Improvement of the Ensemble Atomic Timescale Using Hydrogen Masers in NICT

Hiroyuki Ito, Tetsuya Ido and Yuko Hanado
Space-Time Standards Laboratory
National Institute of Information and Communications Technology
Tokyo, Japan
hito@nict.go.jp

***Summary*— We have developed an improved ensemble atomic timescale to allow hydrogen masers to be used in ensemble calculations. The improved method was shown to be capable of keeping the time difference from Coordinated Universal Time (UTC) to within 1 ns over 200 days when appropriate initial data is used.**

Keywords*— *atomic timescale, UTC(k), Hydrogen maser

I. Introduction

In recent years, the importance of time synchronization technology has increased due to the advancement of information and communication technology. Since UTC(k), which is generated by national measurement laboratory, provides a national time reference, the need for higher precision in its operation is also becoming increasingly important.

Currently, the National Institute of Information and Communications Technology (NICT) generates UTC(NICT) based on the ensemble atomic timescale (TA) calculated from more than 10 commercial cesium atomic clocks. Specifically, UTC(NICT) is generated by adjusting the output signal of the hydrogen maser with an auxiliary output generator (AOG) so that it is phase-locked to the ensemble atomic timescale [1, 2]. However, it has been found that this method does not take advantage of the frequency stability of the hydrogen maser and improving the stability of the ensemble atomic timescale has been a challenge. Therefore, we have confirmed that the stability can be improved by incorporating a hydrogen maser into the ensemble atomic timescale.

II. Atomic Timescale Calculation Algorithm

In NICT, the ensemble atomic timescale is calculated from the time difference data between atomic clocks measured every hour. The current algorithm for the ensemble atomic timescale has two major steps. In the first step, the first-order phase change and the Allan deviation of each atomic clock are calculated against the past ensemble atomic timescale. In the second step, the ensemble atomic timescale at the next updating epoch is calculated by weighted averaging the time difference data corrected for the estimated first-order phase change, using the inverse of the Allan deviations as weights. In this work, we incorporated the hydrogen masers into the ensemble atomic timescale by modifying only the first step, based on the policy of utilizing a current calculation algorithm.

Our conventional current algorithm assumes that the second-order phase change during the evaluation period is

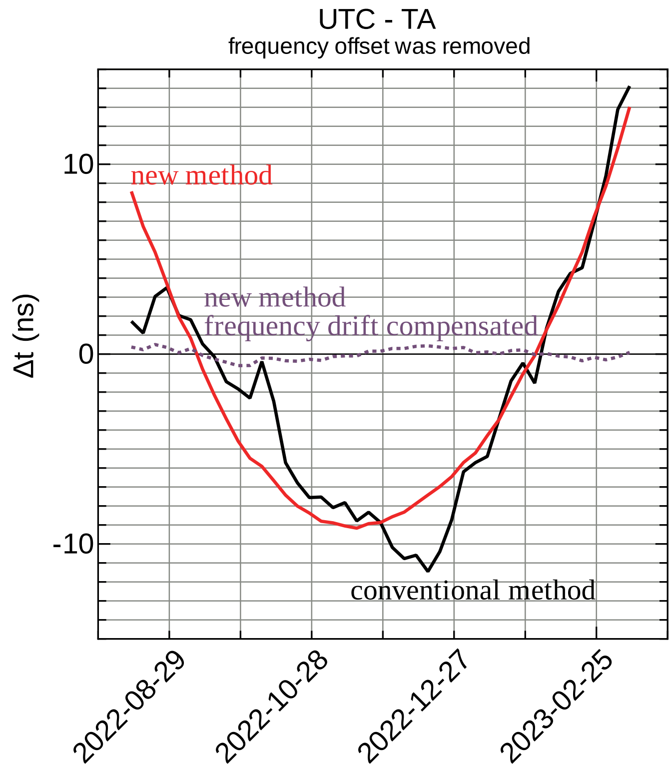

Fig. 1. The time difference between UTC and calculated TA. Black: calculated by conventional method. Red: calculated by new method. Dotted line: residual after the compensation of the frequency drift in the red curve.

sufficiently small. On the other hand, the hydrogen maser has a relatively large frequency drift compared to the cesium atomic clock, which cannot be taken into account in the current algorithm. Hydrogen masers are already used in several timescale algorithms. For example, the weighting algorithm of UTC was updated in 2014 to take in to account the frequency prediction model of the atomic clocks that allows the Hydrogen masers to play a more important role in the timescale [4-6]. In the algorithm, a quadratic term was introduced in a prediction to describe the frequency drift [4] and the weights are obtained by differencing the frequency with the predicted values of each clock [5]. We have adopted a similar approach to these methods.

To improve our conventional algorithm, the following two modifications were made in the first step. First, the phase change was predicted up to the second-order phase change. In addition, the Hadamard deviation, which is not affected by the

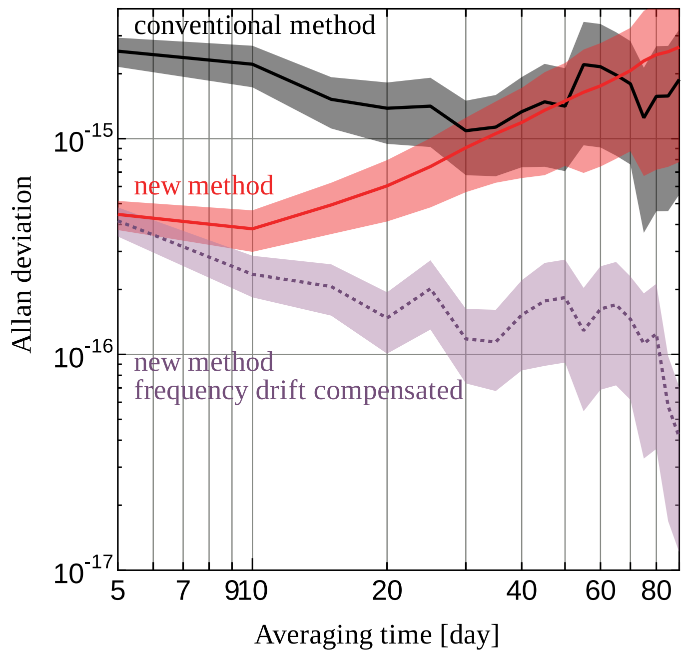

Fig. 2. The Allan deviation referred to UTC for calculated TA. Black: calculated by conventional method. Red: calculated by new method. Dotted line: calculated by new method (frequency drift compensated).

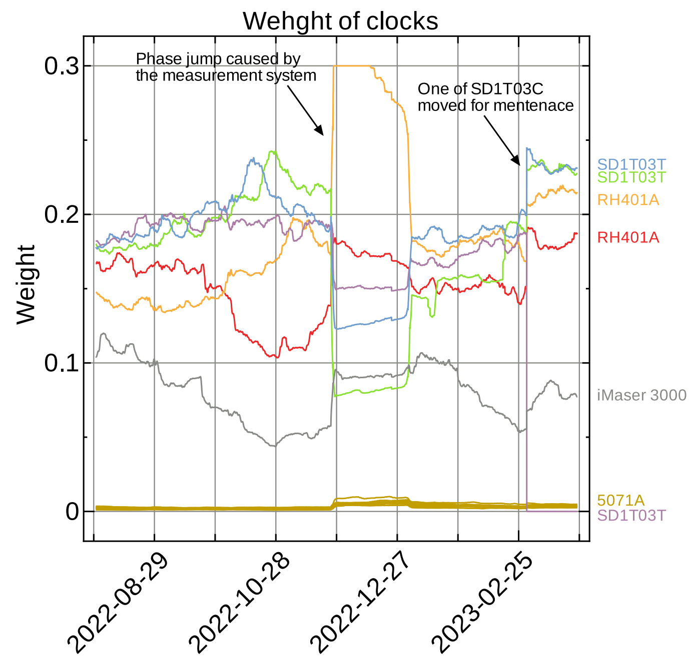

Fig. 3. The contribution of each clock to the TA calculation. RH401A and SD1T03T: Hydrogen maser (Anritsu). iMaser 3000: Hydrogen maser (T4Science). 5071A: Cesium atomic clock (Microchip).

primary frequency drift [3], is used to evaluate the stability of each clock in contrast to the UTC algorithm. These improvements allow the hydrogen maser to be incorporated into the ensemble atomic timescale in a manner that takes full advantage of currently established and proven algorithms.

The conditions for the ensemble atomic time calculation are as follows. We use seventeen cesium atomic clocks (Microchip 5071A high performance) and six hydrogen masers (two Anritsu RH401A, three Anritsu SD1T03C and one T4Science iMaser 3000) for the calculation of the ensemble timescale. For the calculation of the Hadamard deviation to determine the weight of clocks, values with an averaging time of 2 days were used. These average times were used because individual maser characteristics start to appear after two days. Then, the weight for each clock is determined to be proportional to the inverse of the Hadamard deviation. The upper limit for the clock weights is 0.3. This limit of the current algorithm was used.

III. Experimental Results

Fig. 1 shows the time difference between UTC and calculated TA. In the figure, the result of the new method shows a quadratic time variation due to frequency drift. This may be due to the presence of frequency drift in the initial data for the calculation. This frequency drift was estimated to be 4.1×10^{-17} per day. When this frequency drift at the initial data is compensated in advance, the time difference between TA and UTC can be suppressed to within 1 ns as shown dotted line in the Fig. 1 This result suggests that the stability of the TA can be significantly improved by using appropriate initial values.

Fig. 2 shows the Allan deviation referred to UTC for the ensemble atomic timescale calculated with the conventional and improved methods. It can be seen that the stability of the ensemble atomic timescale with the new method is several times better than that with the conventional method in the range of 5 to 30 days. The long-term instability of the new method is the result of the frequency drift as mentioned above. When the frequency drift is corrected, the frequency stability of the new method exceeds that of the conventional method for all averaging times.

Fig. 3 shows the contribution of each clock to the TA calculation. The overall contribution of the cesium atomic clocks was around 10%. For the hydrogen maser, the order of contribution was Anritsu SD1T03T, Anritsu RH401A and T4Science iMaser 3000. The contribution varied largely due to phase jumps caused by the measurement equipment and the removal of a maser for maintenance, but these events did not have a serious impact on the results of the atomic TA calculations.

IV. Conclusions

We have developed a new ensemble atomic timescale calculation algorithm using hydrogen maser. Only the inputs to the main part of the algorithm such as pre-processing of time difference data and stability calculations have been changed. The new calculation method significantly improves the frequency stability of the atomic timescale.

Based on our new algorithm, we started generating real signals in March 2023. The atomic time calculation results corrected for frequency drift are used as initial values. We have also modified the system so that a reference atomic time scale for UTC(NICT) can be selected from several calculation results. We will start generating UTC(NICT) based on the new algorithm soon.

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