Robert C. Byrd Green Bank Telescope
NRAO Green Bank

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GBT SOFTWARE PROJECT NOTE 4.2

Device and Log FITS Files for the GBT

HTML version Available[1]

Contents

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

Abstract

The common FITS format structure is presented for all GBT and related data files. The device FITS files for the GBT 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).

This document describes a set of keywords, a primary HDU, and three binary tables (`STATE`, `PORT`, and `DATA`) which are common among GBT FITS files. A strategy for achieving this standard is proposed. Finally, a list of GBT FITS files is given with short descriptions and references as to their construction.

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. Cosmetic changes only c.f. 8th November 2001 version. Subsequent changes to the content of this document should increment the document version number (Richard Prestage).

27th November 2001 Added the BCPM to the list of devices that produce FITS files in "Description of GBT FITS Files" (Amy Shelton).

2nd December 2004 Changed the format of the value for keyword DATEBLD to be FITS compliant for dates (Mark Clark).

1 Introduction

This document specifies and describes FITS files (labeled FITSVER 2.n) as produced by the GBT M&C and associated systems. "Device FITS files" are written during the observing process and are the resulting raw product of a scan. "Log FITS files" may be written for engineering purposes either continuously by M&C daemons or on demand by users. Both types of files contain data which has been minimally processed in order to speed storage to disk and prevent the loss of information as a result of data reduction.

Section Two of this document describes standards to be followed in the implementation of GBT FITS writers.

At the time of writing the original document, the standards proposed here were not followed (labeled FITSVER 0.0 or unidentified) by any existing GBT FITS writer. Section Three describes a proposed transition scheme.

Section Four describes the structure of the various GBT FITS files.

This document assumes a familiarity with the FITS standard and other reference documents; a full bibliography is given in Appendix A.

2 Standards for Device and Log FITS Files

2.1 General

1. All GBT FITS files shall conform to the FITS standard (i.e. SIMPLE=T).

2. The FITS file layout shall be as follows:

- The primary header composed of the required GBT header keywords, followed any application specific keywords which apply to the file as a whole.
- by convention, no primary data array
- zero or more BINTABLE, TABLE or IMAGE conforming extensions.

3. Wherever possible (i.e. where the concept being expressed is identical) existing FITS keywords shall be used. In order, the following keyword sets should be used:

- the 53 defined standard FITS keywords (Appendix B)
- the additional GBT specific standard keywords (Appendix C)
- the single dish FITS keyword set (Appendix D)
- the FCG dictionary of commonly used FITS keywords (Appendix E)
- the FCG dictionaries of keywords from other sites (Appendix F)

Keywords from the above lists should not be used for anything other than their existing meanings.

If there is no existing keyword describing the required concept, a new one may be constructed. Underscores should be used for punctuation if required (see HEASARC recommendation R1).

4. Where appropriate, use should be made of existing GBT extension structure definitions. If this is not possible, a new structure may be defined, and the standard FITS keyword EXTNAME used to indicate the purpose of the extension. With the exception of the `DATA` binary table extension, extensions with different structures should not be given the same value of EXTNAME. See individual GBT device FITS file Project Notes for existing extension names.

The EXTVER keyword should be used to distinguish different extensions of the same type and with the same value of EXTNAME in a single FITS file. The use of the keyword EXTTYPE is not recommended. See the FITS User's Guide Section 3.3.2 for more details.

5. If a new FITS extension structure is defined, the following HEASARC FITS Working Group recommendations should be followed for the construction of keywords, values and column names:

- R1: use of underscores rather than hyphens,
- R5: physical units for FITS files,
- R15 naming columns in a FITS table.

6. In general, the comment field should be used to expand on the meaning of the value, rather than to restate the information implied by the FITS rules. Unfortunately this is not possible in the case of column keywords generated by the FITSIO library. In this case, additional COMMENT card images should be used immediately preceding the card image in question to provide additional explanations if necessary. e.g:

```
COMMENT   BLANKTIM is the amount of blanking at the start of each phase
TTYPE1  = 'BLANKTIM'           / label for field 1
```

2.2 Device FITS Files Standard

2.2.1 Primary Header Keywords

The Primary Header of all GBT Device FITS file shall start with a number of required keywords as shown in the example below:

```
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= '3.3.0   '           / telescope control software release
FITSVER = '2.1     '           / FITS definition version for this device
DATEBLD = '2004-12-03T00:26:21' / time program was linked
SIMULATE=                    0 / Is the instrument in simulate mode?
DATE-OBS= '2001-11-17T15:54:13' / Manager parameter startTime
TIMESYS = 'UTC     '           / time scale specification for DATE-OBS
TELESCOP= 'NRAO_GBT'           / Green Bank Telescope (Robert C. Byrd 100m)
OBJECT  = '1950+34 '           / Manager parameter source
PROJID  = 'test    '           / Manager parameter projectId
OBSID   = 'map     '           / Manager parameter scanId
SCAN    =                  543 / Manager parameter scanNumber
 :
 :
(other application-specific keywords)
 :
 :
END
```

The first four items are mandatory FITS keywords.

ORIGIN is a reserved FITS standard keyword.

INSTRUME is the FITS standard keyword used to specify the "instrument" responsible for producing the data in the file. In the case of genuine instruments (e.g. the DCR) the appropriate name should be used. For other data sources (e.g. a Sampler value stored by the Archivist or the receiver calibration values stored by the Measurements Manager) the value of the INSTRUME keyword will be that of the program generating the FITS file.

GBTMCVER, FITSVER, DATEBLD, and SIMULATE are GBT-specific keywords.

GBTMCVER refers to the version of the M&C system in use at the time the file was created.

FITSVER refers to the version of the GBT FITS definition the file conforms to. The leading number refers to the global definition version (i.e. this document), while the trailing number refers to a revision specific to this specific type of FITS file. For example, a value of 2.5 in a Spectrometer FITS file would imply the fifth revision of the Spectrometer FITS file definition conforming to the second revision of the global GBT FITS standards.

DATEBLD is generated automatically via the Unix command "date -u +whenever the program which actually writes the FITS file is linked.

SIMULATE specifies whether the program was running in simulation mode when the file was written.

DATE-OBS is the FITS standard keyword to specify the date and time of the start of an observation. As recommended in the standard, the UTC time scale is explicitly specified using the TIMESYS keyword. This time in GBT Device files represents the nominal scheduled time and is therefore represented only to the nearest second.

TELESCOP is a reserved FITS standard keyword.

OBJECT is the FITS standard, and PROJID, OBSID and SCAN pre-existing FITS keywords used to define these quantities, and so are used here. The corresponding GBT M&C (Scan Coordinator) parameters are indicated in the comments.

The one exception to the above set of standard keywords is the scan log FITS file which does not include all of the above keywords in its primary HDU. The scan log (always named "ScanLog.fits") is a listing of all of a project's device FITS files grouped by scan. The purpose is to identify and locate all the device FITS files associated with a given scan. Since it describes many scans and therefore many scan start times, descriptions and numbers, its header does not include the keywords DATE-OBS, TIMESYS, OBSID, OBJECT, and SCAN as shown the following example.

```
ScanLog Primary Header
--------------------------------------------------------------------------------
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= 'ScanLog'            / device or program of origin
GBTMCVER= '3.3.0   '           / telescope control software release
FITSVER = '2.1     '           / FITS definition version for this device
DATEBLD = '2004-12-03T00:26:21' / time program was linked
SIMULATE=                    F / Is the instrument in simulate mode?
TELESCOP= 'NRAO_GBT'           / Green Bank Telescope (Robert C. Byrd 100m)
PROJID  = 'test    '           / Manager parameter projectId
END
```

2.2.2 PORT Binary Table Extension

The PORT binary table extension (EXTNAME=PORT) is used by GBT backends to describe their inputs. Each row is identified by BANK (character) and PORT (non-zero positive integer). Additional backend-specific columns may be included, e.g., level, speed, bandwidth, taper, threshold, attenuation, detected power, or any other port specific settings. This example header is from the Spectrometer.

```
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 =                    5 / number of fields in each row
TTYPE1  = 'BANK                / label for field   1
TFORM1  = '1A      '           / data format of field: 1-byte CHAR
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: 1-byte CHAR
TUNIT3  = 'dBm     '           / physical unit of field
TTYPE4  = 'MEASPWR '           / label for field   4
TFORM4  = '1A      '           / data format of field: 1-byte CHAR
TUNIT4  = 'INDEX   '           / physical unit of field
TTYPE5  = 'LEVEL   '           / label for field   5
TFORM5  = '1I      '           / data format of field: 2-byte INTEGER
TUNIT5  = 'COUNT   '           / physical unit of field
TTYPE6  = 'SPEED   '           / label for field   6
TFORM6  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT6  = 'HZ      '           / physical unit of field
TTYPE7  = 'BANDWDTH'           / label for field   7
TFORM7  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT7  = 'HZ      '           / physical unit of field
TTYPE8  = 'FSTART  '           / label for field   8
TFORM8  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT8  = 'Hz      '           / physical unit of field
TTYPE9  = 'FEND    '           / 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
END
```

2.2.3 STATE Binary Table Extension

The `STATE` table describes the setup of a device's switching signals. This table is used to record the commanded switching signal setup by all backends and the LO1. Note that the times specified in this table are nominal and may be modified due to implementation constraints inherent in the device generating (switching signals' master) the signals. 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  =                   20 / 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   3
TFORM2  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT2  = 'NONE    '           / physical unit of field
TTYPE3  = 'SIGREF  '           / label for field   4
TFORM3  = '1J      '           / data format of field: 2-byte INTEGER
TUNIT3  = 'T/F     '           / physical unit of field
TTYPE4  = 'CAL     '           / label for field   5
TFORM4  = '1J      '           / data format of field: 2-byte INTEGER
TUNIT4  = 'T/F     '           / physical unit of field
NUMPHASE=                    2 / Number of Phases if only Internal Switch Sig
SWPERIOD=            5.466E+00 / Switching period
MASTER  = 'Spectrometer'       / Switching Signals Master
EXTNAME = 'STATE   '           / name of this binary table extension
END
```

```
STATE Binary Tables Extension: Data (complete)
ROW   BLANKTIM  PHSESTRT    SIGREF CAL
1   9.96147E-02 .0000E+00     0     0
2   9.96147E-02 .5000E+00     0     1
```

The definitions of the `STATE` table specific keywords are given below:

NUMPHASE The number of phases in each switching period.

SWPERIOD The the length of the switching period for this scan in seconds.

MASTER The name of the selected device for driving the switching signals.

The definitions of the columns in the binary table are as follows:

BLANKTIM The number of seconds at the start of the phase before integration begins.

PHSESTRT Phase edge in fractions of a switch period. First value is always zero and following values monotonically increase but must terminate less than one.

SIGREF Value of the SIGREF switching signal where zero indicates signal.

CAL Value of the CAL switching signal where zero indicates no noise.

Specific applications my include additional columns which are state dependent, e.g., the Spectral Processor has the columns FFTS and DELETED.

2.2.4 DATA Binary Table Extension

GBT backends (DCR, Spectral Processor, Spectrometer, and Holography) use a binary table extension with EXTNAME=DATA to contain the main data array. The general structure of these extensions is the same in each case, but the specific columns are backend dependent.

The number of columns varies among backends, but the first column is always the start time for the integration time which the row of data contains. It is a double representing the Fractional Julian Date. For pulsar data or other cases where more accuracy is needed, then two additional columns containing the MJD and seconds pass UT midnight are used. The final column is the DATA itself which may be multi-dimensional. The format and units varies among backends. The keyword TDIMn and TDESCn are used to describe the dimensions and names of the data's axes.

```
TTYPE1  = 'DMJD    '           / label for field   1
TFORM1  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT1  = 'd       '           / physical unit of field
TTYPE2  = 'UTDSTART'           / label for field   2
TFORM2  = '1J      '           / data format of field: 4-byte INTEGER
TUNIT2  = 'MJD     '           / physical unit of field
TTYPE3  = 'UTCSTART'           / label for field   3
TFORM3  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT3  = 's       '           / physical unit of field
TTYPE4  = 'DATA    '           / label for field   4
TFORM4  = '32768E  '           / data format of field: 4-byte REAL
TUNIT4  = 'correl  '           / physical unit of field
EXTNAME = 'DATA    '           / name of this binary table extension
TDIM4   = '(8192,2,2)'         / Structure of 3D item (LAG, SAMPLER, ACT_STATE)
CDESC1  = 'LAGS    '           / Axis 1 of DATA
CDESC2  = 'SAMPLER '           / Axis 2 of DATA
CDESC3  = 'ACT_STATE'          / Axis 3 of DATA
```

2.3 Log FITS Files Standard

2.3.1 Primary Header Keywords

The Primary Header of all GBT Log FITS file is shown in the example below:

```
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= 'sampler2log'        / device or program of origin
GBTMCVER= '3.3.0   '           / telescope control software release
FITSVER = '2.1     '           / FITS definition version for this device
DATEBLD = '2004-12-03T00:26:21' / time program was linked
SIMULATE=                    F / Is the instrument in simulate mode?
DATE-OBS= '2001-11-17T15:54:13' / Manager parameter startTime
TIMESYS = 'UTC     '           / time scale specification for DATE-OBS
DEVICE  = 'Rcvr12_18'          / telescope's device
MANAGER = 'Rcvr12_18'          / device's manager
SAMPLER = 'gregorian'          / manager's sampler
COMMENT   Gregorian Receiver data:- monitor rate set by 'gregorianMonitorRate'
```

```
DELTA   =         6.000000E+01 / Minimum time between samples in seconds
UTSTART = 5.19454472192130E+04 / DMJD of first sample
END
```

The Log FITS file's Primary Header is similar to the Device's Primary Header. You will notice that the Log's Primary Header list contains keywords (DEVICE, MANAGER, SAMPLER, DELTA, and UTSTART) which are not in the Device's Primary Header. Conversely, the Device's Primary Header list contains keywords describing a scan (OBJECT, PROJID, OBSID, and SCAN) which the Log's keyword list does not contain since these files are not associated with telescope scans. Also not used in the Log FITS files is TELESCOPE since Log files are not necessarily tied to a specific telescope, e.g., weather stations or a central timing center.

Some of the the standard keywords have slightly difference meanings. DATE-OBS is the date and time of the first data sample in the file; as is UTSTART as Fractional Modified Julian date. The three keywords DEVICE, MANAGER, and SAMPLER unambiguously identify the source of the data in the file. In fact, the files are stored in a directory named for these keywords concatenated together with hyphens, e.g., "Rcvr12_18-Rcvr12_18-gregorian." The keyword DELTA's value is the minimum time between samples in the file. Each possible data source or M&C Sampler has a description associated with it which is included in the header as a COMMENT.

2.3.2 Log Data Binary Table

Following the Primary Header is a BINTABLE header describing the layout of the log data. Each row contains data representing the values at a specific instance. The number of columns varies among files, but the first column is always the time that the sample was taken. It is a double representing the sample's Fractional Julian Date.

```
TTYPE1  = 'DMJD    '           / label for field   1
TFORM1  = '1D      '           / data format of field: 8-byte DOUBLE
TUNIT1  = 'd       '           / physical unit of field
```

2.4 Common GBT Keywords

The keywords described previously are used in tables found in more than one GBT FITS file and are listed in Appendix C. Each GBT FITS file may introduce other keywords specific to that file which are described in its own document. In addition, there are a number of GBT keywords used across GBT FITS files that have the same meaning, but are used in different parts of the file, e.g., sometimes as a header keyword and sometimes as a column identifier. Most of these deal with the IF. These are defined here and listed in Appendix C.

BACKEND This keyword's value is the name of the device which produces a data file from the telescope astronomical signal. It is also the value of the Primary HDU keyword INSTRUME in a data FITS files. For Log and Dap FITS files it is the value of DEVICE. Examples are SpectralProcessor, Spectrometer, DCR, BCPM, and Holography.

PORT This keyword's value is an integer (starting at 1) which, along with BANK, uniquely identifies a specific input to a BACKEND which terminates the signal path. PORT is used as a header keyword in backend FITS files and a column name in the IFManager FITS file.

BANK This keyword's values is a character (*A*, *B*, *C*, ...) which describes a subset of a BACKEND's PORTs. For example, the SpectralProcessor divides its 8 PORTS into 2 BANKS (*A* and *B*) of 4 PORTs each, the Spectrometer dynamically partitions its 40 PORTs among 4 possible BANKS, and the DCR has 2 BANKs of 16 PORTs of which only one BANK may be active at a time. BACKENDs which do not partition their input PORTs are simply defaulted to BANK *A*. Like PORT, BANK is used as a header keyword in backend FITS files and a column name in the IFManager FITS file.

FEED This keyword's value is an integer (starting at 1) which identifies a physical entry point on the RECEIVER for the RF signal. Each FEED has an offset from the antenna's beam. It is used in the Antenna FITS file to specify the offset and in the IFManager FITS file to identify the origin of a telescope signal's path.

RECEPTOR This keyword's value is a name which identifies a distinct signal route, e.g., for separate polarizations, branching off from the FEED in the RECEIVER. It is used in the IFManager FITS file as part of each signal path and in the Calibration FITS file to characterize sets of calibrations.

RECEIVER This keyword's value is a name which identifies a device for capturing the RF signal from a reflector and accepting a sinusoid from the LO1 to produce the Intermediate Frequency (IF) signal, It is used in the IFManager FITS file as the first device in a signal path and in Log and Dap FITS files as the value of DEVICE. Examples are Rcvr1_2, Rcvr40_52, and RcvrPF_1.

In other words, the signal in the GBT may travel along several paths from the RECEIVER to the BACKEND. Starting at one of possibly several FEEDs on a RECEIVER, the signal may be split into separate RECEPTORs. BACKEND inputs are labeled by PORT and BANK.

3 A proposed route to adopting this standard

The following mechanism is proposed to adopt the preceeding standard:

- the absence of the FITSVER keyword in the primary header will be taken to imply FITSVER = '0.0'. The definition of Version 0.0 for each FITS writer has to be inferred from an example FITS file.
- no change will be made to any existing FITS writer unless the result conforms to this (or subsequent) standard definitions.
- the Antenna Manager, Measurements, and Spectrometer FITS writers will adopt this standard for their initial implementations (with FITSVER = '1.1').
- the Scan Coordinator, IF Manager, Archivist, Spectrometer, and Glish client FITS writers will be modified to conform to this standard first.
- the DCR, Spectral Processor and Holography FITS writers will be modified to conform to this standard as time allows.

4 Description of GBT FITS files

At the time of writing, the following Managers either create or are planned to create FITS files. The simpler FITS files are described here, othere are referenced by GBT Software Project Note identifier.

Antenna This Device FITS file is described in GBT Project Software Note 7.0, "GBT Antenna FITS File Specification."

Archivist Each device FITS files as generated by the Archivist contain time-tagged rows of values from a single M&C data monitor sampler for the duration of a scan. The selection of samplers to be included with the scan data set is fully under the control of the user via the Archivist. It is used to attach ancillary information to a scan, usually for engineering purposes. The primary HDU follows the standard with the addition of the keywords DEVICE, MANAGER, SAMPLER, DELTA, and UTSTART as described for the Log Fits files above. Since the contents of the BINTABLE are generated dynamically depending on the M&C sampler selected, the value of the keyword EXTNAME is arbitrarily given as the name of the sampler.

Berkeley Caltech Pulsar Machine (BCPM) This Device FITS file is described in GBT Project Software Note 16.0, "Berkeley Caltech Pulsar Machine FITS File Specification."

Calibration This Device FITS file is described in GBT Project Software Note 11.0, "GBT Calibration FITS File Specification." The Primary HDU follows the standard described above except the definitions of DATE-OBS, OBJECT, OBSID, and SCAN are bent a little. The file contains one or more RX_CAL_INFO tables.

DCR This Device FITS file is described in GBT Project Software Note 13.0, "GBT DCR FITS File Specification."

GO (user interface) This Device FITS file is described in GBT Project Software Note 8.0, "GBT GO FITS File Specification."

Holography This Device FITS file is described in GBT Project Software Note 9.0, "GBT Hologrphay FITS File Specification."

IFManager This Device FITS file is described in GBT Project Software Note 10.0, "GBT IFManager FITS File Specification." The Primary HDU follows the standard described above. The *IF* table is the only table in the file.

LO1 This Device FITS file is described in GBT Project Software Note 6.0, "GBT Tracking Local Oscillator FITS File Specification."

Optical Pointing Camera This Device FITS file is described in GBT Project Software Note 14.0, "GBT Optical Pointing Camera FITS File Specification."

ScanCoordinator The ScanCoordinator produces a FITS file called the scan log. There is one scan log for each project. The scan log was mentioned above as an exception to the standard primary HDU for device FITS files It is an exception because rather than describing a single scan, it describes sets of scans; indeed it is the means that one can readily determine the set of FITS files that represent a specific scan. The scan log's BINTABLE (EXTNAME is ScanLog) contains three columns: the scan nominal scheduled start time as a string (DATE-OBS), the scan number as an integer (SCAN), and a scan description as a string (FILEPATH). Each scan will produce a set of N rows with the same DMJD and SCAN. The FILEPATHs for the first (N - 2) rows are the paths (starting at the project directory) for all the FITS files for the scan. The next row's FILEPATH column contains a string indicating the scan has begun, e.g. "SCAN STARTING AT 51899 18:33:01." The purpose of this row is to indicate to any program reading the file asynchronously that the list of (N - 2) FITS files is complete. The final row for a scan contains a string indicating that the scan has ended, e.g., "SCAN FINISHED AT 51899 18:36:04." The purpose of this row is to indicate that all the contents of the FITS files have been flushed to disk and the files have been closed for writing.

SpectralProcessor This Device FITS file is described in GBT Project Software Note 12.0, "GBT Spectral Processor FITS File Specification."

Spectrometer This Device FITS file is described in GBT Project Software Note 5.0, "GBT Spectrometer FITS File Specification." The Primary HDU follows the standard described above with the addition of the keyword BANK. The file also contains the standard STATE binary table extension to describe the generated switching signals, however, the Spectrometer is able to measure the integration time for each switching signal phase regardless of their source. These values are entered into the ACT_STATE binary table extension.

All of these produce a Primary Header with no Data Array, followed by (generally a single version of) one or more binary tables extension.

A FITS documentation, standards and software

The main sources of FITS information are described at a number of web sites, in particular the FITS Support Office of the NASA Goddard Space Flight Center (http://fits.gsfc.nasa.gov). Other useful sites are the NASA High Energy Astrophysics Science Archive Research Center (http://legacy.gsfc.nasa.gov/docs/heasarc/fits.html) and the NRAO FITS page (http://www.cv.nrao.edu/fits/).

The definition of FITS is given by by the NASA/Science Office of Standards and Technology standard NOST 100-2.0 (http://fits.gsfc.nasa.gov/documents.html). A (somewhat dated) User Guide is available from the same location.

Apart from the formal standard, many of the following recommendations are based on the HEASARC FITS Format recommendations (http://legacy.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_recomm.html)

Links to a number of FITS keyword dictionaries are available from the FITS Coordinating group at http://legacy.gsfc.nasa.gov/fcg). The choice of keywords is described in more detail in section 2.1.

The Single Dish FITS convention is described in AIPS++ Note 236.

Links to a number of FITS-related software libraries and tools are available from the HEASARC web page. In particular, we recommend using FITSIO for creating FITS files, and the FTOOLS package (in particular fv, what else?) for inspecting and analyzing FITS files.

B The 53 defined standard FITS keywords

The 53 keywords currently defined in the FITS standard are as follows:

(blank)	CROTAn	EQUINOX	NAXISn	TBCOLn	TUNITn
AUTHOR	CRPIXn	EXTEND	OBJECT	TDIMn	TZEROn
BITPIX	CRVALn	EXTLEVEL	OBSERVER	TDISPn	XTENSION
BLANK	CTYPEn	EXTNAME	ORIGIN	TELESCOP	
BLOCKED	DATAMAX	EXTVER	PCOUNT	TFIELDS	
BSCALE	DATAMIN	GCOUNT	PSCALn	TFORMn	
BUNIT	DATE	GROUPS	PTYPEn	THEAP	
BZERO	DATE-OBS	HISTORY	PZEROn	TNULLn	
CDELTn	END	INSTRUME	REFERENC	TSCALn	
COMMENT	EPOCH	NAXIS	SIMPLE	TTYPEn	

A concise definition of each of these is available from the FWG html page:
http://legacy.gsfc.nasa.gov/docs/fcg/standard_dict.html

C The additional GBT specific standard keywords

BACKEND
BANDWDTH
BANK
DATEBLD
DEVICE
DELTA
FEED
FITSVER
GBTMCVER
MANAGER
PORT
RECEIVER
RECEPTOR
SAMPLER
SIMULATE
UTCSTART
UTDSTART

D The single dish FITS keyword set

This section is taken verbatim from AIPS++ Note 236

D.1 CORE keywords and columns

These must be provided in all SDFITS tables. They are essential and common to all observations and telescopes. All single dish FITS readers and writers must acknowledge (write and properly interpret) all CORE keywords.

```
OBJECT
     A string value giving an object name.
TELESCOP
     A string value giving the telescope name.
BANDWID
     The total bandwidth of the backend in units of Hertz.
DATE-OBS
     A string giving the observation date and optionally the time at the
     start using the new FITS y2k convention. The TIMESYS keyword may be
     used to indicate the time system. UTC is assumed if TIMESYS is absent.
EXPOSURE
     The effective integration time in seconds.
TSYS
     The system temperature in Kelvin.
```

D.2 SHARED keywords and columns

These have agreeded definitions and interpretations however their presense is optional. These are largely common to all observations and telescopes but not essential. These may be ignored by a single dish FITS reader.

OBSERVER
: A string giving the observer's name.

OBSID
: A string describing the observation.

PROJID
: A string describing the project.

SCAN
: A scan ID number. Typically this is an identification number given to a chunk of data when the data is taken. Not all telescopes provide a scan ID number.

OBSMODE
: The type of data and observing mode (8 characters total). The type (LINE, CONT, PULS, etc) + the mode (PSSW, FQSW, BMSQ, PLSQ, LDSW, TLPW, etc). These rules do NOT define these observing modes. Writers are strongly encouraged to use the FITS comments to document these modes.

MOLECULE
: A string used as a line identifier (with TRANSITI).

TRANSITI
: A string used as a line identifier (with MOLECULE.)

TEMPSCAL
: A string describing the scaling applied to reach the output intensity scale (''TB'',''TA'',''TA*'',''TR'',''TR*'').

FRONTEND
: A string giving the name of the front end device.

BACKEND
: A string giving the name of the back end device.

TCAL
: The calibration temp (K).

THOT
: The hot load temp (K).

TCOLD
: The cold load temp (K).

TRX
: The receiver temp (K).

FREQRES
: The frequency resolution in Hz. This may differ from the channel spacing.

TIMESYS
: The time system which applies to all time columns and keywords (see the y2k FITS DATE agreement).

VELDEF
: The velocity definition and frame (8 characters). The first 4 characters describe the velicity definition. Possible definitions include:

  RADI
  : radio

  OPTI
  : optical

  RELA
  : relativistic

  The second 4 characters describe the reference frame (e.g. ''-LSR'', ''-HEL'', ''-OBS''). If the frequency-like axis gives a frame, then the frame in VELDEF only applies to any velocities given as columns or keywords (virtual columns).

```
VFRAME
     The radial velocity of the reference frame wrt the observer. Vframe -
     Vtelescope.
RVSYS
     The radial velocity, Vsource - Vtelescope.
OBSFREQ
     The observed frequency (Hz) at the reference pixel of the
     frequency-like axis.
IMAGFREQ
     The image sideband freq (Hz) corresp. to OBSFREQ.
LST
     The LST (seconds) at the start of scan.
AZIMUTH
     The azimuth at TIME (deg) (if the TIME axis is non-degenerate, then
     this is the azimuth at the TIME of the first pixel on the TIME axis.
ELEVATIO
     The elevation at TIME (deg) (same caveat as for AZIMUTH)
TAU
     The opacity at OBSFREQ.
TAUIMAGE
     The opacity at IMAGFREQ.
TAUZENIT
     The opacity per unit air mass.
HUMIDITY
     The relative humidity (fraction, 0..1).
TAMBIENT
     The ambient temp (K).
PRESSURE
     The atmospheric pressure (mm Hg).
DEWPOINT
     The dew point (K).
WINDSPEE
     The wind speed (m/s).
WINDDIRE
     The wind direction (deg. west of north).
BEAMEFF
     The main-beam efficiency.
APEREFF
     The antenna aperture efficiency.
ETAL
     The rear spillover and scattering efficiency.
ETAFSS
     The forward spillover and scattering efficiency.
ANTGAIN
     K per Jy.
BMAJ
     The major main-beam FWHM (deg).
BMIN
     The minor main-beam FWHM (deg).
BPA
     The beam position angle (degrees east of north).
SITELONG
     The site longitude (deg).
SITELAT
```

```
     The site latitude (deg).
SITEELEV
     The site elevation (m).
RESTFREQ
     The rest frequency (Hz).
```

E The FCG dictionary of commonly used FITS keywords

http://legacy.gsfc.nasa.gov/docs/fcg/common_dict.html

```
1. Keywords that describe the data or the FITS file itself:

    TITLE FILENAME FILETYPE ROOTNAME
    PROGRAM CREATOR CONFIGUR
    NEXTEND HDUNAME HDUVER HDULEVEL
    TLMINn TLMAXn TDMINn TDMAXn TDBINn
    TSORTKEY PROGRAM CREATOR CONFIGUR
    HDUCLASS HDUDOC HDUVERS HDUCLASn

2.  Keywords that describe the observation:

    SUNANGLE MOONANGL
    RA DEC RA_NOM DEC_NOM
    RA_OBJ DEC_OBJ RA_PNT DEC_PNT PA_PNT
    RA_SCX DEC_SCX RA_SCY DEC_SXY RA_SCZ DEC_SCZ
    ORIENTAT AIRMASS LATITUDE
    OBJNAME OBS_ID

3.  Keywords that describe the instrument that took the data:

    OBS_MODE DATAMODE
    APERTURE DETNAM FILTER FILTERn GRATING GRATINGn
    SATURATE

4.  Keywords that give the date or duration of the observation:

    TIME-OBS TIME-END DATE-END
    EXPOSURE EXPTIME TELAPSE ELAPTIME ONTIME LIVETIME

5.  Keywords that denote non-standard FITS keyword format conventions:

    HIERARCH INHERIT CONTINUE

6.  File checksum keywords:

    CHECKSUM DATASUM CHECKVER

7.  Hierarchical file grouping keywords:

    GRPNAME GRPIDn GRPLCn
```

F The FCG dictionaries of keywords from other sites

http://legacy.gsfc.nasa.gov/docs/fcg/