# 5-2 Generating and Measurement System for Japan Standard Time

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This article introduces the current and future systems for the standard time generating and measurement system at the CRL. The features of these current working systems compared with the former ones are dual redundancy in the main part. It is effective to improve reliable and rapid reaction to emergency situations. We are going to move the system to a new building next year and renew the current system on this opportunity. The new system will have many improvements such as an introduction of a hydrogen maser or multi-channel DMTD system, which enables it to realize a higher performance.

***Keywords***
**UTC (Coordinated Universal Time), JST (Japan Standard Time), Measurement system, Hydrogen maser, DMTD (Dual Mixer Time Difference System)**

## 1 Introduction

Japan Standard Time (JST) is defined as Coordinated Universal Time (UTC) + 9 hours. The BIPM (Bureau International des Poids et Mesures) determines UTC from an ensemble of atomic clocks throughout the world, but UTC is not delivered to each country in real time. Generally, the standard time of a country is prepared based on UTC(k), generated by the standardizing organization of the respective country [the "k" in UTC(k) represents the relevant standardizing organization]. In Japan, the CRL is the national standardizing organization in this area. The CRL generates the UTC(CRL) time scale based on UTC, using local atomic clocks and a standard time generation and measurement system. The UTC(CRL) is the basis of JST, and serves as the time signal for radio and television.

The standard time generation and measurement system features some distinctive elements. For example, the continuity of data is significant in the management of the time. It is not easy to stop the system while in operation, and time, once output, cannot be corrected. In other words, an abnormality cannot be corrected tracing it back to its occurrence. Therefore, in the construction of the system, the reliability of the system and the ease of long-term operation are as important as the system's main functions. In fact, the system may on occasion be constructed to favor reliability over quality.

The generation and measurement system of JST began in 1976 when the first system began operations; the current configuration represents the fourth generation of this system. The first-generation system measured time difference between the Koganei Headquarters and the Nazaki Station using a method known as the TV synchronization signal mediation method, and controlled the system using a process control computer referred to as a mini-computer. After the system was extended to include functions such as high precision time comparison using GPS (1984), the second-generation system, which began operations in 1987, established the framework of the current system with the introduction of the real-time ensemble time method, which uses two or more atomic clocks and high performance measurement equipment controlled by GPIB. The third-generation system, which began operations in 1995, significantly saved labor with improvements such as the distributed processing and a communications facility (both features supported by the network), and greater facilitation of data processing and analysis[1].

The fourth-generation system began operations in the fall of 1999 and has been in use since. The main feature of the system is its complete dual-redundancy, resulting in increased reliability and rapid response in case of abnormality. This system is also deployed at LF standard radio wave transmission stations (referred to as "LF stations" below). Further, we are now developing the fifth-generation system, concurrently with the relocation of the system to a new building to be built at the end of 2003. Many improvements are planned, including extensive hardware replacement, involving the introduction of hydrogen masers as master standard oscillators, a multi-channel Dual Mixer Time Difference System (DMTD), and triple-redundancy in the main body of the system; in addition to software improvements such as the modification of the standard time generation and controller algorithm and the introduction of a database system.

This article describes the generation mechanism of JST in Chapter **2**, introduces the fourth-generation system in Chapter **3**, and introduces the outline of plans for the new fifth-generation system in Chapter **4**.

## 2 How is JST determined?

First, we will introduce the mechanism of JST generation. Fig.1 shows a block diagram of the standard time generation procedure at the CRL Headquarters and the LF stations.

### 2.1 Standard time generation at CRL Headquarters

JST is determined from the average time of a group of cesium atomic clocks (average time scale) at the CRL Koganei Headquarters. The average time scale is calculated based on the time difference data between the component cesium clocks. The details of the calculation method for average time scale are set forth in Article **5-1** of this special issue. Average time scale merely a calculated value, thus, if a real signal is required, the frequency of one of the clocks is adjusted to output a signal that corresponds to the average time scale. However, in consideration of the independence of the atomic clocks, it is not desirable to adjust the atomic clock itself artificially. Thus, a frequency adjuster referred to as an Auxiliary Output Generator (AOG) is introduced, with the atomic clock as its master oscillator, and the AOG is adjusted to generate real signals for average time scale. The real signals generated consist of 5 MHz or 10 MHz signals, the reference values for the frequency standard, and a 1 pps signal, which is the standard for the second.

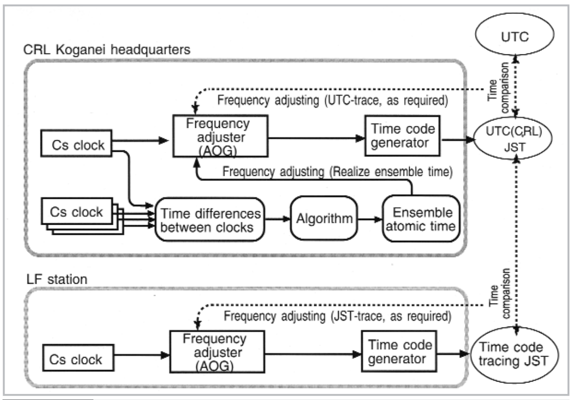

**Fig.1** Generating process of standard time at the CRL and the LF station

The time denoted by this real signal is known as UTC(CRL), referring to the time generated by the CRL based on UTC. JST is 9 hours shifted from UTC(CRL). The time difference between UTC(CRL) and UTC is presented in the Circular-T report published monthly by the BIPM, and we adjust UTC(CRL) whenever necessary with reference to this value.

### 2.2 Standard time generation at LF stations

UTC(CRL) and JST are generated at the CRL Koganei Headquarters, but the reference time signal of the standard frequency broadcast is generated at two LF stations. The details of the LF stations are described in Article **5-3** of this special issue. Here, we will outline the relationship between the time scales generated at the CRL Headquarters and at the LF stations.

The time broadcast from the LF stations is the time generated by the cesium atomic clocks at these stations; their systems consist of cesium clocks and the AOG (the frequency adjuster), reflecting the system setup employed at the CRL Headquarters. However, average time scale calculation is not performed at the LF stations. The time generated at the LF stations is continuously monitored using the GPS common-view method and the two-way satellite time and frequency transfer method, and it is adjusted at the site whenever necessary to synchronize with UTC(CRL) and JST. The time difference between UTC(CRL) and the time generated at each LF station is maintained within 100 ns.

## 3 Current standard time generation and measurement system

Fig.2 shows the outline of the current standard time generation and measurement system at the CRL Koganei Headquarters. The system basically consists of the same components as those discussed in Section **2.1**. The following describes the function of each part.

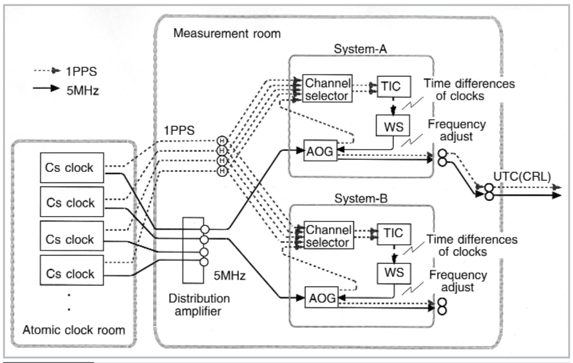


**Fig.2** *Current system for generating and measurement of JST (4th generation). TIC: Time interval counter, WS: Work station*

### 3.1 Components

The most stable clock among the 12 cesium clocks is selected and is used as the master oscillator of the AOG frequency adjuster. The output signals of the AOG are the base signals for UTC(CRL). The only signals generated by the AOG are the 1-pps signal used for the time synchronization and the 5-MHz signal used as the reference frequency. The time signal (the naming of each 1-pps pulse) is generated by secondary equipment such as the NTP server, the standard time delivery system issued via telephone line (Telephone JJY), and transmitting signal-generation equipment for the standard frequency broadcast. The frequency of the AOG is automatically adjusted once a day in accordance with average time scale, and is also adjusted whenever necessary to synchronize with UTC within 50 ns.

Average time scale is calculated from the time difference data between the cesium clocks. The 1-pps signals of the clocks are input into the multi-channel selector. The signals are sequentially switched and the time differences (phase differences) between all possible pairs of the clocks are measured using time interval counters. A workstation controls all the measurement and stores all the data for each system of measurement and calculation. Each piece of the equipment is controlled through GPIB or RS232C. The time of each system as a whole is managed by controlling the time of the workstation using the NTP.

There are two completely separate generation and measurement pathways, each of which passes through the workstations, for the distribution of the cesium clock output signals. These pathways are designated as System A and System B. The UTC(CRL) for outside users is obtained from one of these systems (whichever system is active). The other serves as the stand-by system. If any abnormality should occur at any place in the active pathway, normal UTC(CRL) can be quickly supplied by switching the outputs of System A and System B for UTC(CRL).

### 3.2 Operation

The time differences between the clocks are measured every four hours starting at 0 h UTC. Clocks that require fluctuation monitoring are included in the measurement in addition to the 12 cesium clocks; thus the number of measured pairs exceeds 200. Measurement takes approximately 12 minutes. Among these data measured, the data at 0 h UTC is used to calculate average time scale, and the AOG frequency is automatically adjusted based on this value. System A and System B each performs the measurement and the calculation in the same manner. These two systems are equivalent, although one is generally selected as the active system. If any abnormality is observed in the active system, the output for UTC(CRL) is promptly switched to the stand-by system. Here, the time outputs of these systems are adjusted so that they always synchronize within several nanoseconds, to minimize the time difference in UTC(CRL) at the moment of switching. The measurement data for both systems are backed up in each.

The cesium clocks are placed in a shielded room that also serves as a thermostatic chamber. The status of the cesium clocks, the 5-MHz phase fluctuation, the state of phase synchronization of the AOG, and other values are continuously monitored, and any abnormality is reported to the person in charge via email. The temperature and the humidity of the shielded room and the measurement room are measured every 4 hours, as environmental data. In addition to these remote monitoring functions, the person in charge inspects the site every day. The shielded room and measurement room have uninterruptible power supply systems in case of power outage, and the equipment related to the generation of standard time (the cesium atomic clocks, the AOG, and the distribution amplifier) are further backed up using DC batteries.

UTC(CRL) is regularly compared with the time scale generated by organizations abroad using the GPS common-view method and the two-way satellite time and frequency transfer method. These time comparison data and the time difference data between the clocks measured at 0 h UTC every 5 days (on dates that end with 4 or 9) are sent to the BIPM and are used for the calculation of TAI. The BIPM publishes the time difference of UTC-UTC(k) (where k designates the relevant organization) every month (in the Circular-T report). Based on this value, UTC(CRL) is adjusted such that the time difference relative to UTC is within 50 ns. This is not an automatic adjustment, but is performed manually by the person in charge as required. A problem had been noted in the large fluctuation caused by the removal of the component clocks used in computing average time scale, but now, this problem has been resolved, and the improved average time calculation program is in operation within the stand-by system. (See Article **5-1** of this special issue.)

## 4 New standard time generation and measurement system

It was decided that the standard time generation and measurement system should be transferred to a new building due to the deteriorated condition of the present building. The new building is to be completed at the end of 2003 and the system will be transferred within fiscal 2004. It has also been decided that the system itself should be renovated on the occasion of this transfer. The goals of the new system are to achieve frequency stability of approximately $2\times10^{-15}$ per 30 days, and a synchronization within 10 ns of UTC. Fig.3 shows the planned configuration of the new standard time generation and measurement system. It is basically similar to the current system, as it is also based on the configuration discussed in Section **2.1**. Below we will describe the outline of the system, focusing on the changes from the current system and the points to be noted in system construction.

(1) Hydrogen masers for the standard time master oscillator

The master oscillators at UTC(CRL) will be changed from cesium atomic clocks to hydrogen masers, with the aim of increasing

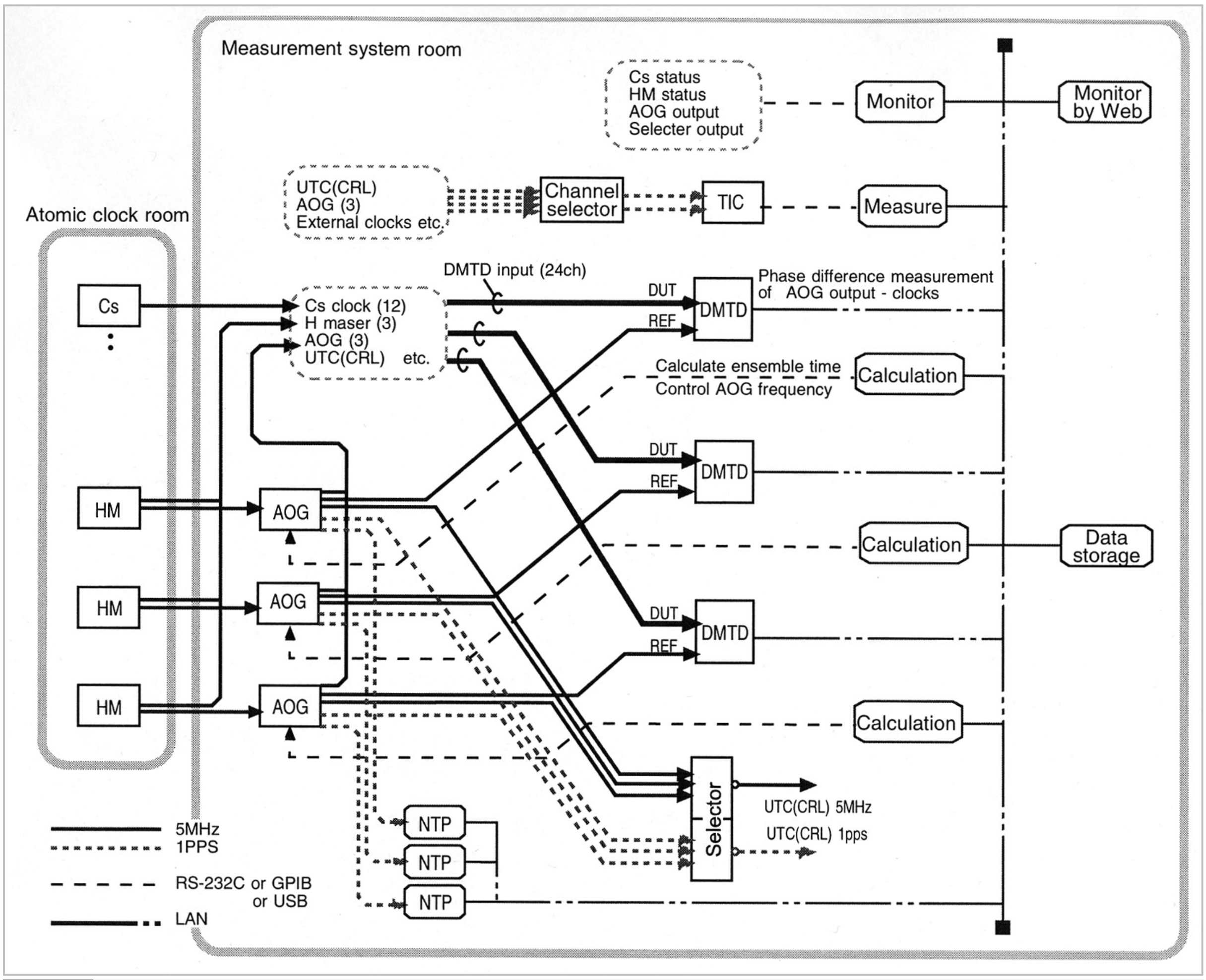


**Fig.3** New system for generating and measurement of JST (5th generation). Cs: Cesium atomic clock, HM: Hydrogen maser, TIC: Time interval counter

short-term stability. Fig.4 shows the stability of various atomic clocks[2]. For $\tau$=5 days (4×$10^5$s) or shorter, the stability of hydrogen masers is superior to that of commercial cesium atomic clocks. However, the stability of cesium clocks is higher over longer periods; thus, we will switch reference atomic clocks according to the interval $\tau$ in order to realize a more stable time scale: the hydrogen masers will be for short-term use and the cesium atomic clocks will be applied to long-term applications. Major revisions will be required in the standard time calculation and adjustment methods; development of the new algorithm is underway. The new system will consist of 12 cesium atomic clocks and 3 hydrogen masers.

(2) 5-MHz phase difference measurement using multi-channel DMTD

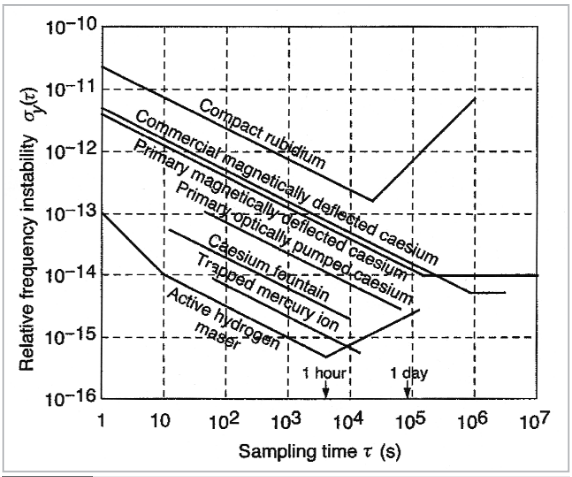


**Fig.4** The frequency stability of various atomic clocks

The method of measurement of the time differences between the clocks will be changed from 1-pps phase difference measurement to 5-MHz phase difference measurement. The increase in the measurement frequency is expected to improve measurement accuracy. The current measurement equipment—the time interval counter—will also be replaced by the DMTD method[3]-[5]. Accordingly, we have developed a multi-channel DMTD for simultaneous measurement of the time difference data between the clocks.

In the calculation of average time scale, time differences between clocks are treated based on the assumption that these time-difference values have been obtained simultaneously. However, this is not the case in practice, as parallel measurements are not possible under the current system. As a result, if the clocks drift during measurement, we are unable to determine clock performance with accuracy. (Currently, optimization in the measurement sequence reduces the time required to measure the time differences between clocks used in the calculation of average time scale to approximately 30 seconds; thus the error of a clock with a drift rate of $2\times10^{-13}$ is approximately 6 ps. However, this error increases in proportion to the time required for measurement.) Simultaneous measurement using multi-channel DMTD will eliminate this problem.

Fig.5 shows the circuit diagram of the DMTD. The reference is the 5-MHz AOG signal, and the DUT (Device Under Test) input is the 5-MHz signal of each clock. Both signals are converted to 1 kHz using the common local signal generated by a DDS (Direct Digital Synthesis) synthesizer prior to phase difference measurement. Measured data is output every second. Time difference data every several hours are sufficient for the calculation of average time scale, but measurement every second is required for the effective detection of abnormalities. It is possible to average the measured data 500 times per second; relative to the 1-pps one-shot measurement of the current system, measurement accuracy is expected to increase, so that system noise of $1\times10^{-13}$ to $2\times10^{-13}$ in $\tau=1$ s will be able to be measured.

(3) Reinforced reliability

Within the current system, one workstation performs all functions. In the new system, improved reliability will be achieved by distributing functions among multiple PCs. By switching from workstations to PCs, the

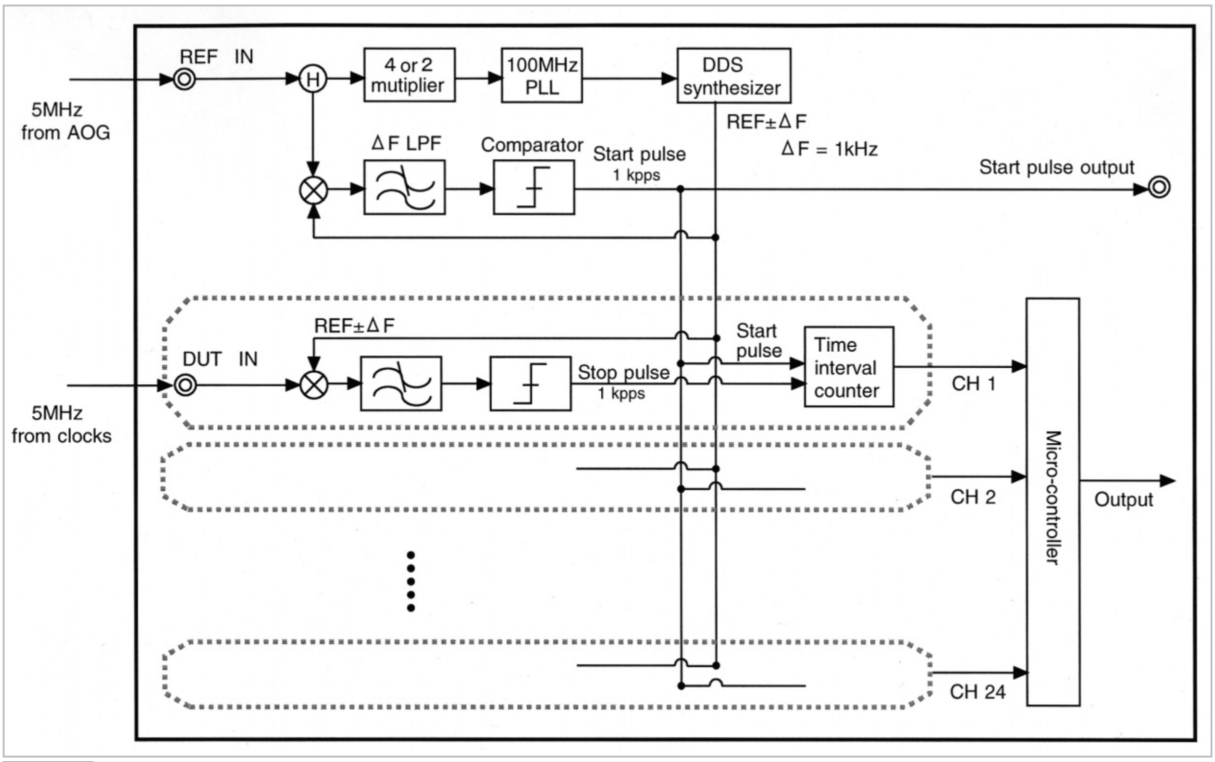


**Fig.5** *Block diagram of DMTD system*

machine-dependent operating system can also be replaced with a versatile OS (such as Windows and Linux), increasing the flexibility of future operations.

The main part of the system will be extended from the current dual-redundant system to a triple-redundant system. The most stable system can be selected from among the three, based on the majority rule. Three NTP server systems are also included to manage system time.

In addition to the previously implemented monitoring functions (temperature, humidity, cesium clock status, AOG status), the status of the DMTD input signal and that of the DMTD itself, the AOG output signal, and the quality of the selector output signal (UTC(CRL)) will also be monitored. Table 1 shows the major items to be monitored. The monitored items are displayed on the Web, and we can obtain nearly real-time information even at remote locations. Any abnormality in the system is displayed on the Web and reported to the person in charge via email.

*Table 1* List of the main monitoring items

| |
|---|
| Status of cesium atomic clocks |
| Status of hydrogen masers |
| Status of AOG |
| Room temperature and humidity |
| Status of output signals from AOG |
| Status of output signals from the Selector |
| Status of DMTD measurements |

(4) Continuity of UTC(CRL) at system switching

When multiplexing systems, care must be taken with the continuity of data at switching. In the current system, System A and System B each calculates average time scale using its own independent measurement data. In this case, even though the clocks that supply the data for calculation may be the same, the measurement equipment is different, and the measurement data and the calculation results are thus different. In other words, in the current system, the continuity of UTC(CRL) is interrupted when the UTC(CRL) output is switched from System A to System B. Under the new system, one set of data is selected from the three sets of data measured by the three systems, and all three systems use this set of data in the calculation of average time scale. Therefore, the continuity of UTC(CRL) is maintained in principle even when switching between systems.

(5) Automatic trace of UTC

In the current system, the person in charge manually adjusts the time difference between UTC and UTC(CRL). In the new system, automatic adjustment will be implemented to achieve synchronization within 10 ns of UTC (with the goal of achieving an eventual margin of 1 to 2 ns). As the UTC-UTC(CRL) time difference is reported by the BIPM only monthly, improved accuracy must be achieved by increasing the stability of UTC(CRL) and by predicting fluctuations. To this end we are conducting studies to investigate these issues in the context of the development of the new algorithm.

## 5 Summary

The generation and measurement system that supports JST, long maintained by the CRL, must satisfy various conditions: for example, it should not fail, it must be easily and quickly be restored if it should fail, it must be able to be extended and improved, and must not be so complex as to constitute a "black box" of calculation. The complete dual-redundancy established in the current fourth-generation system was a means to recover from abnormalities as comprehensively and swiftly as possible with minimum treatment. On the other hand, the computer configuration of the fifth generation system (the new system) is the result of considerations relating to future reliability and flexibility, both in terms of hardware and software.

It is also an important challenge to determine the extent to which the system should be automated. The evaluation and handling of abnormalities is difficult and we must determine how far we can trust the machines to evaluate and judge the various situations that may arise. For example, it has been determined that a person should make any final judgments under the new system as to whether output should be switched upon the occurrence of abnormal events; this is another example of a decision to prioritize reliability.

The current fourth-generation system follows the methods used in the third-generation system, with the exception of several improvements, such as the introduction of redundancy in the system. Relative to these changes, the new fifth-generation system will incorporate major modifications, such as the introduction of hydrogen masers, whose characteristics differ from those of cesium atomic clocks, measurement using the newly developed multichannel DMTD, and the construction of a database all of which features may be integrated with system redundancy. Naturally, many tests will be conducted—including testing to evaluate continuity with the current system—before the new system is put to use.

Finally, we would like to note that the quality of JST has also in a large part been maintained thanks to the continuous efforts of the many individuals involved.

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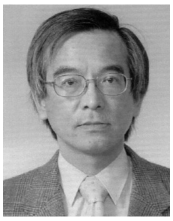


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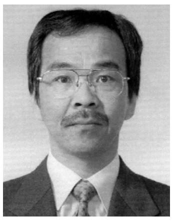


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