Space Vehicles Observations Using "Quasar" VLBI Network

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"Quasar" VLBI network has all the capabilities to perform high-precision ground-based radio observations of the space vehicle in deep space. Multichannel broadband recording of space vehicle and quasars signals combined with the software correlator allows configuring the system for processing the target signals in different radio bands and modes including single dish one. The potential of the "Quasar" VLBI network for ephemeris support of the space programs was confirmed by the following observations: Doppler and phase measurements of RadioAstron spacecraft and VLBI observations of Mars Express, lunar landers, GLONASS and Beidou navigation satellites. The measurements errors correspond to the theoretical values.

Keywords: Space vehicle, VLBI, Doppler measurements, carrier phase measurements.

1 Introduction

The potential of the "Quasar-KVO" VLBI complex for space vehicles observations in the near and deep space is connected with the following factors: the possibility to perform measurements using practically any SV radio signals, from broadband to monochrome ones, in L, S, C, X and Ka bands; flexible preprocessing system based on the use of hardware and software correlators of IAA RAS; high, up to several millimeters, precision of the time delay in VLBI measurements; the possibility of the use of GNSS receivers and vapor water radiometers to compensate the atmospheric delays; the possibility to improve the geometric properties of "Quasar-KVO" VLBI network by adding

stations from the international VLBI networks; experience of VLBI observations of Earth satellites, space probes and landers; the possibility to perform high-precision differential spacecraft and quasar VLBI observations.

"Quasar-KVO" makes VLBI observation of satellites in the two regimes: in the international VLBI networks and according to its own programs. For example, spacecraft Mars Express is observed only within the framework of international programs.

2 Space vehicles observations and results

Generalized scheme of data flows during the planning, performing and processing of VLBI observations is shown in Fig. 1.

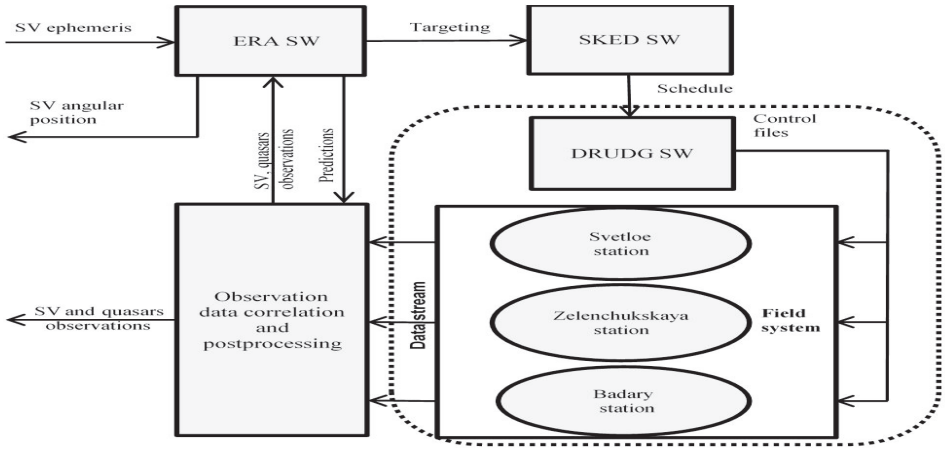

Fig. 1. Data flow during the planning, performing and processing of the VLBI observation

The part of the scheme, encircled by a dotted line, is used in the international programs. The remaining part of the scheme works during observation programs of IAA RAS. These blocks are responsible for observations schedule, predicted angular positions and delays for radio telescopes targeting and correlation processing, for post processing to produce adjusted orbital elements or angular positions of the satellites using differential VLBI observations.

It should be noted that SV observations can be preceded by mathematical modeling using the software ERA [2]. Simulation allows us to evaluate the potential error in determining the parameters of the target spacecraft orbit without performing real measurements and make the optimal observations schedule. Simulation takes into account such parameters as the spacecraft orbital parameters, the model of non-gravitational forces, the types of observations, etc.

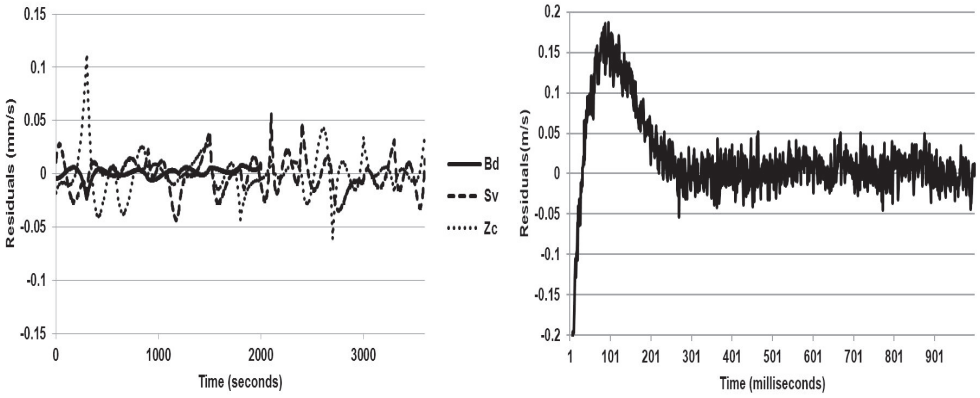

Fig. 2. RadioAstron(on left) and GLONASS(on right) residuals of Doppler measurements

The possibility to use the "Quasar" VLBI network for ephemeris support of the space programs was confirmed by the following observations: Doppler and phase measurements of RadioAstron spacecraft and GLONASS satellites (Fig. 2), VLBI observations of Mars Express, lunar landers, GLONASS and Beidou navigation satellites.

Observations of satellites by IAA RAS programs are performing in order to develop methods of correlation and post-processing of measurement data in differential VLBI mode and measurements in single dish mode.

Making analogies with GNSS it may be stated that the system of "antenna — receivers — time and frequency standard — data acquisition system — software correlator [3]", realized in the "Quasar" VLBI network is a universal software receiver for registering and processing of spacecraft signals. The well-known structure involves the use of the signal code generator in the software correlator and allows obtaining classical pseudorange and phase measurement. Continuous tracking of the spacecraft signal allows measuring the integrated phase with submillimeter accuracy, derivative from the integrated phase measurements give the pseudorange rate (Doppler measurements). The first difference of pseudoranges at different VLBI stations is an analog of interferometric delay, measured by VLBI. The basic structure of GLONASS data processing in pseudorange mode is presented in Fig. 3.

RadioAstron and GLONASS space vehicles (Fig. 2) was selected for test measurements in single dish mode in X- and L-bands, monochrome and wide band signals, correspondingly. Residuals RMS for RadioAstron Doppler measurements was about 0.02 mm/s. For GLONASS Doppler residual RMS was about 1.5 cm/s. RMS difference is explained by different averaging interval for Doppler measurements calculations: 1 millisecond for GLONASS satellite vs 300 seconds for RadioAstron spacecraft.

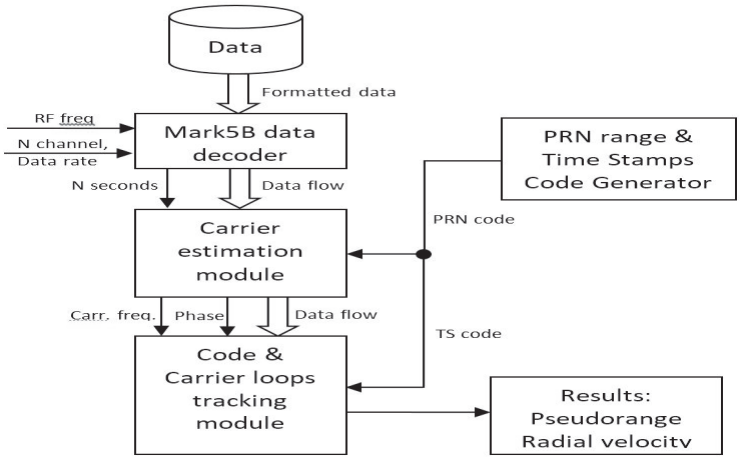

Fig. 3. The basic structure of complex GNSS data processing

3 Conclusions

The potential of the "Quasar" VLBI network for ephemeris support of the space programs was confirmed by the following observations:

1) Doppler and phase measurements of RadioAstron spacecraft and GLONASS navigation satellites;

2) VLBI observations of Mars Express, lunar landers, GLONASS and Beidou navigation satellites.

The measurements errors correspond to the theoretical values.

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