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New Observing Modes for the DBBC3

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Abstract The DBBC3 was further enhanced by introducing new modes. Three different firmwares have recently been implemented for observing: Direct Sampling Conversion (DSC), arbitrary selection of bands (OCT), and Digital Down Conversion (DDC). These modes cover all the requirements of astronomical, VGOS, and legacy geodetic VLBI for the time being and the immediate future. In addition, the DBBC3 offers unsurpassed compatibility to the relatively large number of other existing VLBI backends. A number of test observations were performed in the last months to achieve the best performance of the VGOS modes, and similar tests are planned for the EVN network. At the same time the DBBC3 is an important platform for additional new modes to be implemented for the BRAND receiver. Several DBBC3 systems are deployed in the field and more are under construction, with the number of 4-GHz bands ranging from two up to eight with resulting output data rates from 32 Gbps to 128 Gbps.

1 Introduction

The DBBC3 backend system for VLBI was developed with the support of the Radionet3 joint research activity under the DIVA project. Partners in this development have been the Italian INAF (Istituto Nazionale di Astrofisica), the German MPIfR (Max Planck Institute

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for Radio Astronomy), and the Swedish OSO (Onsala Space Observatory). The backend was developed initially for astronomy with the aim to improve the EVN network data rate and bandwidth. As a natural consequence, it could also be devoted to the EHT (Event Horizon Telescope) and to geodetic VLBI both in the new broadband VGOS network and with the legacy S/X stations.

The DBBC3 constitutes the third generation member of the DBBC family, following the DBBC2 which is still the most widely adopted digital backend in VLBI. The DBBC3 is an evolutionary product that is backwards compatible with the DBBC2 in several ways: observing modes, control software, and parts of the hardware. In principle it is possible to upgrade a DBBC2 system to a DBBC3 by replacing some key parts, but reusing many elements of the existing system including the housing and basically all of the general pieces.

The DBBC3 offers a selection between one and eight IFs, each a maximum of 4 GHz wide to produce a maximum data rate of 16 to 128 Gbps when operating at 2-bit. The hardware is capable of producing a maximum of 512 Gbps when operating with output samples of 8-bit.

A number of modes were commissioned:

- **DSC:** 4 GHz full band/IF;
- **DDC:** 8 BBC/IF with bandwidth in the output channels ranging between 32 and 1 MHz for legacy modes;
- **OCT_S:** 1 x 1 GHz selectable in 4 GHz; and
- **OCT_D:** 2 x 2 GHz in 4 GHz.

A number of additional modes were developed needing to be commissioned and further modes are under development. The goal is to achieve the best possible

compatibility with all the other existing VLBI backend systems in the world and to introduce new modes not yet available in other backends that are deemed greatly useful and desired by the scientific community.

2 DBBC3 Components

The enclosure of a DBBC3 system is, as mentioned, exactly the same as used in the previous versions of the DBBC backend family and so are many ancillary parts such as the cooling section, the power supply, the control computer, and the DBBC stack structure, where a number of boards are connected to one another in a block to perform the main functionalities. Even if a specific board is different from one generation to the next, there is full mechanical and electrical compatibility from the power supply point of view.

The first main active component is the GCoMo2, the second version of the GCoMo analog conditioning module, whose functionality is to adapt the receiver to the sampling process. The new GCoMo2 provides an improved bandwidth over the 4-GHz band. The unit is made to match the receiver electronics with a lot of flexibility with internal and external components; this is very useful to be able to adapt to the various receiver implementations of the radio telescopes. It still can measure the full input band total power before sending the signal to the samplers. The samplers' functionality is operating in the first Nyquist zone; then a direct input of 0–4 GHz is dedicated to a mode that allows full support for the adaptation at the first Nyquist zone of any 4-GHz piece of band in the range from 4 to 15 GHz.

The second element in the processing chain for each 4 GHz piece of band is the ADB3L sampler board. This sampler is the third generation of samplers in the DBBC family and is capable of sampling a band of 4,096 MHz making use of four separate sampler devices accommodated in the same board adjacent to each other. A number of calibration procedures have been implemented in hardware, firmware, and software presenting at the end for the user very simple commands to keep under control elements such as the offset, gain, and delay of the four samplers avoiding artifacts and optimizing the behavior of the sampling process. Several original methods were developed in order to achieve this goal.

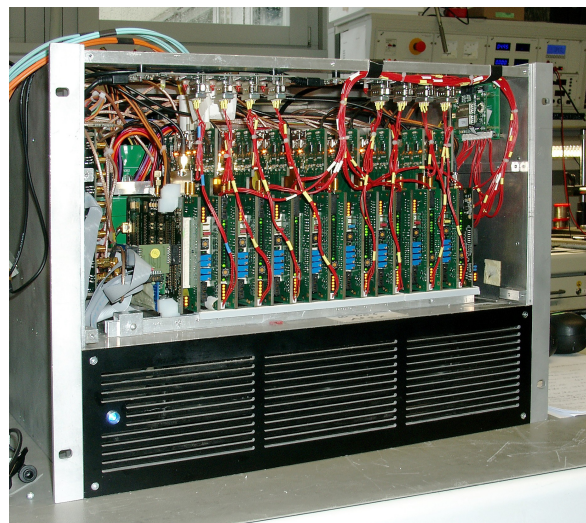**Fig. 1** Front view of the DBBC3.

Fig. 2 DBBC3 VGOS model with eight IFs.

Finally, the last main element is represented by the CORE3H board. Here the data is received by the samplers in digital format and the band forming is done. The functionality is realized by making use of a very high end FPGA device adopting different firmware codes for different observing modes. The data output is handled by four 10 GE transceivers on the board; however, if a higher output data rate is required (up to a maximum of 512 Gbps), a maximum of eight transceiver slots could be populated. The control of the functionalities is assured by three different communication channels: a parallel PCI bus line, an RS232 serial communication link, another RS232 serial channel

for a dedicated GPS receiver system. The control software is very similar to the DBBC2, but it is, of course, adapted to the many more resources available. For instance, in DDC mode the maximum number of BBC units is 128 (in legacy mode), while it was 16 in the DBBC2.

3 Observing Modes

For each IF processed in the system, different modes can be realized depending on the type of observation to be performed. The difference comes from the use of a different firmware inside the FPGA elements of the system, which is highly flexible in this respect.

The samplers produce the digital version of the input band coming from the receivers requiring still to be processed to create frequency channels in tuning, bandwidth, number, and format to be compatible with the VLBI standards as well as with any other VLBI backend and the processing VLBI correlators. The entire process and preparation of the output data format to be recorded or to be transferred electronically directly to the correlators is then realized inside the processing boards (CORE3H) making use of a collection of different firmwares to be loaded on the boards as required by the type of observation.

As mentioned, a number of modes were developed:

- DSC (direct sampling conversion): 4 GHz full band/IF, using this mode it is possible to record a large received bandwidth ranging from 4 GHz up to 32 GHz;
- OCT_S (octopus single band): some examples

  - 0–2, 2–4 GHz
  - 0–1, 1–2, 2–3, 3–4 GHz
  - 0.5–1.0, 1.0–1.5, ..., 3.5–4.0 GHz
  - many others possible;

- OCT_D (octopus double band): some examples

  - 2 x 2 GHz
  - 2 x 1 GHz
  - 2 x 512 MHz
  - 1 x 2 GHz + 1 x 1 GHz
  - many others possible;

- DDC (digital tunable down conversion):

  - V type (VGOS), eight BBC/IF with bandwidth 32 MHz U&L, max 64 BBC in a system;
  - V type (VGOS), 12 BBC/IF with bandwidth 32 MHz (for six IFs systems) U&L, max 96 BBC in a system;
  - L type (legacy), 16 BBC/IF with bandwidth 32-16-8-4-2 MHz U&L, max 128 BBC in a system;
  - H type (high band, under development), 16 BBC/IF with bandwidth 128-64-32-16-8 MHz;
  - P type (tunable PFB, under development), 32 bands tunable 64-32-16-8-4 MHz PFB block in 4 GHz.

For all the configurations an automatic threshold calibration is available for 2-bit output during runtime. The DDC-VGOS mode was the first of its kind and it was widely debugged by the Onsala team over several months. The many improvements were possible due to the large amount of tests performed at that observatory within 24-hour VGOS Test sessions as well as outside of them. The Onsala site is anticipated to function as the main testbed for introducing any new version in the field.