“Quasar” VLBI Network Stations Report

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Abstract The current status, as well as activities in 2019 and 2020, of the “Quasar” VLBI Network stations is presented.

1 General Information

The “Quasar” VLBI Network is a unique Russian astronomical instrument created at the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) [1].

The main purposes of the “Quasar” Network are to improve the celestial and terrestrial reference frames, to monitor the Earth rotation parameters, and to study data essential for understanding the Earth’s environments. The Network consists of three observatories including Svetloe in Leningrad Region, Badary in Eastern Siberia, and Zelenchukskaya in the Northern Caucasus and the Data Processing Center in St. Petersburg. The Svetloe observatory was the first to be put into operation in 1999, the next was Zelenchukskaya in 2002, and the final was Badary in 2005. The baselines of the radio interferometer vary from 2,000 to 4,400 km. Each observatory is equipped with at least three co-located instruments of different techniques: VLBI, SLR, and combined GNSS receivers [2]. In addition, the Badary observatory is equipped with the DORIS system. All observatories are linked by optical fiber lines, are equipped with identical hydrogen Time Standards, and also are equipped with Water Vapor Radiometers and meteorological stations whose data are used for all types of observations.

The basic instruments at each of the three observatories are a 32-m radio telescope (RT-32) and a VGOS radio telescope (RT-13). Figure 1 presents a view of the Badary observatory.

Fig. 1 Badary observatory.

The Legacy 32-m antennas (SVETLOE, ZELENCHK, and BADARY) provide a completely automatic process of observing the radio sources and satellites in a radiometric or radio interferometric mode. The main technical characteristics of the antennas are presented in Table 1. At SVETLOE station, there is a limitation on the maximum number of scans per 24-hour session: no more than 350 scans. Each RT-32 radio telescope is equipped with highly sensitive receivers, providing signal amplification in the K (22.02–22.52 GHz), X (8.18–9.08 GHz), C (4.6–5.5 GHz), S (2.15–2.5 GHz), and L (1.38–1.72 GHz) frequency bands in both circular polarizations. A cooled low-noise amplifier is

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Table 1 Specifications of the RT-32.

Mount	alt-azimuth
Configuration	cassegrain
Subreflector scheme	asymmetrical
Main mirror diameter	32 m
Subreflector diameter	4 m
Focal length	11.4 m
Azimuth speed	$1.0^\circ/$sec
Elevation speed	$0.5^\circ/$sec
Limits by Az	$\pm 265^\circ$
Limits by El	$0^\circ - 85^\circ$
Tracking accuracy	± 10 arcsec
Surface accuracy (RMS)	0.5 mm
Frequency range	1.4–22 GHz
Polarization	LCP + RCP

used at all frequency bands in order to achieve a less than 50 K noise temperature for the radio telescope and radiometer system. We use the R1002M data acquisition system with 16 converters developed at the IAA RAS [3] and the Mark 5B recording system. During the years 2019 and 2020, observational data were transmitted to the ARK correlator [4] in the Data Processing Center at the IAA RAS, which is capable of processing the data in the Mark 5 format received simultaneously from three stations at an average rate up to 2048 Mbps.

Fig. 2 The RT-13 radio telescope at the Svetloe observatory.

In 2015 two multi-band fast rotating antennas with a mirror diameter of approximately 13.2-m (RT-13) were installed at the Zelenchukskaya and Badary stations (ZELRT13V and BADRT13V) [5]. The third RT-13 radio telescope (SVERT13V) was installed in 2018 at the Svetloe observatory (Figure 2) and commissioned on November 24, 2020.

Table 2 presents some specifications of the RT-13 antenna system, which meets all requirements of the VGOS program. Each RT-13 radio telescope is equipped with a specially designed receiver system. The main feature of this system is the cryogenic receiver unit that includes a cooled tri-band feed and low-noise amplifier. Such a design makes it possible to achieve high sensitivity and to receive weak noise signals of cosmic origin. As well, the feed design allows us to receive signals in three frequency bands: S (2.2–2.6 GHz), X (7.0–9.5 GHz), and Ka (28–34 GHz) in both circular polarizations simultaneously [6].

Table 2 Specifications of the RT-13.

Mount	alt-azimuth
Configuration	Cassegrain
Subreflector scheme	ring-focus
Main mirror diameter	13.2 m
Subreflector diameter	1.48 m
Focal length	3.7 m
Azimuth speed	$1.0^\circ/$sec
Elevation speed	$0.5^\circ/$sec
Limits by Az	$\pm 245^\circ$
Limits by El	$6^\circ - 109^\circ$
Operation	24h/7d
Tracking accuracy	± 15 arcsec
Surface accuracy (RMS)	0.1 mm
Frequency range	2–40 GHz
Surface efficiency	> 0.7
Polarization	LCP + RCP

The RT-13 antennas at the Zelenchukskaya and Badary observatories are equipped with the Broadband Acquisition System (BRAS) [7]. The RT-13 antenna at the Svetloe observatory is equipped with the new Multifunctional Digital Backend (MDBE) [9].

Wideband intermediate frequency signals (1.024–1.536 GHz for BRAS or 1.024–2.048 GHz for MDBE) from the receiver output are digitized by BRAS or MDBE. The Digital Backend digitizes the input signals, performs signal processing, and packs the output data into 10 Gigabit Ethernet VDIF frames. The IAA RAS has been conducting observations with the RT-13 radio telescopes with the network BADRT13V–ZELRT13V–SVERT13V in test mode since March 2019 and on a regular basis since the end of 2020. During the observations, the data flow generated by the Digital Backends (up to 16 Gbps) is routed via optical fiber line to the data transfer and recording system (DTRS). The DTRS then transfers the data to the RASFX correlator in the Data Processing Center in St. Petersburg. The registration and transmission procedures take place simultaneously. The RASFX correlator, based on a hybrid-blade HPC cluster, was designed at IAA RAS in 2014 and now is used to process the wideband signals from the RT-13 radio telescopes [8].

2 Staff

The list of the staff members of the "Quasar" VLBI Network stations in 2019–2020 is given below:

- Svetloe:
  Prof. Ismail Rahimov: observatory chief;
  Vladimir Tarasov: chief engineer;
  Tatiana Andreeva: engineer;
  Alexander Isaenko: engineer.
- Zelenchukskaya:
  Andrei Dyakov: observatory chief;
  Dmitry Dzuba: FS, pointing system control;
  Anatoly Mishurinsky: front end, receiver support.
- Badary:
  Valery Olifirov: observatory chief;
  Roman Kuptsov: engineer.
- IAA Operating Center:
  Ilya Bezrukov: data transfer;
  Andrey Mihkailov: FS, observation control;
  Alexey Melnikov: skd for Domestic sessions;
  Mikhail Kharinov: planning of observations.

3 Current Status and Activities

During 2019–2020, the RT-32 and the RT-13 radio telescopes of the "Quasar" VLBI Network participated in both IVS and domestic VLBI observations. Activities of the observatories are presented in Tables 3 and 4. SVERT13V participated in the IVS-R1972 session on November 9, 2020. e-VLBI mode is used for the transfer of the domestic sessions' data.

Table 3 VLBI observations with the RT-32 radio telescopes.

	Sv		Zc		Bd	
Sessions	2019	2020	2019	2020	2019	2020
IVS-R4	18	18	20	12	16	19
IVS-R1		18		16		19
IVS-T2	5	2	2		5	2
EUROPE	1		1		1	
EUR R & D	4		4		4	
AOV		1		1		1
CRF			3	2		2
IVS-Intensive	21	20				
RuE	35	32	35	32	35	32
RI	60	72	359	311	318	326

Table 4 VLBI observations with the RT-13 radio telescopes.

	Sw		Zv		Bv	
Sessions	2019	2020	2019	2020	2019	2020
R	575	1214	1394	1227	1372	1227
RI-RT13			347		347	
24-h		1				
X (S/X/Ka)		349	328	376	328	371

During 2019–2020 the RT-13 radio telescopes participated in the following geodetic sessions:

- R: one-hour geodetic sessions in the S/X bands for UT determination—since 7/8/2020, we have observed these sessions as two-hour sessions;
- RI-RT13: sessions performed simultaneously with RI sessions at RT-32 antennas with the same schedule (RI-RT13);
- X: geodetic sessions in the S/X/Ka bands for UT determination—during the year 2019 they were 30 minutes long and during 2020 one hour long.

From the end of December 2019 until March 2020, a successful series of experimental sessions with new receivers with linear polarization [10] were held on the baseline SVERT13V–BADRT13V, a total of 170 sessions.

Table 5 presents the main types of Russian domestic sessions at the S/X frequency range. The standard

IVS designations of the stations are used in the table: Sv for Svetloe, Zc for Zelenchukskaya, and Bd for Badary for RT-32 and Bv for Badary, Zv for Zelenchukskaya, and Sw for Svetloe for RT-13. Test X sessions at the S/X/Ka frequency range have been observed as a rule once a day by the network BvZvSw (since March of the year 2020).

Table 5 Specifications of domestic sessions at the S/X frequency range.

Program	RI	RuE	R	RI(RT-13)
Stations	BdZc(Sv)	SvZcBd	ZvBvSw	ZvBv
Duration, hours	1	24	1 or 2	1
Aim	dUT1	EOP	dUT1	dUT1
Turn-around time, in hours	2	120	2–6	2–6
Scheduled	daily	weekly	3–4 times	daily
Start time, UT	20:00	Fri, 20:00	per day	20:00
Scan duration, s	22-127	60	10	22-127
Sources	150	60	156	150
set	>0.25 Jy	>0.5 Jy		>0.25 Jy
Sour.number/sess	20	50	60	20
Sampling, bit	1	1	2	1
Bandwidth, MHz	8	8	512	512
Data rate, Mbit/s	256	256	2048	2048
Scan number	25	350	120	25
Obs. number	25	1000	45–120	25
Correlator	IAA ARC	IAA ARC	RASFX	RASFX

During the years 2019–2020, we performed some significant repair and upgrade works at all observatories.

The rail track for the RT-32 radio telescope was repaired at the Zelenchukskaya observatory. In the period from July 7 to July 24 and from August 21 to September 21, 2020, work was carried out to restore two sections of the concrete foundation of the rail of the RT-32 radio telescope at the Zelenchukskaya observatory. The destruction of concrete and embedded parts in these areas caused the rail to sag by 2–3 mm. The old embedded parts were dismantled and replaced by new ones, and the concrete was dismantled to a depth of 350–400 mm and replaced by a new one. After curing, the concrete was treated with penetrating waterproofing. The rail was set to the design height.

For the aim of improving the accuracy of VLBI observations in the K frequency range, during the summer and autumn of 2020, the surface of the counter-reflectors (Figure 3) was replaced for the RT-32 antennas at all observatories.

Fig. 3 Counter-reflector of the RT-32 radio telescope at BADARY.

The new counter-reflector shields have a surface accuracy of 0.2 mm. After the first alignment, the accuracy of the counter-reflector surface reached 0.36 mm (versus 0.65 mm for the old counter-reflector). In 2021, we will continue to align.

In 2020, all observatories were equipped with two new high-performance CH1-1035 hydrogen masers designed at VREMYA-CH Russia JSC. After setting up, we are going to start using them from mid-2021.

Fig. 4 The RT-32 radio telescope at the Svetloe observatory.

16-bit and 24-bit tracking resolver-to-digital converters were installed in the new servo control system of the RT-32 radio telescope. A new version of the RT-32 antenna electric drive control system software was developed, installed, and put into operation.

4 Future Plans

During the next two years, all stations of the "Quasar" VLBI Network will continue to participate in IVS and domestic VLBI observations, upgrade existing equipment, and replace obsolete equipment.

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