PROJECT 2.625
PULSAR SIGNAL PROCESSOR
MEMO NO. 3

30 October 1981

To: Martha Haynes, Director NRAO, Green Bank, WVa.

From: Tim Hankins, NAIC, Arecibo, P. R.

Subject: Pulsar data acquisition system

In response to your request I have written below some thoughts on pulsar data acquisition for NRAO, based on the kinds of observations I would anticipate at NRAO in the next five years. An option which would be very attractive to the pulsar community is portability. If the pulsar data acquisition system were built to be telescope independent, then it would likely be in demand for special projects such as continuous monitoring of pulse arrival times at high latitude observatories, optical observations of the Crab and Vela pulsars, high sensitivity observations at Arecibo, and southern hemisphere observations.

Pulsar observations could be classified according to the time resolution involved; say 0.5, 0.05, and 0.005 ms for low, medium, and high resolution. The signal to noise ratio requirements for high time resolution measurements restrict this kind of observation to the Arecibo telescope. Since high time resolution data acquisition equipment exists at Arecibo for planetary and ionospheric radar observations, I suggest that the NRAO pulsar data acquisition system be restricted to low and medium resolution in the interest of economy.

I anticipate the following kinds of observations will be proposed at NRAO in the near future.

1) Pulse arrival times - for studying neutron star interiors.

2) Single pulse studies of total intensity for mode switching and drifting.

3) High sensitivity average profiles for "outrigger", pedestal, and interpulse studies.

4) Multiple frequency polarization measurements with "low" time resolution.

5) All sky automated searches for new pulsars, searching in position, dispersion and period.

6) Searches for short period pulsars in known objects.

I list below some hardware requirements to accomplish some of these goals. I have included some opinions and comments where I feel they are appropriate.

1) Dispersion removal for signal to noise ratio improvement

Dispersion removal could be achieved both before or after detection. For modest time resolution and wide bandwidths post-detection dispersion removal using a multichannel filter bank and a device to delay and add the detected outputs is recommended.

We would like to accomplish real time dispersion removal over 2 or 4 channels (2 frequencies x 2 polarizations or 4 Stokes parameters. How the Stokes parameters are obtained depends upon the method of dispersion removal and hence the type of polarimeter. The "filter banks" must be stable in both passband gain and shape. It would be highly desirable for the filter bandwidths to be continuously variable from say 10kHz to 1MHz per channel, with 32, 64 or 128 channels. Continuously variable bandwidths allow both optimal matching to the pulsar signal dispersion sweep time across the bandpass and post-detection sampling intervals which divide the pulse period into an integral number of samples.

a) Filter Bank

The filter bank could be built using conventional analog techniques, but I don't see an easy way to get variable bandwidths. A digital filter bank, where the i.f. signal is rapidly sampled and transformed by the FFT to the frequency domain and the power spectrum obtained by digital multiplication, provides all the obvious advantages of digital techniques including gain and passband stability, and continuously variable bandwidths. Only the input sample interval and anti-aliasing filter need be adjusted to vary the bandwidths. Digital post-detection integration and dedispersion follow directly.

If an analog filter bank is built, then the analog to digital conversion should be done immediately following the detector. The technique of using a voltage to frequency converter followed by a prescaler and counter has the advantage of continuous "boxcar" post-detection integration as compared with a detector followed by an RC integrator and analog to digital converter.

The dynamic range required of the filter bank and detector can be estimated from the radiometer equation, $\Delta T/T_{sys} = (Bt)^{-1/2} = 0.03$ where $B_{max} = 10^6$ Hz, $t_{max} = 10^{-3}$ sec. If we set the levels so that the rms noise is 1 digital level, then 5 bits ($0.03 \sim 2^{-5}$) are required for a pulsar with Signal/Noise = 1 in a single channel. For a 32-channel filter bank with a dedisperser capable of 16 bits output, 11 bits (16-5) are available per channel, giving a dynamic range of 2^{11}-$2^5 \sim 2000$ in a single channel, which should be adequate for even the strongest pulsars at low frequencies. Note that providing a dc bias to offset the system temperature T_{sys} does not significantly improve the dynamic range. Therefore, in the interest of simplicity, it is recommended that no provision for a detector offset be included.

For a digital filter bank the number of bits required can also be estimated. If the signal to noise ratio for a strong pulsar for $B = 10^6$ Hz, $t = 10^{-3}$ sec is 2^{11}, then with no integration (i.e. at the detector output) the S/N is $2^{11} \times (10^3)^{-1/2} \sim 2^6$. (Tsys remains at 2^5 units. ΔT increases from 1 to 2^5). The required dynamic range for a single channel at the output of the filter bank detector is then $0.03 \times 2^{11} = 2^{-5} \times 2^{11} = 2^6$. (This corresponds closely to my own observation of predetection S/N of 10 for the strongest pulsars.) This means that the FFT "filter bank" need to have a word length only long enough to preserve 6 bits of accuracy through 6 stages ("butterflies") of the FFT. Such an FFT should not be difficult to build (30 MHz 64 points) using conventional digital circuitry.

b) Dispersion delay compensation

Post detection dispersion removal requires that each channel of the detected filterbank output be delayed by the appropriate amount such that the "swept frequency" pulsar signal can be added together with the dispersion delay removed. This can easily be accomplished for the data rates discussed here by one of the latest 16-bit microprocessors. The signal averaging requirement may also be satisfiable with the same processor.

2) Sampling requirements

a) Up to 8 channels (2 x 4 Stokes parameters) at 0.5 ms rate, continuously, and synchronously with the pulse period, or at 0.05 ms for up to 10% of the pulse period in several windows in order to sample mainpulse, pre-or post-cursor and interpulse regions. Output directly to tape or to signal averager.

b) Up to 32 channels (filter bank outputs) at 1-2 ms continuously for pulsar searching in dispersion and period.

3) Timing requirements

a) A target of timing accuracy to within 1 microsecond of the station clock should be sought.

b) The timing system should be capable of generating a synch pulse at the observed (Doppler shifted) pulsar period with an accumulated "pulse phase" error of less than 1 us/hour. It should produce an integral number of sampling pulses per pulse period, or sampling pulses at a selectable spacing during up to 3 windows.

c) The synch pulse should be adjustable in "pulse phase" by a specified amount (to center the pulse in the pulse period, for example), and it should be possible to start a sequence of synch pulses at a specified epoch to 1 μs accuracy, and perhaps 1 ms resolution. It should also be possible to "read" the epoch of a synch pulse to 1 μs.

4) Software. Programming for the following items would be necessary.

a) Doppler shifted time base correction and control of a phase continuous synthesizer for synch and sample pulse generation. the timing system controls, i.e. sample interval, sampling mode (continuous or window), adjustment of pulse phase should also be software driven.

b) Data acquisition - read data, synchronously average and display and record with an appropriate tape header containing time of day and dates observed period, sample mode and interval, source name and cordinates, bandwidth, etc. Either single or multiple period records or average profiles can be written to tape. For continuous sampling of all filter bank outputs for pulsar searching, consideration should be given to the possibility of on-line processing using peripheral CPU's or a cheap array processor.

c) Provision for local oscillator control should be considered for the case of two or three frequency sampling or "chasing" pulsar signals in frequency.

d) On-line interference rejection (lightning, radar, etc). Single records could be flagged, and for signal averaging, periods with interferences should be rejected before integration.

e) As many experiment parameters as possible should be software controllable.

Redundant manual controls are expensive, confusing, and they tend to set-up errors in routines observing programs.

5) Display

a) Analog: The average profiles should be displayed automatically. They need not be continuously displayed, but they should be frequently updated. A display of the raw data after dispersion removal would be useful for diagnostics and level setting, but it is not required. This could be achieved using a DAC in the signal averaging processor.

b) Digital: A display (CRT) of the experimental parameters controlled or monitored by the control processor would be useful.

6) Technology

a) Since most pulsar observers tend to be "equipment oriented" few "bells and whistles" are needed. So my recommendation is to keep it simple.

b) Stability and reliability should be stressed. Since the equipment will be sporadically used and will occasionally travel, it should be reliable and stable. These requirements rule out, for example, opto-acoustical spctrometers which might otherwise fulfil the variable filter bank needs. All-digital technology seems to hold the most promise. (The Japanese astronomers have recently shown their plans for a 300 MHz, 1024-point FFT. This should serve as a demonstration of at least the possibilities within the state of the art.)

c) One can easily break the system down into modules with limited interconnections, i.e.

1. filter bank and detectors
2. dedisperser and signal averager
3. timing control
4. experiment control
5. data recording

Items 2,3,4 could possibly be implemented using identical microprocessors with a small amount of external logic circuity. The filter bank has been discussed above, and the data recording should be "conventional 9 Tr 1600 bpi tape. The greatest advantage in the microprocessor approach is versatility with reliability second (spare parts count is minimal, facilitating field repair by replacement). I haven't included a rubidium frequency standard and Loran receiver because I assumed they would be available from the observing station. These two items would increase the cost substantially.

TH/czt

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