From BRAND to DBBC4

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Abstract The BRAND project is now overlapping with the DBBC4 project. This is due to the fact that a number of technological solutions already developed and still under development for BRAND are being applied to the DBBC4 front-end. The current status of the BRAND project with its latest achievements will be presented, together with an overview of the new DBBC4 project, which started this year. The DBBC4 is expected to provide new state-of-the-art functionalities for VLBI astronomy, geodesy, and space science.

Keywords Backend, DBBC, Artificial Intelligence

1 Introduction

Since the first implementation, the DBBC systems have pursued original and non-existent solutions. Such uniqueness, due to the adoption of innovative solutions and the best available technologies, has made it possible to develop and establish state-of-the-art solutions. The success of the operation is evidenced by the fact that the European VLBI network EVN adopted for over a decade DBBC systems as the standard back-end of the network, and numerous radio telescopes of the VLBI IVS (International VLBI Service) geodetic network use these systems on a regular basis. The implementation of the third DBBC3 generation is now used for the observations of the Event network Horizon Telescope, is used in the VGOS geodetic network, and is going to be adopted by the EVN for the modernization of the network, which is currently mainly equipped with second generation DBBC2 systems. The different versions DBBC1, DBBC2, FILA10G, and DBBC3 are today in use around the world in more than one hundred units.

Developments in the DBBC family recently have included the BRAND (BRoad-bAND) digital receiver covering the 1.5–15.5 GHz band, now in the final stages of development, and the design of the new DBBC4 digital front-end and back-end system, which has recently been launched with absolutely innovative elements for the characteristics and methods adopted, which allow it to be operated with wide reception bands up to 256 GHz and a product ‘data rate’ up to 4 Tbps.

The graph in Figure 1 shows in logarithmic scale the comparison between the various systems of the family, from which it is possible to highlight the growth in performance, together with some views of some specimens.

2 General Architecture

The new system, in order to maintain compatibility with the previous versions of DBBC systems, has an architecture which can allow an upgrade from previous versions. Such a possibility is guaranteed by the physical structure of the system and the organization of the various parts.

In terms of functionality, anyway, there are important differences, due to the extremely higher performance offered by the new system. Here is described the general architecture with the main parts and the novel functionalities which will be part of the system.

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DBBC Family Evolution (Table)

	DBBC1 (2004)	DBBC2 (2009)	DBBC2010 (2010)	DBBC3 (2014)	BRAND (2020)	DBBC4 (2024)
Max Input Bandwidth (MHz)	512	4096	8192	32768	57600	256000
Max Output Data rate (Mbps)	1024	8192	16384	131072	460800	4000000

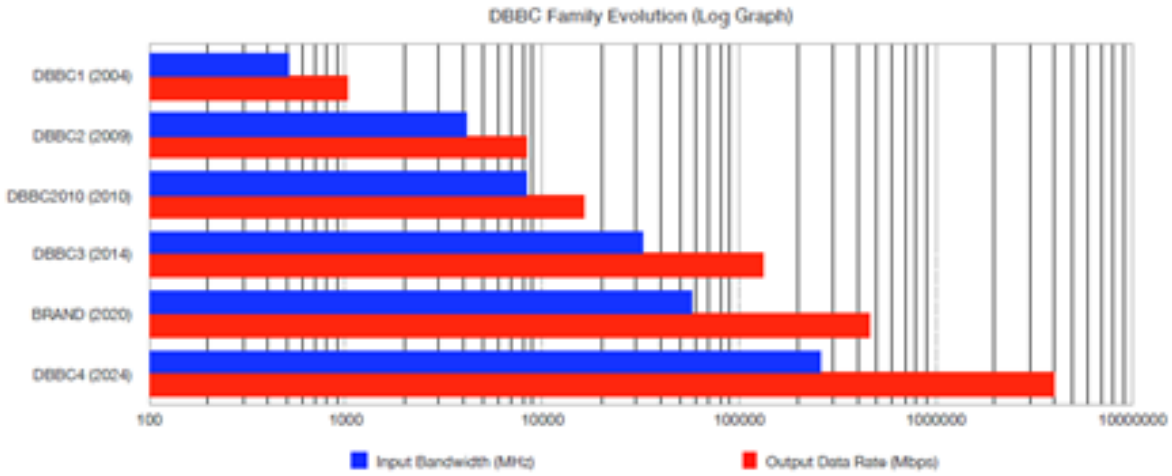

Fig. 1 DBBC family evolution performances.

The main difference which can be considered relevant in the DBBC4 is its nature of 'widespread system'. This means the traditional method for building a digital back-end for radio astronomy was to separate in very different physical positions the analog part of the receiver with respect to the digital part, including the transaction pin and the sampler. This concept was revised in the BRAND EVN project, where the realization of the very wide bandwidth digital front-end (called 'DI-FR-END'), was positioned close to the traditional analog front-end. This solution, even if it presents challenging implementations in terms of RFI shielding, allows superior performance in terms of phase stability, higher dynamic range, and robust and simple methods to transfer the pure sampled or digital preprocessed data to the back-end area, where it is still convenient to maintain a good part of the equipment for RFI shielding purposes.

The DBBC4 is mainly planning to adopt such a distribution between the digital front- and back-end, even if the possibility of performing such entire functionality in the back-end area is maintained. This in particular can be useful when traditional existing receivers are already routed to this area, or when very high frequency (sub-millimeter) receivers are used, then including frequency conversions in the antenna focal area. In order to accomodate such solutions a dedicated module is provided.

The 'widespread system' is not considered only for the digital front-end but includes other possible 'dislocated' elements in support of the more advanced functionalities the DBBC4 offers. These elements are sensors which collaborate with the DBBC4 main unit to provide information in support of new functionalities. Some of those will be defined later in this document, while still a larger number will be defined during the period of development and even at a later stage even with the DBBC4 well operative in the field.

In order to describe the system, it is useful to start from the planned maximum capabilities for its main features:

- Input bandwidth up to: 8 x 28 GHz = 224 GHz aggregate in digital front- or back-end

plus 8 x 4 GHz = 32 GHz aggregate in ancillary digital front

total full aggregate = 256 GHz

- Output data rate up to: 1 Tbps @ 2-bit, 2 Tbps @ 4-bit, 4 Tbps @ 8-bit

- Modes: DSC (full band for data transfer), OCT (wide bands defined in the input band)

- New functionalities: Burst-mode, AI-mode, Net-to-Memory/Disk capability.

The general architecture shown in the picture below is pretty simple and recalls the previous DBBC versions but presents also new elements. Here are the main components:

- 100GCoMo module, analog conditioning element
- ADCore4 module, A/D converter, and digital data processor
- FILA100G, data storage, and standard network interface
- A-EYE, AI deep neural network controller
- DiFrEnd28, digital 28 GHz front-end
- DiFrEnd4, digital 4 GHz front-end
- CONE-x, a number of different elements with dedicated functionalities to operate with the A-EYE Controller
- ROD-y, a number of different elements with dedicated functionalities to operate with the A-EYE Controller.

The signal coming from the analog front-end as usual is required to be conditioned to be adapted before being converted into digital format. For such a purpose, the 100GCoMo module was adopted to perform the functionality of optimizing the amplitude, measuring the total power in pre-determined ranges inside the input band, and applying ad hoc filters, when required. The output signal from the 100GCoMo is directly forwarded to the analog input of the ADCore4.

Alternatively to the analog input, the signal coming from the analog part of the receiver can be digitized by the digital front-end with 28 GHz bandwidth DiFrEnd28 and inserted into the system through the digital input. While the 28 GHz band is an alternative to the analog input version, the 4 GHz bandwidth input can enter the system in digital format only using the DiFrEnd4.

The ADCore4 is the central element of the system and is able to perform the double functionality, analog to digital conversion and digital data processing. As mentioned, the signal can be inserted in both modes, digital or analog for the high band (28 GHz) or only digital for the low band (4 GHz). After conversion, or after the digital data acquisition, the functionality required by the observation to be performed is applied. The modes are DSC, OCT, and DDC, as already well known from the previous versions of DBBC even if relevant differences can be applied, still maintaining compatibility with the existing modes. More details are described in the section describing the ADCore4.

The data with the final bandwidth and data rate, ready to be transferred for correlation or to be recorded, is sent to the FILA100G for the final aggregate format in single or multi-stream, depending on the output data rate. Before the composition of the final format, it is possible to store an amount of data useful for the burst mode functionality. An additional possibility is offered by the data storage on external SSD disks. The direct connection net to PCI-e offers the possibility of skipping any intermedia data transfer with great advantage for the writing data rate.

Particular attention is to be dedicated to the novelty in the DBBC family systems offered by the DBBC4. The Artificial Intelligence controller, called A-Eye, represents a great potentiality in a number of functionalities to which it can be dedicated. This part presents a great potentiality in both single dish observations and VLBI activities. In order to operate in real time the controller can make use of a number of additional elements, named Cone and Rod. The first type is supporting functionalities of preprocessing more complex than the second, which is simply forwarding the required information to the mixed hardware-software deep neural network in order to perform the planned functionality. The A-Eye controller can then interact with the elements mentioned above in both directions to perform the required functionality. More details are described in the dedicated section of this document.

3 100GCoMo

When an analog receiver is coupled with the DBBC4 receiver it is required to adapt the signal with the analog to digital converter. The last component can have different requirements depending on the type adopted. In the DBBC4 we plan to have more components in order to satisfy different types of observations. The bandwidth considered is 28 GHz (class H), but there are plans to consider even wider bands. More details later.

The 100GCoMo is a module having the requirements: power level control in AGC and manual, plus total power measurement in defined frequency ranges. A dedicated section could be added on request for ad hoc band definition/blanking which can also be software controlled. Due to the high frequency range in-

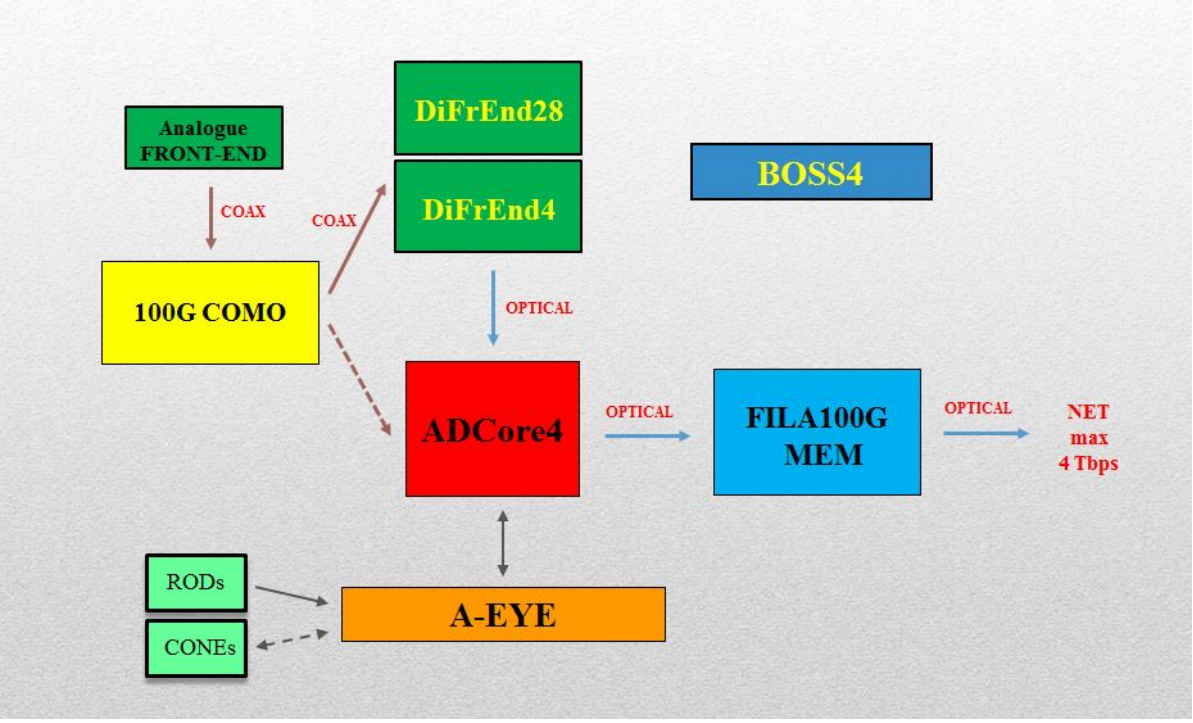

Fig. 2 DBBC4 architecture.

volved, a high class of components can be adopted to match the highest standards, and, for such a reason, the module will be customizable.

An additional novelty will be the introduction of wide band noise generators operating in different bands. This will simplify also the testing operations of the synchronous total power detector.

Communication to the general controller is realized using a serial connection with the option to be optical. This is required when the module is to be integrated into the analog section of the receiver and the digital front-end is adopted.

4 ADCore4

The module ADCore4 is a key element in the DBBC4 and again, similarly to the previous versions in the DBBC family, includes the functionality of the analog to digital conversion and data processing, but with state-of-the-art components and then capabilities.

The flexibility in defining the functionality is, as also in the DBBC4, an important element, and then a number of different options can be selected in order to optimize performance and requirements. Those include:

- ADC bandwidth, in the beginning with the possibility of 28 GHz and 4 GHz;

- Input in analog or digital format; in particular the 28 GHz sampler has both options, while the 4 GHz has only the digital format; when the digital front-end is adopted, the functionality of the 100GCoMo needs to be integrated into the analog front-end;

- More types of processing high-end FPGAs having the same pin-out; this allows adapting the complexity of the device to the process to be realized. The use of a socket to connect the FPGA device to the PCB board will be allowed.

The concept of a stack present in the previous DBBC version is still present but revised in order to optimize the length of the connections and improve the cooling. It could be divided into the functional elements: ADB4 Piggy-back unit, ADB4 Power unit, ADB4 Communication and Monitoring unit, CORE4 Main board, CORE4 Power unit, CORE4 Communication and Monitoring unit, IO4 Transceiver

unit, IO4 Transceiver Power unit, and IO4 Transceiver Communication and Monitoring unit.

The three main units ADB4, CORE4, and IO4 dialogue between each other, and all of them have two channels of communication with the control computer and the A-EYE controller.

The functionality is straightforward: the ADB4 unit required here when the data are inserted into the system in analog format is sampling what is conditioned by the 100GCoMo, and then the digital format of it is transferred to the CORE4 using an aggregate channel of serial lines. When the digital front-ends DiFrEnd28 and DiFrEnd4 are adopted, the information enters the system from the IO4 and is transferred to the CORE4. The required functionality between DSC, OCT, and DDC is then processed and available to the output channels of the IO4 in order to be sent out to the correlator/recorder or to the FILA100GMEM.

5 FILA100GMEM

This unit is useful for additional functionalities but could be skipped in case of modes which do not require them. The main additions involve:

- Memory banks for burst mode observations
- Direct writing of the received packets on SSD NVMe (PCIe mode) disk modules.

The schematic functionality with the main parts is made by the elements:

- Packetizer receiver
- Packetizer controller
- Packetizer transmitter
- Packetizer Communication and Monitoring unit.

The flow of data coming from the ADCore4 is received by the FILA100GMEM module, where the data are selected for a number of functionalities, which include reordering of channels, burst mode, and data storage. Additionally most of the functionalities present in the previous versions of the DBBC family packetized (FILA10G) are maintained.

The module can allocate a variable number of SSD NVMe units, expandable in memory capability as required by the burst mode duty cycle/number of channels/data rate. More FILA100GMEM modules can be used in parallel in order to improve the memory capability or the number of channels to be used in burst mode or to be recorded.

6 A-EYE Controller

Artificial Intelligence functionality meets the VLBI technology. The A-EYE module is a controller making use of artificial intelligence methods to perform a number of functionalities useful for the single dish and interferometric observations.

It will make use mainly of pre-trained networks, ready to be used for a number of functionalities which can include: RFI recognition and mitigation, extraction of non-statistical-noise signals, recognition of human-like extraterrestrial emissions, and other similar or different types of application.

The AI controller adopted for such functionality is a multi-CPU FPGA device optimized for this type of application. The general development working flow consists of a session dedicated to select and pre-train a suitable DNN (deep neural network) configuration with additional training dedicated to the specific purpose to be satisfied. This configuration is then synthesized in a hardware DNN with mixed software dedicated implementation. The entire synthesized solution is running in the above mentioned programmable device which is able to interact with the other units in the DBBC4 in order to drive specific functionalities in the different components of the system.

In order to be able to perform such operations the A-EYE controller can interact with supporter satellite elements, and by now, two of them have been identified: ROD and CONE. The ROD element is able to provide to the A-EYE elementary information, such as temperature, total power, or other physical parameters. The CONE acts like an edge processor, to provide already elaborated information, such as FFT ready data, visual decoded data, sequence recognition, and similar preprocessed elements useful for the AI functionality.

As additional functionality, the possibility of training the DNN in piggy-back mode during ordinary system operation will be implemented, to permit ad hoc network generalization.