Molecular Iodine Optical Clocks for the Field

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The development of mobile optical clocks will improve navigational autonomy, offer remote time standards for geophysical monitoring and distributed coherent sensing, synchronize quantum networks, and provide redundancy for national time standards. Toward that end, vapor cell optical clocks possess practical advantages in that they use no consumables, have relatively simple optical requirements, and can operate in dynamical environments. While not as accurate as leading laboratory clocks or static transportable systems, iodine clocks can outperform masers in a compact, robust, and deployable package.

Vector Atomic has recently developed and fielded multiple optical clocks utilizing molecular iodine. Iodine exhibits modest systematics, including light shifts, magnetic field shifts, temperature-driven collisional shift, and helium collisions, all of which make it an attractive clock candidate for field applications. The clocks require neither laser cooling nor a pre-stabilization cavity and are insensitive to platform motion, allowing high performance mobile operation.

A high-performance version of this clock, which outputs 10 MHz and 100 MHz, was recently developed and integrated into a 30 L, 3U 19-inch rackmount chassis that consumes ~70 Watts. The microwave outputs exhibit $2.5\times10^{-14}/\sqrt{\tau}$ instability and maintain an instability of 2×10^{-15} after one day of averaging. Three first generation rack systems operated continuously aboard a naval ship in the Pacific Ocean for 20 days as part of RIMPAC 2022[1]. Clocks accrued timing errors of less than 300 ps per day ($6\text{x}10^{-15}$ instability at 10^5 seconds) despite diurnal temperature and humidity variations, ship rotation and acceleration, and navigation through Earth's magnetic field.

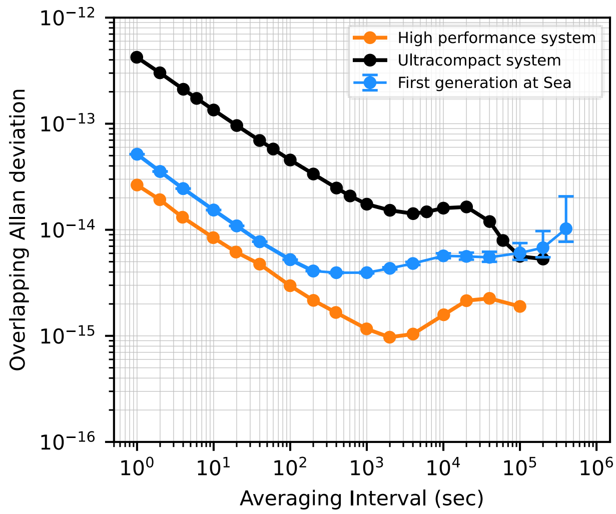

Fig. 1: ADEV for three generations of iodine clocks.

An ultracompact iodine clock is also under development, which includes a 100 cm^3 spectrometer module using a custom, low temp-co iodine cell, and operates with a miniature diode-pumped solid state CW laser system. This combined system displays an instability in the low $10^{-13}/\sqrt{\tau}$ range while maintaining a frequency instability below 1×10^{-14} at 10^5 seconds.

Data underlying multiple demonstrations of these systems will be presented as well as a discussion of the various subsystems, including the spectrometer, laser system, and frequency comb.

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[1] J. Roslund, et al. "Optical clocks at sea." *arXiv preprint arXiv:2308.12457* (2023).