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The GBT Tracking Local Oscillator FITS Keyword Definitions

HTML version Available¹

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Abstract

The FITS format structure is presented for the GBT tracking local oscillator (LO1) 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 LO1 FITS files, produced separately for each LO contains binary tables describing the commanded LO1 frequencies as a function of time throughout the scan. This is separated two components separately describing the effects of Doppler tracking frequency switching.

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

History

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

16th November 2001 Final version agreed for implementation of FITSVER 1.1. Added keywords SITESYS and SITETYPE, and modified discussion of SITELONG, SITELAT, SITEELEV. Changed actual values used. Changed discussion of VELDEF, and move to SOUVEL binary table. Noted VFRAME and RVSYS are true (relativistic) velocities Subsequent changes to the content of this document should increment the document version number (Richard Prestage).

17th December 2001 Documentation corrections for FITSVER 1.1; table names (LO1STATE renamed to STATE, LO1TABLE renamed to LO1TBL), added LSTSTART keyword (Joe Brandt).

15th July 2002 Documentation corrections for FITSVER 1.2; Revised wording of RVSYS keyword and corrected the equation associated with calculating RVSYS.

18th September 2002 Documentation corrections for FITSVER 1.3; Corrected values of SOUVEL table velocity columns to meters/second. Fits files written with FITSVER of 1.2 and below contain values which were incorrectly written in km/sec rather than meters/sec.

3rd April 2008 Documentation change; clarification of meaning of FREQOFF values in STATE table (Bob Garwood).

1 Introduction

This document describes the FITS formatted file written on each scan, by the Tracking Local Oscillator (LO1). One file is written for each of the two synthesisers, LO1A and LO1B. Normally, LO1A will be used for the tracking LO, and LO1B as a test-tone generator. The LO1 FITS files contain a complete description of the setup of the LO; information as to how the LO is connected to the rest of the system is described in the IF Manager FITS file.

LO1 demands sent to the actual synthesiser consists of two components; the base values, which will smoothly vary with time if Doppler tracking is enabled, and offset values which are added to these base values, to implement frequency switching for example. These values are stored in the LO1TBL and STATE binary tables respectively.

In the majority of cases, the LO1 will be asked to track a single source velocity. In some cases however (e.g. solar system objects) it is possible for the LO1 to be passed a “source velocity track”; an array of records containing source velocity values, first and second derivatives for a series of times. aips++ needs to know the desired source velocity so that it can “reverse” the Doppler tracking calculations to allow spectra to be presented in the rest frame of the source. This velocity should be obtained from the GO (User Interface) FITS file. However, for engineering purposes, the actual source velocity track will be stored in the LO1 FITS file in the SOUVEL binary table.

2 Primary Header Keyword Definitions

The LO1 FITS files will contain all of the GBT standard primary header keywords (as described in GBT/SN/004), with their standard meanings. In addition, the following LO1 specific keywords will be supplied:

LSTSTART The apparent local sidereal time corresponding to the instant in (UTC) time specified by the DATE-OBS keyword. LSTSTART time unit is sidereal seconds since local LST midnight.

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, SITELONG, SITELEV, and whether this is a geodetic or geocentric system. The current values are ‘NAD83’, ‘GEODETIC’.

RADESYS, EQUINOX The RADESYS standard FITS keyword specifies the coordinate reference frame for the RA and DEC axis columns. These are described in detail in WCS paper II. For the LO1, RADESYS will normally always be ‘FK5’, with an EQUINOX of 2000.0.

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

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

COSVMODE This value indicates the state of the cosVMode parameter.

IFFREQ This value indicates the desired IF center frequency.

LOOFFSET This value indicates the value of $LO1_{offset}$ in equation (5) of LO1DesignNotes. When non-zero, this value represents a receiver which has an additional mixing stage, which acts as a constant offset in terms of LO frequency. This information is included for engineering purposes only; when non-zero this term will be included in the IF Manager sky frequency formula calculations.

LOMULT This value indicates the LO1 multiplier factor in use. When set to a value other than 1.0, this value represents a frequency multiplier stage between LO and mixer. This information is included for engineering purposes only; when non-unity this term will be included in the IF Manager sky frequency formula calculations.

SIDEBAND This value indicates the LO1 sideband setting. The possible values are “Upper”, “Lower”, or “Test Tone”.

RESTFRQ This is the requested rest frequency, in the rest frame of the object under observation.

REQDPTOL This is the requested Doppler tracking tolerance in Hz.

POWERLVL This denotes in dBm, the LO1 power level setting at the start of the observation.

POSOFFST This denotes the state (T/F) of the usePrimaryOffsets parameter. When true, the primaryOffsets parameter is included in the calculation of antenna look direction.

An example primary header is shown below:

```

SIMPLE   =                               T / file does conform to FITS standard
BITPIX   =                               8 / number of bits per data pixel
NAXIS     =                               0 / number of data axes
EXTEND    =                               T / FITS dataset may contain extensions
ORIGIN    = 'NRAO Green Bank'             /
INSTRUME  = 'LO1 Control Unit'             / device or program of origin
GBTCVER   = '3.3.0'                       / telescope control software release
FITSVER   = '1.1'                         / FITS definition version for this device
DATEBLD   = 'Thu Jun 21 18:46:25 GMT 2001' / time program was linked
SIMULATE  =                               0 / Is the instrument in simulate mode
DATE-OBS  = '2001-11-01T07:06:43'         / Manager parameter startTime
TIMESYS   = 'UTC'                         / time scale specification for DATE-OBS
TELESCOP  = 'NRAO_GBT'                   / Green Bank Telescope (Robert C. Byrd 100m)
OBJECT    = '3C123'                       / Manager parameter source
PROJID    = 'tigerTeam_06'                / Manager parameter projectId
OBSID     = 'map'                         / Manager parameter scanId
SCAN      =                               63 / Manager parameter scanNumber
LSTSTART  = 1.13114117570554E+04          / Start Time in seconds since local sidereal midn
SITELAT   = 3.8433121E+01                 / North latitude of intersection of az/el axes
SITELONG  = 7.9839835E+01                 / West longitude of intersection of az/el axes
SITEELEV  = 8.24551E+02                   / Height of the intersection of az/el axes
SITESYS   = 'NAD83'                       / Coordinate system (datum)
SITETYPE  = 'GEODETIC'                   / Type of position
RAESYS    = 'FK5'                        / Coordinate reference frame of major/minor axes
EQUINOX   = 2.00000E+03                   / Equinox of selected coordinate reference frame
DELTAUTC  = -6.6429E-02                   / UT1 - UTC offset for beginning of scan
IERSPMX   = -1.2272E-05                   / X Polar motion correction for beginning of scan
IERSPMY   = 3.7457E-05                   / Y Polar motion correction for beginning of scan
COSVMODE  = 'OFF'                        / State of cosVMode parameter
RESTFRQ   = 1.40800000000000E+09          / Rest Frequency of source
IFFREQ    = 3.00000000000000E+03          / Specified IF center Frequency
LOOFFSET  = 0.00000000000000E+00          / Additional Frequency offset due to Rcvr interna

```

```

LOMULT  =          1.0000E+00 / Frequency Multiplier due to Rcvr internal multi
REQDPTOL=          1.0000E+00 / Requested Doppler tracking tolerance in Hz
POWERLVL=         -1.100E+01 / Requested LO Power Level in dBm
SIDE BAND= 'LOWER'      / i.e. LOFREQ = (SKY+IFFREQ)/LOMULTI-LOOFFSET
END

```

3 LO1TBL Binary Table

The LO1 calculates a time-tagged series of values of LO1FREQ throughout the scan, sampled finely enough so that the commanded value will always be within REQDPTOL of the ideal value. In the case of no Doppler tracking, the table will simply contain a single entry that represents the value used throughout the scan.

In the case of Doppler tracking during position switching, the LO1FREQ will be updated asynchronously to the backend integrations, at the specified time. The LO1 will assert blanking while the transition is being made. In the case of Doppler tracking while frequency switching, the current time will be checked on each SIG/REF transition. Should a new value of LO1FREQ be required within the next switch period, this will be applied on the SIG/REF transition at the start of the next switch period.

In both of these cases, the table will therefore contain a series of LO1FREQ values, with the DJMD column representing the time at which each new frequency was commanded.

The content of the LO1TBL is described in table 1.

Name	Type	Units
DMJD	1D	days
RA	1D	degrees
DEC	1D	degrees
LO1FREQ	1D	Hertz
VFRAME	1D	$\frac{m}{Sec}$
RVSYS	1D	$\frac{m}{Sec}$

Table 1: Table format for LO1TBL binary table

3.1 LO1TBL Column Definitions

DMJD This item time-stamps the data for the row. Units are days.

RA This field indicates the telescope pointing direction, in degrees of right ascension, in the co-ordinate system described by header keywords RADESYS and EQUINOX

DEC This field indicates the telescope pointing direction, in degrees of declination, in the co-ordinate system described by keywords RADESYS and EQUINOX

LO1FREQ This column specifies the Doppler shifted frequency. This is the actual commanded frequency sent to the synthesizer.

VFRAME (Standard keyword from the GBT Engineering FITS Files document, section D.2.) This field describes the radial velocity of the reference frame with respect to the observer, i.e.:

$$VFRAME = V_{frame} - V_{observer} \quad (1)$$

Note, this is a true (relativistic velocity), independent of the velocity definition and reference frame specified for the source velocity.

RVSYS (Standard keyword from the GBT Engineering FITS Files document, section D.2.) This field contains the systemic radial velocity of the source with respect to the observer

$$RV_{SYS} = (V_{frame} + V_{relative}) / (1 + V_{frame} * V_{relative} / C^2) \quad (2)$$

Note, this is a true (relativistic velocity), independent of the velocity definition and reference frame specified for the source velocity.

An example LO1TBL header is given below:

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                8 / 8-bit bytes
NAXIS   =                2 / 2-dimensional binary table
NAXIS1  =               48 / width of table in bytes
NAXIS2  =                1 / number of rows in table
PCOUNT  =                0 / size of special data area
GCOUNT  =                1 / one data group (required keyword)
TFIELDS =                6 / number of fields in each row
TTYPE1  = 'DMJD'           / label for field  1
TFORM1  = '1D'             / data format of field: 8-byte DOUBLE
TUNIT1  = 'd'              / physical unit of field
TTYPE2  = 'RA'             / label for field  2
TFORM2  = '1D'             / data format of field: 8-byte DOUBLE
TUNIT2  = 'deg'            / physical unit of field
TTYPE3  = 'DEC'            / label for field  3
TFORM3  = '1D'             / data format of field: 8-byte DOUBLE
TUNIT3  = 'deg'            / physical unit of field
TTYPE4  = 'LO1FREQ'        / label for field  4
TFORM4  = '1D'             / data format of field: 8-byte DOUBLE
TUNIT4  = 'Hz'             / physical unit of field
TTYPE5  = 'VFRAME'         / label for field  5
TFORM5  = '1D'             / data format of field: 8-byte DOUBLE
TUNIT5  = 'm/sec'          / physical unit of field
TTYPE6  = 'RVSYS'          / label for field  6
TFORM6  = '1D'             / data format of field: 8-byte DOUBLE
TUNIT6  = 'm/sec'          / physical unit of field
EXTNAME = 'LO1TBL'         / name of this binary table extension
END
```

4 The LO1 STATE binary table

The STATE binary table is an LO1-specific version of the STATE table described in GBT/SPN/004. It has one additional column, the frequency offset in Hz to associate with that phase.

FREQOFF The frequency offset from the sky frequency in Hz. This offset is added to the sky frequency as given by the sky frequency formula described in the IF manager FITS file, GBT/SPN/010, to give the true sky frequency for each state. It is *not* an offset to the LO1FREQ value and it is *not* multiplied by SFF_MULTIPLIER in the sky frequency formula.

An example header and ascii equivalent list is therefore as below:

STATE Binary Tables Extension: Header

```

-----
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                      8 / 8-bit bytes
NAXIS   =                      2 / 2-dimensional binary table
NAXIS1  =                     28 / width of table in bytes
NAXIS2  =                      2 / number of rows in table
PCOUNT  =                      0 / size of special data area
GCOUNT  =                      1 / one data group (required keyword)
TFIELDS =                      5 / number of fields in each row
TTYPE1  = 'BLANKTIM'           / label for field  1
TFORM1  = '1D'                 / data format of field: 8-byte DOUBLE
TUNIT1  = 'SECONDS'            / physical unit of field
TTYPE2  = 'PHSESTRT'           / label for field  2
TFORM2  = '1D'                 / data format of field: 8-byte DOUBLE
TUNIT2  = 'NONE'               / physical unit of field
TTYPE3  = 'SIGREF'             / label for field  3
TFORM3  = '1J'                 / data format of field: 2-byte INTEGER
TUNIT3  = 'T/F'                / physical unit of field
TTYPE4  = 'CAL'                / label for field  4
TFORM4  = '1J'                 / data format of field: 2-byte INTEGER
TUNIT4  = 'T/F'                / physical unit of field
TTYPE5  = 'FREQOFF'           / label for field  5
TFORM5  = '1D'                 / data format of field: 8-byte DOUBLE
TUNIT5  = 'Hz'                 / physical unit of field
NUMPHASE=                      2 / Number of Phases if only Internal Switch Sig
SWPERIOD=                    5.466E+00 / Switching period
MASTER  = 'Spectrometer'       / Switching Signals Master
EXTNAME  = 'STATE'              / name of this binary table extension
END
-----

```

STATE Binary Tables Extension: Data (complete)

```

-----
ROW  BLANKTIM  PHSESTRT  SIGREF  CAL  FREQOFF
1    9.96147E-02 .0000E+00    0    0    0.000E+00
2    9.96147E-02 .5000E+00    1    0    1.000E+07
-----

```

5 The SOUVEL binary table

Although not required by the aips++ filler, for engineering purposes the LO1 FITS file records the requested velocity. In most cases, this will be a constant value, but in the most general case, it may be an array of time, velocity and velocity first and second derivatives. These values are stored in the SOUVEL binary table. This has four columns to represent these quantities; DMJD (modified Julian date in days), VELOCITY, VDOT and VDOTDOT (velocity and derivatives in m/s, etc). There is also one keyword, VELDEF, defined as follows:

VELDEF This keyword describes the velocity definition and reference frame used in the Doppler tracking calculations. The first four characters describe the velocity definition, followed by the rest frame. The possible values are:

- VELO - Relativistic velocity definition

- VOPT - Optical velocity definition
- VRAD - Radio velocity definition

The LO1 reference frames are:

- -TOP - observer (topographic) rest frame
- -GEO - Geocentric
- -BAR - Barycentric rest frame
- -HEL - Helocentric rest frame
- -GAL - Galactocentric rest frame
- -LSD - Dynamical LSR
- -LSR - Kinematical LSR
- -LGR - Local Group LSR
- -COB - COBE rest frame

These are described in detail in WCS Paper III, with the exception of -COB, which is a GBT-specific addition. We do not yet have precise details of how the COBE rest frame will be represented, so values of VELDEF including '-COB' will not appear in FITSVER 1.1 files. WCS Paper III also allows values containing '-SOU' - Source rest frame - this is not relevant to our use and will not appear.

The “dynamical” LSR is a point in the vicinity of the Sun which is in a circular orbit around the Galactic centre. The Sun’s motion with respect to the dynamical LSR is called the “peculiar” solar motion. Delhaye lists the peculiar solar motion [1] as 16.6 km/s towards Galactic coordinates $L2 = 53$ deg, $B2 = +25$ deg, or 17 49 58.7 Ra and +28 07 04 Dec (J2000).

The Kinematical LSR[2], is a point in the vicinity of the Sun which has the motion of 20 km/s towards RA 18h Dec +30d (1900).

For Galactocentric, we use the the radial velocity correction from the dynamical LSR to the galactic center which is defined as:[3] 220 km/s towards 21 12 01.1 Ra, +48 19 47 Dec (J2000).

An example header is shown below:

SOUVEL Binary Tables Extension: Header

```
-----
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                8 / 8-bit bytes
NAXIS   =                2 / 2-dimensional binary table
NAXIS1  =               32 / width of table in bytes
NAXIS2  =                1 / number of rows in table
PCOUNT  =                0 / size of special data area
GCOUNT  =                1 / one data group (required keyword)
TFIELDS =                4 / number of fields in each row
TTYPE1  = 'DMJD'            / label for field  1
TFORM1  = '1D'              / data format of field: 8-byte DOUBLE
TUNIT1  = 'd'               / physical unit of field
TTYPE2  = 'VELOCITY'        / label for field  2
TFORM2  = '1D'              / data format of field: 8-byte DOUBLE
TUNIT2  = 'm/s'             / physical unit of field
TTYPE3  = 'VDOT'            / label for field  3
TFORM3  = '1D'              / data format of field: 8-byte DOUBLE
TUNIT3  = 'm/s/s'           / physical unit of field
TTYPE4  = 'VDOTDOT'         / label for field  4
TFORM4  = '1D'              / data format of field: 8-byte DOUBLE
```



```
TUNIT4  = 'm/s/s/s '           / physical unit of field
VELDEF   = 'VRAD-TOP'          / Velocity definition and reference frame
EXTNAME  = 'SOUVEL'            / name of this binary table extension
END
```

References

- [1] Delhaye, *Stars and Stellar Systems*, vol 5, p73, 1965.
- [2] ed. Meeks, *Methods of Experimental Physics*, vol 12, part C, sec 6.1.5.2, p281.
- [3] L.-B. Kerr, *MNRAS* 221, p1023, 1986.