Application of optical clocks toward real-time generation of a time scale

Time scales are indices of time which we share for recording or scheduling events in our daily life. Various timescales are chosen and shared in the society. Coordinated Universal Time (UTC) has been employed in modern society for decades. It is a numerical product, however, with a latency of one month. Thus, national institutes generate their own real-time signals aiming for synchronization with UTC. The timescale generated in NICT is called UTC(NICT) and it is disseminated to e public as Japan Standard Time (JST) with a +9h time zone correction relative to UTC(NICT).

In the past decade, optical clocks have surpassed microwave clocks in the aspects of accuracy and stability. The application of atomic clocks to timescales, however, requires seamless operation in general. Thus, timescales have not been realized using optical clocks since it is still difficult to operate optical clocks continuously for months or so. In this presentation, we propose and report a demonstration of a hybrid timescale. While a hydrogen maser (HM), as a reliable microwave clock, operates continuously as a flywheel oscillator, its frequency is calibrated by a strontium-based optical lattice clock with much greater accuracy. Over half a year, 3-hour operations of the optical clock were achieved steadily at least once per week. The HM signal is sent to a phase microwave stepper, where the frequency of signal is slightly shifted according to the prediction resulting from the calibration that the optical clock provides. The resultant timescale TA(Sr) was as stable as UTC. The smooth linear trend of TA(Sr) − UTC indicates that the instability of the real-time TA(Sr) is at the same low 10-16 level as the retrospectively evaluated UTC. This also suggests that TA(Sr) may be used to calibrate the scale interval of UTC. The length of “one second” of UTC is monitored by not only Primary Frequency Standards (PFSs) but also Secondary frequency standards (SFSs), both of which are used by the International Bureau for Weights and Measures (BIPM) to determine the frequency correction applied to a free-running timescale computed from more than 400 atomic clocks in metrological institutes worldwide. Although various optical transitions are now recognized as SFSs, the capability of each physical clock must be checked and recognized by a working group (WG) of the Consultative Committee for Time and Frequency (CCTF) to contribute to the steering of UTC. After the first recognition of clocks operated by the French Observatoire de Paris in 2016, a strontium lattice clock at NICT (NICT-Sr1) was recognized in November 2018 after submitting previous evaluation results of the UTC scale interval with respect to Sr and related publications to the WG. For the first time, we then reported an on-time calibration of the UTC scale interval in December 2018. Further reports have been made for three times since then, and have been considered by BIPM to determine the tuning parameter of the UTC scale interval. The detail of the calibration and comparison of our contribution with those from PFSs will be also briefly presented.