High-stability Underwater Frequency Transmission based on Green Laser and Digital Phase Compensation

Fei Yang[1,2], Lili Han[1,2], Kang Cao[1,2], Dijun Chen[1,2], Haiwen Cai[3], Weibiao Chen[1,2]

[1] Aerospace Laser Technology and System Department, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

[2] Key Laboratory of Space Laser Communication and Detection Technology, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China

[3]ZhangJiang Laboratory, Shanghai 201210, China

Email: fyang@siom.ac.cn

With the development of ocean exploitation and utilization, there is an urgent need for high-standard construction and development of underwater space-time reference. High performance underwater time-frequency transmission and synchronization is one of the key issues. Because the radio navigation signal of GNSS is seriously attenuated in water, it is difficult to directly use the radio frequency band for underwater time-frequency transmission. So other means such as sound wave and blue-green laser are required. Based on blue-green laser diode (LD) and optical phase compensation, after 5 m underwater link, the frequency transmission stability reached 2.8×10^{-13} at 1 s and 2.7×10^{-16} at 1000 s, respectively[1].

Recently, we have done some work to further improve stability. In the first experiment, based on 520 nm green LD and direct Bias modulation, we use digital phase compensation to improve the bandwidth of transmission noise compensation to 1 kHz. The stability of 400 MHz frequency signal over 8 m underwater link were 7.9×10^{-14} at 1 s and 2.1×10^{-16} at 1000 s.

In the second experiment, we use modulation frequency doubling laser (FDL) to achieve lower electro-optic conversion noise than LD. The microwave frequency signal was modulated to 1018 nm distributed feedback semiconductor seed laser by a M-Z modulator. Then the seed laser was doubled to 509 nm and transmitted over underwater link. The stability of 500 MHz frequency signal reached 1.2×10^{-14} at 1 s, 9.6×10^{-17} at 1000 s in back-to-back situation by FDL method. After 8 m underwater link transmission and electrical noise compensation, the frequency stability was 5.4×10^{-14} at 1 s and 1.7×10^{-16} at 1000 s.

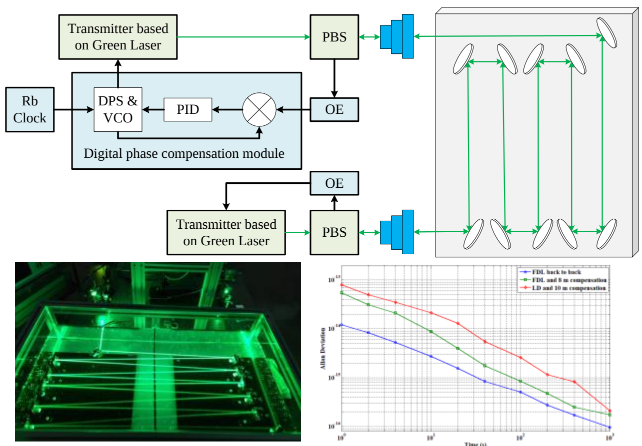

Fig. 1: Experimental diagram, system and Allan Deviation results. PBS: polarization beam splitter, OE:optic-electro conversion, PID: proportional-integral-differential, DPS: digital phase shifter, VCO: voltage controlled oscillator

The stability of underwater time-frequency transmission based on blue-green laser is proven to close to the level of optical fiber microwave frequency transmission on land. It would have broad application prospects in the fields of underwater space-time reference and distributed sensors.

[1] D. Hou, "Laser-based underwater frequency transfer with sub-picosecond timing fluctuation using optical phase compensation," Optics Express 28(22), 33298-33306 (2020).