Report to the 20th Meeting of CCTF

Research Activities on Time and Frequency National Metrology Institute of Japan (NMIJ)/AIST

The National Metrology Institute of Japan (NMIJ) is responsible for almost of all physical and chemical standards and for related technologies in Japan. The Time Standards Group and the Frequency Measurement Group of NMIJ are in charge of time and frequency metrology. We describe the recent activities of these two groups in this report.

1. Cs atomic fountain frequency standards

NMIJ-F1 has been a primary frequency standard with an uncertainty of 4×10^{-15} since 2004. However, the operation of NMIJ-F1 has stopped due to the huge earthquake and depletion of a caesium reservoir since March 2011.

The second fountain, NMIJ-F2, is under construction to achieve less than 1×10^{-15} in uncertainty as an immediate goal. Frequency stability of $8.3\times10^{-14}\ \tau^{-1/2}$ (τ: averaging time) is achieved by using a cryogenic sapphire oscillator with a pulse-tube cryocooler as a local oscillator and increasing the atom number with optical pumping to $m_F = 0$ [1]. As for the uncertainty evaluation, uncertainty due to the major effects except for the microwave power dependence shift is evaluated to be 1.1×10^{-15} [2]. NMIJ-F2 was also used as a fly-wheel for the frequency comparison between our Sr optical lattice clock and the SI seconds [3].

2. Cryogenic sapphire oscillator and calibration service of phase noise

Two units of cryogenic sapphire oscillators (CSOs) using liquid helium as cryogen had been maintained as local oscillators for the Cs atomic fountain frequency standards and for the evaluation of ultra-stable lasers in optical lattice clocks. One of the liquid helium CSOs has been converted into a cryocooled oscillator in 2013, which cools the sapphire crystal using a low-vibration cryostat and a pulse-tube-cryocooler. The Allan deviation of the cryocooled CSO was evaluated to be smaller that 10^{-15} between 2 s and 10000 s.

The calibration range of the phase noise calibration service for "phase noise measurement apparatus" has been extended to the carrier frequency of 100 MHz, and the calibration service of "oscillator" phase noise measurement has been started in 2015 [4,5]. The calibrated phase noise level is (-70 to -140) dBc/Hz for the carrier frequencies of 10 MHz and 100MHz and for the offset frequencies of 10 Hz to 1 MHz.

3. Time keeping

There are four H-maser standards and two Cs atomic clocks to maintain UTC(NMIJ). Now we are reporting the data of three H-masers and two Cs clocks to BIPM every month. The source oscillator of UTC(NMIJ) is one of the three H-masers since 2006. We have introduced a new maser in the fiscal year 2012. Temperature controlled chambers for clocks are working well to keep the inside temperature within 0.2 K of peak-to-peak variation. Frequency steering using AOG has been done appropriately. These activities resulted in generating stable UTC(NMIJ) within ±22 ns to UTC for 3 years between 2012 and 2014. Relative frequency of UTC(NMIJ) to UTC has been kept within $\pm 2.8\times10^{-14}$ (almost less than $\pm 1.0\times10^{-14}$) between 2012 and 2014 as shown in Fig. 1.

4. Time and frequency transfer

We use GPS PPP method for the international time and frequency transfer to contribute to the TAI using Z12-T. NMIJ has been participating in a rapid UTC (UTCr) since January 2012. NMIJ is also maintaining TWSTFT facilities to link Asian institutes and PTB.

For a remote comparison of optical frequency standards, we have been developing an optical carrier transfer system using a spooled fibre. The cancellation of the induced noise on a long-haul optical fibre is achieved with a well-known standard technique using a fibre-based interferometer. The experimental result shows a fractional frequency instability of 5×10^{-18} at 10^{3} s in a fibre link of 90 km which is close to the theoretical limit imposed by delay-unsuppressed phase noise from the fibre link(Fig. 2).

5. Calibration service

NMIJ provides frequency calibration services for both in-house and remote facilities. The CMC is 5×10^{-14} for in-house and 1.1×10^{-13} (Baseline: 50 km), 1.4×10^{-13} (Baseline: 500 km) and 4.9×10^{-13} (Baseline: 1600 km) for remote calibration, respectively. As remote frequency calibration service, traditional GPS common-view method is used in the system. It consists of a user equipment, a data transfer protocol, and a data processing system. Now we are offering the service to 17 remote users. Fig. 3 shows the long-term characteristics of the services to each user. The experimental standard deviations were almost less than 1×10^{-13} level for about 4 years.

This result shows the excellent long-term capability with small uncertainty of calibration.

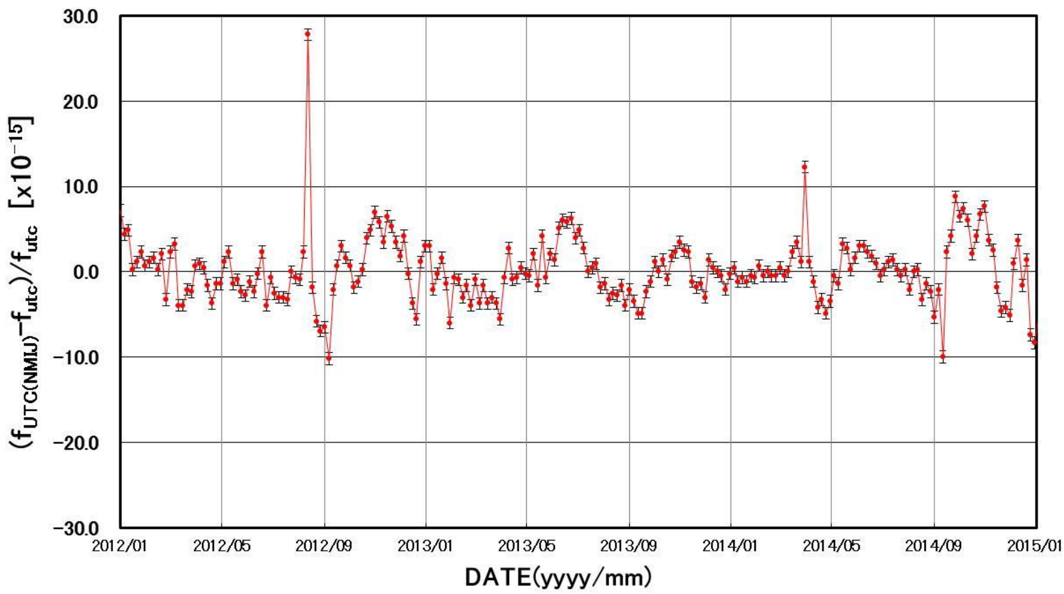

Fig. 1 Relative frequency offset of UTC(NMIJ) to UTC between 2012 and 2014.

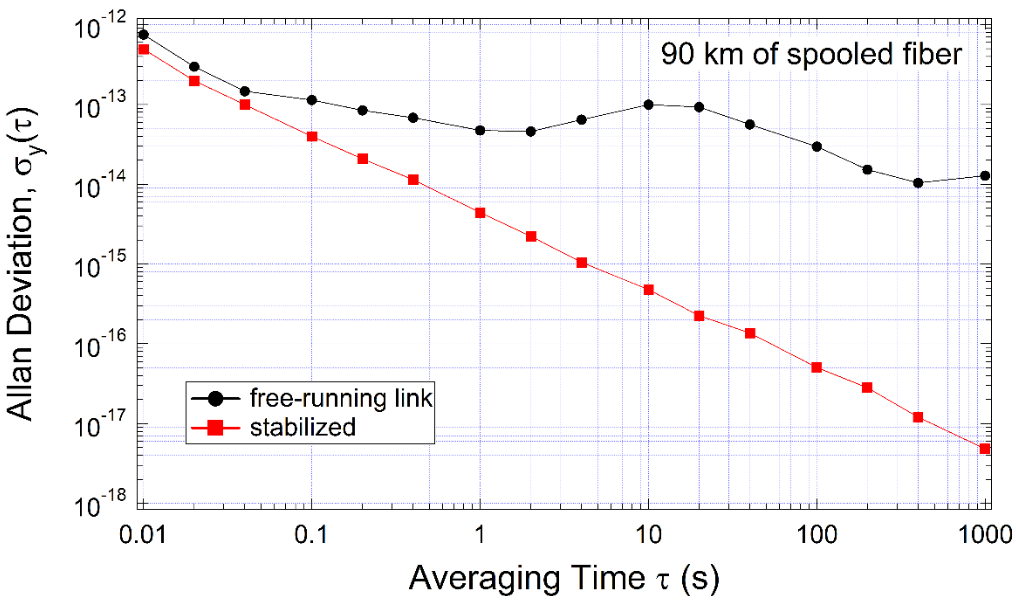

Fig. 2 Fractional frequency instability of the optical carrier transfer system.

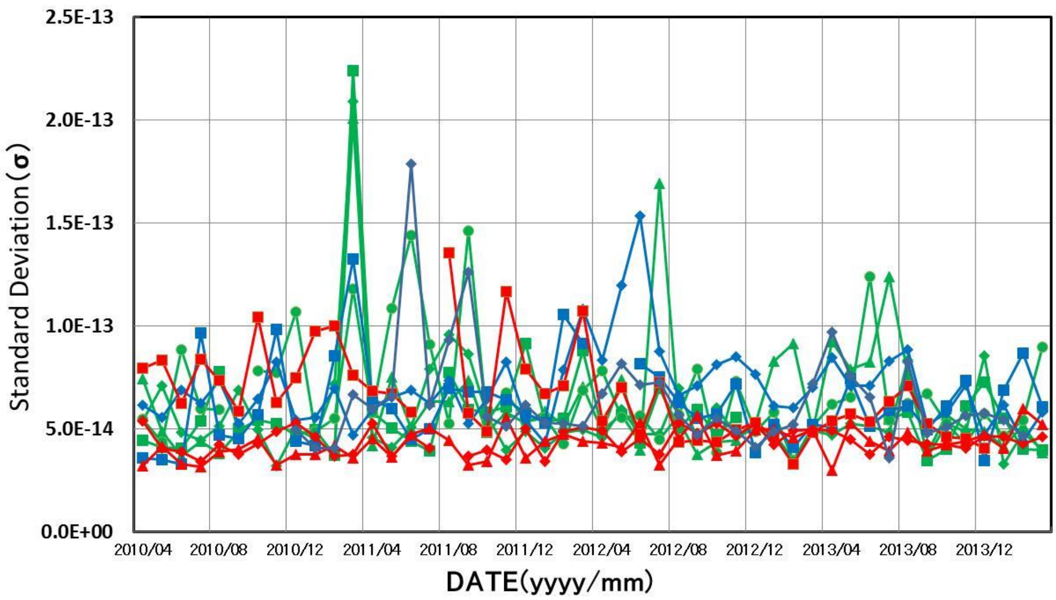

Fig. 3 Long-term characteristic of frequency remote calibration service.

Red : Cs(Free-run), Blue : Rb(GPS-DO), Green : Rb(NMIJ-DO)

6. Optical lattice clocks

We have developed the second optical lattice clock. This system can be used as strontium and ytterbium optical lattice clocks, since the oven is filled with strontium and also ytterbium. To share the optical light source with our first ytterbium optical lattice clock, we have newly developed an injection locking system for 399 nm light source, which delivers the light of around 70 mW for each system. We also improved a light source at 578 nm to drive the clock transition. We have developed an external cavity laser diode operated at 1156 nm with the second harmonic generation scheme by using a periodically poled lithium niobate. The laser is stabilised to the optical frequency comb that is tightly locked to a narrow linewidth master laser operated at 1064 nm. Owing to the relatively large servo bandwidth (> 4 MHz), pre-stabilisation is not needed for phase locking to the comb. We have successfully observed the ytterbium clock transition of 50 Hz in the second optical lattice clock system.

In 2014, the frequency of the clock transition in strontium-87 was measured. The absolute frequency was determined as 429 228 004 229 872.0 (1.6) Hz relative to the SI second [6]. At that time the uncertainty of the absolute frequency was mainly limited by the uncertainty of a comparison with UTC(NMIJ). Recently, they carefully evaluate the uncertainties of the link between the Sr optical lattice clock and TAI via UTC(NMIJ) using a caesium fountain atomic clock located at NMIJ as a transfer oscillator. In this way, they reduced the final uncertainty to one third that of their previous measurement. The absolute value of the transition frequency is 429 228 004 229 873.56(49) Hz [3].

The frequency ratio of the $^1S_0$-$^3P_0$ clock transitions in ytterbium-171 and strontium-87 is measured by an optical-optical direct frequency link between two optical lattice clocks. In this frequency link, an Nd:YAG laser operating at 1064 nm was used as a master laser to stabilised fibre combs and then the two clock lasers for strontium-87 and ytterbium-171 are phase locked to their respective combs[7].

We have developed a Fabry–Pe´rot etalon with an ultralow expansion ceramic spacer and investigated the thermal properties of the ceramic [8]. It is found that the ceramic is an attractive material for long optical cavities, which can reduce the effect of the thermal noise relatively.

7. Frequency comb

A number of fibre-based frequency comb system have been utilized for optical lattice clocks at NMIJ to measure the absolute frequency and the ratio of the clocks, to stabilize the cooling lasers, and to transfer a linewidth of an ultra-stable laser to the clock lasers[9]. We are shifting the comb research to applications such as dual-comb spectroscopy since the frequency comb have been matured for frequency metrology [10].

References

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