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GBT SOFTWARE PROJECT NOTE 7.13

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## **The GBT Antenna Control Unit FITS File Specification**

HTML version Available<sup>1</sup>

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<sup>1</sup><http://www.gb.nrao.edu/GBT/MC/doc/dataproc/gbtAntFits/gbtAntFits/gbtAntFits.html>

### **Abstract**

The FITS format structure is presented for the GBT Antenna Control Unit (ACU) 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 main content of the ACU FITS file is a binary table containing a stream of the actual (indicated) telescope positions sampled at 10Hz through-out the scan.

## 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. Added keywords SITESYS and SITETYPE, and modified discussion of SITELONG, SITELAT, SITEELEV. Changed actual values used. Changed description of contents of MAJOR and MINOR if INDICSYS is OTHER. Subsequent changes to the content of this document should increment the document version number (Richard Prestage).
- 16th October 2002** Added information for initial implementation of beam offsets and multi-feed support. FITSVER revised to 1.3.
- 24th June 2003** Added OBSC\_AZ and OBSC\_EL columns. FITSVER revised to 1.4.
- 9th July 2003** Added SOBSC\_AZ, SOBSC\_EL, SMNT\_AZ, SMNT\_EL, SDMJD, OFFSYS, and ORADESYS primary header keys. FITSVER revised to 1.5.
- 15th December 2003** Added DYN\_ENA, SDYN\_AZ1, SDYN\_AZ2, SDYN\_EL, SDYN\_FTKYP, to primary header keys. Added DYN\_POINT and DYN\_FOCUS tables. FITSVER revised to 1.6.
- 30 Apr 2004** Added notes on beam offset table references. FITSVER revised to 1.7.
- 28 Feb 2006** Corrected 300ms offset in OBSC\_AZ and OBSC\_EL columns. FITSVER revised to 1.8.
- 24 Mar 2006** Added LFC\_\* and FTRK\_\* primary header keywords. FITSVER revised to 2.9.
- 17 May 2006** Added WEATHSTA primary header keyword. FITSVER revised to 2.10 (First Linux version.)
- 1 August 2007** Revised to implement pointing Model 5, revising FITSVER to 2.11. Added additional primary header keywords for new model.
- 28 September 2007** Revised to correct an error introduced in the FITSVER 2.11 version. The version 2.11 files have an error in the SOBSC\_EL keyword and OBSC\_EL column. The values omit refraction. The correct values for OBSC\_EL may be obtained by adding the values from the REFRACT column.
- 31 Jan 2008** Revised description of OBSC\_AZ and OBSC\_EL columns in primary table to include modal behavior. No version revision.
- 28 March 2008** Revised to indicate changes in manager, no FITS format changes.
- 14 May 2010** Revised section 1.6 to fix error in sign of equations showing how to apply the beam offsets.

## 1 Introduction

This document describes the GBT Antenna Control Unit (ACU) scan data FITS files. Each file contains a primary header describing various co-ordinate transformation related parameters, followed by a binary table of positions in one of three possible formats, depending on the telescope optics mode.

The reported antenna positions are derived from the values read back from the encoders. The binary table contains three versions of each position; MOUNT coordinates, FK5 J2000 co-ordinates, and the co-ordinate system in which the antenna was commanded.

This document rather briefly summarizes the structure of the ACU FITS files. More information on the philosophy and details of the co-ordinate positions and transformations represented in the files are described in GBT/SPN/015, which should be read in conjunction with this note.

*Please refer to GBT/SPN/015 for some caveats related to the validity of co-ordinate transformation corrections and the positions recorded in the ACU FITS files under certain circumstances.*

*Note: Antenna files with FITSVER equal to '1.6' have beam offset tables written with offsets relative to the axial center of the receiver mount.*

## 2 Goals of Recent Changes

### 2.1 Items new in version 1.4

Antenna fits version 1.4 adds two new columns in the main data table (3). The column names are OBSC\_AZ and OBSC\_EL, the observed commanded position for the time tag DMJD. The difference between OBSC\_AZ,OBSC\_EL and MNT\_AZ, MNT\_EL is the traditional pointing model, LPC's, and beamOffsets.

The semantics of OBSC\_AZ are mode dependent. If the offset coordinate mode Parameter is set to CABLEWRAP (i.e Encoder), then columns represent the observed command of the tracking center. Commanded offsets do not appear in the command data in this mode. If any other offset coordinate mode is selected the columns represent the observed command of the combined primary and offset position commands.

### 2.2 Items new in version 1.5

The additions in version 1.5 concerned adding a 'summary' set of keywords to the primary header which describe the commands in both observed and encoder coordinates.

### 2.3 Changes in version 1.6

Added Summary dynamic correction (SDYN\_AZ1, SDYN\_AZ2, SDYN\_EL, and SDYN\_Y) keywords. Beam offset table offsets changed as described below.

Changed definition of beam offset table. Antenna files with FITSVER equal to '1.6' have beam offset tables written with offsets relative to the axial center of the receiver mount. Assuming beamZ is the selected tracking beam, to determine the offset of a non-tracked beam with FITSVERS=1.6, use:

$$El_{beamY} = El_{indicated} - (beamY_{eloffset} - beamZ_{eloffset}) \quad (1)$$

$$Az_{beamY} = Az_{indicated} - \frac{(beamY_{xeloffset} - beamZ_{xeloffset})}{\cos(El_{beamY})} \quad (2)$$

where:  $beamZ_{xeloffset}$  and  $beamZ_{eloffset}$  are the beam offsets for the tracked beam, and  $beamY_{xeloffset}$ ,  $beamY_{eloffset}$  are the offsets for the beam in question.

All other FITVERS versions have beam offsets which are relative to the selected tracking beam, so the subtraction of the tracking beam offset is unnecessary:

$$El_{beamY} = El_{indicated} - beamY_{eloffset} \quad (3)$$

$$Az_{beamY} = Az_{indicated} - \frac{beamY_{xeloffset}}{\cos(El_{beamY})} \quad (4)$$

## 2.4 Changes in version 1.7

Restored previous definition of beam offsets. See above.

## 2.5 Changes in version 1.8

Corrected a 300ms misalignment of the OBSC\_AZ and OBSC\_EL columns. The data was associated with times that were 300ms ahead of the correct value. See <http://wiki.gb.nrao.edu/bin/view/Software/ModificationRequest3C206> for additional information.

**Note: Major number incremented to '2', indicating an update in the FITS writer support library, not a change in the antenna or FITS format.**

## 2.6 Changes in version 2.9

Added LFC\_\* and the balance of the focus tracking coefficients (FTRK\*) keywords. Extended the number of digits recorded in most fields to eight digits. The major number was changed from 1 to 2 to denote a revision of the FitsIO library.

## 2.7 Changes in version 2.10

A minor addition of the WEATHSTA primary header keyword; and a change from a Solaris based sparc host to a Linux based Pentium 4 host.

## 2.8 Changes in version 2.11

A number of changes and additions were made to implement a new pointing model, named 'Model-5'. Specific details are discussed in the modification request see: <http://wiki.gb.nrao.edu/bin/view/Software/ModificationRequest1C407> for additional information. **This version contains an error, See notes for version 2.12 below.**

- The value of the FITSVER keyword was incremented from 2.10 to 2.11 to indicate the changes to implement model-5.
- The new keywords PNTAZB02 and PNTAZD02 were added, to record the coefficient values of the new traditional model terms. The values are in radians.
- The new keywords PNTAZH00, PNTAZH01, PNTELH00, and PNTELH01 were added to record the values of the hysteresis correction coefficients.
- The new keywords PNTAZR00, PNTELR00 were added to record the values of the rate-based correction coefficients.
- The new keywords PNTLAMBDA1, PNTLAMBDA2, PNTLAMBDA3, were added to record the average value of the corrections respectively for the scan. Value are in degrees of average correction. For a concise definition of the correction, see PTCS PN-53 equation 48.
- Generally corrected the document, adding units and keywords currently written in the FITS file but not documented here.

## 2.9 Changes in version 2.12

A correction has been made to the 2.11 version which caused values of SOBSC\_EL and OBSC\_EL to be written without refraction. The corrected values for 2.11 files may be obtained by adding the values from the REFRACT column. (In the case of SOBSC\_EL, the REFRACT value at the midpoint of the scan should be used.) Note only files labelled with 2.11 have this problem.

It should be noted that all other fields in the FITS file remain correct, so observers using the sky positional columns will not note any difference in those values between 2.11 and 2.12.

## 2.10 Changes in version 2.13

Revision 2.13 denotes two changes made in the antenna manager. The first was a change to the method of velocity generation for pointing Model 5 hysteresis calculation; the second was a fix added to blend dynamic corrections over a period of several seconds, rather than introducing them as a step. Most observers will never see impact by either of these changes.

## 3 Basic File Layout

Each antenna FITS file has a number of binary tables. The primary table extension is mode dependent, to support both prime-focus and Gregorian observations.

The format is typically:

- The primary header
- The beam-offsets header and data table
- The primary data table (Extension is mode dependent)
- The dynamic pointing and data table
- The dynamic focus header and data table

The following sections describe each of these objects.

## 4 Primary Header Keyword Definitions

**LSTSTART** This lists the calculated local sidereal time in sidereal seconds since local sidereal midnight of the start time for the scan.

**SITELAT, SITELONG, SITELEV** Currently, these keyword values are the location of the intersection of the azimuth and elevation axes in the NAD 83 reference system. These values were provided by the GBT metrology group. The current values are:

Longitude: 79° 50' 23".406 W (79°839835)  
 Latitude: 38° 25' 59".236 N (38°433121)  
 Height: 824.551 m

In the future, we may modify these to be ITRF values; in any event the values may change as we refine our knowledge of the position of the telescope.

**SITESYS, SITETYPE** These keywords specify the coordinate system (datum) in use for SITELAT, SITE-LONG, SITEELEV, and whether this is a geodetic or geocentric system. The current values are ‘NAD83’, ‘GEODETTIC’.

**INDICSYS** This keyword describes the type of positions contained in the MAJOR and MINOR axis columns of the binary table. Possible values are GALACTIC, RADEC, HADEC, AZEL or OTHER. In the case of OTHER, the MAJOR and MINOR columns will contain co-ordinates in the user-defined system.

**OFFSYS** Analogous to the INDCSYS keyword, this keyword describes the command offset coordinate system.

**ORADESYS** Analogous to the RADESYS, this specifies the standard FITS keyword for the offset command coordinate system.

**RADESYS, EQUINOX** For RADEC co-ordinate systems, the RADESYS standard FITS keyword specifies the coordinate reference frame for the MAJOR and MINOR axis columns. The EQUINOX keyword denotes the epoch in use, for the MAJOR and MINOR axis columns. These are described in detail in WCS paper II.

**DELTAUTC** This specifies the UT1 - UTC offset, in use at the beginning of the scan, in seconds of time.

**IERSPMX, IERSPMY** These keywords specify the values of polar motion correction in use at the beginning of the scan.

**PFM\_CONF, PFM\_VERS** These keywords list the pointing focus model configuration name and version.

**REFMODEL** The field lists the refraction model type. Values may be one of ‘NONE’, ‘GbtComMemo16’, or ‘PTCS35.2’, meaning refraction is off, based on GBT commissioning memo 16, or PTCS note 35, version 2 respectively.

**MNTOFFAZ, MNTOFFEL** These keywords specify the encoder offset values, applied by the Az/El servo system (CCU). The values are in degrees.

**LPC\_AZ1, LPC\_AZ2, LPC\_EL** These keywords specify the user provided local pointing correction values for the scan in azimuth, cross-elevation and elevation respectively. The net contribution to pointing by the local pointing correction values can be computed by the relation:

$$az_{lpc} = LPC\_AZ1 + \frac{LPC\_AZ2}{\cos(MNT\_EL)} \quad (5)$$

$$el_{lpc} = LPC\_EL \quad (6)$$

**PNTMODEL** This keyword defines the type of pointing correction model active during the scan. The field currently has two values: ‘GBT MEMO 173’ or ‘NONE’.

**PNTAZD00, PNTAZB01, PNTAZD01, PNTAZA11, PNTAZB11, PNTAZC21, PNTAZD21, PNTAZB02, PNTAZD02** These keywords represent the values of the traditional model coefficients for the azimuth axis. The values are in **radians**, are the coefficients are listed in GBT memo 173.

**PNTELD00, PNTELC10, PNTELD10, PNTELB01, PNTELD01** These keywords represent the values of the traditional model coefficients for the elevation axis. The values are in **radians**, are the coefficients are listed in GBT memo 173.

**PNTAZH00, PNTAZH01, PNTELDH00, PNTELDH01** These keywords record the coefficient values for the hysteresis correction in azimuth and elevation. The terms are defined in the following way:

$$\Delta_{az} = H_{00} \tanh(H_{01} \dot{az}) \quad (7)$$

Where  $H_{00}$  is the maximum amplitude of the correction in radians, and the term  $H_{01}$  is the multiplier of rate, used to control the engagement sensitivity. The term  $\dot{az}$  is in radians per second.

**PNTAZR00, PNTEL R00** These keywords represent the multiplicative coefficient of axis rate, used to derive a friction correction. The term R00 is in units of radians of offset per  $\frac{\text{radians}}{\text{second}}$ .

**PNTLAMBDA1, PNTLAMBDA2, PNTLAMBDA3** The keywords represent the average values of provided from the track correction tables. The value is in degrees, and is an average value for the duration of the scan. For concise definitions of these corrections, see PTCS PN-53, equation 48.

**FTRKXDA, FTRKYDA, FTRKZDA** The GBT uses a focus tracking model of the form:

$$\text{correction} = A + B \cos(el) + C \sin(el) \quad (8)$$

for each of the 3 displacement and 3 tilt axes.

This value indicates the position focus tracking constant coefficient in millimeters, for the X, Y, Z axes.

**FTRKXDB, FTRKYDB, FTRKZDB** The value indicates the  $\cos(el)$  coefficient of the focus tracking model in millimeters.

**FTRKXDC, FTRKYDC, FTRKZDC** The value indicates the  $\sin(el)$  coefficient of the focus tracking model in millimeters.

**FTRKXTA, FTRKYTA, FTRKZTA** This value indicates the focus tracking tilt constant coefficient in degrees, for the X, Y, Z axes.

**FTRKXTB, FTRKYTB, FTRKZTB** The value indicates the  $\cos(el)$  coefficient of the focus tracking model in degrees.

**FTRKXTC, FTRKYTC, FTRKZTC** The value indicates the  $\sin(el)$  coefficient of the focus tracking model in degrees.

**LFC\_X, LFC\_Y, LFC\_Z, LFC\_XT, LFC\_YT, LFC\_ZT** These keywords describe the local focus correction coefficients used during the observation. Displacements are in millimeters, and rotations in degrees.

**DIABMODE** This value indicates the state of whether or not diurnal aberration corrections are active.

**POLARMTN** This value indicates the state of whether or not polar motion corrections are active.

**COSVMODE** This value indicates the state of the cosVMode parameter.

**AMBTEMP** Ambient temperature used for refraction calculations in degrees C

**AMBPRESS** Ambient pressure used for refraction calculations in milliBars

**AMBHUMID** Ambient humidity used for refraction calculations as a fraction (i.e. a range of 0..1.0)

**WEATHSTA** This keyword describes the source of weather information, and may take on the values: User\_Input, Weather\_Station\_1, or Weather\_Station\_2

**OPTICSMD** This value indicates the optical path configuration of the telescope. Values are 'PRIMEFOCUS OPTICS', 'GREGORIAN OPTICS' or 'STOW OPTICS'.

**FOCTRMOD** This value indicates the state of the focusTrackingMode parameter. Values may be either "OFF" or "ON".

**FOCPATM** This value indicates the state of the parallacticAngleTracking parameter. Values may be either "OFF" or "ON".

**TRCKBEAM** This value indicates the ASCII name of the tracked beam.

**TRCKBMXE** This value indicates the cross-elevation offset in degrees, with respect to the normal antenna boresight. In other words this is the offset from the position which would have been used, had the feed been placed in the center of the receiver mount. Note that the actual azimuthal offset is elevation dependent, and varies during a scan. The Az offset is defined as:

$$AzOffset = \frac{TRCKBMXE}{\cos(El)} \quad (9)$$

Note: This value is already accounted for in the (MAJOR,MINOR) and (RAJ2000,DECJ2000) columns, and is included for reference only.

**TRCKBMEL** This value indicates the elevation offset in degrees, with respect to the normal antenna boresight. In other words this is the offset from the position which would have been used, had the feed been placed in the center of the receiver mount.

Note: This value is already accounted for in the (MAJOR,MINOR) and (RAJ2000,DECJ2000) columns, and is included for reference only.

**SDMJD** Describes the time associated as the center of scan, in modified Julian day format.

**SOBSC\_AZ, SOBSC\_EL** This keyword records the refracted topocentric azimuth/elevation command at the scan midpoint. (Time indicated by the SDMJD keyword.) This position is relative to the position of the beam on the sky, rather than the position of the main reflector. Values are in degrees.

**SMNTC\_AZ, SMNTC\_EL** These keywords records the encoder azimuth/elevation command at the midpoint of the scan. (Time indicated by the SDMJD keyword.) The values are in degrees, and are representative of the commanded position of the structure with respect to the track, rather than a beam position on the sky.

**DYN\_ENA** This keyword describes whether the antenna manager is enabling external corrections.

**SDYN\_AZ1,SDYN\_AZ2,SDYN\_EL** These keywords record the dynamic pointing correction in effect for azimuth, cross-elevation and elevation respectively at the midpoint of the scan. Values are recorded in degrees.

**SDYN\_FTKYP** This keyword records the Y-axis dynamic focus correction in effect at the midpoint of the scan in millimeters.

## 5 Beam Offset Binary Table Format

The header will contain a table of data indicating the offsets of each beam relative to the selected beam. The format of the table is listed below.

**NAME** This is a string name for the named beam. The convention used is that beam names which correspond to physical feeds are numeric, and 'virtual' beams begin with a letter. The letter 'C' is usually used to indicate the center of the receiver package.

**BEAMXELOFFSET** Specifies the beam offset in cross-elevation relative to the tracking beam. Units are degrees.

**BEAMELOFFSET** Specifies the beam offset in elevation relative to the tracking beam. Units are degrees.

**SRFEED1, SRFEED2** When performing beam switching, the SRFEED1/SRFEED2 specify the sig and reference beam pair. **Note: The accuracy of this statement is in question. It is unclear at this point how the data processing scripts use this information or whether it is in use at all.**

[h]

Name	Type	Units
NAME	32A	None
BEAMXELOFFSET	1D	Degrees
BEAMELOFFSET	1D	Degrees
SRFEED1	32A	none
SRFEED2	32A	none

## 6 Primary Binary Table Column Format

The bulk of scan position data are contained in binary tables. The extension format is dependent upon the optical configuration. Three extension names are possible: ANTPOSPF, for prime focus observations, ANTPOSGR for Gregorian observations, and ANTPOSST (not a true observing mode).

In prime focus mode, the EXTNAME is 'ANTPOSPF', and the columns are shown in table 1. In Gregorian optics configurations, the EXTNAME is 'ANTPOSGR', and the column format is shown in table 2. Although not intended for general use, a third option with no secondary information is possible in stow optics mode. The EXTNAME in this mode is 'ANTPOSST'. The column format for this mode is shown in table 3.

All tables share the following fields:

- The columns labelled 'RAJ2000' and 'DECJ2000' are the indicated position of the beam on the sky in J2000 coordinates.
- The columns labelled 'MNT\_AZ' and 'MNT\_EL' represent a time series of encoder samples at 10 Hz. These readings indicate the relative angle between a point on the track and the main reflector, (i.e. the position of the structure) as opposed to the position of the beam on the sky. (Normally these are synonymous, but many receivers have feeds which are not aligned with the boresight of the antenna.)
- The columns labelled 'OBSC\_AZ' and 'OBSC\_EL' are the refracted topocentric commanded position of the beam on the sky.  
The semantics of OBSC\_AZ and OBSC\_EL are mode dependent. If the offset coordinate mode Parameter is set to CABLEWRAP (i.e Encoder), then columns represent the observed command of the tracking center. Commanded offsets do not appear in the command data in this mode. If any other offset coordinate mode is selected the columns represent the observed command of the combined primary and offset position commands.
- The column labelled 'REFRACT' is a time series of the refraction correction in elevation.
- The columns labelled 'MAJOR' and 'MINOR' are the indicated position of the beam on the sky in the same reference frame as the commands were specified in. (See the primary header keyword INDICSYS.)

The tables below describe the format for each of these data table extensions.

## 7 The Dynamic Pointing and Data Table

New to FITS version 1.6 are the dynamic pointing and focusing correction tables. These corrections are active if the values are non-zero, and the DYN\_ENA keyword in the primary header is 'ON' or non-zero.

Name	Type	Units
DMJD	1D	days
RAJ2000	1D	degrees
DECJ2000	1D	degrees
MNT_AZ	1D	degrees
MNT_EL	1D	degrees
REFRACT	1D	degrees
MAJOR	1D	degrees
MINOR	1D	degrees
OBSC_AZ	1D	degrees
OBSC_EL	1D	degrees
PF_FOCUS	1D	millimeters
PF_ROTATION	1D	degrees
PF_X	1D	millimeters

Table 1: Column format in prime focus mode

## 7.1 Dynamic Pointing Correction Table

The dynamic pointing correction table lists the corrections as they were received from the precision pointing system. Each correction remains active until the next correction update. All angular values are in degrees.

The table format is:

**DMJD** The time at which the correction became active.

**DYN\_AZ1** The azimuth AZ1 (direct azimuth offset) pointing correction in degrees.

**DYN\_AZ2** The azimuth AZ2 (cross elevation offset) pointing correction in degrees.

**DYN\_EL** The elevation pointing correction in degrees.

## 7.2 Dynamic Focus Correction Table

The dynamic focus correction table lists the corrections as they were received from the precision pointing system. Each correction remains active until the next correction update.

The table format is:

**DMJD** The time at which the correction became active.

**DYN\_Y** The Y axis focus correction in millimeters.

## 8 Example files

This section has been dropped.

<b>Name</b>	<b>Type</b>	<b>Units</b>
DMJD	1D	days
RAJ2000	1D	degrees
DECJ2000	1D	degrees
MNT_AZ	1D	degrees
MNT_EL	1D	degrees
REFRACT	1D	degrees
MAJOR	1D	degrees
MINOR	1D	degrees
OBSC_AZ	1D	degrees
OBSC_EL	1D	degrees
SR_XP	1D	millimeters
SR_YP	1D	millimeters
SR_ZP	1D	millimeters
SR_XT	1D	degrees
SR_YT	1D	degrees
SR_ZT	1D	degrees

Table 2: Column format in Gregorian optics mode

<b>Name</b>	<b>Type</b>	<b>Units</b>
DMJD	1D	days
RAJ2000	1D	degrees
DECJ2000	1D	degrees
MNT_AZ	1D	degrees
MNT_EL	1D	degrees
REFRACT	1D	degrees
MAJOR	1D	degrees
MINOR	1D	degrees
OBSC_AZ	1D	degrees
OBSC_EL	1D	degrees

Table 3: Column format in stow optics mode