NCCS Output Files from Single-Dish Observing

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This document discusses the content and possible formats for output files for recording the data from single dish observing with the NCCS. It is proposed that housekeeping information be recorded in the form of keywords and their associated parameters. Data are recorded in an accompanying array or binary table. The format of files could be in the FITS style, in which all information is formatted into 2880-byte blocks, or in unblocked FITS-like files. Proposed keywords and their parameters are defined. Typical real-world examples are provided. Written in SGML, this document is viewable from the NCCS documentation index at /usr/local/src/nccs/doc/index.html using Netscape, and can be converted to other formats, e.g. latex, plain-text etc. using SGML-tools.

Contents

1 Introduction

1.1 Output files on the HP1000

Like the input file formats on the HP1000, output files for recording observing data have had many and varied formats. Initially data were generally recorded in some form of ASCII, with cryptic numbers in some form of header, followed by data written as sets of numbers. These were largely unintelligible to a human reader. They were soon found to rapidly fill large amounts of very expensive disk space, then costing around R1000 / MB. Access was also very slow for large files. This prompted a change to binary formats, for instance a pure binary file for spectra, and to an ASCII header + binary data for pulsars. These used much less space and could be read and written rapidly. This was an efficient local solution.

However the data were not portable. The outside astronomical world adopted the FITS format for making data transportable. FITS files user headers comprising keywords + parameters, with one keyword + parameter per 80-character line, all stored in one or more 2880-byte blocks, followed by the data in an array of either binary or ASCII format, also stored in multiple 2880-byte blocks. FITS encompasses many different internal formats, and it requires a 96-page manual to define the `FITSStandard` at `/usr/local/src/fits\_standard.ps`. Optional internal FITS structures for data storage include random groups (deprecated), binary tables and ASCII tables.

The recording of cordinates in FITS as also evolved. For further discussion, see `RepresentationsofcelestialcoordinatesinFITS`, of 1996/09/09, by E W Greisen and M Calabretta, in `/usr/local/src/fits/wcs.all.ps`

Unfortunately, HP-Kermit cannot handle the large record length of FITS files, so recourse was made to unblocked ASCII formats for porting data from the HP. In the case of spectra, where I had attempted to implement FITS files on the HP, I used what is essentially an unblocked version of FITS. Pulsar data, stored in binary with a cryptic ascii header, were converted to ASCII. Continuum data, never recorded in binary, were ported off the HP in their existing cryptic ASCII format.

Spectra and drift scans were also exported offsite in a minimalist format of a line of descriptive header, followed by column names, followed by X,Y pairs in two-column format, all written in ASCII. The advantage of this format is its extreme portability, for example being e-mailable and editable with any editor, and its ability to be imported into non-specialist data analysis software such as spreadsheets.

1.2 Recording data on the NCCS

What data should be recorded on the NCCS, and in what format?

In theory we could again return to the efficient binary files, with cryptic, minimal housekeeping, of the HP. However, R1000 now buys 10 GB of disk space, computer speeds are up by a factor of 1000, and experience suggests that we should be recording a maximum of housekeeping information about each observation, not a minimum, in order to provide maximum validation of the data against changes in the system.

It is also beneficial to standardize the definitions used for the housekeeping. In this regard, the use of the FITS concept of keywords followed by parameters is a suitable model to follow. The following example shows the housekeeping associated with spectra files currently being ported from the HP1000. Keywords that follow the FITS standard are identified.

```
BEGIN                          / start of new data set
NAXIS   =  1                   / number of axes in data array (FITS)
NAXIS1  =  256                 / number of values on AXIS1 (FITS)
BUNIT   = 'K'                  / brightness units of data (FITS)
OBJECT  = '339.88-1.26'        / name of object (FITS)
```

```
TELESCOP= 'HartRAO 26M'         / telescope (FITS)
OBSERVER= 'S. GOEDHART'         / observer's name (FITS)
DATE-OBS= '1999-02-13'          / date of observation (FITS)
DATE    = '1999-03-17T13:54:17' / date of creation of header (FITS)
CTYPE1  = 'VELO-LSR KM/S'       / coordinate type for axis 1 (FITS)
CTYPE2  = 'ANTENNA_TEMP'        / brightness type of the data
CRVAL1  =  -43.193              / value at CRPIX1 (FITS)
CRPIX1  =  1                    / location of ref point on axis (FITS)
CDELT1  =   0.11239             / pixel spacing on NAXIS1 (FITS)
RESTFREQ=   6.668518E+09        / line rest frequency in Hz
RA      =   252.1               / RA of EQUINOX in degrees
DEC     =  -46.059              / DEC of EQUINOX in degrees
RADOWN  =   252.1               / RA of EQUINOX for down spectrum
DECDOWN =  -46.059              / DEC of EQUINOX for down spectrum
EQUINOX =   1950.               / equinox in years for coords (FITS)
GLII    =   339.883079          / galactic longitude
GBII    =  -1.25706087          / galactic latitude
GLIIDOWN=   339.883079          / galactic longitude for down posn
GBIIDOWN=  -1.25706087          / galactic latitude for down posn
JULDATE =   2451222.67          / Julian date of SCAN
HA      =  -19.87               / hour angle of SCAN in degrees
POL     =  0                    / polarization
TCAL    =   14.2                / calibration signal value
TCALUNIT= 'K'                   / calibration signal units
TSYS    =   59.0315             / system temperature of SCAN in TCALUNITS
DTSYS   =   2.32639612          / uncertainty in TSYS in TCALUNITS
DUR     =   210.                / total integration time of SCAN in S
RMS     =   0.142293849         / expected rms noise in data in BUNITS
PSS     =   0.                  / point source sensitivity in Jy/K
BW      =   640000.             / original bandwidth of spectrum in Hz
FROFFSET=   320000.             / frequency offset for fr sw sp in Hz
SCAN    =  31322                / scan or observation number
ADDED   =   2.                  / number of spectra averaged
FIRST_CH=  1                    / first valid pixel in data
LAST_CH =  256                  / last valid pixel in data
POLYFIT =  3                    / order of polynomial fit to baseline
FOLDED  =  0                    / =0 unfolded, =1 folded freq. sw.sp.
SMOOTHED=  0                    / =0 unsmoothed =1 smoothed
TRANSFRM=  0                    / =0 spectrum =1 transform
ALTDEG  =  75.03                / telescope altitude (elev) in deg
ATMCORR =  1.0013               / atmospheric atten. corr. applied
PNTCORR =  1.07704318           / pointing correction applied
GAINCORR=  0.0                  / antenna gain correction applied
END                             / end of housekeeping for data set (FITS)
0.336205E+00 0.342031E+00 0.177201E-01 -.336548E+00   / data
-.878676E-02 -.546026E-01 -.264129E+00 -.471806E-03   / next line of data
... repeat to end of data
BEGIN                           / start of next data set
...
```

It should be noted that the housekeeping in the example does not tell us about the details of the feedhorn or receiver or polarization (although there is a keyword for this) that was used, subtleties that we might want to know about.

What are the advantages of the format shown above?

- It is plain ASCII, e-mailable and editable, e.g. to fix errors
- It is extendable: keywords can be added during data processing to record changes or new parameters applied to the data, e.g. ATMCORR is the correction for atmospheric absorption that has been applied to the data.
- It is easily converted to FITS format, if needed
- It is human-friendly, in that it can be read with any standard file viewer, and the meaning of each parameter is defined in the file

What are the disadvantages of this format?

- It is not industry standard
- As it is unblocked, reading and writing files with hundreds of data sets becomes slow, as the files are read and written one line at a time
- software must be written to read and write in this format (exists in fortran for spectra and drift scans)
- it cannot be imported by spreadsheets (but fortran software exists for converting to multi-column ascii for spreadsheets)

The FITS file format is the "industry standard" for astronomy. So for comparison with the first example, this is the "primary HDU" of a small area map observed with the HP1000 (in fact a beam pattern, in decibels) after porting to Linux and conversion to FITS format using the FITSIO subroutine package:

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                  -32 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                  112 / length of data axis 1
NAXIS2  =                  101 / length of data axis 2
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format defined in Astronomy and
COMMENT   Astrophysics Supplement Series v44/p363, v44/p371, v73/p359, v73/p365.
COMMENT   Contact the NASA Science Office of Standards and Technology for the
COMMENT   FITS Definition document #100 and other FITS information.
CTYPE1  = 'RA      '           / COORD TYPE
CRVAL1  =               85.840 / START RA (DEG)
CDELT1  =               -0.040 / RA INTERVAL (DEG)
CTYPE2  = 'DEC     '           / COORD TYPE
CRVAL2  =               20.000 / START DEC (DEG)
CDELT2  =                0.040 / DEC INTERVAL (DEG)
DATE-OBS= '26/03/1985'         / DATE OF OBSERVATION
BUNIT   = 'dB      '           / DATA IN DECIBELS
BSCALE  =                  1.0 / REAL = VALUE*BSCALE + BZERO
BZERO   =                  0.0 /
TELESCOP= 'HART-26M'           / TELESCOPE
```

```
OBSERVER= 'M.J.GAYLARD'        /
INSTRUME= '13CM CIRC FEED'     / RECEIVER
OBJECT  = 'TAURUS A'           /
HISTORY  beam offsets +0.052, +0.012, ie ~ on axis
HISTORY  Fsyn = 23.333MHz, Fobs = 2300 MHz, repeats = 4
HISTORY  ambient GAASFET amplifier, narrowband IF
HISTORY  unsmoothed median linear beam pattern map
END

This was followed by blocks containing the map data as 32-bit binary
integers.
```

While the above looks similar to the spectra example, note that each line is padded with blanks to exactly 80 characters, and the 29 lines shown were followed by 7 blank lines of 80 characters, to produce the HDU comprising 36 lines each of 80 characters, in one 2880-byte block.

Note also that in this case a lot of technical information relevant to the data were presented simply as HISTORY, where appropriate keywords and associated parameters would have provided a better solution.

What are the advantages of true FITS format?

- It is the **industry standard**
- The header containing housekeeping is viewable
- Packaging the data in blocks makes file i/o more efficient
- All astronomical data reduction software "should" be able to read it
- Standard routines for reading and writing FITS format files do exist as FITSIO / CFITSIO from NRAO, which is installed here

What are the disadvantages of true FITS format?

- Some FITS files are more equal than others. There are in fact many ways of packaging housekeeping and data within FITS, and each observatory seems to have its own "FITS standard". For example the ATNF appears to put most housekeeping into a binary table, which is not human-readable using a simple file viewer. Some also use their own extension to FITS (such as RPFITS). Some of these are not understandable elsewhere (without that observatory's software). So **industry standard** may really be "industry standard".
- FITSIO / CFITSIO does not necessarily produce FITS files that other programs understand. I encountered this in trying to convert small area maps (such as the one in the example above) ported from the HP to FITS format for viewing with WIP. WIP absolutely refused to use the BSCALE and BZERO written by FITSIO, even though inspection of the file showed nothing visibly wrong, but WIP was quite happy to use FITS files from Rhodes with BSCALE and BZERO. I understand that these files were written using FITSIO, so the problem could just have been finger trouble or lack of understanding on my part.
- FITS files cannot be imported by spreadsheets, widely used by students. This is partly overcome for Linux users by the new utility program "fv" which lets the user display and work with the data in FITS files, including binary tables.
- information in the ASCII header is not amenable to editing with a normal text editor owing to the blocked format. For example, extra information cannot be added, nor errors corrected, with a standard editor.

Do all observatories use FITS internally?

- No. For example, BIMA record all data using commercial database software.

What should we do for the NCCS?

It is clear that for exporting data, at least two formats are needed:

- version of FITS that is as close to a simple basic standard as possible
- a multicolumn ASCII version that can be imported into spreadsheets

Internally, we should define a set of keywords and associated parameters to cover everything that we might want to record in all types single dish observing, and think hard about unblocked FITS-like files versus "true FITS" for internal use. The weight of opinion seems to be that we should use true FITS output files.

2 Definition of Keywords and Data for Output Files

For true FITS, keywords **must** be in capitals. Permitted characters are 'A' - 'Z', '0' - '9', '+', '-', '_'. FITS uses 7-bit ASCII for character parameters.

The FITS standard also notes that: "The units of all FITS header keyword values should conform with the recommendations of the `IAUStyleManual` at `nccs/doc/IAUunits.txt`.

2.1 FITS-specific keywords

For a full definition of FITS, see the `FITSstandard` at `/usr/local/src/fits\_standard.ps`. Also available in printed form.

For more information on FITS and CFITSIO, refer to the NCCS index.

SIMPLE

Logical description of file format, T if file conforms to FITS standard, otherwise F. (standard FITS, must be first keyword in HDU)

BITPIX

Number of bits per pixel in a FITS data structure. Values are:

- 8 = character or unsigned binary integer,
- 16 = 16-bit twos-complement binary integer
- 32 = 32-bit twos-complement binary integer
- -32 = IEEE single precision floating point
- -64 = IEEE double precision floating point

(standard FITS, must be second keyword)

NAXIS

Number of axes in the primary data array. (standard FITS, must be third keyword). This is zero if the data are in a binary table rather than in the primary data array.

NAXISn

Number of values on the nth axis of the data array, if present. (standard FITS, must be fourth... keyword)

EXTEND

Optional. FITS dataset may contain extensions, T if true, F if false. Must be present if a binary table is used. (standard FITS)

DATE

Date of creation of this HDU (FITS header and data unit). Y2K-compliant date FITS date format is 1999-03-17T13:54:17.321. If the keyword **TIMESYS** is not present, the time system is assumed to be UTC. IAU recommends the use of Terrestrial Time, TT. (standard FITS)

END

End of keyword list. (standard FITS, must be last keyword in HDU)

2.2 Keywords describing the object

OBJECT

Name of object. (standard FITS)

EQUINOX

Equinox in years applicable to equatorial coordinates, e.g. 1950.0 for B1950, 2000.0 for J2000. (standard FITS)

For further discussion, see `RepresentationsofcelestialcoordinatesinFITS`, of 1996/09/09, by E W Greisen and M Calabretta, in `/usr/local/src/fits/wcs.all.ps`

RADECSYS

Frame of reference for an equatorial coordinate system. (Recommended keyword by Greisen and Calabretta, WCS for FITS) Allowed values are:

- 'FK4 ' - mean place, old (pre-IAU 1976) system. Any stated equinox is Besselian.
- 'FK4-NO-E' - mean place, old system, but without e-terms.
- 'FK5 ' - mean place, new (post-IAU 1976) system. Any stated equinox is Julian.
- 'GAPPT ' - geocentric apparent place, post-IAU 1976 system.

RA

Object's RA of EQUINOX in decimal degrees.

DEC

Object's Dec. of EQUINOX in decimal degrees.

GLON

Galactic Longitude of object in decimal degrees. (Recommended keyword in WCS for FITS)

GLAT

Galactic Latitude of object in decimal degrees. (Recommended keyword in WCS for FITS)

ELON

Ecliptic Longitude of object in decimal degrees. (Recommended keyword in WCS for FITS)

ELAT

Ecliptic latitude of object in decimal degrees. (Recommended keyword in WCS for FITS)

OBJFLUX

If the object is a calibrator, this is its flux density at RESTFREQ, computed from the catalogue information, in Jy.

REFERENC

Reference or source of information. (standard FITS)

2.3 Keywords describing the scan

OBSERVER

Principal Investigator's (Observer's) name. (standard FITS)

OBSLOCAL

On-site observer if PI not on site.

PROJECT

Mandatory. Short name for the observing project, taken from the observing proposal. Specified in section 6.10 of the "NCCS Requirements and Specifications".

PROPOSAL

Mandatory. Number of the observing proposal, allocated on acceptance of the observing proposal. Specified in section 6.10 of the "NCCS Requirements and Specifications".

TELESCOP

Telescope name. (standard FITS)

DATE-OBS

Date of observation. Y2K-compliant FITS date format is '1999-03-17T13:54:17.123'. See notes on **DATE**. This is conventionally defined to indicate the start of the observation. (standard FITS)

MJD-OBS

Modified Julian Date (= JD - 2400000.5) of start of SCAN. The number of significant figures used must define the start time to the required accuracy for data reduction purposes. For example, five decimal places defines time to about one second, six to one-tenth of a second etc. What accuracy is needed for pulsars? MJD-OBS is strictly redundant in that it can be calculated from DATE-OBS, but "nice to have", recommended for working with time series of data, and avoids post-observation recalculation. (recommended by Greisen and Calabretta, in WCS for FITS.)

SCAN

Scan or observation number or alphanumeric designator uniquely identifying this scan.

SCANTYPE

Type of scan.

RESTFREQ

Observing frequency or Line rest frequency (spectroscopy) in Hz.

HA

Hour angle recorded at either the start, middle, or end of SCAN in degrees. Used for calculation of atmospheric absorption and gain corrections, where the middle of the scan is usually the most appropriate. Strictly redundant in that the HA can be calculated from the RA and DATE-OBS or JULDATE, but ”nice to have”, avoiding post-observation recalculation.

ALT

Telescope altitude (elevation) in degrees at the middle of the observation, computed from HA and DEC. Used in the correction for atmospheric absorption. Strictly redundant in that the ALT can be calculated from the RA and DATE-OBS or JULDATE, but ”nice to have”, avoiding post-observation recalculation.

2.4 Keywords describing the telescope and receiver configuration

All observers conducting monitoring programs have in the past been bedevilled by undocumented changes in receiver hardware that affect the recorded data. All parameters relevant to observing are now meant to be recorded in SYPARM. Those relevant to the receiver system with which the data were captured can then be defined by suitable keywords. Hardware changes can then be identified post facto through changes in the parameters taken by keywords, instead of by trying to find records of changes in control room diaries.

The following keywords should provide a reasonably complete description of the factors that have the most effect on observations.

SURFACE

Antenna surface status, needed given resurfacing ”in process”. This is descriptive, e.g. ”PANELS 001-0038 REPLACED, PANEL 039 MISSING”. From SYPARM. The effect of changes in the surface can be quantified as a (frequency-dependent) gain factor using the keyword GAINFAC.

GAINFAC

Gain of the telescope at zenith relative to that before the surface upgrade started. From SYPARM. Theoretically, calibrators should be observed after each surface change and these most recent calibrations applied to the data, making use of this keyword unneccessary. Real life may be a little different.

SUBTILT

Subreflector tilt position during the scan. Units are natural readout values - or converted to a real angle in degrees ? Confirms that the subreflector was where it should have been. From STEER.

SUBFOCUS

Subreflector focus position during the scan. Units are natural readout values - or converted to a proper unit of length, i.e. (milli)metres ? Confirms that the subreflector was where it should have been. From STEER.

DICHROIC

Dichroic reflector position, either ON or OFF, during the scan. If the dichroic is on, system temperature and aperture efficiency (usually recorded in the reciprocal form of the Point Source Sensitivity in Jy/K) will change. Default measurements are with the dichroic off. From STEER.

FEEDTYPE

Feed horn type, e.g. RECTANGULAR, CIRCULAR, or DIAGONAL. Each type has different efficiencies and bandwidths. From SYPARM.

BMOFFHA

Beam offset from axis in Hour Angle used for the observation, in units of degrees. Repositioning of feeds will change the PSS and gain surface. From SYPARM.

BMOFFDC

Beam offset from axis in Declination used for the observation, in units of degrees. Repositioning of feeds will change the PSS and gain surface. From SYPARM.

HABMSEP

Beam separation in dual beam systems, in degrees. From SYPARM.

HPBW

Half-power beamwidth (full width at half maximum), in degrees. Necessary for reducing pointing observations. Confirms offsets used for stepping observations. From SYPARM.

FNBW

Beamwidth to first nulls, in degrees. Confirms offsets used for stepping observations. From SYPARM.

SNBW

Beamwidth to second nulls, in degrees. Confirms offsets used for stepping observations. From SYPARM.

RFBANDHI

High frequency end of detected band at the 3dB (6dB? 10dB?) point, in Hz. The RESTFREQ used for the observation may not be centred in the detected band, so this parameter is needed to define the band centre frequency for calibration purposes. RFBANDHI - RFBANDLO should give BW, the effective bandwidth, in Hz. From local oscillator settings and data in SYPARM.

RFBANDLO

Low frequency end of detected band at the 3dB (6dB? 10dB?), in Hz. The RESTFREQ used for the observation may not be centred in the detected band, so this parameter is needed to define the band centre frequency for calibration purposes. From local oscillator settings and data in SYPARM.

NOMTSYS

Nominal minimum system temperature at zenith, in K. Useful for checks on system performance, such as the noise level in the data. From SYPARM.

INSTRUME

Describes the instrument or backend and mode used to acquire the data. From input file. (Standard FITS)

POLn

Polarization of each receiver channel. The FITS standard does not specify how the polarization of data should be recorded. A standard will have to be defined - see examples for possibilities. From SYPARM or input file if selectable.

2.5 Keywords providing calibration information

TCALn

Adopted numerical value of the calibration signal from the calibration noise diode. As two polarizations are recorded in general, TCAL1 and TCAL2 will be needed, one for each polarization. TCAL would normally have been determined by a hot-cold load measurement. Frequency-dependent. From SYPARM.

TCALERRn

Uncertainty in the adopted numerical value of the calibration signal from the calibration noise diode. A value is needed for reach polarization. From SYPARM.

TCALFREQ

Frequency at which the adopted numerical value of the calibration signal was measured, in Hz. From SYPARM.

TCALDATE

Date at which the numerical value of the calibration signal given by TCAL was adopted. From SYPARM.

TCALUNIT

Calibration signal units, analogous to BUNIT, e.g. 'K'. From SYPARM.

TCALCNTn

Counts per Kelvin from noise diode calibration signal, for each receiver channel. Used to calibrate data recorded in raw form. From noise diode firing during this scan.

DCALCNTn

Uncertainty (1 standard deviation) in counts per Kelvin from noise diode calibration signal, for each receiver channel. From noise diode firing during this scan.

CALPSSn

Point Source Sensitivity derived from observations of standard calibrator source(s). Units are Jy/K. Used to rescale data from antenna temperature to flux density. The values may differ in the two polarizations observed. From SYPARM.

CALPSSER

Uncertainty in Point Source Sensitivity derived from observations of standard calibrator source(s). Units are Jy/K. From SYPARM.

CALSRC

Name of flux calibrator used to measure the PSS. From SYPARM.

CALFREQ

Frequency at which the flux calibration was made, in Hz. From SYPARM.

CALFLUX

Calibrator flux density assumed at the time of calibration, in Jy. From SYPARM.

CALDATE

Date of flux calibration. From SYPARM.

Really serious observers may want to record the following parameters of the calibration noise diodes:

- serial number
- measured coupling ratio and its uncertainty
- frequency at which coupling ratio was measured
- date of measurement

2.6 Keywords specific to stepping observations

Stepping data are to be recorded as sets of tracking data. If all the tracks are of equal length, counting the track with calibration as a double track, then the data can be packed into one dimension of an array and decoded using the set of mnemonics defined by STEPSEQ. Alternatively, the data could be recorded in multiple dimensions of an array, permitting unequal length steps. See comments with the example.

STEPSEQ

Sequence of steps performed. Used to interpret the data sequence. Optional description of stepping observations. From input file, otherwise from standard sequence list. For data recorded in a binary table, TTYPn includes the acronym for each step and the polarization.

For example if STEPSEQ followed TNFPC dual beam:

```
FNNACAL, HPNA, ONA, HPSA, FNSA, ZC, FNNB, HPNB, ONB, HPSB, FNSB
```

there would be a double track at the start, followed by ten single tracks, giving a total of twelve tracks. Recording the data for each polarization, this gives 24 data fields.

2.7 Keywords specific to active scans

These are taken directly from the input file keywords.

STARTX

x offset from special point of scan start. Units are decimal degrees.

STARTY

y offset from special point of scan start. Units are decimal degrees.

STOPX

x offset from special point of scan end. Units are decimal degrees.

STOPY

y offset from special point of scan end. Units are decimal degrees.

SCANTIME

Length of scan in seconds.

2.8 Keywords specific to spectroscopy

RAUP

Spectroscopy only. RA of EQUINOX for "up" spectrum. Relevant to offset spectra used to measure the pointing, where RAUP = RA of date +(HPBW/2)/COS(DEC) for spectrum offset East. If not specified in the housekeeping, RAUP = RA of object.

DECUP

Spectroscopy only. Dec of EQUINOX for "up" spectrum. Relevant to offset spectra used to measure the pointing, where DECUP = DEC of date +HPBW/2 for the spectrum offset North. If not specified in the housekeeping, DECUP = DEC of object.

RADOWN

Spectroscopy only. RA of EQUINOX for "down" spectrum.

For frequency-switched spectra, RADOWN = RA of object.

For frequency-switched spectra used to measure the pointing, RADOWN = RA of date - (HPBW/2)/COS(DEC) for spectrum offset West. HPBW is from SYPARM.

For position-switched spectra, RADOWN = RA + RA offset calculated from the SPPS parameters in the input file.

If not specified in the housekeeping, RADOWN = RA of object.

DECDOWN

Spectroscopy only. Dec of EQUINOX for "down" spectrum.

For frequency-switched spectra, DECDOWN = DEC of object.

For frequency-switched spectra used to measure the pointing, DECDOWN = DEC of date -HPBW/2 for spectrum offset South. HPBW is from SYPARM.

For position-switched spectra, DECDOWN = DEC + DEC offset calculated from the SPPS parameters in the input file.

If not specified in the housekeeping, DECDOWN = DEC of object.

GLONUP

Spectroscopy only. Galactic longitude of "up" posn. Optional, derived from RAUP, DECUP, EQUINOX.

GLATUP

Spectroscopy only. Galactic latitude of "up" posn. Optional, derived from RAUP, DECUP, EQUINOX.

GLONDOWN

Spectroscopy only. Galactic longitude of "down" posn. Optional, derived from RADOWN, DECDOWN, EQUINOX.

GLATDOWN

Spectroscopy only. Galactic latitude of "down" posn. Optional, derived from RADOWN, DECDOWN, EQUINOX.

SPVLSR

Spectroscopy only. Optional. Used for spectra of galactic objects. Parameter is the velocity with respect to the local standard of rest at which the spectrum was centred. Units are km/s. An alternative parameter will be used for solar system objects such as comets, e.g. **SPVHEL**.

TSYS

Spectroscopy only (?). Measured system temperature at the middle of the SCAN in TCALUNITS. Used to scale the spectrum and to calculate RMS.

DTSYS

Spectroscopy only (?). Measured uncertainty in TSYS in TCALUNITS.

DUR

Spectroscopy only (?). Duration, or total integration time, of SCAN in seconds. Must be known if RMS is to be calculated.

BW

Spectroscopy only (?). Bandwidth of the detected signal in Hz. Must be known if RMS is to be calculated.

FROFFSET

Spectroscopy only. Frequency offset for frequency-switched spectra, in Hz.

RMS

Spectroscopy only (?). Expected rms noise of the data in BUNITS. Calculated using the radiometer sensitivity equation.

FOLDED

Spectroscopy only. Frequency-shifted spectra are "shifted and folded" to superimpose and add the data in the two halves of the spectra. This keyword indicates whether this has been done. FOLDED =0 unfolded, =1 folded.

TRANSFRM

Spectroscopy only. Indicates whether the data in the array are in their natural form or have been Fourier-transformed. TRANSFORM=0 spectrum, =1 transform.

2.9 Keywords specific to pulsar timing

At the moment, the analysis of pulsar data recorded on the HP1000 requires the source catalogue to be present to provide the requisite housekeeping information. I suggest that this housekeeping information accompany each pulsar timing observation so that the analysis can be done independently of the source catalogue. This provides a definitive record of the actual parameters used at the time of observation, and makes the data portable.

PLPERIOD

The pulsar period in seconds. From the input file or catalogue.

PLPDRV1

The pulsar period derivative, in s/s^1. Also known as "pdot". From the input file or catalogue.

PLPDRV2

The pulsar period second derivative, in s/s^2. Also known as "pdotdot". From the input file or catalogue.

PLDM

The dispersion measure, in units of pc/cm^3. From the input file or catalogue.

PLDMDRV

The rate of change of the dispersion measure with time, in units of $pc/cm^3/s^1$. From the input file or catalogue.

PLEPOCH

The epoch in Julian days (MJD?) applicable to PLPERIOD, PLPDRV1, PLPDRV2, PLDM and PLDMDRV. From the input file or catalogue.

PLPOL

A numerical factor to do with polarization, does what? If PLPOL is omitted, the default value is unity. From the input file or catalogue.

PLPHASE

The phase offset from current ephemeris at the time of the most recent observation, in milliperiods. Also known as the "drift". From the input file or catalogue.

PLTCONST

The time constant that was set for the post-detection filter, from the input file, in microseconds. From the input file or catalogue.

PLPINT

The number of periods that were integrated. From the input file or catalogue.

PLPBARY

Computed current period at epoch of observation, at solar system barycentre (seconds). From the observing program. The nominal time interval between each data point = PLPBARY / number of samples.

PLPAPP

Computed period at epoch of observation corrected for radial velocity doppler shift (seconds). From the observing program. The actual time interval between each data point = PLPAPP / number of samples.

PLFREQ

Sampling frequency that was used (= Nsamples / Papparent, i.e. = NAXIS2 / PLPAPP), in Hz. From the observing program.

2.10 Keywords describing the primary data array

If data are to be stored in true FITS format, certain keywords are mandatory. Others may have to be added to make explicit the nature of the data, as FITS is rather minimalist.

In general the data acquired in single dish observing comprise data streams or sets from the left- and right-circularly polarized receivers. In the case of spectra or a polarimeter, this could alternatively be linearly polarized at some polarization angle or could be the Stokes parameters. Additional data streams might include the RA, Dec or pointing errors. The data may be in various forms eg integer or real, with different degrees of precision.

The best way to handle these multiple data streams in the FITS style is with either an ASCII or binary table. At first sight it might seem that an ASCII table could be imported easily into a spreadsheet, but this is not so, as it is actually a byte-stream stored in 2880-byte blocks. The more compact binary table therefore seems the preferred option for recording the data.

An advantage of the using the primary data array is the coordinates of evenly spaced data are identified very compactly using CRVALn, CRPIXn and CDELTn. In binary tables however, the coordinates are specified as another data field. This is less compact, but does cope automatically with unevenly spaced data.

The keywords in this section cover the primary data array, if used. The keywords for data in a binary table are in the following section.

BUNIT

Physical units in which the quantities of the primary data array are expressed. (standard FITS). The examples quoted in the original FITS papers are 'K' or 'Jy'. However this is ambiguous, as 'K' could be either antenna or brightness temperature, for example. If raw data are recorded, the units are instrumental, e.g. 'COUNTS'.

I suggest the use of BTYPE to specify the quantity, and BUNIT to specify the units unambiguously, following the example of TTYPn and TUNITn specified in the FITS standard for binary tables.

BTYPE

Owing to the deficiencies of the BUNIT specifier, BTYPE is used to define the type of data in the primary data array. For instance, 'RAW DATA' are just that. Alternatives are 'ANTENNA TEMPERATURE', 'BRIGHTNESS TEMPERATURE' and 'FLUX DENSITY', or abbreviated forms of them.

CTYPEn

Name of the coordinate represented by axis n. (standard FITS)

Note that the units can be embedded in CTYPEn, but if they are not they may be ambiguous. This can be a problem. I would be happier if the units were explicitly stated in the keyword, or in another keyword such as CUNIT1. We will need to set local internal standards.

For spatial data, examples in FITS documentation are 'RA', 'DEC' are used for equatorial coordinates, i.e. Right Ascension and Declination, 'GLON', 'GLAT' for Galactic Longitude and Latitude, 'ELON', 'ELAT' for Ecliptic Longitude and Latitude. Units are always degrees for all these.

For spectroscopy, examples given in the original FITS paper are 'VELO' for velocity in meters/second, 'VELO-LSR' for the velocity with respect to the local standard of rest, with units unspecified, VELO-HEL' for heliocentric velocity (wrt the Sun), 'VELO-OBS' for velocity wrt the observer. I used 'VELO-LSR KM/S', for Vlsr from the HP to make the units explicit, the SI units for velocity being m/s.

For pulsar timing, the units appear to be the fractional period, with a random start phase.

CUNITn

Units for the coordinate of axis n.

CRVALn

Value at the coordinate specified by CTYPEn at CRPIXn. The data are always regarded as being evenly spaced. CRVALn, CRPIXn and CDELTn together define how to set up the abscissae for the data. (standard FITS)

CRPIXn

Location of reference point for CRVALn on axis CTYPEn, pixels being numbered 1,2,3...n. Typically the first pixel (1) is used. (standard FITS)

CDELTn

Pixel spacing on NAXISn. (standard FITS)

2.11 Keywords describing binary tables

The first seven keywords must be in the order described, with no intervening keywords. I have not listed every possible keyword, see the FITS standard for more information.

In the examples, in the interests of transparency I have used a separate field for every variable being recorded in the table, in order to make explicit where LCP and RCP data are stored. However it is quite possible to have multiple data (of the same type) per field, such as pairs LCP and RCP data values. The binary table example in the previous version of the FITS standard (NOST 100-1.1), pp 47-49 does this. The absence of such examples from the latest FITS standard does not help :-(

XTENSION

Mandatory. Value field (parameter) must be = 'BINTABLE'. (standard FITS)

BITPIX

Mandatory. Value field must be 8, indicating an array of 8-bit bytes. (standard FITS)

NAXIS

Mandatory. Value field must be 2, indicating that the array is two-dimensional: rows and columns. (standard FITS)

NAXIS1

Mandatory. Value field gives the number of 8-bit bytes in each row of the table. This is the sum of the bytes per field. (standard FITS)

NAXIS2

Mandatory. Value field gives the number of rows in the table. (standard FITS)

PCOUNT

Mandatory. Value field gives the number of bytes that follow the table in any associated extension data. (standard FITS)

GCOUNT

Mandatory. Value field contains the integer 1, indicating that the data records contain a single table. (standard FITS)

TFIELDS

Mandatory. Value field is an integer giving the number of fields in each row. (standard FITS)

TFORMn

Mandatory. Value field of the keyword is a character string of the form rT describing the nth field in the table. The repeat count r is an integer specifying the number of elements in field n, default value is 1. (standard FITS). Some examples of the data type T are:

- 'L' = 1-byte logical
- 'I' = 16-bit integer
- 'J' = 32-bit integer
- '20A' = 20-character string
- 'E' = single precision floating point
- 'D' = double precision floating point

TTYPEn

Optional. Character string giving the name or description of the nth field. Only letters, digits and '_' should be used. Use different names for each field. (standard FITS)

TUNITn

Optional. Character string describing the physical units in which the quantity in field n is expressed, as per BUNIT. (standard FITS)

TNULLn

Optional. Integer that represents an undefined value for data of type B, I or J. (standard FITS)

TSCALn

Optional. Floating point number giving the scale factor for field n. Default value = 1. Physical_value_n = TZEROn + TSCALn * field_value_n. (standard FITS)

TZEROn

Optional. Floating point number giving the zero level for field n. Default value = 0. (standard FITS)

TDISPn

Optional. Character string describing the format for the display of the contents of field n. (standard FITS) Some examples are:

- Aw - character
- Lw - logical
- Iw.m - integer
- Fw.d - single precision real
- Ew.dEe - single precision real, exponential notation
- Dw.dEe - double precision real, exponential notation
- Gw.dEe - general

where **w** is the width in characters ofthe displayed values, **m** is the minimum number of digits displayed, **d** is the number of digits to right of decimal, **e** is number of digits in exponent. **.m** and **Ee** fields are optional. To show all significant figures use I8 for TFORM = I, I12 for J, E15.9 for E and D25.17 for D.

END

Ends the keywords defining this extension. (standard FITS)

This is followed, at the start of the next FITS record, by the binary data table, comprising a two-dimensional byte array. The number of bytes in a row and the number of rows determines the size of the byte array. Every row shall have the same number of bytes. The first row begins at the start of the record immediately following the last header record.

2.12 Keywords describing the processing of the data

The following data processes can be applied to each data channel individually, hence they may need a suffix (e.g. 1 or 2) to indicate the channel to which they have been applied.

ATMCOR

Atmospheric attenuation correction that has been applied to the amplitude of the data. The SLAP formula is used:

```
ABSORB = 1D0 / DEXP(0.0069D0*(1D0/DSIN(ALTRAD)-1D0))
```

A value of zero or unity indicates no correction has been applied.

PNTCOR

Pointing correction that has been applied to the amplitude of the data. The pointing correction is calculated from data obtained on the object, or a nearby object, on source and at the N,S,E,W half-power points of the beam (typically). A value of zero or unity indicates no correction has been applied.

GAINCOR

Antenna gain correction that has been applied to the amplitude of the data. This is derived from a gain surface or gain curve, and is a function of HA,Dec. Care should be taken as to whether this includes or excludes atmospheric absorption. A value of zero or unity indicates no correction has been applied. GAINCORR defines the change in gain of the antenna at the observing position relative to that at zenith.

PSS

Point Source Sensitivity factor in Jy/K that has been used to convert the data from antenna temperature to flux density. It is derived from flux calibrator observations, and is essentially the reciprocal of the aperture efficiency. Set to zero if data have not been converted from Ta/K to S/Jy. Proper usage of this conversion implies that the atmospheric, pointing and gain corrections have been made.

ADDED

Number of compatible data sets that have been averaged to produce the current data. Applicable to spectra and drift scans for example. Default is 1 if not specified.

FIRSTCH

First valid pixel in the data. Applicable to one-dimensional data which may be "windowed", such as spectra and drift scans, where data outside the window are not necessarily discarded. Default is first pixel, if not specified.

LASTCH

Last valid pixel in the data, with notes as above. Default is last pixel, if not specified.

POLYFIT

Spectroscopy and drift scans. Order of polynomial that has been fitted to the spectrum baseline. Used in spectroscopy, may be used elsewhere.

SMOOTHD

Indicates whether a smoothing operation has been applied to the data array. SMOOTHD =0 unsmoothed =1 smoothed. Used in spectroscopy, may be used elsewhere.

3 Examples of Output Files

3.1 Output file from a continuum stepping observation

This is the output file from the first stepping observation defined in the input file example, a `Multi-wavelengthscansofacalibrator`.

In this case the object observed is a flux calibrator, so these data can be used to determine a new value of the point source sensitivity. Pointing offsets can also be determined.

A true FITS format is used for this example, so that the primary header contains the keywords SIMPLE, BITPIX, NAXIS, NAXISn, n = 1, ..., NAXIS, other keywords, END, in that order.

Data regarded as character strings are written within quotes. Numeric parameters should all technically be right justified ending at column 30, although only a few have been written that way here. Logical values are T = True of F = False, again right-justified.

Blank lines are permitted in the housekeeping.

It is proposed for stepping observations that the "raw" data be recorded, not the mean or median value at each step as on the HP, so that every datum is available for post-observation analysis and data-quality verification. "Raw" may be literally the stream of raw counts at 10mS intervals from the counters during each track, or they may have been binned or summed to 100mS intervals to match the angle measurement interval in STEER, depending on how the observing algorithm is implemented.

Because each field (column) in the binary table used to store the data must have the same length, each step must generate the same number of data points. Inefficiently, they could be padded with NULL values to the length of the longest column.

The data recorded during the track at each step are here assumed to be of equal length (here 100 points). Any step with calibration diode firing is recorded as two equal length steps. The raw data in each polarization are recorded in separate fields.

It is possible to record further data in extra fields of the binary table. For example, at each step one could include the hour angle and declination and / or the tracking errors in hour angle and in declination. Then in post-processing, only those data meeting offset error criteria would be included in the data analysis, or variations in system temperature with hour angle could be corrected. Here the data are assumed to be the counts from the radiometer outputs only, with no extra information.

FITSIO recognises units in a comment if they are of the form "/ [unit] rest of comment". This is not part of the FITS standard, but can be helpful.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  = 8                      / not used as NAXIS is 0
NAXIS   = 0                      / number of data axes - no primary data array
EXTEND  =                    T / FITS dataset contains extensions
DATE    = '1999-08-17T12:25:10'/ date of creation of this HDU, UT

COMMENT  information about the object
OBJECT  = '0915-11'            / flux calibrator
EQUINOX =  1950.0              / coordinate equinox
RADECSYS= 'FK4 '               / Besselian equinox, type FK4
RA      =  138.921             / [deg] object RA
DEC     = -11.885              / object DEC, in required decimal degrees
OBJFLUX =  36.45               / flux density from catalogue at restfreq, Jy
REFERENC= 'Ott et al. (1994) AA 284, 331.'

COMMENT  information about the scan
PROJECT = flux calibration
PROPOSAL= 1999.001
OBSERVER= 'G.D. NICOLSON'      / Principal Investigator
DATE-OBS= '1999-08-17T12:13:14'/ UT at start of scan, Y2K-compliant
MJD-OBS =    51187.216818750   / Modified Julian date of start of scan
SCAN    = '19990817121314'     / scan number (identifier)
SCANTYPE= 'STEP'               / set of tracks stepped around object
STEPSEQ = 'FNNCAL, HPN, ON, HPS, FNS, FNE, HPE, ON, HPW, FNW'
RESTFREQ=  1666E6              / rest frequency set by LO chain, in Hz
HA      =  0.101               / HA at middle of scan, degrees
ALT     =  80.305              / altitude (elevation) at middle of scan, deg
COMMENT  TCALCNT not known yet as calibration data have not been processed yet

COMMENT  information on the telescope and receiver configuration
TELESCOP= 'HartRAO 26M'        / telescope
SURFACE = 'PANEL 1 MISSING'    / telescope surface description
GAINFAC =  0.997               / relative to intact surface at upgrade start
SUBTILT =  9.70                / subreflector tilt, arbitrary units
SUBFOCUS=  5.00                / subreflector focus, arbitrary units
DICHROIC= 'OFF'                / dichroic was off
FEEDTYPE= 'CIRCULAR'           / circular, dual-mode feed
BMOFFHA =  0.096               / beam offset in hour angle, deg
BMOFFDC = -0.904               / beam offset in declination, deg
```

```
HPBW    =  0.494              / halfpower beamwidth, deg
FNBW    =  1.190              / first null beamwidth, deg
RFBANDHI=  1671E6             / 10MHz filter centred on 1666 MHz, in Hz
RFBANDLO=  1661E6             / 10MHz filter centred on 1666 MHz, in Hz
NOMTSYS =  35                 / nominal zenith system temperature in Kelvins
INSTRUME= 'NARAD-NA'          / used noise-adding radiometers
POL1    = 'LCP'               / polarization of data for channel 1
POL2    = 'RCP'               / polarization of data for channel 2

COMMENT  information for calibrating the data
TCAL1   =  6.2                / Cal noise diode value for channel 1
TCAL2   =  5.3                / Cal noise diode value for channel 2
TCALERR1=  0.0                / uncertainty in Tcal1 is unknown
TCALERR2=  0.0                / uncertainty in Tcal2 is unknown
TCALFREQ=  1668E6             / frequency the calibration applies to, in Hz
TCALDATE= '1900-01-01'        / unknown calibration date
TCALUNIT= 'K'                 / units for cal noise diode values
CALPSS1 =  5.13               / Point source sens for channel1, Jy/K
CALPSS2 =  5.13               / Point source sens for channel2, Jy/K
CALPSSER=  0.07               / uncertainty in CALPSS
CALSRC  = 'B0915-11'          / object used for calibration
CALFLUX =  36.45              / total flux density assumed at CALFREQ, Jy
CALFREQ = 1668E6              / frequency the calibration applies to, in Hz
CALDATE = '1995-07-26'        / calibration date
REFERENC= 'Ott et al. (1994) AA 284, 331.'

COMMENT  information about the processing of the data
ATMCOR  = 1                   / uncorrected raw data
PNTCOR  = 1                   / uncorrected raw data
GAINCOR = 1                   / uncorrected raw data
END                           / end of HDU

        ...at the start of a new FITS record is the binary table header...

XTENSION                       / start of binary table extension
BITPIX  = 8                    / 8-bit bytes
NAXIS   = 2                    / 2-D table
NAXIS1  = 88                   / bytes per row = 88 * 4
NAXIS2  = 100                  / number of rows
PCOUNT  = 0                    / number of bytes in extension data
GCOUNT  = 1                    / single table
TFIELDS = 22                   / number of fields (columns per row)
COMMENT  above keywords are mandatory for a binary table, in this sequence
COMMENT  information about the data in the binary table follows
TFORM1  = 'J'                  / field = single 32-bit integer
TTYPE1  = 'FNNCAL LCP'         / brightness type - step name + polarization
TUNIT1  = 'COUNTS'             / brightness units - these are raw data
TDISP1  = 'I12'                / recommended display format
TFORM2  = 'J'                  / field = single 32-bit integer
TTYPE2  = 'FNN LCP'            / brightness type - step name + polarization
```

```
TUNIT2  = 'COUNTS'              / brightness units - these are raw data
TDISP2  = 'I12'                 / recommended display format
TFORM3  = 'J'                   / field = single 32-bit integer
TTYPE3  = 'HPN LCP'             / brightness type - step name + polarization
TUNIT3  = 'COUNTS'              / brightness units - these are raw data
TDISP3  = 'I12'                 / recommended display format
TFORM4  = 'J'                   / field = single 32-bit integer
TTYPE4  = 'ON LCP'              / brightness type - step name + polarization
TUNIT4  = 'COUNTS'              / brightness units - these are raw data
TDISP4  = 'I12'                 / recommended display format
TFORM5  = 'J'                   / field = single 32-bit integer
TTYPE5  = 'HPS LCP'             / brightness type - step name + polarization
TUNIT5  = 'COUNTS'              / brightness units - these are raw data
TDISP5  = 'I12'                 / recommended display format
TFORM6  = 'J'                   / field = single 32-bit integer
TTYPE6  = 'FNS LCP'             / brightness type - step name + polarization
TUNIT6  = 'COUNTS'              / brightness units - these are raw data
TDISP6  = 'I12'                 / recommended display format
TFORM7  = 'J'                   / field = single 32-bit integer
TTYPE7  = 'FNE LCP'             / brightness type - step name + polarization
TUNIT7  = 'COUNTS'              / brightness units - these are raw data
TDISP7  = 'I12'                 / recommended display format
TFORM8  = 'J'                   / field = single 32-bit integer
TTYPE8  = 'HPE LCP'             / brightness type - step name + polarization
TUNIT8  = 'COUNTS'              / brightness units - these are raw data
TDISP8  = 'I12'                 / recommended display format
TFORM9  = 'J'                   / field = single 32-bit integer
TTYPE9  = 'ON LCP'              / brightness type - step name + polarization
TUNIT9  = 'COUNTS'              / brightness units - these are raw data
TDISP9  = 'I12'                 / recommended display format
TFORM10 = 'J'                   / field = single 32-bit integer
TTYPE10 = 'HPW LCP'             / brightness type - step name + polarization
TUNIT10 = 'COUNTS'              / brightness units - these are raw data
TDISP10 = 'I12'                 / recommended display format
TFORM11 = 'J'                   / field = single 32-bit integer
TTYPE11 = 'FNW LCP'             / brightness type - step name + polarization
TUNIT11 = 'COUNTS'              / brightness units - these are raw data
TDISP11 = 'I12'                 / recommended display format
TFORM12 = 'J'                   / field = single 32-bit integer
TTYPE12 = 'FNNCAL RCP'          / brightness type - step name + polarization
TUNIT12 = 'COUNTS'              / brightness units - these are raw data
TDISP12 = 'I12'                 / recommended display format
TFORM13 = 'J'                   / field = single 32-bit integer
TTYPE13 = 'FNN RCP'             / brightness type - step name + polarization
TUNIT13  = 'COUNTS'              / brightness units - these are raw data
TDISP13 = 'I12'                 / recommended display format
TFORM14 = 'J'                   / field = single 32-bit integer
TTYPE14 = 'HPN RCP'             / brightness type - step name + polarization
TUNIT14 = 'COUNTS'              / brightness units - these are raw data
TDISP14 = 'I12'                 / recommended display format
```

```
TFORM15 = 'J'                    / field = single 32-bit integer
TTYPE15 = 'ON RCP'               / brightness type - step name + polarization
TUNIT15 = 'COUNTS'               / brightness units - these are raw data
TDISP15 = 'I12'                  / recommended display format
TFORM16 = 'J'                    / field = single 32-bit integer
TTYPE16 = 'HPS RCP'              / brightness type - step name + polarization
TUNIT16 = 'COUNTS'               / brightness units - these are raw data
TDISP16 = 'I12'                  / recommended display format
TFORM17 = 'J'                    / field = single 32-bit integer
TTYPE17 = 'FNS RCP'              / brightness type - step name + polarization
TUNIT17 = 'COUNTS'               / brightness units - these are raw data
TDISP17 = 'I12'                  / recommended display format
TFORM18 = 'J'                    / field = single 32-bit integer
TTYPE18 = 'FNE RCP'              / brightness type - step name + polarization
TUNIT18 = 'COUNTS'               / brightness units - these are raw data
TDISP18 = 'I12'                  / recommended display format
TFORM19 = 'J'                    / field = single 32-bit integer
TTYPE19 = 'HPE RCP'              / brightness type - step name + polarization
TUNIT19 = 'COUNTS'               / brightness units - these are raw data
TDISP19 = 'I12'                  / recommended display format
TFORM20 = 'J'                    / field = single 32-bit integer
TTYPE20 = 'ON RCP'               / brightness type - step name + polarization
TUNIT20 = 'COUNTS'               / brightness units - these are raw data
TDISP20 = 'I12'                  / recommended display format
TFORM21 = 'J'                    / field = single 32-bit integer
TTYPE21 = 'HPW RCP'              / brightness type - step name + polarization
TUNIT21 = 'COUNTS'               / brightness units - these are raw data
TDISP21 = 'I12'                  / recommended display format
TFORM22 = 'J'                    / field = single 32-bit integer
TTYPE22 = 'FNW RCP'              / brightness type - step name + polarization
TUNIT22 = 'COUNTS'               / brightness units - these are raw data
TDISP22 = 'I12'                  / recommended display format
END

The binary table containing the data follows at the start of the next FITS
record.
```

3.2 Output file from a drift scan

This example is the output file from the observation defined in the second input file example, a `RoutinemonitoringofCirX-1`.

In this case I assume that the data will be binned to provide 12 samples per half-power beamwidth. At 3.5cm the HPBW = 0.092 degrees. Each sample is therefore a binning of 0.0077 degrees of RA. At the drift scan rate of 0.004 degrees / second this implies that each sample is an integration of 2 seconds of data. The 1.085 degree drift scan implies that there will be 1.085 / 0.0077 = 141 samples. I also assume that the existing 3.5cm receiver is in place, giving only RCP output. In this example, the raw counts from the radiometer have been scaled to Kelvins using the calibration with the noise diode.

Standard FITS format is assumed. The data are recorded in a binary table.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  = 8                    / not used as NAXIS is 0
NAXIS   = 0                    / number of data axes - no primary data array
EXTEND  =                    T / FITS dataset contains extensions
DATE    = '1999-08-17T12:25:10'/ date of creation of this HDU, UT

COMMENT  information about the object
OBJECT  = 'CIR X-1'
EQUINOX =  1950.0              / B1950 coordinate equinox
RADECSYS= 'FK4 '               / Besselian equinox, type FK4
RA      =  229.201             / RA in decimal degrees
DEC     =  303.013             / Dec in decimal degrees

COMMENT  information about the scan
OBSERVER= 'G.D. NICOLSON'
PROJECT = monitor flux of flaring binary star Circinus X-1
PROPOSAL= 1999.002
SCANTYPE= 'DRIFT'              / drift scan
SCANDIST= 1.082                / scan length, deg
RESTFREQ= 8500E6               / use 3.5cm receiver
HA      = -44.987              / HA at start of scan, degrees
ALT     =  45.305              / altitude (elevation) at middle of scan, deg
TCALCNT1=  433.5               / measured counts per Kelvin from ND cal.
DCALCNT1=  3.7                 / uncertainty in measured counts per Kelvin

COMMENT  information on the telescope and receiver configuration
TELESCOP= 'HartRAO 26M'        / telescope
SURFACE = 'PANEL 13 MISSING'   / telescope surface description
GAINFAC =  0.994               / relative to intact surface at upgrade start
SUBTILT = -0.77                / subreflector tilt, arbitrary units
SUBFOCUS=  8.00                / subreflector focus, arbitrary units
DICHROIC= 'OFF'                / dichroic was off
FEEDTYPE= 'CIRCULAR'           / circular, dual-mode feed
BMOFFHA =  0.015               / beam offset in hour angle, deg
BMOFFDC =  0.588               / beam offset in declination, deg
HABMSEP =  0.254               / beam separation, deg
HPBW    =  0.092               / halfpower beamwidth, deg
FNBW    =  0.230               / first null beamwidth, deg
RFBANDHI=  8980E6              / 10MHz filter centred on 1666 MHz, in Hz
RFBANDLO=  8180E6              / 10MHz filter centred on 1666 MHz, in Hz
NOMTSYS =  65                  / nominal zenith system temperature in Kelvins
INSTRUME= 'DICKERAD'           / instrument - dicke radiometer, beam-switching
POL1    = 'RCP'                / polarization of data for channel 1

COMMENT  information for calibrating the data
TCAL1   =  10.0                / Cal noise diode value for channel 1
TCALERR1=  0.0                 / uncertainty in Tcal1 is unknown
TCALFREQ=  8580E6              / frequency the calibration applies to, in Hz
TCALDATE= '1900-01-01'         / unknown calibration date
TCALUNIT= 'K'                  / units for cal noise diode values
```

```
CALPSS1 =  8.55                / Point source sens for channel1, Jy/K
CALPSSER=  0.12                / uncertainty in CALPSS
COMMENT  if the object is known to be unpolarised
COMMENT  double CALPSS1 and CALPSSER to get the total flux density and unc.
CALSRC  = 'B0915-11'           / object used for calibration
CALFLUX =  7.91                / total flux density assumed at CALFREQ
CALFREQ =  8580E6              / frequency the calibration applies to, in Hz
CALDATE = '1995-07-26'         / calibration date
REFERENC= 'Ott et al. (1994) AA 284, 331.'

COMMENT  information about the processing of the data
ATMCOR  = 1                    / uncorrected raw data
PNTCOR  = 1                    / uncorrected raw data
GAINCOR = 1                    / uncorrected raw data
END                            / end of HDU

        ...at the start of a new FITS record is the binary table header...

XTENSION                        / start of binary table extension
BITPIX  = 8                     / 8-bit bytes
NAXIS   = 2                     / 2-D table
NAXIS1  = 8                     / bytes per row
NAXIS2  = 141                   / number of rows
PCOUNT  = 0                     / number of bytes in extension data
GCOUNT  = 1                     / single table
TFIELDS = 2                     / number of fields (columns)

COMMENT  information about the data in the binary table
TFORM1  = 'E'                   / field = single precision floating point
TTYPE1  = 'RA'                  / type
TUNIT1  = 'deg'                 / units
TDISP1  = 'F8.3'                / recommended display format
TFORM2  = 'E'                   / field = single precision floating point
TTYPE2  = 'ANT_TEMP RCP'        / type
TUNIT2  = 'K'                   / units
TDISP2  = 'E15.9'               / recommended display format
END

The HDU is followed by the binary table comprising the 141 RA and antenna
temperature values written as binary real*4 numbers, packed in 2880-byte
blocks.
```

3.3 Output file from an active scan

This example is the output file from the first scan defined in the input file example, `Scansforalargemap`.

JJ: I have used my input file for this example. Scans are 10 degrees long, scan rate is 0.1 deg/sec, scan spacing is 0.1 deg. Each scan has its own data file. Sampling at 10 Hz, the number of data samples should be 1001 (or 1000 ???). Command coordinates not explicitly stored - they can be determined from header information.

MG: I also assumed that the existing 13cm receiver is in place, giving only RCP output. JJ in the binary table also has LCPcounts being recorded, although the preceding keywords show that only RCP is present. Dual polarization and a polarimeter would give Stokes I, Q, U and V parameters.

Standard FITS format is used, with the data stored in a binary table.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  = 8                    / not used as NAXIS is 0
NAXIS   = 0                    / number of data axes - no primary data array
EXTEND  =                    T / FITS dataset contains extensions
DATE    = '1999-08-17T12:25:10'/ date of creation of this HDU, UT

COMMENT  information about the object
OBJECT  = 'UPSCAN1'
OBJECT  = 'SCAN001X'           / directly from input file
COORDTYP= 'GALACTIC'

COMMENT  information about the scan
OBSERVER= J.L. JONAS
OBSLOCAL= G.D. NICOLSON
PROJECT = galactic plane map at 3.5cm
PROPOSAL= 1999.003
DATE-OBS= '1999-08-17T12:13:14'/ UT at start of scan, Y2K-compliant
MJD-OBS =    51187.216818750   / Modified Julian date of start of scan
SCAN    = '19990817121314'     / scan number (identifier)
SCANTYPE= 'SCAN'
GLON-TAN= 270.0                / Celestial coordinates of map centre and
GLAT-TAN= +20.0                /     type of projection used.
LONGPOLE= 0.0                  / No field rotation
STARTX  = -5.0                 / Scan start and stop offsets in
STOPX   = -5.0                 /   projected coordinate frame.
STARTY  = -5.0                 /
STOPY   = +5.0                 /
SCANTIME= 100.0                / scan duration in seconds
RESTFREQ= 2300E6               / 13cm receiver
TCALCNT1=  433.5               / measured counts per Kelvin from ND cal.
DCALCNT1=  3.7                 / uncertainty in measured counts per Kelvin

COMMENT  information on the telescope and receiver configuration
TELESCOP= 'HartRAO 26M'        / telescope
SURFACE = 'PANEL 113 MISSING'  / telescope surface description
GAINFAC =  0.992               / relative to intact surface at upgrade start
SUBTILT = -0.77                / subreflector tilt, arbitrary units
SUBFOCUS=  8.00                / subreflector focus, arbitrary units
DICHROIC= 'OFF'                / dichroic was off
FEEDTYPE= 'CIRCULAR'           / circular, dual-mode feed
BMOFFHA =  0.059               / beam offset in hour angle, deg
BMOFFDC = -0.427               / beam offset in declination, deg
HPBW    =  0.332               / halfpower beamwidth, deg
FNBW    =  0.800               / first null beamwidth, deg
RFBANDHI=  2360E6              / 10MHz filter centred on 1666 MHz, in Hz
```

```
RFBANDLO=  2210E6              / 10MHz filter centred on 1666 MHz, in Hz
NOMTSYS =  40                  / nominal zenith system temperature in Kelvins
INSTRUME= 'NARAD-NAD'          / instrument
POL1    = 'RCP'                / polarization of data for channel 1

COMMENT  information for calibrating the data
TCAL1   =  3.96                / Cal noise diode value for channel 1
TCALERR1=  0.0                 / uncertainty in Tcal1 is unknown
TCALFREQ=  2272.8E6            / frequency the calibration applies to, in Hz
TCALDATE= '1900-01-01'         / unknown calibration date
TCALUNIT= 'K'                  / units for cal noise diode values
CALPSS1 =  4.86                / Point source sens for channel1, Jy/K
CALPSSER=  0.015               / uncertainty in CALPSS
COMMENT  if the object is known to be unpolarised
COMMENT  double CALPSS1 and CALPSSER to get the total flux density and unc.
CALSRC  = 'B0915-11'           / object used for calibration
CALFLUX =  27.22               / total flux density assumed at CALFREQ
CALFREQ =  2272.8E6            / frequency the calibration applies to, in Hz
CALDATE = '1995-07-26'         / calibration date
REFERENC= 'Ott et al. (1994) AA 284, 331.'

COMMENT  information about the processing of the data
ATMCOR  = 1                    / uncorrected raw data
PNTCOR  = 1                    / uncorrected raw data
GAINCOR = 1                    / uncorrected raw data
END                            / end of HDU

        ...at the start of a new FITS record is the binary table header...

XTENSION                        / start of binary table extension
BITPIX  = 8                     / 8-bit bytes
NAXIS   = 2                     / 2-D table
NAXIS1  = 32                    / bytes per row (8 cols x 4 bytes)
NAXIS2  = 1001                  / number of rows (perhaps 1000)
PCOUNT  = 0                     / number of bytes in extension data
GCOUNT  = 1                     / single table
TFIELDS = 1                     / number of fields (columns)

COMMENT  information about the data in the binary table
TFORM1  = '1E'                  / field = single precision floating point
TTYPE1  = 'X'                   / X offset from field centre
TUNIT1  = 'DEG'                 / units
TDISP1  = 'F8.3'                / recommended display format
TFORM2  = '1E'                  / field = single precision floating point
TTYPE2  = 'Y'                   / Y offset from field centre
TUNIT2  = 'DEG'                 / units
TDISP2  = 'F8.3'                / recommended display format
TFORM3  = '1E'                  / field = single precision floating point
TTYPE3  = 'GLON'                / celestial longitide coordinate
TUNIT3  = 'DEG'                 / units
```

```
TDISP3  = 'F8.3'               / recommended display format
TFORM4  = '1E'                 / field = single precision floating point
TTYPE4  = 'GLAT'               / celestial latitude coordinate
TUNIT4  = 'DEG'                / units
TDISP4  = 'F8.3'               / recommended display format
TFORM5  = '1E'                 / field = single precision floating point
TTYPE5  = 'AZ'                 / telescope azimuth coordinate
TUNIT5  = 'DEG'                / units
TDISP5  = 'F8.3'               / recommended display format
TFORM6  = '1E'                 / field = single precision floating point
TTYPE6  = 'EL'                 / telescope elevation/altitude coordinate
TUNIT6  = 'DEG'                / units
TDISP6  = 'F8.3'               / recommended display format
TFORM7  = '1J'                 / field = 32-bit integer
TTYPE7  = 'LCPcount'           / type
TUNIT7  = 'COUNTS'             / units
TDISP7  = 'I12'                / recommended display format
TFORM8  = '1J'                 / field = 32-bit integer
TTYPE8  = 'RCPcount'           / type
TUNIT8  = 'COUNTS'             / units
TDISP8  = 'I12'                / recommended display format
END                            / end of binary table header


The header and extension are followed by the binary data table, packed in
2880-byte blocks.
```

3.4 Output file from spectroscopy

This example is the output file from the first scan defined in the input file example for spectroscopy, `monitoringamethanolmaser`.

This scan comprises a set three observations, offset NS, offset EW, and ON source, respectively, for determining the pointing error for the subsequent on-source observations. The three observations are recorded as three separate data sets. The first, for the NS pointing spectrum, is shown below.

The last two characters (NS) added to the object name indicate that this is a NS pointing observation. RAUP, DECUP, RADOWN, DECDOWN specify the actual coordinates observed. The HPBW used to offset the object coordinates for the spectra at the half-power points of the beam is listed in the telescope and receiver information.

The format again follows the FITS style.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =  8                   / not used
NAXIS   =  0                   / number of axes in data array
EXTEND  =                    T / FITS dataset may contain extensions
DATE    = '1999-08-17T12:25:10'/ date of creation of this HDU, UT

COMMENT  information about the object
OBJECT  = 'G213.71-12.60 PNTNS'/ NS pointing spectrum
GLON    =  213.710             / object coordinates from input file
```

```
GLAT    = -12.600              / object coordinates from input file

COMMENT  information about the scan
OBSERVER= 'S. GOEDHART'        / observer's name
PROJECT = 6.7-GHz methanol maser monitoring
PROPOSAL= 1999.006
DATE-OBS= '1999-08-17T12:13:14'/ UT at start of scan, Y2K-compliant
MJD-OBS =    51187.216818750   / Modified Julian date of start of scan
SCAN    = '19990817121314'     / scan number (identifier)
SCANTYPE= 'SPECTRUM'           / type of observation
RESTFREQ=  6.668518E+09        / line rest frequency in Hz
SPVLSR  =  11.0                / spectrum centre VLSR, in km/s
BW      =   640000.            / original bandwidth of spectrum in Hz
FROFFSET=   320000.            / frequency offset for fr sw sp in Hz
EQUINOX =  1999.689            / equinox in years for coords
RAUP    =  91.949              / RA of EQUINOX of object
DECUP   = -6.322               / DEC of EQUINOX + HPBW/2 (north pnt offset)
RADOWN  =  91.949              / RA of EQUINOX of object
DECDOWN = -6.438               / DEC of EQUINOX - HPBW/2 (south pnt offset)
COMMENT  the following are parameters measured during the scan
HA      = -44.987              / HA at middle of scan, degrees
ALT     =  45.305              / altitude (elevation) at middle of scan, deg
TSYS    =   59.0315            / measured system temp of SCAN in TCALUNITS
DTSYS   =   2.32639612         / measured uncertainty in TSYS in TCALUNITS
DUR     =   210.               / total integration time of SCAN in S
RMS     =   0.142293849        / expected rms noise in data in BUNITs

COMMENT  information on the telescope and receiver configuration
TELESCOP= 'HartRAO 26M'        / telescope
SURFACE = 'PANEL 103 MISSING'  / telescope surface description
GAINFAC =  0.993               / relative to intact surface at upgrade start
SUBTILT = -0.77                / subreflector tilt, arbitrary units
SUBFOCUS=  8.00                / subreflector focus, arbitrary units
DICHROIC= 'OFF'                / dichroic was off
FEEDTYPE= 'DIAGONAL'           / circular, dual-mode feed
BMOFFHA = -0.472               / beam offset in hour angle, deg
BMOFFDC =  0.010               / beam offset in declination, deg
HPBW    =  0.116               / halfpower beamwidth, deg
FNBW    =  0.000               / first null beamwidth, deg (0 = unknown)
RFBANDHI=  6668.815710E6       / sky freq at video filt upper band edge, in Hz
RFBANDLO=  6668.175710E6       / sky freq at video filt lower band edge, in Hz
NOMTSYS =  45                  / nominal zenith system temperature in Kelvins
INSTRUME= 'SPECTROMETER'       / correlator
POL1    = 'LCP'                / polarization of data for channel 1
POL2    = 'RCP'                / polarization of data for channel 2

COMMENT  information for calibrating the data
TCAL1   =  14.2                / Cal noise diode value for channel 1
TCAL2   =  14.2                / Cal noise diode value for channel 2
TCALERR1=  0.0                 / uncertainty in Tcal1 is unknown
```

```
TCALERR2=  0.0                 / uncertainty in Tcal2 is unknown
TCALFREQ=  6670E6              / frequency the calibration applies to, in Hz
TCALDATE= '1900-01-01'         / calibration date, unknown
TCALUNIT= 'K'                  / units for cal noise diode values
CALPSS1 =  7.85                / Point source sens for channel 1, Jy/K
CALPSS2 =  7.85                / Point source sens for channel 2, Jy/K
CALPSSER=  0.125               / uncertainty in CALPSS
CALSRC  = 'B0915-11'           / object used for calibration
CALFLUX =  9.99                / total flux density assumed at CALFREQ, Jy
CALFREQ =  6670E6              / frequency the calibration applies to, in Hz
CALDATE = '1995-07-26'         / calibration date
REFERENC= 'Ott et al. (1994) AA 284, 331.'

COMMENT  information about the processing of the data
COMMENT  need suffix 1 or 2 to differentiate between channels
ADDED   =  1.0                 / number of data sets averaged
FIRSTCH =  1                   / first valid pixel in data
LASTCH  =  256                 / last valid pixel in data
POLYFIT =  1                   / order of polynomial fit to baseline
FOLDED  =  0                   / =0 unfolded, =1 folded freq. sw.sp.
SMOOTHD =  0                   / =0 unsmoothed =1 smoothed
TRANSFM =  0                   / =0 spectrum =1 transform
ATMCOR  =  1.0                 / atmospheric atten. corr. applied
PNTCOR  =  1.0                 / pointing correction applied
GAINCOR =  0.0                 / antenna gain correction applied
PSS     =  0.0                 / point source sensitivity applied in Jy/K
END                            / end of HDU

        ...at the start of a new FITS record is the binary table header...

XTENSION                        / start of binary table extension
BITPIX  = 8                     / 8-bit bytes
NAXIS   = 2                     / 2-D table
NAXIS1  = 12                    / bytes per row
NAXIS2  = 256                   / number of rows
PCOUNT  = 0                     / number of bytes in extension data
GCOUNT  = 1                     / single table
TFIELDS = 1                     / number of fields (columns)

COMMENT  information about the data in the binary table
TFORM1  = 'E'                   / field = single precision floating point
TTYPE1  = 'VELO-LSR'            / type
TUNIT1  = 'KM/S'                / units
TDISP1  = 'E15.9'               / recommended display format
TFORM2  = 'E'                   / field = single precision floating point
TTYPE2  = 'ANTENNA TEMP LCP'    / type
TUNIT2  = 'K'                   / units
TDISP2  = 'E15.9'               / recommended display format
TFORM3  = 'E'                   / field = single precision floating point
TTYPE3  = 'ANTENNA TEMP RCP'    / type
```

```
TUNIT3  = 'K'                   / units
TDISP3  = 'E15.9'               / recommended display format
END                             / end of binary table header

The header and extension are followed by the binary data table, all packed
in 2880-byte blocks.
```

3.5 Output file from pulsar timing

This example is the output file from the first scan defined in the input file example for pulsar timing, `monitoringtheVelapulsar`.

This scan comprises a single observation, done with calibration.

The format again follows the FITS style.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =  8                   / not used - data not in primary data array
NAXIS   =  0                   / number of axes in data array
EXTEND  =                    T / FITS dataset contains extensions
DATE    = '1999-08-17T12:25:10'/ date of creation of this HDU, UT

COMMENT  information about the object, from input file + catalogue
OBJECT  = 'PSR0833-45'         / Vela pulsar
EQUINOX =  1984.0              / FK4? FK5?
RA      =  128.4138
DEC     = -45.00286
PLPERIOD= 0.089323102747        / seconds
PLPDRV1 = 124.4496E-15          / seconds per second
PLPDRV2 = -230.0E-25            / seconds per second**2
PLDM    = 67.321                / dispersion measure pccm-3
PLDMDRV = -0.05                 / dispersion measure derivative pccm-3s-1
PLEPOCH = 2451041.21556         / pulsar ephemeris epoch in Julian days
PLPHASE = 1000                  / set to deglitch, not latest value
PLTCONST= 150                   / post-det time constant, microseconds
PLPINT  = 500                   / integrate 500 periods at 18cm/1650MHz

COMMENT  information about the scan
OBSERVER= 'C. FLANAGAN'        / observer's name
OBSLOCAL= 'A. CHUKWUDE'        / local observer
PROJECT = daily monitoring of the Vela pulsar
PROPOSAL= 1999.007
DATE-OBS= '1999-08-17T12:13:14'/ UT at start of scan, Y2K-compliant
MJD-OBS =    51187.216818750   / Modified Julian date of start of scan
SCAN    = '19990817121314'     / scan number (identifier)
SCANTYPE= 'PULSAR'             / type of observation
RESTFREQ=  1650E+06            / rest frequency in Hz
PLPBARY =  0.893303419401E-01  / current period, at barycentre, in seconds
PLPAPP  =  0.893304195020E-01  / apparent period at epoch of obs, in seconds
PLFREQ  =  0.878760067448E+04  / sampling freq = nsamples/Papp (NAXIS1/PLPAPP)
COMMENT  the following are parameters measured during the scan
```

```
HA      = -87.987              / HA at middle of scan, degrees
ALT     =  15.305              / altitude (elevation) at middle of scan, deg
TCALCNT1=  13.374              / calibration, counts per Kelvin
DCALCNT1=  0.032               / uncertainty in calibration, counts per K

COMMENT  information on the telescope and receiver configuration
TELESCOP= 'HartRAO 26M'        / telescope
SURFACE = 'PANEL 1 MISSING'    / telescope surface description
GAINFAC =  0.997               / relative to intact surface at upgrade start
SUBTILT =  9.70                / subreflector tilt, arbitrary units
SUBFOCUS=  5.00                / subreflector focus, arbitrary units
DICHROIC= 'OFF'                / dichroic was off
FEEDTYPE= 'CIRCULAR'           / circular, dual-mode feed
BMOFFHA =  0.096               / beam offset in hour angle, deg
BMOFFDC = -0.904               / beam offset in declination, deg
HPBW    =  0.494               / halfpower beamwidth, deg
FNBW    =  1.190               / first null beamwidth, deg
RFBANDHI=  1671E6              / 10MHz filter centred on 1666 MHz, in Hz
RFBANDLO=  1661E6              / 10MHz filter centred on 1666 MHz, in Hz
NOMTSYS =  35                  / nominal zenith system temperature in Kelvins
INSTRUME= 'PULSARTIMER'        / instrument
POL1    = 'LCP'                / polarization of data for channel 1

COMMENT  information for calibrating the data
TCAL1   =  6.2                 / Cal noise diode value for channel 1
TCALERR1=  0.0                 / uncertainty in Tcal1 is unknown
TCALFREQ=  1668E6              / frequency the calibration applies to, in Hz
TCALDATE= '1900-01-01'         / unknown calibration date
TCALUNIT= 'K'                  / units for cal noise diode values
CALPSS1 =  5.13                / Point source sens for channel1, Jy/K
CALPSSER=  0.07                / uncertainty in CALPSS
CALSRC  = 'B0915-11'           / object used for calibration
CALFLUX =  36.45               / total flux density assumed at CALFREQ, Jy
CALFREQ = 1668E6               / frequency the calibration applies to, in Hz
CALDATE = '1995-07-26'         / calibration date
REFERENC= 'Ott et al. (1994) AA 284, 331.'

COMMENT  information about the processing of the data
ATMCOR  =  1.0                 / atmospheric atten. corr. applied
PNTCOR  =  1.0                 / pointing correction applied
GAINCOR =  1.0                 / antenna gain correction applied
PSS     =  0.0                 / point source sensitivity applied in Jy/K
END                            / end of HDU

        ...at the start of a new FITS record is the binary table header...

XTENSION                        / start of binary table extension
BITPIX  = 8                     / 8-bit bytes
NAXIS   = 2                     / 2-D table
NAXIS1  = 8                     / bytes per row
```

```
NAXIS2  = 785                    / number of rows
PCOUNT  = 0                      / number of bytes in extension data
GCOUNT  = 1                      / single table
TFIELDS = 1                      / number of fields (columns)

COMMENT  information about the data in the binary table
TFORM1  = 'E'                    / field = single precision floating point
TTYPE1  = 'PULSE PHASE'          / type
TUNIT1  = 'PERIOD'               / units
TDISP1  = 'E15.9'                / recommended display format
TFORM2  = 'E'                    / field = single precision floating point
TTYPE2  = 'PULSE AMPLITUDE LCP' / type
TUNIT2  = 'COUNTS'               / units
TDISP2  = 'E15.9'                / recommended display format
END                             / end of housekeeping for data set

The header and extension are followed by the binary data table, all packed
in 2880-byte blocks.
```