The S/X/Ka Receiving System for Radio Telescope RT-13 of the "Quasar" VLBI Network

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IAA RAS has already made the radio interferometer which consists of two radio telescopes with dish diameter of 13.2 m. Each radio telescope is equipped with a specially designed receiving system. The main feature of this system is the cryogenic receiving unit that includes cooled tri-band feed and low-noise amplifiers (LNA). Feed design allows to receive signals in three frequency bands S (2.2–2.6 GHz), X (7.0–9.5 GHz) and Ka (28–34 GHz) for both circular polarizations (LCP and RCP) simultaneously.

Keywords: VLBI, geodesy, tri-band receiver, 13.2 antenna.

1 The Receiving System

The design of antenna with a dish diameter of 13.2 m implies that all units of the receiving system are mounted within a focal container which placed in the area near the antenna secondary focus. Schematic diagram of the tri-band receiving system is shown at Fig. 4. The receiving system includes nine blocks. It provides signal reception, amplification, frequency conversion, registration mode switching, amplitude and phase calibration injection and power supply for all units. To achieve and maintain the cryogenic temperature of input stages the receiving system includes a cryogenic and vacuum subsystems. Cryogenic compressor and vacuum pump are allocated outside of the focal container at radio telescope cabin.

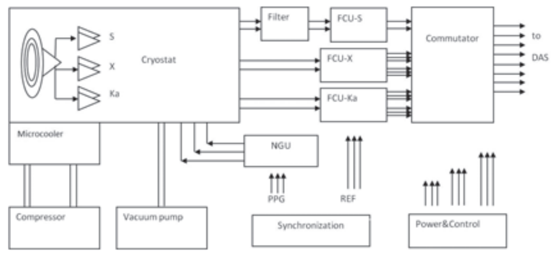

Fig. 1. The block diagram of the tri-band receiving system

2 The Cryostat

The radiation from cosmic source, concentrated with the dish and subreflector, comes to the feed through the radio-transparent cover of cryostat. The feed design allows to split left and right circular polarization signals and to convert them into linear polarized for each operating band. The converted signals are mixed with the calibration ones injected through couplers from calibration unit. The converted signals are amplified by two LNAs for each band, six in total. Operating temperature of LNAs is about 20 K. At the top of the cryostat the radio transparent window is placed. It has minimum absorption of electromagnetic signals at the operating bands. The window consists of 20 mm thick dome-shaped polystyrene, covered by two layers of a 0.05 mm mylar film and 0.1 mm PTFE film on top. Feed design is based on S, X, and Ka bands circular waveguides placed coaxially. The Ka-band has a circular waveguide with a dielectric matching cone and waveguide septum polarizer. In the X-band signal reaches the horn, comes through the differential-phase section and divides over the orthomode transducer. In S-band quarter-wavelength inductive pins and hybrid couplers are applied. The cryogenic LNAs provide more than 30 dB gain and noise temperature not higher than 10 K at S and X bands, and about 30 K at Ka band. All the equipment inside the cryostat is closed with the copper heat shield. At the top of heat shield the infrared filter made with 0.1 mm PTFE is placed. The cooling process, using two-stage refrigerator Sumitomo RDK-408S2, takes 7 hours. The feed and LNAs temperature is stabilized at 26 K and 20 K respectively.

3 Receiver system units

All output signals from cryostat come to the three frequency conversion units (FCU) for S, X, Ka bands that perform secondary amplification and frequency conversion to intermediate frequency (IF). Each FCU has two polarization channels that are distributed into three sub-channels each. Each pair of sub-channels has tunable local oscillator (LO) for operating band selection.

Design of S-band FCU allows one frequency conversion, however the FCU of X and Ka bands has double conversion, reducing image channel. FCUs operating frequency diagram is shown at Fig. 2. Tunable LO with IF filter permit to choose 1 GHz bandwidth from the entire input range. The fixed LO performs second frequency conversion to the 1–2 GHz band that corresponds with VLBI data acquisition system (DAS) registration band. All LOs are synchronized by 100 MHz reference signal from hydrogen time standard. Since VLBI reg-

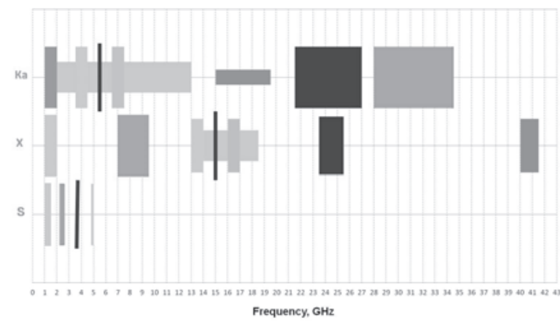

Fig. 2. The operating frequency diagram

istration system has 4 channels for each polarization, the receiving system operates in S/X mode (S-band and three X-band subchannels) or in the X/Ka mode (one X-band and three Ka-band subchannels). Commutator unit allows to select 8 of the 14 input channels for transmission to DAS. Commutator unit also provides radiometric output signal registration for remote diagnostic purpose. Noise generation unit (NGU) contains tunable noise generators for amplitude calibration. Phase calibration pico-second pulse (PPS) signals comes to the NGU where they are mixed with amplitude calibration signals for injection into the cryostat through 27 dB directional couplers, located before the LNAs. The calibration signals are divided by splitter for both polarizations of each frequency band. Receiver system also includes the power supply units to provides separate power control and monitoring for each unit. Operating parameters, such as temperature, pressure, currents consumption are monitored. All communications are carried out via the Ethernet interface.

4 Measurement results

Due to the design features of cryostat, there are no access to the input port in operating mode, so the gain is measured through directional couplers. Fig. 3 shows gain plot for S, X and Ka bands. The results for right and left polarizations channel differ slightly.

S-band occupied by well-known RFI sources such as Wi-Fi and 3G trans-

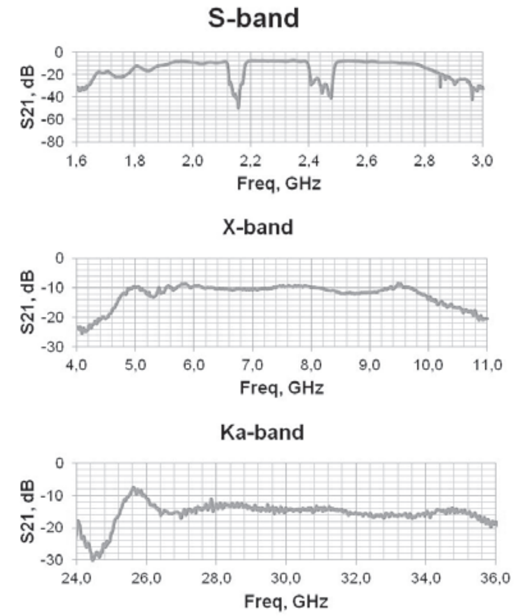

Fig. 3. The tri-band cryostat gain plots

mitters. Filtering of these interferences is clearly shown at the S-band plot. All FCUs were tested on the noise figure analyser. Measurement results of gain and noise temperature are presented at Fig. 4 for each band and at Table 1 for each subchannel.

Table 1

The gain and noise temperature

FCU Band	G1, dB	G2, dB	G3, dB	Tn, K
S RCP/LCP		50.2 / 48.3		230
X RCP/LCP	46.5 / 48	47.2 / 47.8	47 / 46.7	450
Ka LCP/RCP	45 / 46.1	44.8 / 45.9	43.5 / 44.2	310

To measure the noise temperature of the receiving system Y-factor method was applied. Special broadband matched load [1] was used. It is a low-temperature wide-aperture noise generator, that include absorption material enclosed in a container with liquid nitrogen. The matched load is mounted on a cryostat vacuum window flange. The output receiving system signals are measured by spectrum analyser. It allows to get noise temperature vs. frequency plot, to measure the arbitrary band noise and eliminate RFIs. The results of the system noise temperature measurements in different bands are

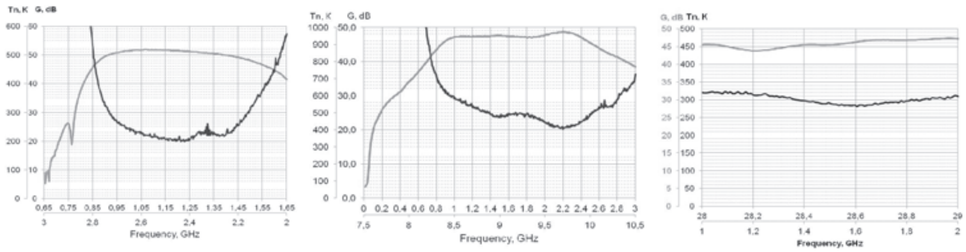

Fig. 4. Gain and noise temperature of FCU-S, FCU-X and FCU-Ka

shown in Fig. 5 as a noise temperature vs. frequency plot. FCUs noise contribution is enough low. The gap on the S-band plot is due to the Wi-Fi reject filter (2.38–2.5 GHz).

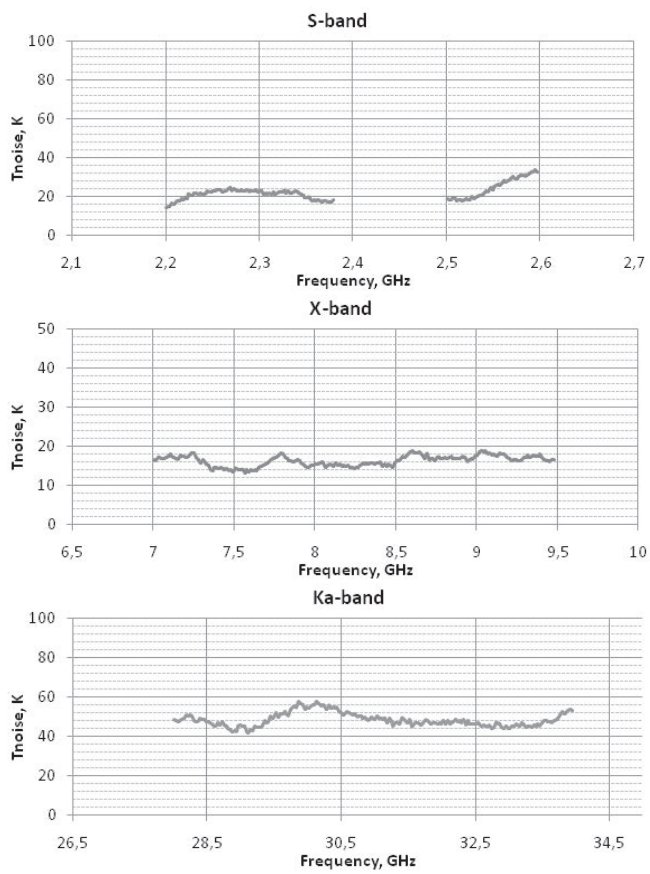

Fig. 5. The receiving system noise temperatures

5 Conclusion

Measured parameters are enough close to the expectable ones. After testing the receiving systems were installed on the RT-13 radio-telescopes of the „Badary“ and „Zelenchukskaya“ observatories. The measurement results of the RT-13 parameters with this receiving system are presented at [2]. Since April 2016 the two-element radio interferometer with the presented receiving system is in operation.

References

1. *Yurchuk E. et. al.* Wide-aperture low temperature noise generator — operating noise temperature measure unit for calibrating the receiving system of the VLBI radio telescope “Quasar-M” // All-Russian astronomical conference (VAK-2013). 23–27 september 2013, St. Petersburg, Russia: abstracts. — SPb. — 2013. — P. 282.
2. *Vekshin Yu. et. al.* The parameters of the RT-13 radio telescopes of the “Quasar” VLBI network of the IAA RAS in S/X/Ka bands // Trudy IPA RAN, 2017. — Is. 41. — P. 135–140.