

AN EXPERIMENT ON RADIO LOCATION OF OBJECTS IN THE NEAR-EARTH SPACE WITH VLBI IN 2012

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Received: 2012 November 13; accepted: 2012 November 28

Abstract. An experiment on radar location of space debris objects using of the method of VLBI was carried out in April, 2012. The radar VLBI experiment consisted in irradiation of some space debris objects (4 rocket stages and 5 inactive satellites) with a signal of the transmitter with RT-70 in Evpatoria, Ukraine. Reflected signals were received by a complex of radio telescopes in the VLBI mode. The following VLBI stations took part in the observations: Ventspils (RT-32), Urumqi (RT-25), Medicina (RT-32) and Simeiz (RT-22). The experiment included measurements of the Doppler frequency shift and the delay for orbit refining, and measurements of the rotation period and sizes of objects by the amplitudes of output interferometer signals. The cross-correlation of VLBI-data is performed at a correlator NIRFI-4 of Radiophysical Research Institute (Nizhny Novgorod). Preliminary data processing resulted in the series of Doppler frequency shifts, which comprised the information on radial velocities of the objects. Some results of the experiment are presented.

Key words: instrumentation: interferometers, Very Long Baseline Interferometry – techniques: interferometric, radar astronomy – ephemeris

1. INTRODUCTION

The measurement of coordinates of a space vehicle is a traditional task in space navigation. Various methods are used to perform this task, including the method of Very Long Baseline Interferometry (VLBI). The determination of angular coordinates of the observed objects with the highest accuracy is achieved by using a differential VLBI method that performs a sequential observation of a satellite and a reference source located at a small angular distance. This method lets to determine the angular coordinates of a spacecraft by single measurement with a high accuracy, within 0.01 arcseconds (Alekseev 1989a,b; Lebreton 2005; Lanyi 2011; Jones 2011).

At the same time, the VLBI-method solves the navigation task only partly since the method does not allow to measure distance and radial velocity of the object. The space navigation methods apply the ranging and Doppler measurements using the on-board transmitters to determine these parameters. The radar VLBI method is used for studying the natural objects (planets, asteroids) and the objects of space debris. It supplements the traditional radar methods with the interferometric reception of a ground-based transmitter's signal reflected from the object (Alekseev 2000; Molotov 2004). Such an addition allows to measure with high resolution the distance, radial velocity, angle and angular velocity of the object.

A radar VLBI method has been used for refinement of the orbit parameters of space debris fragments, near-Earth asteroids and evaluation of rotation of planets. Since 2001 a large number of experiments on radar VLBI of objects in the near-Earth space have been carried out with radio telescopes of Ukraine, Russia, Italy, China, Latvia, etc. (Nechaeva 2007; Molotov 2008). The important results have been obtained on Mars in 2003, the asteroid 2004XP14 in 2006 and Venus in 2007. Precise measurements of the Doppler frequency shifts of the reflected signals relative to the transmitted monochromatic signal were obtained for several tens of space debris objects.

Post-processing of radar VLBI data has allowed to reduce the uncertainty of the object orbit parameters by a factor of ten comparing to the estimates obtained with optical telescopes. Based on the analysis of radiometric, Doppler and interferometric data, the precise rotation period for each of several objects at highly elliptical orbits has been determined, the dimensions and sizes of the objects' elements that give sharply directional reflection have been evaluated, and conclusions about the orientation of the rotation axis for several objects has been drawn.

Despite the fact that these experiments have been conducted since 2001, the main objective of the method – determining the position of a space object – has not been fully solved. By irradiation of the object with a monochromatic signal, high accuracy measurements of the Doppler frequency shifts and radial velocities have been done, but for the measurement of angular coordinates and angular velocities of the object a noisy signal is needed. In the experiments, a linear frequency modulated signal (LFM) was used instead of the noise signal. Processing of LFM signal requires additional analytic calculation of the correlation signal characteristics and the corrections of processing techniques on account of significantly lower signal-to-noise ratio than in the case of monochromatic signal.

In the last two years a new correlator, NIRFI-4, has been constructed in the Radiophysical Research Institute for processing the interferometric experiment data. In 2010, the Ventspils International Radio Astronomy Centre began to develop a correlator, designed for processing of experimental data from the radar VLBI, as a part of the European Social Foundation project “Receiving, transmitting and processing technologies of signals related to artificial Earth satellites”. Advanced algorithms of noise signal processing allows to get the result faster. The latest experiment on irradiation of several calibration objects with monochromatic and LFM-signals was carried out in 2012. This paper presents the first results.

2. EXPERIMENTS

The radar experiment on the investigation of space debris objects with using of VLBI was performed on 2012 April 17–20. The experiment consisted of irradiation of the objects with a signal of the transmitter of the radio telescope RT-70 in Evpatoria (National Space Facilities Control and Test Center), Ukraine. Working frequency of the experiment was 5 GHz. Reflected signals were received in the VLBI mode by a complex of radio telescopes, including the following VLBI-stations: Irbene RT-32 (Latvia), Medicina RT-32 (Italy), Urumqi RT-25 (China) and Simeiz RT-22 (Ukraine). Data processing was implemented on the correlator NIRFI-4 in the Radiophysical Research Institute (Nizhny Novgorod, Russia) and in the Ventspils Radio Astronomy Centre (Ventspils, Latvia).

The objectives of the international multi-purpose VLBI sessions included the following: (a) a study of the space debris objects with using of radar VLBI to measure the Doppler frequency shifts and delays for orbit refining; (b) reception of the reflected signals in the radiometric mode to determine rotation periods and sizes of the objects; (c) testing the features of the radar system on RT-70 (Evpatoria) after updating.

The following objects were observed during the experiment: three rocket stages of the launch vehicle “Molnia” (SL-6) – (22241, 92081D), (15223, 84089D), (08018, 75063D), one rocket stage of the launch vehicle “Proton” (SL-12) – (23720, 95063D), five inactive satellites – ESIAFI 1 (COMSTAR 4) – (12309, 81018A), OPTUS B1 (AUSSAT B1) – (22087, 92054A), RADUGA 9 – (12618, 81069A), GORIZONT 19 – (20263,89081A), EKTRAN 1 – (09503, 76107A).

The observation intervals of space debris objects alternated with observations of the calibration sources. Preparing space debris coordinates for pointing of all antennas was done by a method of consecutive refinements of the object orbital parameters from the data of the international TLE catalogues (<http://www.idb.com.au>, <https://www.space-track.org>).

The Nikolaev Astronomical Observatory (Shulga et al. 2008, Kara et al. 2011) and the observatories of the Ukrainian network of optical observations and research of satellites (UMOS) provided an optical support to the radar experiment. Optical positional observations of the objects served for updating the ephemeris, and photometric observations were used for a comparison with the results of radio observations. This permitted to reach high accuracy in calculations of targeting for antenna pointing.

Experimental program involved four intervals lasting for 3.5 hours each in the period of April 17–20. Due to technical problems with the transmitter on April 17 and the extreme weather conditions in Ukraine on April 18, the radiolocation

of the debris objects was successful only on April 19 and 20.

The planetary radar of RT-70 (Evpatoria, Ukraine) emitted the signal on the frequency of 5010.024 MHz with a power of 30 kW in the direction of the selected space objects. During the first 20 minutes of each session, a monochromatic signal was emitted, and then the LFM mode of radiation was activated for 5 min with a frequency deviation of 512 kHz and a period of 1 ms (on April 20 the location occurred with the monochromatic signal only).

The stations at Medicina, Urumqi and Simeiz were performed for the reception only of left circular-polarized signal, and the station at Irbene received both left and right circular-polarized signals. Data recording was carried out in the frequency band 2 MHz. The following recording systems were used in the experiment: TN16 and MK5b (Irbene), MK5b (Simeiz), MK5a (Medicina), MK5b (Urumqi).

The processing of experimental data was performed on the correlator NIRFI-4. The use of different recording systems required software improvements to convert the recorded data into a common format. The records of the test monochromatic signals made with the radio telescopes at Irbene and Urumqi after the experiment were checked for the correctness of the data conversion.

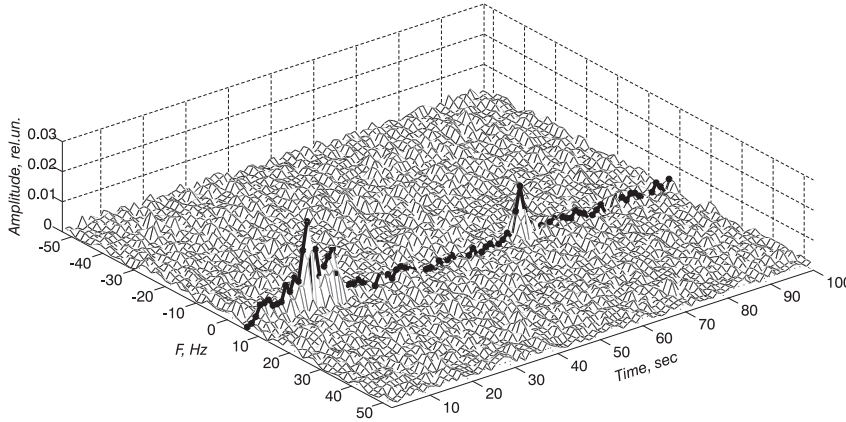


Fig. 1. Dynamic power spectrum of correlation of the signal radiated by the transmitter RT-70 at Evpatoria, and the signal, reflected from the space debris object ‘09503’ and received by RT-25 at Urumqi. The vertical axis shows the amplitude of the power spectrum in relative units, the horizontal axes show the frequency in Hz and time in seconds. 2012-04-20, 13:54 UT.

3. RESULTS

The next stage of the experiment was to process the recorded data. This procedure generally consists of correlation and spectral analysis of the obtained information and is implemented in two ways. The first routine is the mode of bi-static location, at which the correlation of the signal transmitter and the signal reflected from the objects and received by one radio telescope is calculated to measure the frequency difference between the emitted and the received signals. The difference, namely Doppler frequency shift, is conditional on the radial velocity of the object on the track “transmitter – space debris object – receiver”. The second routine is the VLBI mode, at which the multiplication of signals, recorded

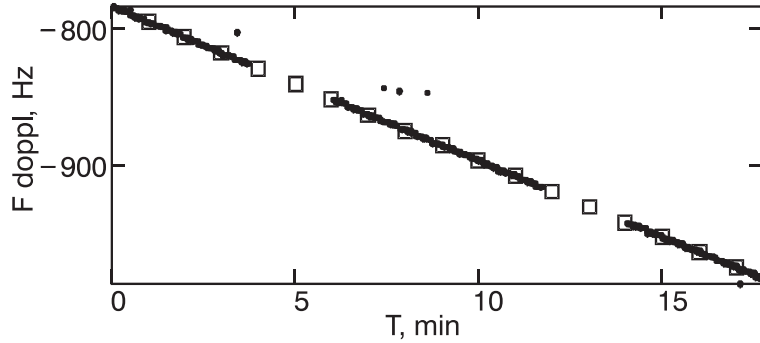


Fig. 2. Time dependence of the Doppler shift for the space debris object ‘12309’, measured at Irbene. Dots are the measured values, squares are the values calculated with the known parameters of the object. 2012-04-20, 12:06 UT.

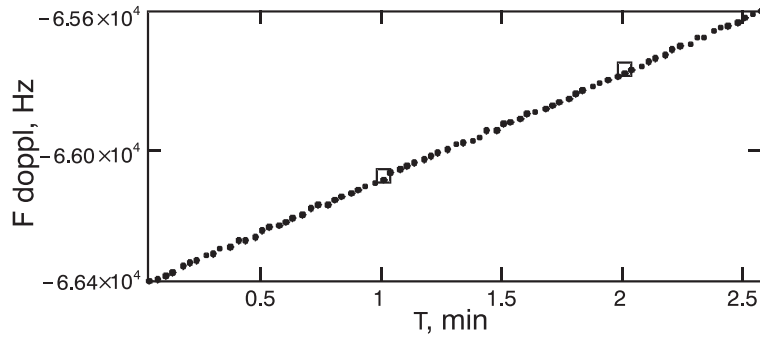


Fig. 3. Time dependence of the Doppler shift for the space debris object ‘8018’, measured at Irbene. 2012-04-19, 17:00 UT. For the meaning of symbols see Figure 2.

in two VLBI-stations, is carried out to measure the frequency of the interference (fringe rate), which depends on the angular velocity of the investigated object. If the object is located with a noise or the LFM-signal for a given mode, the spatial delay is measured. This delay represents the time difference of the signal propagation from the object to the two receiving telescopes and it is determined from the angular coordinates of the object.

By now the data processing on the first routine is finished for the signals recorded at Irbene and Urumqi. This procedure consisted of multiplication of the transmitted and received signals with pre-compensated delay and frequency shift, occurring on the propagation path. The results, obtained after the multiplication of the signals, were split into time bins of 0.5 s or 1 s, depending on the object velocity, and the power spectra for each bin were plotted. The Doppler shift was determined using the peaks of the frequency spectra.

Figure 1 shows an example of the dynamic power spectrum of the output interferometer signal, calculated in analysis of the signal, reflected from the object ‘09503’ and received by radio telescope at Urumqi. The vertical axis shows the amplitude of the correlation signal in relative units, horizontal axes display frequency in Hertz and time from the beginning of the processed interval in seconds.

As follows from the figure, the behaviour of curve, describing the variation of interferometer signal amplitude, is periodical due to the rotation of the observed object.

The measurement of the frequency of the spectrum maximum gives the Doppler frequency shift, which depends on the radial velocity of the object with respect to the transmitting and receiving stations. The graph shows the changes of the spectrum maximum frequency as a function of time for a fast-moving object.

According to the results of spectral processing of data, recorded at Irbene, the series of Doppler frequency shifts were measured for all objects, on which irradiation was performed. Figures 2 and 3 display examples of the time dependences of the Doppler shift. Boxes show the values, calculated from the known parameters of orbits, points show the experimentally measured values.

Currently, spectral analysis of the signals, detected with radio telescopes at Urumqi and Medicina, is in progress. The processing of the interferometer responses is started in a mode of VLBI in order to obtain the frequencies of interference and spatial delays. Future plans include the implementation of post-processing with the aim to obtain the wanted parameters, such as radial and angular velocities and angular coordinates of space debris objects.

The resumption of international radar VLBI experiments at a higher technical level makes it possible to develop the methods of the near-Earth space monitoring with the purpose to ensure safety of the space satellites and manned space stations operating, as well as to evaluate the hazard of asteroid impacts.

ACKNOWLEDGMENTS. The used results are based on observations with the following radio telescopes: Evpatoria RT-70 (National Space Centre, Ukraine), Irbene RT-32 (Ventspils International Radioastronomy Centre, Latvia), Medicina RT-32 (INAF – Istituto di Radioastronomia, Italy), Urumqi RT-25 (Xinjiang Astronomical Observatory, China), Simeiz RT-22 (Crimean Astrophysical Observatory, Ukraine). The researches were supported by the European Social Fund's Project "Receiving, transmitting and processing technologies of signals related to artificial Earth satellites" (2009/0231/1DP/1.1.1.2.0/09/APIA/VIAA/151).

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