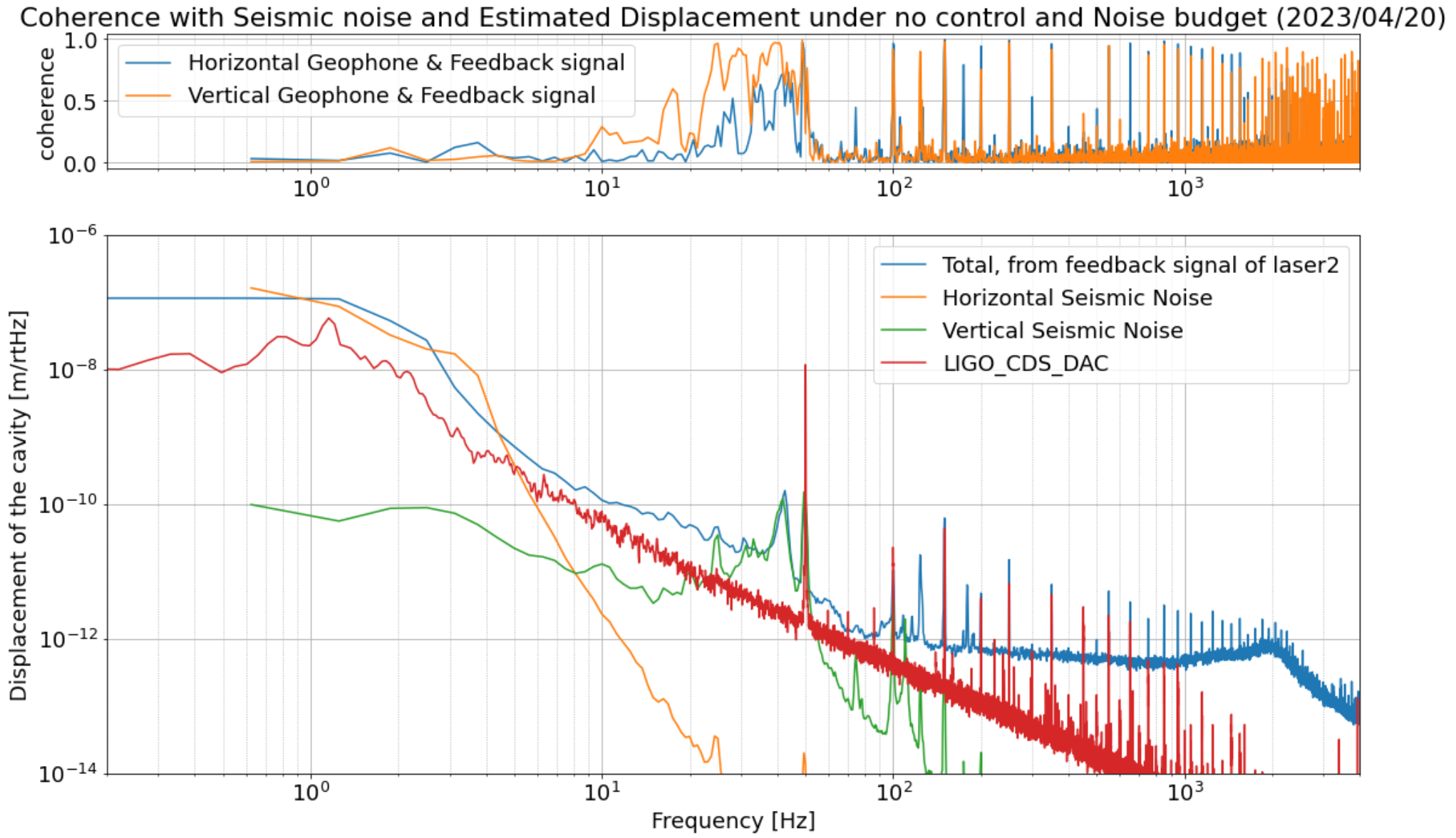
Current Status of Noise Budget ノイズバジェットの現状



The roughly estimated spectrum of the displacement of the cavity in the free-running (OPLEV is implemented)

LIGO CDS DAC Noise デジタルシステムのDACの電気的雑音

To reduce DAC noise…

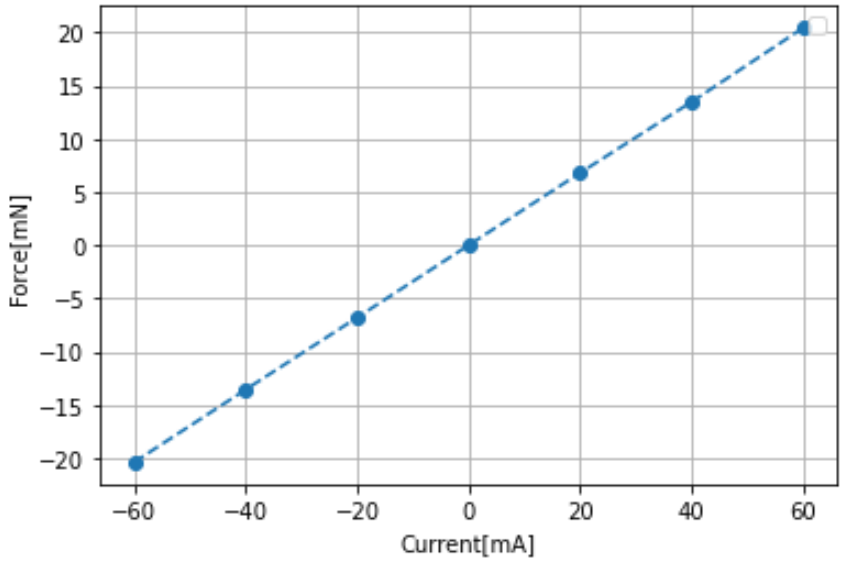
High actuator efficiency of coil-magnet

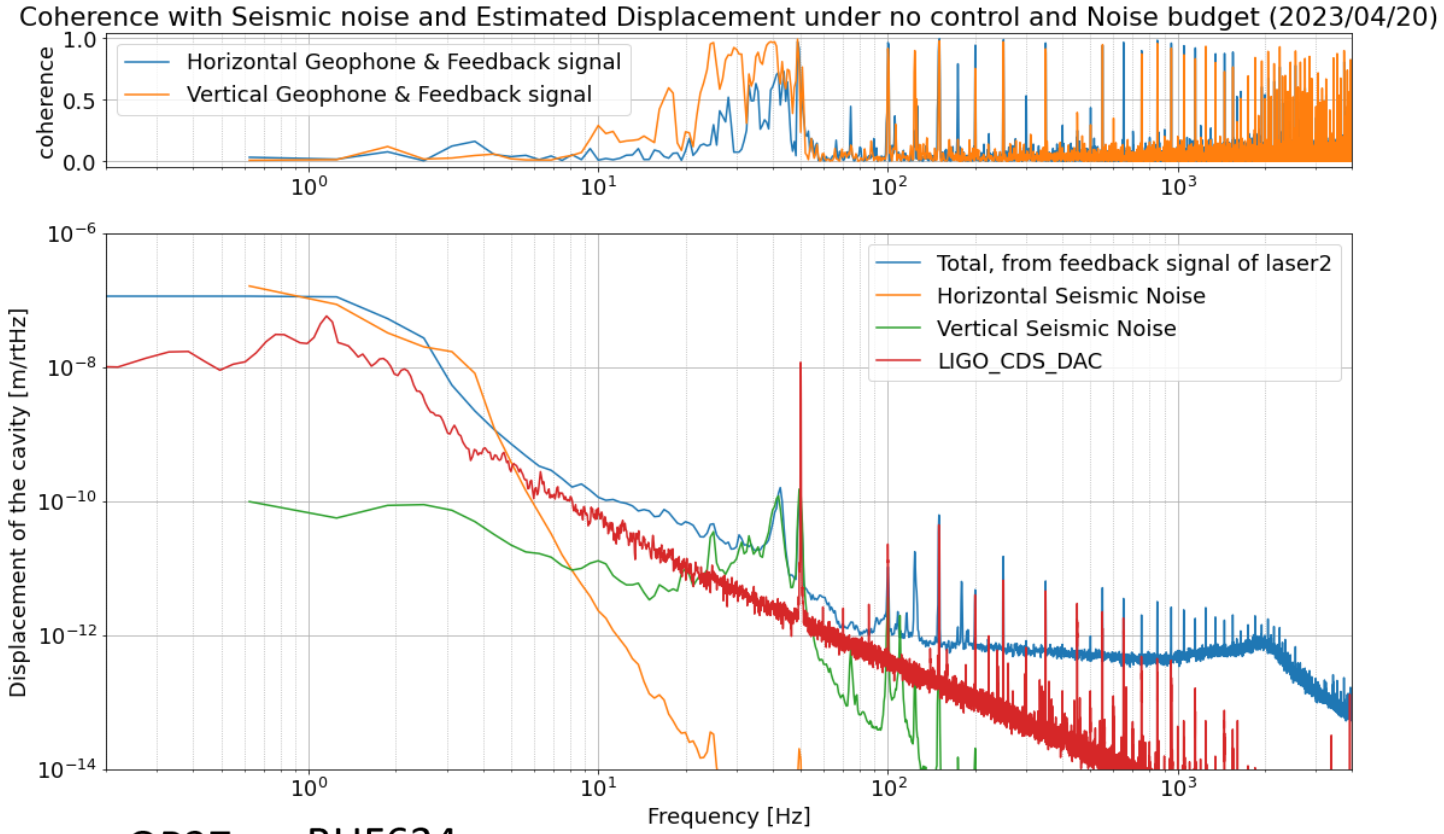
$$\frac{1}{3}\ [\mathrm{N/A}]$$

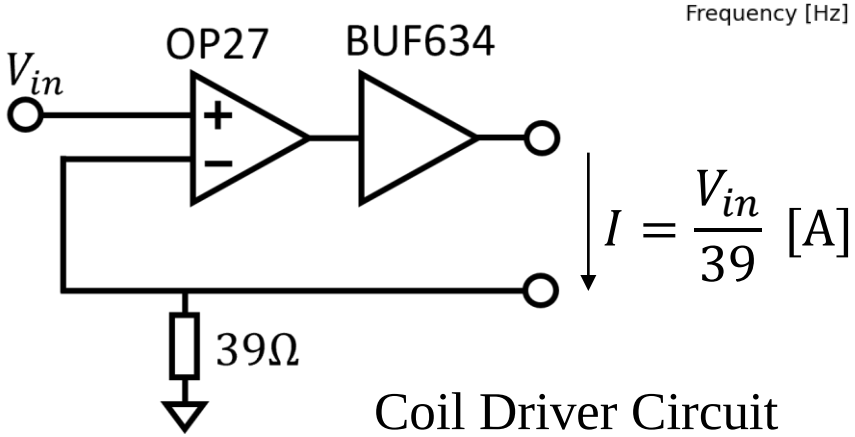
So, replacing with higher value resistor to reduce actuator efficiency

$$39\ [\Omega] \rightarrow 390\ [\Omega]$$

Measured Current to Force of coil magnet actuator

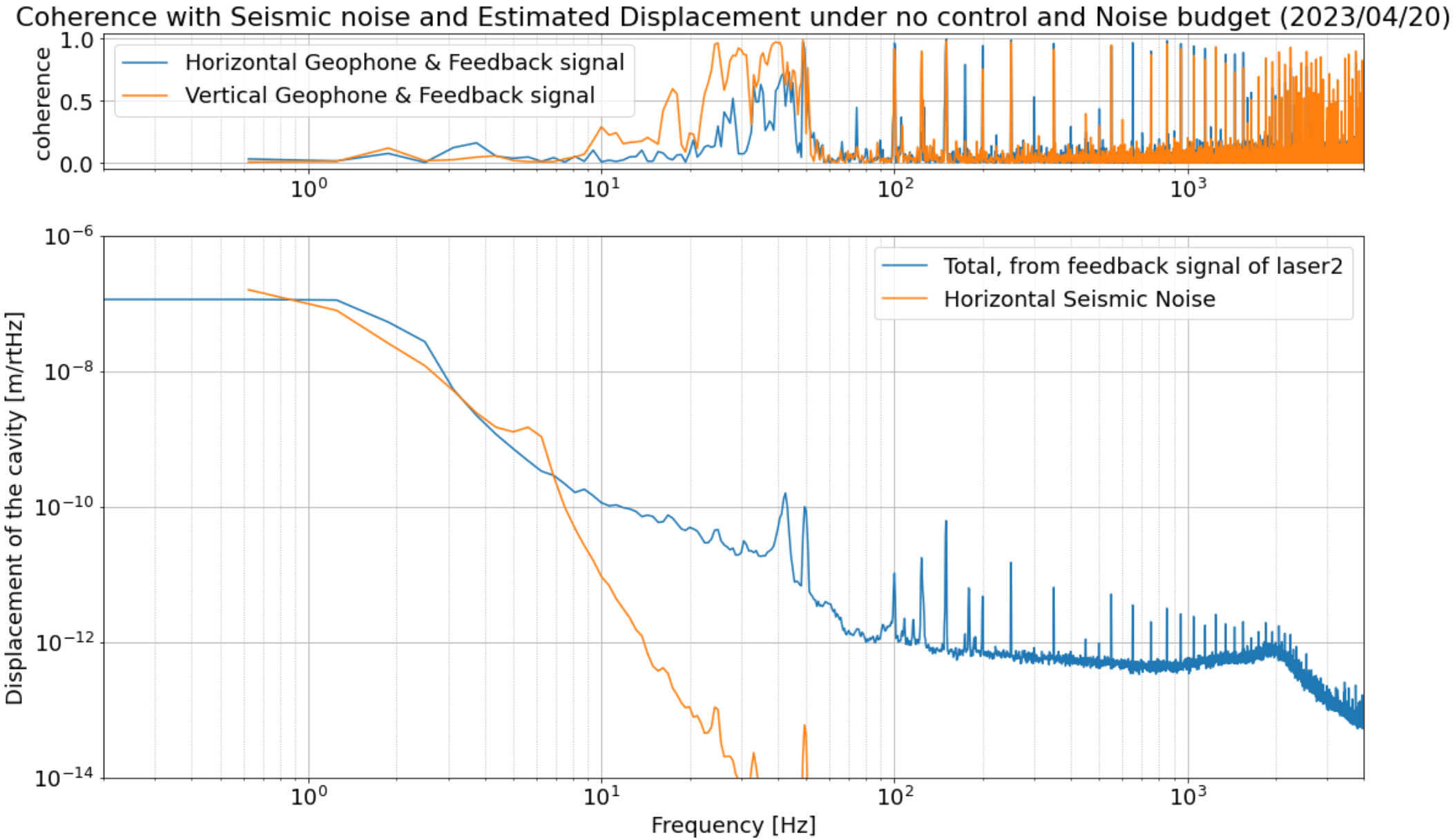






Coil Driver Circuit

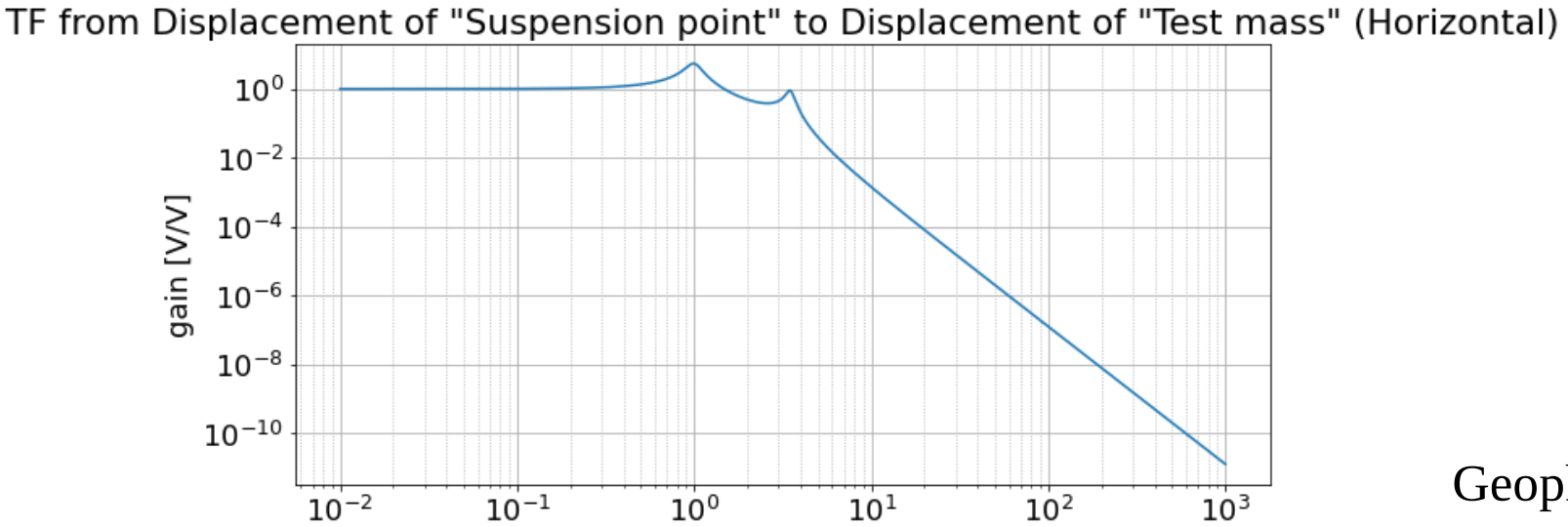
Horizontal Seismic Noise 水平方向の地面振動雑音

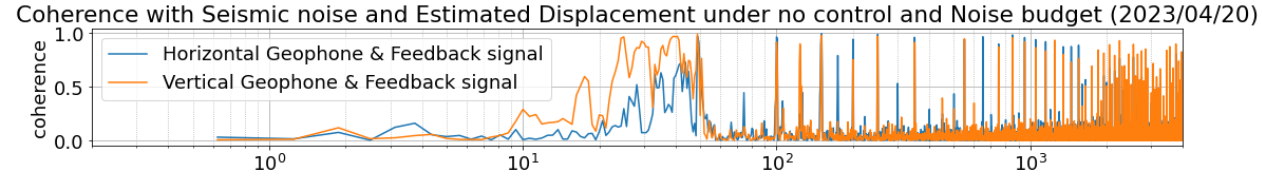


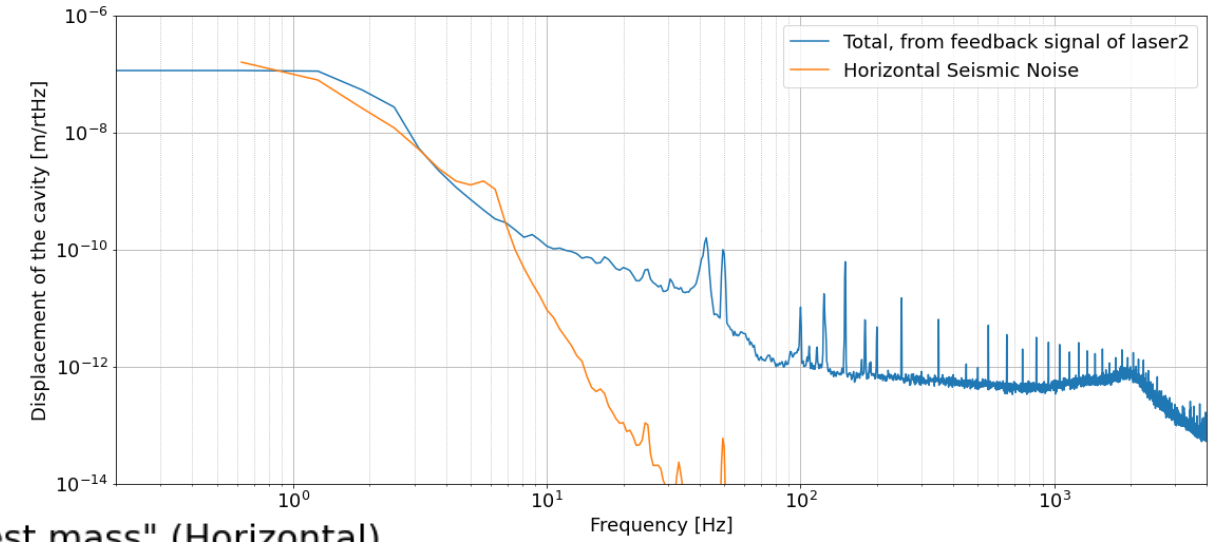
Horizontal Seismic Noise 水平方向の地面振動雑音

Assuming, parameters of 2-stage suspension

$$f_0 = 1.28\ [\mathrm{Hz}]$$
$$Q_0 = 5$$
$$f_1 = 3.5\ [\mathrm{Hz}]$$
$$Q_1 = 10$$

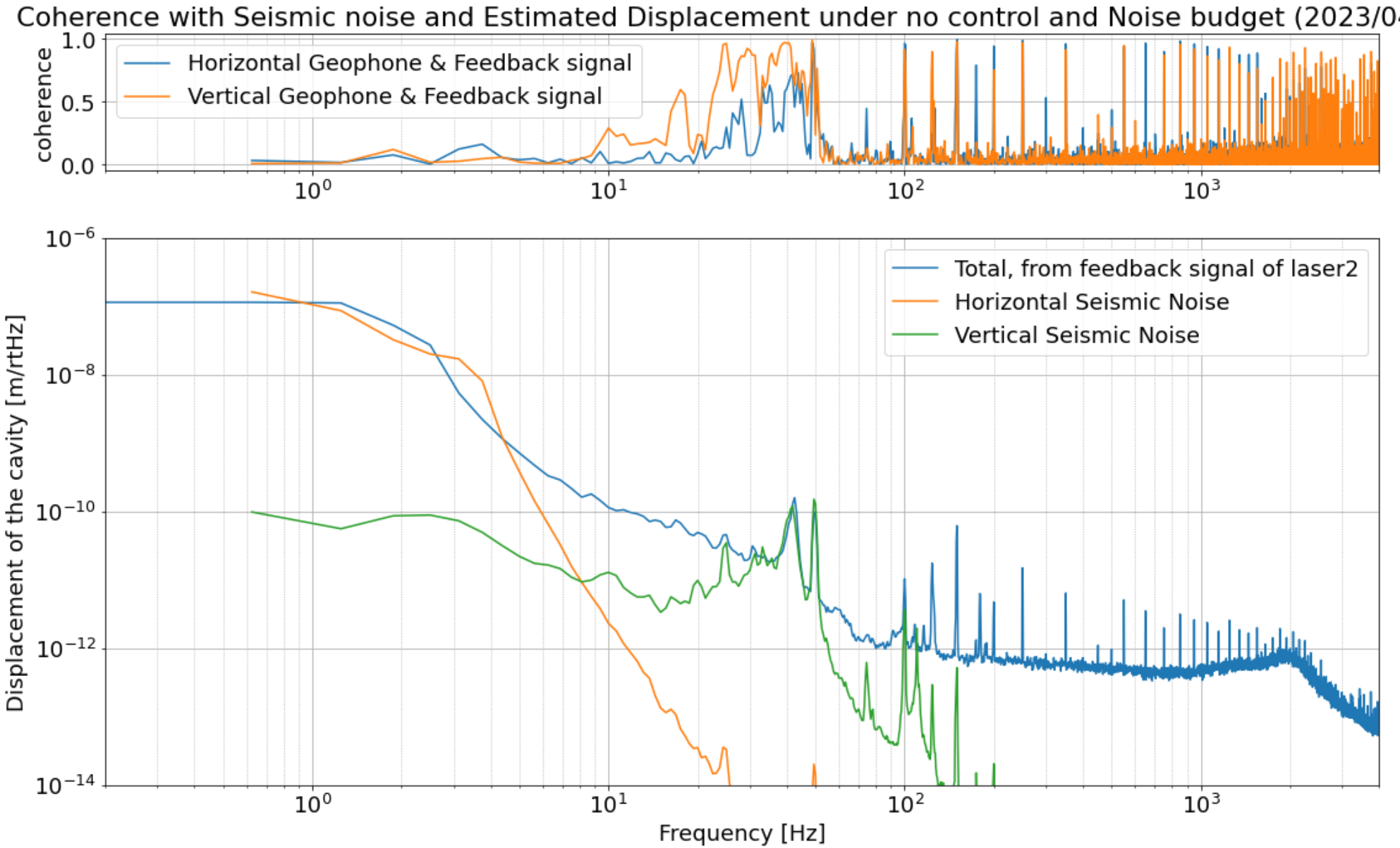






Geophone to measure horizontal seismic noise

Vertical Seismic Noise 鉛直方向の地面振動雑音



Vertical Seismic Noise 鉛直方向の地面振動雑音

Coupling constant
from “Vertical motion” to “Horizontal motion”

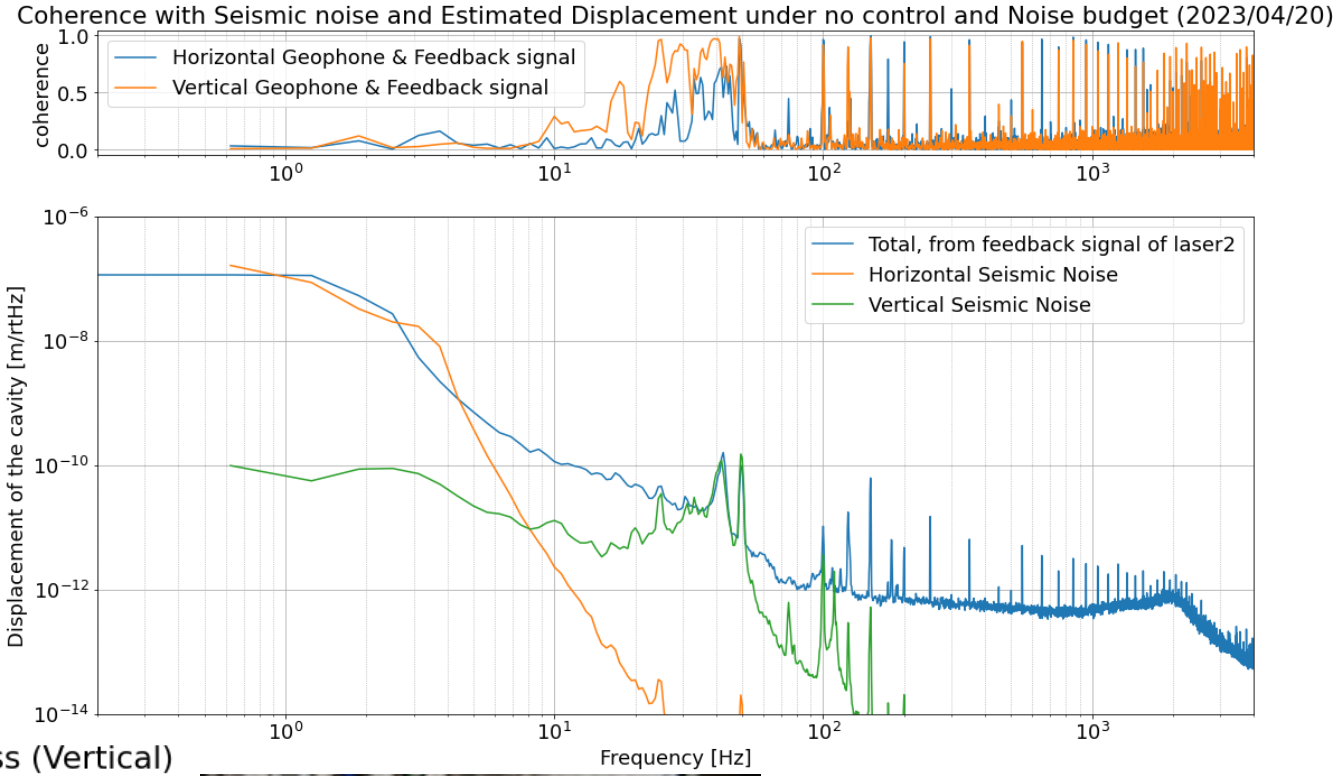
$$\gamma_{VH} = 0.00848$$

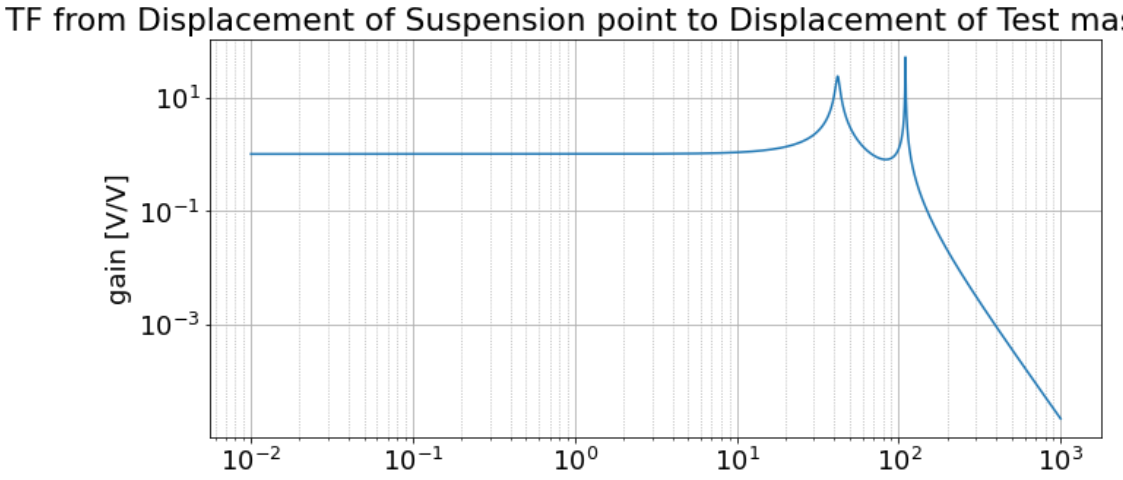
Resonant frequency of the blade spring

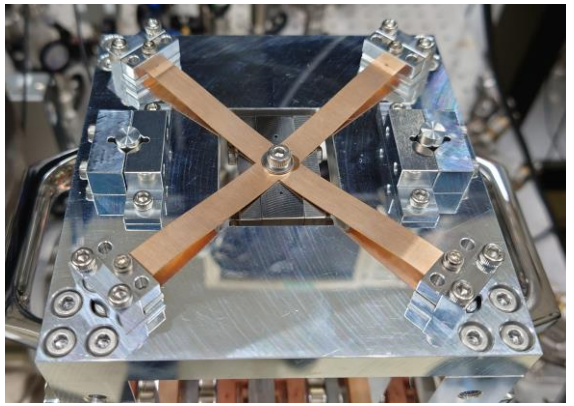
$$f_B = 42\ [\mathrm{Hz}]$$
$$Q_B = 20$$

Resonant frequency of tungsten wires

$$f_w = 110\ [\mathrm{Hz}]$$
$$Q_w = 300$$







The blade spring of the suspension

Assessment of RMS and Range of Actuator RMSの評価とレンジのとの比較

In free running,

$$\delta x_{\mathrm{RMS}} = 0.134\ \mu\mathrm{m}$$

$$\leftrightarrow\ 68\ \mathrm{MHz}$$

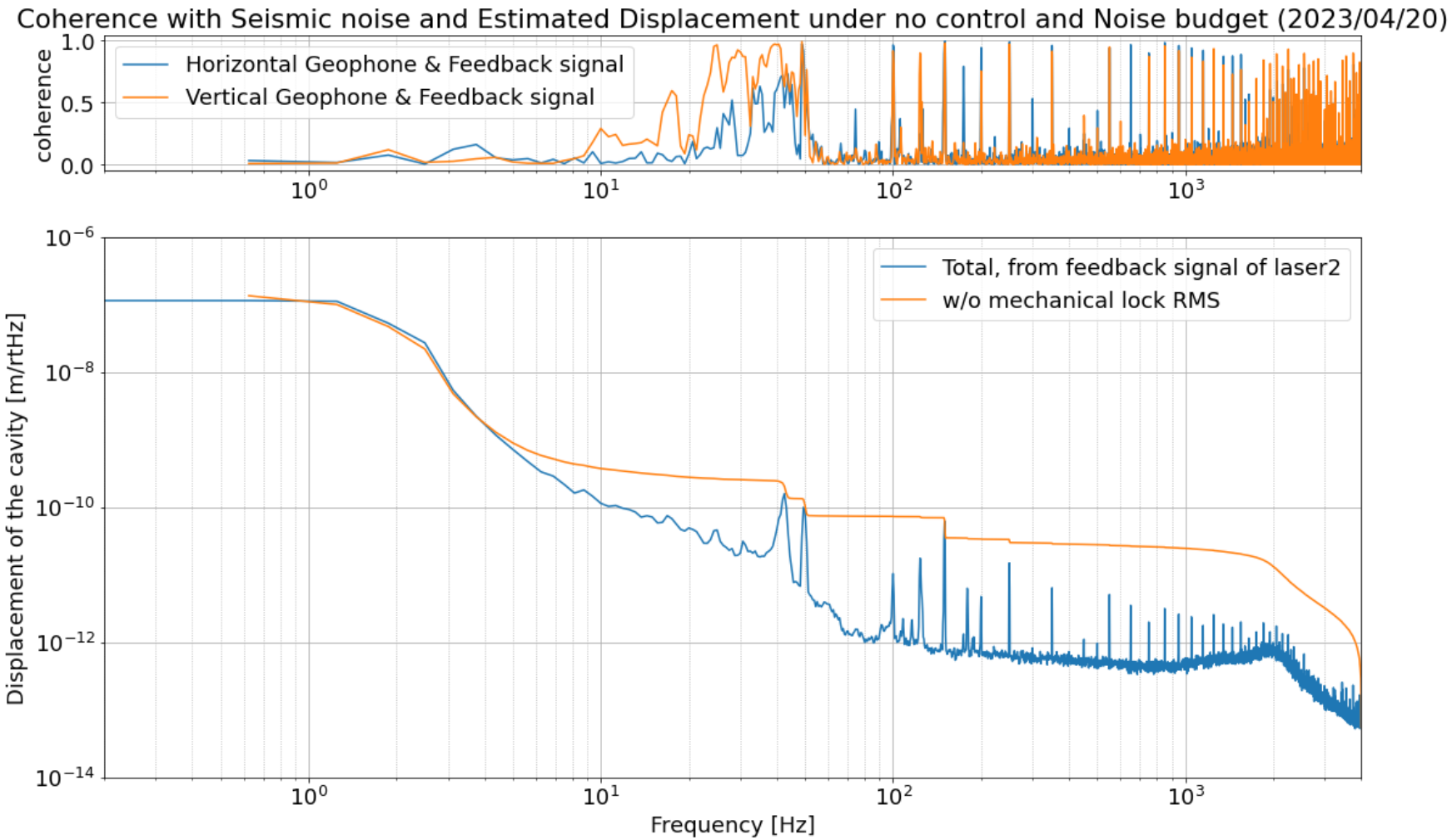
1 FSR = 532 nm = 268 MHz

$$\boxed{\delta x_{\mathrm{RMS}} = \frac{1}{4}\ \mathrm{FSR}}$$

Frequency actuator range

800 MHz

Used laser, Koheras BASIK Y10



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Some update plans for My Experimental Setup 実験系のアップデート

So many kinds of noises if we pursue sensitivity

From the environment

Seismic noise => Rubbers under the table

Air turbulence, Sounds } => A clean room

From the lasers

Frequency noise => Frequency stabilization using a reference cavity

Intensity noise => Intensity stabilization using EOAM

From other devices

Mechanical resonance(Bounce mode, Violin mode, etc)

Electrical noise (Diodes, Circuits, Digital system, GND, etc) => Whitening, Dewhitening, optimizing some filters

Beam jitter noise

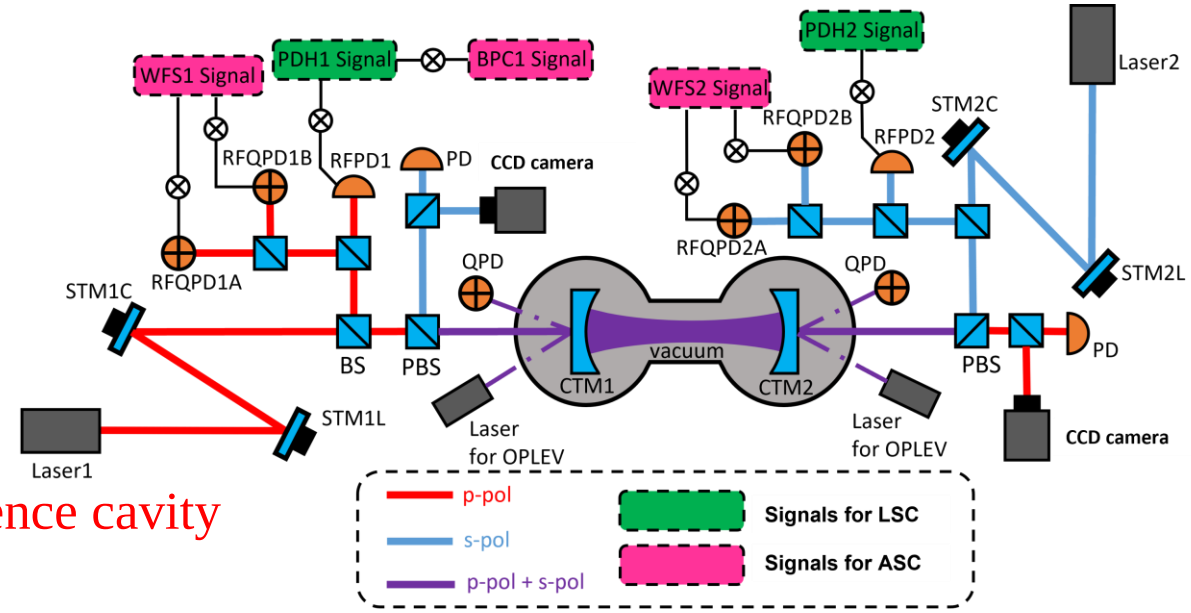
Thermal noise of wires => Making wires thin

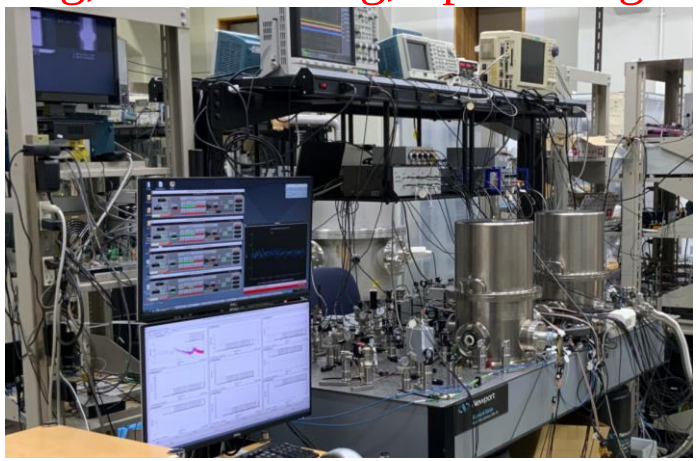
Coating thermal noise

Quantum noises

Shot noise

Radiation pressure noise





Isolation from, Air turbulence, sound noise, and seismic noise

To isolate the setup from Air turbulence and sound noise…

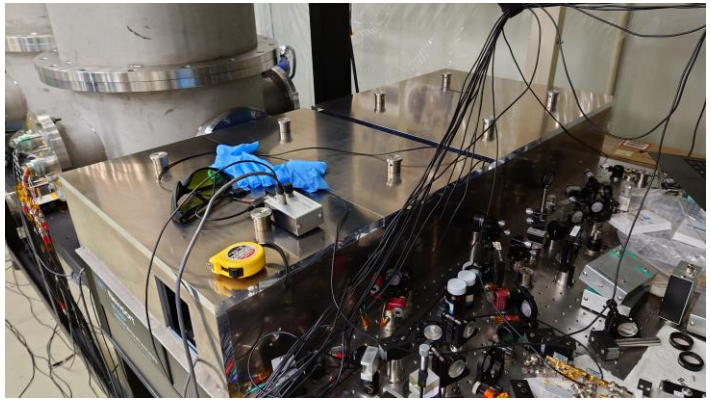
Ultrasonic bath (Noisy)

Proposal 1

Preparing some walls and roofs surrounding the optical system like DANCE setup and optomechanics setup

Assumed problems

Taking time to design(How to access optical components, What material is better? Acrylic, Aluminum or Styrofoam)



Walls and Roofs

Proposal 2

Preparing a clean room like TOBA setup and optomechanics setup

Assumed problems

Space

Clean room

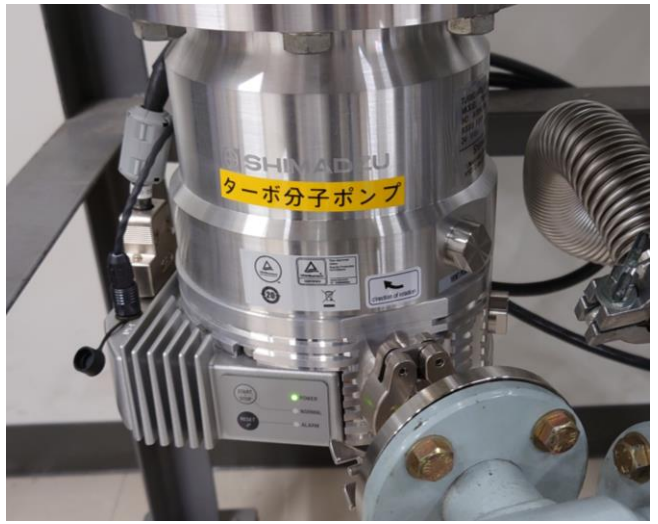
Isolation from seismic noise, Air turbulence and sound noise

Regarding the vacuum environment

Installing a turbomolecular pump for higher level of vacuum ($1\text{Pa} \rightarrow 10^{-4}\text{Pa}$)

Assumed problems

Vacuum chambers are made of aluminum (How much they leak air, Can they stay rigid?(Distortion, Durability))

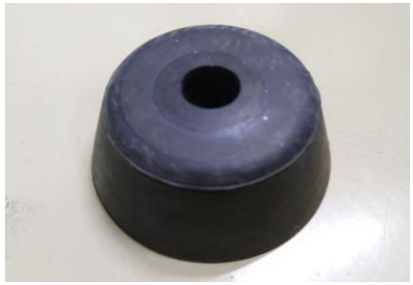


Turbomolecular pump

To isolate the setup from seismic noise…

Putting rubbers under the table

Leg of the table



Rubber

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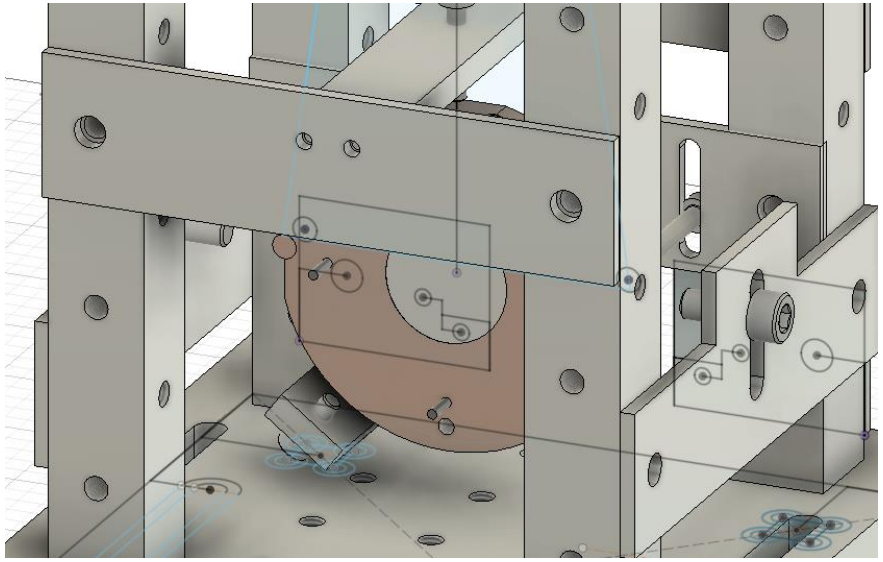
Some update plans for our suspension 振り子のアップデート

Photo sensors
To assess our suspension, adding photo sensors

We can use the suspension 4th-year students used last time

For now, there are safety devices around the test mass, I think it is not necessary unless we use the suspension roughly. So, It is better to replace them with photo sensors

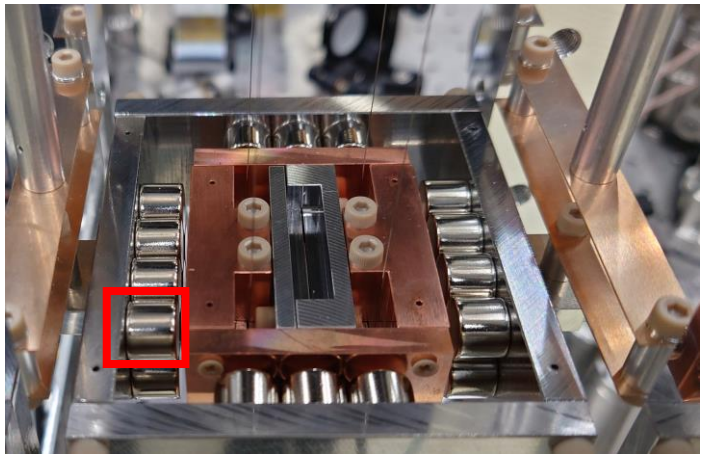


Magnets for Eddy-current damping

Eddy-current damping seems over-damping now.

We use cylinder-shaped Φ 10 mm ×8 mm magnets for Eddy-current damping

Aiming for the optimal damping by making the height of magnets 6 or 7 mm or reduce the number of magnets



Applying the suspension to B-L DM search experiment

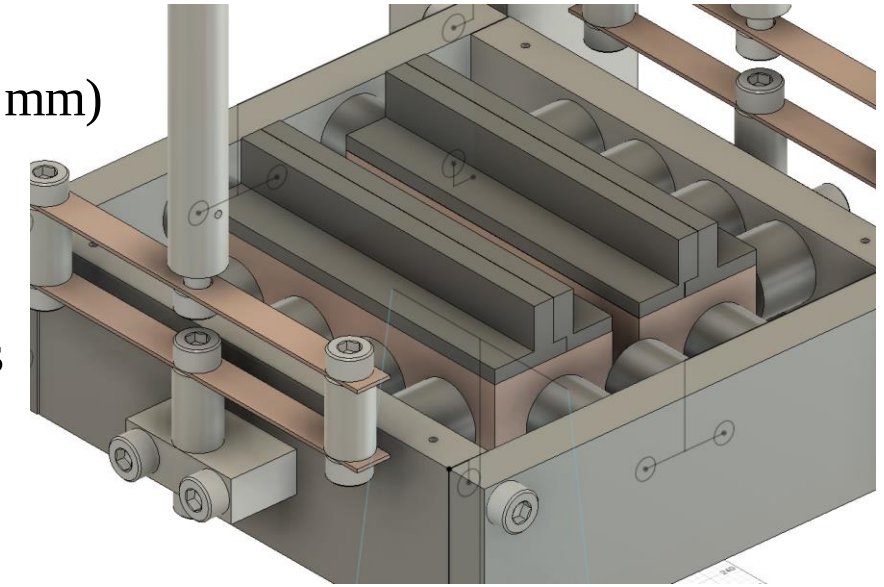
Design a new masses

In B-L DM search experiment, we need a small cavity (Length = 5 mm)

We will suspend two pendulums from one roof

In the middle of designing an intermediate mass as the right figures

It is still on the level of a conceptual design

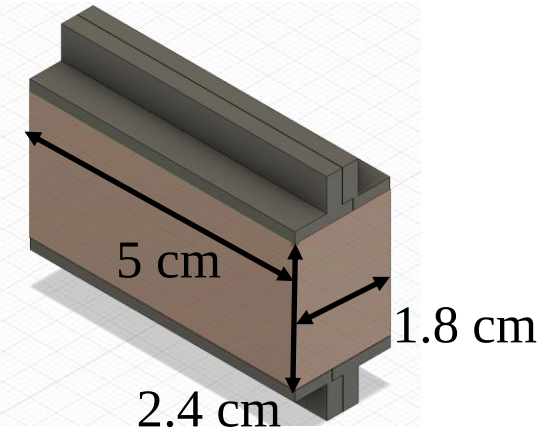


Some specific details

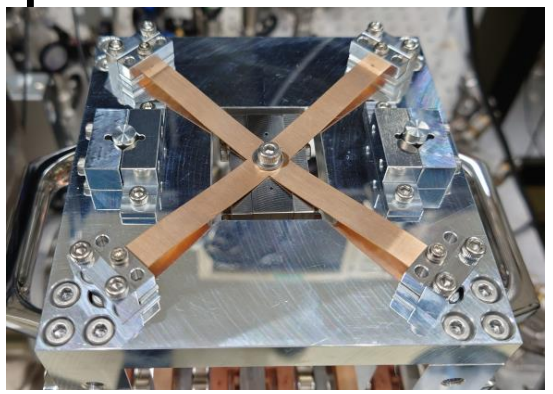
High resonant frequency in the pitch direction

Materials : Top and bottom are **stainless steel** while the middle is **Cu**

We still need to consider how to suspend it…(Jigs, Guide)



Update the suspension for Precise Measurement experiment



Re-design blade springs

Now, I found the resonant frequency of the blade spring is 42 Hz

We need to design a new blade spring again

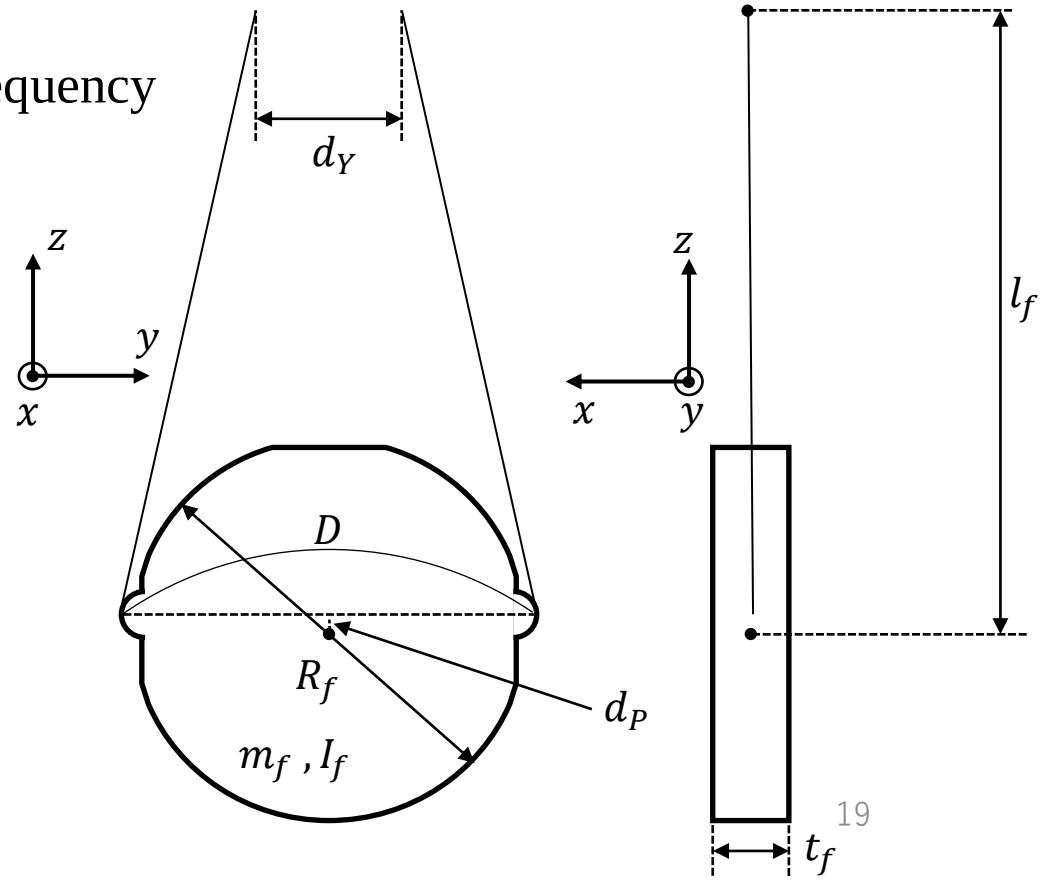
Geometric Anti-Spring will be needed to realize a low resonant frequency

Making pitch resonant frequency higher

The resonant frequency in the pitch direction is 2 Hz.
It is for the demonstration of ASC of DECIGO

For the precise measurement,
We no longer need the fluctuation in the angle direction

Pitch resonant frequency $f_p = \frac{1}{2\pi}\sqrt{\frac{m_f g(d_p+l_f)}{I_f l_f}}$ [Hz]



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Developing Circuits 回路の開発

Some kinds of circuits we often use should be packaged to save time and share their characteristic

I plan to design Printed Circuit Boards (PCBs) and order to P-ban.com

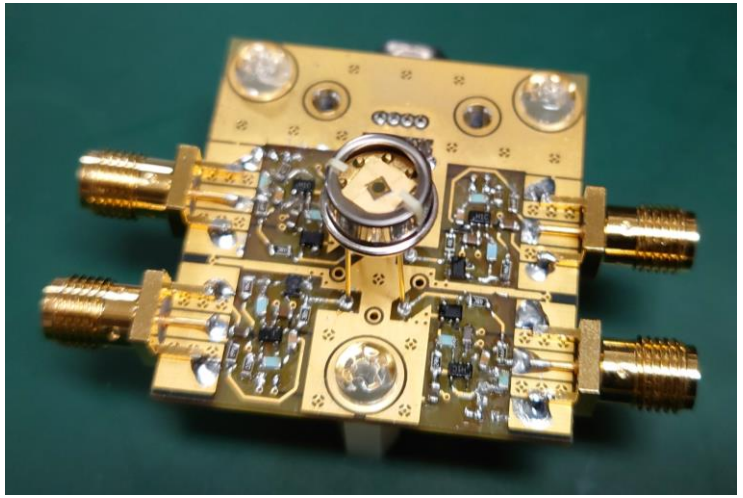
Now Komori-san and I have been designing PCB of Broadband RFPD

Broadband RFPD

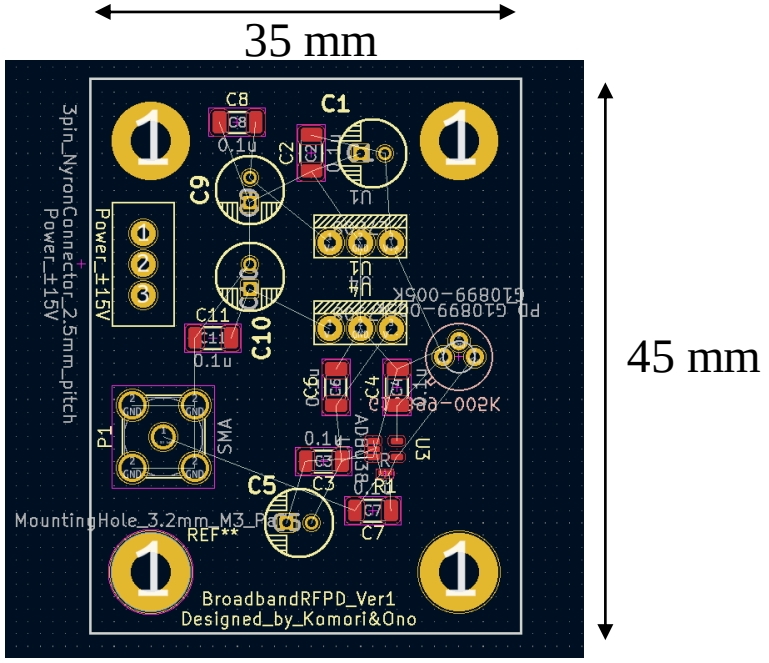
Komori-san developed Broadband RFQPD for LISA at JAXA

We customize the configuration of the RFQPD for the environment of Ando Group

Now Komori-san and I have been designing PCB of Broadband RFPD



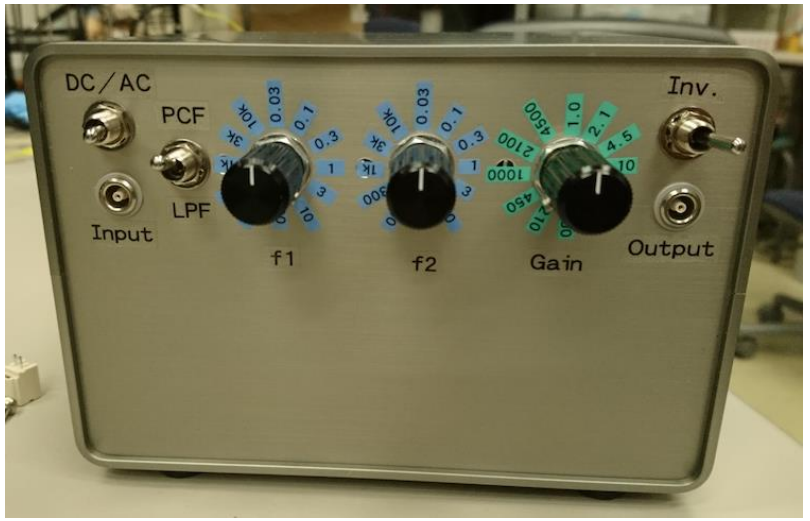
Komori-san's RFQPD



New RFPD for us(in designing)

What should be developed ?

- circuits only for adjusting gain
- Offset Circuits
- The Flexible Filter ST560 from Ando Lab Company like SR560
- Analog interfaces for LIGO CDS



ST560 in our group

We already have ordered…

- Resonant-type RFQPD
- 4ch Demodulator (from TAMA Design)
- Coil Driver Circuit
- D-sub9pin BNC for ADC board (from LIGO and KAGRA)
- D-sub9pin BNC for DAC board (from LIGO and KAGRA)

Please suggest !

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Summary

・After realizing a situation seismic noise limits the displacement of the cavity at low frequencies and frequency noise limits it at high frequency, I will start writing a paper

・DECIGO DPFP cavity experiment has a potential to achieve a good sensitivity. So the setup will remain after the demonstration of ASC of DPFP cavity is finished

・Many kinds of noises are expected.

・It is important to take the necessary measures in order from dominant noises we can see