Gbit/s VLBI and eVLBI with off-the-shelf components

Jouko Ritakari, Ari Mujunen

Metsähovi Radio Observatory

Contact author: Jouko Ritakari, e-mail: Jouko.Ritakari@hut.fi

Abstract

Metsähovi Radio Observatory has pioneered in the use of off-the-shelf microcomputers in VLBI. During the years 2001 and 2002 MRO developed an hard-disk based data acquisition and playback terminal for VLBI. The recording system is VSI-H compatible and uses off-the-shelf microcomputers with unmodified Linux operating system. Only minimal hardware and software development were needed. One data acquisition terminal can record at 512 Mbit/s speed, but the system is designed to be easily scalable to multi-gigabit per second speeds. The system is compatible with most of the standards used in VLBI, it can record data from the ADS-1000 Gbit/s sampler developed in CRL, VLBA samplers, VLBA formatter, Mk4 formatter and S2. K4 compatibility has been designed but not yet tested. It must be emphasized that the MRO data acquisition terminal is not a prototype but a mass-produced product. Boards for sixty data acquisition terminals have been produced in August 2002 and seventeen terminals have been deployed to nine radio telescopes so far. During the years 2002 and 2003 Metsähovi made several 1Gbit/s and 2Gbit/s VLBI observations with Kashima station at 22GHz frequency. These observations used the ADS-1000 sampler and were correlated with an high-speed software correlator at Kashima. In May 2003 Metsähovi and Jodrell Bank Observatory succeeded in the first European 1Gbit/s Mk5-style VLBI experiment. Data was recorded in MRO-designed hard disk recorders, transferred to JIVE via Internet and played back to the correlator with Mk5 terminals. During the second half of 2003 the MRO team has concentrated in evaluating the new reliable UDP-based protocols for eVLBI. Several candidates have been found. Initial tests using these protocols are very promising and demonstrate the advantages of having the data in normal Linux files.

1. Basic ideas

The MRO data acquisition system was built to test the idea that VLBI data can be treated like any normal data. It can be captured with normal microcomputers, stored in normal files and transferred with standard networking tools. Correlation is nothing special, it is only computing.

2. Equipment

Two printed circuit boards were developed for the MRO data acquisition system: the VSIB data acquisition board for the microcomputer and the VSIC stand-alone universal converter board.

Both of the boards have been mass-produced in August 2002. The firmware and software have been frozen in 2002 and are fully operational with no known errors.

2.1. The VSIB data acquisition board

The VSIB data acquisition board is the core of the MRO system. The VSIC is one of the first VSI-H standard compatible data acquisition systems.

When the design was started in mid-2001, design goal for one microcomputer was 256 Mbit/s recording speed and 600GB capacity (same as in one Mark4 thin tape). During the design work we

found out that the performance was even better than expected: one microcomputer could reliably record data at 512 Mbit/s and the capacity with the new 320GB hard disks is 1.2TB.

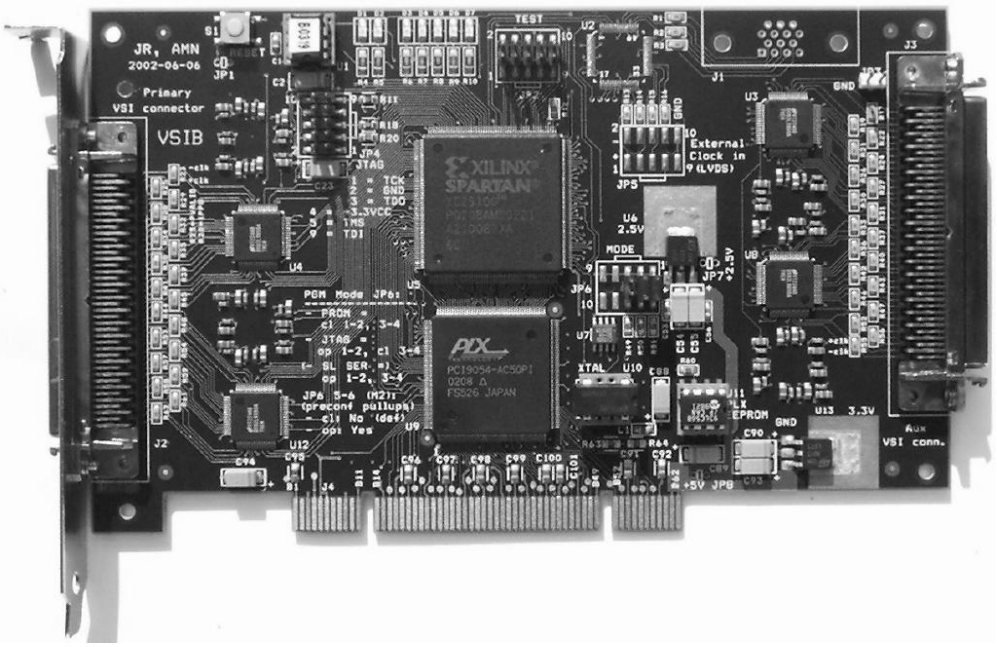

Figure 1. **The VSIB Data Acquisition Board**

2.2. The VSIC universal converter

The VSIC universal converter board is a byproduct of the development project. Originally the development project was divided in two parts: Metsähovi was designiung the data acquisition part and JIVE was developing the Mark4 to VSI converter, the data distributor.

When the VSIB design was completed it became clear that an interim solution was needed for testing the VSIB. Minimum requirements were a test vector generator and 32-track Mark4 formatter interface. During the design of the VSIC it became apparent that VLBI used lots of different cabloing standards that all used 40-wire twisted pair flat cables and differential signalling. It was possible to design an universal converter to convert anything to the VSI-H standard.

The VSIC was designed very quickly, in two weeks of time. It supports the following standards:

- VLBA samplers
- VLBA formatter output, both data raplacement and non-replacement modes
- Mark4 formatter outputs, heads 1 and 2
- S2 DAS (with an adapter cable)
- K4 (design complete, not tested yet)

Additionally the VSIC converter board can operate as a test vector generator either in ramp signal mode or in the VSI mode.

3. Compatibility with other systems used in VLBI

The MRO system is directly compatible with all the VSI-H compliant devices, for example the ADS-1000 Gbit/s sampler developed in Communications Research Laboratory.

With the VSIC converter the MRO system can record data from most of the legacy interfaces.

Data formats are compatible with the Mark5A system, data recorded with the MRO system can be played back with an Mark5A.

4. Experiments with the MRO system

The MRO system has been used in a series of successful eVLBI experiments and several world records have been achieved:

- 12-Jul-2002 First fringes with MRO system between Westerbork and Jodrell Bank at 256 Mbit/s
- 24..26-Sep-2002 iGrid eVLBI demo at 256 Mbit/s
- 16-Oct-2002 First Kashima - Metsähovi 1Gbit/s experiment [1]
- 5..14-Feb-2003 Second Kashima - Metsähovi 1Gbit/s experiment
- 12-Mar-2003 First European 1Gbit/s experiment Metsähovi - Jodrell Bank
- 17-Jun-2003 First Kashima - Metsähovi 2Gbit/s experiment [2]

The 1Gbit/s and 2Gbit/s experiments between Metsähovi and Kashima used direct IF sampling with the ADS-1000 Gigabit Sampler. Data was correlated in CRL Kashima with an high-speed software correlator.

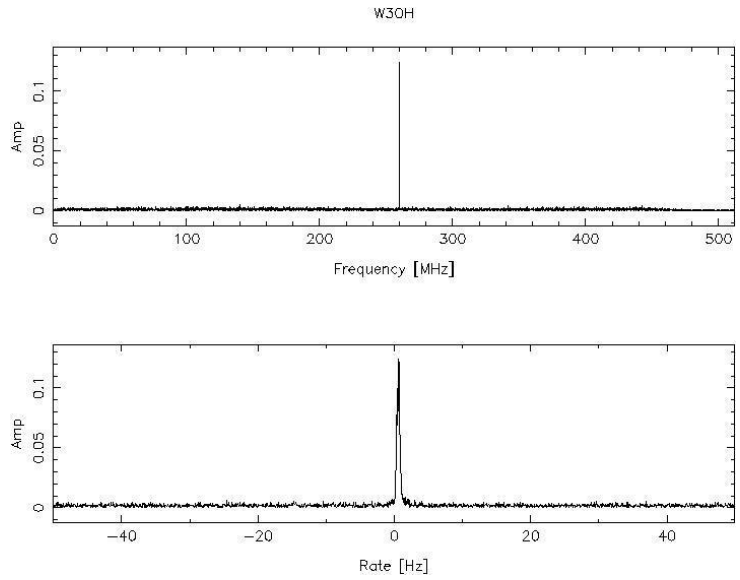

Figure 2. **1Gbps Fringe Metsähovi - Kashima**

The 1Gbit/s experiment between Metsähovi and Jodrell Bank recorded data from Mark4 formatter in Mark5A compatible format. Data was transferred to JIVE correlator via Internet and was played back to the correlator with Mark5A terminals.

5. Future: Off-the-shelf eVLBI

The off-the-shelf approach has proved to be very powerful, standard Unix tools can be used to manipulate or transfer the data if it is stored in normal Unix files.

Our next area of interest will be data communications protocols for eVLBI. At this moment the international Internet trunk lines are fast enough for real eVLBI work, but the protocols have serious drawbacks: TCP is too slow for high-speed long-delay networks and transfer with UDP is unreliable.

Several solutions have been proposed: Use of jumbo frames, use of several TCP streams in parallel, use of RTP protocol.

Fortunately the telecom industry is solving the same problems. We have made a quick survey and located several promising new protocols that can be used in eVLBI:

- UDT (UDP Data Transfer) [3]
- Sabul (Simple Available Bandwidth Utilization Library)
- Tsunami
- FOBS
- RBUDP (Reliable Blast UDP) [4]
- GTP (Group Transfer Protocol)

These protocols are either reliable UDP variants or combinations of UDP protocol used for transmitting the data and TCP protocol used for control.[5] The Linux source code of most of these protocols is available in Internet.

References

[1] Y. Koyama, T. Kondo, J. Nakajima, M. Kimura, H. Uose, S. Iwamura, International e-VLBI Experiments, In: IVS CRL Technology Development Center News, No.21, pp.23, November 2002.

[2] M. Kimura, J. Nakajima, J. Ritakari, A. Mujunen, First detection of 2-Gbps wideband fringes between two PCbased VLBI systems, In: IVS CRL Technology Development Center News, No.22, pp.5, June 2003.

[3] R. Grossman, Y. Gu, Introduction to SABUL/UDT, `http://www.ncne.org/training/techs/2003/0803/presentations/pptfiles/0803-grossman1.ppt`

[4] E. He, J. Leigh, O. Yu,T. DeFanti Reliable Blast UDP: Predictable High Performance Bulk Data Transfer, `http://www.evl.uic.edu/cavern/papers/cluster2002.pdf`

[5] R. Wu, A. Chien, Evaluation Of Rate Based Transport Protocols For Lambda-Grids, `http://dsd.lbl.gov/DIDC/PFLDnet2004/papers/Wu.pdf`