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Mark IV: A Phase Coherent Observing System for Pulsars

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1. Introduction

We have built a new radio astronomical receiving system designed specifically for very high precision timing and polarimetry of fast pulsars. Unlike most detectors currently used to study pulsars, this intrument does not square the received signal at the time of observation. Instead, voltages proportional to the instantaneous electric vectors of incoming signals are digitized, time-tagged, and recorded on high speed magnetic media. We have tested the system using a 5 MHz bandwidth signal with 2-bit digitization at the Greenbank 140 foot telescope. Full polarization information was obtained with a 0.2 μs time resolution. We have used this system to study the giant pulses emitted by PSR B0531+21 and PSR B1937+21, to determine high precision dispersion measures, and to perform high precision timing and polarimetry.

2. Coherent Dedispersion

Pulsar observations made with standard post-detection dispersion removal techniques are limited in time resolution by the dispersive smearing across the channel bandwidth of the system. These systems measure the average signal intensity over some channel bandwidth and time interval for a given number of channels. These measured intensities are proportional to the mean square of the received electric field, and square-law detection of the signal causes all information about the relative phases of signal components at different frequencies to be lost. Thus it is no longer possible to correct for the phase retardation introduced by interstellar dispersion across each channel.

Coherent dedisperion systems, on the other hand, have time resolutions equal to the inverse of their bandwidth. These systems remove the effects of interstellar dispersion before square-law detection. With this method, voltages proportional to the received electric field vectors are recorded using the full bandwidth of the system. Upon playback, the digitized data streams are convolved with an inverse "chirp" function that unwinds the phase retardation introduced by dispersion. This chirp function has length equal to the dispersive delay across the bandwidth. Relevant self- and cross- products of orthogonal polarization components then yield the desired intensity and polarization information.

3. Mark IV Design

The final Mark IV system will be able to record two orthogonal polarizations with 2-bit digitization across a 10 MHz bandwidth, which is ideally suited for the 430 MHz line feed at Arecibo. We have tested two baseband recording systems, the first of which ('Mark IVa') was designed by P. Perrilat and was limited by the recording media to a 1 MHz bandwidth. In November 1994 we conducted a series of test observations at Arecibo using this system. Two circularly-polarized signals were complex sampled with 2-bit digitization across an 833 kHz bandwidth and written to a pair of Exabyte 8500's.

In September 1995 we tested a new system designed and built at Princeton ('Mark IVb') using a 5 MHz bandwidth at the Greenbank 140 foot telescope. This system is able to start on a reference time tick and employs much sharper filters than the first system. Two circularly-polarized signals were received at 351.25 and 388.75 MHz, mixed to baseband, and passed through 2.5 MHz low-pass filters. The four resulting real signals were 2-bit sampled every 0.2 μs, packed into bytes, and written to disk for later copying to Exabyte tapes.

4. Results

We analyzed the data using 6 Sparc 20 class workstations in parallel, and have achieved processing to recording time ratios of 40:1 for half million point transforms of the Mark IVb data.

Timing of PSR B1937+21 produced $\sim$300 ns measurement uncertainties for 10 s integrations using Mark IVa. We also timed this pulsar using Mark IVb over a 4 day period. Although the measurement uncertainties were much greater for the Mark IVb data, both systems produced TEMPO post-fit timing residuals of approximately 2.5 μs. The timing precision of PSR B1937+21 is limited at these frequencies by the interstellar medium.

In the course of our observations using the Mark IVa system we obtained 1.2 μs time resolution polarization profiles of several millisecond pulsars, including B1534+12 and B1257+12. The Mark IVb observations of PSR B0531+21 confirmed that its main pulse and precursor have the same linear polarization angle at 352.5 and 390 MHz. From the dual frequency Mark IVb observations we obtained a DM measurement for PSR B1937+21 of 71.03674 $\pm$ 0.00014.

This system is well suited for single pulse studies because of its high time resolution. We confirmed the existence of giant pulses from PSR B1937+21, and established a power law distribution for its giant main and inner pulses (Cognard *et al.*, 1996). We also performed dual frequency observations of giant pulses from PSR B0531+21 at 352.5 and 390 MHz, and obtained the power law indices for the giant main and inner pulses at these two frequencies.

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References

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