Status Report to the 18th meeting of the CCTF on Time and Frequency Activities at KRISS

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1. Microwave Atomic Frequency Standards

1.1 Optically pumped atomic beam frequency standard (KRISS-1)

KRISS has carried out accuracy evaluation and frequency measurement of an optically pumped cesium beam frequency standard KRISS-1 [1, 2]. The first report on KRISS-1 was submitted to the BIPM Time Section on December 5, 2008 and reviewed by the Working Group on Primary Frequency Standards. The results of frequency measurement in the report were published in the Circular T 253 in 2009.

KRISS-1 typically performs at a short term stability of $1.3\times10^{-12}/\tau^{1/2}$ with a combined uncertainty of 1.0×10^{-14}. The Allan deviation at an averaging time of one day is about 4×10^{-15}. Table 1 shows the uncertainty budget of KRISS-1.

Table 1: Frequency Biases and relevant type-B Uncertainty

Physical Effect	Bias ($\times10^{-14}$)	Uncertainty ($\times10^{-14}$)
Quadratic Zeeman	48581.5	0.1
Quadratic Doppler	-38.02	0.1
Cavity Pulling	-0.46	0.07
Bloch-Siegert	0.37	0.002
Rabi Pulling	-0.35	0.1
Gravitation	0.9	0.1
Blackbody Radiation	-1.66	0.02
End to end Cavity Phase	117.1 (east to west) 113.0 (west to east)	(Type-A) 0.41
Light Shift	0	0.9
Majorana	0	0.2
C-field Inhomogeneity	0	0.05
Ramsey Pulling	0	0.01
Distributed Cavity Phase	0	0.1
Combined		**1.0**

Frequency measurement and accuracy evaluation of KRISS-1 were performed three times over the 15 day period of MJD 54654 to 54669, the 10 day period of MJD 54699 to 54709, and the 20 day period of MJD 54719 to 54739 (from Jul. 7 to Sep. 30, 2008). During the same periods, the frequency deviation between our reference H-maser and UTC has also been measured, which can be found in Circular T of BIPM. Using these data, we compared the frequency difference between UTC and our reference H-maser to the frequency difference between KRISS-1 and the maser for three separate occasions: MJD 54654-54669, 54689-54709 and 54719-54739. The results are shown in Fig. 1.

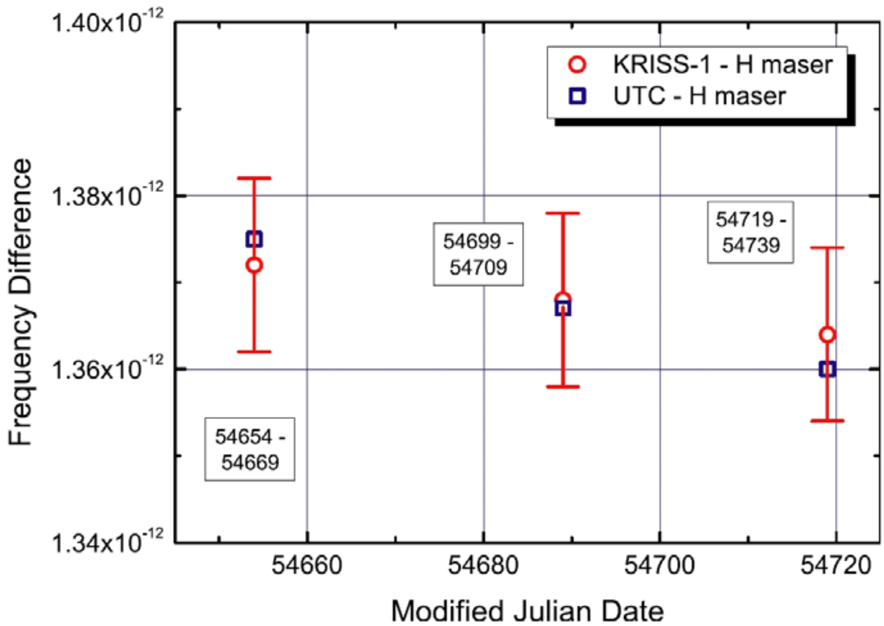

Figure 1. The frequency difference between KRISS-1 and the maser is compared with the frequency difference between the maser and UTC.

KRISS started again the operation of KRISS-1 as a primary frequency standard from May, 2009, after replacement of the exhausted Cs ampules by new ones.

1.2 Cesium atomic fountain standard

KRISS has developed a cesium atomic fountain frequency standard. However, there is no significant change in the KRISS fountain [3, 4] since last CCTF meeting. Most of our resources have been directed to the completion of KRISS-1, an optically pumped thermal beam primary frequency standard.

At present, KRISS is going to modify the laser cooling part of the previous fountain system and introduce a new laser system with a high power laser diode.

1.3 Optical RF generator for atomic fountain standard

Development of an optical RF generator for an atomic fountain standard is in progress. A DBR laser injection-locked by the optical comb is frequency-stabilized to the Cs D2 transition line by using a modulation transfer technique preliminary to frequency stabilization with an ultra-stable optical cavity. The short-term stability of the repetition rate of optical comb is 2×10^{-13} at the sampling time of 1 s. The measured stability is limited to the stability of a Hydrogen maser used as a reference for frequency measurement. We are going to stabilize laser frequency with an ultra-stable optical cavity.

2. Optical Frequency Standard

We are developing an Yb optical lattice clock. To prepare Yb atoms in an optical lattice, we used two-stage cooling and trapping to make the temperature of Yb atoms low enough to be captured in the optical lattice potential. A light source with wavelength of 556 nm for the 2nd stage cooling based on all solid state laser system was developed. It is composed of an external cavity diode laser (ECDL) of 70 mW-1112 nm as a master laser, an Yb-doped fiber amplifier for amplification of the master laser, a periodically-poled lithium niobate (PPLN) for the second harmonic generation of 1112 nm, and a high-finesse cavity for further reduction of the laser linewidth. We obtained 20 mW-556 nm laser with sub-kHz linewidth. The center frequency of the laser is stabilized by the fluorescence signal from the collimated thermal atomic beam.

The diameter of the 1st stage trapping laser beam was 15 mm with 3 mW power per axis. The beam was switched with fast mechanical shutter located at focal position of the laser beam to make have switching time of 50 μs. On the other hand the 2nd stage trapping laser had AOM switching for the multi-purposes-switching, modulation, and attenuation. For the AOM driver of 556 nm trapping laser, we used voltage controlled oscillator (VCO) controlling FM modulation range with 0~10 volts, where we used precise voltage reference with 10^{-4} stability so that AOM frequency shift had sub-kHz uncertainty. By using a bias-T the reference voltage was added with the modulation voltage having 1 V peak to peak sine wave which gave 2 MHz modulation depth. We observed that 65 % of Yb atoms in 1st stage blue MOT was transferred to the green MOT. The temperature and number of atoms in green-MOT was about 100 μK and 600,000, respectively. Since the temperature is still high to load atoms into optical lattice, optimizing the experimental parameters is required to lower the temperature and to increase the atom number.

To probe the narrow clock transition, we are developing 578 nm probe laser by using second harmonic generation (SHG) and sum frequency generation (SFG). In SHG method we used two diode lasers with 1156 nm-40 mw and a MgO-PPLN. A master ECDL was pre-stabilized to a high finesse cavity (F~10,000) using a Pound-Drever-Hall technique. The linewidth of the laser was measured to be sub-kHz. The output from the master laser was injected to another diode laser for a power amplification and we got 40 mW amplified output which had the same frequency property as the master laser. A MgO-doped WG-PPLN doubled the frequency of slave laser, which produced 2.5 mW -578 nm light. In SFG method we used a 80 mW-1030 nm fiber laser, a 150 mW-1319 nm Nd:YAG laser, and another MgO-PPLN crystal. Since the linewidth of the lasers are very narrow (1030 nm fiber laser-20 kHz, 1319 nm Nd:YAG laser-1 kHz), we expect the output linewidth will have linewidth of around 40 kHz without pre-stabilization.

3. Time and Frequency Comparisons

To maintain UTC(KRIS) against UTC, we have conducted several types of time transfer methods. For the regular international time comparison, we have been operating two modes of four GPS receivers (Ashtech Z12T and Septentrio PolaRX2e) for P3-code and carrier phase time transfer, and operating a multi-channel GPS receiver (Topcon Euro-80), a GPS/GLONASS receiver (R100-40T) and two single channel receivers (Austron TTR6) as a backup time transfer system.

At KRISS, three TWSTFT systems had been installed. One is for Asia-link via JCSAT-1B satellite, another for Oceania region via IS-8 satellite, and the other for Europe-link via IS-4 satellite. But recently, the satellite for Asia-link was changed from JCSAT-1B to IS-8., and Oceania-link has been stopped since the end of March 2009. Time comparison at KRISS has been carried out with 4 stations of NICT, JJY-40, JJY60 of Japan and NTSC of China via IS-8 satellite.

KRISS introduced a SATRE modem, which replaces a NICT multi-channel modem, for time comparison with PTB and OP at the beginning of April, 2009.

The time difference data obtained from a subset of such network were used for the comparison between GPS time transfer and TWSTFT via IS-8 and IS-4 satellites. Fig. 2 shows the whole link picture by the NICT modem via IS-8 and the SATRE one via IS-4 for TWSTFT at KRISS.

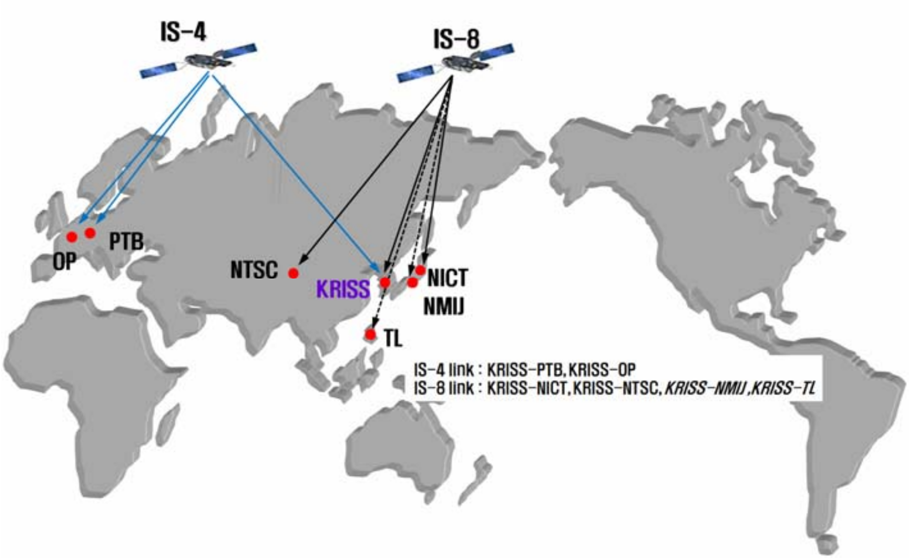

Fig. 2. TWSTFT link at KRISS.

4. Dissemination of Time and Frequency

KRISS maintains 5 Cesium clocks (HP5071A) and 2 Hydrogen masers (a Sigmatau and a KVARZ) to keep UTC(KRIS). The time difference between UTC and UTC(KRIS) shows about -5.4 ns with 13.4 ns rms value for the last three months (from Jan. to Mar. 2009). Researches to improve the accuracy and uncertainty of UTC(KRIS) with respect to UTC are on the way. Two Hydrogen masers (KVARZ) have been repaired and they will be added to the clock ensemble within a few months after testing the operation. For temperature and humidity stabilization, all the clocks are in the environmental control chambers where temperature is controlled within 60.1 ℃ and relative humidity within 61 %. We expect that this would improve the stability of UTC(KRIS). We are also developing doubly redundant UTC(KRIS) generating systems with one system as a main and the other as a backup to avoid unwanted failure in time keeping.

For time dissemination, we are operating 2 Linux based time-server workstations allowing users to synchronize their computer clocks via the Internet using Simple Network Protocol (SNTP). The number of connections to the servers is around 700 packets per second (about 60 million for a day). A 5 MHz broadcasting station (call sign: HLA) is maintained for dissemination of Korea Standard Time (KST) and Korea Standard Frequency (KSF). It is expected that the equipment of the station will be upgraded to provide more stable and reliable signals. More than 100 organizations in Korea are using the signals for the reference of their time and frequency equipment.

References

[1] Soo Heyong Lee, Young-Ho Park, Sang Eon Park, Ho Seong Lee, Sung Hoon Yang, Dai-Hyuk Yu, and Taeg Yong Kwon, “Accuracy Evaluation of an Optically Pumped Caesium Beam Frequency Standard KRISS-1”, Metrologia 46, 227-236 (2009).

[2] Young-Ho Park, Soo Heyong Lee, Sang Eon Park, Jong Koo Lee, Hoonsoo Kang, Ho Seong Lee, Sung Hoon Yang, Dai-Hyuk Yu, and Taeg Yong Kwon, “Compensation of systematic errors in acompact atomic beam frequency standard due to evanescent field inside a Ramsey cavity”, Metrologia **46**, 272-276 (2009).

[3] H.S. Lee, T.Y. Kwon, S.E. Park, S.K. Choi, and Y.H. Park, “Research on Cesium Atomic Clocks at the Korea Research Institute of Standards and Science”, J. Korean Phys. Soc., 45(2), 256, 2004.

[4] T.Y. Kwon, H.S. Lee, S.H. Yang, and S.E. Park, “Development of a cesium atomic fountain frequency standard”, IEEE Tarns. Instr. Meas., 52, 263-266 (2003).