

The Australian experience with the PC-EVN recorder

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Abstract.

We report on our experiences using the Metsähovi Radio Observatory's (MRO) VLBI Standard Interface (VSI, Whitney 2002) recorder in a number of astronomical applications. The PC-EVN device is a direct memory access (DMA) interface which allows 512 megabit per second (Mbps) or better recording to "off the shelf" PC components. We have used this setup to record at 640 Mbps for a pulsar coherent dispersion system and at 256 Mbps for a global VLBI session. We have also demonstrated recording at 512 Mbps and will shortly form cross correlations between the CPSR-II and the PC-EVN systems.

1. Introduction

Astronomy has always battled against the extremely weak signals received from objects impossibly far away. We can improve the situation by recording the signals with cooler feeds, observing for longer, or by collecting wider bandwidths, as expressed by the radiometer equation (see e.g. Kraus 1986). Cooler feeds are difficult and telescope time is precious, so the most profitable area for improvement is to record wider bands. The Long Baseline Array (LBA) uses a bandwidth of 16MHz, from receivers with a bandpass that is typically the order of a GigaHertz. This is almost criminally wasteful.

With modern digital technology it is possible to sample increasingly wider bandwidths with a higher number of bits. Furthermore by recording to consumer electronic hardware (the so called "Commercial off the Shelf" or COTS approach (e.g. Whitney 2003)) the equipment is cheap, reliable and easy to repair, replace and upgrade.

In Australia the VLBI recorders are S2s (plus a few sites with MkIIIs which will be all upgraded to MkVs soon). The S2 is a multi-video tape digital recorder (Cannon *et al.* 1997) which records 128Mb/s. In Australia it is fed by the ATNF Data Acquisition System (ATNF DAS). We have found that, with very little effort, the DAS can be configured to drive Metsähovi's PC-EVN card. The maximum data rate of the DAS is 512 Mb/s which nicely matches the quoted maximum rate of a single PC-EVN. If we wish to use the flexible digital filters of the DAS we are, however, constrained to 256 Mb/s.

CSIRO has secured agreement with AARNet to provide access to dark fibres that pass near their research centres in regional areas. The network will be equipped with 10 Gbs capable (Dense Wave Division Multiplexing) infrastructure. The VLBI project is providing the major scientific impetus for this bandwidth. As a demonstration system for real time VLBI we have installed a parallel "fringe checker" system where the PC-

EVN recorder driven by the data-out port of the S2. We now can confirm the data integrity of an experiment during the run. We are also taking part in the differential VLBI tracking of the Huygens probe (Gurvits *et al.* 2004) using this same hardware.

2. PC-EVN Hardware

The boards purchased from MRO were their two VSI boards; VSIB (a DMA card) and VSIC (a converter card). The VSIB card allows data to be written to or read from the hard drives on the PC. The provided operating system was debian linux (the stable woody series with kernel 2.4.19 and the big physical area patch). The recommended PC motherboard is the K7 series from MSI with an AMD processor. In Hobart we use these with four IDE disks (200 GBytes in size) from the motherboard. A boot disk (and CD) is run from a PCI IDE card, making the total disk capacity one terabyte. The data disks are mounted in a (software) RAID0 array, see Figure 1. Swinburne used the Dell 1600C server machine, because with these the data disks can be external Apple Xraid disks on a 64 bit PCI bus. These were run using SuSe 8.2 linux OS. Using alternate motherboards and OS versions caused no problems.

A third system has just been purchased, which is primarily for the Huygens experiment, but also is being used as a test bed. This is based on the K8 motherboard, which has a 1GB ethernet on-board (so not on the same data bus as the hard drives). This is being used to investigate direct streaming of the data collected by the VSIB across the network. It is currently configured with four 400 GB hard drives.

The VSI cards cost 565 Euros each, the PC the order of AU\$2000 and about the same for four multi Gbyte hard drives. Therefore the total cost of the system was around AU\$5500.



Fig. 1. The VLBI system for Ceduna with four demountable 200GB IDE drives. The VSIC connector is the 50 way ribbon connector at the bottom right.

3. The VLBI system

The VSIC card converts many “legacy” VLBI digital signals into the ordering and levels (LVDS) of the VSI standard required by the VSIB DMA card. In the Hobart system the VSIC card is mounted and powered inside the PC case. It can be seen at the bottom right of the PC shown in Figure 1. For the Swinburne systems the VSIC card was enclosed in its own box. The card will handle up to 32 channels of data, plus the required signal clocks and 1PPS signals.

The VSIC card will format data with S2 pin outputs (as well as VLBA, Mk3 and Mk4 formats), so it was a trivial task to connect the VSIC to the cable normally going to the S2 recorder. The provided program `wr` was used to collect the data. `wr` reads a minimum of 8 channels, whilst the maximum rate S2 recording modes (32x4-2) records two IFs of 16 MHz of data at 2 bits into 4 channels. The DAS modes used (VSOP and MP16S), however, encode four IFs of 16 MHz of data at 2 bits into 8 channels. Therefore we could record double the usual LBA bandwidth using the PC-EVN system. We have altered `wr` to allow us to drop subsections of the data read, before writing. These modes allow longer, and more flexible recording programs. More details can be found in Dodson (2004).

We have performed (in April 2004) global eVLBI observations. Most Australian telescopes (**ATCA**, **Mopra**, **Parkes**, **Tidbinbilla** and **Ceduna**) recorded on PC-EVN machines, and **Hobart** recorded to their Mk5a system. Also recording on Mk5 systems were **Hartebeesthoek** (SA) and **Pietown** (USA). Data was recorded to the K5 system at **Kashima** in Japan. The global VLBI data has been transported (by shipping the disks) to Swinburne, and correlated on their supercomputer. A full report on the software correlator, the experiments and the results is in preparation, but phase closure has been shown between the telescopes.

During the experiment small sections of the recorded data from Ceduna, Mopra, Parkes, Tidbinbilla and Narrabri were transferred to various software correlators to perform near real

time fringe checking. After the success of this (and the ‘on the fly’ discovery of a swapped polarisation at the ATCA) we set to developing a permanent, parallel fringe checking system. The S2 system mirrors the data in (on port C1) on a data out port (C2a). We now record this during regular VLBI experiments, and immediately provide data integrity confirmation. The fringe checking experiments are limited to the ATNF antenna at present, but we have plans to expand this to Tidbinbilla, Hobart and Ceduna. The data transport requirements are slight; if we checked one second of data every hour the rate would be less than 5kB/s.

4. Differential VLBI observations of the Huygens Probe

JIVE has proposed to use a global array of VLBI antennae to observe the Huygens probe during its descent into the atmosphere of Titan on 14 January 2005. One of the key science goals is to measure the dynamics of Titan’s atmosphere. Phase referenced VLBI will be used to track the probes position during its descent. Along with the Doppler shift of the probes signal, the full 3 dimensional velocity of the probe will be measured. LBA participation in the experiment will be important due to the position of the probe on the sky. Now that Australia has the capability to install 0.5 Gb/s recorders at all antennae for a few thousand (AU) dollars we are able to commit a significant number of baselines to this project.

For this experiment two DASs per PC-EVN recorder are required, so where possible the MkV system is being used freeing up resources for other antennae. While an individual DAS can provide two 64 MHz bands the digital filters are limited to providing four narrower (16 MHz) bands (from within the input 64 MHz bands). As observations need to be spread over a large frequency range for the atmospheric calibration the only solution is to have two separate systems, one for the probe signal, and one for the spread frequency calibration signal. Combining the signals from two (independent) DAS, driven by the clock from one of them, is an issue but has been demonstrated within the last few days.

5. Other Projects

The Metsähovi recorder, being a bare-bones, and therefore very flexible, system has led us to use it for a number of other projects. These required a AD converter, buffered out as LVDS levels into the VSIB.

5.1. The Mt. Pleasant Pulsar backend

Hobart has been monitoring the Vela pulsar’s pulse time of arrival (TOA) for over twenty years. The original system (which caught a glitch in the first week of operation (McCulloch *et al.* 1983)) has been upgraded over the years to one that;

- monitors Vela for 18 hours a day (and a second glitching pulsar for the remaining 6 hours).
- collects two minute averaged profiles at three frequencies (635, 990 and 1390 MHz). The bandwidth is matched to the

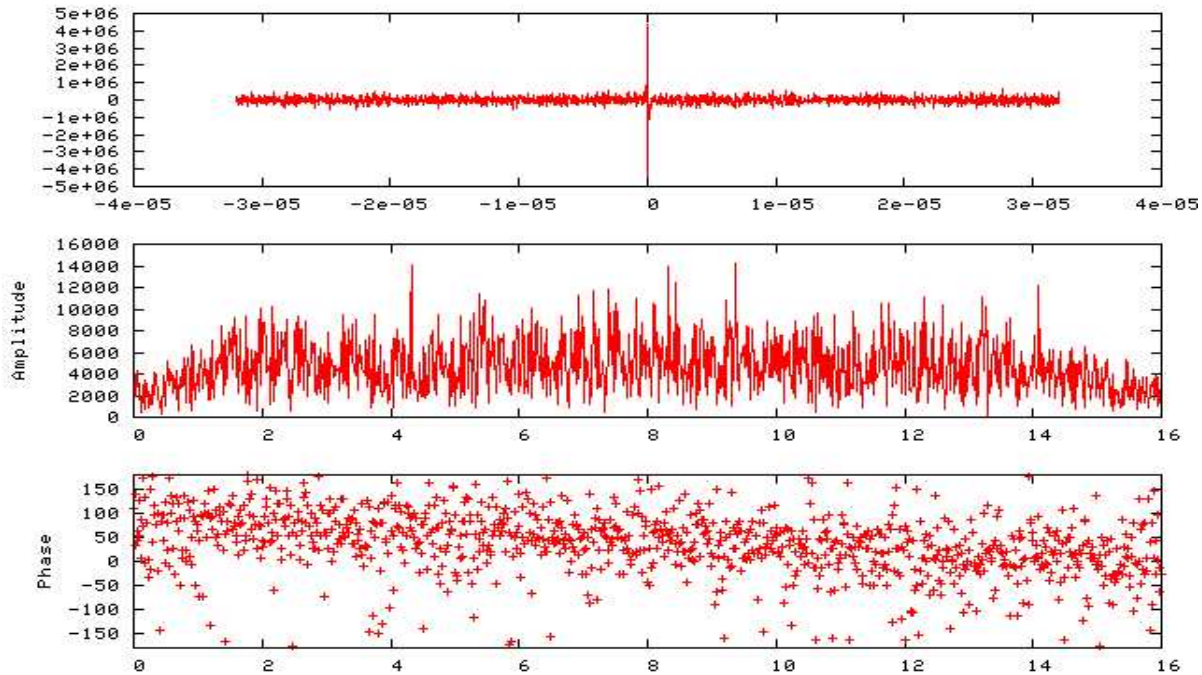


Fig. 2. The automatic fringe checkers output from an experiment on Sept 12 between ATCA and Parkes. Observing 1104-445 at L band for one second with a 16 MHz bandpass.

dispersion time (for a dispersion measure of 69 pc cm^{-3}). The automatically generated fit to these data is available on the web¹.

- collects continuously sampled data at 990 MHz (incoherently dedispersed to increase the bandwidth by a factor of eight). From this single pulse system 10 second profiles are constantly formed and checked for the occurrence of a glitch. These data are saved for 3 days for deep analysis of immediate post (and pre) glitch behaviour (Dodson, McCulloch & Lewis 2002).
- now also collects continuous sampled data at 635 MHz across a 25 MHz bandpass offset from baseband by 10 MHz, increasing the bandwidth one hundred fold. This data is buffered for 2.5 hours, after which it is overwritten. Once a glitch is detected by the single pulse system the data is saved for off-line coherent dedispersion and profile forming.

Our new system produces TOA's with accuracy of the order of 0.1 msec every second (as opposed to every 10 seconds with the single pulse or 120 seconds with the multi-frequency systems).

The IF (baseband to 40 MHz) was fed in to a MAXIM 1448 A/D mounted on an evaluation card (AU\$330 each), along with a 80 MHz clock. Two of these provide the two polarisations. The output of these are TTL, so the four most significant bits (of the 10 bits provided by the MAX1448 card) are buffered to LVDS along with the clock signal, and combined with an external 1PPS signal. These are fed directly into the VSIB. In

running the VSIB at 80 MHz we are clocking the data at two and a half times the VSI standard, nevertheless this produced no complications. The recording software is that provided (**wr**), with minor modifications to allow continuous looped recording and shared memory control. This system is now running and recording data. However it missed the last glitch (Dodson *et al.* 2004) as we switched to a debugging mode 24 minutes before the event (Murphy per. comm.).

5.2. The Stromlo Streamer

For radio astronomers, the radio frequency interference (RFI) environment continues to get worse, and has become a critically important issue in the development of the next generation of radio telescopes, including the Square Kilometre Array. For the SKA site evaluations and interference mitigation investigations Mount Stromlo Observatory (Australian National University) has used a near identical setup to the pulsar system as a flexible test bed for emulating radio astronomy backends in software. The system is portable, carrying with it a low-precision 64 MHz clock and 4 MAXIM 1448 A/D cards for accepting 4 IFs as input. The flexibility provided by the MRO **wr** routine allows the A/Ds to deliver different numbers of bits precision and different sampling rates without reconfiguring the hardware. The most often used application has been in the area of RFI mitigation to further the program described in Briggs, Bell and Kesteven (2000).

¹ <http://www-ra.phys.utas.edu.au/~rdodson/0835-4510.par>

5.3. A mobile VLBI recorder

We are collaborating with Auckland University of Technology to build a VLBI recorder for use with a satellite tracking dish. This is a demonstration project for future, large scale, VLBI between Australia and New Zealand. The recorder is a Dell system, writing to an Xraid disk pack. The time standard is a GPS disciplined clock. Again we are going to use the MAX1448 AD to sample the analogue baseband signal, and will record two 16 MHz bands for correlation with antennae in Australia. This baseline fills a significant gap between Hartebeesthoek and the Australian LBA baselines.

6. The future

Using the PC-EVN systems in place we will collect the data from the S2 formatter output port (C2a), and fringe check the data on the fly during all VLBI observations. Automation of the data collection and checking is being fine tuned. This will allow rapid checking and debugging of the array and will further improve the success rate of VLBI observations

The ATNF expect to have a 10 Gb/s network installed at all their telescope sites by early 2005. We will, therefore, be able to quickly catch up with the current e-VLBI systems of the Europe, Japan and the USA. The project time line is to have 0.5 Gb/s recording available at all antennae by the mid 2005. This will be recorded to removable disks and correlated in the Swinburne software correlator (West 2004). The new ATCA broadband backend (sited at Narrabri) is projected to be completed in 2007. It will be able to correlate the VLBI-station data, delivered over fibre, in real time. The correlator will be free as during the VLBI runs the ATCA operates as a VLBI-station itself.

As a demonstration we have collected the data from the DAS correlator port rather than the S2 connector port, which allows us to record 2 IFs of 64 MHz (at 2 bits). Figure 3 shows the bandpass collected at Hobart looking at the methanol maser G309.9+0.5. There is also a test tone 3 MHz below the band centre.

At Parkes we collected coincident data recorded on the CPSR-II system to produce the zero baseline cross correlations. We will shortly attempt to correlate CPSR-II data (from Parkes) with data from two PC-EVN machines (at ATCA) to demonstrate 1 Gbps VLBI in Australia.

The recording rate limitations are from that sustainable by the hard drives (about 800 Mbs for the slowest system), however even when greater speeds are possible (with Serial IDE drives or just general improvements) we will be at the PCI maximum rate. Already we'd like to be able to read and write over the same bus at the same time, in which case developing the VSIB card to run on the faster, emerging, technologies would be of great priority. The estimated cost for this is 3 man months, and if sufficient interest is generated this will be undertaken at Metsähovi.

7. Conclusions

We have demonstrated the adaptability of the PC-EVN system, and its low cost of setup in both hardware and manpower. We

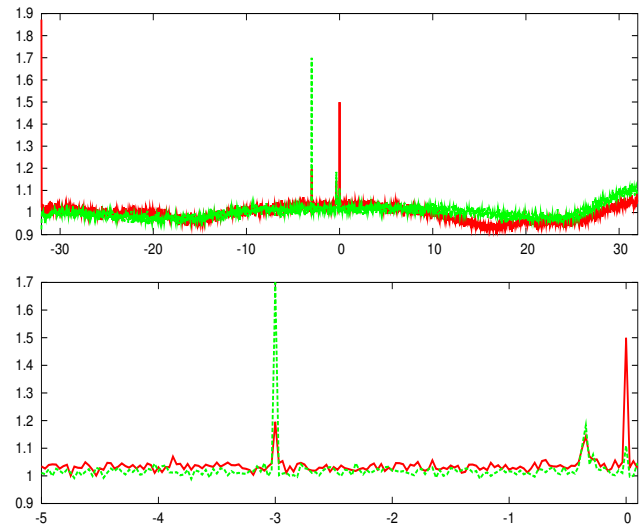


Fig. 3. Autocorrelation of 0.7 seconds of 64 MHz bandwidth data observing the maser G309.9+0.5. Both polarisations have been recorded and a test tone has been included at 3 MHz below band centre (which is 6667 MHz). The bandpass fed into the DAS is not very sharp and the aliased edges folded back into the 64 MHz causing the rise in the system temperatures at ± 32 MHz.

have used it for analog RF recording systems and as a digital recorder for the Australian VLBI system. We will use it as the basis for a fringe checker system, and as the wide bandwidth recorder for the Huygens experiment. We expect to continue to find new and varied uses for these cards.

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