Development of Modern Data Acquisition Systems at IAA RAS

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Abstract

The data acquisition system for VLBI radio telescopes downconverts, filters and digitizes analog signals coming from the receiving system. During the last ten years, IAA RAS has made great progress in data acquisition systems development: from fully analog to fully digital devices, with a significant improvement in both performance and functionality. This paper gives an overview of the aforementioned systems and the prospects of further development.

Keywords: Data Acquisition System, VLBI, backend, ADC, FPGA, MDBE, BRAS, R1002M, Quasar network.

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Introduction

The data acquisition system (DAS) is a backend of the signal chain in VLBI radio telescopes. DAS receives signals of intermediate frequencies (up to 2 GHz) from the receiving system of a radio telescope and prepares them for recording. Usually it includes downconversion of the required parts of the signal spectrum to the baseband forming the required bandwidth, quantizing signals to 2-bit samples, and sending them to the recorder in the required VLBI data format. Ten years ago, most of VLBI DASs in use were based on analog electronics. This limited the performance of DASs and radio interferometers in general. New high-performance digital electronics, such as wideband analog-to-digital converters (ADC), field programmable gate arrays (FPGA) with hundreds of embedded multipliers and multigigabit transceivers allows designing much more advanced and powerful DASs. This paper describes the evolution of the DASs developed by IAA RAS for radio telescopes of Quasar VLBI network.

Evolution of Data Acquisition Systems

Digital signal processing has unbeatable advantages over analog processing in radio astronomical applications. It allows engineers to develop system with a stable and reproducible frequency response, which is identical over all channels in every radio telescope, and that is important for minimizing instrumental sensitivity loss in VLBI applications. Unlike analog devices, the digital devices are insensitive to temperature and voltage variations. Besides, modern FPGAs can implement complex processing algorithms, which are not possible to handle in analog electronics. One more advantage of modern digital devices is on-the-fly firmware reloading, which makes it possible to perform all types of radio astronomical observations with the same all-purpose hardware. All this led to conversion of the Quasar network radio telescopes from fully analog DASs to fully digital ones (Fig. 1).

Baseband converters of analog DASs, which were in use until 2011, contained mixers for frequency conversion, wideband phase shifters and summators for image rejection, low-pass filters for shaping the frequency response (Fig. 1*a*). In 2011, all the various DASs of RT-32 radio telescopes were replaced by R1002M DAS [1] developed by IAA RAS. The new DAS is not yet completely digital, as it still uses analog mixers and local oscillators, but all the processing in the baseband including image rejection and bandwidth shaping is performed in digital form by FPGA (Fig. 1*b*). R1002M DAS supports up to 16 channels with up to 32 MHz bandwidth per channel. It produces VSI-H output data stream, which can be used for recording by the commonly used Mark-5B recording system with the total data rate of up to 2 Gbit/s. The use of R1002M DAS significantly reduced instrumental sensitivity losses of the radio telescopes [2].

The next step in DAS development was digitizing the intermediate frequency range signals from the receiving system without analog frequency conversions (Fig. 1*c*). This was implemented in the Broadband Acquisition System (BRAS), which was put into operation on RT-13 radio telescopes in 2015 [3]. BRAS has 8 channels of 512 MHz bandwidth each. The system is based on simple inexpensive FPGAs and has no subchannelization, which limits its compatibility with legacy DASs. Output data is transmitted through fiber link by 10G Ethernet interface. The total output data rate can be as high as 16 Gbps.

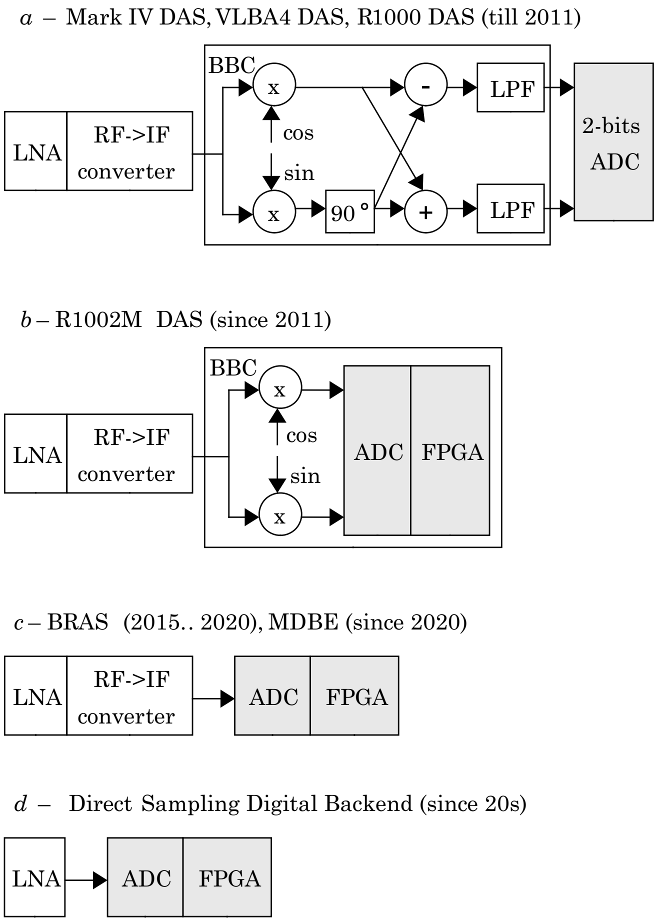

Fig. 1. Signal chain evolution in radio telescopes of Quasar VLBI network. *a* — legacy analog DASs; *b* — semi-digital R1002M DAS; *c* — fully digital DASs; *d* — DAS based on direct sampling at radio frequencies. LNA — low noise amplifier, RF and IF — radio and intermediate frequencies, BBC — baseband converter, LPF — low-pass filter

Fig. 2. Digital data acquisition systems developed in IAA RAS in the last ten years. *a* — R1002M DAS; *b* — Broadband Acquisition System; *c* — Multifunctional Digital Backend with 4 channels inserted

Table

Basic parameters of digital DASs developed at IAA RAS

Parameter	R1002M DAS	BRAS	MDBE
Input frequency range	0.1–1 GHz	1–1.5 GHz	0.01–2 GHz
Max. number of channels	16	8	12
Max. bandwidth of channels	32 MHz	0.5 GHz	2 GHz
Max. total data rate @2 bits	2 Gbps	16 Gbps	96 Gbps
Outputs	VSI–H, copper	VDIF, 10GE per channel, fiber	VDIF, 40+10 GE per channel, fiber
Operation modes	down-converters	wideband channels	downconverters, wideband channels, radiometric, spectrometric

In the coming 2020–2021, both R1002M DAS and BRAS will be replaced by Multifunctional Digital Backend (MDBE) [4]. MDBE can have up to 12 channels with up to 2 GHz bandwidth. Each channel is based on a powerful FPGA chip capable of performing complex signal processing algorithms. This will allow to incorporate digital downconverters into MDBE for subchannelization and to make them compatible with all the existing DASs. Maximum data rate of the fully equipped system reaches 96 Gbps. MDBE supports various VLBI observation modes, as well as single-dish applications. Apart from its main functions, MDBE also performs a number of auxiliary functions of signal analysis, such as signal distribution measurements and phase calibration signal extraction [5].

Main parameters of the described systems are summarized in the Table. It can be seen that each subsequent system developed gives a significant gain in the main parameters and performance, which becomes possible due to the advantages of digital signal processing. It is also true for the usability, the cost and the size of the systems (Fig. 2). Further improvements can be achieved by digitizing signals directly in the radio frequencies range, which eliminates almost all the analog devices (and corresponding sources of instrumental sensitivity loss) in the signal chain (Fig. 1*d*). Though there is a lot of challenges along this path, IAA RAS plans to start the project of developing new Direct Sampling Digital Backend in the near future [6].

Conclusion

In the last ten years, IAA RAS has come a long way in designing the data acquisition systems for VLBI applications transforming them from fully analog to fully digital systems. The current generation of DAS created by IAA RAS fully complies with the modern requirements and will ensure a reliable and high quality operation of the Quasar network for the coming years. The experience of the design team will be used for further advancement of the Direct Sampling Digital Backend.

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