Development of the interferometer module for DECIGO Pathfinder

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DECIGO Pathfinder

• the first milestone mission for DECIGO
• carries stabilized laser source and Fabry-Perot cavity
• observe GW and measure gravitational field of the Earth
• earliest possible launch: ~2015-16
• what I do: assemble BBM of the interferometer module and verify the operation
Interferometer Module

- 2 monolithic optical benches, 2 test masses, thermal shields + servo system (PDH, WFS)
Mass Module

- surrounded by 12 electrodes work as electrostatic sensors/actuators

*see poster by A. Shoda (#59)
Overview of the BBM Experiment

• aim: test the operation on the ground
  - components are the same scale as BBM
  - realistic digital servo system
    same FPGA board used for the prototype of SWIMμν*

• what’s different?
  - test masses are suspended
    the shape of the test mass is slightly different from the original BBM

*GW detector launched in 2009 see poster by W. Kokuyama (#31)
Status of the BBM Experiment

- making the suspension system
- installing the monolithic optical bench
- fiber injection
- cavity length control by PDH
- coil-magnet actuators first
- digital servo using FPGA
- alignment control by WFS
currently working on QPD circuits
- electrostatic actuators, modularization
- thermal shields, vacuum …..
Experimental Setup

- lock cavity length by PDH
Experimental Setup

- laser source (1064nm)
- isolator
- optical bench
- fiber EOM
- FP cavity
- PD
- FP cavity
- laser source (1064nm)
- isolator
- optical bench
- fiber EOM
- PD
Suspension of the Test Mass

- aluminum, 70mm cube, 0.71kg
- 4 magnets for actuation
- suspended by 4 wires near the center of mass
- resonant frequency (calculated)

\[
\begin{align*}
f_x &= 0.91 \text{ Hz} \\
f_{\text{pitch}} &= 3.24 \text{ Hz} \\
f_{\text{yaw}} &= 0.24 \text{ Hz}^{\text{pitch}}
\end{align*}
\]
Fabry-Perot Cavity

- Finesse: 208 (designed)

Front Mirror
  plane
  PR=98%

End Mirror
  r=500mm
  PR=99%

waist size: 0.29mm

cavity length: 30cm
Optical Bench

- Pyrex glass base plate with the optical components silicate bonded to it

350 × 200 × 35 mm
Optical Bench

FP cavity

fiber collimator

WFS(end)

WFS(front)

PDH

PD
Servo System

- digital control by FPGA
- same board used for the prototype of SWIMμν
  \( f_s = 26.8\text{kHz} \), PD servo
- coil-magnet actuators
Openloop Transfer Function

- Gain: $\sim 3 \times 10^5$
- Phase Margin: $\sim 40\text{deg}$
- UGF: $\sim 1$ kHz

![Graph showing openloop transfer function with frequency on the x-axis and gain/phase on the y-axis. The graph includes data points and a fitted line.]
Cavity Length Noise Spectra

- spectrum when the servo is turned off (green) is estimated by openloop calibration

- servo off: RMS = $6 \times 10^{-7}$ m
- servo on: RMS = $2 \times 10^{-11}$ m
Next Step

- install QPDs
- alignment control by WFS
Summary

- DPF is the first milestone mission for DECIGO
- BBM experiment is ongoing
- succeeded in the cavity length control monolithic optical bench digital control using FPGA coil-magnet actuators
- next step is to install QPDs and start the alignment control
Suspension Frame

Size of the interferometer module (800 × 300 × 300mm)

Stage for alignment adjustment

Suspended by 4 wires (W, φ=0.1mm, l~30cm)

Optical axis

Monolithic optical bench

FP cavity

Test mass (70mm cube)
FPGA

• Field Programmable Gate Array
• sampling frequency: 26.8kHz
• PD servo

\[ fb[k]=P \times er[k]+D \times (er[k]-er[k-1]) \]
Actuation Efficiency

- measured using photo-sensors