[1] Koji Nagano et al 2021 Class. Quantum Grav. **38** 085018.

Demonstration of a dual-pass differential Fabry–Perot interferometer for future interferometric space gravitational wave antennas: DECIGO and B-DECIGO

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Abstract

A dual-pass differential Fabry–Perot interferometer (DPDFPI) is one candidate of the interferometer configurations utilized in future Fabry–Perot type space gravitational wave antennas, such as Deci-hertz Interferometer Gravitational wave Observatory (DECIGO) and B-DECIGO. In this poster, the working principle of the DPDFPI has been investigated and necessity to adjust the absolute length of the cavity for the operation of the DPDFPI has been found. In addition, using the 55 cm-long prototype, the operation of the DPDFPI has been demonstrated for the first time and it has been confirmed that the adjustment of the absolute arm length reduces the cavity detuning as expected. This work provides the proof of concept of the DPDFPI for application to the future Fabry–Perot type space gravitational wave antennas. For detail, please see [1].

1. Introduction

- For the 0.1-Hz-band gravitational wave observation, DECi-hertz Interferometer Gravitational wave Observatory (DECIGO) and its precursor mission B-DECIGO are proposed [2].
- They are planning to utilize a 1000 (or 100) km Fabry–Perot interferometer to enhance the sensitivity.
- **The Fabry–Perot interferometer gives DECIGO the possibility even to observe a stochastic gravitational wave background generated in the early Universe.**
- As a conceptual design of DECIGO and B-DECIGO, a dual-pass Fabry–Perot interferometer configuration is proposed.

- For further proceedings of the DECIGO and B-DECIGO, **we propose a realistic interferometric space detector configureation, a dual-pass differential Fabry–Perot interferometer (DPDFPI).**
- We analytically investigate the working principle of the DPDFPI for the first time and show the requirement of the cavity length adjustment for the operation of the DPDFPI. Moreover, we constructed the first experimental prototype of the DPDFPI for its proof of concept.

2. Formalization of the DPDFPI

A) We present the working principle of the DPDFPI using the block diagram as shown in figs. 1 and 2.

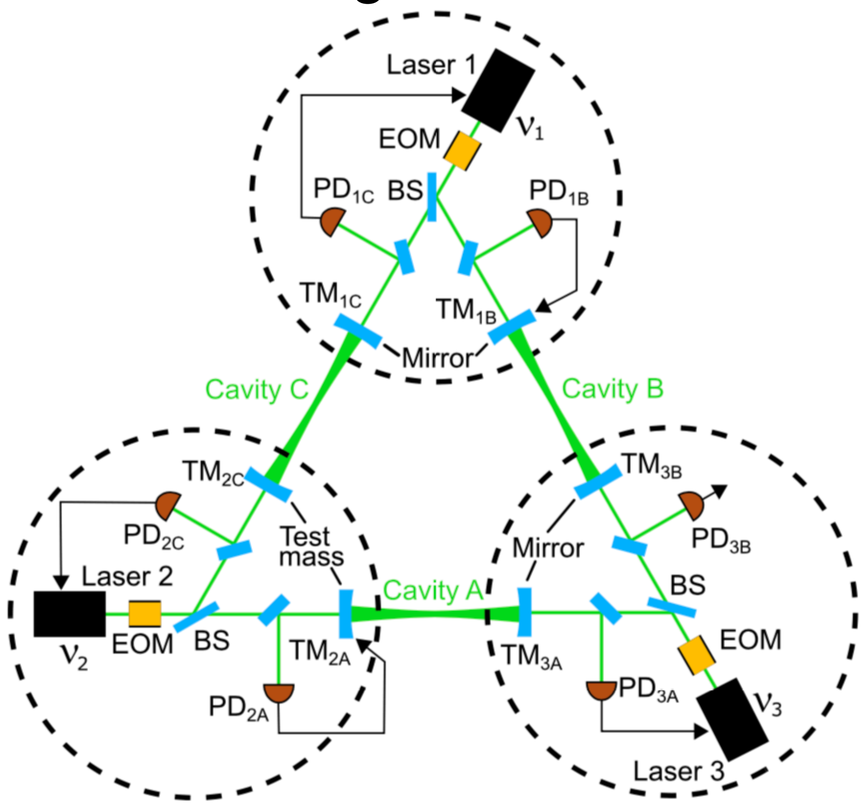

Fig. 1: Schematic view of the DPDFPI considered for DECIGO.

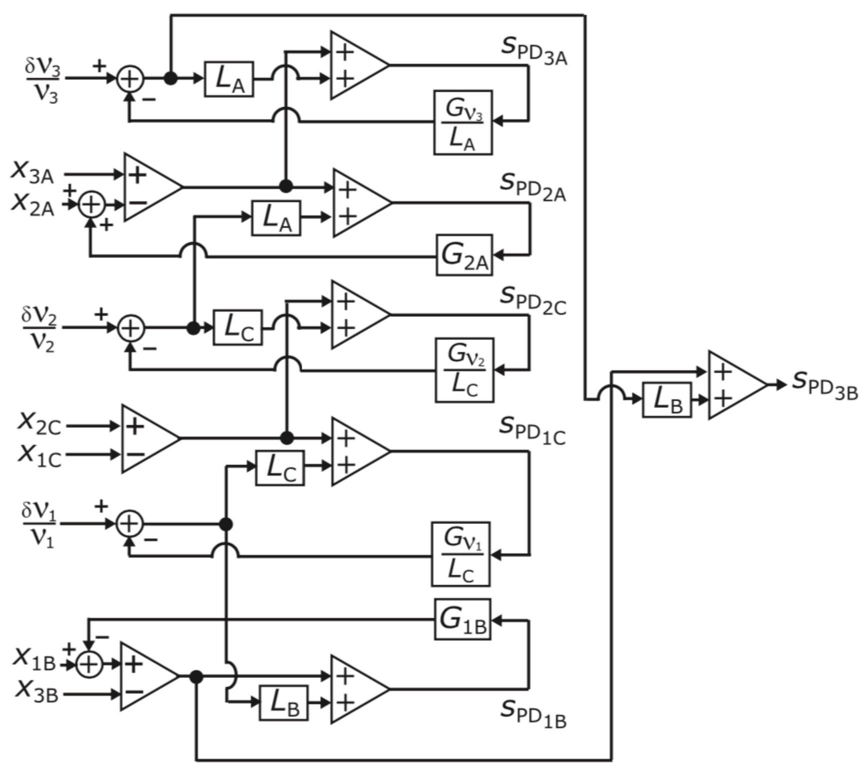

Fig. 2: Block diagram of the DPDFPI shown in fig. 1.

$$
\begin{cases}
s_{\mathrm{PD1B}} = \dfrac{1}{1+G_{1\mathrm{B}}}\left(-\Delta x_{\mathrm{C}} + \Delta x_{\mathrm{B}}\right), \\
s_{\mathrm{PD2A}} = \dfrac{1}{1+G_{2\mathrm{A}}}\left(-\Delta x_{\mathrm{C}} + \Delta x_{\mathrm{A}}\right), \\
s_{\mathrm{PD3B}} = \begin{cases} -\Delta x_{\mathrm{A}} + \Delta x_{\mathrm{B}} & (|G_{1\mathrm{B}}| \ll 1,\ |G_{2\mathrm{A}}| \ll 1) \\ \dfrac{1}{1+G_{1\mathrm{B}}}\left(-\Delta x_{\mathrm{A}} + \Delta x_{\mathrm{B}}\right) & (G_{2\mathrm{A}} \simeq G_{1\mathrm{B}}) \end{cases}
\end{cases}
$$

Differential signals, i.e. GW signals, can be obtained with the DPDFPI.

B) We found **the necessity to adjust the absolute length of the cavity for the operation of the DPDFPI.**

Resonant conditions of each cavity

$$
\begin{cases}
f_1 = n_{1c}\dfrac{c}{2L_c},\ f_2 = n_{2a}\dfrac{c}{2L_a},\ f_3 = n_{3b}\dfrac{c}{2L_b}, \\
f_1 = n_{1b}\dfrac{c}{2L_b},\ f_2 = n_{2c}\dfrac{c}{2L_c},\ f_3 = n_{3a}\dfrac{c}{2L_a}
\end{cases}
$$

L_a, L_b, L_c: Cavity length
f_1, f_2, f_3: Laser frequency
n: Integer

If $L_a \neq L_b \neq L_c$, all above resonant conditions cannot be met at the same time since n is integer. The detuning of the cavity should be well reduced by adjusting all the cavity lengths.

→ For (B-)DECIGO, ΔL should be less than 2 km (40 m)

3. Experimental setup for the demonstration of the DPDFPI

- We had the experimental to demonstrate our formalization of the DPDFPI as shown in fig. 3.

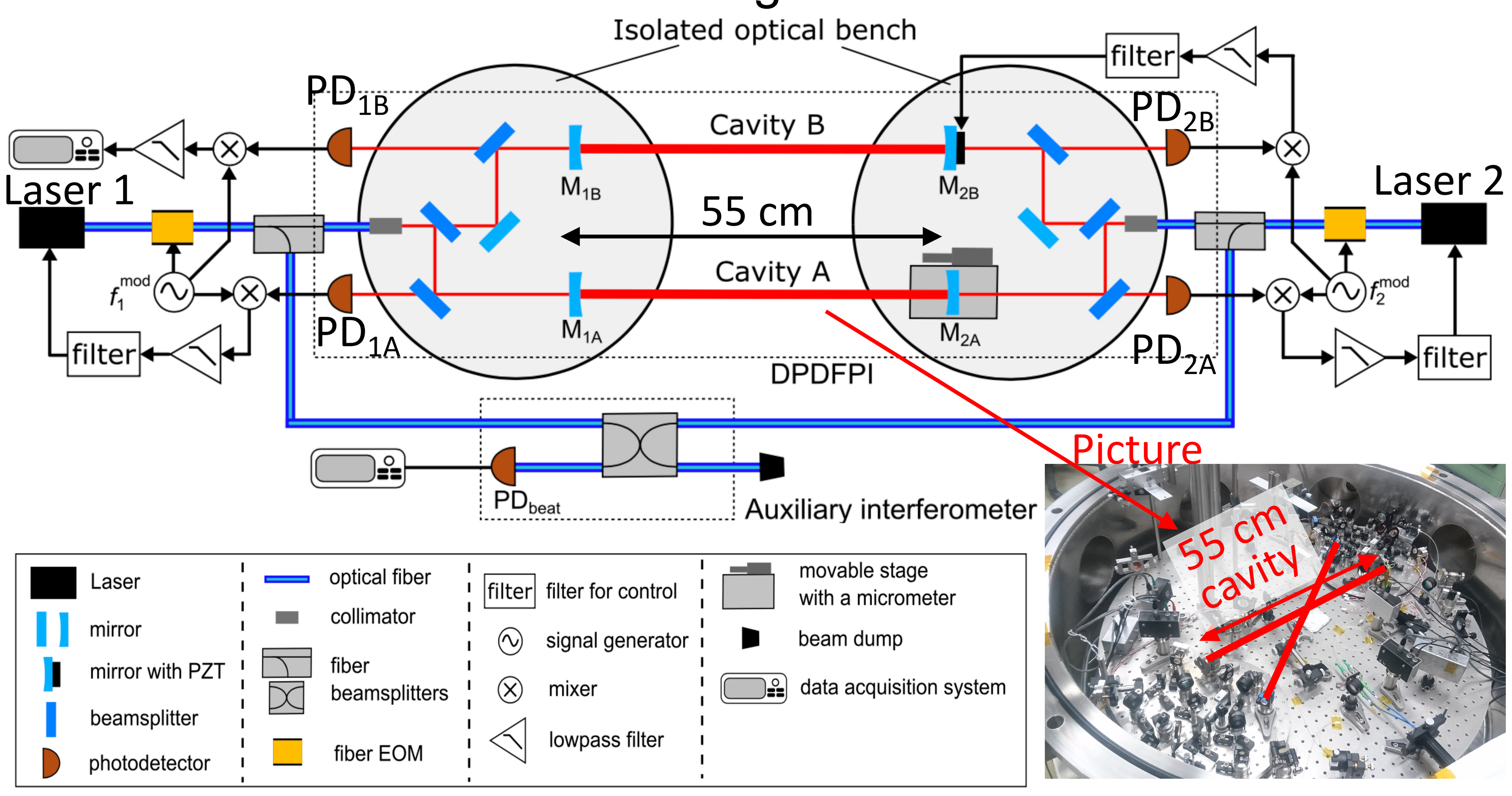

Fig. 3: Schematic of the DPDFPI experiment. The free-space interferometer on the isolated optical bench is the DPDFPI. The fiber-based interferometer is the auxiliary interferometer for the cavity absolute length measurement.

4. Results and discussions of the demonstration experiment

- Figure 4 shows that **the cavity detuning is reduced by adjusting the cavity detuning following our expectation.**

- After the cavity length adjustment, the noise spectra of the interferometer were measured as shown in fig. 5.
- **If the DPDFPI in figure 3 is properly operated, the same spectra can be measured as shown in fig. 5.**

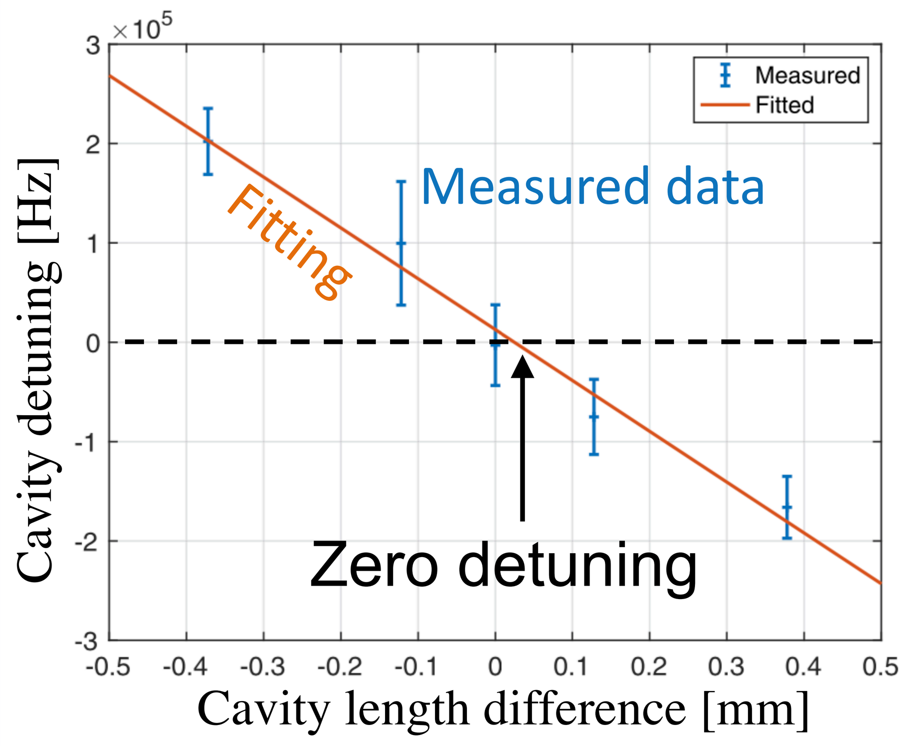

Fig. 4: Measured cavity detuning.

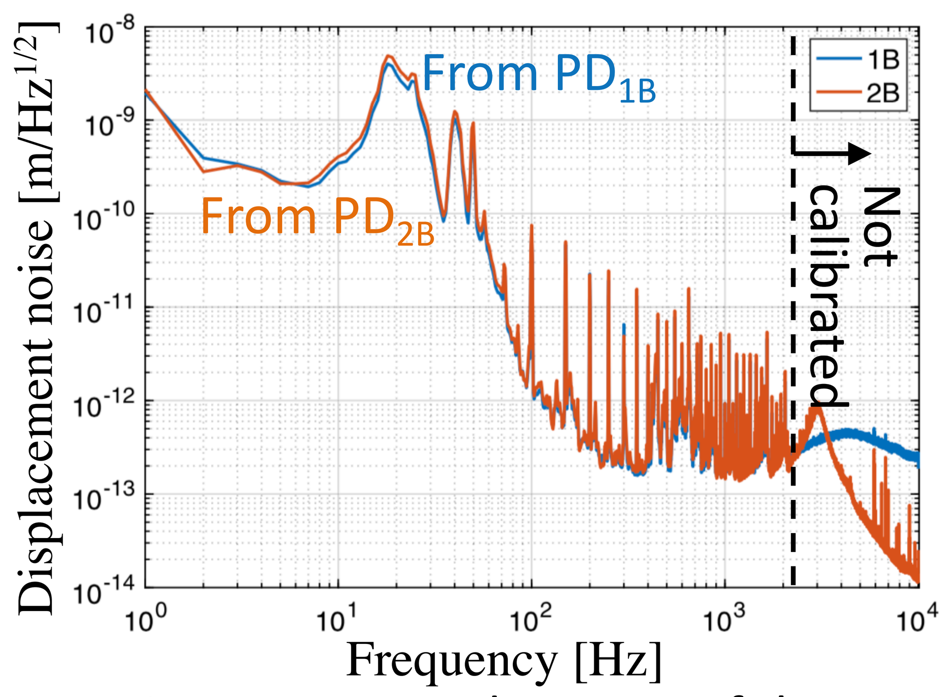

Fig. 5: Measured spectra of the differential displacement signals.

5. Conclusion

- We presented the working principle of the DPDFPI for the first time.
- For the operation of the DPDFPI, the absolute length adjustment is necessary.
- Using the 55 cm-long prototype, we demonstrated the DPDFPI.
- **We conclude that the proof of concept of the interferometer sensing scheme that can be applied to the future Fabry–Perot type interferometric space gravitational wave antennas has been demonstrated theoretically and experimentally.**

References

[1] Koji Nagano et al 2021 Class. Quantum Grav. **38** 085018.
[2] Seiji Kawamura et al 2011 Class. Quantum Grav. **28** 094011.

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