RT-13 VLBI Receivers

© A. A. Evstigneev, V. K. Chernov, O. Eu. Evstigneeva, I. A. Ipatova, Eu. Yu. Khvostov, A. P. Lavrov, I. A. Pozdnyakov, Yu. V. Vekshin, M. B. Zotov

Institute of Applied Astronomy of the Russian Academy of Sciences,
St. Petersburg, Russia

Abstract

This article gives a detailed overview of the radioastronomic receivers for the Institute of Applied Astronomy of the Russian Academy of Science (IAA RAS) RT-13 fast radio telescopes that are intended for expanding the capabilities of the Russian VLBI network Quasar for continuous observations and joint operations with the global VGOS network.

For work with different VGOS stations, IAA RAS has developed two types of receivers: a tri-band (S/X/Ka bands, circular polarizations) and a wideband receiver (3–16 GHz, linear polarizations). The article provides a summary of the development process, schematic diagrams, technical data, and design features. The results of RT-13 observations in single-dish mode and VLBI mode for both types of the receivers are presented.

The Russian VLBI complex Quasar was improved significantly by construction of three fast RT-13 telescopes with two types of swappable receivers per each station enabling it to join VGOS networks and obtain necessary observation data.

Keywords: VLBI, VGOS, RT-13, small dish, fast radio telescopes, receivers, tri-band, S/X/Ka, wideband.

Contacts: Alexander Evstigneev (Alex_evst@iaaras.ru).
Received January 20, 2020, accepted March 27, 2020, published 30 December, 2020.

For citation: Evstigneev A. A., Chernov V. K., Evstigneeva O. Eu., Ipatova I. A., Khvostov Eu. Yu., Lavrov A. P,, Pozdnyakov I. A., Vekshin Yu. V., Zotov M. B. RT-13 VLBI receivers // Transactions of IAA RAS. 2020. Vol. 55. P. 36–40.
https://doi.org/10.32876/ApplAstron.55.36-40

Introduction

In 2005, the International VLBI Service (IVS) recommended [1] to review the equipment of the existing VLBI network stations in order to achieve better (1 mm and less) accuracy of location and continuous observations to measure the Earth Orientation Parameters. These goals can be only achieved with new fast (5 deg/sec and faster) small (15 m and smaller) dishes, such as those of RT-13, and new receiving systems. There are two types of VLBI receivers, namely, tri-band (S/X/Ka bands, right/left circular polarizations RCP+LCP) [2] and wideband (3−6 GHz, vertical/horizontal linear polarizations VLP+HLP) [3].

The development of the tri-band system began in 2012 simultaneously with the RT-13 construction at Badary and Zelenchukskaya. In 2015, when the construction was complete, the tri-band systems were installed and regular observations started. The third RT-13 at Svetloe was built in 2018.

The wideband system development was started in 2013 when the first tests of the wideband cryogenic equipment (low noise amplifiers (LNA) feed) were made. In 2015, construction of the wideband system prototype was started. This early prototype was tested in Zelenchukskaya in 2017 and the “first light” from the wideband system was observed. In 2018, the wideband system was expanded and tested at the Svetloe observatory.

Two types of the receiving systems imply two swappable focal modules per each RT-13. To swap them fast, the radio telescope has a rail system designed to move the focal module from the cabin floor (service position) to the focus area (working position). During installation, the focal module is placed in the cabin, mounted on the rails and slid up to the end of the focal tube. This rail system allows to use different types of receivers that can be swapped relatively fast.

Despite the differences, both receiving systems have some similarities in design. The RT-13 is a fast antenna system with a relatively small dish. For high enough signal/noise ratios (SNR), the receiver system noise should be as low as possible. To reduce the noise, the receivers’ feeds and LNAs are placed in a cryogenic unit (Dewar). Frequency convertors are placed near it to avoid high losses in long cable lines. The focus point of feed must match the secondary focus point of RT-13, so all the signal processing equipment must be placed near it and contained in the focal module. This module provides signal for the VLBI acquisition system.

Tri-band Receiver System

The schematic diagram of the tri-band receiver [4, 5] is given in Fig. 1. Signal from the source is focused with antenna and directed to the feed through radio transparent vacuum window. It is split into three wavelength bands and two circular polarizations. The aperture part of the feed is made with the use of circular waveguides of the S-, X-, and Ka-bands positioned coaxially. The Ka-band passes a circular waveguide with a dielectric

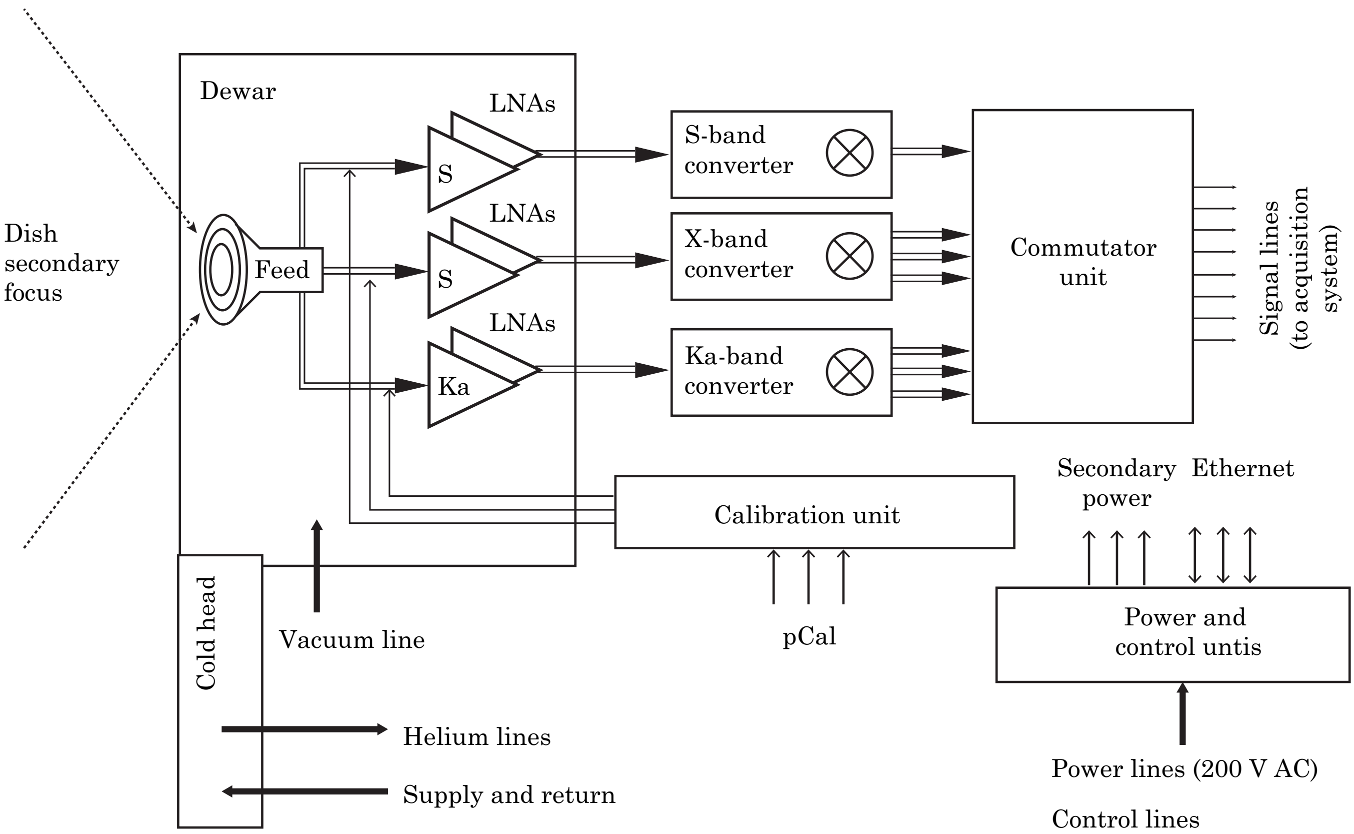

Fig. 1. Schematic diagram of the tri-band receiver focal module

cone and a waveguide septum polarizer. The X-band signal passes through the differential-phase section and divides over the orthomode transducer. In the S-band quarter-wavelength, inductive pins and hybrid couplers are used.

Signals of each band and polarization are mixed with the noise and phase calibration signals and amplified by cooled low-noise amplifiers. All the amplified signals go to the frequency converter units, which provide subchannel splitting and frequency converting to the digital acquisition system band. The S-band conversion is the most simple; it has one subchannel and a single stage mixer. The X- and Ka-bands have three subchannels each and use dual frequency conversion, up-down for the X-band and down-down for the Ka-band. This solution allows selecting a recording bandwidth (1 GHz) from the wider working bandwidths (2.5 GHz for the X- and 6 GHz for the Ka-bands, respectively).

Note that the receiver has three bands but four acquisition channels per each polarization. Thus, the X- and Ka-bands are split into three subchannels and either the S/X mode (S-channel and three X-subchannels) or X/Ka mode (one X-subchannel and three Ka-subchannels) is used. The S/X or X/Ka modes are selected by the commutator unit. The receiver parameters obtained at the Svetloe observatory are presented in Table 1.

During the development of the receiver for the Svetloe station, the tri-band focal module design was improved by the addition of a new, more lightweight structure with a new outer cover and a new cable set, which replace waveguides in the Ka-band and, in the near future, new power and control systems. These improvements made the tri-band system more reliable and maintainable.

Table 1

Parameters of the tri-band receiver at the Svetloe observatory

Band	Trec, K	Tsys, K	SEFD, Jn	Antenna Efficiency
S	22	40	1140	0.7
X	20	30	760	0.8
Ka	50	73	2000	0.75

Wideband Receiver System

One more receiver type used at IAA RAS is a wideband receiver [6]. This receiver has the same output parameters as the tri-band receiver, namely, four channels of 1024–2048 MHz bandwidth with two polarizations per channel. The polarizations obtained are dual orthogonal linear ones.

In the wideband system, a single feed is applied to split the incoming signal into two linear polarizations. The two signals are mixed with calibration signals in the direct coupler and amplified with cryogenic LNAs. The Dewar design for the wideband receiver is not as complicated as in the tri-band unit. It consists of three main components: a quadridge flare horn feed designed at IAA RAS, direct couplers (A-INFO, China), and cryogenic LNAs (Low Noise Factory, Sweden). The cold head used is the same type as in the tri-band system (RDK-408S2, Sumitomo Heavy Industries, Japan).

According to the schematic diagram (Fig. 2), each signal is divided into four subchannels by splitter units. The splitter units contain three 2-way coaxial splitters providing four equal channels each. Losses in the splitters are compensated for by a wideband preamplifier. After splitting, the signals are converted to intermediate frequency (IF) by dual-channel frequency convertors (FCU), one channel per each polarization. The channels have identical structure and include an up-converting mixer, an IF-1 filter for 23–24 GHz, and a down-converting mixer for the IF-2 module. The local oscillators have two outputs, tunable (27–40 GHz) and fixed (22 GHz), and their signals are distributed to mixers by dividers. The IF-2 modules provide additional filtering and variable gain.

The wideband system was installed at the Svetloe observatory. The test data (Fig. 3) shows that azimutal and elevation scans of Cassiopeia give more visible sidelobes only in one channel corresponding to vertical or horizontal polarization. The noise temperature of the receiver system is less than 35 K.

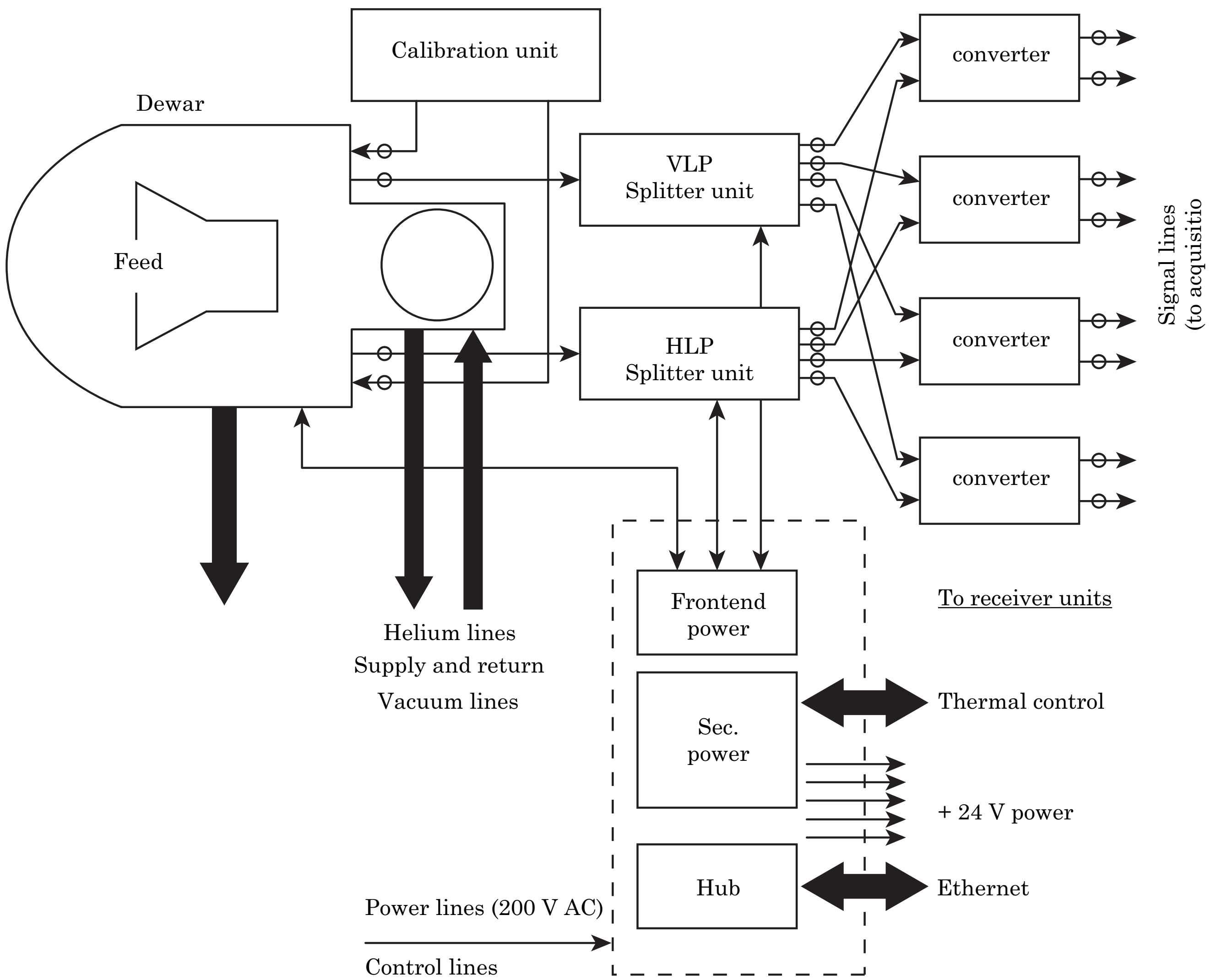

Fig. 2. Schemantic diagram of the wideband receiver focal module

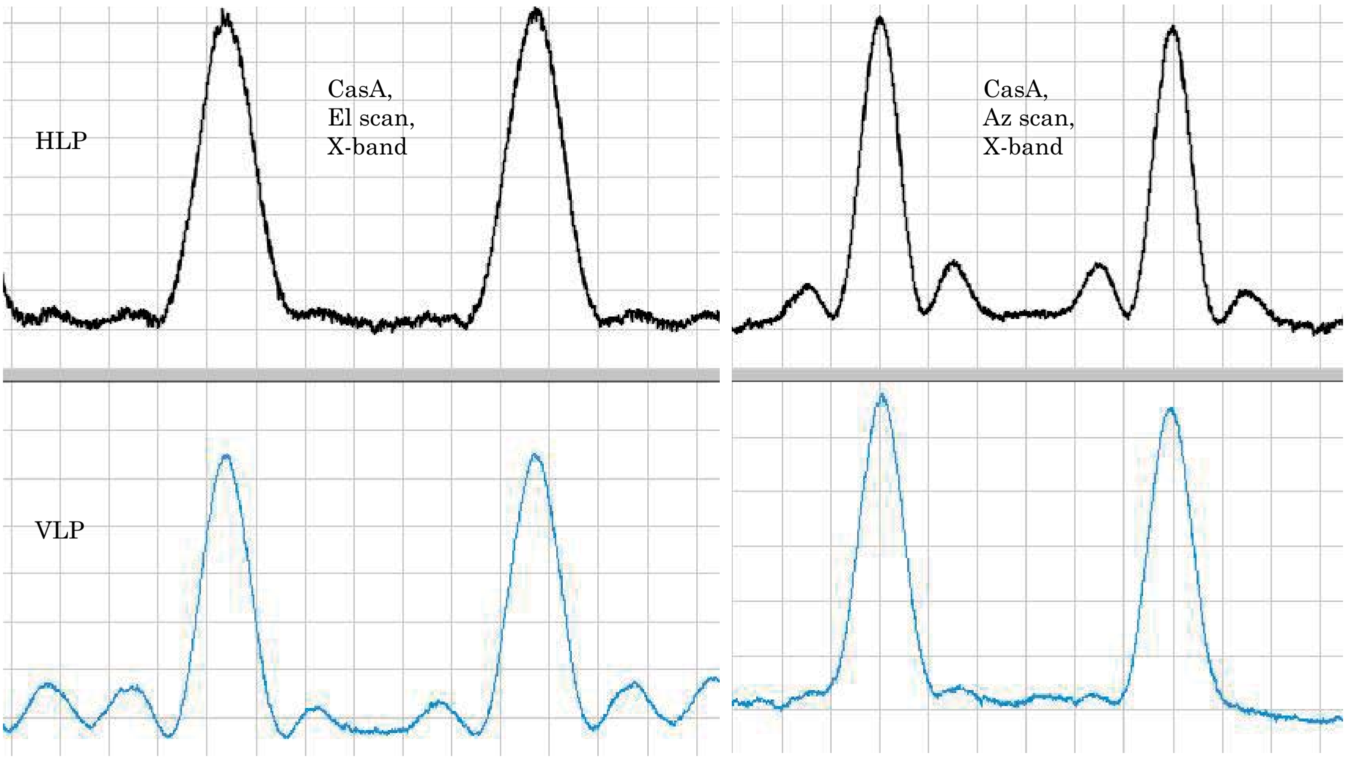

Fig. 3. The "first light" of the wideband receiver

Table 2

X-band VLBI test data
Receivers used: wideband (Svetloe – "ss"), tri-band (Badary – "bv"; Zelenchukskaya – "zv")

Scanname	GrChMode	Tau, ns	Fi, MHz	Amp	NsAver	NsSigma	SNR
1440_bv1zv1	X1_L_L-L	4.576373	–26.8193	2815.5	9.101	4.754	592.4
1440_bv1zv1	X2_L_L-L	4.576373	–26.8193	2815.5	9.101	4.754	592.4
1440_ss01zv0	X1_L_R-R	3.583832	–261.1418	1557.3	9.038	4.727	327.5
1440_ss01zv0	X2_L_R-R	3.583832	–261.1418	1557.3	9.038	4.727	327.5

Further tests of the wideband system at Svetloe included observations in VLBI mode in X-band with tri-band systems installed at Badary and Zelenchukskaya. The results of the X-band VLBI fringe tests (Table 2) show that with the use of the wideband system, the SNR is two times lower than expected.

In 2019, two wideband systems were made and used in full-scale VLBI tests with linear polarizations in the 3–16 GHz band.

Conclusion

In the seven years from 2012 to 2019, the Russian VLBI complex Quasar was improved significantly by the installation of three RT-13 small dish telescopes. Two designs of VLBI receivers (tri-band and a wideband one) were implemented in two types of swappable focal modules per each station. The RT-13 Quasar complex can operate with VGOS networks of any type.

References

1. *Niell A. E., Whitney A., Petrachebko B., et al.* VLBI2010: current and future requirements for geodetic VLBI systems. Tech. Rep. of Working Group 3 to the IVS Directing Board. Greenbelt: IVS Coordinating Center, NASA Goddard Space Flight Center, 2005. 32 p.

2. *Lopez-Perez J. A., Lopez-Fernandez J. A., Tercero F., et al.* A triband cryogenic receiver for VGOS radio telescopes. 2014 General Meeting Proceedings: "VGOS: The New VLBI Network", ed. by D. Behrend, K. D. Baver, K. L. Armstrong. Beijing: Science Press, 2014. P. 115–117.

3. *Petrachenko B., Niell A., Behrend D., et al.* Design aspects of the VLBI2010 system. Progress report of the IVS VLBI2010 committee, June 2009. NASA/TM-2009-214180, 2009.

4. *Chernov V. K., Evstigneev A. A., Evstigneeva O. G., et al.* The S/X/Ka receiving system for radio telescope RT-13 of the "Quasar" VLBI Network. *Transactions of IAA RAS.* Vol. 41. 2017. P. 79–84. (In Russ.).

5. *Ipatova I. A., Ipatov A. V., Mardyshkin V. V., et al.* Triband receiving system for the interferometer. VGOS: The New VLBI Network. Proc. conf. "IVS 2014 General Meeting" / ed. by D. Behrend, K. D. Baver, K. L. Armstrong. Beijing: Science Press, 2014. P. 118–121.

6. *Evstigneev A. A., Evstigneeva O. G., Khvostov E. Y., et al.* The ultra-wideband receiver system for RT-13 radio telescope IAARAS "Quasar" Network. IAA RAS Transactions. Vol. 41. 2017. P. 49–52.