DBBC3 - EVN and VGOS All-Inclusive VLBI System

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Abstract The DBBC3 project is rapidly evolving in all its main components. The hardware of the astronomical L version is complete in the main parts, and the VGOS H version is progressing as planned. The DBBR receiver is under test and is expected to be placed in the antenna in the next few months. A first implementation of the L version includes the possibility to support the VGOS requirements. A detailed status of the different structural parts are described, ranging from the front-end to the 32 Gbps disk and network capability, expandable up to 64 Gbps.

Keywords backend, DBBC

1 Introduction

The development of the DBBC started in 2004 and during the previous few years ad-hoc laboratory experiments and experiments with real sky signals had indeed demonstrated as it could be possible to emulate with fully digital equipment the entire functionality of the MK4 VLBI analogue terminal. In the digital process the signal available as IF from the receiver is immediately converted to a digital representation. This complete digital process could not be fully implemented at a reasonable cost, and moreover at that time it was a technical challenge due to the wide band and the high frequencies involved. During the first decade of 2000 with progressive improvements the DBBC project evolved to cope with an input bandwidth of up to 4×1 GHz. The first DBBC version (DBBC1; 2004 – 2008) was a backwards compatible replacement of the existing VLBI terminal, while with the DBBC2 (2007 to date) additional observing modes became available, which did not exist in the analogue backend. The enhanced version of the DBBC2 for VGOS the DBBC2010 (2009 to date) is compatible with the proposed VGOS observing providing that an appropriate down-conversion of the broad band is realized in the analogue domain. With new wide-band receivers the demand for backends which can handle bandwidhts of several GHz has arisen. So both, the new VGOS network and the EVN have been increasing their maximum data rate demand from a maximum of 1 Gbps with the MK4 analogue backend to something ranging between 32 up to 64 Gbps. In particular for EVN the preparation for receivers and IF systems which will deliver up to 4 GHz (and later more) bandwidth to the backends it was felt necessary to develop a system which can process an instantaneous bandwidth of 4 GHz per polarization as a minimum. The resulting output data rate for a dual polarisation receiver should be at least 32 Gbps, with the option of 64 Gbps for a 4 IF system. Such a backend is the intermediate goal of the DBBC3 project. The specifications of VGOS define a set of features of the receiving/backend system to achieve the goal of greatly improved geodetic measurement precision. The telescopes will operate in a single broad band ranging from 2 to 14 GHz observing in dual linear polarization. Inside this frequency range a subset of four 1024 MHz wide pieces will be selected, in both polarizations. It is worth to notice that then the actual selected input data rate is so equivalent in both EVN and VGOS. The wide band of the new VGOS network will realize bandwidth synthesis (phase slopes fitted over a wide frequency range) for

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a much wider portion of the spectrum than is possible with the present system. Such a wide input band could also be of great interest for astronomy because of the significant increase in sensitivity. Being able to process an entire 14 GHz wide piece of band could be a quantum leap in the digital radioastronomy data acquisition. This goal is very ambitious and its implementation in a radio astronomy backend would be a novelty. To digitally sample and process the whole 14 GHz wide band or a number of sub-bands thereof is the final goal for the DBBC3 project.

2 DBBC3 Structure

The DBBC3 system needs to meet some compulsory requirements: it has to be backwards compatible with the existing backends of the previous generations and has to be able to realise the new functionality in the very wide band. Moreover it should be able to accomplish all the required functionalities, for the planned EVN goals (min 2×4 GHz bandwidth) and VGOS (2×14 GHz bandwidth). Moreover as many stations are active in both the network a single system is mandatory and flexibility is a requirement due to the different radiotelescope and their dissimilar receivers and IF systems in terms of number and type of IFs. To be compatible with the existing systems, the new hardware needs to be mechanically and electrically level-compatible. This aspect is useful because existing DBBC terminals in the field could be upgraded to meet the new performance requirement by replacing the necessary parts. Components of the DBBC3 can be inserted in existing DBBC2 and DBBC2010 backends to augment their performance with additional functionalities. The much higher performance of the new backends requires new hardware parts, to be supported by new firmware able to perform new functionality, that are a challenge for data volume and rate. A clear development path has been layed out to minimise the risk in the project. In a first step a DBBC3-L will be developed which can be seen as a fully qualified 4 GHz DBBC and at the same time will allow us to study how best to achieve the final goal of a 14 GHz DDBC3-H. The first step is able to support both modes EVN and VGOS, even if in this last case the input band is divided in four continuous progressive portions wide 4 GHz, up to 16 GHz.

The main features of the DBBC3-L system are:

- Maximum number of wide input IFs: 4 per polarization
- Instantaneous bandwidth in each IF : 4 GHz
- Sampling representation: 10 bit
- Processing capability N x 5 TMACS (multiplication-accumulation per second), with N number of processing nodes
- Output data rate: max 64 Gbps
- Compatibility with the existing DBBC

The main features of the DBBC3-H system are:

- Max number of wide input IFs: 4 per polarization
- Instantaneous bandwidth in each IF : 14 GHz
- Sampling representation: 8 bit
- Processing capability N x 5 TMACS
- Output data rate: max 896 Gbps
- Compatibility with the existing DBBC

In this paper we describe mainly the DBBC3-L version which is being specifically developed for the EVN network and is supported by Radionet3. As already mentioned this version will also used in the first VGOS implementation. In the figure 1 the overall structure of the DBBC3 including the data flow of both -L and H is shown.

The structure of the system is straightforward. Four IFs 4 GHz wide are sampled with 10-bit representation. This data is then transferred to one or more dedicated processing nodes, with their own single element identity and functionality. The processors then extract from the digital data streams portions of the band (with digitally tunable mixers or fixed filters) and produce as VLBI-compatible output VDIF packets. The last element of the chain is the FILA40G subunit whose function is to condense the data onto single optical fibers at 40Gbps data rate and to handle the data at network packet level. A dedicated version, the FILA40G-ST, will in addition have storing capabilities.

3 DBBR - Digital Broadband Receiver

The first unit mainly devoted to VGOS is the broad band receiver. The feed is coming from a deeply modified original project for telecommunication and renamed as quad ridge in resonant chamber . This because having to cool it down at crygenic temperatures, the performance are stronlgy influenced by the vacuum chamber and related shields. So it appeared convenient

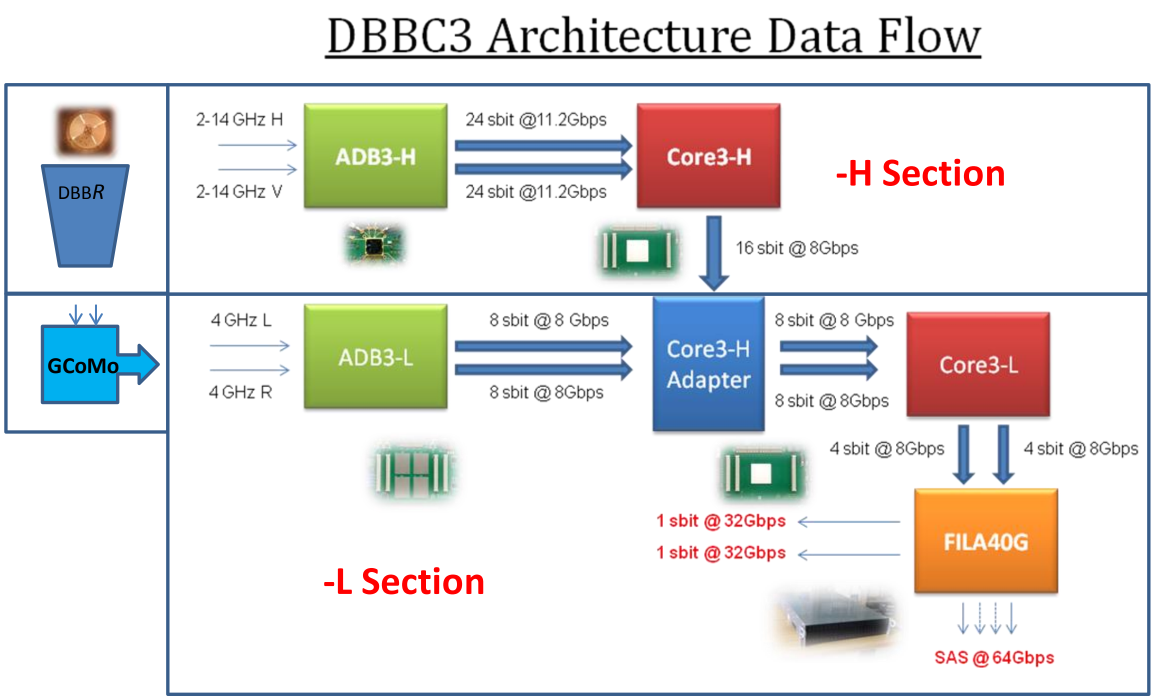

Fig. 1 DBBC3 General Structure

to have included as active part the dewar mechanics and so to use is as an advantage more than a side effect to endure. The main characteristics of the DBBR are:

- Dual linear polarization
- 1 LNA per polarization
- Full range 1 16 GHz
- Radiation pattern vs frequency optimized for 3-14 GHz: 40 - 20 degrees @ -3dB
- Antenna factor vs frequency optimized for 3-14 GHz: 33 - 40 dB/m
- Optimized for cryogenic use (dewar is active part)
- Entirely in copper
- Custom cryogenic filters integration in the antenna body

The receiver is extremely compact and well suitable for 12 m class antennas. Its first use will be with the Noto antenna where will be adapted using a tertiary mirror.

4 GCoMo - Giga Conditioning Module

In a standard DBBC3 system there could be from 1 to 4 units, available in more flavors with the capability to support a selection of 4 different frequency ranges: A(0-4 GHz), B(4-8 GHz), C(8-12 GHz), D(12-16 GHz). For each range the down-converted and the purely conditioned version will be available. This could help to simplify the receivers connection to the system. In the first VGOS implementation this unit will allow to access the entire inut range to be used with the ADB3-L samplers. Features of this unit are:

- Input: in real mode 4 pre-filtered 4GHz Nyquist bands, in complex mode 2 pre-filtered 8GHz bands
- Total power detectors independent in all the Nyquist zones
- Modular construction: any zone can be included
- Power level control in agc and manual mode

- Compatibility with the existing DBBC

5 ADB3-L Sampler

The massive 4 GHz sampling is performed by state of the art sampler chips. An extensive analysis is under way to determine the phase performance of those devices, as the interferometric use calls for high absolute phase stability and low temporal jitter. An alternative general method to increase the bandwidth is to make use of complex samples. Two channels in quadrature are sampled at a clock frequency equal to the full instantaneous bandwidth. A single ADB3-L has onboard four complete samplers, with the possibility to arrange them for a variety of functionalities, single and multiple, real or complex. Indeed for example in real mode the four samplers can be fed with a single input signal for the full 4 GHz functionality, so as they can be fed with two signals 2 GHz instantaneous bwd each, or finally with four signals 1 GHz bwd each. Sampled data are transferred to the processing unts at a data rate of 80 Gbps fr each ADB3-L board. Main features:

- Number of IFs: 1 - 4
- Equivalent Sample Rate for full IF: 8 GSps
- Instantaneous bandwidth: 4 GHz
- Sampling representation: 10 bit
- Real/Complex Sampling
- Compatibility with existing DBBC

In the figure 2 is shown a ADB3-L board.

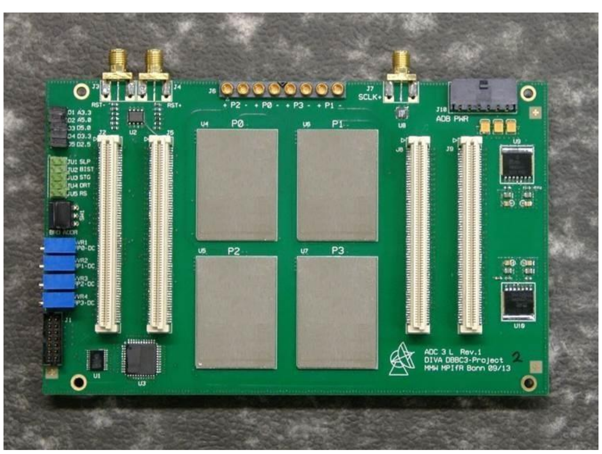

Fig. 2 ADB3-L board

6 CORE3-L Processing Node

Data coming from the samplers board ADB3-L are routed to the processing node CORE3 using the lanes of the high speed input bus. This board is able to process data in different ways: DSC (Direct Sampling Conversion), DDC (Digital Down Converter) and PFB (Polyphase Filter Bank) functionalities. Additional capabilities will be spectroscopic and polarimetry observations. From the pool of channels a subset is selected according to the desired output data rate defined by the observer or allowed by the recording or network media. The data is output through the high speed output bus. Additional input and output connections are available to maintain the compatibility with the DBBC2 stack. The large DSP resources available in the FPGA chosen for the CORE3-L allows digital filters in the class of 100dB in/out band rejection. This feature is required for the expected presence of large RFI signals in the very wide input band. This very strong discrimination together with the tuning ability should be appropriate to obtain useful down-converted and clean pieces of the observed band. As an alternative input the board will be able to receive data packets from a block of ADB3-H/CORE3-H units to be routed to the rest of of the system for additional data processing. The functionality of the FILA10G used in the DBBC2 will be integrated in this unit for multiple 10G data I/O. In partiulr this method is the output connection for the FILA40G unit. In the figure 3 a pphoto of the Core3-L board. In the following list the main performance:

- Number of I/O: max 40 serial links 12.5Gbps
- Number of Output: max 32 serial links 11.2Gbps
- Input Sampling Representation: 8-10 bit
- Processing capability: max 3 TMACS
- Processing capability: WB-DDC, WB-PFB, WB-DCS
- Output: VDIF 10GE packets
- Compatibility with existing DBBC

7 FILA40G Network and Buffering Node

Data from the converted bands are finally transferred to the network controller FILA40G as multiple 10GE connections. The number of connections is then accumulated into a 40GE data stream to be transferred to

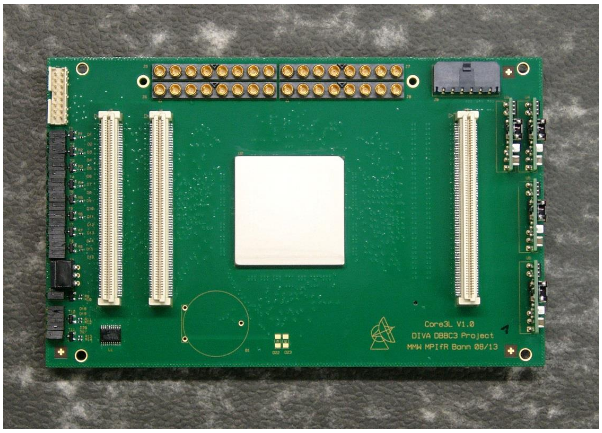

Fig. 3 CORE3-L board

the final destination points. Such final points could be recorders, nodes of VLBI correlators or a buffer cloud. In addition to the 40G network capability the FILA40G unit will be able to manipulate the data packets in order to perform functionalities like corner-turning, pulsar-gating, packet filtering and routing, burst mode accumulation, and other functionalities that could be required at the packet level as soon as the VLBI methods evolve. In addition a dedicated version will be provided which can include storage elements for data buffering and recording. General features:

- 8 x 10GE Inputs
- 2 x 40GE Output
- Optional disk storage
- Expected to record at 32Gbps
- Compatibilty with Mark6 disk packs/chassis being investigated
- Stream aggregation
- Format conversion/VDIF threading
- Packet filtering
- Pulsar gating
- Timekeeping via NTP and/or GPS module
- Propagates UTC to other connected devices via DBBC Local Network (DLN)

10G skills available:

- MK5B up to 4 Gbps (native is 2Gbps)
- VDIF Single Thread up to 8Gbps
- VDIF Multiple Threads up to 8Gbps
- RAW (no headers) up to 8Gbps
- Threads can be fed by a selection of data channels eventually corner-turned
- The 10G Ethernet ports are independent in the destination address in VDIF-ST and MK5B
- The 10G Ethernet ports in multi-thread mode support an independent block of destination addresses coupled with the thread content selection
- Decimation and bit-mask are selectable at this level

In the figure 4 a view of the FILA40G.

Fig. 4 FILA40G

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