Operating Experience with the Broadband Acquisition System on the RT-13 Radio Telescopes

Evgeny Nosov, Dmitriy Marshalov, Alexey Melnikov

Abstract The Broadband Acquisition System (BRAS) was designed to digitize wideband signals from receivers of radio telescopes, pack the digital samples into VDIF frames, and transmit them through 10G Ethernet interface. The system has been installed at the Badary and Zelenchukskaya observatories on the recently constructed 13-meter radio telescopes (RT-13) in February–March 2015 [1]. Since November 2015, IAA RAS performs regular observations with the RT-13 equipped with BRAS. In addition, BRAS has been used in several international experiments. The paper describes the design of BRAS and its performance and results.

Keywords Digital backend, BRAS, DAS, RT-13, radio telescope, VLBI, Quasar network, Kvazar

1 Introduction

In 2015, the Institute of Applied Astronomy finished constructing a new radio interferometer based on fast-slewing 13-meter antennas built at the Zelenchukskaya and Badary observatories. To compensate for the sensitivity loss caused by the small antenna diameter the recorded signal bandwidth had to be significantly increased. The then-existing narrow-band data acquisition systems like R1002M DAS [2] could not satisfy the new requirements. To equip these new radio telescopes with a wide bandwidth digital backend, IAA RAS has designed the Broadband Acquisition System (BRAS). The system is in operation since the beginning of 2015 and it works on a regular basis in everyday VLBI observations.

Institute of Applied Astronomy of RAS (IAA RAS)

2 Structure of the Broadband Acquisition System

BRAS contains eight identical units (wideband channels) that allow to digitize the input signals of 512 MHz bandwidth (Figure 1). Each unit is based on high-speed ADC and low-cost FPGA performing the necessary signal processing. The required Nyquist zone is selected by an input antialising filter, with the third Nyquist zone from 1024 to 1536 MHz being the default. Each wideband channel of BRAS outputs data packed into VDIF frames through a 10 Gigabit Ethernet fiber link. BRAS is relatively small in size (one 19″ rack with 6U units) and is located in the focal cabin of the antenna close to the receivers. It allows eliminating the transmission of analog signals over a long distance and all related instabilities and performance degradation.

A matrix switch in the receiving system (Figure 2) provides two possible switching modes: S/X and X/Ka. In S/X mode, BRAS digitizes one signal in S-band and three signals in X-band for both right (RCP) and left (LCP) circular polarizations (Figure 3). In X/Ka mode, BRAS digitizes one signal in X-band and three signals in Ka-band, also in both polarizations. The local oscillators of the receiving system allow the frequencies of the wideband channels in all ranges marked in Figure 3. More information about the BRAS structure and performance can be found in [3, 4].

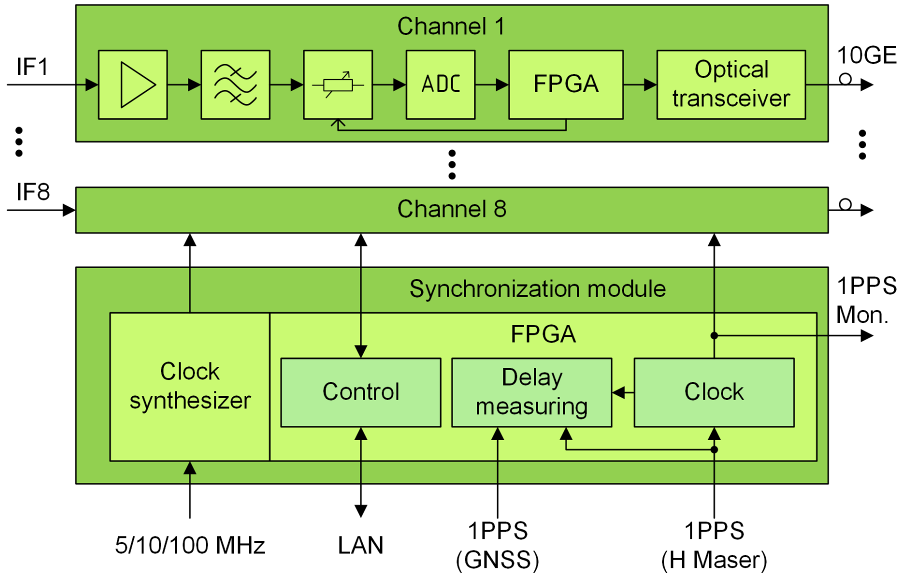

Fig. 1 Structure of the Broadband Acquisition System (BRAS).

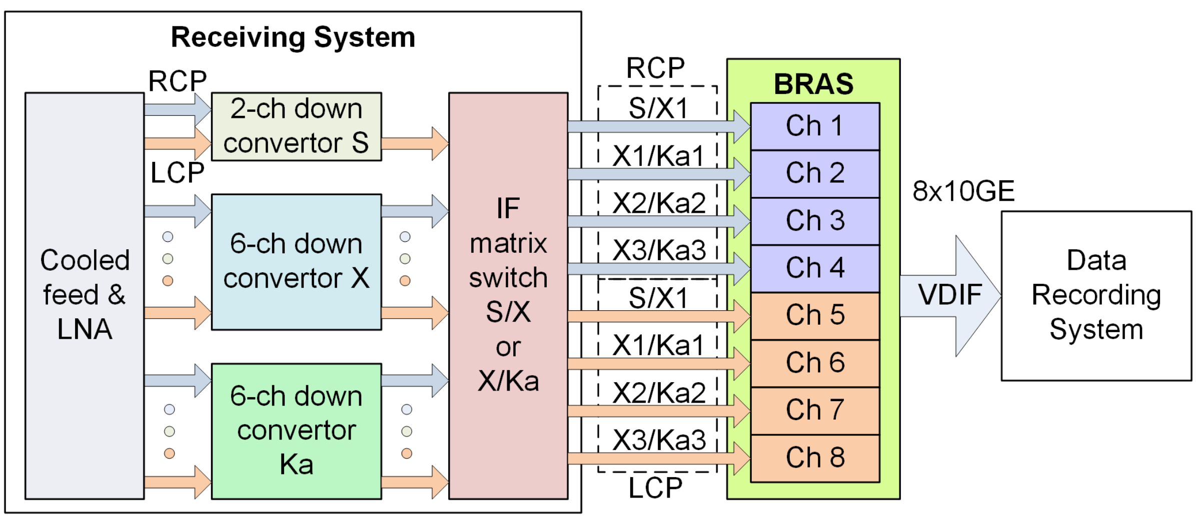

Fig. 2 Signal chain of the RT-13 radio telescopes.

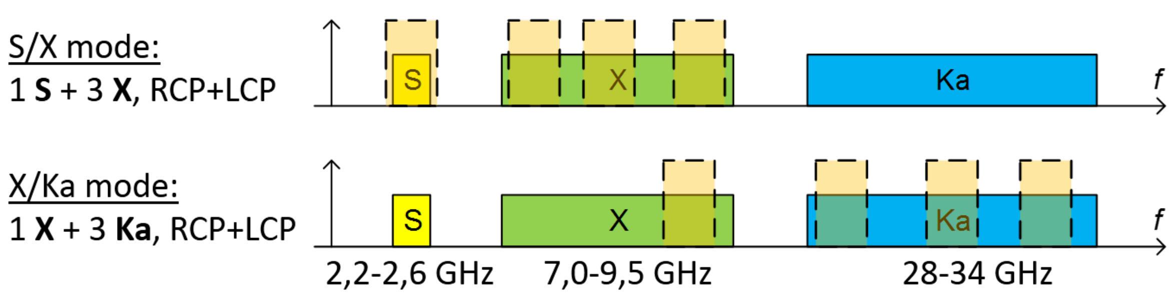

Fig. 3 Switching modes of the RT-13 radio telescopes.

3 System Diagnostics and Signal Analysis Features

Since BRAS is located in the focal cabin and most of the signal processing is digital, it is impossible to use traditional methods of system diagnostics based on indicators and electronic measuring instruments. Instead, BRAS implements a rich set of embedded functions for remote control of the system status and input signal behavior. Along with monitoring the conventional parameters like currents in power circuits, temperatures inside the system, and lock detect signals of the clock synthesizers, BRAS provides the following features:

- Signal power measurement,
- 2-bit sample distribution estimation,
- 1PPS internal-external delay monitoring,
- Input/output (8/2-bits) signal capture, and
- Phase calibration (PCAL) signal extraction.

The signal power measurement is performed in each wideband channel four times per second. The measurements are used to control the signal chain condition and evaluate the system temperature. The estimation of 2-bit sample distribution is convenient for automatic detection of input signal distortions and strong RFI. As an example, Figure 4 represents a 2-bit distribution in S-band measured at Badary observatory with enabled (top) and disabled (bottom) DORIS transmitter. When the DORIS transmitter is disabled, the distribution corresponds to a Gaussian white noise (0.16, 0.34, 0.34, 0.16 with 1σ quantization threshold), while when the DORIS transmitter is enabled the distribution is like sinusoidal (0.25 for each bin).

Another useful feature is the 1PPS delay monitoring implemented in BRAS for the delay measurement between the internal clock of BRAS and the 1PPS signals from the H-maser and the GNSS receiver. Comparing these delays one can detect and isolate failures in the time synchronization system. The accuracy of the time delay measurement is 4 ns. The other two features are input and output (8- and 2-bits) signal capture and PCAL extraction. On request BRAS can capture 1 μs of input and output signals and send it to the control software so that they can be viewed in the digital oscilloscope and analyzed in the time and frequency domain. Figure 5 gives an example of the power spectral density (PSD) estimated using Fast Fourier Transform and averaging among several realizations of the captured input signal in X-band. This feature is a handy tool for on-the-fly control of the signal chain condition and their maintenance and repair.

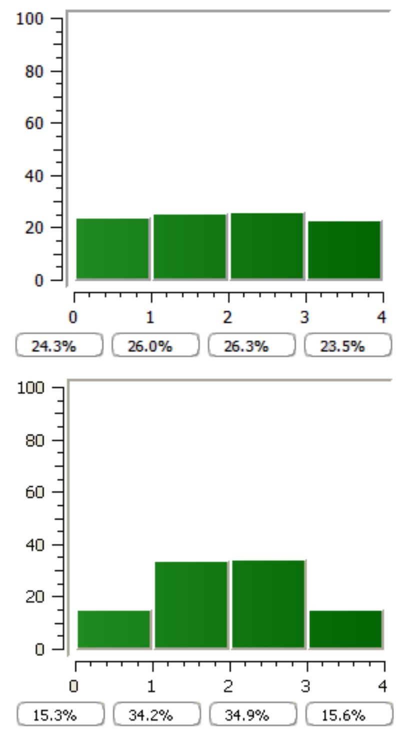

Fig. 4 Measured 2-bit distribution with enabled (top) and disabled (bottom) DORIS transmitter at S-band at Badary.

The injection of the PCAL signal into the signal chain not only helps with wide bandwidth synthesis, but it also simplifies hardware debugging. BRAS extracts the PCAL signal by averaging it in one-second intervals. By extracting the PCAL signal from the noise, it is possible to estimate the phases and amplitudes of the PCAL tones and its variation in time as well as the group delay of the PCAL signals for each channel.

4 Observation Results and Conclusions

In the end of 2014, BRAS was tested for the first time with real observations on the RT-32 radio telescopes and fringes were obtained [5]. In the beginning of 2015, it was installed on the new RT-13 radio telescopes and used for their adjustment. On 16 April 2015, BRAS was used in the first VLBI observation with the RT-13 radio telescopes and first

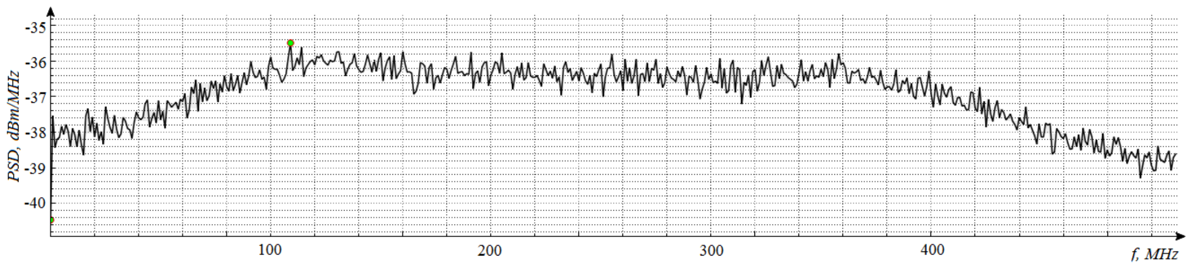

Fig. 5 PSD estimated by using captured input signal in X-band at the Zelenchukskaya observatory.

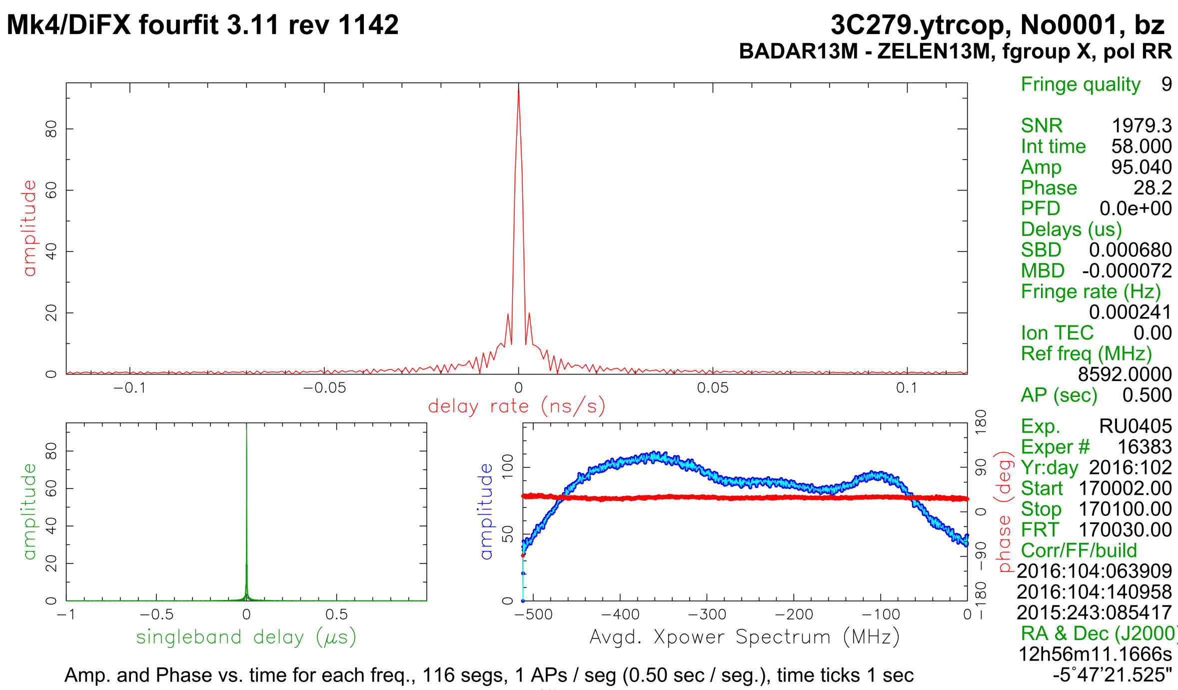

Fig. 6 Fringes found with BRAS on the Badary–Zelenchukskaya baseline in the RU0405 experiment.

fringes were successfully obtained. On 29 April 2015, the first international observations were performed with the Yebes and Wettzell observatories. On 19 May 2015, the official inauguration of the new radio interferometer equipped with BRAS took place during the EVGA 2015 meeting [6]. The recorded data was processed by three correlators: the GPU-based and DiFX correlators of IAA RAS in St. Petersburg and the DiFX correlator of MPIfR in Bonn. During a year of BRAS service, several minor hardware and software bugs were detected and fixed. Figure 6 shows an example of fringes found with BRAS. It is important to point out that compatibility between the BRAS and DBBC systems was confirmed with real observations [7, 8]. Currently BRAS is used on a regular basis in the day-to-day work. Altogether BRAS was used in about two-hundred international and domestic observations in 2015 and in about 300 observations in the first quarter of 2016.

References

1. A. Ipatov, D. Ivanov, G. Ilin, V. Olifirov, V. Mardyshkin, I. Surkis, L. Fedotov, I. Gayazov, V. Stempkovsky, Yu. Bondarenko. “Russian Radio Interferometer of New Generation.”, In: R. Haas, F. Colomer (eds.), Proceedings of 22nd EVGA Working Meeting, 2015, pages 75–79.
2. S.A. Grenkov, E.V. Nosov, L.V. Fedotov, N.E. Koltsov. “A Digital Radio Interferometric Signal Conversion System.”,

Instruments and Experimental Techniques, Vol.53. No.5, 2010, pages 675–681.

3. N.E. Koltsov, D.A. Marshalov, E.V. Nosov, L.V. Fedotov. “A data acquisition system of the S/X-wave range of the radio interferometer for the universal time on-line monitoring.” Instruments and Experimental Techniques, Vol.56, No.3, 2013, pages 339–346.
4. E. Nosov, A. Berdnikov, S. Grenkov, D. Marshalov, A. Melnikov, L. Fedotov. “Current Development State of the Russian VLBI Broadband Acquisition System.” IVS 2014 General Meeting Proceedings. Science Press, Beijing, China, pages 82–85.
5. D.A. Marshalov, A.S. Berdnikov, S.A. Grenkov S.A., A.V. Krohalev, E.V. Nosov E.V., L.V. Fedotov, A.V. Shemanaev. “The results of Preliminary Tests of Broadband Digital Conversion System for Radiotelescopes” . IAA Transactions. Issue 32. St.Petersburg, 2015. Pages 27–33.
6. V. Ken, I. Surkis, Y. Kurdubova, A. Melnikov, N. Mishina, V. Mishin, V. Shantyr. “IAA VGOS GPU-based Software Correlator: current status andbroadband processing.” In: R. Haas, F. Colomer (eds.), Proceedings of 22nd EVGA Working Meeting, 2015, pages 40–42.
7. A. Neidhardt, P. De Vicente, A. Hellerschmied, D. Mayer, A. Melnikov, C. Plötz, G. Kronschnabl, “First results of the FAST-S/X-sessions with new VGOS antennas.” In this proceedings.
8. A. Melnikov, P. De Vicente. “First 2 Gbps observations between KVAZAR VGOS antennas and Yebes RAEGE antenna.” In this volume.