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First results of European VLBI radar observations of space objects

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Abstract. Since 1999 we carried out seven trial VLBI radar experiments under LFVN project. The aim of this work is to adjust new research technique for investigating the Solar system bodies (planets, asteroids, space debris). It is planned to obtain the information on their movement parameters, proper rotation and structure of surface. The transmitter of Evpatoria RT-70 sounded the space objects. Array of Bear Lakes RT-64, Noto RT-32, Urumqi RT-25, Simeiz RT-22 received the echo-signals. The data were processed with NIRFI-3 Mk-2 correlator in N. Novgorod, Russia and NRTV processor in Noto, Italy. The first results of these experiments are presented.

1. Introduction

In 1998, Evpatoria RT-70 was joined to the LFVN project (Molotov et al. 2003) that has the purpose to arrange the international VLBI cooperation with participation of former Soviet Union radio telescopes. The fully steerable 70 m dish is equipped with one from most powerful 6-cm band transmitter in Europe that was used for the deep spacecraft communications and the radar research of Mars, Venus and Mercury (Molotov 2004). Since 1999, the radar researches of the Solar system bodies were renewed using unique experience of LFVN team on the differential VLBI measurements of spacecraft trajectories (Alexeev et al. 1989). The seven trial experiments were carried out to adjust the VLBI radar procedure, which joins the "classic" radar and differential VLBI measurements. Such combination can provide new scientific instrument to measure the variations of proper rotation of the Solar system bodies, determine their trajectories at Radio Reference Frame, to obtain the data on the object sizes and structure of surface. The radar system of Evpatoria RT-70 at Ukraine provided the sounding of space targets (Earth group planets, near-Earth asteroids and space debris objects) with help of 200 kW transmitter of continuous power at 5010 MHz. The reflected echo-signals were received at Bear Lakes RT-64, Noto RT-32, Urumqi RT-25, Simeiz RT-32 and Kalyazin RT-64. At first, the Mk-2 and S2 VLBI terminals were used for recording the echoes (the recorded data were processed by NIRFI-3 Mk-2 correlator in N. Novgorod). Then, new specialized NRTV (near-real-time-VLBI) terminals and correlator were designed in Noto, Italy (Tuccari et al. 2002). In common, the echoes of Mars, Venus and about 50 orbital objects were detected.

2. Observations and processing

The some results of the experiments VLBR03.1 and VLBR04.2 are presented below. The sessions were carried out in the period of July 23 – 29, 2003, and July 23 – 29, 2004. The scientific program included Venus, 2000 PH5 asteroid and a number of space debris objects at geostationary, highly-elliptical and half-day circular orbits.

The first stage of processing includes the auto-correlation of the recorded tapes to detect the echo-signals from each object on each receiving antenna (Fig. 1).

The next stage is the cross-correlation processing of the transmitted signals and received echoes for each baseline "transmitting antenna – receiving antenna". As a result of spectral analysis the frequency of doppler shift is measured (Fig. 2).

The recording of echo intensity at Bear Lakes RT-64 allows to evaluate the main period of the object rotation (see Fig. 3a). Fourier transformation of the single impulse of an object rotation gives the one-dimensional convolution of the reflected region in wavelengths to estimate the sizes of the object. While the record of intensity is not performed at other receiving sites, we are tracking the time evolution of maximum of cross-spectrum ("transmitting antenna – receiving antenna"), that is equivalent to echo intensity changing.

The recording of intensity demonstrates the period of rotation for "Raduga-9" as 83 s, the time dependence of spectral maximum on baseline Evpatoria – Bear Lakes confirmed this result, while spectrum Evpatoria-Urumqi demonstrates in two time longer period. This means that Raduga 9 has symmetric elements (solar batteries) that are visible from Bear Lakes and Urumqi under different angles.

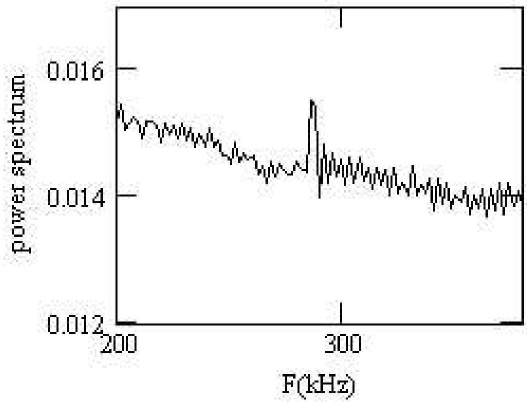

Fig. 1. Power spectrum of result of autocorrelation for echo from Venus, receipted at Bear Lakes (27 July, 2004; signal-to-noise ratio 3.4, frequency resolution $df = 1.9$ kHz).

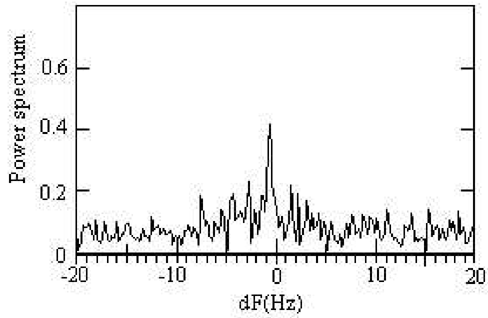

Fig. 2. The cross-spectrum of echo from "Raduga-9", receipted at Urumqi, and transmitted signal from Evpatoria. Doppler shift evaluated according frequency of spectral maximum $F = 1574.147$ Hz. (28 July 2003, 19:47; frequency resolution $df = 0.234$ Hz).

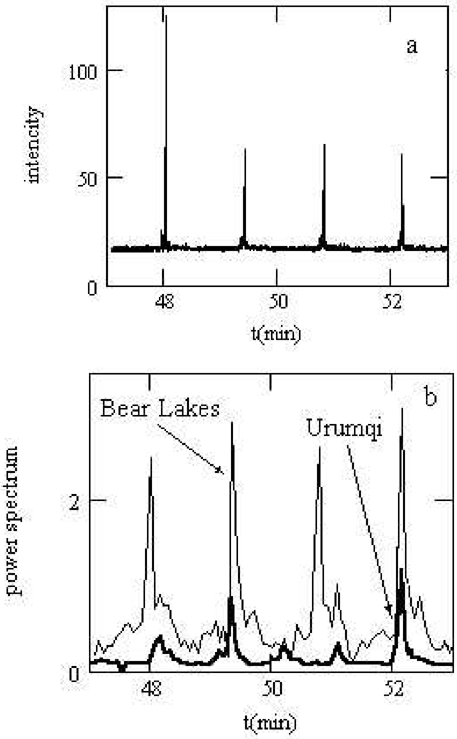

Fig. 3. a) Recording of echo intensity of "Raduga-9"; time resolution dt=0.017 s; estimated period of rotation is 83 s; b) Dependence of spectral maximum on time (cross-spectrums for "Raduga-9" on Evpatoria-Bear Lakes and Evpatoria-Urumqi baselines), time resolution dt=4.26 s, real period of rotation is 166 s.

Then the cross-correlation of echo signals is obtained for baselines between receiving antennas. Analysis of time evolution of spectral maximum at different baseline allows to estimate the direction of object rotation axis.

The signal delay-time dependence in the form of a 3rd degree polynomial is calculated with respect to a preliminary trajectory model of the object, coordinates of VLBI points and cycle time. This calculation takes into consideration the near-field effect associated with the movement of the object with respect to the center and rotation of the Earth. This polynom is used for the computation of the time delay, which are compensated during the correlation processing of the radar echo received at each VLBI point of the interferometer baseline.

At final stage the measured fringe rate is analyzed and relative (echo - reference quasar) fringe rate value is calculated.

3. Results

Currently, the rows of Doppler shift measurements were obtained for baselines Evpatoria – Bear Lakes, Evpatoria – Noto and Evpatoria – Urumqi. In principle, it is enough to solve the coordinate goal using of object trajectory model (Alexeev et al. 1989). The mean-root-square error is 0.096 Hz (corresponding to 3 mm/s rate), that is three times worse than apparatus mistake (1 mm/s rate).

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