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The NFRA *Pu*lsar *Ma*chine *PuMa*

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Abstract. The Westerbork Telescope has good low-frequency capability, with receivers covering much of the frequency range from 250 to 1800 MHz. For pulsar observations the array elements can be coherently summed to provide the equivalent of a 93 m aperture. To exploit this potential, a new backend, PuMa, has recently been commissioned. It can be configured in various ways, with up to 4096 frequency channels per band, a total bandwidth of 80 MHz, and time resolution of 50 nanoseconds. PuMa can be used in search mode, recording just two polarization channels, or for observations of known pulsars, determining all four Stokes parameters and correcting for dispersion and Faraday rotation. In many of the low-frequency bands (especially 300 - 380 and 800 - 900 MHz) interference-free observing is possible much of the time, enabling wide-band studies of ISS, refraction and the Faraday effect.

1. Introduction

Pulsars, the radio counterparts of neutron stars, emit short bursts of broadband radio emission with extremely accurate repetition periods ranging from just over 1 ms to nearly 10 s (Taylor, Manchester, & Lyne 1993). This radiation can be studied both for its own sake, and to probe the interstellar medium via propagation effects (e.g. Manchester & Taylor 1977). The strength of the emission declines rapidly with increasing frequency, so pulsars are a natural subject of low-frequency radio studies. But even at low frequencies, most pulsars are weak radio sources, requiring large telescopes with sensitive receivers to observe them effectively.

As broadband emitters, one naturally wants to observe pulsars with the greatest possible bandwidth (compatible with the interference environment and other practical considerations) to achieve the best sensitivity. However, dispersion in the ISM produces a frequency-dependent delay in the signal:

$$t \propto DM/\nu^2 \tag{3}$$

To prevent temporal smearing from exceeding some minimum time interval, Δt, the bandwidth must be limited to,

$$\delta\nu \propto (\Delta t/DM)\,\nu^3 \tag{4}$$

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To achieve an overall bandwidth of $\Delta\nu$ requires a receiver with a large number of channels, namely $\Delta\nu/\delta\nu$. PuMa has been designed to provide the required number of channels so that (practically) all known pulsars can be observed at the lowest frequency available on the Westerbork Telescope (WSRT). With the large number of channels involved (up to 65 000) the problem becomes essentially one of data rate, storage and processing.

2. PuMa and its Capability

At the heart of PuMa (or more correctly, in its brain) is the SHARC Digital Signal Processor (DSP). This commercially available processor is able to execute a 2048 point complex FFT in about 1 ms, the fastest floating point DSP on the market. Filling the SHARC with 2048 data points requires 0.1 ms, and further processing and storage after the FFT an additional 1 ms, so about 21 SHARCs are required to handle the 20 MHz input rate, itself necessary to Nyquist sample the WSRT 10 MHz bands. In fact, 24 SHARCs (mounted on 4 boards) are used to handle the data from each of up to 8 WSRT bands.

One of the features of PuMa is its flexibility, enabling the user to configure it in ways which are best-matched to the particular goals of the observation in question. For measurements of known pulsars, one can use PuMa as a filter bank receiver, but one in which the number of frequency channels, $N_{\rm ch}$, and the integration time, Δt, can be tailored to the observing frequency (ν) and pulsar dispersion measure (DM). The SHARCs will then FFT the number of time samples (of 128, 256, 512,... points) required to create a spectrum of the desired frequency resolution, and sum the number of frequency spectra needed to produce the required time resolution. By treating the X- and Y-dipole signals as the real and imaginary inputs to the FFT, PuMa is able to construct the Stokes parameters directly.

In addition to operating as a filter-bank receiver, PuMa can be configured to record the baseband signal of each 10 MHz input channel, for both polarizations. The output voltage signals are then available for further analysis, for example in order to carry out coherent dedispersion. This enables studies of pulse structure to be carried out with temporal resolution as fine as the Nyquist sampling (50 ns). To analyze baseband data, offline software has been developed to coherently dedisperse the signals. There are also programs to search for pulses over a range of periods and DMs, to look for binary pulsars, as well as general-purpose software for analysis and display of pulsar data.

PuMa was designed for use with the WSRT, a 14 element synthesis interferometer (Baars & Hooghoudt 1974, Högbom & Brouw 1974), so the interface had to be designed with this in mind. Each telescope produces two 80 MHz signals (for both polarizations) which are treated in the normal way for standard synthesis interferometry up to the delay compensation (where the original 80 MHz signals have been split into 10 MHz bands). After the delay, the $2 \times 14 \times 8 \times 10$ MHz bands go to an adding unit (which is also used for VLBI observations) which sums all bands of the same frequency for each polarization, outputting 2×8 bands of 10 MHz each, which are then fed to PuMa. Each band is first mixed down to video, and then matching polarization pairs feed a group of four

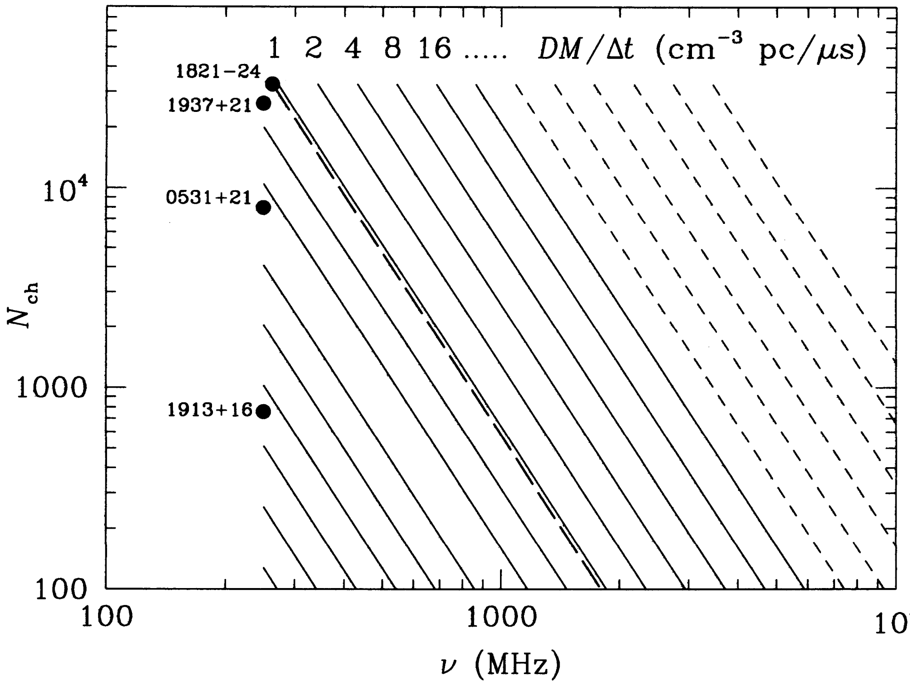

Figure 1. Relationship between the number of PuMa channels and observing frequency for different values of $DM/\Delta t$ (five of which are labelled across the top). Since $N_{\rm ch}$ has to be a multiple of 2, the values which can be actually chosen are indicated by dotted horizontal lines. The locations of four pulsars (at the lowest frequency where they could be observed by the WSRT) are shown, where $N_{\rm ch}$ has been chosen such that the temporal smearing will just match the pulse width. For PSR 1821 − 24 a dashed line shows how the choice of $N_{\rm ch}$ varies with frequency for continued optimal matching. At the higher frequencies, temporal resolution can be increased by increasing $N_{\rm ch}$

SHARC boards via an AGC unit. After the SHARC processing, the data are channelled via HP743RT processors to hard disk storage.

For a fixed bandwidth, $\Delta\nu$, the number of frequency channels required is, $N_{\rm ch} \propto \delta\nu^{-1}$. Then, from eq. (2),

$$N_{\rm ch} \propto DM \Delta t^{-1} \nu^{-3} \tag{5}$$

Fig. 1 shows lines of constant $DM/\Delta t$ (in units of $\rm cm^{-3}\ pc/\mu s$) in the $N_{\rm ch}$ vs. ν plane. Also shown are the locations of several pulsars at the lowest WSRT frequency where each could be observed for the case of pulse duration just being matched to the temporal smearing over the channel width. Table 1 lists the frequency bands available with the WSRT, where the different columns indicate which bands can be at the focus of a telescope at the same time.

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Table 1. Westerbork MFFE frequency coverage

	(coaxial)	←Band→ (coaxial)			Frequency range (MHz)
UHF_{low}	$\Longrightarrow$	$\Longrightarrow$	$\Longrightarrow$	$\Longrightarrow$	250 – 460
	92 cm				305 – 390
	13 cm				2215 – 2375
	3.6 cm				8150 – 8650
		50 cm			(580) – 615
		6 cm			4770 – 5020
			UHF_{high}		800 – 1200
				L	1150 – 1750

3. Science Themes

With its flexibility and huge data capacity, PuMa is able to tackle a wide variety of pulsar research topics. Thus far, various research groups have done single pulse studies, targeted searches, multifrequency observations (at the moment this is done by splitting the WSRT into sub-arrays), and we have initiated a timing program. We are also planning to study polarization, and try larger-scale searches, pulse scattering and propagation effect studies. The wide instantaneous bandwidths provided by the WSRT (Table 1), especially at the lower frequencies, are of particular interest for investigating propagation in the ISM. Interference permitting, it is possible to observe simultaneously over several 10 MHz bands in the 92 cm or UHF_{high} frequency channels.

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