Methodological demonstration of laser beam pointing control for space gravitational wave detection missions

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Introduction

The angular jitter of the transmitting light will cause phase noise δφ due to the geometrical distortion of remote telescope [1, 2]:

$$\delta\varphi = \frac{1}{32}\left(\frac{2\pi}{\lambda}\right)^3 dD^2 \theta_{dc} \delta\theta$$

where θ_{dc} is the static offset error in the pointing, $\delta\theta$ is the pointing jitter, D is diameter of telescope, d is amplitude of curvature error in the wavefront and λ is laser wavelength. To achieve the desired beam pointing stability, active feed-back beam pointing control system is required. A demonstration of such system is performed, where Differential Wave-front Sensing (DWS) technique[3] is used to sense the beam pointing jitter.

Experiment setups

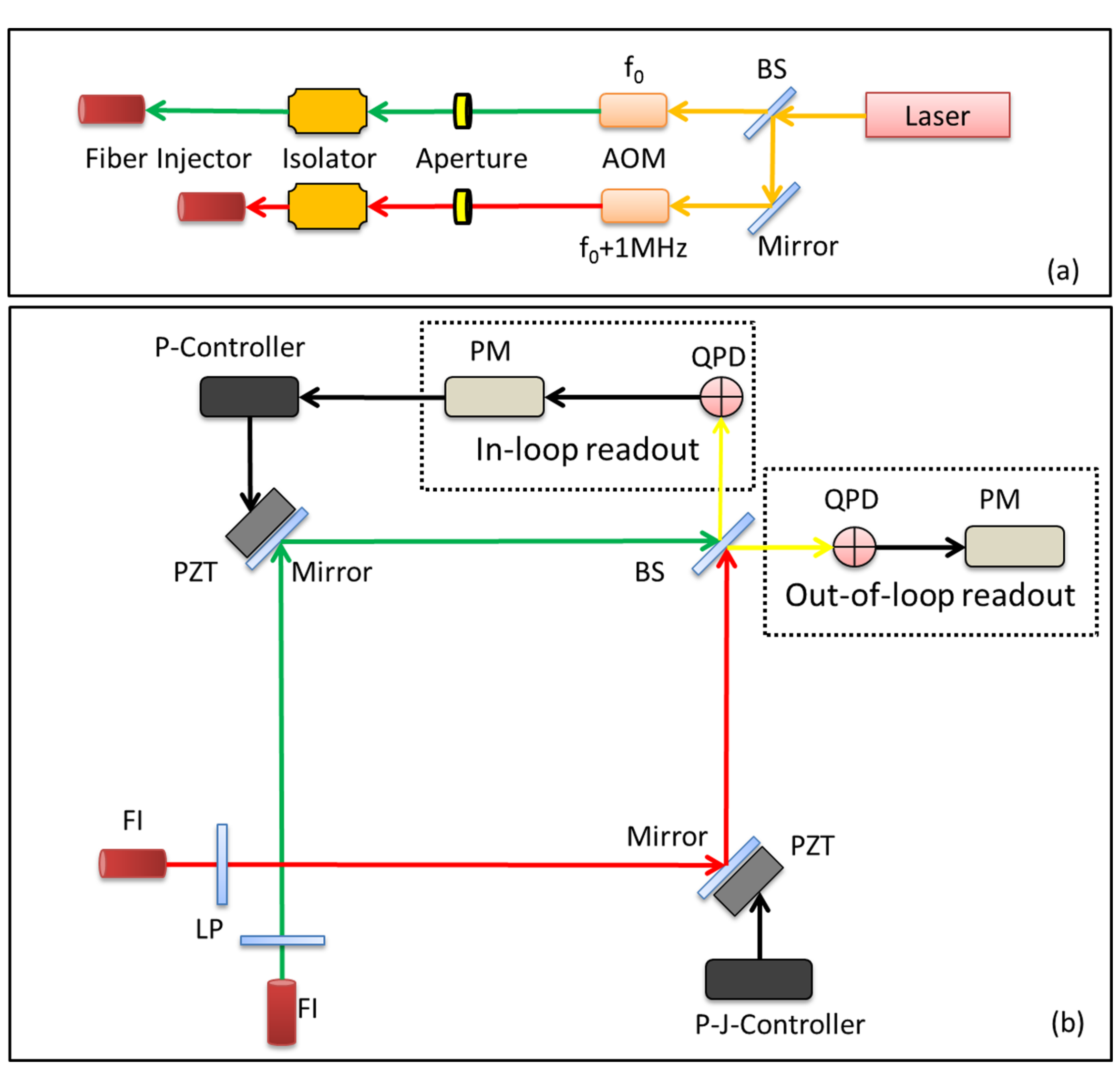

FIG. 1. Schematic diagram of the beam pointing control system: (a) laser modulation bench of pointing control system; (b) ultra-stable optical bench of pointing control system.

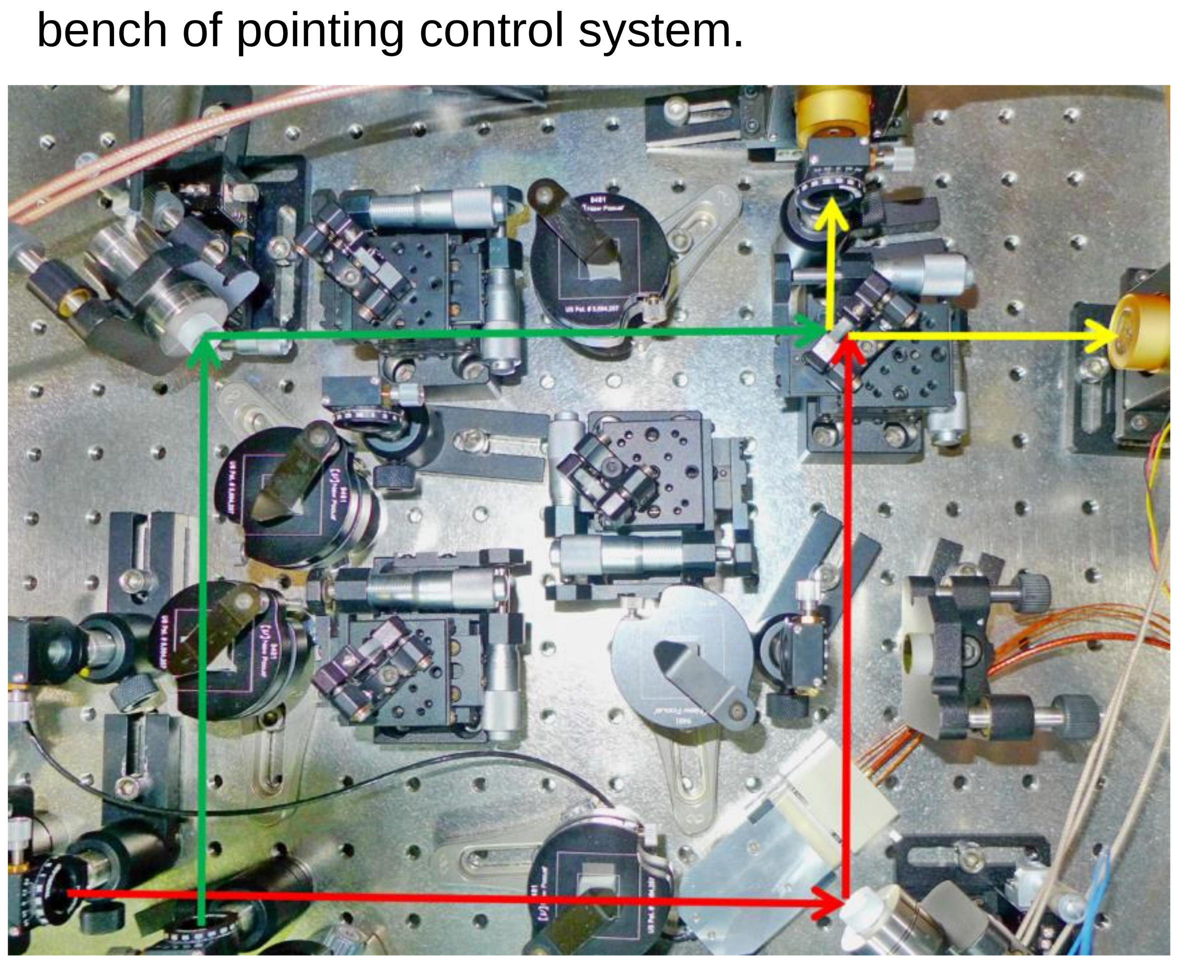

FIG. 2. Layout of laser beam pointing control system.

DWS techniques

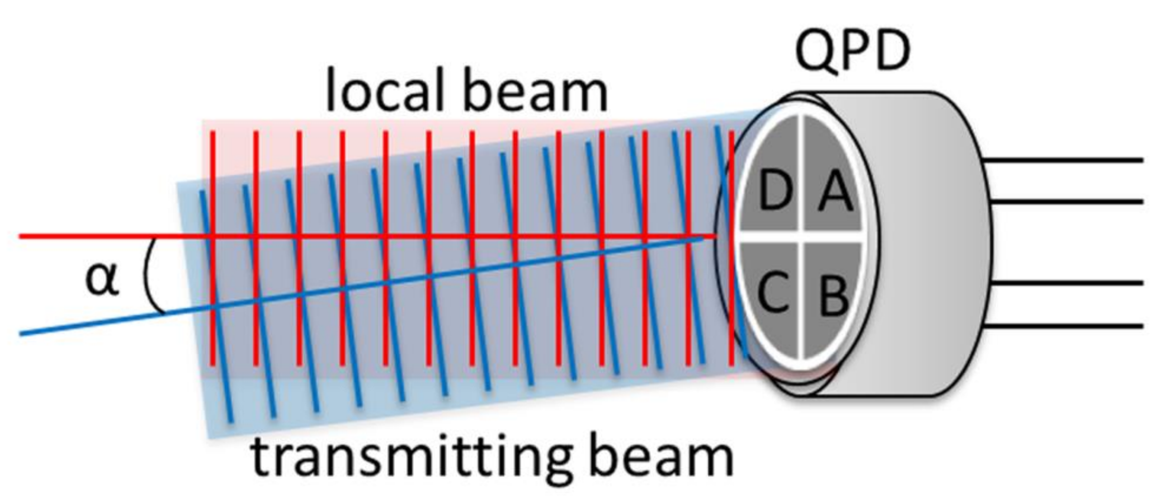

FIG. 3. Principle of DWS technique.

In small misalignment, the average phase difference Δθ between opposing halves of QPD can be approximated shown as[4]:

$$\Delta\theta \approx \frac{16r}{3\lambda}\cdot\alpha = k\cdot\alpha$$

where α is the relative wave-front tilt, r is the beam radius, λ is the laser wavelength and k is the conversion factor.

Calibration

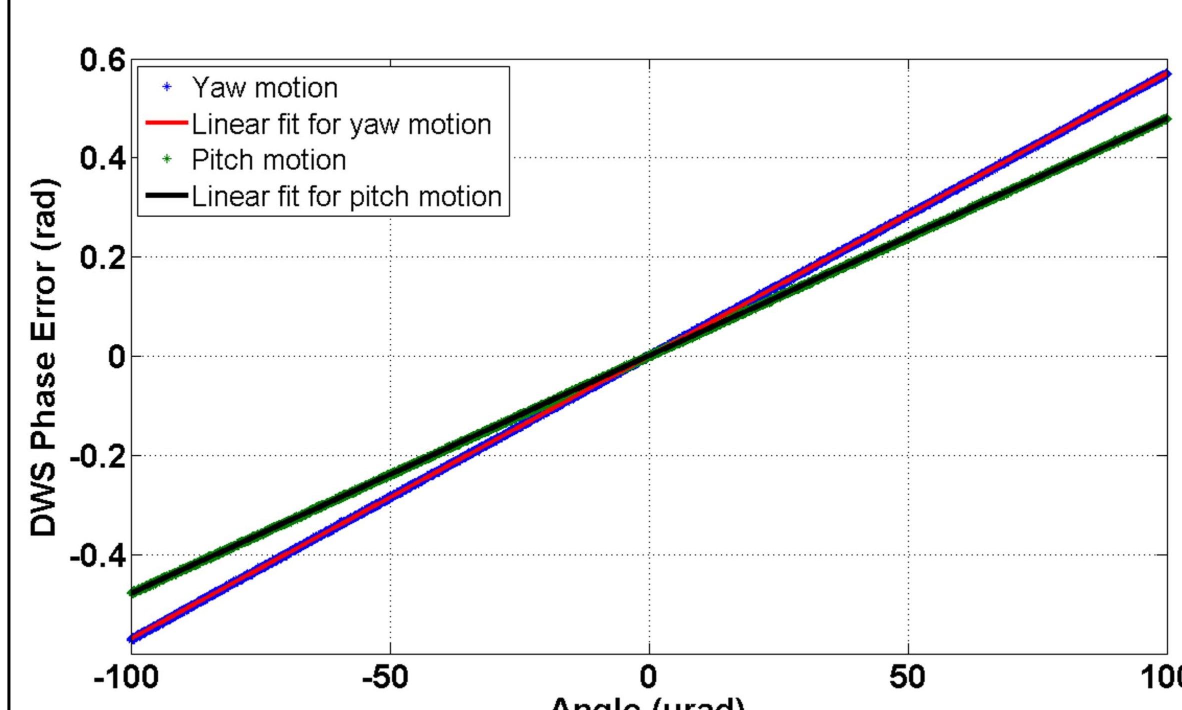

FIG. 4. Linear fit for yaw motion and pitch motion.

The conversion factors for yaw and pitch motion can be obtained from linear fitting curve:

$$k_{yaw} = 5703\,rad/rad$$

$$k_{pitch} = 4790\,rad/rad$$

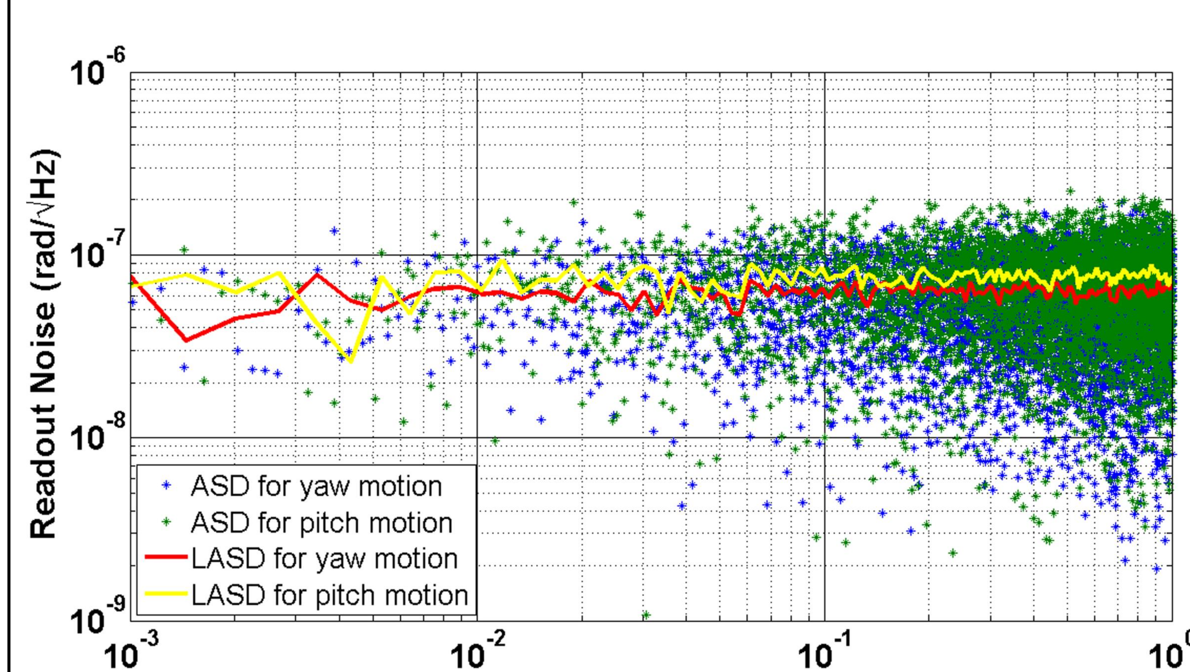

FIG. 5. Readout noise of the pointing system in yaw and pitch motion.

Results and discussions

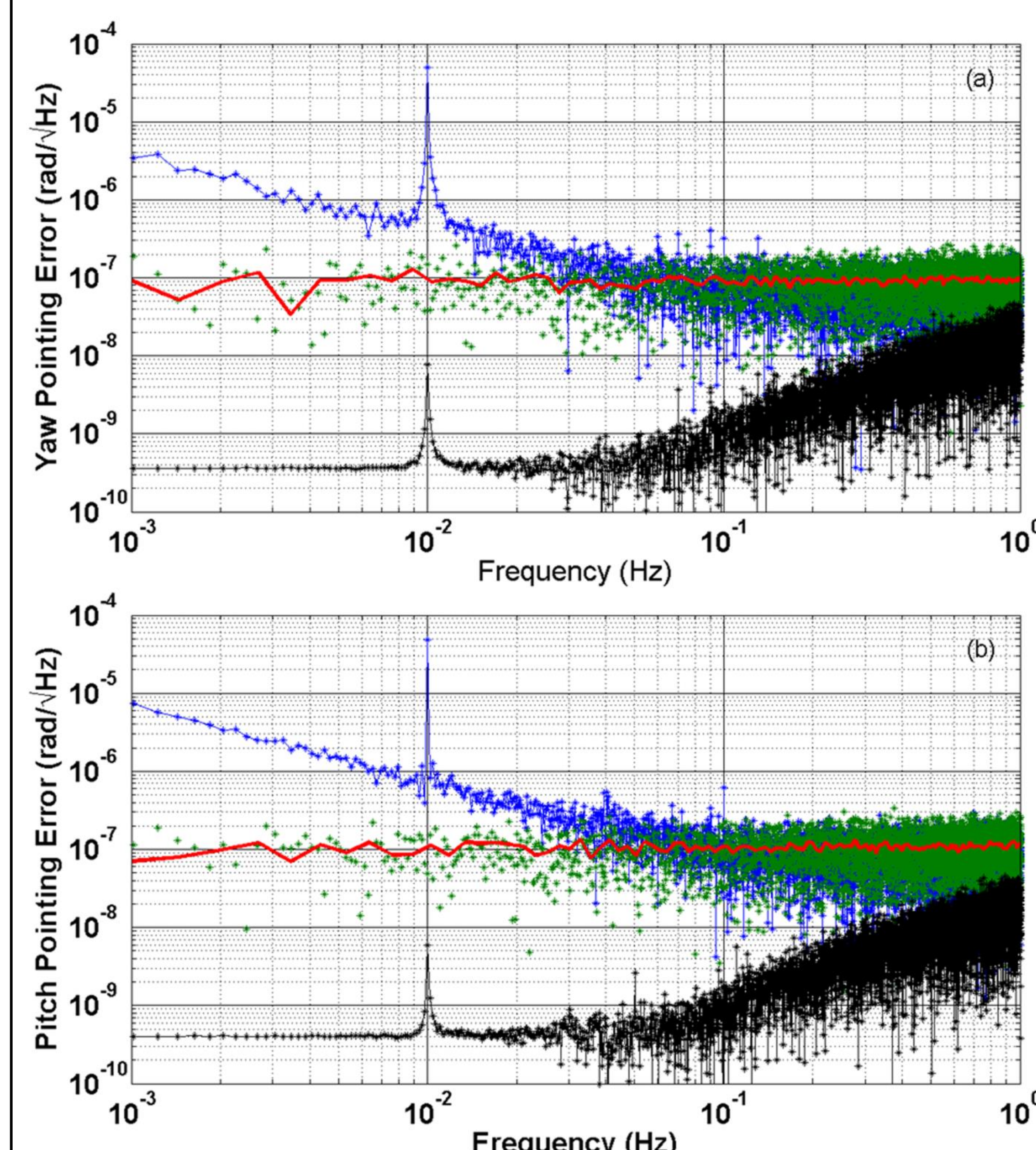

FIG. 6. (a) Results of rotating around yaw axis before control (blue points) and in control (green points) in the amplitude of 50μrad/√Hz; (b) Results of rotating around pitch axis before control (blue points) and in control (green points) in the amplitude of 50μrad/√Hz. The red curves present the LASD of yaw motion or pitch motion in out-of-loop; the black dotted lines are in-loop data for yaw and pitch motion.

Conclusions

A methodological demonstration of laser beam pointing control system for space gravitational wave detection missions has been accomplished. Pointing jitter of 50 μrad is produced to simulate the situation of eLISA or future satellite gravity missions. With beam pointing control system turned on, the stability of beam pointing direction can be kept at 80 nrad/√Hz and 90 nrad/√Hz at frequencies from 1 mHz to 1 Hz.

References

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