VLBI Observation of Spacecraft for Navigation

–Approaches with Group Delay and Phase Delay –

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Very long baseline interferometry (VLBI) has high sensitivity in coordinate measurement in the celestial sphere. Range observation of spacecraft, which is the conventional technique for spacecraft navigation in the deep space, is sensitive in the line of sight (LoS) but insensitive in the plane perpendicular to the LoS. Thus joint use of these two techniques is expected to enhance the accuracy of spacecraft navigation in deep space. Group delay measurement of radio signal from spacecraft has been used for spacecraft navigation by JPL/NASA as delta differential one way range (DDOR) technique. Since precision of delay measurement of the DDOR is limited by bandwidth of spacecraft signal, long baseline is necessary for high angular resolution. Phase delay of VLBI has potential to enable about 2 orders of higher precision of delay measurement than group delay. However unknown ambiguity is the main problem to use phase delay observable. One approach to overcome this problem is connecting phase continuously between scans to scans. Even if total ambiguity of phase delay is unknown, least square analysis can be applied for simultaneous estimation of radio source coordinates and delay offset by reducing number of unknowns.

Spacecraft NOZOMI, which was the first Japanese Mars mission, was observed with VLBI by wide support of Japanese VLBI community and Algonquin observatory in Canada. Since NOZOMI was observed continuously, phase delay was successfully connected for over 24 hours. Closure relation of phase delay could be used to support the phase connection procedure. Figure 1 shows comparison of spacecraft coordinates between VLBI solution and orbit determined by R&RR measurement. It shows VLBI solution converged close to the coordinates of R&RR solution (origin of the plot) consistently as increasing the number of baselines included in the solution.

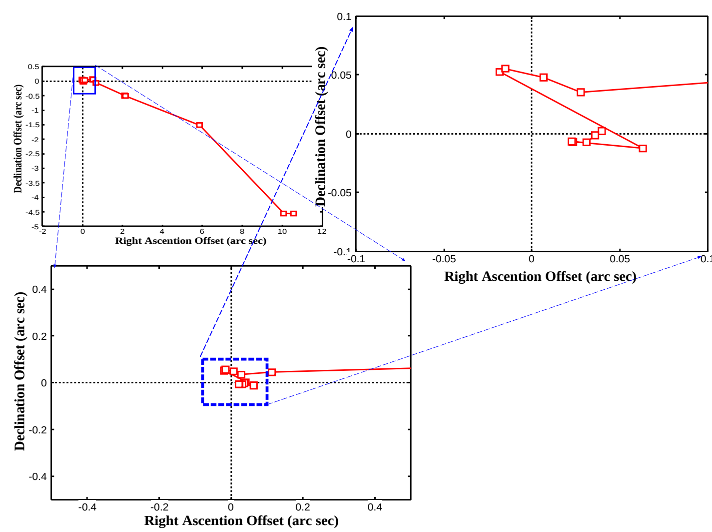

Figure 1: Celestial coordinates of NOZOMI estimated by VLBI observations on 4th June 2003 is plotted. The origin of plot is the orbit determined by R&RR measurements. The track of the plots indicates that the VLBI solutions of NOZOMI's coordinates converged to consistent solution with the R&RR data as increasing the number of baselines.

Observation of continuous tracking of spacecraft has benefit for phase connection but calibration of atmospheric delay may be insufficient, thus its solution may potentially include systematic error. Differential (switching) VLBI is a technique to calibrate error due to propagation medium. That is sometimes used in astronomical VLBI observations, but application to spacecraft differential phase delay observation is not so easy. Because predicted orbit of spacecraft is not so accurate as radio source coordinates used in astronomy, and wrong coordinates of radio source cause larger fringe rate residual. Optimum switching interval, which is short enough for phase connection and long enough for reference source observation, is the key.

An effort to increase the group delay precision is on going. Cross correlation processing between data observed at different stations is employed so far as the same with standard VLBI data processing. Although, cross correlation of observed data with replica of transmitted original signal is expected to increase signal to noise ratio (SNR) and precision of delay measurement. Now we are testing this processing scheme, and some results are presented in this paper.