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Pulsar Coherent De-dispersion Experiment at Urumqi Observatory

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Abstract A Pulsar coherent de-dispersion experiment has been carried out using the 25-m Nanshan radio telescope at Urumqi Observatory. It uses a dual polarization receiver operating at 18 cm and a VLBI back-end: Mark5A, the minimum sampling time is 5 ns. The data processing system is based on a C program on Linux and a 4-node Beowulf cluster. A high quality data acquisition system and a cluster with more processors are needed to build an online pulsar coherent de-dispersion system in future. The main directions for the instrument are studies of pulsar timing, scintillation monitoring, etc.

Key words: techniques: Parallel Computing — instrumentation: Mark5A & Cluster — methods: Coherent De-dispersion

1 INTRODUCTION

Pulsar radio signals interact with the interstellar medium, which causes dispersion of the pulse signal (Hewish 1968). There are two main approaches to de-dispersion: incoherent de-dispersion and coherent de-dispersion (Hankins & Ricket 1975). The incoherent de-dispersion approach is limited by the smearing across the channel bandwidth itself, and the number of frequency channels that can be constructed depends on the hardware resources available and increasing frequency resolution is expensive and technically complicated; However, the coherent de-dispersion method completely removes the effect of dispersion and restores the original pulse (Lorimer & Kramer 2005), only the sampler has to be very fast and the rest of the problem is digital signal processing that can be carried out in software and not necessarily in real time.

A pulsar coherent de-dispersion system consists of two main parts: The first is a data acquisition system which provides the signal conditioning and sampling of the radio data; The second part is a powerful cluster of PC processors for observation data processing. The availability of cheap computer hardware in recent years has provided a new alternative to dedicated hardware based solutions used in the past for this purpose.

Therefore, Beowulf cluster approaches to data reduction either arrive at or close to realtime processing rates, and such systems are becoming more common. A number of systems are development at Jodrell Bank (COBRA: Coherent Online Baseband Receiver for Astronomy) (Joshi & Lyne 2003; Kramer et al. 2001); ATNF (CPSR2: Caltech Parkes Swinburne RecorderII, the system originated from Swinburne, installed at ATNF) (Hotan 2004); Princeton (The MkIV off-line system which originated from Princeton, installed at Arecibo and Jodrell Bank) (Stairs 1998; Ord 2001); Arecibo (ASP: Arecibo Signal Processor) and Green Bank (GASP: Green Bank Astronomical Signal Processor) (Joshi et al. 2003).

A cluster-based pulsar coherent de-dispersion instrument had been constructed at UO (Urumqi Observatory) to process data acquired with the Mark5A system. The current systems is an off-line processor using software and high-performance computers. Its primary function is to perform coherent de-dispersion of pulsar data from NanShan radio telescope.

2 SOFTWARE & HARDWARE

The implementation of coherent de-dispersion consists of creating complex-mixed base-band data which are Nyquist-sampled (VLBI back-end: Mark5A) (Whitney 2003), a Fast-Fourier-Transform (FFT) brings

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the signal into the frequency domain, the correction of the phases is achieved by subsequent application of a "chirp" function, before finally transforming the signal back into the time domain with another FFT and folding (Kramer & Lyne 2001). The system is a coherent filterbank (Jenet et al. 1997), the dataset is divided into n frequency channels by FFTing adjacent n point blocks of data. Unlike the incoherent filterbank, the power is not detected and each channel is coherently dedispersed separately and the then reassembled into one long time series. Figure 1 shows block diagram of the pulsar coherent de-dispersion system in UO.

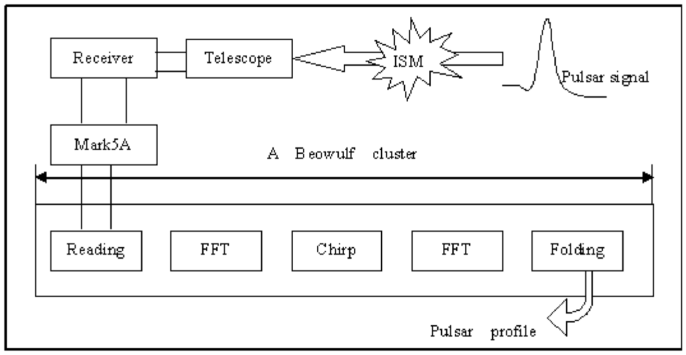

Fig. 1 Diagram of the pulsar coherent de-dispersion system in UO.

The "Chirp" function is

$$T_k H_k^{-1} = \frac{1}{N}\Big[1+\Big(\frac{f_k}{0.47B}\Big)^{80}\Big]^{-1/2} \exp\Big\{-i\Big[\frac{\pm \mathrm{DM} f_k^2}{(2.41\times 10^{-10}) f_c^2 (f_c \pm f_k)}\Big]\Big\}\,, \tag{1}$$

where f_c is center frequency; B signal bandwidth and DM dispersion measure.

The Mark5A samples raw voltages generated by the telescope receiver at the Nyquist rate, allowing complete reconstruction all information (both amplitudes and phases) present in the signal. This produces a great amount of data (30 Megabytes per second in the present configuration), which needs a cluster for recording and analysis.

A small 4-node Beowulf cluster had been constructed (Becker & Sterling 1994), which will service as a parallel processor to process observing data. Each nodes uses striped SATA disks as a cost-effective means of achieving the desired I/O rates. The whole cluster is managed by Rocks software (Rocksclusters 2004).

The coherent de-dispersion code is a C program on Linux. The code implement parallel computing with Message Passing Interface (MPI), and the Fourier transform operation is carried out using Fast Fourier Transform in West (FFTW) algorithm.

3 OBSERVATIONS

Observations were implemented by using the 25-m telescope at UO between January and May, 2005. Data were obtained at 1600 MHz with an observing bandwidth of 8 MHz at each polarization. The system temperatures are 22 K and 24 K respectively. All data were acquired by using the Mark5A system of UO.

Frame by frame, Mark5A recorded the data into a high-speed disk array. However, in each frame of 2500 bytes data, first 20 bytes are replaced by a set of header information in Mark5A. Thus, we have to replace again all the header information with zero in the off-line data processing (Whitney 2000; Westford 2001).

4 RESULTS & FUTURE

Several pulsar profiles have been obtained during these observations. Figure 2 shows the average profiles for PSR B0329+54 at 1650 MHz obtained by using incoherent and coherent de-dispersion methods (Integrating time=120 s, Bandwidth=16 MHz). The dual-polarization signals are 2-bit quantized.

We plan to build a dual-polarization on-line pulsar coherent de-dispersion system at 327MHz and 610MHz, with a bandwidth of 60 MHz for each frequency. In order to achieve that, a high quality data

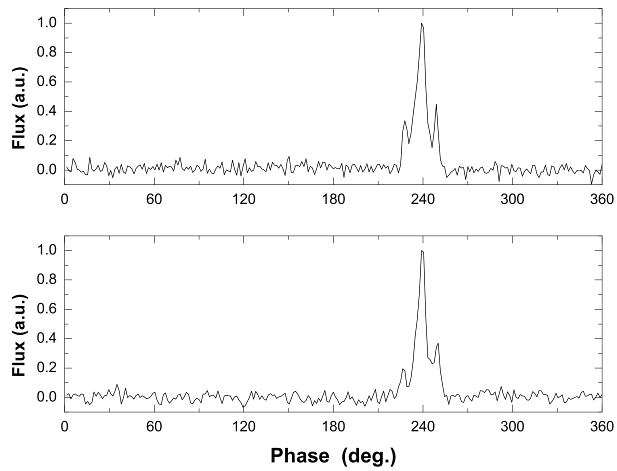

Fig. 2 The mean pulse profiles of PSR B0329+54 at 1650 MHz obtained by implementing incoherent (upper panel) and coherent dedispersion (bottom panel).

acquisition system and a cluster with more processors are needed.Based on the experiment with 4 nodes, a cluster of 162 processors can run in realtime mode when observing below about 610 MHz with a bandwidth of 64 MHz.

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