

# MeasurementSet definition version 3.0

MSv3 team (to be filled in)

December 2017

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# 1 Summary

This note describes a revised MeasurementSet definition which extends that previously given in casacore Note 229 (Kemball and Wieringa 2000).

## 2 Introduction

## 3 Summary of changes

This section contains a description of the changes proposed for each table in the MS definition. A full definition of the v3.0 MS format is given in Section 4.

- Add explicit primary keys.
- Support versioning of DATA, WEIGHTS and FLAG columns. Remove SIGMA, SIGMA\_SPECTRUM.
- Remove FLAG\_ROW, WEIGHT columns, make spectral information (FLAG, WEIGHT\_SPECTRUM) information non-optional.
- Formalize combinations of MeasurementSets (“Multi-MS”) for parallel processing.
- Remove DATA\_DESC\_ID.

## 4 MS v3.0 layout

There is a MAIN table containing a number of data columns and keys into various subtables. There is at most one of each subtable. The subtables are stored as keywords of the MS, and all defined sub-tables are tabulated below. Optional sub-tables are shown in italics.

Subtables		
Table	Contents	Keys
ANTENNA ( <i>DOPPLER</i> )	Antenna characteristics Doppler tracking	ANTENNA_ID DOPPLER_ID, SOURCE_ID
FEED	Feed characteristics	FEED_ID, AN- TENNA_ID, TIME, SPEC- TRAL_WINDOW_ID
FIELD	Field position	FIELD_ID
FLAG.CMD ( <i>FREQ-OFFSET</i> )	Flag commands Frequency offset infor- mation	TIME FEED_ID, ANTENNA <sub>n</sub> , FEED_ID, TIME, SPEC- TRAL_WINDOW_ID
HISTORY	History information	OBSERVATION_ID, TIME
OBSERVATION ( <i>PHASED-ARRAY</i> )	Observer, Schedule, etc Phased array informa- tion	OBSERVATION_ID ANTENNA_ID
POINTING	Pointing information	ANTENNA_ID, TIME
POLARIZATION	Polarization setup	POLARIZATION_ID
PROCESSOR	Processor information	PROCESSOR_ID
( <i>SOURCE</i> )	Source information	SOURCE_ID, SPEC- TRAL_WINDOW_ID, TIME
SPECTRAL_WINDOW	Spectral window setups	SPECTRAL_WINDOW_ID
STATE	State information	STATE_ID
( <i>SYSCAL</i> )	System calibration char- acteristics	FEED_ID, AN- TENNA_ID, TIME, SPEC- TRAL_WINDOW_ID
( <i>WEATHER</i> )	Weather info for each an- tenna	ANTENNA_ID, TIME

Note that all optional columns are indicated in italics and in parentheses.

#### 4.1 MAIN table: Data, coordinates and flags

MAIN table: Data, coordinates and flags				
Name	Format	Units	Measure	Comments
Columns				
Keywords				
MS.VERSION (SORT_COLUMNS) (SORT_ORDER)	Float String String			MS format version Sort columns Sort order
Key				
TIME (TIME_EXTRA_PREC)	Double Double	s s	EPOCH	Integration midpoint extraTIME precision
ANTENNA1	Int			First antenna
ANTENNA2	Int			Second antenna
(ANTENNA3)	Int			Third antenna
FEED1	Int			Feed on ANTENNA1
FEED2	Int			Feed on ANTENNA2
(FEED3)	Int			Feed on ANTENNA3
SPECTRAL_WINDOW_ID	Int			Spectral window id.
POLARIZATION_ID	Int			Polarization id.
PROCESSOR_ID	Int			Processor id.
(PHASE_ID)	Int			Phase id.
FIELD_ID	Int			Field id.
Non-key attributes				
INTERVAL	Double	s	EPOCH	Sampling interval
EXPOSURE	Double	s		The effective integration time
TIME.CENTROID	Double	s		Time centroid
(PULSAR_BIN)	Int			Pulsar bin number
(PULSAR_GATE_ID)	Int			Pulsar gate id.
SCAN_NUMBER	Int			Scan number
ARRAY_ID	Int			Subarray number
OBSERVATION_ID	Int			Observation id.
STATE_ID	Int			State id.
(BASELINE_REF)	Bool			Reference antenna
UVW	Double(3)	m	UVW	UVW coordinates
(UVW2)	Double(3)	m	UVW	UVW (baseline 2)
Data				
(DATA)	Complex( $N_c, N_f$ )			Complex visibility matrix (synthesis arrays)
(VIDEO_POINT)	Complex( $N_c$ )			Video point
(LAG_DATA)	Complex( $N_c, N_l$ )			Correlation function
(WEIGHT_SPECTRUM)	Float( $N_c, N_f^*$ )			Weight for each channel
(MODEL_DATA)	Complex( $N_c, N_f$ )			Model visibility
Flag information				
FLAG	Bool( $N_c, N_f^*$ )			Cumulative data flags

**Notes:**

Note that  $N_l$ = number of lags,  $N_c$ = number of correlators,  $N_f$ = number of frequency channels, and  $N_{cat}$ = number

of flag categories.

**MS\_VERSION** The MeasurementSet format revision number, expressed as *major\_revision.minor\_revision*. This version is 2.0.

**SORT\_COLUMNS** Sort indices, in the form "*index<sub>1</sub>, index<sub>2</sub> ...*", for the underlying MS. A string containing "NONE" reflects no sort order. An example might be SORT\_COLUMNS="TIME ANTENNA1 ANTENNA2", to indicate sorting in in time-baseline order.

**SORT\_ORDER** Sort order as either "ASCENDING" or "DESCENDING".

**TIME** Mid-point (not centroid) of data interval.

**TIME\_EXTRA\_PREC** Extra time precision.

**ANTENNA<sub>n</sub>** Antenna number ( $\geq 0$ ), and an index into the ANTENNA sub-table. For  $n > 2$ , triple-product data are implied.

**FEED<sub>n</sub>** Feed number ( $\geq 0$ ). For  $n > 2$ , triple-product data are implied.

**SPECTRAL\_WINDOW\_ID** Spectral window identifier ( $\geq 0$ ), an index into the SPECTRAL\_WINDOW sub-table.

**PROCESSOR\_ID** Processor identifier ( $\geq 0$ ), and an index into the PROCESSOR sub-table.

**PHASE\_ID** Switching phase identifier ( $\geq 0$ )

**FIELD\_ID** Field identifier ( $\geq 0$ ).

**INTERVAL** Data sampling interval. This is the nominal data interval and does not include the effects of bad data or partial integration.

**EXPOSURE** Effective data interval, including bad data and partial averaging.

**PULSAR\_BIN** Pulsar bin number for the data record. Pulsar data may be measured for a limited number of pulse phase bins. The pulse phase bins are described in the PULSAR sub-table and indexed by this bin number.

**PULSAR\_GATE\_ID** Pulsar gate identifier ( $\geq 0$ ), and an index into the PULSAR\_GATE sub-table.

**SCAN\_NUMBER** Arbitrary scan number to identify data taken in the same logical scan. Not required to be unique.

**ARRAY\_ID** Subarray identifier ( $\geq 0$ ), which identifies data in separate subarrays, as defined in Section 3.3.

**OBSERVATION\_ID** Observation identifier ( $\geq 0$ ), which identifies data from separate observations, as defined in Section 3.3.

**STATE\_ID** State identifier ( $\geq 0$ ), as defined in Section 3.1.5.

**BASELINE\_REF** Flag to indicate the original correlator reference antenna for baseline-based correlators (True for ANTENNA1; False for ANTENNA2).

**UVW** *uvw* coordinates for the baseline from ANTENNE2 to ANTENNA1, i.e. the baseline is equal to the difference POSITION2 - POSITION1. The UVW given are for the TIME\_CENTROID, and correspond in general to the reference type for the PHASE\_DIR of the relevant field. I.e. J2000 if the phase reference direction is given in J2000 coordinates. However, any known reference is valid. Note that the choice of baseline direction and UVW definition (*W* towards source direction; *V* in plane through source and system's pole; *U* in direction of increasing longitude coordinate) also determines the sign of the phase of the recorded data.

**UVW2** *uvw* coordinates for the baseline from ANTENNE3 to ANTENNA1 (triple-product data only), i.e. the baseline is equal to the difference POSITION3 - POSITION1. The UVW given are for the TIME\_CENTROID, and correspond in general to the reference type for the PHASE\_DIR of the relevant field. I.e. J2000 if the phase reference direction is given in J2000 coordinates. However, any known reference is valid. Note that the choice of baseline direction and UVW definition (*W* towards source direction; *V* in plane through source and system's pole; *U* in direction of increasing longitude coordinate) also determines the sign of the phase of the recorded data.

**DATA, LAG\_DATA** At least one of these columns should be present in a given MeasurementSet. In special cases one or more could be present (e.g., single dish data used in synthesis imaging or a mix of auto and crosscorrelations on a multi-feed single dish). If only correlation functions are stored in the MS, then  $N_f^*$  is the maximum number of lags ( $N_l$ ) specified in the LAG table for this LAG\_ID. If both correlation functions and frequency spectra are stored in the same MS, then  $N_f^*$  is the number of frequency channels, and the weight information refers to the frequency spectra only. The units for these columns (eg. 'Jy') specify whether the data are in flux density units or correlation coefficients.

**VIDEO\_POINT** The video point for the spectrum, to allow the full reverse transform.

**SIGMA** The estimated rms noise for a single channel, for each correlator.

**SIGMA\_SPECTRUM** The estimated rms noise for each channel.

**WEIGHT** The weight for the whole data matrix for each correlator, as assigned by the correlator or processor.

**WEIGHT\_SPECTRUM** The weight for each channel in the data matrix, as assigned by the correlator or processor. The weight spectrum should be used in preference to the WEIGHT, when available.

**FLAG** An array of Boolean values with the same shape as DATA (see the DATA item above) representing the cumulative flags applying to this data matrix. Data are flagged bad if the FLAG array element is True.

## 4.2 ANTENNA: Antenna characteristics

ANTENNA: Antenna characteristics				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Keywords</i>				
(TELESCOPE_CENTER)	Double(3)	m	POSITION	Center of telescope
<i>Key</i>				
ANTENNA_ID	Int			Antenna ID
<i>Data</i>				
NAME	String			Antenna name
STATION	String			Station name
TYPE	String			Antenna type
MOUNT	String			Mount type:alt-az, equatorial, X-Y, orbiting, bizarre
POSITION	Double(3)	m	POSITION	Antenna X,Y,Z phase reference positions
OFFSET	Double(3)	m	POSITION	Axes offset of mount to FEED REFERENCE point
DISH_DIAMETER	Double	m		Diameter of dish
(ORBIT_ID)	Int			Orbit id.
(MEAN_ORBIT)	Double(6)			Mean Keplerian elements
(PHASED_ARRAY_ID)	Int			Phased array id.

**Notes:** This sub-table contains the global antenna properties for each antenna in the MS. It is indexed from MAIN via ANTENNA $n$ .

**NAME** Antenna name (e.g. "NRAO\_140")

**STATION** Station name (e.g. "GREENBANK")

**TYPE** Antenna type. Reserved keywords include: ("GROUND-BASED" - conventional antennas; "SPACE-BASED" - orbiting antennas; "TRACKING-STN" - tracking stations).

**MOUNT** Mount type of the antenna. Reserved keywords include: ("EQUATORIAL" - equatorial mount; "ALT-AZ" - azimuth-elevation mount; "X-Y" - x-y mount; "SPACE-HALCA" - specific orientation model.)

**POSITION** In a right-handed frame, X towards the intersection of the equator and the Greenwich meridian, Z towards the pole. The exact frame should be specified in the MEASURE\_REFERENCE keyword (ITRF or WGS84). The reference point is the point on the az or ha axis closest to the el or dec axis.

**OFFSET** Axes offset of mount to feed reference point.

**DISH\_DIAMETER** Nominal diameter of dish, as opposed to the effective diameter.

**ORBIT\_ID** Orbit identifier. Index used in ORBIT sub-table if ANTENNA.TYPE is "SPACE-BASED".

**MEAN\_ORBIT** Mean Keplerian orbital elements, using the standard convention (Flatters 1998):

- **0:** Semi-major axis of orbit ( $a$ ) in  $m$ .
- **1:** Ellipticity of orbit ( $e$ ).
- **2:** Inclination of orbit to the celestial equator ( $i$ ) in  $deg$ .
- **3:** Right ascension of the ascending node ( $\Omega$ ) in  $deg$ .

- **4:** Argument of perigee ( $\omega$ ) in *deg*.
- **5:** Mean anomaly ( $M$ ) in *deg*.

**PHASED\_ARRAY\_ID** Phased array identifier. Points to a PHASED\_ARRAY sub-table which points back to multiple entries in the ANTENNA sub-table and contains information on how they are combined.



### 4.3 BEAM: Beam information

BEAM: Beam information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
Beam_ID	Int			Beam ID
<i>Data</i>				
TYPE	String			Beam definition type
COEFFICIENTS	Array of doubles			Coefficients describing beam model
(ALTERNATE_URL)	String			URL with alternate data

**Notes:** This sub-table contains a description of beam models. It is indexed from MAIN via BEAM\_ID.

**TYPE** Beam definition type, e.g. POLYNOMIAL, AIRY, NUMERIC, IMAGE, etc.

**COEFFICIENTS** Depending on type polynomial or numeric values rescaled at 1 GHz .

**ALTERNATE\_URL** Alternate url, for beam models which cannot be specified by coefficients (e.g. images).

#### 4.4 DOPPLER: Doppler tracking information

DOPPLER: Doppler tracking information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
DOPPLER_ID	Int			Doppler tracking id.
SOURCE_ID	Int			Source id.
<i>Data</i>				
TRANSITION_ID	Int			Transition id.
VELDEF	Double	m/s	Doppler	Velocity definition of Doppler shift.

**Notes:** This sub-table contains frame information for different Doppler tracking modes. It is indexed from the SPECTRAL\_WINDOW\_ID sub-table (with SOURCE\_ID as a secondary index) and thus allows the specification of a source-dependent Doppler tracking reference for each SPECTRAL\_WINDOW. This model allows multiple possible transitions per source per spectral window, but only one reference at any given time.

**DOPPLER\_ID** Doppler identifier, as used in the SPECTRAL\_WINDOW sub-table.

**SOURCE\_ID** Source identifier (as used in the SOURCE sub-table).

**TRANSITION\_ID** This index selects the appropriate line from the list of transitions stored for each SOURCE\_ID in the SOURCE table.

**VELDEF** Velocity definition of the Doppler shift, e.g., RADIO or OPTICAL velocity in m/s.

## 4.5 FEED: Feed characteristics

FEED: Feed characteristics				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
ANTENNA_ID	Int			Antenna id
FEED_ID	Int			Feed id
SPECTRAL_WINDOW_ID	Int			Spectral window id.
TIME	Double	s	EPOCH	Interval midpoint
INTERVAL	Double	s		Time interval
<i>Data description</i>				
NUM_RECEPTORS	Int			# receptors on this feed
<i>Data</i>				
BEAM_ID	Int			Beam model
BEAM_OFFSET	Double(2, NUM_RECEPTORS)	rad	DIRECTION	Beam position offset (on sky but in antenna reference frame).
(FOCUS_LENGTH)	Double	m		Focus length
(PHASED_FEED_ID)	Int			Phased feed
POLARIZATION_TYPE	String (NUM_RECEPTORS)			Type of polarization to which a given RECEPTOR responds.
POL_RESPONSE	Complex (NUM_RECEPTORS, NUM_RECEPTORS)			Feed polzn. response
POSITION	Double(3)	m	POSITION	Position of feed relative to feed reference position for this antenna
RECEPTOR_ANGLE	Double (NUM_RECEPTORS)	rad		The reference angle for polarization.

**Notes:** A feed is a collecting element on an antenna, such as a single horn, that shares joint physical properties and makes sense to calibrate as a single entity. It is an abstraction of a generic antenna feed and is considered to have one or more RECEPTORS that respond to different polarization states. A FEED may have a time-variable beam and polarization response. Feeds are numbered from 0 on each separate antenna for each SPECTRAL\_WINDOW\_ID. Consequently, FEED\_ID should be non-zero only in the case of feed arrays, i.e. multiple, simultaneous beams on the sky at the same frequency and polarization.

**ANTENNA\_ID** Antenna number, as indexed from ANTENNA $n$  in MAIN.

**FEED\_ID** Feed identifier, as indexed from FEED $n$  in MAIN.

**SPECTRAL\_WINDOW\_ID** Spectral window identifier. A value of -1 indicates the row is valid for all spectral windows.

**TIME** Mid-point of time interval for which the feed parameters in this row are valid. The same Measure reference used for the TIME column in MAIN must be used.

**INTERVAL** Time interval.

**NUM\_RECEPTORS** Number of receptors on this feed. See POLARIZATION\_TYPE for further information.

**BEAM\_ID** Beam identifier. Points to an optional BEAM sub-table defining the primary beam and polarization response for this FEED. A value of -1 indicates that no associated beam response is defined.

**BEAM\_OFFSET** Beam position offset, as defined on the sky but in the antenna reference frame.

**FOCUS\_LENGTH** Focus length. As defined along the optical axis of the antenna.

**PHASED\_FEED\_ID** Phased feed identifier. Points to a PHASED\_FEED sub-table which in turn points back to multiple entries in the FEED table, and specifies the manner in which they are combined.

**POLARIZATION\_TYPE** Polarization type to which each receptor responds (e.g. "R", "L", "X" or "Y"). This is the receptor polarization type as recorded in the final correlated data (e.g. "RR"); i.e. as measured after all polarization combiners.

**POL\_RESPONSE** Polarization response at the center of the beam for this feed. Expressed in a linearly polarized basis ( $\vec{e}_x, \vec{e}_y$ ) using the IEEE convention.

**POSITION** Offset of feed relative to the feed reference position for this antenna (see ANTENNA sub-table).

**RECEPTOR\_ANGLE** Polarization reference angle. Converts into parallactic angle in the sky domain.

## 4.6 FIELD: Field positions for each source

FIELD: Field positions for each source				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
FIELD_ID	Int			Field ID
<i>Data</i>				
NAME	String			Name of field
CODE	String			Special characteristics of field
TIME	Double	s	EPOCH	Time origin for the directions and rates
NUM_POLY	Int			Series order
DELAY_DIR	Double(2, NUM_POLY+1)	rad	DIRECTION	Direction of delay center.
PHASE_DIR	Double(2, NUM_POLY+1)	rad	DIRECTION	Phase center.
REFERENCE_DIR	Double(2, NUM_POLY+1)	rad	DIRECTION	Reference center
SOURCE_ID	Int			Index in Source table
(EPHEMERIS_ID)	Int			Ephemeris id.

**Notes:** The FIELD table defines a field position on the sky. For interferometers, this is the correlated field position. For single dishes, this is the nominal pointing direction.

**NAME** Field name; user specified.

**CODE** Field code indicating special characteristics of the field; user specified.

**TIME** Time reference for the directions and rates. Required to use the same TIME Measure reference as in MAIN.

**NUM\_POLY** Series order for the \*\_DIR columns.

**DELAY\_DIR** Direction of delay center; can be expressed as a polynomial in time. Final result converted to the defined Direction Measure type.

**PHASE\_DIR** Direction of phase center; can be expressed as a polynomial in time. Final result converted to the defined Direction Measure type.

**REFERENCE\_DIR** Reference center; can be expressed as a polynomial in time. Final result converted to the defined Direction Measure type. Used in single-dish to record the associated reference direction if position-switching has already been applied. For interferometric data, this is the original correlated field center, and may equal DELAY\_DIR or PHASE\_DIR.

**SOURCE\_ID** Points to an entry in the optional SOURCE subtable, a value of  $-1$  indicates there is no corresponding source defined.

**EPHEMERIS\_ID** Points to an entry in the EPHEMERIS sub-table, which defines the ephemeris used to compute the field position. Useful for moving, near-field objects, where the ephemeris may be revised over time.

## 4.7 FREQ\_OFFSET: Frequency offset information

FREQ_OFFSET: Frequency offset information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
ANTENNA1	Int			Antenna 1.
ANTENNA2	Int			Antenna 2.
FEED_ID	Int			Feed id.
SPECTRAL_WINDOW_ID	Int			Spectral window id.
TIME	Double	s	EPOCH	Interval midpoint
INTERVAL	Double	s		Time interval
<i>Data</i>				
OFFSET	Double	Hz		Frequency offset

**Notes:** The table contains frequency offset information, to be added directly to the defined frequency labeling in the SPECTRAL\_WINDOW sub-table as a Measure offset. This allows bands with small, time-variable, ad hoc frequency offsets to be labeled as the same SPECTRAL\_WINDOW\_ID, and calibrated together if required.

**ANTENNA $n$**  Antenna identifier, as indexed from ANTENNA $n$  in MAIN.

**FEED\_ID** Antenna identifier, as indexed from FEED $n$  in MAIN.

**SPECTRAL\_WINDOW\_ID** Spectral window identifier.

**TIME** Mid-point of the time interval for which this offset is valid. Required to use the same TIME Measure reference as used in MAIN.

**INTERVAL** Time interval.

**OFFSET** Frequency offset to be added to the frequency axis for this spectral window, as defined in the SPECTRAL\_WINDOW sub-table. Required to have the same Frequency Measure reference as CHAN\_FREQ in that table.

## 4.8 HISTORY: History information

HISTORY: History information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
TIME	Double	s	EPOCH	Time-stamp for message
OBSERVATION_ID	Int			Points to OBSERVATION table
<i>Data</i>				
MESSAGE	String			Log message
PRIORITY	String			Message priority
ORIGIN	String			Code origin
OBJECT_ID	String			Originating ObjectID
APPLICATION	String			Application name
CLI.COMMAND	String(*)			CLI command sequence
APP_PARAMS	String(*)			Application paramters

**Notes:** This sub-table contains associated history information for the MS.

**TIME** Time-stamp for the history record. Required to have the same TIME Measure reference as used in MAIN.

**OBSERVATION\_ID** Observation identifier (see the OBSERVATION table)

**MESSAGE** Log message.

**PRIORITY** Message priority, with allowed types: ("DEBUGGING", "WARN", "NORMAL", or "SEVERE").

**ORIGIN** Source code origin from which message originated.

**OBJECT\_ID** Originating ObjectID, if available, else blank.

**APPLICATION** Application name.

**CLI.COMMAND** CLI command sequence invoking the application.

**APP\_PARAMS** Application parameter values, in the adopted project-wide format.

## 4.9 INTERFEROMETER\_MODEL

INTERFEROMETER_MODEL				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
FIELD_ID	Int			Refers back to FIELD table
ANTENNA_ID	Int			Refers back to ANTENNA table
TIME INTERVAL SPECTRAL_WINDOW_ID	Double Double Int	s	EPOCH	Refers back to SPECTRAL_WINDOW
<i>Data</i>				
PHASE_DELAY	Double( $N_r, N_{poly}$ )			Phase delay polynomial for each receptor
GROUP_DELAY	Double( $N_r, N_{poly}$ )	s		Group delay polynomial for each receptor
PHASE_RATE	Double( $N_r, N_{poly}$ )	Hz		Rate of change of phase delay
GROUP_RATE	Double( $N_r, N_{poly}$ )			Rate of change of group delay
DISP_DELAY	Double( $N_r, N_{poly}$ )			Dispersive delay
DISP_DELAY_RATE	Double( $N_r, N_{poly}$ )			Rate of dispersive delay
CLOCK_ERROR	Double( $N_r, N_{poly}$ )	s		Clock error as delay polynomial
CLOCK_ERROR_RATE	Double( $N_r, N_{poly}$ )			Rate of clock error modeled as delay rate polynomial

**Notes:** Note that  $N_r$ = number of receptors.

TODO: Description (refer back to FITS-IDI description?)



## 4.10 OBSERVATION: Observation information

OBSERVATION: Observation information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
OBSERVATION_ID	Int			Observation ID
<i>Data</i>				
TELESCOPE_NAME	String	s	EPOCH	Telescope name
TIME_RANGE	Double(2)			Start, end times
OBSERVER	String			Name of observer(s)
LOG	String(*)			Observing log
SCHEDULE_TYPE	String			Schedule type
SCHEDULE	String(*)			Project schedule
PROJECT	String	s	EPOCH	Project identification string.
RELEASE_DATE	Double			Target release date

**Notes:** This table contains information specifying the observing instrument or epoch. See the discussion in Section 3.3 for details. It is indexed directly from MAIN via OBSERVATION\_ID.

**TELESCOPE\_NAME** Telescope name (e.g. "WSRT" or "VLBA").

**TIME\_RANGE** The start and end times of the overall observing period spanned by the actual recorded data in MAIN. Required to use the same TIME Measure reference as in MAIN.

**OBSERVER** The name(s) of the observer(s).

**LOG** The observing log, as supplied by the telescope or instrument.

**SCHEDULE\_TYPE** The schedule type, with current reserved types ("VLBA-CRD", "VEX", "WSRT", "ATNF").

**SCHEDULE** Unmodified schedule file, of the type specified, and as used by the instrument.

**PROJECT** Project code (e.g. "BD46")

**RELEASE\_DATE** Project release date. This is the date on which the data may become public.

#### 4.11 PHASED\_ARRAY: Phased array information

PHASED_ARRAY: Phased array information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
ANTENNA_ID	Int			Antenna id.
<i>Data</i>				
POSITION	Double(3)	m	POSITION	Reference position
COORDINATE_SYSTEM	Double(3,3)	m	DIRECTION	Local coordinate system
ELEMENT_OFFSET	Double(3, nelements)	m	POSITION	Offset per element
BEAM_ID	Int			Beam id.

## 4.12 POINTING: Antenna pointing information

POINTING: Antenna pointing information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
ANTENNA_ID	Int			Antenna id.
TIME	Double	s	EPOCH	Interval midpoint
INTERVAL	Double	s		Time interval
<i>Data</i>				
NAME	String			Pointing position desc.
NUM_POLY	Int			Series order
TIME_ORIGIN	Double	s	EPOCH	Origin for the polynomial
DIRECTION	Double(2, NUM_POLY+1)	rad	DIRECTION	Antenna pointing direction
TARGET	Double(2, NUM_POLY+1)	rad	DIRECTION	Target direction
(POINTING_OFFSET)	Double(2, NUM_POLY+1)	rad	DIRECTION	A priori pointing correction
(SOURCE_OFFSET)	Double(2, NUM_POLY+1)	rad	DIRECTION	Offset from source
(ENCODER)	Double(2)	rad	DIRECTION	Encoder values
(POINTING_MODEL_ID)	Int			Pointing model id.
TRACKING	Bool			True if on-position
(ON_SOURCE)	Bool			True if on-source
(OVER_THE_TOP)	Bool			True if over the top

**Notes:** This table contains information concerning the primary pointing direction of each antenna as a function of time. Note that the pointing offsets for individual feeds on a given antenna are specified in the FEED sub-table with respect to this pointing direction.

**ANTENNA\_ID** Antenna identifier, as specified by ANTENNA<sub>*n*</sub> in MAIN.

**TIME** Mid-point of the time interval for which the information in this row is valid. Required to use the same TIME Measure reference as in MAIN.

**INTERVAL** Time interval.

**NAME** Pointing direction name; user specified.

**NUM\_POLY** Series order for the polynomial expressions in DIRECTION and POINTING\_OFFSET.

**TIME\_ORIGIN** Time origin for the polynomial expansions.

**DIRECTION** Antenna pointing direction, optionally expressed as polynomial coefficients. The final result is interpreted as a Direction Measure using the specified Measure reference.

**TARGET** Target pointing direction, optionally expressed as polynomial coefficients. The final result is interpreted as a Direction Measure using the specified Measure reference. This is the true expected position of the source, including all coordinate corrections such as precession, nutation etc.

**POINTING\_OFFSET** The a priori pointing corrections applied by the telescope in pointing to the DIRECTION position, optionally expressed as polynomial coefficients. The final result is interpreted as a Direction Measure using the specified Measure reference.

**SOURCE\_OFFSET** The commanded offset from the source position, if offset pointing is being used.

**ENCODER** The current encoder values on the primary axes of the mount type for the antenna, expressed as a Direction Measure.

**TRACKING** True if tracking the nominal pointing position.

**ON-SOURCE** True if the nominal pointing direction coincides with the source, i.e. offset-pointing is not being used.

**OVER-THE-TOP** True if the antenna was driven to this position "over the top" (az-el mount).

### 4.13 POLARIZATION: Polarization setup information

POLARIZATION: Polarization setup information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
POLARIZATION_ID	Int			Polarization id.
<i>Data description columns</i>				
NUM_CORR	Int			# correlations
<i>Data</i>				
CORR_TYPE	Int(NUM_CORR)			Polarization of correlation
CORR_PRODUCT	Int(2, NUM_CORR)			Receptor cross-products

**Notes:** This table defines the polarization labeling of the DATA array in MAIN, and is directly indexed from the MAIN table via POLARIZATION\_ID.

**NUM\_CORR** The number of correlation polarization products. For example, for (RR) this value would be 1, for (RR, LL) it would be 2, and for (XX,YY,XY,YX) it would be 4, etc.

**CORR\_TYPE** An integer for each correlation product indicating the Stokes type as defined in the Stokes class enumeration.

**CORR\_PRODUCT** Pair of integers for each correlation product, specifying the receptors from which the signal originated. The receptor polarization is defined in the POLARIZATION\_TYPE column in the FEED table. An example would be (0,0), (0,1), (1,0), (1,1) to specify all correlations between two receptors.

#### 4.14 PROCESSOR: Processor information

PROCESSOR: Processor information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
PROCESSOR.ID	Int			Processor ID
<i>Data</i>				
TYPE	String			Processor type
SUB_TYPE	String			Processor sub-type
TYPE.ID	Int			Processor type id.
MODE.ID	Int			Processor mode id.
(PASS.ID)	Int			Processor pass number

**Notes:** This table holds summary information for the back-end processing device used to generate the basic data in the MAIN table. Such devices include correlators, radiometers, spectrometers, pulsar-timers, amongst others. See Section 4.0.4 for further details.

**TYPE** Processor type; reserved keywords include ("CORRELATOR" - interferometric correlator; "SPECTROMETER" - single-dish correlator; "RADIOMETER" - generic detector/integrator; "PULSAR-TIMER" - pulsar timing device).

**SUB\_TYPE** Processor sub-type, e.g. "GBT" or "JIVE".

**TYPE.ID** Index used in a specialized sub-table named as *subtype.type*, which contains time-independent processor information applicable to the current data record (e.g. a JIVE-CORRELATOR sub-table). Time-dependent information for each device family is contained in other tables, dependent on the device type.

**MODE.ID** Index used in a specialized sub-table named as *subtype.type.mode*, containing information on the processor mode applicable to the current data record. (e.g. a GBT-SPECTROMETER.MODE sub-table).

**PASS.ID** Pass identifier; this is used to distinguish data records produced by multiple passes through the same device, where this is possible (e.g. VLBI correlators). Used as an index into the associated table containing pass information.

#### 4.15 SCAN: Scan information

SCAN: Scan information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
SCAN_NUMBER	Int			Scan number
<i>Data</i>				
SCAN_INTENT	String			Scan intent
(EXECBLOCK_ID)	Int			Scheduling id

**Notes:** This table contains information on scans, specified from the main table through SCAN\_NUMBER.

**SCAN\_NUMBER** Scan number, as specified in MAIN.

**SCAN\_INTENT** Scan intent, e.g. CAL\_POINTING, TARGET.

**EXECBLOCK\_ID** A number by the online system to refer back to execution block observation.

## 4.16 SOURCE: Source information

SOURCE: Source information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
SOURCE_ID	Int			Source id
TIME	Double	s	EPOCH	Midpoint of time for which this set of parameters is accurate
INTERVAL	Double	s		Interval
SPECTRAL_WINDOW_ID	Int			Spectral Window id
<i>Data description</i>				
NUM_LINES	Int			Number of spectral lines
<i>Data</i>				
NAME	String			Name of source as given during observations
CALIBRATION_GROUP	Int			# grouping for calibration purpose
CODE	String			Special characteristics of source, e.g. Bandpass calibrator
DIRECTION	Double(2)	rad	DIRECTION	Direction (e.g. RA, DEC)
(POSITION)	Double(3)	m	POSITION	Position (e.g. for solar system objects)
PROPER_MOTION	Double(2)	rad/s		Proper motion
(TRANSITION)	String(NUM_LINES)			Transition name
(REST_FREQUENCY)	Double(NUM_LINES)	Hz	FREQUENCY	Line rest frequency
(SYSVEL)	Double(NUM_LINES)	m/s	RADIAL VELOCITY	Systemic velocity at reference
(SOURCE_MODEL)	TableRecord			Default csm
(PULSAR_ID)	Int			Pulsar id.

**Notes:** This table contains time-variable source information, optionally associated with a given FIELD\_ID.

**SOURCE\_ID** Source identifier ( $\geq 0$ ), as specified in the FIELD sub-table.

**TIME** Mid-point of the time interval for which the data in this row is valid. Required to use the same TIME Measure reference as in MAIN.

**INTERVAL** Time interval.

**SPECTRAL\_WINDOW\_ID** Spectral window identifier. A -1 indicates that the row is valid for all spectral windows.

**NUM\_LINES** Number of spectral line transitions associated with this source and spectral window id. combination.

**NAME** Source name; user specified.

**CALIBRATION\_GROUP** Calibration group number to which this source belongs; user specified.

**CODE** Source code, used to describe any special characteristics of the source, such as the nature of a calibrator. Reserved keyword, including ("BANDPASS CAL").



**DIRECTION** Source direction at this TIME.

**POSITION** Source position  $(x, y, z)$  at this TIME (for near-field objects).

**PROPER\_MOTION** Source proper motion at this TIME.

**TRANSITION** Transition names applicable for this spectral window (e.g. "v=1, J=1-0, SiO").

**REST\_FREQUENCY** Rest frequencies for the transitions.

**SYSVEL** Systemic velocity for each transition.

**SOURCE\_MODEL** Reference to an assigned component source model table.

**PULSAR\_ID** An index used in the PULSAR sub-table to define further pulsar-specific properties if the source is a pulsar.

#### 4.17 SPECTRAL\_WINDOW: Spectral window description

SPECTRAL_WINDOW: Spectral window description				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
SPECTRAL_WINDOW_ID	Int			Spectral window id.
<i>Data description columns</i>				
NUM_CHAN	Int			# spectral channels
<i>Data</i>				
NAME	String			Spectral window name
REF_FREQUENCY	Double	Hz	FREQUENCY	The reference frequency.
CHAN_FREQ	Double(NUM_CHAN)	Hz	FREQUENCY	Center frequencies for each channel in the data matrix.
CHAN_WIDTH	Double(NUM_CHAN)	Hz		Channel width for each channel in the data matrix.
MEAS_FREQ_REF	Int			FREQUENCY Measure ref.
EFFECTIVE_BW	Double(NUM_CHAN)	Hz		The effective noise bandwidth of each spectral channel
RESOLUTION	Double(NUM_CHAN)	Hz		The effective spectral resolution of each channel
TOTAL_BANDWIDTH	Double	Hz		total bandwidth for this window
NET_SIDE BAND	Int			Net sideband
(BBC_NO)	Int			Baseband converter no.
(BBC_SIDE BAND)	Int			BBC sideband
IF_CONV_CHAIN	Int			The IF conversion chain
(RECEIVER_ID)	Int			Receiver id.
FREQ_GROUP	Int			Frequency group
FREQ_GROUP_NAME	String			Freq. group name
(DOPPLER_ID)	Int			Doppler id.
(ASSOC_SPW_ID)	Int(*)			Associated spw_id.
(ASSOC_NATURE)	String(*)			Nature of association

**Notes:** This table describes properties for each defined spectral window. A spectral window is both a frequency label for the associated DATA array in MAIN, but also represents a generic frequency conversion chain that shares joint physical properties and makes sense to calibrate as a single entity.

**NUM\_CHAN** Number of spectral channels.

**NAME** Spectral window name; user specified.

**REF\_FREQUENCY** The reference frequency. A frequency representative of this spectral window, usually the sky frequency corresponding to the DC edge of the baseband. Used by the calibration system if a fixed scaling frequency is required or in algorithms to identify the observing band.

**CHAN\_FREQ** Center frequencies for each channel in the data matrix. These can be frequency-dependent, to accommodate instruments such as acousto-optical spectrometers. Note that the channel frequencies may be in

ascending or descending frequency order.

**CHAN\_WIDTH** Nominal channel width of each spectral channel. Although these can be derived from CHAN\_FREQ by differencing, it is more efficient to keep a separate reference to this information.

**MEAS\_FREQ\_REF** Frequency Measure reference for CHAN\_FREQ. This allows a row-based reference for this column in order to optimize the choice of Measure reference when Doppler tracking is used. Modified only by the MS access code.

**EFFECTIVE\_BW** The effective noise bandwidth of each spectral channel.

**RESOLUTION** The effective spectral resolution of each channel.

**TOTAL\_BANDWIDTH** The total bandwidth for this spectral window.

**NET\_SIDE BAND** The net sideband for this spectral window.

**BBC\_NO** The baseband converter number, if applicable.

**BBC\_SIDE BAND** The baseband converter sideband, is applicable.

**IF\_CONV\_CHAIN** Identification of the electronic signal path for the case of multiple (simultaneous) IFs. (e.g. VLA: AC=0, BD=1, ATCA: Freq1=0, Freq2=1)

**RECEIVER\_ID** Index used to identify the receiver associated with the spectral window. Further state information is planned to be stored in a RECEIVER sub-table.

**FREQ\_GROUP** The frequency group to which the spectral window belongs. This is used to associate spectral windows for joint calibration purposes.

**FREQ\_GROUP\_NAME** The frequency group name; user specified.

**DOPPLER\_ID** The Doppler identifier defining frame information for this spectral window.

**ASSOC\_SPW\_ID** Associated spectral windows, which are related in some fashion (e.g. "channel-zero").

**ASSOC\_NATURE** Nature of the association for ASSOC\_SPW\_ID; reserved keywords are ("CHANNEL-ZERO" - channel zero; "EQUAL-FREQUENCY" - same frequency labels; "SUBSET" - narrow-band subset).

## 4.18 STATE: State information

STATE: State information				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
STATE_ID	Int			State id.
<i>Data</i>				
SIG	Bool			Signal
REF	Bool			Reference
CAL	Double	K		Noise calibration
LOAD	Double	K		Load temperature
SUB_SCAN	Int			Sub-scan number
OBS_MODE	String			Observing mode

**Notes:** This table defines the state parameters for a particular data record as they refer to external loads, calibration sources or references, and also characterizes the observing mode of the data record, as an aid to defining the scheduling heuristics. It is indexed directly via STATE\_ID in MAIN.

**SIG** True if the source signal is being observed.

**REF** True for a reference phase.

**CAL** Noise calibration temperature (zero if not added).

**LOAD** Load temperature (zero if no load).

**SUB\_SCAN** Sub-scan number ( $\geq 0$ ), relative to the SCAN\_NUMBER in MAIN. Used to identify observing sequences.

**OBS\_MODE** Observing mode; defined by a set of reserved keywords characterizing the current observing mode (e.g. "OFF-SPECTRUM"). Used to define the schedule strategy.

## 4.19 SYSCAL: System calibration

SYSCAL: System calibration				
Name	Format	Units	Measure	Comments
<b>Columns</b>				
<i>Key</i>				
ANTENNA_ID	Int			Antenna id
FEED_ID	Int			Feed id
SPECTRAL_WINDOW_ID	Int			Spectral window id
TIME	Double	s	EPOCH	Midpoint of time for which this set of parameters is accurate
INTERVAL	Double	s		Interval
<i>Data</i>				
(PHASE_DIFF)	Float	rad		Phase difference between receptor 0 and receptor 1
(TCAL)	Float ( $N_r$ )	K		Calibration temp
(TRX)	Float ( $N_r$ )	K		Receiver temperature
(TSKY)	Float ( $N_r$ )	K		Sky temperature
(TSYS)	Float ( $N_r$ )	K		System temp
(TANT)	Float ( $N_r$ )	K		Antenna temperature
(TANT_TSYS)	Float ( $N_r$ )			$\frac{T_{ant}}{T_{sys}}$
(TCAL_SPECTRUM)	Float ( $N_r, N_f$ )	K		Calibration temp
(TRX_SPECTRUM)	Float ( $N_r, N_f$ )	K		Receiver temperature
(TSKY_SPECTRUM)	Float ( $N_r, N_f$ )	K		Sky temperature spectrum
(TSYS_SPECTRUM)	Float ( $N_r, N_f$ )	K		System temp
(TANT_SPECTRUM)	Float ( $N_r, N_f$ )	K		Antenna temperature spectrum
(TANT_TSYS_SPECTRUM)	Float ( $N_r, N_f$ )			$\frac{T_{ant}}{T_{sys}}$ spectrum
<i>Flags</i>				
(PHASE_DIFF_FLAG)	Bool			Flag for PHASE_DIFF
(TCAL_FLAG)	Bool			Flag for TCAL
(TRX_FLAG)	Bool			Flag for TRX
(TSKY_FLAG)	Bool			Flag for TSKY
(TSYS_FLAG)	Bool			Flag for TSYS
(TANT_FLAG)	Bool			Flag for TANT
(TANT_TSYS_FLAG)	Bool			Flag for $\frac{T_{ant}}{T_{sys}}$

**Notes:** This table contains time-variable calibration measurements for each antenna, as indexed on feed and spectral window. Note that  $N_r$ = number of receptors, and  $N_f$ = number of frequency channels.

**ANTENNA\_ID** Antenna identifier, as indexed by ANTENNA $n$  in MAIN.

**FEED\_ID** Feed identifier, as indexed by FEED $n$  in MAIN.

**SPECTRAL\_WINDOW\_ID** Spectral window identifier.

**TIME** Mid-point of the time interval for which the data in this row are valid. Required to use the same TIME Measure reference as that in MAIN.

**INTERVAL** Time interval.

**PHASE\_DIFF** Phase difference between receptor 0 and receptor 1.

**TCAL** Calibration temperature.

**TRX** Receiver temperature.

**TSKY** Sky temperature.

**TSYS** System temperature.

**TANT** Antenna temperature.

**TANT\_TSYS** Antenna temperature over system temperature.

**TCAL\_SPECTRUM** Calibration temperature spectrum.

**TRX\_SPECTRUM** Receiver temperature spectrum.

**TSKY\_SPECTRUM** Sky temperature spectrum.

**TSYS\_SPECTRUM** System temperature spectrum.

**TANT\_SPECTRUM** Antenna temperature spectrum.

**TANT\_TSYS\_SPECTRUM** Antenna temperature over system temperature spectrum.

**PHASE\_DIFF\_FLAG** True if PHASE\_DIFF flagged.

**TCAL\_FLAG** True if TCAL flagged.

**TRX\_FLAG** True if TRX flagged.

**TSKY\_FLAG** True if TSKY flagged.

**TSYS\_FLAG** True if TSYS flagged.

**TANT\_FLAG** True if TANT flagged.

**TANT\_TSYS\_FLAG** True if TANT\_TSYS flagged.

## 4.20 WEATHER: weather station information

WEATHER: weather station information				
Name	Format	Units	Measure	Comments
Columns				
Key				
ANTENNA_ID	Int		EPOCH	Antenna number
TIME	Double	s		Mid-point of interval
INTERVAL	Double	s		Interval over which data is relevant
Data				
(H2O)	Float	$m^{-2}$		Average column density of water
(IONOS_ELECTRON)	Float	$m^{-2}$		Average column density of electrons
(PRESSURE)	Float	hPa		Ambient atmospheric pressure
(REL_HUMIDITY)	Float			Ambient relative humidity
(TEMPERATURE)	Float	K		Ambient air temperature for an antenna
(DEW_POINT)	Float	K		Dew point
(WIND_DIRECTION)	Float	rad		Average wind direction
(WIND_SPEED)	Float	m/s		Average wind speed
Flags				
(H2O_FLAG)	Bool			Flag for H2O
(IONOS_ELECTRON_FLAG)	Bool			Flag for IONOS.ELECTRON
(PRESSURE_FLAG)	Bool			Flag for PRESSURE
(REL_HUMIDITY_FLAG)	Bool			Flag for REL.HUMIDITY
(TEMPERATURE_FLAG)	Bool			Flag for TEMPERA-TURE
(DEW_POINT_FLAG)	Bool			Flag for DEW_POINT
(WIND_DIRECTION_FLAG)	Bool			Flag for WIND.DIRECTION
(WIND_SPEED_FLAG)	Bool			Flag for WIND.SPEED

**Notes:** This table contains mean external atmosphere and weather information.

**ANTENNA\_ID** Antenna identifier, as indexed by ANTENNA $n$  from MAIN.

**TIME** Mid-point of the time interval over which the data in the row are valid. Required to use the same TIME Measure reference as in MAIN.

**INTERVAL** Time interval.

**H2O** Average column density of water.

**IONOS.ELECTRON** Average column density of electrons.

**PRESSURE** Ambient atmospheric pressure.

**REL\_HUMIDITY** Ambient relative humidity.

**TEMPERATURE** Ambient air temperature.  
**DEW\_POINT** Dew point temperature.  
**WIND\_DIRECTION** Average wind direction.  
**WIND\_SPEED** Average wind speed.  
**H2O\_FLAG** Flag for H2O.  
**IONOS\_ELECTRON\_FLAG** Flag for IONOS\_ELECTRON.  
**PRESSURE\_FLAG** Flag for PRESSURE.  
**REL\_HUMIDITY\_FLAG** Flag for REL\_HUMIDITY.  
**TEMPERATURE\_FLAG** Flag for TEMPERATURE.  
**DEW\_POINT\_FLAG** Flag for DEW\_POINT.  
**WIND\_DIRECTION\_FLAG** Flag for DEW\_POINT.  
**WIND\_SPEED\_FLAG** Flag for DEW\_POINT.

## 5 Correction and additions

## 6 References

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