

# SIGPROC–v3.7 : (Pulsar) Signal Processing Programs

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**Summary:** The SIGPROC package is a collection of programs written to convert and process fast-sampled pulsar data into a compact and easy-to-use format suitable for off-line analyses for searching, timing and polarimetry applications. This document describes how to install and run the various programs. Several example applications are presented using real and simulated data sets.

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# 1 About SIGPROC

SIGPROC is a package designed to standardize the initial analysis of the many types of fast-sampled pulsar data. Currently recognized machines are the Wide Band Arecibo Pulsar Processor (WAPP), the Penn State Pulsar Machine (PSPM), the Arecibo Observatory Fourier Transform Machine (AOFTM), the Berkeley Pulsar Processors (BPP), the Parkes/Jodrell 1-bit filterbanks (SCAMP) and the filterbank at the Ooty radio telescope (OOTY). The package should help users look at their data quickly, without the need to write (yet) another routine to read data or worry about big/little endian compatibility (byte swapping is handled automatically). The current suite of programs is:

**filterbank** - convert raw pulsar-machine data to filterbank format: a stream of n-bit numbers corresponding to multiple polarization and/or frequency channels.

**splice** - join together multiple filterbank files which have the same time stamp.

**fake** - produce fake filterbank format data containing periodic signals immersed in Gaussian noise for testing and calibration of downstream programs.

**decimate** - add together frequency channels and/or time samples of incoming filterbank data to reduce the time and/or frequency resolution (useful for quick-look purposes).

**dedisperse** - correct incoming filterbank data for interstellar dispersion, writing the output time series as one or more dedispersed sub-bands.

**fold** - fold incoming filterbank or time series data modulo a pulse period. Pulses are output in ASCII EPN (§C) or PSRFITS format. An Expect script to generate polynomial coefficients is also available.

**profile** - displays profiles from **fold** in ASCII or pseudo grey-scale plots to the standard output.

**pgplotter** - displays profiles from **fold** and other SIGPROC output to a PGPLOT window.

**bandpass** - write out the mean bandpass to an ASCII file.

**header** - read raw data files, filterbank or time series data and display header info as plain ASCII.

**reader** - read the filterbank or time series data and display in human-readable form.

**quicklook** - csh script to perform a quick analysis of total-power filterbank data on a known pulsar.

**monitor** - wish script to monitor programs running in a given directory using a Tk pop-up widget.

All of the programs within SIGPROC are written in C and can be run from the UNIX command-line. Use is made of standard input and output streams so that piping between programs is possible to “glue” together various tasks. As an example, the following pipeline:

```
% filterbank B0823+26.pspm | dedisperse -d 19 -s 4 | fold -p polyco.dat > B0823+26.prf
```

will read in and dedisperse raw PSPM data into four subbands which are then folded modulo the pulse period based on a set of polynomial coefficients generated by TEMPO stored in the file `polyco.dat`. The folded profiles for each band are written in ASCII format to the file `B0823+26.prf`.

A detailed description of these programs and scripts is given in the remainder of this document which is structured as follows: in §2 we describe how to install SIGPROC; §3 describes the filterbank data and header format used by all the programs; producing real and fake filterbank data is described in §4 and §5 respectively; programs to look at the headers and raw data are discussed in §6 and §7; data reduction tasks (decimation and dedispersion) are described in §8; folding filterbank data to produce pulse profiles is described in 9; a script do quick data analyses is presented in §10 respectively; version history and plans for future work (§11). Supplementary appendices deal with monitoring the programs (§A), generating `polyco.dat` files using TEMPO (§B) and the EPN data format (§C).

## 2 Installation procedure

SIGPROC has so far been successfully installed for use on Solaris, Linux, HP-UX and Macs. ANSII C was (hopefully!) adhered to fairly closely during writing of the programs so that installation on other operating systems should also be possible. Installation proceeds as follows:

**0:** Download the package from <http://www.jb.man.ac.uk/~drl/sigproc/sigproc.tar.gz>

**1:** Unpack the gzip-compressed tar file and extract its contents:

```
gunzip -c sigproc-3.7.tar.gz | tar xvf -
```

**2:** The contents of the tar file will be distributed in the directory `sigproc-3.7/`. Go into this directory and run the configuration script by typing:

```
cd sigproc-3.7
./configure
```

When prompted, supply the name of a directory in which you would like the SIGPROC executables to be placed. If compiling on more than one system, log into the the other system and run the same script on this computer. Note that only one copy of the source code is required if you are compiling under multiple platforms.

**3:** For each operating system you are using, type:

```
make
```

in the `sigproc-3.7` directory and let the compiler go to work.

Four other software packages are desirable, but not absolutely necessary. To output profiles in PSRFITS format, you will need CFITSIO ([heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html](http://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html)) and uncomment and edit the appropriate path to the LFITS variable in your `makfile.osname` file. To take advantage of the FFTW subroutines, you will need to install version 3 of this package (available from [fftw.org](http://fftw.org)) and then uncomment and edit the LFFTW variable in `makfile.osname`. To create files containing polynomial coefficients for high-precision folding, install the TEMPO software package which is freely available from the Princeton pulsar website ([pulsar.princeton.edu](http://pulsar.princeton.edu)). To monitor the programs using a Tk pop-up widget make sure that the `wish` shell is in your path (we recommend use of Tcl/Tk version 8.0 or higher). This is freely available from [scriptics.com](http://scriptics.com). For making diagnostic plots you will need to compile the `quickplot` Fortran program which requires the PGPLOT graphics package available from [astro.caltech.edu/~tjp/pgplot](http://astro.caltech.edu/~tjp/pgplot). Edit the `makefile` to give the appropriate path to PGPLOT on your system before typing `make quickplot`.

### 3 Header information and data format

Before describing the programs in detail, some description of the header and data formats used within SIGPROC is appropriate for those wishing to read the data into other programs. The `filterbank` program (see §4) reads in the raw data files produced by the machine, dealing with the header information contained in the files and the (usually non-trivial) channel ordering of the samples. `filterbank` outputs the data in the following way:

```
HEADER_START stream_of_header_parameters HEADER_END stream_of_data_values
```

The `HEADER_START` and `HEADER_END` character strings signal the start and finish of a stream of header parameters that describe the data. The default is to include these at the beginning of the data file. We recognize that some users will prefer not to have to deal with the header in this way. For these users, `filterbank` has a `-headerfile` command-line option to pipe the header into a separate ASCII file (this is described along with the other command-line options later on).

The header variables have been restricted to key parameters for ease of use. Currently these are:

- `telescope_id` (int): 0=fake data; 1=Arecibo; 2=Ooty... others to be added
- `machine_id` (int): 0=FAKE; 1=PSPM; 2=WAPP; 3=OOTY... others to be added
- `data_type` (int): 1=filterbank; 2=time series... others to be added
- `rawdatafile` (char []): the name of the original data file
- `source_name` (char []): the name of the source being observed by the telescope
- `barycentric` (int): equals 1 if data are barycentric or 0 otherwise
- `pulsarcentric` (int): equals 1 if data are pulsarcentric or 0 otherwise
- `az_start` (double): telescope azimuth at start of scan (degrees)
- `za_start` (double): telescope zenith angle at start of scan (degrees)
- `src_raj` (double): right ascension (J2000) of source (hhmmss.s)
- `src_dej` (double): declination (J2000) of source (ddmmss.s)
- `tstart` (double): time stamp (MJD) of first sample
- `tsamp` (double): time interval between samples (s)
- `nbits` (int): number of bits per time sample
- `nsamples` (int): number of time samples in the data file (rarely used any more)
- `fch1` (double): centre frequency (MHz) of first filterbank channel
- `foff` (double): filterbank channel bandwidth (MHz)
- `FREQUENCY_START` (character): start of frequency table (see below for explanation)
- `fchannel` (double): frequency channel value (MHz)

- **FREQUENCY\_END** (character): end of frequency table (see below for explanation)
- **nchans** (int): number of filterbank channels
- **nifs** (int): number of separate IF channels
- **refdm** (double): reference dispersion measure ( $\text{cm}^{-3} \text{ pc}$ )
- **period** (double): folding period (s)

A given header stream will contain most, but not necessarily all, of the above variables.

In the general case, the data consists of **nifs** polarization channels of **nchans** frequency channels of **nbit** numbers. The data stream following the header can then be thought of as 1-D array of  $N$  elements with indices running between 0 and  $N - 1$ , where

$$N = \mathbf{nifs} \times \mathbf{nchans} \times \mathbf{nsamples},$$

and **nsamples** is the observation time divided by **tsamp**. Thus, for a given IF channel  $i = (0, 1, 2, 3)$  and frequency channel  $c = (0 \dots \mathbf{nchans} - 1)$ , the array index for sample  $s = (0, 1, 2 \dots)$  is

$$s \times \mathbf{nifs} \times \mathbf{nchans} + i \times \mathbf{nchans} + c.$$

The sky frequency of channel  $c$  is then simply

$$\mathbf{fch1} + c \times \mathbf{foff}.$$

We follow the Parkes/Jodrell Bank convention of assigning a negative frequency to **foff** in the headers to signify that the highest frequency channel is **fch1**. Currently, all filterbank data is written out in this order and the **dedisperse** program relies on this fact in its dedispersing algorithm (see §8).

Although this system works well for most applications, from version 2.3 there is a more flexible way of describing the frequency channels. Instead of writing **fch1** and **foff**, it is now possible to write the individual frequency channel frequencies directly into the header in the following way:

```
FREQUENCY_START f1 f2 f3 f4 FREQUENCY_END
```

where **f1**, **f2**.... are the frequency channel values in MHz. These may be in any order, *provided that* the **f1** is the highest frequency (again this is stipulated because of **dedisperse**'s algorithm). This frequency table approach is used by the **splice** program to deal with non-contiguous data described next.

## 4 Data conversion using filterbank and splice

The interface between the raw data and the rest of the SIGPROC package is the `filterbank` program. As with all the programs on-line help is obtained by typing the name of the program followed by `help`:

```
% filterbank help
```

```
filterbank - convert raw pulsar-machine data to filterbank format
```

```
usage: filterbank <rawdatafile1> .... <rawdatafileN> -{options}
```

```
rawdatafile - raw data file (recognized machines: WAPP, PSPM, OOTY)
```

```
options:
```

```
-o filename - output file containing filterbank data (def=stdout)
```

```
-s skiptime - skip the first skiptime (s) of data (def=0.0)
```

```
-r readtime - read readtime (s) of data (def=all)
```

```
-i IFstream - write IFstream (IFstream=1,2,3,4)
```

```
-n nbits - write n-bit numbers (def=input format)
```

```
-c minvalue - clip DM=0 samples > mean+minvalue*sigma (def=noclip)
```

```
-swapout - perform byte swapping on output data (def=native)
```

```
-floats - write floating-point numbers (equal to -n 32)
```

```
-sumifs - sum IFs 1+2 to form total-power data
```

```
-headerfile - write header parameters to an ASCII file (head)
```

```
-headeronly - write ONLY binary header parameters
```

```
options for correlator (currently WAPP) data:
```

```
-hamming - apply Hamming window before FFT (def=nowindow)
```

```
-hanning - apply Hanning window before FFT (def=nowindow)
```

```
-novanvleck - don't do van Vleck correction before FFT (def=doit)
```

```
-invert - invert the band after FFT (def=noinversion)
```

```
-zerolag - write just the zero-lag value for each IF
```

```
-rawcfs - write raw correlation functions (novanvleck)
```

```
-corcfs - write corrected correlation functions (vanvleck)
```

Given just the name of the raw data file as the argument, `filterbank` will determine the origin of the data and, if it can read the file, unpack the samples before writing the header parameters and data as described in §3. The header and data go to the standard output by default but can be redirected to a file using the `-o filename` option, or in the standard way:

```
% filterbank rawdatafile > filterbankfile
```

With no further options, `filterbank` will read and unscramble all the data in the original file. A specific portion of the data can be specified using the `-r` and `-s` command-line options. For example:

```
% filterbank rawdatafile -r 10.0 > filterbankfile
```

reads just the first 10 seconds of data. These options are useful for a quick look at the data.

## Selecting and/or summing IF streams

By default, all the IF streams (if there are more than one) in the file are read and processed. To select one or more of these, ignoring the others, use the `-i` option:

```
% filterbank rawdatafile -i 1 -i 2 > filterbankfile
```

will process just the first two IF channels of the raw data file. `filterbank` provides the option to sum *just the first two* IF channels (to form total-power data) via the `-sumifs` option:

```
% filterbank rawdatafile -sumifs > filterbankfile
```

This is a useful, for example, to get just total power from polarimetry data for off-line searching.

## ASCII headers

As mentioned in §3, `filterbank` will broadcast a header stream before writing the data. This header is used by other downstream SIGPROC programs to process the data. To make use of it in analysis with other programs, call the function `read_header` and link with the other routines contained in the file `read_header.c`. For those who prefer not to be bothered with these routines, use the `-headerfile` option when calling `filterbank`. For example:

```
% filterbank B0823+26.pspm -headerfile > B0823+26.fil
```

will create the file `B0823+26.fil` containing just the filterbank channels along with the relevant header parameters in an ASCII file `head`. In this case:

```
Original PSPM file: B0823+26.pspm
Sample time (us): 80.000002
Time stamp (MJD): 51740.882986111108
Number of samples/record: 512
Center freq (MHz): 430.000000
Channel band (kHz): 62.000000
Number of channels/record: 128
```

the user is then left to parse this file as he/she feels fit. An alternative means of getting header information would be to use the `header` program in the following example:

```
% filterbank B0823+26.pspm | header -tstart
```

which will return `51740.882986111108` to the standard output. Any of the header variable names listed in §3 can be given as a command-line option to the `header` program. Further details are given in §7.

## Changing the number of bits per sample

By default, `filterbank` will write the outgoing data with the same number of bits per sample as the native format (e.g. 4 bits per sample for PSPM). For machines which write out larger numbers of bits (e.g. the WAPP) it is useful to be able to pack the data more efficiently using the `-n` option. For example, the sequence:

```
% filterbank wappdatafile -n 8 > filterbankfile
```

will process a WAPP data file (usually 16 bits per sample) and pack the outgoing samples as single-byte integers. For search purposes, where only marginal loss in sensitivity is seen and data products are reduced significantly, use of this option is highly recommended. For WAPP data, the loss in sensitivity from 16 to 8 bits is negligible, packing down to 4 bits results in losses  $\sim 5\%$ .

## Floating-point output

Currently, no descaling parameters are given in the header when packing down data. This means that for applications where the absolute value of the data is necessary (e.g. polarization work) it is necessary to store the data as floating-point numbers. The option `-floats` is provided for this purpose (although this is really just an alias for `-n 32`).

## Byte swapping issues

Multi-byte precision data are written in different orders depending on your machine's operating system. The original WAPP data, for example, was written on a PC (little endian format). The `filterbank` program knows about this and *automatically* does any byte swapping required while reading. When it comes to writing the data out, however, the program will always write data in the native order of the processing machine. To swap the bytes around before writing for use on other machines, use the `-swapout` option.

## Correlator-specific options

Presently, the WAPP is the only correlator machine recognized by SIGPROC which records auto- and, in polarization mode, cross-correlation functions for given numbers of lags. The autocorrelation function  $R(\tau)$ , as a function of lag  $\tau$  is defined by:

$$R(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T V(t)V^*(t + \tau)dt,$$

where  $V(t)$  is the complex signal voltage as a function of time  $t$ . From the Weiner-Khinchin theorem, the power spectral density function  $P(f)$  is the Fourier transform of  $R(\tau)$ :

$$P(f) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} R(\tau)e^{-2\pi if\tau} d\tau.$$

In practice to obtain the equivalent of frequency channels of a filterbank, the lags from each IF channel need to be corrected for finite-level quantization — the so-called van Vleck correction (see for example Hagen & Farley 1973, *Radio Science*, **8**, 775–784) before the Fast Fourier Transform (FFT) to obtain the

spectra. For reference, the three-level van Vleck formula used within `filterbank` to correct measured auto-correlation values ( $r$ ) to unbiased ones ( $\rho$ ) can be written as

$$r = \frac{1}{\pi} \int_0^\rho \left( \exp\left(\frac{-(\alpha/\sigma)^2}{1+x}\right) + \exp\left(\frac{-(\alpha/\sigma)^2}{1-x}\right) \right) \frac{dx}{\sqrt{(1-x^2)}},$$

where  $\alpha$  is the digitizer threshold and  $\sigma$  the rms voltage. This correction is what `filterbank` does by default before FFTing the correlation functions to produce spectra.

A number of options exist to modify the default processing. To reduce FFT leakage, either a Hanning or Hamming window can be applied to the correlation functions via the `-hamming` and `-hanning` switches. Select `-rawcfs` to output the raw correlation functions quantized to the precision specified by `nbits`. To get at the raw correlation functions, include the floating-point option:

```
% filterbank wappdatafile -rawcfs -floats > rawcfile
```

The `-corcfs` option will write out the correlation functions *applying* the van Vleck correction.

## Obscure correlator options

For completeness, we mention two other correlator specific options: `-novanvleck` and `-zerolag`. The `-novanvleck` option will not apply the quantization correction before the FFT. This feature is really for instructional purposes since, to FFT the data to get frequency channels, signal-to-noise will be lost if the van Vleck correction is not applied. Another option that is primarily used for testing is `-zerolag`. If selected, this outputs just the first correlation function for each IF (the so-called zero lag) as a floating-point number. Inserting  $\tau = 0$  into the above expression for  $P(f)$ , we note that the zero lag is just the sum over all the frequency channels — equivalent to a time series with no dispersion measure correction.

For WAPP data, one final option is `-invert` which inverts the band after the FFT to change the frequency ordering. This should normally be dealt with in the WAPP header but is included here to process data where the header information about frequency ordering is incorrect.

## Splicing files

Most data acquisition systems store the collected data as single files per observation. For the new multiple WAPP system at Arecibo, where each machine runs independently to sample a different part of the band, a number of data files result for each frequency band. In order to analyse these datasets together, the `splice` program will join multiple filterbank files, provided that they all have on the same time stamp. The syntax is very simple:

```
splice file1.fil file2.fil file3.fil > splice.fil
```

where it is assumed that the input files `file1.fil`, `file2.fil` and `file3.fil` have already been converted into filterbank format as described above. The resulting file, `splice.fil` in this example, is also in filterbank format and can be read by subsequent programs. Although the files need not span a contiguous radio frequency band, `splice` will complain if the input files do not all have the same time stamp, or if they are not ordered in descending frequency order. The latter check is done so that the data conform to the order expected by the dedispersion algorithm (§8).

## 5 Creating mock data sets using fake

The fake program was written to create test data sets containing pulses hidden in Gaussian noise:

```
% fake help

fake - produce fake filterbank format data for testing downstream code

usage: fake -{options}

options:

-period    p - period of fake pulsar in ms (def=random)
-width     w - pulse width in percent (def=4)
-snrpeak   s - signal-to-noise ratio of single pulse (def=1.0)
-dm        d - dispersion measure of fake pulsar (def=random)
-nbits     b - number of bits per sample (def=4)
-nchans    n - number of filterbank channels (def=128)
-tsamp     t - sampling time in us (def=80)
-tobs      t - observation time in s (def=10)
-tstart    t - MJD time stamp of first sample (def=50000.0)
-nifs      n - number of IFs (def=1)
-fch1     f - frequency of channel 1 in MHz (def=433.968)
-foff     f - channel bandwidth in MHz (def=0.062)
-seed     s - seed for Numerical Recipes ran1 (def=seconds since midnight)
-nosmear   - do not add in dispersion/sampling smearing (def=add)
-swapout   - perform byte swapping on output data (def=none)
-evenodd   - even channels=1 odd channels=0 (def=noise+signal)
-headerless - do not write header info at start of file (def=header)

binary options:

-binary    - create binary system
-bper      - orbital period in hours (def=10.0)
-becc      - eccentricity (def=0.0, circular)
-binc      - inclination in degrees (def=90.0)
-bomega    - longitude of periastron in degrees (def= 0.0)
-bphase    - starting orbital phase (number between 0 and 1, def=0.0)
-bpmass    - pulsar mass in solar units (def=1.4)
-bcmass    - companion mass in solar units (def=5.0)
```

Default parameters are a filterbank similar to the PSPM. As an example, consider some fake PSPM data for a 42-s observation of a pulsar with a period of  $\sim \pi$  ms, a duty cycle of 10% and a DM of 30:

```
% fake -period 3.1415927 -width 10 -dm 30 -tobs 42 -nbits 4 > pspm.fil
```

Each channel of fake data has a zero mean and unit rms. The signal-to-noise ratio refers to the height of a single pulse in each channel. In the above example, the default signal-to-noise was used. Weaker

pulsars can be easily made to challenge limits of off-line search algorithms etc. By default, the fake pulse width  $w$  is smeared by an amount dependent on the filterbank setup using the quadrature sum:

$$\sqrt{w^2 + \text{tsamp}^2 + t_{\text{DM}}^2},$$

where  $t_{\text{DM}}$  is the dispersion smearing of the pulse over a single filterbank channel given by:

$$t_{\text{DM}} = 8.3 \times 10^6 \text{ms DM } \Delta\nu/\nu^3,$$

assuming the centre frequency  $\nu$  is much larger than the channel bandwidth  $\Delta\nu$  (both measured in MHz). Smearing can be disabled using the `-nosmear` option. Bit-format and byte-swapping options are identical to those described for the `filterbank` program in the previous section. The starting seed of the random number generator defaults to a number obtained by starting with the number of seconds since midnight and calling the random number generator that many times. This can be overridden by specifying a seed using the `-seed` option.

## 6 Looking at headers using header

The `header` program allows humans easy access to the raw data file, or the binary header string in the filterbank data format. As an example of the full output, here is the header of our PSPM test data:

```
% header B0823+26.fil

Data file           : B0823+26.fil
Header size (bytes) : 191
Data size (bytes)   : 2359296
Data type           : filterbank
Telescope           : Arecibo
Datataking Machine  : PSPM
Frequency of channel 1 (MHz) : 433.968000
Channel bandwidth   (MHz) : -0.062000
Number of channels  : 128
Time stamp of first sample (MJD) : 51740.882986111108
Gregorian date (YYYY/MM/DD) : 2000/07/15
Sample time (us)    : 80.00000
Number of samples   : 36864
Observation length (seconds) : 2.949120
Number of bits per sample : 4
Number of IFs       : 1
```

alternatively, `header` can be used with one or more of the above command-line options to return just the value of the parameter of interest (this is particularly useful when getting values from within scripts without having to parse the standard output). Currently available options are:

```
-telescope - return telescope name
-machine   - return datataking machine name
-fch1     - return frequency of channel 1 in MHz
-off      - return channel bandwidth in MHz
```

-nchans - return number of channels  
-tstart - return time stamp of first sample (MJD)  
-tsamp - return sample time (us)  
-nbits - return number of bits per sample  
-nifs - return number of IF channels  
-headersize - return header size in bytes  
-datasize - return data size in bytes if known  
-nsamples - return number of samples if known  
-tobs - return length of observation if known (s)

It should be noted that **headersize**, **datasize**, **nsamples** and **tobs** are not header variables *per se*; they are derived by the program, based upon the file size and the real header variables.

## 7 Looking at data using bandpass, reader and pgplotter

The `bandpass` program is a simple utility to read incoming data and output a time-averaged bandpass:

```
% bandpass help
```

```
bandpass - outputs the pass band from a filterbank file
```

```
usage: bandpass {filename} --{options}
```

```
options:
```

```
    filename - filterbank data file (def=stdin)
```

```
-d numdumps - number of dumps to average over (def=all)
```

```
-t dumptime - number of seconds to average over (def=all)
```

In its simplest form, `bandpass` averages over the entire data file. The data for Fig. 1 were obtained using:

```
% filterbank B0823+26.pspm | bandpass > bandpass.ascii
```

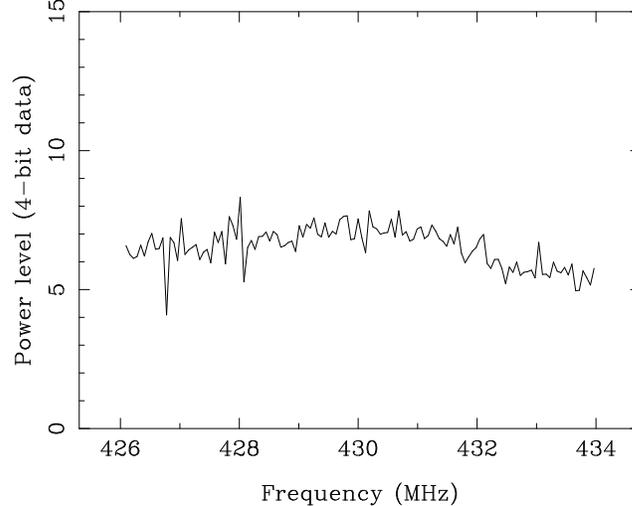


Figure 1: *Output data from `bandpass` for the test observation of PSR B0823+26 using the PSPM.*

The ASCII data is written in a simple format with one line for each frequency channel: `frequency if1 if2...` for up to `nifs` separate IFs. The `-d` and `-t` options allow averaging and output of the bandpass for a given number of dumps, or seconds. Each dump is encapsulated within `#START` and `#STOP` separators:

```
#START
freq(1)      if(1) .... if(nifs)
...         .     ..   ...
freq(nchans) if(1) .... if(nifs)
#STOP
```

where the `freq(1)` is the sky frequency of channel 1 in MHz and so on for all `nchans` channels. Although plotting is left up to the users discretion in general, SIGPROC provides a little PGPLOT utility `pgplotter` which plots data streams passed in this format. For example, try

```
% filterbank B0823+26.pspm | bandpass | pgplotter
```

Another useful program is `reader` which will print out filterbank-format data as an ASCII stream to the standard output.

```
% reader help
```

```
reader - look at filterbank data in ASCII format
```

```
usage: reader {filename} --{options}
```

```
filename is the filterbank data file (def=stdin)
```

```
options:
```

```
-c      c - output only frequency channel c (1..nchans) (def=all)
```

```
-i      i - output only IF channel i (1..nifs) (def=all)
```

```
-numerate - precede each dump with sample number (def=time)
```

```
-noindex - do not precede each dump with number/time
```

```
-stream - produce a stream of numbers with START/STOP boundaries
```

In the general case, a filterbank file with **nchans** channels and **nifs** IFs, output is of the form:

```
% reader filterbankfile
```

```
time(1) if(1)c(1) if(1)c(2) .... if(1)c(nchans) ..... if(nifs)c(nchans)
```

```
time(2) if(1)c(1) if(1)c(2) .... if(1)c(nchans) ..... if(nifs)c(nchans)
```

```
time(3) if(1)c(1) if(1)c(2) .... if(1)c(nchans) ..... if(nifs)c(nchans)
```

the default case is to print out all IF and frequency channels. The output can be tailored by the `-i` and `-c` options to get just specific channels of interest. For example:

```
% filterbank B0823+26.pspm | reader -c 1 -c 2 -c 3 -c 4 | head
```

```
0.000000 5.000000 5.000000 6.000000 5.000000
0.000080 7.000000 5.000000 7.000000 6.000000
0.000160 7.000000 5.000000 6.000000 6.000000
0.000240 5.000000 5.000000 5.000000 7.000000
0.000320 5.000000 4.000000 5.000000 6.000000
0.000400 5.000000 4.000000 5.000000 6.000000
0.000480 5.000000 5.000000 5.000000 6.000000
0.000560 5.000000 5.000000 6.000000 5.000000
0.000640 6.000000 4.000000 5.000000 7.000000
0.000720 6.000000 6.000000 6.000000 5.000000
```

shows just the first four frequency channels of the PSPM data as a function of time. The `-numerate` switch will change this time stamp to an integer counter. Time or integer counters can be turned off completely via the `-noindex` option. The `-stream` option will, as in the case of the continuous `bandpass` output above, output a stream of numbers encapsulated by `#START` and `#STOP` separators. As before, this format may be passed to `pgplotter` for plotting.

## 8 Data reduction using decimate and dedisperse

Adding of adjacent time and/or frequency channels together to reduce the original resolution and size of the original data file is possible using the `decimate` program:

```
% decimate help
```

```
decimate - reduce time and/or frequency resolution of filterbank data
```

```
usage: decimate {filename} -{options}
```

```
options:
```

```
    filename - filterbank data file (def=stdin)
-c numchans - number of channels to add (def=all)
-t numsamps - number of time samples to add (def=none)
-T numsamps - (alternative to -t) specify number of output time samples
-n numbits  - specify output number of bits (def=input)
-headerless - do not broadcast resulting header (def=broadcast)
```

Output data from `decimate` is in standard filterbank format so that it can be easily read in by other SIGPROC programs. To get ASCII data, use the `reader` program (see §7). The following example adds all the frequency channels together, and every 32 time samples, to create the time series shown in Fig. 2.

```
% filterbank B0823+26.pspm | decimate -t 32 -n 32 | reader > timeseries.ascii
```

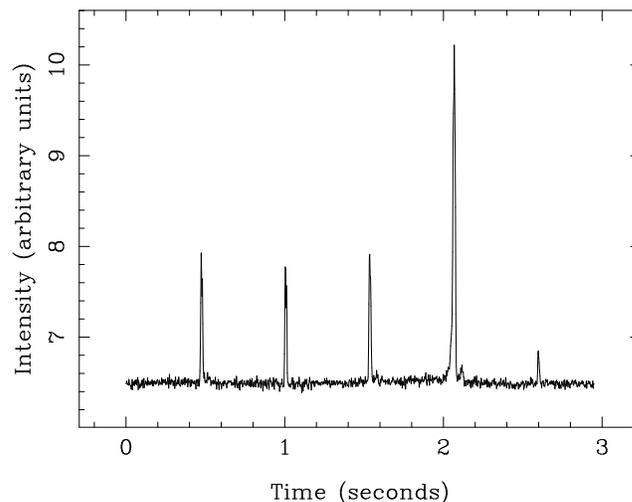


Figure 2: *Output time series from decimate for the test observation of PSR B0823+26 using the PSPM.*

Note that we have used the `-n` option to force the output number of bits per sample to be 32. By default `decimate` outputs data with the same number of bits as the incoming filterbank data. In this case, where there are strong single pulses, adding all the channels together would result in a signal-to-noise loss when trying to write the output time series with 4-bit precision.

While `decimate` is a good means for getting time series of weakly dispersed pulsars, it does not take into account the effects of dispersion by the interstellar medium where pulses emitted at higher radio

frequencies travel faster through the interstellar medium, arriving earlier than those emitted at lower frequencies. The time delay  $\Delta t$  between a high frequency  $\nu_{\text{hi}}$  relative to a lower one  $\nu_{\text{lo}}$  is

$$\Delta t = 4.15 \times 10^6 \text{ ms} \times (\nu_{\text{lo}}^{-2} - \nu_{\text{hi}}^{-2}) \times \text{DM},$$

where the frequencies are in MHz and the dispersion measure  $\text{DM} = \int_0^d n_e dl$  ( $\text{cm}^{-3} \text{ pc}$ ) is the integrated column density of free electrons along the line of sight. Here,  $d$  is the distance to the pulsar (pc) and  $n_e$  is the free electron density ( $\text{cm}^{-3}$ ). For distant high-DM pulsars, especially those with short periods, dispersion needs to be accounted for to retain full time resolution. The `dedisperse` program does this by adding frequency channels with the appropriate time delays given a DM value:

```
% dedisperse help
```

```
dedisperse - form time series from filterbank data or profile from folded data
```

```
usage: dedisperse {filename} -{options}
```

```
options:
```

```

    filename - full name of the raw data file to be read (def=stdin)
-d dm2ddisp - set DM value to dedisperse at (def=0.0)
-b numbands - set output number of sub-bands (def=1)
-B num_bits - set output number of bits (def=32)
-o filename - output file name (def=stdout)
-c minvalue - clip samples > minvalue*rms (def=noclip)
-f reffreq   - dedisperse relative to reffreq MHz (def=topofsubband)
-F newfreq   - correct header value of centre frequency to newfreq MHz (def=header value)
-n num_bins  - set number of bins if input is profile (def=input)
-i filename  - read list of channels to ignore from a file (def=none)
-p np1 np2   - add profile numbers np1 thru np2 if multiple WAPP dumps (def=all)
-j Jyfactor  - multiply dedispersed data by Jyfactor to convert to Jy
-J Jyf1 Jyf2 - multiply dedispersed data by Jyf1 and Jyf2 to convert to Jy (use only for two-polar)
-wappinvert  - invert WAPP channel order (when using LSB data) (def=USB)
-wappoffset  - assume wapp fsky between two middle channels (for pre-52900 data ONLY)
-swapout     - perform byte swapping on output data (def=native)
-nobaseline  - don't subtract baseline from the data (def=subtract)
-sumifs      - sum 2 IFs when creating the final profile (def=don't)
-headerless  - write out data without any header info
-epn        - write profiles in EPN format (def=ASCII)
-asciipol   - write profiles in ASCII format for polarization package
-stream     - write profiles as ASCII streams with START/STOP boundaries

```

The dedispersion algorithm reads in a block of data and gets the appropriately delayed sample by looking forward in the array. This therefore requires that the frequency channels are passed down in descending frequency order and `dedisperse` will complain if this condition is not met!

In the example data for the 1.5578-ms pulsar B1937+21 shown in Fig. 3, the left panel was produced via:

```
% filterbank B1937+21.539 | dedisperse -d 71.04 | reader > timeseries.ascii
```

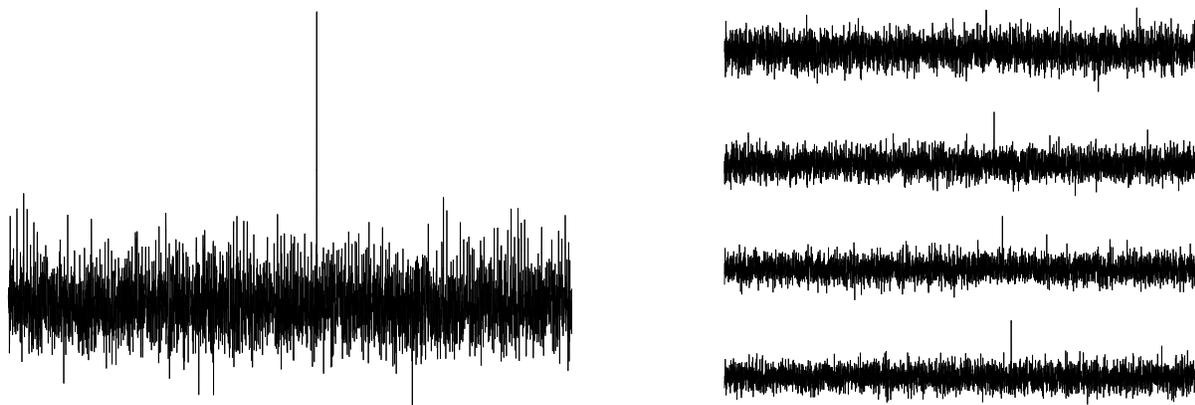


Figure 3: A WAPP observation of the millisecond pulsar *B1937+21* showing a single “giant” pulse. Left: the dedispersed time series over the entire 100-MHz band. Right: the pulse seen in four dedispersed 25-MHz subbands. The length of the time series segment is  $\sim 0.26$  s. The sampling time is  $63.32 \mu\text{s}$ .

This single pulse is shown in four dedispersed frequency subbands in the right-hand panel of Fig. 3. These were obtained by adding a `-b 4` option into the dedisperse command-line in the above pipeline. In this case, dedispersion is carried out relative to the frequency of the first summed channel in each of the bands.

## 9 Getting pulse profiles using `fold` and `profile`

Obtaining integrated pulse profiles, and single pulses, from your data files is possible using the `fold` program which allows you to fold filterbank data modulo a pulse period to produce pulse profiles. In addition, there is now a basic ASCII viewing program `profile` which displays profiles from `fold` to the standard output. `fold` accepts any number of IF and/or frequency channels, producing `nifs`  $\times$  `nchans` sets of profiles. The folding algorithm used is a simple one: for each time sample, compute the phase based on a, possibly time-dependent, value of the pulse period and add that sample to the nearest phase bin of the appropriate profile. The synopsis of `fold` is summarized below:

```
% fold help

fold - fold filterbank channels/time series data

usage: fold {filename} -{options}

options:

    filename - full name of the raw data file to be read (def=stdin)
-o out_file - output file for pulse profile data (def=stdout)
-p fold_prd - period to fold (ms) or polyco file (def=polyco.dat)
-a accelern - fold using constant acceleration (def=0 m/s/s)
-f p_factor - multiply the period by p_factor (def=1.0)
-m m_factor - output multiple profiles (STREAM only; def=1)
-n num_bins - number of bins in folded profile(s) (def>window/tsamp)
-d time/num - dump profiles every time s or num pulses (def=nodumps)
-t samptime - hard-wire the sampling time (us) (def=header)
-l phaseval - phase value (turns) of left edge of pulse (def=0.0)
```

```

-r phaseval - phase value (turns) of right edge of pulse (def=1.0)
-j Jyfactor - multiply all profiles by Jyfactor to convert to Jy
-b baseline - subtract baseline from all profiles (def=autobase)
-dt timeoff - add a time offset in seconds to tstart (def=0.0)
-sk skiptim - skip the first skiptim s before folding (def=0.0)
-re readtim - read and fold only readtim s of data (def=ALL)
-ascii      - write profiles as ASCII numbers (this is the default)
-epn        - write profiles in EPN format (def=ASCII)
-acc         - write out accumulated profiles (def=subints)
-bin         - write profiles in SIGPROC binary format (def=ASCII)
-sub subint - shorthand for -nobaseline -stream -d subint.0
-psrfits    - write profiles in PSRFITS format (def=ASCII)
-totalpower - sum polarizations 1+2 before writing (def=nosumming)
-asciipol   - write profiles in JMCs ASCII format for polarization
-stream     - write profiles as ASCII streams with START/STOP bounds
-nobaseline - don't subtract baseline from profiles (def=subtract)

```

## Folding data at a fixed period

Consider folding a series containing our fake  $\sim \pi$ -ms pulsar:

```
% fake -period 3.14159 -nchans 1 -nbits 32 | fold -p 3.14159 > profile.ascii
```

Note that the default profile output is in ASCII format. This may be substituted by EPN or PSRFITS using the `-epn` or `-psrfits` options on the command line. The format of this output is a line for each bin:

```
bin_number if(1)c(1) if(1)c(2) .... if(1)c(nchans) ..... if(nifs)c(nchans)
```

In order to avoid overflows during folding, `fold` will by default subtract an offset from each folded sample calculated as the median value of a given data block. To turn off this feature, use the `-nobaseline` option. The default number of bins is given by the next largest integer value to the ratio of the folding period divided by the sampling time. This is, however, completely flexible. A lower number of bins would be desirable, for example, when folding data for a faint pulsar or candidate. `fold` will permit oversampling which can pay dividends for high signal-to-noise observations of short-period pulsars.

A useful feature of `fold` for weak pulsars, and those for which the pulse happens to lie on the edge of the window is the `-m` option which allows the display of multiple pulses. For example, try:

```
% fake -period 3.14159 -nchans 1 -nbits 32 | fold -p 3.14159 -m 2 | pgplotter
```

## Folding data using polynomial coefficients

For practical applications, the apparent pulse period is time-variable during the integration due to Doppler shifts resulting from the Earth's motion and (for binary pulsars) from Doppler shifts induced by orbiting companions. To account for these the folding period needs to be updated during the integration. The TEMPO timing package can be used to create a set of polynomial coefficients to predict the change in

period with time and `fold` can read these “polyco” files from TEMPO for these purposes. A script to run TEMPO to produce these files is described in §B. To tell `fold` to read a polyco file, supply the name of the filename with the `-p` option.

```
% filterbank B0823+26.pspm | fold -p polyco.dat -n 128 -epn > B0823+26.epn
```

will fold each channel of the sample PSPM data for PSR B0823+26 to produce 128-bin profiles written to the file `B0823+26.epn` in EPN format. If no `-p` option is given to `fold` the program will look for the file `polyco.dat` as a matter of course so that, in the above case, it was not strictly necessary to specify the name of the polyco file. This is assumed in the following pipeline where the data are first dedispersed at the reference DM value of  $19.4 \text{ cm}^{-3} \text{ pc}$  before being passed to `fold`:

```
% filterbank B0823+26.pspm | dedisperse -d 19.4 -epn | fold > B0823+26.epn
```

## Getting sub-integrations

In the above examples, `fold` produces one profile for each of `nchans`  $\times$  `nifs` incoming data streams which corresponds to folding over the entire data set. It is often desirable to look at sub-profiles dumped at regular intervals during the observation — the `-d` (dump) option allows you to do this. Specifying a floating-point number, say  $f$  seconds, in this mode will output the accumulated profile every  $f$  seconds. The following example on our fake millisecond pulsar data would dump a subintegration exactly every 15 seconds:

```
% fold fakepulsar.fil -d 15.0 -p 3.1415927 -epn > fakeprofiles.epn
```

Supplying an integer argument with the `-d` option, say  $n$ , the profiles are dumped every  $n$  pulses. So `-d 15` in the above example results in a profile being dumped every 15 periods (about 47 ms).

## Single pulses and windowing profiles

Individual pulses can be obtained by specifying `-d 1` to the `fold` command line. The following example demonstrates this for the PSR B0823+26 PSPM data:

```
% filterbank B0823+26.pspm | dedisperse -d 19.4 | fold -d 1 -epn > B0823+26.epn
```

The resulting EPN file contains a record for each single pulse. For this short data set, this amounts to just five single pulses shown in Fig. 4.

For single-pulse applications, where the off-pulse region of the profile is usually not interesting, it is desirable to be able to set a window around the pulse. The `fold` program allows setting of windows via the `-l` and/or `-r` command-line options which specify the left and right-hand phase values of the windows. Phase values should be specified in turns ranging between 0.0 and 1.0. For example, the pulses in the lower panel of Fig. 4 were obtained using `fold -l 0.825 -r 0.925` for the PSR B0823+26 dataset. As before for the full profile, unless specified otherwise, `fold` will choose the number of bins based on the size of the window divided by the sampling interval.

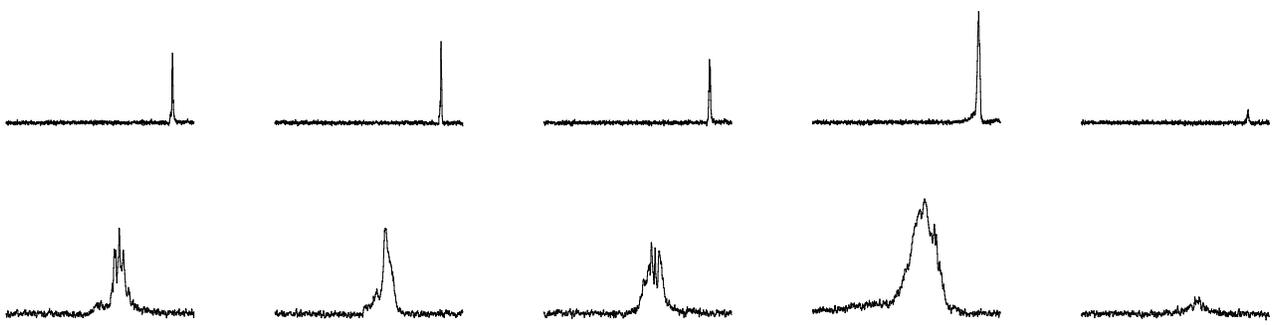


Figure 4: *Top: dedispersed single pulses for the PSPM test observation of PSR B0823+26. Bottom: the same data set after applying a phase window of 0.825 to 0.925 (see text)*

All of the above examples have used a separate plotting program to produce the profiles for the figures. Since each user tends to have his/her favourite method for producing such plots, no facility exists within SIGPROC to do this. To get a quick look at profiles, there is now a program `profile` which will display ASCII representations to the standard output. The program has two modes of operation: 2-D profile “plots” or 1-D grey-scale representations. To get a 2-D profile - the output from `fold` needs to come in the standard ASCII format. For example, let’s create and fold data from a 1-s pulsar:

```
fake -period 1000.0 -nchans 1 | fold -p 1000.0 | profile
```

The output from `profile` would then be a mock 2-D profile and will look something like this:

```

##
##
##
##
##
##
##
##
##
##
##
###
####
####
####
#
####
# # ## # # # ## ##### # ## # # # ##### ### ##
#####

```

To get a 1-D pseudo “grey-scale” plot, the profiles need to be output from `fold` using the `stream` option. This is particularly useful if you wish to display profiles as sub-integrations or folded frequency channels. For example, to display additions of every 2 pulses from our 1-s fake pulsar we would do the following:

```
fake -period 1000.0 -nchans 1 | fold -p 1000.0 -stream -d 2 -nobaseline | profile
```

to produce the following output showing subintegration index and elapsed time to the left of each profile:

```
|0001|00:00:00|           , $#,           |
|0002|00:00:02|           $#,           |
|0003|00:00:04|           , # $,        |
|0004|00:00:07|           , @ #:        |
|0005|00:00:09|           ##,           |
|0006|00:00:09|           $#,           |
```

Where the `-nobaseline` option during folding has been used to preserve the original levels which would otherwise get changed each subintegration. Note also that the last “subintegration” in this plot is in fact the integrated profile which is dumped by `fold` as a matter of course. Frequency channel plots can be produced in a similar way. For example, try creating a 100-ms pulsar with 32 channels and a DM of 500 and piping this through `fold` and `profile`.

```
fake ..... | fold -p 100.0 -stream -nobaseline | profile -frequency
```

where the `-frequency` option will be required to label the frequency channels correctly.

## 10 Putting it all together: the quicklook data reduction script

As an application of most of the programs discussed in the preceding sections, we conclude with the `quicklook` data analysis script which is designed to dedisperse and fold raw pulsar machine data taken on a known pulsar and produce a diagnostic output plot summarizing various aspects of the data:

```
% quicklook help
```

```
usage: quicklook <filename> -{options}
```

```
options:
```

```
-read time    - read and process only time (s) of data
-skip time    - skip the first time (s) of data
-addc nchans  - add nchans chans together before dedispersion (def=none)
-addt nsamps  - add nsamps samples together before dedispersion (def=none)
-nsints n     - specify number of time sub-integrations (def=8)
-nbands n     - specify number of frequency sub-bands (def=8)
-period p     - fold data at constant period (ms) (def=polyco)
-dm dmvalue   - dedisperse using dmvalue (pc cm-3) (def=polyco)
-clip value   - clip samples that deviate more than value*rms (def=noclipping)
-nbins n      - fold data using n bins (def=128)
-left phase   - specify left-hand phase window (def=0.0)
-right phase  - specify right-hand phase window (def=0.0)
-singlepulse  - set number of subints to be the number of pulses
-psr name     - fix source name for running TEMPO (def=filestem)
-mypolyco     - use an existing polyco file (def=make one)
-fakescale    - plot channels/bands using fake grey scale (def=real)
```

-clean            - remove large files before and after (def=keep them)  
-wipe            - remove large files beforehand (def=keep them)  
-ext string      - add a file extension string to output files (def=none)

As an example, the command:

```
% quicklook J1713+0747.744 -nbands 64 -nsints 32 -read 5
```

reduces the first 5 seconds of a WAPP observation of the millisecond pulsar J1713+0747 producing the plot shown in Fig. 10. N.B. Use of this script assumes that you have the `quickplot` program compiled (see §2 for further details).

QUICKLOOK: Arecibo WAPP datafile: J1713+0747.744  
 Source: 1713+07 MJD: 51853.743935185186 Date: 2000/11/05  
 Obs Freq: 1.420 GHz Bandwidth: 100.0 MHz Channels: 128  
 t(samp): 127.32 us t(bin): 35.70 us N(bins): 128 SNR: 378.7  
 Folding period: 4.5702374260 ms DM: 15.99 pc/cc

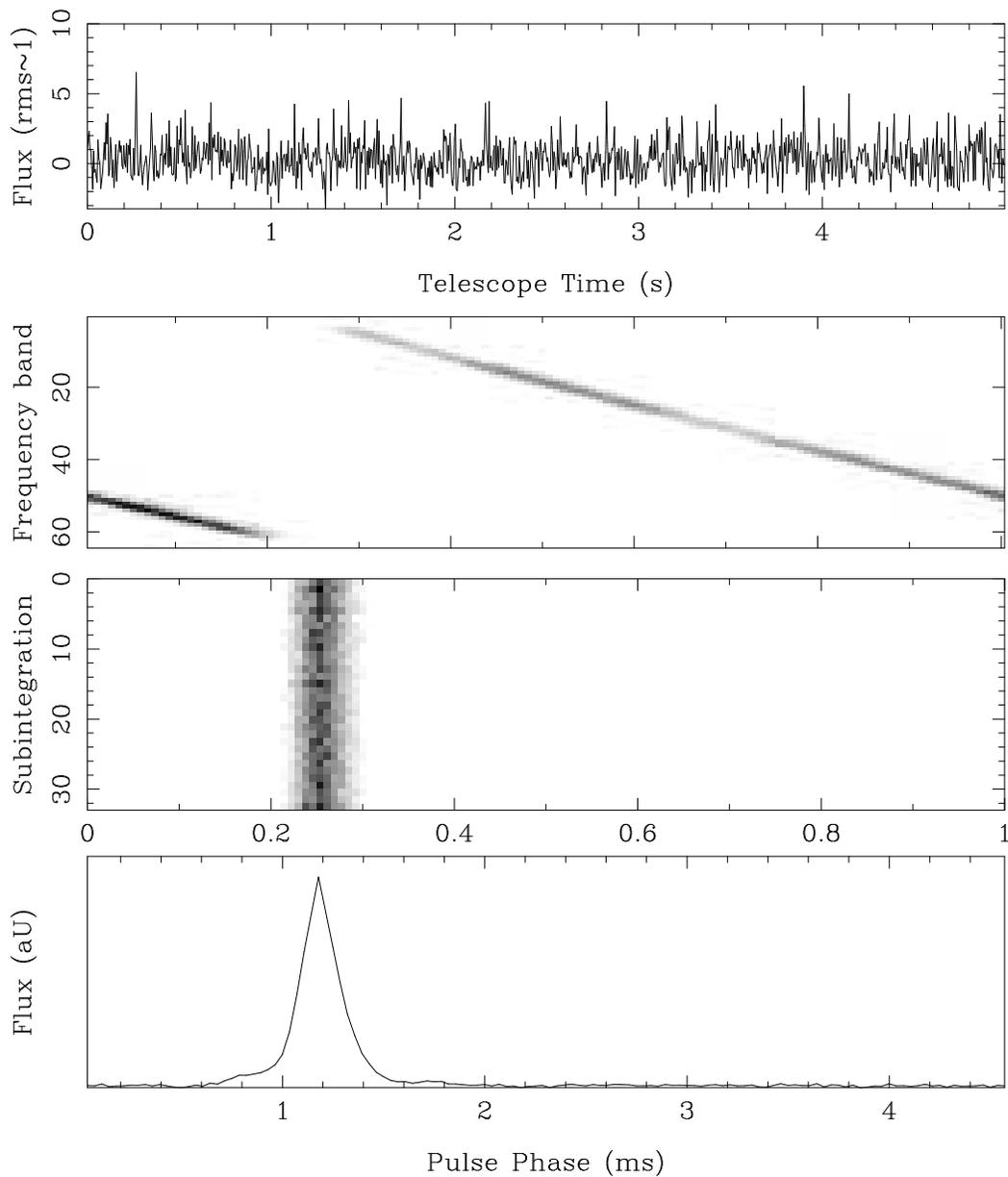


Figure 5: Sample output from the `quicklook` script for the millisecond pulsar *J1713+0747* observed by the WAPP. Top panel shows a 1024-point average of the dedispersed time series which has been normalised (as far as possible) so that it has a zero mean and unit rms. Below this are two panels showing the dedispersed frequency sub-bands (which clearly show the dispersion of the pulsar) and time sub-integrations as a function of pulse phase. The bottom plot is the integrated pulse profile. The signal-to-noise ratio of this profile is reported at the top of the plot along with essential header information.

## 11 Version history and plans for future work

The file `version.history` summarizes the work done on SIGPROC to date:

- 1.0 - 2001/02/26 - first version developed between summer 1999 and early 2001
- 1.1 - 2001/11/16 - filterbank now accepts multiple files as input
- 1.2 - 2001/12/20 - filterbank can now accept Parkes/Jodrell 1-bit data
- 1.3 - 2002/01/17 - merged IHS modifications to dedisperse WAPP folded data
- 1.4 - 2002/01/29 - fixed bug in period calculation and check source name
- 1.5 - 2002/02/07 - added `-invert` to filterbank and `<50MHz bw` to `wapp2fb`
- 1.6 - 2002/02/19 - upgraded old BACSPIN reader to read BCPM search data
- 1.7 - 2002/04/15 - added profile program, `wapp2fb` can now read 8-bit data
- 1.8 - 2002/05/16 - fixed bug in updating polyco when folding long timeseries
- 1.9 - 2002/06/25 - fold can now take constant acceleration to update period
- 2.0 - 2003/04/02 - added SIGPROC binary profile format for input to dedisperse
- 2.1 - 2003/06/03 - added `pgplotter` utility and frequency tables in headers
- 2.2 - 2003/09/20 - works for new WAPP format (use 2.1 for `_very_early` data)
- 2.3 - 2003/10/24 - added `depolyco` utility for resampling time series
- 2.4 - 2003/10/29 - dedisperse profiles using Ingrid/Joe's `fftshift` routines
- 2.5 - 2004/06/21 - fix polyco bug, write PSRFITS profiles, Ingrid's WAPP mods
- 2.6 - 2004/07/02 - re-introduced use of FFTW libraries
- 2.7 - 2004/08/18 - updated `quickplot` and filterbank following first ALFA run
- 2.8 - 2004/08/22 - added barycentre program and, unofficially, `find` and `best`
- 2.9 - 2004/09/06 - small changes to scripts and capability to read >2 GB files
- 3.0 - 2004/11/06 - fold now dumps at exact tsec intervals. `*new*` blanker prog
- 3.1 - 2005/03/24 - fix single-pulse time stamps and correct TEMPO site in `.prf`
- 3.2 - 2005/04/18 - `find.f` now changed to `seek.f` `npts.inc` changed to `2**23`
- 3.3 - 2005/05/02 - incorporated Ramach's implementation of the tree algorithm!
- 3.4 - 2005/07/15 - filterbank can now read GMRT fast-sampled filterbank data
- 3.5 - 2006/01/16 - fake does binaries (ta Mike and Ralph!) and `peak.f` from `seek`
- 3.6 - 2006/02/28 - added `dice.c` and Maura's mods to single-pulse searching
- 3.7 - 2006/03/01 - added Mike's `tune.c` and mods from MMB search processing

All suggestions for improvements, including (best of all!) offers to contribute write and/or improved routines for future releases of the package are most welcome via email: [drl@jb.man.ac.uk](mailto:drl@jb.man.ac.uk).

## Acknowledgements

In putting together the SIGPROC package, I had the good fortune to work with a number of people who kindly donated existing routines or offered to write new ones. Andy Dowd wrote the original version of what became the `wapp2fb` routine for converting raw WAPP correlation values into spectra. Jeff Hagen also contributed to this effort and wrote the routines used for reading WAPP headers and byte swapping. Ingrid Stairs provided the `pspm_decode` routine — a C-version of an original Fortran-77 subroutine written by Alex Wolsczcan. Ingrid also debugged `dedisperse` so that it can handle WAPP timing-mode data. Mike Keith and Ralph Eatough added the binary options to `fake`. Use was also made of some Numerical Recipes routines for FFTs and random number generation in `fake`. Finally, many thanks to Jim Cordes, Maura Mclaughlin, Ramesh Bhat, Ingrid Stairs and Joanna Rankin for their help in putting together and debugging some of the routines, and their suggestions for functionality.

## A Monitoring programs using the Tk monitor widget

The SIGPROC programs run without any messages to the standard output. To keep track of their progress, a `wish` script: `monitor` can run in the background.

To start the `monitor` script running, go to the directory where you are processing your files and type `monitor`. For example, starting a `filterbank` command:

```
% filterbank J1713+0747.744 -sumifs > J1713+0747.744.fil
```

will cause the following status bar to appear in the upper left-hand corner of the screen:

```
filterbank input: J1713+0747.744 status: time:30.5s output: stdout elapsed time: 37 s
```

This counter will tick away updating as the file gets updated until the program is finished. If you have several jobs running, in a pipeline for example, several status bars will appear until their respective job is completed. To stop the `monitor` script at any time, type:

```
% monitor off
```

Once the program is finished what it is doing, the `monitor` will go to sleep and wait for another SIGPROC program to start.

Note that you will confuse the script if you have two programs running from the same directory (for example two `filterbank` processes running on different raw datafiles) since the `programname.monitor` file will get updated by both programs. For such applications, run the programs from separate directories.

The `monitor` script polls programs by looking at logfiles which are written whenever the file `monitor.running` exists in the working directory. If you prefer not to use `monitor` but would like to look at these logfiles, simply create the file `monitor.running` in your area

```
% touch monitor.running
```

then run a SIGPROC program and `tail` the resulting `programname.monitor` file to keep track of what is going on. For example, while `dedisperse` is running in a pipeline you would see the following:

```
% tail dedisperse.monitor
input stdin status time:0.1s:DM:35.0pc/cc output stdout
input stdin status time:0.2s:DM:35.0pc/cc output stdout
```

To turn off this logging mode, simply delete the `monitor.running` file.

## B Running TEMPO to generate polynomial coefficients

If you have `expect` in your path, you will also be able to take advantage of `polyco` a simple script designed to take the pain out of running TEMPO to generate files containing polynomial coefficients for use by `fold`. The synopsis of `polyco` is as follows:

```
% polyco help
```

```
polyco - a script to run TEMPO to generate a polyco.dat file
```

```
usage: polyco psrname -{options}
```

```
psrname   - name of the pulsar as it appears in tztot.dat
```

```
-freq    f - frequency in MHz (def=1410 MHz)  
-nspan   n - span of each polyco set in minutes (def=15 min)  
-ncoeff  n - number of coefficients in each polyco set (def=9)  
-maxha   h - maximum hour angle (def=2 hours)  
-mjd     m - mjd to calculate for (def=today)  
-mjds    s - starting mjd (def=today)  
-mjdf    f - finishing mjd (def=today)  
-par     p - specify parfile (def=tzpar area)  
-site    s - specify site code or alias (def=Arecibo)
```

It is assumed that you have TEMPO installed on your computer so that the `tempo` executable file is in your path, and the TEMPO environment variable set. At Arecibo, a solaris version of TEMPO can be found in `/home/pulsar/bin/tempo` and the TEMPO environment variable should be set to `/home/pulsar/tempo11`.

Running `polyco` is then a matter of giving a pulsar name from the list of ephemerides contained in `$TEMPO/tztot.dat` and the start and stop MJD ranges over which you wish the coefficients to apply. The default is to generate coefficients for use at the time you run TEMPO.

## C The EPN data format

The **European Pulsar Network** (“EPN”) is an association of European astrophysical research institutes that co-operate in the subject of pulsar research. The EPN format was developed for the exchange of pulse profiles between different groups of individuals to permit a free interchange of data. The following text was taken from a paper which originally appeared in *Astronomy & Astrophysics Supplement Series* (1998) **128** 541–544 and is included here for quick reference.

Each EPN file consists of one or more blocks. The basic structure of an EPN block is shown in Fig. 6. Each file has a common fixed length *header* followed by a number of individual *data streams* of equal length. The header describes the data, containing information on the pulsar itself, the observing system used to make the observation as well as some free-form information about the processing history of the data. The onus is on the site-specific conversion process to ensure correct conversion to the standardized entries and reference to common catalogues (e.g. the Taylor et al. 1993 catalogue of pulsar parameters). The full list of header variables is given in Tables 1 and 2.

The data streams themselves may be outputs of different polarization channels, or individual channels (bands) of a filterbank or a combination thereof. In total, there may be  $N_{\text{freq}}$  data streams of i.e. different frequencies for each polarization. Each data stream starts with a small, fixed length sub-header in front of the actual data values. The number of data streams and their length may vary between different EPN files, but is constant within each file. A character field and an ordinal number is provided for each stream for its identification.

Position	Name	Format	Unit	Comment
1	version	A8		EPN + version of format (presently EPN05.00)
9	counter	I4		No. of records contained in this data block
13	history	A68		comments and history of the data
81	jname	A12		pulsar jname
93	name	A12		common name
105	$P_{\text{bar}}$	F16.12	s	current barycentric period
121	DM	F8.3	pc cm <sup>-3</sup>	dispersion measure
129	RM	F10.3	rad m <sup>-2</sup>	rotation measure
139	CATREF	A6		pulsar parameter catalogue in use
145	BIBREF	A8		bibliographical reference key (or observer's name)
153		8X		blank space free for future expansion
161	$\alpha_{2000}$	I2,I2,F6.3	hhmmss	right ascension of source
171	$\delta_{2000}$	I3,I2,F6.3	ddmmss	declination of source
182	telname	A8		name of the observing telescope (site)
190	EPOCH	F10.3	day	modified Julian date of observation
200	OPOS	F8.3	degrees	position angle of telescope
208	PAFLAG	A1		A = absolute polarization position angle, else undefined
209	TIMFLAG	A1		A = absolute time stamps (UTC), else undefined
210		31X		blank space free for future expansion
241	$x_{\text{tel}}$	F17.5	m	topocentric X rectangular position of telescope
258	$y_{\text{tel}}$	F17.5	m	topocentric Y rectangular position of telescope
275	$z_{\text{tel}}$	F17.5	m	topocentric Z rectangular position of telescope
292		29X		blank space free for future expansion
321	CDATE	I2,I2,I4	d m y	creation/modification date of the dataset
329	SCANNO	I4		sequence number of the observation
333	SUBSCAN	I4		sub-sequence number of the observation
337	$N_{\text{pol}}$	I2		number of polarizations observed
339	$N_{\text{freq}}$	I4		number of frequency bands per polarisation
343	$N_{\text{bin}}$	I4		number of phase bins per frequency (1-9999)
347	$t_{\text{bin}}$	F12.6	$\mu\text{s}$	duration (sampling interval) of a phase bin
359	$t_{\text{res}}$	F12.6	$\mu\text{s}$	temporal resolution of the data
371	$N_{\text{int}}$	I6		number of integrated pulses per block of data
377	$n_{\text{cal}}$	I4	$t_{\text{bin}}$	bin number for start of calibration signal
381	$l_{\text{cal}}$	I4	$t_{\text{bin}}$	length of calibration signal
385	FLUXFLAG	A1		F = data are flux calibrated in mJy, else undefined
386		15X		blank space free for future expansion
401		80X		blank space free for future expansion

Table 1: A description of the EPN format variables.

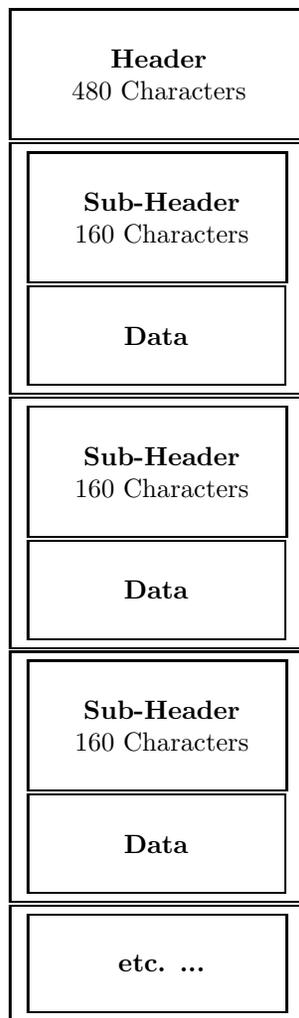


Figure 6: *Schematic representation of an EPN data block.*

## Format Compatible Software

To incorporate the capability to read and write data in this format within existing analysis software, a simple routine exists which can read and write data in this format. In addition, we have written some sample programs which can plot the data and display the header parameters. The software are written in *Fortran—77*<sup>1</sup> and have been packaged into a single UNIX tar file which is freely available via the *Internet* from <http://www.jb.man.ac.uk/~drl/download/epn.tar.gz>

To uncompress and extract the contents of the tar file on a UNIX operating system, issue the commands:

```
% gunzip epnsoft.tar.gz
% tar xvf epnsoft.tar
```

The present package contains some sample data and two example programs — `plotepn` and `viewepn` which plot and view EPN files respectively. The ASCII file **00README** in this packages gives further details of the software and how to use it.

<sup>1</sup>some simple C utilities are planned for a future version of SIGPROC

Position	Name	Format	Unit	Comment
481	IDfield	A8		type of data stream (I,Q,U,V etc.)
489	$n_{\text{band}}$	I4		ordinal number of current stream
493	$n_{\text{avg}}$	I4		number of streams averaged into the current one
497	$f_0$	F12.8		effective centre sky frequency of this stream
509	$U_f$	A8		unit of $f_0$
517	$\Delta f$	F12.6		effective band width
529	$U_{\Delta}$	A8		unit of $\Delta f$
537	$t_{\text{start}}$	F17.5	$\mu\text{s}$	time of first phase bin w.r.t. EPOCH
554		7X		blank space free for future expansion
561	SCALE	E12.6		scale factor for the data
573	OFFSET	E12.6		offset to be added to the data
585	RMS	E12.6		rms for this data stream
597	$P_{\text{app}}$	F16.12	s	apparent period at time of first phase bin
613		28X		blank space free for future expansion
641	Data(1)	I4		scaled data for first bin
$4(N_{\text{bin}} - 1) + 641$	Data( $N_{\text{bin}}$ )	I4		data for last bin of stream
$640 + N_{\text{records}} * 80$				end of first stream

Table 2: *The sub-header variables within an EPN file*

## D Barycentre correction using barycentre

A simple utility `barycentre` exists to convert a time series or filterbank file to an equivalent frame which is at rest with respect to the solar system barycentre. The synopsis of the program is

```
% barycentre help
```

```
barycentre - refer a datafile to a frame at rest wrt the solar system barycentre
```

```
usage: barycentre inputfile -{options} > outputfile
```

```
inputfile   - the name of the filterbank/time series file
-mypolyco   - take user-defined polyco.bar file (def=create one)
-verbose    - write out barycentre information to stderr (def=quiet)
```

By default, `barycentre` runs `TEMPO` to create a file `polyco.bar` which it then uses to perform the correction. If you would prefer to supply a file to do this, create one in advance, call it `polyco.bar` and use the `-mypolyco` option.

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