The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

TRACKING DATA MESSAGE

REVISED RECOMMENDED STANDARD

CCSDS 503.0-P-1.0.3

PINK BOOK

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STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of its members. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommended Standards** and are not considered binding on any Agency.

This **Recommended Standard** is issued by, and represents the consensus of, the CCSDS members. Endorsement of this **Recommendation** is entirely voluntary. Endorsement, however, indicates the following understandings:

- o Whenever a member establishes a CCSDS-related **standard**, this **standard** will be in accord with the relevant **Recommended Standard**. Establishing such a **standard** does not preclude other provisions which a member may develop.
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  - -- The **standard** itself.
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- o Specific service arrangements shall be made via memoranda of agreement. Neither this **Recommended Standard** nor any ensuing **standard** is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this **Recommended Standard** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

In those instances when a new version of a **Recommended Standard** is issued, existing CCSDS-related member standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such standards or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommended Standard.

FOREWORD

This document is a Recommended Standard for tracking data messages and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The tracking data message described in this Recommended Standard is the baseline concept for tracking data interchange applications that are cross-supported between Agencies of the CCSDS.

This Recommended Standard establishes a common framework and provides a common basis for the format of tracking data exchange between space agencies. It allows implementing organizations within each Agency to proceed coherently with the development of compatible derived standards for the flight and ground systems that are within their cognizance. Derived Agency standards may implement only a subset of the optional features allowed by the Recommended Standard and may incorporate features not addressed by this Recommended Standard.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, as defined in the *Organization and Processes for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

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Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

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- Swedish Space Corporation (SSC)/Sweden.
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DOCUMENT CONTROL

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CCSDS 503.0-P-1.0.1 Cor. 1	Technical Corrigendum 1	September 2010	Updates RANGE and CLOCK_BIAS keyword specifications.
CCSDS 503.0-P.1.0.1	Tracking Data Message Pink Sheets version 1.0.1	January 2014	Updates from 5 Year Review
CCSDS 503.0-P.1.0.2	Tracking Data Message Pink Sheets	December 2014	Continued updates from 5 Year Revision process
CCSDS 503.0-P.1.0.3	Tracking Data Message Pink Sheets	February 2016	Continued updates from 5 Year Revision process

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1 INTRODUCTION

1.1 PURPOSE

1.1.1 This Tracking Data Message (TDM) Recommended Standard specifies a standard message format for use in exchanging spacecraft tracking data between space agencies. Such exchanges are used for distributing tracking data output from routine interagency cross-supports in which spacecraft missions managed by one agency are tracked from a tracking station managed by a second agency. The standardization of tracking data formats facilitates space agency allocation of tracking sessions to alternate tracking resources.

1.1.2 This document includes requirements and criteria that the message format has been designed to meet. For exchanges where these requirements do not capture the needs of the participating Agencies another mechanism can be selected.

1.2 SCOPE AND APPLICABILITY

1.2.1 This Recommended Standard contains the specification for a Tracking Data Message designed for applications involving tracking data interchange between space data systems. Tracking data includes data types such as Doppler, transmit/received frequencies, range, angles, Delta-DOR, DORIS, PRARE, media correction, weather, etc. The rationale behind the design of the message is described in annex F and might help the application engineer construct a suitable message. It is acknowledged that this version of the Recommended Standard might not apply to every single tracking session or data type; however, it is desired to focus on covering approximately the ‘95% level’ of tracking scenarios, and to expand the coverage in future versions as experience with the TDM is gained.

1.2.2 This message is suited to inter-agency exchanges that involve automated interaction. The attributes of a TDM make it primarily suitable for use in computer-to-computer communication because of the large amount of data typically present. The TDM is generally intended to be used in conjunction with an Interface Control Document (ICD) written jointly by the service provider and customer agency. The ICD outlines TDM options that have been exercised in the specific implementation.

1.2.3 Definition of the accuracy pertaining to any particular TDM is outside the scope of this Recommended Standard and is recommended to be specified via an Interface Control Document (ICD) between data exchange participants.

1.2.4 This Recommended Standard is applicable only to the message format and content, but not to its transmission. The method of transmitting the message between exchange partners is beyond the scope of this document and is recommended to be specified in the ICD. Message transmission could be based on a CCSDS data transfer protocol, file based transfer protocol such as SFTP, stream-oriented media, or other secure transmission mechanism. In general, the transmission mechanism does not place constraints on the technical data content of a TDM.

1.2.5 There are some specific exclusions to the TDM, as listed below:

1.2.5.1 Satellite Laser Ranging (SLR) 'Fullrate' and/or 'Normal Points' format (sometimes referred to as 'Quicklook'), which are already transferred via a standardized format documented at http://ilrs.gsfc.nasa.gov/;

1.2.5.2 Exchanges of raw Global Navigation Satellite System (GNSS) data, which is standardized via the RINEX format (https://igscb.jpl.nasa.gov/components/formats.html);

1.2.5.3 Global Positioning Satellite (GPS) navigation point solutions, which are standardized via the SP3 format (http://www.ngs.noaa.gov/orbits/);[1]

1.2.5.4 Optical data from navigation cameras (pixel based, row-column, etc.);

1.2.5.5 LIDAR data (which could include a laser range finder); however, such data could conceivably be transferred via TDM with a 'RANGE' keyword (see 3.5.2.7); and

1.2.5.6 Altimeter data; however, such data could conceivably be transferred via TDM with a 'RANGE' keyword (see 3.5.2.7).

1.2.6 Description of the message format based on the use of eXtensible Markup Language (XML) is now detailed in Section 5 of this document..

1.3 CONVENTIONS AND DEFINITIONS

1.3.1 Conventions and definitions of navigation concepts such as reference frames, time systems, etc., are provided in reference [1].

1.3.2 The following conventions apply throughout this Recommended Standard:

- the words 'shall' and 'must' imply a binding and verifiable specification;
- the word 'should' implies an optional, but desirable, specification;
- the word 'may' implies an optional specification;
- the words 'is', 'are', and 'will' imply statements of fact.

- The word 'participant' denotes an entity that has the ability to acquire or broadcast navigation messages and/or radio frequencies, for example, a spacecraft, a quasar, a tracking station, a tracking instrument, or an agency.

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[1] It has been suggested that the statement regarding navigation solutions being standardized by SP3 is not correct, because SP3 prescribes equidistant data (ephemerides), which are in general not provided by each GPS/GNSS receiver. It was proposed that the navigation solution data (epoch, x, y, z, v_x, v_y, v_z) should be provided in the TDM, with the velocities as optional values. However, this would require major changes to the TDM that are contrary to its intended purpose. As an alternative, the CCSDS Orbit Data Messages OEM (Orbit Ephemeris Message) (reference [4]) could be used to convey the navigation solution if all position and velocity components are transferred. The OEM is already set up to convey all the required values, and can be used to convey orbit reconstructions as well as orbit predictions. Also, the CCSDS Navigation Hardware Message (in progress) will be designed to include the GPS point solutions.

– The term 'agency' denotes an exchange partner. This usage is due to the history of the CCSDS, which was formed as a coalition of the world's space agencies. Over time, as the space industry and the CCSDS have evolved, there is a wider group of organizations (e.g., military, commercial) that could utilize CCSDS standards. In this document, the term 'agency' is meant to encompass any and all of these exchange partners.

– The term ‘n/a’ or ‘N/A’ denotes an attribute that is not applicable or not available.

1.3.3 The following conventions for unit notations apply throughout this Recommended Standard. Insofar as possible, an effort has been made to use units that are part of the International System of Units (SI Units); units are either SI base units, SI derived units, or units outside the SI that are accepted for use with the SI (see reference [8]). There are a small number of specific cases where units that are more widely used in the navigation community are specified, but every effort has been made to minimize these departures from the SI.

%:	percent
dBHz:	decibels referenced to one Hz
dBW:	decibels referenced to one Watt
deg:	degrees of plane angle
hPa:	hectoPascal
Hz:	Hertz
K:	Kelvin
km:	kilometers
m:	meters
m**2:	square meters
RU:	range units
s:	seconds
TECU:	Total Electron Count Units

1.4 STRUCTURE OF THIS DOCUMENT

1.4.1 Section 2 provides a brief overview of the CCSDS-recommended Tracking Data Message (TDM).

1.4.2 Section 3 provides details about the structure and content of the TDM.

1.4.3 Section 4 provides details about the syntax used in the TDM.

1.4.4 Section 5 discusses a CCSDS schema for the TDM.

1.4.5 Annex A provides a normative list of approved values for selected TDM Metadata Section keywords.

1.4.6 Annex B discusses the Implementation Conformance Statement (ICS) for the TDM.

1.4.7 Annex C lists a number of items that are recommended to be covered in interagency ICDs prior to exchanging TDMs on a regular basis. There are several statements throughout the document that refer to the desirability or necessity of such a document; this annex consolidates all the suggested ICD items in a single list.

1.4.8 Annex D shows how various tracking scenarios can be accommodated using the TDM, via several examples.

1.4.9 Annex E contains a list of informative references.

1.4.10 Annex F lists a set of requirements and desirable characteristics that were taken into consideration in the design of the TDM.

1.4.11 Annex G discusses security, the Space Assigned Numbers Authority (SANA), and patent considerations with respect to the TDM

1.4.12 Annex H is a list of abbreviations and acronyms applicable to the TDM.

1.4.13 Annex I provides a TDM Summary Sheet, or 'Quick Reference'.

1.5 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommended Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Standard are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

[1] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, May 2010.

[2] *Information Technology—8-Bit Single-Byte Coded Graphic Character Sets—Part 1: Latin Alphabet No. 1*. International Standard, ISO/IEC 8859-1:1998. Geneva: ISO, 1998.

[3] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, November, 2010.

[4] *Orbit Data Messages*. Recommendation for Space Data System Standards, CCSDS 502.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, November 2009.

[6] *XML Schema Part 2: Datatypes*. 2nd ed. P. Biron and A. Malhotra, eds. W3C Recommendation 28. n.p.: W3C, 2004.

[7] *IEEE Standard for Binary Floating-Point Arithmetic*. IEEE Std 754-2008. New York: IEEE, 2008.

[8] *The International System of Units (SI)*. 8th ed. Sèvres, France: BIPM, 2006.

[9] *Attitude Data Messages*. Recommendation for Space Data System Standards, CCSDS 504.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 2008.

[10] *XML Specification for Navigation Data Messages*. Recommendation for Space Data System Standards, CCSDS 505.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, December 2010.

[11] Henry S. Thompson, et al., eds. *XML Schema Part 1: Structures*. 2nd ed. W3C Recommendation. N.p.: W3C, October 2004. <http://www.w3.org/TR/2004/REC-xmlschema-1-20041028/>

[12] United Nations Office for Outer Space Affiars, Outer Space Objects Index, http://www.unoosa.org/oosa/osoindex/index.jspx

NOTE – Informative references are provided in annex E.

2 OVERVIEW

2.1 GENERAL

This section provides a high-level overview of the CCSDS recommended Tracking Data Message, a message format designed to facilitate standardized exchange of spacecraft tracking data between space agencies.

2.2 THE TRACKING DATA MESSAGE (TDM) BASIC CONTENT

2.2.1 The TDM is realized as a sequence of plain ASCII text lines (reference [2]), which could be in either a file format or a real-time stream. The content is separated into three basic types of computer data structure as described in section 3. The TDM architecture takes into account that some aspects of tracking data change on a measurement-by-measurement basis (data); some aspects change less frequently, but perhaps several times per track (metadata); and other aspects change only rarely, e.g., once per track or perhaps less frequently (header). The TDM makes it possible to convey a variety of tracking data used in the orbit determination process in a single data message (e.g., standard Doppler and range radiometrics in a variety of tracking modes, transmit/receive frequencies, VLBI data, antenna pointing angles, etc.). To aid in precision trajectory modeling, additional ancillary information can be included within a TDM if it is desired and/or available (e.g., media corrections, meteorological data, clock data, and other ancillary data). Facilities for documenting comments are provided.

2.2.2 The Tracking Data Message in this version of the Recommended Standard is ASCII-text formatted. While binary-based tracking data message formats are computer efficient and minimize overhead during data transfer, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, ASCII format character-based tracking data representations are useful in transferring data between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable dumps of text to displays, emails, documents or printers are possible without preprocessing. The penalty for this convenience is some measure of inefficiency (based on early tests, such penalty would be greatly reduced if the data is compressed for transmission).

2.2.3 The ASCII text in a TDM can be exchanged in either of two formats: a 'keyword-value notation' format (KVN) or an XML format. The KVN formatted TDM and XML formatted TDM are described in this document. Further information on XML is detailed in an integrated XML schema document for all Navigation Data Messages (reference **Error! Reference source not found.**[10]). It is recommended that exchange participants specify in the ICD which TDM ASCII format will be exchanged, the KVN or the XML format.

2.2.4 Normally a TDM will contain tracking data for a single spacecraft participant, unless the tracking session is spacecraft-to-spacecraft in nature. If a tracking operation involves information from multiple spacecraft participants tracked from the ground, the data could be included in a single TDM by using multiple segments (see 3.1); or multiple TDMs could be used, one per spacecraft participant.

2.2.5 For a given spacecraft participant, multiple tracking data messages could be provided in a message exchange session to achieve the tracking data requirements of the participating agencies (e.g., launch supports with periodically delivered TDMs, or other critical events such as maneuvers, encounters, etc.).

2.2.6 Provisions for the frequency of exchange and special types of exchanges are recommended to be specified in an ICD.

3 TRACKING DATA MESSAGE STRUCTURE AND CONTENT

3.1 GENERAL

3.1.1 The TDM shall consist of digital data represented as ASCII text lines (see reference [2]) in KVN format (see section 4) or XML format (see Section 5). The lines constituting a TDM shall be represented as a combination of:

a) a Header (see 3.2);

b) a Metadata Section (data about data) (see 3.3); and

c) a Data Section (tracking data represented as 'Tracking Data Records') (see 3.4).

Optional comments may appear in specified locations in the Header, Metadata, and Data Sections (see 4.5).

3.1.2 Taken together, the Metadata Section and its associated Data Section shall be called a TDM Segment.

3.1.3 Each TDM shall have a Header and a Body. The TDM Body shall consist of one or more TDM Segments. There shall be no limit to the number of Segments in a given TDM Body, beyond practical constraints, as shown in table 3-1. Each Segment shall consist of a Metadata Section and a Data Section that consists of a minimum of one Tracking Data Record. Therefore, the overall structure of the TDM shall be:

– TDM = Header + Body;

– Body = Segment [+ Segment + ... + Segment];

– Segment = Metadata Section + Data Section;

– Data Section = Tracking Data Record (TDR) [+ TDR + TDR … + TDR].

Table 3-1: TDM Structure

Item			Mandatory?
Header			Yes
Body	Segment 1	Metadata 1	Yes
		Data 1	
	Segment 2	Metadata 2	No
		Data 2	
	. . .	. . .	. . .
	Segment n	Metadata n	No
		Data n	

3.1.4 The TDM shall consist of tracking data for one or more tracking participants at multiple epochs contained within a specified time range. (Note that the term ‘participant’ applies equally to spacecraft, quasars, tracking stations, and agency centers, as discussed in reference [1]. Thus there may exist Tracking Data Messages for which there is no applicable spacecraft.) Generally, but not necessarily, the time range of a TDM may correspond to a ‘tracking pass’.

3.1.5 The TDM shall be easily readable by both humans and computers.

3.1.6 It shall be possible to exchange a TDM either as a real-time stream or as a file.

3.1.7 The TDM file naming scheme should be agreed to on a case-by-case basis between the participating agencies, and should be specified in an ICD.

3.1.8 The method of exchanging TDMs shall be decided on a case-by-case basis by the participating agencies and should be documented in an ICD. The exchange method shall not constrain the tracking data content.

3.2 TDM HEADER

3.2.1 The TDM shall include a Header that consists of information that identifies the basic parameters of the message. The first Header line must be the first non-blank line in the message.

3.2.2 A description of TDM Header items and values is provided in table 3-2, which specifies for each item:

– the keyword to be used;

– a short description of the item;

– examples of allowed values; and

– whether the item is mandatory oroptional.

3.2.3 Only those keywords shown in table 3-2 shall be used in a TDM Header. The order of occurrence of the mandatory and optional KVN assignments shall be fixed as shown in table 3-2.

Table 3-2: TDM Header

Keyword	**Description**	**Examples**	**Mandatory**
CCSDS_TDM_VERS	Format version in the form of '*x.y*', where '*y*' shall be incremented for corrections and minor changes, and '*x*' shall be incremented for major changes.	0.12 (for testing) 1.0 (previous version) 2.0 (this version)	Yes
COMMENT	See 4.5.	COMMENT This is a comment	No
CREATION_DATE	Data creation date/time in UTC. For format specification, see 4.3.9.	2001-11-06T11:17:33 2002-204T15:56:23.4 2006-001T00:00:00Z	Yes
ORIGINATOR	Creating agency. Value should be an entry in the SANA Registry http://sanaregistry.org/r/organizations/organizations.html	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes

3.2.4 Each line in the TDM Header, with the exception of COMMENTs, shall have the following generic format:

```
keyword = value
```

3.2.5 The TDM Header shall provide a CCSDS Tracking Data Message version number that identifies the format version; this is included to anticipate future changes and to provide the ability to extend the standard with no disruption to existing users. The version keyword is CCSDS_TDM_VERS and the value shall have the form of *x.y* where *y* is incremented for corrections and minor changes, and *x* is incremented for major changes. Version 1.0 shall be reserved for the initial version accepted by the CCSDS as an official Recommended Standard ('Blue Book'). Interagency testing of TDMs shall be conducted using version numbers less than 1.0 (e.g., '0.*y*'). Specific TDM versions that will be exchanged between agencies should be documented via the ICD.

3.2.6 The TDM Header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the data was created (file creation time if in file format, or first data point in stream), as specified in reference [3] (ASCII Time Code A or B).

3.3 TDM METADATA

3.3.1 GENERAL

3.3.1.1 The TDM shall include at least one Metadata Section that contains configuration details (metadata) applicable to the Data Section in the same TDM Segment. The information in the Metadata Section aligns with the tracking data to provide descriptive information (typically, the metadata is the type of information that does not change frequently during a tracking session).

3.3.1.2 Each line in the TDM Metadata Section, with the exception of COMMENTs, shall have the following generic format:

```
keyword = value
```

3.3.1.3 A single TDM Metadata Section shall precede each Data Section.

3.3.1.4 When there are changes in the values assigned to any of the keywords in the Metadata Section, a new Segment must be started (e.g., mode change from one-way to two-way tracking).

3.3.1.5 The first and last lines of a TDM Metadata Section shall consist of the META_START and META_STOP keywords, respectively. These keywords are used to facilitate parsing.

3.3.1.6 Table 3-3 specifies for each Metadata item:

– the keyword to be used;

– a short description of the item;

– a list of required values or examples of allowed values; and

– whether the item is mandatory or not mandatory.

The column marked 'N/E' will contain an 'N' if the column marked 'Normative Values / Examples' contains normative values, and will contain an 'E' if the column contains example values that are non-normative. For normative values, a fully enumerated set of values may be provided, or the contents of table 3-3 may be a sample of values that are fully enumerated in an annex. In this latter case, the necessary annex is identified.

3.3.1.7 Only those keywords shown in table 3-3 shall be used in a TDM Metadata Section. Mandatory items shall appear in every TDM Metadata Section. Items that are not mandatory may or may not appear in any given TDM Metadata Section, at the discretion of the data producer, based on the requirements of the data and its intended application (see annex I for a TDM Summary Sheet that illustrates the relationships between data types and metadata). For most metadata keywords there is no default value; where there is a default value, it is specified at the end of the 'Description' section for the given keyword. If a keyword is not present in a TDM, and a default value is defined, the default shall be assumed.

3.3.1.8 The order of occurrence of the mandatory and optional KVN assignments shall be fixed as shown in table 3-3.

3.3.1.9 The Metadata Section shall describe the participants in a tracking session using the keyword 'PARTICIPANT_n'. There may be several participants associated with a tracking data session (the number of participants is always greater than or equal to one, and generally greater than or equal to two). The 'n' in the keyword is an indexer. The indexer shall not be the same for any two participants in a given Metadata Section.

3.3.1.10 The value associated with any given PARTICIPANT_n keyword may be a ground tracking station, a spacecraft, a quasar catalog name; or may include non-traditional objects, such as landers, rovers, balloons, etc. The list of eligible names that is used to specify participants should be documented in the ICD. Subsections 3.3.2 through 3.3.2.7 provide an explanation of the tracking modes and participant numbers. Participants may generally be listed in any order.

3.3.1.11 In this version of the TDM, the maximum number of participants per segment shall be five. If more than five participants are defined (i.e., PARTICIPANT_6 +), then special arrangements between exchange participants are necessary. These arrangements should be documented in an ICD. Note that although the restriction to five participants may appear to be a constraint it is probably not, because of other aspects of the TDM structure. Five participants easily allow the user to describe the great majority of tracking passes. In some cases there may be 'critical event' tracking sessions in which a single spacecraft is tracked by a large number of antennas, such that the total number of participants appears to be six or more. However, because of the nature of the 'PATH' keyword, several TDM Segments would be required to describe the full set of tracking data. For the critical event example scenario just given, one TDM Segment would be used to describe the two-way connection, and one additional segment would be required for each three-way connection; it would not be possible to provide a single 'PATH' statement that would convey the multiple signal paths.

Table 3-3: TDM Metadata Section

Keyword	Description	Normative Values / Examples	N/E	Mandatory
`META_START`	The `META_START` keyword shall delineate the start of the TDM Metadata Section within the message. It must appear on a line by itself; i.e., it shall have no parameters, timetags or values.	N/A	-----	Yes
`COMMENT`	See 4.5. Note that if comments are used in the metadata, they shall only appear at the beginning of the Metadata Section.	COMMENT file = tdm.dat	E	No
`DATA_TYPES`	Comma separated list of data types in the Data Section. The elements of the list are the data types shown in Table 3-5, with the exception of the DATA_START, DATA_STOP, and COMMENT keywords.	See Table 3-5	N	No
`TIME_SYSTEM`	The `TIME_SYSTEM` keyword shall specify the time system used for timetags in the associated Data Section. This should be UTC for ground-based data. The value associated with this keyword must be selected from the full set of allowed values enumerated in annex A.	`UTC, TAI, GPS, SCLK`	E	Yes

`START_TIME`	The `START_TIME` keyword shall specify the UTC start time of the total time span covered by the tracking data immediately following this Metadata Section. For format specification, see 4.3.9.	`1996-12-18T14:28:15.1172`
		
		`1996-277T07:22:54`
		`2006-001T00:00:00Z`
			E	No

`STOP_TIME`	The `STOP_TIME` keyword shall specify the UTC stop time of the total time span covered by the tracking data immediately following this Metadata Section. For format specification, see 4.3.9.	`1996-12-18T14:28:15.1172`
		
		`1996-277T07:22:54`
		`2006-001T00:00:00Z`
			E	No

Keyword	**Description**	**Normative Values / Examples**	**N/E**	**Mandatory**
`PARTICIPANT_n` `n = {1, 2, 3, 4, 5}`	The `PARTICIPANT_n` keyword shall represent the participants in a tracking data session. It is indexed to allow unambiguous reference to other data in the TDM (max index is 5). At least two participants must be specified for most sessions; for some special TDMs such as tropospheric media only, only one participant need be listed. Participants may include ground stations, spacecraft, quasars, and or debris fragments. Participants represent the classical transmitting parties, transponding parties, and receiving parties, while allowing for flexibility to consider tracking sessions that go beyond the familiar one-way spacecraft-to-ground, two-way ground-spacecraft-ground, etc. Participants may be listed in any order, and the PATH keywords specify the signal paths. For spacecraft identifiers, there is no CCSDS-based restriction on the value for this keyword, but names could be drawn from the United Nations Outer Space Objects Index (reference [12]), which includes Object name and international designator of the participant. [xxx need to add CATALOG as well like in CDM??? xxx]The list of eligible names that is used to specify participants should be documented in the ICD.	DSS-63-S400K ROSETTA <Quasar catalog name> 1997-061A	E	Yes (at least one)
`MODE`	The `MODE` keyword shall reflect the tracking mode associated with the Data Section of the segment. The value 'SEQUENTIAL' applies only for frequencies, range, Doppler, angles, and line-of-sight ionosphere calibrations; the name implies a sequential signal path between tracking participants. The value 'SINGLE_DIFF' applies for differenced data. In other cases, such as troposphere, weather, clocks, etc., use of the MODE keyword does not apply.	`SEQUENTIAL` `SINGLE_DIFF`	N	No

Keyword	Description	Normative Values / Examples	N/E	Mandatory
PATH PATH_1, PATH_2	The PATH keywords shall reflect the signal path by listing the index of each participant in order, separated by commas, with no inserted white space. The integers 1, 2, 3, 4, 5 used to specify the signal path are correlated with the indices of the PARTICIPANT keywords. The first entry in the PATH shall be the transmit participant. The non-indexed 'PATH' keyword shall be used if the MODE is SEQUENTIAL (i.e., MODE=SEQUENTIAL is specified). The indexed 'PATH_1' and 'PATH_2' keywords shall be used where the MODE is 'SINGLE_DIFF'. Examples: 1,2 = one-way; 2,1,2 = two-way; 3,2,1 = three-way; 1,2,3,4 = four-way.	PATH = 1,2,1 PATH_1 = 1,2,1 PATH_2 = 3,1	E	No
EPHEMERIS_NAME_n n = {1, 2, 3, 4, 5}	Unique name of the external ephemeris file used for tracking one of the n PARTICIPANTs. The 'n' corresponds to the 'n' associated with the PARTICIPANT keyword (e.g., EPHEMERIS_NAME_1, if present, applies to PARTICIPANT_1).	SATELLITE_A_EPHEM27	E	No
TRANSMIT_BAND	The TRANSMIT_BAND keyword shall indicate the frequency band for transmitted frequencies. The frequency ranges associated with each band should be specified in the ICD.	S X Ka L UHF	E	No
RECEIVE_BAND	The RECEIVE_BAND keyword shall indicate the frequency band for received frequencies. Although not required in general, the RECEIVE_BAND must be present if the MODE is SINGLE_DIFF and differenced frequencies or differenced range are provided in order to allow proper frequency dependent corrections to be applied. The frequency ranges associated with each band should be specified in the ICD.	S X Ka L UHF	E	No
TURNAROUND_NUMERATOR	The TURNAROUND_NUMERATOR keyword shall indicate the numerator of the turnaround ratio that is necessary to calculate the coherent downlink from the uplink frequency. The value shall be an integer. Also may be specified in ICD if the value is always constant.	240 880	E	No

Keyword	Description	Normative Values / Examples	N/E	Mandatory
TURNAROUND_DENOMINATOR	The TURNAROUND_DENOMINATOR keyword shall indicate the denominator of the turnaround ratio that is necessary to calculate the coherent downlink from the uplink frequency. The value shall be an integer. Also may be specified in ICD if the value is always constant.	221 749	E	No
TIMETAG_REF	The TIMETAG_REF keyword shall provide a reference for time tags in the tracking data. This keyword indicates whether the timetag associated with the data is the transmit time or the receive time. This keyword is provided specifically to accommodate two special cases: (1) systems where a received range data point has been timetagged with the time that the range tone signal was transmitted (i.e., TIMETAG_REF=TRANSMIT), and (2) for quasar DOR, where the transmit frequency is the interferometer reference frequency at receive time (i.e., TIMETAG_REF=RECEIVE). It is anticipated otherwise that transmit-related data will generally be timetagged with the time of transmission, and that receive-related data will generally be timetagged with the time of receipt; in these two standard cases, it is not necessary to specify the TIMETAG_REF keyword.	TRANSMIT RECEIVE	N	No
INTEGRATION_INTERVAL	The INTEGRATION_INTERVAL keyword shall provide the Doppler count time in seconds for Doppler data or for the creation of normal points (also applicable for differenced Doppler; also sometimes known as 'compression time', 'condensation interval', etc.). The data type shall be positive double precision.	60.0 0.1 1.0	E	No
INTEGRATION_REF	The INTEGRATION_REF keyword shall be used in conjunction with the INTEGRATION_INTERVAL and TIMETAG_REF keywords. This keyword indicates the relationship between the INTEGRATION_INTERVAL and the timetag on the data, i.e., whether the timetag represents the start, middle, or end of the integration period.	START MIDDLE END	N	No
FREQ_OFFSET	The FREQ_OFFSET keyword represents a frequency in Hz that must be added to every RECEIVE_FREQ (see 3.5.2.8) to reconstruct it. One use is if a Doppler shift frequency observable is transferred instead of the actual received frequency. The data type shall be double precision, and may be negative, zero, or positive. Examples are shown in the 'Normative Values / Examples' column. The default shall be 0.0 (zero).	0.0 8415000000.0	E	No

Keyword	**Description**	**Normative Values / Examples**	**N/E**	**Mandatory**
RANGE_MODE	The value of the RANGE_MODE keyword shall be 'COHERENT', in which case the range tones are coherent with the uplink carrier, and the range unit must be defined in an ICD; 'CONSTANT', in which case the range tones have a constant frequency; or 'ONE_WAY' (used in Delta-DOR). NOTE – It cannot be determined in advance whether the range mode is coherent or non-coherent. For ESA and JAXA, it is important for the two/three-way Doppler to be coherent, but not the RANGE. This keyword may not be applicable for differenced range data.	COHERENT CONSTANT ONE_WAY	N	No
RANGE_MODULUS	The value associated with the RANGE_MODULUS keyword shall be the modulus of the range observable in the units as specified by the RANGE_UNITS keyword; i.e., the actual (unambiguous) range is an integer *k* times the modulus, plus the observable value. RANGE_MODULUS shall be a non-negative double precision value. For measurements that are not ambiguous range, the MODULUS setting shall be 0 to indicate an essentially infinite modulus. The default value shall be 0.0. NOTE – The range modulus is sometimes also called the 'range ambiguity'.	32768.0 2.0e+23 0.0 161.6484	E	No
RANGE_UNITS	The RANGE_UNITS keyword specifies the units for the range observable. 'km' shall be used if the range is measured in kilometers. 's' shall be used if the range is measured in seconds. 'RU', for 'range units', shall be used where the transmit frequency is changing, and the method of computing the range unit should be described in the ICD. The default (preferred) value shall be 'km'.	km s RU	N	No
ANGLE_TYPE	The ANGLE_TYPE keyword shall indicate the type of antenna geometry represented in the angle data (ANGLE_1 and ANGLE_2 keywords). The value shall be one of the values: – AZEL for azimuth, elevation (local horizontal); – RADEC for right ascension, declination or hour angle, declination (needs to be referenced to an inertial frame); – XEYN for *x*-east, *y*-north; – XSYE for *x*-south, *y*-east. Other values are possible, but must be defined in an ICD.	AZEL RADEC XEYN XSYE	N	No

Keyword	Description	Normative Values / Examples	N/E	Mandatory
REFERENCE_FRAME	The REFERENCE_FRAME keyword shall be used in conjunction with the 'ANGLE_TYPE=RADEC' keyword/value combination, indicating the inertial reference frame to which the antenna frame is referenced. The origin (center) of the reference frame is assumed to be at the antenna reference point. Applies only to ANGLE_TYPE = RADEC. The value associated with this keyword must be selected from the full set of allowed values enumerated in annex A.	EME2000	E	No
MAG_TYPE	The MAG_TYPE keyword shall specify the magnitude type for an optical observation (principally orbital debris objects). The apparent magnitude of an object is a measure of its brightness as seen by an observer on Earth, adjusted to the value it would have in the absence of the atmosphere. The absolute magnitude is defined as the apparent magnitude that the object would have if it were one astronomical unit (AU) from both the Sun and the observer.	APPARENT ABSOLUTE	N	No
INTERPOLATION	The INTERPOLATION keyword shall specify the interpolation method to be used to calculate a transmit phase count at an arbitrary time in tracking data where the uplink frequency is not constant.	HERMITE LAGRANGE LINEAR	E	No
INTERPOLATION_DEGREE	The INTERPOLATION_DEGREE keyword shall specify the recommended degree of the interpolating polynomial used to calculate a transmit phase count at an arbitrary time in tracking data where the uplink frequency is not constant. The value must be an integer, and must be used if the 'INTERPOLATION' keyword is used.	3 5 7 11	E	No

Keyword	Description	Normative Values / Examples	N/E	Mandatory

`TRANSMIT_DELAY_n`
`n = {1, 2, 3, 4, 5}`
	The `TRANSMIT_DELAY_n` keyword shall specify a fixed interval of time, in seconds, required for the signal to travel from the transmitting electronics to the transmit point. This may be used to account for gross factors that do not change from pass to pass, such as antennas with remote electronics, arraying delays, or spacecraft transponder delays. The 'n' corresponds to the 'n' associated with the PARTICIPANT keyword (e.g., TRANSMIT_DELAY_1, if present, applies to timetags for PARTICIPANT_1). Delays associated with uplink antenna arraying should be indicated with this keyword. If the user wishes to convey a ranging transponder delay, then one half of the transponder delay should be specified via the TRANSMIT_DELAY_n keyword. The TRANSMIT_DELAY should generally not be included in ground corrections applied to the tracking data. The TRANSMIT_DELAY shall be a non-negative double precision value. The default value shall be 0.0.
	NOTE – This value should not be used to convey clock bias information. See the 'CLOCK_BIAS' keyword in the Data Section keywords.
		`1.23`
		`0.0326`
		`0.00077`
			E	No

`RECEIVE_DELAY_n`
`n = {1, 2, 3, 4, 5}`
	The `RECEIVE_DELAY_n` keyword shall specify a fixed interval of time, in seconds, required for the signal to travel from the tracking point to the receiving electronics. This may be used to account for gross factors that do not change from pass to pass, such as antennas with remote electronics, arraying delays, or spacecraft transponder delays. The 'n' corresponds to the 'n' associated with the PARTICIPANT keyword (e.g., RECEIVE_DELAY_1, if present, applies to timetags for PARTICIPANT_1).
	Delays associated with downlink antenna arraying should be indicated with this keyword. If the user wishes to convey a ranging transponder delay, then one half of the transponder delay should be specified via the RECEIVE_DELAY_n keyword. The RECEIVE_DELAY should generally not be included in ground corrections applied to the tracking data. The RECEIVE_DELAY shall be a non-negative double precision value. The default value shall be 0.0.
	NOTE – This value should not be used to convey clock bias information. See the 'CLOCK_BIAS' keyword in the Data Section keywords.
		`1.23`
		`0.0326`
		`0.00777`
			E	No

Keyword	Description	Normative Values / Examples	N/E	Mandatory
`DATA_QUALITY`	The `DATA_QUALITY` keyword may be used to provide an estimate of the quality of the data, based on indicators from the producers of the data (e.g., bad time synchronization flags, marginal lock status indicators, etc.). A value of 'RAW' shall indicate that no quality check of the data has occurred (e.g., in a real-time broadcast or near–real-time automated file transfer). A value of 'VALIDATED' shall indicate that data quality has been checked, and passed tests. A value of 'DEGRADED' shall indicate that data quality has been checked and quality issues exist. 'Checking' may be via human intervention or automation. Specific definitions of 'RAW', 'VALIDATED', and 'DEGRADED' that may apply to a particular exchange should be listed in the ICD. If the value is 'DEGRADED', information on the nature of the degradation may be conveyed via the COMMENT mechanism. Note that because of the nature of TDM metadata, if 'DEGRADED' is specified, it applies to all the data in the segment. Thus degraded data should be isolated in dedicated segments. The default value shall be 'RAW' (rationale: agencies often do not validate tracking data before export).	RAW VALIDATED DEGRADED	N	No

`CORRECTION_ANGLE_1`
`CORRECTION_ANGLE_2`
`CORRECTION_DOPPLER`
`CORRECTION_MAG`
`CORRECTION_RANGE`
`CORRECTION_RECEIVE`
`CORRECTION_TRANSMIT`
 	
`measurement noise weighting in TDM ? Ask Takeuchi and Border. Data weighting? Add in Data Section?`
	The set of `CORRECTION_*` keywords may be used to reflect the values of corrections that have been added to the data or should be added to the data (e.g., ranging station delay calibration, etc.). This information may be provided to the user, so that the base measurement could be recreated if a different correction procedure is desired. Tracking data should be corrected for ground delays only. Note that it may not be feasible to apply all ground corrections for a near–real-time transfer. Units for the correction shall be the same as those for the applicable observable. All corrections should be signed, double precision values. Examples are shown in the 'Normative Values / Examples' column.	-1.35
		0.23
		-3.0e-1
		150000.0
			E	No

Keyword	Description	Normative Values / Examples	N/E	Mandatory
CORRECTIONS_APPLIED	This keyword is used to indicate whether or not the values associated with the CORRECTION_* keywords have been applied to the tracking data. This keyword is required if any of the CORRECTION_* keywords is used. Because of the nature of TDM metadata, the application of corrections applies to all of the data described by a given Metadata Section. Thus all of the data in a given segment must have corrections applied or corrections not applied. The value of this keyword thus applies to all the data related to a Metadata Section in which it is used.	YES NO	N	No
META_STOP	The META_STOP keyword shall delineate the end of the TDM Metadata Section within the message. It must appear on a line by itself; i.e., it shall have no parameters, timetags, or values.	N/A	-----	Yes

3.3.2 MODE AND PATH SETTINGS FOR TYPICAL TRACKING SESSIONS

NOTE – The following subsections discuss possible relationships between the 'MODE', 'PATH', and 'PARTICIPANT_n' keywords. This discussion is provided in order to facilitate the implementation of TDM generation for typical tracking sessions (e.g., one-way, two-way, three-way, etc.). Annex I supplies recommendations of the metadata keywords that should be used to properly describe the tracking data of various types depending on the settings of the MODE and PATH keywords, with allowance for characteristics of the uplink frequency (if applicable).

3.3.2.1 One-Way Data

3.3.2.1.1 The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

3.3.2.1.2 For one-way data, the signal path generally originates at the spacecraft transmitter, so the spacecraft's participant number shall be the first number in the value assigned to the PATH keyword. The receiver, which may be a tracking station or another spacecraft, shall be represented by the second number in the value of the PATH keyword.

EXAMPLES – 'PATH=1,2' indicates transmission from PARTICIPANT_1 to PARTICIPANT_2; 'PATH=2,1' indicates transmission from PARTICIPANT_2 to PARTICIPANT_1.

3.3.2.1.3 To facilitate generation of the one-way tracking observable, the nominal spacecraft transmit frequency should be provided via a TRANSMIT_FREQ_n keyword in TDMs that contain one-way receive frequency data. The transmit frequency data may be in the same segment as the receive frequency data, or a separate segment, at the preference of the TDM originator.

NOTE – See figures D-1 and D-2 for example TDMs containing one-way tracking data.

3.3.2.2 Two-Way Data

3.3.2.2.1 The setting of the ‘MODE’ keyword shall be ‘SEQUENTIAL’.

3.3.2.2.2 For two-way data, the signal path originates at a ground antenna (or a ‘first spacecraft’), so the uplink (or crosslink) transmit participant number shall be the first number in the value assigned to the PATH keyword. The participant number of the transponder onboard the spacecraft to which the signal is being uplinked shall be the second number in the value assigned to the PATH keyword. The third entry in the PATH keyword value shall be the same as the first (two way downlink is received at the same participant which transmits the uplink/crosslink). Both PARTICIPANT_1 and PARTICIPANT_2 may be spacecraft as in the case of a spacecraft-spacecraft exchange.

EXAMPLES – ‘PATH=1,2,1’ indicates transmission from PARTICIPANT_1 to PARTICIPANT_2, with final reception at PARTICIPANT_1; ‘PATH=2,1,2’ indicates transmission from PARTICIPANT_2 to PARTICIPANT_1, with final reception at PARTICIPANT_2.

NOTE – See figures D-3, D-4, and D-9 for example TDMs containing two-way tracking data.

3.3.2.3 Three-Way Data

3.3.2.3.1 The setting of the ‘MODE’ keyword shall be ‘SEQUENTIAL’.

3.3.2.3.2 For three-way data, the signal path originates with a ground station (uplink antenna), so the participant number of the uplink station shall be the first entry in the value assigned to the PATH keyword. The participant number of the transponder onboard the spacecraft to which the signal is being uplinked shall be the second number in the value assigned to the PATH keyword. The participant number of the downlink antenna shall be the third number in the value assigned to the PATH keyword.

3.3.2.3.3 For three-way data, the first and last numbers in the value assigned to the PATH keyword must be different.

EXAMPLES – ‘PATH=1,2,3’ indicates transmission from PARTICIPANT_1 to PARTICIPANT_2, with final reception at PARTICIPANT_3.

NOTE – See figure D-5 for an example TDM containing three-way tracking data.

3.3.2.4 *N*-Way Data

3.3.2.4.1 One-way, two-way, and three-way tracking cover the bulk of tracking sequences. However, four-way and greater (*n*-way) scenarios are possible (e.g., via use of one or more relay satellites). These may be accomplished via the sequence assigned to the PATH keyword.

3.3.2.4.2 The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

3.3.2.4.3 The value assigned to the PATH keyword shall convey the signal path among the participants followed by the signal; e.g., 'PATH=1,2,3,2,1' and 'PATH=1,2,3,4' represent two different four-way tracking signal paths.

3.3.2.4.4 In this version of the TDM, the maximum number of participants per segment shall be five. If more than five participants are defined (i.e., PARTICIPANT_6 +), then special arrangements shall be made; these should be specified in the ICD.

NOTE – See figure D-6 for an example TDM containing four-way tracking data.

3.3.2.5 Differenced Modes and VLBI Data

3.3.2.5.1 Differenced data and VLBI data may also be exchanged in a Tracking Data Message. Differenced data may include differenced Doppler and differenced range (see references [E3] and [E4]).

3.3.2.5.2 The setting of the 'MODE' keyword shall be 'SINGLE_DIFF'.

3.3.2.5.3 When the MODE is 'SINGLE_DIFF', two path keywords, 'PATH_1' and 'PATH_2', shall be used to convey the signal paths that have been differenced.

3.3.2.5.4 When the mode is 'SINGLE_DIFF', the observable shall be calculated by subtracting the value achieved for the measurement using PATH_1 from the value achieved using PATH_2, i.e., PATH_2 – PATH_1. Only the final observable shall be communicated via the TDM.

3.3.2.5.5 If the TDM contains differenced Doppler shift data, the 'RECEIVE_FREQ' keyword shall be used for the observable (the 'RECEIVE_FREQ' keyword is a Data Section keyword not yet described in the text—see 3.5.2.8).

3.3.2.5.6 If the TDM contains two-way or three-way differenced Doppler data, then a history of the uplink frequencies shall be provided with the TRANSMIT_FREQ_n keyword in order to process the data correctly (the 'TRANSMIT_FREQ_n' keyword is a Data Section keyword not yet described in the text—see 3.5.2.9).

3.3.2.5.7 If differenced range is provided, the 'RANGE' keyword shall be used for the observable (the 'RANGE' keyword is a Data Section keyword not yet described in the text—see 3.5.2.7).

3.3.2.5.8 If the TDM contains differenced data collected during a Delta-Differential One Way Range (Delta-DOR) session with a spacecraft, then the DOR keyword shall be used for the observable (the ‘DOR’ keyword is a Data Section keyword not yet described in the text—see 3.5.3.2).

3.3.2.5.9 If the TDM contains differenced data collected during a VLBI session with a quasar, then the VLBI_DELAY keyword shall be used for the observable (the ‘VLBI_DELAY’ keyword is a Data Section keyword not yet described in the text—see 3.5.3.3).

NOTE – See figures D-10 and D-11 for example TDMs containing single differenced tracking data.

3.3.2.6 Angle Data

Angle data is applicable for any tracking scenario where MODE=SEQUENTIAL is specified, but is based on pointing with respect to the two final participants only (e.g., spacecraft downlink to an antenna, direction of a participant measured by a navigation camera, etc.).

NOTE – See figures D-8 and D-12 for example TDMs containing angle data.

3.3.2.7 Media, Weather, Ancillary Data

3.3.2.7.1 When all the data in a TDM Segment is media related, weather related, or ancillary-data related, then the use of the MODE keyword may or may not apply as discussed below.

3.3.2.7.2 Data of this type may be relative to a reference location within the tracking complex; in this case the methods used to extrapolate the measurements to other antennas should be specified in the ICD. In the case where a reference location is used, there shall be only one participant (PARTICIPANT_1), which is the reference antenna, and the MODE keyword shall not be used. This case corresponds to tropospheric correction data, zenith ionospheric correction data, and weather data.

3.3.2.7.3 When ionospheric charged particle delays are provided for a line-of-sight between the antenna and a specific spacecraft, the participants include both the antenna and the spacecraft, the MODE should be set to ‘SEQUENTIAL’, and a standard PATH statement should be used.

NOTE – See figures D-13 through D-15 for example TDMs containing tracking data of these types.

3.4 TDM DATA SECTION (GENERAL SPECIFICATION)

3.4.1 The Data Section of the TDM Segment shall consist of one or more Tracking Data Records. Each Tracking Data Record shall have the following generic format:

```
keyword  =  timetag   measurement
```

NOTE – More detail on the generic format of a Tracking Data Record is shown in table 3-4.

Table 3-4: Tracking Data Record Generic Format

Element		Description	Examples	Mandatory
<keyword>		Data type keyword from the list specified in 3.5.	See annex D.	Yes (at least one keyword must be used)
=		Equals sign	=	Yes
value	<timetag>	Time associated with the tracking observable according to the TIME_SYSTEM keyword. For requirements on the timetag, see 3.4.8 through 3.4.12. For format specification, see 4.3.9.	2003-205T18:00:01.275 2003-205T18:00:01Z	Yes
	<measurement>	Tracking observable (measurement or calculation) in units defined in the TDM.	See 3.5.	Yes

3.4.2 Each Tracking Data Record must be provided on a single line.

3.4.3 Each Tracking Data Record shall contain a value that depends upon the data type keyword used. The value shall consist of two elements: a timetag and a tracking observable (a measurement or calculation based on measurements); either without the other is useless for tracking purposes. Hereafter, the term 'measurement' shall be understood to include calculations based on measurements as noted above.

3.4.4 At least one blank character must be used to separate the timetag and the observable in the value associated with each Tracking Data Record.

3.4.5 Applicable keywords and their associated characteristics are detailed in 3.5.

3.4.6 There shall be no mandatory keywords in the Data Section of the TDM Segment, with the exception of 'DATA_START' and 'DATA_STOP', because the data presented in any given TDM is dependent upon the characteristics of the data collection activity.

3.4.7 The Data Section of the TDM Segment shall be delineated by the 'DATA_START' and 'DATA_STOP' keywords. These keywords are intended to facilitate parsing, and will also serve to advise the recipient that all the Tracking Data Records associated with the immediately preceding TDM Metadata Section have been received (the rationale for including this is that data volumes can be very large, so knowing when the data ends is desirable). The TDM recipient may process the 'DATA_STOP' keyword as a 'local' end-of-file marker.

3.4.8 Tracking data shall be tagged according to the value of the 'TIME_SYSTEM' metadata keyword.

3.4.9 Interpretation of the timetag for transmitted data is straightforward; it is the transmit time. Interpretation of the timetag for received data is determined by the values of the 'TIMETAG_REF', 'INTEGRATION_REF', and 'INTEGRATION_INTERVAL' keywords, as applicable (see table 3-3 and 3.5.2.8). For other data types (e.g., meteorological, media, clock bias/drift), the timetag represents the time the measurement was taken.

3.4.10 In general, no required ordering of Tracking Data Records shall be imposed, because there are certain scenarios in which data are collected from multiple sources that are not processed in strictly chronological order. Thus it may only be possible to generate data in chronological order if it is sorted post-pass. However, there is one ordering requirement placed on Tracking Data Records; specifically, in any given Data Section, the data for any given keyword shall be in chronological order. Also, some TDM creators may wish to sort tracking data by keyword rather than by timetag. Special sorting requirements should be specified in the ICD.

3.4.11 Each keyword/timetag combination must be unique within a given Data Section (i.e., a given keyword/timetag combination shall not be repeated in the same set of Tracking Data Records).

3.4.12 The time duration between timetags may be constant, or may vary, within any given TDM.

3.4.13 Every tracking instrument shall have a defined reference location. This reference location shall not depend on the observing geometry. The tracking instrument locations should be conveyed via an ICD. The ICD information should include a complete description of the station locations and characteristics, including the antenna coordinates with their defining system, plate motion, and the relative geometry of the tracking point and cross axis of the antenna mount, accommodations for antenna tilt to avoid keyhole problems, etc. The station location could be provided via an OPM (reference [4]). Antenna geometry may be necessary for exceptional cases, where the station location is not fixed during track, for example.

3.4.14 The measurement shall be converted to an equipment-independent quantity; e.g., frequencies shall be reported at the 'sky level' (i.e., actual transmitted/received frequencies, unless the FREQ_OFFSET keyword is used in the metadata). It should not be necessary for the data recipient to have detailed information regarding the internal network of the data producer.

3.4.15 Tracking data is normally subject to a number of corrections, as described in the following paragraphs.

3.4.15.1 The tracking data measurements shall be corrected with the best estimate of all known instrument calibrations, such as path delay calibrations between the reference point and the tracking equipment, if applicable.

NOTE – These measures should reduce the requirement for consumers of tracking data to have detailed knowledge of the underlying structure of the hardware/software system that performed the measurements.

3.4.15.2 Tracking data should be corrected for ground delays only. The corrections that have been applied may be specified to the message recipient via use of the optional 'CORRECTION_*' keywords in the metadata.

NOTE – The 'TRANSMIT_DELAY' and 'RECEIVE_DELAY' keywords do not represent 'ground corrections' per se. They are meant to convey gross factors that do not change from pass-to-pass. However, if exchange partners agree via the ICD, 'TRANSMIT_DELAY' and 'RECEIVE_DELAY' could be removed from the measurements. It is generally operationally inconvenient for the producer to treat these values as corrections because of the possible requirement to alter uplink timetags; thus these delays are best handled in orbit determination post-processing. Modifying timetags to account for these delays also complicates the use of differenced measurements. It is thus more straightforward to allow the recipient to process these delays rather than to correct the data prior to exchange.

3.4.15.3 If correction values are indicated via any of the 'CORRECTION_*' keywords, then the TDM producer must indicate whether these correction values have or have not been applied to the tracking data. This indication is accomplished via the use of the metadata keyword 'CORRECTIONS_APPLIED'; this metadata item must have a value of 'YES' or 'NO'.

3.4.15.4 Media corrections (ionosphere, troposphere) should not be applied by the TDM producer; media corrections may be applied by the TDM recipient using the data conveyed in the STEC, TROPO_WET, and TROPO_DRY Data Section keywords.

3.4.15.5 The party that will perform any applicable spin corrections should be specified in the ICD (most appropriate party may be the party that operates the spacecraft).

3.4.15.6 Special correction algorithms that are more complex than a simple scalar value should be specified in the ICD.

3.4.15.7 Any other corrections applied to the data should be agreed by the service provider and the customer Agencies and specified in an ICD.

3.4.16 All data type keywords in the TDM Data Section must be from 3.5, which specifies for each keyword:

– the keyword to be used;

– applicable units for the associated values;

– a reference to the text section where the keyword is described in detail.

NOTES

1 The standard tracking data types are extended to cover also some of the ancillary data that may be required for precise orbit determination work. Subsection 3.5 identifies the most frequently used data and ancillary types.

2 See annex D for detailed usage examples.

3 Annex I supplies recommendations of the metadata keywords that should be used to properly describe the tracking data of various types depending on the settings of the MODE and PATH keywords, with allowance for characteristics of the uplink frequency (if applicable).

4 The TDM structure allows a great deal of flexibility in terms of the content of a Data Section. However, as a practical consideration given the challenges of implementing generic TDM readers, early implementers of the TDM have tended to minimize the number of data types represented in any given TDM segment. For example, for a two-way tracking pass with ranging, the TDM originator may provide three segments: one for transmit frequencies, one for received frequencies, and one for range measurements.

3.5 TDM DATA SECTION KEYWORDS

3.5.1 OVERVIEW

This subsection describes each of the keywords that may be used in the Data Section of the TDM Segment. In general, there is no required order in the Data Section of the TDM Segment. Exceptions are the 'DATA_START' and 'DATA_STOP' keywords, which must be the first and last keywords in the Data Section, respectively. For ease of reference, table 3-5 containing all the keywords sorted in alphabetical order is shown immediately below. Table 3-6 repeats the information from table 3-5 in category order. Descriptive information about the keywords is shown starting in 3.5.2. The remainder of this subsection is organized according to the class of data to which the keyword applies (e.g., all the signal related keywords are together, all media related keywords are together, etc.).

Table 3-5: Summary Table of TDM Data Section Keywords (Alpha Order)

Keyword	Units	Text Link
ANGLE 1	deg	3.5.4.2
ANGLE 2	deg	3.5.4.3
CARRIER POWER	dBW	3.5.2.1
CLOCK BIAS	s	3.5.6.1
CLOCK DRIFT	s/s	3.5.6.2
COMMENT	n/a	3.5.9.1
DATA START	n/a	3.5.9.2
DATA STOP	n/a	3.5.9.3
DOPPLER COUNT	n/a	3.5.2.4
DOPPLER INSTANTANEOUS	km/s	3.5.2.2
DOPPLER INTEGRATED	km/s	3.5.2.3
DOR	s	3.5.3.2
MAG	n/a	3.5.5.1
PC N0	dBHz	3.5.2.4
PR N0	dBHz	3.5.2.6
PRESSURE	hPa	3.5.8.1
RANGE	km, s, or RU	3.5.2.7
RCS	m**2	3.5.5.2
RECEIVE FREQ n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.8
RECEIVE FREQ	Hz	3.5.2.8
RECEIVE PHASE CT n	n/a	3.5.2.11
RHUMIDITY	%	3.5.8.2
STEC	TECU	3.5.7.1
TEMPERATURE	K	3.5.8.3
TRANSMIT FREQ n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.9
TRANSMIT FREQ RATE n (n = 1, 2, 3, 4, 5)	Hz/s	3.5.2.10
TRANSMIT PHASE CT n	n/a	3.5.2.12
TROPO DRY	m	3.5.7.2
TROPO WET	m	3.5.7.3
VLBI DELAY	s	3.5.3.3

Table 3-6: Summary Table of TDM Data Section Keywords (Category Order)

Keyword	Units	Text Link
Signal Related Keywords		3.5.2
CARRIER_POWER	dBW	3.5.2.1
DOPPLER_COUNT	n/a	3.5.2.4
DOPPLER_INSTANTANEOUS	km/s	3.5.2.2
DOPPLER_INTEGRATED	km/s	3.5.2.3
PC_N0	dBHz	3.5.2.4
RECEIVE_PHASE_CT_n	n/a	3.5.2.11
TRANSMIT_PHASE_CT_n	n/a	3.5.2.12
PR_N0	dBHz	3.5.2.6
RANGE	km, s, or RU	3.5.2.7
RECEIVE_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.8
RECEIVE_FREQ	Hz	3.5.2.8
TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.9
TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5)	Hz/s	3.5.2.10
VLBI/Delta-DOR Related Keywords		3.5.3
DOR	s	3.5.3.2
VLBI_DELAY	s	3.5.3.3
Angle Related Keywords		3.5.4
ANGLE_1	deg	3.5.4.2
ANGLE_2	deg	3.5.4.3
Optical/Radar Related Keywords		3.5.5
MAG	n/a	3.5.5.1
RCS	m**2	3.5.5.2
Time Related Keywords		3.5.6
CLOCK_BIAS	s	3.5.6.1
CLOCK_DRIFT	s/s	3.5.6.2
Media Related Keywords		3.5.7
STEC	TECU	3.5.7.1
TROPO_DRY	m	3.5.7.2
TROPO_WET	m	3.5.7.3
Meteorological Related Keywords		3.5.8
PRESSURE	hPa	3.5.8.1
RHUMIDITY	%	3.5.8.2
TEMPERATURE	K	3.5.8.3
Miscellaneous Keywords		3.5.9
COMMENT	n/a	3.5.9.1
DATA_START	n/a	3.5.9.2
DATA_STOP	n/a	3.5.9.3

3.5.2 SIGNAL RELATED KEYWORDS

3.5.2.1 CARRIER_POWER

The CARRIER_POWER keyword conveys the strength of the radio signal transmitted by the spacecraft as received at the ground station or at another spacecraft (e.g., in formation flight). This reports the strength of the signal received from the spacecraft, in decibels (referenced to 1 watt). The unit for the CARRIER_POWER keyword is dBW. The value shall be a double precision value, and may be positive, zero, or negative. The value is based on the last leg of the signal path (PATH keyword), e.g., spacecraft downlink to an antenna. Additional TDM Segments should be used for each participant if it is important to know the carrier power at each participant in a PATH that involves more than one receiver.

3.5.2.2 DOPPLER_INSTANTANEOUS

The value associated with the DOPPLER_INSTANTANEOUS keyword represents the instantaneous range rate of the spacecraft. The observable may be one-way, two-way or three-way. The value shall be a double precision value and may be negative, zero, or positive. Units are km/s. In order to ensure that corrections due to the ionosphere and solar plasma are accurately applied, the transmit frequency and receive frequency should be supplied when this data type is exchanged.

NOTE – The DOPPLER_INSTANTANEOUS assumes a fixed uplink frequency (or one with small RTLT errors), and thus should not be used in cases where there is a deep space ramped uplink (the TRANSMIT_FREQ and RECEIVE_FREQ keywords should be used instead).

3.5.2.3 DOPPLER_INTEGRATED

The value associated with the DOPPLER_INTEGRATED keyword represents the mean range rate of the spacecraft over the INTEGRATION_INTERVAL specified in the Metadata Section. The timetag and the time bounds of the integration interval are determined by the TIMETAG_REF and INTEGRATION_REF keywords. The observable may be one-way, two-way or three-way. For one-way data, the observable is the mean range rate of the spacecraft over the INTEGRATION_INTERVAL. For two-way and three-way data, the ICD should specify whether the observable is the calculated mean range rate, or half the calculated mean range rate (due to the signal's having traveled to the spacecraft and back to the receiver). The value shall be a double precision value and may be negative, zero, or positive. Units are km/s. In order to ensure that corrections due to the ionosphere and solar plasma are accurately applied, the transmit frequency and receive frequency should be supplied when this data type is exchanged.

NOTE – The DOPPLER_INTEGRATED assumes a fixed uplink frequency (or one with small RTLT errors), and thus should not be used in cases where there is a deep space ramped uplink (the TRANSMIT_FREQ and RECEIVE_FREQ keywords should be used instead).

3.5.2.4 DOPPLER_COUNT

The value associated with the DOPPLER_COUNT keyword represents a count of the number of times the phase of a received signal slips one cycle with respect to a transmitted signal (or reference signal). The value shall be an integer and may be negative, zero, or positive. Units are not applicable. Note that it may be necessary to process this data type in conjunction with an Orbit Ephemeris Message (OEM, reference [4]) in order to understand the velocity of the spacecraft transmitter.

3.5.2.5 PC_N0

The value associated with the PC_N0 keyword shall be the carrier power to noise spectral density ratio (Pc/No). The units for PC_N0 shall be dBHz. The value shall be a double precision value.

3.5.2.6 PR_N0

The value associated with the PR_N0 keyword shall be the ranging power to noise spectral density ratio (Pr/No). The units for PR_N0 shall be dBHz. It shall be a double precision value, and may be positive, zero, or negative.

3.5.2.7 RANGE

The value associated with the RANGE keyword is the range observable. The values represent measurements from ambiguous ranging systems, differenced range, skin radar, proximity radar, or similar radar. The units for RANGE shall be as determined by the ‘RANGE_UNITS’ metadata keyword (i.e., either ‘km’, ‘s’, or ‘RU’). The ‘RANGE_UNITS’ metadata keyword should always be specified, but if it is not, the default (preferred) value shall be ‘km’. If different range units are used by the tracking agency (e.g., ‘DSN range units’), the definition of the range unit should be described in the ICD. Note that for many applications, proper processing of the RANGE will require a time history of the uplink frequencies. If ambiguous range is provided (i.e., the RANGE_MODULUS is non-zero), then the RANGE does not represent the actual range to the spacecraft; a calculation using the RANGE_MODULUS and the RANGE observable must be performed. For two-way and three-way data, the ICD should specify whether the observable is based upon the round trip light time, or half the round trip light time (due to the signal’s having traveled to the spacecraft and back to the receiver). If differenced range is provided (MODE = SINGLE_DIFF), the ‘RANGE’ keyword shall be used to convey the difference in range.

The value shall be a double precision value, and is generally positive (exceptions to this could occur if the data is a differenced type, or if the observable is a one-way pseudorange).

NOTE – The TDM specifically excludes Satellite Laser Ranging (SLR), which is already transferred via an internationally standardized format documented at http://ilrs.gsfc.nasa.gov/.

3.5.2.8 RECEIVE_FREQ (and RECEIVE_FREQ_n)

3.5.2.8.1 The RECEIVE_FREQ keyword shall be used to indicate that the values represent measurements of the received frequency. It is suitable for use with deep space ramped uplink if the TRANSMIT_FREQ is also exchanged. The keyword is indexed to accommodate a scenario in which multiple downlinks are used; it may also be used without an index where the frequency cannot be associated with a particular participant (e.g., in the case of a differenced Doppler shift measurement). The value associated with the RECEIVE_FREQ keyword shall be the average frequency observable over the INTEGRATION_INTERVAL specified in the metadata, at the measurement timetag. The interpretation of the timetag shall be determined by the combined settings of the TIMETAG_REF, INTEGRATION_REF, and INTEGRATION_INTERVAL keywords (see table 3-3 for a description of how the settings of these values affect the interpretation of the timetag). Correlation between the RECEIVE_FREQ and the associated TRANSMIT_FREQ may be determined via the use of an a priori estimate and should be resolved via the orbit determination process. The units for RECEIVE_FREQ shall be Hertz (Hz). The value shall be a double precision value (generally positive, but could be negative or zero if used with the ‘FREQ_OFFSET’ metadata keyword).

3.5.2.8.2 Using the RECEIVE_FREQ, the instantaneous Doppler measurement in Hz is calculated as follows:

$$D_m = ((F_t * tr) - F_r)$$

where ‘D_m’ is the Doppler measurement, ‘F_t’ is the transmitted frequency, ‘tr’ is the transponder ratio (tr=1 for one-way), and ‘F_r’ is the RECEIVE_FREQ.

For integrated Doppler, the Doppler measurement in Hz is calculated as follows, where t is the timetag, and Δt is the value assigned to the INTEGRATION_INTERVAL keyword:

$$D_m = \frac{1}{\Delta t} \int_{t+(\frac{-1}{2}+\alpha)\Delta t}^{t+(\frac{1}{2}+\alpha)\Delta t} ((F_t * tr) - F_r)\,dt$$

The limits of integration are determined by the INTEGRATION_REF keyword in the metadata; the constant α in the equation has the value -½, 0, or ½ for the INTEGRATION_REF values of ‘END’, ‘MIDDLE’, or ‘START’, respectively (see reference [E4]).

INTEGRATION_REF	END	MIDDLE	START
α	$\alpha = -\frac{1}{2}$	$\alpha = 0$	$\alpha = \frac{1}{2}$
Upper Limit	t	$t + \frac{1}{2}\Delta t$	$t + \Delta t$
Lower Limit	$t - \Delta t$	$t - \frac{1}{2}\Delta t$	t

3.5.2.8.3 If differenced Doppler is provided, the non-indexed 'RECEIVE_FREQ' keyword shall be used to convey the difference in Hz.

3.5.2.8.4 The transponder ratios used for interagency exchanges should be specified in the ICD if they are always constant. They may also be specified in the metadata by using the TURNAROUND_NUMERATOR and TURNAROUND_DENOMINATOR keywords.

3.5.2.8.5 The equation for four-way Doppler, if it is to be exchanged, should be in the ICD since the four-way connections tend to be implementation dependent.

3.5.2.9 TRANSMIT_FREQ_n

The TRANSMIT_FREQ keyword shall be used to indicate that the values represent measurements of a transmitted frequency, e.g., from an uplink operation. The TRANSMIT_FREQ keyword is indexed to accommodate scenarios in which multiple transmitters are used. The value associated with the TRANSMIT_FREQ_n keyword shall be the starting frequency observable at the timetag. The units for TRANSMIT_FREQ_n shall be Hertz (Hz). The value shall be a positive double precision value. The turnaround ratios necessary to calculate the predicted receive frequency may be specified using the TURNAROUND_NUMERATOR and TURNAROUND_DENOMINATOR metadata keywords, or may be specified in the ICD. In the case of software defined radios, the metadata keywords may be preferable as the ratios can change with some regularity and it is necessary to get the applicable ratio with the tracking data. Usage notes: when the data mode is one-way (i.e., MODE=SEQUENTIAL, PATH=1,2 or PATH=2,1), the signal is at the beacon frequency transmitted from the spacecraft. If a given spacecraft has more than one transponder, then there should be unique names specified in the ICD for each transponder (e.g., Cassini_S, Cassini_X, Cassini_Ka). If a TDM is constructed with only transmit frequencies, then the MODE is 'SEQUENTIAL' and the PATH keyword defines the signal path. Generally the timetag for the TRANSMIT_FREQ_n keywords should be the time that the signal was transmitted. For quasar DOR, the TRANSMIT_FREQ_n is the interferometer reference frequency at the receive time (thus TIMETAG_REF=RECEIVE for this case). If the transmit frequency varies in the TDM segment, then the TRANSMIT_FREQ_RATE_n keyword should be used to convey the frequency rate between transmit frequencies (see next section); otherwise, the frequency rate is assumed to be zero and a step function results.

3.5.2.10 TRANSMIT_FREQ_RATE_n

The value associated with the TRANSMIT_FREQ_RATE_n keyword is the linear rate of change of the frequency starting at the timetag and continuing until the next TRANSMIT_FREQ_RATE timetag (or until the end of the data). The units for TRANSMIT_FREQ_RATE_n shall be Hertz-per-second (Hz/s). The value shall be a double precision value, and may be negative, zero, or positive. If the TRANSMIT_FREQ_RATE_n is not specified, it is assumed to be zero (i.e., constant frequency).

3.5.2.11 RECEIVE_PHASE_CT_n

The value associated with the RECEIVE_PHASE_CT keyword is the number of phase cycles at the receiver. There are no applicable units for the RECEIVE_PHASE_CT. The value shall be a string representing a real number that can be any number of digits required to convey the necessary precision.

3.5.2.12 TRANSMIT_PHASE_CT_n

The value associated with the TRANSMIT_PHASE_CT keyword is the number of phase cycles at the transmitter. There are no applicable units for the TRANSMIT_PHASE_CT. The value shall be a string representing a real number that can be any number of digits required to convey the necessary precision.

3.5.3 VLBI AND DELTA-DOR RELATED KEYWORDS

3.5.3.1 Overview

In VLBI, a signal source is measured simultaneously using two receivers in different antenna complexes, achieving a long baseline (up to thousands of kilometers). The signals recorded at the two complexes are correlated and differenced to produce the observable, which may be further processed by navigation software. 'Delta-DOR' sessions are a VLBI application in which the antenna slews from a spacecraft source to a quasar source and back to the spacecraft during the tracking pass. This sequence may occur multiple times. There are two data keywords that relate to VLBI and Delta-DOR measurements, and several metadata keyword settings are applicable (MODE=SINGLE_DIFF, PATH_1 and PATH_2).

3.5.3.2 DOR

The observable associated with the DOR keyword represents the range measured via PATH_2 minus the range measured via PATH_1. The timetag is the time of signal reception via PATH_1. This data type is normally used for the spacecraft observable in a Delta-DOR measurement. The range is either one-way, two-way, or three-way, depending on the values of the PARTICIPANT_n and PATH keywords. TRANSMIT_FREQ_n shall provide the spacecraft beacon frequency if one-way, or the transmit frequency at the uplink station if two-way or three-way, at the signal transmission time. The DOR measurement shall be a double precision value. Units shall be seconds.

3.5.3.3 VLBI_DELAY

The observable associated with the VLBI_DELAY keyword represents the time of signal arrival via PATH_2 minus the time of signal arrival via PATH_1. The timetag is the time of signal reception via PATH_1. This data type is normally used for the quasar observable in a Delta-DOR measurement. TRANSMIT_FREQ_n shall provide the interferometer reference frequency. The VLBI_DELAY measurement shall be a double precision value. Units shall be seconds.

3.5.4 ANGLE DATA KEYWORDS

3.5.4.1 General

Angle data is measured at the ground antenna, using downlink data only, regardless of the mode of the tracking session. There shall be two angle keywords: ANGLE_1 and ANGLE_2. The ANGLE_TYPE metadata keyword indicates how these two keywords should be interpreted. Some TDM users may require that the ANGLE_1 keyword is followed immediately by the corresponding ANGLE_2 keyword; however, this sort is not a general TDM requirement. Special sorting requirements should be specified in the ICD.

3.5.4.2 ANGLE_1

The value assigned to the ANGLE_1 keyword represents the azimuth, right ascension, or ‘X’ angle of the measurement, depending on the value of the ANGLE_TYPE keyword. The angle measurement shall be a double precision value as follows: -180.0 <= ANGLE_1 < 360.0. Units shall be degrees.

3.5.4.3 ANGLE_2

The value assigned to the ANGLE_2 keyword represents the elevation, declination, or ‘Y’ angle of the measurement, depending on the value of the ANGLE_TYPE keyword. The angle measurement shall be a double precision value as follows: -180.0 <= ANGLE_2 < 360.0. Units shall be degrees.

3.5.5 OPTICAL/RADAR RELATED KEYWORDS

3.5.5.1 MAG

The value assigned to the MAG keyword shall represent either the apparent or absolute magnitude of an object when observed with an optical telescope. The value associated with the MAG_TYPE keyword shall determine whether or not the data is the apparent magnitude or the absolute magnitude. Units are not applicable. The MAG measurement shall be a double precision value, and may be positive or negative.

3.5.5.2 RCS

The value assigned to the RCS keyword shall represent the radar cross section of an object being tracked with a radar. The RCS shall be computed from radar measurements to provide an indication of the detected object size, orientation, and surface properties. It is the measure of a target's ability to reflect radar signals in the direction of the radar receiver. A larger RCS indicates that an object will be more easily detected. The RCS measurement shall be a positive double precision value. Units shall be square meters (m**2).

3.5.6 TIME RELATED KEYWORDS

3.5.6.1 CLOCK_BIAS

In general, the timetags provided for the tracking data should be corrected, but when that is not possible (e.g., for three-way data or differenced data types), then this data type may be used. The CLOCK_BIAS keyword can be used by the message recipient to adjust timetag measurements by a specified amount with respect to a common reference. For example, the CLOCK_BIAS keyword may be used to show the difference between UTC and a station clock by setting PARTICIPANT_1 to the name of the station clock and PARTICIPANT_2 to 'UTC'. The observable should be calculated as clock#2 minus clock#1 (i.e., UTC – ST, where ST is the station time), consistent with the TDM convention for differenced data. This parameter may also be used to express the difference between two station clocks, for example, for differenced data including Delta-DOR. If used for Delta-DOR, only a single CLOCK_BIAS should be provided per daily VLBI session, with a time-tag strictly before the first data point (e.g., one minute prior), and with the understanding that the clock will continue to drift throughout the session. An exception could be made for the (rare) case where a station clock is re-set in the middle of a VLBI session, in which case a second CLOCK_BIAS measurement may be provided. The clock bias is stated in the data, but the timetags in the message have not been corrected by applying the bias; application of the bias is up to the user of the data. Normally the time related data such as CLOCK_BIAS data and CLOCK_DRIFT data should appear in a dedicated TDM Segment, i.e., not mixed with signal data or other data types. The units for CLOCK_BIAS shall be seconds. The value shall be a double precision value, and may be positive, zero, or negative. The default value shall be 0.0.

3.5.6.2 CLOCK_DRIFT

In general, ground-based clocks in tracking stations are sufficiently stable that a measurement of the clock drift may not be necessary. However, for spacecraft-to-spacecraft exchanges, there may be onboard clock drifts that are sufficiently significant that they should be accounted for in the measurements and calculations. Drift in clocks may also be an important factor when differenced data is being exchanged. The CLOCK_DRIFT keyword should be used to adjust timetag measurements by an amount that is a function of time with respect to a common reference, normally UTC (as opposed to the CLOCK_BIAS, which is meant to be a constant adjustment). Thus CLOCK_DRIFT could be used to calculate an interpolated CLOCK_BIAS between two timetags, by multiplying the CLOCK_DRIFT measurement at the timetag by the number of seconds desired and adding it to the CLOCK_BIAS. The drift should be calculated as a drift of clock#2 with respect to clock#1, consistent with the TDM convention for differenced data. Normally the time related data such as CLOCK_DRIFT data and CLOCK_BIAS data should appear in a dedicated TDM Segment, i.e., not mixed with signal data or other data types. The units for CLOCK_DRIFT shall be seconds-per-second (s/s). The value shall be a double precision value, and may be positive, zero, or negative. The default value shall be 0.0.

3.5.7 MEDIA RELATED KEYWORDS

3.5.7.1 STEC

The STEC keyword (Slant Total Electron Count) shall be used to convey the line of sight, one way charged particle delay or total electron count (TEC) at the timetag associated with a tracking measurement, which is calculated by integrating the electron density along the propagation path (electrons/m^2). The charged particles could have several sources, e.g., solar plasma, Earth ionosphere, or the Io plasma torus. The units for the STEC keyword are Total Electron Count Units (TECU), where 1 TECU = 10^{16} electrons/m^2 = 1.661 x 10^{-8} mol/m^2 (SI Units). The value shall be a positive double precision value (the TEC along the satellite line of sight may vary between 1 and 400 TECU; larger values may be observed during periods of high solar activity). This keyword should appear in its own TDM Segment with PARTICIPANTs being one spacecraft and one antenna, and a MODE setting of ‘SEQUENTIAL’. Exchange partners who wish to distinguish between ionospheric and interplanetary STEC should indicate so in the ICD, and the data must be provided in separate TDM Segments.

3.5.7.2 TROPO_DRY

The value associated with the TROPO_DRY keyword shall be the dry zenith delay through the troposphere measured at the timetag. There should be agreed upon elevation mappings for the dry component specified in the ICD (e.g., the Niell mapping function developed for VLBI applications). Tropospheric corrections should be applied by the recipient of the TDM; the required correction is the value associated with this keyword at the timetag. Recommended polynomial interpolations (if applicable) should be specified in the ICD. The units for TROPO_DRY shall be meters (m). The value shall be a non-negative double precision value (0.0 <= TROPO_DRY).

3.5.7.3 TROPO_WET

The value associated with the TROPO_WET keyword shall be the wet zenith delay through the troposphere measured at the timetag. There should be agreed upon elevation mappings for the wet component specified in the ICD (e.g., the Niell mapping function developed for VLBI applications). Tropospheric corrections should be applied by the recipient of the TDM; the required correction is the value associated with this keyword at the timetag. Recommended polynomial interpolations (if applicable) should be specified in the ICD. The units for TROPO_WET shall be meters (m). The value shall be a non-negative double precision value (0.0 <= TROPO_WET).

3.5.8 METEOROLOGICAL RELATED KEYWORDS

3.5.8.1 PRESSURE

The value associated with the PRESSURE keyword shall be the atmospheric pressure observable as measured at the tracking participant, specified in hectopascal (1 hectopascal (hPa) = 1 millibar). The PRESSURE shall be a double precision value; practically speaking it is always positive.

3.5.8.2 RHUMIDITY

The value associated with the RHUMIDITY keyword shall be the relative humidity observable as measured at the tracking participant, specified in percent. RHUMIDITY shall be a double precision type value, 0.0 <= RHUMIDITY <= 100.0.

3.5.8.3 TEMPERATURE

The value associated with the TEMPERATURE keyword shall be the temperature observable as measured at the tracking participant, specified in Kelvin (K). The TEMPERATURE shall be a positive double precision type value.

3.5.9 MISCELLANEOUS KEYWORDS

3.5.9.1 COMMENT

The COMMENT keyword is not required. See 4.5 for full details on usage of the COMMENT keyword.

3.5.9.2 DATA_START

The 'DATA_START' keyword must be the first keyword in the Data Section of the TDM Segment, which serves to delimit the Data Section. The keyword shall appear on a line by itself with no timetags or values. Example: 'DATA_START'.

3.5.9.3 DATA_STOP

The 'DATA_STOP' keyword must be the last keyword in the Data Section of the TDM Segment, which serves to delimit the Data Section. The keyword shall appear on a line by itself with no timetags or values. Example: 'DATA_STOP'.

4 TRACKING DATA MESSAGE SYNTAX

4.1 GENERAL

The TDM shall observe the syntax described in 4.2 through 4.5.

4.2 TDM LINES

4.2.1 The TDM shall consist of a set of TDM lines. The TDM line must contain only printable ASCII characters and blanks. ASCII control characters (such as TAB, etc.) must not be used, except as indicated below for the termination of the TDM line. A TDM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

4.2.2 Each TDM line shall be one of the following:

– Header line;

– Metadata Section line;

– Data Section line;

– blank line.

4.2.3 All Header, Metadata Section, and Data Section lines, with exceptions as noted below, shall use ‘keyword = value’ syntax, abbreviated as KVN.

4.2.4 Only a single ‘keyword = value’ assignment shall be made on a TDM line.

4.2.5 The following distinctions in KVN syntax shall apply for TDM lines:

– TDM lines in the Header and Metadata Section shall consist of a keyword, followed by an equals sign ‘=’, followed by a single value assignment. Before and after the equals sign, blank characters (white space) may be added, but shall not be required.

– TDM lines in the Data Section shall consist of a keyword, followed by an equals sign ‘=’, followed by a value that consists of two primary elements (essentially an ordered pair): a timetag and the measurement or calculation associated with that timetag (either without the other is unusable for tracking purposes). Before and after the equals sign, blank characters (white space) may be added. The timetag and measurement/calculation in the value must be separated by at least one blank character (white space).

– The keywords COMMENT, META_START, META_STOP, DATA_START, and DATA_STOP are exceptions to the KVN syntax.

4.2.6 Keywords must be uppercase and must not contain blanks.

4.2.7 Any white space immediately preceding or following the keyword shall not be significant.

4.2.8 Any white space immediately preceding or following the equals sign '=' shall not be significant.

4.2.9 Any white space immediately preceding the end of line shall not be significant.

4.2.10 Blank lines may be used at any position within the TDM.

4.2.11 TDM lines shall be terminated by a single Carriage Return or a single Line Feed or a Carriage Return/Line Feed pair or a Line Feed/Carriage Return pair.

4.3 TDM VALUES

4.3.1 A non-empty value field must be specified for each keyword provided.

4.3.2 Integer values shall consist of a sequence of decimal digits with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading zeros may be used. The range of values that may be expressed as an integer is:

$$-2\,147\,483\,648 <= x <= +2\,147\,483\,647 \text{ (i.e., } -2^{31} <= x <= 2^{31}-1\text{)}.$$

4.3.3 Non-integer numeric values may be expressed in either fixed-point or floating-point notation. Both representations may be used within a TDM.

4.3.4 Non-integer numeric values expressed in fixed-point notation shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading and trailing zeros may be used. At least one digit shall be used before and after a decimal point. The number of digits shall be 16 or fewer.

4.3.5 Non-integer numeric values expressed in floating-point notation shall consist of a sign, a mantissa, an alphabetic character indicating the division between the mantissa and exponent, and an exponent, constructed according to the following rules:

– The sign may be '+' or '-'. If the sign is omitted, '+' shall be assumed.

– The mantissa must be a string of no more than 16 decimal digits with a decimal point '.' in the second position of the ASCII string, separating the integer portion of the mantissa from the fractional part of the mantissa.

– The character used to denote exponentiation shall be 'E' or 'e'. If the character indicating the exponent and the following exponent are omitted, an exponent value of zero shall be assumed (essentially yielding a fixed-point value).

– The exponent must be an integer, and may have either a '+' or '-' sign (if the sign is omitted, then '+' is assumed).

– The maximum positive floating-point value is approximately 1.798E+308, with 16 significant decimal digits precision. The minimum positive floating-point value is approximately 4.94E-324, with 16 significant decimal digits precision.

NOTE – These specifications for integer, fixed-point, and floating-point values conform to the XML specifications for the data types four-byte integer 'xsd:int', 'decimal', and 'double', respectively (see reference [6]). The specifications for floating-point values conform to the IEEE 754 double precision type (see reference [7]). Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies because of their implementation specific attributes. The special values 'NaN', '-Inf', '+Inf', and '-0' are not supported in the TDM.

4.3.6 Blanks shall not be permitted within numeric values and time values.

4.3.7 Text value fields may be constructed using mixed case; case shall not be significant. All upper case text values are preferred.

4.3.8 In value fields that are text, an underscore shall be equivalent to a single blank. Individual blanks between non-blank characters shall be retained (shall be significant) but multiple blanks shall be equivalent to a single blank.

4.3.9 In value fields that represent a timetag or epoch, one of the following two formats shall be used:

YYYY-MM-DDThh:mm:ss[.d→d][Z]

or

YYYY-DDDThh:mm:ss[.d→d][Z]

where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the time in hours, minutes seconds, and optional fractional seconds; 'Z' is an optional time code terminator (the only permitted value is 'Z' for Zulu, i.e., UTC). All fields shall have leading zeros. See reference [3], ASCII Time Code A and B.

4.3.10 There are four types of TDM values that represent a timetag or epoch, as shown in the applicable tables. The time system for the CREATION_DATE, START_TIME, and STOP_TIME shall be UTC. The time system for the timetags in the TDM Data Section shall be determined by the TIME_SYSTEM metadata keyword.

4.4 UNITS IN THE TDM

Units are not explicitly displayed in the TDM. The units associated with values in the TDM are as specified in table 3-5.

4.5 COMMENTS IN A TDM

4.5.1 Comments may be used to provide any pertinent information associated with the data that is not covered via one of the keywords. This additional information is intended to aid in consistency checks and elaboration where needed. Comments shall not be required for successful processing of a TDM; i.e., comment lines shall be optional.

NOTE – Given that TDMs may consist of large amounts of data, and are generally produced via automation, using the COMMENT feature of the TDM may have limited usefulness. On the other hand, a simple utility could be developed to search for and extract all the comments in a TDM to make them easily reviewable. Existing built-in utilities (e.g., UNIX ‘grep’) or ‘freeware’ utilities could also be used for this purpose.

4.5.2 Comment lines, if used, shall only occur:

– at the beginning of the TDM Header (i.e., between the CCSDS_TDM_VERS keyword and the CREATION_DATE keyword, as shown in table 3-2);

– at the beginning of the TDM Metadata Section (i.e., between the META_START keyword and the DATA_TYPES keyword, as shown in table 3-3);

– at the beginning of the TDM Data Section (i.e., between the ‘DATA_START’ keyword and the first Tracking Data Record).

4.5.3 All comment lines shall begin with the ‘COMMENT’ keyword followed by at least one space (note: may also be preceded by spaces). The ‘COMMENT’ keyword must appear on every comment line, not just the first comment line. After the keyword, the remainder of the line shall be the comment value. White space shall be retained (is significant) in comment values.

4.5.4 Conventions for particular comments in the TDM that may be required between any two participating agencies should be specified in the ICD.

4.5.5 Descriptions of any ancillary data that cannot be accommodated via keywords in the TDM may have to be specified via comments, and should be outlined in the ICD.

5 TDM CONTENT/STRUCTURE IN XML

5.1 DISCUSSION—THE TDM/XML SCHEMA

The TDM/XML schema is available on the SANA Web site. SANA is the registrar for the protocol registries created under CCSDS.

The TDM XML schema explicitly defines the permitted data elements and values acceptable for the XML version of the TDM message.

The location of the TDM/XML schema is:

http://sanaregistry.org/r/ndmxml/ndmxml-1.0-tdm-2.0.xsd

Where possible this schema uses simple types and complex types used by the constituent schemas that make up NDMs (see reference [10]).

An Extensible Stylesheet Language Transformations (XSLT) converter is available on the SANA Web site to transform an XML TDM to a KVN TDM if desired by the TDM recipient. The location of the TDM/XML XSLT converter is http://sanaregistry.org/r/ndmxml/ndmxml-1.0-tdm-1.0.xsl.

5.2 TDM/XML BASIC STRUCTURE

1.1.1 Each TDM shall consist of a <header> and a <body>.

1.1.2 The TDM <body> shall consist of one or more <segment> constructs.

1.1.3 Each <segment> shall consist of a <metadata>/<data> pair, as shown in figure 5-1.

```
<header>
</header>
<body>
  &lt;segment&gt;
    <metadata>
    </metadata>
    <data>
    </data>
  &lt;/segment&gt;
  &lt;segment&gt;
    <metadata>
    </metadata>
    <data>
    </data>
  &lt;/segment&gt;
</body>
```

Figure 5-1: TDM XML Basic Structure

1.1.4 XML tags shall be uppercase and correspond with the KVN keywords in Section 3 of this document (uppercase with '_' [the underscore character] as separators). The XML logical tags related to message structure shall be in lowerCamelCase.

5.3 CONSTRUCTING A TDM/XML INSTANCE

5.3.1 OVERVIEW

This subsection provides more detailed instructions for the user on how to create an XML message based on the ASCII-text KVN-formatted message described in section 3.

5.3.2 XML VERSION

The first line in the instantiation shall specify the XML version:

```
<?xml version="1.0" encoding="UTF-8"?>
```

This line must appear on the first line of each instantiation, exactly as shown.

5.3.3 BEGINNING THE INSTANTIATION: ROOT DATA ELEMENT

1.1.4.1 A TDM instantiation shall be delimited with the <tdm></tdm> root element tags using the standard attributes documented in reference [11].

1.1.4.2 The XML Schema Instance namespace attribute must appear in the root element tag of all TDM/XML instantiations, exactly as shown:

xmlns:xsi = "http://www.w3.org/2001/XMLSchema-instance"

1.1.4.3 If it is desired to validate an instantiation against the CCSDS Web-based schema, the xsi:noNamespaceSchemaLocation attribute must be coded as a single string of non-blank characters, with no line breaks, exactly as shown:

xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"

NOTE – The length of the value associated with the xsi:noNamespaceSchemaLocation attribute can cause the string to wrap to a new line; however, the string itself contains no breaks.

1.1.4.4 For use in a local operations environment, the schema set may be downloaded from the SANA Web site to a local server that meets local requirements for operations robustness.

1.1.4.5 If a local version is used, the value associated with the xsi:noNamespaceSchemaLocation attribute must be changed to a URL that is accessible to the local server.

1.1.4.6 The final attributes of the <tdm> tag shall be 'id' and 'version'.

1.1.4.7 The ‘id’ attribute shall be ‘id="CCSDS_TDM_VERS"’.

1.1.4.8 The ‘version’ attribute shall be ‘version="2.0"’.

NOTE – The following example root element tag for a TDM instantiation combines all the directions in the preceding several subsections:

```
<?xml   version="1.0" encoding="UTF-8"?>
<tdm    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
        id="CCSDS_TDM_VERS" version="2.0">
```

1.1.5 THE TDM/XML HEADER SECTION

1.1.5.1 The TDM header shall have a standard header format, with tags <header> and </header>.

1.1.5.2 Immediately following the <header> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

1.1.5.3 The standard TDM header shall contain the following element tags:

a) <CREATION_DATE>;

b) <ORIGINATOR>.

NOTE – The rules for these keywords are specified in 3.2. The header would look like this:

```
<header>
   <COMMENT>Some comment string, which is not required.</COMMENT>
   <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
   <ORIGINATOR>NASA</ORIGINATOR>
</header>
```

1.1.6 THE TDM/XML BODY SECTION

1.1.6.1 After coding the <header>, the instantiation must include a `<body></body>` tag pair.

1.1.1.1 The TDM `<body>` shall consist of one or more <segment> constructs (see Figure 5-1).

1.1.1.2 Each <segment> shall consist of a `<metadata>` section and a `<data>` section.

1.1.1.3 The keywords in the `<metadata>` and `<data>` sections shall be those specified in 3.3 and 3.5 respectively.

1.1.1.4 Tags for TDM keywords shall be all uppercase.

1.1.2 TDM/XML keywords that do not correspond directly to a KVN keyword shall be in 'lowerCamelCase'.

1.1.7 THE TDM/XML METADATA SECTION

1.1.7.1 Immediately following the <metadata> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

1.1.7.2 Between the <metadata> and </metadata> tags, the keywords shall be those specified in Table 3-3.

1.1.8 THE TDM/XML DATA SECTION

1.1.8.1 Each data section shall follow the corresponding metadata section and shall be set off by the <data></data> tag combination.

1.1.8.2 Immediately following the <data> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

1.1.8.3 Between the <data> and </data> tags, the keywords shall be those specified in Table 3-5.

1.1.9 SPECIAL TDM/XML TAGS

NOTE – In addition to the TDM keywords specified in section 3, there is a special tag associated with the TDM body as described in the next subsection.

1.1.2.1 The `<observation>` tag shall be used to encapsulate the keywords associated with one of the tracking data types in the TDM.

1.1.2.2 The `<observation>` tag shall consist of two subcomponents:

a) the time tag (`<EPOCH>` tag); and

b) one specific data type (e.g., `<RECEIVE_FREQ>`).

NOTE – Thus a received frequency observation would appear in an NDM/XML TDM as follows:

```
<observation>
   <EPOCH>2008-200T12:34:56.789</EPOCH>
```

```
   <RECEIVE_FREQ>8415000000</RECEIVE_FREQ>
</observation>
```


1.1.10 UNITS IN THE TDM/XML

The units in the TDM/XML shall be the same units used in the KVN-formatted TDM described in section 3.

1.2 DISCUSSION—TDM/XML EXAMPLE

See Example D-18 for a sample of a TDM in XML format.

ANNEX A

VALUES FOR TIME_SYSTEM AND REFERENCE_FRAME

(NORMATIVE)

The values in this annex represent the set of acceptable values for the TIME_SYSTEM and REFERENCE_FRAME keywords. For details and description of these time systems, see reference [1]. If exchange partners wish to use different settings, they should be documented in the ICD.

A1 TIME_SYSTEM METADATA KEYWORD

Time System Value	Meaning
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System
SCLK	Spacecraft Clock (receiver)
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time
TT	Terrestrial Time
UT1	Universal Time
UTC	Coordinated Universal Time

A2 REFERENCE_FRAME KEYWORD

Reference Frame Value	Meaning
EME2000	Earth Mean Equator and Equinox of J2000
ICRF	International Celestial Reference Frame
ITRFnnnn	International Terrestrial Reference Frame, "nnnn" >= 2000
ITRF-nn	International Terrestrial Reference Frame 19nn
TOD	True of Date

ANNEX B

IMPLEMENTATION CONFORMANCE STATEMENT (ICS)

(NORMATIVE)

NOTE: In the 'Status' column, M = 'mandatory' and O = 'optional'.

A1 INTRODUCTION

A1.1 OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of *Tracking Data Message* (CCSDS 503.0). The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation shall satisfy the mandatory conformance requirements referenced in the RL.

The RL in this annex is blank. An implementation's completed RL is called the ICS. The ICS states which capabilities and options have been implemented. The following can use the ICS:

– the implementer, as a checklist to reduce the risk of failure to conform to the standard through oversight;

– a supplier or potential acquirer of the implementation, as a detailed indication of the capabilities of the implementation, stated relative to the common basis for understanding provided by the standard ICS proforma;

– a user or potential user of the implementation, as a basis for initially checking the possibility of interworking with another implementation (it should be noted that, while interworking can never be guaranteed, failure to interwork can often be predicted from incompatible ICSes);

– a tester, as the basis for selecting appropriate tests against which to assess the claim for conformance of the implementation.

A1.2 ABBREVIATIONS AND CONVENTIONS

The RL consists of information in tabular form. The status of features is indicated using the abbreviations and conventions described below.

<u>Item Column</u>

The item column contains sequential numbers for items in the table.

Feature Column

The feature column contains a brief descriptive name for a feature. It implicitly means 'Is this feature supported by the implementation?'

NOTE – The features itemized in the RL are elements of a TDM. Therefore support for a mandatory feature indicates that generated messages will include that feature, and support for an optional feature indicates that generated messages can include that feature.

Keyword Column

The keyword column contains, where applicable, the TDM keyword associated with the feature.

Reference Column

The reference column indicates the relevant subsection or table in *Tracking Data Message* (CCSDS 503.0) (this document).

Status Column

The status column uses the following notations:

M mandatory.

O optional.

Support Column Symbols

The support column is to be used by the implementer to state whether a feature is supported by entering Y, N, or N/A, indicating:

Y Yes, supported by the implementation.

N No, not supported by the implementation.

N/A Not applicable.

A1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called an ICS. The implementer shall complete the RL by entering appropriate responses in the support or values supported column, using the notation described in **Error! Reference source not found.**. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

A2 ICS PROFORMA FOR TRACKING DATA MESSAGE

A2.1 GENERAL INFORMATION

A2.1.1 Identification of ICS

Date of Statement (DD/MM/YYYY)	
ICS serial number	
System Conformance statement cross-reference	

A2.1.2 Identification of Implementation Under Test (IUT)

Implementation name	
Implementation version	
Special Configuration	
Other Information	

A2.1.3 Identification of Supplier

Supplier	
Contact Point for Queries	
Implementation Name(s) and Versions	
Other information necessary for full identification, e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	

A2.1.4 Document Version

CCSDS 503.0 Document Version	
Have any exceptions been required? (Note: A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming.	Yes _____ No_____

A2.1.5 Requirements List

Seq #	Protocol Feature	Protocol Keyword	Reference (Blue Book)	Status	Support
1	TDM Header	N/A	Table 3-2	M	
2	TDM version	CCSDS_TDM_VERS	Table 3-2	M	
3	Comment	COMMENT	Table 3-2	O	
4	Message creation date/time	CREATION_DATE	Table 3-2	M	
5	Message originator	ORIGINATOR	Table 3-2	M	
6	TDM Metadata	META_START	Table 3-3	M	
7	Comment	COMMENT	Table 3-3	O	
8	Specifies data types in data section	DATA_TYPES	Table 3-3	O	
9	Specifies time system relevant to timetags	TIME_SYSTEM	Table 3-3	M	
10	Start time of data	START_TIME	Table 3-3	O	
11	Stop time of data	STOP_TIME	Table 3-3	O	
12	Participants in the tracking session	PARTICIPANT_n	Table 3-3	M	
13	Mode of the tracking session	MODE	Table 3-3	O	
14	Signal path in the tracking session	PATH PATH1, PATH2	Table 3-3	O	
15	Name of the ephemeris file used, if any.	EPHEMERIS_NAME_n	Table 3-3	O	
16	Frequency band of the transmitted data	TRANSMIT_BAND	Table 3-3	O	
17	Frequency band of the received data	RECEIVE_BAND	Table 3-3	O	
18	Numerator of the turnaround ratio	TURNAROUND_NUMERATOR	Table 3-3	O	
19	Denominator of the turnaround ratio	TURNAROUND_DENOMINATOR	Table 3-3	O	
20	Specifies whether data is transmitted or received	TIMETAG_REF	Table 3-3	O	
21	Data compression rate	INTEGRATION_INTERVAL	Table 3-3	O	
22	Reference point of the timetag	INTEGRATION_REF	Table 3-3	O	
23	Specifies a base frequency to which frequency data is referenced.	FREQ_OFFSET	Table 3-3	O	
24	Specifies the ranging method	RANGE_MODE	Table 3-3	O	
25	Specifies the ranging modulus	RANGE_MODULUS	Table 3-3	O	
26	Specifies the units for ranging data	RANGE_UNITS	Table 3-3	O	
27	Specifies the angle type for angle data	ANGLE_TYPE	Table 3-3	O	
28	Specifies the reference frame for specific angle types	REFERENCE_FRAME	Table 3-3	O	
29	Specifies the magnitude type for optical magnitude data	MAG_TYPE	Table 3-3	O	
30	Specifies the interpolation method recommended for phase count data	INTERPOLATION	Table 3-3	O	

Seq #	Protocol Feature	Protocol Keyword	Reference (Blue Book)	Status	Support
31	Specifies the degree of the interpolating polynomial for phase count data	INTERPOLATION_DEGREE	Table 3-3	O	
32	Specifies a fixed delay time applicable to transmitted data	TRANSMIT_DELAY_n n = {1, 2, 3, 4, 5}	Table 3-3	O	
33	Specifies a fixed delay time applicable to received data	RECEIVE_DELAY_n n = {1, 2, 3, 4, 5}	Table 3-3	O	
34	Indicates the data quality	DATA_QUALITY	Table 3-3	O	
35	Specifies a correction value to be added to each data point	CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 CORRECTION_DOPPLER CORRECTION_MAG CORRECTION_RANGE CORRECTION_RECEIVE CORRECTION_TRANSMIT	Table 3-3	O	
36	Specifies whether corrections have been applied, or have not	CORRECTIONS_APPLIED	Table 3-3	O	
37	End of TDM Metadata	META_STOP	Table 3-3	M	
38	TDM Data	DATA_START	Table 3-5	M	
39	Comment	COMMENT	Table 3-5	O	
40	Angle related data	ANGLE_1 ANGLE_2	Table 3-5	O	
41	Carrier signal related data	CARRIER_POWER PC_N0	Table 3-5	O	
42	Clock related data	CLOCK_BIAS CLOCK_DRIFT	Table 3-5	O	
43	Doppler data	DOPPLER_INSTANTANEOUS DOPPLER_INTEGRATED DOPPLER_COUNT	Table 3-5	O	
44	Media related data	STEC TROPO_DRY TROPO_WET	Table 3-5	O	
45	Meteorological data	PRESSURE RHUMIDITY TEMPERATURE	Table 3-5	O	
46	Optical/radar related data	MAG RCS	Table 3-5	O	
47	Range related data	RANGE PR_N0	Table 3-5	O	
48	Receive related data	RECEIVE_FREQ_n (n = 1, 2, 3, 4, 5) RECEIVE_FREQ RECEIVE_PHASE_CT (n = 1, 2, 3, 4, 5)	Table 3-5	O	

Seq #	Protocol Feature	Protocol Keyword	Reference (Blue Book)	Status	Support
49	Transmit related data	TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5) TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5) TRANSMIT_PHASE_CT (n = 1, 2, 3, 4, 5)	Table 3-5	O	
50	VLBI related data	DOR VLBI_DELAY	Table 3-5	O	
51	End of TDM Data	DATA_STOP	Table 3-4	M	

ANNEX C

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

In several places in this document there are references to items which should be specified in an Interface Control Document (ICD) between agencies participating in an exchange of tracking data, if they are applicable to the particular exchange. The ICD should be jointly produced by both Agencies participating in a cross-support activity involving the collection, analysis, and transfer of tracking data. This section compiles those items into a single location.

The greater the amount of material specified via ICD, the lesser the utility/benefit of the TDM (custom programming may be required to tailor software for each ICD). It is suggested to avoid a large number of items specified via ICD, to ensure full utility/benefit of the TDM.

For example, although turnaround ratios may not change frequently, having a TDM producer include the turnaround keywords TURNAROUND_NUMERATOR and TURNAROUND_DENOMINATOR in the TDM will increase the level of automation possible in an exchange partner's TDM reader.

From an implementation standpoint, it is probable that many of the items that need to be negotiated via ICD will be introduced into the system that processes tracking data via one or more configuration files that specify the settings of specific, related parameters that will be used during the tracking session, for example, the value of the turnaround ratio to be used for the tracking data. This may vary between exchange participants. Different versions of programs could be used to prepare the tracking data where these parameters differ; however, a more efficient design would be to have a single program that is configured based on tracking pass specific information. It seems likely that there may be at least two configuration files necessary, one which contains Agency-specific parameters that do not change between tracking passes, and one which contains spacecraft/mission-specific parameters that could change with every tracking pass.

Another thought on ICDs is that it might be feasible for participating agencies to have a generic baseline ICD (‘standard service provider ICD’) that specifies mission/spacecraft-independent entities on the interface, e.g., those associated with the agency’s ground antennas (axis offsets, station locations, side motions, reference frame, epoch, supported frequency bands, etc.). Then smaller ICDs could be used for the mission/spacecraft-specific arrangements.

The following table lists the items that should be covered in an ICD, along with where they are discussed in the text:

Item	Section
1. Definition of accuracy requirements pertaining to any particular TDM.	1.2.3
2. Method of exchanging TDMs (e.g., post-processed SFTP, real-time stream, etc.).	1.2.4, 3.1.8
3. Whether the KVN or XML format of the TDM will be exchanged.	2.2.3
4. Frequency of exchange, special types of exchange, and conditions under which multiple TDMs will be exchanged (e.g., launch supports with periodic TDMs, critical maneuvers, orbit insertions, etc.).	2.2.6
5. TDM file naming conventions.	3.1.7
6. List of valid values that may be used for 'ORIGINATOR' keyword in the TDM Header (NOTE: may just be the SANA registry).	3.2.3
7. Specific TDM version number(s) that will be exchanged.	3.2.5
8. Antenna geometry, if not accommodated by built-in values of 'ANGLE_TYPE' keyword.	table 3-3
9. The list of eligible names that is used for PARTICIPANT keywords.	table 3-3, 3.3.1.10
10. Definitions of 'RAW', 'VALIDATED', and 'DEGRADED' as they apply to data quality for a particular exchange (DATA_QUALITY keyword).	table 3-3
11. The range of frequencies associated with each value of the 'TRANSMIT_BAND' and 'RECEIVE_BAND' metadata keywords.	table 3-3
12. If more than five participants are necessary, special arrangements are necessary.	3.3.1.11, 3.3.2.4.4
13. When all the data in a TDM Segment is media related or weather related, the observable may be relative to a reference location within the tracking complex; the methods used to extrapolate the measurements to other antennas should be specified in the ICD.	3.3.2.7
14. Complete description of the station locations and characteristics.	3.4.13
15. Whether TRANSMIT_DELAY and RECEIVE_DELAY are processed by the producer or the consumer of the tracking data.	3.4.15.2
16. Special sort orders that may be required by the producer or recipient.	3.4.10, 3.5.4.1
17. Spin correction arrangements (who will do the correction, the agency providing the tracking or the agency that operates the spacecraft).	3.4.15.5
18. Correction algorithms that are more complex than a simple scalar value.	3.4.15.6
19. Standard corrections that will (or will not) be applied to the data (e.g., tropospheric, meteorological, media, transponder, etc.), miscellaneous corrections.	3.4.15.7

Item	Section
20. Definition of the range unit, if it is not kilometers or seconds.	3.5.2.7, table 3-3
21. Equation for calculation of four-way Doppler shift, if applicable.	3.5.2.8.5
22. Transponder turnaround ratios necessary to calculate predicted downlink frequency and the Doppler measurement; also includes cases such as dual uplink where a ‘beacon’ or ‘pilot’ frequency is used (e.g., TDRS, DRTS, COMETS).	3.5.2.8.4, 3.5.2.9, table 3-3
23. Whether or not it is necessary to distinguish the separate Slant Total Electron Count contributions between ionospheric and interplanetary STEC.	3.5.7.1
24. Elevation mapping function for the tropospheric data.	3.5.7.2, 3.5.7.3
25. Recommended polynomial interpolations for tropospheric data.	3.5.7.2, 3.5.7.3
26. If non-standard floating-point numbers in extended-single or extended-double precision are to be used, then discussion of implementation-specific attributes is required.	4.3.5
27. Information which must appear in comments for any given TDM exchange.	4.5.4
28. Description of any ancillary data not already included in the Tracking Data Record definition.	4.5.5
29. Interagency Information Technology (IT) security requirements in TDMs.	**Error! Reference source not found.**
30. Time systems not shown in annex A.	annex A
31. Reference frames not shown in annex A.	annex A
32. Whether the mean range rate for 2W and/or 3W Doppler is based on the one-way light time or two-way light time.	3.5.2.3
33. Whether the RANGE observable for 2W and/or 3W range is based on the round trip light time, or half the round trip light time.	3.5.2.7

ANNEX D

EXAMPLE TRACKING DATA MESSAGES

(INFORMATIVE)

```
CCSDS_TDM_VERS = 2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down
CREATION_DATE = 2005-160T20:15:00Z
ORIGINATOR = NASA

META_START
COMMENT Data quality degraded by antenna pointing problem...
COMMENT Slightly noisy data
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 0
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
DATA_QUALITY = DEGRADED
META_STOP

DATA_START
COMMENT  TRANSMIT_FREQ_2 is spacecraft reference downlink
TRANSMIT_FREQ_2 =  2005-159T17:41:00     32023442781.733
RECEIVE_FREQ_1 =   2005-159T17:41:00     32021034790.7265
RECEIVE_FREQ_1 =   2005-159T17:41:01     32021034828.8432
RECEIVE_FREQ_1 =   2005-159T17:41:02     32021034866.9449
RECEIVE_FREQ_1 =   2005-159T17:41:03     32021034905.0327
RECEIVE_FREQ_1 =   2005-159T17:41:04     32021034943.0946
RECEIVE_FREQ_1 =   2005-159T17:41:05     32021034981.2049
RECEIVE_FREQ_1 =   2005-159T17:41:06     32021035019.2778
RECEIVE_FREQ_1 =   2005-159T17:41:07     32021035057.3773
RECEIVE_FREQ_1 =   2005-159T17:41:08     32021035095.4377
RECEIVE_FREQ_1 =   2005-159T17:41:09     32021035133.5604
RECEIVE_FREQ_1 =   2005-159T17:41:10     32021035171.5861
RECEIVE_FREQ_1 =   2005-159T17:41:11     32021035209.6653
RECEIVE_FREQ_1 =   2005-159T17:41:12     32021035247.7804
RECEIVE_FREQ_1 =   2005-159T17:41:13     32021035285.8715
RECEIVE_FREQ_1 =   2005-159T17:41:14     32021035323.8187
RECEIVE_FREQ_1 =   2005-159T17:41:15     32021035361.9571
RECEIVE_FREQ_1 =   2005-159T17:41:16     32021035400.0304
RECEIVE_FREQ_1 =   2005-159T17:41:17     32021035438.0126
RECEIVE_FREQ_1 =   2005-159T17:41:18     32021035476.1241
RECEIVE_FREQ_1 =   2005-159T17:41:19     32021035514.1714
RECEIVE_FREQ_1 =   2005-159T17:41:20     32021035552.2263
RECEIVE_FREQ_1 =   2005-159T17:41:21     32021035590.2671
RECEIVE_FREQ_1 =   2005-159T17:41:22     32021035628.304
RECEIVE_FREQ_1 =   2005-159T17:41:23     32021035666.3579
RECEIVE_FREQ_1 =   2005-159T17:41:24     32021035704.3745
RECEIVE_FREQ_1 =   2005-159T17:41:25     32021035742.4425
RECEIVE_FREQ_1 =   2005-159T17:41:26     32021035780.4974
RECEIVE_FREQ_1 =   2005-159T17:41:27     32021035818.5158
RECEIVE_FREQ_1 =   2005-159T17:41:28     32021035856.5721
RECEIVE_FREQ_1 =   2005-159T17:41:29     32021035894.5601
DATA_STOP
```

Figure D-1: TDM Example: One-Way Data

```
CCSDS_TDM_VERS = 2.0

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down

CREATION_DATE = 2005-160T20:15:00
ORIGINATOR = NASA

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-159T17:41:00
STOP_TIME = 2005-159T17:41:40
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 32021035200.0
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
DATA_QUALITY = RAW
META_STOP

DATA_START
TRANSMIT_FREQ_2 =  2005-159T17:41:00   32023442781.733
RECEIVE_FREQ_1   =   2005-159T17:41:00   -409.2735
RECEIVE_FREQ_1   =   2005-159T17:41:01   -371.1568
RECEIVE_FREQ_1   =   2005-159T17:41:02   -333.0551
RECEIVE_FREQ_1   =   2005-159T17:41:03   -294.9673
RECEIVE_FREQ_1   =   2005-159T17:41:04   -256.9054
RECEIVE_FREQ_1   =   2005-159T17:41:05   -218.7951
RECEIVE_FREQ_1   =   2005-159T17:41:06   -180.7222
RECEIVE_FREQ_1   =   2005-159T17:41:07   -142.6227
RECEIVE_FREQ_1   =   2005-159T17:41:08   -104.5623
RECEIVE_FREQ_1   =   2005-159T17:41:09    -66.4396
RECEIVE_FREQ_1   =   2005-159T17:41:10    -28.4139
RECEIVE_FREQ_1   =   2005-159T17:41:11      9.6653
RECEIVE_FREQ_1   =   2005-159T17:41:12     47.7804
RECEIVE_FREQ_1   =   2005-159T17:41:13     85.8715
RECEIVE_FREQ_1   =   2005-159T17:41:14    123.8187
RECEIVE_FREQ_1   =   2005-159T17:41:15    161.9571
RECEIVE_FREQ_1   =   2005-159T17:41:16    200.0304
RECEIVE_FREQ_1   =   2005-159T17:41:17    238.0126
RECEIVE_FREQ_1   =   2005-159T17:41:18    276.1241
RECEIVE_FREQ_1   =   2005-159T17:41:19    314.1714
RECEIVE_FREQ_1   =   2005-159T17:41:20    352.2263
RECEIVE_FREQ_1   =   2005-159T17:41:21    390.2671
RECEIVE_FREQ_1   =   2005-159T17:41:22    428.3040
RECEIVE_FREQ_1   =   2005-159T17:41:23    466.3579
RECEIVE_FREQ_1   =   2005-159T17:41:24    504.3745
RECEIVE_FREQ_1   =   2005-159T17:41:25    542.4425
RECEIVE_FREQ_1   =   2005-159T17:41:26    580.4974
RECEIVE_FREQ_1   =   2005-159T17:41:27    618.5158
RECEIVE_FREQ_1   =   2005-159T17:41:28    656.5721
RECEIVE_FREQ_1   =   2005-159T17:41:29    694.5601
RECEIVE_FREQ_1   =   2005-159T17:41:30    732.5939
RECEIVE_FREQ_1   =   2005-159T17:41:31    770.6275
RECEIVE_FREQ_1   =   2005-159T17:41:32    808.6377
RECEIVE_FREQ_1   =   2005-159T17:41:33    846.6657
RECEIVE_FREQ_1   =   2005-159T17:41:34    884.6911
RECEIVE_FREQ_1   =   2005-159T17:41:35    922.6890
RECEIVE_FREQ_1   =   2005-159T17:41:36    960.7083
RECEIVE_FREQ_1   =   2005-159T17:41:37    998.7493
RECEIVE_FREQ_1   =   2005-159T17:41:38   1036.7388
RECEIVE_FREQ_1   =   2005-159T17:41:39   1074.7529
RECEIVE_FREQ_1   =   2005-159T17:41:40   1112.7732
DATA_STOP
```

Figure D-2: TDM Example: One-Way Data w/Frequency Offset

```
CCSDS_TDM_VERS=2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
CREATION_DATE=2005-184T20:15:00
ORIGINATOR=NASA
META_START
TIME_SYSTEM=UTC
START_TIME=2005-184T11:12:23
STOP_TIME=2005-184T13:59:43.27
PARTICIPANT_1=DSS-55
PARTICIPANT_2=yyyy-nnnA
MODE=SEQUENTIAL
PATH=1,2,1
INTEGRATION_INTERVAL=1.0
INTEGRATION_REF=MIDDLE
META_STOP
DATA_START
TRANSMIT_FREQ_1=2005-184T11:12:23     7175173383.615373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:23  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:24     7175173384.017573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:24  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:25     7175173384.419773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:25  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:26     7175173384.821973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:26  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:27     7175173385.224173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:27  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:28     7175173385.626373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:28  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:29     7175173386.028573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:29  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:30     7175173386.430773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:30  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:31     7175173386.832973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:31  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:32     7175173387.235173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:32  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:33     7175173387.637373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:33  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:34     7175173388.039573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:34  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:35     7175173388.441773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:35  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:36     7175173388.843973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:36  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:37     7175173389.246173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:37  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:38     7175173389.648373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:38  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:39     7175173390.050573
RECEIVE_FREQ_1=2005-184T13:59:27.27  8429753135.986102
RECEIVE_FREQ_1=2005-184T13:59:28.27  8429749428.196568
RECEIVE_FREQ_1=2005-184T13:59:29.27  8429749427.584727
RECEIVE_FREQ_1=2005-184T13:59:30.27  8429749427.023103
RECEIVE_FREQ_1=2005-184T13:59:31.27  8429749426.346252
RECEIVE_FREQ_1=2005-184T13:59:32.27  8429749425.738658
RECEIVE_FREQ_1=2005-184T13:59:33.27  8429749425.113143
RECEIVE_FREQ_1=2005-184T13:59:34.27  8429749424.489933
RECEIVE_FREQ_1=2005-184T13:59:35.27  8429749423.876996
RECEIVE_FREQ_1=2005-184T13:59:36.27  8429749423.325228
RECEIVE_FREQ_1=2005-184T13:59:37.27  8429749422.664049
RECEIVE_FREQ_1=2005-184T13:59:38.27  8429749422.054996
RECEIVE_FREQ_1=2005-184T13:59:39.27  8429749421.425801
RECEIVE_FREQ_1=2005-184T13:59:40.27  8429749420.824186
RECEIVE_FREQ_1=2005-184T13:59:41.27  8429749420.204178
RECEIVE_FREQ_1=2005-184T13:59:42.27  8429749419.596043
RECEIVE_FREQ_1=2005-184T13:59:43.27  8429749418.986191
DATA_STOP
```

Figure D-3: TDM Example: Two-Way Frequency Data for Doppler Calculation

```
CCSDS_TDM_VERS = 2.0
   COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
   CREATION_DATE = 2005-191T23:00:00
   ORIGINATOR = NASA
META_START
   COMMENT Range correction applied is range calibration to DSS-24.
   COMMENT Estimated RTLT at begin of pass = 950 seconds
   COMMENT Antenna Z-height correction 0.0545 km applied to uplink signal
   COMMENT Antenna Z-height correction 0.0189 km applied to downlink signal
   TIME_SYSTEM = UTC
   PARTICIPANT_1 = DSS-24
   PARTICIPANT_2 = yyyy-nnnA
   MODE = SEQUENTIAL
   PATH = 1,2,1
   INTEGRATION_REF = START
   RANGE_MODE = COHERENT
   RANGE_MODULUS = 2.0e+26
   RANGE_UNITS = RU
   TRANSMIT_DELAY_1 = 7.7e-5
   RECEIVE_DELAY_1  = 7.7e-5
   CORRECTION_RANGE = 46.7741
   CORRECTIONS_APPLIED = YES
META_STOP
DATA_START
   TRANSMIT_FREQ_1      =  2005-191T00:31:51    7180064367.3536
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:31:51    0.59299
   RANGE                =  2005-191T00:31:51    39242998.5151986
   PR_N0                =  2005-191T00:31:51    28.52538
   TRANSMIT_FREQ_1      =  2005-191T00:34:48    7180064472.3146
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:34:48     0.59305
   RANGE                =  2005-191T00:34:48    61172265.3115234
   PR_N0                =  2005-191T00:34:48    28.39347
   TRANSMIT_FREQ_1      =  2005-191T00:37:45    7180064577.2756
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:37:45    0.59299
   RANGE                =  2005-191T00:37:45    15998108.8168328
   PR_N0                =  2005-191T00:37:45    28.16193
   TRANSMIT_FREQ_1      =  2005-191T00:40:42    7180064682.2366
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:40:42    0.59299
   RANGE                =  2005-191T00:40:42    37938284.4138008
   PR_N0                =  2005-191T00:40:42    29.44597
   TRANSMIT_FREQ_1      =  2005-191T00:43:39    7180064787.1976
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:43:39    0.60774
   RANGE                =  2005-191T00:43:39    59883968.0697146
   PR_N0                =  2005-191T00:43:39    27.44037
   TRANSMIT_FREQ_1      =  2005-191T00:46:36    7180064894.77345
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:46:36    0.60989
   RANGE                =  2005-191T00:46:36    14726355.3958799
   PR_N0                =  2005-191T00:46:36    27.30462
   TRANSMIT_FREQ_1      =  2005-191T00:49:33    7180065002.72044
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.60989
   RANGE                =  2005-191T00:49:33    36683224.3750253
   PR_N0                =  2005-191T00:49:33    28.32537
   TRANSMIT_FREQ_1      =  2005-191T00:52:30    7180065110.66743
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:52:30    0.60983
   RANGE                =  2005-191T00:52:30    58645699.4734682
   PR_N0                =  2005-191T00:52:30    29.06158
   TRANSMIT_FREQ_1      =  2005-191T00:55:27    7180065218.61442
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.60989
   RANGE                =  2005-191T00:55:27    13504948.3585422
   PR_N0                =  2005-191T00:55:27    27.29589
   TRANSMIT_FREQ_1      =  2005-191T00:58:24    7180065326.56141
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.62085
   RANGE                =  2005-191T00:58:24    35478729.4012973
   PR_N0                =  2005-191T00:58:24    30.48199
   TRANSMIT_FREQ_1      =  2005-191T01:01:21    7180065436.45167
   RANGE                =  2005-191T01:01:21    57458219.0681689
   PR_N0                =  2005-191T01:01:21    27.15509
DATA_STOP
```

Figure D-4: TDM Example: Two-Way Ranging Data Only

```
CCSDS_TDM_VERS = 2.0

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)

CREATION_DATE = 2005-184T20:15:00
ORIGINATOR = NASA

META_START
TIME_SYSTEM = UTC
START_TIME =  2005-184T11:12:23
STOP_TIME  =  2005-184T13:59:40.27
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = yyyy-nnnA
PARTICIPANT_3 = DSS-15
MODE = SEQUENTIAL
PATH = 1,2,3
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-184T11:12:23     7175173383.615373
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:27.27  8429753135.986102
TRANSMIT_FREQ_1 = 2005-184T11:12:24     7175173384.017573
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:28.27  8429749428.196568
TRANSMIT_FREQ_1 = 2005-184T11:12:25     7175173384.419773
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:29.27  8429749427.584727
TRANSMIT_FREQ_1 = 2005-184T11:12:26     7175173384.821973
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:30.27  8429749427.023103
TRANSMIT_FREQ_1 = 2005-184T11:12:27     7175173385.224173
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:31.27  8429749426.346252
TRANSMIT_FREQ_1 = 2005-184T11:12:28     7175173385.626373
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:32.27  8429749425.738658
TRANSMIT_FREQ_1 = 2005-184T11:12:29     7175173386.028573
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:33.27  8429749425.113143
TRANSMIT_FREQ_1 = 2005-184T11:12:30     7175173386.430773
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:34.27  8429749424.489933
TRANSMIT_FREQ_1 = 2005-184T11:12:31     7175173386.832973
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:35.27  8429749423.876996
TRANSMIT_FREQ_1 = 2005-184T11:12:32     7175173387.235173
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:36.27  8429749423.325228
TRANSMIT_FREQ_1 = 2005-184T11:12:33     7175173387.637373
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:37.27  8429749422.664049
TRANSMIT_FREQ_1 = 2005-184T11:12:34     7175173388.039573
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:38.27  8429749422.054996
TRANSMIT_FREQ_1 = 2005-184T11:12:35     7175173388.441773
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:39.27  8429749421.425801
TRANSMIT_FREQ_1 = 2005-184T11:12:36     7175173388.843973
TRANSMIT_FREQ_RATE_1 = 2005-184T11:12:23     0.40220
RECEIVE_FREQ_3  = 2005-184T13:59:40.27  8429749420.824186
DATA_STOP
```

Figure D-5: TDM Example: Three-Way Frequency Data

```
CCSDS_TDM_VERS = 2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (JAXA)
CREATION_DATE = 1998-06-10T01:00:00
ORIGINATOR = JAXA

META_START
TIME_SYSTEM = UTC
START_TIME =  1998-06-10T00:57:37
STOP_TIME  =  1998-06-10T00:57:44
PARTICIPANT_1 = NORTH
PARTICIPANT_2 = F07R07
PARTICIPANT_3 = E7
MODE = SEQUENTIAL
PATH = 1,2,3,2,1
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
RANGE_MODE = CONSTANT
RANGE_MODULUS = 0
RANGE_UNITS = km
ANGLE_TYPE = AZEL
META_STOP

DATA_START
RANGE    =   1998-06-10T00:57:37          80452.7542
ANGLE_1      =   1998-06-10T00:57:37            256.64002393
ANGLE_2      =   1998-06-10T00:57:37             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:37    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:37     2287487999.0

RANGE    =   1998-06-10T00:57:38          80452.7368
ANGLE_1      =   1998-06-10T00:57:38            256.64002393
ANGLE_2      =   1998-06-10T00:57:38             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:38    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:38     2287487999.0

RANGE    =   1998-06-10T00:57:39          80452.7197
ANGLE_1      =   1998-06-10T00:57:39            256.64002393
ANGLE_2      =   1998-06-10T00:57:39             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:39    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:39     2287487999.0

RANGE    =   1998-06-10T00:57:40          80452.7025
ANGLE_1      =   1998-06-10T00:57:40            256.64002393
ANGLE_2      =   1998-06-10T00:57:40             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:40    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:40     2287487999.0

RANGE    =   1998-06-10T00:57:41          80452.6854
ANGLE_1      =   1998-06-10T00:57:41            256.64002393
ANGLE_2      =   1998-06-10T00:57:41             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:41    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:41     2287487999.0

RANGE    =   1998-06-10T00:57:42          80452.6680
ANGLE_1      =   1998-06-10T00:57:42            256.64002393
ANGLE_2      =   1998-06-10T00:57:42             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:42    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:42     2287487999.0

RANGE    =   1998-06-10T00:57:43          80452.6503
ANGLE_1      =   1998-06-10T00:57:43            256.64002393
ANGLE_2      =   1998-06-10T00:57:43             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:43    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:43     2287487999.0

RANGE    =   1998-06-10T00:57:44          80452.6331
ANGLE_1      =   1998-06-10T00:57:44            256.64002393
ANGLE_2      =   1998-06-10T00:57:44             13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:44    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:44     2287487999.0
DATA_STOP
```

Figure D-6: TDM Example: Four-Way Data

```
CCSDS_TDM_VERS = 2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)

COMMENT This example TDM describes a scenario such as might occur with a
COMMENT spacecraft like Cassini, which has 3 transponders:  X/S, X/X, X/Ka.
COMMENT In this tracking session all 3 transponders were used.
COMMENT This requires a TDM with 3 segments, because a single segment would
COMMENT not be able to specify a 'PATH' statement that would describe the
COMMENT S-down, X-down, and Ka-down signal paths.

CREATION_DATE = 2006-347T22:51
ORIGINATOR = NASA

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-X
MODE = SEQUENTIAL
PATH = 1,2,1
INTEGRATION_INTERVAL = 300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34  7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  8430849716.68
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-KA
MODE = SEQUENTIAL
PATH = 1,2,1
INTEGRATION_INTERVAL = 300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34   7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  32037228923.40
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-S
PARTICIPANT_3 = DSS-24
MODE = SEQUENTIAL
PATH = 1,2,3
INTEGRATION_INTERVAL = 300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 7.7e-5
RECEIVE_DELAY_3 =  7.7e-5
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34  7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  2299322650.01
DATA_STOP
```

Figure D-7: TDM Example: One S/C, X-up, S-down, X-down, Ka-down, Three Segments

```
CCSDS_TDM_VERS = 2.0
COMMENT GEOSCX_INP
CREATION_DATE = 2007-08-30T12:01:44.749
ORIGINATOR = DLR
META_START
TIME_SYSTEM = UTC
START_TIME = 2007-08-29T07:00:02.000
STOP_TIME = 2007-08-29T14:00:02.000
PARTICIPANT_1 = HBSTK
PARTICIPANT_2 = SAT
MODE = SEQUENTIAL
PATH = 1,2,1
INTEGRATION_INTERVAL =  1.0
INTEGRATION_REF = END
ANGLE_TYPE = XSYE
DATA_QUALITY = RAW
META_STOP
DATA_START
DOPPLER_INTEGRATED    = 2007-08-29T07:00:02.000          -1.498776048
ANGLE_1               = 2007-08-29T07:00:02.000           67.01312389
ANGLE_2               = 2007-08-29T07:00:02.000           18.28395556
DOPPLER_INTEGRATED    = 2007-08-29T08:00:02.000          -2.201305217
ANGLE_1               = 2007-08-29T08:00:02.000           67.01982278
ANGLE_2               = 2007-08-29T08:00:02.000           21.19609167
DOPPLER_INTEGRATED    = 2007-08-29T12:00:02.000           2.248620597
ANGLE_1               = 2007-08-29T12:00:02.000          -84.79697583
ANGLE_2               = 2007-08-29T12:00:02.000            4.11574444
DOPPLER_INTEGRATED    = 2007-08-29T13:00:02.000           1.547592295
ANGLE_1               = 2007-08-29T13:00:02.000          -85.14762500
ANGLE_2               = 2007-08-29T13:00:02.000            4.35471389
DOPPLER_INTEGRATED    = 2007-08-29T14:00:02.000           0.929545817
ANGLE_1               = 2007-08-29T14:00:02.000          -89.35626083
ANGLE_2               = 2007-08-29T14:00:02.000            2.78791667
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2007-08-29T06:00:02.000
STOP_TIME = 2007-08-29T12:00:02.000
PARTICIPANT_1 = WHM1
PARTICIPANT_2 = SAT
MODE = SEQUENTIAL
PATH = 1,2,1
INTEGRATION_INTERVAL =  1.0
INTEGRATION_REF = END
RANGE_MODE = CONSTANT
RANGE_MODULUS =   1.000000E+07
ANGLE_TYPE = AZEL
DATA_QUALITY = RAW
META_STOP
DATA_START
RANGE                 = 2007-08-29T06:00:02.000  4.00165248953670E+04
DOPPLER_INTEGRATED    = 2007-08-29T06:00:02.000          -0.885640091
ANGLE_1               = 2007-08-29T06:00:02.000           99.53204250
ANGLE_2               = 2007-08-29T06:00:02.000            1.26724167
RANGE                 = 2007-08-29T07:00:02.000  3.57238793591890E+04
DOPPLER_INTEGRATED    = 2007-08-29T07:00:02.000          -1.510223139
ANGLE_1               = 2007-08-29T07:00:02.000          103.33061750
ANGLE_2               = 2007-08-29T07:00:02.000            4.77875278
RANGE                 = 2007-08-29T08:00:02.000  2.90270197047210E+04
DOPPLER_INTEGRATED    = 2007-08-29T08:00:02.000          -2.229907387
ANGLE_1               = 2007-08-29T08:00:02.000          104.60635806
ANGLE_2               = 2007-08-29T08:00:02.000            5.47492500
RANGE                 = 2007-08-29T12:00:02.000  2.81439006334980E+04
DOPPLER_INTEGRATED    = 2007-08-29T12:00:02.000           2.222121620
ANGLE_1               = 2007-08-29T12:00:02.000          240.89006194
ANGLE_2               = 2007-08-29T12:00:02.000            6.71215556
DATA_STOP
```

Figure D-8: TDM Example: Angles, Range, Doppler Combined in Single TDM

```
CCSDS_TDM_VERS = 2.0
COMMENT  This TDM example contains range data timetagged at transmit time
CREATION_DATE = 2005-09-17T23:59:59
ORIGINATOR = JAXA

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-09-17T00:41:38.0000
STOP_TIME =  2005-09-17T00:42:58.0000
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = USC1
MODE = SEQUENTIAL
PATH = 2,1,2
TRANSMIT_BAND = S
RECEIVE_BAND = S
TIMETAG_REF = TRANSMIT
INTEGRATION_REF = START
RANGE_MODE = CONSTANT
RANGE_MODULUS = 1.0E7
RANGE_UNITS = km
DATA_QUALITY = VALIDATED
CORRECTION_RANGE = 0.0
CORRECTIONS_APPLIED = YES
META_STOP
DATA_START
RANGE = 2005-09-17T00:41:38.000000  3198.03679519614
RANGE = 2005-09-17T00:41:40.000000  3199.82505720811
RANGE = 2005-09-17T00:41:42.000000  3201.61631714467
RANGE = 2005-09-17T00:41:44.000000  3203.40832656236
RANGE = 2005-09-17T00:41:46.000000  3205.20108546120
RANGE = 2005-09-17T00:41:48.000000  3206.99384436004
RANGE = 2005-09-17T00:41:50.000000  3208.79110014575
RANGE = 2005-09-17T00:41:52.000000  3210.58535800688
RANGE = 2005-09-17T00:41:54.000000  3212.38336327374
RANGE = 2005-09-17T00:41:56.000000  3214.18136854059
RANGE = 2005-09-17T00:41:58.000000  3215.98012328859
RANGE = 2005-09-17T00:42:00.000000  3217.78037699888
RANGE = 2005-09-17T00:42:02.000000  3219.58287915260
RANGE = 2005-09-17T00:42:04.000000  3221.38613078747
RANGE = 2005-09-17T00:42:06.000000  3223.19013190349
RANGE = 2005-09-17T00:42:08.000000  3224.99488250065
RANGE = 2005-09-17T00:42:10.000000  3226.80113206010
RANGE = 2005-09-17T00:42:12.000000  3228.60963006298
RANGE = 2005-09-17T00:42:14.000000  3230.41587962244
RANGE = 2005-09-17T00:42:16.000000  3232.22587658761
RANGE = 2005-09-17T00:42:18.000000  3234.03662303393
RANGE = 2005-09-17T00:42:20.000000  3235.84886844254
RANGE = 2005-09-17T00:42:22.000000  3237.65961488886
RANGE = 2005-09-17T00:42:24.000000  3239.47560770319
RANGE = 2005-09-17T00:42:26.000000  3241.28860259295
RANGE = 2005-09-17T00:42:28.000000  3243.10384592614
RANGE = 2005-09-17T00:42:30.000000  3244.92133770276
RANGE = 2005-09-17T00:42:32.000000  3246.73882947939
RANGE = 2005-09-17T00:42:34.000000  3248.55856969945
RANGE = 2005-09-17T00:42:36.000000  3250.37681095722
RANGE = 2005-09-17T00:42:38.000000  3252.19879962071
RANGE = 2005-09-17T00:42:40.000000  3254.02003880307
RANGE = 2005-09-17T00:42:42.000000  3255.84352642885
RANGE = 2005-09-17T00:42:44.000000  3257.66851301693
RANGE = 2005-09-17T00:42:46.000000  3259.49125116157
RANGE = 2005-09-17T00:42:48.000000  3261.31848619307
RANGE = 2005-09-17T00:42:50.000000  3263.14572122459
RANGE = 2005-09-17T00:42:52.000000  3264.97295625609
RANGE = 2005-09-17T00:42:54.000000  3266.80169024990
RANGE = 2005-09-17T00:42:56.000000  3268.63267268713
RANGE = 2005-09-17T00:42:58.000000  3270.46440460551
DATA_STOP
```

Figure D-9: TDM Example: Range Data with TIMETAG_REF=TRANSMIT

```
CCSDS_TDM_VERS = 2.0

COMMENT  This TDM example contains single differenced Doppler data.

CREATION_DATE = 2006-354T01:38:00Z
ORIGINATOR = NASA


META_START
TIME_SYSTEM = UTC
START_TIME = 2003-07-08T04:45:25.0000
STOP_TIME =  2003-07-08T04:48:25.0000
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-24
PARTICIPANT_3 = DSS-25
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
INTEGRATION_INTERVAL = 10.0
INTEGRATION_REF = MIDDLE
RECEIVE_DELAY_2 = 0.00007732
RECEIVE_DELAY_3 = 0.00007732
DATA_QUALITY = VALIDATED
META_STOP


DATA_START

COMMENT  Transmit frequency is S/C beacon one OWLT prior to receive time

TRANSMIT_FREQ_1 = 2003-07-08T04:10:0000      8.435360E+09

RECEIVE_FREQ = 2003-07-08T04:45:25.0000      8.738750457763670E+00
RECEIVE_FREQ = 2003-07-08T04:45:35.0000      8.320683479309080E+00
RECEIVE_FREQ = 2003-07-08T04:45:45.0000      7.909399032592770E+00
RECEIVE_FREQ = 2003-07-08T04:45:55.0000      7.490205764770500E+00
RECEIVE_FREQ = 2003-07-08T04:46:05.0000      7.149572372436510E+00
RECEIVE_FREQ = 2003-07-08T04:46:15.0000      6.808938980102530E+00
RECEIVE_FREQ = 2003-07-08T04:46:25.0000      6.481011390686030E+00
RECEIVE_FREQ = 2003-07-08T04:46:35.0000      6.167441368103020E+00
RECEIVE_FREQ = 2003-07-08T04:46:45.0000      5.865190505981440E+00
RECEIVE_FREQ = 2003-07-08T04:46:55.0000      5.590643882751460E+00
RECEIVE_FREQ = 2003-07-08T04:47:05.0000      5.330531120300290E+00
RECEIVE_FREQ = 2003-07-08T04:47:15.0000      5.083267211914060E+00
RECEIVE_FREQ = 2003-07-08T04:47:25.0000      4.850607872009270E+00
RECEIVE_FREQ = 2003-07-08T04:47:35.0000      4.643701979796000E+00
RECEIVE_FREQ = 2003-07-08T04:47:45.0000      4.453802272725000E+00
RECEIVE_FREQ = 2003-07-08T04:47:55.0000      4.281702585856000E+00
RECEIVE_FREQ = 2003-07-08T04:48:05.0000      4.127402919189000E+00
RECEIVE_FREQ = 2003-07-08T04:48:15.0000      3.990903272724000E+00
RECEIVE_FREQ = 2003-07-08T04:48:25.0000      3.872203646461000E+00

DATA_STOP
```

Figure D-10: TDM Example: Differenced Doppler Observable

```
CCSDS_TDM_VERS = 2.0
COMMENT This TDM example contains Delta-DOR data.
COMMENT Quasar CTD 20 also known as J023752.4+284808 (ICRF), 0234+285 (IERS)
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2004-136T15:42:00.0000
STOP_TIME = 2004-136T16:02:00.0000
PARTICIPANT_1 = VOYAGER1
PARTICIPANT_2 = DSS-55
PARTICIPANT_3 = DSS-25
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
TIMETAG_REF = RECEIVE
RANGE_MODE = ONE_WAY
RANGE_MODULUS = 1.674852710000000E+02
RECEIVE_DELAY_3 = 0.000077
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT Timetag is time of signal arrival at PARTICIPANT_2.
COMMENT Transmit frequency is spacecraft beacon a OWLT before receive time.
DOR = 2004-136T15:42:00.0000 -4.911896106591159E-03
DOR = 2004-136T16:02:00.0000 1.467382930436399E-02
TRANSMIT_FREQ_1 = 2004-136T14:42:00.0000 8.415123456E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2004-136T15:52:00.0000
STOP_TIME = 2004-136T15:52:00.0000
PARTICIPANT_1 = CTD 20
PARTICIPANT_2 = DSS-55
PARTICIPANT_3 = DSS-25
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
TIMETAG_REF = RECEIVE
RANGE_MODE = ONE_WAY
RANGE_MODULUS = 1.674852710000000E+02
RECEIVE_DELAY_3 = 0.000077
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT Timetag is time of signal arrival at PARTICIPANT_2.
COMMENT Transmit frequency is reference for 2-station interferometer.
VLBI_DELAY = 2004-136T15:52:00.0000 -1.911896106591159E-03
TRANSMIT_FREQ_1 = 2004-136T15:42:00.0000 8.415123000E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = DSS-25
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:41:00.0000 -4.59e-7
DATA_STOP
```

Figure D-11: TDM Example: Delta-DOR Observable

```
CCSDS_TDM_VERS = 2.0

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek: one minute of launch angles from DSS-16

CREATION_DATE = 2005-157T18:25:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2004-216T07:44:00
STOP_TIME =  2004-216T07:45:00
PARTICIPANT_1 = DSS-16
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = XSYE
CORRECTION_ANGLE_1 = -0.09
CORRECTION_ANGLE_2 = 0.18
CORRECTIONS_APPLIED = NO
META_STOP

DATA_START

ANGLE_1 = 2004-216T07:44:00 -23.62012
ANGLE_2 = 2004-216T07:44:00 -73.11035

ANGLE_1 = 2004-216T07:44:10 -23.04004
ANGLE_2 = 2004-216T07:44:10 -72.74316

ANGLE_1 = 2004-216T07:44:20 -22.78125
ANGLE_2 = 2004-216T07:44:20 -72.53027

ANGLE_1 = 2004-216T07:44:30 -22.59180
ANGLE_2 = 2004-216T07:44:30 -72.37598

ANGLE_1 = 2004-216T07:44:40 -22.40527
ANGLE_2 = 2004-216T07:44:40 -72.23730

ANGLE_1 = 2004-216T07:44:50 -22.23047
ANGLE_2 = 2004-216T07:44:50 -72.08887

ANGLE_1 = 2004-216T07:45:00 -22.08984
ANGLE_2 = 2004-216T07:45:00 -71.93750

DATA_STOP
```

Figure D-12: TDM Example: Angle Data Only

```
CCSDS_TDM_VERS = 2.0

COMMENT TDM example created by NASA/JPL Navigation System Engineering

CREATION_DATE = 2005-282T23:00:00
ORIGINATOR = NASA

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-274T12:00:00
STOP_TIME =  2005-280T12:00:00
PARTICIPANT_1 = DSS-14
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT  Elevation mapping function is Niell model
TROPO_DRY = 2005-274T12:00:00  2.0526
TROPO_DRY = 2005-275T12:00:00  2.0530
TROPO_DRY = 2005-276T12:00:00  2.0533
TROPO_DRY = 2005-277T12:00:00  2.0537
TROPO_DRY = 2005-278T12:00:00  2.0540
TROPO_DRY = 2005-279T12:00:00  2.0544
TROPO_DRY = 2005-280T12:00:00  2.0547

TROPO_WET = 2005-274T12:00:00  0.1139
TROPO_WET = 2005-275T12:00:00  0.1126
TROPO_WET = 2005-276T12:00:00  0.1113
TROPO_WET = 2005-277T12:00:00  0.1099
TROPO_WET = 2005-278T12:00:00  0.1086
TROPO_WET = 2005-279T12:00:00  0.1074
TROPO_WET = 2005-280T12:00:00  0.1061
DATA_STOP



META_START
COMMENT Line of vertical ionospheric calibration for yyyy-nnnA
COMMENT Time tags are end time of 15 minute measurement interval
TIME_SYSTEM = UTC
START_TIME = 2005-280T21:45:00
STOP_TIME =  2005-281T00:00:00
PARTICIPANT_1 = DSS-14
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
DATA_QUALITY = VALIDATED
META_STOP

DATA_START

STEC = 2005-280T21:45:00  23.1
STEC = 2005-280T22:00:00  22.8
STEC = 2005-280T22:15:00  23.2
STEC = 2005-280T22:30:00  24.4
STEC = 2005-280T22:45:00  23.6
STEC = 2005-280T23:00:00  22.4
STEC = 2005-280T23:15:00  22.6
STEC = 2005-280T23:30:00  24.6
STEC = 2005-280T23:45:00  24.0
STEC = 2005-281T00:00:00  22.2
DATA_STOP
```

Figure D-13: TDM Example: Media Data Only

```
CCSDS_TDM_VERS = 2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT JPL/DSN/Goldstone (DSS-10) weather for DOY 156, 2005
CREATION_DATE = 2005-156T06:15:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2005-156T00:03:00
STOP_TIME =  2005-156T06:03:00
PARTICIPANT_1 = DSS-10
DATA_QUALITY = VALIDATED
META_STOP

DATA_START

TEMPERATURE = 2005-156T00:03:00 302.95
PRESSURE    = 2005-156T00:03:00 896.2
RHUMIDITY   = 2005-156T00:03:00 12.0

TEMPERATURE = 2005-156T00:33:00 304.05
PRESSURE    = 2005-156T00:33:00 895.9
RHUMIDITY   = 2005-156T00:33:00 11.0

TEMPERATURE = 2005-156T01:03:00 302.55
PRESSURE    = 2005-156T01:03:00 895.7
RHUMIDITY   = 2005-156T01:03:00 12.0

TEMPERATURE = 2005-156T01:33:00 302.65
PRESSURE    = 2005-156T01:33:00 895.7
RHUMIDITY   = 2005-156T01:33:00 11.0

TEMPERATURE = 2005-156T02:03:00 301.55
PRESSURE    = 2005-156T02:03:00 895.9
RHUMIDITY   = 2005-156T02:03:00 11.0

TEMPERATURE = 2005-156T02:33:00 300.45
PRESSURE    = 2005-156T02:33:00 895.9
RHUMIDITY   = 2005-156T02:33:00 12.0

TEMPERATURE = 2005-156T03:03:00 299.55
PRESSURE    = 2005-156T03:03:00 896.1
RHUMIDITY   = 2005-156T03:03:00 14.0

TEMPERATURE = 2005-156T03:33:00 298.65
PRESSURE    = 2005-156T03:33:00 896.2
RHUMIDITY   = 2005-156T03:33:00 15.0

TEMPERATURE = 2005-156T04:03:00 298.05
PRESSURE    = 2005-156T04:03:00 896.4
RHUMIDITY   = 2005-156T04:03:00 17.0

TEMPERATURE = 2005-156T04:33:00 297.15
PRESSURE    = 2005-156T04:33:00 896.8
RHUMIDITY   = 2005-156T04:33:00 19.0

TEMPERATURE = 2005-156T05:03:00 294.85
PRESSURE    = 2005-156T05:03:00 897.3
RHUMIDITY   = 2005-156T05:03:00 21.0

TEMPERATURE = 2005-156T05:33:00 293.95
PRESSURE    = 2005-156T05:33:00 897.3
RHUMIDITY   = 2005-156T05:33:00 23.0

TEMPERATURE = 2005-156T06:03:00 293.05
PRESSURE    = 2005-156T06:03:00 897.3
RHUMIDITY   = 2005-156T06:03:00 25.0

DATA_STOP
```

Figure D-14: TDM Example: Meteorological Data Only

```
CCSDS_TDM_VERS = 2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT The following are clock offsets, in seconds between the
COMMENT clocks at each DSN complex relative to UTC(NIST).  The offset
COMMENT is a mean of readings using several GPS space vehicles in
COMMENT common view.  Value is "station clock minus UTC".
CREATION_DATE = 2005-161T15:45:00
ORIGINATOR = NASA


META_START
COMMENT Note:  SPC10 switched back to Maser1 from Maser2 on 2005-142
TIME_SYSTEM = UTC
START_TIME = 2005-142T12:00:00
STOP_TIME =  2005-145T12:00:00
PARTICIPANT_1 = DSS-10
PARTICIPANT_2 = UTC-NIST

META_STOP

DATA_START
CLOCK_BIAS  =  2005-142T12:00:00      9.56e-7
CLOCK_DRIFT =  2005-142T12:00:00      6.944e-14
CLOCK_BIAS  =  2005-143T12:00:00      9.62e-7
CLOCK_DRIFT =  2005-143T12:00:00     -2.083e-13
CLOCK_BIAS  =  2005-144T12:00:00      9.44e-7
CLOCK_DRIFT =  2005-144T12:00:00     -2.778e-13
CLOCK_BIAS  =  2005-145T12:00:00      9.20e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-142T12:00:00
STOP_TIME =  2005-145T12:00:00
PARTICIPANT_1 = DSS-40
PARTICIPANT_2 = UTC-NIST

META_STOP

DATA_START
CLOCK_BIAS  =  2005-142T12:00:00     -7.40e-7
CLOCK_DRIFT =  2005-142T12:00:00     -3.125e-13
CLOCK_BIAS  =  2005-143T12:00:00     -7.67e-7
CLOCK_DRIFT =  2005-143T12:00:00     -1.620e-13
CLOCK_BIAS  =  2005-144T12:00:00     -7.81e-7
CLOCK_DRIFT =  2005-144T12:00:00     -4.745e-13
CLOCK_BIAS  =  2005-145T12:00:00     -8.22e-7
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-142T12:00:00
STOP_TIME =  2005-145T12:00:00
PARTICIPANT_1 = DSS-60
PARTICIPANT_2 = UTC-NIST

META_STOP

DATA_START
CLOCK_BIAS  =  2005-142T12:00:00      -1.782e-6
CLOCK_DRIFT =  2005-142T12:00:00       1.736e-13
CLOCK_BIAS  =  2005-143T12:00:00      -1.767e-6
CLOCK_DRIFT =  2005-143T12:00:00       1.157e-14
CLOCK_BIAS  =  2005-144T12:00:00      -1.766e-6
CLOCK_DRIFT =  2005-144T12:00:00       8.102e-14
CLOCK_BIAS  =  2005-145T12:00:00      -1.759e-6
DATA_STOP
```

Figure D-15: TDM Example: Clock Bias/Drift Only

```
CCSDS_TDM_VERS = 2.0
COMMENT All the angular data provided are free of any aberration effect.
CREATION_DATE = 2012-10-30T20:00
ORIGINATOR = ESA

META_START
TIME_SYSTEM = UTC
START_TIME = 2012-10-29T17:46:39.02
STOP_TIME = 2012-10-29T18:01:28.02
PARTICIPANT_1 = TFRM
PARTICIPANT_2 = TRACK NUMBER 001
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
REFERENCE_FRAME = EME2000
MAG_TYPE = APPARENT
META_STOP
DATA_START
ANGLE_1 = 2012-10-29T17:46:39.02     332.2298750
ANGLE_2 = 2012-10-29T17:46:39.02     -16.3028389
MAG =     2012-10-29T17:46:39.02    12.1
ANGLE_1 = 2012-10-29T17:48:46.02     332.7485833
ANGLE_2 = 2012-10-29T17:48:46.02     -16.1876917
MAG =     2012-10-29T17:48:46.02    12.3
ANGLE_1 = 2012-10-29T17:50:53.02     333.2668750
ANGLE_2 = 2012-10-29T17:50:53.02     -16.0716806
MAG =     2012-10-29T17:50:53.02    12.3

META_START
TIME_SYSTEM = UTC
START_TIME = 2012-10-29T17:46:39.02
STOP_TIME = 2012-10-29T18:01:28.02
PARTICIPANT_1 = TFRM
PARTICIPANT_2 = TRACK NUMBER 003
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
REFERENCE_FRAME = EME2000
MAG_TYPE = APPARENT
META_STOP
DATA_START
ANGLE_1 = 2012-10-29T17:46:39.02     335.1698333
ANGLE_2 = 2012-10-29T17:46:39.02     -17.7212861
MAG =     2012-10-29T17:46:39.02    11.8
ANGLE_1 = 2012-10-29T17:48:46.02     335.7062083
ANGLE_2 = 2012-10-29T17:48:46.02     -17.6950278
MAG =     2012-10-29T17:48:46.02    12.4
ANGLE_1 = 2012-10-29T17:50:53.02     336.2425833
ANGLE_2 = 2012-10-29T17:50:53.02     -17.6673694
MAG =     2012-10-29T17:50:53.02    13.1
```

Figure D-16: TDM Example: Ground Based Optical Tracking with Magnitude

```
CCSDS_TDM_VERS = 2.0
COMMENT Test file
CREATION_DATE = 2011-05-12T00:00:00.000
ORIGINATOR = ESA
META_START
COMMENT
TIME_SYSTEM = UTC
PARTICIPANT_1 = CAMRA
PARTICIPANT_2 = CRYOSAT
MODE = SEQUENTIAL
PATH = 1,2,1
EPHEMERIS_NAME = 3203_2013-11-09T23-02-30
RANGE_UNITS = km
ANGLE_TYPE = AZEL
CORRECTION_RANGE =  -1.48
CORRECTIONS_APPLIED = NO
META_STOP
DATA_START
RANGE =         2011-05-11T10:26:33.2613    2808.2696
ANGLE_1 =       2011-05-11T10:26:33.2613     191.40208435
ANGLE_2 =       2011-05-11T10:26:33.2613      25.44166756
CARRIER_POWER = 2011-05-11T10:26:33.2613     -36.73723984
RCS =           2011-05-11T10:26:33.2613       2.984
RANGE =         2011-05-11T10:26:33.7008    2803.1731
ANGLE_1 =       2011-05-11T10:26:33.7008     191.43959045
ANGLE_2 =       2011-05-11T10:26:33.7008      25.51874924
CARRIER_POWER = 2011-05-11T10:26:33.7008     -35.88296509
RCS =           2011-05-11T10:26:33.7008       2.992
RANGE =         2011-05-11T10:26:33.9686    2799.8754
ANGLE_1 =       2011-05-11T10:26:33.9686     191.46458435
ANGLE_2 =       2011-05-11T10:26:33.9686      25.56875038
CARRIER_POWER = 2011-05-11T10:26:33.9686     -36.67897415
RCS =           2011-05-11T10:26:33.7008     2.986
DATA_STOP
```

Figure D-17: TDM Example: Ground Based Radar Tracking with RCS

```
CCSDS_TDM_VERS=2.0
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
CREATION_DATE=2005-184T20:15:00
ORIGINATOR=NASA
META_START
TIME_SYSTEM=UTC
START_TIME=2005-184T11:12:23
STOP_TIME=2005-184T13:59:43.27
PARTICIPANT_1=DSS-55
PARTICIPANT_2=yyyy-nnnA
MODE=SEQUENTIAL
PATH=1,2,1
INTEGRATION_INTERVAL=1.0
INTEGRATION_REF=MIDDLE
FREQ_OFFSET=0.0
INTERPOLATION = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP
DATA_START
TRANSMIT_PHASE_CT_1=2005-184T11:12:23       7175173383.615373
TRANSMIT_PHASE_CT_1=2005-184T11:12:24      14350346766.632946
TRANSMIT_PHASE_CT_1=2005-184T11:12:25      21525520150.052719
TRANSMIT_PHASE_CT_1=2005-184T11:12:26      28700693531.874692
TRANSMIT_PHASE_CT_1=2005-184T11:12:27      35875866917.098865
TRANSMIT_PHASE_CT_1=2005-184T11:12:28      43051040300.725238
TRANSMIT_PHASE_CT_1=2005-184T11:12:29      50226213683.753811
TRANSMIT_PHASE_CT_1=2005-184T11:12:30      57401387067.184584
TRANSMIT_PHASE_CT_1=2005-184T11:12:31      64576560451.017557
TRANSMIT_PHASE_CT_1=2005-184T11:12:32      71751733834.252730

RECEIVE_PHASE_CT_1=2005-184T13:59:27.27     8429753135.986102
RECEIVE_PHASE_CT_1=2005-184T13:59:28.27    16859502564.182670
RECEIVE_PHASE_CT_1=2005-184T13:59:29.27    25289251991.767397
RECEIVE_PHASE_CT_1=2005-184T13:59:30.27    33719001418.790500
RECEIVE_PHASE_CT_1=2005-184T13:59:31.27    42148750841.136752
RECEIVE_PHASE_CT_1=2005-184T13:59:32.27    50578500270.875410
RECEIVE_PHASE_CT_1=2005-184T13:59:33.27    59008249695.988553
RECEIVE_PHASE_CT_1=2005-184T13:59:34.27    67437999120.478486
RECEIVE_PHASE_CT_1=2005-184T13:59:35.27    75867748544.355482
RECEIVE_PHASE_CT_1=2005-184T13:59:36.27    84297497967.680710

DATA_STOP
```

Figure D-18: TDM Example: Two-Way Phase Data for Doppler Calculation

```xml
<?xml version="1.0" encoding="UTF-8"?>
<tdm xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
     xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-
master.xsd"
     id="CCSDS_TDM_VERS" version="1.0">

   <header>
               <CREATION_DATE>2007-094T23:53:59.659</CREATION_DATE>
               <ORIGINATOR>NASA</ORIGINATOR>
  </header>
   <body>
      &lt;segment&gt;
         <metadata>
               <TIME_SYSTEM>UTC</TIME_SYSTEM>
               <PARTICIPANT_1>'DSS-25'</PARTICIPANT_1>
               <PARTICIPANT_2>MYSC</PARTICIPANT_2>
               <MODE>SEQUENTIAL</MODE>
               <PATH>1,2</PATH>
               <TRANSMIT_BAND>X</TRANSMIT_BAND>
        </metadata>
         <data>
            <observation>
               <EPOCH>2007-069T15:22:22.000</EPOCH>
               <TRANSMIT_FREQ_1>7167941264.0</TRANSMIT_FREQ_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:22:22.000</EPOCH>
               <TRANSMIT_FREQ_RATE_1>0.0</TRANSMIT_FREQ_RATE_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:23:30.000</EPOCH>
               <TRANSMIT_FREQ_1>7167941264.0</TRANSMIT_FREQ_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:23:30.000</EPOCH>
               <TRANSMIT_FREQ_RATE_1>0.0</TRANSMIT_FREQ_RATE_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:23:38.000</EPOCH>
               <TRANSMIT_FREQ_1>7167941264.0</TRANSMIT_FREQ_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:23:38.000</EPOCH>
               <TRANSMIT_FREQ_RATE_1>0.0</TRANSMIT_FREQ_RATE_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:34:36.000</EPOCH>
               <TRANSMIT_FREQ_1>7167941264.0</TRANSMIT_FREQ_1>
           </observation>
            <observation>
               <EPOCH>2007-069T15:34:36.000</EPOCH>
               <TRANSMIT_FREQ_RATE_1>0.0</TRANSMIT_FREQ_RATE_1>
           </observation>
        </data>
     &lt;/segment&gt;
  </body>
</tdm>
```

Figure D-19: TDM Example: XML Format

The following are some additional scenarios that are not currently considered in the example set, but could be included in later versions of the TDM:

a) S/C-S/C crosslinks;

b) Ground based transponder;

c) ‘DORIS’;

d) Arrayed downlink;

e) Orbital debris example;

f) Combination of radiometric types with media or meteorological data.

ANNEX E

INFORMATIVE REFERENCES

(INFORMATIVE)

NOTE – Normative references are provided in 1.5.

[E1] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVIIth Plenary Assembly*. Geneva: CCIR, 1990.

[E2] *Radio Metric and Orbit Data*. Recommendation for Space Data System Standards, CCSDS 501.0-B-1-S. Historical Recommendation. Issue 1-S. Washington, D.C.: CCSDS, January 1987.

[E3] Catherine L. Thornton and James S. Border. *Radiometric Tracking Techniques for Deep-Space Navigation*. JPL Deep Space Communications and Navigation Series. Hoboken, New Jersey: Wiley, February 2003.

[E4] Theodore D. Moyer. *Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation*. JPL Deep Space Communications and Navigation Series. Hoboken, New Jersey: Wiley, January 2003.

[E5] *Organization and Processes for the Consultative Committee for Space Data Systems*. CCSDS A02.1-Y-4. Yellow Book. Issue 4. Washington, D.C.: CCSDS, April 2014.

[E6] *The Application of CCSDS Protocols to Secure Systems*. Report Concerning Space Data System Standards, CCSDS 350.0-G-2. Green Book. Issue 2. Washington, D.C.: CCSDS, January 2006.

ANNEX F

RATIONALE FOR TRACKING DATA MESSAGES

(INFORMATIVE)

F1 GENERAL

This annex presents the rationale behind the design of the Tracking Data Message. It may help the application engineer construct a suitable message. Corrections and/or additions to these requirements may occur during future updates.

A specification of requirements agreed to by all parties is essential to focus design and to ensure the product meets the needs of the Member Agencies. There are many ways of organizing requirements, but the categorization of requirements is not as important as the agreement to a sufficiently comprehensive set. In this section, the requirements are organized into three categories:

Primary Requirements - These are the most elementary and necessary requirements. They would exist no matter the context in which the CCSDS is operating, i.e., regardless of pre-existing conditions within the CCSDS or its Member Agencies.

Heritage Requirements - These are additional requirements that derive from pre-existing Member Agency requirements, conditions, or needs. Ultimately these carry the same weight as the Primary Requirements. This Recommended Standard reflects heritage requirements pertaining to some of the technical participants' home institutions collected during the preparation of the Recommended Standard; it does not speculate on heritage requirements that could arise from other Member Agencies.

Desirable Characteristics - These are not requirements, but they are felt to be important or useful features of the Recommended Standard.

F2 PRIMARY REQUIREMENTS ACCEPTED FOR TRACKING DATA MESSAGES

Table F-1: Primary Requirements

ID	Requirement	Rationale	Trace
F-1-1	Data must be provided in digital form.	Facilitates computerized processing of TDMs.	3.1.1
F-1-2	The object being tracked must be clearly identified and unambiguous.[1]	Ensures proper processing of the tracking data in orbit determination.	3.3
F-1-3	All primary resources used in the tracking session must be clearly identified and unambiguous.	Ensures proper processing of the tracking data in orbit determination.	3.3
F-1-4	Time measurements (time stamps, timetags, or epochs) must be provided in a commonly used, clearly specified system.	The CCSDS objective of promoting interoperability is not met if time measurements are produced in esoteric or proprietary time systems.	3.3
F-1-5	The time bounds of the tracking data must be unambiguously specified.	The accuracy of orbit determination is highly dependent on accurately knowing the time at which measurements are taken.	3.3, 3.4
F-1-7	Tracking Data Messages must have means of being uniquely identified and clearly annotated.	If discussions of tracking file content are necessary, parties can ensure they are speaking of the same data.	3.2
F-1-9	The Tracking Data Message format shall be independent of the equipment that was used to perform the tracking.	The producer of a Tracking Data Message has knowledge of their network that may not be available to the user of the data.	3.4
F-1-10	Every tracking instrument shall have a defined reference location that could be defined in the ODM format, possibly extended to define spacecraft body-fixed axis. This reference location should not depend on the observing geometry.	The accuracy of orbit determination is highly dependent on accurately knowing the location of the tracking instruments.	3.4
F-1-11	The timetag of the tracking data shall always be unambiguously specified with respect to the measurement point or instrument reference point.	The accuracy of orbit determination is highly dependent on accurately knowing the time at which measurements are taken.	3.4
F-1-12	The observable shall be corrected with the best estimate of all known tracking instrument calibrations, such as pass-specific path delay calibrations between the reference point and the tracking equipment, if applicable.	The producer of a Tracking Data Message has knowledge of their network that may not be available to the user of the data.	3.4

[1] SANA may have upcoming standards in this area.

ID	Requirement	Rationale	Trace
F-1-13	The observable shall be converted to an equipment-independent quantity; e.g., frequencies shall be reported at the 'sky level' (i.e., actual transmitted/received frequencies).	The producer of a Tracking Data Message has knowledge of the details of the equipment in their network that may not be available to the user of the data.	3.4
F-1-14	The data transfer mechanism shall not place constraints on the tracking data content.	The tracking data measurements are taken prior to transfer from originator to user, so should not affect the data content.	3.1.8
F-1-15	The standard must provide for clear specification of units of measure.	Without clear specification of units of measure, mistakes can be made that involve the unit system in effect (e.g., Metric or Imperial) and/or orders of magnitude (e.g., meters or kilometers).	4.4, table 3-5

Table F-2: Heritage Requirements

ID	Requirement	Rationale	Trace
F-2-1	The standard shall be, or must include, an ASCII format.	ASCII character-based messages promote interoperability. ASCII messages are useful in transferring data between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable dumps of text to displays, emails, documents or printers are possible without preprocessing.	4.2
F-2-2	The standard shall not require software supplied by other agencies.	Provides the greatest flexibility to both the originator of a tracking data message and the consumer of the data.	3

Table F-3: Desirable Characteristics

ID	Requirement	Rationale	Trace
F-3-1	The standard should apply to non-traditional objects, such as landers, rovers, balloons, spacecraft-spacecraft tracking data exchange, etc.	There are many different types of spacecraft that are tracked by space agencies. The broader the applicability of the standard, the more useful it will be.	3.3, 3.4

ID	Requirement	Rationale	Trace
F-3-2	The standard should be extensible with no disruption to existing users/uses.	Space agencies and operators upgrade systems and processes on schedules that make sense for their organizations. In practice, some organizations will be early adopters but others will opt to wait until performance of a new version of the TDM has been proven in other operations facilities.	3.2
F-3-3	Keywords, values, and terminology in the TDM should be the same as those in the other CCSDS standards, where applicable.	Helps to ensure similar "look and feel" across the various CCSDS flight dynamics standards.	3.2, 3.3, 3.5, 4
F-3-4	The standard shall not preclude an XML implementation.	The CCSDS Management Council (CMC) has indicated that the Navigation WG must produce standards that can be represented in XML.	3, 1.2.6
F-3-5	Other corrections applied to the data, such as media corrections, should be agreed upon by the service-providing and the customer Agencies via an ICD.	The user of the data must know what types of corrections and calibrations have been applied to the data in order to process it correctly.	3.4

ANNEX G

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

G1 SECURITY CONSIDERATIONS

A2.2 ANALYSIS OF SECURITY CONSIDERATIONS

This section presents the results of an analysis of security considerations applied to the technologies specified in this Recommended Standard.

A2.3 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

The consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include potential loss, corruption, and theft of data. Because these messages are used in spacecraft orbit determination analyses, the consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include compromise or loss of the mission if malicious tampering of a particularly severe nature occurs.

A2.4 POTENTIAL THREATS AND ATTACK SCENARIOS

Potential threats or attack scenarios include, but are not limited to, (a) unauthorized access to the programs/processes that generate and interpret the messages, (b) unauthorized access to the messages during transmission between exchange partners and (c) modification of the messages between partners. Protection from unauthorized access during transmission is especially important if the mission utilizes open ground networks, such as the Internet, to provide ground-station connectivity for the exchange of data formatted in compliance with this Recommended Standard. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented be addressed by the management of those systems and networks.

A2.5 DATA PRIVACY

Privacy of data formatted in compliance with the specifications of this Recommended Standard should be assured by the systems and networks on which this Recommended Standard is implemented.

A2.6 DATA INTEGRITY

Integrity of data formatted in compliance with the specifications of this Recommended Standard should be assured by the systems and networks on which this Recommended Standard is implemented.

A2.7 AUTHENTICATION OF COMMUNICATING ENTITIES

Authentication of communicating entities involved in the transport of data which complies with the specifications of this Recommended Standard should be provided by the systems and networks on which this Recommended Standard is implemented.

A2.8 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

The transfer of data formatted in compliance with this Recommended Standard between communicating entities should be accomplished via secure mechanisms approved by the Information Technology Security functionaries of exchange participants.

A2.9 CONTROL OF ACCESS TO RESOURCES

Control of access to resources should be managed by the systems upon which originator formatting and recipient processing are performed.

A2.10 AUDITING OF RESOURCE USAGE

Auditing of resource usage will be handled by the management of systems and networks on which this Recommended Standard is implemented.

A2.11 UNAUTHORIZED ACCESS

Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited in order to minimize potential threats and attack scenarios.

A2.12 DATA SECURITY IMPLEMENTATION SPECIFICS

Specific information-security interoperability provisions that may apply between agencies and other independent users involved in an exchange of data formatted in compliance with this Recommended Standard should be specified in an ICD.

G2 SANA CONSIDERATIONS

The following TDM related items will be registered with the SANA Operator.
. The registration rule for new entries in the registry is the approval of new requests by the CCSDS Area or Working Group responsible for the maintenance of the TDM at the time of the request. New requests for this registry should be sent to SANA (mailto:info@sanaregistry.org).

- The TDM XML schema;

- A transform from the TDM XML to the TDM KVN version (????); and

- Values for the ORIGINATOR keyword in http://sanaregistry.org/r/organizations/organizations.html . The CCSDS Navigation WG has no purview over the contents of this registry. Suggestions should be sent to the SANA Operator at info@sanaregistry.org .

- andspacecraft names and identifiers that appear as values for the PARTICIPANT_n keywords in the TDM metadata.

G3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

ANNEX H

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ADM	Attitude Data Message
ASCII	American Standard Code for Information Interchange
AU	Astronomical Unit
AZEL	Azimuth-Elevation
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee for Space Data Systems
Delta-DOR	Delta Differential One-Way Ranging
DOR	Differential One-Way Ranging
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
K	Kelvin
KVN	Keyword = Value Notation
LIDAR	Light Detection and Ranging
MOIMS	Mission Operations and Information Management Services
N/A or n/a	Not Applicable / Not Available
ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
Pc/No	Carrier Power to Noise Spectral Density ratio

Pr/No	Ranging Power to Noise Spectral Density ratio
PRARE	Precise Range and Range Rate Equipment
RADEC	Right Ascension-Declination
RINEX	Receiver Independent Exchange
RTLT	Round-Trip Light Time
SANA	Space Assigned Numbers Authority
SCLK	Spacecraft Clock
SFTP	Secure File Transfer Protocol
SLR	Satellite Laser Ranging
TDM	Tracking Data Message
TEC	Total Electron Count
TECU	Total Electron Count Units
UTC	Coordinated Universal Time
VLBI	Very Long Baseline Interferometry
XEYN	X:East, Y:North
XSYE	X:South, Y:East
XML	eXtensible Markup Language

ANNEX I

TDM SUMMARY SHEET [NOTE: NOT YET REVISED]

(INFORMATIVE)

The tables in the following pages of this annex show the association between data types and metadata keywords. There are only a few required metadata keywords, but many more that are applicable to one or more of the various data types. Additionally, there are some keywords that are only applicable in certain restricted situations. Finally, there are some metadata keywords that are completely optional. This summary may assist the user in constructing a TDM that captures the data from a specific measurement session.

[xxx NOTE: Not yet updated for new keywords xxx]

1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n

a) either constant uplink frequency or measurements are not directly influenced by uplink frequency

	Range Data	Doppler Data			
Data Keywords [unit]	RANGE [km, s, or RU]	DOPPLER_INSTANTANEOUS [km/s]	RECEIVE_FREQ_n TRANSMIT_FREQ_n [Hz]	DOPPLER_INTEGRATED [km/s]	
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM RANGE_MODE RANGE_MODULUS RANGE_UNITS INTEGRATION_REF	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM TRANSMIT_FREQ_n * RECEIVE_FREQ *	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM INTEGRATION_INTERVAL INTEGRATION_REF TRANSMIT_FREQ_n * RECEIVE_FREQ *	
Situationally Required Metadata	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_RANGE TIMETAG_REF	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_DOPPLER TIMETAG_REF	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_TRANSMIT CORRECTION_RECEIVE INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_DOPPLER TIMETAG_REF	
Optional Metadata	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND INTEGRATION_INTERVAL	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND	

* The TRANSMIT_FREQ_n and RECEIVE_FREQ keywords are TDM Data Section keywords that are recommended to be exchanged for this data type. See 3.5.2.2 and 3.5.2.3.

1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n

b) changing uplink, described in TRANSMIT_FREQ either in tabular form or with the help of TRANSMIT_FREQ_RATE					
	Range Data	Doppler Data			
Data Keywords [unit]	RANGE [km, s, or RU]		RECEIVE_FREQ_n TRANSMIT_FREQ_n [Hz] TRANSMIT_FREQ_RATE_n [Hz/s]		
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM RANGE_MODE RANGE_MODULUS RANGE_UNITS INTEGRATION_REF		META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM		
Situationally Required Metadata	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_RANGE TIMETAG_REF		TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_TRANSMIT CORRECTION_RECEIVE INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET		
Optional Metadata	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND INTEGRATION_INTERVAL		COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND		

1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n

c) Frequency independent

	Angle Data	Media Related Data			
Data Keywords [unit]	ANGLE_1 ANGLE_2 [deg]	STEC [TECU]			
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM ANGLE_TYPE	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM			
Situationally Required Metadata	DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 REFERENCE_FRAME	DATA_QUALITY			
Optional Metadata	COMMENT START_TIME STOP_TIME RECEIVE_BAND	COMMENT START_TIME STOP_TIME			

2. MODE = SINGLE_DIFF, described within PATH_1, PATH_2 and PARTICIPANT_n either constant or changing uplink (as above)					
	Range Data		Doppler Data	VLBI Data	
Data Keywords [unit]	RANGE [km, s, or RU]		RECEIVE_FREQ_n TRANSMIT_FREQ_n [Hz] TRANSMIT_FREQ_RATE_n [Hz/s]	DOR [s]	VLBI_DELAY [s]
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND RANGE_MODE RANGE_MODULUS RANGE_UNITS INTEGRATION_REF		META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND RANGE_MODE RANGE_MODULUS TIMETAG_REF	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND RANGE_MODE RANGE_MODULUS TIMETAG_REF
Situationally Required Metadata	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_RANGE TIMETAG_REF		TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_TRANSMIT CORRECTION_RECEIVE INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY
Optional Metadata	COMMENT START_TIME STOP_TIME INTEGRATION_INTERVAL		COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME RANGE_UNITS	COMMENT START_TIME STOP_TIME RANGE_UNITS

3. MODE = Not applicable, not specified			
	Time Data	Media Related Data	Meteorological Data
Data Keywords [unit]	CLOCK_BIAS [s] CLOCK_DRIFT [s]	TROPO_DRY/TROPO_WET [m]	PRESSURE [hPa] RHUMIDITY [%] TEMPERATURE [K]
Required Metadata	META_START META_STOP PARTICIPANT_n TIME_SYSTEM	META_START META_STOP PARTICIPANT_n TIME_SYSTEM	META_START META_STOP PARTICIPANT_n TIME_SYSTEM
Situationally Required Metadata	DATA_QUALITY	DATA_QUALITY	DATA_QUALITY
Optional Metadata	COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME