Planning of an Experiment for VLBI Tracking of GNSS Satellites

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Abstract

As a preparation for future possible orbit determination of GNSS satellites by VLBI observations an initial three-station experiment was planned and performed in January 2009. The goal was to get first experience and to verify the feasibility of using the method for accurate satellite tracking. GNSS orbits related to a satellite constellation can be expressed in the Terrestrial Reference Frame. A comparison with orbit results that might be obtained by VLBI can give valuable information on how the GNSS reference frame and the VLBI reference frame are linked. We present GNSS transmitter specifications and experimental results of the observations of some GLONASS satellites together with evaluations for the expected signal strengths at telescopes. The satellite flux densities detected on the Earth's surface are very high. The narrow bandwidth of the GNSS signal partly compensates for potential problems at the receiving stations, and signal attenuation is necessary. Attempts to correlate recorded data have been performed with different software.

1. Introduction

Several possibilities are known to track high orbiting satellites using the VLBI technique. VLBI geodetic observations by radio telescope networks [11] demonstrated the feasibility of using the method for accurate tracking of the communications satellite TACSAT and for geodesy already in 1972.

Phase referencing observations with respect to the background radio sources is often used today for Deep Spacecraft navigation [8], [10]. However phase referencing observations show differences of the propagation media for the sources at infinity and the near-Earth satellites. Such differences need to be studied in more detail.

The use of dedicated emitters directly installed on GNSS satellites sending signals to Earth radio telescopes is also a promising method for orbitography. An early proposal [3] foresaw the installing of additional transmitters on a GPS satellite and using the signal for interferometric techniques with fairly simple ground equipment. The project was called Miniature Interferometer Terminal for Earth Surveying (MITES), but it was never built in the proposed way, the system was only privately built to prove the concept by D. Steinbrecher and C. Counselman. Anyway, many of today's algorithms for GPS carrier phase measurements can be tracked back to this development [13]. A slight different principle has been recently proposed [5], [7]. According to this method GPS data are acquired with a modified receiver and then recorded with VLBI equipment.

At present two projects aboard multitechnique satellites are carried out by JPL and GFZ. GRASP (Geodetic Reference Antenna in Space) a mission to enhance the Terrestrial Reference Frame is developed at JPL [2] and MicroGEM, a small LEO satellite that can, among other things,

receive GNSS signals, can be tracked with SLR, and can send artificial VLBI signals [18], is under development at GFZ Potsdam.

In this paper we present some observations that we performed in a geodetic VLBI mode to receive the signals of GLONASS satellites.

2. Goals and Characteristics of the Experiment

An initial three-VLBI-station experiment was planned to track the same satellite in geodetic VLBI mode. We chose GLONASS satellites since the frequencies of emitted signals were observable by the L-band receivers of the three involved European stations Medicina, Noto, and Onsala. Several tests were performed during 2009 with the goal to develop and test the scheduling for different satellites, to verify satellite tracking at different azimuth and elevation, to test possible necessary signal attenuation, and to verify correlation detection. GLONASS carrier signals in L1 band are in the interval 1602.56 MHz and 1615.50 MHz. On L1 a C/A code of 1.022 MHz bandwidth and a P code of 10.220 MHz are superimposed. The effectively isotropic radiated power (EIRP) is on the order of 26 dBW, and considering the distance from the Earth of about 19,000 km, the calculated receiving temperature for Medicina and Noto is $1.5{\times}10^6$ K.

We performed tests at 1 MHz and 10 MHz bandwidth using an artificial signal with the same power as the GNSS satellites. The receiver could still work in the linear area without reaching saturation. At Onsala, a 20 dB attenuation was necessary during these tests with artificial signals.

The four satellites PR02, PR03, PR17, and PR18 were simultaneously visible at Medicina, Noto, and Onsala on January 21, 2009 from 08:00 UT to 12:00 UT. Observations were performed using the standard Mark IV VLBI data acquisition rack for Onsala and Medicina, and a VLBA rack for Noto. Two channels (VCs) of 8 MHz bandwidth (upper, 1 RHCP, 1 LHCP) were selected at all the stations. Individual signal attenuation was used at the stations. The formatted data were recorded with Mark 5A equipment, and phasecal was used. The telescopes were positioned stepwise with 20 seconds updates to follow the satellites. The recording scans had a length of 10 seconds, so 5 seconds were left to point the antenna to the new satellite position. After the satellite tracking, a one-minute-long observation was carried out on Cygnus A using the same setup, but with different attenuation at the stations.

3. Results and Future Developments

Signal spectra have been recorded individually at all three stations, both for LHCP and RHCP, see for example the case for Onsala in Figure 1. In general the power level was quite different for RHCP and LHCP. For example, at Onsala the RHCP signal was 20 dB stronger than the LHCP signal. This is consistent with the LHCP component originating at the satellite since the GLONASS signal is specified to have RHCP stronger than LHCP by 16 dB [6]. The difference of 20 dB versus 16 dB might originate from possible imperfections in the VLBI feed, for example insufficient polarization isolation. The LHCP channel might have picked up some RHCP signal.

Later, when the calibrator Cygnus A was observed, it was necessary to reduce the additional attenuation again. It was necessary to reduce attenuation by 19 dB / 16 dB (RHCP / LHCP) at Noto, 29 dB / 10 dB (RHCP / LHCP) at Medicina, and 27 dB / 5 dB (RHCP / LHCP) at Onsala. This gives an impression on how much stronger the satellite signals are than signals from natural radio sources.
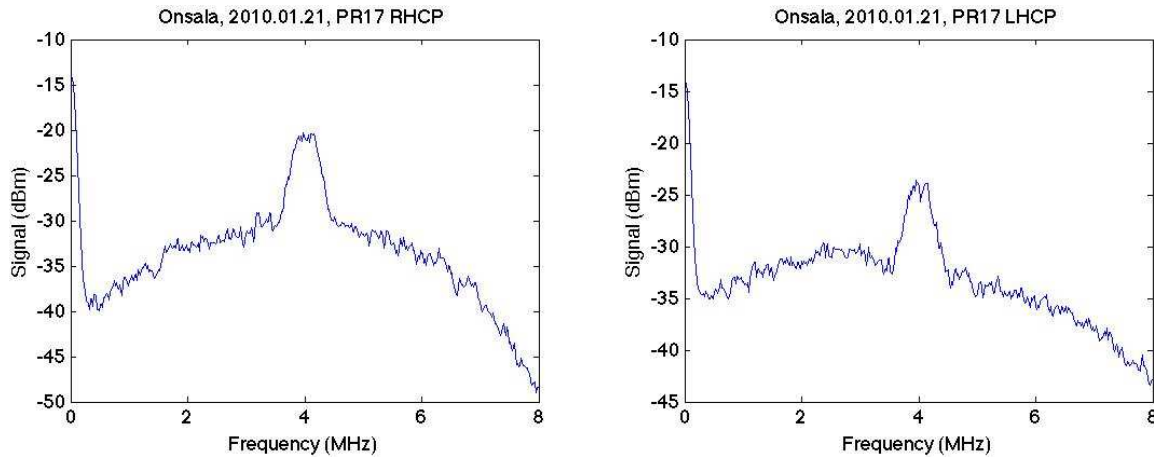
Figure 1. Spectra of the LHCP and RHCP signals of PR17 GLONASS satellite observed at Onsala.

The spectrometer graph from Medicina, see Figure 2 (left), clearly shows the 10 seconds acquisition and the time intervals where no acquisition is made. Signal power fluctuations are therefore present. At some epochs the signal fluctuations were very large, for example at Medicina in Figure 2 (right), and similar effects were observed for Onsala and Noto, too. The reason of these strong fluctuations still needs to be investigated.
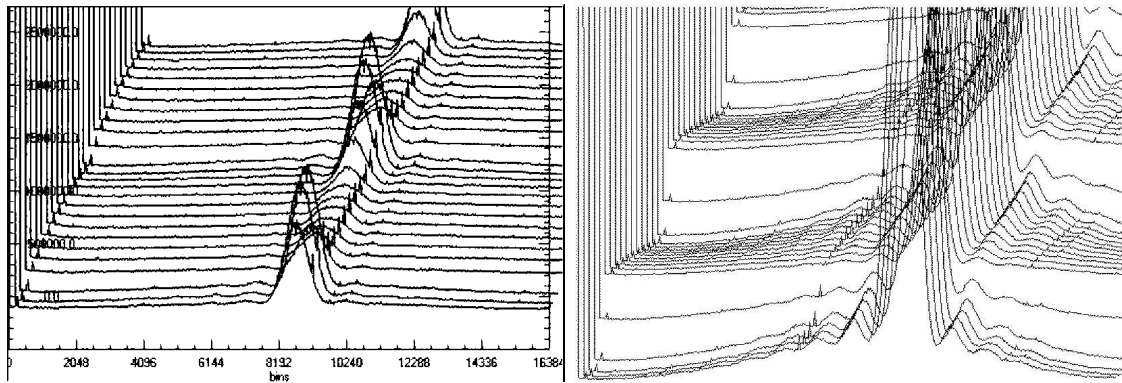

Figure 2. Temporal evolution of spectra for GLONASS satellites PR17 (left) and PR03 (right) observed at Medicina. In a right-hand-coordinate system the X-axis shows frequency, the Y-axis time, and the Z-axis signal strength in arbitrary units. These spectra cannot be compared directly to the ones observed at Onsala shown in Figure 1. Strong variations in signal strength become clearly visible.

Attempts to correlate the recorded data have been performed with the DiFX software correlator [4] and the Space Navigation Signal correlator at JIVE and Metsähovi, SWspec and SCtracker software [14]. Unfortunately, it turned out that there was a recording problem at Noto and that the VC center frequencies had been chosen slightly differently at Medicina and Onsala. Thus, the cross-correlation attempts were not successful. However, auto-correlation of the Medicina data and the Onsala data worked fine. Figure 3 shows autocorrelation results for both LHCP and RHCP

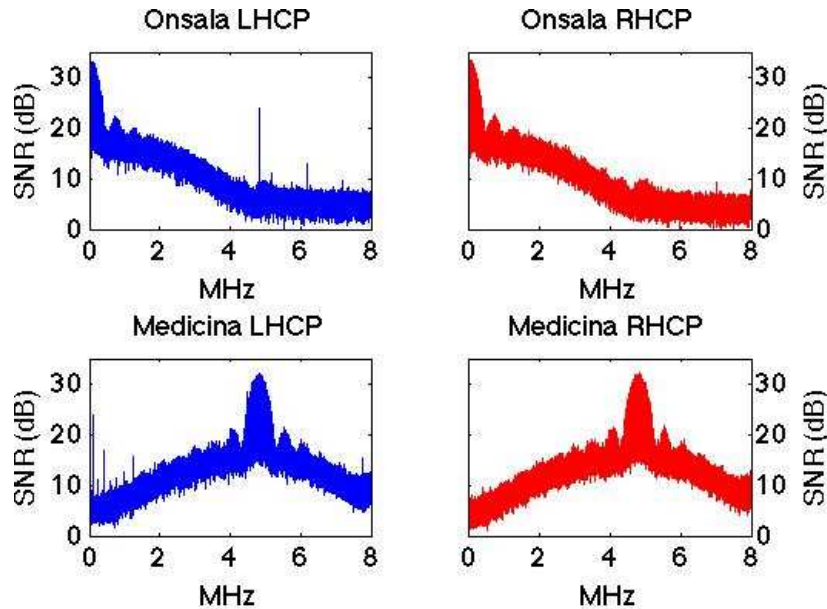data of one of the observed GLONASS satellites at Medicina and Onsala.

Figure 3. Autocorrelation spectra of the LHCP and RHCP signals of one GLONASS satellite observed at Onsala and Medicina.

Our experiment shows that it is in principle possible to track GNSS satellites directly with VLBI telescopes. To achieve successful correlation a number of aspects has to be revisited, e.g. the setup of the data acquisition system. A simplification of satellite tracking by an inclusion of the SatTrack-module for the FS in the nest official FS-release is desirable. We plan to perform simulations to improve the routines and to perform new experiments and new observations.

VLBI tracking of GNSS satellites might have an impact on GNSS orbitography. This is in particular interesting since there are new systems in development, e.g. Galileo and Compass. A direct comparison of orbits derived from GNSS themselves, SLR and VLBI can support orbit calculations. For the future, artificial VLBI beacons on LEO satellites could support VLBI phase calibration.

4. Acknowledgements

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