# Error Correction of Precise Time Transfer Experiment between Ground and ETS-VIII

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***Abstract*—The Engineering Test Satellite-VIII (ETS-VIII) is a Japanese geostationary satellite. Its missions include basic satellite positioning experiments using onboard atomic clocks. The National Institute of Information and Communications Technology (NICT) developed special equipment for this time transfer link. This link makes precise time transfer between the onboard atomic clock and a ground reference clock using two way time transfer method and carrier phase measurement for the first time in the world. We have corrected ionosphere error by two received downlink measurement data and compared to obtain a precision as better than 3ps between both clocks.**

## I. INTRODUCTION

A satellite navigation system is important as an infrastructure for economic and human activities. The Global Positioning System (GPS)[1] was developed by the United States and has become the popular satellite navigation system in the world, as it can be used for many purposes.

In Japan, the Subcommittee for Satellite Navigation Technology of the Committee on Planning under the Space Activities Commission was organized in 1997. The Subcommittee suggested that Japanese organizations should study the following basic technologies to improve the country's satellite navigation system [2].

1) Development of a space-borne atomic clock;

2) Time and frequency management;

3) Precise orbit determination techniques.

By conducting these studies, we can make technical improvements in the satellite navigation system and contribute to a next generation satellite navigation system.

This system is aimed to establish the technology of time and frequency management, such as monitor and control of atomic clocks. The JAXA (Japan Aerospace Exploration Agency) and the NICT intend many positioning experiments to obtain basic satellite positioning system technology using the ETS-VIII. Our goal is to perform a precise and accurate time and frequency transfer between an onboard atomic clock and a ground reference clock.

## II. ETS-VIII AND ONBOARD ITS EQUIPMENT

In Japan, the ETS series run by the JAXA aims at developing satellite common base technologies. Overview of the ETS-VIII [3] is shown in Fig. 1. The ETS-VIII was launched in December 2006 by an H-IIA launch vehicle at the JAXA's Tanegashima Space Center, was developed primarily to establish and verify the world's largest class geostationary satellite bus technology, which is necessary for future space missions. The ETS-VIII is conducting many orbital experiments. One of them is a satellite positioning experiment, which uses a satellite positioning equipment include a highly precise onboard atomic clock.

This onboard atomic clock is the same type as that used for GPS satellites. Its specification is as follows:

- Type : cesium atomic clock
- Output frequency : 10.23MHz
- Weight : 13.6kg

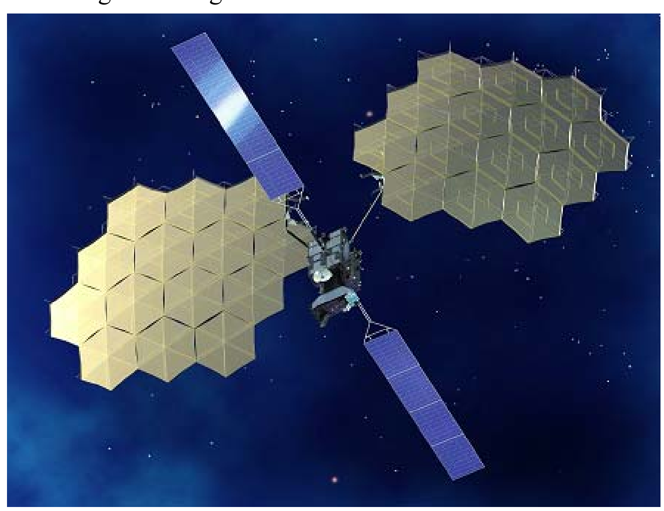

Fig. 1 Overview of the ETS-VIII.

Fig. 2 Flight Model of the TCE.

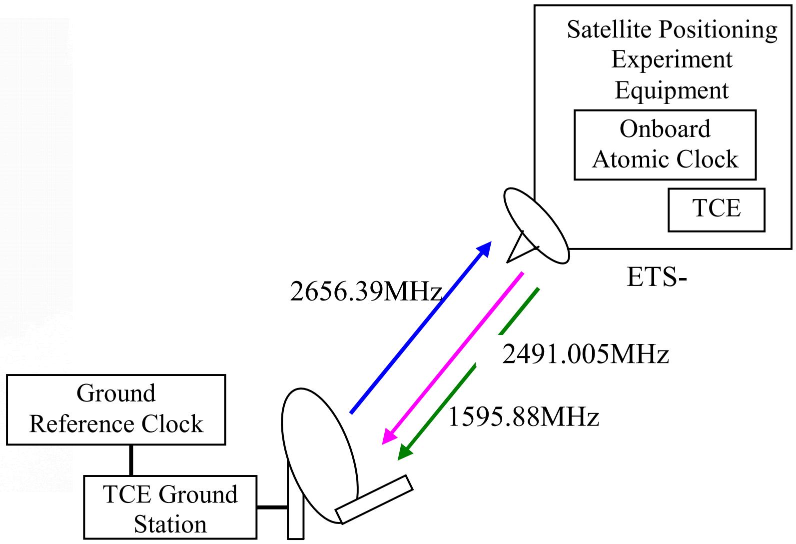


Fig. 3 Concept of the Experimental System.

- Frequency stability : $1*10^{-11}$ (t=1 - 3.6s)

  $1.89*10^{-11}$ t -0.5 (t=3.6 - $10^5$s)

  $6*10^{-14}$ (t=$10^5$ - $10^6$s)

Using the frequency of this clock as a reference, the positioning signals in the L-band and S-band, which are modulated by the same code as GPS C/A code, are transmitted. The ETS-VIII has an antenna of 1.0 m in diameter to transmit and receive both L-band and S-band signals. The receiving power at the ground is expected same as that from the GPS satellite, but the frequency in L-band is a little different from that of GPS. And an array of mirrors for a satellite laser ranging (SLR) was equipped. These were developed by JAXA[4]. The NICT developed the Time Comparison Equipment (TCE) [5], which was the onboard unit of the time and frequency transfer system of ETS-VIII. The flight model of TCE is shown in Fig. 2.

## III. EXPERIMENTAL SYSTEM

Fig. 3 shows concept of the experimental system for precise time transfer experiment using the onboard satellite positioning equipment and the TCE ground station. There are three features of this system. The first is the adoption of a two way signal transfer method between the satellite and the TCE ground station. The second is the use of signal carrier phase information. The third is the self calibration function. The block diagram of the onboard satellite positioning equipment is shown in Fig. 4.

The use of carrier phase information is important because both stations have highly stable atomic clocks, similar to those used by the GPS. Since all modulation signals and carriers are generated coherently, we can use carrier phase information, inaddition to the modulated signals, to compare the timing of the signals to within a few pico seconds using carrier phases as well as codes. The internal delay measurement function of the TCE allows us to address any delay time variation due to temperature variation and aging.

We maintained two TCE ground stations, shown in Fig. 5, are a fixed station and removal station. The TCE ground station is composed of a 2.4 m diameter antenna, an RF section and a processing unit similar to the TCE. The UTC(NICT) was used as a ground reference clock by the TCE ground station, that is the Coordinated Universal Time determined by NICT.

## IV. PURPOSE OF THE EXPERIMENTS USING TCE

We planned precise time transfer using the TCE and the TCE ground station. We can attain sub-nano second of precision by using only the modulation signal measurement. And pico second order time comparison can be made using the carrier phase measurement.

Purposes of this time transfer experiment are as follows;

- Precise monitoring of onboard atomic clocks,
- Study of time management for satellite navigation system.

The main purpose of our experiment is to evaluate stability of the onboard atomic clocks using TCE. This stability will be obtained by a highly accurate time comparison that can be used for many applications. We are planning application experiment as follows;

- High accuracy time transfer between two TCE ground stations via ETS-VIII.
- High accuracy ranging and orbit determination.

The development of satellite positioning system using quasi zenith satellite (QZS)[6] has begun in Japan, and the result of the TCE experiment is used for its time management system[7].

## V. METHOD OF THE TIME TRANSFER

This precise time transfer experiment uses the two way time (and frequency) transfer method.

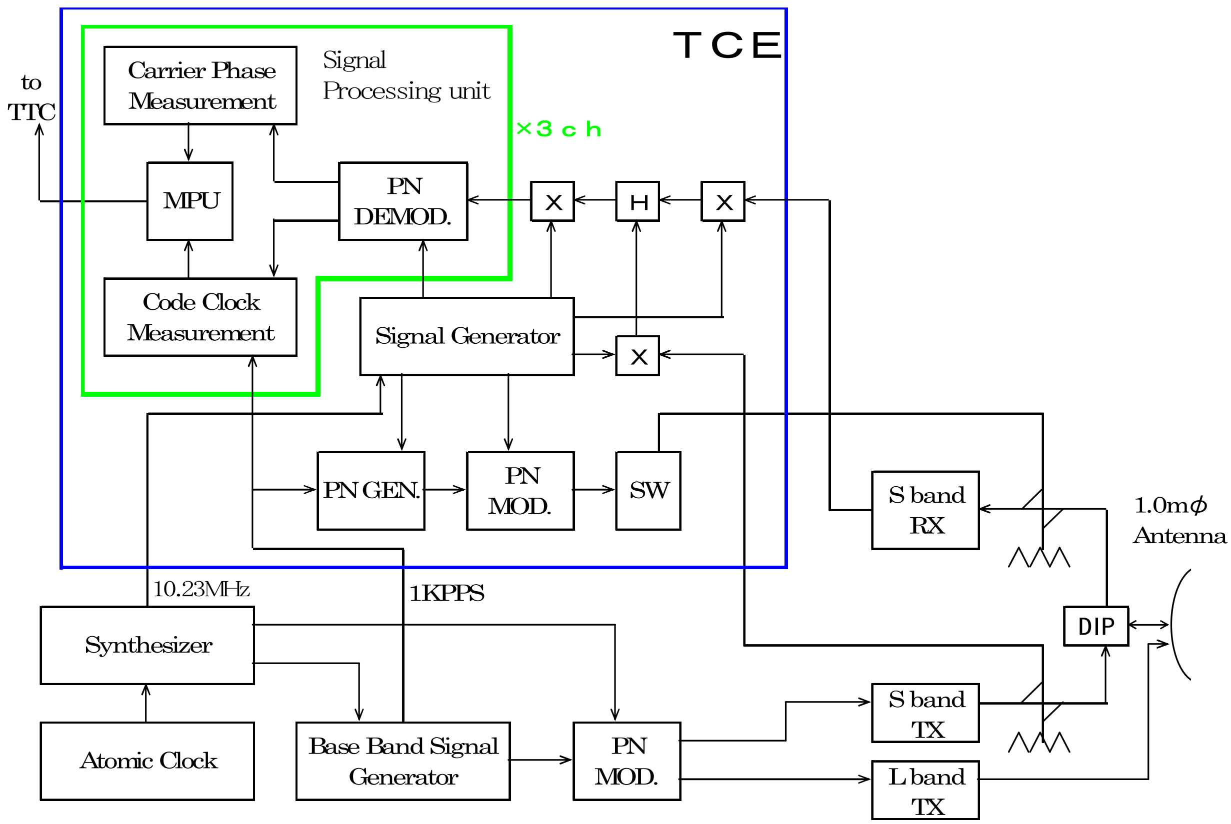


Fig. 4 Block diagram of the TCE.

In this case as shown in Fig. 3, signal for time transfer are transmitted from the satellite to the ground station, and from the ground station to the satellite. Both stations measure the received signal and calculate the time difference. The measurement values are expressed as follows;

$$\text{Uplink} \quad : t1 = tg + Ts - Te \qquad (1)$$

$$\text{Downlink} : t2 = tg + Te - Ts. \qquad (2)$$

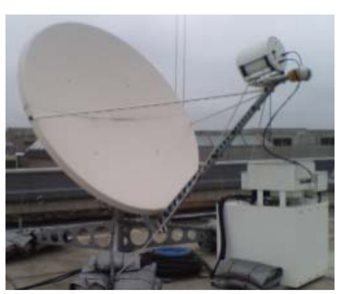

Fig. 5 Antenna of TCE Ground Stations.

where

t1 : measured time difference between the signal from the ground and the satellite time Ts ;

t2 : measured time difference between the signal from the satellite and the ground time Te ; and

tg : propagation time between the satellite and the ground.

Adding and subtracting these expressions yields the following :

$$\text{Uplink - downlink} = t1- t2 = 2\ (Ts - Te)\ . \qquad (3)$$

$$\text{Uplink +downlink} = t1+ t2 = 2\ tg \quad . \qquad (4)$$

The subtracting yields the time difference , and the addition yields the propagation time. This propagation time can be calculated to distance between the satellite and the ground station.

In principle, the advantage of the two way time transfer method is that because both ground-to-satellite and satellite-to-ground signals propagate along the same path in opposite directions, and the delay caused in the ionosphere and the atmosphere can be canceled if the uplink frequency is same as that of downlink. Such cancellation largely reduces measurement uncertainty and enables us to make a precise

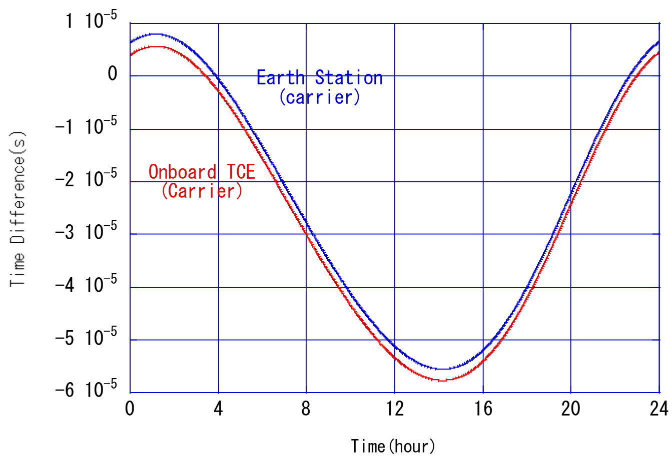


Fig. 6 Measurement result of the received signal at the TCE and the earth station in carrier phase (S-band) .

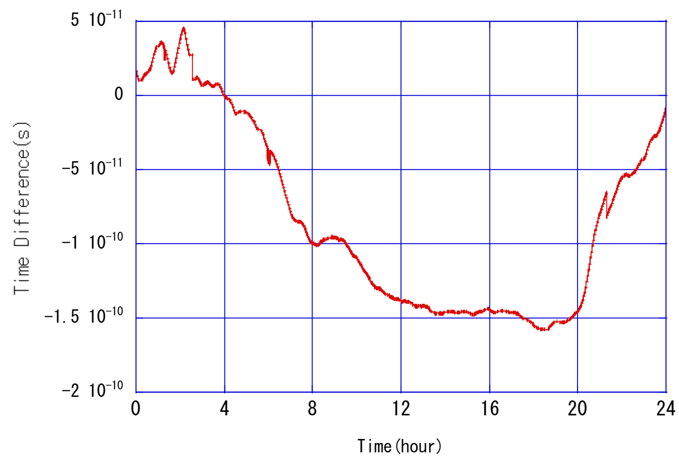


Fig. 7 Amount of the correction of ionosphere delay by downlink received signal .

time transfer. By using the carrier phase information, much higher resolution is obtained since both stations have highly stable atomic clocks.

Actually, the part which cannot be canceled remains because the uplink frequency and the downlink frequency are a little different. And delay time variation from transmit route and receiving route give error to time transfer. Therefore, error sources are corrected to receive two downlink frequency (S-band, L-band), and to measure delay times of transmit root and receiving root.

## VI. MEASUREMENT RESULT

We are continuing time transfer experiment between the onboard clock and the UTC (NICT) intermittently.

Fig. 6 shows a measurement result of the received signal at the TCE and the earth station in carrier phase (S-band).Fig. 7 shows the amount of the correction of ionosphere delay was calculated from downlink received signal by both S-band and L-band.

Fig. 8 shows an experimental result of the time transfer between the onboard atomic clock and the UTC(NICT) in carrier and code phases. First order trends are removed and the value of time difference for code and carrier phases at t=0 are 0ns and 5ns respectively. The same trend in both measured data is seen. The measurement precision of the carrier phase is far better than that of the code phase, and the variations of code and carrier phases agree very well with each other.

Fig. 9 shows frequency stabilities (Allan deviation) calculated from the same data in Fig. 8 with the specification of the onboard atomic clock (HAC clock). Its time transfer resolutions are 0.7ns using code phase and better than 3ps using carrier phase at 1s averaging time. As shown in the Fig. 9, making use of the carrier phase data, we can obtain the stability of the onboard atomic clock.

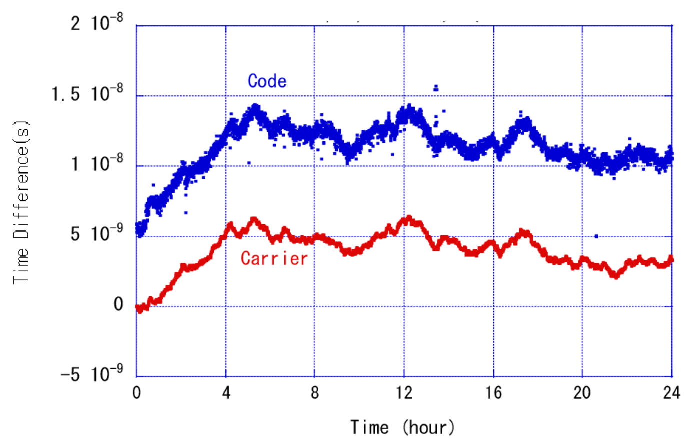


Fig. 8 Experimental result of the time transfer between the on-board atomic clock and the UTC(NICT) in code phase and carrier phase.

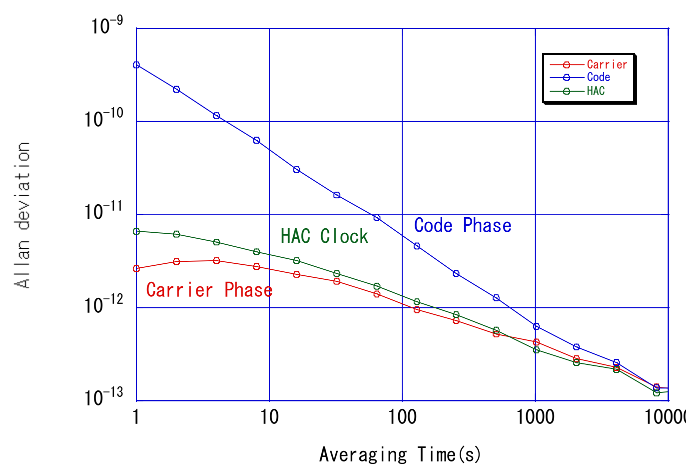


Fig. 9 Frequency stabilities (Allan deviation) calculated from the same data in Fig. 8 with spec of the on-board atomic clock.

## VII. CONCLUSION

The result of precise time transfer experiment between the ground and the ETS-VIII is shown. The resolution in time transfer is 0.7 ns using the code phase and 3 ps using carrier phase for averaging time of one second.

The measurement using TCE has continued. All the onboard equipment was verified as normal and the expected time comparison results have been obtaining. We are still carrying out the experiments for three years, and also try various experiments.

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