Very long baseline comparison of Sr lattice clocks using carrier-phase two-way satellite frequency transfer

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Rapid progress of optical frequency standards has raised a discussion toward an optical redefinition of the second. A crucial factor for the redefinition is to confirm and maintain frequency agreement between these standards on a global scale. We have demonstrated a direct frequency comparison of two ^{87}Sr lattice clocks, one at NICT in Japan and the other at PTB in Germany, using a lately-developed satellite-based technique.

Two-way satellite time and frequency transfer utilizes phase-modulated signals and the modulation phase is normally used to measure the signals' time-of-arrival at the remote sites. Using the carrier-phase is an alternative and the improved measurement precision was recently observed on short baselines up to 100 km[1] and further on an intercontinental baseline of 9000 km between NICT and PTB. At both institutes ^{87}Sr lattice clocks were in operation. Thus, the two-way carrier phase technique (TWCP) was applied to perform a real-time frequency comparison of optical clocks on an intercontinental scale. During the measurement campaign, the clock frequencies were measured referring to respective local hydrogen masers (H-masers). The frequency difference of the two H-masers was simultaneously evaluated by the TWCP technique. An Yb^+ clock was also operated at PTB to bridge offline-times of the Sr clock at PTB, and thus reduced the statistical uncertainty of the measurement.

We performed the comparison during four days in late June 2013. The direct Sr lattice clock comparison worked for ~70 000 s, extended to 84 000 s by the Yb^+ clock. The total measurement time leads to a statistical uncertainty of 1.2×10^{-15}. Considering the systematic uncertainties, the total uncertainty was determined to be 1.6×10^{-15}, whereas the frequency difference was consistent with zero.

The reproducibility of ^{87}Sr lattice clocks has been confirmed in Europe with an uncertainty of 6×10^{-16} by absolute frequency measurements[2,3]. The same level of agreement has been also reached inside Japan by an all-optical fiber link[4]. The agreement between the two regions, on the other hand, is limited to an uncertainty of $>3\times10^{-15}$. The direct comparison demonstrated here has reduced this uncertainty close to the 10^{-16} level.

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