Robust Optical Clocks for International Timescales (ROCIT)

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The recently concluded collaborative European project "Robust optical clocks for international time-scales" (ROCIT) [2] tackled some of the key challenges on the roadmap towards a redefinition of the second. The overall aim was to bring European optical clocks to the stage where they can contribute regularly to International Atomic Time (TAI) as secondary representations of the second.

Improvements to optical clock robustness and reductions to data latency are key enablers for their use in time scales. Advances were made in the robustness of both trapped ion optical clocks and neutral atom optical lattice clocks, with the focus on the systems that were known to require most frequent user intervention. Developments included new approaches for automatic long-term control of laser systems and for automated adjustment of optical setups, and enabled unattended optical clock uptimes exceeding 80 % over 2 weeks to be achieved in several laboratories.

Two coordinated programmes of frequency comparisons were carried out to verify the international consistency of optical clocks. The second of these involved 11 optical clocks in seven different countries, including one outside Europe (^{171}Yb at NMIJ). Both optical fibre links and satellite-based techniques were used to compare clocks in different locations, maximizing participation and enabling results obtained by different techniques to be compared. The remote comparisons were supplemented by local optical frequency comparisons, including the measurement of several optical frequency ratios that had never been determined directly before. Traceability to the present definition of the second was ensured by including caesium primary frequency standards in the comparison programme.

Methods were developed for on-the-fly evaluation and correction of systematic frequency shifts, and for real-time validation of data provided by optical clocks, preparing the way for steering of UTC(k) time scales. Steering algorithms able to handle low uptimes and periods of data unavailability were also developed. Building on these developments, NPL and LNE-SYRTE independently and simultaneously demonstrated prototype optically steered time scales, termed UTCx(NPL) and UTCx(OP) respectively, based on data from one or more optical clocks with high uptimes. These time scales were directly compared using a GPS PPP link, and their offset was observed to remain smaller than the offset between the corresponding operational UTC(k) time scales over the same period.

When optical clocks contribute to TAI, they do so with the uncertainty of the recommended frequency value for the secondary representation of the second, as approved by the Consultative Committee for Time and Frequency (CCTF). The most recent (2021) update to these values was influenced by our work showing the importance of including correlations between frequency ratio measurements in the analysis. During the ROCIT project, twelve optical clocks within the consortium were used to evaluate the frequency of a hydrogen maser contributing to the computation of TAI, over a total of 55 periods ranging from 5 to 35 days. Three of these optical clocks (SYRTE-Sr2, IT-Yb1 and NPL-Sr1) have been approved by the CCTF Working Group on Primary and Secondary Frequency Standards and are contributing data to the BIPM for TAI steering, whilst others will be submitted for approval pending updated uncertainty budgets and peer-reviewed publications.

References

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[2] Project website: http://empir.npl.co.uk/rocit/