# The Ultra-Wideband Receiver System for RT-13 Radio Telescope IAA RAS QUASAR Network

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The report describes results of development in IAA RAS receiving system, operating in ultra -wide 4-16 GHz band (UWB). An overview of existing and developing UWB systems for VGOS network is provided. The principles of design, management, integrating with RT‑13 radio telescope, control and power supply for IAA RAS UWB receiving system are shown. Expected and measured technical parameters are given.

Technical data on receiver units such as: basic structure, frontend cooled feed, splitter and up-down convertor are presented. Special attention is focused on the frontend cryoelectronic unit, the information about the design, feed, LNAs used, results and parameters obtained during the test is provided.

*Fig.1. RT-13 Radio telescope at Badary station*

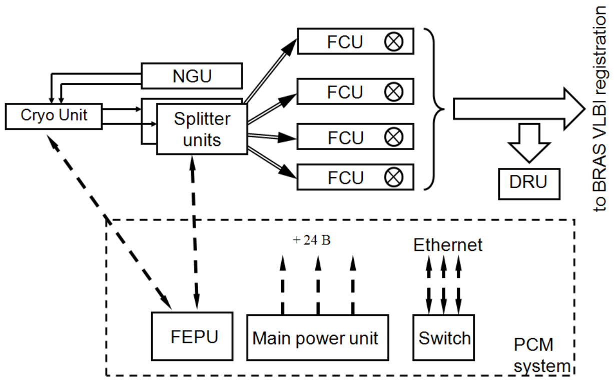


*Fig. 2. UWB (ultra-wideband) system schematic diagram*

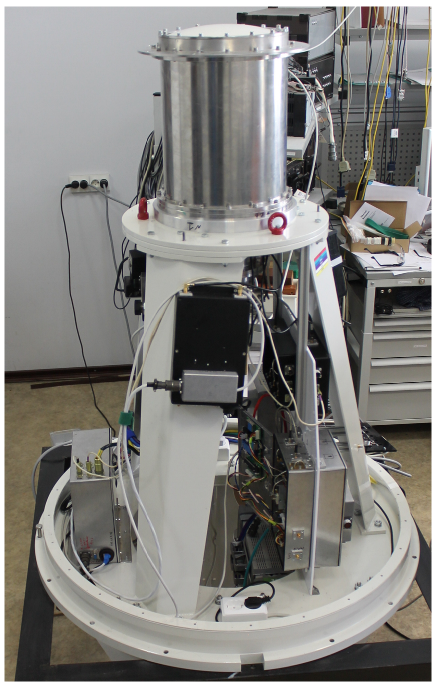

*Fig. 3. Focal unit with UWB system in laboratory*

### Introduction

The UWB (ultra-wideband) receiving system designed in IAA RAS is purposed for implementing in QUASAR VLBI network small (13.2 m) dish radio telescopes (fig.1). These radio telescopes are based in «Zelenchuckskaya» and «Badary» stations and working now with Tri-band S/X/Ka receiving system [1]. UWB receiving system operates in 4-16 GHz band on dual linear orthogonal polarizations and it is fully compartible with RT-13 mechanical, cryogenic and electric interfaces. As supposed, it can replace Tri-band system and be replaced by it on demand.

### The System

Like the Tri-band, UWB receiving system is made as focal container with working position near the dish secondary focus. According to schematic diagram (fig. 2) and photo (fig. 3) given, the receiver itself consists of parts following:

1. cryoelectronic focal receivig unit (cryounit). This is hard-walled vacuum chamber that contains cooled QRFH (quad-ridged flared horn) feed [2], LNAs and directional couplers for calibration signals;
2. NGU (noise generator unit) for injecting amplitude and phase calibration signals. Phase calibration signals come from outer unit — picosecond pulse generator (PPG);
3. two 4-way splitter units, one for each polarization, which form 8 receiving channels in total;
4. four dual-polarization FCUs (frequency conversion units, prototyped), that converts tunable 1 GHz band from input ultra-wide band to 1-2 GHz IF acquisition band.
5. DRU (digital radiometric unit, in development) that converts part of system output radiometric signal to digital data.
6. Agilent 1914A power meter as temporary replacement for DRU.

PCM (power, control and monitoring) equipment [3] includes units following:

7. FEPU (frontend power unit) that provides power for cryounit and splitter units as long as cryogenic temperature mesurement;
8. main power unit that provides supply voltage to another receiver units;
9. Ethernet switch that connects all controllable units to network.

The following equipment is nessesary for system functional but not shown on the diagram:

10. System holding structure — the base of focal unit, that provides place and position for all receiver units.
11. Vacuum equipment — gauge, electric and manual valves, hose.
12. Temporary soft waterproof cover;
13. Hard outer cover (in developmet) for soft cover future replacement.

### Operation Principle

The UWB system operates in the way following. The radiation from source, concentrated with the dish and subreflector, comes through the radio-transparent cover of cryounit and focuses in the focal center of QRFH feed, where it is separated by vertical and horizontal linear polarizations. The terms «vertical» and «horizontal» are nominal because of non-strict position of feed. Two signals, mixed with calibration signals on the direct coupler, are amplified with cryogenic LNAs and every signal is divided in 4 ways by the splitter unit. Splitter unit also includes room temperature preamplifiers.

FCUs are dual-channel up-down convertors with common local oscillator for both channels. Upconversion on first mixer uses tunable LO frequency in range of 28-39 GHz with filter on first intermediate frequency (IF) of 23‑24 GHz band. Without any amplification, it is downconverted on second mixer with 22 GHz fixed LO. Variable signal gain is obtained on the last IF band with the use of amplifiers chain, ceramic filters and digital attenuator.

### Units Overview

Cryounit (fig. 6) is the crucial unit of receiving system, with parameters (gain and noise temperature), that have the most influence on the total system parameters. It`s made from following main components:

- QRFH feed, calculated, designed and tested in IAA RAS. According to [2] it has 120 degrees beam width at –15 lB level in 4-16 GHz band with typical VSWR of 1.8.
- Krytar direct couplers, model 1824. It has working bandwith of 2-18 GHz, that exceeds the bandwith of feed.
- Cryogenic LNAs, manufactured by LowNoise Factory (Sweden), model LNF-LNC4_16A. Total bandwith of system is limited by 4-16 GHz LNAs bandwith.
- Sumitomo Heavy Industries coldhead that works with SRDK-408S cryogenic system. The working temperature of cryounit components is about 20 K.

Splitter units contains three coaxial splitters, that provide four equal channels. At first unit version, splitters were preceded by one preamplifier. According to later measurement results, this solution can`t provide enough gain and noise balance, so preamplifiers were moved after splitters, to FCU input. High noise temperature of FCU increased the number of preamplifiers from 2 to 8 for one system.

Splitter units and cryounit form frontend and has the common power unit (FEPU) with relays and primary power sources. Secondary power sources for cryo LNAs are placed near the cryounit in order to reduce the length of cables and power RFIs pick up. Specially designed board converts cryosensors` resistance to voltage, which is digitised and converted to cryotemperature value.

FCU prototype (fig. 5) has two channels for both polarizations of signal. Channels has the same structure and include upconverting mixer, IF1 filter on 23-24 GHz, amplifier (was withdrawn from device due to excess gain) and downconverting mixer. Powerful LO has two outputs - tunable 27-40 GHz and fixed 22 GHz, distributed on mixers by splitters. Channels were intentionally made different — one has cavity filter and coaxial mixer, in another planar microstrip and waveguide mixer were used. IF2 modules are the same with both channes and they provide 1-2 GHz band filtering with addition variable gain up to 30 dB.

NGU (fig. 4) contains wideband noise generation on coaxial IMPATT diode, direct coupler for unification of aplitude calibration noise and outer picosecond pulses. Total signal splits by two channels and injects in cryounit calibration inputs. The amplitude of noise and picosecond pulses can be tuned by 0.5 dB step digital attenuators.

DRU contains 8 equal channels units with splitter, loss compensation amplifier, step attenuator and diode detector for power-voltage conversion. Output voltage amplified and digitised. Acquisition and accumulation of signal in order to obtain radiometric gain is perfomed by MCU, separate for each channel. Master-MCU gatheres data from channel in format «total sum — number of points», skipping dividing as slow and difficult operation, and transfer it to computer for logging and visualisation.

Main power unit has the powerful external source of +24V supply and switching relays for 4 FCUs, NGU, vacuum valve. It also controls primary ~220V power for FEPU and provide thermostate power and control for 2 splitter units, 4 FCUs, NFU and DRU. Thermostable units contains only executive part (Peltier elements

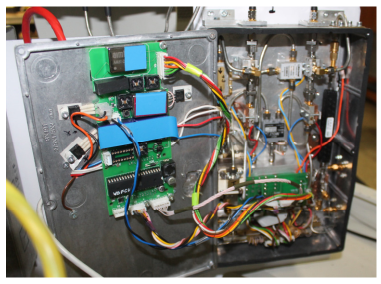

*Fig. 4. Frequency convertion unit prototype*

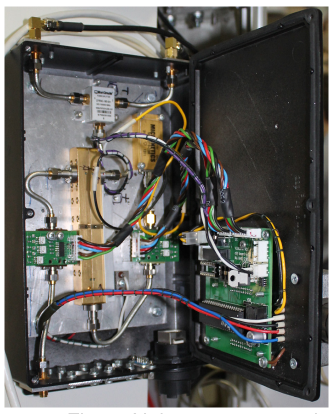

*Fig. 5. Noise generator unit*

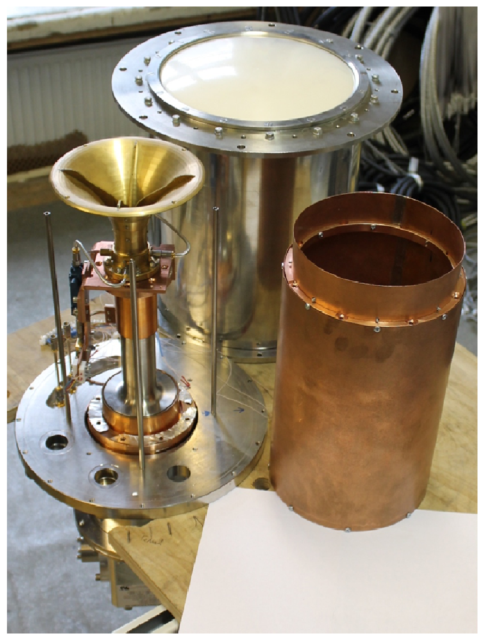

*Fig. 6. Cryounit assembly*

| Unit | Cryo unit | Splitter unit | | FCU | | | |
|---|---|---|---|---|---|---|---|
| Element | | Splitters | Preamp | Mixer | Filter | Mixer | IF2 module |
| Gain (loss), dB | 40 | -12 | 30 | -20 | -3 | -6 | 47 |
| Gain (loss), times | 0,000 | 15,849 | 0,001 | 100 | 1,995 | 3,981 | 0,000 |
| Physical temp., K | 20 | 300 | 300 | 300 | 300 | 300 | 300 |
| Noise temp., K | 50,0 | 281,1 | 500,0 | 297,0 | 149,6 | 224,6 | 500,0 |
| Noise contribution | 50,0 | 0,03 | 0,79 | 0,00 | 0,02 | 0,00 | 0,63 |
| **Total Noise, K** | **51,5** | | | | | | |
| **Total Gain, dB** | **76** | | | | | | |

### Calculated and Measured Parameters

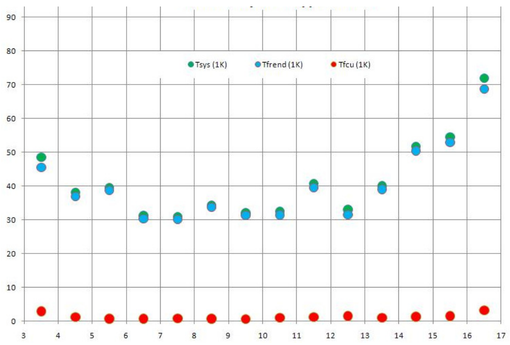


*Fig. 7. Noise (K) vs. frequency (GHz) measured*

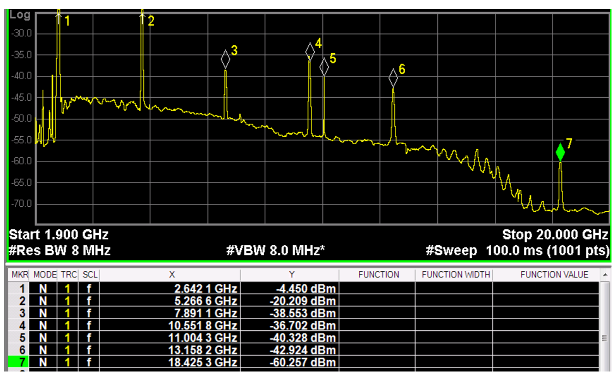


*Fig. 8. RFIs measured at UWB frontend output .*

The calculations of main UWB system parameters, such as gain and noise temperature, is presented in the table above. According to given data, total system noise should be about 50 K with the gain of 80 dB. The highest contribution to noise comes from cryounit. High gain of cooled cryo LNAs allows to use passive wideband splitter with 12 dB loss. Noise temperature of FCU is compensated with wideband preamplifier in splitter unit. To increase dynamic range, IF1 20-db amplifier was removed from FCU, with the increasing of IF2 module gain up to 50 dB.

Noise temperature measurements were obstructed by the RFI (fig. 8) problem that is inherent for UWB system. Despite the upshifting of receiving bandwith from 2-3 GHz S-band, occupied by well-known RFI sources such as Wi-Fi and 3G, large number of RFI is observed with open feed input. This means increasing of requierements for shielding during the measurment process. The quality of FCU IF1 filter also has crucial value for RFI suppressing. Frequnce scanning signal diagrams presented show that cavity filter with 11 sections provides much better signal sensivity than simple microstrip 3-section structure.

Total noise temperature measurements (fig. 8) were made with hot and cold match load method. The results given show that total system noise is less than 50 K, that matches with calculations and system requierements. Noise contribution of FCU is lowered enough. Some spurs on second channel may be caused by RFIs or feed mismatch.

Phase measurements included short-term phase noises and long-term LO frequency deviation. Phase noises were estimated by measurement of high quality test tone from Agilent E8257D generator. This tone converts up and down in FCU, so it undergoes by phase noises of both LOs. According to total measuremet results on highest LO frequency, integrated phase noise is about 7 degrees.

For measuring LO frequency deviation, BRAS VLBI registrator [4] was used. It has the option of tracking picosecond pulse harmonics, so the test tone from E8257D was set to tracked harmonic frequency and injected at phase calibration input of system. Than this frequency was fine tuned until the displayed phase of harmonic becomes constant. Total deviation of LO frequency assumed and fine tuned was tabled and it is less than 1 Hz. This results must be taken in calculations of Doppler shift during VLBI observations.

### Conclusion

The focal module of new generation UWB receiving system was designed and prototyped in IAA RAS. This module contains all nesessary equipment for system functioning and it is fully compartible by cryogenic, output signal, primary power and Ethernet-control interfaces with RT-13 radiotelescope. First cycle of laboratory tests has shown good match of expected and measured parameters, revealed problems and verified solutions. The UWB system will be ready for field tests soon.

### Links

1. **Evgeniy Khvostov.** The S/X/Ka receiver system for radio telescope RT-13 of Quazar VLBI Network.

2. **Alexey Lavrov.** Receiver module Power, Control and Monitoring system for RT-32 and RT-13 radio telescopes.

3. **Vitaliy Chernov.** Feeds of the Radio Telescopes RT-13 of the Quasar VLBI Network

4. **Melnikov A., et. al.** First Fringes with BRAS on VLBI Network “Quasar”. // IVS 2014 General Meeting Proceedings. Science Press, Beijing, China. P.134-137.