Report to the 15th Session of CCTF

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

(Formerly called "National Research Laboratory of Metrology")

1. Primary Frequency Standard [1]

We changed the evaluation procedure of the quadratic Zeeman shift in our optically pumped cesium frequency standard, NRLM-4, which has been operating as a primary frequency standard since February 1998. The quadratic Zeeman shift is estimated from the frequencies of the neighboring Zeeman transition, which are about 70kHz from the clock transition. Formerly, we measured the Zeeman shift only twice after and before the continuous operation for TAI evaluation. Currently, the Zeeman shift is measured almost continuously. The new procedure is the repetition of the following 4 steps, (1)normal clock operation (about 7minutes), (2)measurement of the neighboring Zeeman transition frequency on high frequency side (about 30seconds), (3)normal clock operation(about 7minutes), (4)measurement of the neighboring Zeeman transition frequency on low frequency side (about 30seconds). During the steps (2) and (4), the local oscillator is not controlled, i.e., free running. Degradation of frequency stability due to the free running period was negligible, since the local oscillator was sufficiently stable in short time of 30s. Figure 1 shows an example of the behavior of the Zeeman shift. The fructuation of the order of 0.0001 Hz which corresponds to the shift of 10^{-14} was observed. It seems to be due to the temperature dependence of the current source to generate C-field. In principle, the C-field can be stabilized by servo-mechanism. However, at present, it is not controlled and the correction of this shift is based on the average for operating period.

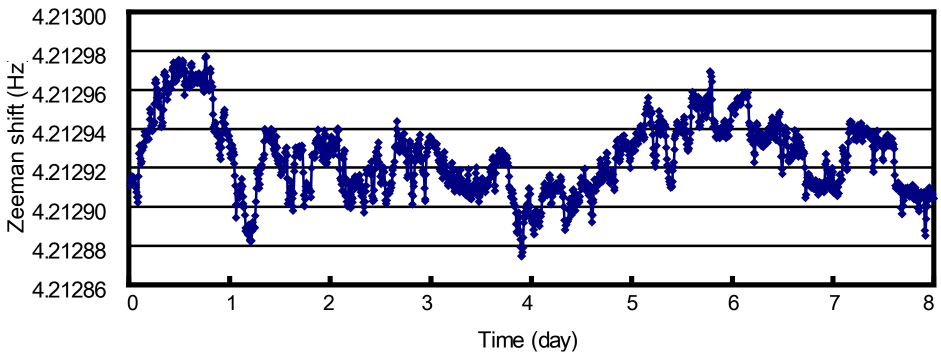

Figure 1. Behavior of Zeeman shift.

We have been measureing the duration of TAI scale interval using NRLM-4. Our procedure consists of the following steps. (1) We measure the microwave-powerdependent frequency shifts in opposite Cs beam directions, and determine the difference of the cavity phase shift as quickly as possible, before the hydrogen maser drifts. (2) After that, NRLM-4 is operated continuously for at least 5 days at the optimum microwave power without changing the operational parameters, and compared with the master clock (HP 5071A), which is linked to TAI. Our results are shown in Fig.2. The vertical axis denotes the value of $(u_{UTC}-u_0)/u_0$, where u_{UTC} and u_0 are the lengths of 1 second of TAI and the primary standard, respectively.

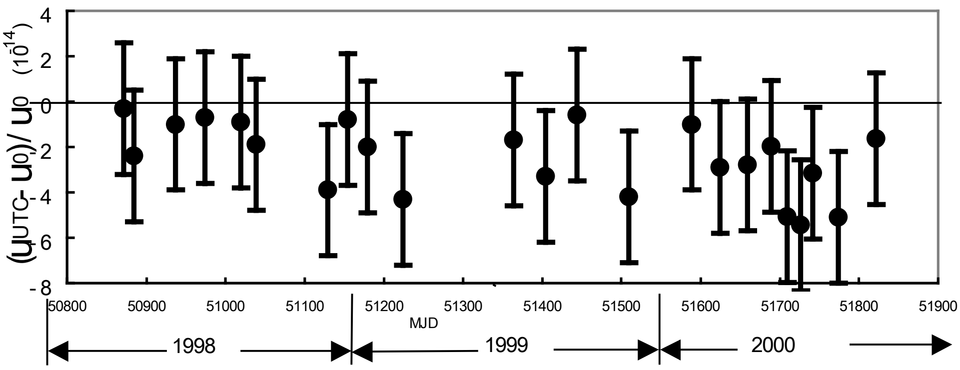

Figure 2. Calibration of TAI by the primary prequency standard, NRLM-4.

In November 2000, we had to move to a new building and we had taken NRLM-4 apart to pieces and has been overhauling it. We expect to NRLM-4 to operate with smaller uncertainty in the new laboratory with better environment after reconstruction and re-evaluation of uncertainty.

2. Development of a Cs Atomic Fountain Frequency Standard

Last year, our laboratory had to move to a new building and the experiment using a vacuum system had been interrupted. The new laboratory was at the level of B3F under the ground, where good temperature stability was expected. We manufactured a TE_{011} microwave cavity for Ramsey interrogation and another TE_{011} cavity for the state selection. Both cavities had a Q of 15,000 and are adjusted their resonance frequencies same within 100 kHz. They have no elements for tuning and can be tuned to the resonance frequency of Cs only by temperature. As a source for exciting the 9.192631 GHz transition of Cs, we developed two microwave oscillators using a dielectric resonator oscillator (DRO) and a sapphire loaded cavity oscillator (SLCO), respectively. Both oscillators were frequncy stabilized by a 10 MHz reference signal that was produced by a frequency synthesizer based on a H-maser. They showed similar short-term stability when locked to the H-maser. We controled the 10 MHz frequency through the synthesizer to stabilize the 9.192631 GHz frequency to the Cs fountain. In this way, we could obtain 10 MHz standard frequency that was stabilized by the Cs fountain. The short term stability of the standard frequency was measured to be 10^{-13} at τ=10 s by means of the phase comparison with another H-maser.

3. Time Comparison

We have been continuing the two-way satellite time transfer experiment to link two institutes, NRLM and CRL. Also, we introduced a GPS carrier-phase receiver [2].

4. Optical Frequency Measurement

We have been developing an optical frequency measurement system connecting a cesium microwave frequency standard and optical frequencies.

We developed stable and widely-tunable, continuous-wave optical parametric oscillators (cw-OPOs) [3,4] and realized a phase-coherent optical frequency division by 3 of 532nm laser light from a Nd:YAG laser, which produced 798nm and 1596nm light phase-locked to 532nm light [5]. In addition, we constructed the optical frequency interval bisection system to produce a phase-locked 912nm light whose frequency is the average of those of 798nm and 1064nm light[6].

The periodic pulse train of a mode-locked laser can be described in the frequency domain as a comb of spectral lines equally separated by the pulse repetition frequency f_{rep}. This frequency comb has been applied for measurement of the frequency intervals in the optical region [Udem et al. 1999]. The spectral bandwidth of an ultra-fast mode-locked $Ti:Al_2O_3$ (TiS) laser can be coherently broadened over one-octave by self-phase modulation in a photonic-crystal (PC) fiber [Wadsworth et al. 2000]. A direct comparison between microwave and optical frequencies has been realized by using the one-octave optical frequency comb [Diddams 2000, Jones 2000, Holzwarth 2000]. We decided to introduce the ultra-fast mode-locked laser to realize a direct comparison between microwave and optical frequencies [7].

Our source of an optical frequency comb was a chirped-mirror- dispersion-controlled mode-locked TiS laser, of which f_{rep} and pulse duration were 150 MHz and 11 fs, respectively. By using a PC fiber, made at University of Bath, the comb was broadened over one octave, i.e., from 530 nm to 1190 nm at -20 dB. We found that rotation of chirped mirrors, position of the crystal and change of the pump-laser power can be used for controlling of the carrier-envelope-offset frequency f_{CEO}.

We are trying to measure the frequencies of the frequency-stabilized lasers developed at NMIJ/AIST. The first target is an iodine-stabilized Nd:YAG laser [Hong 1999]. We measured its frequency by measuring the frequency interval between its fundamental and second harmonic at 1064 nm and 532 nm, respectively. The one-octave frequency comb was used as a floating ruler while the f_{rep} was stabilized to a rf reference locked to a cesium clock. We have so far conducted this f:2f frequency interval measurement in two separate days. Four trials showed standard deviations of 7 - 10 kHz at 532 nm with an averaging time of 10 s.

To realize absolute frequency measurement of any optical frequencies within the comb and to improve the measurement precision, we stabilized the f_{CEO} to a rf reference locked to the cesium clock by a self-referencing technique [Jones 2000]. The beat note generated by the overlapping between the fundamental and second harmonic of the frequency comb was detected with a signal-to-noise ratio over 40 dB with a detection bandwidth of 300 kHz. We controlled the pump-laser power by using an elecrtooptic modulator for locking. We measured the frequency of an iodine-stabilized He-Ne laser at 633 nm [Ishikawa 1996] with this absolute frequency comb. The standard deviation of the beat frequency between the He-Ne laser and a mode of the comb was 1.5 kHz with an averaging time of 10 s.

Evaluation and improvement of the uncertainty of our measurement is now undergoing to determine the absolute frequencies of the frequency-stabilized lasers. Also, we plan to evaluate the uncertainty and the noise characteristics of the comb using the phase-locked cw-OPO system.

References

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