Overview of Japan Standard Time generation

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Abstract

National Institute of Information and Communications Technology (NICT) generates and supplies Japan Standard Time (JST). JST is made from an average atomic time which is calculated by using 18 commercial Cs atomic clocks. In this calculation, there are some original methods in estimating the clock rate and clock weighting. The actual signal of JST is generated by the realization of this average atomic time. In this process, the frequency control method was optimized recently and frequency stability of JST has been largely improved.

1. Introduction

Japan Standard Time (JST) is generated by the National Institute of Information and Communications Technology (NICT). JST is defined as UTC(NICT) + 9 hours, where UTC(NICT) is a local realization of Coordinated Universal Time (UTC). UTC(NICT) is continuously generated from the weighted average of atomic clocks at the Koganei headquarters. The first system started in 1976, several renewals have been carried out, and current system is the fifth version which started operation in 2006. This system (called "JST system" hereafter) precisely measures the atomic clocks, calculates the average atomic time by using the clock data, and generates the actual signal of UTC(NICT). In this paper, we focus on how to generate UTC(NICT). For acquiring the whole concept, the JST system is introduced in section 2 at first. Next, the calculation of average atomic time and its realization method are explained in section 3 and 4, respectively. In the last section, current status and future plan are summarized.

2. System of Japan Standard time

The process flow of JST system is shown in Fig.1. In the lower block of Fig. 1, Cs clocks are regularly compared with each other, and the average atomic time of JST (called as NICT ensemble time "NET" hereafter) is made from these data (see section 3). NET is a virtual timescale which numerically exists only in a computer. In the upper block of Fig. 1, one atomic clock is used as the signal source of UTC(NICT). Continuous signal of this source clock is steered by a precise frequency adjuster AOG to follow NET (see section 4), so that steered signal of AOG becomes the realization of NET. This output signals of AOG are adjusted to trace UTC, so that they become the signals of UTC(NICT).

Figure 2 shows the block diagram of JST system [1]. We use 18 commercial Cs clocks (5071A) to make NET keep stable in long-term. In the clock measurement, we use a combination of 5MHz measurement by original 24ch-DMTD system [2] and 1pps measurement by a time-interval-counter. Former is for precise and simultaneous measurement, and latter is for ensuring the phase continuity of measured data. NET is calculated every hour from measured clock data. In the generation of UTC(NICT), we use a hydrogen maser (H-maser) as a source clock to get high frequency stability in short-term. AOG is automatically steered to realize NET every 8 hours, and sometimes manually steered to trace UTC. UTC(NICT) is compared with various other standard times by using a GPS time

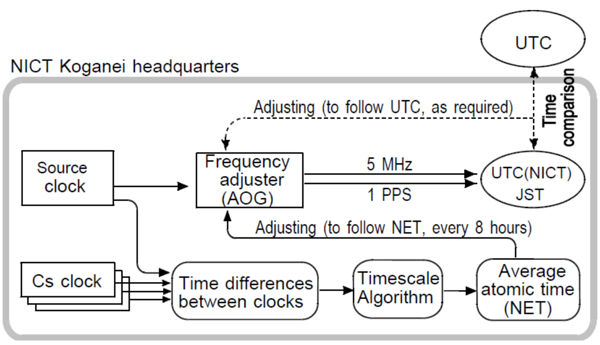

Fig.1 Process flow of JST system.

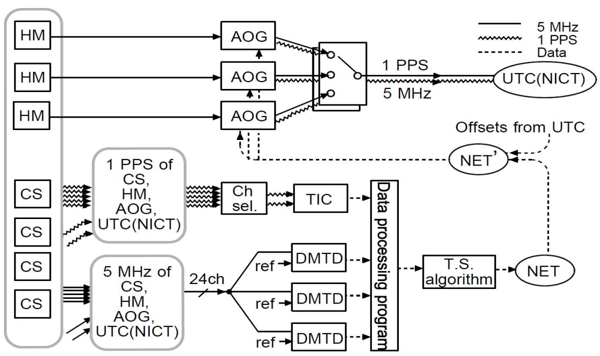

Fig.2 Block diagram JST system.

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transfer and a two way satellite time and frequency transfer (TWSTFT) method. Important devices, the DMTD systems and the set of H-maser plus AOG, have triplet redundancy. In the design of the system as a whole, we gave the priority to the following three points in terms of robustness; the simple configuration for intuitive understanding, the easiness of process checking for troubleshooting, and the quick escape methods according as the level of emergency.

3. Making an average atomic timescale

3.1 Principle

The basic concept of NET is described [3,4], so only the outline is introduced. An average atomic time (usually called "TA") is defined as

$$TA(t_k) \equiv \sum_{i=1}^{N} w_i(t_k)\{h_i(t_k) - \hat{x}_i(t_k)\}, \quad \sum_{i=1}^{N} w_i(t_k) = 1, \tag{1}$$

here the suffix i indicates each clock (i=1,,,N), w is the weight, h is the time offset of a clock from the ideal time, $\hat{x}$ is a linear factor of parameter x which is the time defined as follows.

$$x_i(t_k) \equiv h_i(t_k) - TA(t_k) \tag{2}$$

$$\hat{x}_i(t_k) \equiv x_i(t_{k-1}) + \hat{y}_i(t_{k-1}) \cdot (t_k - t_{k-1}) \tag{3}$$

$$\hat{y}_i(t_k) = \{x_i(t_k) - x_i(t_k - T_R)\}/T_R \tag{4}$$

Here $\hat{y}$ is the clock rate obtained from the interval T_R. The relations of various parameters are shown in Fig.3.The fluctuation factor ε of a clock is expressed by using x and $\hat{x}$ as

$$\varepsilon_i(t_k) \equiv \{TA(t_k) + x_i(t_k)\} - \{TA(t_{k-1}) + \hat{x}_i(t_k)\}, \tag{5}$$

then TA is expressed by using ε as follows.

$$TA(t_k) = TA(t_{k-1}) + \sum_{i=1}^{N} w_i(t_k)\varepsilon_i(t_k) \tag{6}$$

This expression shows that TA is the accumulation of fluctuation factors of each clock.

Though eq. (1) and eq. (6) show the essential meaning of TA, they are not used in the actual calculation program because the values of h and ε cannot be numerically obtained. The parameter h is conceptual and cannot be expressed by numerical value. The parameter ε is defined by using TA, so its value cannot be obtained before TA is fixed. For these reasons, TA should be indirectly defined by using x with the relation of eq. (2). We pick up one clock as the reference clock S, and then TA is expressed as $TA(t_k) = h_S(t_k) - x_S(t_k)$. This means that "TA is the defined time with a time shift by x_S from the clock S ", and the process of defining TA is getting the time series of parameter x. In the calculation program of TA, eq. (3) and the following two equations are used to get the time series of $x_i(t_k)$.

$$x_S(t_k) = \sum_{i=1}^{n} w_i(t_k)\{\hat{x}_i(t_k) - X_{iS}(t_k)\} \tag{7}$$

$$x_i(t_k) = x_S(t_k) + X_{iS}(t_k) \tag{8}$$

Here X_{iS} is the time difference of clock i and S,

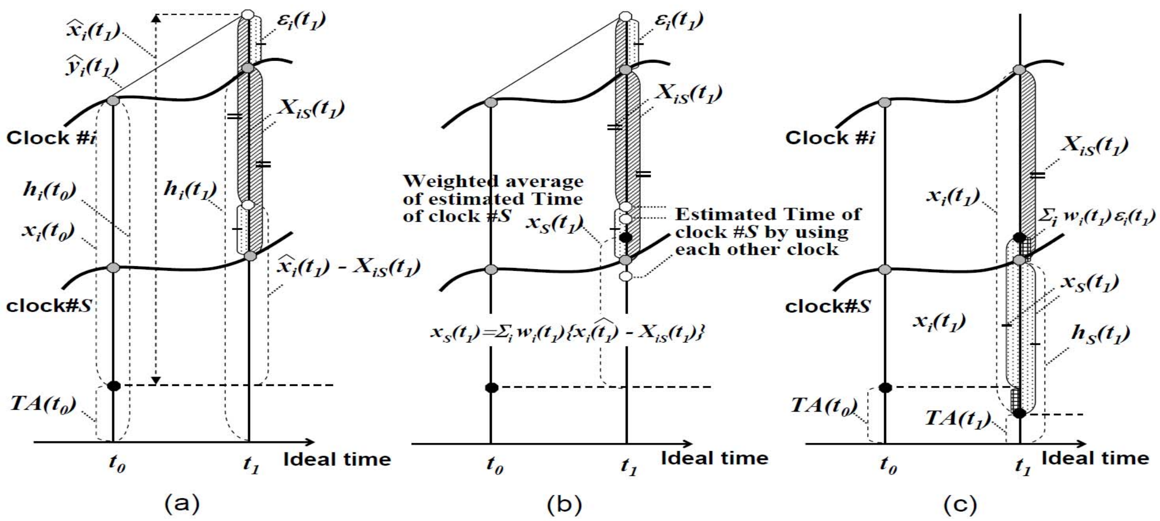

Fig. 3 Relation of the parameters in TA equations.

$$X_{iS}(t_k) \equiv h_i(t_k) - h_S(t_k) = x_i(t_k) - x_S(t_k) \quad (9)$$

and its numerical value can be obtained by measurement. This is a basic and popular process in other algorithms [3].

3.2 Calculation

In the calculation of TA, how to estimate the clock rate and the weighting show the feature of the calculation. As for the clock rate in NET, we choose the length of T_R in eq. (4) is 30 days because the 5071A Cs clocks typically show the best stability in this interval. We also use the clock rate for detecting clock anomalies [5]. If a frequency of some clock largely drifts so that $\hat{y}(t_k) - y(t_k - T_R)$ is over the maximum limit, the weight of this clock forced to be zero. We set the maximum limit as the average of Allan deviation $\sigma_y\,(\tau{=}30$ days$)$ of all clocks.

As for the clock weighting, stable clocks acquire high weights in averaging. The weight of each clock is calculated as follows

$$w_i(t_k) = (1/z_i) \Big/ \sum_{i=1}^{N} (1/z_i), \quad \sum_{i=1}^{N} w_i(t_k) = 1 \quad \cdot \quad (10)$$

For the value of z, we use the Allan deviation σ_y instead of the Allan variance σ_y^2. This reason is to decrease the influence of miss-optimization in weighting. The most stable clock in short-term may not be the most stable in long-term. In such a case, the highest weighting to this clock makes TA stable in short-term but makes TA unstable in long-term. Weighting by using σ_y^2 gives strong contrast to the clocks, which may increase the risk of miss-optimization. Weighting by using σ_y may not give the best optimization but is more moderate and safe. The detail of this consideration is described in [5]. To avoid the weight concentration to a few clocks, the highest weight is limited according to the number of available clocks.

As for the timing of TA calculation, we set the calculation interval $(t_k - t_{k-1})$ as one hour. Measurement data X_{is} is hourly averaged and available after one hour, so the newest NET is one hour past value.

4. Realization of TA – generation of UTC(NICT)

The eq. (2) means that TA is the defined time shifted by x_i from the time of clock i. This is the principle of TA realization. If a clock is intentionally adjusted for this purpose, it cannot join with the TA calculation. So we use a precise frequency adjuster AOG driven by an H-maser instead of a Cs clock.

Here the suffix A and H express AOG and H-maser respectively. The AOG time h_A is expressed as follows.

$$h_A(t_{k+1}) = h_A(t_k) + \{\hat{y}_H(t_k) + y_{adj}(t_k)\} \cdot (t_{k+1} - t_k) + \varepsilon_H(t_{k+1}) \quad (11)$$

Here y_{adj} is the adjusting frequency given to AOG to trace TA, $\hat{y}_H$ is the clock rate of H-maser. Here we assume $\varepsilon_H(t_{k+1})$ is zero because $\varepsilon_H(t_{k+1})$ cannot be known.

If $h_A(t_{k+1})$ is equal to $TA(t_{k+1})$, AOG realizes TA. As $TA(t_{k+1})$ cannot be known at t_k, we assume $TA(t_{k+1}) = TA(t_k)$.

$$TA(t_k) = h_A(t_k) - x_A(t_k) = h_A(t_k) - \{x_S(t_k) + X_{AS}(t_k)\} \quad (12)$$

By setting $h_A(t_{k+1})$ in eq. (11) equal to $TA(t_k)$ in eq. (12), y_{adj} is obtained as follows.

$$y_{adj}(t_k) = \frac{X_{SA}(t_k) - x_S(t_k)}{t_{k+1} - t_k} - \hat{y}_H(t_k) \quad (13)$$

By adding this y_{adj} to AOG, its output signal is considered as the realization TA. The first term of the right hand in eq. (13) shows the frequency offset, and the second term shows the time offset from TA. The relations of parameters are shown in Fig. 4. Realization of TA is not perfectly equal to TA, because $TA(t_{k+1})$ is not usually equal to $TA(t_k)$ and $\varepsilon_H(t_{k+1})$is not usually zero.

AOG has been controlled by using above method, but optimization of some parameters has been required. We carried out some improvements recently, and the outline is introduced here.

Figure 5 shows the stability of UTC(NICT), H-maser, and NET. We can see that UTC(NICT) follows the stability of H-maser in short-term and the stability of TA in-long term. This behavior is basically reasonable, however, the stability of UTC(NICT) in the middle-term (from a few hours to 10 days) is worse than the expected value from the performance of H-maser. It is because the adjusting

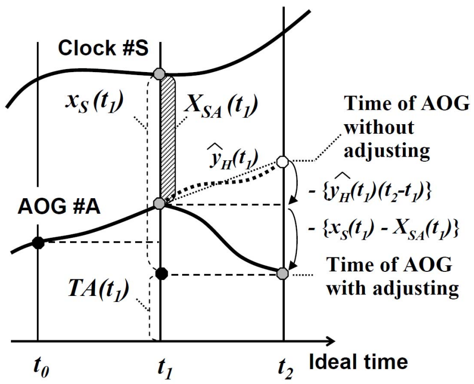

Fig.4 Parameters in TA realization.

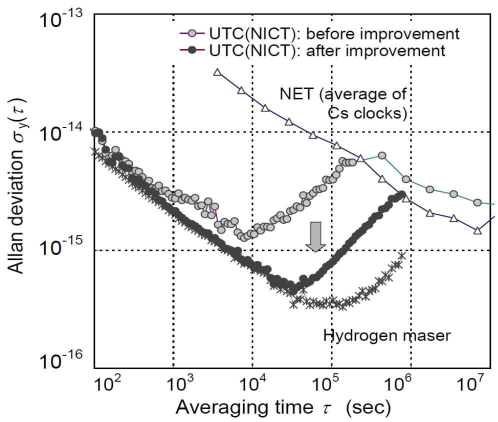

Fig. 5 Improvement of frequency stability of UTC(NICT).

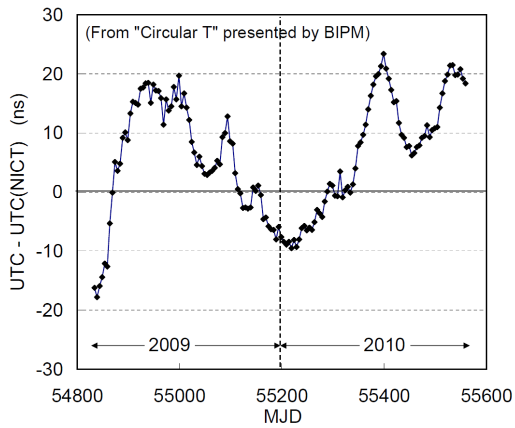

Fig.6 UTC - UTC(NICT) in 2009-2010.

parameters of AOG were not optimized. We investigated three important parameters; the interval T_1 of $\hat{y}_H$ estimation, the feedback duration T_2 of time and frequency offset, and the interval T_3 of AOG adjusting. Before the improvement, the parameters were T_1=5 days, T_2=2 days, and T_3=24 hours. We thought that too short T_1 and T_2 may spoil the middle-term stability of UTC(NICT) because the stability of H-maser at $\tau=10^6$ sec is still better than NET (Fig.5). The optimized parameters were found by simulation; T_1=10 days, T_2=10 days, T_3=8 hours, and they were installed to the JST regular operation in May, 2010. We can see the middle-term stability of UTC(NICT) largely becomes better after this improvement. Detail will be published elsewhere in near future.

5. Current status and future plan

Figure 6 shows the behavior of UTC(NICT) via UTC in 2009 and 2010. The interval of each data is five days. Time difference from UTC is almost within 20 ns, and we aim to decrease this value. In addition, some improvements are planned. One plan is developing an average atomic time of H-masers. We have four available H-masers now, but their data have not used for making NET now. If their averaging is combined with the current Cs average atomic time, NET will be more stable in short-term. Another plan is the link with the primary frequency standard. We developed a Cs fountain-type frequency standard, NICT-CsF1[6], and plan to use it for the frequency calibration of NET. Both plans are being investigated by some simulation, and brushed up now.

6. Acknowledgement

Highly qualified and reliable operation of Japan standard time has been achieved by continuous struggle of many persons in charge in long term. Authors respect their sincerity and contributions to this work and greatly appreciate their cooperation with this paper.

7. References

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