2-8 Generation, Comparison, and Dissemination of the National Standard on Time and Frequency in Japan

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In this paper, ordinary business concerning the operation and the dissemination of JST (Japan Standard Time) at NICT (National Institute of Information and Communications Technology) is introduced. UTC (NICT), which is essential to JST, is generated by composing more than one cesium atomic clocks. JST is compared with the national standards of the world every day and keeps its precision high, and contributes to the determination of UTC. JST generated in this manner is bulletined to every place in Japan and supports the people's living.

This paper presents the summary of each system of generation, comparison, and dissemination of JST.

Keywords

JST (Japan Standard Time), UTC (Coordinated Universal Time), Frequency standard, Standard time and frequency signal emission, Time dissemination

1 Introduction

By generating, maintaining and disseminating Japan Standard Time and standard frequency, the NICT conducts business activities closely related to the people's lives. These business activities are performed pursuant to the Act on the National Institute of Information and Communications Technology, an Independent Administrative Agency whereby Article 14, Paragraph 3 of the Act sets forth that the NICT shall “establish the values of frequency standard, disseminate standard radio waves and bulletin Japan Standard Time”. In order to generate the values of frequency standard and the Japan Standard Time, the NICT operates various types of atomic clocks and primary frequency standards, carries out research and development to operate them with high accuracy and improves them while performing regular business activities. Furthermore, the generated standard time uses a system that performs international comparisons through highly accurate comparison methods and this is then disseminated using some methods such as radio waves and cable lines to make it practical use in our everyday lives. In this paper, we will provide an explanation of each of the system elements which are focused on regular operations.

2 Method of generating the Japan Standard Time

First, we will introduce the structure of the method to generate the Japan Standard Time. At first, as shown in Fig. 1, the average atomic time is calculated from multiple atomic clocks (atomic clock ensemble) based on the measurement values of mutual clock comparison. The average atomic time which is periodically adjusted to the Coordinated Universal Time UTC (hereinafter, “UTC”) is referred to as UTC (NICT)[1] and the Japan standard Time is gen-

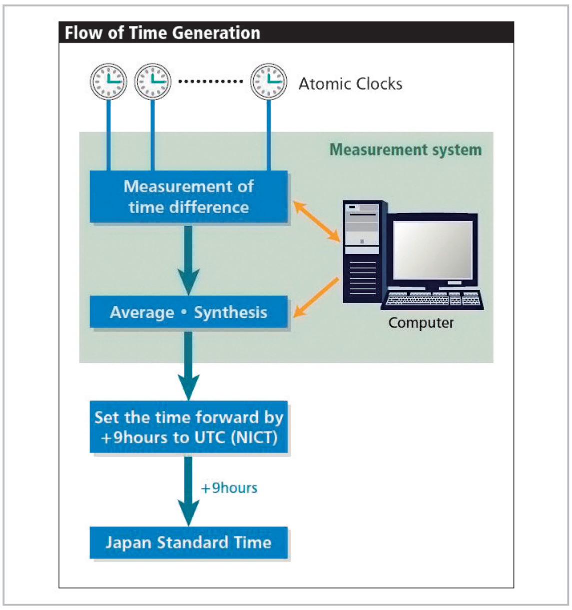


Fig.1 *Generation of the Japan Standard Time*

erated by adding 9 hours to this UTC (NICT). The atomic clocks utilized for this system comprise of approximately 18 Cesium atomic clocks (5071A made by Symmetricom) (hereinafter, “Cs atomic clock”) and 4 hydrogen maser frequency standards (RH401A and SA0D05A made by Anritsu)(hereinafter, “H maser”). The number of clocks is not definite since it is subject to be changed. Currently, only Cs atomic clocks are used to calculate the average atomic time and H masers are used as a reference to generate actual UTC (NICT) signals taking the advantage of short-term stability. The generation system for the Japan Standard Time consists of 3 sets of the same devices to maintain redundancy and 3 of the 4 H masers are used as a reference for each device respectively and remaining one as a reserve. Please refer to the reference [2] for the system details such as the algorithms used to generate the Japan Standard Time from the ensemble of the atomic clocks.

2.1 Hydrogen maser frequency standards

The H maser is a device that has better short-term stability than a Cs atomic clock. This “short-term stability” signifies a value within approximately 1 day. One of the ways to utilize this characteristic is as signal source of a Very Long Baseline Interferometer (VLBI) that measures intercontinental distance very precisely. A disadvantage of the H maser frequency standard, however, is that it is generally large and heavy, since it requires devices such as a cavity resonator and an ion pump system in order to transmit maser signals.

Table 1 *Specifications for hydrogen maser frequency standards*

Type	RH401A	SA0D05A
Output Signal	5 MHz 10 MHz 100 MHz 1.4 GHz 1 PPS	5 MHz 10 MHz 100 MHz 1.4 GHz 1 PPS
Frequency Stability	<2E-15 (1000s)	<3E-15 (3600s)
Size(mm)	1610×600×675	1265×512×512
Weight	450 kg	120 kg

The specifications of the H masers used in the Japan Standard Time generation system are shown in Table 1. There are two types of H masers: one is the RH401A shown on the right side of Fig. 2, and the other is the SA0D05A shown in Fig. 3. Each type is connected to a computer for control and monitoring purposes. In comparison to the RH401A, the SA0D05A is a newer model with small-size and light weight. Figure 4 shows the measurement results of frequency stability of mutual comparisons conducted on 3 H masers. These results show the same good characteristics of the averaging time within 1 day (approximately 10^5 seconds). A good level of stability during this short period is utilized in order to generate the Japan Standard Time. The level of stability declines after 1 day. This is also a characteristic of the H masers. The device indicated as HM-JST#05 in the figure is a SA0D05A type, and in comparison to the other RH401A model, it is estimated that the tendency of not having good long-term stability is due to the individual specificity.

2.2 Cesium atomic clock

Since the Cs atomic clocks used to generate the Japan Standard Time (referred to as “com-

Fig.2 *Cesium atomic clock and hydrogen maser frequency standard*

Fig.3 *New model of hydrogen maser frequency standard*

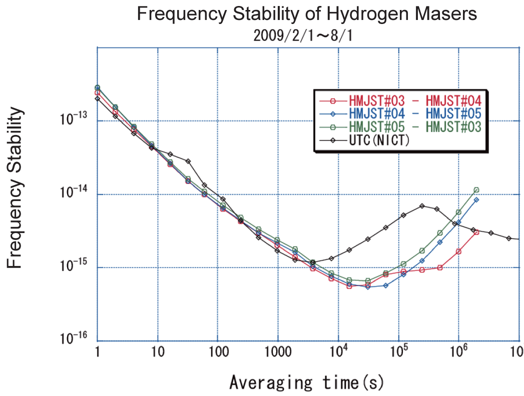


Fig.4 *Stability of hydrogen maser frequency standards*

mercial Cs atomic clocks") are small-sized continuously operable devices with a life span of 5 to 10 years, they are the most widely used clocks by standards institutions around the world. By way of an example, four commercial Cs atomic clocks stored in one shelf are shown on the left side of Fig. 2.

Although commercial Cs atomic clocks are more stable over the long term, they do not have the function to measure frequency shift factors by the device itself. As a result, it is necessary to evaluate and calibrate the "accuracy" that shows an exact second using a Primary Frequency Standard. The NICT operates a Cesium Atomic Fountain Primary Frequency Standard that contributes to gaining higher precision of the International Atomic Time (hereinafter, "TAI"). Please refer to the reference [3] for the details regarding the Cs atomic fountain primary frequency standards.

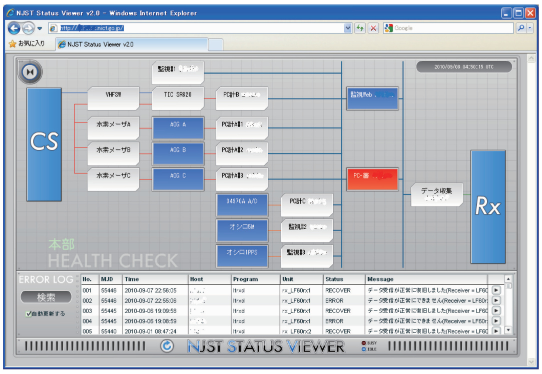
2.3 Measurement system

The measurement system for the Japan Standard Time (Fig. 5) is a device that measures the above H maser and Cs atomic clock signals with high accuracy, processes the averages and generates UTC (NICT). As mentioned above, the system comprises 3 sets of the same devices and one of them is selected to output UTC (NICT). The core devices are the AOG (Auxiliary Output Generator: AOG-110 made by Symmetricom) that is a frequency adjusting device with accuracy of 10^{-19} decimals using the stability of the H masers and the DMTD (Dual Mixer Time Difference System)[4] that measures the time difference between clocks with the resolution of a pico second level. Since differences between two or more with 5 MHz are measured by the DMTD phase ambiguities cannot be removed. Consequently, a time interval counter (SR620 made by Standford Research Systems) using 1 PPS has also been installed.

Fig.5 Japan Standard Time System

From the 4 measured values of the 3 DMTDs and the 1 time interval counter for measuring the time difference of clocks, one value is determined using the majority-voting averaging method. With this method, two considerable disparities between data are removed and the average of the remaining two values is calculated, which ensures fewer measurement errors. In addition, with this method, values can be acquired, even if 3 of the 4 fail to be measured even at worst. Normally, the time difference of clocks is calculated from the highly accurate measurement values acquired by DMTD[5].

Furthermore, some kinds of monitoring systems have been established in order to increase the reliability of operations. The operation of each measurement computer, the data in the database and the real-time wave form of the 1 PPS signals and carrier signal, output of AOG and essential to UTC (NICT), are monitored. Figure 6 shows an example screenshot of monitoring computer. The monitoring computer is connected to the network within the NICT and monitoring status can be checked at any time via an internet interface. This computer also contains functions to process various data. The example in the figure shows the existence of irregularities in red and any problems such as insufficient data in the database, etc., are recognized. These functions assist the operation of the Japan Standard Time.



No.	MJD	Time	Host	Program	Unit	Status	Message
001	55446	2010-09-07 22:56:05	[redacted]	lfrxd	rx_LF60rx1	RECOVER	データ受信が正常に復旧しました(Receiver = LF60
002	55446	2010-09-07 22:55:06	[redacted]	lfrxd	rx_LF60rx1	ERROR	データ受信が正常にできません(Receiver = LF60r
003	55445	2010-09-06 19:09:58	[redacted]	lfrxd	rx_LF60rx1	RECOVER	データ受信が正常に復旧しました(Receiver = LF60
004	55445	2010-09-06 19:08:59	[redacted]	lfrxd	rx_LF60rx1	ERROR	データ受信が正常にできません(Receiver = LF60r
005	55440	2010-09-01 08:47:24	[redacted]	lfrxd	rx_LF60rx2	RECOVER	データ受信が正常に復旧しました(Receiver = LF60

Fig.6 Monitoring screen

3 Comparisons and contributions to UTC

As stated above, although the Japan Standard Time is largely based on the generation of UTC (NICT), UTC (NICT) itself is not defined as it is. It is required to show the clear correlation with UTC.

First, we will briefly discuss how UTC is generated. Please refer to the references [6][7] for further details.

The revision of the current definition of a second based on cesium 133 was made at the General Conference on Weights and Measures (CGPM) held from 1967 to 1968; consequently, a second, namely, frequency is generated using Cs atomic clocks. Regarding time, TAI was defined at the International Committee for Weights and Measures (CIPM) and started from January 1, 1958 at 00:00:00 AM (formally ephemeris time). To realize TAI, a reliable and stable time system is generated by averaging the atomic clocks of research institutions, etc., around the world. Since universal time "UT" based on the rotation of the earth is not stable, time difference from TAI gradually and very slightly deviates from TAI. To keep the time difference between UTC and TAI within 0.9 seconds, UTC is the time system that is adjusted by so-called “leap second”. As a result, although UTC is in synchronization with the pace of TAI, it differs by an integer second. From the starting point of TAI until the present (2010), UTC is 34 seconds behind TAI.

As stated above, UTC (based on TAI) is generated by using the atomic clocks of research institutions, etc., around the world. For this purpose, it is necessary to compare between the atomic clocks of each country with high accuracy. The current main methods of comparison are carried out by utilizing satellite technology, such as communications satellites and GPS satellites. Please refer to the reference [8] for further details.

Each atomic clock in each institution around the world is compared in this manner and the Bureau International des Poids et Mesures evaluates the level of stability. Averages are found using the method of placing weight on the clocks depending on the level of stability and then TAI is determined according to accuracy evaluations using a primary frequency standard. Figure 7 is the graph of the weight transition of each institution which has good weighted average of contributing to TAI. The atomic clocks possessed by the NICT contribute to approximately 10% of the determination of TAI. The institution with the most weight is the US Naval Observatory (USNO), which, as of July 2010 (current), possesses 74 of the total 341 atomic clocks used to determine TAI (22% of the total). The NICT reports clock data from 30 atomic clocks (8.8% of the total), placing it as the second largest contributor to the determination of TAI.

Consequently, through the NICT’s contribution to the determination of TAI and the linking of UTC and UTC (NICT) by time transfers, a traceable relationship has been constructed. The 5th generation of the Japan Time Standard system started to operate since 2006. The relationship between UTC and UTC (NICT) for the preceding and 5th generations is shown in Fig. 8. The range of the variation of UTC (NICT) with 5th generation is becoming smaller in comparison to that with the preceding generation, and the short term variation is being

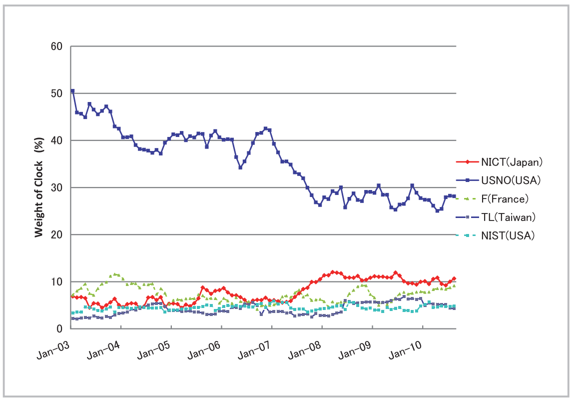


Fig.7 Clock weights at each institution in determination of TAI

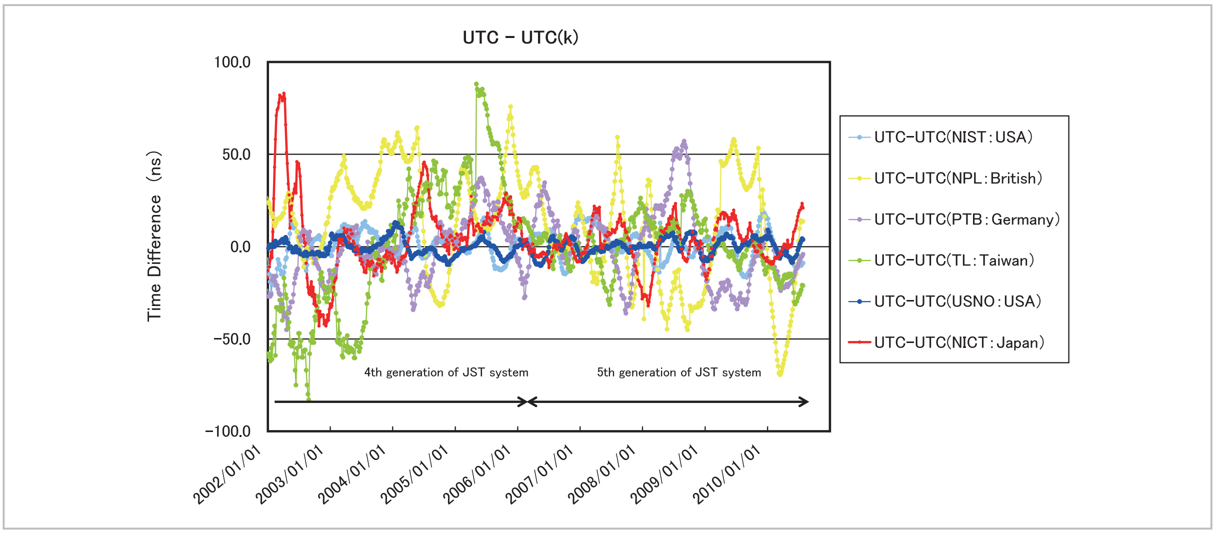


Fig.8 UTC and the Japan Standard Time

greatly improved (though this is not clear from the figure).

4 The provision of the Japan Standard Time

As previously stated, the Japan Standard Time is supplied to be utilized in various forms. Services are being offered by way of standard radio waves, networks, telecommunication lines (telephone JJY) and Time Business with respect to the Japan Standard Time provision, and standard radio waves and calibration (carry-in calibration and remote calibration) with respect to the standard frequency provision.

4.1 Standard radio waves

The NICT disseminates standard radio waves as the provision of frequency and time services using radio waves. For a long time standard radio waves have acted as a “lighthouse for radio waves” and have supported the management of radio waves. In Japan, standard radio waves commenced with short waves from 1940 and time signals began to be superimposed in 1948.

Currently, standard radio waves through short waves are still being used in many countries. Although short wave has the advantage of reaching long distances using ionospheric reflected waves, there are problems with international interferences and mixed signals and the Doppler Effect caused by fluctuations in the ionosphere reflection attitude makes it difficult to transmit short waves with a high frequency precision.

On the other hand, since standard radio waves using long waves have an extremely long wavelength, the disadvantages are that large transmission antennas and facilities are required. However, the advantages are that a higher frequency precision can be secured on the receiving side because propagation is conducted through the ground wave. Furthermore, since a core type antenna can be used for a receiver as opposed to short waves, long waves have the advantage of using a compact receiver. In addition to these advantages, a transition is being made to long wave standard radio waves, which can be applied to radio controlled clocks, from 1999 in Japan and short waves were abolished in 2001. Currently, there are two long wave standard radio wave transmission stations that cover the whole Japan[9].

Standard radio wave signals are generated using Cs atomic clocks equipped in each transmission station. The reason why frequency standards and the Japan Standard Time generated at the NICT headquarters are not transmitted to the transmission stations for disseminating them as they are as standard radio wave signals is that signal delays and fluctuations occur by the impact during the transmission route and then accuracy may be decreased. The Cs atomic clocks installed in the transmission stations are compared to those of the NICT headquarters with the same method as the time transfers between countries and then adjusted to synchronize with the Japan Standard Time. Although the accuracy of the standard frequency ultimately generated at the transmission stations is operated within 1×10^{-13} to UTC (NICT) and the synchronized time precision is within 100 ns, the transmission output is impacted by the transmitter and the low transmission frequency signals, and thus the frequency accuracy is regulated to be within 1×10^{-12} , and the synchronized within 10 μs.

Ever since the establishment of the long wave standard radio wave stations in 1999, radio controlled clocks and watches have become more popular resulting in an estimated 50 million or more nationally accumulated shipments.

4.2 Time provision though the network

With the expansion of the network, time synchronization between computers that process information is being increasingly emphasized, and with the expansion of the internet into general homes, the number of computers connected to networks has reached an extraordinary number. Since each computer contains a clock and each major OS has the synchronizing function using NTP, time is automatically synchronized by setting the machine to refer to the trustworthy NTP (Network Time Protocol).

From 1994, the NICT has been conducting joint research with institutions in Japan. In 2001, it commenced joint experiments on internet time service with 4 institutions. From 2005 it commenced the "Network Time Service" for public institutions, time dissemination enterprise accredited by time business and corporate bodies of internet related business operators, etc., as an independent NICT service[10]. This service is to synchronize time through a direct connection to the exclusive NTP server in the NICT (Fig. 9) using an exclusive line. The above experiments on internet time service have enabled this service to continue into the present through Internet MultiFeed, Co. under the name "Time Information Service for Public".

Furthermore, from 2006, the NICT commenced the "Internet Time Service (public NTP)". Since the internet time synchronization server, which is independently developed by the NICT (Fig. 10), is used for this service. It has the following characteristics: (1) the server precision does not degrade, even for requests on the wire-rate, due to it being completely hardware-implemented by FPGA; (2) since it is a hardware consisting of simple functions, the system is not vulnerable to intrusions such as cracking. Time precision is within 10 ns to UTC (NICT) and its processing capability can be 1 million requests per second[11].

As this service is conducted by accessing to the NTP server located in the NICT, from the user's perspective, the distance caused larger and propagation delays fluctuate depending on the network environment used by the user. As the fluctuation of propagation delays is connected to time synchronization variations, in 2010, the NICT commenced transmissions from the internet exchange point (IX) aiming at improving precision and reliability. For this transmission, an NTP server was installed in Japan Internet Exchange Co., Ltd. (JPIX) in Otemachi, Tokyo. This enables UTC (NICT) and an NTP server in JPIX to be synchronized with a precision of 1 ns by utilizing a two-way time synchronizing system[12] that provides two-way communications by connecting the NICT headquarters and JPIX with single-core optical fiber and inputting time data on the same optic wavelength. As a result, the NTP service was completed with high precision and superior redundancy.

Fig.9 NTP server

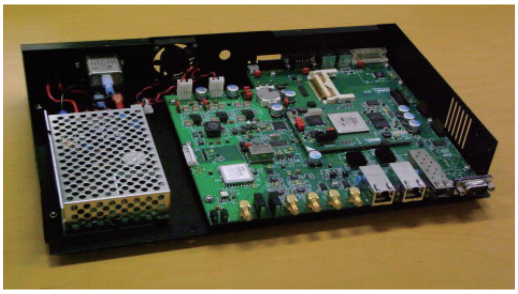


Fig.10 Time synchronizing server for the internet

4.3 Telephone JJY

Telephone JJY is a name commonly used for the standard time provision system using public telephone lines. Commencing in 1995, this service is utilized as a system for achieving time synchronization within 1 ms using two-way telephone lines.

Domestic experiments for time transfers using telephone lines were conducted in the 1980's. At that time, experiments carried out in 6 domestic locations (from Sapporo to Okinawa) resulted in an accuracy of $\pm 200\ \mu s$ through measurements by using acoustic couplers and time interval counters[13]. In the 1990's, a time provision device was made on an experimental base using this method and a time synchronization variation within ±1 ms was achieved by automatically measuring and correcting the time delay of telephone lines[14]. Using this device for its actual service, the telephone JJY system is a system that can handle multiple telephone lines (Fig. 11).

The telephone JJY, which uses analog public telephone lines, is increasingly being used as it can be available in locations where radio waves cannot be accessed (inside buildings, etc.) and security measures such as those required for the internet are not required. Figure 12 shows a graph of the monthly access of the telephone JJY service from its commencement up to the present. Although access to the system showed a temporary decline, it has continued to increase since 2003.

However, difficulties in acquiring analog modems remain a problem. As stated above, the quality of modems is important in order to ensure a time synchronization variation within 1 ms. Table 2 shows the results of variation conducted on 5 modems. Each modem was connected to the telephone JJY system through telephone lines and the time delays of back and forth signal was measured by the loop-back function in the telephone JJY device. The delay was measured by using a time interval counter and the standard variation was found from the values of 100 times measurement. As can be seen from the table, since the delay amount varied according to the modem, the larger delay amount leads to the better delay correction. As the standard variation for modem C to E exceeded 1 ms, it may be difficult to achieve a final time synchronization variation within 1 ms (since this is loop-back delayed time, there is a 50% impact in a one-way direction). It is recommended that 300 – 2400 bps connection between the modems and protocols such as compression and revisions shall not be applied. The telephone JJY system, however, is equipped with a function to respond to various types of protocols. Variation increases, when protocols such as MNP5, V42bis., or so forth are used. Furthermore, the public telephone lines have been digitalized in recent years, and thus there is no more guarantee that the loop-back route is the same as the situation with the old analog line. The precision of the telephone lines is impacted, when using this method to correct time from the time measurements of the loop-back delay, on the assumption that time delay corrections are conducted on the same loop-back route. Consequently, the development of the next generation telephone JJY has become an urgent matter.

Fig.11 *Telephone JJY system*

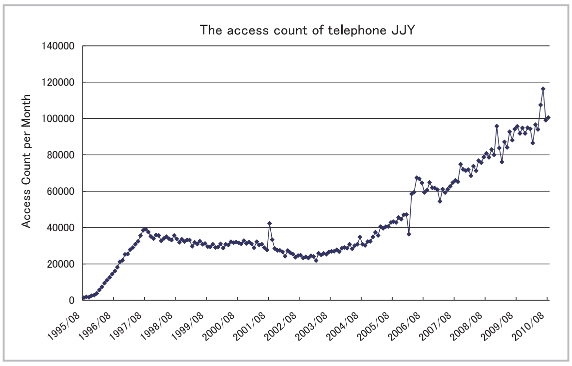


Fig.12 *Access number to telephone JJY*

4.4 Other services

There are other services than those stated above that provide the Japan Standard Time and standard frequency. As providing time services, one is the "Time Information Service"

Table 2 *Errors based on modems*

	Standard Deviation of Delay time (ms)				
Baud Rate of Modem to Modem Baud Rate of Terminal to Modem Connection Protocol	Modem A	Modem B	Modem C	Modem D	Modem E
1200 bps 1200 bps None	0.301	0.382	1.98	1.98	2.32
2400 bps 2400 bps None	0.181	0.178	1.08	1.31	1.27
2400 bps 9600 bps None	—	—	1.19	—	—
2400 bps 9600 bps MNP5	—	—	1.57	—	—
2400 bps 9600 bps V42bis	—	—	5.55	—	—
Spec. of Modem	2400 bps Modem Same as Telephone JJY system	2400 bps Modem MNP4 function	2400 bps Modem Every Protocol function	9600 bps Modem Every Protocol function	14400 bps Modem Every Protocol function

and the other is the "Electric Time Authentication". Since these services mainly intended for time business related enterprises, the "Time Transfer Service using Portable Clocks," "Emergency Assistance Service for Time Businesses" and the above "Network Time Information Service" are included. Each of these services is provided to trace the time source of time business enterprises with the Japan Standard Time with high accuracy. Please refer to the reference[15] for details regarding time business.

The NICT provides a service referred to as "calibration" in regard to the provision of frequency. This is a service that compares the frequency standard possessed by the user with the national standard of NICT, measures frequency variations and issues calibrations results. It includes "calibration of measuring equipments used by registered inspection business operators, etc." pursuant to the Radio Law, "jcss calibration" pursuant to the Measurement Law, "ASNITE calibration" pursuant to the accreditation system of the National Institute of Technology and Evaluation and "commissioned calibration" which is not dependant on any of the above. Apart from the "calibration of measuring equipments used by registered inspection business operators, etc", "carry-in calibration" for items brought to NICT and "remote calibration" are also performed. Please refer to the reference[16] for further details.

5 Conclusion

The regular operation of the Japan Standard Time requires a series of operations such as the generation, comparison and dissemination of standard time and standard frequency, and the operating system covers wide range. Most of this system was developed using the research results and technology accumulated by the NICT. Further improvements are required in the future in order to respond to the rapid advancements.

As a result, the service now directly available to the general public with the spread of the radio controlled clocks or NTP, the importance of the Japan Standard Time is constantly increasing. Furthermore, initiatives such as those aimed at improving the precision of time frequency which plays an important role in the development of science and technology will surely continue to be developed in the future.

References

1 Y. HANADO et al., "The New Generation System of Japan Standard Time at NICT," IJNO, Vol. 2008, Article ID 841672, P. 7.

2 F. NAKAGAWA et al., "Development of Multichannel Dual Mixer Time Difference System to Generate UTC(NICT)," IEEE Trans. on IM, Apr. 2005.

3 Y. HANADO et al., "The New Generation System of JAPAN Standard Time at NICT," ATF2006, TF6p32, Dec. 2006.

4 T. MORIKAWA, "Definision of Time and Frequency Standard," Journal of the NICT, Vol. 50, Mar./Jun. 2003.

5 C Thomas and J Azoubib, "TAI computation: study of an alternative choice for implementing an upper limit of clock weights," Metrologia, Vol. 33, No. 3, 1996.

6 N. KURIHARA, "JJY, The National Standard on Time and Frequency in Japan," Journal of the NICT, Vol. 50, Mar./Jun. 2003.

7 K. IMAMURA et al., "Time Distribution Using the Network," Journal of the NICT, Vol. 50, Mar./Jun. 2003.

8 A. TORIYAMA, A. MACHIZAWA, and T. IWAMA, "Development of a Hardware SNTP server," IEICE Transactions on Communications, Vol. J89-B, No. 10, pp.1867–1873, 2006. (in Japanese)

9 A. TORIYAMA, A. MACHIZAWA, and T. IWAMA, "Time Transfer Device Using Single-Fiber Single-Wavelength Time Division Duplex," IEICE Transactions on Communications, Vol. J91-B, No. 4, pp.407–414, Apr. 2008. (in Japanese)

10 M. AIDA, T. SATOH, and S. YAMAMORI, "Time Comparison Using Telephone Line," Review of the RRL, Vol. 49, Nos. 1/2, Mar./Jun. 2003. (in Japanese)

11 N. MORIYA et al., "Time Data Transmission Using Telephone Line," Journal of the Horological Inst. of Japan, No. 142, 1992. (in Japanese)

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