The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

TRACKING DATA MESSAGE

DRAFT RECOMMENDED STANDARD

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STATEMENT OF INTENT

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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.

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FOREWORD

(WHEN THIS RECOMMENDED STANDARD IS FINALIZED, IT WILL CONTAIN THE FOLLOWING 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 *Procedures Manual 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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PREFACE

This document is a draft CCSDS Recommended Standard. Its 'Red Book' status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned **not** to fabricate any final equipment in accordance with this document's technical content.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 503.0-R-1	Tracking Data Message, Draft Recommended Standard, Issue 1	November 2005	~~Current~~ Initial draft
CCSDS 503.0-R-1.1	Tracking Data Message, Draft Recommended Standard, Issue 1.1	May 03, 2006	RID's approved at 04/20/2006 telecon, plus a number of other editorial RID's.
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CCSDS 503.0-R-1.8	Tracking Data Message, Draft Recommended Standard, Issue 1.8	August 25, 2006	RID's approved at 08/25/2006 telecon
CCSDS 503.0-R-1.9	Tracking Data Message, Draft Recommended Standard, Issue 1.9	September 21, 2006	RID's approved at 09/14/2006 and 09/21/2006 telecons
CCSDS 503.0-R-1.10	Tracking Data Message, Draft Recommended Standard, Issue 1.10	November 9, 2006	Final RID's, corrections, general cleanup, etc.
CCSDS 503.0-R-1.11	Tracking Data Message, Draft Recommended Standard, Issue 1.11	November 28, 2006	Added Siegmar's data table, results of telecon 11/22/2006, additional prep for Agency Review #2
CCSDS 503.0-R-1.12	Tracking Data Message, Draft Recommended Standard, Issue 1.12	December xx, 2006	Added results of telecon 11/22/2006, additional prep for Agency Review #2

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Table

1 INTRODUCTION

1.1 PURPOSE

1.1.1 This Tracking Data Message (TDM) draft Recommended Standard specifies a standard message format for use in exchanging spacecraft tracking data between space ~~A~~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 ground station managed by a second agency. The standardization of tracking data formats facilitates space agency allocation of tracking sessions to alternate tracking resources. This draft Recommended Standard has been developed via consensus of the Navigation Working Group of the CCSDS Mission Operations and Information Management Services (MOIMS) area.

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 may be selected.

1.2 SCOPE AND APPLICABILITY

1.2.1 This draft Recommended Standard contains the specification for a Tracking Data Message standard designed for applications involving tracking data interchange between space data systems (tracking data includes data types such as Doppler, transmit/received frequencies, range, angles, DORIS, PRARE, weather, media correction, Delta-DOR, etc.). The rationale behind the design of the message is described in annex A and may help the application engineer construct a suitable message. It is acknowledged that this first version of the Recommended Standard may 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 ~~more~~ 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 self-contained, with no additional information required beyond that specified in an Interface Control Document (ICD) written jointly by the service provider and customer agency.

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

1.2.4 This draft Recommended Standard is applicable only to the message format and content, but not to its transmission. The method of transmitting~~ssion~~ of the message between ~~agencies~~ exchange partners is beyond the scope of this document and should 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 must not place constraints on the technical data content of a TDM.

1.2.5 There are some specific exclusions to the TDM. The TDM specifically excludes, as listed below:

1.2.5.1 Satellite Laser Ranging (SLR) 'Fullrate' and/or 'Normal PointsQuicklook' 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 GPSGlobal Navigation Satellite System (GNSS) data, which is standardized via the RINEX format (http://gps.wva.net/html.common/rinex.html);

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

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

1.2.5.5 LIDAR data (which may include a laser range finder), however, such data could conveivably be transferred via TDM with a 'RANGE_OBS' keyword (see 3.5.2.5); and

1.2.5.6 Altimeter data, however, such data could conceivably be transferred via TDM with a 'RANGE_OBS' keyword (see 3.5.2.5).

1.2.6 Description of the message format based on the use of eXtensible Markup Language (XML) will beis detailed in an future integrated XML schema document for all Navigation Data Messages Recommendations: (Attitude Data Messages (ADM), Orbit Data Messages (ODM), and Tracking Data Message (TDM)). See reference [E9][E9].

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].

1.3.2 The following conventions apply throughout this draft Recommended Standard:

– the words 'shall' and 'must' imply a binding and verifiable specification;

– the word 'should' implies an optional, but desirable, specification;

[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, x′, y′, 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) (Ref [4]) could be used to convey the navigation solution. 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.

– the word ‘may’ implies an optional specification;

– the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

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 security considerations for the TDM.

~~1.4.4~~1.4.5 Annex A lists a set of requirements and desirable characteristics that were taken into consideration in the design of the TDM.

~~1.4.5~~1.4.6 Annex B lists a number of items that should 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 in the document.

~~1.4.6~~1.4.7 Annex C is a list of abbreviations and acronyms applicable to the TDM.

~~1.4.7~~1.4.8 Annex D shows how various tracking scenarios can be accommodated ~~via~~using the TDM, via several examples.

~~1.4.8~~1.4.9 Annex E contains a list of informative references.

1.4.10 Annex F provides a normative list of approved values for selected TDM Metadata Section keywords.

1.4.11 Annex G 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 draft Recommended Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this draft 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-2. Green Book. Issue 2. Washington, D.C.: CCSDS, November 2005.

[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-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, January 2002.

[4] Orbit Data Messages. Recommendation for Space Data System Standards, CCSDS 502.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2004.

[5] *Spacewarn Bulletin*. Greenbelt, MD, USA: WDC-SI. <http://nssdc.gsfc.nasa.gov/spacewarn>.

NOTE – Informative references are provided in annex E.

~~1.6INFORMATION SECURITY~~

~~Navigation Data Messages (including the ODM, ADM and TDM) may require moderate security measures to protect the data from unauthorized access. Protection from unauthorized access is especially important if the mission utilizes open ground networks such as the Internet to provide ground station connectivity for the exchange of Navigation Data Messages. In order to provide requisite security, it is recommended that Navigation Data Messages be transferred between participants via Secure FTP (SFTP), real-time authentication such as that incorporated in the Real-Time Radio Metric Data Transfer Service (RRMDT), or other secure mechanisms approved by the IT Security functionaries of exchange participants. As noted elsewhere in this document, this document does not deal specifically with the means of transferring Navigation Data Messages, focusing rather on message content. Specific information security provisions that may apply between agencies involved in an exchange should be specified in an ICD.~~

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.

The Tracking Data Message in this version of the draft 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 text files 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 files or objects to displays, emails, documents or printers are possible without preprocessing. The penalty for this convenience is some measure of inefficiency. Description of the message formats based on XML will be detailed in a future integrated XML schema document for all Navigation Data Messages (reference [E9][E9]).

2.2 THE TRACKING DATA MESSAGE (TDM) BASIC CONTENT

2.2.1 The TDM is realized as a sequence of plain ASCII text lines, which may be in either a file format or a real time stream. The content is separated into 3 basic types of computer data structure as described in section 3. The TDM architecture takes into account that some aspects change on a second-by-second 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, VLBI data, antenna pointing angles, clock data, etc.). To aid in precision trajectory modeling, additional ancillary information may be included within a TDM if it is desired and/or available (e.g., media corrections, meteorological data, and other ancillary data). Facilties for documenting comments are provided.

2.2.2 The Tracking Data Message in this version of the draft 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. Description of the message format based on XML is detailed in an integrated XML schema document for all Navigation Data Messages (reference [E9][E9]). To aid in precision trajectory modeling, additional ancillary information may be included within a TDM if it is desired and/or available (e.g., meteorological data or tropospheric data). There are keywords in the TDM grammar that may be used to add such ancillary information.Exchange participants should specify in the ICD which TDM format will be exchanged, the "plain ASCII" or the XML format.

2.3 EXCHANGE OF MULTIPLE TDMS / TRACKING OFAND MULTIPLE OBJECTS

2.3.1 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 may be included in a single TDM by using multiple segments; or multiple TDM's files may be used, one per spacecraft participant.

2.3.2 For a given spacecraft participant, multiple tracking data messages may 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.).

2.3.3 Provisions for these and other special types of exchanges should be specified in an ICD.

3 TRACKING DATA MESSAGE STRUCTURE AND CONTENT

3.1 GENERAL

3.1.1 The TDM shall consist of be a digital data represented as file comprised of plain ASCII text lines (see reference [2][2]) in KVN format (Keyword = Value Notation—see section 4). The filelines constituting a TDM shall be represented as a combination of:

a) a Header (see 3.23.1.3);

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); and.

d)oOptional 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.

3.1.23.1.3 Each TDM shall have a Header and a Body. set of minimum required sections; some sections may be repeated, as shown in table 3-1. Each Metadata block must be accompanied by a minimum of one Tracking Data Record. Taken together, the metadata block and its associated Tracking Data Record(s) shall be called a TDM segment. The TDM Body shall consist of one or more TDM Segments.[1] There shall be no limit to the number of Segments in a given TDM Body, beyond practical constraints, as shown in table 3-13-1. 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

[1] The ‘segment’ and ‘body’ concepts are introduced here in preparation for the upcoming XML implementation.

Table 3-1: TDM ~~File Layout Specifications~~Structure

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

~~3.1.3~~**3.1.4** The TDM shall ~~be a text file~~ consist~~ing~~ of tracking data for ~~a single tracking participant, or for multiple~~one or more tracking participants~~,~~ at multiple epochs contained within a specified time range. (Note that the term 'participant' applies equally to spacecraft, tracking stations, and agency centers, as discussed in reference [1]~~[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'.

~~3.1.4~~**3.1.5** The TDM shall be easily readable by both humans and computers.

~~3.1.5~~**3.1.6** It shall be possible to exchange a TDM either as a real-time stream or as a file.

~~3.1.6~~**3.1.7** The TDM file naming scheme shall be agreed to on a case-by-case basis between the participating agencies, typically specified in an ICD. In general, the file name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies for processing tracking data.

~~3.1.7~~**3.1.8** The method of exchanging TDMs shall be decided on a case-by-case basis by the participating agencies and 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 ~~file~~message.

3.2.2 A description of TDM Header items and values is provided in table 3-2~~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 obligatory or not obligatory.

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

Table 3-2: TDM Header

Keyword	Description	Examples	Obligatory
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 ~~0.12 (for testing)~~	Yes
COMMENT	See 4.5.	COMMENT This is a comment	No
CREATION_DATE	~~File~~ Data creation date/time in UTC. For format specification, see 4.3.9. ~~in one of following formats: 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 UTC time in hours, minutes, seconds, and optional fractional seconds; 'Z' is an optional trailing constant. There is no fixed limit on the precision of the fractional seconds (the 'd' characters to the right of the period). All fields require leading zeros.~~	2001-11-06T11:17:33 2002-204T15:56:23.4 2006-001T00:00:00Z	Yes
ORIGINATOR	Creating agency. Value should be specified in the ICD.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes
~~COMMENT~~	~~See 4.5.~~	~~COMMENT This is a comment~~	~~No~~

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

```
keyword = value
```

~~**3.2.4**~~**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.

~~**3.2.5**~~**3.2.6** The TDM ~~File~~ Header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the ~~file~~ 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 ~~block~~ Section that contains configuration details (metadata) applicable to the ~~set of Tracking Data Records~~Data Section in the same TDM S~~s~~egment. The information in the Metadata ~~block~~ 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
```

~~**3.3.1.2**~~**3.3.1.3** A single TDM Metadata ~~block~~ Section shall precede each ~~block of Tracking Data Records~~Data Section.

~~**3.3.1.3**~~**3.3.1.4** When there are changes in the values assigned to any of the keywords in the Metadata ~~block~~Section, a new ~~s~~Segment must be started (e.g., mode change from one-way to two-way tracking).

~~**3.3.1.4**~~**3.3.1.5** The first and last lines of a TDM ~~m~~Metadata ~~block~~ Section shall consist of the META_START and META_STOP keywords, respectively. These keywords are used to facilitate ~~file~~ parsing.

~~**3.3.1.5**~~**3.3.1.6** Table 3-3~~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 obligatory or not obligatory.

~~**3.3.1.6**~~**3.3.1.7** Only those keywords shown in table 3-3~~3-3~~ shall be used in a TDM Metadata ~~block~~Section. Obligatory items shall appear in every TDM Metadata ~~block~~Section. Items that are not obligatory may or may not appear in any given TDM Metadata ~~block~~Section, at the discretion of the ~~file originator~~data producer, based on the requirements of the data and its intended application (See annex G 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 provided, the default shall be assumed~~ where applicable~~.

~~**3.3.1.7**~~**3.3.1.8** The order of occurrence of the obligatory and optional KVN assignments shall be fixed as shown in table 3-3~~3-3~~.

~~3.3.1.8~~3.3.1.9 The Metadata ~~block~~ 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 ~~the same~~a given ~~m~~Metadata ~~block~~Section.

~~3.3.1.9~~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 3.3.9 provide an explanation of the tracking modes and participant numbers. Participants may generally be listed in any order.

~~3.3.1.10Participants may generally be listed in any order; however, there are some exceptions in which a specific convention must be observed with respect to the order in which the participants are listed (exceptions noted in table 3-3 and subsection 3.3.7).~~

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~~ due to 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 ~~segment~~Segments would be required to describe the full set of tracking data. For the example scenario just given, one TDM Segment would be used to describe the 2-way connection, and one additional segment would be required for each 3-way connection; it would not be possible to provide a single 'PATH' statement that would convey the multiple signal paths. ~~Even if a 'PATH' statement could be contrived to cover such a case, there would likely be violations of the 'keyword/timetag uniqueness' restriction.~~

Table 3-3: TDM Metadata ~~Block~~Section

Keyword	Description	Normative Values / Examples	Obligatory
META_START	The META_START keyword shall delineate the start of the TDM Metadata ~~block~~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 ~~m~~Metadata Section.	COMMENT file = tdm.dat	No
TIME_SYSTEM	The TIME_SYSTEM keyword shall specify the time system used for timetags in the associated ~~Tracking Data Records~~Data Section. This should be UTC for ground-based data. Examples are shown in the "Normative Values / Examples" column. The full set of allowed values ~~are~~ is enumerated in Annex F. ~~the same as in the ODM, but also may include a local spacecraft clock, as applicable. See references [1] and [4].~~	UTC, TAI, GPS, SCLK	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. Examples are shown in the "Normative Values / Examples" column. For format specification, see 4.3.9.	1996-12-18T14:28:15.1172 1996-277T07:22:54 2006-001T00:00:00Z	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. Examples are shown in the "Normative Values / Examples" column. For format specification, see 4.3.9	1996-12-18T14:28:15.1172 1996-277T07:22:54 2006-001T00:00:00Z	No

Keyword	Description	Normative Values / Examples	Obligatory
PARTICIPANT_n n = {1, 2, 3, 4, 5}	The PARTICIPANT_n keyword shall represents 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 media only or clock bias only, only one participant need be listed. Participants may include ground stations, spacecraft, and/or quasars. 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. For MODE='SINGLE DIFF' or 'DOUBLE DIFF', the order in which participants are listed is important. See 3.3.7 below for details of the ordering. For mode='SEQUENTIAL', p Participants may be listed in any order, and the PATH keywords specifyies 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 SPACEWARN Bulletin (reference [5][5]), which includes Object name and international designator of the participant. The list of eligible names that is used to specify participants should be documented in the ICD. Examples are shown in the "Normative Values / Examples" column.	DSS-63-S400K ROSETTA <Quasar catalog name> 1997-061A	Yes (at least one)
MODE	The MODE keyword shall reflect the tracking mode associated with the Data portionSection of the segment. This keyword must have aone of the values from the "Normative Values / Examples" column. the set at right. If the actual value is not known, the best hypothesis shall be provided. The value "SEQUENTIAL" Use of this keyword is conditional: it applies only for range, Doppler, and angles; the name implies a sequential signal path between tracking participants. The value "SINGLE_DIFF" applies for and differenced data. Other cases, such as transmit only, media, weather, etc., use 'N/A' as the MODE setting.	SEQUENTIAL SINGLE-_DIFF DOUBLE-DIFF N/A	Yes

Keyword	Description	Normative Values / Examples	Obligatory
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 correlate with the indexers of the PARTICIPANT keywords. The first entry in the PATH shall be the transmit participant. The non-indexed 'PATH' keyword shall be used This keyword is applicable only 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'. The integers 1, 2, 3, 4, 5 correlate with the indexer of the PARTICIPANT keyword. Examples: 1,2 = one-way; 2,1,2 = two-way; 3,2,1 = three-way; 1,2,3,4 = four-way. Further examples are shown in the "Normative Values / Examples" column. The default value shall be 'N/A'.	1,2,1 1,2,4,3 N/A PATH = 1,2,1 PATH_1 = 1,2,1 PATH_2 = 3,1 N/A	No
TRANSMIT_BAND	The TRANSMIT_BAND keyword shall indicate the frequency band for transmitted frequencies. Example values are shown in the "Normative Values / Examples" column. The frequency ranges associated with each band should be specified in the ICD.	S X Ka L UHF	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. Example values are shown in the "Normative Values / Examples" column. The frequency ranges associated with each band should be specified in the ICD.	S X Ka L UHF	No
DIFF_MODE	The DIFF_MODE keyword is required only if the MODE is SINGLE-DIFF or DOUBLE-DIFF. 'DELAY' shall be used if the differenced observable is a time value, and 'RANGE' shall be used if the observable is a distance value. The default value shall be 'N/A'.	DELAY RANGE N/A	No

Keyword	Description	Normative Values / Examples	Obligatory
TIMETAG_REF	The TIMETAG_REF keyword shall provide a reference for downlink time tags in the tracking data. This keyword must have one of the values from the "Normative Values / Examples" column, This keyword must have a value from the set at right, which indicates whether the timetag associated with the downlink data is the transmit time or the receive time. The default value shall be 'RECEIVE'. 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 intuitively obvious cases, it is not necessary to specify the TIMETAG_REF keyword. NOTE For uplink data, the timetag always represents the transmit time, so TIMETAG_REF need not be specified.	TRANSMIT RECEIVE	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. The default value shall be 1.0. Examples are shown in the "Normative Values / Examples" column.	60.0 0.1 1.0	No
INTEGRATION_REF	The INTEGRATION_REF keyword shall be used in conjunction with the INTEGRATION_INTERVAL and TIMETAG_REF and INTEGRATION_INTERVAL keywords. This keyword must have one of the values from the "Normative Values / Examples" columnThis keyword must have a value from the set at right, which 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. The default value shall be MIDDLE.	START MIDDLE END	No

Keyword	Description	Normative Values / Examples	Obligatory
FREQ_OFFSET	The FREQ_OFFSET keyword represents a frequency in Hz that must be added to every RECEIVE_FREQ (see section 3.4) to reconstruct it; used if ~~the~~ a Doppler shift frequency observable is transferred instead of the RECEIVE_FREQ. 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	No
RANGE_MODE	The RANGE_MODE keyword must have one of the values from the "Normative Values / Examples" column.~~must have a value from the set at right.~~ The value of the RANGE_MODE 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~~,~~; ~~or~~ 'CONSTANT', in which case the range tones have a constant frequency; or 'ONE_WAY' (used in Delta-DOR). ~~The default value shall be 'COHERENT'.~~ 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	No
RANGE_MODULUS	The value associated with the RANGE_MODULUS keyword shall be the modulus of the range observable in km, i.e., the actual (unambiguous) range is an integer *k* times the modulus, plus the observable value. RANGE_MODULUS shall be a positive double precision value (normally integer for range, but can be non-integer for differenced range). For measurements that are not ambiguous range, the MODULUS setting shall be 0 to indicate an essentially infinite modulus. Examples are shown in the "Normative Values / Examples" column. 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	No
~~RANGE_UNITS~~	~~The RANGE_UNITS keyword specifies the units for the range observable and range rate. 'RU', for 'range units', shall be used where the transmit frequency is changing. 'S', for 'seconds', shall be used where the transmit frequency is constant. 'KM' shall be used if the range is measured in kilometers. The default value shall be 'S'.~~	~~RU~~ ~~S~~ ~~KM~~	~~No~~

Keyword	Description	Normative Values / Examples	Obligatory
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 should generally be one of the values from the set shown in the "Normative Values / Examples" column. at right: – RADEC for right ascension, declination or hour angle, declination (needs to be referenced to inertial frame); – 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 should be defined in an ICD. The default value shall be 'N/A'.	AZEL RADEC AZEL XEYN XSYE N/A	No
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 default value shall be 'N/A'. Examples are shown in the "Normative Values / Examples" column. See Annex F for the full set of approved values.	JEME2000 N/A	No

Keyword	Description	Normative Values / Examples	Obligatory
TRANSMIT_DELAY_n n = {1, 2, 3, 4, 5}	The TRANSMIT_DELAY_n keyword shall specify a fixed delay in seconds that should be added to each TRANSMIT timetaginterval 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 (i.ee.g., TRANSMIT_DELAY_1, if present, applies to timetags for PARTICIPANT_1). Delays associated with uplink antenna arraying should be indicated with this keyword. One half of a Ttransponder delays (e.g., for spacecraft-spacecraft ranging) should be specified via the TRANSMIT_DELAY_n and RECEIVE_DELAY_n keywords. The TRANSMIT_DELAY should generally not be included in ground corrections applied to the tracking data. The TRANSMIT_DELAY shall be a positive double precision value. The default value shall be 0.0. Examples are shown in the "Normative Values / Examples" column. NOTE – This value is different from the 'CLOCK_BIAS' keyword in the Tracking Data RecordsData Section keywords.	1.23 0.0326 0.00077	No

Keyword	Description	Normative Values / Examples	Obligatory
RECEIVE_DELAY_n n = {1, 2, 3, 4, 5}	The RECEIVE_DELAY_n keyword shall specify a fixed delay in seconds that should be subtracted from each RECEIVE timetaginterval 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 (i.ee.g., RECEIVE_DELAY_1, if present, applies to timetags for PARTICIPANT_1). Delays associated with downlink antenna arraying should be indicated with this keyword. One half of a Ttransponder delays (e.g., for spacecraft-spacecraft ranging) should be specified via the TRANSMIT_DELAY_n and RECEIVE_DELAY_n keywords. The RECEIVE_DELAY should generally not be included in ground corrections applied to the tracking data. The RECEIVE_DELAY shall be a positive double precision value. The default value shall be 0.0. Examples are shown in the "Normative Values / Examples" column. NOTE – This value is different than the 'CLOCK_BIAS' keyword in the Tracking Data RecordsData Section keywords.	1.23 0.0326 0.00777	No
START_TIME	The START_TIME keyword shall specify the start time of total time span covered by tracking data immediately following this metadata block, in one of the two following formats: 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 UTC time in hours, minutes, seconds, and optional fractional seconds; 'Z' is an optional trailing constant. There shall be no fixed limit on the precision of the fractional seconds (the 'd' characters to the right of the period). All fields shall have leading zeros.	1996-12-18T14:28:15.1172 1996-277T07:22:54	Yes

Keyword	Description	Normative Values / Examples	Obligatory
STOP_TIME	The STOP_TIME keyword shall specify the stop time of total time span covered by tracking data immediately following this metadata block, in one of the two following formats: 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 UTC time in hours, minutes, seconds, and optional fractional seconds; 'Z' is an optional trailing constant. There shall be no fixed limit on the precision of the fractional seconds (the 'd' characters to the right of the period). All fields shall have leading zeros.	1996-12-18T14:28:15.1172 1996-277T07:22:54	Yes
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.). This keyword must have one of the values from the "Normative Values / Examples" column. 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 due to 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 'VALIDATEDRAW'. (rationale: agencies often do not validate tracking data before export).	RAW VALIDATED DEGRADED	No

Keyword	Description	Normative Values / Examples	Obligatory
CORRECTION_RANGE CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 CORRECTION_DOPPLER CORRECTION_RANGE CORRECTION_RECEIVE CORRECTION_TRANSMIT CORRECTION_DOPPLER CORRECTION_TROPO_DRY CORRECTION_TROPO_WET CORRECTION_CP__*	The set of CORRECTION_ keywords may be used to reflect the values of corrections that have been applied 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. Examples are shown in the "Normative Values / Examples" column. * The CORRECTION_CP keyword applies to ionospheric correction only, not solar plasma or other plasmas.	1.35 0.23 3e-1 150000	No
META_STOP	The META_STOP keyword shall delineate the end of the TDM Metadata blockSection 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

The following sections discuss possible relationships between the 'MODE', 'PATH', and 'PARTICIPANT_n' keywords. This section is provided in order to facilitate codingthe implementation of TDMs that correspond to generation for typical tracking sessions (e.g., one-way, two-way, three-way, etc.).

3.3.3 ONE-WAY DATA

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

3.3.3.2 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.

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

3.3.4 TWO-WAY DATA

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

3.3.4.2 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 does 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-3~~ and D-4~~D-4~~ for example TDMs containing two-way tracking data.

3.3.5 THREE-WAY DATA

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

3.3.5.2 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.

3.3.5.3 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~~D-5~~ for an example TDM containing three-way tracking data.

3.3.6 *N*-WAY DATA

3.3.6.1 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.

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

3.3.6.3 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’ or ‘PATH=1,2,3,4’ represent two different four-way tracking signal paths.

3.3.6.4 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~~D-6~~ for an example TDM containing four-way tracking data.

3.3.7 DIFFERENCED MODES ~~-~~AND VLBI DATA

3.3.7.1 ~~For d~~Differenced data and VLBI data may also be exchanged in a Tracking Data Message. ~~, there are two different values of the MODE keyword that apply: ‘SINGLE-DIFF’ and ‘DOUBLE-DIFF’.~~ Differenced data can include differenced Doppler and differenced range (see references [E8]~~[E8]~~ and [E10]~~[E10]~~).

3.3.7.2 The setting of the ‘MODE’ keyword shall be ‘SINGLE_DIFF’.

~~**3.3.7.2**~~**3.3.7.3** When the MODE is ‘~~SINGLE-DIFF~~SINGLE_DIFF’, ~~at least three participants shall be present. PARTICIPANT_1 must be the transmitting participant (source of the signal). PARTICIPANT_2 and PARTICIPANT_3 are the receiving participants~~two path keywords ‘PATH_1’ and ‘PATH_2’ shall be used to convey the signal paths that have been differenced.

~~**3.3.7.3**~~**3.3.7.4** When the mode is ‘~~SINGLE-DIFF~~SINGLE_DIFF’, the observable is calculated by subtracting the value achieved for the measurement using PATH_2 from the value achieved using PATH_1, i.e., PATH_1 – PATH_2. ~~between PARTICIPANT_2 and PARTICIPANT_1 from the measurement between PARTICIPANT_3 and PARTICIPANT_1 (i.e., ‘p_3p_1-p_2p_1’, where ‘p_n’ represents ‘PARTICIPANT_*n*’ and p_ip_j represents a measurement between p_i and p_j).~~ Only the final observable shall be communicated via the TDM.

~~**3.3.7.4**The ‘DOUBLE-DIFF’ value of MODE applies in cases where two signal sources are measured simultaneously (e.g., same beam interferometry or a delta-DOR [delta differenced one-way range] measurement session where the quasar and spacecraft downlinks are measured simultaneously). This observation pattern is performed simultaneously using two receivers in different antenna complexes, achieving the long baseline desired. The signals recorded at the two complexes are correlated, and pointing angle values are differenced to derive the observable.~~

~~**3.3.7.5**When the MODE is ‘DOUBLE-DIFF’, at least four participants shall be present. PARTICIPANT_1 and PARTICIPANT_2 must be the transmitting participants (source of the signals). PARTICIPANT_3 and PARTICIPANT_4 are the receiving participants.~~

~~**3.3.7.6**When the MODE is 'DOUBLE-DIFF', the observable is calculated (p_4p_2-p_3p_2) - (p_4p_1-p_3p_1), where 'p_n' represents 'PARTICIPANT_*n*' and p_ip_j represents a measurement between p_i and p_j. Only the final observable shall be communicated via the TDM.~~

~~NOTE In many measurement sessions that are called 'delta-DOR', the measurement data is collected via a process in which the antenna slews from a spacecraft downlink to a quasar and back to the spacecraft during the tracking pass. This sequence may occur multiple times. This observation pattern is performed 'simultaneously' using two receivers in different antenna complexes, achieving the long baseline desired. However, because the measurements are not truly simultaneous, the output data are actually data that can be single-differenced and then extrapolated to achieve a simulated simultaneous measurement. The collection of data that contains some actual measurement data and some extrapolated data is then differenced to create a pseudo double-differenced data product.~~

~~**3.3.7.7**For differenced data types, there is a metadata keyword 'DIFF_MODE' that determines how the observable should be interpreted. If the differenced or VLBI observable is a value with units of 'seconds', then the 'DIFF_MODE' of DELAY applies. This value of 'DIFF_MODE' indicates that the observable represents the difference in arrival time for a given wavefront at the two stations involved in the measurement. If the differenced or VLBI observable is a distance, then the 'DIFF_MODE' of RANGE applies. This value of 'DIFF_MODE' indicates that the observable represents the difference in distance to the spacecraft at a given reception time.~~

3.3.7.5 If the TDM contains differenced Doppler ~~is provided~~ 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 3.5.2.7).

3.3.7.6 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 3.5.2.8).

3.3.7.7 If differenced range is provided, the 'RANGE_OBS' keyword shall be used for the observable (the 'RANGE_OBS' keyword is a Data Section keyword not yet described in the text…see 3.5.2.4).

~~**3.3.7.8**If the TDM contains two-way or three-way differenced Doppler data, then a history of the uplink frequencies shall be provided with the RECEIVE_FREQ_n keyword in order to process the data correctly.~~

3.3.7.8 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).

3.3.7.9 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-8, D-9, and Figure D-10D-10 and Figure D-11 for example TDMs containing single differenced tracking data. See figure D-11 for an example TDM containing double differenced tracking data.

3.3.8 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, pointing of a CCD cameradirection of a participant measured by a navigation camera, etc.).

NOTE – See Figure D-8figure D-12 and Figure D-12 for an example TDM's containing angle data.

3.3.9 MEDIA, WEATHER, ANCILLARY DATA, & UPLINK ONLY

When all the data in a TDM segmentSegment is media related, weather related, or ancillary-data related, or uplink data only, then the value of the MODE keyword shall be 'N/A' and the PATH keyword shall not be used. 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), and it is the reference antenna. An exception to the single participant segment would be where ionospheric charged particle delays are provided for a line-of-sight between the antenna and a specific spacecraft.; in such a case the participants should include both the antenna and the spacecraft.

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

3.4 TDM DATA ~~BLOCK~~SECTION (GENERAL SPECIFICATION)

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

```
keyword = timetag  measurement [unit]
```

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

Table 3-4: Tracking Data Record Generic Format

Element		Description	Examples	Obligatory
<keyword>		Data type keyword from the list specified in 3.5. ~~Note that some keywords constitute a hierarchy, and are constructed from a <prefix><suffix> construction pair (in preparation for the XML implementation).~~	See 3.5	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. ~~Timetags may be in a non-chronological sequence. Tracking data shall be tagged in the applicable TIME_SYSTEM. Format shall be the same as for START_TIME and STOP_TIME metadata keywords.~~ For requirements on the timetag, see 3.4.8 through 3.4.12. For format specification, see 4.3.9. ~~Interpretation of the timetag is as follows:~~ ~~Uplink data: transmit time.~~ ~~Downlink data: determined by values of TIMETAG_REF, INTEGRATION_REF, and INTEGRATION_INTERVAL keywords, as applicable. Other data (e.g., meteorological, media, clock bias/drift): the time the measurement was taken.~~	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
	<unit>	Optional display of the applicable units for the measurement.	See 4.4, table 3-5~~3-5~~.	No

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 primary ~~components~~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. The measurement may optionally be followed by the applicable units.

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.

~~**3.4.4**~~**3.4.5** Applicable keywords and their associated characteristics are detailed in 3.5.

~~**3.4.5**~~**3.4.6** ~~In any particular block of Tracking Data Records, all keywords shall be optional because they depend upon the characteristics of the data collection activity; however, the keyword associated with at least one tracking data type must be present.~~There shall be no obligatory 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.

~~**3.4.6**At least one blank character must be used to separate the timetag and the observable in the value associated with each Tracking Data Record.~~

3.4.7 The Data ~~portion~~Section of the TDM ~~segment~~Segment shall be delineated by the 'DATA_START' and 'DATA_STOP' keywords. These keywords are intended to facilitate ~~file~~ parsing, and will also serve to advise the recipient that all the ~~data~~ Tracking Data Records associated with the immediately preceding TDM Metadata ~~block~~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 3.5.2.7). 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, ~~N~~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. ~~; t~~Thus it ~~is~~ 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.

3.4.93.4.13 Every tracking instrument shall have a defined reference location that could be defined in the Orbit Data Messages (ODM) format (reference [4]), possibly extended to define spacecraft body-fixed axes. This reference location shall not depend on the observing geometry. The tracking instrument locations should be conveyed via an ICD.

3.4.103.4.14 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 of 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 sections.

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

NOTE 1 – 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.

NOTE 2 – 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 operationally inconvenient for the producer to treat these values as corrections due to 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.

3.4.123.4.15.2 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. Other corrections applied to the data, such as media corrections, shall be agreed by the service provider and the customer Agencies and specified in an ICD.

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.

3.4.12.13.4.15.3 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).

3.4.12.23.4.15.4 In general, tMedia ropospheric corrections (ionosphere, troposphere) shall should not be applied by the TDM producer; troposphericmedia corrections shall may be applied by the TDM recipient using the data conveyed in the STEC, TROPO_WET and TROPO_DRY Data Section keywords. (Note that a 'CORRECTION_TROPO' keyword is provided, in the event that the TDM recipient desires to receive data that has already been corrected).

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

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

3.4.133.4.16 The TDM Tracking Data RecordData Section keyword assignments are shown in 3.5, which specifies for each keyword:

– the keyword to be used;

– the data type to which it applies;

– applicable units for the associated values;

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

– the range of values, where applicable;

– default values, where applicable;

– applicable comments.

NOTE – See annex D for detailed usage examples.

3.4.143.4.17 All data type keywords in the TDM Data Block Section must be from 3.5. The standard tracking data types are extended to cover also some of the ancillary data that may be required for precise trajectory orbit determination work. Subsection 3.5 identifies the most frequently used data and ancillary types.

3.5 TDM DATA BLOCK SECTION KEYWORDS

3.5.1 OVERVIEW

This subsection describes each of the keywords that may be used in the Data portionSection of the TDM segmentSegment. In general, there is no required order in the Data portionSection of the TDM segmentSegment. Exceptions are the 'DATA_START' and 'DATA_STOP' keywords, which must be the first and last keywords in the Data BlockSection, respectively. For ease of reference, table 3-53-5 containing all the keywords sorted in alphabetical order is shown immediately below. Table 3-63-6 repeats the information from table 3-53-5 in category order.; D-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 angle signal related keywords are together, all media related keywords are together, etc.).

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

Keyword	Units	Text Link
AGC	dBm	3.5.2.1
ANGLE_1	deg	3.5.4.2
ANGLE_2	deg	3.5.4.3
CARRIER_POWER	dBm	3.5.2.1
AZIMUTH_RATE	deg/s	3.5.2.2
CARRIER_SNR	dB-Hz	3.5.2.2
CLOCK_BIAS	s	3.5.5.1
CLOCK_DRIFT	s/s	3.5.5.2
COMMENT	n/a	3.5.8.1
CPDELAY	TECU	3.5.5.1
DATA_START	n/a	3.5.8.2
DATA_STOP	n/a	3.5.8.3
DOR	s	3.5.3.2
DOPPLER_INSTANTANEOUS	km/s	3.5.2.2
DOPPLER_INTEGRATED	km/s	3.5.2.3
PC_N0	dB-Hz	3.5.2.4
PR_N0	dB-Hz	3.5.2.5
PRESSURE	hPa (hectopascal)	3.5.7.1
RANGE_OBS	kmper RANGE_UNITS keyword in metadata	3.5.2.63.5.2.5
RANGE_RATE	per RANGE_UNITS keyword in metadata	3.5.2.4
RANGE_SNR	dB-Hz	3.5.2.5
RECEIVE_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.7
RECEIVE_FREQ	Hz	3.5.2.7
RHUMIDITY	%	3.5.7.2
STEC	TECU	3.5.6.1
TEMPERATURE	K	3.5.7.3
TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.8

Keyword	Units	Text Link
TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5)	Hz/s	3.5.2.93.5.2.6
TROPO_DRY	m	3.5.6.23.5.5.2
TROPO_WET	m	3.5.6.33.5.5.2
VLBI_DELAY	s	3.5.3.3

NOTE Table 3-63-6 repeats the information from table 3-53-5 in Category Order.

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

Keyword	Units	Text Link
Signal Related Keywords		3.5.2
~~AGC~~CARRIER_POWER	dBm	3.5.2.1~~3.5.2.1~~
~~AZIMUTH_RATE~~	~~deg/s~~	~~3.5.2.2~~
~~CARRIER_SNR~~	~~dB-Hz~~	~~3.5.2.2~~
DOPPLER_INSTANTANEOUS	km/s	3.5.2.2
DOPPLER_INTEGRATED	km/s	3.5.2.3
PC_N0	dB-Hz	3.5.2.4
PR_N0	dB-Hz	3.5.2.5
RANGE_OBS	~~per RANGE_UNITS keyword in metadata~~km	3.5.2.6~~3.5.2.5~~
~~RANGE_RATE~~	~~per RANGE_UNITS keyword in metadata~~	~~3.5.2.4~~
~~RANGE_SNR~~	~~dB-Hz~~	~~3.5.2.5~~
RECEIVE_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.7
RECEIVE_FREQ	Hz	3.5.2.7
TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5)	Hz	3.5.2.8
TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5)	Hz/s	3.5.2.9~~3.5.2.6~~
VLBI/Delta-DOR Related Keywords		
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
Time Related Keywords		3.5.5
CLOCK_BIAS	s	3.5.5.1
CLOCK_DRIFT	s/s	3.5.5.2
Media Related Keywords		3.5.6
~~CPDELAY~~STEC	TECU	3.5.6.1~~3.5.5.1~~
TROPO_DRY	m	3.5.6.2~~3.5.5.2~~
TROPO_WET	m	3.5.6.3~~3.5.5.2~~
Meteorological Related Keywords		3.5.7
PRESSURE	hPa ~~(hectopascal)~~	3.5.7.1
RHUMIDITY	%	3.5.7.2

Keyword	Units	Text Link
TEMPERATURE	K	3.5.7.3
Miscellaneous Keywords		3.5.8
COMMENT	n/a	3.5.8.1
DATA_START	n/a	3.5.8.2
DATA_STOP	n/a	3.5.8.3

3.5.2 SIGNAL RELATED KEYWORDS

3.5.2.1 AGCCARRIER_POWER

The AGC 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). The Automatic Gain Control (AGC) level reports how much it was necessary to amplify the incoming signal before passing it on to downstream components. This is an indirect way of reportsing the strength of the signal received from the spacecraft, in decibels (referenced to 1 milliwatt). The unit for the AGCCARRIER_POWER keyword is dBm. 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.

3.5.2.2AZIMUTH_RATE

The AZIMUTH_RATE keyword shall represent an interferometer azimuth rate, for example, in a Connected Element Interferometry session. The units for AZIMUTH_RATE shall be deg/s. The value shall be a double precision value.

3.5.2.3CARRIER_SNR

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

3.5.2.2 DOPPLER_INSTANTANEOUS

The value associated with the DOPPLER_INSTANTANEOUS keyword represents a calculation in which the instantaneous Doppler shift is multiplied by the speed of light, representing the instantaneous velocity of the spacecraft. The value shall be a double precision value. Units are km/s.

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 an observable created by extracting an incremental phase shift from a measurement of accumulated phase shift over the INTEGRATION_INTERVAL specified in the Metadata Section, and multiplying by the speed of light. The timetag and the time bounds of the integration interval are determined by the TIMETAG_REF and INTEGRATION_REF keywords. The value shall be a double precision value and may be negative, zero, or positive. Units are km/s.

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 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 dB-Hz. The value shall be a double precision value.

3.5.2.5 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 dB-Hz. It shall be a double precision value, and may be positive, zero, or negative.

~~3.5.2.4~~3.5.2.6 RANGE_OBS

~~3.5.2.4.1The RANGE keyword prefix shall be used to indicate that the values represent measurements from ambiguous ranging systems, differenced range, skin radar, proximity radar, or similar radar. There shall be three suffixes associated with the RANGE prefix, i.e., _OBS, _RATE, and _SNR. Thus the three keywords are RANGE_OBS, RANGE_RATE, and RANGE_SNR.~~

~~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/ .~~

~~RANGE_OBS:~~

The value associated with the RANGE_OBS 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_OBS shall be ~~as specified by the 'RANGE_UNITS' metadata keyword (either 'RU' for 'range units', 'S' for 'seconds', or~~

'KM' km' for 'kilometers'). If different range units are used by the tracking agency (e.g., 'DSN range units'), the measurements should be converted to kilometers prior to exchanging the data. Note that for many applications, proper processing of the RANGE_OBS 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_OBS does not represent the range to the spacecraft. If differenced range is provided (MODE = SINGLE_DIFF), the 'RANGE_OBS' keyword shall be used to convey the difference in range., the definition of the range unit should be specified in the ICD. 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/ .

3.5.2.4.2RANGE_RATE: The value associated with the RANGE_RATE keyword is the rate of change in the RANGE_OBS starting at the timetag and continuing until the next timetag. The units for RANGE_RATE shall be congruent with the decision on units for RANGE_OBS, i.e., if the units specified in the metadata are 'RU', then the units for RANGE_RATE are 'RU/S'; if the units specified in the metadata are 'S', then the units for RANGE_RATE are 'S/S'; and if the units specified in the metadata are 'KM', then the units for RANGE_RATE are 'KM/S'.

3.5.2.53.5.2.7 RANGE_SNR: RECEIVE_FREQ (and RECEIVE_FREQ_n)

3.5.2.5.13.5.2.7.1 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 keyword settings of the TIMETAG_REF, INTEGRATION_REF, and INTEGRATION_INTERVAL keywords. 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). Note that the downlink band is not specified in the TDM; rather, it is inferred from the received frequency.

3.5.2.5.23.5.2.7.2 Using the RECEIVE_FREQ, the instantaneous Doppler measurement is calculated as follows:

Doppler_shift = –((transmit_freq * transponder_ratio) - receive_freq) or

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 is calculated as follows, where t is the timetag, and Δt is the value assigned to the INTEGRATION_INTERVAL keyword:

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

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 [E10][E10]).

INTEGRATION_REF	END	MIDDLE	START
α	α = -½	α = 0	α = ½
Upper Limit	t	t + ½Δt	t + Δt
Lower Limit	t - Δt	t - ½Δt	t

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

3.5.2.5.33.5.2.7.4 The transponder ratios used for interagency exchanges should be specified in the ICD.

3.5.2.5.43.5.2.7.5 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.

3.5.2.63.5.2.8 TRANSMIT_FREQ_n

~~**3.5.2.6.1**The TRANSMIT keyword prefix shall be used to indicate that the values represent measurements of the transmitted frequency from uplink operations. The TRANSMIT keywords are indexed to accommodate scenarios in which multiple uplinks are used. There shall be two suffixes associated with the TRANSMIT prefix, i.e., _FREQ and _FREQ_RATE. Thus the two keywords are TRANSMIT_FREQ and TRANSMIT_FREQ_RATE.~~

TRANSMIT_FREQThe TRANSMIT_FREQ keyword shall be used to indicate that the values represent measurements 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 should be specified in the ICD. 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).

3.5.2.9 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).

3.5.2.5.4Usage 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 'N/A' and the PATH keyword defines the signal path.

3.5.3 VLBI AND DELTA-DOR RELATED KEYWORDS

3.5.3.1 General

In VLBI, a signal source is measured simultaneously using two receivers in different antenna complexes, achieving a long baseline (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_1 minus the range measured via PATH_2. The Timetag is the time of signal reception via PATH_2. This data type is normally used for the spacecraft observable in a Delta-DOR measurement. The range is either 1-way, 2-way or 3-way, depending on the values of the PARTICIPANT_n and PATH keywords. TRANSMIT_FREQ_n shall provide the spacecraft beacon frequency if 1-way, or the transmit frequency at the uplink station if 2-way or 3-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_1 minus the time of signal arrival via PATH_2. The Timetag is the time of signal reception via PATH_2. 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.

~~3.5.3~~3.5.4 ANGLE DATA KEYWORDS

~~3.5.3.1~~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.

~~3.5.3.2~~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.

~~3.5.3.3~~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.

~~3.5.4~~3.5.5 TIME RELATED KEYWORDS

~~3.5.4.1~~3.5.5.1 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, normally UTC. 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~~Segment, i.e., not mixed with signal data or other data types. A single participant (PARTICIPANT_1) is acceptable for use with CLOCK_BIAS data. The units for CLOCK_BIAS shall be ~~shown in~~ seconds~~ of clock bias~~. The value shall be a double precision value, and may be positive or negative. The default value shall be 0.0.

~~3.5.4.2~~3.5.5.2 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 where 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. Normally the time related data such as CLOCK_DRIFT data and CLOCK_BIAS data should appear in a dedicated TDM ~~segment~~Segment, i.e., not mixed with signal data or other data types. A single participant (PARTICIPANT_1) is acceptable for use with CLOCK_DRIFT data. The units for CLOCK_DRIFT shall be ~~shown in~~ seconds-per-second (s/s)~~ of clock drift~~. The value shall be a double precision value, and may be positive or negative. The default value shall be 0.0.

~~3.5.5~~3.5.6 MEDIA RELATED KEYWORDS

~~3.5.5.1~~3.5.6.1 ~~CPDELAY~~STEC

The ~~CPDELAY~~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 CPDELAYSTEC keyword are Total Electron Count Units (TECU), where 1 TECU = 10^{16} electrons/m**2. 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 tracking data segmentTDM Segment with PARTICIPANTs being one spacecraft and one antenna, and a MODE setting of 'N/A'. 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.

3.5.5.2TROPO

3.5.5.2.1The TROPO keyword prefix shall be used to indicate that the values represent measurements associated with the dry and wet zenith delay through the troposphere at the timetag. There shall be two suffixes associated with the TROPO prefix, i.e., _DRY and _WET. Thus the two keywords are TROPO_DRY and TROPO_WET. There should be an agreed upon elevation mapping specified in the ICD (e.g., the Niell mapping function developed for VLBI applications). Tropospheric corrections should be done 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.

3.5.6.2 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 double precision value (0.0 <= TROPO_DRY).

3.5.6.3 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 double precision value (0.0 <= TROPO_WET).

~~3.5.6~~3.5.7 METEOROLOGICAL RELATED KEYWORDS

~~3.5.6.1~~3.5.7.1 PRESSURE

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

~~3.5.6.2~~3.5.7.2 RHUMIDITY

The value associated with the RHUMIDITY keyword shall be the relative humidity observable, specified in percent. RHUMIDITY shall be a double precision type value, 0 <= RHUMIDITY <= 100.

~~3.5.6.3~~3.5.7.3 TEMPERATURE

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

~~3.5.7~~3.5.8 MISCELLANEOUS KEYWORDS

~~3.5.7.1~~3.5.8.1 COMMENT

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

~~3.5.7.2~~3.5.8.2 DATA_START

The ‘DATA_START’ keyword must be the first keyword in the Data ~~portion~~Section of the TDM ~~segment~~Segment, which serves to delimit the Data Section. The keyword shall appear on a line by itself with no timetags or values~~, which serves to delimit the Tracking Data Records section~~. Example: ‘DATA_START’.

~~3.5.7.3~~3.5.8.3 DATA_STOP

The ‘DATA_STOP’ keyword must be the last keyword in the Data ~~portion~~Section of the TDM ~~segment~~Segment, which serves to delimit the Data Section. The keyword shall appear on a line by itself with no timetags or values~~, which serves to delimit the Tracking Data Records section~~. 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 ~~file~~ 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 ~~block~~ Section line;

– ~~Tracking~~ Data ~~Record~~Section line;

~~–Comment line;~~

– blank line.

4.2.3 All Header, Metadata ~~block~~Section, and ~~Tracking Data Record~~Data Section lines, with exceptions as noted below, shall use ‘keyword = value’ syntax, abbreviated as KVN. Only a single 'keyword = value', assignment small be made on a line.

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

– TDM lines in the Header and Metadata ~~block~~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 ~~block~~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 Tracking Data Record line must be separated by at least one blank character (white space). The measurement may optionally be followed by the applicable units, as defined in table 3-5~~3-5~~.

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

~~4.2.4~~4.2.5 Keywords must be uppercase and must not contain blanks.

~~4.2.5~~4.2.6 Any white space immediately preceding or following the keyword shall not be significant.

~~4.2.6~~4.2.7 Any white space immediately preceding or following the equals sign '=' shall not be significant.

~~4.2.7~~4.2.8 Any white space immediately preceding the end of line shall not be significant.

~~4.2.8~~4.2.9 Blank lines may be used at any position within the TDM.

~~4.2.9~~4.2.10 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-null value field must be specified for each obligatory keyword provided. ~~If an actual observable value is not available, then 'N/A' must be the value specified for an obligatory keyword.~~

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 (i.e., $-2^{31} <= x <= 2^{31}-1$).

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 1 digit is required before and after a decimal point. ~~If the fractional part is zero, the decimal point and following zero(s) may be omitted. There must be a leading zero if -1.0 < x < 1.0 .~~ The number of digits shall be ~~18~~ 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. The specifications for floating-point values conform to the IEEE double precision type. 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.

4.3.6 Text value fields may be constructed using mixed case; case shall not be significant.

4.3.7 Blanks shall ~~be prohibited~~not be permitted within numeric values and time values.

4.3.8 In value fields that are text, an underscore shall be equivalent to a single blank. Individual blanks between values shall be retained (shall be significant) but multiple blanks shall be equivalent to a single blank. Value fields that are text shall begin and end with a quotation mark (single or double) if blanks within the text are needed. If no quotation marks are used blanks are not permitted. The COMMENT keyword is an exception to this requirement.

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].

4.3.10 There are 4 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 TRACKING DATA RECORD

4.4.1 For documentation purposes and clarity, units may be included as ASCII text after a value in the Data Section. If units are displayed, they must exactly match the units specified in table 3-53-5 (including case). If units are displayed, then:

a) there must be at least one blank character between the value and the units text;

b) the units must be enclosed within square brackets (e.g. ‘[km]’); and

c) exponents of units shall be denoted with a double asterisk (i.e. ‘**’, for example, m/s^2=m/s**2).; and

d)The units documentation may be constructed using all uppercase or all lowercase characters.

4.4.2 Since the units are fixed in the TDM, and the units are provided only as documentation, the units shall not be used to make processing decisions, i.e., they shall be treated as comments and not part of the value.

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 fileTDM; i.e., comment lines shall be optional.

NOTE – Given that TDM's may consist of large amounts of data, and generally produced via automation, using the COMMENT feature of the TDM may have limited utility. 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 'freeware' utilities (e.g., UNIX 'grep') could also be used for this purpose.

4.5.2 Comment lines may if used, shall only occur:

– at any position after the first non-blank line in the TDM Headerat 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 blockSection (i.e., between the META_START keyword and the TIME_SYSTEM keyword, as shown in Table 3-3);

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

4.5.3 Comments must not appear between Tracking Data Records.

4.5.44.5.3 All comment lines shall begin with the 'COMMENT' keyword followed by a singleat 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. Comments need not be delimited with quotation marks.

~~4.5.5~~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.

~~4.5.6~~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.

~~4.5.7Given that TDM files may be very large, and generally produced via automation, using the COMMENT feature of the TDM may have limited utility. 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 'freeware' utilities (e.g., UNIX 'grep') could also be used for this purpose.~~

~~The connection between the various Metadata and Data Section Keywords could be represented in the following abbreviated way:~~

~~1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n~~					
~~a) either constant uplink or measurements are not directly influenced~~					
	~~Range Data~~	~~Doppler Data~~			~~Angle Data~~
~~Data Keywords~~	~~RANGE_OBS~~	~~DOPPLER_INSTANTANEOUS [KM/S]~~	~~RECEIVE_FREQ [HZ] TRANSMIT_FREQ_n~~	~~DOPPLER_INTEGRATED [KM/S]~~	~~ANGLE_1 ANGLE_2 [DEG]~~
~~Metadata Keywords~~	~~RANGE_MODE RANGE_MODULUS RANGE_UNITS~~			~~INTEGRATION_INTERVAL INTEGRATION_REF~~	~~ANGLE_TYPE REFERENCE_FRAME~~
~~b) changing uplink, described in TRANSMIT_FREQ either in tabular form or with the help of TRANSMIT_FREQ_RATE~~					
		~~Doppler Data~~			
~~Data Keywords~~			~~RECEIVE_FREQ [HZ] TRANSMIT_FREQ_n TRANSMIT_FREQ_RATE_n~~		
~~Metadata Keywords~~					

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	RANGE_OBS		RECEIVE_FREQ [HZ] TRANSMIT_FREQ_n	DOR [SEC]	VLBI_DELAY [SEC]
Metadata Keywords	RANGE_MODE RANGE_MODULUS RANGE_UNITS			RANGE_MODE RANGE_MODULUS	

Of course, TIME_SYSTEM and TIMETAG_REF would have to be specified for all the measurement types.

In addition to these common tracking data types Media data (troposphere and ionosphere) and other useful data such as corrections and offsets or frequencies and signal strength could be transmitted next to the actual tracking measurements.

5 SECURITY

5.1 GENERAL

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

5.2 SECURITY CONCERNS RELATED TO THIS RECOMMENDED STANDARD

5.2.1 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.

5.2.2 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.

5.2.3 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.

5.2.4 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 IT Security functionaries of exchange participants.

5.2.5 CONTROL OF ACCESS TO RESOURCES

This Recommended Standard assumes that control of access to resources will be managed by the systems upon which provider formatting and recipient processing are performed.

5.2.6 AUDITING OF RESOURCE USAGE

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

5.3 POTENTIAL THREATS AND ATTACK SCENARIOS

There are no certain potential threats or attack scenarios that apply specifically to the technologies specified in this Recommended Standard. Potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented should be addressed by the management of those systems and networks. Protection from unauthorized access 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.

5.4 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

There are no known consequences of not applying security to the technologies specified in this Recommended Standard. 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.

5.5 DATA SECURITY IMPLEMENTATION SPECIFICS

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

ANNEX A

RATIONALE FOR TRACKING DATA MESSAGES

(INFORMATIVE)

A1 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 draft Recommended Standard reflects heritage requirements pertaining to some of the technical participants' home institutions collected during the preparation of the draft 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 draft Recommended Standard.

A2 PRIMARY REQUIREMENTS ACCEPTED FOR TRACKING DATA MESSAGES

Table A-1: Primary Requirements

ID	Requirement	Trace
A-1-1	Data must be provided in digital form (computer file).	3.1.12.2
A-1-2	The object being tracked must be clearly identified and unambiguous.[1]	3.3
A-1-3	All primary resources used in the tracking session must be clearly identified and unambiguous.	3.3
A-1-4	Time measurements (time stamps, timetags, or epochs) must be provided in a commonly used, clearly specified system.	3.3
A-1-5	The time bounds of the tracking data must be unambiguously specified.	3.3, 3.4
A-1-6	The standard must provide for clear specification of units of measure.	4.40
A-1-7	Files Tracking Data Messages must be readily portable between and useable within 'all' computational environments in use for the processing of tracking data by Member Agencies.	3.13
A-1-8	Files Tracking Data Messages must have means of being uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose.	3.23.1.4
A-1-9	If in file format, the Tracking Data Message fFile name syntax and length must not violate computer constraints for those computing environments in use for the processing of tracking data by Member Agencies.	3.1.72.2
A-1-10	The Tracking Data Message format shall be independent of the equipment that was used to perform the tracking.	3, 44.2
A-1-11	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.	3.4
A-1-12	The timetag of the tracking data shall always be unambiguously specified with respect to the measurement point or instrument reference point.	3.4
A-1-13	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.	3.4
A-1-14	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).	3.4
A-1-15	Other corrections applied to the data, such as media corrections, shall be agreed upon by the service-providing and the customer Agencies via an ICD.	4.5
A-1-16	The data transfer mechanism shall not place constraints on the tracking data content.	3.1.81.2

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

Table A-2: Heritage Requirements

	Requirement	Trace
A-2-1	The standard shall be, or must include, an ASCII format.	4.2
A-2-2	The standard shall not require software supplied by other agencies.	3, 4.2

Table A-3: Desirable Characteristics

ID	Requirement	Trace
A-3-1	The standard should apply to non-traditional objects, such as landers, rovers, balloons, spacecraft-spacecraft tracking data exchange, etc.	3.3, 3.4
A-3-2	The standard should be extensible with no disruption to existing users/uses.	3.23.1.4
A-3-3	Keywords, values, and terminology in the TDM should be the same as those in the ODM and ADM, where applicable.	3.23.1.4, 3.3, 3.4, 4.5, 3.3, 3.5, 4
A-3-4	The standard shall not preclude an XML implementation.	32

ANNEX B

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.

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 name of the time system 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
51. Definition of accuracy requirements pertaining to any particular TDM.	1.2.31.2
62. Method of exchanging TDMs (e.g., post-processed SFTP, real-time stream, etc.).	1.2, 2.21.2.4, 3.1.8
7Interagency Information Technology (IT) security requirements in TDMs.	1.6
3. Whether the ASCII or XML format of the TDM will be exchanged.	2.2.2
4. Conditions under which multiple TDMs will be exchanged (e.g., launch supports with periodic TDMs; critical maneuvers, orbit insertions, etc.).	2.3
85. TDM file naming conventions.	3.1.72.2
9Conditions under which multiple TDMs will be exchanged (e.g., launch supports with periodic TDMs; critical maneuvers, orbit insertions, etc.).	2.3
6. List of valid values that may be used for 'ORIGINATOR' keyword in the TDM Header.	3.2.3
107. -Specific TDM version number(s) that will be exchanged.	3.2.53.1.4
11List of valid values that may be used for 'ORIGINATOR' keyword in the TDM Header.	3.1.4
128. Antenna geometry, if not accommodated by built-in values of 'ANTENNA_FRAME''ANGLE_TYPE' keyword.	Table 3-33.3
139. The list of eligible names that is used for PARTICIPANT keywords.	Table 3-3, 3.3.1.103.3
1410. Definitions of 'RAW', 'VALIDATED', and 'DEGRADED' as they apply to data quality for a particular exchange.	Table 3-33.3
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, 3.3.6.4
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.	3.3.9
14. Complete description of the station location(s), 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 would be necessary for exceptional cases, where the station location is not fixed during track, for example.	3.4.13

Item	Section
15. Whether TRANSMIT_DELAY and RECEIVE_DELAY are processed by the producer or the consumer of the tracking data.	3.4.15.1
15If more than five participants are necessary, special arrangements are necessary.	3.3.6
16When all the data in a TDM segment is media related or weather related, then the value of the MODE keyword is 'N/A'. Data of this type 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.	3.3.9
1.Complete description of the station location(s), 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 would be necessary for exceptional cases, where the station location is not fixed during track, for example.	3.4
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). Spin corrections should be applied by the OPERATOR of the spacecraft.	3.4.15.3
18. Correction algorithms that are more complex than a simple scalar value.	3.4.15.5
1719. Standard corrections that will (or will not) be applied to the data (e.g., tropospheric, meteorological, media, transponder, etc.).	3.4.15.63.4
18Spin correction arrangements (who will do the correction… the agency providing the tracking or the agency that operates the spacecraft). Spin corrections should be applied by the OPERATOR of the spacecraft.	3.4
19Definition of the range unit.	3.5.2.4
2020. Equation for calculation of four-way Doppler shift, if applicable.	3.5.2.7
2121. 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).	3.5.2.7, 3.5.2.8
22. Whether or not it is necessary to distinguish the separate Slant Total Electron Count contributions between ionospheric and interplanetary STEC.	3.5.6.1
2223. Elevation mapping function for the tropospheric data.	3.5.6.2, 3.5.6.33.5.5.2

Item	Section
~~23~~24. Recommended polynomial interpolations for tropospheric data.	3.5.6.2, 3.5.6.3~~3.5.5.2~~
~~24~~25. 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 in an ICD between participating agencies.	4.3.5~~4.3~~
~~25~~26. Information which must appear in comments for any given TDM exchange.	4.5.4~~4.5~~
~~26~~27. Description of any ancillary data not already included in the Tracking Data Record definition.	4.5.5~~4.5~~
28. Interagency Information Technology (IT) security requirements in TDMs.	5.5
~~27 Correction algorithms that are more complex than a simple scalar value.~~	~~N/A~~
~~28 Whether the ASCII or XML format of the TDM will be exchanged.[1]~~	~~N/A~~
29. Time systems not shown in Annex F	Annex F
30. Reference frames not shown in Annex F	Annex F

~~[1] Currently the XML implementation does not exist, so the only format that can be exchanged is the ASCII version).~~

ANNEX C

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ADM	Attitude Data Message
ASCII	American Standard Code for Information Interchange
AZEL	Azimuth-Elevation
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee on Space Data Systems
Delta-DOR	Delta Differential One-Way Ranging
~~DSS~~	~~Deep Space Station~~
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
MOIMS	Mission Operations and Information Management Services
N/A	Not Applicable / Not Available
ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
Pr/No	Ranging Power to Noise Spectral Density ratio
RADEC	Right Ascension-Declination
SANA	Space Assigned Numbers Authority
SCLK	Spacecraft Clock
SFTP	Secure File Transfer Protocol
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 D

EXAMPLE TRACKING DATA MESSAGES

(INFORMATIVE)

~~This annex will explain various tracking data scenarios and how they may be expressed in the Tracking Data Message.[1]~~

~~Table D-1 below provides suggestions as to the metadata and data keywords that may be useful for specific measurement scenarios. In some cases, particular keyword settings are included. In most cases, these are not requirements; however, they may assist the user in constructing a TDM that captures the data from a specific measurement session.~~

~~[1] As of TDM version 1.0, this annex is still under development.~~

Table D-1: Measurement Specific Keywords and Settings

Data Type	Metadata Keywords	Data Keywords
Range	CORRECTION_RANGE DATA_QUALITY PATH INTEGRATION_REF MODE=SEQUENTIAL RANGE_MODE RANGE_MODULUS RANGE_UNITS RECEIVE_DELAY_n TIMETAG_REF TRANSMIT_DELAY_n	RANGE_OBS RANGE_RATE RANGE_SNR TRANSMIT_FREQ TRANSMIT_FREQ_RATE CLOCK_BIAS CLOCK_DRIFT
Differenced Range	CORRECTION_RANGE DATA_QUALITY DIFF_MODE MODE=SINGLE-DIFF PATH RANGE_MODULUS RECEIVE_DELAY_n TIMETAG_REF TRANSMIT_DELAY_n	RANGE_OBS TRANSMIT_FREQ
Doppler	INTEGRATION_INTERVAL CORRECTION_DOPPLER DATA_QUALITY FREQ_OFFSET INTEGRATION_REF MODE=SEQUENTIAL PATH RECEIVE_DELAY_n TRANSMIT_DELAY_n	TRANSMIT_FREQ TRANSMIT_FREQ_RATE RECEIVE_FREQ CLOCK_BIAS CLOCK_DRIFT
Differenced Doppler	INTEGRATION_INTERVAL CORRECTION_DOPPLER DATA_QUALITY DIFF_MODE INTEGRATION_REF MODE=SINGLE-DIFF RECEIVE_DELAY_n TRANSMIT_DELAY_n	RECEIVE_FREQ CLOCK_BIAS CLOCK_DRIFT
Delta-DOR	INTEGRATION_INTERVAL DATA_QUALITY DIFF_MODE INTEGRATION_REF MODE=DOUBLE-DIFF RANGE_MODE RANGE_MODULUS RANGE_UNITS RECEIVE_DELAY_n TIMETAG_REF TRANSMIT_DELAY_n	RANGE_OBS TRANSMIT_FREQ CLOCK_BIAS CLOCK_DRIFT
Meteorological	DATA_QUALITY MODE=N/A	HUMIDITY PRESSURE TEMPERATURE

Data Type	Metadata Keywords	Data Keywords
Media	DATA_QUALITY MODE=N/A CORRECTION_TROPO_DRY CORRECTION_TROPO_WET CORRECTION_CP	CPDELAY TROPO_DRY TROPO_WET
Time Related (clock bias and drift)	DATA_QUALITY MODE=N/A	CLOCK_BIAS CLOCK_DRIFT
Angles	ANGLE_TYPE CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 DATA_QUALITY MODE=SEQUENTIAL PATH REFERENCE_FRAME	ANGLE_1 ANGLE_2

The figures on the following pagesin this Annex are example Tracking Data Messages. For actual TDMs, the ratio of tracking data to metadata will probably be higher than appears in these samples in most cases. Also, many of the examples portray a single data type for the sake of simplicity, and to illustrate the concepts of the various keywords.; hHowever, the TDM Recommended Standard does not require thisthat only a single data type be used in a given TDM. ; aAny of the keywords can appear in the same TDM data segmentSegment, as long as the associated metadata accurately provides the context.

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-160T20:15:00
ORIGINATOR = NASA/JPL

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/JPL

META_START
COMMENT Data quality degraded by antenna pointing problem...
slightly noisy COMMENT Slightly noisy data
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
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 0
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
START_TIME = 2005-159T17:41:00
STOP_TIME = 2005-159T17:41:40
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
RECEIVE_FREQ_1 =   2005-159T17:41:30     32021035932.5939
RECEIVE_FREQ_1 =   2005-159T17:41:31     32021035970.6275
RECEIVE_FREQ_1 =   2005-159T17:41:32     32021036008.6377
RECEIVE_FREQ_1 =   2005-159T17:41:33     32021036046.6657
RECEIVE_FREQ_1 =   2005-159T17:41:34     32021036084.6911
RECEIVE_FREQ_1 =   2005-159T17:41:35     32021036122.689
RECEIVE_FREQ_1 =   2005-159T17:41:36     32021036160.7083
RECEIVE_FREQ_1 =   2005-159T17:41:37     32021036198.7493
RECEIVE_FREQ_1 =   2005-159T17:41:38     32021036236.7388
RECEIVE_FREQ_1 =   2005-159T17:41:39     32021036274.7529
RECEIVE_FREQ_1 =   2005-159T17:41:40     32021036312.7732
```

```
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0

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/JPL


COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down
COMMENT Data quality degraded by antenna pointing problem... slightly noisy
data

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
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 32021035200.0
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
START_TIME = 2005-159T17:41:00
STOP_TIME = 2005-159T17:41:40
DATA_QUALITY = DEGRADEDRAW
META_STOP

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

```
RECEIVE_FREQ_1   =   2005-159T17:41:39   1074.7529  [HZHz]
RECEIVE_FREQ_1   =   2005-159T17:41:40   1112.7732  [HZHz]
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0

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

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


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

META_START
TIME_SYSTEM = UTC
START_TIME=2005-184T11:12:23
STOP_TIME=2005-184T13:59:48.27
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 1,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 0.0
START_TIME = 2005-184T11:12:23
STOP_TIME = 2005-184T13:59:48.27
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-184T11:12:23     7175173383.615373
TRANSMIT_FREQ_1 = 2005-184T11:12:24     7175173384.017573
TRANSMIT_FREQ_1 = 2005-184T11:12:25     7175173384.419773
TRANSMIT_FREQ_1 = 2005-184T11:12:26     7175173384.821973
TRANSMIT_FREQ_1 = 2005-184T11:12:27     7175173385.224173
TRANSMIT_FREQ_1 = 2005-184T11:12:28     7175173385.626373
TRANSMIT_FREQ_1 = 2005-184T11:12:29     7175173386.028573
TRANSMIT_FREQ_1 = 2005-184T11:12:30     7175173386.430773
TRANSMIT_FREQ_1 = 2005-184T11:12:31     7175173386.832973
TRANSMIT_FREQ_1 = 2005-184T11:12:32     7175173387.235173
TRANSMIT_FREQ_1 = 2005-184T11:12:33     7175173387.637373
TRANSMIT_FREQ_1 = 2005-184T11:12:34     7175173388.039573
TRANSMIT_FREQ_1 = 2005-184T11:12:35     7175173388.441773
TRANSMIT_FREQ_1 = 2005-184T11:12:36     7175173388.843973
TRANSMIT_FREQ_1 = 2005-184T11:12:37     7175173389.246173
TRANSMIT_FREQ_1 = 2005-184T11:12:38     7175173389.648373
TRANSMIT_FREQ_1 = 2005-184T11:12:39     7175173390.050573
TRANSMIT_FREQ_1 = 2005-184T11:12:40     7175173390.452773
TRANSMIT_FREQ_1 = 2005-184T11:12:41     7175173390.854973
TRANSMIT_FREQ_1 = 2005-184T11:12:42     7175173391.257173
TRANSMIT_FREQ_1 = 2005-184T11:12:43     7175173391.659373
TRANSMIT_FREQ_1 = 2005-184T11:12:44     7175173392.061573
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
RECEIVE_FREQ_1  = 2005-184T13:59:44.27  8429749418.356392
RECEIVE_FREQ_1  = 2005-184T13:59:45.27  8429749417.791263
RECEIVE_FREQ_1  = 2005-184T13:59:46.27  8429749417.142501
RECEIVE_FREQ_1  = 2005-184T13:59:47.27  8429749416.544415
RECEIVE_FREQ_1  = 2005-184T13:59:48.27  8429749415.910163
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0

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

   CREATION_DATE = 2005-191T23:00:00
   ORIGINATOR = NASA/JPL

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

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 1.8183e-07 s0.0545 km applied to uplink
signal path
   COMMENT Antenna Z-height correction 6.3141e-08 s0.0189 km applied to downlink
signal path

   TIME_SYSTEM = UTC
   START_TIME = 2005-191T00:31:51
   STOP_TIME = 2005-191T01:13:09
   PARTICIPANT_1 = DSS-24
   PARTICIPANT_2 = yyyy-nnnA
   MODE = SEQUENTIAL
   PATH = 1,2,1
   TIMETAG_REF = RECEIVE
   INTEGRATION_REF = START
   RANGE_MODE = COHERENT
   RANGE_MODULUS = 2.0e+26
RANGE_UNITS = RU
   TRANSMIT_DELAY_1 = 7.7e-5
   TRANSMIT_DELAY_2 = 0.0
   RECEIVE_DELAY_1  = 7.7e-5
   RECEIVE_DELAY_2  = 0.0
START_TIME = 2005-191T00:31:51
STOP_TIME = 2005-191T01:13:09
   CORRECTION_RANGE = 164927.6946.7741
META_STOP

DATA_START
   TRANSMIT_FREQ_1  =  2005-191T00:31:51    7180064367.3536
   RANGE_OBS        =  2005-191T00:31:51    39242998.5151986
   RANGE_SNRPR_N0        =  2005-191T00:31:51    28.52538
   TRANSMIT_FREQ_1  =  2005-191T00:34:48    7180064472.3146
   RANGE_OBS        =  2005-191T00:34:48    61172265.3115234
   RANGE_SNRPR_N0        =  2005-191T00:34:48    28.39347
   TRANSMIT_FREQ_1  =  2005-191T00:37:45    7180064577.2756
   RANGE_OBS        =  2005-191T00:37:45    15998108.8168328
   RANGE_SNRPR_N0        =  2005-191T00:37:45    28.16193
   TRANSMIT_FREQ_1  =  2005-191T00:40:42    7180064682.2366
   RANGE_OBS        =  2005-191T00:40:42    37938284.4138008
   RANGE_SNRPR_N0        =  2005-191T00:40:42    29.44597
   TRANSMIT_FREQ_1  =  2005-191T00:43:39    7180064787.1976
   RANGE_OBS        =  2005-191T00:43:39    59883968.0697146
   RANGE_SNRPR_N0        =  2005-191T00:43:39    27.44037
   TRANSMIT_FREQ_1  =  2005-191T00:46:36    7180064894.77345
   RANGE_OBS        =  2005-191T00:46:36    14726355.3958799
   RANGE_SNRPR_N0        =  2005-191T00:46:36    27.30462
   TRANSMIT_FREQ_1  =  2005-191T00:49:33    7180065002.72044
   RANGE_OBS        =  2005-191T00:49:33    36683224.3750253
   RANGE_SNRPR_N0        =  2005-191T00:49:33    28.32537
   TRANSMIT_FREQ_1  =  2005-191T00:52:30    7180065110.66743
   RANGE_OBS        =  2005-191T00:52:30    58645699.4734682
   RANGE_SNRPR_N0        =  2005-191T00:52:30    29.06158
   TRANSMIT_FREQ_1  =  2005-191T00:55:27    7180065218.61442
   RANGE_OBS        =  2005-191T00:55:27    13504948.3585422
   RANGE_SNRPR_N0        =  2005-191T00:55:27    27.29589
   TRANSMIT_FREQ_1  =  2005-191T00:58:24    7180065326.56141
   RANGE_OBS        =  2005-191T00:58:24    35478729.4012973
   RANGE_SNRPR_N0        =  2005-191T00:58:24    30.48199
   TRANSMIT_FREQ_1  =  2005-191T01:01:21    7180065436.45167
   RANGE_OBS        =  2005-191T01:01:21    57458219.0681689
   RANGE_SNRPR_N0        =  2005-191T01:01:21    27.15509
   TRANSMIT_FREQ_1  =  2005-191T01:10:12    7180065768.96387
   RANGE_OBS        =  2005-191T01:10:12    56322324.0168757
   RANGE_SNRPR_N0        =  2005-191T01:10:12    28.73831
```

```
   TRANSMIT_FREQ_1  =  2005-191T01:13:09    7180065879.80127
   RANGE_OBS        =  2005-191T01:13:09    11216037.9857342
   RANGE_SNRPR_N0        =  2005-191T01:13:09    28.63882
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0

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

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


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

META_START
TIME_SYSTEM = UTC
START_TIME =  2005-184T11:12:23
STOP_TIME  =  2005-184T13:59:48.27
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = yyyy-nnnA
PARTICIPANT_3 = DSS-25
MODE = SEQUENTIAL
PATH = 1,2,3
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
START_TIME =  2005-184T11:12:23
STOP_TIME  =  2005-184T13:59:48.27
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2005-184T11:12:23     7175173383.615373
RECEIVE_FREQ_3  = 2005-184T13:59:27.27  8429753135.986102
TRANSMIT_FREQ_1 = 2005-184T11:12:24     7175173384.017573
RECEIVE_FREQ_3  = 2005-184T13:59:28.27  8429749428.196568
TRANSMIT_FREQ_1 = 2005-184T11:12:25     7175173384.419773
RECEIVE_FREQ_3  = 2005-184T13:59:29.27  8429749427.584727
TRANSMIT_FREQ_1 = 2005-184T11:12:26     7175173384.821973
RECEIVE_FREQ_3  = 2005-184T13:59:30.27  8429749427.023103
TRANSMIT_FREQ_1 = 2005-184T11:12:27     7175173385.224173
RECEIVE_FREQ_3  = 2005-184T13:59:31.27  8429749426.346252
TRANSMIT_FREQ_1 = 2005-184T11:12:28     7175173385.626373
RECEIVE_FREQ_3  = 2005-184T13:59:32.27  8429749425.738658
TRANSMIT_FREQ_1 = 2005-184T11:12:29     7175173386.028573
RECEIVE_FREQ_3  = 2005-184T13:59:33.27  8429749425.113143
TRANSMIT_FREQ_1 = 2005-184T11:12:30     7175173386.430773
RECEIVE_FREQ_3  = 2005-184T13:59:34.27  8429749424.489933
TRANSMIT_FREQ_1 = 2005-184T11:12:31     7175173386.832973
RECEIVE_FREQ_3  = 2005-184T13:59:35.27  8429749423.876996
TRANSMIT_FREQ_1 = 2005-184T11:12:32     7175173387.235173
RECEIVE_FREQ_3  = 2005-184T13:59:36.27  8429749423.325228
TRANSMIT_FREQ_1 = 2005-184T11:12:33     7175173387.637373
RECEIVE_FREQ_3  = 2005-184T13:59:37.27  8429749422.664049
TRANSMIT_FREQ_1 = 2005-184T11:12:34     7175173388.039573
RECEIVE_FREQ_3  = 2005-184T13:59:38.27  8429749422.054996
TRANSMIT_FREQ_1 = 2005-184T11:12:35     7175173388.441773
RECEIVE_FREQ_3  = 2005-184T13:59:39.27  8429749421.425801
TRANSMIT_FREQ_1 = 2005-184T11:12:36     7175173388.843973
RECEIVE_FREQ_3  = 2005-184T13:59:40.27  8429749420.824186
TRANSMIT_FREQ_1 = 2005-184T11:12:37     7175173389.246173
RECEIVE_FREQ_3  = 2005-184T13:59:41.27  8429749420.204178
TRANSMIT_FREQ_1 = 2005-184T11:12:38     7175173389.648373
RECEIVE_FREQ_3  = 2005-184T13:59:42.27  8429749419.596043
TRANSMIT_FREQ_1 = 2005-184T11:12:39     7175173390.050573
RECEIVE_FREQ_3  = 2005-184T13:59:43.27  8429749418.986191
TRANSMIT_FREQ_1 = 2005-184T11:12:40     7175173390.452773
RECEIVE_FREQ_3  = 2005-184T13:59:44.27  8429749418.356392
TRANSMIT_FREQ_1 = 2005-184T11:12:41     7175173390.854973
RECEIVE_FREQ_3  = 2005-184T13:59:45.27  8429749417.791263
TRANSMIT_FREQ_1 = 2005-184T11:12:42     7175173391.257173
RECEIVE_FREQ_3  = 2005-184T13:59:46.27  8429749417.142501
TRANSMIT_FREQ_1 = 2005-184T11:12:43     7175173391.659373
RECEIVE_FREQ_3  = 2005-184T13:59:47.27  8429749416.544415
TRANSMIT_FREQ_1 = 2005-184T11:12:44     7175173392.061573
RECEIVE_FREQ_3  = 2005-184T13:59:48.27  8429749415.910163
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0

COMMENT TDM example created by yyyyy-nnnA Nav Team (JAXA)

CREATION_DATE = 1998-06-10T01:00:00
ORIGINATOR = JAXA


COMMENT TDM example created by yyyyy-nnnA Nav Team (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
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
RANGE_MODE = CONSTANT
RANGE_MODULUS = 0
RANGE_UNITS = KM
ANGLE_TYPE = AZEL
START_TIME =  1998-06-10T00:57:37
STOP_TIME  =  1998-06-10T00:57:44
META_STOP

DATA_START
RANGE_OBS    =   10-JUN-1998T00:57:37          80452.7542
RANGE_RATE   =   10-JUN-1998T00:57:37            924.355
ANGLE_1      =   10-JUN-1998T00:57:37            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:37             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:37     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:38          80452.7368
RANGE_RATE   =   10-JUN-1998T00:57:38            924.354
ANGLE_1      =   10-JUN-1998T00:57:38            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:38             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:38     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:39          80452.7197
RANGE_RATE   =   10-JUN-1998T00:57:39            924.279
ANGLE_1      =   10-JUN-1998T00:57:39            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:39             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:39     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:40          80452.7025
RANGE_RATE   =   10-JUN-1998T00:57:40            924.267
ANGLE_1      =   10-JUN-1998T00:57:40            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:40             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:40     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:41          80452.6854
RANGE_RATE   =   10-JUN-1998T00:57:41            924.224
ANGLE_1      =   10-JUN-1998T00:57:41            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:41             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:41     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:42          80452.6680
RANGE_RATE   =   10-JUN-1998T00:57:42            924.190
ANGLE_1      =   10-JUN-1998T00:57:42            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:42             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:42     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:43          80452.6503
RANGE_RATE   =   10-JUN-1998T00:57:43            924.163
ANGLE_1      =   10-JUN-1998T00:57:43            256.64002393
ANGLE_2      =   10-JUN-1998T00:57:43             13.38100016
RECEIVE_FREQ =   10-JUN-1998–T00:57:43     2287487999.0

RANGE_OBS    =   10-JUN-1998T00:57:44          80452.6331
RANGE_RATE   =   10-JUN-1998T00:57:44            924.109
```

```
ANGLE_1      =   10-JUN-1998T00:57:44           256.64002393
ANGLE_2      =   10-JUN-1998T00:57:44            13.38100016
RECEIVE_FREQ =   10-JUN-1998-T00:57:44     2287487999.0
DATA_STOP
```

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

~~The next example TDM describes a scenario such as might occur with a spacecraft like Cassini, which has 3 transponders: X/S, X/X, X/Ka. In this scenario, a tracking session in which all 3 transponders were used requires a TDM with 3 segments. This is because a single segment would have duplications of keyword and timetag in the same segment, given the S-down, X-down, and Ka-down measurements at the same time tags. A single TDM segment could be coded with five participants (Cassini S-down, X-down, and Ka-down transponders as the spacecraft participants, and the two ground antennas). However, it would not be possible to specify a 'PATH' statement that would meet this scenario.~~

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2003-268T20:15:00
ORIGINATOR = NASA/JPL
COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT THIS EXAMPLE IS STILL IN PROGRESS.
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 in which 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/JPL

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-X
MODE = SEQUENTIAL
PATH = 1,2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
START_TIME = 2003-268T13:12:10
STOP_TIME =  2003-268T13:14:30
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2003-268T13:12:10  7123456789.000000
TRANSMIT_FREQ_1 = 2006-347T03:50:34  7175802770.23
RECEIVE_FREQ_1  = 2003-268T13:12:30  8369351234.567890
RECEIVE_FREQ_1  = 2003-268T13:13:30  8369351245.567890
RECEIVE_FREQ_1  = 2003-268T13:14:30  8369351256.567890
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
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
START_TIME = 2003-268T13:12:10
STOP_TIME =  2003-268T13:14:30
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34   7175802770.23
TRANSMIT_FREQ_1 = 2003-268T13:12:10  7123456789.000000
RECEIVE_FREQ_1  = 2003-268T13:12:30 32369351234.567890
RECEIVE_FREQ_1  = 2003-268T13:13:30 32369351245.567890
RECEIVE_FREQ_1  = 2003-268T13:14:30 32369351256.567890
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
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 7.7e-5
RECEIVE_DELAY_3 =  7.76e-5
```

```
START_TIME = 2003-268T13:12:10
STOP_TIME =  2003-268T13:14:30
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34  7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  2299322650.01
TRANSMIT_FREQ_1 = 2003-268T13:12:10 7123456789.000000
RECEIVE_FREQ_3 = 2003-268T13:12:30 2282549571.91
RECEIVE_FREQ_3 = 2003-268T13:13:30 2282549671.91
RECEIVE_FREQ_3 = 2003-268T13:14:30 2282549771.91
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT  This TDM example contains single differenced range data.


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-25
PARTICIPANT_3 = DSS-55
MODE = SINGLE-DIFF
DIFF_MODE = RANGE
TIMETAG_REF = RECEIVE
RANGE_MODE = COHERENT
RANGE_MODULUS = 1.616485E+02
RANGE_UNITS = S
TRANSMIT_DELAY_2 = .000077
RECEIVE_DELAY_2 = .000077
START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP


DATA_START
RANGE_OBS = 2004-136T15:30:00.0000  -2.563490649E-03
TRANSMIT_FREQ_2 = 2004-136T15:42:00.0000  7.156430612053E+09
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000  -4.59e-7
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000  -2.953e-6
DATA_STOP
```

```
CCSDS_TDM_VERS = 1.0
COMMENT  GEOSCX
CREATION_DATE = 2006-12-08T10:12:40.472
ORIGINATOR = GSOC

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-12-15T00:00:02.000
STOP_TIME = 2005-12-15T00:00:52.000
PARTICIPANT_1 = WHM1
PARTICIPANT_2 = EW5
MODE = SEQUENTIAL
PATH = 1,2,1
```

```
INTEGRATION_INTERVAL =  10.0
INTEGRATION_REF = END
RANGE_MODULUS =   1.000000E+07
DATA_QUALITY = RAW
META_STOP

DATA_START
ANGLE_1             = 2005-12-15T00:00:02.000         57.691180  [deg]
ANGLE_2             = 2005-12-15T00:00:02.000         37.052172  [deg]
RANGE_OBS           = 2005-12-15T00:00:02.000   3.824634898E+04  [km]
DOPPLER_INTEGRATED  = 2005-12-15T00:00:02.000      -1.781311000  [km/s]
ANGLE_1             = 2005-12-15T00:00:12.000         57.680980  [deg]
ANGLE_2             = 2005-12-15T00:00:12.000         37.064578  [deg]
RANGE_OBS           = 2005-12-15T00:00:12.000   3.824629493E+04  [km]
DOPPLER_INTEGRATED  = 2005-12-15T00:00:12.000      -1.761957000  [km/s]
ANGLE_1             = 2005-12-15T00:00:22.000         57.661380  [deg]
ANGLE_2             = 2005-12-15T00:00:22.000         37.070919  [deg]
RANGE_OBS           = 2005-12-15T00:00:22.000   3.824631757E+04  [km]
DOPPLER_INTEGRATED  = 2005-12-15T00:00:22.000      -1.749465000  [km/s]
ANGLE_1             = 2005-12-15T00:00:32.000         57.664436  [deg]
ANGLE_2             = 2005-12-15T00:00:32.000         37.017756  [deg]
RANGE_OBS           = 2005-12-15T00:00:32.000   3.824629454E+04  [km]
DOPPLER_INTEGRATED  = 2005-12-15T00:00:32.000      -1.766237000  [km/s]
ANGLE_1             = 2005-12-15T00:00:42.000         57.662018  [deg]
ANGLE_2             = 2005-12-15T00:00:42.000         37.038975  [deg]
RANGE_OBS           = 2005-12-15T00:00:42.000   3.824626363E+04  [km]
DOPPLER_INTEGRATED  = 2005-12-15T00:00:42.000      -1.747080000  [km/s]
ANGLE_1             = 2005-12-15T00:00:52.000         57.684659  [deg]
ANGLE_2             = 2005-12-15T00:00:52.000         37.111503  [deg]
RANGE_OBS           = 2005-12-15T00:00:52.000   3.824624141E+04  [km]
DOPPLER_INTEGRATED  = 2005-12-15T00:00:52.000      -1.735425000  [km/s]
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT  This TDM example contains single differenced Doppler data.


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-25
PARTICIPANT_3 = DSS-55
MODE = SINGLE-DIFF
DIFF_MODE = DELAY
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 580
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_2 = .000077
RECEIVE_DELAY_2 = .000077
START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP


DATA_START
TRANSMIT_FREQ_2 = 2004-136T15:30:00.0000  7.156430845899E+09
RECEIVE_FREQ    = 2004-136T15:30:00.0000  15100.837278
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000   -4.59e-7
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A

START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:30:00.0000   -2.953e-6
DATA_STOP
```

```
CCSDS_TDM_VERS = 1.0

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 =  2005-09-17T00:4x:xx.0000
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = USC1
MODE = SEQUENTIAL
PATH = 2,1,2
TRANSMIT_BAND = S
```

```
RECEIVE_BAND = S
TIMETAG_REF = TRANSMIT
INTEGRATION_INTERVAL = ?????
INTEGRATION_REF = START
RANGE_MODULUS = 0.0
DATA_QUALITY = VALIDATED
CORRECTION_RANGE = 0.0
META_STOP

DATA_START
RANGE_OBS = 2005-09-17T00:41:38.000000  3198.03679519614
RANGE_OBS = 2005-09-17T00:41:40.000000  3199.82505720811
RANGE_OBS = 2005-09-17T00:41:42.000000  3201.61631714467
RANGE_OBS = 2005-09-17T00:41:44.000000  3203.40832656236
RANGE_OBS = 2005-09-17T00:41:46.000000  3205.2010854612
RANGE_OBS = 2005-09-17T00:41:48.000000  3206.99384436004
RANGE_OBS = 2005-09-17T00:41:50.000000  3208.79110014575
RANGE_OBS = 2005-09-17T00:41:52.000000  3210.58535800688
RANGE_OBS = 2005-09-17T00:41:54.000000  3212.38336327374
RANGE_OBS = 2005-09-17T00:41:56.000000  3214.18136854059
RANGE_OBS = 2005-09-17T00:41:58.000000  3215.98012328859
RANGE_OBS = 2005-09-17T00:42:00.000000  3217.78037699888
RANGE_OBS = 2005-09-17T00:42:02.000000  3219.5828791526
RANGE_OBS = 2005-09-17T00:42:04.000000  3221.38613078747
RANGE_OBS = 2005-09-17T00:42:06.000000  3223.19013190349
RANGE_OBS = 2005-09-17T00:42:08.000000  3224.99488250065
RANGE_OBS = 2005-09-17T00:42:10.000000  3226.8011320601
RANGE_OBS = 2005-09-17T00:42:12.000000  3228.60963006298
RANGE_OBS = 2005-09-17T00:42:14.000000  3230.41587962244
RANGE_OBS = 2005-09-17T00:42:16.000000  3232.22587658761
RANGE_OBS = 2005-09-17T00:42:18.000000  3234.03662303393
RANGE_OBS = 2005-09-17T00:42:20.000000  3235.84886844254
RANGE_OBS = 2005-09-17T00:42:22.000000  3237.65961488886
RANGE_OBS = 2005-09-17T00:42:24.000000  3239.47560770319
RANGE_OBS = 2005-09-17T00:42:26.000000  3241.28860259295
RANGE_OBS = 2005-09-17T00:42:28.000000  3243.10384592614
RANGE_OBS = 2005-09-17T00:42:30.000000  3244.92133770276
RANGE_OBS = 2005-09-17T00:42:32.000000  3246.73882947939
RANGE_OBS = 2005-09-17T00:42:34.000000  3248.55856969945
RANGE_OBS = 2005-09-17T00:42:36.000000  3250.37681095722
RANGE_OBS = 2005-09-17T00:42:38.000000  3252.19879962071
RANGE_OBS = 2005-09-17T00:42:40.000000  3254.02003880307
RANGE_OBS = 2005-09-17T00:42:42.000000  3255.84352642885
RANGE_OBS = 2005-09-17T00:42:44.000000  3257.66851301693
RANGE_OBS = 2005-09-17T00:42:46.000000  3259.49125116157
RANGE_OBS = 2005-09-17T00:42:48.000000  3261.31848619307
RANGE_OBS = 2005-09-17T00:42:50.000000  3263.14572122459
RANGE_OBS = 2005-09-17T00:42:52.000000  3264.97295625609
RANGE_OBS = 2005-09-17T00:42:54.000000  3266.8016902499
RANGE_OBS = 2005-09-17T00:42:56.000000  3268.63267268713
RANGE_OBS = 2005-09-17T00:42:58.000000  3270.46440460551
DATA_STOP
```

Figure D-9: TDM Example: ~~Differenced Doppler Observable~~Range Data with TIMETAG_REF=TRANSMIT

```
CCSDS_TDM_VERS = 1.0
COMMENT  This TDM example contains single differenced Doppler data.

CREATION_DATE = 2005-178T21:45:002006-354T01:38:00Z
ORIGINATOR = NASA/JPL

COMMENT  This TDM example contains single differenced Doppler data.
COMMENT  This example still in progress.


META_START
TIME_SYSTEM = UTC
START_TIME = 2003-07-08T04:45:25.0000
STOP_TIME =  2003-07-08T04:47:25.0000
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = DSS-245
PARTICIPANT 3 = DSS-2555
MODE = SINGLE-DIFFSINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
DIFF_MODE = DELAY
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 58010.0
INTEGRATION_REF = MIDDLE
TRANSMITRECEIVE_DELAY_2 = 0.00007732
RECEIVE_DELAY_32 = 0.00007732
START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP


DATA_START
TRANSMIT_FREQ_1 = 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
```

```
META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A
TIMETAG_REF = RECEIVE
START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A
```

```
TIMETAG_REF = RECEIVE
START_TIME = 2004-136T15:30:00.0000
STOP_TIME =  2004-136T15:30:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
DATA_STOP
```

Figure D-10: TDM Example: Differenced Doppler Observable[1]

[1] Waiting for some differenced spacecraft to spacecraft Doppler data… [figure] is same as [previous] example.

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-178T21:45:00
ORIGINATOR = NASA/JPL

COMMENT  This TDM example contains delta-DOR data.
COMMENT  Quasar CTD 20 also known as J023752.4+284808 (ICRF) and 0234+285 (IERS)

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = yyyy-nnnA
PARTICIPANT_2 = CTD 20
PARTICIPANT_3 = DSS-25
PARTICIPANT 4 = DSS-55
MODE = DOUBLE-DIFF
DIFF_MODE = RANGE
TIMETAG_REF = RECEIVE
RANGE_MODE = COHERENT
RANGE_MODULUS = 1.674852710000000E+02
RANGE_UNITS = S
TRANSMIT_DELAY_3 = .000077
RECEIVE_DELAY_3 = .000077
START_TIME = 2004-136T15:42:00.0000
STOP_TIME =  2004-136T15:42:00.0000
DATA_QUALITY = VALIDATED
META_STOP


DATA_START
RANGE_OBS = 2004-136T15:42:00.0000  -4.911896106591159E+06
TRANSMIT_FREQ_3 = 2004-136T15:42:00.0000  7.156430830844751E+09
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
MODE = N/A

TRANSMIT_DELAY_1 = .000077
RECEIVE_DELAY_1 = .000077
START_TIME = 2004-136T15:42:00.0000
STOP_TIME =  2004-136T15:42:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:42:00.0000  -4.59e-7
DATA_STOP


META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55
MODE = N/A
START_TIME = 2004-136T15:42:00.0000
STOP_TIME =  2004-136T15:42:00.0000
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:42:00.0000  -2.953e-6
DATA_STOP
```

```
CCSDS_TDM_VERS = 1.0
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/JPL

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_3.
COMMENT Transmit frequency is spacecraft beacon a OWLT before receive time.
DOR = 2004-136T15:42:00.0000 -4.911896106591159E+06
DOR = 2004-136T16:02:00.0000 1.467382930436399E+07
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_3.
COMMENT Transmit frequency is reference for 2-station interferometer.
VLBI_DELAY = 2004-136T15:52:00.0000 -1.911896106591159E+06
TRANSMIT_FREQ_1 = 2004-136T15:42:00.0000 8.415123000E+09
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2004-136T15:42:00.0000
STOP_TIME = 2004-136T16:02:00.0000
PARTICIPANT_1 = DSS-25
MODE = N/A
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
CLOCK_BIAS = 2004-136T15:42:00.0000 -4.59e-7
CLOCK_BIAS = 2004-136T16:02:00.0000 -4.59e-7
DATA_STOP
```

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

```
CCSDS_TDM_VERS = 1.0

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/JPL

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

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
TIMETAG_REF = RECEIVE
ANGLE_TYPE = XSYE
START_TIME = 2004-216T07:44:00
STOP_TIME =  2004-216T07:45:00
CORRECTION_ANGLE_1 = -0.09
CORRECTION_ANGLE_2 = 0.18
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 = 1.0

COMMENT TDM example created by NASA/JPL Navigation System Engineering

CREATION_DATE = 2005-223T23:00:00
ORIGINATOR = NASA/JPL


COMMENT TDM example created by NASA/JPL Navigation System Engineering

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-274T12:00:00
STOP_TIME =  2005-280T12:00:00
PARTICIPANT_1 = DSS-14
MODE = N/A
START_TIME = 2005-275T12:00:00
STOP_TIME =  2005-280T12:00:00
DATA_QUALITY = VALIDATED
META_STOP

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

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-10
MODE = N/A
START_TIME = 2005-280T21:45:00
STOP_TIME =  2005-281T00:00:00
DATA_QUALITY = VALIDATED
META_STOP

DATA_START

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

Figure D-13: TDM Example: Media Data Only

```
CCSDS_TDM_VERS = 1.0

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT JPL/DSN/Goldstone (DSS-10) weather for 06/05/2005

CREATION_DATE = 2005-156T06:15:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT JPL/DSN/Goldstone (DSS-10) weather for 06/05/2005

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-156T00:03:00
STOP_TIME =  2005-156T06:03:00
PARTICIPANT_1 = DSS-10
MODE = N/A
START_TIME = 2005-156T00:03:00
STOP_TIME =  2005-156T06:03:00
DATA_QUALITY = VALIDATED
META_STOP

DATA_START

TEMPERATURE = 2005-156T00:03:00 302.95   [K]
PRESSURE    = 2005-156T00:03:00 896.2    [HPAhPa]
RHUMIDITY   = 2005-156T00:03:00 12.0     [%]

TEMPERATURE = 2005-156T00:33:00 304.05   [K]
PRESSURE    = 2005-156T00:33:00 895.9    [HPAhPa]
RHUMIDITY   = 2005-156T00:33:00 11.0     [%]

TEMPERATURE = 2005-156T01:03:00 302.55   [K]
PRESSURE    = 2005-156T01:03:00 895.7    [HPAhPa]
RHUMIDITY   = 2005-156T01:03:00 12.0     [%]

TEMPERATURE = 2005-156T01:33:00 302.65   [K]
PRESSURE    = 2005-156T01:33:00 895.7    [HPAhPa]
RHUMIDITY   = 2005-156T01:33:00 11.0     [%]

TEMPERATURE = 2005-156T02:03:00 301.55   [K]
PRESSURE    = 2005-156T02:03:00 895.9    [HPAhPa]
RHUMIDITY   = 2005-156T02:03:00 11.0     [%]

TEMPERATURE = 2005-156T02:33:00 300.45   [K]
PRESSURE    = 2005-156T02:33:00 895.9    [HPAhPa]
RHUMIDITY   = 2005-156T02:33:00 12.0     [%]

TEMPERATURE = 2005-156T03:03:00 299.55   [K]
PRESSURE    = 2005-156T03:03:00 896.1    [HPAhPa]
RHUMIDITY   = 2005-156T03:03:00 14.0     [%]

TEMPERATURE = 2005-156T03:33:00 298.65   [K]
PRESSURE    = 2005-156T03:33:00 896.2    [HPAhPa]
RHUMIDITY   = 2005-156T03:33:00 15.0     [%]

TEMPERATURE = 2005-156T04:03:00 298.05   [K]
PRESSURE    = 2005-156T04:03:00 896.4    [HPAhPa]
RHUMIDITY   = 2005-156T04:03:00 17.0     [%]

TEMPERATURE = 2005-156T04:33:00 297.15   [K]
PRESSURE    = 2005-156T04:33:00 896.8    [HPAhPa]
RHUMIDITY   = 2005-156T04:33:00 19.0     [%]

TEMPERATURE = 2005-156T05:03:00 294.85   [K]
PRESSURE    = 2005-156T05:03:00 897.3    [HPAhPa]
RHUMIDITY   = 2005-156T05:03:00 21.0     [%]

TEMPERATURE = 2005-156T05:33:00 293.95   [K]
PRESSURE    = 2005-156T05:33:00 897.3    [HPAhPa]
RHUMIDITY   = 2005-156T05:33:00 23.0     [%]

TEMPERATURE = 2005-156T06:03:00 293.05   [K]
PRESSURE    = 2005-156T06:03:00 897.3    [HPAhPa]
RHUMIDITY   = 2005-156T06:03:00 25.0     [%]
```

```
DATA_STOP
```

Figure D-14: TDM Example: Meteorological Data Only

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-161T15:45:00
ORIGINATOR = NASA/JPL

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.  Times assumed to be EOD. Value is "station clock
COMMENT minus UTC".

CREATION_DATE = 2005-161T15:45:00
ORIGINATOR = NASA/JPL


COMMENT Note:  SPC10 switched back to Maser1 from Maser2 on 2005-142

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 =  2005-148T12:00:00
PARTICIPANT_1 = DSS-10
MODE = N/A

START_TIME = 2005-142T12:00:00
STOP_TIME =  2005-148T12:00:00
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
MODE = N/A

START_TIME = 2005-142T12:00:00
STOP_TIME =  2005-148T12:00:00
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 =  2005-148T12:00:00
PARTICIPANT_1 = DSS-60
MODE = N/A

START_TIME = 2005-142T12:00:00
STOP_TIME =  2005-148T12:00:00
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 = 1.0
CREATION_DATE = 2005-156T22:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT Uplink frequencies for StarTrek spacecraft at DSS-65 2005-06-06

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-65
PARTICIPANT_2 = yyyy-nnnA
MODE = N/A

START_TIME = 2005-157T08:22:46
STOP_TIME =  2005-157T18:54:53
META_STOP

DATA_START
TRANSMIT_FREQ_1        = 2005-157T08:22:46     7175516847.11634
TRANSMIT_FREQ_RATE_1 = 2005-157T08:22:46     0.29989
TRANSMIT_FREQ_1        = 2005-157T08:44:51     7175517244.46444
TRANSMIT_FREQ_RATE_1 = 2005-157T08:44:51     0.35889
TRANSMIT_FREQ_1        = 2005-157T09:05:48     7175517695.59096
TRANSMIT_FREQ_RATE_1 = 2005-157T09:05:48     0.41798
TRANSMIT_FREQ_1        = 2005-157T09:27:40     7175518243.98194
TRANSMIT_FREQ_RATE_1 = 2005-157T09:27:40     0.47836
TRANSMIT_FREQ_1        = 2005-157T09:49:39     7175518874.93938
TRANSMIT_FREQ_RATE_1 = 2005-157T09:49:39     0.53529
TRANSMIT_FREQ_1        = 2005-157T10:09:26     7175519510.33008
TRANSMIT_FREQ_RATE_1 = 2005-157T10:09:26     0.59170
TRANSMIT_FREQ_1        = 2005-157T10:31:48     7175520304.38500
TRANSMIT_FREQ_RATE_1 = 2005-157T10:31:48     0.65041
TRANSMIT_FREQ_1        = 2005-157T10:54:31     7175521190.89022
TRANSMIT_FREQ_RATE_1 = 2005-157T10:54:31     0.70797
TRANSMIT_FREQ_1        = 2005-157T11:17:44     7175522177.09923
TRANSMIT_FREQ_RATE_1 = 2005-157T11:17:44     0.76105
TRANSMIT_FREQ_1        = 2005-157T11:38:57     7175523145.91484
TRANSMIT_FREQ_RATE_1 = 2005-157T11:38:57     0.81257
TRANSMIT_FREQ_1        = 2005-157T12:03:36     7175524347.71014
TRANSMIT_FREQ_RATE_1 = 2005-157T12:03:36     0.86496
TRANSMIT_FREQ_1        = 2005-157T12:29:22     7175525684.93754
TRANSMIT_FREQ_RATE_1 = 2005-157T12:29:22     0.91200
TRANSMIT_FREQ_1        = 2005-157T12:53:35     7175527010.07869
TRANSMIT_FREQ_RATE_1 = 2005-157T12:53:35     0.95621
TRANSMIT_FREQ_1        = 2005-157T13:22:49     7175528687.26789
TRANSMIT_FREQ_RATE_1 = 2005-157T13:22:49     0.99899
TRANSMIT_FREQ_1        = 2005-157T13:55:19     7175530635.30759
TRANSMIT_FREQ_RATE_1 = 2005-157T13:55:19     1.03477
TRANSMIT_FREQ_1        = 2005-157T14:29:53     7175532781.42341
TRANSMIT_FREQ_RATE_1 = 2005-157T14:29:53     1.06353
TRANSMIT_FREQ_1        = 2005-157T15:24:49     7175536286.82686
TRANSMIT_FREQ_RATE_1 = 2005-157T15:24:49     1.07367
TRANSMIT_FREQ_1        = 2005-157T16:20:22     7175539865.36148
TRANSMIT_FREQ_RATE_1 = 2005-157T16:20:22     1.05186
TRANSMIT_FREQ_1        = 2005-157T17:00:34     7175542402.44054
TRANSMIT_FREQ_RATE_1 = 2005-157T17:00:34     1.02238
TRANSMIT_FREQ_1        = 2005-157T17:33:07     7175544399.14254
TRANSMIT_FREQ_RATE_1 = 2005-157T17:33:07     0.98827
TRANSMIT_FREQ_1        = 2005-157T18:01:57     7175546108.84817
TRANSMIT_FREQ_RATE_1 = 2005-157T18:01:57     0.95097
TRANSMIT_FREQ_1        = 2005-157T18:28:34     7175547627.55415
TRANSMIT_FREQ_RATE_1 = 2005-157T18:28:34     0.91035
TRANSMIT_FREQ_1        = 2005-157T18:54:53     7175549064.99311
DATA_STOP
```

~~**Figure D-16: TDM Example: Uplink Frequencies Only**~~

~~In general practice, it is expected that Doppler, range and angle data will not be interspersed in a single TDM segment, because of issues with interpreting the meaning of certain metadata keywords, in particular, the 'DATA_QUALITY' keyword. However, the specification does not prohibit such a combination.~~

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-156T22:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT Uplink frequencies for StarTrek spacecraft at DSS-65 2005-06-06

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-65
PARTICIPANT_2 = yyyy-nnnA
MODE = N/A
START_TIME = 2005-157T08:22:46
STOP_TIME =  2005-157T18:54:53
META_STOP

DATA_START

COMMENT   this example still in progress… but see Figure 6 for the time
COMMENT being… it has downlink frequencies, range, range rate, and angles
COMMENT combined in a single TDM segment.

DATA_STOP
```

~~**Figure D-16: TDM Example: Combined Doppler, Range, Angles**~~

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE = 2005-156T22:45:00
ORIGINATOR = NASA/JPL

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT Uplink frequencies for StarTrek spacecraft at DSS-65 2005-06-06

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25-X
PARTICIPANT_2 = DSS-25-Ka
PARTICIPANT_3 = yyyy-nnnA
PARTICIPANT_4 = yyyy-nnnA-beacon
MODE = N/A
START_TIME = 2005-157T08:22:46
STOP_TIME =  2005-157T18:54:53
META_STOP

DATA_START

COMMENT   THIS EXAMPLE STILL IN PROGRESS

DATA_STOP
```

~~Figure D-17: TDM Example: Two Uplinks~~

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';[1]

d) Arrayed downlink;[2]

e) Orbital debris example;

f) Combine radiometric types with media or meteorological data.

Keyword Coverage (still a few keywords not in examples).

Keyword
AGC
AZIMUTH_RATE add an example
CARRIER_SNR
CORRECTION_ANGLE1 CORRECTION_ANGLE2 CORRECTION_TRANSMIT CORRECTION_RECEIVE CORRECTION_DOPPLER CORRECTION_MEDIA CORRECTION_TROPO_DRY CORRECTION_TROPO_WET

[1] Note to DSB: p.621.

[2] Must identify the phase center.

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

[E4] *IEEE Standard for Binary Floating-Point Arithmetic*. IEEE Std 754-1985. New York: IEEE, 1985.

[E5] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

[E6] *The Application of CCSDS Protocols to Secure Systems*. Report Concerning Space Data System Standards, CCSDS 350.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, March 1999.

[E7] *Attitude Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 504.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.

[E8] Catherine L. Thornton and James S. Border. *Radiometric Tracking Techniques for Deep-Space Navigation*. JPL Deep Space Comminications and Navigation Series. Hoboken, New Jersey: Wiley, 2003.

[E9] *XML Specification for Navigation Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 505.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.

[E10] Theodore D. Moyer. *Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation*. JPL Deep Space Comminications and Navigation Series. Hoboken, New Jersey: Wiley, 2003.

ANNEX F

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 Ref [1]. If exchange partners wish to use different settings, they should be documented in the ICD.

F1 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

F2 REFERENCE FRAME KEYWORD

Reference Frame Value	Meaning
EME2000	Earth Mean Equator and Equinox of J2000
ICRF	International Celestial Reference Frame
ITRF2000	International Terrestrial Reference Frame 2000
ITRF-93	International Terrestrial Reference Frame 1993
ITRF-97	International Terrestrial Reference Frame 1997
TOD	True of Date

ANNEX G

TDM SUMMARY SHEET

(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.

1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n					
a) either constant uplink or measurements are not directly influenced					
	Range Data	Doppler Data			Angle Data
Data Keywords [unit]	RANGE_OBS [km]	DOPPLER_INSTANTANEOUS [km/s]	RECEIVE_FREQ_n TRANSMIT_FREQ_n [Hz]	DOPPLER_INTEGRATED [km/s]	ANGLE_1 ANGLE_2 [deg]
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM RANGE_MODE RANGE_MODULUS INTEGRATION_INTERVAL INTEGRATION_REF	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM INTEGRATION_INTERVAL INTEGRATION_REF	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM ANGLE_TYPE
Situationally Required Metadata	TIMETAG_REF TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_RANGE	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_DOPPLER	INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_TRANSMIT CORRECTION_RECEIVE	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_DOPPLER	REFERENCE_FRAME DATA_QUALITY CORRECTION_ANGLE_1 CORRECTION_ANGLE_2
Optional Metadata	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	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND	COMMENT START_TIME STOP_TIME

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_OBS [km]		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 INTEGRATION_INTERVAL INTEGRATION_REF		META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM		
Situationally Required Metadata	TIMETAG_REF TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_RANGE		INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_TRANSMIT CORRECTION_RECEIVE		
Optional Metadata	COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND		COMMENT START_TIME STOP_TIME TRANSMIT_BAND RECEIVE_BAND		

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_OBS [km]		RECEIVE_FREQ_n TRANSMIT_FREQ_n [Hz] TRANSMIT_FREQ_RATE_n	DOR [sec]	VLBI_DELAY [sec]
Required Metadata	META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM PATH_1 PATH_2 RANGE_MODE RANGE_MODULUS INTEGRATION_INTERVAL INTEGRATION_REF TRANSMIT_BAND RECEIVE_BAND		META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM PATH_1 PATH_2 META_START META_STOP TRANSMIT_BAND RECEIVE_BAND	META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM PATH_1 PATH_2 TRANSMIT_BAND RECEIVE_BAND TIMETAG_REF RANGE_MODE RANGE_MODULUS	META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM PATH_1 PATH_2 TRANSMIT_BAND RECEIVE_BAND TIMETAG_REF RANGE_MODE RANGE_MODULUS
Situationally Required Metadata	TIMETAG_REF TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_RANGE		INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY CORRECTION_TRANSMIT CORRECTION_RECEIVE	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY
Optional Metadata	COMMENT START_TIME STOP_TIME		COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME

3. MODE = N/A			
	Time Data	Media Related Data	Meteorological Data
Data Keywords [unit]	CLOCK_BIAS [s] CLOCK_DRIFT [s]	STEC [TECU] TROPO_DRY/TROPO_WET [m]	PRESSURE [hPa] RHUMIDITY [%] TEMPERATURE [K]
Required Metadata	META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n TIME_SYSTEM
Situationally Required Metadata	DATA_QUALITY	PATH DATA_QUALITY	DATA_QUALITY
Optional Metadata	COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME	COMMENT START_TIME STOP_TIME

ANNEX H

QUESTIONS FOR NAV WG / TO DO LIST

1. For DOPPLER_INSTANTANEOUS, we need to specify the meaning of the term "instantaneous"?

2. Should units be allowed on metadata items such as INTEGRATION_INTERVAL, etc.?