AIPS Memo No. 102:

The FITS Interferometry Data Interchange Format

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Public Review Draft No. 2 (December 3 1998)

Revision history:

September 16 1998	Public review draft 1
December 3 1998	Public review draft 2. AIPS memo number added. Reference to TFORMn keyword corrected to TTYPEn in UV_DATA chapter.

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CHAPTER 1

Preface

The FITS Interferometry Data Interchange (FITS-IDI) format is a variant of FITS that may be used to archive raw radio interferometry data and to transport it between institutions. It may be used to store both interferometry data and calibration data that is associated with it.

This document is a guide to the FITS-IDI format for those who wish to create FITS-IDI files. It describes the FITS-IDI format as read by the FITLD program in the 15OCT98 release of *AIPS*.

Other Documents

The original proposal for the FITS-IDI format was *VLBA Correlator Memo No. 108: FITS Format for Interferometry Data Interchange* by P.J. Diamond, J. Benson, W.D. Cotton, D.C. Wells, J. Romney and G. Hunt (June 1997). *Memo No. 108* describes a format that differs from that actually adopted by the VLBA in a number of ways and should not be taken as an authoritative guide to the FITS-IDI format. The present document is intended to replace *Memo No. 108* as the definition of the FITS-IDI format. Support for several features that were proposed in *Memo No. 108* is not available in the current FITS-IDI format. These features may be added in future revisions.

The current definition of FITS is *NOST 100-1.2: Definition of the Flexible Image Transport System (FITS)* from the NASA Office of Standards and Technology. FITS-IDI files must conform to this standard[1].

The theory of radio interferometry is described in *Interferometry and Aperture Synthesis in Radio Astronomy* by A. Richard Thompson, James M. Moran, and George W. Swenson, Jr. (Wiley Interscience, 1986). The definitions of interferometric quantities that are used in this text correspond to those assumed in the present document except where explicitly noted.

How To Use This Document

You should begin by reading the preface and the introduction. The preface introduces the notation used in this document while the introduction provides an overview of the contents of a FITS-IDI file and introduces the terminology and conventions used to describe this data. The remaining chapters contain reference material and may be read in any order.

In the interests of keeping this document to a reasonable length, the reference chapters do not make any specific mention of any elements that can be inferred to be present from the requirements that FITS-IDI files be valid FITS files as defined by NOST 100-1.2 unless they have some additional meaning in the context of a FITS-IDI file (e.g. NAXIS values in tables). Although they are omitted from this document these elements should be taken to be mandatory in FITS-IDI files.

The Use of Fonts

Character strings that should appear in FITS-IDI files exactly as they are written will be presented in a `typewriter-like` font. This font will also be used for the names of computer programs. Character string values for FITS header keywords and for fields in FITS tables will also be written in a typewriter font but will be marked with single quotation marks, as in `'a character string'`; the quotation marks do not form a part of the string.

1. At this time NOST 100-1.2 is still a draft standard.

Some keywords used in FITS files consist of a fixed portion followed by an integer suffix that may be different in different context. These will be indicated like `NAXISn`, where the *n* denotes the integer suffix.

Parameters that may have different values under different circumstances are denoted using *this font*.

The Use of Language

The use of the word "shall" in this document should be interpreted as indicating a requirement on FITS-IDI file. The use of the words "shall not" should be interpreted as indicating a prohibition.

Notational Conventions for Types and Array Dimensions

Each keyword in a FITS header is associated with a value that has a specific type. In this document, these types are denoted by the letters shown in Table 1.

TABLE 1. Type Codes for Keyword Values

Code	Type
I	integer
L	logical
A	character string
E	floating-point number
D	date

A date is a character string in 1 of 2 specific formats. The first format is *'DD/MM/YY'*, where *DD* is a 2-digit day number, *MM* is a 2-digit month number and *YY* is the last 2 digits of the year number. This form may be used for dates in the twentieth century. The alternative format is *'YYYY-MM-DD'* where *YYYY* is a 4-digit year number, *MM* is a 2-digit month number and *DD* is a 2-digit day number. This form may be used for any date.

Although the FITS standard allows times to be appended to the second form of a date string, times should not be appended to date strings in FITS-IDI files.

Each column in a FITS binary table has a type which denotes the kinds of values that may appear in that column. Each column hold a 1-dimensional array of some base type with a fixed number of elements. The base type of an array is denoted by a single-character code in this document. These codes correspond to those used for the `TFORM`*n* values in the table header and are listed in Table 2.

TABLE 2. Basic Types for Fields in Binary Tables

Code	Type
`L`	logical
`I`	16-bit integer
`J`	32-bit integer
`A`	character
`E`	32-bit floating-point number
`D`	64-bit floating-point number

In the simplest case the number of elements in the array is given as a repeat count preceding the code for the basic type (e.g. `4J` for an array of four 32-bit integers). Some fields are, however, considered to be multidimensional arrays in FITS-IDI tables despite being declared as 1-dimensional arrays in the FITS header. In these cases the array dimensions will appear in parentheses following the basic type (e.g. `E(4, 32)` for a 2-dimensional array of 32-bit floating-point numbers with 4 rows and 32 columns). In the table header the repeat count should be the product of all the dimensions and the data in the array should be laid out so the index of the first dimension varies the fasted, followed by the second dimension and so on. The FITS-IDI format does not use the proposed multidimensional array convention described in Appendix B.2 of *NOST 100-1.2* and programs that read FITS-IDI files should not rely on the presence of `TDIM`*nn* keywords.

This document occasionally uses parenthesized dimensions for 1-dimensional arrays instead of a repeat-count prefix.

Character strings are a special case in that a 1-dimension array of characters should be taken to be a single string rather than an array of separate characters. Repeat-count prefixes will always be used to describe columns that contain character strings.

A number of arrays have dimensions that depend on the parameters of the data set or of the table to which they belong. The notations used for these parameters are listed in Table 3.

TABLE 3. Data Set Parameters

Notation	Parameter
n_{stokes}	The number of Stokes parameters in the data set
n_{band}	The number of bands in the data set
n_{chan}	The number of channels in the data set
n_{tone}	The maximum number of pulse-cal tones in a `PHASE-CAL` table
n_{orb}	The number of orbital parameters in an `ANTENNA_GEOMETRY` table
n_{poly}	The number of terms in a delay polynomial in an `INTERFEROMETER_MODEL` table
n_{tab}	The maximum number of tabulated values or terms for a gain curve in a `GAIN_CURVE` table

CHAPTER 2

Introduction

A FITS-IDI file contains raw visibility data and the information that is required in order to be able to interpret that data. It may also contain information that may be used to calibrate the raw data. Astronomical institutions mays use the FITS-IDI format to exchange data with other institutions or to archive data.

The information contained in a FITS-IDI file is carried in a set of FITS binary tables. This makes the FITS-IDI format more resilient to media errors than the random group FITS format that is commonly used to transport radio interferometry data: the effects of a single media error are confined to the table in which it occurs in the FITS-IDI file while a single media error may render an entire random groups file unusable. Programs that write FITS-IDI files may break the data into many small tables to minimize the risk to the data.

Visibility Data

The main content of a FITS-IDI file is visibility data. This is stored in one or more `UV_DATA` tables.

Measurements of the visibility function depend on several parameters including the antennas from which the signals are correlated, the polarizations of the feeds that were used at each antenna, the coordinates of the interferometer baseline, the sky frequency to which the measurement corresponds, and the polarizations measured at each antenna.

Some of these parameters can be mapped onto a regular grid. These parameters are termed *regular parameters*. Visibility measurements are arranged in a multidimensional *data matrix* in which each axis corresponds to a regular parameter. Grid cells are numbered along each axis starting with 1. The general form of the mapping between cells in the data matrix and the regular parameters is established for each axis by specifying a *reference value* for the parameter c_{val}, the grid coordinate or *reference pixel* coordinate to which this value applies p_{ref} (not necessarily an integer), and the increment in the parameter value between grid cells Δc. The parameter value corresponding to a cell at location *i* on the axis in question is then given by Equation 1.

$$c = c_{val} + (i - p_{ref}) \cdot \Delta c \qquad \textbf{(EQ 1)}$$

Frequency coordinates are a special case and will be dealt with in another section. See “Frequency Setups” on page 15.

Those parameters that are not mapped to axes of the data matrix are termed *random parameters*. Visibility data in a FITS-IDI file is stored as a set of data matrices, each of which is labelled by a set of random parameter values. Every data matrix has the same dimensions and is labelled using the same list of random parameters.

Each visibility measurement is recorded as a complex number and is assigned a real weight. There a two possible weighting conventions.

1. The weight may be a number between 0.0 and 1.0 and represents the fraction of the integration time for which valid data was accumulated. In this case it is assumed that the visibility data in the FITS-IDI file should be normalized by dividing by the weight wherever the weight is not zero.
2. The weight may be a data validity flag which either has the value 0.0 if the measurement is not valid or the value 1.0 if the measurement is valid.

Note that the second case can be regarded as a special case of the first in which data is either accumulated for the whole integration period or not at all.

A visibility measurement is assumed to be formed from the product of the output from the first antenna of a baseline pair and the complex conjugate of the output from the second antenna of the pair while baseline coordinates are assumed to be the coordinates of the first antenna of the pair with respect to the second antenna of the pair. Both conventions are consistent with those used in Interferometry and Aperture Synthesis in Radio Astronomy and in the NRAO Summer School lectures on synthesis imaging. However, the phase convention is the opposite of that used in the random groups FITS files written by the *AIPS* program `FITTP`, although the baseline convention is the same.

Arrays

The antennas used for the observations in a FITS-IDI file are grouped into *arrays*. There must be at least one array in the file and each array is assigned a number. The array numbers must be contiguous as must start with one.

A single antenna may belong to more than one array but can not be observing as part of more than one array at any given time. Interferometers may only be formed between antennas that are observing as members of the same array.

Each array has a corresponding `ARRAY_GEOMETRY` table in the FITS-IDI file. This table contains information about the time system used by the array and the coordinates of the antennas that form the array. It also specifies an *array reference frequency*. Frequencies for observations taken using this array are given relative to this frequency.

Frequency Setups

In general, a correlator produces visibility measurements at a fixed number of evenly spaced frequency channels. Each such grouping of frequencies is termed a *band*. A single interferometer can produce data for several bands. The FITS-IDI format assumes that each interferometer used in the observations produces the same number of bands and labels them by number from 1 to n_{band} so that the band number may be mapped onto one axis of the data matrix. Each band is assumed to have an identical number of channels and the channels are mapped to another axis of the data matrix.

Each band is characterized by a frequency offset, a channel bandwidth and a sideband. The frequency at the center of channel *c* in band *b* is given by Equation 2 for an upper sideband and Equation 3 for a lower sideband where ν_a is the array reference frequency, $\nu_s(b)$ is a source-specific frequency offset for band *b*, $\nu_{off}(b)$ is the frequency offset of the band, p_{ref} is the reference pixel for the frequency axis, and $\Delta\nu(b)$ is the channel spacing for the band. Note that $\Delta\nu(b)$ is always positive.

$$\nu(c, b) = \nu_a + \nu_s(b) + \nu_{off}(b) + (c - p_{ref}) \cdot \Delta\nu(b) \qquad \text{(EQ 2)}$$

$$\nu(c, b) = \nu_a + \nu_s(b) + \nu_{off}(b) + (c - (1 + n_{chan} - p_{ref})) \cdot \Delta\nu(b) \qquad \text{(EQ 3)}$$

The characteristic settings for a band may be changed during the course of the observations. At complete set of frequency offsets, channel bandwidths and sideband settings for every IF in the band is termed a *frequency setup*. The frequency setups used in the file are listed in a `FREQUENCY` table and each setup is assigned a unique number. This number is one of the random parameters of the data matrix.

Frequency setup information can be omitted from a FITS-IDI file if and only if

- there is only one band in the file,
- that band is an upper sideband, and
- the channel bandwidth is constant throughout the observations.

In this case the frequencies for each channel are calculated using Equation 1.

Sources

Each position on the sky that has been observed is termed a *source*, regardless of whether there is an actual radio source at that location. Information about the sources for which data exists in the FITS-IDI file is recorded in a `SOURCE` table. Each source is assigned a unique *source identification number.* This number is one of the random parameters of the data matrix.

Source information can be omitted if and only if the file contains observations of a single source.

Feed Polarization

Each feed on an antenna is nominally sensitive to a single hand of polarization and is given a label that indicates the polarization to which it is nominally sensitive. These labels are listed in Table 6. The horizontal axis of an alt-azimuth antenna is taken to be perpendicular to the line of sight and parallel to the horizon when the antenna is observing a source at the horizon while the vertical axis is taken to be perpendicular to the horizon. The horizontal axis of an equatorial antenna is taken to be perpendicular to the line of sight and parallel to the celestial equator when the antenna is observing a source on the equator while the vertical axis is perpendicular to the equator. A feed is said to be sensitive to horizontal linear polarization if it is primary sensitive to radiation with an electric vector parallel to the horizontal axis of the antenna.

TABLE 4. Feed Polarization Labels

Label	Nominal Sensitivity
R	Right circular (IAU convention)
L	Left circular (IAU convention)
X	Horizontal linear
Y	Vertical linear

Real feeds are not purely sensitive to one polarization but are also partially sensitive to the orthogonal polarization. This may be characterized in two ways.

The simplest is a linear approximation in which the output of a feed that is nominally sensitive to polarization *i* has the form shown in Equation 4 where E_i is the incident electric field with polarization *i*, E_j is the incident electric field with the orthogonal polarization and D_{ij} is a complex constant that is called a *leakage term* and for which $|D_{ij}| \ll 1$.

$$V_i \propto E_i + D_{ij} \cdot E_j \quad \text{(EQ 4)}$$

A more general parameterization is in terms of the orientation and ellipticity of the feed. The orientation of the feed is the angle of the major axis of the ellipse generated by the electric field to which the feed is sensitive, measure from the vertical axis as defined above and increasing counter clockwise as viewed along the line of sight. The ellipticity of the feed is the arctangent of the ratio of the minor axis of this ellipse to its major axis and is positive if the feed is sensitive to right circular polarization. The orientations and ellipticities of ideal feeds are summarized in Table 5.

TABLE 5. Orientation/Ellipticity Parameters for Ideal Feeds

Polarization	Orientation	Ellipticity
R	0°	45°
L	0°	–45°
X	0°	0°
Y	90°	0°

Information about the leakage terms associated with a feed or about the orientation and ellipticity of a feed may be carried in an ANTENNA table.

Stokes Parameters

Each visibility measurement measures a combination of two polarizations, one from each component of the interferometer. There are four possible combinations for circular polarizations that are labelled RR, LL, RL, and LR and four possible combinations for linear polarizations that are labelled XX, YY, XY and YX; in each case the first letter labels the polarization of the first input and the second that of the second input.

In either case, the simple polarizations may be combined to obtain visibility measurements for the Stokes parameters I, Q, U, and V (IAU definitions are used). FITS-IDI follows AIPS terminology by using the term “Stokes parameters” to refer to both the true Stokes parameters and the simple polarization combinations.

Each Stokes parameter is assigned a numeric code as shown in Table 6 so that the Stokes parameter may form a regular axis of the data matrix. Note that linear and circular polarizations may not be combined.

TABLE 6. Numeric Codes for Stokes Parameters

Code	Parameter
1	I
2	Q
3	U
4	V
-1	RR
-2	LL
-3	RL
-4	LR
-5	XX
-6	YY
-7	XY
-8	YX

Calibration and Flagging Information

A FITS-IDI file may also contain optional information that maybe used to calibrate and edit the data.

`FLAG` tables list data that is known or suspected to be bad and that should be removed from the data set before further processing.

`SYSTEM_TEMPERATURE` tables list system and antenna temperatures for some or all of the antennas that were used during the observations. If the system (T_s) and antenna temperatures (T_a) are known for both antennas *i* and *j* used as an interferometer pair then the true visibility $\Gamma(i, j)$ is related to the quantity measured by the interferometer $\gamma(i, j)$ by Equation 5 where *S* is the flux density of the source being observed.

$$\Gamma(i, j) = \sqrt{\frac{T_s(i)}{T_a(i)}} \cdot \sqrt{\frac{T_s(j)}{T_a(j)}} \cdot S \cdot \gamma(i, j) \qquad \text{(EQ 5)}$$

If the antenna temperatures are not known then the antenna gains $G(i)$ and $G(j)$ must be used as in Equation 6. Antenna gains are carried in a `GAIN_CURVE` table, either as tabulated values or as parameterized functions.

$$\Gamma(i, j) = \sqrt{\frac{T_s(i)}{G(i)}} \cdot \sqrt{\frac{T_s(j)}{G(j)}} \cdot \gamma(i, j) \qquad \text{(EQ 6)}$$

The hybrid case may also be used if antenna temperatures are available for one antenna of the pair and an antenna gain for the other.

FITS-IDI files may also carry phase calibration data. The phases of signals injected at discrete frequencies at some defined point in the receiver path may be measured by the correlator and are recorded in `PHASE-CAL` tables. These measurements may be used to correct bandpass phases for frequency-dependent phase offsets that have been introduced in the receiving system.

CHAPTER 3

FITS-IDI File Structure

As pointed out in the introduction, all of the data in a FITS-IDI file is carried in the form of binary tables. The primary header-data unit (HDU) contains no data.

The Primary HDU

The primary HDU serves three purposes.

1. It indicates that the file contains FITS-IDI data.
2. It carries general information that applies to all of the FITS-IDI data in the file.
3. It carries a record of the processing performed on the data up to the point that the file was written.

In addition to the keywords mandated by the FITS standard, the primary header of a FITS-IDI file shall contain the keywords listed in Table 7 on page 22 with the values shown in that table. This combination of keywords and values is the signature of a FITS-IDI file. Note that this is the header for a random groups FITS data set that contains no data.

TABLE 7. Mandatory Keywords for the Primary Header

Keyword	Value Type	Value
NAXIS	I	0
EXTEND	L	T
GROUPS	L	T
GCOUNT	I	0
PCOUNT	I	0

The keyword shown in Table 8 is used to record the version number of the VLBA software that generated a VLBA FITS-IDI export tape. This keyword triggers special processing in FITLD to deal with VLBA data that includes multiple integration times. It should not be used in FITS-IDI files from other sources.

TABLE 8. Primary Header Keywords Reserved for the VLBA

Keyword	Value Type	Value
FXCORVER	A	Version number of VLBA correlator software that produced the file

Information about the processing up to the point where the FITS file was created should be recorded in HISTORY records in the primary header.

Binary Tables

The first FITS extension in the file shall follow immediately after the primary header.

The FITS-IDI data is carried in binary tables which can be identified by the value of their EXTNAME keyword. If a table has an EXTNAME keyword that is listed in

Table 9 then it shall have the structure described in the corresponding chapter of this document..

TABLE 9. FITS-IDI Binary Tables

EXTNAME	Contents
ANTENNA	Antenna polarization information
ARRAY_GEOMETRY	Time system information and antenna coordinates
FLAG	Flagged data
FREQUENCY	Frequency setups
GAIN_CURVE	Antenna gain curves
INTERFEROMETER_MODEL	Correlator model
PHASE-CAL	Phase cal measurements
SOURCE	Sources observed
SYSTEM_TEMPERATURE	System and antenna temperatures
UV_DATA	Visibility data

TABLE 10. Proposed FITS-IDI Binary Tables

EXTNAME	Contents
BANDPASS	Bandpass functions
BASELINE	Baseline-specific gain factors
CALIBRATION	Gains as a function of time
WEATHER	Meteorological data

Other FITS extensions may be freely interleaved with these binary tables but should not use extension names listed in Table 9, Table 10, nor Table 11

TABLE 11. Extension Names Reserved for use by the VLBA

EXTNAME	Contents
CALC	Inputs to the CALC program
MODEL_COMPS	Models generated by CALC
GATEDUTY	Pulsar gating information
GATEMODL	Model used for pulsar gating
SPACECRAFT_ORBIT	Spacecraft coordinates
TAPE_STATISTICS	Tape statistics
VLBA_EPHEMERIS	Ephemeris data
VLBA_SAMPLER	Sampler settings

Common Keywords

All of the tables that are part of the FITS-IDI data set shall contain the keywords listed in Table 12. The values for OBSCODE, NO_STKD, STK_1, NO_BAND, NO_CHAN, REF_FREQ, CHAN_BW, and REF_PIXL must be the same in each table. In future revisions of the FITS-IDI format, it may be possible for a single file to contain several data sets in which case these keywords will be used to identify the data set to which a table belongs. The current version of the FITS-IDI format only allows one data set per file but these keywords are still needed to establish the overall characteristics of the data.

TABLE 12. Mandatory Keywords for FITS-IDI Tables

Keyword	Type	Value
EXTNAME	A	Table name
TABREV	I	Revision number of the table definition
NO_STKD	I	The number of Stokes parameters
STK_1	I	The first Stokes parameter
NO_BAND	I	The number of bands
NO_CHAN	I	The number of spectral channels
REF_FREQ	E	The file reference frequency in Hz

TABLE 12. Mandatory Keywords for FITS-IDI Tables

Keyword	Type	Value
CHAN_BW	E	Channel bandwidth in Hz for the first band in the frequency group with frequency ID number 1
REF_PIXL	E	The reference pixel for the frequency axis

These keywords will not necessarily be repeated in the descriptions of the individual tables in subsequent chapters.

Table Order

It is recommended that the tables be divided into three groups.

1. The ARRAY_GEOMETRY, SOURCE, and FREQUENCY tables.
2. The ANTENNA, FLAG, GAIN_CURVE, INTERFEROMETER_MODEL, PHASE-CAL and SYSTEM_TEMPERATURE tables.
3. The UV_DATA tables.

These groups should occur in the order that they are listed but the tables within each group may appear in any order.

This ordering allows FITS-IDI data to be interpreted in a single-pass through the file.

CHAPTER 4

The UV_DATA Table

A UV_DATA table contains a set of visibility data matrices. If there is more than one UV_DATA table in the file then no two tables shall contain data for overlapping times and the tables shall appear in time order in the file[1].

The Data Matrix and Random Parameters

The structure of the UV_DATA table follows the conventions established in the draft document *A FITS Binary Table Convention for Interchange of Single Dish Data in Radio Astronomy* by Harvey S. Liszt. Each row in the table contains a single data matrix that is stored in a designated column of the table. The remaining columns correspond to the random parameters. The column containing the data matrix shall be indicated by setting the string-valued keyword TTYPE*n* to 'FLUX' and the logic-valued keyword TMATX*n* to T where *n* is the number of the column containing the data matrix. The TUNIT*n* keyword shall be either have the value 'JY' or 'UNCALIB'. An NMATRIX keyword shall be present with the value 1 to indicate that there is one data matrix for each row.

1. These restrictions may be lifted in future revisions of the FITS-IDI format.

The number of axes for the data matrix shall be given as the value of the MAXIS keyword. Each axis shall have a corresponding MAXIS*n* keyword that gives the number of pixels along that axis, a CTYPE*n* keyword which gives the name of the axis, a CDELT*n* keyword that gives the parameter increment for that axis, a CRVAL*n* keyword that gives the reference value for that axis, and a CRPIX*n* keyword that gives the reference pixel coordinate.

The column containing the data matrix shall be a single-precision floating-point column and each entry in this column shall have a number of elements equal to the product of the values of the MAXIS*n* keywords.

Regular Axes

The axis names listed in Table 13 are recognized in the current version of the FITS-IDI format. Most of these are required to be present.

TABLE 13. Regular Axes for the Data Matrix

Name	Mandatory	Description
COMPLEX	yes	Real, imaginary, weight
STOKES	yes	Stokes parameter
FREQ	yes	Frequency (spectral channel)
BAND	no	Band number
RA	yes	Right ascension of phase center
DEC	yes	Declination of phase center

The COMPLEX Axis. The COMPLEX axis shall be the first (i.e. that fastest changing) axis in the data matrix. It shall have a MAXIS1 value of 2 or 3 and CDELT1, CRPIX1,and CRVAL1 shall all have the value 1.0.

The first entry on this axis contains the real component of a complex visibility and the second contains the corresponding imaginary component. If a third element is present then this shall contain the weight for this visibility measurement. See “Visibility Data” on page 13.

The STOKES Axis. The STOKES axis enumerates polarization combinations. The corresponding MAXIS*n* value shall be no less than 1 and no greater than 4. The CRPIX*n* value shall be 1.0. See “Stokes Parameters” on page 18.

The value of the MAXIS*n* keyword shall match that of the NO_STKD keyword and the value of the CRVAL*n* keyword shall match that of the STK_1 keyword. See “Common Keywords” on page 24.

The FREQ Axis. The FREQ axis enumerates frequency channels. The corresponding CRVAL*n* keyword shall have the reference frequency for array number 1 as its value. Both CRVAL*n* and CDELT*n* are given in Hz. See “Frequency Setups” on page 15.

The value of the MAXIS*n* keyword shall be identical to that of the NO_CHAN keyword, the value of the CRVAL*n* keyword shall be identical to that of the REF_FREQ keyword, the value of the CRPIX*n* keyword shall be identical to that of the REF_PIXL keyword, and the value of the CDELT*n* keyword shall be identical to that of the CHAN_BW keyword. See “Common Keywords” on page 24.

The BAND Axis. The BAND axis enumerates frequency bands. The CRVAL*n*, CRPIX*n*, and CDELT*n* keywords shall all have the value 1.0. See “Frequency Setups” on page 15.

The MAXIS*n* keyword shall have the same value as the NO_BAND keyword. See “Common Keywords” on page 24.

The BAND axis may be omitted if and only if there is only one band and there is only one frequency setup. In this case the NO_BAND keyword shall have the value 1.

The RA and DEC Axes. The RA and DEC axes shall both have MAXIS*n* values of 1. If only a single source is observed in the file and no SOURCE tables are present then the CRVAL*n* keyword for the RA axis shall give the right ascension of the phase center in degrees and the CRVAL*n* keyword for the DEC axis shall give the declination of the phase center in degrees.

If more than one source is observed in the file then the CRVAL*n* keywords for both the RA and the DEC axis shall have the value 0.0.

Random Parameters

The name of each random parameter is given as the value of the corresponding TTYPE*n* keyword. The recognized values are listed in Table 14.

TABLE 14. Random Parameter Names

Name	Type	Units	Description
UU	1D or 1E	SECONDS	*u* baseline coordinate (natural system)
VV	1D or 1E	SECONDS	*v* baseline coordinate (natural system)
WW	1D or 1E	SECONDS	*w* baseline coordinate (natural system)
UU--SIN	1D or 1E	SECONDS	*u* baseline coordinate (natural system)
VV--SIN	1D or 1E	SECONDS	*v* baseline coordinate (natural system)
WW--SIN	1D or 1E	SECONDS	*w* baseline coordinate (natural system)
UU--NCP	1D or 1E	SECONDS	*u* baseline coordinate (NCP system)
VV--NCP	1D or 1E	SECONDS	*v* baseline coordinate (NCP system)
WW--NCP	1D or 1E	SECONDS	*w* baseline coordinate (NCP system)
DATE	1D	DAYS	Julian date at 0h
TIME	1D	DAYS	Time elapsed since 0 hours
BASELINE	1J		Baseline number
ARRAY	1J or 1I		Array number
SOURCE_ID	1J or 1I		Source ID number
FREQID	1J or 1I		Frequency ID number
INTTIM	1D or 1E	SECONDS	Integration time
WEIGHT	E(n_{stokes}, n_{band})		Weights
GATEID	1J		VLBA specific
FILTER	1J		VLBA specific

Baseline Coordinates. Three of the random parameters shall be used to specify the baseline coordinates for the visibility measurements in light seconds. The three coordinates are designated by names that begin with UU, VV, and WW, which correspond to the *u*, *v*, and *w* coordinates. The first two letters of the name may be followed by an optional suffix that indicates the coordinate system used for the baseline coordinates.

If the suffix is --SIN then the *w* axis lies along the line of sight to the source and the *u* and *v* axes lies in a plane perpendicular to line of sight with *v* increasing to the north and with *u* increasing to the east.

If the suffix is --NCP then the *w* axis points to the north pole, the *v* axis is parallel to the projection of the line of sight into the equator with the *v* coordinate increasing away from the source and the *u* coordinate completes the right-handed Cartesian triad (*u*, *v*, *w*).

The suffixes must match on all three baseline coordinate parameters.

If the suffix is omitted then the --SIN convention is assumed.

Important Note. VLBA archive data incorrectly labels the *u*, *v*, and *w* parameters as UU-L, VV-L, WW-L and versions of FITLD prior to the 15OCT98 release of *AIPS* will only recognize these incorrect forms of the labels. This is an error[1]. These labels should not appear in FITS-IDI files. In 15OCT98 and later releases of *AIPS*, FITLD recognizes the correct forms of these labels and handles archival data that contains this error by treating UU-L, VV-L, and WW-L as equivalent to UU--SIN, VV--SIN, and WW--SIN.

Date and Time. Two random parameters shall be used to record the time at which the visibility measurements in a record were taken. The value of the DATE parameter shall be the Julian date at midnight on the day the measurement was made using the appropriate time system for the array used for the measurement. The TIME parameter shall be the number of days that have elapsed since midnight.

The time recorded using DATE and TIME shall be the central time in the integration period and shall also be the time at which the *u*, *v*, *w* coordinates are valid.

1. The -L suffix is conventionally interpreted to indicate a baseline coordinate that is given in wavelengths.

Integration Time. The length of the period over which data were integrated may optionally be supplied in seconds as the value of the TIMINT parameter.

Baseline Specification. The baseline from which the data were obtained shall be specified using two parameters. The ARRAY parameter shall give the number of the array that was used for the observations and the BASELINE parameter shall give the antenna numbers of the two antennas in this array.

The baseline number is formed by multiplying the number of the first antenna by 256 and then adding the number of the second antenna.

The ARRAY parameter may be omitted if there is only one array defined in the file.

Source Identification Number. If the file contains observations of more than one source then the identification number of the source being observed shall be given as the value of the SOURCE_ID parameter.

Frequency Setup Number. If the file contains observations made using more than one frequency setup then the identification of the frequency setup that was used shall be recorded as the value of the FREQID parameter.

Weights. If the weights assigned to all spectral channels in a band are guaranteed to be identical the weights may be recorded in a WEIGHT random parameter. The value of this parameter shall be an array that is indexed by band number and by pixel coordinates on the STOKES axis. Each element in this array is the weight that should be given to data points for that band and polarization.

If MAXIS1 has the value 2 then a WEIGHT parameter must be present. Conversely, a WEIGHT parameter must no be present if MAXIS1 has the value 3.

Header Keywords

The keywords and values shown in Table 15 must appear in the header of each UV_DATA table.

TABLE 15. Mandatory UV_DATA Table Keywords

Keyword	Type	Value
EXTNAME	A	'UV_DATA'
TABREV	I	2
NMATRIX	I	1
MAXIS	I	See "Regular Axes" on page 28.
MAXISn	I	See "Regular Axes" on page 22.
CTYPEn	I	See "Regular Axes" on page 22.
CDELTn	E	See "Regular Axes" on page 22.
CRPIXn	E	See "Regular Axes" on page 22.
CRVALn	E	See "Regular Axes" on page 22.
TMATXn	L	See "Regular Axes" on page 28.
OBSCODE	A	See "Common Keywords" on page 18.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 18.
NO_BAND	I	See "Common Keywords" on page 18.
NO_CHAN	I	See "Common Keywords" on page 18.
REF_FREQ	E	See "Common Keywords" on page 18.
CHAN_BW	E	See "Common Keywords" on page 18.
REF_PIXL	E	See "Common Keywords" on page 18.

The keywords and values shown in Table 16 are optional.

TABLE 16. Optional UV_DATA Table Keywords

Keyword	Type	Value
DATE-OBS	D	Observing date
TELESCOP	A	Telescope name
OBSERVER	A	Observer's name
VIS_SCAL	E	Visibility scale factor
SORT	A	Sort order

Observing Date. The observing date shall be the date on which the observations were taken.

Telescope Name. The telescope name shall be a short string that is used to identify the instrument used to make the observations. This will normally identify the correlator.

Observer's Name. The observer's name will be a short string that is used to identify the observer or the project to which the data belong.

Visibility Scaling Factor. The visibility scaling factor is a normalization factor which should be used to divide the amplitudes of all of the visibility data. This may be used to reduce the computational load on near-real time systems: such systems may write accumulated sums in the data matrix and store the normalization factor as the value of this keyword.

Sort Order. The sort order is a string of two letters that indicate that the data in the UV_DATA table are sorted. The first letter gives the primary sort key and the second letter the secondary sort key. In other words the data are sorted in the order specified by the first letter and those records with identical values of this key are sorted according to the second letter.

The sort codes are listed in Table 17.

TABLE 17. Sort Codes for the UV_DATA Table

Code	Sort Key
*	no key
T	time (ascending)
B	baseline number (ascending)
X	*u* coordinate (ascending)
Y	*v* coordinate (ascending)

Differences from Earlier Revisions of this Table

The VLBA currently writes `UV_DATA` tables with a revision number of 2. There appear to be no significant changes between revision 1 and revision 2 of this table.

CHAPTER 5

The ARRAY_GEOMETRY Table

The ARRAY_GEOMETRY tables define the arrays used in the file. Each ARRAY_GEOMETRY table lists the antennas that are part of that array together with their coordinates. It also provides information about the time system used for that array.

The Table Header

The table header shall contain the keywords and values listed in Table 18.

TABLE 18. **Mandatory Keywords for the ARRAY_GEOMETRY table**

Keyword	Type	Value
EXTNAME	A	‘ARRAY_GEOMETRY’
TABREV	I	1
EXTVER	I	Array number
ARRNAM	A	Array name
FRAME	A	Coordinate frame
ARRAYX	E	*x* coordinate of array center

TABLE 18. **Mandatory Keywords for the ARRAY_GEOMETRY table**

Keyword	Type	Value
ARRAYY	E	*y* coordinate of array center
ARRAYZ	E	*z* coordinate of array center
NUMORB	I	n_{orb}
FREQ	E	Reference frequency
TIMSYS	A	Time system
RDATE	D	Reference date
GSTIA0	E	GST at 0h on reference data
DEGPDY	E	The Earth's rotation rate
UT1UTC	E	UT1 - UTC
IATUTC	E	IAT - UTC
POLARX	E	*x* coordinate of north pole
POLARY	E	*y* coordinate of north pole
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.
NO_CHAN	I	See "Common Keywords" on page 24.
REF_FREQ	E	See "Common Keywords" on page 24.
CHAN_BW	E	See "Common Keywords" on page 24.
REF_PIXL	E	See "Common Keywords" on page 24.

Array Number. The array number for the array described by an ARRAY_GEOMETRY file shall be recorded as the value of the EXTVER keyword. Each ARRAY_GEOMETRY table in a FITS-IDI file must have a distinct value of EXTVER and there must be an ANTENNA_GEOMETRY table with an EXTVER value of 1.

Array Name. The value of the ARRNAM keyword shall be an array name that may be used in reports presented to human readers. Array names need not be unique and may not be longer than 8 characters.

Coordinate Frame. The value of the FRAME keyword shall be a string that identifies the coordinate system used for the antenna coordinates.

If the FRAME keyword has the value 'GEOCENTRIC' then the coordinates are given in an earth-centred, earth-fixed, Cartesian reference frame. The origin of the coordinates is the earth's centre of mass. The *z* axis is parallel to the direction of the conventional origin for polar motion. The *x* axis is parallel to the direction of the intersection of the Greenwich meridian with the mean astronomical equator. The *y* axis completes the right-handed, orthogonal coordinate system. The coordinates are given in meters.

No other values for the FRAME keyword may be used. Other coordinate definitions may be added in future revisions of the FITS-IDI format.

Array Center. The ARRAYX, ARRAYY, and ARRAYZ keywords shall give the coordinates of the array center in the coordinate frame specified by the FRAME keyword. Antenna coordinates in the main part of the table are given relative to the array center.

Number of Orbital Parameters. The value of the NUMORB keyword shall be the number of elements in the ORBPARM array in the main part of the table. This shall either be 0 or 6.

Reference Frequency. The value of the FREQ keyword shall be the reference frequency for the array described by the ARRAY_GEOMETRY table in Hz. See "Frequency Setups" on page 15.

If the array number is 1 then the value of the FREQ keyword shall be identical to that of the REF_FREQ keyword. See "Common Keywords" on page 24.

Time System. The TIMSYS keyword shall specify the time system used for the array. It shall either have the value 'IAT', denoting international atomic time, or have the value 'UTC', denoting coordinated universal time. This indicates whether the zero hour for the TIME parameter in the UV_DATA table is midnight IAT or midnight UTC.

Reference Date. The value of the RDATE parameter will be the date for which the time system parameters GSTIA0, DEGPDY, UT1UTC, and IATUTC apply. If the table contains orbital parameters for orbiting antenna this keyword also designates the epoch for the orbital parameters. See "Orbital Parameters" on page 41.

GST at Midnight. The value of the GSTIA0 keyword shall be the Greenwich sidereal time in degrees at zero hours on the reference date for the array in the time system specified by the TIMSYS keyword.

Earth Rotation Rate. The value of the DEGPDY keyword shall be the rotation rate of the Earth in degrees per day on the reference date for the array.

Difference between UT1 and UTC. The value of the UT1UTC keyword shall be the difference between UT1 and UTC in seconds on the reference date for the array.

Difference between IAT and UTC. The value of the IATUTC keyword shall be the difference between IAT and UTC in seconds on the reference date for the array. Note that this always has an integral value and is the same as the number of accumulated leap seconds on that date.

Polar Position. The values of the POLARX and POLARY keywords shall give the *x* and *y* offsets of the North pole in meters on the reference date for the array with respect to the coordinate system specified using the FRAME keyword.

Table Structure

Each row in the table provides information about a single antenna. Each of the columns listed in Table 19 must be present. The order of the columns does not matter.

TABLE 19. Mandatory Columns for the ANTENNA_GEOMETRY Table

Title	Units	Type	Description
ANNAME	METERS	8A	Antenna name
STABXYZ	METER/S	3D	Station coordinates
DERXYZ		3E	First order derivatives of the station coordinates with respect to time
ORBPARM		D(n_{orb})	Orbital parameters
NOSTA		1J	Station number
MNTSTA		1J	Mount type
STAXOF	METERS	3E	Axis offset

Antenna Name. The antenna name shall be a character string that may be used to identify the antenna for a human user.

Station Coordinates. The `STABXYZ` array shall give the coordinate vector (element one is the *x* coordinate, element 2 is the *y* coordinate, and element 3 is the *z* coordinate) of the antenna relative to the array centre defined in the header provided that the antenna is not an orbiting antenna. The coordinate system used for the antenna coordinates is indicated by the value of the `FRAME` keyword in the header.

The `DERXYZ` array shall give the first-order derivatives of the antenna coordinate vector with respect to time (in seconds) provided that the antenna is not an orbiting antenna.

Orbital Parameters. If the antenna is an orbiting antenna and orbital information is available then the `ORBPARM` array will contain the orbital parameters for the reference antenna as shown in Table 20. The orbital elements shall be those for 0 hours on the reference date for the array in the time system used for the array. The reference frame for the orbital parameters shall be the same as that used for the *u*, *v*, *w* coordinates in the `UV_DATA` table.

TABLE 20. Contents of the ORBPARM Array

Index	Parameter	Units
1	Semi-major axis of orbit (a)	meters
2	Ellipticity of orbit (e)	
3	Inclination of the orbit to the celestial equator (i)	degrees
4	The right ascension of the ascending node (Ω)	degrees
5	The argument of perigee (ω)	degrees
6	The mean anomaly (M)	degrees

The dimension of the `ORBPARM` array is given by the `NUMORB` keyword. If the value associated with `NUMORB` is zero then the table can not contain orbital elements. If `NUMORB` is 6 then all 6 orbital elements shall be set to NaN for all antennae for which `MNTSTA` is not 2.

Station Number. The `NOSTA` column shall contain a positive integer value that uniquely identifies the antenna within the array. If the same antenna appears in more than one array it need not have the same station number in each array.

This is the antenna identification number that is used in other FITS-IDI tables.

Mount Type. The `MNTSTA` column shall contain an integer value that encodes the mount type of the antenna as shown in Table 21[1].

TABLE 21. Mount Type Codes

Code	Mount Type
0	alt-azimuth
1	equatorial
2	orbiting

Axis Offset. The `STAXOF` column shall contain the axis offset for the antenna.

1. VLBA Memo 108 assigned code 2 to X-Y mounts and code 3 to orbiting antenna which differs from established usage. The codes specified here are consistent with common usage. No standard codes have yet been assigned to X-Y mounts.

CHAPTER 6

The ANTENNA Table

The ANTENNA table contains information about the antennas used in a FITS-IDI file that may change with time or with frequency setup. These characteristics include the polarization properties of the feeds and the number of digitizer levels.

The Table Header

The table header shall contain the keywords and values listed in Table 22.

TABLE 22. Mandatory Keywords for the ANTENNA Table

Keyword	Type	Value
EXTNAME	A	‘ANTENNA’
TABREV	I	1
NOPCAL	I	n_{pcal}
OBSCODE	A	See “Common Keywords” on page 24.
NO_STKD	I	See “Common Keywords” on page 24.
STK_1	I	See “Common Keywords” on page 24.
NO_BAND	I	See “Common Keywords” on page 24.

TABLE 22. Mandatory Keywords for the ANTENNA Table

Keyword	Type	Value
NO_CHAN	I	See “Common Keywords” on page 24.
REF_FREQ	E	See “Common Keywords” on page 24.
CHAN_BW	E	See “Common Keywords” on page 24.
REF_PIXL	E	See “Common Keywords” on page 24.

In addition, the keywords shown in Table 23 may be present.

TABLE 23. Optional Keywords for the ANTENNA Table

Keyword	Type	Value
POLTYPE	A	The feed polarization parameterization

Number of Polarization Calibration Constants. The ANTENNA table may carry information about the polarization characteristics of the feeds if this is known. If information about the polarization characteristics of the feeds is contained in the table then the NOPCAL keyword shall have the value 2. If no information about the polarization characteristics is contained in the table then the NOPCAL keyword shall have the value 0.

Polarization Parameterization. If the table contains information about the polarization characteristics of the feeds then the feed parameterization that is used shall be indicated by the value of the POLTYPE keyword as given in Table 23. See “Feed Polarization” on page 17.

TABLE 24. Values for the POLTYPE Keyword

Value	Model
‘APPROX’	Linear approximation for circular feeds
‘X-Y LIN’	Linear approximation for linear feeds
‘ORI-ELP’	Orientation and ellipticity

Table Structure

Each row in the table gives the parameters for one antenna in one frequency setup over a designated period. Each of the columns listed in Table 25 shall be present. The order of the columns does not matter.

TABLE 25. Mandatory Columns for the ANTENNA Table

Title	Units	Type	Description
TIME	DAYS	1D	Central time of period covered by record
TIME_INTERVAL	DAYS	1E	Duration of period covered by record
ANNAME		8A	Antenna name
ANTENNA_NO		1J	Antenna number
ARRAY		1J	Array number
FREQID		1J	Frequency setup number
NO_LEVELS		1J	Number of digitizer levels
POLTYA		1A	Feed A polarization label
POLAA	DEGREES	E(n_{band})	Feed A orientation
POLCALA		E(n_{pcal}, n_{band})	Feed A polarization parameters
POLTYB		1A	Feed B polarization label
POLAB	DEGREES	E(n_{band})	Feed B orientation
POLCALB		E(n_{pcal}, n_{band})	Feed B polarization parameters

Time Covered by the Record. The value in the TIME column shall be the number of days that have elapsed between 0 hours on the reference date for the current array and the center of the time period covered by the current row. The value in the TIME_INTERVAL column shall be the number of days covered by the current row.

Antenna Identification. The value in the ANNAME column shall be the name of the antenna to which the current row applies. This should be identical to the name given in the ARRAY_GEOMETRY table. The value in the ANTENNA_NO column shall be the antenna identification number and that in the ARRAY column shall be the array number of the antenna to which the current row applies.

Frequency Setup Number. The value in the FREQID column shall be the number of the frequency setup to which the current record applies.

Number of Digitizer Levels. The value in the NO_LEVELS column shall be the number of digitizer levels for the antenna. This shall be 2 for Mk II and Mk III terminals and may be either 2 or 4 for VLBA terminals (depending on observing mode).

Polarization Types. The value in the POLTYA column shall be the feed polarization of feed A. This corresponds to polarization 1 in calibration tables. The value in the POLTYB column shall be the feed polarization of feed B (if any). See “Feed Polarization” on page 17.

The two feeds may either be circularly polarized or linearly polarized. Mixtures of linear and circular polarizations are forbidden.

If 2 orthogonal polarizations are used, it is strongly recommended that feed A shall be ‘R’ or ‘X’ and feed B be ‘L’ or ‘Y’.

Feed Orientations. The value in the POLAA column shall be an array, each element of which is the orientation of feed A in the corresponding band, given in degrees. The POLAB column shall contain the feed orientations for feed B. See “Feed Polarization” on page 17.

Polarization Parameters. If the value of the NOPCAL keyword is 2 then the POLCA and POLCB columns shall contain 2 polarization parameters for each band for feeds A and B respectively. If the value of the POLTYPE keyword is ‘APPROX’ or ‘X-Y LIN’ then the first parameter shall be the real part of the leakage term and the second shall be the imaginary part of the leakage term. If the value of the POLTYPE keyword is ‘ORI-ELP’ then the first parameter shall be the orientation and the second shall be the ellipticity and both shall be given in radians. See “Feed Polarization” on page 17.

CHAPTER 7

The FREQUENCY Table

The FREQUENCY table provides information about the frequency setups used in a FITS-IDI file. There shall be no more than one FREQUENCY table in a FITS-IDI file. If the FREQID parameter is used in UV_DATA tables then a FREQUENCY table is mandatory.

The Table Header

The table header shall contain the keywords and values listed in Table 26.

TABLE 26. **Mandatory Keywords for the FREQUENCY Table**

Keyword	Type	Value
EXTNAME	A	'FREQUENCY'
TABREV	I	1
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.

TABLE 26. Mandatory Keywords for the FREQUENCY Table

Keyword	Type	Value
NO_CHAN	I	See “Common Keywords” on page 24.
REF_FREQ	E	See “Common Keywords” on page 24.
CHAN_BW	E	See “Common Keywords” on page 24.
REF_PIXL	E	See “Common Keywords” on page 24.

Table Structure

Each row in the table provides information about a single frequency setup. Each of the columns listed in Table 27 must be present. The order of the columns does not matter..

TABLE 27. Mandatory Columns for the FREQUENCY Table

Title	Units	Type	Description
FREQID		1J	Frequency setup number
BANDFREQ	HZ	D(n_{band})	Frequency offsets
CH_WIDTH	HZ	R(n_{band})	Individual channel widths
TOTAL_BANDWIDTH	HZ	R(n_{band})	Total bandwidths of bands
SIDEBAND		J(n_{band})	Sideband flag

Frequency group number. The FREQID column shall contain the frequency setup number for the frequency setup. This shall be a positive integer that uniquely identifies the frequency setup. One of the frequency setups shall be assigned the frequency setup number 1.

Band Frequency. The BANDFREQ column shall contain a one dimensional array of band-specific frequency offsets. There shall be one element for each band in the file. The offset for the first band in the frequency setup with FREQID 1 should be 0 Hz.

Bandwidths. The CH_WIDTH column shall contain a one-dimensional array of channel bandwidths. There shall be one element for each band in the file and each element is the frequency spacing between adjacent channels in the corresponding band for the current frequency group. Each entry shall be positive.

The channel bandwidth for the first band in the frequency setup with FREQID 1 shall be identical to the value of the CHAN_BW keyword.

The TOTAL_BANDWITH column shall contain a one-dimensional array of total bandwidths for each band. There shall be one element for each band in the file. The total bandwidth for a band is normally obtained by multiplying the channel bandwidth by the number of channels.

Sidebands. The SIDEBAND column shall contain a one-dimensional array of sideband flags. There shall be one entry for every band in the file. Each flag shall have the value +1 if the corresponding band is an upper-sideband band in the current frequency setup or -1 if the corresponding band is a lower-sideband band in the current frequency setup.

CHAPTER 8

The SOURCE Table

The SOURCE table contains information about the sources for which data is available in the FITS-IDI file. There shall be no more than one SOURCE table in a FITS-IDI file. If the SOURCE_ID random parameter is used in the UV_DATA tables then the SOURCE table is mandatory.

The Table Header

The table header shall contain the keywords and values listed in Table 28.

TABLE 28. Mandatory Keywords for the SOURCE Table

Keyword	Type	Value
EXTNAME	A	'SOURCE'
TABREV	I	1
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.

TABLE 28. Mandatory Keywords for the SOURCE Table

Keyword	Type	Value
NO_CHAN	I	See "Common Keywords" on page 24.
REF_FREQ	E	See "Common Keywords" on page 24.
CHAN_BW	E	See "Common Keywords" on page 24.
REF_PIXL	E	See "Common Keywords" on page 24.

Table Structure

Each row in the table provides information for one source for each frequency setup in which it is observed. Each of the columns listed in Table 29 must be present. The order of the columns does not matter.

TABLE 29. Mandatory Columns for the SOURCE Table

Title	Units	Type	Description
SOURCE_ID		1J	Source ID number
SOURCE		16A	Source name
QUAL		1J	Source qualifier
CALCODE		4A	Calibrator code
FREQID		1J	Frequency group ID
IFLUX	JY	E(n_{band})	Stokes I flux density
QFLUX	JY	E(n_{band})	Stokes Q flux density
UFLUX	JY	E(n_{band})	Stokes U flux density
VFLUX	JY	E(n_{band})	Stokes V flux density
ALPHA		E(n_{band})	Spectral index for each band
FREQOFF	HZ	E(n_{band})	Frequency offset for each band
RAEPO	DEGREES	1D	Right ascension at mean equinox
DECEPO	DEGREES	1D	Declination at mean epoch

TABLE 29. Mandatory Columns for the SOURCE Table

Title	Units	Type	Description
EQUINOX		8A	Mean equinox
RAPP	DEGREES	1D	Apparent right ascension
DECAPP	DEGREES	1D	Apparent declination
SYSVEL	METERS/S	D(n_{band})	Systemic velocity for each band
VELTYP		8A	Velocity type
VELDEF		8A	Velocity definition
RESTFREQ	HZ	D(n_{band})	Line rest frequency for each band
PMRA	DEGREES/DAY	1D	Proper motion in RA
PMDEC	DEGREES/DAY	1D	Proper motion in declination
PARALLAX	ARCSEC	1E	Parallax of source

Source ID Number. The SOURCE_ID column shall contain the *source idenitification number* for the source. The source idenitification number is a positive integer that uniquely identifies the source.

Source Name and Qualifier. The SOURCE column shall contain the name of the source.

The QUAL column shall contain a *source qualifier*. The source qualifier is an integer that is used in combination with the name of the source to identify it to a human user. For example, if several regions around a named radio source are observed, the same source name may be used for all of them and they may be distinguished by having different source qualifiers.

Calibrator Code. The CALCODE column shall contain a *calibrator code*. A calibrator code is an instrument-specific code that encodes information about the suitability of the source for use as a calibrator.

Frequency ID. The FREQID column shall contain the frequency setup number of the frequency setup to which the current row applies.

Flux Density Information. The IFLUX column shall contain an array of flux densities. There shall be one entry for every band in the file and each entry shall be the flux density of the source in Stokes I at the reference frequency for that band in the current frequency setup. If the flux density is unknown then the value shall either be zero or NaN (not a number).

The `QFLUX` column shall contain an array of flux densities. There shall be one entry for every band in the file and each entry shall be the flux density of the source in Stokes parameter Q at the reference frequency for that band in the current frequency setup. If the flux density is unknown then the value shall either be zero or NaN (not a number).

The `UFLUX` column shall contain an array of flux densities. There shall be one entry for every band in the file and each entry shall be the flux density of the source in Stokes parameter U at the reference frequency for that band in the current frequency setup. If the flux density is unknown then the value shall either be zero or NaN (not a number).

The `VFLUX` column shall contain an array of flux densities. There shall be one entry for every band in the file and each entry shall be the flux density of the source in Stokes parameter V at the reference frequency for that band in the current frequency setup. If the flux density is unknown then the value shall either be zero or NaN (not a number).

Spectral Indices. The `ALPHA` column shall contain an array of spectral indices. There shall be one entry for every band in the file and each entry shall be the spectral index of the source for that band in the current frequency setup. The spectral index, α, is defined such that the flux density at a frequency ν, $S(\nu)$, is related to the flux density at the reference frequency, $S(\nu_0)$, as follows.

$$S(\nu) = S(\nu_0) \cdot (\nu - \nu_0)^{-\alpha} \qquad \textbf{(EQ 7)}$$

Source-Specific Frequency Offsets. The `FREQOFF` column shall contain an array of frequency offsets. There shall be one entry for every band in the file and each entry shall contain the source-specific frequency offset for that band in the current frequency group. See “Frequency Setups” on page 15.

Source Positions. The `RAEPO` column shall contain the right ascension of the phase center associated with the source at the standard mean epoch. The `DECEPO` column shall contain the declination of the phase center at the standard mean epoch.

The `EQUINOX` column shall contain a string identifying the standard mean epoch used for the current source. This shall be either `'1950.0B'` or `'J2000'`.

The RAAPP column shall contain the best available approximation[1] of the right ascension of the phase center associated with the source at 0 hours on the reference date for array 1. The DECAPP column shall contain the best available approximation of the right ascension of the phase center associated with the source at 0 hours on the reference data for array 1.

The PMRA column should contain the proper motion of the source in right ascension if known. The PMDEC column should contain the proper motion of the source in declination, if known. If the proper motion is unknown then both fields should be set to zero.

Velocity Information. The SYSVEL column shall contain an array of velocities. There shall be one entry for each band in the file and each entry shall give the systemic velocity of the source at the reference frequency for that band in the current frequency group.

The VELTYP column shall contain a string that specifies the frame of reference for the systemic velocities. This string shall be one of those listed in Table 30.

TABLE 30. **Frames of Reference for VELTYP**

Value	Frame of Reference
LSR	Local standard of rest
BARYCENT	Solar system barycenter
GEOCENTR	Center of mass of the earth
TOPOCENT	Uncorrected

The VELDEF column shall contain a string indicating the convention used for the systemic velocities. It shall be either 'RADIO' or 'OPTICAL'.

The RESTFREQ column shall contain an array of rest frequencies. There shall be one entry for every band in the file and each entry shall contain the nominal rest frequency for the line being observed in the corresponding band for this source using the current frequency group. If the rest frequency is not available for a particular band then the corresponding entry should be zero or NaN.

1. There are no enforceable standards for the quality of this approximation. For example, the VLBA merely repeats the coordinates for the standard mean epoch in these fields.

Parallax. The PARALLAX column should contain the parallax of the source if it is known. If the parallax is not known then this field should be set to zero.

CHAPTER 9

The INTERFEROMETER_MODEL Table

The INTERFEROMETER_MODEL tables contain information about the interferometer models used by the correlator. INTERFEROMETER_MODEL tables are optional.

The Table Header

The table header shall contain the keywords and values listed in Table 31.

TABLE 31. Mandatory Keywords for the INTERFEROMETER_MODEL table

Keyword	Type	Value
EXTNAME	A	‘INTERFEROMETER_MODEL’
TABREV	I	2
NPOLY	I	n_{poly}
NO_POL	I	Number of polarizations in table
OBSCODE	A	See “Common Keywords” on page 24.
NO_STKD	I	See “Common Keywords” on page 24.

TABLE 31. Mandatory Keywords for the INTERFEROMETER_MODEL table

Keyword	Type	Value
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.
NO_CHAN	I	See "Common Keywords" on page 24.
REF_FREQ	E	See "Common Keywords" on page 24.
CHAN_BW	E	See "Common Keywords" on page 24.
REF_PIXL	E	See "Common Keywords" on page 24.

Number of Polynomial Terms. Delays and rates are given as polynomials with n_{poly} terms. The number of polynomial terms shall be given as the value of the NPOLY keyword. This shall be a positive integer.

Number of Polarizations. The INTERFEROMETER_MODEL table may contain information for one or two orthogonal polarizations. The number of polarizations shall be given as the value of the NO_POL keyword.

Table Structure

Each row in the table shall give the model information applicable to one antenna over a range of time. Each of the columns listed in Table 32 must be present. The order of the columns does not matter.

TABLE 32. Mandatory Columns for the INTERFEROMETER_MODEL Table

Title	Units	Type	Description
TIME	DAYS	1D	Starting time of interval
TIME_INTERVAL	DAYS	1E	Duration of interval
SOURCE_ID		1J	Source ID number
ANTENNA_NO		1J	Antenna number
ARRAY		1J	Array number

TABLE 32. Mandatory Columns for the INTERFEROMETER_MODEL Table

Title	Units	Type	Description
FREQID		1J	Frequency setup number
I.FAR.ROT	RAD/M**2	1E	Ionospheric Faraday rotation
FREQ.VAR	HZ	E(n_{band})	Time-variable frequency offsets
PDELAY_1	TURNS	E(n_{poly}, n_{band})	Phase delay polynomials for polarization 1
GDELAY_1	SECONDS	E(n_{poly}, n_{band})	Group delay polynomials for polarization 1
PRATE_1	HZ	E(n_{poly}, n_{band})	Phase delay rate polynomials for polarization 1
GRATE_1	SEC/SEC	E(n_{poly}, n_{band})	Group rate polynomials for polarization 1
DISP_1	SECONDS	1E	Dispersive delay for polarization 1 at 1m wavelength
DDISP_1	SEC/SEC	1E	Rate of change of dispersive delay for polarization 1 at 1m wavelength

If the table contains two polarizations then the columns listed in Table 33 must also be present. Polarization 1 corresponds to feed A in the ANTENNA table and polarization 2 to feed B.

TABLE 33. Additional Mandatory Columns for INTERFEROMETER_ MODEL Tables with Two Polarizations

Title	Units	Type	Description
PDELAY_2	TURNS	E(n_{poly}, n_{band})	Phase delay polynomials for polarization 2
GDELAY_2	SECONDS	E(n_{poly}, n_{band})	Group delay polynomials for polarization 2
PRATE_2	HZ	E(n_{poly}, n_{band})	Phase delay rate polynomials for polarization 2
GRATE_2	SEC/SEC	E(n_{poly}, n_{band})	Group rate polynomials for polarization 2
DISP_2	SECONDS	1E	Dispersive delay for polarization 2 at 1m wavelength
DDISP_2	SEC/SEC	1E	Rate of change of dispersive delay for polarization 2 at 1m wavelength

Time Covered by the Row. The TIME column shall contain the earliest time covered by the current row as the number of days that have elapsed since 0 hours on the reference date in the time system used for the array. This is also the zero time for the delay and rate polynomials.

The TIME_INTERVAL column shall contain the number of days for which the model described by the row remains valid.

Note that the INTERFEROMETER_MODEL table differs from other FITS-IDI tables in that the value in the TIME column is the beginning of the interval covered and not the center of the interval.

Source Identification Number. The SOURCE_ID column shall contain the source identification number of the source for which the model is valid.

Antenna and Array Numbers. The ANTENNA_NO column shall contain the antenna identification number of the antenna to which the model applies. The ARRAY column shall contain the array number of the array to which the antenna belongs.

Frequency Setup Number. The FREQID column shall contain the frequency setup number of the frequency setup for which the model applies.

Ionospheric Faraday Rotation. The I.FAR.ROT column shall contain the value of any ionospheric Faraday rotation correction applied at the correlator. If no correction has been applied then this field shall contain the value 0.0.

Time Variable Frequency Offsets. The FREQ.VAR column shall contain an array of time-variable frequency offsets that were applied to each band. The array is indexed by band number.

Phase and Group Delay Polynomials. The GDELAY_1 and GDELAY_2 columns shall contain polynomial terms for the group delays for each band in polarization 1 and 2. The group delay is calculated from these according to Equation 8 where Δt is the number of seconds that have elapsed since the beginning of the interval covered by the model and p_i is the polynomial term with index i for the current band.

$$\tau_g = \sum_{i=1}^{n_{poly}} p_i \cdot \Delta t^{i-1} \qquad \text{(EQ 8)}$$

The PDELAY_1 and PDELAY_2 columns shall contain the polynomial terms for the phase delay evaluated at the reference frequency for each band in the same format.

Phase and Group Delay Rates. The GRATE_1 and GRATE_2 columns shall contain polynomial terms for the group delay rates (i.e. the time derivatives of the group delays) for each band in polarization 1 and polarization 2. The PRATE_1 and PRATE_2 columns shall contain the polynomial terms for the phase delay rates. The same conventions are used as for the group delay terms.

Note that the rate terms may be expected to be approximately equal to the delay terms but shifted by one position but that exact equivalence is not required. This allows for correlators such as the VLBA which model delay and rate separately.

Dispersive Delays. The DISP_1 and DISP_2 columns shall contain the components of the group delays for polarization 1 and 2 that scale with the square of the wavelength (e.g. ionospheric delay). These shall be specified by giving the delays at 1 meter wavelength.

The DDISP_1 and DDISP_2 columns shall contain the time derivatives of the dispersive delays values in DISP_1 and DISP_2.

Previous Table Revisions

Revision 2 INTERFEROMETER_MODEL tables differ from Revision 1 in the naming of some of the fields as shown in Table 33.

TABLE 34. **Changed Field Names for the INTERFEROMETER_MODEL Table**

Revision 2	Revision 1
PDELAY_1	PDELAY 1
GDELAY_1	GDELAY 1
PRATE_1	PRATE 1
GRATE_1	GRATE 1
DISP_1	DISP 1
DDISP_1	DDISP 1
PDELAY_2	PDELAY 2
GDELAY_2	GDELAY 2
PRATE_2	PRATE 2
GRATE_2	GRATE 2
DISP_2	DISP 2
DDISP_2	DDISP 2

CHAPTER 10

The SYSTEM_TEMPERATURE Table

The SYSTEM_TEMPERATURE table contains a record of system and antenna temperatures for antennas used in the FITS-IDI file. It is an optional table.

The Table Header

The table header shall contain the keywords and values listed in Table 35.

TABLE 35. **Mandatory Keywords for the SYSTEM_TEMPERATURE Table**

Keyword	Type	Value
EXTNAME	A	'SYSTEM_TEMPERATURE'
TABREV	I	1
NO_POL	I	Number of polarizations in the table
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.
NO_CHAN	I	See "Common Keywords" on page 24.

TABLE 35. Mandatory Keywords for the SYSTEM_TEMPERATURE Table

Keyword	Type	Value
REF_FREQ	E	See "Common Keywords" on page 24.
CHAN_BW	E	See "Common Keywords" on page 24.
REF_PIXL	E	See "Common Keywords" on page 24.

Number of Polarizations. If the table contains information for two polarizations the value of the NO_POL keyword shall be 2. If the table only contains information for one polarization then the value of the NO_POL keyword shall be 1.

Table Structure

Each row contains system temperatures and antenna temperatures for a single antenna using a single frequency setup and that is valid for a limited range of times. Each row shall contain the columns shown in Table 35. If the NO_POL keyword has the value 2 then the columns shown in Table 35 shall also be present. The columns may be written in any order.

TABLE 36. Mandatory Columns for the SYSTEM_TEMPERATURE Table

Title	Units	Type	Description
TIME	DAYS	1D	Central time of interval covered
TIME_INTERVAL	DAYS	1E	Duration of interval
SOURCE_ID		1J	Source ID number
ANTENNA_NO		1J	Antenna number
ARRAY		1J	Array number
FREQID		1J	Frequency setup number
TSYS_1	KELVIN	E(n_{band})	System temperatures for polarization 1
TANT_1	KELVIN	E(n_{band})	Antenna temperatures for polarization 1

TABLE 37. Additional Mandatory Fields for SYSTEM_TEMPERATURE Tables with Two Polarizations

Title	Units	Type	Description
TSYS_2	KELVIN	E(n_{band})	System temperatures for polarization 2
TANT_2	KELVIN	E(n_{band})	Antenna temperatures for polarization 2

Time Covered by the Row. The TIME column shall contain the number of days that have elapsed between 0 hours on the reference date for the current array and the center of the time period covered by the current row. The TIME_INTERVAL column shall contain the number of days covered by the current row.

Source Identification Number. The SOURCE_ID column shall contain the source identification number of the source to which the current record applies.

Antenna Identification. The ANTENNA_NO column shall contain the antenna identification number and the ARRAY column shall contain the array number of the antenna to which the current row applies.

Frequency Setup Number. The FREQID column shall contain the frequency setup number of the frequency setup to which the current record applies.

System Temperatures. The TSYS_1 and TSYS_2 columns shall contain arrays of system temperatures indexed by band number. If system temperature information is not available for any band in either polarization then the corresponding elements of the arrays shall be set to NaN.

Antenna Temperatures. The TANT_1 and TANT_2 columns shall contain arrays of antenna temperatures indexed by band number. If antenna temperature information is not available for any band in either polarization then the corresponding elements of the arrays shall be set to NaN. If no antenna temperature is available in any band then the arrays shall be filled with NaNs.

CHAPTER 11

The GAIN_CURVE Table

The GAIN_CURVE table contains tabulated or parameterized gain curve information for antennas used in the FITS-IDI file. It is an optional table.

The Table Header

The table header shall contain the keywords and values listed in Table 38.

TABLE 38. Mandatory Keywords for the GAIN_CURVE Table

Keyword	Type	Value
EXTNAME	A	'GAIN_CURVE'
TABREV	I	1
NO_POL	I	Number of polarizations in the table
NO_TABS	I	n_{tab}
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 24.

TABLE 38. Mandatory Keywords for the GAIN_CURVE Table

Keyword	Type	Value
NO_BAND	I	See “Common Keywords” on page 24.
NO_CHAN	I	See “Common Keywords” on page 24.
REF_FREQ	E	See “Common Keywords” on page 24.
CHAN_BW	E	See “Common Keywords” on page 24.
REF_PIXL	E	See “Common Keywords” on page 24.

Number of Polarizations. If the table contains information for two polarizations the value of the NO_POL keyword shall be 2. If the table only contains information for one polarization then the value of the NO_POL keyword shall be 1.

Number of Tabulated Values. The value of the NO_TABS keyword shall be the maximum number of tabulated values or parameters for a gain curve in the table. This shall be a positive number.

Table Structure

Each row contains gain information for a single antenna using a single frequency setup. Each record shall contain the columns shown in Table 39. If the NO_POL keyword has the value 2 then the columns shown in Table 40 shall also be present. The columns may be written in any order.

TABLE 39. Mandatory Columns for the GAIN_CURVE Table

Title	Units	Type	Description
ANTENNA_NO		1J	Antenna number
ARRAY		1J	Array number
FREQID		1J	Frequency setup number
TYPE_1		J(n_{band})	Gain curve types for polarization 1
NTERM_1		J(n_{band})	Numbers of terms or entries for polarization 1
X_TYP_1		J(n_{band})	*x* value types for polarization 1

TABLE 39. Mandatory Columns for the GAIN_CURVE Table

Title	Units	Type	Description
Y_TYP_1		J(n_{band})	*y* value types for polarization 1
X_VAL_1		E(n_{band})	*x* values for polarization 1
Y_VAL_1		E(n_{tab}, n_{band})	*y* values for polarization 1
GAIN_1		E(n_{tab}, n_{band})	Relative gain values for polarization 1
SENS_1	K/JY	E(n_{band})	Sensitivities for polarization 1

TABLE 40. Additional Mandatory Columns for GAIN_CURVE Tables with Two Polarizations

Title	Units	Type	Description
TYPE_2		J(n_{band})	Gain curve types for polarization 2
NTERM_2		J(n_{band})	Numbers of terms or entries for polarization 2
X_TYP_2		J(n_{band})	*x* value types for polarization 2
Y_TYP_2		J(n_{band})	*y* value types for polarization 2
X_VAL_2		E(n_{band})	*x* values for polarization 2
Y_VAL_2		E(n_{tab}, n_{band})	*y* values for polarization 2
GAIN_2		E(n_{tab}, n_{band})	Relative gain values for polarization 2
SENS_2	K/JY	E(n_{band})	Sensitivities for polarization 2

Antenna Identification. The `ANTENNA_NO` column shall contain the antenna identification number and the `ARRAY` column shall contain the array number of the antenna to which the current row applies.

Frequency Setup Number. The `FREQID` column shall contain the frequency setup number of the frequency setup to which the current row applies.

Gain Curve Encoding

A separate gain curve shall be provided for each band in each polarization. Each gain curve may be provided as a list of tabulated values, as a polynomial in a single variable, or as a spherical harmonic expansion in hour angle and codeclination ($90° - declination$) as used by the Green Bank 140-foot telescope. The type of gain curve provided is indicated by the value of the `TYPE_1` or `TYPE_2` array corresponding to the band as indicated in Table 41. Different types of gain curve may be provided for different bands.

TABLE 41. Gain Curve Types

Code	Gain Curve Type
1	Tabulated
2	Polynomial
3	Spherical harmonic

In each case the gain curve values are dimensionless and should be multiplied by the sensitivity for the corresponding band to obtain the actual gain. The sensitivities for each band are listed in the `SENS_1` and `SENS_2` columns indexed by band number.

Tabulated Gain Curves

If the gain curve for a given band is tabulated then the number of tabulated values shall be given in the `NTERM_1` or `NTERM_2` column for that band (depending on the polarization). This shall be a positive number and shall not be greater than n_{tab}.

The variable against which the gain values are tabulated shall be indicated by the value in the `Y_TYP_1` or `Y_TYP_2` column for the corresponding band as shown in Table 42.

TABLE 42. Types for x and y Values

Code	Value Type
0	None
1	Elevation in degrees
2	Zenith angle in degrees

TABLE 42. Types for x and y Values

Code	Value Type
3	Hour angle in degrees
4	Declination in degrees
5	Codeclination in degrees

The values against which the gain is tabulated shall be listed in the first elements of the Y_VAL_1 or Y_VAL_2 matrix column that corresponds to the band and the gain values shall be listed in the corresponding entries of the GAIN_1 or GAIN_2 matrices. Unused entries in the Y_VAL_1, Y_VAL_2, GAIN_1, and GAIN_2 arrays shall be set to NaN.

If the gain curve is tabulated against hour angle then the entry in X_TYP_1 or X_TYP_2 for the band shall be 4 (declination) and the corresponding entry in X_VAL_1 or X_VAL_2 shall be the declination at which the gain curve is tabulated in degrees. In all other cases the X_TYP_1 or X_TYP_2 entry shall be zero and the X_VAL_1 or X_VAL_2 entry shall be NaN.

Polynomial Gain Curves

If the gain curve for a given band is polynomial then the value in the Y_TYP_1 or Y_TYP_2 column corresponding to the band shall designate the polynomial variable as shown in Table 42 and the value in the NTERM_1 or NTERM_2 column corresponding to the band shall be the number of terms in the polynomial. This must be a positive number but may not be larger than n_{tab}. The polynomial coefficients shall be listed in the first elements in the column of GAIN_1 or GAIN_2 that corresponds to the band starting with the coefficient of the zeroth order term. Unused elements in GAIN_1 and GAIN_2 shall be set to 0.0 or to NaN.

If the gain curve is a polynomial of hour angle then the value in X_TYP_1 or X_TYP_2 that corresponds to the band shall be set to 4 and the corresponding element in X_VAL_1 or X_VAL_2 shall be the declination at which the gain curve is evaluated. In all other cases the X_TYP_1 or X_TYP_2 entry shall be zero and the X_VAL_1 or X_VAL_2 entry shall be NaN.

All entries in the Y_VAL_1 or Y_VAL_2 arrays corresponding to the band shall be NaN.

Spherical Harmonics

If the gain curve for a band is a spherical harmonic then the value in NTERM_1 or NTERM_2 corresponding to the band shall be the number of terms in the expansion. This must be a positive number but may not be larger than n_{tab}. The column of the GAIN_1 or GAIN_2 matrix that corresponds to the band shall hold the coefficients of the harmonic expansion as listed in Table 43.

TABLE 43. **Spherical Harmonic Coefficients in GAIN_1 and GAIN_2**

Index	Coefficient
1	A00
2	A10
3	A11E
4	A110
5	A20
6	A21E
7	A210
8	A22E
9	A220
10	A30

The value in X_TYP_1 or X_TYP_2 corresponding to the band shall be 5 (codeclination) and the corresponding value in Y_TYP_1 or Y_TYP_2 shall be 3 (hour angle). All entries in X_VAL_1 and Y_VAL_1 or X_VAL_2 and Y_VAL_2 that correspond to the band shall be set to NaN.

CHAPTER 12

The PHASE-CAL Table

The PHASE-CAL[1] table contains phase calibration data. It is an optional table.

The Table Header

The table header shall contain the keywords and values listed in Table 44.

TABLE 44. Mandatory Keywords for the PHASE-CAL Table

Keyword	Type	Value
EXTNAME	A	'PHASE-CAL'
TABREV	I	2
NO_POL	I	Number of polarizations in the table
NO_TONES	I	n_{tone}
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.

1. Note that the table name contains a hyphen rather than an underscore.

TABLE 44. Mandatory Keywords for the PHASE-CAL Table

Keyword	Type	Value
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.
NO_CHAN	I	See "Common Keywords" on page 24.
REF_FREQ	E	See "Common Keywords" on page 24.
CHAN_BW	E	See "Common Keywords" on page 24.
REF_PIXL	E	See "Common Keywords" on page 24.

Number of Polarizations. If the table contains information for two polarizations the value of the NO_POL keyword shall be 2. If the table only contains information for one polarization then the value of the NO_POL keyword shall be 1.

Number of Tones. The value of the NO_TONES keyword shall be the maximum number of phase-cal tones in a single band. This must be a positive number.

Table Structure

Each table row contains phase-cal data for a single antenna using a single frequency setup over a limited interval of time. The table shall contain the columns shown in Table 45. If the NO_POL keyword has the value 2 then the columns shown in Table 46 shall also be present. The columns may be written in any order.

TABLE 45. Mandatory Columns for the GAIN_CURVE Table

Title	Units	Type	Description
TIME	DAYS	1D	Central time of interval covered
TIME_INTERVAL	DAYS	1E	Duration of interval
SOURCE_ID		1J	Source ID number
ANTENNA_NO		1J	Antenna number
ARRAY		1J	Array number
FREQID		1J	Frequency setup number

TABLE 45. Mandatory Columns for the GAIN_CURVE Table

Title	Units	Type	Description
CABLE_CAL	SECONDS	1E	Cable calibration measurement
STATE_1	PERCENT	I($4, n_{band}$)	State counts for polarization 1
PC_FREQ_1	HZ	D(n_{tone}, n_{band})	Phase cal tone frequencies for polarization 1
PC_REAL_1		E(n_{tone}, n_{band})	real parts of phase-cal measurements for polarization 1
PC_IMAG_1		E(n_{tone}, n_{band})	imaginary parts of phase-cal measurements for polarization 1
PC_RATE_1	SEC/SEC	E(n_{tone}, n_{band})	phase-cal rates for polarization 1

TABLE 46. Additional Mandatory Columns for GAIN_CURVE Tables with Two Polarizations

Title	Units	Type	Description
STATE_2	PERCENT	I($4, n_{band}$)	State counts for polarization 2
PC_FREQ_2	HZ	D(n_{tone}, n_{band})	Phase cal tone frequencies for polarization 2
PC_REAL_2		E(n_{tone}, n_{band})	real parts of phase-cal measurements for polarization 2
PC_IMAG_2		E(n_{tone}, n_{band})	imaginary parts of phase-cal measurements for polarization 2
PC_RATE_2	SEC/SEC	E(n_{tone}, n_{band})	phase-cal rates for polarization 2

Time Covered by the Row. The TIME column shall contain the number of days that have elapsed between 0 hours on the reference date for the current array and the center of the time period covered by the current row. The TIME_INTERVAL column shall contain the number of days covered by the current record.

Source Identification. The SOURCE_ID column shall contain the source identification number of the source to which the current row applies.

Antenna Identification. The ANTENNA_NO column shall contain the antenna identification number and the ARRAY column shall contain the array number of the antenna to which the current record applies.

Frequency Setup Number. The FREQID column shall contain the frequency setup number of the frequency setup to which the current record applies.

Cable Cal. The CABLE_CAL column shall contain the measured cable cal value in seconds. If this is not available then the column shall contain a NaN.

State Counts. The STATE_1 and STATE_2 columns shall contain the percentage of time that the digitizer spent in each of its lowest, medium-low, medium-high, and highest states for each band. Entries where this data is not available shall be set to NaN.

Phase-Cal Tone Frequencies. The PC_FREQ_1 and PC_FREQ_2 columns shall list the sky-frequencies of the phase cal tones for each band. Unused entries in these columns shall be set to NaN.

Phase-Cal Measurements. The phase-cal measurements shall be reported as complex quantities with the real parts listed in PC_REAL_1 and PC_REAL_2 and the imaginary parts listed in PC_IMAG_1 and PC_IMAG_2. The PC_RATE_1 and PC_RATE_2 columns shall list the rates of change of the phase-cal phase over the interval covered by the record. Unused entries in these columns shall be set to NaN as shall entries corresponding to missing data.

Previous Table Revisions

Revision 2 PHASE-CAL tables differ from Revision 1 in the naming of some of the fields as shown in Table 47.

TABLE 47. Changed Field Names for the INTERFEROMETER_MODEL Table

Revision 2	Revision 1
PC_FREQ_1	PC_FREQ 1
PC_REAL_1	PC_REAL 1
PC_IMAG_1	PC_IMAG 1
PC_RATE_1	PC_RATE 1
PC_FREQ_2	PC_FREQ 2
PC_REAL_2	PC_REAL 2
PC_IMAG_2	PC_IMAG 2
PC_RATE_2	PC_RATE 2

These fields were renamed to be consistent with the conventions used in other tables.

CHAPTER 13 The FLAG Table

The FLAG table designates data that are to be regarded as invalid. It is an optional table.

The Table Header

The table header shall contain the keywords and values listed in Table 48.

TABLE 48. Mandatory Keywords for the FLAG Table

Keyword	Type	Value
EXTNAME	A	'FLAG'
TABREV	I	2
OBSCODE	A	See "Common Keywords" on page 24.
NO_STKD	I	See "Common Keywords" on page 24.
STK_1	I	See "Common Keywords" on page 24.
NO_BAND	I	See "Common Keywords" on page 24.
NO_CHAN	I	See "Common Keywords" on page 24.
REF_FREQ	E	See "Common Keywords" on page 24.

TABLE 48. Mandatory Keywords for the FLAG Table

Keyword	Type	Value
CHAN_BW	E	See “Common Keywords” on page 24.
REF_PIXL	E	See “Common Keywords” on page 24.

Table Structure

Each row in the table specifies a set of data to be flagged. These specifications are independent and may overlap. The table may be regarded as specifying a set of data to be flagged which is the union of the sets specified by its constituent rows. The table shall contain the columns shown in Table 49. The columns may be written in any order.

TABLE 49. Mandatory Columns for the FLAG Table

Title	Units	Type	Description
SOURCE_ID		1J	Source ID number
ARRAY		1J	Array number
ANTS		2J	Antenna numbers
FREQID		1J	Frequency setup number
TIMERANG	DAYS	2E	Time range
BANDS		J(n_{band})	Band flags
CHANS		2J	Channel range
PFLAGS		4J	Polarization flags
REASON		24A	Reason for flag
SEVERITY		1J	Severity code

Source Identification. If the SOURCE_ID column contains a non-zero value then all data for the source with the identification number matching this value that match the other criteria specified by the current record should be flagged. If the value of this field is 0 then all data matching the other criteria specified by the current record should be flagged irrespective of the source identification number.

Array Number. If the ARRAY column contains a non-zero value then all data from the array with this array number that match the other criteria specified by the current row should be flagged. If the value of this field is 0 then all data matching the other criteria specified by the current row should be flagged irrespective of the array number.

Antennas. If both elements in the ANTS column are zero then all data that match the other criteria specified by the current row should be flagged irrespective of the baseline from which they were obtained. If the first element is positive and the second element is zero then all data that match the other criteria specified by the current row and that are obtained from baselines involving the antenna with the antenna identification number given in the first element should be flagged. If both elements are positive then all data that match the other criteria specified by the current row and that are obtained from the baseline defined by the antennas with identification numbers given by the first and second elements should be flagged.

Frequency Setup Number. If the FREQID column contains a positive value then all data taken using the setup that has been assigned this frequency setup number and that match the other criteria specified by the current row should be flagged. If it has the value 0 or -1 then all data that match the other criteria specified by the current row should be flagged regardless of frequency setup.

Band Flags. If the entry in BANDS column that corresponds to a given band number is not zero then all data for this band that meet the other criteria specified by the current row should be flagged. If this entry is 0 then the current row specifies no flags for this band.

Channel Range. Data from channels with numbers in the range specified by the two elements in the CHANS column that meet the other criteria specified by the current row should be flagged. The first element shall be less than or equal to the second element. If both elements are zero then the channel range is taken to cover all channels.

Polarization Flags. If an element in the PFLAGS column is not zero then all data that have the corresponding index on the STOKES axis of the data matrix and that meet the other criteria specified by the current row should be flagged.

Reason. The REASON column shall contain a short string explaining why the data specified by the current record were flagged.

Severity Code. The SEVERITY column shall contain a severity code that applies to the current record. Recommended severity codes are listed in Table 50. Software may use the severity keywords to decide whether to apply the flags specified by individual records.

TABLE 50. Recommended Severity Codes

Code	Severity Level
`-1`	No severity level assigned
`0`	Data are known to be useless
`1`	Data are probably useless
`2`	Data may be useless

Previous Table Revisions

Revision 2 `FLAG` tables differ from revision 1 tables in using an array of flags to specify the bands that should be flagged. In revision 1 tables the `BANDS` field contained a 2-element array of integers that specified a contiguous range of band numbers to be flagged.

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