Current status of laser intensity stabilization system in KAGRA

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On behalf of KAGRA collaboration

Overview

1. Introduction

- Significance of intensity stabilization

2. Intensity stabilization system

-Outline of intensity stabilization system

- Intensity stabilization system in KAGRA

3. Results of intensity stabilization

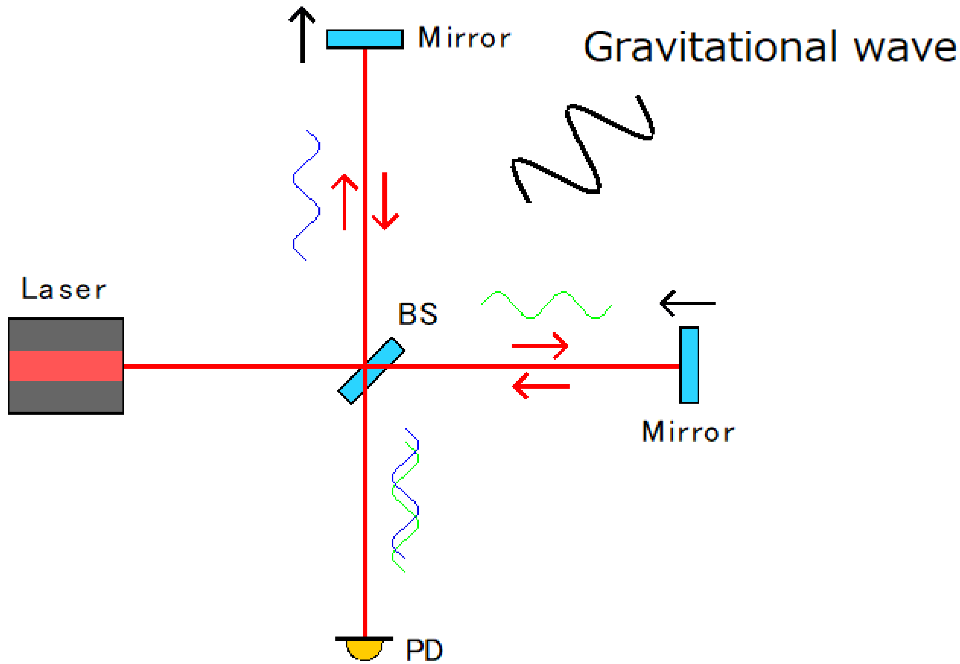
- Results of relative intensity noise

- Contribution to sensitivity of KAGRA

4. Conclusion

・The current mainstream gravitational wave telescope is based on the Michelson interferometer.

・When the gravitational wave arrives, the two optical paths of the interferometer change differentially, and the light intensity on the detector changes.



The amplitude of the gravitational wave is too small **10^{-22}**

very small!

Various noises should be eliminated
and we are especially working on reducing **laser intensity noise**.

What is the laser intensity noise？

Cause

1. Noise caused by laser light shaking the mirror (=Displacement noise)

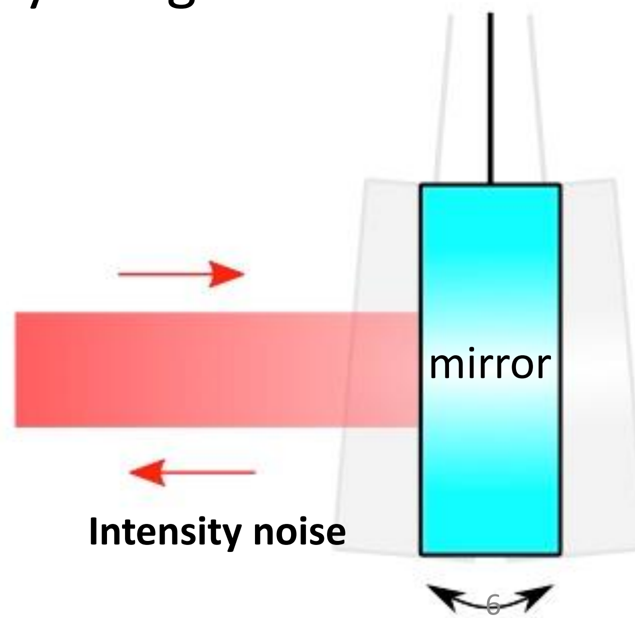
2. Noise generated when laser light is detected by the sensor(=sensor noise)
   The photo diode detects the laser power. So the laser intensity noise directry concerns the singnal noises.

1.Displacement noise

Laser light pushes mirror = **Radiation pressure**

Laser intensity noise causes fluctuations in radiation pressure,
It causes the mirror to be shaked. → The distance between mirrors changes.

This cannot be distinguished from the displacement by the gravitational wave.

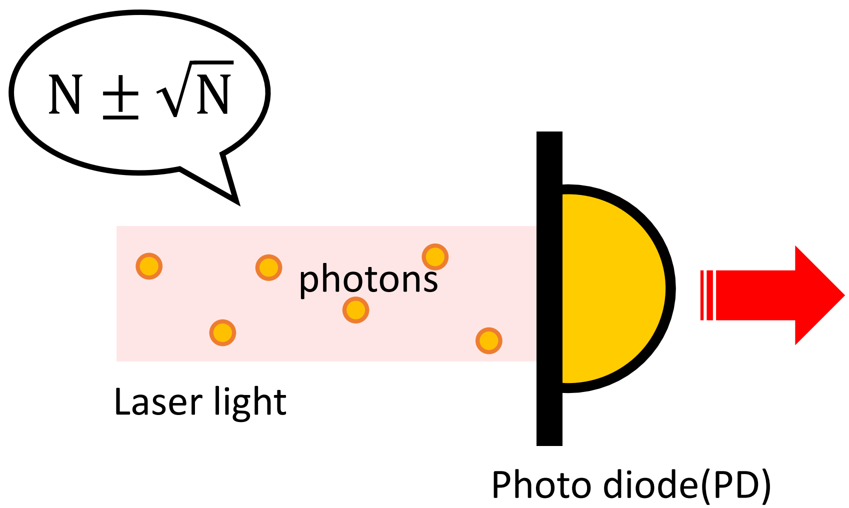


2.Sensor noise

If the laser intensity fluctuates,
The output of the photo diode fluctuates as well.
→ **It is difficult to distinguish this from gravitational wave signals**.

theoretically, the intensity noise can be reduced down to the shot noise limit.

If the average number of photons is N, it always fluctuates by $\sqrt{N}$ due to the uncertainty principle. This fluctuates the output of the photodetector = **Shot noise**.



Required value of laser intensity noise

the target sensitivity of KAGRA for gravitational wave signals.

the required value of laser intensity noise for our first observation in 2020 is
$\mathbf{1 \times 10^{-7}/\sqrt{Hz}}$ in the relative intensity.

2． Intensity stabilization system

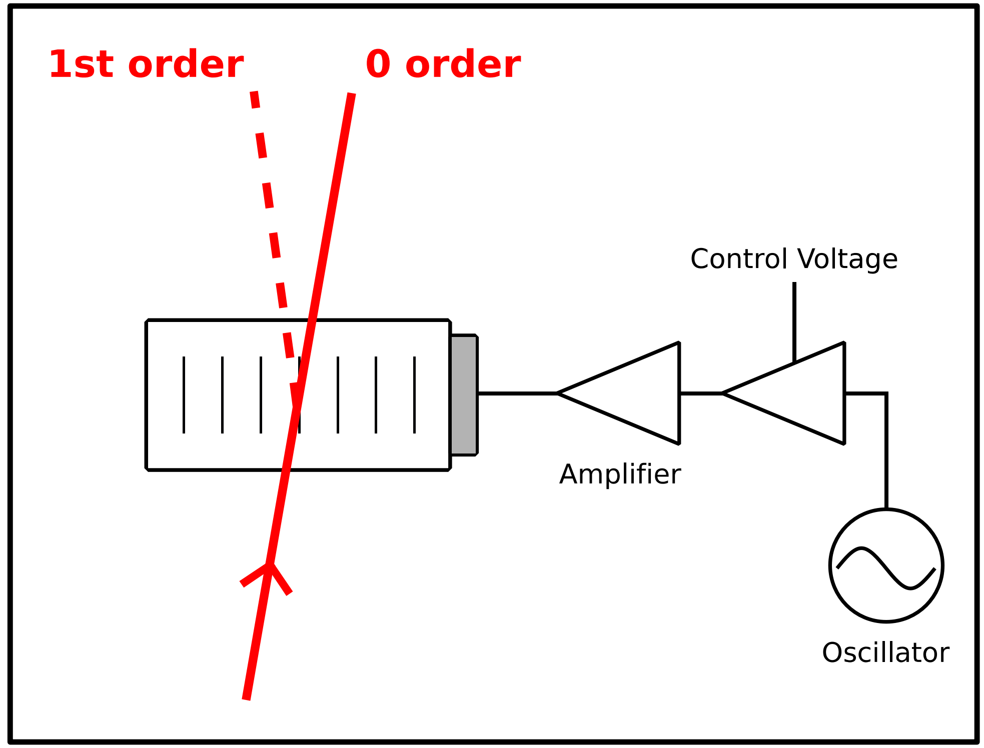
The intensity stabilization system uses
an **Acousto-Optic Modulator (AOM)** to reduce the laser intensity fluctuation.

AOM is an optical element based on Bragg diffraction.

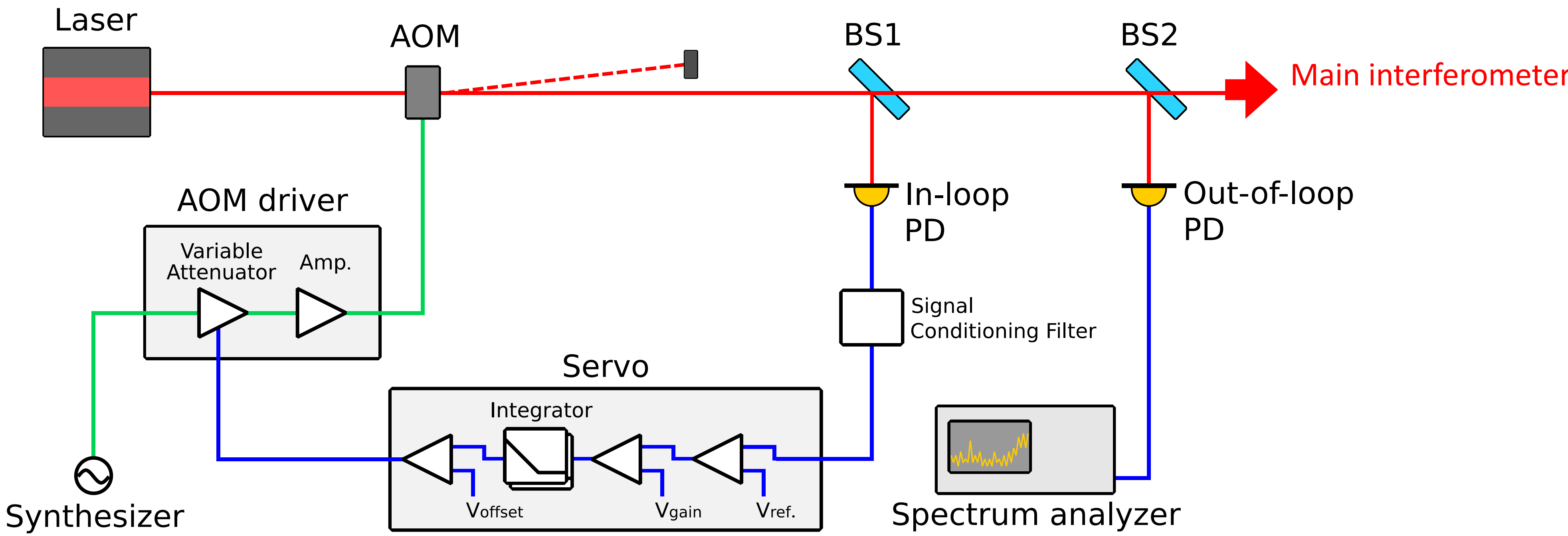
An RF signal is transduced into a sound wave in the internal crystal, which acts as a diffraction grating.

The power of the diffracted light (primary light) depends on the amplitude of the input RF signal.

※ Zero-order light is used in the intensity stabilization system.



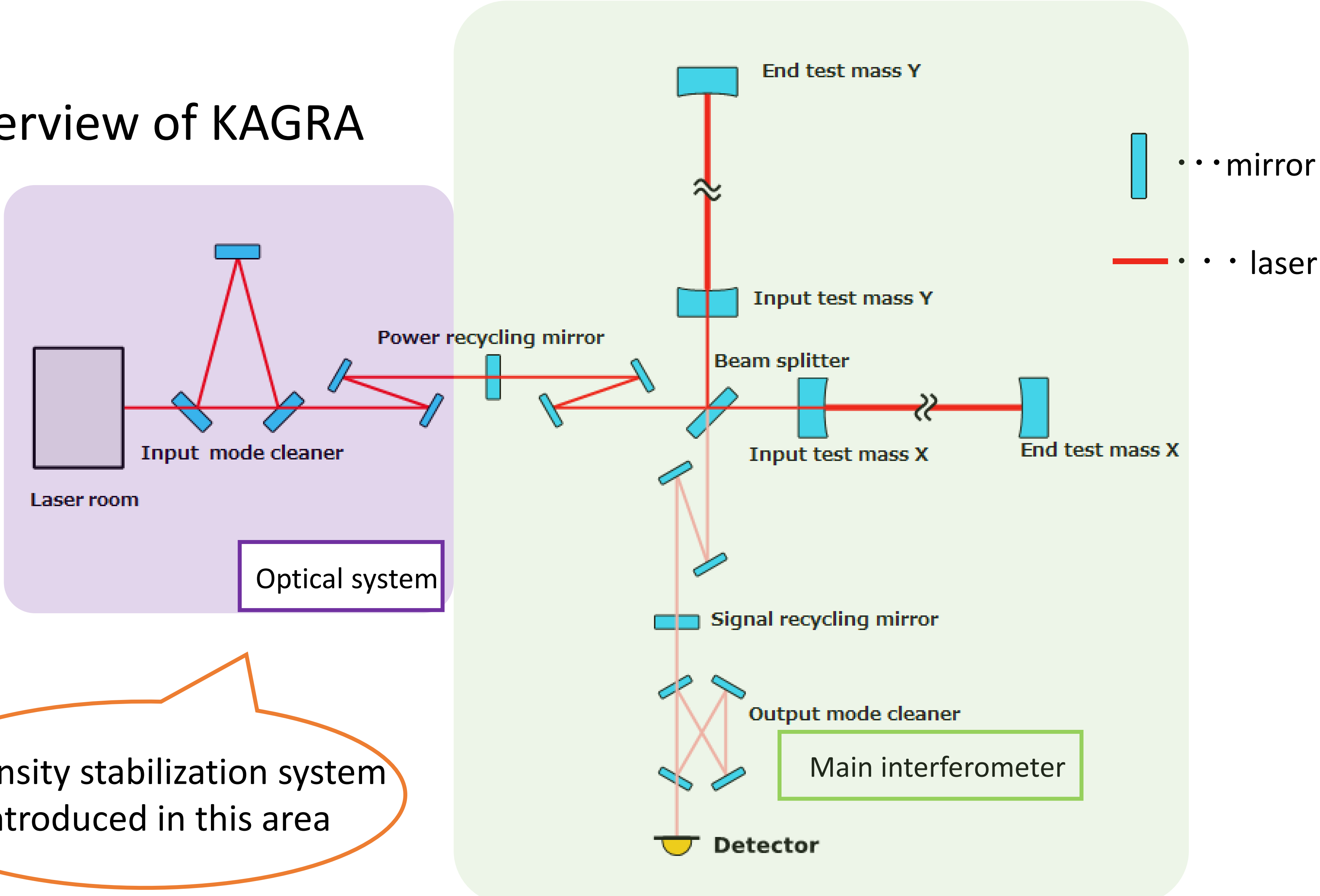
outline of AOM



～ Flow of intensity stabilization system ～

1. A part of the laser beam is monitored with an In-loop photodiode (PD), and the intensity noise of the laser is converted into a voltage signal.
2. The signal conditioning filter and servo circuits amplify and filter the signal into an appropriate frequency response for control.
3. Control signal is fed back to AOM to control the transmission of the laser.
4. Repeat steps 1-3

Overview of KAGRA



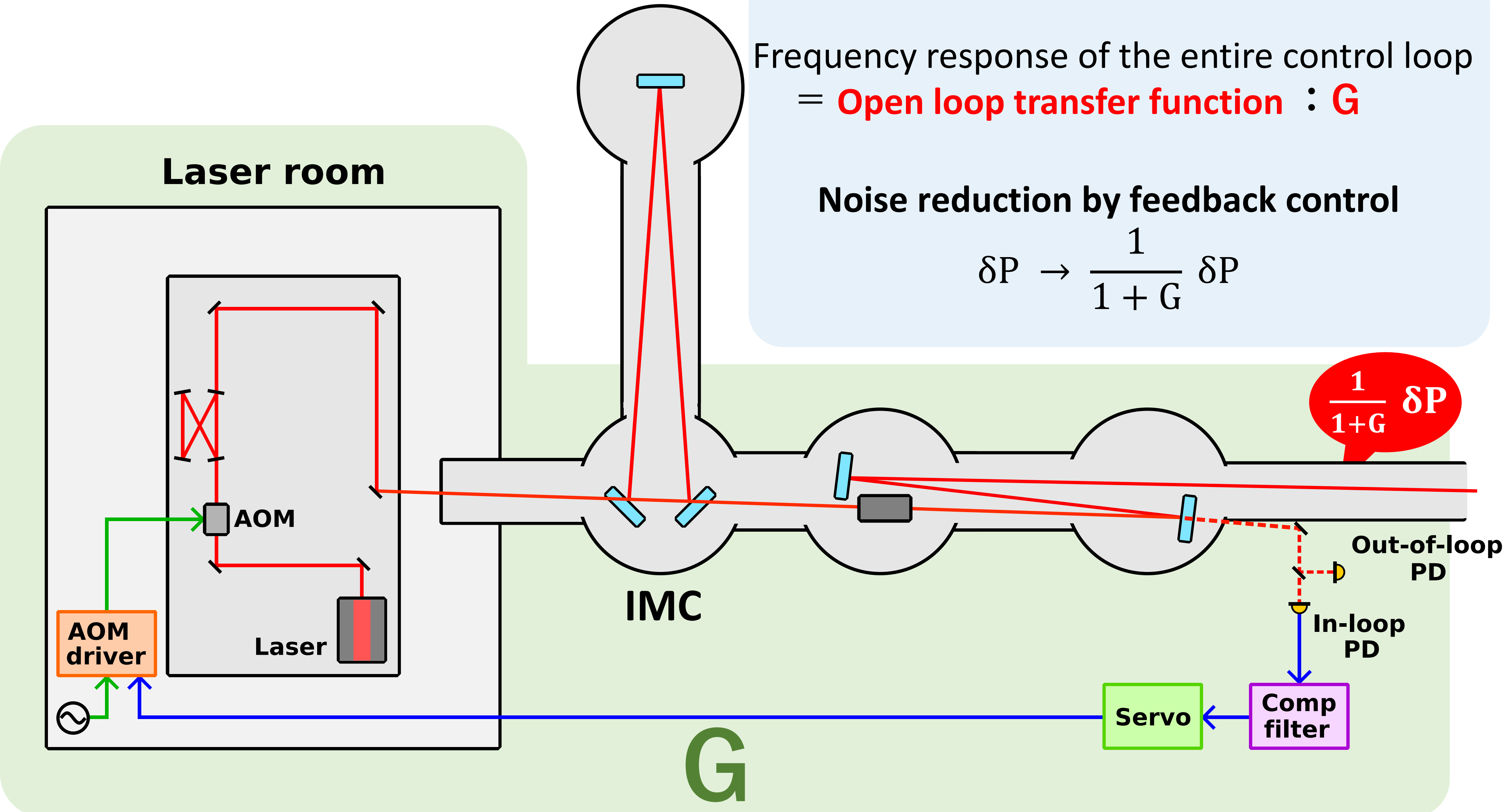
Intensity stabilization system is introduced in this area

Frequency response of the entire control loop

= **Open loop transfer function ： G**

Noise reduction by feedback control

$$\delta P \rightarrow \frac{1}{1+G}\,\delta P$$



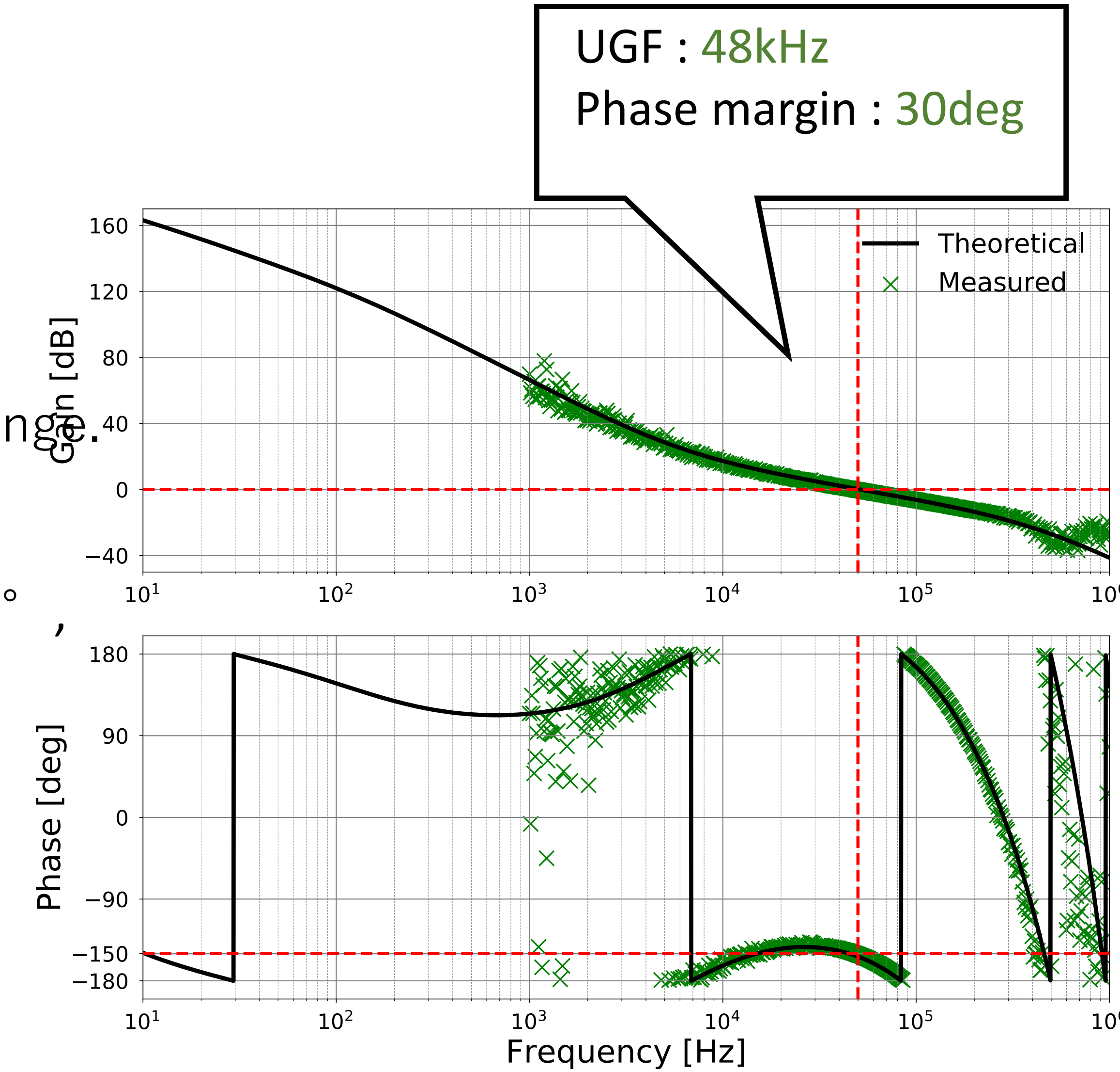
Open loop transfer function

1) Unity Gain Frequency : UGF

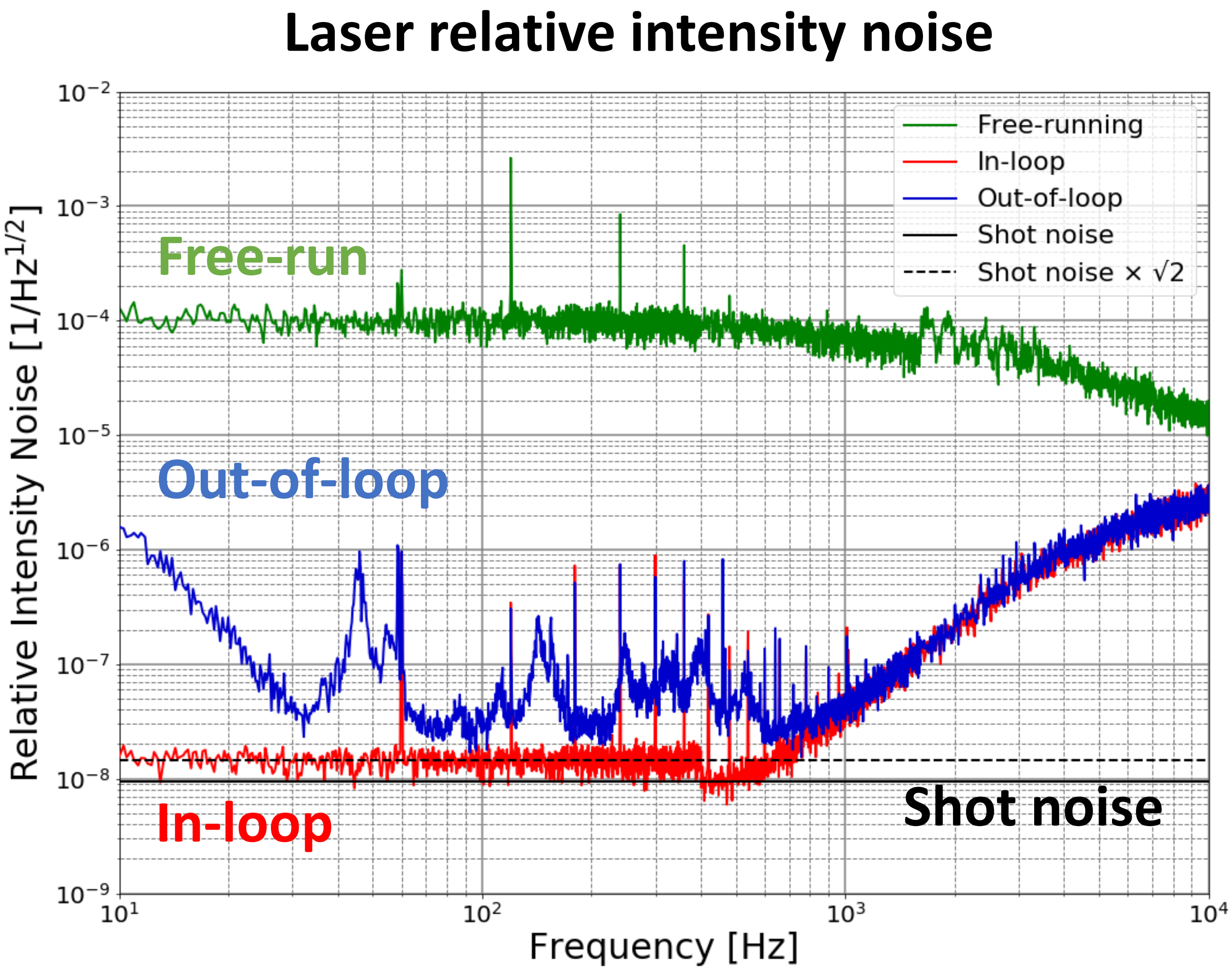
The frequency at which the gain is 0 dB.
A higher UGF is preferable for the higher gain in the low frequency range.

2) Phase margin

If the phase at the UGF is turned by 180°, the control becomes unstable.
Generally, it is desirable that the phase margin is 30° or more.



3. Results of intensity stabilization



Required value

$1 \times 10^{-7} /\sqrt{\mathrm{Hz}}$

Laser power

In-loop

5.5mW

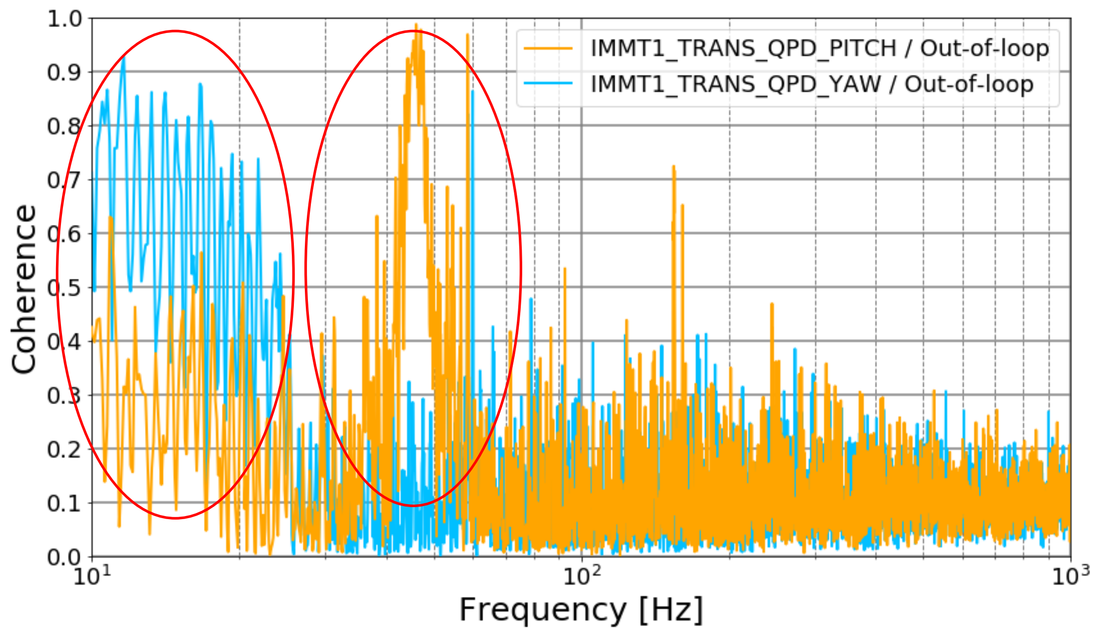
Out-of-loop

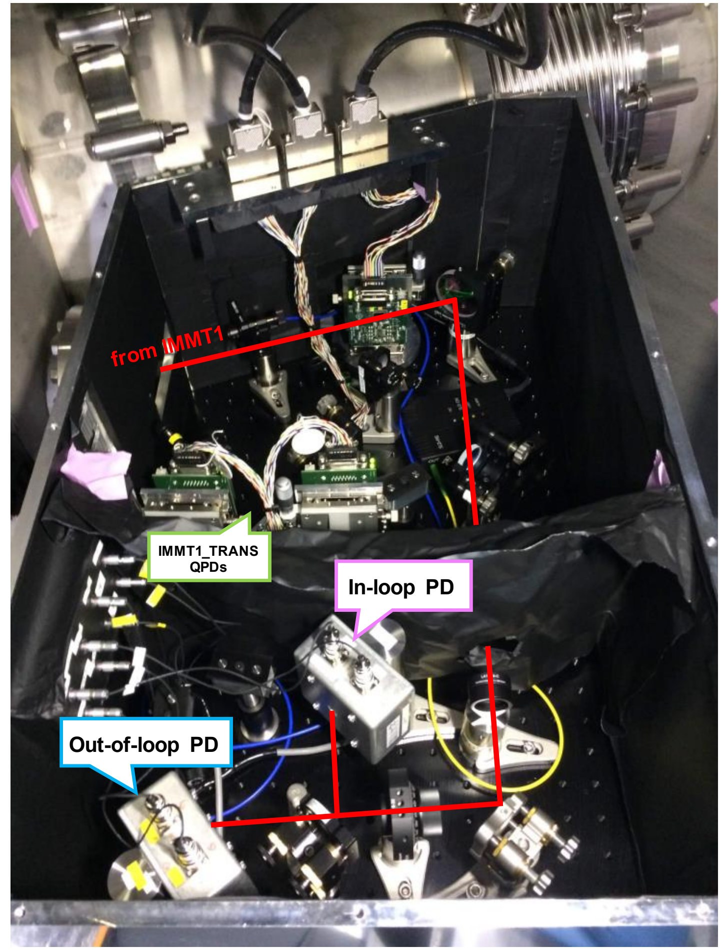
4.6mW

Correlation with the optical axis fluctuation

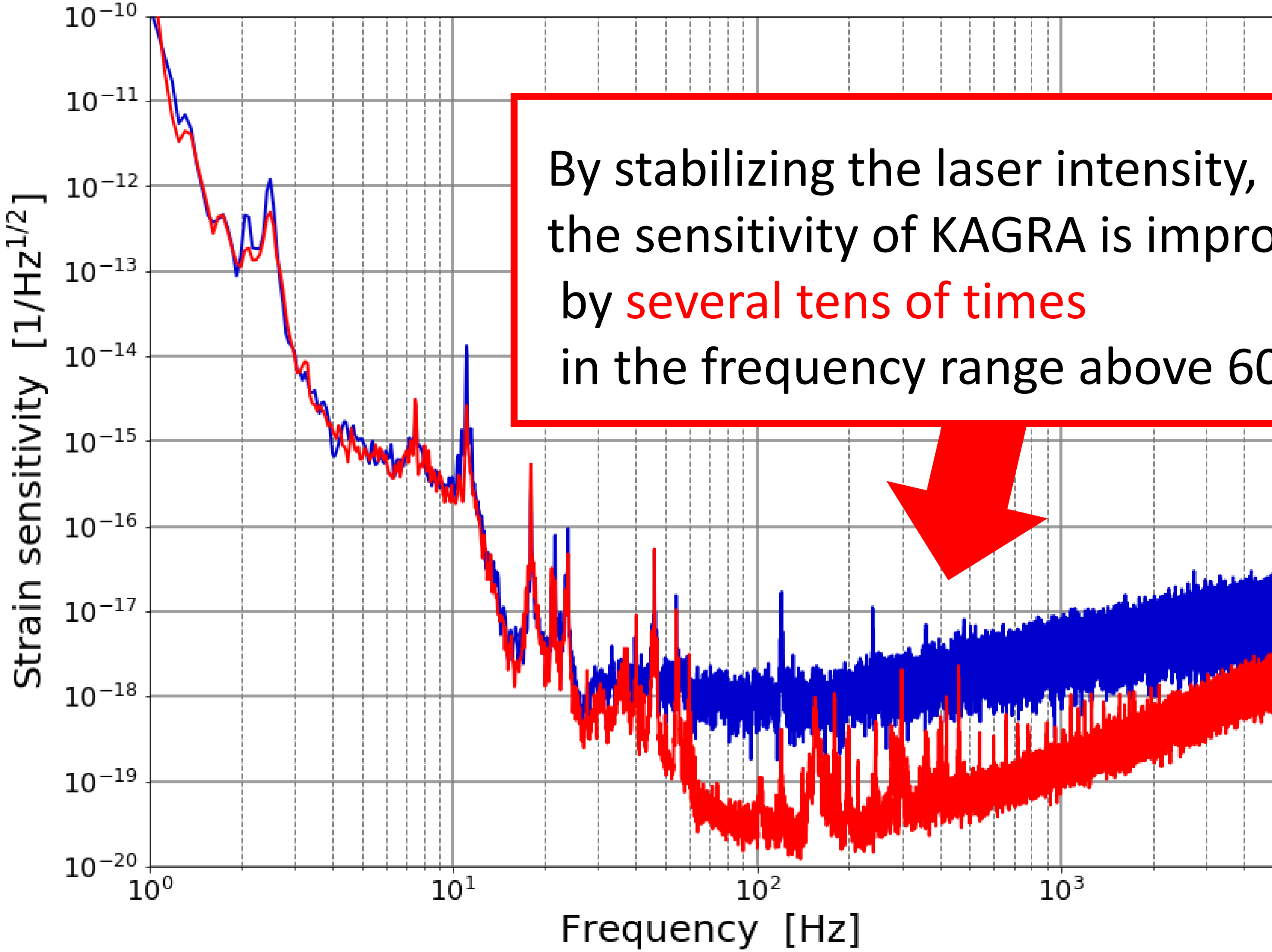
The optical axis is fluctuation is measured with
A quadrant photodiode(QPD).
A correlation was found between the horizontal and vertical fluctuations of the optical axis and the intensity noise.

horizontal ： 25 Hz or less





KAGRA sensitivity curve (November 13, 2019)



By stabilizing the laser intensity,
the sensitivity of KAGRA is improved
by several tens of times
in the frequency range above 60Hz !!!

4 . Conclusion

results

- Successfully closed the control loop of intensity stabilization system in KAGRA.

→ Achieved the required value $\mathbf{1 \times 10^{-7} / \sqrt{Hz}}$ in the frequency range between 25Hz and 5kHz.

- Greatly contributes to improving the sensitivity of KAGRA.

→ By stabilizing the intensity, we succeeded in improving the sensitivity of KAGRA by about one to two orders of magnitude over the 60Hz band.

Future outlook

- Identify noise sources in the 100 Hz to 1 kHz band.
- Advance the development of systems to be installed into the KAGRA vacuum chamber for further noise reduction.
- Aim for the final required value $2 \times 10^{-9} / \sqrt{\mathrm{Hz}}$ (@ 30Hz).