Russian VLBI System of New Generation

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Abstract The VGOS Program is being implemented in Russia to create the new generation of VLBI systems. The new generation radio interferometer provides implementation of perspective requirements for determining and predicting the Earth orientation parameters. The work was started in 2012, and the two-element radio interferometer will be created by the end of 2015 at the Badary and Zelenchukskaya co-location stations. The program includes the creation of two fast moving 13.2-m radio telescopes equipped with the receiving systems which will receive radio signals at three bands (S, X, and Ka) and two circular polarizations simultaneously. The digital broadband acquisition system provides a conversion to the 1 GHz band. The VDIF-formatted digitized data will be transferred to the St. Petersburg Correlation Processing Center by the communication channels. The current state of the program is presented.

Keywords VLBI, EOP, VGOS

1 Introduction

At the present time, high-precision determination of the Earth Orientation Parameters (EOP) and the well-timed determination of Universal Time (UT1) for GLONASS are provided by means of the QUASAR VLBI Network. At the same time, the QUASAR network works in cooperation with IVS and provides relevant data on the Earth rotation parameters and terrestrial and celestial reference frames.

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Characteristics of perspective GLONASS make higher demands on the full range of fundamental parameters, including determination and forecasting of EOP:

– *EOP determinations:* not worse than 3 mm for the pole coordinates, 10 μs for UT1 and 100 μas for precession and nutation;

– *Operational UT1 determinations:* 3–4 times a day with an error of 20 μs.

The achievement of the accuracy and rapidity are the most important for determination of Universal Time. The implementation of such Intensive sessions will be possible after principal modernization of the QUASAR network stations on the basis of small-diameter antennas. The antenna systems of the new VLBI network must work every day and on a 24-hour basis.

The simulation showed that the optimal diameter of the new antenna system should be about 13 m. This will cause the loss of flux sensitivity of the new antenna system by a factor of 7 compared to the QUASAR VLBI network antenna. This is compensated by an increase of bandwidth (not less than six times) and the number of observations of radio sources (not less than eight times). The first requirement is achieved by using wideband receivers with a registration frequency bandwidth of 1 GHz, and the second by a significant increase in the speed of antenna motion from one radio source to another (at least 5-6 deg/s in elevation and 12 deg/s in azimuth). The desired accuracy of UT1 determination can be achieved with the Badary-Zelenchukskaya baseline of the QUASAR network if the duration of observation scans will be up to 20 seconds. The number of observations obtained per day at such duration and speeds of antenna motion allows estimation of EOP with the desired accuracy.

The “Quasar-M” project, focused on constructing the two-element radio interferometer, is currently realized at the IAA.

2 VLBI2010 (VGOS) Antenna System

The IAA analyzed in detail all possible variants of the new generation antenna system (AS) for the purpose of fulfilling VLBI2010 (VGOS) requirements. Also taken into account were the possibility of placing the receiving equipment, the shipping cost, and the volume of work required to install the equipment. As a result, the 13.2-m AS produced by Vertex Antennentechnik GmbH was chosen (Figure 1). Vertex Antennentechnik GmbH also provided modernization of the AS to satisfy climatic and seismic conditions in the placements.

– Frequency range: 2–40 GHz;
– Main reflector diameter: 13.2 m;
– Overall surface accuracy: 0.2 mm (RMS);
– Mount: Elevation over Azimuth;
– Ring focus antenna;
– Subreflector mount: hexapod;
– Efficiency: 0.8;
– Max AZ velocity: 12 deg/s;
– Max EL velocity: 6 deg/s;
– Overall pointing accuracy: 16 arcsec.

Fig. 1 New 13.2-m VERTEX antenna in Badary (Feb. 2014).

3 Tri-band Receiving System

The tri-band receiving system provides signal amplification in S, X, and Ka frequency bands in both circular polarizations [1]. The main receiver system parameters are presented in Table 1. In order to improve the signal-to-noise ratio, the tri-band feed and the frontend LNAs are mounted in a single unit and cooled by closed cycle refrigerator to the temperature of liquid hydrogen (20 K) (Figures 2 and 3). The LNA outputs are connected to the inputs of the converter units. Each converter unit provides additional signal amplification, conversion of the signal frequency to the intermediate frequency (IF) band of 1–2 GHz, formation of the output signal bandwidth, and signal filtering. The commutator unit provides two modes of operation and forms four frequency channels in different frequency bands: 1S+3X or 1X+3Ka. Synchronization of the frequency converters is provided by the frequency-time synchronization system of the radio telescope. The radio telescope receiver units are placed in the focal cabin.

Table 1 Tri-band receiving system parameters.

Band	Freq. band GHz	Polarization	Estimated T_{sys},K	Radiation angle, deg	Number of channels	Working mode
S	2.2–2.6	RCP	23.2		2	1S+3X
X	7.0–9.5	+/−	29.7	130	6	or
Ka	28–34	LCP	44.5		6	1X+3Ka

4 Broadband Data Acquisition System

The BRoadband data Acquisition System (BRAS) is the digital backend of the radio telescope [2]. The system consists of eight identical Digital Converter Channels (Figure 4). Each channel has an input frequency range of 1 to 1.5 GHz and 512 MHz bandwidth. The

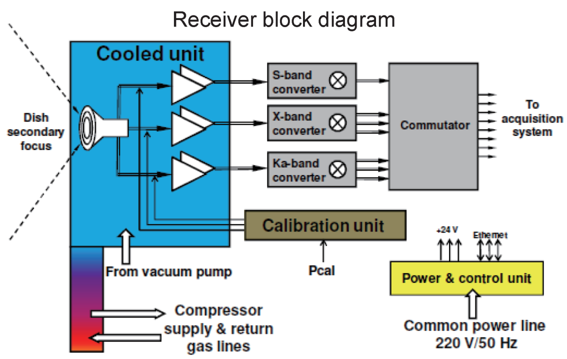

Fig. 2 Tri-band receiver block diagram.

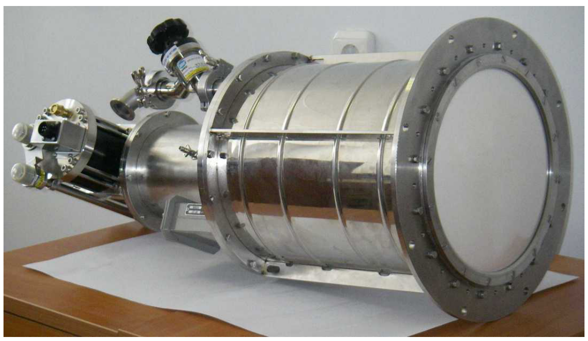

Fig. 3 Cooled unit.

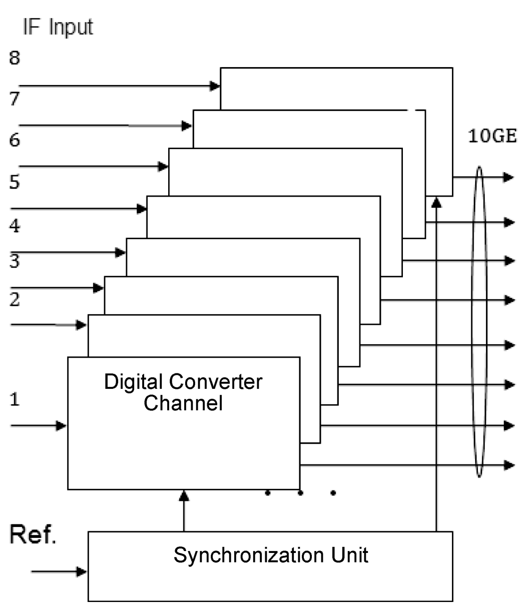

Fig. 4 The structure of BRAS.

input of each channel is connected to one of the IF outputs of the receiving system. Each channel has an ADC and an FPGA. The signal power measurement, 2-bit sampling, and data stream formatting are performed in the digital form. The Synchronization Unit is intended for formation and distribution of clock signals between all channels. Phases of these signals are synchronized with a 100 MHz signal from an H-maser and 1 PPS from the time scale of a radio telescope. Through the 10 GE interface data streams arrive at fiber lines. The total rate of the data stream at the system output is 16 Gbps. The system has built-in controls and diagnostics, including measurements of signal levels, current consumption, temperature on boards and chip, selection of the phase calibration signal, control of phase and amplitude characteristics, control of the locked-in state, and control of the statistics of the signal distribution on sampling levels. The system is controlled by computer. BRAS is implemented in a conventional 19" rack and located in the focal cabin of the antenna. Currently two samples of the system are ready to be installed on the antennas.

5 Time and Frequency Synchronization System

The time and frequency synchronization system (TFSS) provides transmission of high stable reference time and frequency signals to the focal cabin of the antenna where the tri-band receiving system and BRAS are located. For this purpose, special devices were designed, which allow reduction of the transmission loss of reference signals (Figures 5 and 6). For transmitting reference signals to the radio telescope, a new method is used. The reference signals are transferred through a fiber optic line that has better spectral characteristics than coaxial cable. For compensation of phase fluctuations due to the telescope motion, a phase stabilization scheme is used. The time synchronization unit provides time delay measurement and compensation in transmission lines. The p-cal signal generator with a frequency range up to 35 GHz was developed for wideband receiver phase calibration. All units of TFSS are placed into thermostabilized boxes.

Fig. 5 Unit for the formation reference frequency signal at an antenna.

Fig. 6 Time synchronization unit.

6 Center of Control and Scheduling

All systems developed for the new generation network are equipped by internal controllers with Ethernet interfaces. Monitoring and control are provided locally at the station and via Internet from the Center of control and scheduling at IAA RAS. We plan not to use pure remote control of operations. Session schedules should be loaded remotely from the Center and then run locally at the stations. This will improve reliability on unstable communication channels. However, remote control and monitoring capabilities will be improved relative to the existing system. The software development for remote control is in progress and is taking into account the security of the remote access.

7 Buffering and Data Transmission System

IAA RAS develops buffering and data transmission systems which realize VLBI2010 (VGOS) requirements [3]:

– recording of eight data streams (with scalability up to 16 data streams) in the VDIF format with 2 Gbps data speed from each channel;

– realizing data transfer to the Data Processing Center at 10 Gbps simultaneously with recording and buffering data;

– storing observational data up to 20 TB in size in the generic file structure with a set of disk pools.

The Data Recording System (DRS) is based on Commercial Off-The-Shelf (COTS) hardware [4, 5]. The DRS consists of a rack server Dell PowerEdge R720 with two Intel CPU Xeon E5-2643 3.30 GHz or Xeon E5-2650 2.0 GHz, 96 Gb RAM, and two disk enclosures Dell PowerVault MD1220 (up to 24 2.5″ hot-pluggable small-form-factor drives) (Figure 7). With this configuration, the disk subsystem of the server setup consists of three SAS backplanes, up to 64 2.5″ drives maximum. Each SAS-backplane is attached to an LSI SAS2008 based SAS HBA by two 24 Gbps SAS 2.0 channels. Up to four dual-port 10 Gigabit Ethernet Intel network cards (Intel X520) are used. The connection of DRS with digital backend was carried out in two ways: a direct connection from each BRAS channel to the 10 GbE network interface server and an Ethernet switched connection through the Cisco Catalyst c4900M switch, as seen in Figure 8. The DRS provides temporary storage for VDIF data of a single hour-long VLBI session that comes from BRAS (8 channels x 2 Gbps) placed at QUASAR network observatories and simultaneous data transmission from two observatories over fiber lines (the transmission rate is up to 8 Gbps). It also provides data storage for all three or four hour-long VLBI sessions at IAA RAS in St. Petersburg. This DRS is compatible with international registration systems. Data transmission is performed via Internet using broadband communication channels. The 10 Gbps Internet channel will let us carry out hour-long VLBI sessions three or four times a day.

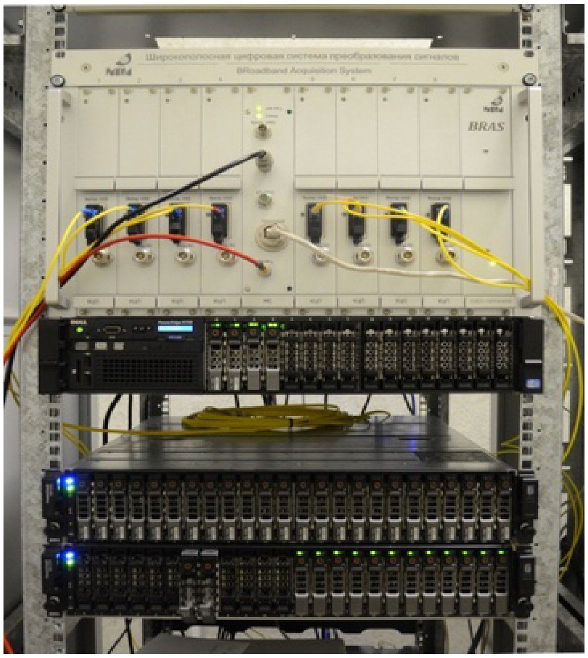

Fig. 7 Data Recording System: Server Dell PE R720 with storage Dell PV MD1220 (bottom) and digital backend BRAS (top).

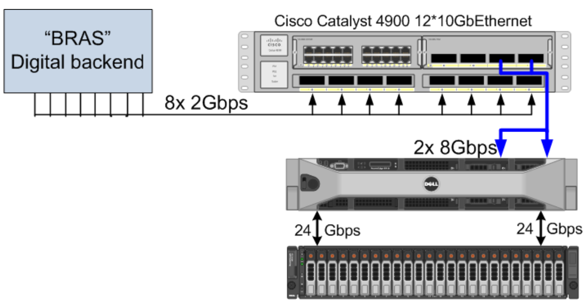

Fig. 8 Ethernet switched connection through the Cisco Catalyst c4900M switch.

8 Water Vapor Radiometer

Water vapor radiometers were constructed to have near real time information about tropospheric zenith wet delay (ZWD) in QUASAR network observatories for use in VLBI data processing and UT1 calculation. Two models of WVRs were tested at the Svetloe observatory [6]. One of them is fully steerable to have the ability to follow VLBI radio telescope RT-32 ,and another one is measuring ZWD. Comparing ZWD obtained with WVR and ZWD determined from GNSS observations demonstrates the coincidence with the accuracy of (3-5) mm (RMS) on an interval of several months, excluding periods of rainfall. WVRs are equipped with rain intensity sensors.

WVRs will be installed at the Badary and Zelenchukskaya observatories at the end of 2014.

For more accurate ZWD measurements, all QUASAR network sites will be equipped with atmosphere temperature profiles MTP-5 [6].

9 Summary

The two-element interferometer at the co-location stations Badary and Zelenchukskaya will be created in the framework of the "Quasar-M" project. This interferometer will determine UT1 3–4 times per day with an accuracy of 20 microseconds.

Milestones of the "Quasar-M" project are:

2013 – production of main equipment prototypes (feed, front-end, DAS);
2013 – building of the radio telescope foundation;
2014 – assembly of antenna parts at the observatories;
2015 – first VLBI observations.

The use of the created two-element radio interferometer in joint observation sessions with international global network stations will perform pole position determinations with an accuracy of 3 mm, nutation and precession angles with an accuracy of 100 μas, and determination of Universal Time with an error of 10 microseconds.

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