CCSDS TDM Support in ODTK v7.9

1 Overview

ODTK supports three forms of the CCSDS Tracking Data Message (TDM):

- Standard format (CCSDS 503.0-B-2)
- Standard XML format (CCSDS 505.0-B-1)
- Specialized TDRS XML format (99-P56508V Revision H)*

Additionally, ODTK supports the DSN implementation of the DSN TDM Interface** for range and Doppler measurement types.

The purpose of this document is to explicitly define how and to what level the designated CCSDS TDM formats are supported in ODTK. A tenet of the CCSDS recommendations is that ambiguities or deficiencies of a particular recommendation are to be overcome via agreement between parties as documented in an Interface Control Document (ICD). This approach is not compatible with the incorporation of logic to read the TDM format in commercial software where only one side of the data interchange is known. Hopefully, this document will allow users of ODTK to determine if the ODTK implementation of the CSSDS TDM is sufficient and compatible with the TDM formatted data they wish to process.

*Not covered in this document, covered in reference: “Space Network (SN) Ground Segment Sustainment (SGSS) to Flight Dynamics Facility (FDF) Interface Control Document,” 99-P56508V Rev. H.

**820-013, 0212-Tracking-TDM DSN Tracking Data Message (TDM) Interface, Revision F, April 2021

2 Metadata Support

In both standard and XML CCSDS TDM formats, a metadata block precedes actual tracking data and provides additional information which is required to properly interpret measurement values. The following table serves to indicate how ODTK will disposition keyword/value pairs in the metadata. A status of *Ignored* is meant to indicate that ODTK will not make use of the keyword/value pair due to it having no effect on ODTK processing. A status of *Not Supported* indicates that the keyword/value pair pertains to functionality or a data type which is not currently connected to ODTK through the TDM format. Additionally, there are some keyword/value pairs which are read in and validated but have no effect on processing.

TDM Metadata Keyword	Valid options / notes for ODTK
COMMENT	*Ignored except in the special case of metadata for DSN Range observations.*
TRACK_ID	*Ignored*

DATA_TYPES	*Ignored*
TIME_SYSTEM	UTC, TAI, GPS, TT, TDB
START_TIME	Supported formats: YYYY-MM-DDT:HH:MM:SS.SSSS YYYY-DDDT:HH:MM:SS.SSSS JJJJJJJ.JJJJJJJJ
STOP_TIME	Supported formats: YYYY-MM-DDT:HH:MM:SS.SSSS YYYY-DDDT:HH:MM:SS.SSSS JJJJJJJ.JJJJJJJJ
PARTICIPANT_n	n = {1, 2, 3, 4, 5} Participant ids should start at 1 and increase without skipping any id numbers. A participant should only be identified once in the list of participants but can appear multiple times in the PATH (Ex: PATH = 1,2,1). NOTE: The TDM format allows for participant names to be given as strings as opposed to integer identifiers used by most tracking data formats. Proper resolution of the identifier strings in ODTK requires the use of the ODTK tracking ID alias system. Objects such as Facilities and Satellites have a TrackingIDAlias list which can contain a set of mapping values and ID strings. Participant IDs from the TDM files should be added these TrackingIDAlias lists with associated mapping values ("TDM" for example). When the TDM file is added to the list of measurement files at the scenario level, the correct mapping value can then be chosen to enable the resolution of the string based tracking IDs.
MODE	SEQUENTIAL, SINGLE_DIFF Note: Although the SINGLE_DIFF mode is not seen as an error, differenced measurements are currently ***Not Supported***
PATH	SEQUENTIAL definitions of the signal path for non-differenced measurement types
PATH_1	***Not Supported***: used for differenced measurements

PATH_2	***Not Supported***: used for differenced measurements
TRANSMIT_BAND	S, X, KA, KU, L, UHF *Required when processing DSN Range and Doppler measurements.*
RECEIVE_BAND	S, X, KA, KU, L, UHF *Ignored*: Value is read but not currently used
TURNAROUND_NUMERATOR	Positive integer, default value of 1
TURNAROUND_DENOMINATOR	Positive integer, default value of 1
TIMETAG_REF	TRANSMIT, RECEIVE Used in the processing of the following TDM data types: RANGE, DOPPLER_INSTANTANEOUS, DOPPLER_INTEGRATED
INTEGRATION_INTERVAL	Value > 0. Used in the processing of the following TDM data types: DOPPLER, DOPPLER_COUNT, RECEIVE_FREQ (RECEIVE_FREQ_n)
INTEGRATION_REF	START, MIDDLE, END Used in the processing of the following TDM data types: DOPPLER_INTGRATED, DOPPLER_COUNT, RECEIVE_FREQ (RECEIVE_FREQ_n)
FREQ_OFFSET	Used in the processing of the following TDM data types if TRANSMIT_FREQ records are not provided: RECEIVE_FREQ (RECEIVE_FREQ_n), RECEIVE_PHASE_CT (RECEIVE_PHASE_CT_n), DOPPLER_COUNT. Note: Sometimes used to specify the spacecraft transmit frequency in the case of 1W DSN Doppler and 1W DSN TCP.
RANGE_MODE	COHERENT, CONSTANT, ONE_WAY *Ignored*: Value is read but not currently used
RANGE_MODULUS	Used in the processing of RANGE measurements
RANGE_UNITS	KM, S, NANOSEC, NS, RU Note: NANOSEC and NS both refer to nanoseconds and neither is a standard TDM value. They are included here due to observed usage.

	Note: Use of RU (Range Units) is supported but requires that uplink frequency information be supplied as TRANSMIT_FREQ_1 and TRANSMIT_FREQ_RATE_1 measurements from the uplink station to the spacecraft.
TWO_WAY_REPRESENTATION	ONEWAY, TWOWAY ODTK custom keyword/value pair that allows for the specification of how observation values for two-way range and two-way Doppler measurements should be interpreted. In the absence of this keyword, the setting on the CCSDS TDM tracking data provider will be used. This setting, which defaults to TWOWAY, can be accessed through the ODTK Edit menu by selecting Preferences, then selecting Plugins on the resulting dialog. Locate the CCSDS TDM reader in the list and scroll all the way to the right in the window to expose the Config column. Clicking on “click to display” on the CCSDS TDM line will expose the desired setting. Note: Specification of DSN measurements should be specified in the two-way sense.
ANGLE_TYPE	AZEL, RADEC, XEYN, XSYE, DIRCOS_XEYN Note: See Supported Data Types table for description of X-Y angle support. DIRCOS_XEYN is an AGI extension to the TDM standard.
REFERENCE_FRAME	EME2000, EMEJ2000, ICRF, TOD, TOD_EARTH Used in the processing of the following TDM data types: ANGLE_1, ANGLE_2 when ANGLE_TYPE is RADEC
INTERPOLATION	*Not Supported*: Used in conjunction with transmit and receive phase observables which are not currently supported
INTERPOLATION_DEGREE	*Not Supported*: Used in conjunction with transmit and receive phase observables which are not currently supported
DOPPLER_COUNT_BIAS	Used in the processing of the following TDM data types: DOPPLER_COUNT
DOPPLER_COUNT_SCALE	Used in the processing of the following TDM data types: DOPPLER_COUNT
DOPPLER_COUNT_ROLLOVER	*Not Supported*
TRANSMIT_DELAY_n	n = {1, 2, 3, 4, 5} *Not Supported*

RECEIVE_DELAY_n	n = {1, 2, 3, 4, 5} *Not Supported*
DATA_QUALITY	*Ignored*
CORRECTION_s	S = {ANGLE_1, ANGLE_2, DOPPLER, RANGE, RECEIVE_FREQ} Note: Corrections are added to observation values if CORRECTIONS_APPLIED is NO or FALSE. Example: If reporting range measurements containing a known 5 km range bias, such that reported range = true range + 5 km, then the CORRECTION_RANGE value would be -5 km, so that applying the correction results in the true value of the range would be: true range = reported range – 5 km.
CORRECTIONS_APPLIED	YES, NO, TRUE, FALSE

3 Supported Data Types

The following table provides a mapping between CCSDS observation keywords and matching ODTK measurement types. Note that a single CCSDS keyword can map to more than one ODTK measurement type dependent upon the PARTICPANT path specified in the TDM metadata. CCSDS TDM observation keywords not listed in the table below, or the subsequent table for meteorological keywords, are not supported.

Note: Supported measurement types are assumed to be associated with ground-based tracking stations. Corresponding measurement types, such as space-based range, are not currently supported.

TDM Observation Keyword	ODTK Mapping
ANGLE_n	n = {1, 2}, mapping depends on ANGLE_TYPE AZEL – Azimuth & Elevation RADEC – Right Ascension & Declination XEYN – X Angle & Y Angle* XSYE - X Angle & Y Angle* DIRCOS_XEYN** *East/North or South/East definition for X-Y angles in ODTK is controlled through the AntennaMountType setting of the Facility object. For XEYN angles use the XY_NS mount type. For XSYE angles use the

	XY_EW mount type. When data is read from a TDM file, the mount type is specified through the tracking data interface and overrides the value set in the facility. **Specifies direction cosine measurements with the X component being measured from the local East direction and the Y component being measured from the local North direction. Direction cosine measurements are not part of the current TDM spec so the DIRCOS_XEYN type is an ODTK specific extension of the spec.
DOPPLER_COUNT	Mapping depends on PATH. PATH = 1,2,1 – Doppler PATH = 1,2,3 – 1W Bistatic Doppler PATH = 2,1 – 1W Doppler Doppler information is presented as counts of a Doppler signal generated from the received signal from the spacecraft. Requires the proper specification of the DOPPLER_COUNT_SCALE and DOPPLER_COUNT_BIAS in the metadata. The scale and bias are used in conversion from Doppler counts to a range-rate representation used in the process of Doppler, 1W Bistatic Doppler and 1W Doppler in ODTK. Processing of Doppler Count types requires that appropriate transmit frequency be supplied in the same tracking data file. In the case 1W Doppler the spacecraft transmit frequency may be specified via TRANSMIT_FREQ records or in the metadata using the FREQ_OFFSET keyword.
DOPPLER_INSTANTANEOUS	Mapping depends on PATH. PATH = 1,2,1 – Doppler PATH = 1,2,3 – 1W Bistatic Doppler PATH = 2,1 – 1W Doppler Note: The specified Doppler value should nominally be as measured over the entire signal path. So, for a path of 1,2,1, the Doppler value should be the two-way Doppler and for a path of 1,2,3 the Doppler value should include contributions from both the uplink and downlink segments of the signal path. A one-way value can be specified for two-way measurement (path of 1,2,1) if the TWO_WAY_REPRESENTATION setting indicates that one-way values will be specified.
DOPPLER_INTEGRATED	Mapping depends on PATH.

	PATH = 1,2,1 – Doppler PATH = 1,2,3 – 1W Bistatic Doppler PATH = 2,1 – 1W Doppler Note: The specified Doppler value should nominally be as measured over the entire signal path. So, for a path of 1,2,1, the Doppler value should be the two-way Doppler and for a path of 1,2,3 the Doppler value should include contributions from both the uplink and downlink segments of the signal path. A one-way value can be specified for two-way measurement (path of 1,2,1) if the TWO_WAY_REPRESENTATION setting indicates that one-way values will be specified.
RANGE	Mapping depends on PATH. PATH = 1,2,1 – Range, DSN Seq Range, DSN PN Range PATH = 1,2,3 – 1W Bistatic Range, DSN 3W Seq Range, DSN 3W PN Range PATH = 2,1 – 1W Range Note: The specified range value should nominally be as measured over the entire signal path. So, for a path of 1,2,1, the range value should be the two-way range and for a path of 1,2,3 the range value should include contributions from both the uplink and downlink segments of the signal path. A one-way value can be specified for two-way measurement (path of 1,2,1) if the TWO_WAY_REPRESENTATION setting indicates that one-way values will be specified. Note: Following JPL/DSN conventions, DSN range types are identified by having one of the following comment lines at the top of the Metadata section describing the ranging data. COMMENT SEQUENTIAL RANGE COMMENT PN RANGE The type of DSN range is identified by which comment is present. Processing of DSN range types specified in range units (RU) requires that appropriate transmit frequency be supplied in the same tracking data file.
RECEIVE_FREQ RECEIVE_FREQ_n	Mapping depends on PATH. PATH = 1,2,1 – DSN Doppler PATH = 1,2,3 – DSN 3W Doppler

	PATH = 2,1 – DSN 1W Doppler Use of the indexed version of the keyword is valid for (n=1,2,3) where n is the PATH id of the receiving station. The indexed versions should always specify the id of the last element of the PATH. For the examples presented above, the indexed version of the keyword would be RECEIVE_FREQ_1 (DSN Doppler), RECEIVE_FREQ_3 (DSN 3W Doppler) and RECEIVE_FREQ_2 (DSN 1W Doppler) respectively. Processing of DSN Doppler types requires that appropriate transmit frequency be supplied in the same tracking data file. In the case of DSN 1W Doppler the spacecraft transmit frequency may be specified via TRANSMIT_FREQ records or in the metadata using the FREQ_OFFSET keyword.
RECEIVE_PHASE_CT RECEIVE_ PHASE_CT _n	Mapping depends on PATH. PATH = 1,2,1 – DSN TCP PATH = 1,2,3 – DSN 3W TCP PATH = 2,1 – DSN 1W TCP Use of the indexed version of the keyword is valid for (n=1,2,3) where n is the PATH id of the receiving station. The indexed versions should always specify the id of the last element of the PATH. For the examples presented above, the indexed version of the keyword would be RECEIVE_ PHASE_CT_1 (DSN TCP), RECEIVE_ PHASE_CT_3 (DSN 3W TCP) and RECEIVE_ PHASE_CT_2 (DSN 1W TCP) respectively. Processing of DSN TCP types requires that appropriate transmit frequency be supplied in the same tracking data file. In the case of DSN 1W TCP the spacecraft transmit frequency may be specified via TRANSMIT_FREQ records or in the metadata using the FREQ_OFFSET keyword.
TRANSMIT_FREQ TRANSMIT_FREQ_n TRANSMIT_FREQ_RATE TRANSMIT_FREQ_RATE_n	PATH = 1,2 Use of the indexed version of the keyword is valid for (n=1) where n is the PATH id of the transmitting station. The indexed versions should always specify the id of the first element of the PATH. Used to specify frequency ramp information for use in processing DSN range and Doppler observations. Processing of measurements specified using RECEIVE_FREQ, RECEIVE_PHASE and DOPPLER_COUNT keywords requires that appropriate transmit frequency be supplied in the same tracking data file. In the case of 1-way data, the spacecraft transmit frequency may be specified via TRANSMIT_FREQ records or in the metadata using the FREQ_OFFSET keyword.

Notes on Doppler measurements: The TDM format allows for a distinction between integrated and instantaneous Doppler measurements. Integrated Doppler measurements are computed over a time interval specified by the

TDM keyword INTEGRATION_INTERVAL. If the INTEGRATION_INTERVAL keyword is not specified, integrated Doppler measurements will be processed using the CountInterval from the tracking facility measurement statistics. Doppler count measurements are treated in the same manner as integrated Doppler measurements. The TDM format also allows the time tag for integrated Doppler measurements to be at the END, MIDDLE, or START of the integration interval via the INTEGRATION_REF keyword. The ODTK Doppler model, however, assumes that the time tag is at the END. Therefore, if MIDDLE or START is specified, the TDM reader will move the time tag of the measurement to the end time of the integration interval to allow proper processing of the data. The ODTK Doppler model operates on a nonzero integration interval. If instantaneous Doppler measurements are specified, the CountInterval from the tracking facility measurement statistics is used in processing the data. It is typical for transmit frequency to be supplied in support of the processing of Doppler count observations. This is discussed in more detail below in the section on Frequency Ramps. If transmit frequency is not explicitly provided, then the FREQ_OFFSET from the metadata is assumed to be the constant transmit frequency.

Notes on received frequency measurements: Measurements specified using the RECEIVE_FREQ keyword will be interpreted as DSN Doppler, DSN 1W Doppler or DSN 3W Doppler measurements depending on the specification of the PATH. DSN Doppler measurements are computed over a time interval specified by the TDM keyword INTEGRATION_INTERVAL. If the INTEGRATION_INTERVAL keyword is not specified, DSN Doppler measurements will be processed using the CountInterval from the tracking facility measurement statistics. The TDM format also allows the time tag for integrated Doppler measurements to be at the END, MIDDLE, or START of the integration interval via the INTEGRATION_REF keyword. The ODTK DSN Doppler model, however, assumes that the time tag is at the MIDDLE. Therefore, if END or START is specified, the TDM reader will move the time tag of the measurement to the middle of the integration interval to allow proper processing of the data. It is typical for transmit frequency to be supplied in support of the processing of receive frequency observations. This is discussed in more detail below in the section on Frequency Ramps. If transmit frequency is not explicitly provided, then the FREQ_OFFSET from the metadata is assumed to be the constant transmit frequency.

Doppler or received frequency measurements which cannot be properly described by the same metadata block should not be combined under a common metadata block. For example, if the measurements differ in terms of the integration reference or integration interval, they should be reported under separate metadata blocks.

Notes on received phase measurements: Measurements specified using the RECEIVE_PHASE keyword will be interpreted as DSN TCP, DSN 1W TCP or DSN 3W TCP measurements depending on the specification of the PATH. The total count phase measurement is obtained by differencing two adjacent RECEIVE_PHASE measurements with the observation epoch being placed at the time of the later RECEIVE_PHASE measurement. It is typical for transmit frequency to be supplied in support of the processing of receive frequency observations. This is discussed in more detail below in the section on Frequency Ramps. If transmit frequency is not explicitly provided, then the FREQ_OFFSET from the metadata is assumed to be the constant transmit frequency.

4 Meteorological Data

The following table provides a list of supported CCSDS observation keywords related to meteorological data values. Meteorological data which is specified as an observation type in the CCSDS TDM format in conjunction with tracking observables will be passed through the ODTK tracking data interface and can be used in support of measurement model corrections related to the effect of the troposphere. Tracking facilities need to have registered aliases that are mapped to the TDM tracking data file for MET data to be successfully transported from the tracking data file to measurement modeling.

TDM Observation Keyword	Units
TEMPERATURE	Kelvin
PRESSURE	hPa (millibar)
RHUMIDITY	Percent

5 Frequency Ramps

The NASA Deep Space Network (DSN) often uses ramped frequencies when tracking spacecraft in deep space. Knowledge of the ramping strategy is required for processing of the tracking observables. The CCSDS TDM format allows for specification of frequency ramps through the TRANSMIT_FREQ and TRANSMIT_FREQ_RATE observation keywords (described above). Constant transmit frequency can also be specified using the TRANSMIT_FREQ observation keyword. It is common for transmit frequency information to be provided under a separate metadata section than the related tracking observations (RECEIVE_FREQ, RECEIVE_PHASE_CT, DOPPLER_COUNT), but it can also be mixed in with the observations under the same metadata section. Provided transmit frequency information must cover the roundtrip light time delay period prior to the observation time tag for observations to be properly processed.

6 Simulation Notes

The CCSDS TDM tracking data provider has two settings that affect how the output tracking data file is created during a simulation run. These settings are exposed by clicking on the Config column of the CCSDS TDM row on the Plugins tab of the Edit-Preferences dialog. alias mapping.

CCSDS TDM Setting	Description
SectionByMeasType	If true, simulated observations will be separated into sections by measurement type even if they share common paths. Exceptions are angle measurements such as Azimuth/Elevation or RA/Declination and transmit frequency and transmit frequency rates which will be grouped together. If false, all observations which share a common signal path will be grouped together.
LTDOffsetForSavingFreqRamps	Provided transmit frequency information must cover the roundtrip light time delay period prior to the observation time tag for observations to be properly processed. The time tag of the first entries for constant transmit frequency sections will be set prior to the time of the first DSN range or Doppler observation by this amount.

Most tracking data formats use integer ids to identify entities such as ground stations and satellites that are involved in the taking of observations. ODTK is primarily designed to work with such integer ids. The CCSDS TDM

format, however, uses textual names instead of integer ids. To accommodate the writing of textual ids in the simulated tracking data file, when a file in the CCSDS TDM format is selected as the output file for an ODTK Simulator object, an additional setting, AliasMapping, is exposed in the Simulator properties. The AliasMapping setting allows for the selection of an alias category to enable the proper use of a textual name for each object involved in the measurement strands. This same system is used when CCSDS TDM files are used as input files. Additional information on the ODTK Tracking ID Alias system is located in the ODTK help system, but as a simple example, a user might create an AliasMapping called “CCSDS” and associate AliasID of “DSS-26” with the DSN DSS-26 ground station (integer tracking id is 26). If the “CCSDS” AliasMapping is then selected for the Simulator output file, ODTK will know to write the string “DSS-26” to the TDM file to identify that ground station.