



Doc. No.: SRT-MAN-10000-003

Issue No.: 01

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Title: FITS and MBFITS output formats in Nuraghe

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FITS and MBFITS output formats in Nuraghe

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Nuraghe output files

The Nuraghe system is provided with data-writing *containers/components* able to gather the data coming from the fully integrated backends and record them into two possible formats:

- 1) *FitsZilla* → substantially standard FITS;
- 2) *MBFitsWriter* → hierarchical MBFITS (*not fully tested*)

This document, referring to Nuraghe 0.3, aims at describing these formats in order to allow the users to find the data and ancillary information recorded inside the files.

MBFitsWriter is not yet available at the SRT, as it is still under testing. Nonetheless, we anticipate here the main features of the MBFITS format it will produce. Since this format is very vast and complex, only a general description is provided here; the reader is invited to access the full manual and other literature resources to read the details (see MBFITS section).

1 FITS

This version of the output file is an almost-standard FITS made out of the following extensions:

Index	Extension	Type
<input type="checkbox"/> 0	Primary	Image
<input type="checkbox"/> 1	SECTION TABLE	Binary
<input type="checkbox"/> 2	RF INPUTS	Binary
<input type="checkbox"/> 3	FEED TABLE	Binary
<input type="checkbox"/> 4	DATA TABLE	Binary
<input type="checkbox"/> 5	ANTENNA TEMP TABLE	Binary
<input type="checkbox"/> 6	SERVO TABLE	Binary

It opens and plots with any software reading regular FITS (FitsViewer, IDL routines, FITS I/O libraries, etc...).

Nuraghe writes a FITS file for each subscan composing the ongoing observation, according to the following convention:

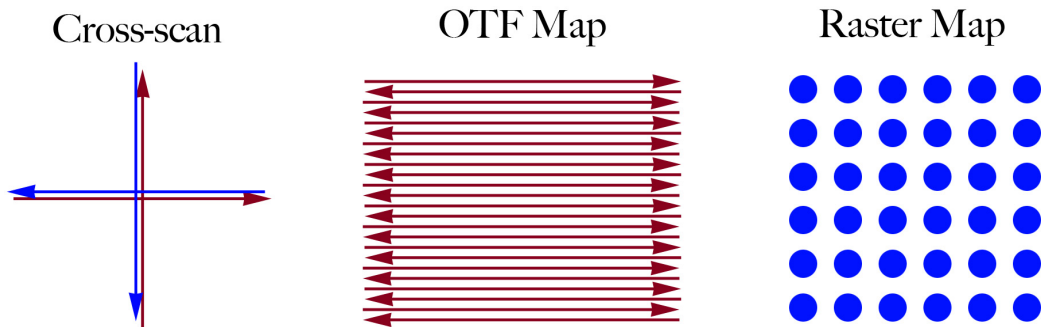
Scan

It is the lowest level object normally used by an observer. *It is a sequence of one or more subscans that share a single goal*: for instance cross-scans and maps involve a pattern of subscans. Whether OTF maps mosaicing observations are considered a single scan or a series of scans is rather a matter of how the user would like to define it. In our implementation each map is considered a scan.

Subscan

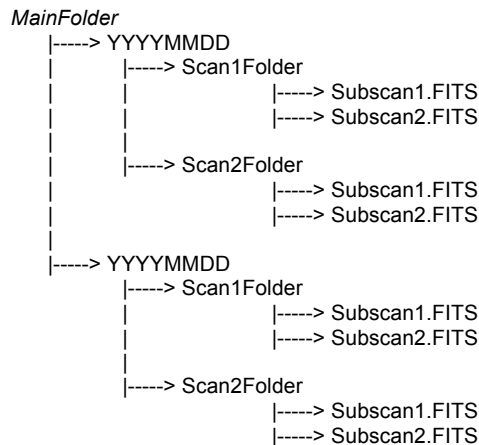
it is the minimal amount of data acquisition that can be commanded at the script language level. It is highly desirable that it is a simple enough element. For example, it is the single OTF “line” of a map or of a cross-scan.

The figure below visually represents what cross-scans, OTF maps and raster maps are.



In the case of cross-scan, a subscan is a single arrow (a line across the target), four arrows – i.e. two full crosses – constitute the schema which might be repeated as many times as needed within the scan. For OTF maps, the subscan is again the single arrow, and the scan coincides with the whole map obtained with lines along one axis only (e.g. along RA or Dec). For raster maps, which are based on discrete acquisitions, each point is a subscan, and the final map constitutes the scan.

When choosing FITS as the data output format, a distinct FITS file is produced for each subscan listed in the schedule.



Scan folder names are composed as: **YYYYMMDD-HHMMSS-Project-Suffix**

where

HHMMSS is the UT time associated to the first sample of the acquisition

Project is the code/name specified using the “project=” command, or when starting a schedule with “startSchedule=project/scheduleName.scd,N”

Suffix is a user-defined string retrieved from the schedule files. Though no control can be applied on the choice/check of this string, the agreement is that it should coincide with the target name.

FITS files, each corresponding to a subscan, are named like:

YYYYMMDD-HHMMSS-Project-Suffix_Scan#_Subscan#.fits



→ *Notice* The FITS content will undergo revisions in a near future. For example, several keywords will be added, others will be renamed in order to converge to the MBFITS keyword containing the same information (both for consistency and to better develop a common archiving system); the keywords to be renamed are written in **bold** in the following lists.

1.0 PRIMARY HEADER

Here the compulsory FITS header keywords are stored. A list of keywords dedicated to observing site info and telescope setup details then follows.

SIMPLE	T	file does conform to FITS standard
BITPIX	8	number of bits per data pixel
NAXIS	0	number of data axes
EXTEND	T	FITS data set may contain extensions
DATE	'2013-11-15T16:38:13'	file creation date (YYYY-MM-DDThh:mm:ss UT)
HIERARCH Project_Name	'SRT-SCICOM_Test_3C295_K_2'	Name of the project
OBSERVER	' '	Name of the observer
ANTENNA	'SRT '	Name of the station
HIERARCH SiteLongitude	0.161358481873679	Longitude of the site (radians)
HIERARCH SiteLatitude	0.689283579621821	Latitude of the site (radians)
HIERARCH SiteHeight	650.	Height of the site (meters)
BEAMS	7	Number of beams
SECTIONS	14	Total number of sections
HIERARCH Sample Size	4	Number of bytes of a data
HIERARCH Receiver Code	'KKG '	Keyword that identifies the receiver
SOURCE	'3C295 '	Source identifier
HIERARCH RightAscension	3.71468605789256	Source right ascension at J2000 (radians)
HIERARCH Declination	0.91110550277234	Source declination at J2000 (radians)
VLSR	0.	Source radial velocity
HIERARCH Azimuth Offset	0.	Longitude offset in horizontal frame
HIERARCH Elevation Offset	0.	Latitude offset in horizontal frame
HIERARCH RightAscension Offset	0.	Longitude offset in equatorial frame
HIERARCH Declination Offset	0.00148352986419518	Latitude offset in equatorial frame
HIERARCH GalacticLon Offset	0.	Longitude offset in galactic frame
HIERARCH GalacticLat Offset	0.	Latitude offset in galactic frame
SCANID	1	Scan Identifier
HIERARCH SubScanID	2	Subscan Identifier
HIERARCH ScheduleName	'/archive/schedules/scicom/SRT-SCICOM_Test_3C295_K_2.sc'	
HIERARCH SubScanType	'RA '	describes the scan type based on telescope m [i.e. scan axis]
HIERARCH Scan Tag	1	Scan tag identifier



1.1 SECTION TABLE

It shows basic info about the sections (i.e. “logical channels”).

Select	<input type="checkbox"/> id	<input type="checkbox"/> type	<input type="checkbox"/> sampleRate	<input type="checkbox"/> bins	<input type="checkbox"/> flux
	J	6A	D	J	D
<input type="checkbox"/> All			MHz		
Invert	Modify	Modify	Modify	Modify	Modify
1	0	simple	2.500000000000E-05	1	0.000000000000E+00
2	1	simple	2.500000000000E-05	1	0.000000000000E+00

Column meanings and units are also described in its header, as it happens for all the tables. Each row is dedicated to one section:

id = section number

type = simple (total power) or full (Full Stokes, i.e. including polarimetry)

sampleRate = data sampling rate (MHz)

bins = number of frequency bins (1 for total power)

Header example:

XTENSION= 'BINTABLE'	'BINTABLE'	binary table extension
BITPIX	8	8-bit bytes
NAXIS	2	2-dimensional binary table
NAXIS1	30	width of table in bytes
NAXIS2	14	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	'id '	label for field 1
TFORM1	'J '	data format of field: 4-byte INTEGER
TTYPE2	'type '	label for field 2
TFORM2	'6A '	data format of field: ASCII Character
TTYPE3	'sampleRate'	label for field 3
TFORM3	'D '	data format of field: 8-byte DOUBLE
TUNIT3	'MHz '	physical unit of field
TTYPE4	'bins '	label for field 4
TFORM4	'J '	data format of field: 4-byte INTEGER
TTYPE5	'flux '	label for field 5
TFORM5	'D '	data format of field: 8-byte DOUBLE
EXTNAME	'SECTION TABLE'	name of this binary table extension
HIERARCH Integration	20	Integration time (milliseconds)



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1.2 RF INPUTS

Receiver general setup.

Select	<input type="checkbox"/> feed	<input type="checkbox"/> ifChain	<input type="checkbox"/> polarization	<input type="checkbox"/> frequency	<input type="checkbox"/> bandWidth	<input type="checkbox"/> localOscillator	<input type="checkbox"/> attenuation	<input type="checkbox"/> calibrationMark
J	J	8A	D	D	D	D	D	D
All				MHz	MHz	MHz	db	K
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	0	0	left	5.000000000000E+03	1.500000000000E+02	4.900000000000E+03	1.100000000000E+01	5.880000000000E+00
2	0	1	right	5.000000000000E+03	1.500000000000E+02	4.900000000000E+03	9.000000000000E+00	5.710000000000E+00

feed = feed number

ifChain = IF number

polarisation = left or right

frequency = observed frequency at the beginning of the band (MHz)

bandWidth = actual observed bandwidth (MHz)

localOscillator = LO frequency (MHz)

attenuation = attenuation (dB) applied to the section

calibrationMark = temperature of the calibration mark

section = number of section associated to this RF input

Header example:

XTENSION	'BINTABLE'	binary table extension
BITPIX	8	8-bit bytes
NAXIS	2	2-dimensional binary table
NAXIS1	60	width of table in bytes
NAXIS2	14	number of rows in table
PCOUNT	0	size of special data area
GCOUNT	1	one data group (required keyword)
TFIELDS	9	number of fields in each row
TTYPE1	'feed '	label for field 1
TFORM1	'J '	data format of field: 4-byte INTEGER
TTYPE2	'ifChain '	label for field 2
TFORM2	'J '	data format of field: 4-byte INTEGER
TTYPE3	'polarization'	label for field 3
TFORM3	'8A '	data format of field: ASCII Character
TTYPE4	'frequency'	label for field 4
TFORM4	'D '	data format of field: 8-byte DOUBLE
TUNIT4	'MHz '	physical unit of field
TTYPE5	'bandWidth'	label for field 5
TFORM5	'D '	data format of field: 8-byte DOUBLE
TUNIT5	'MHz '	physical unit of field
TTYPE6	'localOscillator'	label for field 6
TFORM6	'D '	data format of field: 8-byte DOUBLE
TUNIT6	'MHz '	physical unit of field
TTYPE7	'attenuation'	label for field 7
TFORM7	'D '	data format of field: 8-byte DOUBLE



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TUNIT7	'db '	physical unit of field
TTYPE8	'calibratonMark'	label for field 8
TFORM8	'D '	data format of field: 8-byte DOUBLE
TUNIT8	'K '	physical unit of field
TTYPE9	'section '	label for field 9
TFORM9	'J '	data format of field: 4-byte INTEGER
EXTNAME	'RF INPUTS'	name of this binary table extension

1.3 FEED TABLE

Information on the feeds position (meaningful for Multi Feed receivers).

Select	<input type="checkbox"/> id	<input type="checkbox"/> xOffset	<input type="checkbox"/> yOffset	<input type="checkbox"/> relativePower
	J	D	D	D
<input type="checkbox"/> All				
Invert	Modify	Modify	Modify	Modify
1	0	0.000000000000E+00	0.000000000000E+00	1.000000000000E+00

id = feed number

xOffset = x offset position (radians) w.r.t. the central feed, computed along azimuth axis: $x > 0$ for increasing azimuth, when the receiver is in its reference position (no rotation is applied to dewar)

yOffset = y offset position (radians) w.r.t. the central feed, computed along elevation axis: $y > 0$ for increasing elevation, when the receiver is in its reference position (no rotation is applied to dewar)

relativePower = nominal ratio between this feed gain and the central feed gain

Header example:

XTENSION	'BINTABLE'	binary table extension
BITPIX	8	8-bit bytes
NAXIS	2	2-dimensional binary table
NAXIS1	28	width of table in bytes
NAXIS2	7	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	'id '	label for field 1
TFORM1	'J '	data format of field: 4-byte INTEGER
TTYPE2	'xOffset '	label for field 2
TFORM2	'D '	data format of field: 8-byte DOUBLE
TTYPE3	'yOffset '	label for field 3
TFORM3	'D '	data format of field: 8-byte DOUBLE
TTYPE4	'relativePower'	label for field 4
TFORM4	'D '	data format of field: 8-byte DOUBLE
EXTNAME	'FEED TABLE'	name of this binary table extension



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1.4 DATA TABLE

Large table containing all the raw data, one row for each sample.

Select	<input type="checkbox"/> time	<input type="checkbox"/> raJ2000	<input type="checkbox"/> decJ2000	<input type="checkbox"/> az	<input type="checkbox"/> el	<input type="checkbox"/> par_angle
	D	D	D	D	D	D
	MJD	radians	radians	radians	radians	radians
<input type="checkbox"/> All	Modify	Modify	Modify	Modify	Modify	Modify
Invert	Modify	Modify	Modify	Modify	Modify	Modify
1	5.620864923078E+04	3.539233784069E+00	5.263401486723E-01	4.785854189601E+00	7.194297091147E-01	9.646495431911E-01
2	5.620864923124E+04	3.539237361840E+00	5.263799951818E-01	4.785897311538E+00	7.194528632743E-01	9.646782785212E-01
3	5.620864923170E+04	3.539240744999E+00	5.264197574649E-01	4.785940469868E+00	7.194758301985E-01	9.647069412629E-01
4	5.620864923216E+04	3.539241727067E+00	5.264584805811E-01	4.785984077214E+00	7.194964870541E-01	9.647346894536E-01
5	5.620864923263E+04	3.539242709136E+00	5.264972036974E-01	4.786027684561E+00	7.195171439096E-01	9.647624390526E-01
6	5.620864923309E+04	3.539243691205E+00	5.265359268137E-01	4.786071291907E+00	7.195378007652E-01	9.647901900599E-01
7	5.620864923355E+04	3.539244673274E+00	5.265746499300E-01	4.786114899253E+00	7.195584576207E-01	9.648179424756E-01
8	5.620864923402E+04	3.539245655342E+00	5.266133730462E-01	4.786158506599E+00	7.195791144763E-01	9.648456963001E-01
9	5.620864923448E+04	3.539246637411E+00	5.266520961625E-01	4.786202113945E+00	7.195997713318E-01	9.648734515333E-01
10	5.620864923494E+04	3.539249027335E+00	5.266879665544E-01	4.786241695889E+00	7.196197940337E-01	9.648992526268E-01
11	5.620864923540E+04	3.539251618427E+00	5.267234293212E-01	4.786280702643E+00	7.196397261215E-01	9.649247755651E-01
12	5.620864923587E+04	3.539254209518E+00	5.267588920879E-01	4.786319709398E+00	7.196596582094E-01	9.649502997672E-01

<input type="checkbox"/> derot_angle	<input type="checkbox"/> flag_cal	<input type="checkbox"/> flag_track	<input type="checkbox"/> weather	<input type="checkbox"/> Ch0	<input type="checkbox"/> Ch1
D	J	J	3D	1E	1E
radians					
Modify	Modify	Modify	Modify	Modify	Modify
3.333578870000E-01	0	1	Plot	2.216350E+03	1.453575E+03
3.333578870000E-01	0	1	Plot	2.204175E+03	1.479800E+03
3.333578870000E-01	0	1	Plot	2.208875E+03	1.511650E+03
3.333578870000E-01	0	1	Plot	2.187675E+03	1.532025E+03
3.333578870000E-01	0	1	Plot	2.187600E+03	1.546700E+03
3.333578870000E-01	0	1	Plot	2.175500E+03	1.560325E+03
3.333578870000E-01	0	1	Plot	2.179525E+03	1.602375E+03
3.333578870000E-01	0	1	Plot	2.153625E+03	1.599475E+03
3.333578870000E-01	0	1	Plot	2.147000E+03	1.625500E+03
3.333578870000E-01	0	1	Plot	2.138850E+03	1.637875E+03
3.333578870000E-01	0	1	Plot	2.142100E+03	1.666600E+03
3.333578870000E-01	0	1	Plot	2.129500E+03	1.653550E+03

Columns:

time = MJD (Modified Julian Day)

raJ2000 = J2000.0 Right Ascension (radians)

decJ2000 = J2000.0 Declination (radians)

az = azimuth (radians)

el = elevation (radians)

par_angle = parallactic angle (radians)

derot_angle = rotation angle of the dewar (radians), at present it still is a dummy value

flag_cal = calibration mark flag, 0=off, 1=on

flag_track = tracking flag: 1 = pointing error is < 0.1*HPBW, 0 = pointing error is > 0.1*HPBW

weather = array of three values: temperature (°C), relative humidity (%) and atmospheric pressure (hPa), measured at ground level

Ch0,...,ChN = N columns, one for each section, containing the signal intensity in arbitrary counts

Header example:

XTENSION	'BINTABLE'	binary table extension
BITPIX	8	8-bit bytes
NAXIS	2	2-dimensional binary table
NAXIS1	144	width of table in bytes
NAXIS2	165	number of rows in table



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PCOUNT	0	size of special data area
GCOUNT	1	one data group (required keyword)
TFIELDS	24	number of fields in each row
TTYPE1	'time '	label for field 1
TFORM1	'D '	data format of field: 8-byte DOUBLE
TUNIT1	'MJD '	physical unit of field
TTYPE2	'raj2000 '	label for field 2
TFORM2	'D '	data format of field: 8-byte DOUBLE
TUNIT2	'radians '	physical unit of field
TTYPE3	'decj2000'	label for field 3
TFORM3	'D '	data format of field: 8-byte DOUBLE
TUNIT3	'radians '	physical unit of field
TTYPE4	'az '	label for field 4
TFORM4	'D '	data format of field: 8-byte DOUBLE
TUNIT4	'radians '	physical unit of field
TTYPE5	'el '	label for field 5
TFORM5	'D '	data format of field: 8-byte DOUBLE
TUNIT5	'radians '	physical unit of field
TTYPE6	'par_angle'	label for field 6
TFORM6	'D '	data format of field: 8-byte DOUBLE
TUNIT6	'radians '	physical unit of field
TTYPE7	'derot_angle'	label for field 7
TFORM7	'D '	data format of field: 8-byte DOUBLE
TUNIT7	'radians '	physical unit of field
TTYPE8	'flag_cal'	label for field 8
TFORM8	'J '	data format of field: 4-byte INTEGER
TTYPE9	'flag_track'	label for field 9
TFORM9	'J '	data format of field: 4-byte INTEGER
TTYPE10	'weather '	label for field 10
TFORM10	'3D '	data format of field: 8-byte DOUBLE
TTYPE11	'Ch0 '	label for field 11
TFORM11	'1E '	data format of field: 4-byte REAL
TTYPE12	'Ch1 '	label for field 12
TFORM12	'1E '	data format of field: 4-byte REAL
TTYPE13	'Ch2 '	label for field 13
TFORM13	'1E '	data format of field: 4-byte REAL
TTYPE14	'Ch3 '	label for field 14
TFORM14	'1E '	data format of field: 4-byte REAL
TTYPE15	'Ch4 '	label for field 15
TFORM15	'1E '	data format of field: 4-byte REAL
TTYPE16	'Ch5 '	label for field 16



TFORM16	'1E '	data format of field: 4-byte REAL
TTYPER17	'Ch6 '	label for field 17
TFORM17	'1E '	data format of field: 4-byte REAL
TTYPER18	'Ch7 '	label for field 18
TFORM18	'1E '	data format of field: 4-byte REAL
TTYPER19	'Ch8 '	label for field 19
TFORM19	'1E '	data format of field: 4-byte REAL
TTYPER20	'Ch9 '	label for field 20
TFORM20	'1E '	data format of field: 4-byte REAL
TTYPER21	'Ch10 '	label for field 21
TFORM21	'1E '	data format of field: 4-byte REAL
TTYPER22	'Ch11 '	label for field 22
TFORM22	'1E '	data format of field: 4-byte REAL
TTYPER23	'Ch12 '	label for field 23
TFORM23	'1E '	data format of field: 4-byte REAL
TTYPER24	'Ch13 '	label for field 24
TFORM24	'1E '	data format of field: 4-byte REAL
EXTNAME	'DATA TABLE'	name of this binary table extension

1.5 ANTENNA TEMP TABLE

It contains N columns (Ch0, ..., ChN) with the signal converted in antenna temperature (K). Conversion is performed using a counts-to-K factor retrieved from the last available T_{sys} measurement. This means that the conversion factor, if the T_{sys} value had been achieved in a distant time or position w.r.t. the data stream, could be obsolete and/or not applicable to the data! Pay much attention to the usage of this table, as discussed in the "Observing at the SRT with Nuraghe" user's guide.

Header example:

XTENSION	'BINTABLE'	binary table extension
BITPIX	8	8-bit bytes
NAXIS	2	2-dimensional binary table
NAXIS1	112	width of table in bytes
NAXIS2	165	number of rows in table
PCOUNT	0	size of special data area
GCOUNT	1	one data group (required keyword)
TFIELDS	14	number of fields in each row
TTYPER1	'Ch0 '	label for field 1
TFORM1	'D '	data format of field: 8-byte DOUBLE
TUNIT1	'K '	physical unit of field
TTYPER2	'Ch1 '	label for field 2
TFORM2	'D '	data format of field: 8-byte DOUBLE
TUNIT2	'K '	physical unit of field



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TTYPE3	'Ch2 '	label for field 3
TFORM3	'D '	data format of field: 8-byte DOUBLE
TUNIT3	'K '	physical unit of field
TTYPE4	'Ch3 '	label for field 4
TFORM4	'D '	data format of field: 8-byte DOUBLE
TUNIT4	'K '	physical unit of field
TTYPE5	'Ch4 '	label for field 5
TFORM5	'D '	data format of field: 8-byte DOUBLE
TUNIT5	'K '	physical unit of field
TTYPE6	'Ch5 '	label for field 6
TFORM6	'D '	data format of field: 8-byte DOUBLE
TUNIT6	'K '	physical unit of field
TTYPE7	'Ch6 '	label for field 7
TFORM7	'D '	data format of field: 8-byte DOUBLE
TUNIT7	'K '	physical unit of field
TTYPE8	'Ch7 '	label for field 8
TFORM8	'D '	data format of field: 8-byte DOUBLE
TUNIT8	'K '	physical unit of field
TTYPE9	'Ch8 '	label for field 9
TFORM9	'D '	data format of field: 8-byte DOUBLE
TUNIT9	'K '	physical unit of field
TTYPE10	'Ch9 '	label for field 10
TFORM10	'D '	data format of field: 8-byte DOUBLE
TUNIT10	'K '	physical unit of field
TTYPE11	'Ch10 '	label for field 11
TFORM11	'D '	data format of field: 8-byte DOUBLE
TUNIT11	'K '	physical unit of field
TTYPE12	'Ch11 '	label for field 12
TFORM12	'D '	data format of field: 8-byte DOUBLE
TUNIT12	'K '	physical unit of field
TTYPE13	'Ch12 '	label for field 13
TFORM13	'D '	data format of field: 8-byte DOUBLE
TUNIT13	'K '	physical unit of field
TTYPE14	'Ch13 '	label for field 14
TFORM14	'D '	data format of field: 8-byte DOUBLE
TUNIT14	'K '	physical unit of field
EXTNAME	'ANTENNA TEMP TABLE'	name of this binary table extension



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1.6 SERVO TABLE (SRT only)

It contains the readout of each axis for every servo system involved.

Servo systems are:

Primary focus (PFP)

Gregorian focus (SRP, GFR)

BWG (SRP, GRF, M3R)

PFP: Primary Focus Positioner

SRP: SubReflector Positioner, Gregorian Feed Rotator

M3R: Mirror 3 Rotator

Notice: the present release of this table contains several errors. For example, measure units specified in the header are wrong/missing.

Select	<input type="checkbox"/> time	<input type="checkbox"/> SRP_TX	<input type="checkbox"/> SRP_TY	<input type="checkbox"/> SRP_TZ	<input type="checkbox"/> SRP_RX	<input type="checkbox"/> SRP_RY	<input type="checkbox"/> SRP_RZ	<input type="checkbox"/> GFR_RZ
<input type="checkbox"/> All	D	D	D	D	D	D	D	D
<input type="checkbox"/> Invert	MJD	TX	TY	TZ	RX	RY	RZ	mm
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	5. 673273613461E+04	-1. 499927034393E+00	1. 479600033567E+01	1. 966389330694E+00	4. 141411823968E-02	-3. 610823004669E-02	3. 196720137144E-06	1. 323500000000E+03
2	5. 673273613472E+04	-1. 499925806685E+00	1. 479731217005E+01	1. 966724363668E+00	4. 141076104813E-02	-3. 610835363404E-02	3. 278719121723E-06	1. 323500000000E+03
3	5. 673273613484E+04	-1. 499924579325E+00	1. 479862400443E+01	1. 967059396642E+00	4. 140740385658E-02	-3. 610847722139E-02	3. 360718106302E-06	1. 323500000000E+03
4	5. 673273613495E+04	-1. 499923351791E+00	1. 479993583881E+01	1. 967394429615E+00	4. 140404666503E-02	-3. 610860080874E-02	3. 442717090881E-06	1. 323500000000E+03
5	5. 673273613507E+04	-1. 499922124257E+00	1. 480124767319E+01	1. 967729462589E+00	4. 140068947348E-02	-3. 610872439609E-02	3. 524716075460E-06	1. 323500000000E+03
6	5. 673273613519E+04	-1. 499920896722E+00	1. 480255950757E+01	1. 968064495562E+00	4. 139733228193E-02	-3. 610884798344E-02	3. 606715060038E-06	1. 323500000000E+03
7	5. 673273613530E+04	-1. 499919669188E+00	1. 480387134195E+01	1. 968399528536E+00	4. 139397509038E-02	-3. 610897157079E-02	3. 688714044617E-06	1. 323500000000E+03
8	5. 673273613542E+04	-1. 499918441654E+00	1. 480518317633E+01	1. 968734561510E+00	4. 139061789883E-02	-3. 610909515813E-02	3. 770713029196E-06	1. 323500000000E+03

time = MJD associated to the following positions

SRP_TX = SRP translation along the X axis (mm)

SRP_TY = SRP translation along the Y axis (mm)

SRP_TZ = SRP translation along the Z axis (mm)

SRP_RX = SRP rotation around the X axis (mm)

SRP_RY = SRP rotation around the Y axis (mm)

SRP_RZ = SRP rotation around the Z axis (mm)

GFR_RZ = GFR rotation (mm)

Header example:

XTENSION	'BINTABLE'	binary table extension
BITPIX	8	8-bit bytes
NAXIS	2	2-dimensional binary table
NAXIS1	64	width of table in bytes
NAXIS2	285	width of table in bytes
PCOUNT	0	size of special data area
GCOUNT	1	one data group (required keyword)
TFIELDS	8	number of fields in each row
TTYPE1	'time '	label for field 1
TFORM1	'D '	data format of field: 8-byte DOUBLE
TUNIT1	'MJD '	physical unit of field
TTYPE2	'SRP_TX '	label for field 2
TFORM2	'D '	data format of field: 8-byte DOUBLE
TUNIT2	'TX '	physical unit of field
TTYPE3	'SRP_TY '	label for field 3
TFORM3	'D '	data format of field: 8-byte DOUBLE
TUNIT3	'TY '	physical unit of field



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TTYPE4	'SRP_TZ '	label for field 4
TFORM4	'D '	data format of field: 8-byte DOUBLE
TUNIT4	'TZ '	physical unit of field
TTYPE5	'SRP_RX '	label for field 5
TFORM5	'D '	data format of field: 8-byte DOUBLE
TUNIT5	'RX '	physical unit of field
TTYPE6	'SRP_RY '	label for field 6
TFORM6	'D '	data format of field: 8-byte DOUBLE
TUNIT6	'RY '	physical unit of field
TTYPE7	'SRP_RZ '	label for field 7
TFORM7	'D '	data format of field: 8-byte DOUBLE
TUNIT7	'RZ '	physical unit of field
TTYPE8	'M3R_RZ '	label for field 8
TFORM8	'D '	data format of field: 8-byte DOUBLE
TUNIT8	'RZ '	physical unit of field
EXTNAME	'SERVO TABLE'	name of this binary table extension



2 MBFITS

The Multi-Beam FITS format has been conceived, as its name suggests, to handle multi-beam observations.

Following the official document listing its features ([APEX Report APEX-MPI-ICD-0002](#)) the MBFITS produced by Nuraghe is a hierarchical structure of FITS files, each devoted to the storage of a different set of data and environmental info acquired during the observation. Details on the system component MBFitsWriter can be found inside the IRA Technical Report 461/12.

The MBFITS hierarchical grouping directory structure is defined as follows:

- Main directory name
- Inside this main directory, there are the files for the scan-level tables:
 - The grouping table file: **GROUPING**.fits
 - The scan table file: **SCAN**.fits
 - The FEBEPAR table files for each FEBE combination: **<FEBE name>-FEBEPAR**.fits
- The actual data is stored in subdirectories, one for each subscan, named according to the subscan number.

Each subdirectory contains the following types of member files:

 - The MONITOR table file: **MONITOR**.fits
 - One ARRAYDATA table file for each FEBE combination and baseband: **<FEBE name>-ARRAYDATA-<Baseband number>**.fits
 - One DATAPAR table file for each FEBE combination: **<FEBE name>-DATAPAR**.fits

2.0 GROUPING Table

This table exists only in the hierarchical implementation of the MBFITS format and it is created once for each scan. It is used to store the locations of the member files, plus other details which can be exploited to speed up searching when reading the files.

2.1 SCAN Table

It is stored for every scan. It contains parameters which do not change among the subscans, including:

- telescope and observatory parameters
- time system
- coordinate system
- velocity system
- project ID
- target of the scan and its coordinates
- observing mode
- pointing model coefficients

2.2 FEBEPAR Table

The FEBEPAR table is stored per FEBE (FrontEnd–BackEnd) combination for each scan and contains the frontend-backend setup. Parameters common to all FEBEs are written in the SCAN table.

It includes:

- FEBE setup: number of pixels, polarisations and basebands
- pointing model coefficients specific to this FE
- calibration parameters specific to this FEBE



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2.3 ARRAYDATA Table

A new ARRAYDATA table is created for each subscan, for each FEBE and for each baseband. It stores the data description (header) and the data (table).

It includes:

- frequency band setup: frequency, bins (freq. channels), polarisations, line ID
- data axes description

If some parameters change for the individual subscan with respect to the general value stored in the SCAN table, data analysis applications should get these values from the ARRAYDATA table rather than from the SCAN one.

2.4 DATAPAR Table

A new DATAPAR table is created for each subscan and for each FEBE.

Parameters common to all the subscans are written in the SCAN table, while the FEBE setup is recorded in the FEBEPAR table (also assumed to be constant for all subscans).

The DATAPAR table contains those data-associated parameters which change with the integration, but not the data themselves – as they are stored in the ARRAYDATA table.

The table includes:

- time and coordinates information, specific to this subscan and integration
- interpolated data from the MONITOR table, resampled to the timestamps of the midpoints of the integrations, as given by the MJD timestamp.

2.5 MONITOR Table

This table stores raw monitoring data (real-time updates other than the backend data) at their natural rate, i.e. not synchronised to backend dump times.

The monitor data are stored as time-keyword-units-values.

The update intervals for any monitor stream are thus fully flexible.

It is recommended that the telescope control system should call for updates on monitor points at least at the beginning and end of the scans. As many of these as possible should be measured at these times. For points where a new measurement is not possible the last measurement should be saved again in the MONITOR table with its original timestamp. In this way, interpolation between points to fill in the DATAPAR table will be possible even without access to previous/later scan data.

MONITOR table updates:

- at the beginning/end of scans: calibration data, pointing data, radiometer data, weather station data
- at the beginning of integrations: frequencies, current real antenna positions
- at the end of observations: current real antenna positions.