

# High Resolution Ranging Experiment using the Time Comparison Equipment

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The Japan Aerospace Exploration Agency (JAXA) and the National Institute of Information and Communications Technology (NICT) intend many positioning experiments to obtain basic satellite positioning system technology using the Engineering Test Satellite-VIII(ETS-VIII). The NICT developed the on-board Time Comparison Equipment (TCE) and was carried out experiment of time transfer of the time difference between on-board standards and the ground reference clocks intermitting. This paper describes experimental principle and result of ranging between the satellite and the ground station using time transfer data.

## 1 Introduction

ETS-VIII (Engineering Test Satellite VIII)<sup>[1]</sup>, launched in December 2006, is a satellite for the development of advanced common base technologies necessary for future space activities. With the satellite, various experiments including mobile communication tests using a large deployable antenna have been conducted.

One of the technological features of ETS-VIII is that an atomic clock was carried on the satellite, a first time for Japan. Basic research on satellite positioning technologies was then planned and conducted with the clock. Mostly for performance evaluation of the atomic clock on the satellite orbit, the National Institute of Information and Communications Technology (NICT) installed high precision time comparison equipment (TCE)<sup>[2]</sup> as part of its missions, and planned<sup>[3]</sup> and performed a satellite-earth high precision time transfer experiment. Meanwhile, the Japan Aerospace Exploration Agency (JAXA) has made a high precision orbit estimate as part of its base experiments on the positioning satellite. Since the time transfer data can be utilized for high precision ranging, the mechanism and results are reported in this paper.

## 2 Summary of high precision ranging experiments

### 2.1 Necessity of high precision ranging

The orbit determination of ordinary communication satellites requires an accuracy from several hundred meters

to several kilometers. However satellites for the U.S. GPS (Global Positioning System) and other satellite positioning systems are used to determine user position from the satellite positions. The satellite position determination is therefore crucial. Hence an important experiment theme for JAXA is to determine the orbit of ETS-VIII. The orbit determination was achieved<sup>[4]</sup> at an accuracy of 15 m (within the target of 100 m) by using S and L band signals and SLR (Satellite Laser Ranging).

On the other hand, NICT mainly aimed to conduct satellite-earth high precision time transfer experiments using TCE and observe the atomic clock behavior on the orbit. Besides that, NICT used data obtained in these experiments for high precision ranging and determined the accuracy of the ranging.

### 2.2 High precision time transfer experiment system

The experiment system used by NICT for high precision time transfer experiments consists of a JAXA-developed high accuracy clock (HAC)<sup>[5]</sup> on satellite and of TCE and earth stations for high precision time transfer (TCE earth stations (fixed and mobile ones)) developed by NICT. See references for details.

### 2.3 Basis of high precision ranging

In the satellite-earth high precision time transfer experiments<sup>[6]</sup>, a two-way time transfer method is used. A time transfer signal is transmitted and received by both sides and the received data are analyzed to determine the

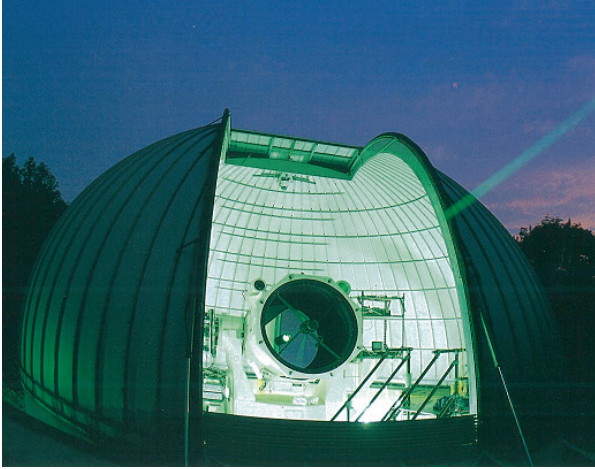


Fig. 1 Optical Center (1.5 m diameter telescope)

time difference between the clocks on the two locations. The details are shown in what follows. Let  $\tau_s$  and  $\tau_e$  be the time measured at the satellite and the TCE earth station respectively,  $T_s$  and  $T_e$  be the time at the satellite and the earth respectively, and  $c$  be the speed of light. Then  $\tau_s$  and  $\tau_e$  are expressed by the following equations:

$$\text{Uplink: } \tau_s = \tau_g + T_s - T_e \tag{1}$$

$$\text{Downlink: } \tau_e = \tau_g + T_e - T_s \tag{2}$$

The time difference between the satellite and the earth  $\Delta T$  is given by

$$\Delta T = (\tau_s - \tau_e) / 2 \tag{3}$$

On the other hand, the propagation time between the satellite and the earth station  $\tau_g$  and the propagation distance  $R$  are given by

$$\tau_g = (\tau_s + \tau_e) / 2 \tag{4}$$

$$R = c \cdot \tau_g = c \cdot (\tau_s + \tau_e) / 2 \tag{5}$$

These equations are accurate if the propagation time is the same in the uplink and the downlink and the in-device time delay does not change. In actual situations, however, the frequency in the uplink is different from that in the downlink, and hence the measurements are affected by a time delay due to the ionosphere, or by a change in the in-device time delay due to temperature, or other factors. These influences are almost compensated for each other in the two-way time transfer, but not in the ranging. However the time difference between the two clocks and its change do not affect the ranging measurements.

There is an ambiguity of 1.2 m in the carrier phase measurement and of about 300 km which corresponds to 1ms in the code length measurement. Also since the positional relation of the antennas used for LRRR and the time transfer is not specified, the absolute values of the ambiguities are not known.

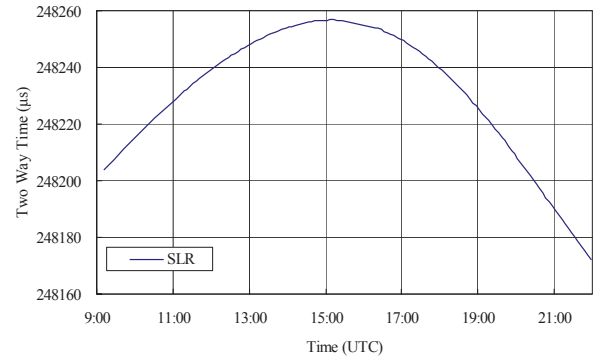


Fig. 2 Ranging result of SLR (upper) and ranging result obtained from time transfer data (lower)

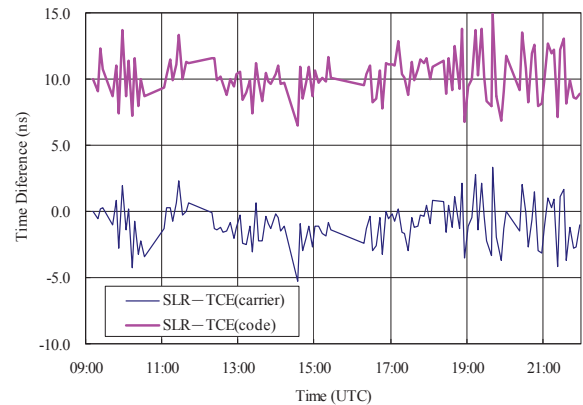


Fig. 3 Difference between ranging result of SLR and ranging result obtained from time transfer data

### 2.4 Ranging experiments

As shown in 2.3, data obtained from the TCE for the satellite-earth time transfer and from the TCE earth stations can be utilized to make high precision ranging. This calculation needs to be verified. ETS-VIII has an LRRR (Laser Retroreflector Array) for ranging with a laser beam. The TCE earth station (main station) at NICT headquarters (Koganei, Tokyo) has an Optical Center (Fig. 1) with a 1.5 m telescope that can perform laser ranging against a geostationary satellite. Laser ranging data obtained at the Optical Center were used as reference.

About 200 m distance between the TCE earth station (fixed station) and the Optical Center was ignored since the present experiments were performed only to check the performance of the ranging operation.

### 3 Example of ranging experiment results

Figure 2 shows an example of the results (code phase and carrier phase) of ranging calculation based on the measurement data that the TCE earth fixed station obtained from the satellite-earth time transfer, and an example of the result (5-minute average) of the SLR ranging at the Optical Center. The results show the time of propagation to and from the satellite. As mentioned above, the ranging measurement by TCE is ambiguous and hence the absolute values are not known. However, still the change in the ranging measurement by TCE is in good agreement with the result of SLR. Figure 3 shows the difference between the ranging result of SLR and that obtained from the time transfer data (i.e. SLR - code phase, SLR - carrier phase). Since the absolute value has no meaning, the data are plotted with 0 ns and 10 ns chosen as starting points. The magnitude of the variation of the difference is up to about 8.6 ns, which is about 2.6 m length. This is significantly smaller than JAXA's orbit determination accuracy of 15 m.

### 4 Conclusions

It was shown that the satellite-earth two-way time transfer data could be utilized for high precision ranging. In contrast to SLR, which can be made only on a clear night, the present method using radio waves can perform high precision ranging regardless of the time of day or night and regardless of the weather (unless heavy rain causes rain attenuation and line disconnection). If this system is used for orbit determination of a positioning satellite, the orbit determination can be made more accurate.

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development, tests, and experiments of TCE and TCE earth stations since a TCE experiment was planned in 1997, and NICT and other related corporations express thanks to them.

### References

- 1 Homma, M., et. al., "Engineering Test Satellite-8 for Mobile Communication and Navigation Experiment," IAF, No. IAF-00-M.3.01, pp. 256-263, 2000.
- 2 Y. Takahashi, et. al., "Experimental Plan for Time Comparison Equipment for ETS-VIII Satellite," Trans. on IEICE, Vol. J84-B, No. 12, pp. 2101-2107. (in Japanese)
- 3 Y. Takahashi, et. al., "Experimental Plans Using Time Comparison Equipment," Journal of CRL, Vol. 50, Nos. 3/4, pp. 269-277.
- 4 T. Tsukashima, "Development Result of LDR and HAC," Symposium of results and utilization of ETS-VIII, Oct. 2009. (in Japanese)
- 5 H. Noda, et. al., "High Accuracy Clock (HAC)," Journal of CRL, Vol. 50, Nos. 3/4, pp. 101-107.
- 6 M. Nakamura, et. al., "Experiment using the Time Comparison Equipment on-board ETS-VIII," Special issue of this NICT Journal, 5-1, 2014.

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