Max-Planck-Institut
für Radioastronomie

Pulsar Instrumentation

Fundamental Physics in Radio Astronomy and Digital Laboratory

MAX-PLANCK-GESELLSCHAFT

Abstract:

The large collecting area and sensitive receivers of the Effelsberg 100-m Radio Telescope is an excellent combination for studying radio pulsars. With appropriate instruments, high precision pulsar timing, high time resolution single pulse studies and the discovery of newer pulsars can be carried out at an unprecedented level. Moreover, with the recent addition of the 7-Beam front end receiver, the telescope's field-of-view has considerably increased to ~1° at 1400 MHz. To take advantage of the upgrades in the telescope, a recently developed instrument and the new ones considered are presented below. Wider bandwidths and better sampling resolution in these instruments result in large data rates and volumes. We employ the "divide-and-conquer" approach by capturing the data in a distributed fashion. Processing of the data is done on a separate computer cluster. For data capture, 120 TB of storage space is distributed over 8 computers. A total of 400 processor cores are available for various pulsar processing requirements. An additional 140 TB of disk space is currently available to buffer pulsar data before being archived on to LTO-4 magnetic tapes.

Pulsar Signals:

- ☐ Pulsar signals can be seen as amplitude modulated noise signals.
- ☐ Propagation in the interstellar medium results in dispersive smearing of the pulsar signal. If left uncorrected, the effect can completely wash out the pulsed emission rendering it undetectable.
- ☐ Dispersion can be corrected before or after signal detection and is called coherent or incoherent dedispersion respectively. Coherent dedispersion needs raw voltages from the telescope which requires baseband recorders.
- ☐ Coherent dedispersion corrects dispersion completely but is computationally intensive while the less-demanding incoherent dedispersion removes smearing partially limiting the maximum time-resolution achieved.

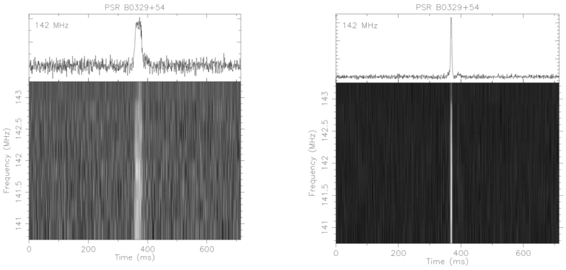
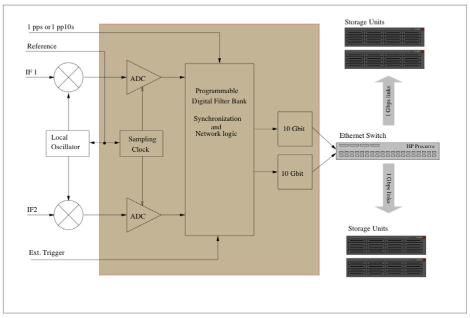


Figure 1: Plots illustrating the effect on the pulsar signal using the two different dedispersion techniques. PSR B0329+54 observed at 142 MHz using a 2.5 MHz bandwidth is shown above as frequency-time plot in the lower panels, and the average pulse profile in the top panels. The image on the left shows dispersion smearing within each channel, while the plot on the right shows coherently dedispersed signal. The "sharpness" of the pulse profile and hence the better time resolution obtained by coherent dedispersion is evident.

Baseband Recorders and Coherent Dedispersion

Digitizing and recording raw voltages corresponding to large bandwidths from a radio telescope results in a large data rate that demands large sustained throughput to hard disks. One solution to this problem is to divide large bandwidths to smaller subbands which are then stored on separate computers. These smaller bands can be coherently dedispersed in software. Digitally implemented polyphase filters offers a way to form these subbands efficiently.

Figure 2: Proposed coherent dedispersion system for the Effelsberg Radio Telescope. The intermediate frequency signals (300 – 500 MHz-wide) from the telescope are converted to video signals. These are then sampled at 8-bit resolution by the analog-to-digital converter units (ADCs). A polyphase filterbank (PPF) implemented on a Field Programmable Gate Array (FPGA) generates smaller subbands which are sent to 1-Gigabit network switch. The switch in turn distributes the data to 8—16 high performance computers. Various options for the shaded region are considered in the adjacent box.



The need for high time resolution ….

The accuracy in the measurement of pulsar arrival times depends directly on the signal- to-noise (S/N) ratio of the signal and an appropriate fiducial point in the pulse profile. Sharp features in the average profile is hence a natural reference. Therefore, for a better S/N ratio and the recovery of narrow emission signatures, coherent dedispersion is the preferred method to process the pulsar signals.

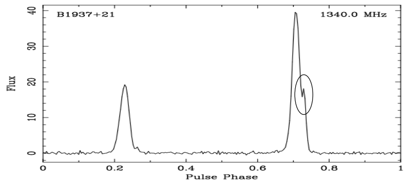


Figure 3: Average emission profile of PSR B1937+21 at 1340 MHz and 160 MHz bandwidth. The signal was sampled at 25-ns and coherently dedispersed resulting in 1024 bins across the pulse period. The narrow "notch" feature, circled in the plot cannot be recovered without the application of coherent dedispersion.

Pulsar Search Hardware – 7-Beam Backend

The 7-Beam Pulsar backend was built by the MPIfR Digital Labs and was recently installed at the 100-m Telescope. The system consists of eight module each providing 256-channel filterbanks which are based on the AFFTS Spectrometer [1]. Seven of these modules receive dual-polarization inputs from the seven-beam frontend. The modules are equipped with high performance Xilinx FPGA in which the 256-channel poly-phase filterbank, time-averaging and polarization sums are done on the signal, resulting in a final time resolution of 54 – 65 μs. The output from these modules is captured by dedicated server-class computers, each with 16 TB storage space and dual 6-core processors.

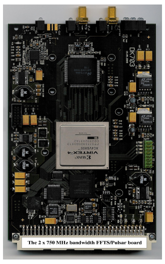


Figure 4a: A photo of the AFFTS ADC+FPGA module is displayed on the left. These units are equipped with 1.5 Gsamples/sec 8-bit converters and a powerful Virtex-4 Xilinx FPGA. Onboard 100Mbit interfaces is provided to download firmware on to the FPGA and a 1 Gbit Ethernet interface serves as a fast data link to the storage computers. Provision exists for the input of external station reference. The pulsar filterbank firmware currently transmits data as light-weight UDP packets, and can reach a maximum of 900 Mbits/sec.

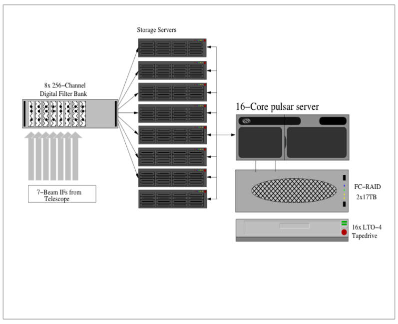


Figure 4b: A block diagram representation of the 7-Beam Pulsar Search System currently in operation at Effelsberg. Each module of the filterbank system has a dedicated 1Gbps link to a data acquisition computer. The computers are each equipped with dual 6-core processors, 32 GB RAM and 16 TB of storage space. The pulsar server with 38 TB of storage and a 12.4 TB LTO-4 tape drive are also depicted.

Baseband Options:

Currently a survey of suitable baseband hardware is underway. The emphasis is on minimal developmental time, and to use well-tested off-the-shelf system components.

- ☐ in-house solution from the MPIfR Digital Lab. This will be based on expanding the ADC Card shown in Figure 4a above and [1]. Significant portion of previous developments can be re-used in this case.
- ☐ baseband option of the ATNF DFB, similar to [4]. This awaits a new firmware from the DFB suppliers.
- ☐ ROACH/iBoB [2,3] hardware from CASPER (Figure 5). These are powerful FPGA based solutions developed for complex signal processing applications in radio astronomy, e.g. for the upcoming Square Kilometer Array telescope.

Figure 5: An image of the iBoB is shown on the left and the ROACH board is on the right. The ROACH has a more power FPGA and therefore can process larger bandwidth. The iBoB can be used for bandwidths up to 200 MHz, as the FPGAs in this board are based on an older technology. The ADC units for these boards operate in the 200 – 1500 MHz range.

References:

1. Klein, B., Proceedings of the 19th Symposium on Space Terahertz Technology, Groningen
2. http://casper.berkeley.edu/wiki/IBOB
3. http://casper.berkeley.edu/wiki/ROACH
4. http://astronomy.swin.edu.au/pulsar/?topic=apsr