

# **UPDATE OF RESEARCH ACTIVITIES IN TIME AND FREQUENCY AT THE NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY (NICT)**

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## **Abstract**

*The time and frequency standards related groups in the National Institute of Information and Communications Technology (NICT), were integrated into one large group in April 2006. All the activities of the research and service have been continued and are in progress. In this paper, we will show the activities in time and frequency, such as atomic frequency standards, time transfer, and timekeeping.*

## **1. INTRODUCTION**

In April 2006, the time and frequency standards groups in the National Institute of Information and Communications Technology (NICT), which had consisted of the following six groups: the Atomic Frequency Standards Group, the Time and Frequency Measurements Group, the Japan Standard Time, the Quasi-Zenith Satellite System Group, the Radio Astronomy Applications Group, and the Time Stamp Platform Group in, were integrated into one large group, the Space-Time Standards Group, with four subsidiary projects: the Space-Time Applications Project, the Time and Frequency Measurement Project, the Next Generation Time and Frequency Standards Project, and the Japan Standard Time Project. All the activities of the research and service have continued and progressed.

## **2. ATOMIC FREQUENCY STANDARDS**

### **2.1. Optically Pumped Standard, NICT-O1**

The first optically pumped cesium primary frequency standard CRL-O1 changed its name to NICT-O1 in April 2004. NICT-O1 operated from April 2000 to June 2006. The data of the accuracy evaluation of TAI scale unit have been sent to BIPM twice a year on average. The Type B uncertainty of the standard

was estimated as  $5.4 \times 10^{-15}$ . In most cases during the evaluation period, the total uncertainties of the standard were less than  $1 \times 10^{-14}$



Figure 1. Optically pumped cesium primary frequency standard (NICT-O1).

## 2.2. Fountain

NICT has conducted the development of a cesium atomic fountain primary frequency standard. We named it NICT-CsF1. It has achieved a frequency stability better than  $5 \times 10^{-13} / t^{1/2}$ . Several frequency shifts due to the systematic effects have been evaluated. So far, the combined frequency uncertainty has been estimated to be less than  $2 \times 10^{-15}$ . A paper on NICT fountain was presented by Kumagai *et al.* at ATF2006.

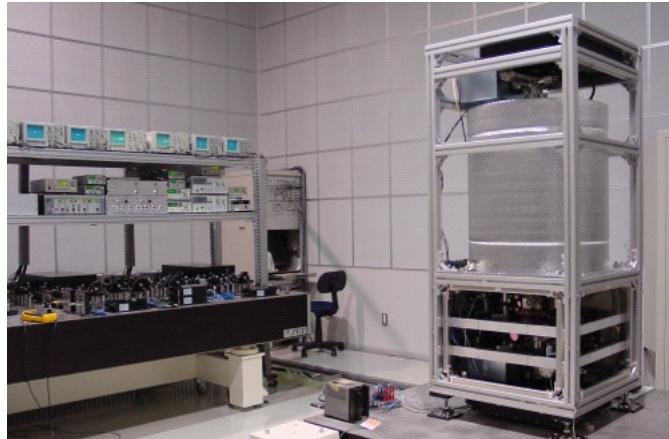


Figure 2. The cesium atomic fountain primary frequency standard (NICT-CsF1).

## 2.3. Optical Frequency Standard

NICT has developed an optical frequency standard using an electric quadrupole transition in single, laser-cooled, trapped  $\text{Ca}^+$  ions [1, 2]. For a 729-nm clock laser system, we have obtained a laser linewidth of 66 Hz and a root Allan variance of  $2 \times 10^{-13}$  at 1 s. The electric quadrupole transition of single  $40\text{Ca}^+$

ions was detected by the shelving method, and we have measured the transition spectrum. For the optical-frequency measurement, a frequency comb system has been developed by using a broadband femtosecond-pulse laser.



Figure 3. Optical frequency standard using an electric quadrupole transition in single, laser-cooled, trapped Ca+ ions.

### 3. TIMEKEEPING

The generation system of Japan Standard Time (JST) has been largely renewed by using the occasion of moving the system to a new building. We have four hydrogen masers and 18 Cs atomic clocks. Hydrogen masers have been introduced into the JST system for the first time. The signal source of JST has been changed from a Cs atomic clock to a hydrogen maser, which improves the short-term frequency stability of both UTC (NICT) and JST. We developed a 24ch-DMTD system for the simultaneous measurements of time differences among the clocks [3]. The precision of measurements is about one hundred times better than that by a time-interval counter in the previous system. The reliability of this system has been strengthened by the improved monitor functions and triple redundancy. The time-scale algorithm of the system has been also improved [4]. This new JST system has been operating since 7 February 2006. UTC (NICT) generated by this system has been synchronized with UTC to within around 10 ns since then.

### 4. PRECISE TIME TRANSFER

#### 4.1. GPS

NICT has changed the P3 and Multi-Channel (MC) GPS receivers from an ASHTECH Z-XII Metronome and a Topcon Euro-80 to a Septentrio PolaRX2, on 7 February 2006. We have provided both P3 and MC CCTF data from the same receiver in order to avoid any errors caused by using different receivers [5].

We have also made a redundant system with three Septentrio receivers. These receivers are connected to independent AOG signals, and as a consequence, the system is robust in the case that the receiver or the

distribution system has trouble (Fig. 4).

In addition, observation at the IGS station of NICT (whose site name is KGN0) ended on 1 April 2006. Our RINEX files are continuously available for the carrier-phase time transfer at <http://www3.nict.go.jp/w/w114/data/GPS/rinex/>.

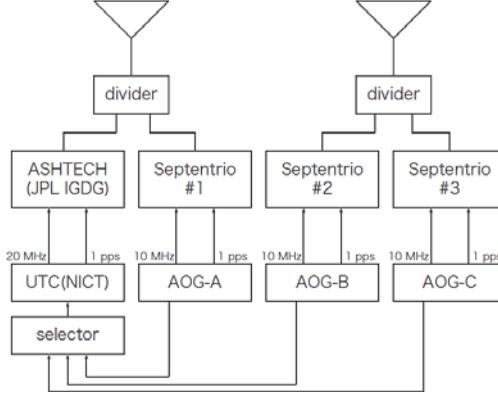


Figure 4. Interplay between time and frequency stability.

#### 4.2. TWSTFT

NICT and major T&F institutes in the Asia-Pacific region, such as NMJJ in Japan, NMIA in Australia, NTSC in China, TL in Chinese Taipei, KRISS in Korea, and SPRING in Singapore, are cooperatively constructing a TWSTFT network in this region. To operate those links, we use a multi-channel modem (NICT modem) developed by NICT. Time transfer is regularly performed and data/hour are reported to the BIPM. NICT carried out calibration trips by using a portable station between NICT and TL in February 2006.

A TWSTFT link between NICT and PTB was established in July 2005. This link is connected by using the NICT modem. The time transfer is hourly performed and the data are also reported to the BIPM. The TWSTFT link to the USA was experimentally started between NICT and USNO by using a SATRE modem via VDB in April 2006. Since the link is conducted at a very low elevation angle and the quality of the link is insufficient, we plan to change the relay station to Hawaii.



Figure 5. TWSTFT: NICT multi-channel modem and portable station.

#### 4.3. ETS VIII

NICT plans to conduct a precise time and frequency transfer experiment between a ground-reference clock and an atomic clock on the satellite ETS-8 (Engineering Test Satellite-8). ETS-8, which will be launched in late 2006, is a Japanese geostationary satellite equipped with cesium-beam frequency standards. NICT developed equipment to carry out two-way time transfer by carrier-phase measurement. It is also possible to calibrate internal delays and delay variations of the transmitting and receiving paths between the satellite and the ground station. By using this method, we expect to achieve precision of approximately 10 ps. We completed electrical tests and environmental tests of the equipment, and the ground stations are almost ready.

#### 4.4. QZSS

Japan started the Quasi-Zenith Satellite System (QZSS) project in 2003. QZSS will be highly useful as a supplement to the modernized GPS in urban canyons and mountainous areas with its high visibility brought about by its inclined orbits. In this project, NICT is to develop a space-borne hydrogen maser (SHM) and a time management system, and to carry out experiments using them [6]. By conducting two-way time transfer between the on-board clock and the ground clock by using a Ku-band link, the management of the QZSS system time, which is linked to UTC (NICT), is expected to achieve nanosecond level. The engineering models (EM) of this on-board equipment were developed and environmental tests have been made. The first satellite is planned to be launched in 2010.

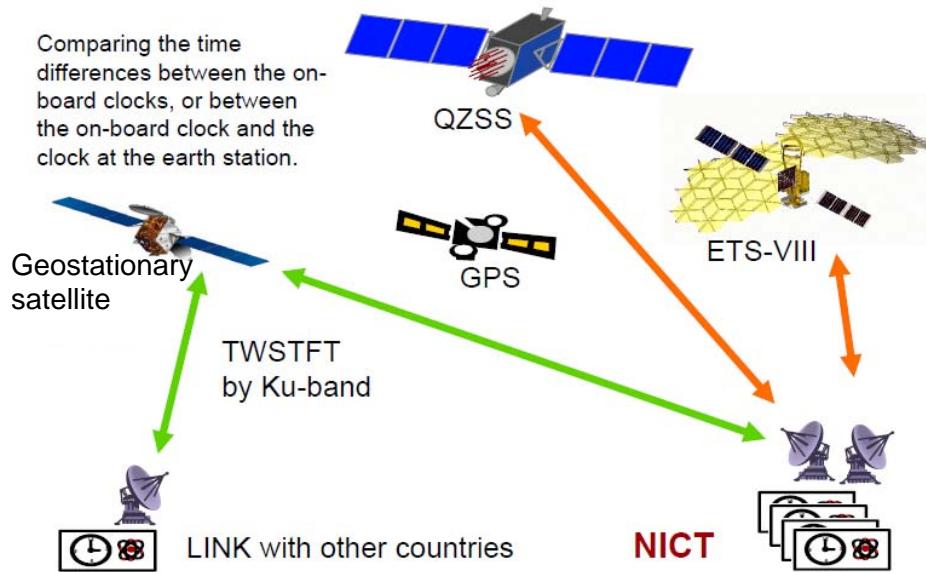


Figure 6. Time transfer systems at NICT.

## 5. DISSEMINATION

### 5.1. STANDARD-FREQUENCY AND TIME-SIGNAL EMISSIONS

NICT provides the dissemination service of standard frequency and time signal via the LF band, as shown in Fig. 7. The signals from the two LF stations, namely Ohtakadoya-yama and Hagane-yama, cover all of Japan. Table 1 shows the characteristics of the stations. Both stations operate 24 hours a day. A market of radio-controlled watches and clocks has developed.

### 5.2. FREQUENCY CALIBRATION SYSTEM FOR TRACEABILITY

NICT has been conducting a frequency calibration service referenced to UTC (NICT). In order to fulfill the requirements of global MRA, NICT has established a quality system for the frequency calibration service, which was assembled by the accreditation body, the National Institute of Technology and Evaluation. The conformity to ISO17025 was certified at the end of March 2001. The BMC of the system is  $1 \times 10^{-13}$ .

Table 1. Characteristics of LF stations.

	Ohtakadoya-yama	Hagane-yama
Frequency	40 kHz	60 kHz

E.I.R.P	13 kW	23 kW
Antenna	250 m height	200 m height
Latitude	37°22' N	33°28' N
Longitude	140°51' E	130°11' E

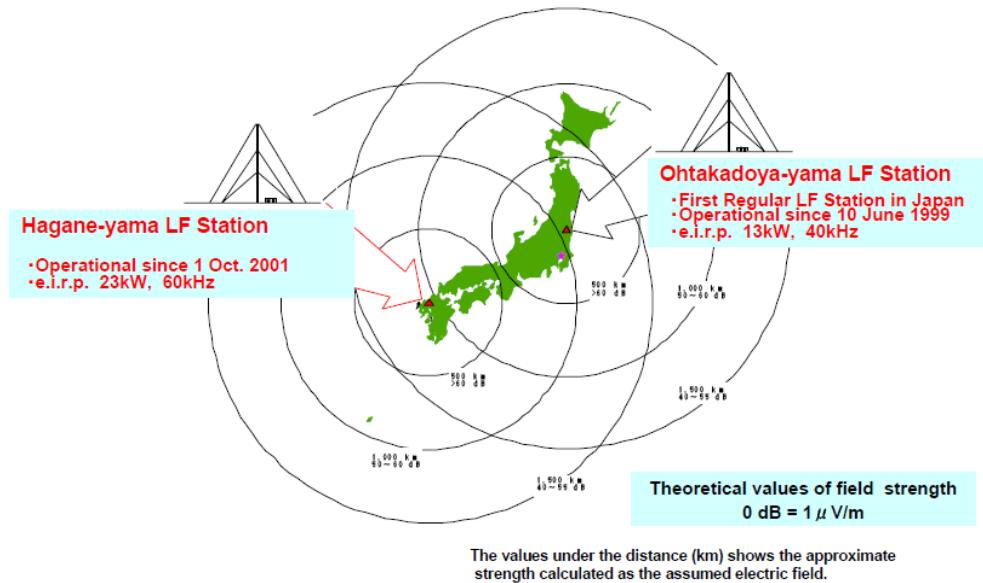


Figure 7. LF time and frequency service stations in Japan. The values under the distance (km) shows the approximate strength calculated as the assumed electric field.

### 5.3. PUBLIC NETWORK TIME PROTOCOL SERVICE

NICT has developed a new hardware SNTP server which can handle with a million requests per second. By using this server, we started the public NTP service in June this year.

## 6. TRUSTED TIMESTAMPING

Accurate and trusted time is required for safe use of electronic commerce or other important information exchanges. NICT has developed timestamping platform systems for verifying new techniques under an actual operation environment. The following experiments have been conducted in collaboration with timestamping service providers:

- (1) using two different timestamping methods at the same time for making a stronger defense against compromise of the encryption algorithm
- (2) a new time transfer technique to ensure time traceability
- (3) the validity term extension method with re-timestamping
- (4) the validity term extension method with hysteresis signature techniques.

## 7. SPACE MEASUREMENTS AND OTHER ACTIVITIES

Very Long Baseline Interferometer (VLBI) technology has been developed in the Kashima branch of NICT [7]. Since this spring, this team has been a part of the space-time standards group. Recent topics in this field are the development of an e-VLBI system and the measurement of positions of spacecraft such as Nozomi and Hayabusa [8].

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