Robert C. Byrd Green Bank Telescope
NRAO Green Bank

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GBT SOFTWARE PROJECT NOTE 5.5

GBT Spectrometer FITS File Specification

HTML version Available[1]

Contents

Abstract

The FITS format structure is presented for the GBT spectrometer scan data files. The scan data FITS files are permanently archived after each observation, and will usually be input to the aips++ filler, which has the task of combining all scan data FITS files into an aips++ Measurement Set. This data may then either be processed further in aips++, or written out in an aips++ supported FITS format (one of which is single dish FITS).

The scan data FITS files contain both 1) a complete description of the spectrometer setup for the observation and 2) measurement data with a FITS keyword description of the data organization. The `ACT_STATE`, `PORT`, `STATE` and `SAMPLER` tables describe the setup and the `DATA` table contains measured values.

[1] http://www.gb.nrao.edu/GBT/MC/doc/dataproc/gbtSpecFits/gbtSpecFits/gbtSpecFits.html

History

8th November 2001 Penultimate definition of FITSVER 1.1; released for general comment (Richard Prestage).

16th November 2001 Final version agreed for implementation of FITSVER 1.1. No changes c.f. 8th November 2001 version. Subsequent changes to the content of this document should increment the document version number (Richard Prestage).

28th November 2001 Revised comment in PHDU section for DATE-OBS,

14th March 2002 Corrected description of ACT_STATE table (Mark Clark).

27th June 2002 Modifications for FITSVER 1.2. The polarity of the active switching signals in the `ACT_STATE` were reversed in previous versions (Mark Clark). OBJECT, PROJID, OBSID, and SCAN (Amy Shelton).

8th March 2007 Bug fix for FITSVER 2.3. The `INTEGRAT` column in `DATA` was being incorrectly written in column-dominant fashion when it should have been written in row-dominant fashion (John Ford, Melinda Mello, Mark Clark).

1 Background

All GBT scan data FITS files should conform to the standards specified in the GBT Software Project Note 4.0, "Device and Log FITS Files for the GBT." A bank of the spectrometer is created by combining the output lag data from one or more of the quadrants of the spectrometer. Each quadrant can produce up to 8 correlations simultaneously. Four GBT Spectrometer binary table extensions will be produced for each bank of the spectrometer used for the observations: `PORT`, `SAMPLER`, `STATE`, `ACT_STATE` and `DATA`, and these tables will be placed in a single scan data FITS file for each scan. Since one spectrometer FITS file will be created for each bank, a constraint on each bank output is that all correlations for a given bank will have the same number of lags. Different banks may produce correlations with different numbers of lags.

In the current version of the design (`FITSVER 1.2`) the Spectrometer Manager will not perform any FFTs, and so only correlation functions will be written to file, using the third column in the DATA table. This fact is indicated by the keyword/value pair `FFT = F` in the primary header. If in the future, we support fourier transforms and other data processing in the Spectrometer Manager, the structure definition for the FITS file will need to be modified accordingly.

2 Primary HDU keywords

The Spectrometer FITS keywords for the primary HDU conforms to the definition for common FITS headers as described in GBT Software Project Note 4.0 "Device and Log FITS Files for the GBT." Only the keywords FFT (already described), BANK and QUADRANT are added to identify the bank and set of quadrants used to generate the data. Note that the Spectrometer unlike other GBT backends produces concurrently separate files for each BANK rather than collating them into one file or forcing the selection of only one bank. The FITS file HDU provides a summary of the file contents.

The primary header keywords are as follows:

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                    8 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
ORIGIN  = 'NRAO Green Bank'    /
INSTRUME= 'Spectrometer'       / device or program of origin
GBTMCVER= '3.4.5   '           / telescope control software release
FITSVER = '1.2     '           / FITS definition version for this device
DATEBLD = 'Wed Jun 26 20:16:27 GMT 2002' / time program was linked
SIMULATE=                    0 / Is the instrument in simulate mode?
DATE-OBS= '2002-06-26T20:25:42' / Manager parameter startTime
TIMESYS = 'UTC     '           / time scale specification for DATE-OBS
TELESCOP= 'NRAO_GBT'           / Green Bank Telescope (Robert C. Byrd 100m)
OBJECT  = 'test    '           / Manager parameter source
PROJID  = 'spec1.2 '           / Manager parameter projectId
OBSID   = 'test    '           / Manager parameter scanId
SCAN    =                    1 / Manager parameter scanNumber
FFT     =                    0 / Have the data been Fourier transformed?
BANK    = 'A       '           / set of quadrants identifier
QUADRANT= '1       '           / Quadrants contributing to Bank
NLAGS   =                 8192 / number of lags in correlation function
MODE    = '1N2-0A-50-9'        / Spectrometer mode
NYQUIST =                    0 / Twice Nyquist Sampling Flag
SELFTEST=                    0 / Is the spectrometer in self-test mode?
END
```

There are seven non-standard GBT keywords. For the keyword FFT, false indicates that the `DATA` table contains lags and true indicates Fourier transformed data. The keyword BANK identifies which of four possible banks (A, B, C or D) the file represents and QUADRANT lists which of the four quadrants were used. MODE is a string used to describe the basic setup of a set of quadrants used for engineering purposes. NYQUIST indicates whether the setup will generate twice Nyquist sampling or not.

Note that the `SIMULATE` keyword indicates that the Spectrometer Manager is running in simulate mode (most likely on a machine other than the VME sparc board), and any data stored is generated by the software itself. The mode of observation where the system is actually reading out the spectrometer hardware, but the hardware is in self-test mode is described by the keyword SELFTEST.

As for all GBT scan data FITS files, the `DATE-OBS` keyword takes the value of the Manager parameter `startTime`. This is the scheduled start time for the scan as a whole. The actual time at which an integration is initiated is recorded in the `DATA` table.

3 PORT Binary Table Extension

The Spectrometer FITS keywords for the `PORT` table conforms to the definition for common FITS headers as described in GBT Software Project Note 4.0 “Device and Log FITS Files for the GBT.”

```
PORT Binary Tables Extension: Header
--------------------------------------------------------------------------------
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   43 / width of table in bytes
NAXIS2  =                    2 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    9 / number of fields in each row
TTYPE1  = 'BANK    '           / label for field   1
TFORM1  = '1A      '           / data format of field: ASCII Character
TUNIT1  = 'INDEX   '           / physical unit of field
TTYPE2  = 'PORT    '           / label for field   2
TFORM2  = '1I      '           / data format of field: 2-byte INTEGER
TUNIT2  = 'INDEX   '           / physical unit of field
TTYPE3  = 'ATTENSET'           / label for field   3
TFORM3  = '1E      '           / data format of field: 4-byte REAL
TUNIT3  = 'dBm     '           / physical unit of field
TTYPE4  = 'MEASPWR '           / label for field   4
TFORM4  = '1E      '           / data format of field: 4-byte REAL
TUNIT4  = 'V       '           / physical unit of field
TTYPE5  = 'RATIO   '           / label for field   5
TFORM5  = '1E      '           / data format of field: 4-byte REAL
TUNIT5  = 'none    '           / physical unit of field
TTYPE6  = 'LEVEL   '           / label for field   6
TFORM6  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT6  = 'COUNT   '           / physical unit of field
TTYPE7  = 'SPEED   '           / label for field   7
TFORM7  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT7  = 'Hz      '           / physical unit of field
TTYPE8  = 'BANDWDTH'           / label for field   8
TFORM8  = '1D      '           / data format of field: 8-byte DOUBLE
```

```
TUNIT8  = 'Hz      '           / physical unit of field
TTYPE9  = 'FSTART  '           / label for field   9
TFORM9  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT9  = 'Hz      '           / physical unit of field
EXTNAME = 'PORT    '           / name of this binary table extension
COMMENT   Channel Frequency Formula:
COMMENT   12.5 and 200 MHz BANDWDTH: F = FSTART + BANDWDTH * (N - 1)/NLAGS
COMMENT   50 and 800 MHz BANDWDTH: F = FSTART - BANDWDTH * (N - 1)/NLAGS
END
--------------------------------------------------------------------------------

PORT Binary Tables Extension: Data (complete)
--------------------------------------------------------------------------------

      BANK      PORT        ATTENSET         MEASPWR           RATIO         LEVEL
        1A        1I              1E              1E              1E            1J
     INDEX     INDEX             dBm               V            none         COUNT
1        A         9    1.500000E+01    4.882812E-03    0.000000E+00             9
2        A        13    1.500000E+01    4.882812E-03    0.000000E+00             9

                 SPEED               BANDWDTH                FSTART
                    1D                     1D                    1D
                    Hz                     Hz                    Hz
1   1.000000000000E+08   5.000000000000E+07   1.000000000000E+08
2   1.000000000000E+08   5.000000000000E+07   1.000000000000E+08
--------------------------------------------------------------------------------
```

The columns BANK and PORT identify an IF input into the Spectrometer and uniquely defines a row in the table.

The columns ATTENSET, MEASPWR and RATIO are associated with the total power at the port as defined by the associated attenuator setting in the Converter Rack, the resultant measured power at the Analog Filter Rack and the ratio of zero to non-zero duty cycle counts in the Spectrometer.

The column LEVEL identifies either 3 or 9 level sampling mode.

The column speed specifies either 100,000,000 or 1,600,000,000 Hz sampling speed.

The columns BANDWDTH and FSTART describe the port's frequency width; and starting frequencies as generated by the A/Ds. The center frequency for each channel may be computed using the "Channel Frequency Formula" as described in the comments.

4 STATE Binary Table Extension

The Spectrometer FITS keywords for the `STATE` table conforms to the definition for common FITS headers as described in GBT Software Project Note 4.0 "Device and Log FITS Files for the GBT." To reiterate from that document, value 0 indicates signal and non-zero indicates some reference; and value 1 indicates CAL signal was on and value 0 indicates CAL signal off. This table is used to record the commanded switching signal setup, but will not normally be needed for calibration of spectrometer data, as all the information needed for calibration will be measured and placed in the `DATA` table. An example `STATE` header, plus ASCII listing of typical table data, is given below:

```
STATE Binary Tables Extension: Header
--------------------------------------------------------------------------------
XTENSION= 'BINTABLE'           / binary table extension
```

```
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   24 / width of table in bytes
NAXIS2  =                    4 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    4 / number of fields in each row
TTYPE1  = 'BLANKTIM'           / label for field   1
TFORM1  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT1  = 'SECONDS '           / physical unit of field
TTYPE2  = 'PHSESTRT'           / label for field   2
TFORM2  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT2  = 'NONE    '           / physical unit of field
TTYPE3  = 'SIGREF  '           / label for field   3
TFORM3  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT3  = 'T/F     '           / physical unit of field
TTYPE4  = 'CAL     '           / label for field   4
TFORM4  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT4  = 'T/F     '           / physical unit of field
EXTNAME = 'STATE   '           / name of this binary table extension
NUMPHASE=                    4 / Number of Phases if only Internal Switching Sig
SWPERIOD=            4.000E+00 / Switching period
MASTER  = 'Spectrometer'       / Switching Signals Master
END
--------------------------------------------------------------------------------

STATE Binary Tables Extension: Data (complete)
--------------------------------------------------------------------------------
             BLANKTIM             PHSESTRT       SIGREF          CAL
                   1D                   1D           1J           1J
              SECONDS                 NONE          T/F          T/F
1  9.961472000000E-02   0.000000000000E+00            0            0
2  9.961472000000E-02   2.500000000000E-01            0            1
3  9.961472000000E-02   5.000000000000E-01            1            0
4  9.961472000000E-02   7.500000000000E-01            1            1
--------------------------------------------------------------------------------
```

Note that this table describes the Spectrometer's internal configuration of switching signals, it is name `STATE` in accordance with common M&C usage and convention in the other GBT backend FITS files. It is possible that the Spectrometer is being driven by external signals (or a combination of both!), and so the actual switching signals in use are given in the `ACT_STATE` table described below.

5 SAMPLER Binary Table Extension

The `SAMPLER` table describes the correlation functions. The order of the rows of the `SAMPLER` table define the order of the correlations in the `DATA` column `SAMPLER` axis in the `DATA` binary table extension (see below). An example header, plus ASCII listing of typical table data, is given below:

```
SAMPLER Binary Tables Extension: Header
--------------------------------------------------------------------------------
XTENSION= 'BINTABLE'           / binary table extension
```

```
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                  118 / width of table in bytes
NAXIS2  =                    2 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    4 / number of fields in each row
TTYPE1  = 'BANK_A'             / label for field   1
TFORM1  = '1A      '           / data format of field: 2-byte INTEGER
TUNIT1  = 'INDEX   '           / physical unit of field
TTYPE2  = 'PORT_A'             / label for field   2
TFORM2  = '1I      '           / data format of field: 2-byte INTEGER
TUNIT2  = 'INDEX   '           / physical unit of field
TTYPE3  = 'BANK_B'             / label for field   3
TFORM3  = '1A      '           / data format of field: 2-byte INTEGER
TUNIT3  = 'INDEX   '           / physical unit of field
TTYPE4  = 'PORT_B'             / label for field   4
TFORM4  = '1I      '           / data format of field: 2-byte INTEGER
TUNIT4  = 'INDEX   '           / physical unit of field
POLARIZE= 'AUTO'               / 'CROSS' implies poln measurement, else 'AUTO'
NUMSAMP =                    2 / Number of Samplers Used
SAMPUSED= '0 4     '           / Samplers used
EXTNAME = 'SAMPLER '           / name of this binary table extension
END
-------------------------------------------------------------------------------

SAMPLER Binary Tables Extension: Data (complete)
-------------------------------------------------------------------------------
ROW BANK_A   PORT_A   BANK_B   PORT_B
1     A        9        A        9
2     A       13        A       13
-------------------------------------------------------------------------------
```

Each row of the SAMPLER table describes one correlation function produced by the spectrometer. The total number of rows therefore defines the size of the second dimension (`TDESC2 = 'SAMPLER'`) of the third column (`TTYPE3 = 'DATA'`) of the `DATA` table described in Section 7, and the row number provides the index into this dimension.

Each row contains the value of two ports (which are connected directly to either a fast or slow sampler), `PORTA` and `PORTB` (range 1 to 40). For *auto* correlation, `PORTA` and `PORTB` have the same sampler number. For *cross* correlation, the samplers will have different values. For example in the case of measurement of polarization, two samplers will be used in 4 rows of this table, and the entries will be e.g. XX, XY, YX, YY where X and Y are the two samplers used. For convenience, the `POLARIZE` keyword specifies whether the scan was intended to be a polarization measurement, in which case FITS file contains cross-correlation data, otherwise it will only contain auto-correlation data.

The definitions of the `SAMPLER` table-specific keywords are as follows:

POLARIZE String describing the polarization state of the correlations. Values are AUTO or CROSS correlations.

NUMSAMP Number of samplers used for this scan. Note that `NUMSAMP` is not always the same as the number of rows in the `SAMPLER` table.

SAMPUSED The samplers which were actually used for fast (range 0 to 7) and slow (range 0 to 31) samplers.

6 ACT_STATE Binary Table Extension

The spectrometer ACT_STATE table describes the state of the calibration and switching signals input to the spectrometer at the time of the correlations. The order of the rows of the ACT_STATE table define the order of the correlations in the DATA column ACT_STATE axis in the DATA binary table extension (see below).

An example ACT_STATE header, plus ASCII listing of typical table data, is given below:

```
ACT_STATE Binary Tables Extension: Header
--------------------------------------------------------------------------------
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   24 / width of table in bytes
NAXIS2  =                    4 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    6 / number of fields in each row
TTYPE1  = 'ISIGREF '           / label for field   1
TFORM1  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT1  = 'T/F     '           / physical unit of field
TTYPE2  = 'IASIGREF'           / label for field   2
TFORM2  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT2  = 'T/F     '           / physical unit of field
TTYPE3  = 'ICAL    '           / label for field   3
TFORM3  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT3  = 'T/F     '           / physical unit of field
TTYPE4  = 'ESIGREF '           / label for field   4
TFORM4  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT4  = 'T/F     '           / physical unit of field
TTYPE5  = 'EASIGREF'           / label for field   5
TFORM5  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT5  = 'T/F     '           / physical unit of field
TTYPE6  = 'ECAL    '           / label for field   6
TFORM6  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT6  = 'T/F     '           / physical unit of field
EXTNAME = 'ACT_STATE'          / name of this binary table extension
END
--------------------------------------------------------------------------------

ACT_STATE Binary Tables Extension: Data (complete)
--------------------------------------------------------------------------------
      ISIGREF     IASIGREF         ICAL      ESIGREF     EASIGREF          ECAL
           1J           1J           1J           1J           1J            1J
          T/F          T/F          T/F          T/F          T/F           T/F
1           1            0            1            0            0             0
2           0            0            1            0            0             0
3           1            0            0            0            0             0
4           0            0            0            0            0             0
--------------------------------------------------------------------------------
```

There can be different numbers of active columns in the ACT_STATE tables corresponding to the number of switching signals selected for the bank during a scan. The Keyword NAXIS2 is the number of rows in the table and defines the number of states of the spectrometer during an integration. The number of rows in the

ACT_STATE table is a power of 2, where the power is the number of active columns of the table. For example if there are 3 switching signals used, then there will be 3 columns in the table whose values are changing from row to row resulting in 8 rows.

Note: In the above example, the states occur temporally in the order 4, 2, 3 and 1 as specified in the example STATE *table.*

The inputs to the spectrometer are arranged into two groups, internal and external inputs. There are 4 internal states and 4 external states. Only 6 of these inputs may be selected for any one scan.

The definitions of the possible ACT_STATE table columns are as follows:

ISIGREF Signal-Reference beam indicator. Value zero indicates signal beam, a non-zero value indicates a reference location.

IASIGREF Internal Advanced Signal/Reference input. This may be used to trigger some devices (especially mechanical ones) to start switching between states in advance of the ISIGREF signal.

ICAL Indicates that the switching CAL noise diode was on during the this state of the spectrometer integration. Value one indicates CAL signal was on. Value zero indicates the CAL signal off.

Identical columns labelled ESIGREF, EASIGREF and ECAL are used for the external switching signals.

6.1 A Note on Blanking

The blanking signal is generally referred to as one of the "switching" signals. However, the two levels of the blanking signal do not correspond to two different states; rather they determine whether data will be added, or ignored, into the state defined by the other switching signals. Thus the internally (or externally) generated blanking signal will never appear as one of the switching signals used in the ACT_STATE table to define the states.

If the Spectrometer is the Switching Signal Master (as recorded by the STATE table keyword MASTER, then information about the blanking applied during the scan is available from the BLANKTIM column in the STATE table. If some other device is the Master, then the information about blanking must be derived from the FITS file written by that device.

7 DATA Binary Table Extension

The DATA table contains a (large) DATA column containing correlations from one bank of the spectrometer plus coordinate values to calibrate the correlations.

An example extension header, and a subset of the data is given below:

```
DATA Binary Tables Extension: Header
--------------------------------------------------------------------------------
TENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =               262160 / width of table in bytes
NAXIS2  =                   11 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    3 / number of fields in each row
TTYPE1  = 'DMJD    '           / label for field   1
TFORM1  = '1D      '           / data format of field: 8-byte DOUBLE
```

```
TUNIT1  = 'd       '           / physical unit of field
TTYPE2  = 'INTEGRAT'           / label for field   2
TFORM2  = '16D     '           / data format of field: 8-byte DOUBLE
TUNIT2  = 'sec     '           / physical unit of field
TDIM2   = '(2,8)   '           / Structure of 3D item
TDESC2  = 'SAMPLER,ACT_STATE'  / definition of axes
TTYPE3  = 'DATA    '           / label for field   3
TFORM3  = '65536E  '           / data format of field: 4-byte REAL
TUNIT3  = 'correl  '           / physical unit of field
TDIM3   = '(32768,2,8)'        / Structure of 3D item
TDESC3  = 'LAG,SAMPLER,ACT_STATE'  / definition of axes
CRPIX1  =                1E+00 / Reference Pixel of Lag data
CRVAL1  =                0E+00 / Reference Value of Ref. Pixel
CDELT1  =                0E+00 / Time offset between Lags
HBTLNGTH=          1.31072E-03 / Length of a memory cycle (heartbeat) in seconds
HBTPERSW=                  764 / Number of heartbeats per switching period
SWPERINT=                    5 / Number of switching periods per integration
UTCSTART= 8.79800000000000E+03 / Actual start time in seconds since midnight
UTDSTART=                52192 / Actual start time in MJD
EXTNAME = 'DATA    '           / name of this binary table extension
END
-----------------------------------------------------------------------------

DATA Binary Tables Extension: Data (1 row)
-----------------------------------------------------------------------------
ROW         DMJD             INTEGRAT        DATA(63336)
1    5.4575432654E+04  5.465702024000E+00  1.2000E+05
-----------------------------------------------------------------------------
```

In this version of the Spectrometer FITS file definition, the data may only be `LAGS` (correlations). Susequent versions may allow `SPECTRA` to be stored in the table; this will required additional header keywords and/or table columns to define the data processing performed.

The `DATA` table contains rows describing each correlation obtained during the scan. Both the `INTEGRAT` and `DATA` columns contain multi-dimensional entries, with variable size axes. Within one scan all correlations must have the same number of lags. The `INTEGRAT` column is column 2, and the structure of this 2 dimensional element is specified by the keyword `TDIM2`. The `DATA` column is column 3, and the structure of this 3 dimensional element is specified by the keyword `TDIM3`. For example, in a typical polarization observation with 256 lags, a switched noise cal, but no beam switching then `DATA` has shape TDIM3=(256,4,2). The `INTEGRAT` column for this observation would have TDIM2=(4,2).

The table FITS keywords are described below:

CRPIX1 Reference lag in the DATA column. This is an index in the Lag data.

CRVAL1 Lag value for the reference lag in the data column. (usually 0)

CDELT1 Increment between samples in the DATA column.

HBTLNGTH Length in seconds of the fundamental memory cycle, i.e., the heartbeat, of the device which is synchronized to the 1 PPS.

HBTPERSW Number of heartbeats or memory cycles per switching period.

SWPERINT Number of switching periods per integration. Note that the number of integrations (or rows in the DATA table) per scan is given by NAXIS2.

UTCSTART and UTDSTART Exact start time of the scan, should differ from DATE-OBS only for use in pulsar mode.

The columns of the table are defined as follows:

DMJD Column 1 of the table contains the date and time of the start of the integration (double modified Julian day including fractional day).

INTEGRAT Column 2 of the table contains the data integration times in each of the states. The total number of elements in this column entry is $1 \times N_{sampler} \times N_{actstate}$.

DATA Third column of the table is a three dimensional array of autocorrelation lags data (float). The size of the array is $N_{lags} \times N_{sampler} \times N_{actstate}$.

TDIM2 The dimensions of the `INTEGRAT` column entry are described by this keyword. The first dimension always has only one element.

TDIM3 The dimensions of the DATA column entry are described by this keyword.

TDESC2 Type of data along the axes of the 2 dimensional table element in the second column.

TDESC3 Type of data along the axes of the 3 dimensional table element in the third column.

Note that $N_{sampler}$ is the number of rows in the `SAMPLER` table and $N_{actstate}$ is the number of rows in the `ACT_STATE` table. The `NUMSAMP` keyword in the `SAMPLER` table is not necessarily the same as $N_{sampler}$.

The purpose of the three keywords `CRPIX1, CRVAL1` and `CDELT1` is to describe the relationship of the autocorrelation data to the input IF signals. The autocorrelations could be provided in different orders (largest lag first or smallest lag first), and these keywords document this. Also note that autocorrelation data is taken from the IF 50 to 100 MHz band for the low speed samplers and IF band 800 to 1600 MHz for the high speed samplers.

The lag time for each lag in the DATA column is calculated according to the following formula:

$$Coordinate(N) = CRVAL1 + ((N - CRPIX1) \times CDELT1)$$

where N is the lag number.

8 SUMMARY

The definition of FITS file keywords and table columns conforms to the standard for the GBT project as a whole.

This version of the specification only defines the format for lag data, but includes keywords which will be used in future to determine whether a file contains lags or spectra. In the case that we begin storing the data as spectra, additional keywords and/or columns will be defined to describe the processing that has been performed.