ESTIMATION OF THE GROUND-SPACE INTERFEROMETER PARAMETERS DURING RADIOASTRON MISSION

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ABSTRACT. The model of motion of the space radio telescope (SRT) was developed for calculation of the interferometer delay and other parameters to ensure the proper work of the Astro Space Center correlator during the Radioastron mission. The ARIADNA package was used as base for correlation process. This package was used for estimation of the ground-space interferometer parameters too.

1. INTRODUCTION

The RadioAstron project is an international collaborative mission to launch a satellite carrying a 10-meter space radio telescope (SRT) on the elliptical orbit around the Earth. The aim of the mission is to create the ground-space VLBI to observe the radio sources with high angular resolution. The orbit of the SRT has an apogee altitude of about 330 000 km, a period of 8–9 days, and an eccentricity of about 0.9. The ground-space VLBI observations at a standard radio astronomical wavelength set of 1.35, 6, 18, and 92 cm with such orbit would provide information about structure of the galactic and extragalactic radio sources at microarcsecond level.

Our goal is to use the ground-space VLBI observations for the solution of some astrometric problems such as study of the defining sources structures and their variations, connection of the ICRF and dynamical system based on the pulsar timing, by means of measuring the ground telescopes coordinates relative to the center of mass of the Earth.

The key for solution of these problems is the reconstruction of the SRT precise orbit. A model of motion of the SRT was developed for calculation of the interferometer delay and other parameters to ensure the proper work of the Astro Space Center correlator. The ARIADNA package was used as base for correlation process.

2. MODELLING OF THE SRT TRAJECTORY

In order to model the SRT trajectory the ARIADNA package was transformed significantly and was named as ORBITA [1]. Main difference of new package from the ARIADNA package is calculation of the SRT motion parameters.

The orbital elements of the SRT are chosen to maximize their evolution by weak gravitational perturbations from the Moon and the Sun [2]. Such an evolution provides a possibility to observe many radio sources, located on the sky at directions close to the orbit plane, to start their study with moderate angular resolution.

The initial elements of orbit were established: apogee height $H_a = 333455$ km; perigee height $H_p = 578$ km; longitude of ascending node $\Omega = 342.2°$; ascending node-perigee angle $\omega = 302.0°$; inclination of the orbit $i = 51.4°$; eccentricity $e = 0.93$. Initial rotation period is about 8.32 days.

From the ballistic point of view the SRT is a difficult object. The pressure of solar radiation produces different effects on the different elements of the spacecraft construction. As a result, a force-moment appears around the spacecraft center of mass. The reaction-wheel system is used to keep spacecraft orientation constant. Long-run effects of force-moments lead to a permanent increase of angular momentum that requires unloading the momentum of the spinning reaction wheels by switching the gas engines on.

Such operations result in perturbations of the motion of the SRT center of mass. Estimations show that the velocity changes caused by such perturbation can achieve values of 1–5 mm/s.

Ballistic navigation information (vector of state of spacecraft, range and radial velocity measured by ground tracking stations, etc.) used in the ORBITA package is distributed by the Keldysh Institute of Applied Mathematics. It is named for this study as "reference".

We had not real noisy signals received by the ground telescope and SRT. So at the first stage of work the reference trajectory of the SRT (really unknown) was used for calculation of the vectors of state $\mathbf{X_S}, \dot{\mathbf{X}}_\mathbf{S}, \ddot{\mathbf{X}}_\mathbf{S}$ beginning from t_0 to moment of observation t_j $(j = 0, 1, 2, ..)$. Then the digitized noisy signal (bit sequence) $x(t_j)$ for the terrestrial telescope was generated. Similar signal $y(t_j)$ for the SRT was generated by shifting the bit sequence $x(t_j)$ on calculated delay, fringe frequency and adding the phase drift due to relativistic effects. Test of correlation (calculation of delay, fringe frequency and phase by the ORBITA software for reference trajectory of the SRT) was done according to the diagram in Figure 1a.

For the second test the "model" trajectory of the SRT was generated. Numerical integration of the differential equations was used. We consider that this trajectory is known and can be reconstructed on base of known forces. The vector of state for time t_0 was taken from the "reference" orbit. Because the forces acting on the SRT in the ORBITA package differ from ones and used for calculation of the reference trajectory the "model" trajectory will go away from it. The vectors of state $\mathbf{X^m_S}, \dot{\mathbf{X^m}}_\mathbf{S}, \ddot{\mathbf{X^m}}_\mathbf{S}$ for moments of observation t_j $(j = 0, 1, 2, ..)$ are known and used for calculation of delay, fringe frequency and phase as apriori parameters for correlator. Method of generation of the signal and correlation test for this stage are shown in Figure 1b.

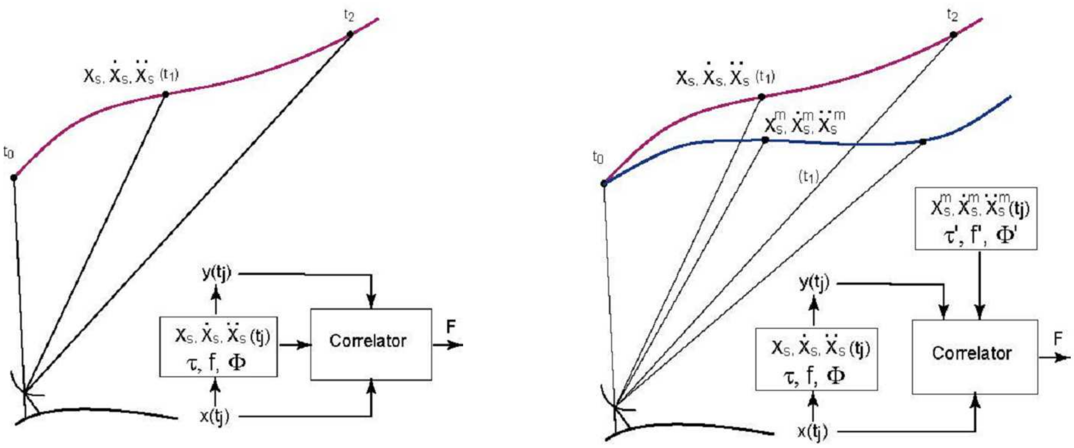

Figure 1: Method of the correlator test a) for the reference trajectory of the SRT and b) for the reference and "model" trajectories.

Two stages of simulation allow to estimate the effect of uncertainty of the vectors of state $\mathbf{X^m_S}, \dot{\mathbf{X^m}}_\mathbf{S}, \ddot{\mathbf{X^m}}_\mathbf{S}$ for different moments of observation t_j on coherent time of integration. Uncertainty means here the differences $|\mathbf{X_S} - \mathbf{X^m_S}|, |\dot{\mathbf{X}}_\mathbf{S} - \dot{\mathbf{X^m}}_\mathbf{S}|, |\ddot{\mathbf{X}}_\mathbf{S} - \ddot{\mathbf{X^m}}_\mathbf{S}|$ that will increase with t_j because trajectories will go away.

The last stage of simulation is connected with estimation of such parameters of the ground-space VLBI as sensitivity and its dependence from the integration time. Such estimation can be done by adding independent noise signals with known amplitude for each bit sequences $x(t_j)$ and $y(t_j)$. Varying signal-to-noise ratio and uncertainty of the vectors of state $\mathbf{X^m_S}, \dot{\mathbf{X^m}}_\mathbf{S}, \ddot{\mathbf{X^m}}_\mathbf{S}$ one can estimate sensitivity of the ground-space interferometer for different ground telescopes. As example the cross-correlation function for SRT – Simeiz interferometer is shown in Figure 2.

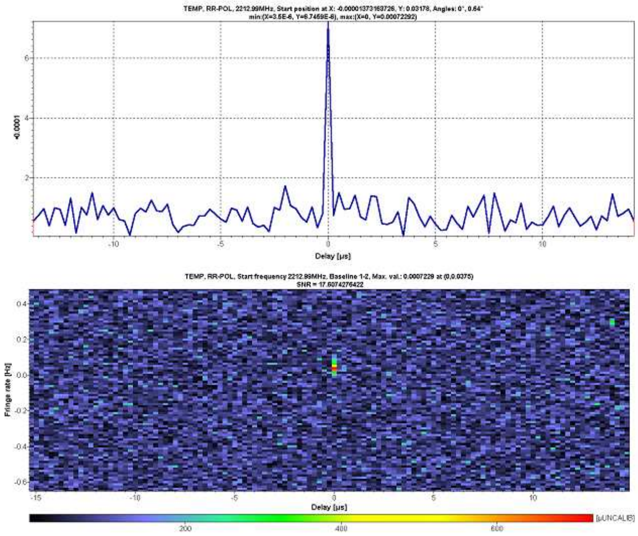

Figure 2: Modelled interferometer pattern for SRT – Simeiz VLBI.

3. CONCLUSION

It was shown that the key for success of the Radioastron mission is the reconstruction of the SRT precise orbit. A model of motion of the SRT was developed for calculation of the interferometer delay and other parameters to ensure the proper work of the Astro Space Center correlator. The ARIADNA/ORBITA package was used as base for correlation process. To study the parameters of the ground-space interferometer two noisy signals "received" by the ground telescope and SRT were emulated. At first, the position and velocity of the SRT were varied relative to the known (reference) trajectory and then the signal to noise ratio (SNR) was changed. The Correlation of signals gives us the possibility to estimate such parameters of the ground-space VLBI as sensitivity and its dependence from the integration time, the coherence time and dependence from the SNR and the SRT position errors. It was shown that to ensure the mission success, the different methods of SRT orbit control have to be developed and applied.

The first observations were made on November 15, 2011 at 18 cm wavelength [3]. The quasar 0212+735 was observed and fringes were found on December 8, 2011 between the space radio telescope and the following ground based radio telescopes: the 32-meter Russian "Quasar" antennas at Svetloe, Zelenchukskaya, and Badary of the Institute of Applied Astronomy, Russian Academy of Sciences, the 64-meter Ukranian antenna at Evpatoria, the State Space Agency of Ukraine, and the Max-Planck-Institute for Radio Astronomy 100-meter antenna at Effelsberg, Germany.

This result confirmed estimates based on our simulations.

4. REFERENCES

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[3] http://www.asc.rssi.ru/radioastron/news/newsl/en/newsl_10_en.pdf