The Institute of Applied Astronomy
of the Russian Academy of Sciences

The S/X/Ka receiver system for radio telescope RT-13 of Quazar VLBI Network

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IAA RAS has already established two-element radio interferometer which consists of two radio telescopes with dish diameter of 13.2 m. Each radio telescope is equipped with a specially designed receiver system. The main feature of this system is the cryogenic receiver unit that includes cooled tri-band feed and LNAs. Such design makes possible to achieve high sensitivity to receive weak noise signals of cosmic origin. As well, 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) both in LCP and RCP simultaneously.

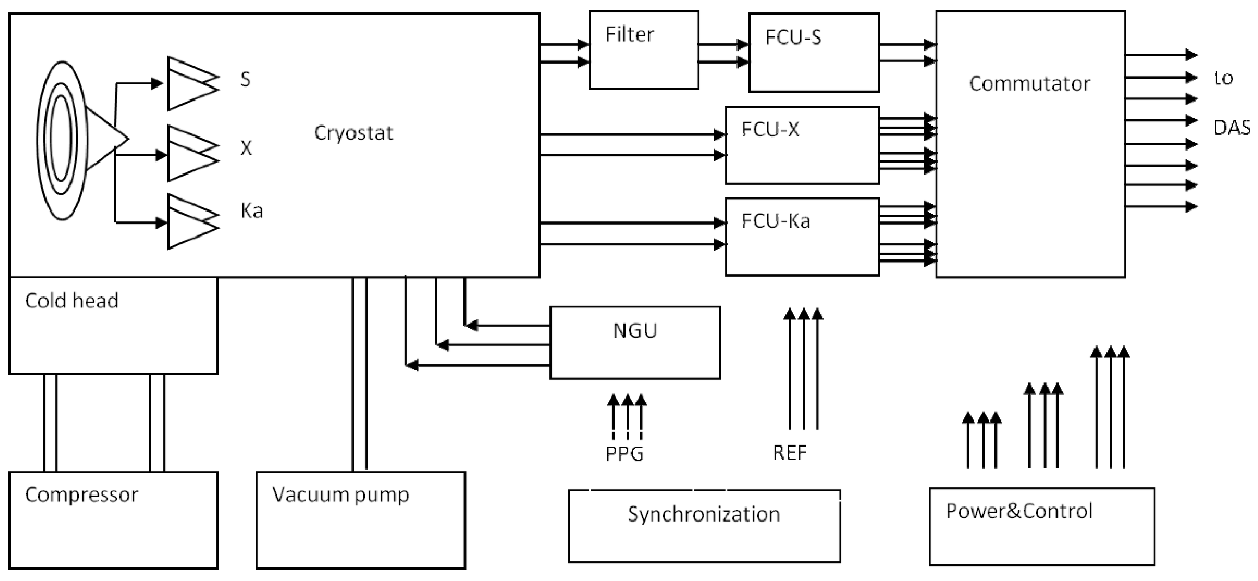
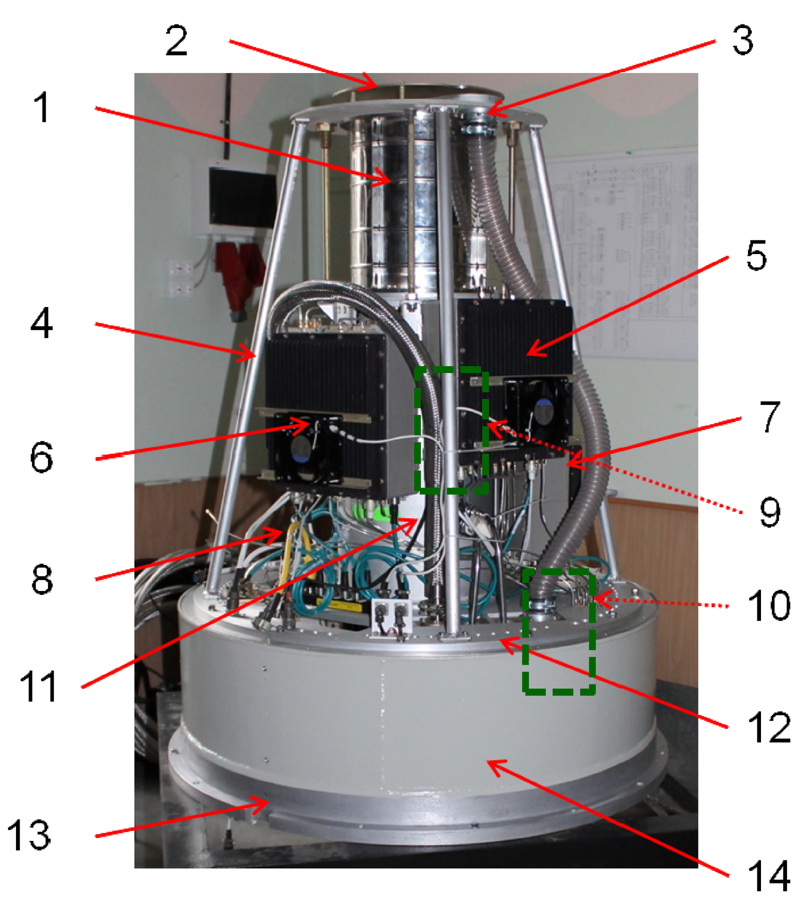


Fig.1 Block diagram of tri—band receiving system

The receiving system presented at fig.1 consists of six UHF units, provides reception, the primary gain, signal conversion, switching modes of registration and injection amplitude and phase calibration.

To achieve and maintain the cryogenic temperature the receiver includes a cryogenic and vacuum subsystems. Also in block diagram presents frequency timing synchronization system. Control the receiving system is carried out by the central PC with Ethernet interface.

All units of receiver are mounted within a housing of focal container (Fig. 2) placed in the space near the secondary focus of the antenna. This configuration caused by design of hydrogen cooled receiving feed placed into cryogenic focal unit.



1– Cryostat
2—Vacuum window
3—blower
4—Frame beam
5—X-band FCU
6—Ka-band FCU
7—Commutator
8—NGU
9—S-band FCU
10—Power and control unit
11—Frame
12—Interface flange
13—Brackets place
14—Base ring frame

Fig.2 Photo of tri—band receiver system without casing

All amplified signals go to the FCUs (Frequency Converter Unit) These units provide subchannel splittering and frequency converting to the IF band. Subchannels are routed by commutator unit from 14 to 8 channals to record by DAS.

NGU contains adjustable noise source for each band. External picosecond pulse for the phase calibration are injected in NGU and mix with amplitude signals.

System is powered by unified supply voltage and controlled via Ethernet interface. Large amount of telemetric information such as temperatures, supply voltages, currents consumption, is gathered.

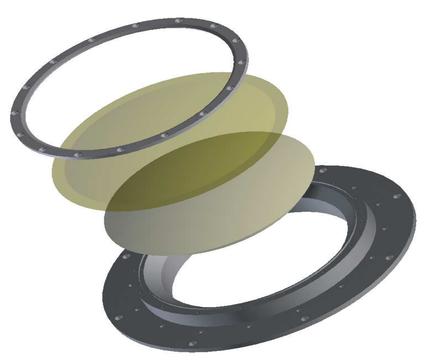


Fig.3 Parts of vacuum window

Electromagnetic waves focused with antenna goes to the feed inside the cryostat through radio-transparent cover based on vacuum window. They are separated to three bands and two circular polarizations, mixed with the noise and phase calibration signals and amplified with LNA. Almost all the equipment located inside the cryostat is cooled to the temperature near ***20 degrees Kelvin*** , significantly reducing the noise temperature of the system.

Vacuum window is closed with radio-transparent cover, which consists of two parts (see fig. 4) - films and support layer. External sealing surface is assembling of Mylar film ***0.05 mm*** thick covered by Teflon film ***0.1 mm*** thick and . The film is supported by the inner layer of solid foam polyester of ***70 mm*** thick.

Fig.4 Vacuum window

The feed is constructed with the use of circular waveguides of the S,X and Ka bands placed coaxially. The Ka-band has a circular waveguide with a dielectric cone and waveguide septum polarizer. In the X-band signal reaches the horn, passes through the differential-phase section and divides over the orthomode transducer. In S-band quarter-wavelength inductive pins and hybrid couplers are applied.

All the equipment of cryostat for both polarizations of all three bands is tightly placed in the space between the feed and coldhead flange. S and X bands signal lines are coaxial, Ka-band is fully waveguide. Equipment is closed with the metal radiation shield. Between the feed and the vacuum window the infrared filter is placed. It is a 0.1 mm thin teflon film.

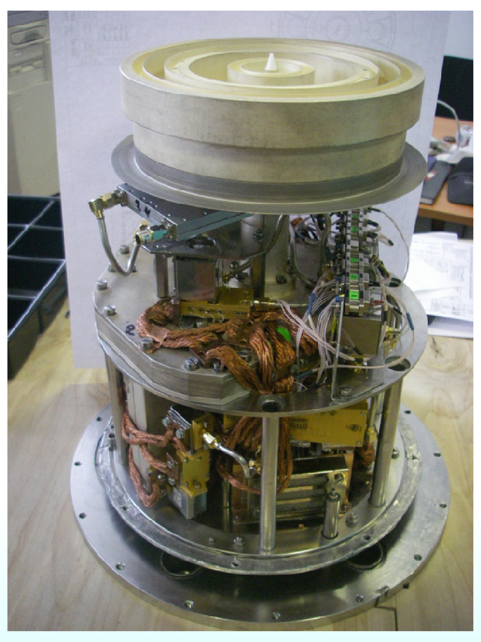


Fig.5 The cryostat unit assemble

For injection of calibration signals are used direct couplers placed before the LNAs. Their coupling factor is about -27 dB. Due to two-way-splitters
the injection of calibration signals is simultaneous in both channels This solution let us use only one calibration signal input per band.

The cryogenic LNA Ka-band based on waveguide. For S and X band are coaxial connectorized modules. They have a gain more than 30 dB, and their noise temperature is not higher than 5 K.

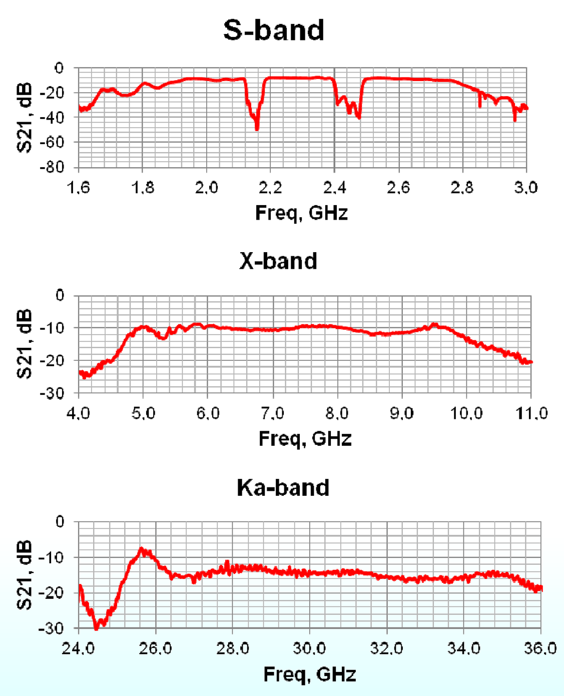


Fig.6 Gain plots of the cooled unit

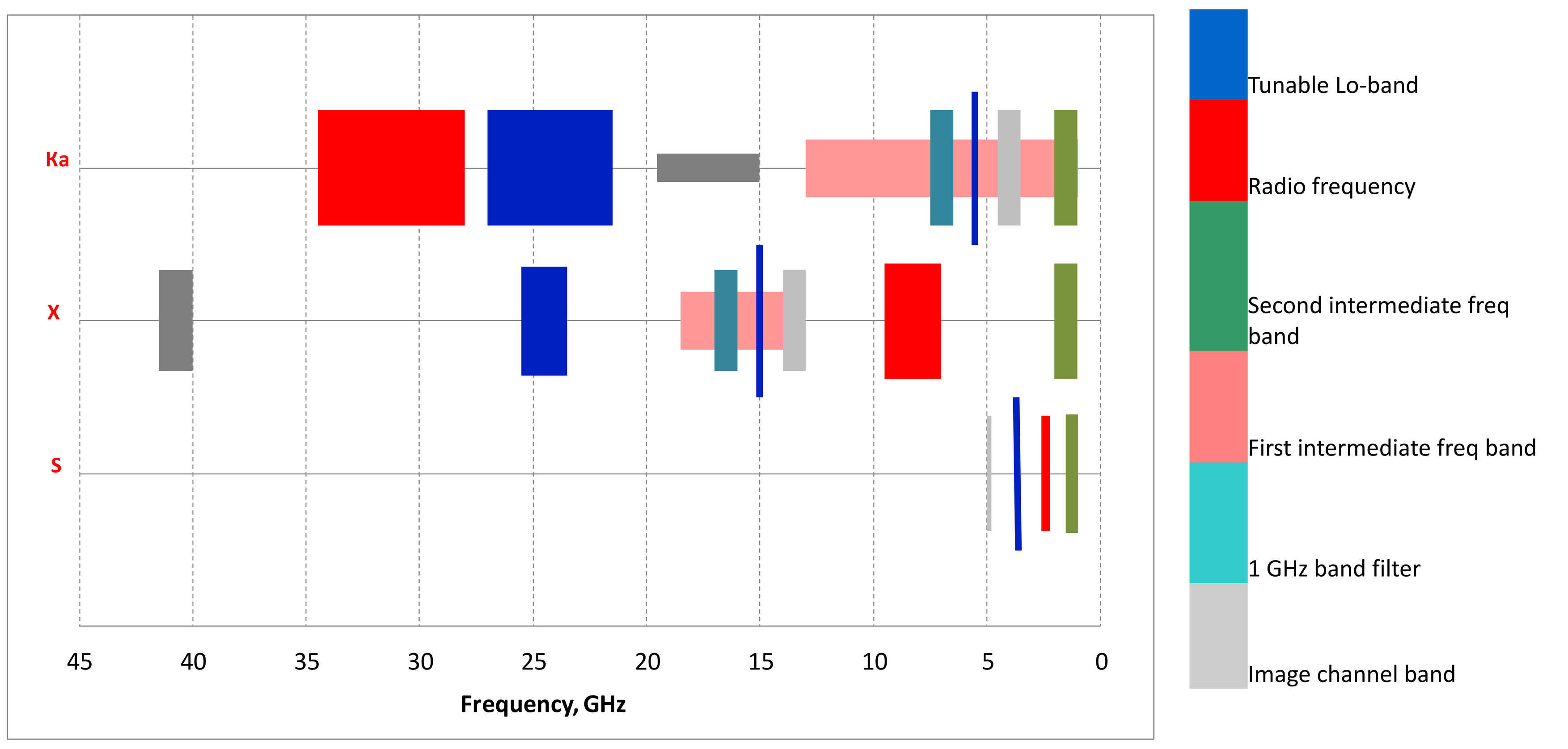


Fig.7 Frequency plan for three band

Conversion of signals are carried out in 3 FCUs. One for each frequency band. Each FCU has two inputs for RCP and LCP respectively. Each channel provide gain, the frequency convertion to the IF band. FCUs X - and Ka-bands provides additional splyttering of each channel to three subchannels and carry out a double frequency conversion,

Frequency plan for all three ranges is shown at diagram (Fig. 8). X and Ka bands is much higher than the IF band. Design of FCUs makes possible to change the frequency of the first local oscillator, which allows us to choose the correct range for the conversion. For example, by choosing 24 GHz at the Ka LO1 (frequency synthesizer), the frequency IF1 (first intermediate) will be 4-10 GHz, which will pass through the filter of 6.5-7.5 GHz. After second mixer with LO2 frequency 5.5 GHz, we will get the IF2 with band of 1-2 GHz, which corresponds to the radio frequency band 30,5– 31,5 GHz

The main features of FCU such as gain and noise figure are presented at table 1 for each channel. Gain plots of the FCUs are given at fig. 9,10,11. There are only one plot for each FCU are presented.

Table.1 Gain and noise temperature of FCUs

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

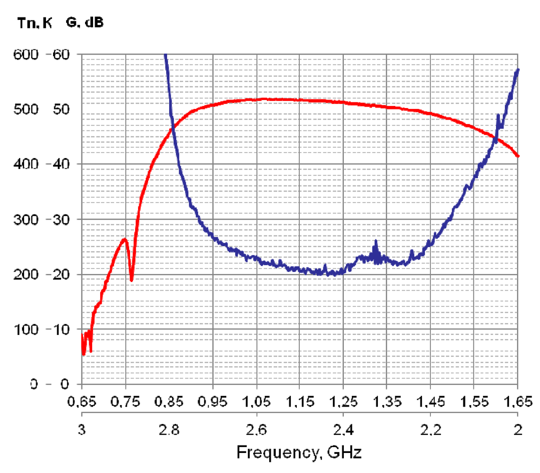


Fig.9 Gain plots of the FCU-S

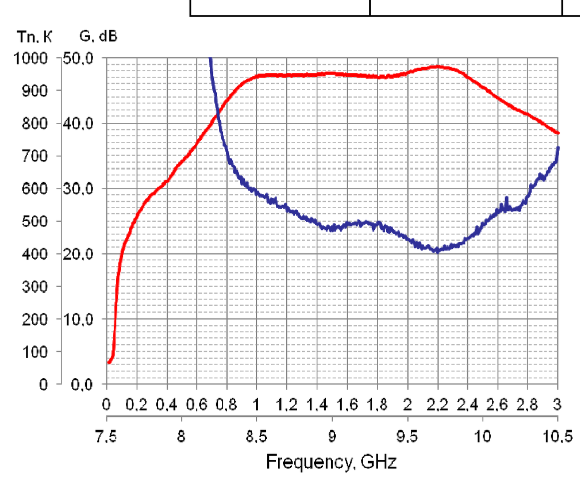


Fig.10 Gain plots of the FCU-X

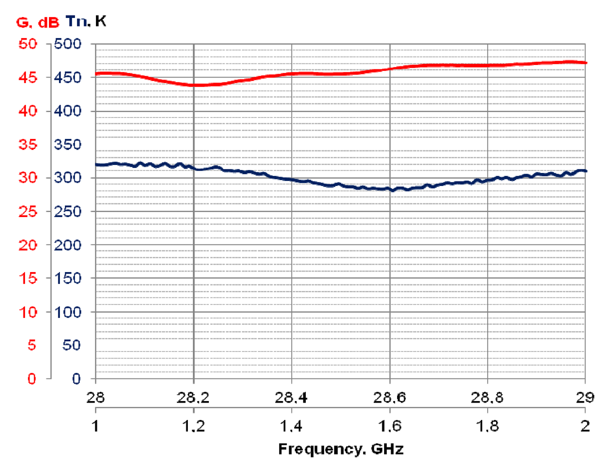
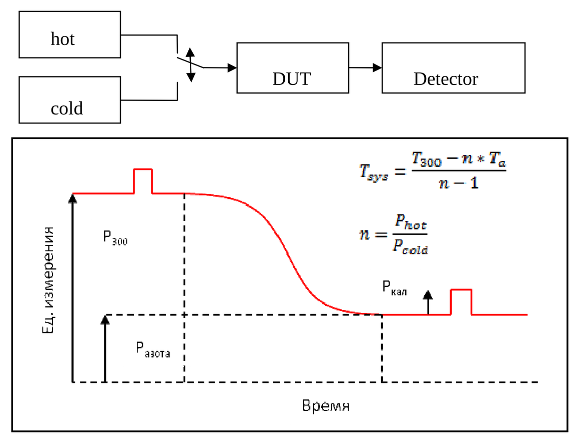


Fig.10 Gain plots of the FCU-Ka

For calibration and measure equivalent noise temperature of our receiver unit we used two points method, which require two noise sources with different RF brightness temperature. For example ambient temperature (“hot” load) and liquid nitrogen temperature (“cold” load). This plot illustrates typical calibrating process. For the start using the hot load, for the next step, use the cold load, and at the end we removing the load and expose feed to the sky. If we inject some cal noise in the feed, that we can calibrate this signal too.



Due to selected receiver design with the feed placed inside the cryostat, is not possible to measure the equivalent input noise figure with standard methods using traditional matched loads. This obstacle is forced us to develop for complex calibration systems of the telescope noise figure. The main element of this calibration system is a low noise generator unit. It is a low-temperature wide-aperture radiator (LTWAR) designed by Russian Institute of Federal agency on Technical regulating and metrology.

Special broadband matched load was applied for measuring the noise temperature of cryostat. It is a low temperature wide-aperture load, which is enclosed in a Dewar where it cooling with liquid nitrogen. The load is mounted on a mobile base, allowing to match it with the device under test during the movement. The distance between the load and cooled unit are very low to reduce the influence of moisture in the air . This equipment provides «cold» load. For a «hot» load the absorbent material plate with the room temperature is applied.

The results of the noise temperature measurements and calculations in different ranges are presented in this table 2. The difference of left and right circular polarization channels is insignificant.

Table.2 Gain and noise temperature of FCUs

Band	T receiver, K
S	21
X	17
Ka	50

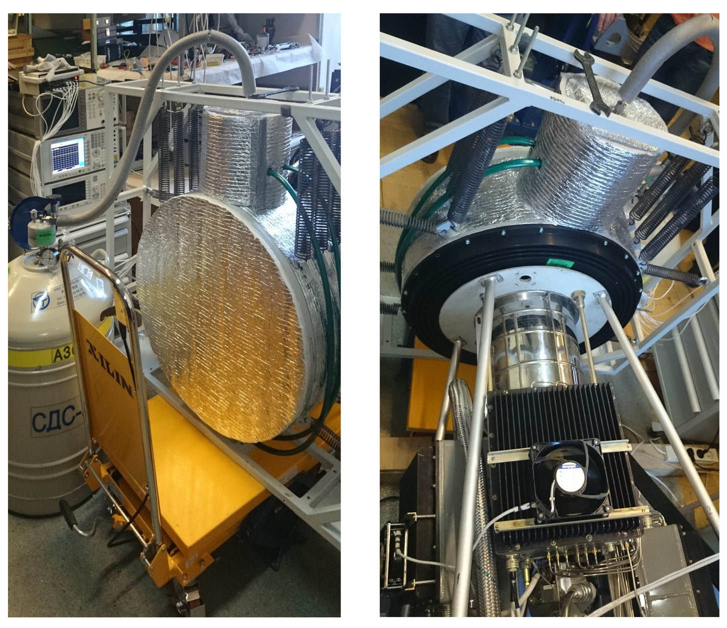


Fig.11 LTWAR in use for calibration receiving system

Conclusion:

Measured by this method parameters are enough close to the calculated ones. After testing the receiving system was installed on the telescope. In 2014 two receiving systems was install at the observatories “Zelenchukskaya” and “Badary”.

Since April 2016 a two-element radio interferometer with the presented receiving system in operation.

References:

1. **Yuriy Vekshin** (Institute of Applied Astronomy, Russia) *The parameters of the RT-13 radio telescopes of the "Quasar" VLBI network of the IAA RAS in S/X/Ka bands*
2. **Vitaliy Chernov** (Institute of Applied Astronomy, Russia) *Feeds of the Radio Telescopes RT-13 of the Quasar VLBI Network*