Demonstration of a Field-Deployable Ytterbium Cell Clock - a Robust Optical Atomic Clock for Real World Applications

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Atomic clocks generate an output frequency that is directly connected to an atomic transition which in turn derives its value from the fundamental laws of physics. Given the presumed stability of these laws, atomic clocks deliver the strong foundation of our time and frequency measurement systems. Lab-based optical atomic clocks have demonstrated extremely high performance, reaching fractional frequency instabilities in the 10^{-19} range at long timescales. However, field-deployable commercial clocks offer significantly worse performance around the 10^{-12} range over a second of integration time. Here we present an optical atomic clock based on spectroscopy of the relatively narrow $^1S_0 \leftrightarrow {}^3P_1$ intercombination line in neutral ytterbium that is intended to start to overcome this deficit. We show that this technique is not only able to achieve short- and medium-term frequency instability better than 10^{-14} but is also compact and robust. We demonstrate the potential of this system by performing extensive field testing of the clock with an integrated optical frequency comb in a harsh maritime environment.

We have developed a complete optical clock system based on the 182kHz wide $^1S_0 \leftrightarrow {}^3P_1$ transition in ^{174}Yb at 556nm, which is interrogated using modulation transfer spectroscopy. The modulation, demodulation, and frequency stabilization processes are all performed using a custom field-programmable gate array (FPGA) suite. The stabilized optical output of the clock is used as the reference for a home built optical frequency comb, which in turn performs the frequency down conversion from the optical to the microwave domain, producing a useful clock output.

We have built two complete optical clocks using this architecture, one prototype for lab-based testing and a second clock that has been ruggedized for field deployment. Direct frequency comparisons have been made between the optical outputs of the two clocks that show a 1s frequency instability of 2×10^{-14}. We have also tested the outputs of these clocks against a separate high-performance deployable optical clock based around a two-photon Rb transition using the frequency comb, as well as making comparisons with best-in-class commercial microwave clocks using the RF outputs of the frequency comb. These comparisons have been made under both controlled laboratory conditions and demanding environments including a moving van travelling on second-class roads around the city, as well as in an unsupervised trial for weeks on the deck of a large maritime vessel over six week. Once fully packaged for deployment the clock has the size, weight, and power of a mini-fridge.

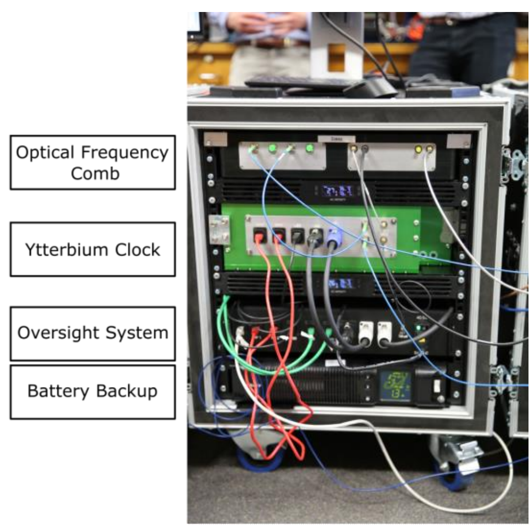

Fig. 1. Fully packaged deployable ytterbium clock including optical frequency comb.

We will present the results from these trials and demonstrate the ability to operate as a turn-key device with stable optical and microwave outputs with frequency instabilities in the 10-15 range over intermediate time-scales.