Steering of a time scale using an optical clock

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1. Introduction

One of important role that frequency standards play is the evaluation of the scale interval of time scales. For instance, the scale of Universal Coordinated Time (UTC), which is produced by BIPM using data from more than 400 atomic clocks, is steadily checked by Cs fountains operated in National Metrological Institute. As a next step, the calibration using optical clocks instead of microwave standards is definitely attractive. The strong point of optical clocks is in the high stability which is more than an order of magnitude superior to fountain-based microwave standards. We can evaluate the frequency of a hydrogen maser (HM) in a few hours with reference to an optically-generated microwave from an optical clock. This rapid evaluation reveals fast and small fluctuation of HM frequency, which was difficult to detect by using a fountain. In contrast to the state-of-the-art fountains operated almost continuously these days [1, 2], however, continuous operation of optical clocks for time keeping is still a difficult task because we need to stabilize nearly ten laser frequencies in addition to a clock laser. However, the capability of rapid frequency evaluations enables a generation of a stable time scale without seamless operation. We demonstrated that infrequent operation of an optical clock and steering of the HM frequency in accordance with the measurement result realize a time scale with stability similar to that of UTC.

2. Methods

We generated a real signal of a time scale for five months (May – Sep, 2016). Once in a week or more, a strontium lattice clock was operated for 10^4 second, and the HM frequency is accurately obtained. For the conversion from the optical frequency to the microwave, we assumed the optical clock frequency identical to our latest absolute frequency measurement [3,4], which is 5×10^{-16} different from that of the CIPM recommendation. The results of the four operations in the past three weeks allowed us to estimate the linear drift rate of the HM frequency for the next week. Based on this estimation, the parameter of a phase micro stepper was adjusted in every four hours so as to compensate the predicted frequency drift of the HM.

3. Result

The resultant time scale was compared with UTC. In five months' generation of the time scale, the relative phase against the UTC gradually expanded to 6 ns. Within 1 ns, this difference is as same as that of TT(BIPM), which is an ideal time scale post-processed by BIPM considering all the calibrations reported from various primary frequency standards (PFS) worldwide. The result clearly demonstrates that steering according to the intermittent operation of optical clocks is a promising route to incorporate an optical clock into a time scale. The data obtained in the five-months data also allowed us to estimate one-month mean of the TAI scale interval. We found that the five results showed excellent agreement with those reported by the sate-of-the-art PFS.

4. References

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