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1. R1002M Data Acquisition System (DAS)

The new DAS R1002M is developed by IAA RAS for replacement of existing analog DASs of the VLBI network "Quasar" [1]. The R1002M system was set in operation at the Svetloe, Zelenchukskaya, and Badary observatories.

R1002M uses digital signal processing on video frequencies and provides enhanced performance. It is compatible with existing analog DASs. The system consists of 16 Base Band Converters (BBC), IF-distributor, Clock Generator, Data Stream Combining Board (DSCB), and auxiliary units (Figure 1). It has four IF-inputs which can be electronically connected to the BBCs in the required way by IF-distributor unit. The BBCs' output data streams are combined via DSCB and available in its output in VSI-H format with up to 2048 Mbps data rate (Table 1). The DAS is well suited to work with the Mark 5B+ recording system, but it can also work with Mark 5B in case of 1024 Mbps and lower data rates. For proper synchronization, the DAS is required for 1PPS and 5 or 10 MHz signals. The clock generator automatically determines which input reference frequency (5 or 10 MHz) is used.

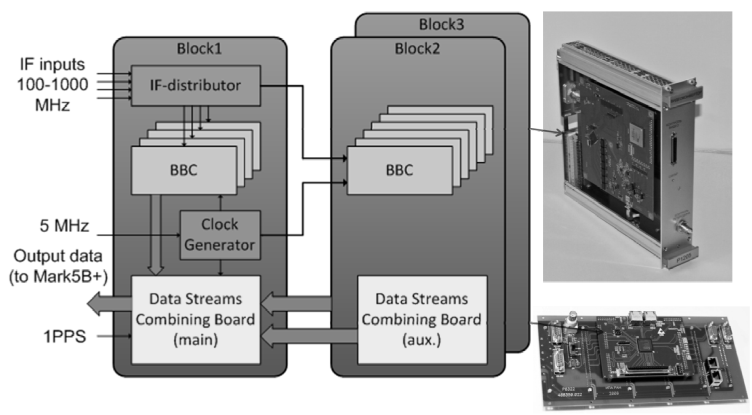

Figure 1. Simplified structure of R1002M DAS and pictures of the BBC and DSCB.

In R1002M the translation to baseband is performed by high quality analog mixer and local oscillator (LO). The output signals of the mixer are then digitized, and all subsequent processing is implemented by an FPGA. The digitizing is performed by 2-channels analog-to-digital converter (ADC) with a sample rate of 64 Msps (Figure 2). To separate the side bands a special multirate filter bank with complex-valued coefficients was developed and realized as FPGA. Use of this technique allows the achievement of a relatively high image rejection rate. The typical value for the digital BBC is −40 to −45 dB (at frequencies below 16 MHz) while in existing analog BBCs the typical value is about −20 to −25 dB.

A few additional switchable FIR-filters are used for forming six possible bandwidths: 0.5, 2, 4, 8, 16, and 32 MHz. The resulting amplitude-frequency characteristics of the digital BBCs are made similar to BBCs of existing analog DASs for improving compatibility between the systems.

Table 1. R1002M DAS specification

Input frequency range	100 to 1000 MHz
Number of IF-inputs	4
Number of channels (BBCs)	16
Selectable bandwidths	0.5, 2, 4, 8, 16, 32 MHz
Separated sidebands	Both lower and upper
Image rejection rate (typ.)	−40 to −45 dB
Commutation of input and output signals	Electronically
Local oscillators phase noise (rms)	$\leq 0.7°$ (measured in 30 Hz÷30 MHz range)
Ripple of amplitude-frequency response of the BBCs	≤ 0.3 dB
Output data format	VSI-H
Output data rate	Up to 2 Gbps
Available control interfaces	RS-232, RS-485, 100/10 Ethernet
Total dimension (three 19″ subracks)	$445 \times 950 \times 315$ mm

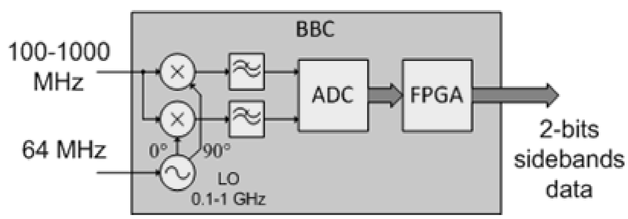

Figure 2. Simplified structure of the BBC.

From November 2011 all observations on the VLBI network "Quasar" have been performed by using R1002M DAS (Figure 3). It decreases the errors of EOP measurements (root-mean square deviation from the IERS 08 C04 series) on network "Quasar" to 0.38 mas for Celestial Pole position, 1 mas for Pole position, and 34 microseconds for Universal Time.

2. Broadband Phase Calibration System

The primary goal of the phase calibration system is to monitor the instrumental phase delay. For this purpose a spectrally pure reference signal is transmitted by cable to the mirror room of the radio telescope where it synchronizes generator of very short impulses of about 40 ps duration. In the current phase calibration system the impulses are injected through direction coupler into the input of receiver before the first LNA and passed with the received signal through receiver and data acquisition devices to digitization, after which the phases of the tones are extracted.

The broadband phase calibration system has been developed for the Russian VLBI new generation network. The goal of this phase calibration system is to radiate phase cal impulses from a special broadband feed (TEM horn, Figure 4) located ahead of the receiving feed. The main advantage of injecting phase cal ahead of the receiving feed is in putting most of the VLBI signal path into the phase calibration loop.

The broadband phase calibration system consists of TEM horn connected to the generator of picosecond-level impulses. The generator is placed into the thermo stating block, providing a time-

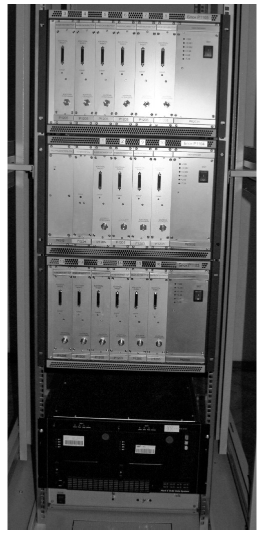

Figure 3. R1002M DAS and Mark 5B+ in Svetloe observatory.

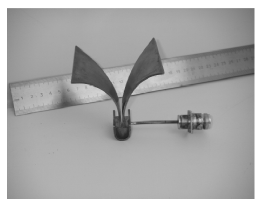

Figure 4. TEM horn.

constant temperature. All of the system together with power units is located in the all-weather plastic case, which easily mounts on a metal ware of a radio telescope.

The breadboard model of the broadband phase calibration system has been mounted on a radio telescope in the "Svetloe" observatory (Figure 5), and some testing on radiation of a phase calibration signal through a broadband horn has been carried out.

The impulses of two signals are registered upon exiting the receiver. The first impulse is from the regular generator of picosecond-level impulses, and the second is from the block of the broadband phase calibration system (Figure 6). These experiments showed the absence of multipath effects in the external radiation phase cal signal.

However, further research has revealed essential non-uniformity of phase calibration signal in different bands. Power of a cal signal upon exit of the S and X-band receivers differs by 10 dB. Analytical estimations (calculated by taking into account horn gain, losses in a radio line and gain of receivers) and experimental values of phase calibration power upon exit of the S and X-band receivers are represented in Table 2.

At the same time, in all channels of the receiver equipment the signal has sufficient (and at places even superfluous) power for the correct operation of the phase calibration system. It means that additional balance of power at various places along a frequency band is needed. Probably, the cascade of the adjustable filters located between the picosecond-level generator and the TEM horn is capable of solving this problem. But it demands additional research.

Table 2. Power of a cal signal upon exit of S and X-band receivers

Band	Power of a signal upon exit of receivers	
	Analytical estimations	Experimental
X	−80 dBm	−85 dBm
S	−70 dBm	−72 dBm

Figure 5. The breadboard model of the broadband phase calibration system mounted on a radio telescope ("Svetloe" observatory).

Figure 6. Oscillogram of output signal for S-band receiver.

References

[1] S. A. Grenkov, E. V. Nosov, L. V. Fedotov, N. E. Koltsov. A Digital Radio Interferometric Signal Conversion System. Instruments and Experimental Techniques, 2010, Vol. 53, No. 5. P. 675–681.