MeasurementSet definition version 3.0

MSv3 team (to be filled in)

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Contents

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 **??**.

- 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	Antenna characteristics	ANTENNA_ID
(*DOPPLER*)	Doppler tracking	DOPPLER_ID, SOURCE_ID
FEED	Feed characteristics	FEED_ID, ANTENNA_ID, TIME, SPECTRAL_WINDOW_ID
FIELD	Field position	FIELD_ID
FLAG_CMD	Flag commands	TIME
(*FREQ_OFFSET*)	Frequency offset information	FEED_ID, ANTENNAn, FEED_ID, TIME, SPECTRAL_WINDOW_ID
HISTORY	History information	OBSERVATION_ID, TIME
OBSERVATION	Observer, Schedule, etc	OBSERVATION_ID
(*PHASED_ARRAY*)	Phased array information	ANTENNA_ID
POINTING	Pointing information	ANTENNA_ID, TIME
POLARIZATION	Polarization setup	POLARIZATION_ID
PROCESSOR	Processor information	PROCESSOR_ID
(*SOURCE*)	Source information	SOURCE_ID, SPECTRAL_WINDOW_ID, TIME
SPECTRAL_WINDOW	Spectral window setups	SPECTRAL_WINDOW_ID
STATE	State information	STATE_ID
(*SYSCAL*)	System calibration characteristics	FEED_ID, ANTENNA_ID, TIME, SPECTRAL_WINDOW_ID
(*WEATHER*)	Weather info for each antenna	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	Float			MS format version
(SORT_COLUMNS)	String			Sort columns
(SORT_ORDER)	String			Sort order
Key				
TIME	Double	s	EPOCH	Integration midpoint
(TIME_EXTRA_PREC)	Double	s		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		Sampling interval
EXPOSURE	Double	s		The effective integration time
TIME_CENTROID	Double	s	EPOCH	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 "$index_1$, $index_2$ ..., 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*n* Antenna number (≥ 0), and an index into the ANTENNA sub-table. For $n > 2$, triple-product data are implied.

FEED*n* Feed number (≥ 0). For $n > 2$, triple-product data are implied.

SPECTRAL_WINDOW_ID Spectral window identifier (≥ 0), an index into the SPECTRAL_WINDOW sub-table.

PROCESSOR_ID Processor indentifier (≥ 0), and an index into the PROCESSOR sub-table.

PHASE_ID Switching phase identifier (≥ 0)

FIELD_ID Field identifier (≥ 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 (≥ 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 (≥ 0), which identifies data in separate subarrays, as defined in Section 3.3.

OBSERVATION_ID Observation identifier (≥ 0), which identifies data from separate observations, as defined in Section 3.3.

STATE_ID State identifier (≥ 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
Columns				
Keywords				
(TELESCOPE_CENTER)	Double(3)	m	POSITION	Center of telescope
Key				
ANTENNA_ID	Int			Antenna ID
Data				
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 ANTENNAn.

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 (Ω) in deg.

- **4:** Argument of perigee (ω) 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
Columns				
Key				
Beam_ID	Int			Beam ID
Data				
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
Columns				
Key				
DOPPLER_ID	Int			Doppler tracking id.
SOURCE_ID	Int			Source id.
Data				
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
Columns				
Key				
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
Data description				
NUM_RECEPTORS	Int			# receptors on this feed
Data				
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 ANTENNAn in MAIN.

FEED_ID Feed identifier, as indexed from FEEDn 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 $(\vec{\mathbf{e}}_{\mathbf{x}}, \vec{\mathbf{e}}_{\mathbf{y}})$ 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
Columns				
Key				
FIELD_ID	Int			Field ID
Data				
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
Columns				
Key				
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
Data				
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.

ANTENNAn Antenna identifier, as indexed from ANTENNAn in MAIN.

FEED_ID Antenna identifier, as indexed from FEEDn 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
Columns				
Key				
TIME	Double	s	EPOCH	Time-stamp for message
OBSERVATION_ID	Int			Points to OBSERVATION table
Data				
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
Columns				
Key				
TIME	Double	s	EPOCH	
INTERVAL	Double			
Data				
FIELD_ID	Int			Refers back to FIELD table
ANTENNA_ID	Int			Refers back to ANTENNA table
ARRAY_ID	Int			Same meaning as in Main table
SPECTRAL_WINDOW_ID	Int			Refers back to SPECTRAL_WINDOW
PHASE_DELAY	Double(N_r, N_{poly})			Phase delay polynomial for each receptor
GROUP_DELAY	Double(N_r, N_{poly})			Group delay polynomial for each receptor
PHASE_RATE	Double(N_r, n_{poly})			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})			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
Columns				
Key				
OBSERVATION_ID	Int			Observation ID
Data				
TELESCOPE_NAME	String			Telescope name
TIME_RANGE	Double(2)	s	EPOCH	Start, end times
OBSERVER	String			Name of observer(s)
LOG	String(*)			Observing log
SCHEDULE_TYPE	String			Schedule type
SCHEDULE	String(*)			Project schedule
PROJECT	String			Project identification string.
RELEASE_DATE	Double	s	EPOCH	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
Columns				
Key				
ANTENNA_ID	Int			Antenna id.
Data				
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
Columns				
Key				
ANTENNA_ID	Int			Antenna id.
TIME	Double	s	EPOCH	Interval midpoint
INTERVAL	Double	s		Time interval
Data				
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 ANTENNAn 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
Columns				
Key				
POLARIZATION_ID	Int			Polarization id.
Data description columns				
NUM_CORR	Int			# correlations
Data				
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
Columns				
Key				
PROCESSOR_ID	Int			Processor ID
Data				
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
Columns				
Key				
SCAN_NUMBER	Int			Scan number
Data				
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
Columns				
Key				
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
Data description				
NUM_LINES	Int			Number of spectral lines
Data				
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 (≥ 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 f 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
Columns				
Key				
SPECTRAL_WINDOW_ID	Int			Spectral window id.
Data description columns				
NUM_CHAN	Int			# spectral channels
Data				
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_SIDEBAND	Int			Net sideband
(BBC_NO)	Int			Baseband converter no.
(BBC_SIDEBAND)	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 Nomical 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_SIDEBAND The net sideband for this spectral window.

BBC_NO The baseband converter number, if applicable.

BBC_SIDEBAND 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
Columns				
Key				
STATE_ID	Int			State id.
Data				
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 (≥ 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
Columns				
Key				
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
Data				
(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
Flags				
(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 ANTENNAn in MAIN.

FEED_ID Feed identifier, as indexed by FEEDn 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			Antenna number
TIME	Double	s	EPOCH	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 TEMPERATURE
(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 ANTENNAn 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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