The Bonn Astro/Geo Mark IV Correlator

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Abstract

The Bonn MK IV VLBI correlator is operated jointly by the MPIfR (Bonn), the GIUB (Bonn) and the BKG (Frankfurt). This report describes the present status and capabilities, gives an overview over the correlation load, and the plans for implementing MK V in the near future.

1. Introduction

The Bonn MK IV correlator is jointly operated by the *MPIfR*[1] and by the *BKG*[2] in cooperation with the *GIUB*[3]. It is a major correlator for MPIfR's astronomical projects, the CMVA[4], and geodetic observations. After the installation in December 1999 production correlation was started a few months later. The initially incomplete correlator software has been upgraded since the installation by Haystack under contract with NASA, USNO, and BKG. For a more detailed introduction see [1].

2. Status and Capabilities of the Bonn MK IV VLBI Correlator

The correlator in Bonn is one of four world-wide MK IV VLBI data processors. It consists of the standard 16 station capable correlator unit and nine Honeywell/Metrum 96 tape drives, each of which is connected to the correlator via a standard MK IV station unit and high speed data links.

The tape units are all thin-tape capable. They are equipped with new digitally-switched equalizer boards developed in Bonn which allow playback of thin and thick tapes recorded at normal (80/135 ips) and double speed (160/270 ips).

The supported formats are MK IIIA, MK IV and VLBA, both MK IV and VLBA with 1- or 2-bit sampling. Fan-in modes are not supported while all the fan-out modes 1:1 and 1:2 and 1:4 are possible. Any number of up to 16 frequency channels can be used, both upper and lower sidebands. Multiple passes are needed for modes with more than 16 channels. Channel bandwidths of 2, 4, 8 and 16 MHz can be utilized. Observing modes with up to 512 Mbits/s have been correlated successfully. The latter has to be done in two correlation passes, as 512 Mbits/s are recorded with 2 heads simultaneously, while the correlator tape units possess only 1 playback head.

The correlator software can now handle all nine tape units in a correlator mode with 32 lags, auto-correlations and 1 s pre-averaging. Full polarization correlation is possible with 8 stations simultaneously. For improved spectral line resolution, correlator modes with up to 4096 lags are available. This drives the correlator control computer (CCC) to its limits. To be able to process the data from nine tape drives simultaneously a second HP workstation had to be acquired for correlation setup, data inspection, fringe-fitting, and data export. The sheer volume of correlated

[1] Max-Planck-Institut für Radioastronomie, Bonn, Germany, http://www.mpifr-bonn.mpg.de
[2] Bundesamt für Kartographie und Geodäsie, Frankfurt, Germany, http://www.ifag.de/Geodaesie/gf_e.htm
[3] Geodetic Institute, University of Bonn, Germany, http://giub.geod.uni-bonn.de/vlbi
[4] Coordinated mm-VLBI Array, see http://web.haystack.mit.edu/cmva/index.html

Figure 1. Student operators and geodetic supervisors at the Bonn MPIfR/BKG MK IV correlator.

data is so great that the disk space has had to be increased to a total of about 200 GBytes with a further expansion to 380 GBytes planned for early 2002.

A big improvement in throughput was achieved in 2001 by the introduction of parallel correlation streams. This means that up to 4 independent experiments or sub-nets can be processed simultaneously, provided sufficient tape drives are available. As a result geodetic and mm-VLBI observation with sub-netting can be correlated more efficiently. Also the introduction of better pass/track finding software, including a data base of pass positions for each tape, can be counted as a big improvement for the correlation, as well as numerous bug fixes.

In the middle of 2001 the correlation of mm-VLBI observations became workable with the introduction of switchable equalizers for normal and double speed recordings (4 and 8 Mbits/s/track) in all tape units. Even though towards the end of 2001 a correlation speed-up factor of 2 was implemented, some recordings still have to be played back at the speed at which they were recorded due to poorly understood effects in the station units.

The time needed to synchronize the tapes was reduced to less than 10 s for all playback speeds. Another important milestone is the extraction of 510 kHz phase-cal tones, as are often used in mm-VLBI. It is even possible now to extract any phase-cal frequency in steps of 10 kHz. The geometric correlator model is CALC 8. The pre-averaging time is flexible from 0.5 to 5 seconds.

Better data inspection software written by members of the geodetic correlator group in Bonn, as well as software for automatic generation of re-correlation lists, further increased the throughput

of geodetic correlation.

Fringe-fitting is done off-line by the program FOURFIT. Dual frequency observations are done in a single execution of the program while dual/cross-polarization experiments have to be fringe-fitted in multiple executions.

The raw and fringe-fitted data are archived on DDS2 or DDS3 DAT cassettes. The archive contains the root, the raw correlator data (type 1 files), the fringe-fitted data (type 2), and the station-based files (type 3 files). All the processed geodetic data are also exported with the geodetic post-correlation software interface CALC/SOLVE.

In the summer of 2001 finally data export became possible for astronomical observations by the introduction of the program MK4IN written at MPIfR and a new version of FOURFIT. In a first step a best data set without duplicates is selected using the HOPS software (Haystack). The data are fringe-fitted with FOURFIT in a special mode where the cross-spectrum of each accumulation period of each frequency channel is stored on disc. These cross-spectra are fully "sanitized" by applying all correlator flags, and all phase-corrections like phase-cal and lower-/upper-sideband corrections. The resulting data file is read by the AIPS[5] task MK4IN, and is stored as an AIPS disk file. The solutions found by FOURFIT are carried into AIPS as well, and a program is being written which will derive a set of antenna-based solutions which can be used to calibrate the data.

AIPS allows fringe-fitting, calibration and mapping of the data. It can even be used to glue together the data from the 2-pass 512 Mbits/s correlation. A future version of MK4IN will transfer the correlator delay polynomials so that a full geodetic analysis for data from MK IV correlators will become possible via AIPS. For data export to other observatories the data can be written to tape (or disk) in FITS[6] format.

An up-to-date list of correlator capabilities can be found on the Internet under http://www.mpifr-bonn.mpg.de/EVN/MK4CORstatus.

Further improvements in the correlator software are needed to bring the data processor closer to the original specifications. Significant anomalies remain in the station units: in some modes occasionally the data streams from one or more tracks lose sync with the data-time which leads to partial or complete loss of fringes. In 2-bit modes with 1:4 fan-out (which has to be used for 1 GBits/s recording) the phase-cal does not work correctly. Pulsar astrometry cannot be done as gating is not yet implemented in the station units.

The correlator throughput could be increased if a continuous correlation mode was implemented. At present a scan-wise mode is used in which each observed scan is set up for correlation and is then correlated. In a continuous mode the scan boundaries are not "visible" to the correlator, the tapes are kept running, and the set-up time for each scan becomes negligible. Later the data are split again into scans. This mode is implemented at NRAO[7] and JIVE[8].

3. Correlator Operations

The correlator is typically manned for about 11 hours per day, seven days per week. Of the nearly 4000 hours of correlation time available in 2001 approximately 67% were used for IVS related tasks. This comprised setup and production processing of IRIS-S, EUROPE and CORE

[5] Astronomical Image Processing System, NRAO
[6] Flexible Image Transport System, NRAO, see e.g. [2] and references therein
[7] National Radio Astronomy Observatory, Socorro, New Mexico, USA
[8] Joint Institute for VLBI in Europe, Dwingeloo, The Netherlands

(Core-3, Core-OHIG, Core-CC) experiments. Another 26% were used for astronomy correlation such as the processing of millimeter-wave radio astronomy observations and other MPIfR-based VLBI observations and about 6% of the time was needed for maintenance and tests. Forty-seven geodetic observations were processed which is about 1/3 of the worldwide geodetic correlation.

The correlator is run by two full time operators and 12 student operators, 10 of which are being paid by the geodesists. The geodetic observations are supervised by the equivalent of 2.75 people. The correlator hardware is maintained by two engineers and one technician, while the manpower which goes into software is more than 50% of the time of one of the operators and a small fraction of one scientist. The group is led by another scientist. These two scientists share responsibility for supervising the correlation of astronomical projects.

4. Outlook

According to the contract between GIUB and BKG, IVS will be supported by the processing of about 50 experiments per year at the MPIfR/BKG correlator. In 2002 the observations will have 8 to 9 stations typically instead of the present limit of 6, with twice the recorded bandwidth.

MPIfR decided to financially support Haystack in the development of the MK V A and the MK V B systems. The major advantage of MK V for MPIfR's scientific projects is in the higher bit-rate of up to 1 Gbits/s per unit. With MK V B two units can be used in parallel to record a maximum of 1.8 Gbits/s with 14 BBCs, which is essential for future progress in mm-VLBI.

In 2002 we want to install at least two MK V units for test purposes. After a successful test phase, more units will be acquired, both for the correlator and for mm-VLBI.

References

[1] Alef, W., Graham, D.A., Zensus, J.A., Müskens, A., Schlüter, W., "The new MPIfR-BKG MK IV correlator", in Proceedings of the 14th Working Meeting on European VLBI for Geodesy and Astrometry, edited by P. Tomasi, F. Mantovani, M. Perez Torres, Consiglio Nazionale delle Ricerche - Istituto di Radioastronomia, 2000.

[2] Cotton, W. D., Tody, D. B., and Pence, W. D., Binary Table Extension to FITS, Astronomy and Astrophysics Supplement Series, 113, 159-166, 1995.