Status Report to the 20th meeting of the CCTF on Time and Frequency Activities at KRISS

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1. Atomic Fountain Frequency Standard

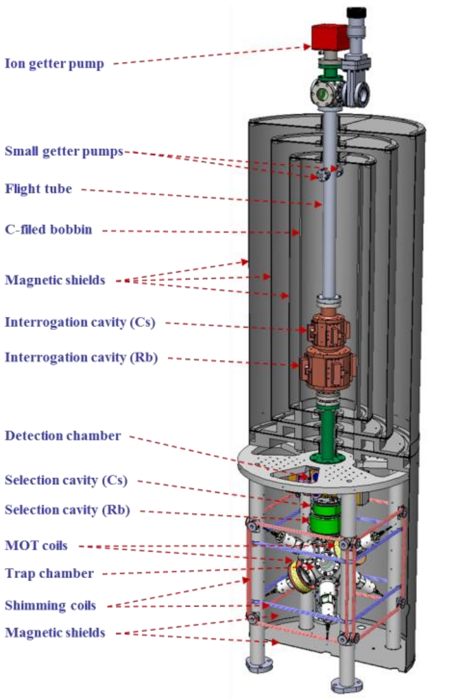

Fig. 1. Cs/Rb dual foutain clock at KRISS

KRISS is developing an atomic fountain frequency standard, KRISS-F1 since 2010. The newly designed atomic fountain clock at KRISS is a Rb/Cs double fountain [1]. We will trap two species of atoms simultaneously with cooling laser beams of (111)-geometry. However, as the laser system only for cesium was presently prepared, we have been experimenting with a Cs fountain. Cs atoms are trapped and cooled with MOT and optical molasses, respectively. The trap chamber made of titanium has fourteen ports. Among them six windows are used for laser cooling with (111)-geometry. Precisely pre-aligned six fiber collimators with 22.5-mm collimated beam diameter ($1/e^2$ level) are directly attached to the surfaces of trap chamber ports to avoid beam misalignments. Two CCD cameras are installed on two ports of trap chamber to monitor cloud size and initial position right before launching cold atoms during fountain operation. We monitor the temperature of the physics package with several calibrated sixteen PT-100 temperature sensors that are distributed over the physics package. A fluorescence collecting system is designed in order to measure TOF signal of Cs and Rb atoms independently with high efficient color filters. Fluorescence from atoms is integrated in the fluorescent collecting system. We installed two cylindrical TE_{011} cavities for ^{133}Cs and ^{87}Rb interrogation that are newly designed to minimize the distributed cavity phase (DCP) shift error collaborating with The Pennsylvania State University [3, 4]. Each cavity has four rectangular TE_{012} waveguides placed at every $\pi/4$ of cavity body. The rectangular waveguides are fed by four independent cables. There are two coupling holes for each waveguide to minimize longitudinal phase gradient. We adapted a Cs cavity of the same design with NPL-CsF3 [4] and designed a new Rb cavity using the same ideas.

In the year 2014, we have been introduced a liquid helium Cryo-ooled Sapphire Oscillator (CSO) to generate an ultra-stable X-band signal [5]. Our CSO implementation is collaboration with the University of Adelaide under an ARC (Australian Research Council) Linkage project. A closed system ultra-low-vibration pulse-tube cryocooler reduces the operating cost. The CSO is the source for a new low-noise frequency synthesizer we developed for the KRISS-F1 Cs/Rb dual fountain. The short-term stability of KRISS-F1(Cs) is 3.5×10^{-14} at 1-s integration time with MOT (magneto-optical trap) operation.

At the end of 2014 the KRISS-F1 was moved to a new building with improved temperature and humidity control. We are currently evaluating the cold collision and DCP shifts for an accuracy evaluation of the Cs fountain standard. We aim for a total uncertainty of KRISS-F1(Cs) at the low 10^{-16} level. After completing accuracy evaluation of the atomic fountain, we hope it will contribute to the generation of TAI and be used as a reference standard for frequency comparison of an Yb optical lattice clock under development at KRISS.

2. Optical Frequency Standard

After 19^{th} meeting of CCTF, a frequency stability of a clock laser at 578 nm, which had been the main limiting factor in the first absolute frequency measurement [6], was improved with short-term linewidth of 3.5 Hz at 1 s and mid-term frequency jitter of about 25 Hz at 10 s by moving the reference cavity setup down to the basement floor and also by optimizing the position of the cavity support and the temperature. As a result of this stability improvement, the frequency of the clock laser can be locked to the clock transition of the ytterbium lattice clock, which leads to lower frequency uncertainty [7]. In addition, after the temperature of the super-cavity was stabilized to the point for the zero thermal expansion, the frequency of the clock laser showed only a linear drift due to the ULE material aging, which reduces the uncertainty in the frequency measurement using an optical frequency comb. A cutout-type vibration-insensitive ULE cavity has been used as a reference cavity. The location of four support points by small Viton rubber balls were determined to minimize the vibration sensitivity. We performed finite element analysis and experimentally studied this support-area-dependence of the position in a cutout optical cavity [8].

The achievement in clock laser has been followed by reductions of spectrum linewidth of clock transition and the system uncertainties of ^{171}Yb optical lattice clock. Collisional shift has been analyzed and reduced to 10^{-17} level. We analyze both s- and p-wave cold collisions and obtained an analytic solution for the collision shift, for the first time, under typical clock operation conditions. We also proposed an over-π pulse interrogation scheme for canceling the collision shift in optical lattice clocks using Rabi spectroscopy. We applied our analysis to the experimentally measured collisional frequency shift in an Yb optical lattice clock. Although shift and uncertainty on the 10^{-17} level were achieved due to operation at slightly off of collision-shift-free conditions, it is shown that shift and uncertainty on the 10^{-18} level can be reached under experimentally achievable conditions [9].

Currently, the total uncertainty is mainly dominated by the shifts due to the lattice laser and blackbody radiation. We are making efforts to evaluate the lattice laser induced shift (linear ac Stark and hyper-polarizability shifts) with uncertainty below 10^{-17} by using build-up cavity with enhanced optical lattice depth. Blackbody radiation (BBR) shift mostly comes from the uncertainty of vacuum chamber temperature. To reduce BBR shift, a chamber with better temperature-controlled spectroscopy environment is under development.

3. Time and Frequency Transfer

In order to contribute to the generation of TAI and keep UTC(KRIS) traceable to UTC, KRISS is operating GNSS and TWSTFT time transfer systems. Time transfers using P3 code, precise point positioning, and C/A code of GNSS are being carried out with two Ashtech Z12T receivers, a Septentrio PolaRX2eTR, two Septentrio PolaRX3eTR and a multi-channel GPS receivers (Topcon Euro-80) (Fig. 1). Recently, three Dicom GTR51 and one PikTime TTS-4 GNSS receivers were introduced for time transfer using GPS, GLONASS, GALILEO and SBAS (or WAAS). It is highly expected that the Dicom GTR51 receivers will play the main role of the time comparisons substituting for current Ashtech Z12T in the near future. The GIPSY-OASIS II Ver.6.1 software is currently used for PPP computations and it was used to compare the frequencies of optical clocks between KRISS and NICT. Also we have the schedule of introducing Bernese for GPS CP and this will be done in the near future.

For TWSTFT links, two sets of TWSTFT system have been settled in the new building. One of them is for Asia-link via the Eutelsat172 (old GE-23) satellite and the other for Europe-link via the AM4R satellite (aimed but not yet confirmed). At present, the time comparison using the Asia-link is performed according to the provided schedule and the results are going to be uploaded to the corresponding BIPM directory. The Europe-link is on standby due to the missing of a proper satellite and its radio license.

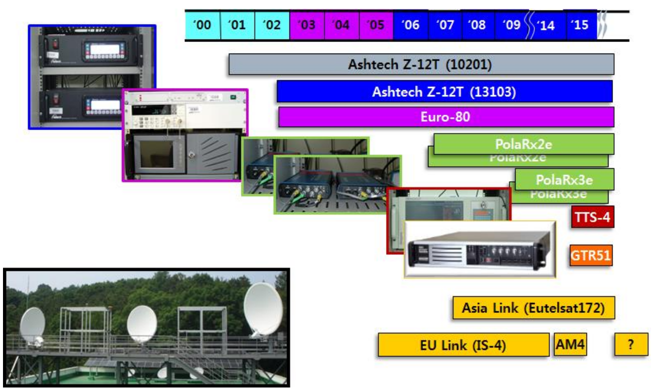

Fig. 2. Time Transfer system at KRISS.

We also implemented a fiber-optic dissemination system of time and frequency between two buildings connected by about 1 km underground optical fiber inside KRISS campus. This optical link was used to confirm stable operations of H-masers relocated to a new building by comparison with H-masers in the old building. For the frequency transfer, the laser intensity is modulated at 1 GHz synthesized from the H-maser and the fiber noise is actively compensated. In case of the time transfer, the commercial time code generator is used to encode timing signals on the laser pulse and the change of propagation delay in the fiber was compensated by post-processing.

For advanced time and frequency transfer, it has been nowadays conceived to use VLBI for space geodesy (operated by National Geographic Information Institute) or SLR (operated by Korea Astronomy and Space Science Institute) which are located about 30 km away from KRISS. Although the delivery of the optical carrier frequency itself has shown best performance in distance and stability, it always requires a frequency comb for the practical use, so we decided to transfer a radio-frequency (RF) to these sites. Because fiber links to these facilities were not established yet, we tested other research fiber network called Korea Research Environment Open Network (KREONET) operated by Korea Institute of Science and Technology Information (KSITI). It is a pair of 56-km dark fibers going from KRISS to the local station located in the other city (Cheongju-si). This is not a favorable link for the frequency transfer because its one-way loss is as high as 20 dB and most of connectors are PC type, leading to high Fresnel reflections. To avoid unwanted reflections, we used lasers with different wavelength and filtered out unwanted light using optical bandpass filters before the photodetectors. The fractional frequency instability after noise compensation was 5×10^{-14} at an averaging time of 1 s and 1.2×10^{-16} at 1000 s.

4. Dissemination of Time and Frequency

We are operating two NTP time servers and provide a software (UTCk3.1) allowing users to synchronize their computer clocks via the internet. Currently, we limit the number of requests per second below 3000 to avoid too much traffic from degrading network capability. Upgrading UTCk3.1 is underway.

A 5 MHz broadcasting station (call sign: HLA) has been in operation to disseminate Korea Standard Time (KST) and Korea Standard Frequency (KSF) since 1984. Form 2015, we started to build a long-wavelength broadcasting station to disseminate the same timing signal. This project is scheduled for five years to design and build a key system for broadcasting. We are in the designing phase to investigate an optimum carrier frequency, modulation technique, infrastructure for broadcasting not only for timing information but also for necessary public information. After completing the design and key system developments, we are planning to construct a site and station building to broadcast timing and public information nationwide.

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