Report to the 18th Session 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 and Frequency Division of NMIJ is in charge of time and frequency metrology. Three sections, Time Standards Section, Frequency Measurement Systems Section, and Wavelength Standards Section, are making research and development in time and frequency standards field. We describe the recent activities of these three sections in this report.

1. Cs Atomic Fountain Frequency Standards, NMIJ-F1 and NMIJ-F2

NMIJ has been operating the NMIJ-F1 with an uncertainty of $4\text{x}10^{-15}$ since 2005 in order to calibrate International Atomic Time (TAI). Although the uncertainty is not relatively small, the operational rate has been increased, as is shown in Fig.1. Owing to the modification of electronics and optics [1,2], more reliability was acquired in the operationality of NMIJ-F1. This improvement is useful for the domestic activities; evaluation of an optical lattice clock , development of NMIJ-F2, as well as for the international one. For the purpose of obtaining the uncertainty of the order of 10^{-16}, the development of NMIJ-F2 has been started. The NMIJ-F2 adopts (1,1,1) atomic fountain geometry and microwave cavities which are parts of a vacuum chamber. The vacuum chamber and the optical system are arranged for use. The signal of Cs atoms with the launch velocity of 3 m/s was measured at 30 cm over the molasses region.

2. Optically Pumped Cs Beam Frequency Standard, NRLM-4

In order to reduce the distributed cavity phase shift which is the largest source of uncertainty in NRLM-4, the Ramsey microwave cavity was replaced with a novel H-bend-type ring cavity, in which the direction of C-field and oscillating microwave field is perpendicular to the Cs beam propagation direction. The distributed cavity shift was reduced to 1.4×10^{-15} and the total uncertainty was reevaluated to be 6.7×10^{-15}, which is four times better than the previous value [3].

3. Cryogenic Sapphire Oscillator

A reference signal with 10^{-15} level fractional frequency stability for averaging times longer than 1 s based on a cryogenic sapphire oscillator (CSO) has been used as a local oscillator for the Cs atomic fountain [4,5]. Also, optical frequency synthesis from the CSO has been implemented using a fiber-based frequency comb to evaluate the performance of an ultra-stable laser at 578 nm for an Yb optical lattice clock. The Allan deviation between the synthesized optical frequency and the ultra-stable laser was measured to be ~2×10^{-14} at an averaging time of 10 s.

4. Coherent Population Trapping towards a practical vapor frequency standard

As one of the candidates of practical frequency standards, characteristics of coherent population trapping signal in a Cs vapor cell including N_2 as buffer gas was examined. High-contrast coherent population trapping signals were observed on the Cs-D_1 line by use of a bichromatic linear polarized light (lin || lin field). A maximum absorption contrast of about 10 % was obtained. This was nearly twice as high as that measured with the standard configuration of bichromatic circularly polarized light (σ - σ field) [6].

5. Time keeping

We have five Cs atomic clocks and four H-maser standards to maintain UTC(NMIJ). We equipped the temperature control chambers for the Cs clocks. It can keep the inside temperature within 0.2 K of peak-to-peak variation. Same kind of temperature control chambers are used for H-masers. Starting from March, 2006, we use a H-maser for the source oscillator of UTC(NMIJ) to improve the short term stability of UTC(NMIJ). By this replacement, we could improve the uncertainty of the calibration service for the time and frequency traceability [7].

6. Time and Frequency transfer

We use GPS P3 method for the international time and frequency transfer to contribute to the TAI using Z12-T. The receiver used for P3 time transfer also is participating to the TAI PPP experiment organized by BIPM from the beginning of 2008. NMIJ has joined to the TWSTFT link using IS-4 between Asian institutes and PTB starting form September, 2007 on a regular basis.

For the development of precise time transfer techniques, we are conducting basic study about carrier phase TWSTFT method [8]. Fig. 2 shows the temperature stabilized earth stations for this purpose and fig. 3 shows the block diagram of the experimental system of the carrier phase TWSTFT method. The system is aiming to obtain 10^{-16} - 10^{-17} of frequency uncertainty at the averaging time of one day. We are also making development of precise frequency transfer system using optical fiber cable and fig. 4 shows the block diagram and its preliminary results [9].

7. Remote calibration service

NMIJ has been developing the remote calibration system in several metrological fields, such as time and frequency, length, temperature etc., and this project is named "e-trace". Time and frequency division is in charge of remote frequency calibration system using GPS common-view method under the e-trace project. It consists of user equipment, data transfer protocol, and data processing system. Fig. 5 shows the user equipment for the remote frequency calibration system developed by the e-trace project and it is commercially available **[10]**.

8. Frequency measurement of Sr optical lattice clock

The optical frequency of the $^1S_0$ - $^3P_0$ transition in ^{87}Sr atoms trapped in an optical lattice was measured by the NMIJ, the Univ. of Electro-communication and the Univ. of Tokyo to be 429 228 004 229 874.1 Hz with an uncertainty of 2.4 Hz (fractional uncertainty of $5.6x10^{-15}$) referenced to (TAI) [11]. The precision frequency measurement was realized by using a phase-stabilized 120-km optical fiber link over a physical distance of 50 km between Tokyo and Tsukuba. The center value of our newly determined Sr frequency agrees with the center values of the JILA [12] and SYRTE [13] results with a standard deviation of 0.27 Hz (fractional uncertainty of 6×10^{-16}).

9. Yb optical lattice clock

Development of an Yb optical lattice clock is in progress at the NMIJ. We obtained a magneto-optical trap (MOT) of ^{171}Yb atoms using the spin-forbidden transition ($^1S_0$-$^3P_1$: 556 nm). We measured the temperature of ultracold atoms to be 30uK by the time-of-flight method, which is less than the potential height of the lattice far-off-resonant trap (FORT). We have succeeded in trapping ultracold fermionic ^{171}Yb atoms in a 1D lattice. A light source for the clock transition at 578 nm generated by a Nd:YAG laser and an Yb:YAG laser using a sum-frequency generation scheme has been developed. The light at 578 nm is stabilized to a vertical cavity made form ultra low expansion glass. In order to investigate the laser stability, the optical frequency at 578 nm has been measured using a femtosecond optical frequency comb and the stability of ~ 2×10^{-14} for an averaging time of 10 s is obtained. We have observed the Yb clock transition $^1S_0$-$^3P_0$ at 578nm.

10. Fiber frequency comb

Various types of fiber-based frequency comb system have been developed in recent 3 years. Each system is fabricated for each specific object. Typically, these systems can be operated over a continuous period of more than one month. For example, one of the systems is used to measure a 578 nm laser for the spectroscopy of the clock transition in our Yb optical lattice clock. A fiber comb was shipped to NMI, Australia and compared with their comb. The frequency consistency of the two combs was approximately 8×10^{-17} [14]. Our measurement capability for optical frequencies using a frequency comb has been registered in CMC. One of the comb systems is used as the national standard of length in Japan.

References

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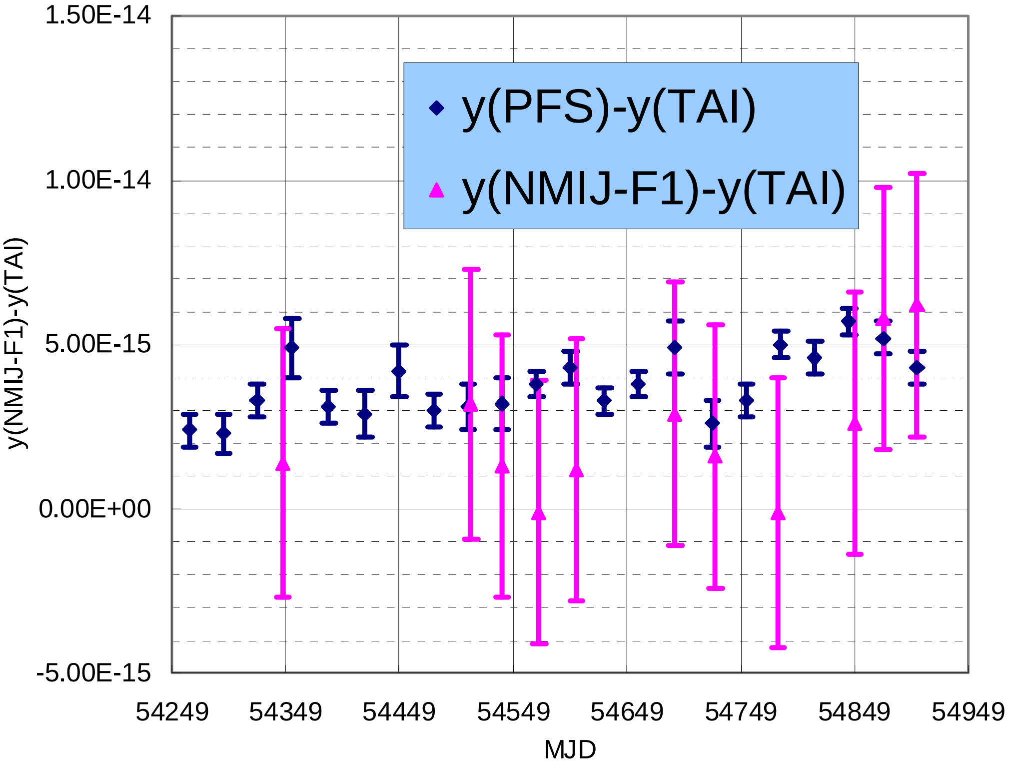


Fig.1 Frequency comparison between NMIJ-F1 and TAI

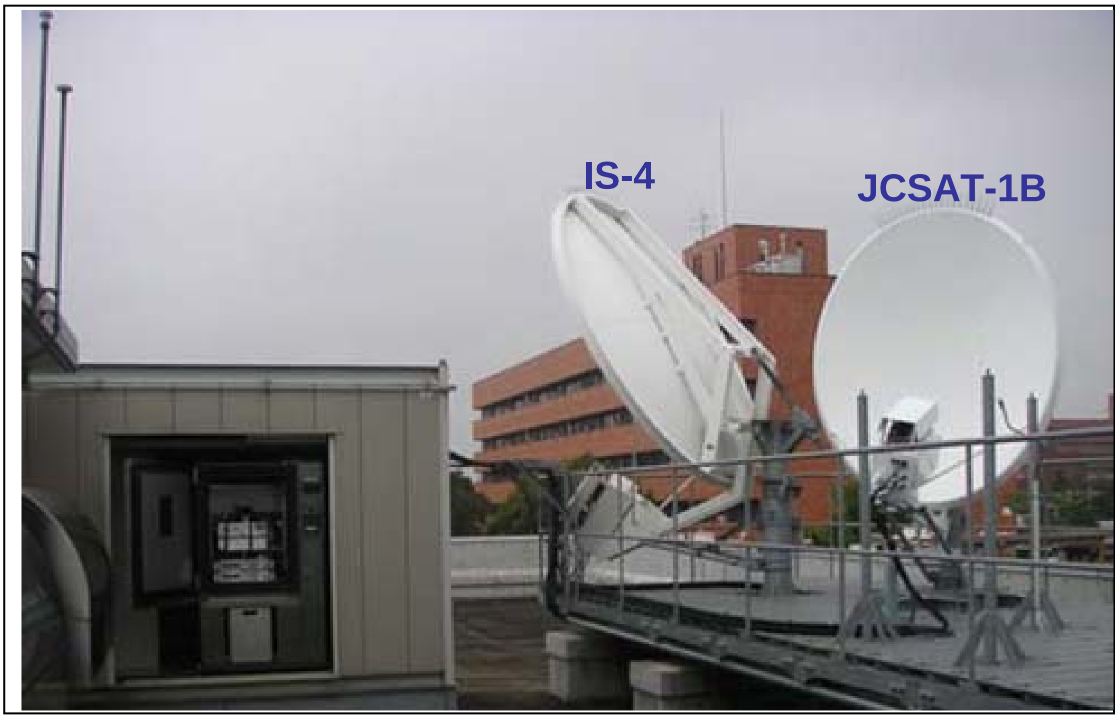


Fig.2. Earth stations for TWSTFT at NMIJ. The LNAs at front-end and SSPAs are temperature stabilized by using a temperature controlled box and a temperature control chamber.

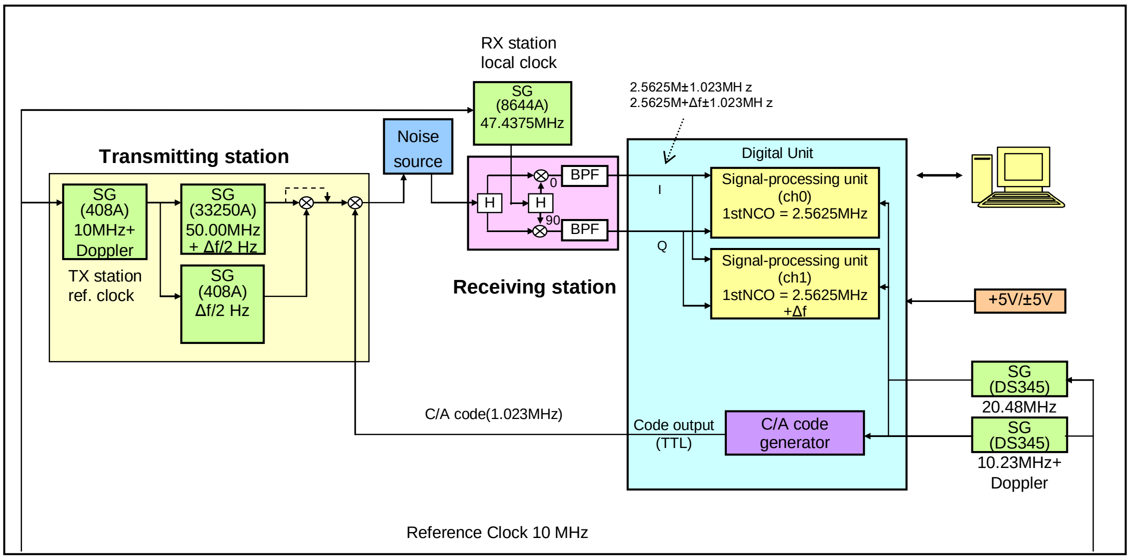
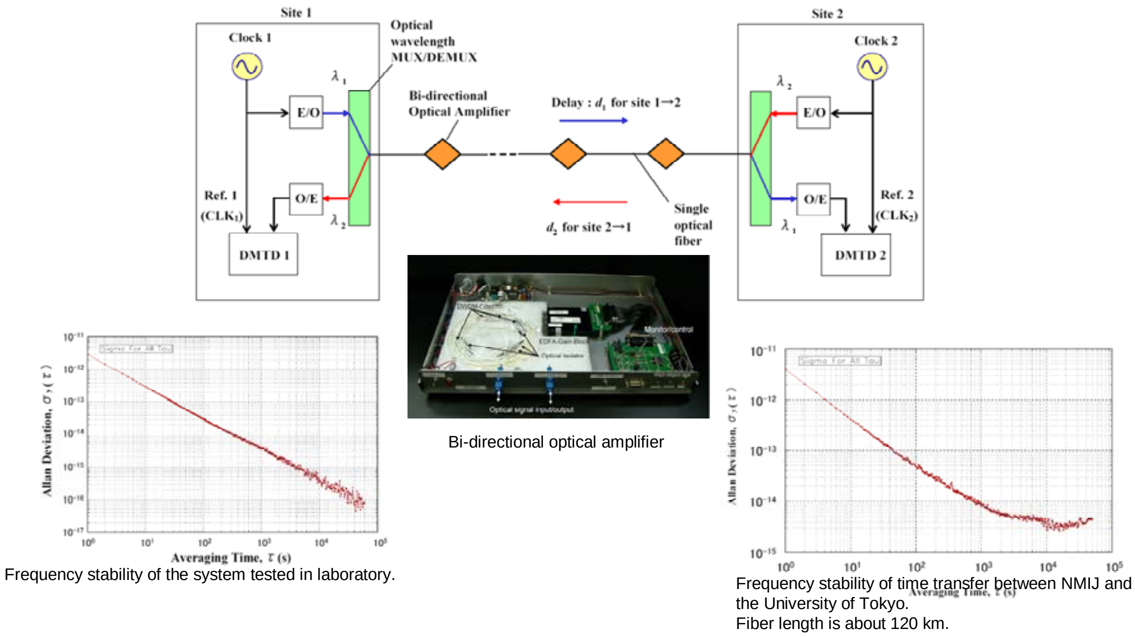


Fig.3. A block diagram of the carrier phase TWSTFT proto-type one of data processing part.



Frequency stability of the system tested in laboratory.

Bi-directional optical amplifier

Frequency stability of time transfer between NMIJ and the University of Tokyo.
Fiber length is about 120 km.

Fig. 4. Bi-directional Optical Amplifier Developed for Stable Time and Frequency Comparison.

Fig. 7. Terminal equipment of frequency remote calibration service.