# Status Report to the 17th meeting of the CCTF on Time and Frequency Activities at KRISS

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## 1. Atomic Frequency Standards

### 1.1 The KRISS-1 frequency standard

There have been many improvements in the apparatus inside a vacuum chamber such as Ramsey cavity, fluorescence collector, Cs oven, and c-field rods. The pumping scheme has been changed. The frequency of pumping laser is stabilized to F=4 to F'=3 transition. The signal to noise ratio is increased by the newly designed Cs oven and the fluorescence collector. Therefore the frequency stability of KRISS-1 improved by 5 times, results in the Allan deviation of $8.7\times10^{-13}\tau^{-1/2}$ as shown in Fig. 1. The limit of the long term stability is $5.5\times10^{-15}$ at the sampling time of $3\times10^{4}$ s.

The magnetic inhomogeneity is reduced to less than 0.1 % which corresponds to the uncertainty of $\leq10^{-15}$ caused by the quadratic Zeeman shift. The light shift due to the scattering light is reduced down to $10^{-14}$. Recently we developed the calculation method to precisely determine the velocity distribution and the Rabi frequency (b-value). This method gives better results than any other method. The uncertainty of b-value is estimated as 0.02% according to our simulation result. We have adapted this method to the experimental situations at present.

Table 1 shows the uncertainty budget of KRISS-1.

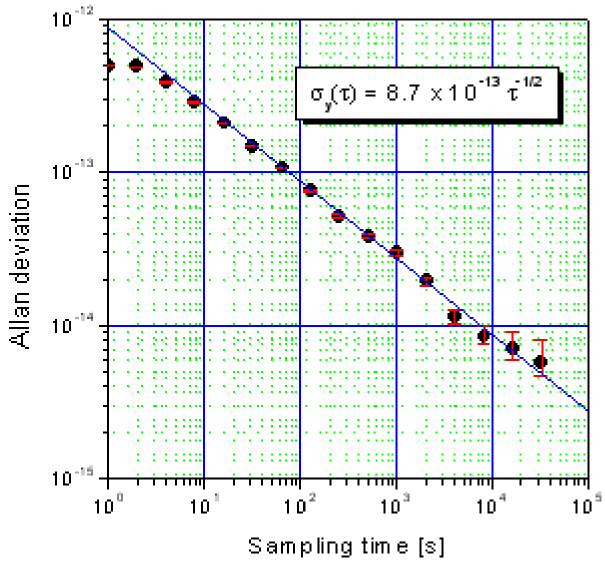


Fig. 1. Allan deviation of KRISS-1.

Table 1. Uncertainty budget.

| Physical Effect | Shift ($\times10^{-14}$) | Uncertainty ($\times10^{-14}$) |
|---|---|---|
| Quadratic Zeeman | 46837.5 | 0.1 |
| Magnetic Field Inhomogeneity | 0 | 0.042 |
| Resonance Inhomogeneity | 0 | <0.2 |
| Second-Order Doppler | -31.1 | 0.05 |
| Cavity Pulling | 0 | 0.5 |
| Bloch-Siegert Shift | 0.35 | 0.0002 |
| Rabi Pulling | 0 | 0.2 |
| Gravitational Shift | 0.95 | 0.1 |
| Black Body Radiation | -1.64 | 0.02 |
| End-to-end Cavity Phase Shift | 0 | <0.1 |
| Electronics | 0.8 | 0.8 |
| Combined Type B Uncertainty | | 1.3 |

## 1.2 Cesium atomic fountain standard

We have constructed a second cesium atomic fountain frequency standard with modifications to overcome several shortcomings in our original one [1]. We were able to observe Ramsey fringes of 1 Hz linewidth on the 9.2 GHz clock transition of cesium atoms. We are currently trying to improve signal-to-noise ratio of Ramsey fringes and stabilize microwave to the center of Ramsey fringes.

## 2. Absolute frequency measurement of Cesium D2 line

We have measured an absolute optical frequency of the cesium D2 line F=4 → F'=5 transition (852.3 nm) with a cesium vapor cell [2]. To measure the frequency of the cesium optical transition the frequency of the extended cavity diode laser (ECDL) is stabilized using the modulation transfer spectroscopy (MTS). The laser power and the temperature of the vapor cell is stabilized. The frequency of ECDL is measured by a optical frequency synthesizer based on the mode-locked femtosecond laser with a repetition rate of 1 GHz. The optical frequency comb is stabilized by using a microwave synthesizer, which is referenced to a hydrogen maser. We employed the optical injection-locked DBR laser by the one component of optical frequency comb to enhance the signal-to-noise ratio. The heterodyne-beat frequency between two lasers is measured by using a frequency counter. We evaluated the frequency shift and the uncertainty for various experimental parameters. The dominant frequency shift is caused by the power of pump and probe laser. We find the optical frequency of the cesium D2 line F=4 → F'=5 transition to be 315 721 960 559(79) kHz.

## 3. Optical Frequency Standard under Development

We have started a research project toward the realization of an Yb optical lattice clock at the optical frequency domain. The idea of the optical lattice clock was originally proposed by Katori with $^{87}$Sr fermions. Among the group-II atoms, we have pointed out that $^{171}$Yb fermions (natural abundance 14.4%, nuclear spin = 1/2) are also have unique features for the ultimate operation of the optical lattice clock with the natural line width of 10 mHz [3]. Especially, we have demonstrated a compact violet Yb MOT with InGaN violet laser diodes, in which we could trap more than 1.4 x $10^6$ $^{171}$Yb fermions, with $6s^2\ ^1S_0$ - $6s6p\ ^1P_1$ dipole-allowed transitions at 398.9 nm. We now replaced the proto-typed MOT with an 18-faced windows vacuum chamber for optical lattice configuration with Zeeman slower with which we can configure 3-D optical lattice. Now we are establishing an ultra narrow linewidth laser with high frequency stability at 578.4 nm by frequency doubling from 1156 nm laser which will be obtained from DFB LD of 10 mW and amplified by optical parametric amplification or other methods. In addition, we have completed the development of an optical frequency synthesizer with a phase-locked femtosecond mode-locked Ti:Sapphire that can be used not only for the absolute optical frequency measurement, but also for the optical lattice clock work. In order to load the cold Yb atoms into the optical lattice formed by an intense single-mode electric field at the magic wavelength near 759 nm, we need to make the temperature of Yb atom cloud below 10 μK, which is possible by cooling $6s^2\ ^1S_0$ - $6s6p\ ^3P_1$ intercombination transition (555.8 nm ) for second-stage trapping. For obtaining this deep cooling light source, we are now trying to use the second-harmonic of solid-state DFB fiber lasers emitting tunable single-mode outputs ( > 1 W output power) at the fundamental wavelengths of 1111.6 nm. We expect at the end of year 2007 we can try to detect the first signal from the Yb optical lattice.

## 4. Time and Frequency Comparisons

To maintain UTC(KRIS) against UTC, we've conducted several types of time transfer methods. For the regular international time comparison, we operate two geodetic GPS receivers (Ashtech Z12T) for P3-code and carrier phase time transfer, and utilize a multi-channel GPS receiver (Topcon Euro-80) and a GPS/GLONASS receiver (R100-40T) as a backup system. Since April 2006, Z12T has been used for main time transfer link and the results of comparison have been reported to BIPM using the R2CGGTTS software provided by BIPM.

At KRISS, three TWSTFT systems have been constructed. One is for Asia link via JCSAT-1B satellite, another for Oceania region via PAS-8 satellite, and the other for Europe link via PAS-4 satellite. Those are operating by use of multi-channel modems developed by NICT, which have capability of performing simultaneous two-way time transfer functions among the maximum 7 stations [4]. For now, the time transfer experiments via JCSAT-1B have been accomplished between 6 institutes which are NICT, NMIJ, NTSC, TL, SPRING and KRISS. And the time transfer via PAS-8 has been conducted between KRISS and NMIA. Additionally KRISS and PTB have been linked via PAS-4 satellite and we are evaluating the performance at present.

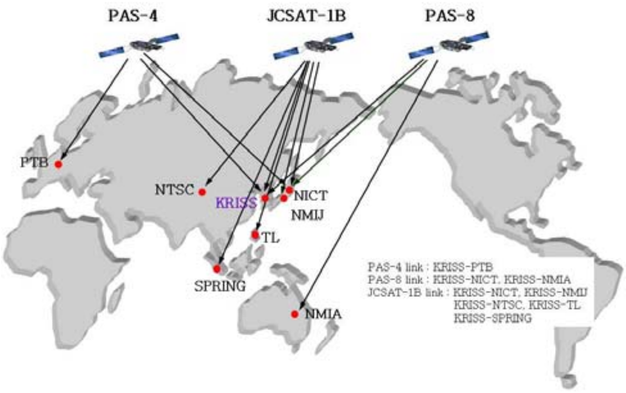


Fig. 2. TWSTFT link at KRISS.

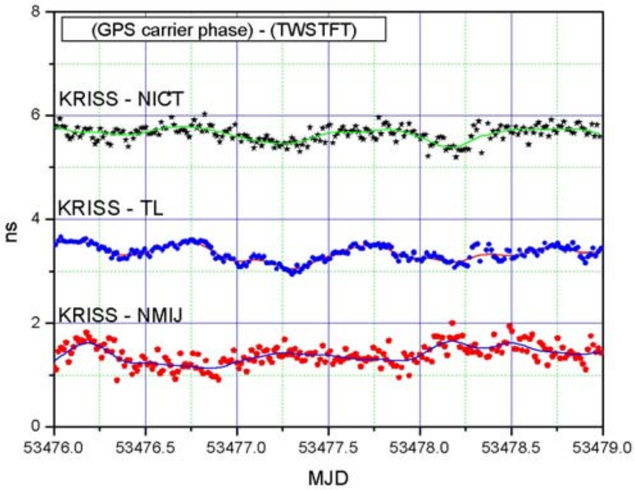


Fig. 3. Time difference between carrier phase and TWSTFT.

The time difference data obtained from a subset of such network were used for the comparison between GPS time transfer and multi-channel TWSTFT via JCSAT-1B. To analyze the GPS carrier phase data, an in-house software developed by KRISS is used.

Fig. 2 shows the whole links connected by the multi-channel modem for TWSTFT at KRISS. And Fig. 3 shows the time difference between GPS carrier phase and two-way time transfer among the aforementioned 4 institutes (KRISS, NICT, TL, NMIJ). Vertical offsets are intentionally shifted for easy distinction [5].

## 5. Dissemination of Time and Frequency

KRISS maintains 5 Cesium clocks (HP5071A) and 3 Hydrogen masers (Sigmatau and KVARZ) to keep UTC(KRIS). The difference between UTC and UTC(KRIS) shows 11.0 ns rms value. Researches to improve the accuracy and uncertainty of UTC(KRIS) with respect to UTC are on the way. One more Hydrogen maser will be added to the clock ensemble and all the clocks will be temperature and hymidity stablized inside the environmental chambers. We hope this would improve the stability of UTC(KRIS). We are also developing doubly redundant UTC(KRIS) generating system with one system as main and another backup to avoid unwanted failure in time keeping. We are operating three time server workstations to allow users to synchronize computer clocks via the Internet using Simple Network Protocol (SNTP). The number of connections to the servers is around 15 million per day. We are testing Linux based timeserver and improving network configuration to serve better and to make the time dissemination system more stable. A 5-MHz broadcasting station (call sign: HLA) is maintained for dissemination of Korea Standard Time (KST) and Korea Standard Frequency (KSF). More than 100 organizations are using the signal for the reference.

## References


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