The Bonn Astro/Geo Correlator

Laura La Porta [1], Walter Alef [2], Alessandra Bertarini [1,2], Simone Bernhart [1,2], Gabriele Bruni [2], Arno Müskens [1], Helge Rottmann [2], Alan Roy [2], Gino Tuccari [2,3]

Abstract The Bonn Distributed FX (DiFX) correlator is a software correlator operated jointly by the Max-Planck-Institut für Radioastronomie (MPIfR), the Institut für Geodäsie und Geoinformation der Universität Bonn (IGG), and the Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt, Germany.

1 Introduction

The Bonn correlator is located at the MPIfR[1] in Bonn, Germany. It is operated jointly by the MPIfR and the BKG[2] in cooperation with the IGG[3]. It is a major correlator for geodetic observations and astronomical projects (for instance, those involving pulsar gating, millimeter wavelengths, astrometry, and RadioAstron[4]).

1. Institut für Geodäsie und Geoinformation der Universität Bonn
2. Max-Planck-Institut für Radioastronomie
3. Istituto di Radioastronomia - INAF

[1] http://www.mpifr-bonn.mpg.de/
[2] http://www.bkg.bund.de/
[3] http://www.gib.uni-bonn.de/
[4] http://www.asc.rssi.ru/radioastron/

2 Present Correlator Capabilities

The DiFX correlator[5] was developed at Swinburne University in Melbourne by Adam Deller and other collaborators. It was adapted to the VLBA operational environment by Walter Brisken and the NRAO staff, and it is constantly updated by the worldwide DiFX developers group. In Bonn, the DiFX is running on a High Performance Compute Cluster (HPC cluster), whose features are:

- 60 nodes (eight compute cores each)
- four TFlops in the Linpack benchmark test
- 20 Gbps Infiniband interconnection
- 13 RAIDs (about 480 TB storage capacity)
- one control node for correlation (*fxmanager*)
- one computer (*frontend*) for executing parallelized jobs on the cluster, e.g. post-correlation applications
- one control computer (*appliance*) for installing and monitoring the cluster
- closed loop rack cooling

The HPC cluster connected via 20 Gbps Infiniband to 14 Mark 5 units[6] is used for playing back the data. If more than 14 playback units are required, and in the case of e-VLBI, the data are copied to the RAIDs prior to correlation. The Mark 5 units can deal with all types of Mark 5 formats (A/B/C). The disk modules in the Mark 5 are controlled via the NRAO's mk5daemon program. The available functionality includes recording the directories of the modules, resetting and rebooting the units, and module conditioning. In 2013, the

[5] DiFX: A Software Correlator for Very Long Baseline Interferometry using Multiprocessor Computing Environments, 2007, PASP, 119, 318
[6] http://www.haystack.mit.edu/tech/vlbi/mark5/

Software Development Kit (SDK) of the Mark 5 units was upgraded to version 9.1, which enables the usage of larger disks. A summary of the capabilities of the DiFX software correlator is presented in Table 1.

3 Staff

The people in the Geodesy VLBI group at the Bonn correlator are:

Arno Müskens - group leader and scheduler of T2, OHIG, EURO, and INT3 sessions.

Simone Bernhart - support scientist, e-transfer supervision and operations, experiment setup and evaluation of correlated data for geodesy and RadioAstron, and media shipping.

Alessandra Bertarini - Friend of the correlator, experiment setup and evaluation of correlated data for both astronomy (e.g. APEX) and geodesy, and digital baseband converter (DBBC) testing.

Laura La Porta - support scientist, e-transfer supervision and operations, geodetic experiment setup and evaluation of correlated data, media shipping, DBBC testing, and programmer for automated preparation of correlator reports.

The people in the astronomical group at the Bonn correlator are:

Walter Alef - head of the VLBI technical department, computer systems, and cluster administration.

Alan Roy - deputy group leader, support scientist (water vapor radiometer, technical assistance, development of FPGA firmware for linear to circular polarization conversion, and project manager for equipping APEX for millimeter VLBI).

Gabriele Bruni - support scientist for RadioAstron, experiment setup and evaluation of correlated data, and e-transfer supervision and operations.

Armin Felke - FPGA programming for DBBC.

Heinz Fuchs - correlator operator, responsible for the correlator operator schedule, daily operations, and media shipping.

David Graham - consultant (technical development, DBBC development, and testing).

Rolf Märtens - technician maintaining cluster hardware and Mark 5 playbacks.

Helge Rottmann - software engineer for correlator development and operation, cluster administration, DBBC and RDBE control software, and the Field System.

Hermann Sturm - correlator operator, correlator support software, media shipping, and Web page development.

Gino Tuccari - guest scientist from INAF, DBBC development, and DBBC project leader.

Jan Wagner - PhD student, support scientist for APEX, DBBC development, and DiFX developer.

Michael Wunderlich - engineer, development and testing of DBBC components.

4 Status

Experiments: In 2013 the Bonn group correlated 54 R1, six EURO, seven T2, six OHIG, 35 INT3, and about 40 astronomical sessions (including data from Early-Science and the first two A0-1 projects of RadioAstron).

e-VLBI: The total disk space available for e-VLBI data storage at the correlator is about 130 TB. The Web page that shows current active e-transfers and helps to coordinate transfer times and rates on a first come-first served basis[7], reports also the storage capacity at the three correlators (Washington, Haystack, and Bonn). On average $\geq$ 80 % of the stations do e-transfer. The average amount of e-transferred data per week is about 8 TB, considering only the regular INT3 and R1 experiments. Most transfers are done using the UDP-based Tsunami protocol, and the achieved data rates range from 100 Mb/s to 800 Mb/s. The upgrade of the 1 Gbps Internet connection to meet the requirements of VLBI2010 Global Observing System (VGOS) has not been realized yet, due to funding issues.

DiFX software correlator: The DiFX software correlator has been operated in Bonn since 2009 and is continuously updated. The stable DiFX release 2.2 was installed in 2013.

Two other branch versions of the DiFX software correlator are available in Bonn: a DiFX version for RFI mitigation, developed by J. Wagner, and a DiFX version dedicated to RadioAstron (a Russian satellite that observes in conjunction with ground-based telescopes), developed by J. Anderson.

DBBC: The Bonn group is involved in the develop-

[7] `http://www3.mpifr-bonn.mpg.de/cgi-bin/showtransfers.cgi`

Table 1 Correlator capabilities.

Playback Units	
Number available	14 Mark 5 (four Mark 5A, two Mark 5B, eight Mark 5C)
Playback speed	1.5 Gbps
Formats	Mark 5A, Mark 5B, VDIF
Sampling	1 bit, 2 bits
Fan-out (Mark 5A)	1:1, 1:2, 1:4
No. channels	$\leq$ 16 USB and/or LSB
Bandwidth/channel	(2, 4, 6, 8, 32) MHz
Signal	Single-, dual-frequency; all four Stokes parameters for circular and linear polarization
Correlation	
Geometric model	CALC 9
Phase cal	Phase-cal extraction of all tones in a sub-band simultaneously
Pre-average time	Milliseconds to seconds
Spectral channels	Max no. of FFT tested 2^{18}
Export	FITS export. Interface to Mk IV data format which enables the use of geodetic analysis software and Haystack fringe fitting program.
Pulsar	Pulsar with incoherent de-dispersion

ment and testing of the DBBC for the European VLBI Network (EVN) and geodesy. The DBBC is designed as a full replacement for the existing analog BBCs. The following stations have already bought one or more DBBCs: APEX, AuScope (Australia), HartRAO (Africa), Effelsberg, Medicina, Onsala, Pico Veleta, Yebes, Wettzell, and Warkworth. Recently, the HartRAO and Onsala stations switched to DBBCs also for geodetic experiments, whereas Yebes, Medicina, and Wettzell are still in the testing process. The remaining stations routinely use the DBBCs.

A prototype of the next generation DBBC (DBBC3-L) was realized, which can handle a larger bandwidth of 4 GHz. In a second stage the DBBC3-H will be able to sample the full frequency range of 1 to 14 GHz without performing any downconversion.

APEX: The Bonn VLBI group has equipped the APEX telescope for VLBI observations at 1 mm. In 2013 APEX got into science operations by taking part in the Event Horizon Telescope (EHT) campaign. Observations were carried out at 4 Gbps, lasted about 50 hours and provided good detections for several sources (see Figure 1 for an example).

5 Outlook for 2014

DiFX Correlator: A proposal to replace the now six year old cluster with a more modern system is being prepared. Two Mark 6 units with 16 Gbps recording capability have been bought to comply with VGOS requirements. The Mark 6 units will be installed and tested. The RadioAstron DiFX branch versions will be merged with the current development version of the DiFX.

e-VLBI: Purchase of a new 80 TB RAID for RadioAstron.

DBBC: Continue testing for the stations that recently acquired DBBCs. Wide bandwidth modes are also under test. Testing of DBBC3.

Phasing up ALMA: The group is involved in an international project to add array phasing capability to ALMA. ALMA will record with a data rate of 64 Gbps, thus being an extremely sensitive station in 1 mm VLBI experiments, which will be correlated in Bonn.

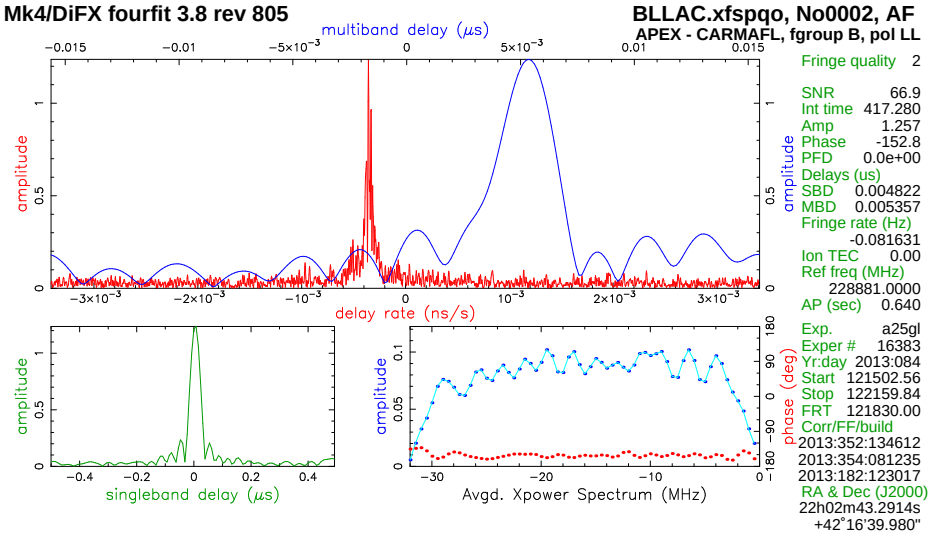

Fig. 1 1 mm observations of the source BL Lacertae in March 2013, baseline APEX-Combined Array for Research in Millimeter-wave Astronomy (CARMA, California). The fringe spacing was 29 microarcseconds, the finest yet achieved.