Clean-up laser system for the remote terminal of an optical clock

Przemysław Krehlik[1], Łukasz Śliwczyński[1], Łukasz Buczek[1], Tomasz Kawalec[2], Adam Wojciechowski[2], Antoni Węglarz[2], Jakub Dobosz[3]
Email: krehlik@agh.edu.pl
[1]Faculty of Computer Science, Electronics and Telecommunications, AGH University of Krakow, Poland
[2]Faculty of Physics, Astronomy and Computer Science, Jagiellonian University in Krakow, Poland
[3]Faculty of Physics, University of Warsaw, Poland

***Abstract*—In this work we present the concept and verification of the ULE cavity based clean-up system for a remote terminal of an optical atomic clock. Thanks to this solution the short-term stability of the signal provided by a long-haul optical fiber link is be significantly improved, to the level guaranteed by the high-finesse cavity, incorporated in the clean-up setup.**

Keywords*—*fiber-optic frequency transfer, clean-up laser system, noise cancelation

I. Introduction

Ultra-stable optical frequency reference signals are produced by optical atomic clocks, which are extremely complicated and not transportable installations. Therefore, for wider use of these signals, they should be distributed to remote locations with as little performance degradation as possible. The frequently used solution is based on dedicated fiber optic links, with active cancellation of the phase noise induced by the environmental factors influencing the signal propagation [1]. Thanks to applying phase noise cancellation scheme, the long-term instability of fiber links may be reduced to below 10^{-19} for 1000 s and longer observation time. In short terms, however, the noise cancellation is not fully efficient, because of inherently limited bandwidth of the noise cancelation loop. This leads to some residual phase noise of the remote optical signal, usually located in the spectral range from some Hertz to some hundreds of Hertz – see Fig. 1. This residual noise is not an issue when the fiber link is used for comparison of two remote optical clocks, but leads to signal quality degradation in real-time applications, as for instance optical comb synchronization or high-resolution spectroscopy.

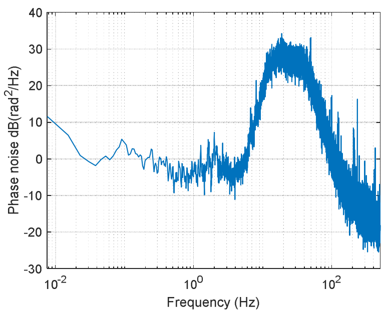

Fig. 1. Residual phase noise at the end of the fiber link.

II. Clean-up system

The underlying idea of a clean-up system (see Fig. 2) is that the ECL laser is tightly locked, using standard Pound–Drever–Hall (PDH) scheme, to an optical cavity (12.5 cm, finesse of 415 000) and, additionally, weakly locked to the remote copy of the optical clock signal delivered by the stabilized fiber-optic link. In this way, the laser inherits the short-term stability of the cavity and the long-term stability of the distant optical clock (see also [2]). The weak (slow) lock to the signal from the fiber is realized by slow corrections of the frequency steering an additional acousto-optic modulator (AOM), placed between the laser and the PDH subsystem. The bandwidth of this lock is generally low, and may be adjusted in the range 0.1 Hz to 10 Hz. Flexible adjusting of the system transfer function is realized by a dedicated digital servo controller running on the Raspberry Pi platform. As the relation between the optical frequency transferred by the fiber and the cavity modes is uncontrollable, the beat-note frequency may be even close to 1 GHz. Thus, the programmable dividers are used for achieving full flexibility in terms of the supported beat-note frequency.

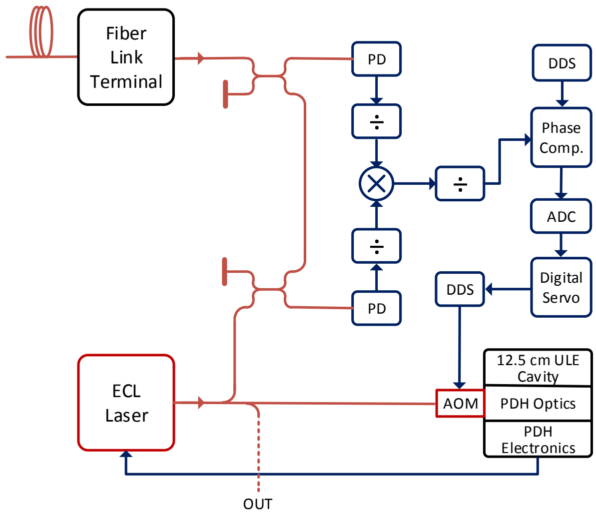

Fig. 2. Block diagram of the clean-up system. PD stands for photodiode, AOM - acousto-optic modulator, DDS - direct digital synthesis generator, ULE - ultra-low expansion.

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III. Experimental verification

To evaluate the developed clean-up system we connected its input to an ultra-stable laser (Menlo Mini ORS), with the AOM in between. The AOM was driven by a phase-modulated signal to mimic the residual phase noise at the fiber link end. The second AOM was added at the output of the ECL laser, this time to mimic the phase noise of the ECL laser referenced to the ULE cavity - see Fig. 3a. By applying the phase modulation to the first AOM we measured the suppression of the link noise, and modulating the signal provided to the second one we determined the suppression of the clean-up system noise. Fig. 3b shows frequency characteristics of the noise suppression, for two different tracking bandwidths, determined by digital servo settings. Comparing the results with the spectrum of the residual noise of the fiber link (Fig. 1), it may be noticed that substantial reduction of this noise may be obtained. Particular value of the tracking bandwidth should be optimized in target conditions, having in mind that lower tracking bandwidth improves fiber residual noise suppression, but increases the impact of the cavity long-term instability.

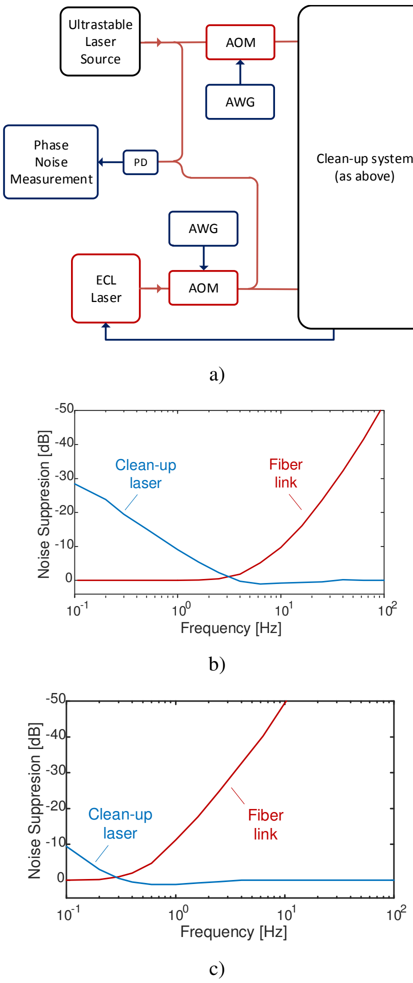

Fig. 3. Experimental setup (a), noise suppression characteristics for different tracking bandwidths (b and c).

IV. Conclusions and outlook

The proposed clean-up system suppresses the residual phase noise of the ultra-stable optical reference signal transferred by the stabilized fiber optic link. This way, both the short-term and long-term stability at the remote end come close to that of the original signal produced by the optical clock. In Poland strontium optical clocks are operated at FAMO lab in Toruń, and their reference frequency will be delivered to the new NMI campus in Kielce. The optical signals will be transferred through a 900 km-long fiber link, and then delivered to the clean-up system.

References

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