# 2-2 Summary and Improvement of Japan Standard Time Generation System

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Japan Standard Time (JST) is generated by JST generation system in NICT. The JST system has been properly renewed using new technologies. The present system, which is the 5th generation, has regularly operated since February 2006 and we have stably kept and provided JST without any large troubles. Since staring regular operation, we have modified the system, when necessary, in order to progress the reliability of the system and the precision of JST.

***Keywords***
Japan Standard Time, Standard frequency, UTC, Time scale algorithm

## 1 Introduction

JST (Japan Standard Time) is defined as UTC (Coordinated Universal Time) + 9 hours. UTC has long-term stability but it is a paper clock which does not actually exist. Each standards organization in the world provides actual time by generating an independent time system (referred to as UTC(k); the k is replaced with the relevant organization name) synchronized with UTC. NICT generates UTC(NICT) using cesium atomic clocks and hydrogen masers and creates JST by adding nine hours to UTC(NICT). The JST is supplied in various ways such as JJY, NTP, TEL-JJY and frequency calibration. UTC(NICT) and the JST require both high accuracy and high reliability as a standard time and a standard frequency. UTC(NICT) and JST are generated by the Japan Standard Time Generation System (hereinafter “JST system”), which has been improved as technology progresses.

In this paper, we will first provide an outline of the 5th JST system that was renewed in February 2006 and introduce different points from 4th JST system. Then we will discuss the revision of the time scale algorithm and the optimization of the frequency adjustment parameters that were performed after the introduction of the 5th system and finally we will introduce the remaining issues regarding the improvement of accuracy.

## 2 The 5th Japan Standard Time generation system

Here we will explain the current 5th JST system and the differences from the preceding 4th system.

### 2.1 Japan Standard Time outline

The JST system generates UTC(NICT) synchronized with UTC. The system requires both a high reliability and a high accuracy. Consequently, the system has been periodically renewed in line with the adapted technology of the times. The current system is the 5th JST system (new system)[1]. The new system has been in regular operation since February 2006. A configuration of the new system is almost the same as one of the 4th JST System (former system). In the new and the former systems, an ensemble atomic time is decided from cesium atomic clocks and the output of a source clock is synthesized with the ensemble atomic time using frequency adjuster. The basic structure of the JST system is shown in Fig. 1.

In the new system, the sources of JST are hydrogen masers and eighteen cesium atomic clocks. 5 MHz and 1 pps signals are sent from these atomic clocks to the measurement system where the time differences between the clocks are measured. Using these data, the ensemble Atomic Time (hereinafter “TA”) is calculated by the weighted average of all cesium atomic clocks based on time scale algorithms[2]. TA is a reference time system of UTC(NICT) and a paper clock with high frequency stability in the long-term. An output signal of the hydrogen maser as the source clock is automatically and regularly adjusted to synchronized with TA by a frequency adjuster (in the JST System, the Auxiliary Output Generator manufactured by Symmetricom is used; hereinafter, “AOG”). In this process, the AOG generate 1 pps (pulse per second) and 5 MHz signals. The 5 MHz signal is used as the frequency standard, and the time of UTC(NICT) is determined by counting up the 1 pps signal. The time system generated by the AOG is UTC(NICT) and JST is created adding nine hours to the time system.

UTC(NICT) is used to perform international time transfers to other standard organizations by two-way satellite time and frequency transfers method via communications satellites[3] and common-view method using GPS[4], and the results of these time transfer are reported to the Bureau International des Poids et Mesures (BIPM). BIPM reports the time differences between UTC and UTC(k) by Circular-T every month. Since UTC(NICT) is a time system aimed to synchronize with UTC, apart from the automatic frequency adjustments, the frequency of UTC(NICT) for synchronizing with UTC is manually adjusted occasionally one time per month based on the results of Circular T.

A source clock, measurement system and the AOG are the core components of the JST system. In the new system, there are three core components for redundancy, and three time signals are generated from each component, independently. A selected time signal from three signals is used as UTC(NICT) and the remaining two signals are used as reserves. Although the former system consisted of two core components, the new system not only added another reserve core component, but also enabled an irregular component to be easily specified by examining the comparison with the three time signals, which realized vast improvement of reliability.

### 2.2 Standards and measuring system

In the former system, two cesium atomic

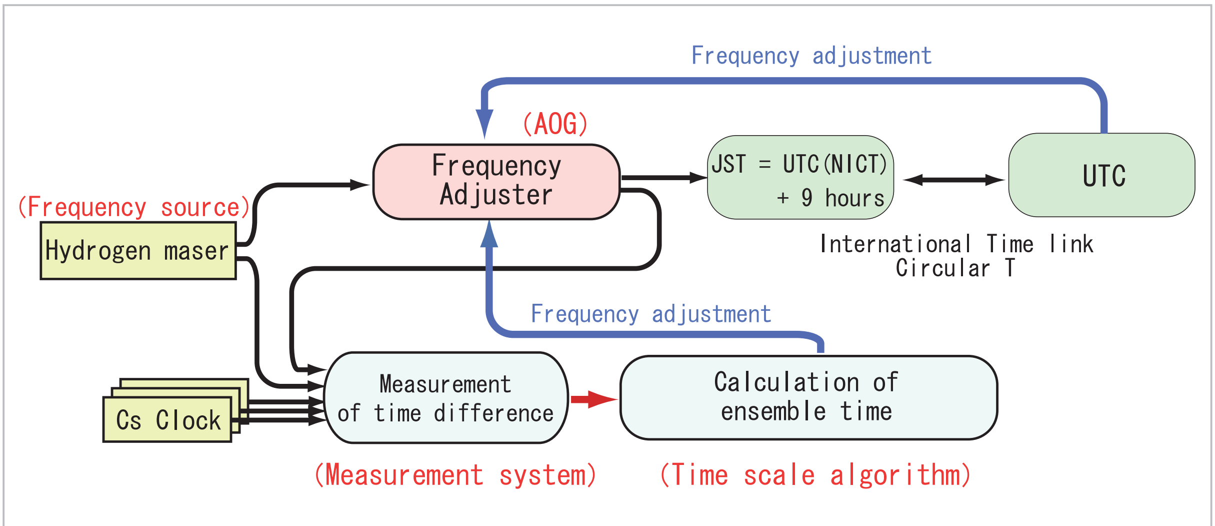


**Fig.1** *Basic configuration of the JST system*

clocks which have good frequency stability in the short-term are selected from all of the cesium atomic clocks, and are used as each source clock. In the new system, we adopted four hydrogen masers which have better frequency stability in the short-term than one of cesium atomic clocks. Three hydrogen masers are used as each source clock, and another one is a reserve. As stated above, since the JST system makes a time system by adjusting the frequency of the output of the source clock, a frequency stability of UTC(NICT) in the short-term largely depends on one of the source clocks. So the frequency stability of UTC(NICT) is improved by using hydrogen masers as the source clocks.

Atomic clocks (the eighteen cesium atomic clocks and the four hydrogen masers) are located in four Clock Rooms where the electric and magnetic fields are shielded and the temperature and humidity are closely controlled.

In addition to the Universal Time Interval Counter (hereinafter, “TIC”) system as measurement system, a multi-channel DMTD system was newly developed and adopted in order to measure hydrogen masers for the new system[5]. In the former measurement system (TIC system), two 1 pps signals are selected from each atomic clock with a VHF switch and measured the time differences of each clock using the TIC only one time per hour, sequentially. In the multi-channel DMTD system, time differences between a reference clock and twenty four DUT (Device Under Test) clocks are measured using 5 MHz signals with high precision every second, simultaneously. Consequently, by calculating the difference of the measurement results for the twenty four clocks, the time differences between all atomic clocks can be acquired every second with high precision.

Figure 2 shows the frequency stability of a hydrogen maser, a cesium atomic clock and system noise of the DMTD system and counter system. When the frequency of the hydrogen maser is measured using the TIC, an averaging time of several hours is required. However, it is confirmed that using the DMTD system, measurements of hydrogen masers can be performed in a short-term. Not only can hydrogen masers be used from a short-term averaging time as a result of adopting the DMTD system, but anomalies of hydrogen masers can be quickly detected by monitor of the measurement results of each second, and so both the precision and the reliability of JST are improved by the adoption of the DMTD system.

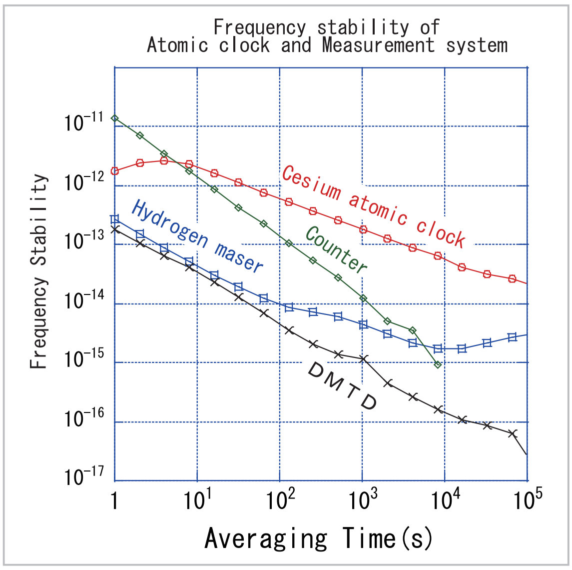


**Fig.2** *Frequency stabilities of source clocks and measurement systems*

Although the DMTD system enables us to measure the time difference with high precision, it is difficult to measure the absolute value of time differences since a 5 MHz phase difference is measured. Conversely, TIC systems do not perform highly accurate measurement, but absolute values can be measured since measurements are carried out by using 1 pps. So, in the new JST system, we have adopted one TIC system together with three DMTD systems as the measurement system. In the processing of measurement data, an absolute time difference data is decided with high precision by the integration of measurement data by DMTD system with the absolute initial value measured by TIC system.

### 2.3 Monitoring system and power system

The JST System requires constant operation which must never be suspended. It is also important to quickly detect and respond to some anomalies in devices, etc., in order to keep generating the stable JST. For these reasons, the JST system monitors and controls each device and equipment by a monitoring system. With this monitoring system, following functions are more important.

- Monitoring the status of atomic clocks
- Monitoring the status of AOG
- Monitoring the temperature and humidity in clock rooms
- Monitoring the time difference between three AOG output signals

The monitoring system periodically monitors the status of all equipment. When each status exceeds the threshold, it will be determined as an anomaly. Monitoring periods are established in accordance with the level of importance of the subject equipment. Since the monitoring of the AOG output signals and hydrogen masers as the source clock is most important, the conditions of them are acquired and monitored every second. Furthermore, as an anomaly of the AOG also has a high impact, this is monitored every ten minutes and the status of other matters is monitored every hour. If some important anomalies occur, an emergency email is automatically transmitted and a notification is sent to the mobile phone of the staff members, and they take actions such as emergency responses. The JST system is maintained by the various monitoring of other equipment, too. An anomaly can be quickly detected by notifications sent by email and inspections of the various statuses on the internet (a screen shooting of the monitoring and control system in operation on the internet is shown in Fig. 3).

In regard to the power source, the building where the new JST system is located has a large UPS system and a power generator with a motor as a backup power supply in case of power outages. Furthermore, DC battery of long-term power supply for atomic clocks and AOG and general UPS systems for other equipment are prepared against power outages.

## 3 The improvement of Time scale algorithms

TA is calculated and decided using the time difference data collected from numerous atomic clocks by a Time scale algorithm (hereinafter, “algorithm”). Here, we will introduce the improvements of the algorithm adopted in 2008 in order to improve the long-term stability of UTC(NICT) after the introduction of the 5$^{th}$ JST system.

### 3.1 Time scale algorithm of Japan Standard Time system and improvements

JST is decided by the ensemble atomic time

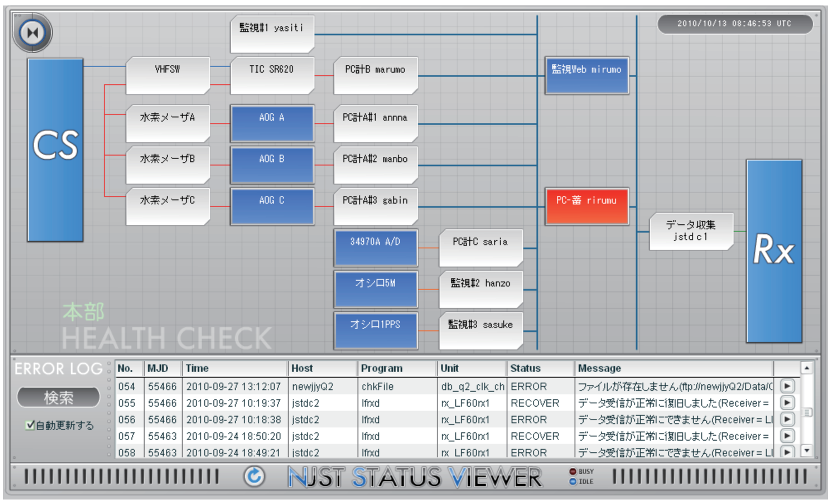


**Fig.3** Monitoring and control system with WEB

(TA) which is calculated by the weighted average from eighteen cesium atomic clocks[2]. In the JST system, this weight consists of values corresponding to the frequency stability of each clock[6] and the maximum value is limited lest a small number of clocks should be disproportionately weighted. By using this method, the influence on TA from a clock with worse frequency stability is decreased. However, if the frequency of a stable clock which has large weight dramatically changes due to some breakdown, the frequency stability of the clock directly connected to weight will not suddenly decrease and after a while it will maintain its large weight. As a result, frequencies of the TA and UTC(NICT) will be changed along with the frequency of the clock. Thus, a new algorithm to remove these types of irregular clocks has been tested using simulations and developed for the actual system.

### 3.2 Example of dramatic frequency changes

Figure 4 shows an example of the impact on TA by sudden frequency changes in a cesium atomic clock. This shows the time differences between UTC, TA and CS#36 (CS is an abbreviation of cesium clock and #36 is a number used to differentiate each clock) were calculated using Circular T from June 14, 2006 (53900 (MJD)) until April 10, 2007 (54200 (MJD). Although the frequency of UTC(NICT) was sometimes adjusted in order to synchronize with UTC, a dramatic change of the time difference between UTC(NICT) and UTC was occurred in 54084 (MJD). An investigation of the cause found that the previously extremely stable frequency of CS#36 experienced a rapid change, which greatly caused a major change in the frequency of TA. Since CS#36 had high frequency stability until this change in frequency, the weight of CS#36 for the TA was also high. So, this change had quite an impact on TA following the change in frequency, which led to the dramatic change in UTC(NICT).

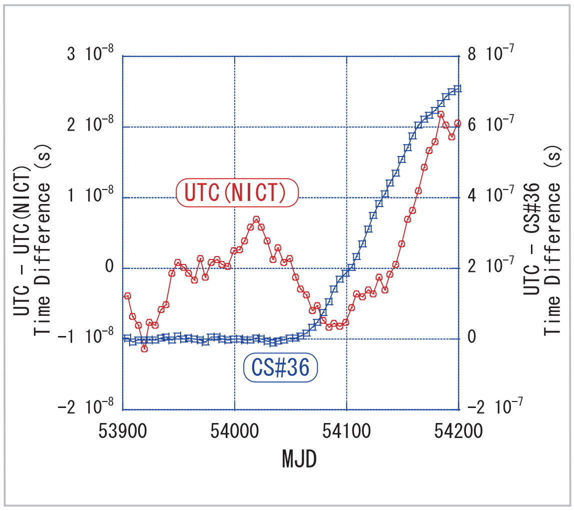


**Fig.4** *Time differences between UTC, UTC (NICT) (left vertical axis) and CS#36 (right vertical axis) evaluated from Circular T*

CS#36 data were primarily approximated with gradients removed prior to anomalous occurrence.

### 3.3 The improvements and adaptability results for Time scale algorithms

In order to resolve these problems, a new algorithm that is not impacted by rapid frequency changes from irregular clocks toward TA was examined. In the new algorithm, clocks that have rapid frequency changes are determined as irregular clocks and weights of these clocks become 0. A developed method is that the last and past frequency deviations of a cesium atomic clock using TA are calculated and compared, and if the difference exceeds the established threshold, the weight of the clock becomes 0. It is important for the algorithm to determine data how much tracing back to the past to compare and how to establish thresholds; Please refer to the reference [7] for further details.

The results of simulations performed to verify the improvements by the new algorithm are shown below. The results of comparing the former algorithms with the new algorithms are shown in Fig. 5 for the same period as Fig. 4. This figure shows the time differences between UTC and TA generated using the former and new algorithms with the weight of CS#36 in the new algorithms. In the new algorithm, the weight of CS#36 becomes 0 prior to the 54084 (MJD) where irregularities were confirmed on

CS#36. The TA calculated by former algorithm led to the rapid decrease, but the TA by the new algorithm became more smooth and stable. The frequency stability of TA calculated by the former and new algorithms is shown in Fig. 6. We confirm that the frequency stability in the long-term is improved by the new algorithms.

The new algorithm has been applied to the operation of the actual system since January 27, 2009. As a result, improvements in long-term stability and accuracy of synchronizing UTC(NICT) with UTC were achieved.

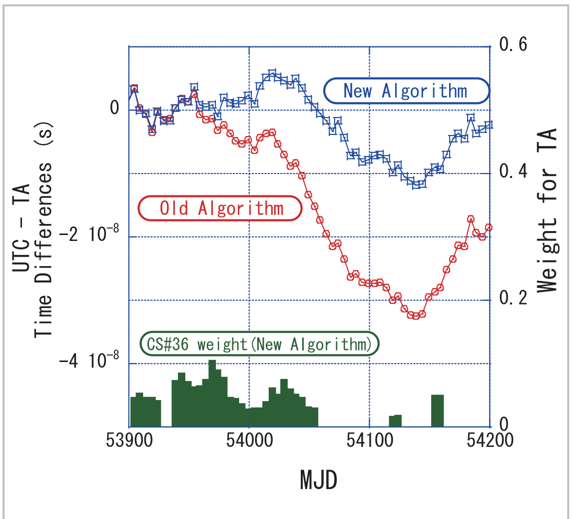


**Fig.5** *The weight of CS#36 for new algorithm, and the time differences between UTC and TA produced by the former and new algorithms*

For each time difference datum, drifts due to the primary fitting were evaluated for the 53904~53949 (MJD) period and removed.

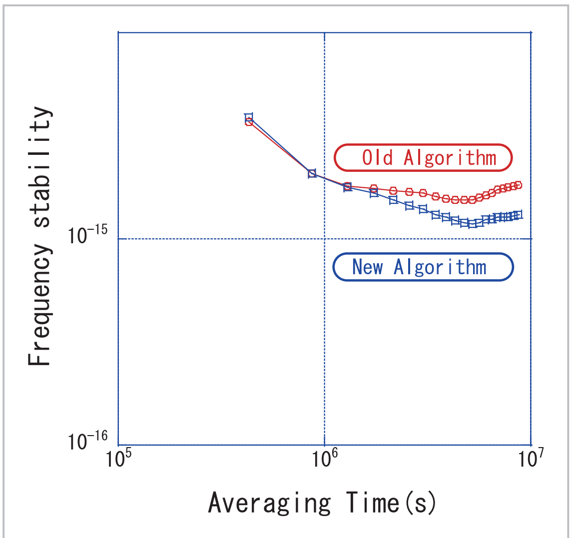


**Fig.6** *Frequency stability of UTC-TA before and after improving algorithms*

## 4 Optimizations of frequency adjustment parameter

Here, we will introduce the optimizations of the frequency adjustment parameters implemented in 2010 for the purpose of improving the frequency stability of UTC(NICT) in the medium-term.

### 4.1 Frequency adjustment and optimization for the Japan Standard Time system

UTC(NICT) is generated by an adjustment of frequency of the hydrogen maser as a source clock using AOG, and the purpose of the adjustment is to synchronize with the TA which has long-term stability. As a result, UTC(NICT) has good frequency stability the same as the hydrogen maser in the short and medium-term, and the same as TA in the long-term. The frequency stability of the hydrogen maser as the source clock, TA and UTC(NICT) from 2007 until 2009 is shown in Fig. 7. This shows that the frequency stability of UCT(NICT) is closely connected with the hydrogen maser for the short-term and the TA for the long-term. The small degradation in frequency stability is caused by system noise of AOG and frequency adjustments. However, it is apparent that the frequency stability of UTC(NICT) in the medium-term (approximately several hours – 10 days) is much worse than that of hydrogen masers. This is considered to be caused by the inappropriate frequency adjustment parameters in AOG and it seems that the frequency stability of hydrogen masers cannot be fully utilized. Consequently, we have reviewed and optimized each frequency parameter for the purpose of improving the frequency stability of UTC(NICT) in the medium-term.

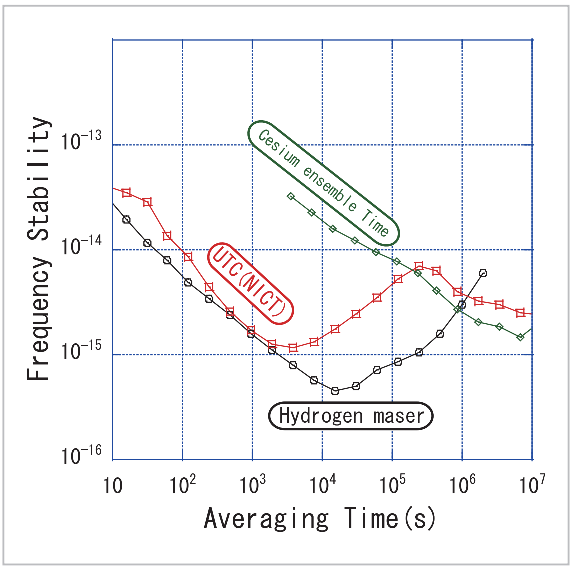


**Fig.7** *Frequency stabilities of the source clock hydrogen maser, TA and UTC(NICT) for 2007/2/1~2010/7/27 (long-term) and 2009/2/1~2009/7/27 (~midterm)*

## 4.2 Frequency adjustment parameters and adjustment simulations

The purpose of the frequency adjustment is to create a time system synchronized with TA by a frequency adjuster for the signal of the source clock and the output is a signal of UTC(NICT). On this occasion, there are three parameters for frequency adjustment using AOG.

(a) The data usage period when the frequency deviation between the TA and the hydrogen maser as the source clock is calculated using the least-square method (fitting period)

(b) The period required to return the time difference between AOG output and TA to 0 (adjustment gain)

(c) The period of implementing frequency adjustments (adjustment period)

These parameter values were optimized under the following conditions in order to improve the frequency stability of UTC(NICT).

- Maintaining the reliability of the existing system and improving frequency stability of UTC(NICT)
- Ensuring there are no large deviations from TA and no large fluctuations of UTC(NICT) for the purpose of the original frequency adjustments
- Parameters do not rely on the characteristics of individual hydrogen masers

The last condition is required from the fact that the parameters cannot be established for each of the three core components and the characteristics of the hydrogen masers may be changed.

In view of these conditions, since it is hazardous to perform direct parameter optimization experiments with the system in operation, simulations of frequency adjustment were performed using a calculator, the trends of three parameters were examined and the optimal parameter values for the JST system was determined. In this examination, using actual data of TA and the hydrogen maser as the source clock the frequency adjuster as AOG is simulated and we verified the effects while comparing the output signal with actual UTC(NICT) for time differences and frequency stability. The results of parameter trends confirmed by the simulations are shown below.

- The longer the fitting period and the adjustment gain are, the better the frequency stability becomes. However, if it is too long, the frequency stability in the long-term degrades depending on the hydrogen maser. In addition, if these parameters are too long, the receptivity for irregularities increases and a term of the impact, when system irregularities occur, becomes longer.
- In the current system, the frequency of the source clock is estimated by linear approximation, but output of hydrogen masers have secondary drift. As a result, offset errors between TA and the output of AOG occur. The size of error is almost approximate to the adjustment gain and the fitting period, and so the longer these parameters are, the larger the offset errors become.
- Although shorter adjustment period increases frequency stability, the effect of improvement becomes smaller if the adjustment strength is sufficiently short.

In consideration of the characteristics of the JST system and hydrogen masers as the source clock, the frequency adjustment parameters

**Table 1** *Each parameter before and after optimization with frequency adjustment parameters*

| | Fitting period | Adjustment Gain | Adjustment period |
|---|---|---|---|
| Old parameters | 120 hours | 48 hours | 24 hours |
| New parameters | 240 hours | 240 hours | 8 hours |

were decided to be changed as mentioned on Table 1 using the parameter trend results acquired from the above simulations.

### 4.3 Results of adapting parameter optimization to the actual system

The modified parameters were implemented on May 11, 2010 based on the results of the simulations. Figure 8 shows the adjusted frequency values for ten days before and after the implementation of the optimized parameters. By lengthening the fitting period and the adjustment gain, it is apparent that the modified adjustment value is smaller and smoother. Next, Fig. 9 shows the frequency stability of UTC(NICT) before and after optimizing parameters, TA and the hydrogen maser as the source clock. By optimizing the parameters, the improvement of frequency stability of the UTC(NICT) can be verified within the averaging time from 1000 seconds to several days. Comparisons of the frequency stabilities of UTC(NICT) after optimization with the hydrogen maser show that UTC(NICT) is still not as good as the hydrogen maser. This is attributable to one of the aims of this optimization, namely "parameters that do not rely on individual source clock characteristics". It could be said that it is the margin for using other hydrogen masers as source clocks. It seems that the next target of parameter optimizations is fully to utilize the characteristics of hydrogen masers.

## 5 UTC(NICT) in the future

We have discussed the progress of the JST system by the introduction of the 5th JST sys-

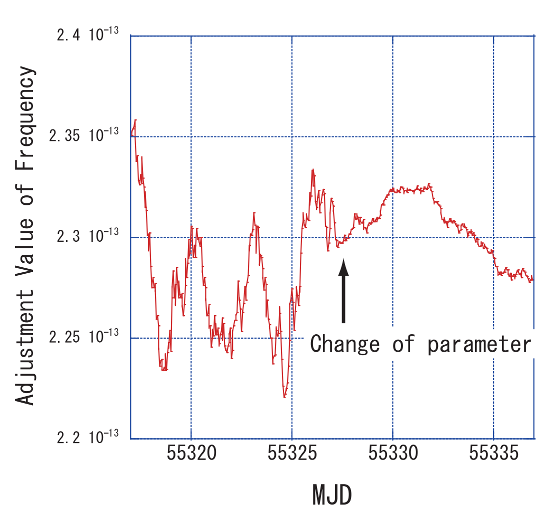


**Fig.8** *Time-series data of adjusted frequency values for the actual system before and after parameter optimization*

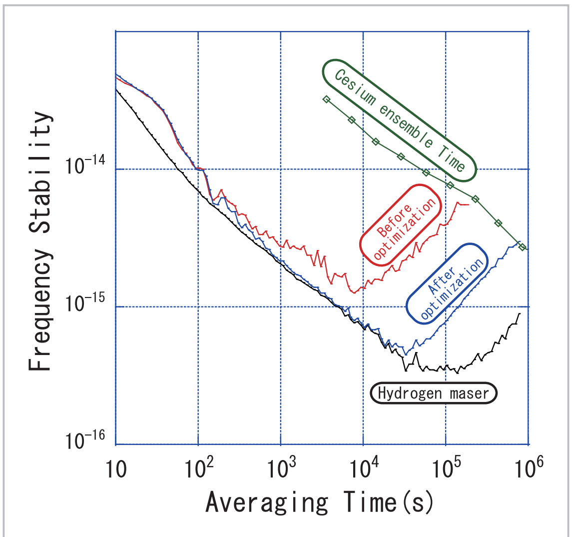


**Fig.9** *Frequency stabilities of the source clock Hydrogen Maser, TA and UTC(NICT) before and after parameter optimization*

tem, subsequent improvements to algorithms and the optimization of frequency adjustment parameters. Now, we will introduce the current research and development being conducted in order to further improve the JST.

(1) Ensemble atomic time using hydrogen masers

Four hydrogen masers were newly adopted when the new JST system was introduced. However, the hydrogen masers were only used as source clocks for the purpose of improving the frequency stability of UTC(NICT) in the short-term and the information on time differences between each of the hydrogen masers is not utilized. Consequently, the generation of an ensemble atomic time using several hydrogen masers is considered. A frequency stability of the hydrogen maser ensemble time is expected to improve by the weighted average of the hydrogen masers, since a characteristic of the hydrogen masers in the averaging time of several hours is frequency white-noise. Currently the hydrogen maser ensemble time using actual measurement data is being created. Figure 10 shows the frequency stabilities of the hydrogen maser ensemble time simulated within a calculator and three hydrogen masers used for this ensemble time. The hydrogen maser ensemble time was made from three hydrogen masers by weighted average which corresponds to the frequency stability of each hydrogen maser. By comparing the ensemble time with the three source hydrogen masers, the frequency stability of the ensemble time improved at an averaging time of shorter than $10^5$ seconds. Currently, we aim to realize this ensemble time as an actual time system utilizing a frequency adjuster. If it is capable of being adapted to UTC(NICT), further short-term stability improvements can be expected.

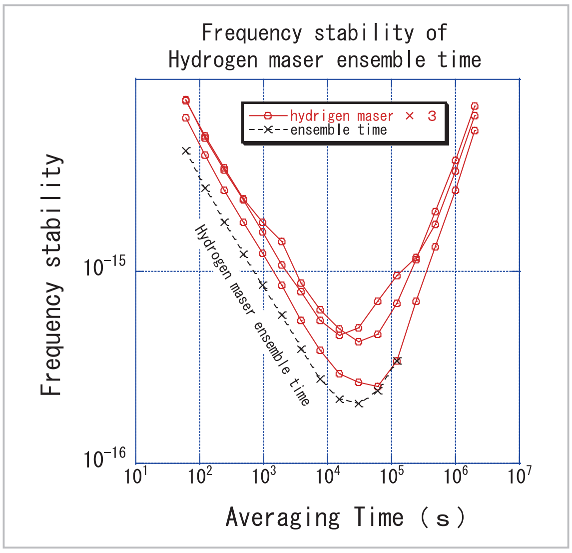


**Fig.10** *Frequency stabilities of the ensemble atomic time using three hydrogen masers and each of three hydrogen masers*

(2) Utilizing hydrogen masers for long-term stability

In the current JST system, hydrogen masers are only used as the source clocks and although the long-term frequency stability of UTC(NICT) reflects the TA using cesium atomic clocks, this is not good as the long-term frequency stability of hydrogen masers. If the long-term stability of hydrogen masers is sufficient, frequency information of hydrogen maser can be added to the TA and the long-term stability of TA and UTC(NICT) can be expected. The long-term stability of hydrogen masers is mainly influenced by the linear drift of frequency, in other words, the secondary drift of phase. If these secondary drifts can be estimated and removed, hydrogen masers may be capable of being adapted to various time systems. Although the adaptation of hydrogen masers for the improvement of UTC(NICT) stability by secondary drift estimates has been examined, the secondary drift estimates make the errors larger by the square of time, and factors such as temporal changes of the characteristics and differences in each hydrogen maser have not realized the adaptation to an actual time system. Therefore, solving these difficulties is the future issue to achieve a higher development of the time system.

(3) Links with primary frequency standards

NICT is one of the few standards institutions in the world that operate the primary frequency standard. This enables the length of one second to be realized based on its definition.

Currently, the atomic fountain primary frequency standard NICT-CsF1[8] provides the misaligned amount for the definition of a UTC second to BIPM with UTC(NICT) acting as an agent and generates the UTC time system. The results are posted in the Circular T issued by BIPM. However, although the NICT-CsF1 value is currently mediated by UTC(NICT), it is not directly used to adjust the frequency of UTC(NICT). If information about the primary frequency standard can be directly used for UTC(NICT), the frequency of UTC(NICT) can be calibrated and long-term stability can be expected to improve. However, the problem is that the UTC is not aligned with the defined value of a second utilizing a primary frequency standard reported around the world and if the results of primary frequency standards are directly reflected to UTC(NICT), the UTC value will not be aligned. It is considered that some effort is required to create UTC(NICT) that is synchronized with UTC and directly reflects the values of primary frequency standards. In order directly to utilize the primary frequency standards, it is essential to increase the frequency that NICT-CsF1 is operated, and at the same time, how to calibrate frequency when NICT-CsF1 is not in operation remains an issue that needs to be address in the future.

## 6 Conclusion

In this paper, we have provided an outline of the current JST system and discussed the improved time scale algorithm, the optimization of frequency adjustment parameters and future issues for improving the standard time system. Since JST requires both a high level of reliability and accuracy, the JST system that creates this time also requires a high level of reliability and accuracy. Since the transition to the new system, a highly accurate time system has been generated and supplied without any major incidents through the tireless efforts of numerous people and more efforts will be made to maintain this reliability and accuracy and a steady supply in the future. In addition, development and technology will be further progressed and the system will be renewed in order to provide higher accuracy and reliability.

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