Evaluation of Differential VLBI Phase Delay Observable for Spacecraft Navigation
– ΔVLBI observation of HAYABUSA at touchdown to Itokawa –

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1 Introduction

Very long baseline interferometry (VLBI) is a technique to measure the angular position of celestial radio source with very high resolution (order of a few nano radians). Thus it is useful tool not only for radio astronomy but also measurement of spacecraft orbit. Range and range rate (R&RR) observation is one of the major ground based observables for orbit determination of spacecrafts in the deep space. Though it has sensitivity for spacecraft coordinates mainly in direction of the line of sight (LoS). Especially then the radio source is in low equatorial region, its sensitivity to the declination coordinates decreases significantly. VLBI technique has complementarily sensitive to the radio source coordinates in the plane perpendicular to the LoS. For the purpose to improve the precision of orbit determination, NASA/JPL has been jointly using both VLBI and R&RR for orbit determination by so called differential delta one-way range (DDOR) technique[1].

2 Conditions in Spacecraft VLBI observation

To satisfy the requirements of higher precision of orbit determination in recent space missions, JAXA/ISAS, NICT, and NAOJ have started collaboration to use VLBI for spacecraft navigation. We have made a series of VLBI experiments[2] for Japanese spacecraft NOZOMI and HAYABUSA with support of Japanese Institutes involved in research work with VLBI (NAOJ, GSI, Gifu Univ. Hokkaido Univ., Yamaguchi Univ.) and Canadian Algonquin Observatory operated by NRCan and Crestech. The DDOR method is based on group delay observation and its resolution is inversely proportional to both the signal to noise ratio (SNR) and signal bandwidth. However Japanese spacecrafts have not been originally designed for ΔVLBI observation, which requires wide frequency band at their transponders, thus the delay precision was limited. Additionally the baseline lengths, which dominate the angular resolution, among Japanese domestic VLBI stations are one order smaller than those of NASA/JPL. These conditions are disadvantages in our VLBI application to spacecraft navigation.

3 ΔVLBI Observation of HAYABUSA's touchdown to ITOKAWA

In November 2005, spacecraft HAYABUSA has made touchdown to the asteroid ITOKAWA. In this occasion, we organized ΔVLBI observation of HAYABUSA with six Japanese domestic VLBI stations. We used phase delay as observable for the spacecraft observation. Phase delay has advantages of higher delay resolution and free from the requirement of bandwidth. Drawback is uncertainty of phase ambiguity of 2πn. Fortunately at this event, both HAYABUSA and ITOKAWA were at the same coordinates within one fringe phase. And the orbit of asteroid ITOKAWA is supposed to be known with enough accuracy owing to optical and radar observations. Therefore the phase delay could be directly used as absolute delay observable with replying on theoretical delay prediction and assumption of zero phase ambiguity. This became a good chance to evaluate the accuracy of the calibration with ΔVLBI technique applied to spacecraft. Inherently VLBI delay observable contains excess delay bias, which is mainly caused from atmosphere and clock-synchronization error between atomic standards at observation stations. The ΔVLBI is a technique for calibrating the excess delay by frequent switching observation between target radio source and its nearby reference radio sources. By using phase delay observable, we evaluated the accuracy of ΔVLBI calibration with high precision.

To take into account the difference of atmospheric path length between target and reference radio sources caused by difference of elevation angle from observation site, we estimated the atmospheric delay and clock parameters (offset, rate) from the excess delay with mapping function of the troposphere. Then excess delay correction was applied to the target radio source. An example of the excess delay correction is demonstrated in Fig. 1. Detailed procedure of the modeling and correction is described in the other paper[4]. Atmospheric zenith delay was modeled by piece-wise linear function with time interval of 30 min. The achieved correction accuracy was around several hundreds of pico seconds. There is still unknown systematic variation of delay residual in 1 hour time scale. Since this excess delay correction (Fig. 1) was made by using group delay of reference radio source (quasar) for convenience, and was applied to phase delay of target source ('Phase delay - Group delay' correction). Thus dispersive delay caused by cold plasma in the ionosphere and solar wind may affect two fold in the residual, and these are suspected to be the reason of the delay variation. Now, extracting phase delay observable from reference radio source data is in progress. The result of 'Phase delay - Phase delay' correction will be presented in this conference.

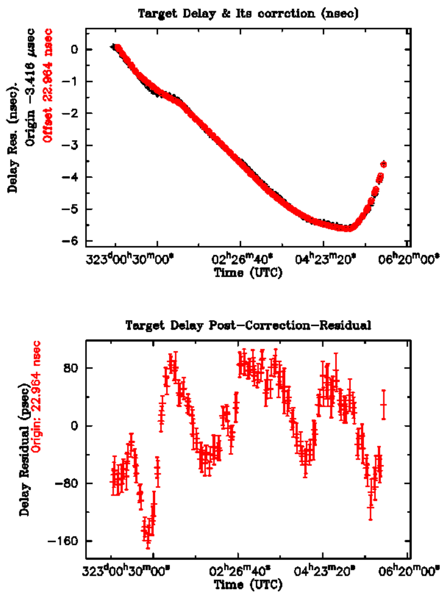

Figure 1: Example of delay correction with ΔVLBI. Marked by '+' is delay observable O-C for target radio source (HAYABUSA). Atmospheric delay and clock parameters were estimated by model fitting to delay data of reference radio sources and correction was applied to target (solid line in upper panel). Delay residual after model correction is displayed in the lower panel.

References

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