The Consultative Committee for Space Data Systems

The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

TRACKING DATA MESSAGE

RECOMMENDED DRAFT STANDARD

CCSDS 503.0-~~B~~P-2.0.3

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This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS documents is detailed in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4), and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the e-mail address below.

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Email: secretariat@mailman.ccsds.org

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STATEMENT OF INTENT

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

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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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CCSDS has processes for identifying patent issues and for securing from the patent holder agreement that all licensing policies are reasonable and non-discriminatory. However, CCSDS does not have a patent law staff, and CCSDS shall not be held responsible for identifying any or all such patent rights.

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). 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 sent to the CCSDS Secretariat at the email address indicated on page i.

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– United States Geological Survey (USGS)/USA.

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DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 503.0-B-1	Tracking Data Message, Recommended Standard, Issue 1	November 2007	Original issue
CCSDS 503.0-B-2	Tracking Data Message, Recommended Standard, Issue 2	June 2020	Issue 2
CCSDS 503.0-~~B~~P-2.0.3	Tracking Data Message, Recommended Standard, Issue 2	~~June 2020~~July 2025	Current draft update: – Substantive changes from the ~~original~~prior issue are enumerated in ~~1.2.6~~annex J.

NOTE – Textual changes from the ~~original issue~~prior issues are too numerous to permit meaningful application of change bars.

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1 INTRODUCTION

1.1 PURPOSE

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

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

1.2 ~~SCOPE AND~~SCOPE AND APPLICABILITY

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

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

1.2.3 Definition of the accuracy pertaining to any particular TDM is outside the scope of this Recommended Standard and should be ~~specified via an ICD~~coordinated between data ~~exchange participants~~exchanging entities by mutual agreement.

1.2.4 This Recommended Standard is applicable only to the message format and content, but not to its transmission. The method of transmitting the message between exchange partners is beyond the scope of this document and should be ~~specified in the ICD.~~ otherwise pre-coordinated between exchanging entities by mutual agreement. Message transmission could be based on a CCSDS data transfer protocol, file~~-~~-based transfer protocol such as Secure File Transfer Protocol (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.

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1.2.5 There are someother specific exclusions to the TDM case standards defined outside of this standard, as listed below:

a) Satellite Laser Ranging (SLR) 'Fullrate' and 'Normal Points' format (sometimes referred to as 'Quicklook'), which are already transferred via a standardized format documented at https://ilrs.cddis.eosdis.nasa.gov/; however, such data could conceivably be transferred via TDM with a 'RANGE' keyword (see 3.5.2.6);

b) exchanges of raw Global Navigation Satellite System (GNSS) data, which is standardized via the RINEX format (http://www.igs.org);

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

d) optical files.igs.org/pub/data from navigation cameras (pixel-based, row-column, etc.);

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

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

1.2.6 Changes in Version 2 of the Tracking Data Message include the following:

1.2.6.1c) Description of the message /format based on the use of eXtensible Markup Language (XML) is now detailed in section 5 of this document./sp3_docu.txt),

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1.2.6.2 References, including inline references to various Web sites, have been updated as applicable.

1.2.6.3 The labeling of several annexes has changed, primarily in order to respond to changing CCSDS document requirements, for example, the Implementation Conformance Statement (ICS) (annex A) was added, causing several prior annex labels to shift; and the Security section was converted from a main document section (5) to an annex (annex C).

1.2.6.4 The Space Assigned Numbers Authority (SANA) Registry is now a source of values for some keywords, as noted in the relevant tables.

1.2.6.5 The word 'obligatory' is no longer used; 'mandatory' is substituted based on the requirements of the ICS.

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

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~~**1.2.6.6** There are several new Data Section keywords added based on suggestions/recommendations by TDM version 1 users. These include transmit/receive phase; optical magnitude and radar cross section based on space situational awareness applications; and Doppler counts. For each of these new data types there are one or more related Metadata Section keywords.~~

1.3 CONVENTIONS AND DEFINITIONS

1.3.1 GENERAL

Conventions and definitions of navigation concepts such as reference frames, time systems, etc., are provided in reference ~~[F7].~~[H7]. (Also see SANA Registries specified in annex C.)

1.3.2 NORMATIVE TEXT

The following conventions apply for the normative specifications in this Recommended Standard:

a) the words ‘shall’ and ‘must’ imply a binding and verifiable specification;

b) the word ‘should’ implies an optional, but desirable, specification;

c) the word ‘may’ implies an optional specification;

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

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

1.3.3 INFORMATIVE TEXT

In the normative sections of this document (sections 3–5), informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

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1.3.4 DEFINITIONS

1.3.4.1 Terms

participant: An entity that has the ability to acquire, broadcast, or reflect navigation messages and/or electromagnetic frequencies, for example, a spacecraft, a quasar, a tracking station, a tracking instrument, or an agency center, as discussed in reference ~~[F7].~~[H7]. Thus there may exist Tracking Data Messages for which there is no applicable spacecraft.

agency: An exchange partner.

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

n/a, N/A: Not applicable or not available.

1.3.4.2 Unit Notations

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

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

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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 in Keyword-Value Notation (KVN) format.

1.4.4 Section 5 discusses a CCSDS XML schema for the TDM and how to create an XML instantiation of a TDM.

1.4.5 Annex A provides an ICS for the TDM.

1.4.6 Annex B discusses values for selected TDM Metadata Section keywords.

1.4.7 Annex C discusses security, SANA, and patent considerations with respect to the TDM.

1.4.8 Annex ~~D~~D is a list of abbreviations and acronyms applicable to the TDM.

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

1.4.10 Annex F details the conventions used in this document for the definition of tracking data.

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

1.4.12 Annex H contains a list of informative references.

~~**1.4.8**~~**1.4.13** Annex I 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.

~~**1.4.9**~~ Annex ~~E shows how various tracking scenarios can be accommodated using the TDM, via several examples.~~

~~**1.4.10** Annex F contains a list of informative references.~~

~~**1.4.11** Annex G~~J lists ~~a set of requirements and desirable characteristics that were taken into consideration~~changes in ~~the design of the TDM.~~

~~**1.4.12**~~**1.4.14** ~~Annex H is a list of abbreviations and acronyms applicable~~this document relative to ~~the TDM~~prior versions.

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1.4.131.4.15 Annex K provides a TDM Summary Sheet, or 'Quick Reference'.

1.5 REFERENCES

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

[1] "Outer Space Objects Index." United Nations Office for Outer Space Affairs. http://www.unoosa.org/oosa/osoindex/index.jspx.

[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*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 301.0-B-4. Washington, D.C.: CCSDS, November 2010.

[4] *Orbit Data Messages*. Issue 23. Recommendation for Space Data System Standards (Blue Book), CCSDS 502.0-B-23. Washington, D.C.: CCSDS, November 2009April 2023.

[5] Paul V. Biron and Ashok Malhotra, eds. *XML Schema Part 2: Datatypes*. 2nd ed. W3C Recommendation. W3C, October 2004. http://www.w3.org/TR/2004/REC-xmlschema-2-20041028/

[6] *IEEE Standard for Floating-Point Arithmetic*. 2nd ed. IEEE Std. 754-2008. New York: IEEE, 2008.

[7] *The International System of Units (SI)*. 9th ed. Sèvres, France: BIPM, 2009.

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

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

[10] Henry S. Thompson, et al., eds. "XML Schema Part 1: Structures." W3C Recommendation. 2nd ed., 28 October 2004. The World Wide Web Consortium (W3C). http://www.w3.org/TR/2004/REC-xmlschema-1-20041028/.

[6] Paul V. Biron and Ashok Malhotra, eds. *XML Schema Part 2: Datatypes*. 2nd ed. W3C Recommendation. W3C, October 2004. http://www.w3.org/TR/2004/REC-xmlschema-2-20041028/

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[7] *IEEE Standard for Floating-Point Arithmetic*. 2nd ed. IEEE Std. 754-2008. New York: IEEE, 2008.

[8] *The International System of Units (SI)*. 9th ed. Sèvres, France: BIPM, 2019.

[9] *Attitude Data Messages*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 504.0-B-2. Washington, D.C.: CCSDS, January 2024.

[10] *XML Specification for Navigation Data Messages*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 505.0-B-3. Washington, D.C.: CCSDS, May 2023.

[11] "Organizations." Space Assigned Numbers Authority. https://sanaregistry.org/r/organizations.

[12] "Time Systems." Space Assigned Numbers Authority. https://sanaregistry.org/r/time_systems.

[13] "Celestial Body Reference Frames." Space Assigned Numbers Authority. https://sanaregistry.org/r/celestial_body_reference_frames.

NOTE – Informative references are provided in annex H.

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2 OVERVIEW

2.1 GENERAL

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

2.2 ~~THE~~THE TRACKING ~~DATA MESSAGE~~DATA MESSAGE (TDM) ~~BASIC CONTENT~~BASIC CONTENT

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

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

2.2.3 The ASCII text in a TDM can be exchanged in either of two formats: a KVN format or an XML format. The KVN formatted TDM and XML formatted TDM are described in this document. Further information on XML is detailed in an integrated XML schema document for all Navigation Data Messages (reference [10]). It is recommended that exchange participants ~~specify in the ICD~~pre-coordinate which TDM ASCII format will be exchanged, the KVN or the XML format.

2.2.4 Normally a TDM will contain tracking data for a single spacecraft participant, unless the tracking session is spacecraft-to-spacecraft in nature. If a tracking operation involves information from multiple spacecraft participants tracked from the ground, the data may be

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included in a single TDM by using multiple segments (see 3.1); or multiple TDMs may be used, one per spacecraft participant.

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

2.2.6 Provisions for the frequency of exchange and special types of exchanges should be ~~specified in an ICD~~pre-coordinated between exchanging entities by mutual agreement.

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3 TRACKING DATA MESSAGE STRUCTURE AND CONTENT

3.1 GENERAL

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

a) a Header (see 3.2);

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

c) a Data Section (tracking data represented as ‘Tracking Data Records’) (see 3.4, ~~3.5~~3.5).

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

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

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

– TDM = Header + Body;

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

– Segment = Metadata Section + Data Section;

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

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Table 3-1: TDM Structure

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

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3.1.4 The TDM shall consist of tracking data for one or more tracking participants (see 1.3.4.1) at multiple epochs contained within a specified time range. Generally, but not necessarily, the time range of a TDM may correspond to a 'tracking pass'.

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

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

3.1.7 The method of exchanging TDMs shall be decided on a case-by-case basis by the participating agencies and should be ~~documented in an ICD.~~pre-coordinated between exchanging entities by mutual agreement. The exchange method shall not constrain the tracking data content.

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3.2 TDM HEADER

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

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

– the keyword to be used;

– a short description of the item;

– examples of allowed values; and

– ~~whether the item is mandatory or optional.~~

– whether the item is Mandatory (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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

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Table 3-2: TDM Header

Keyword	Description	Examples	~~Mandatory~~ M/O/C
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 (2007 version) 2.0 (2020 version) 3.0 (this version)	~~Yes~~M
COMMENT	~~(See 4.5.)~~(See 4.5.)	COMMENT This is a comment	~~No~~O
CLASSIFICATION	The CLASSIFICATION keyword shall specify the level of classification applied to the data within the Metadata and Data sections of the TDM. It shall also be utilized to indicate any special handling designators that apply, limiting the release and distribution of the data. For example, the value may be formed by two comma-separated values. The first being either UNCLASSIFIED, CONFIDENTIAL, SECRET or TOP SECRET; and the second indicating any handling instructions such as CUI (for Controlled Unclassified Information).	UNCLASSIFIED, CUI	O
CREATION_DATE	~~Data creation~~Creation date/time. Value should be in UTC. (For format specification, see ~~4.3.9~~4.3.11.)	2001-11-06T11:17:33 2002-204T15:56:23.4 2006-001T00:00:00Z	~~Yes~~M
ORIGINATOR	Creating ~~agency~~entity/organization. Value should be an entry from the 'Abbreviation' column in the SANA Organizations Registry, https://sanaregistry.org/r/organizations/organizations.html (reference ~~[11]).~~[11]).	CNES~~,~~ ESA~~,~~ GSFC~~,~~ DLR~~,~~ JPL~~,~~ JAXA~~, etc.~~	~~Yes~~M
MESSAGE_ID	ID that uniquely identifies a message from a given originator. The format and content of the message identifier value are at the discretion of the originator.	201113719185	~~No~~O

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

```
keyword = value
```

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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. Versions x.0, where x≥1, shall be reserved for versions 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~~pre-coordinated between exchanging entities by mutual agreement.

3.2.6 The TDM Header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the data was created (file creation time if in file format, or ~~first data point in stream~~header transmission time if message is streamed), as specified in ~~4.3.9.~~4.3.11.

~~**3.2.6**~~

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3.3 TDM METADATA

3.3.1 GENERAL

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

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

keyword = value

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

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

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

3.3.1.6 Table ~~3-3~~3-3 specifies for each Metadata item:

– the keyword to be used;

– a short description of the item;

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

~~– whether the item is mandatory or optional.~~

– whether the item is Mandatory (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

The column marked 'N/E' will contain an 'N' if the column marked 'Normative Values / Examples' contains normative values, and will contain an 'E' if the column contains example values that are non-normative. For normative values, a fully enumerated set of values is provided.

3.3.1.7 Only those keywords shown in table ~~3-3~~3-3 shall be used in a TDM Metadata Section. Mandatory items shall appear in every TDM Metadata Section~~.~~, unless defined previously in a referenced TDM Metadata section (see 3.3.1.11). Items that are optional may or may not appear in any given TDM Metadata Section, at the discretion of the data producer, based on the requirements of the data and its intended application (see annex K for a TDM Summary Sheet that illustrates the relationships between data types and metadata). For most metadata keywords there is no default value; where there is a default value, it is specified at the end of the 'Description' section for the given keyword. If a keyword is not present in a TDM, and a default value is defined, the default shall be assumed.

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

3.3.1.9 The Metadata Section shall describe the participants in a tracking session using the keyword 'PARTICIPANT_n'. There may be several participants associated with a tracking data session (the number of participants is always greater than or equal to one, and generally greater than or equal to two). The 'n' in the keyword is an indexer. The indexer shall start at 1 and not be the same for any two participants in a given Metadata Section.

3.3.1.10 The value associated with any given PARTICIPANT_n keyword may ~~be~~represent 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.~~pre-coordinated between exchanging entities by mutual agreement. Subsections ~~3.3.2~~3.3.2.1 through ~~3.3.2.7~~3.3.2.8 identify the relationships between the MODE, the PATH, and PARTICIPANT_n keywords for typical tracking sessions. Participants may generally be listed in any order.

3.3.1.11 ~~In this version of the TDM, the maximum number of participants per segment shall be five. If more than five participants are defined (i.e., PARTICIPANT_6 +), then special arrangements between exchange participants are necessary. These arrangements should be documented in an ICD. It should be noted that although the restriction to five participants may appear to be a constraint it is probably not, because of other aspects of the TDM structure. Five participants easily allow the user to describe the great majority of tracking passes. In some cases there may be 'critical event' tracking sessions in which a single spacecraft is tracked by a large number of antennas, such that the total number of participants appears to be~~

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six or more. However, because of the nature of the 'PATH' keyword, several TDM Segments with fiveConsecutive TDM segments, that require the repetition of the same exact Metadata previously defined, may employ the use of the TRACK_ID keyword as a substitute for the contents of the TDM Metadata Section. The referenced TDM Metadata Section shall contain all mandatory and relevant keywords, in addition to the TRACK_ID keyword and associated unique identifier. This unique identifier shall be referenced in successive TDM segments by assigning the value to the TRACK_ID keyword. All other keywords (mandatory or optional) in successive TDM segments may be omitted, except for META_START and META_STOP keywords which shall be present per table 3-3. See example from figure A-27.

3.3.1.12 TDM Metadata Section keyword definitions are provided in table 3-3.

3.3.1.11 or fewer participants would be required to describe the full set of tracking data. For the critical event example scenario just given, one TDM Segment would be used to describe the two-way connection, and one additional segment would be required for each three-way connection; it would not be possible to provide a single 'PATH' statement that would convey the multiple signal paths.

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Table 3-3: TDM Metadata Section

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
META_START	The META_START keyword shall delineate the start of the TDM Metadata Section within the message. It must appear on a line by itself; that is, it shall have no parameters, timetags or values.	N/A	-----	YesM
COMMENT	(See 4.5.)(See 4.5.) It should be noted that if comments are used in the metadata, they shall only appear at the beginning of the Metadata Section.	COMMENT file = tdm.dat	E	NoO
TRACK_ID	The TRACK_ID keyword specifies a unique identifier for the tracking data in the associated data sectionData Section. The value may be a freely selected string of characters and numbers, only required to be unique for each track of the corresponding sensor. For example, the value may be constructed from the measurement date and time and a counter to distinguish simultaneously tracked objects. A Universal Unique Identifier (UUID) is also an acceptable value. For some users such as space surveillance, this identifier is necessary to be applied to all measurements that the sensor attributes to a single object, with the data so designated furnished in the same TDM. In addition, when a prior instance of the Metadata has been previously defined (see 3.3.1.11), this keyword may be used as a substitute for all keywords defined in this table (table 3-3), including mandatory keywords, except for META_START and META_STOP keywords. The TRACK_ID keyword shall be included in this scenario. An example use case is the transmission of real-time tracking data.	20190918_1200135-0001	E	NoC
TRACK_ID_SEGMENT	The TRACK_ID_SEGMENT keyword may be used to identify a sequential increment in data segments provided in the case where the TRACK_ID keyword is utilized as a reference to a previously defined Metadata Section as described in 3.3.1.11. The value shall be initialized at 1 and increment a single value with each new associated tracking data segment that follows. This provides the user of the data with a method to verify the reception of the tracking data segments. For example, a user receives a last segment with a TRACK_ID_SEGMENT value of 900. The user notices that segments 40 through 234 are missing and requests a playback of the missing data.	1 2 3	E	O

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
PREVIOUS_MESSAGE_ID	Free-text field containing an ID that uniquely identifies a related previous message from this message originator. The format and content of the message identifier value are at the discretion of the originator. The values used for this field should be consistent across segments in the TDM.	201113719184	E	O
NEXT_MESSAGE_ID	Free-text field containing an ID that uniquely identifies the next related message from this message originator. The format and content of the message identifier value are at the discretion of the originator. The values used for this field should be consistent across segments in the TDM.	201113719186	E	O
DATA_TYPES	Comma-separated list of data types in the Data Section. The elements of the list shall be selected from the data types shown in table 3-53-6, with the exception of the DATA_START, DATA_STOP, and COMMENT keywords.	RANGE TRANSMIT_FREQ_n1 RECEIVE_FREQ ANGLE_1, ANGLE_2	E	NoO
TDM_BASIS	The TDM_BASIS keyword shall indicate the modality of the data being transmitted, specifying whether the data is from an operational tracking event, from a tracking event defined to test or verify a system, from a simulated tracking scenario, or played back. “OPERATIONAL” should be used to transmit data from an operational tracking event. “TEST” should be used when testing the transmission of tracking data. “SIMULATED” should be used to indicate the data is fabricated and is not to be used operationally. “PLAYBACK” should be utilized when retransmitting “OPERATIONAL” data.	OPERATIONAL TEST SIMULATED PLAYBACK	N	O

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
TDM_BASIS_ID	The TDM_BASIS_ID keyword shall contain the identification number for the tracking session the tracking data message is based on. The keyword value may be composed of a tasking identifier, followed by a collection identifier; both separated by a dash. The tasking identifier indicates the particular tasking request to which this tracking data is a response. The collection identifier indicates the collection session during which the data were taken. This designation is useful when several objects within close proximity of each other are tracked by a sensor that may associate measurements to incorrect object identifiers. Given that all associated data are assigned the same collection identifier, the correlation center can group all of these submissions and re-accomplish the association, understanding that all of the data were physically proximate. Additionally, the use of a collection identifier enables processing systems to estimate and/or assign systematic errors (such as angle biases) for the entire set of data within the collection.	123g4567-426614174000	E	O
TIME_SYSTEM	The TIME_SYSTEM keyword shall specify the time system used for timetags in the associated Data Section. This should be UTC for ground-based data. The value associated with this keyword must be selected from the full set of allowed values enumerated in the SANA Time Systems Registry https://sanaregistry.org/r/time_systems (reference ~~[12]).~~[12]). (See annex B.)	UTC, TAI, GPS, SCLK	E	~~Yes~~M
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~~.~~, utilizing the time system specified by the TIME_SYSTEM keyword. (For format specification, see 4.3.11.)	1996-12-18T14:28:15.1172 1996-277T07:22:54 2006-001T00:00:00Z	E	~~No~~O
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~~.~~, utilizing the time system specified by the TIME_SYSTEM keyword. (For format specification, see 4.3.11.)	1996-12-18T14:28:15.1172 1996-277T07:22:54 2006-001T00:00:00Z	E	~~No~~O

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
PARTICIPANT_n n = {1, 2, 3, 4, 5}…}	TheEach PARTICIPANT_n keyword shall represent the participantsparticipant number 'n' (see 1.3.4.1) in a tracking data session. It is indexed to allow unambiguous reference to other data in the TDM (max index is 59 for XML). At least two participants must be specified for most sessions; for some special TDMs such as tropospheric media, only one participant need be listed. ParticipantsObservation participants may generally 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, etcobserving parties and observed parties. Participants may be listed in any order, and the PATH keywords specify the signal paths. For spacecraft identifiers, there is no CCSDS-based restriction on the value for this keyword, but names could be drawn from the United Nations Outer Space Objects Index (reference [1][1]), 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 pre-coordinated between exchanging entities by mutual agreement. For example, the ICD. The PARTICIPANT_n may be 'UNKNOWN', for example, unknown in initial space surveillance object detection. and assigned an incremental designator based on best estimate of objects within a session, UNKNOWN-<object count>.	DSS-63-S400K ROSETTA <Quasar catalog name> 1997-061A UNKNOWN-00005	E	Yes M (at least one)
ADM_MSG_LINK_n n = {1, 2, 3, 4, …}	The ADM_MSG_LINK keyword specifies a unique identifier for an attitude data message that is linked (relevant) to this tracking data segment. The ADM message may be specified via its corresponding MESSAGE_ID keyword or another unique identifier pre-coordinated between exchanging entities by mutual agreement. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., ADM_MSG_LINK_1, if present, applies to PARTICIPANT_1).	201113719186	E	O

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
CDM_MSG_LINK_n n = {1, 2, 3, 4, …}	The CDM_MSG_LINK keyword specifies a unique identifier for a conjunction data message that is linked (relevant) to this tracking data segment. The CDM message may be specified via its corresponding MESSAGE_ID keyword or another unique identifier pre-coordinated between exchanging entities by mutual agreement, for example the filename of a relevant CDM. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., CDM_MSG_LINK_1, if present, applies to PARTICIPANT_1).	201113719187	E	O
ODM_MSG_LINK_n n = {1, 2, 3, 4, …}	The ODM_MSG_LINK keyword specifies a unique identifier for an orbit data message that is linked (relevant) to this tracking data segment. The ODM message may be specified via its corresponding MESSAGE_ID keyword or another unique identifier pre-coordinated between exchanging entities by mutual agreement, for example the filename of a relevant ODM. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., ODM_MSG_LINK_1, if present, applies to PARTICIPANT_1). Note: Where ephemeris is supplied in non-ODM format see EPHEMERIS_NAME keyword below.	201113719188	E	O
PRM_MSG_LINK_n n = {1, 2, 3, 4, …}	The PRM_MSG_LINK keyword specifies a unique identifier for a pointing request message that is linked (relevant) to this tracking data segment. The PRM message may be specified via its corresponding MESSAGE_ID keyword or another unique identifier pre-coordinated between exchanging entities by mutual agreement. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., PRM_MSG_LINK_1, if present, applies to PARTICIPANT_1).	201113719189	E	O
RDM_MSG_LINK_n n = {1, 2, 3, 4, …}	The RDM_MSG_LINK keyword specifies a unique identifier for a reentry data message that is linked (relevant) to this tracking data segment. The RDM message may be specified via its corresponding MESSAGE_ID keyword or another unique identifier pre-coordinated between exchanging entities by mutual agreement. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., RDM_MSG_LINK _1, if present, applies to PARTICIPANT_1).	201113719190	E	O

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
MODE	The MODE keyword shall reflect the tracking mode associated with the Data Section of the segment. The value 'SEQUENTIAL' applies for frequencies, phase, range, Doppler, carrier power, carrier-power-to-noise spectral density, ranging-power-to-noise spectral density, optical, angles, and line-of-sight ionosphere calibrations; the name implies a sequential signal path between tracking participants. The value 'SINGLE_DIFF' applies only for differenced data. The value 'RELAY' applies when relay tracking is performed utilizing coherent frequency translation sources, separate from the main measurement paths. In other cases, such as troposphere, weather, clocks, etc., use of the MODE keyword does not apply.	SEQUENTIAL SINGLE_DIFF RELAY	N	NoO
PATH_m PATH_m = {1, PATH_2, 3}	The PATH keywords shall reflect the signal path by listing the index of each participant in order, separated by commas, with no inserted white space. The integers 1, 2, 3, 4, 5 used to specify the signal path are correlated with the indices of the PARTICIPANT_n keywords. The first entry in the PATH shall be the transmit participant. TheA non-indexed 'PATH' keyword shall be used if the MODE is SEQUENTIAL (i.e., MODE=SEQUENTIAL is specified). The indexed 'PATH_1' and 'PATH_2' keywords shall be used where the MODE is 'SINGLE_DIFF'. Indexed PATH_m with three paths may be used when MODE=RELAY, with need to inform of reference frequency links. Examples: 1,2 = one-way; 2,1,2 = two-way; 3,2,1 = three-way; 1,2,3,4,5 = four-way. The PATH keyword should only be omitted when just one participant is defined.	PATH = 1,2,1 PATH_1 = 1,2,1 PATH_2 = 3,1	E	No C

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
EPHEMERIS_NAME_n n = {1, 2, 3, 4, ~~5}~~…}	Unique name of the external ephemeris file used for tracking one of the n PARTICIPANTs. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., EPHEMERIS_NAME_1, if present, applies to PARTICIPANT_1). The use of the 'n' index is optional when omitting it is unambiguous. Message originators are encouraged to employ ODM_MSG_LINK to reference ephemerides in ODM format. Otherwise, the EPHEMERIS_NAME keyword should be used to reference ephemeris files that are not in ODM format (for backward compatibility purposes).	SATELLITE_A_EPHEM27	E	~~No~~O
TRANSMIT_BAND_n	The TRANSMIT_BAND keyword shall indicate the frequency band for transmitted frequencies. The frequency ranges associated with each band should be ~~specified in the ICD.~~ pre-coordinated between exchanging entities by mutual agreement. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., TRANSMIT_BAND_1, if present, applies to PARTICIPANT_1).	S X Ka Ku L UHF GREEN	E	~~No~~O
RECEIVE_BAND_n	The RECEIVE_BAND keyword shall indicate the frequency band for received frequencies. Although not required in general, the RECEIVE_BAND must be present if the MODE is SINGLE_DIFF and differenced frequencies or differenced range are provided in order to allow proper frequency dependent corrections to be applied. The frequency ranges associated with each band should be ~~specified in the ICD.~~ pre-coordinated between exchanging entities by mutual agreement. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., RECEIVE_BAND_1, if present, applies to PARTICIPANT_1).	S X Ka Ku L UHF GREEN	E	~~No~~O
TURNAROUND_NUMERATOR_n	The TURNAROUND_NUMERATOR keyword shall indicate the numerator of the turnaround ratio that is necessary to calculate the coherent downlink from the uplink frequency. The value shall be an integer. ~~Also~~This information may also be ~~specified in the ICD~~pre-coordinated between exchanging entities by mutual agreement if the value is always constant. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., TURNAROUND_NUMERATOR_2, if present, applies to PARTICIPANT_2).	240 880	E	~~No~~O

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
TURNAROUND_DENOMINATOR_n	The TURNAROUND_DENOMINATOR keyword shall indicate the denominator of the turnaround ratio that is necessary to calculate the coherent downlink from the uplink frequency. The value shall be an integer. ~~Also~~This information may also be ~~specified in the ICD~~pre-coordinated between exchanging entities by mutual agreement if the value is always constant. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., TURNAROUND_DENOMINATOR_2, if present, applies to PARTICIPANT_2).	221 749	E	~~No~~O
TIMETAG_REF	The TIMETAG_REF keyword shall provide a reference for time tags in the tracking data. This keyword indicates whether the timetag associated with the data is the transmit time or the receive time. This keyword is provided specifically to accommodate two special cases: (1) systems where a received range data point has been timetagged with the time that the range tone signal was transmitted (i.e., TIMETAG_REF=TRANSMIT), and (2) for quasar DOR, where the transmit frequency is the interferometer reference frequency at receive time (i.e., TIMETAG_REF=RECEIVE). It is anticipated otherwise that transmit-related data will generally be timetagged with the time of transmission, and that receive-related data will generally be timetagged with the time of receipt; in these two standard cases, it is not necessary to specify the TIMETAG_REF keyword.	TRANSMIT RECEIVE	N	~~No~~ O
TIMETAG_UNCERTAINTY	The TIMETAG_UNCERTAINTY keyword shall provide the 1-sigma estimated uncertainty value for the observation timetags in seconds.	0.0000001 1e-7	E	O

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
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 INTEGRATION_INTERVAL keyword shall also convey the interval utilized to resolve range measurements. The data type shall be positive double precision. Note that if both Doppler and Range data require specifying the INTEGRATION_INTERVAL keyword, two distinct Metadata and Data sections are required. If both data are included under the same metadata, the INTEGRATION_INTERVAL value shall apply to only the Doppler data types.	60.0 0.1 1.0	E	~~No~~O
INTEGRATION_REF	The INTEGRATION_REF keyword shall be used in conjunction with the INTEGRATION_INTERVAL and TIMETAG_REF keywords. This keyword indicates the relationship between the INTEGRATION_INTERVAL and the timetag on the data, i.e., whether the timetag represents the start, middle, or end of the integration period.	START MIDDLE END	N	~~No~~O
FREQ_OFFSET	The FREQ_OFFSET keyword represents a frequency in Hz that must be added to every RECEIVE_FREQ (see 3.5.2.7~~) to reconstruct it.~~), RECEIVE_PHASE_CT difference (see 3.5.2.10), TRANSMIT_FREQ (see 3.5.2.8) and TRANSMIT_PHASE_CT difference (see 3.5.2.11) to reconstruct them. One use is if a Doppler shift frequency observable is transferred instead of the actual received frequency. The data type shall be double precision, and may be negative, zero, or positive. Examples are shown in the 'Normative Values / Examples' column. The default shall be 0.0 (zero). If the keyword value is not provided, the default value shall apply. Note that if transmit and receive data require the use of the FREQ_OFFSET keyword, two distinct Metadata and Data sections are required. If both data are included under the same metadata, the FREQ_OFFSET value shall apply to only the receive data types and the transmit data is assumed to not incur a frequency offset.	0.0 8415000000.0	E	~~No~~C

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Keyword	**Description**	**Normative Values / Examples**	**N/E**	**~~Mandatory~~ M/O/C**
RANGE_MODE	The value of the RANGE_MODE keyword shall be 'COHERENT', in which case the range tones are coherent with the uplink carrier, and the range unit must be ~~defined in an ICD~~pre-coordinated between exchanging entities by mutual agreement; 'CONSTANT', in which case the range tones have a constant frequency; or 'ONE_WAY' (used in Delta-DOR). NOTE – It cannot be determined in advance whether the range mode is coherent or non-coherent. For ESA and JAXA, it is important for the two/three-way Doppler to be coherent, but not the RANGE. This keyword may not be applicable for differenced range data.	COHERENT CONSTANT ONE_WAY	N	~~No~~O
RANGE_MODULUS	The value associated with the RANGE_MODULUS keyword shall be the modulus of the range observable in the units as specified by the RANGE_UNITS keyword; that is, the actual (unambiguous) range is an integer *k* times the modulus, plus the observable value. RANGE_MODULUS shall be a non-negative double precision value. For measurements that are not ambiguous range, the MODULUS setting shall be 0 to indicate an essentially infinite modulus. The default value shall be 0.0. NOTE – The range modulus is sometimes also called the 'range ambiguity'.	32768.0 2.0e+23 0.0 161.6484	E	~~No~~C
RANGE_UNITS	The RANGE_UNITS keyword specifies the units for the range observable. 'km' shall be used if the range is measured in kilometers. 's' shall be used if the range is measured in seconds. 'RU', for 'range units', shall be used where the transmit frequency is changing, and the method of computing the range unit should be ~~described in the ICD.~~pre-coordinated between exchanging entities by mutual agreement. The default (preferred) value shall be 'km'.	km s RU	N	~~No~~C

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Keyword	**Description**	**Normative Values / Examples**	**N/E**	**~~Mandatory~~ M/O/C**

`ANGLE_TYPE`	The `ANGLE_TYPE` keyword shall indicate the type of antenna geometry represented in the angle data (ANGLE_1 and ANGLE_2 keywords). The value shall be one of the values:
	– AZEL for azimuth, elevation (local horizontal);
	– RADEC for right ascension, declination or hour angle, declination (must be referenced to an inertial frame);
	– XEYN for *x*-east, *y*-north;
	– XSYE for *x*-south, *y*-east.
	Other values are possible~~, but must be defined in an ICD.~~ but must be pre-coordinated between exchanging entities by mutual agreement. This field is mandatory if angle measurements are reported.
		`AZEL`
		`RADEC`
		`XEYN`
		`XSYE`
			N	~~No~~C

`REFERENCE_FRAME`	The `REFERENCE_FRAME` keyword shall be used in conjunction with the ‘ANGLE_TYPE=RADEC’ keyword/value combination, indicating the inertial reference frame to which the antenna frame is referenced. The origin (center) of the reference frame is assumed to be at the antenna reference point. Applies only to ANGLE_TYPE = RADEC. The value associated with this keyword must be selected from the full set of allowed values enumerated in the SANA Celestial Body Reference Frames Registry https://sanaregistry.org/r/celestial_body_reference_frames (reference ~~[13]).~~[13]). (See annex B.)	`EME2000`
		`ICRF`
		~~`ITRF1993`~~
		~~`ITRF2000`~~
		`TOD_EARTH`
			E	~~No~~C

`INTERPOLATION`	The `INTERPOLATION` keyword shall specify the interpolation method to be used to calculate a transmit phase count at an arbitrary time in tracking data where the uplink frequency is not constant.	`HERMITE`
		`LAGRANGE`
		`LINEAR`
			E	~~No~~O

`INTERPOLATION_DEGREE`	The `INTERPOLATION_DEGREE` keyword shall specify the recommended degree of the interpolating polynomial used to calculate a transmit phase count at an arbitrary time in tracking data where the uplink frequency is not constant. The value must be an integer and must be used if the `INTERPOLATION` keyword is used.	`3`
		`5`
		`7`
		`11`
			E	~~No~~O

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
~~DOPPLER_COUNT~~RECEIVE_PHASE_CT_BIAS	~~Doppler counts are generally biased so as~~The RECEIVE_PHASE_CT_BIAS keyword shall specify a frequency measurement bias value. Phase counts may be biased to accommodate negative Doppler within an accumulator. In order to reconstruct the measurement, the bias shall be subtracted from the ~~DOPPLER_COUNT~~differenced RECEIVE_PHASE_CT data ~~value~~values. The data type shall be double precision, and shall be positive. Examples are shown in the 'Normative Values / Examples' column. Units are Hz. The default shall be 0 (zero). If the keyword value is not provided, the default value shall apply.	2.~~4e6~~4e8 240000000.0	E	~~No~~O
~~DOPPLER_COUNT~~RECEIVE_PHASE_CT_SCALE	~~Doppler~~The RECEIVE_PHASE_CT_SCALE keyword shall specify a frequency measurement scale value. Phase counts ~~are generally~~may be scaled ~~so as~~ to capture partial cycles in an integer count. In order to reconstruct the measurement, the ~~DOPPLER_COUNT~~RECEIVE_PHASE_CT data value shall be divided by the scale factor. The data type shall be integer, and shall be positive. Examples are shown in the 'Normative Values / Examples' column. The default shall be 1 (one). If the keyword value is not provided, the default value shall apply.	1000 250 100 1	E	~~No~~O
~~DOPPLER_COUNT_ROLLOVER~~	~~Doppler counts may overflow the accumulator and roll over in cases where the track is of long duration or very high Doppler shift. This flag indicates whether or not a counter rollover has occurred during the track.~~	~~YES~~ ~~NO~~	~~N~~	~~No~~

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Keyword	**Description**	**Normative Values / Examples**	**N/E**	**~~Mandatory~~ M/O/C**

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

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
RECEIVE_DELAY_n n = {1, 2, 3, 4, 5}…}	The RECEIVE_DELAY_n keyword shall specify a fixed interval of time, in seconds, required for the signal to travel from the tracking point to the receiving electronics. This may be used to account for gross factors that do not change from pass to pass, such as antennas with remote electronics, arraying delays, or spacecraft transponder delays. The 'n' corresponds to the 'n' associated with the PARTICIPANT_n keyword (e.g., RECEIVE_DELAY_1, if present, applies to timetags for PARTICIPANT_1). Delays associated with downlink antenna arraying should be indicated with this keyword. If the user wishes to convey a ranging transponder delay, then one half of the transponder delay should be specified via the RECEIVE_DELAY_n keyword., unless an associated transponder receive delay is known. The RECEIVE_DELAY should generally not be included in ground corrections applied to the tracking data. The RECEIVE_DELAY shall be a non-negative double precision value. The default value shall be 0.0. NOTE – This value should not be used to convey clock bias information. (See the 'CLOCK_BIAS' keyword in the Data Section keywords.)	1.23 0.0326 0.00777	E	NoO
SYSTEM_CONFIG_n_START n = {1, 2, 3, 4, …}	The SYSTEM_CONFIG_n_START keyword shall delineate the start of a system configuration subsection within the Metadata Section of the message. It must appear on a line by itself; that is, it shall have no parameters, timetags, or values. The keyword is indexed to accommodate scenarios, where informing of configurations for multiple systems is desirable. The 'n' index is associated the corresponding PARTICIPANT system.	N/A	-----	C
<CONFIGURATION PARAMETERS>	The SYSTEM_CONFIG_n subsection shall be composed of lines of system configuration parameter definitions. The addition of these configuration parameters provides the user with useful information in deriving accurate products. The format of the configuration definition lines, along with a list of common parameters and possible value allocations can be found in section 3.3.1.14 and table 3-4. Not all possible configuration parameters need to be defined in each system configuration subsection. See examples A-14 and A-29.	FRONT_END_ID=OPT1 ASTROMETRY_CATALOG_NAME=UCAC5	E	O

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Keyword	Description	Normative Values / Examples	N/E	~~Mandatory~~ M/O/C
SYSTEM CONFIG n STOP n = {1, 2, 3, 4, …}	The SYSTEM CONFIG n STOP keyword shall delineate the end of a system configuration subsection within the Metadata Section of the message. It must appear on a line by itself; that is, it shall have no parameters, timetags, or values. The keyword is indexed to accommodate scenarios where informing of configurations for multiple systems is desirable. The 'n' index is associated the corresponding PARTICIPANT system.	N/A	-----	C

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`DATA_QUALITY`	The `DATA_QUALITY` keyword ~~may~~shall be composed of a comma-separated list of indicators paired with their respective symbols separated by white space. These indicators are used to provide an estimate of the quality of the data, based on indicators from the producers of the data (e.g., bad time synchronization flags, marginal lock status indicators, etc.). ~~A value of 'RAW' shall indicate~~Indicator-symbol pairs should be selected from the following selection: • 'RAW R' indicates 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~~. • 'VERIFIED V' indicates that ~~data~~ conditions for providing quality ~~has~~data have been ~~checked,~~met and/or rough verification of values was conducted. • 'VALIDATED A' indicates that data quality has been checked against required accuracy and passed ~~tests. A value of 'DEGRADED' shall indicate~~evaluation. • 'DEGRADED D' indicates 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~~, however the ~~value is 'DEGRADED', information on the nature of the degradation may be conveyed via the COMMENT mechanism. It should be noted that because of the nature of TDM metadata, if 'DEGRADED' is specified,~~data may provide some value. • 'INVALID I' indicates the data has not passed checks and must not be used for operational purposes (e.g., this data could be shared for analysis purposes). See examples A-1, A-23. Two implementation options are supported: 1) A single value is provided instead of a list, and it applies to all the data in the segment. ~~Thus degraded data should be isolated in dedicated segments.~~ In this case, the indicator shall be provided without the paired symbol. 2) The ~~default value shall be 'RAW' (rationale: agencies often do not validate tracking data before export).~~list of values specified provides the symbols to be linked to each observable in the Data Section. See section 0 on utilizing quality indicator	VERIFIED V, INVALID I ~~RAW~~ VALIDATED A, DEGRADED D, INVALID I RAW VERIFIED VALIDATED DEGRADED INVALID	~~N~~E	~~No~~O

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
	symbols linked to each observation in the Data Section.			
CORRECTION_ANGLE_1_n CORRECTION_ANGLE_2_n CORRECTION_DOPPLER_n CORRECTION_MAG_n CORRECTION_RANGE_n CORRECTION_RCS_n CORRECTION_RECEIVE CORRECTION_TRANSMIT CORRECTION_ABERRATION_YEARLY_ANGLE_1_n CORRECTION_ABERRATION_YEARLY_ANGLE_2_n CORRECTION_ABERRATION_DIURNAL_ANGLE_1_n CORRECTION_ABERRATION_DIURNAL_ANGLE_2_n CORRECTION_TIMETAG_k	The set of CORRECTION_* keywords may be used to reflect the values of corrections that have been added to the data or should be added to the data (e.g., ranging station delay calibration, etc.). This information may be provided to the user, so that the base measurement could be recreated if a different correction procedure is desired. Tracking data should be corrected for ground delays only.all known instrument calibrations. It should be noted that it may not be feasible to apply all ground corrections for a near–real-time transfer. Units for the correction shall be the same as those for the applicable observable. All corrections should be signed, double precision values. Examples are shown in the 'Normative Values / Examples' column. See section 3.3.1.13 for definitions of the different correction keywords.	-1.35 0.23 -3.0e-1 150000.0	E	NoO
CORRECTIONS_ORDER_n n = {1, 2, 3, 4, …}	The CORRECTIONS_ORDER_n keyword shall be composed of a comma-separated list of CORRECTION keywords that apply to PARTICIPANT 'n'. The order of the list of CORRECTION keywords shall indicate the order of the CORRECTION values as provided in the Data Section under the CORRECTIONS_n keyword (see 3.5.9.2). Note that section 3.3.1.13 defines abbreviations that may be used to identify each correction. CORRECTION_* keywords and This keyword must be provided when CORRECTION values are dynamically updated during a tracking event. CORRECTION_* keywords shall not be provided in the Metadata Section if they are dynamically provided in the Data Section. See example A-28.	ANG1, ANG2	N	C

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
CORRECTIONS_APPLIED_n	This keyword is used to indicate whether or not the values associated with the CORRECTION_* keywords and PARTICIPANT 'n' have been applied to the tracking data. This keyword is required if any of the CORRECTION_* keywords isare used. Because of the nature of TDM metadata, the application of corrections applies"Yes" or "No" values shall apply to all of the data described by a given Metadata Section. Thus all of the data inAlternatively, a given segment mustlist of comma-separated correction keywords may be provided to indicate only the keywords for corrections that have correctionsbeen applied or corrections not applied. The value of this keyword thus applies to all the data related to a Metadata Section in which it isthe data. Note that section 3.3.1.13 defines abbreviations that may be used.— to identify each correction. See example A-29.	YES NO ANG1, ANG2	N	NoC
CORRECTION_TIMETAG_OBS_k	The CORRECTION_TIMETAG_OBS_k keyword identifies the applicable observable keywords that are subject to the correction defined by the corresponding CORRECTION_TIMETAG_k keyword. Keywords are provided as a list of comma-separated values. The "k" represents an index used to group the different observables with their respective applicable timetag corrections. See example A-30.	ANG1, ANG2	N	O
OBS_COVARIANCE_OBS_k	The OBS_COVARIANCE_OBS_k keyword shall provide an ordered list of comma-separated observables used to populate a variance-covariance matrix. This keyword shall be used in combination with the OBS_COVARIANCE_VALS_k keyword, such that an ordered set of variance and covariance values can be provided by the OBS_COVARIANCE_k keywords in the DATA section. The "k" represents an index used to group the different observables with their respective applicable OBS_COVARIANCE_VALS_k and OBS_COVARIANCE_k keywords. See annex F5 for additional details on the use of this keyword.	ANGLE_1, ANGLE_2, RANGE, ANGLE_1_RATE, ANGLE_2_RATE	E	C

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Keyword	Description	Normative Values / Examples	N/E	Mandatory M/O/C
OBS_COVARIANCE_VALS_k	The OBS_COVARIANCE_VALS_k keyword shall provide an ordered list of comma-separated variance and covariance elements from a variance-covariance matrix. Each element is identified using a “row column” pair, separated by white space. This keyword shall be used in combination with the OBS_COVARIANCE_OBS_k keyword, such that an ordered set of variance and covariance values can be provided by the OBS_COVARIANCE_k keywords in the DATA section. The “k” represents an index used to group the different observables with their respective applicable OBS_COVARIANCE_OBS_k and OBS_COVARIANCE_k keywords. See annex F5 for additional details on the use of this keyword.	1 1, 2 1, 2 2, 3 1, 3 2, 3 3, 4 1, 4 2, 4 3, 4 4, 5 1, 5 2, 5 3, 5 4 ,5 5	E	C
META_STOP	The META_STOP keyword shall delineate the end of the TDM Metadata Section within the message. It must appear on a line by itself; that is, it shall have no parameters, timetags, or values.	N/A	-----	YesM

3.3.1.13 Correction Keyword Definitions

Correction values shall have been added by the TDM producer to the corresponding data when corrections have been applied. Correction values may be added to the corresponding data by the end user when corrections have not been applied. The abbreviations captured in square brackets ‘[]’ after the correction names below may be used to reduce lengthy text lines when defining keywords: CORRECTIONS_ORDER_n, CORRECTIONS_APPLIED_n and CORRECTION_TIMETAG_OBS_k.

CORRECTION_ANGLE_1_n [ANG1_n] represents an angle correction value in degrees, corresponding to data provided in the Data Section under the ANGLE_1 keyword. The ‘_n’ index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_ANGLE_2_n [ANG2_n] represents an angle correction value in degrees, corresponding to data provided in the Data Section under the ANGLE_2 keyword. The ‘_n’ index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_DOPPLER_n [DOP_n] represents a correction value in Hz, corresponding to data provided by the RECEIVE_FREQ or RECEIVE_PHASE_CT keywords. The ‘_n’ index

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shall be included to indicate the relevant PARTICIPANT_n, when it is necessary to differentiate corrections from multiple sets of CORRECTION_DOPPLER values. The '_n' index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_MAG_n [MAG_n] represents a correction value in units as defined for the MAG keyword, corresponding to the data provided in the Data Section under the MAG keyword. The '_n' index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_RANGE_n [RNG_n] represents a correction value in units as defined for the RANGE keyword, corresponding to the data provided in the Data Section under the RANGE keyword. The '_n' index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_RCS_n [RCS_n] represents a correction value in units of square meters (m**2), corresponding to the data provided in the Data Section under the RCS keyword. The '_n' index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_RECEIVE [RX] is obsolete, it provides compatibility with earlier versions of this recommended standard.

CORRECTION_TRANSMIT [TX] is obsolete, it provides compatibility with earlier versions of this recommended standard.

CORRECTION_ABERRATION_YEARLY_ANGLE_1_n [ABER_Y1_n] and CORRECTION_ABERRATION_YEARLY_ANGLE_2_n [ABER_Y2_n] represent angle corrections in degrees, corresponding to an apparent angle discrepancy when optically tracking objects. This is caused by the motion of an observer on Earth as the planet revolves around the Sun. Separate corrections are provided for each applicable angle. The '_n' index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_ABERRATION_DIURNAL_ANGLE_1_n [ABER_D1_n] and CORRECTION_ABERRATION_DIURNAL_ANGLE_2_n [ABER_D2_n] represent angle corrections in degrees, corresponding to an apparent angle discrepancy when optically tracking objects. This is caused by the motion of an observer on Earth as the planet rotates. Separate corrections are provided for each applicable angle. The '_n' index shall be included to indicate the association with PARTICIPANT_n, when it is necessary to differentiate corrections attributed to different participants.

CORRECTION_TIMETAG_k [TT_k] represents a correction time value in seconds that applies to each timetag in the Data Section. The "k" represents an index, corresponding to the applicable observation keywords that are identified with the CORRECTION_TIMETAG_OBS_k keyword.

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3.3.1.14 System Configuration Parameters

The parameters specified with each SYSTEM_CONFIG_n metadata subsection provide the user with system configuration information to aid in deriving accurate products. A list of common parameters and possible value allocations can be found in table 3-4. Note that not all possible configuration parameters need to be included in the SYSTEM_CONFIG_n subsection. Other parameters of interest may be defined by prior mutual agreement between data exchange parties.

Each subsection shall be initialized with the SYSTEM_CONFIG_n_START keyword, with the ‘n’ representing the indexed participant identified by the relevant PARTICIPANT_n keyword. The SYSTEM_CONFIG_n_START keyword shall be followed by lines of applicable system configuration definitions applicable to the given participant. These lines are formed by a parameter name, followed by an equal sign ‘=’ and the applicable parameter value. The subsection end shall be delineated with the inclusion of the corresponding SYSTEM_CONFIG_n_STOP keyword.

EXAMPLE:

SYSTEM_CONFIG_3_START
FRONT_END_ID=OPT1
SYSTEM_PATH=CCD2x2
SYSTEM_CONFIG_3_STOP

NOTE – System configuration parameters apply to all data in the data segment. See 3.5.9.8 for system status definitions and updates within the data segment, which also make use of the definitions provided in table 3-4.

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Table 3-4: TDM System Configuration and Status Subsections

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Parameter	Description	Normative Values / Examples	N/E	M/O/C
ABSORPTION_NORMALIZATION_APPLIED	The ABSORPTION_NORMALIZATION_APPLIED parameter shall indicate whether data normalization for atmospheric absorption has been applied to the optical observation data.	YES NO	N	O
APERTURE_FILTER	The APERTURE_FILTER parameter shall indicate a comma-separated list of name(s) of any photometric filters applied during the tracking. The following is a set of predefined filter names: NONE, JOHNSON B, SLOAN z, JC_V, RECTANGULAR_V, GAIA_G, SDSS_R. A value of 'NONE' shall indicate an open aperture.	NONE JOHNSON B SLOAN z	E	O
APERTURE_FILTER_ZERO_PT	For each of the filters specified in the APERTURE_FILTER parameter, the APERTURE_FILTER_ZERO_PT parameter shall indicate the telescope photometric zero point in stellar magnitudes and its associated uncertainty (standard deviation, in photon flux [photons/m2/sec]). Values are provided in pairs in a vector format. Values within each pair are separated by white space. Pairs of values are separated by commas.	0.0 0.0 0.0 0.0, 1.0 1.0	N	O
ASTROMETRY_CATALOG_NAME	The ASTROMETRY_CATALOG_NAME parameter shall provide indication of the reference catalog utilized for the astrometric data capture event.	UCAC5 GAIA DR2	E	O
BEAMFORMER_BIAS	The BEAMFORMER_BIAS parameter shall provide information on the multiple access beamformer telemetry. Values are provided in units of seconds.	0.015	E	O
BEAMFORMER_NOISE	The BEAMFORMER_NOISE parameter shall provide information on the multiple access beamformer telemetry. Values are provided in units of seconds.	0.12	E	O
CARRIER_STATUS	Carrier acquisition and tracking status shall be reported via the CARRIER_STATUS parameter.	Lock Acq Search	E	O
CORRECTIONS_NOT_APPLIED	The CORRECTIONS_NOT_APPLIED parameter shall be utilized to provide a comma separated list of corrections that are not applied to the data and which values are not provided via CORRECTION_* keywords. String values used to denote each correction can be found in Section 3.3.1.13.	CORRECTION_RANGE ABER_D1, ABER_Y1	E	O
ELEVATION_MAPPING	The ELEVATION_MAPPING parameter shall be utilized to provide a model name that applies to the TROPO_DRY and/or TROPO_WET keywords in the Data Section.	NIELL	E	O

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Parameter	Description	Normative Values / Examples	N/E	M/O/C
EXPOSURE_TIME	The EXPOSURE_TIME parameter shall specify the value associated with the exposure time in photometric-based tracking. The value shall be a provided in units of rational seconds.	0.01	E	O
FRONT_END_ID	The FRONT_END_ID_n parameter shall specify a unique identifier within each participant system that refers to the front-end taking part in the tracking session. For example, in radiometric tracking the front-end of a space object would be one antenna assembly out of potentially several. Another example front-end is the optical head for an optical-based observation session.	HGA1 OMNI OPT2 OPT1 SA1 MAF1	E	O
NORMALIZATION_DISTANCE	The NORMALIZATION_DISTANCE parameter shall provide a distance in kilometers indicating the value used in the normalization for standard slant range.	450.0	E	O
NORMALIZATION_PHASE_ANGLE	The NORMALIZATION_PHASE_ANGLE parameter shall provide an angle in degrees indicating the value used in the normalization for standard phase angle.	0.015	E	O
OBS_CALIBRATION	The OBS_CALIBRATION parameter shall be used to indicate observation calibration updates. The parameter shall be populated with two comma-separated fields. The first indicates the relevant observable (e.g. 'RANGE'). The second field can be 'yes' or the number of averaged calibrations that were performed.	RANGE, yes RANGE, 5	E	O
OBS_GRANULARITY	The OBS_GRANULARITY parameter shall convey the smallest change in the value of an observable that can be provided in the message. The parameter shall be populated with two comma-separated fields. The first indicates the relevant observable (e.g. 'RANGE'). The second field indicates the granularity value in the same units used for the particular observable (e.g. seconds).	RANGE, 0.00390625	E	O
OBS_RESOLUTION	The OBS_RESOLUTION parameter shall convey the accuracy in determining the value of an observable that can be provided in the message. The parameter shall be populated with two comma-separated fields. The first indicates the relevant observable (e.g. 'RANGE'). The second field indicates the resolution value in the same units used for the particular observable (e.g. RU).	RANGE, 0.06	E	O

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Parameter	Description	Normative Values / Examples	N/E	M/O/C
OBS_UNCERTAINTY	The OBS_UNCERTAINTY parameter shall convey the uncertainty associated with an observable that can be provided in the message. The parameter shall be populated with two comma-separated fields. The first indicates the relevant observable (e.g. 'RANGE'). The second field indicates the uncertainty value in the same units used for the particular observable (e.g. RU). Unless otherwise established by agreement between exchange entities, the values correspond to 68.27 % uncertainties (1-sigma for normal distributions). Uncertainty for MAG is expressed as a Poisson second moment in photon flux units (photons/m**2/sec), as the errors more closely follow a normal distribution. See example A-23. NOTE – Multiple OBS_UNCERTAINTY parameters may be specified, each referencing a different observable type to define separate uncertainty values for the different measurement types.	RANGE, 3.5 MAG, 0.01	E	O
PHOTOMETRY_CATALOG_NAME	The PHOTOMETRY_CATALOG_NAME parameter shall provide indication of the reference catalogue utilized for the photometric data capture event.	UCAC5 GAIA DR2 NOMAD	E	O
PN_STATUS	PN Code acquisition and tracking status shall be reported via the PN_STATUS parameter.	Lock Sync Search	E	O

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Parameter	Description	Normative Values / Examples	N/E	M/O/C
POINTING_MODE	The POINTING_MODE parameter shall indicate the tracking method utilized by the participant designated by the '*n*' from the SYSTEM_STATUS_n keyword, especially when intending to derive angle observables. Typical operational modes include autotrack (i.e. closed-loop tracking), program track (i.e. open-loop tracking), manual or locked (i.e. angles commanded by a separate tracking system). The POINTING_MODE parameter shall be utilized in the Data Section to provide flexibility in covering a mix of angle data modes that may take place throughout a tracking session. For example, a ground terminal may begin tracking an object in program track mode and transition to autotrack once a solid signal is being tracked. The POINTING_MODE parameter applies to all successive related observation keywords in the Data Section. A POINTING_MODE parameter supersedes all prior POINTING_MODE parameters within the Data Section. In the absence of this parameter, angle data is assumed to be provided in autotrack mode.	AUTOTRACK PROGRAM MANUAL LOCKED SIDEREAL	E	O
RANGE_QUALITY_FACTOR	The RANGE_QUALITY_FACTOR parameter shall provide an estimate of confidence in resolving the ranging measurement. The value shall be a number between 0 and 1.	0.91 0.0 1.0	E	O
RCS_MAX	The RCS_MAX keyword shall indicate the maximum object RCS that could have been detected by the selected waveform and detection sequence, for the observing session contained in this TDM. This parameter is specified in units of square meters (m**2).	2.50	E	O
RCS_MIN	The RCS_MIN keyword shall indicate the minimum object RCS that could have been detected by the selected waveform and detection sequence, for the observing session contained in this TDM. This parameter is specified in units of square meters (m**2).	0.02	E	O
RECEIVE_PHASE_CT_ROLLOVER	The RECEIVE_PHASE_CT_ROLLOVER parameter shall be used to indicate that the RECEIVE_PHASE_CT keyword has experienced a counter rollover due to a limitation in the number of digits utilized to convey the phase counts. "yes" indicates that a rollover has occurred.	yes no	E	O

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Parameter	Description	Normative Values / Examples	N/E	M/O/C
SENSOR_OFFSET	The SENSOR_OFFSET X, Y and Z cartesian coordinate parameters shall represent the sensor's positional offset from a body-frame reference, in units of rational meters. Offsets should coincide with attitude reference frame from an applicable ADM referenced via ADM_MSG_LINK_n for the same participant. If no ADM is linked, offsets shall be interpreted in a pre-coordinated default body-frame for that participant. Values are provided as a list separated by commas.	1.243, -5.345, 0.076	E	O
SIGNAL_SNR	The SIGNAL_SNR parameter shall provide an estimate of the signal to noise ratio received by the system. The value shall be provided in units of dBHz.	25.45 17.04	E	O
SYSTEM_MODE	The SYSTEM_MODE parameter shall specify the system mode of operation for a particular participant during the tracking session. For example, a space relay may specify if the mode is single access or multiple access.	SINGLE ACCESS MULTIPLE ACCESS	E	O
SYSTEM_PATH	The SYSTEM_PATH parameter shall specify a path within each participant system that reflects the hardware configuration for the tracking session. For example, a ground terminal specifies which modem, switches, upconverters and polarization is used for the tracking event. For optical sensors the value should reflect the Charged-Couple Device (CCD) binning applied during the tracking.	MOD1-SW1-POL1 CCD2x2	E	O
SYSTEM_TEMPERATURE	The SYSTEM_TEMPERATURE parameter shall specify a system temperature value in K.	283.8	E	O
TFR_ID	The TFR_ID parameter shall specify a unique identifier within each participant system that refers to the Time and/or frequency reference source taking part in the tracking session. For example, a ground terminal specifies which configuration is utilized for the tracking event.	TFR2 CLK1	E	O
TRANMSIT_PHASE_CT_ROLLOVER	The TRANSMIT_PHASE_CT_rollover parameter shall be used to indicate that the TRANSMIT_PHASE_CT keyword has experienced a counter rollover due to a limitation in the number of digits utilized to convey the phase counts. "yes" indicates that a rollover has occurred.	yes no	E	O

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Parameter	Description	Normative Values / Examples	N/E	M/O/C
WIND_DIRECTION	The WIND_DIRECTION parameter shall indicate the apparent wind direction, in degrees from North, as measured in proximity of PARTICIPANT n. Values should be provided in the range from 0 to 360 degrees.	272.7	E	O
WIND_SPEED	The WIND_SPEED parameter shall indicate the apparent wind speed, in kilometers per hour, as measured in proximity of PARTICIPANT_n. The value is provided in units of kilometers per hour.	14.32	E	O

3.3.2 MODE AND PATH SETTINGS FOR TYPICAL TRACKING SESSIONS

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

3.3.2.1 One-Way Data

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

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

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

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

NOTE – Figures ~~E-1 and E-2~~A-1 and A-2 are examples TDMs containing one-way tracking data.

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3.3.2.2 Two-Way Data

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

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

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

NOTE – Figures E-3, E-4, E-9, E-18, E-19, and E-20A-3, A-4, A-9, A-20, A-21, and A-22 are example TDMs containing two-way tracking data.

3.3.2.3 Three-Way Data

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

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

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

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

NOTE – Figure E-5A-5 is an example TDM containing three-way tracking data.

3.3.2.4 'RELAY' Mode

3.3.2.4.1 The 'RELAY' mode describes tracking configurations where signal paths include relay satellites or intermediate nodes. It consists of a main signal path defined by PATH_1 (e.g., 'PATH_1=1,2,3,4,5'), which traces the complete signal path. Additional reference signal paths may support relay operations: PATH_2 can define the reference frequency signal path for the transmitting relay (e.g., 'PATH_2=6,7'), while PATH_3 can define the reference

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frequency signal path for the receiving relay (e.g., 'PATH_3=8,9'). These reference signals enable frequency translation operations for some relay nodes. For example, in 'PATH_1=1,2,3,4,5', if PARTICIPANT_2 is a transmitting relay satellite, 'PATH_2=6,7' would specify that PARTICIPANT_6 provides a reference frequency to PARTICIPANT_7. While PARTICIPANT_7 is the same physical entity as PARTICIPANT_2, it is identified separately to allow specifying the reference signal.

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

3.3.2.4.3 The value assigned to the PATH_1 keyword shall convey the signal path among the participants followed by the main signal; for example, 'PATH_1=1,2,3,2,1' or 'PATH_1=1,2,3,4,5' represent two different four-way relay-tracking signal paths. The value assigned to the PATH_2 keyword shall convey the signal path of the reference signal provided to the transmitting relay; for example, 'PATH_2=6,7'. The value assigned to the PATH_3 keyword shall convey the signal path of the reference signal provided to the receiving relay; for example, 'PATH_3=8,9'.

NOTE – Figure A-26 is an example TDM containing 'RELAY' tracking data.

~~3.3.2.4~~3.3.2.5 *N*-Way Data

~~3.3.2.4.1~~**3.3.2.5.1** One-way, two-way, and three-way tracking cover the bulk of tracking sequences. However, other four-way and greater (*n*-way) scenarios are possible (e.g., via use of one or more relay satellites). These may be accomplished via the sequence assigned to the PATH keyword.

~~3.3.2.4.2~~**3.3.2.5.2** The setting of the 'MODE' keyword shall be 'SEQUENTIAL'.

~~3.3.2.4.3~~**3.3.2.5.3** The value assigned to the PATH keyword shall convey the signal path among the participants followed by the signal; for example, 'PATH=1,2,3,2,1' and 'PATH=1,2,3,~~4'~~4,5' represent two different four-way tracking signal paths.

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

NOTE – Figure ~~E-6~~A-6 is an example TDM containing four-way tracking data.

~~3.3.2.5~~3.3.2.6 Differenced Modes and VLBI Data

~~3.3.2.5.1~~**3.3.2.6.1** Differenced data and VLBI data may also be exchanged in a Tracking Data Message. Differenced data may include differenced Doppler (i.e. differenced frequency) and differenced range (see references ~~[F3]~~[H3] and [H4]).

~~3.3.2.5.2~~**3.3.2.6.2** The setting of the 'MODE' keyword shall be 'SINGLE_DIFF'.

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

3.3.2.5.43.3.2.6.4 When the MODE is 'SINGLE_DIFF', the observable shall be calculated by subtracting the value achieved for the measurement using PATH_1 from the value achieved using PATH_2, that is, PATH_2 – PATH_1. Only the final observable shall be communicated via the TDM.

3.3.2.5.53.3.2.6.5 If the TDM contains differenced Doppler shift(i.e. differenced frequency) 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).

3.3.2.5.63.3.2.6.6 If the TDM contains two-way or three-way differenced Doppler (i.e. differenced frequency) 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).

3.3.2.5.73.3.2.6.7 If differenced range is provided, the 'RANGE' keyword shall be used for the observable (the 'RANGE' keyword is a Data Section keyword not yet described in the text – see 3.5.2.6).

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

3.3.2.5.93.3.2.6.9 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 3.5.3.5).

3.3.2.6.10 If the TDM contains differenced data collected during a Time Difference of Arrival (TDOA) session with a spacecraft, then the TDOA keyword shall be used for the observable (see 3.5.3.8).

3.3.2.6.11 If the TDM contains differenced data collected during a Frequency Difference of Arrival (FDOA) session with a spacecraft, then the FDOA keyword shall be used for the observable (see 3.5.3.9).

NOTE – Figures E-10A-10, A-11 and E-11A-30 are example TDMs containing single differenced tracking data.

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~~3.3.2.6~~3.3.2.7 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 rightmost~~may be collected by participants ~~listed in~~that are tracking the specific participant object of the ~~PATH statement~~tracking session (e.g., spacecraft downlink to an antenna, direction of a participant measured by a navigation camera, etc.).

NOTE – Figures ~~E-8~~A-8 and ~~E-12~~A-13 are example TDMs containing angle data.

~~3.3.2.7~~3.3.2.8 Media, Weather, Ancillary Data

NOTE – Figures ~~E-13~~A-14 through ~~E-15~~A-17 are example TDMs containing tracking data related to media, weather, and ancillary data.

~~3.3.2.7.1~~3.3.2.8.1 When all the data in a TDM Segment is media related, weather related, or ancillary-data related, then the use of the MODE keyword may or may not apply as discussed below.

~~3.3.2.7.2~~3.3.2.8.2 Data of this type may be relative to a reference location within the tracking complex; in this case the methods used to extrapolate the measurements to other antennas should be ~~specified in the ICD.~~pre-coordinated between exchanging entities by mutual agreement. In the case where a reference location is used, there shall be only one participant (PARTICIPANT_1), which is the reference antenna, and the MODE keyword shall not be used. This case corresponds to tropospheric correction data, zenith ionospheric correction data, and weather data.

~~3.3.2.7.3~~3.3.2.8.3 When ionospheric charged particle delays are provided for a line-of-sight between the antenna and a specific spacecraft, the participants include both the antenna and the spacecraft, the MODE should be set to 'SEQUENTIAL', and a standard PATH statement should be used.

3.4 TDM DATA SECTION (GENERAL SPECIFICATION)

3.4.1 The Data Section of the TDM Segment shall consist of one or more Tracking Data Records. Each Tracking Data Record shall have the following generic format, where the indicator field is optional:

keyword = timetag measurement indicator

NOTE – More detail on the generic format of a Tracking Data Record is shown in table 3-5.

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Table 3-5: Tracking Data Record Generic Format

Element		Description	Examples	Mandatory
`<keyword>`		Data type keyword from the list specified in 3.53.5.	(See annex E.)G)	Yes (at least one keyword must be used)
=		Equals sign	=	Yes
value	`<timetag>`	Time associated with the tracking observable according to the TIME_SYSTEM keyword. (For requirements on the timetag, see 3.4.8 through 3.4.12. For format specification, see 4.3.11.)	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.)(See 3.5)	Yes
	`<indicator symbol>`	Indicator symbol corresponding to data quality indicators defined by the DATA_QUALITY keyword.	(See 0)	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 or three 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 third element consists of an optional quality indicator symbol.

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

3.4.5 Applicable keywords and their associated characteristics are detailed in 3.53.5.

3.4.6 There shall be no mandatory keywords in the Data Section of the TDM Segment, with the exception of 'DATA_START' and 'DATA_STOP', because the data presented in any given TDM is dependent upon the characteristics of the data collection activity. 'DATA_START' and 'DATA_STOP' keywords are only intrinsically included in XML formatted data, per section 5.

3.4.7 The Data Section of the TDM Segment shall be delineated by the 'DATA_START' and 'DATA_STOP' keywords. These keywords are intended to facilitate parsing, and will also serve to advise the recipient that all the Tracking Data Records associated with the immediately preceding TDM Metadata Section have been received. The TDM recipient may process the 'DATA_STOP' keyword as a 'local' end-of-file marker.

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

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

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

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

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

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

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

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

3.4.15.2 Tracking data should be corrected for ground delays only. all known instrument calibrations. The corrections that have been applied may be specified to the message recipient via use of the optional 'CORRECTION_*' keywords in the metadata or dynamically updated via the optional 'CORRECTIONS_n' keywords within the Data Section.

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

3.4.15.3 If correction values are indicated via any of the 'CORRECTION_*' or 'CORRECTIONS_n' keywords, then the TDM producer must indicate whether these correction values have or have not been applied to the tracking data. This indication is accomplished via the use of the metadata keyword 'CORRECTIONS_APPLIED'; this metadata item must have a value of 'YES' or 'NO', 'NO' or a list of comma-separated correction keywords. 'YES' or 'NO' values apply to all 'CORRECTION_*' keywords and all corresponding data in the Data Section. Alternatively, a list of comma-separated correction keywords may be provided to indicate only the keywords for corrections that have been applied to the data.

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

3.4.15.5 The party that will perform any applicable spin corrections should be specified in the ICDpre-coordinated between exchanging entities by mutual agreement (most appropriate party may be the party that operates the spacecraft).

3.4.15.6 Special correction algorithms that are more complex than a simple scalar value should be specified in the ICDpre-coordinated between exchanging entities by mutual agreement.

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

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

– the keyword to be used;

– applicable units for the associated values;

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

NOTES

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

2 Annex ~~E~~G provides detailed usage examples.

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

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

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3.5 TDM DATA SECTION KEYWORDS

3.5.1 OVERVIEW

This subsection describes each of the keywords that may be used in the Data Section of the TDM Segment. In general, there is no required order in the Data Section of the TDM Segment. Exceptions are the ‘DATA_START’ and ‘DATA_STOP’ keywords, which must be the first and last keywords in the Data Section, respectively. For ease of reference, table ~~3-5~~3-6 containing all the keywords sorted in alphabetical order is shown immediately below. Table 3-7 repeats the information from table ~~3-5~~3-6 in category order. Descriptive information about the keywords is shown starting in 3.5.2. The remainder of this subsection is organized according to the category of data to which the keyword applies (e.g., all the signal related keywords are together, all media related keywords are together, etc.).

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

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Keyword	Units	Text Link
ANGLE_1_n	deg	~~3.5.4.2~~3.5.4.2
ANGLE_1_RATE_n	deg	3.5.4.3
ANGLE_2_n	deg	~~3.5.4.3~~3.5.4.4
ANGLE_2_RATE_n	deg	3.5.4.5
ASTROMETRIC_STAR_COUNT	n/a	3.5.5.2
CARRIER_POWER	dBW	~~3.5.2.1~~3.5.2.1
CLOCK_BIAS	s	~~3.5.6.1~~3.5.6.1
CLOCK_DRIFT	s/s	~~3.5.6.2~~3.5.6.2
COMMENT	n/a	~~3.5.9.1~~3.5.9.1
CORRECTIONS_n	see 3.5.9.2	3.5.9.2
DATA_START	n/a	~~3.5.9.2~~3.5.9.3
DATA_STOP	n/a	~~3.5.9.3~~3.5.9.4
~~DOPPLER_COUNT~~Data Quality Indicator Symbols	n/a	~~3.5.2.4~~0
FDOA	Hz	3.5.3.9
DOPPLER_INSTANTANEOUS	km/s	~~3.5.2.2~~3.5.2.2
DOPPLER_INTEGRATED	km/s	~~3.5.2.3~~3.5.2.3
DOR	s	3.5.3.2
DOR_AMBIGUITY	s	3.5.3.4
DOR_RATE	s/s	~~3.5.3.2~~3.5.3.3
FRAME_LIMITING_BRIGHTNESS	Stellar magnitude	3.5.5.5
MAG	n/a	3.5.5.1
OBS_COVARIANCE_k	Product of observable units	3.5.9.6
PC_N0	dBHz	~~3.5.2.5~~1.1.1.1
PHOTOMETRIC_SNR	n/a	3.5.5.4
PHOTOMETRIC_STAR_COUNT	n/a	3.5.5.3
PR_N0	~~dBHz~~dBHz	3.5.2.5
PRESSURE	hPa	~~3.5.8.1~~3.5.8.1
RANGE	km, s, or RU	~~3.5.2.7~~3.5.2.6
RCS	m**2	3.5.5.6
RECEIVE_FREQ_n (n = 1, 2, 3, 4, ~~5)~~…)	Hz	~~3.5.2.8~~3.5.2.7
~~RECEIVE_FREQ~~	~~Hz~~	~~3.5.2.8~~
RECEIVE_PHASE_CT_n (n = 1, 2, 3, 4, ~~5)~~…)	n/a	3.5.2.10
RHUMIDITY	%	~~3.5.8.2~~3.5.8.2
STEC	TECU	~~3.5.7.1~~3.5.7.1
SYSTEM_STATUS_n_START	n/a	3.5.9.7

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Keyword	Units	Text Link
<System Status Parameters>	See 3.5.9.8	3.5.9.8
SYSTEM_STATUS_n_STOP	n/a	3.5.9.9
TDOA	s	3.5.3.8
TEMPERATURE	K	3.5.8.33.5.8.3
TRANSMIT_FREQ_n (n = 1, 2, 3, 4, 5)…)	Hz	3.5.2.93.5.2.8
TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, 5)…)	Hz/s	3.5.2.103.5.2.9
TRANSMIT_PHASE_CT_n (n = 1, 2, 3, 4, 5)…)	n/a	3.5.2.11
TROPO_DRY	m	3.5.7.23.5.7.2
TROPO_WET	m	3.5.7.33.5.7.3
VLBI_DELAY	s	3.5.3.5
VLBI_DELAY_AMBIGUITY	s	3.5.3.7
VLBI_DELAY_RATE	s/s	3.5.3.33.5.3.6

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Table 3-7: Summary Table of TDM Data Section Keywords (Category Order)

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Keyword	Units	Text Link
Signal Related Keywords		3.5.2
__CARRIER_POWER	dBW	3.5.2.1
~~DOPPLER_COUNT~~	~~n/a~~	~~3.5.2.4~~
__DOPPLER_INSTANTANEOUS	km/s	3.5.2.2
__DOPPLER_INTEGRATED	km/s	3.5.2.3
__PC_N0	dBHz	1.1.1.1
__PR_N0	dBHz	3.5.2.5
__RANGE	km, s, or RU	3.5.2.6
__RECEIVE_~~PHASE_CT~~FREQ_n (n = 1, 2, 3, 4, ~~5)~~…)	~~n/a~~ Hz	~~3.5.2.11~~3.5.2.7
__TRANSMIT_~~PHASE_CT~~FREQ_n (n = 1, 2, 3, 4, ~~5)~~…)	~~n/a~~Hz	~~3.5.2.12~~3.5.2.8
~~PR_N0~~	~~dBHz~~	~~3.5.2.6~~
~~RANGE~~	~~km, s, or RU~~	~~3.5.2.7~~
~~RECEIVE~~__TRANSMIT_FREQ_RATE_n (n = 1, 2, 3, 4, ~~5)~~…)	Hz/s	~~3.5.2.8~~3.5.2.9
~~RECEIVE_FREQ~~	~~Hz~~	~~3.5.2.8~~
~~TRANSMIT_FREQ~~__RECEIVE_PHASE_CT_n (n = 1, 2, 3, 4, ~~5)~~…)	~~Hz~~n/a	~~3.5.2.9~~3.5.2.10
__TRANSMIT_~~FREQ_RATE~~PHASE_CT_n (n = 1, 2, 3, 4, ~~5)~~…)	~~Hz/s~~n/a	~~3.5.2.10~~3.5.2.11
Differenced Modes/VLBI/Delta-DOR Related Keywords		3.5.3
__DOR	s	3.5.3.2
__DOR_RATE	s/s	3.5.3.3
__DOR_AMBIGUITY	s	3.5.3.4
__VLBI_DELAY	s	3.5.3.5
__VLBI_DELAY_RATE	s/s	~~3.5.3.3~~3.5.3.6
__VLBI_DELAY_AMBIGUITY	s	3.5.3.7
__TDOA	s	3.5.3.8
__FDOA	Hz	3.5.3.9
Angle Related Keywords		3.5.4
__ANGLE_1_n	deg	3.5.4.2

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Keyword	Units	Text Link
__ANGLE_1_RATE_n	deg/s	3.5.4.3
__ANGLE_2_n	deg	3.5.4.4
__ANGLE_2_RATE_n	deg/s	3.5.4.5
Optical/Radar Related Keywords		3.5.5
__MAG	n/a	3.5.5.1
__ASTROMETRIC_STAR_COUNT	n/a	3.5.5.2
__PHOTOMETRIC_STAR_COUNT	n/a	3.5.5.3
__PHOTOMETRIC_SNR	n/a	3.5.5.4
__FRAME_LIMITING_BRIGHTNESS	Stellar magnitude	3.5.5.5
__RCS	m**2	3.5.5.6
Time Related Keywords		3.5.6
__CLOCK_BIAS	s	3.5.6.1
__CLOCK_DRIFT	s/s	3.5.6.2
Media Related Keywords		3.5.7
__STEC	TECU	3.5.7.1
__TROPO_DRY	m	3.5.7.2
__TROPO_WET	m	3.5.7.3
Meteorological Related Keywords		3.5.8
__PRESSURE	hPa	3.5.8.1
__RHUMIDITY	%	3.5.8.2
__TEMPERATURE	K	3.5.8.3
Miscellaneous Keywords		3.5.9
__COMMENT	n/a	3.5.9.1
__CORRECTIONS_n	see 3.5.9.2	3.5.9.2
__DATA_START	n/a	3.5.9.3
__DATA_STOP	n/a	3.5.9.4
__Data Quality Indicator Symbols	n/a	0
__OBS_COVARIANCE_k	Product of observable units	3.5.9.6
__SYSTEM_STATUS_n_START	n/a	3.5.9.7

Keyword	Units	Text Link
<System Status Parameters>	See 3.5.9.8	3.5.9.8
SYSTEM_STATUS_n_STOP	n/a	3.5.9.9

3.5.2 SIGNAL RELATED KEYWORDS

3.5.2.1 CARRIER_POWER

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

3.5.2.2 DOPPLER_INSTANTANEOUS

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

NOTE – The DOPPLER_INSTANTANEOUS assumes a fixed uplink frequency (or one with small Round-Trip Light Time [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). Additionally, this keyword represents an estimation of a range-rate value and not directly an instantaneous Doppler value, since the units are km/s.

3.5.2.3 DOPPLER_INTEGRATED

The value associated with the DOPPLER_INTEGRATED keyword represents the mean range rate of the spacecraft over the INTEGRATION_INTERVAL specified in the Metadata Section. The timetag and the time bounds of the integration interval are determined by the TIMETAG_REF and INTEGRATION_REF keywords. The observable may be one-way, two-way, or three-way. For one-way data, the observable is the mean range rate of the spacecraft over the INTEGRATION_INTERVAL. For two-way and three-way data, ~~the ICD~~exchanging entities should ~~specify~~pre-coordinate by mutual agreement whether the observable is the calculated mean range rate, or half the calculated mean range rate (due to the signal's having

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traveled to the spacecraft and back to the receiver). The value shall be a double precision value and may be negative, zero, or positive. Units are km/s. In order to ensure that corrections due to the ionosphere and solar plasma are accurately applied, the transmit frequency and receive frequency should be supplied when this data type is exchanged.

NOTE – The DOPPLER_INTEGRATED assumes a fixed uplink frequency (or one with small RTLT errors), and thus should not be used in cases where there is a deep space ramped uplink (the TRANSMIT_FREQ and RECEIVE_FREQ keywords should be used instead). Additionally, this keyword represents an estimation of a range-rate value and not directly an integrated Doppler value, since the units are km/s.

~~3.5.2.4 DOPPLER_COUNT~~

~~The value associated with the DOPPLER_COUNT keyword represents a count of the number of times the phase of a received signal slips one cycle with respect to a transmitted signal (or reference signal). The DOPPLER_COUNT keyword should be used in conjunction with the DOPPLER_COUNT_BIAS, DOPPLER_COUNT_SCALE, and DOPPLER_COUNT_ROLLOVER metadata. The value shall be an integer and should be positive (though in unlikely cases it may be zero). Units are not applicable. It should be noted that it may be necessary to process this data type in conjunction with a suitable Orbit Data Message (ODM, reference [4]) in order to understand the velocity of the spacecraft transmitter. The calculation to reconstruct the Doppler into units of Hertz is:~~

~~$\{[(DOPPLER\_COUNT_{n+1} - DOPPLER\_COUNT_n)/(t_{n+1} - t_n)] - DOPPLER\_COUNT\_BIAS\}/DOPPLER\_COUNT\_SCALE$~~

~~3.5.2.5~~3.5.2.4 PC_N0

The value associated with the PC_N0 keyword shall be the carrier power to noise spectral density ratio (P_c/N_0). The units for PC_N0 shall be dBHz. The value shall be a double precision value, and may be positive, zero, or negative.

~~3.5.2.6~~3.5.2.5 PR_N0

The value associated with the PR_N0 keyword shall be the ranging power to noise spectral density ratio (P_r/N_0). The units for PR_N0 shall be dBHz. It shall be a double precision value, and may be positive, zero, or negative.

~~3.5.2.7~~3.5.2.6 RANGE

The value associated with the RANGE keyword is the range observable. The values represent measurements from ambiguous ranging systems, differenced range, skin radar, proximity radar, or similar radar. The units for RANGE shall be as determined by the 'RANGE_UNITS' metadata keyword (i.e., either 'km', 's', or 'RU'). The 'RANGE_UNITS' metadata keyword

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should always be specified, but if it is not, the default (preferred) value shall be 'km'. If different range units are used by the tracking agency (e.g., 'DSN range units'), the definition of the range unit should be ~~described in the ICD.~~pre-coordinated between exchanging entities by mutual agreement. It should be noted that for many applications, proper processing of the RANGE will require a time history of the uplink frequencies. If ambiguous range is provided (i.e., the RANGE_MODULUS is non-zero), then the RANGE does not represent the actual range to the spacecraft; a calculation using the RANGE_MODULUS and the RANGE observable must be performed. For two-way and three-way data, ~~the ICD~~exchanging entities should ~~specify~~pre-coordinate by mutual agreement whether the observable is based upon the round-~~-~~trip light time, or half the round-~~-~~trip light time (due to the signal's having traveled to the spacecraft and back to the receiver). If differenced range is provided (MODE = SINGLE_DIFF), the 'RANGE' keyword shall be used to convey the difference in range. The value shall be a double precision value, and is generally positive (exceptions to this could occur if the data is a differenced type, or if the observable is a one-way pseudorange).

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

~~3.5.2.8~~3.5.2.7 RECEIVE_FREQ (and RECEIVE_FREQ_n)

~~3.5.2.8.1~~3.5.2.7.1 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).~~conveying differences between received frequencies). The value associated with the RECEIVE_FREQ keyword shall be the average frequency observable over the INTEGRATION_INTERVAL specified in the metadata, at the measurement timetag. The interpretation of the timetag shall be determined by the combined settings of the TIMETAG_REF, INTEGRATION_REF, and INTEGRATION_INTERVAL keywords (see table 3-3 for a description of how the settings of these values affect the interpretation of the timetag). Correlation between the RECEIVE_FREQ and the associated TRANSMIT_FREQ may be determined via the use of an a priori estimate and should be resolved via the orbit determination process. The units for RECEIVE_FREQ shall be Hertz (Hz). The value shall be a double precision value (generally positive, but could be negative or zero if used with the 'FREQ_OFFSET' metadata keyword).

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

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

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

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

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

The limits of integration are determined by the INTEGRATION_REF keyword in the metadata; the constant α in the equation has the value −½, 0, or ½ for the INTEGRATION_REF values of 'END', 'MIDDLE', or 'START', respectively (see reference [F4]).

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

NOTE – See annex F2 for details on use of the RECEIVE_FREQ keyword.

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

3.5.2.8.43.5.2.7.3 The transponder ratios used for interagency exchanges should be specified in the ICDpre-coordinated between exchanging entities by mutual agreement if they are always constant. They may also be specified in the metadata by using the TURNAROUND_NUMERATOR and TURNAROUND_DENOMINATOR keywords.

3.5.2.8.53.5.2.7.4 The equation for four-way Doppler, if it is to be exchanged, should be in the ICDpre-coordinated between exchanging entities by mutual agreement since the four-way connections tend to be implementation dependent.

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3.5.2.93.5.2.8 TRANSMIT_FREQ_n

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

The FREQ_OFFSET Metadata keyword can be used to provide an offset frequency in Hz that must be added to every TRANSMIT_FREQ keyword to reconstruct it. The purpose of this would be to reduce the required number of digits to be provided with every TRANSMIT_FREQ keyword.

NOTE – If transmit and receive data require the use of the FREQ_OFFSET keyword, two distinct Metadata and Data sections are required. If both data are included under the same metadata, the FREQ_OFFSET value shall apply to only the receive data types and the transmit data is assumed to not incur a frequency offset.

3.5.2.103.5.2.9 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).

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~~3.5.2.11~~3.5.2.10 RECEIVE_PHASE_CT_n

The value associated with the RECEIVE_PHASE_CT keyword ~~is~~represents the number of phase cycles measured at the receiver. There are no applicable units for the RECEIVE_PHASE_CT. The keyword is indexed to enable association with the PARTICIPANT_n. The value shall be a string representing a real number that can be any number of digits required to convey the necessary precision. If the received phase difference over a time interval is not based on the true frequency but an intermediate frequency from which the true received frequency is calculated, the FREQ_OFFSET metadata keyword should be specified to provide the ~~intermediate~~applicable frequency difference.

The RECEIVE_PHASE_CT keyword may be used in conjunction with the RECEIVE_PHASE_CT_BIAS and RECEIVE_PHASE_CT_SCALE metadata. See annex F3 for usage and a relation of RECEIVE_PHASE_CT with RECEIVE_FREQ.

If RECEIVE_PHASE_CT_BIAS and RECEIVE_PHASE_CT_SCALE keywords are not used, their respective default values of 0 and 1 apply, resulting in backwards compatibility with prior definitions of the RECEIVE_PHASE_CT keyword.

NOTE – It may be necessary to process this data type in conjunction with a suitable Orbit Data Message (ODM, reference [4]) in order to understand the velocity of a spacecraft transmitter.

~~3.5.2.12~~3.5.2.11 TRANSMIT_PHASE_CT_n

The value associated with the TRANSMIT_PHASE_CT keyword is the number of phase cycles at the transmitter. The TRANSMIT_~~FREQ~~PHASE_CT keyword is indexed to enable association with the PARTICIPANT_n. There are no applicable units for the TRANSMIT_PHASE_CT. The value shall be a string representing a real number that can be any number of digits required to convey the necessary precision. If the transmit phase difference over a time interval is not based on the true frequency but an intermediate frequency from which the true transmit frequency is calculated, the FREQ_OFFSET metadata keyword should be used to provide the intermediate frequency. If the uplink frequency is not constant, then the INTERPOLATION and INTERPOLATION_DEGREE metadata keywords shall be used to characterize the uplink behavior. See annex F4 for additional information.

NOTE – If transmit and receive data require the use of the FREQ_OFFSET keyword, two distinct Metadata and Data sections are required. If both data are included under the same metadata, the FREQ_OFFSET value shall apply to only the receive data types and the transmit data is assumed to not incur a frequency offset.

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3.5.3 DIFFERENCED MODES, VLBI AND DELTA-DOR RELATED KEYWORDS

3.5.3.1 Overview

Differenced observables are measurements produced when two or more tracking systems record or directly measure the same signal source. These measurements can be differenced in various ways to produce navigation observables.

Time and Frequency-Based Differencing: Time Difference of Arrival (TDOA) and Frequency Difference of Arrival (FDOA) measurements can be used independently or in combination by navigation software. These measurements require specific metadata keyword settings (MODE=SINGLE_DIFF, PATH_1 and PATH_2).

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

3.5.3.2 DOR

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

3.5.3.3 DOR_RATE

The observable associated with the DOR_RATE keyword represents the time derivative of the DOR observable. The timetag is the time of signal reception via PATH_1. This data type is normally used for the spacecraft observable in a Delta-DOR measurement. The received signal may be non-coherent or coherent with an uplink signal depending on the PARTICIPANT_n and PATH keywords. TRANSMIT_FREQ_n shall provide the spacecraft beacon frequency if non-coherent, or the transmit frequency at the uplink station if coherent, at the signal transmission time. The DOR_RATE measurement shall be a double precision value and may be negative or positive. Units shall be seconds/second.

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3.5.3.4 DOR_AMBIGUITY

The DOR_AMBIGUITY keyword defines the ambiguity inherent in the DOR observable keyword. An integer number of ambiguity values may be added or subtracted from the DOR observable value to get the final DOR value. The DOR_AMBIGUITY value shall be a double precision value and must be a non-zero positive number. Units shall be seconds. If the RANGE_MODULUS keyword is included, it shall be set to 0.0 whenever DOR_AMBIGUITY is specified.

~~3.5.3.3~~3.5.3.5 VLBI_DELAY

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

3.5.3.6 VLBI_DELAY_RATE

The observable associated with the VLBI_DELAY_RATE keyword represents the time derivative of the VLBI_DELAY observable. The timetag is the time of signal reception via PATH_1. This data type is normally used for the quasar observable in a Delta-DOR measurement. TRANSMIT_FREQ_n shall provide the interferometer reference frequency. The VLBI_DELAY_RATE measurement shall be a double precision value and may be negative or positive. Units shall be seconds/second.

3.5.3.7 VLBI_DELAY_AMBIGUITY

The VLBI_DELAY_AMBIGUITY keyword defines the ambiguity inherent in the VLBI_DELAY observable keyword. An integer number of ambiguity values may be added or subtracted from the VLBI_DELAY observable value to get the final VLBI_DELAY value. The VLBI_DELAY_AMBIGUITY value shall be a double precision value and must be a non-zero positive number. Units shall be seconds. If the RANGE_MODULUS keyword is included, it shall be set to 0.0 whenever VLBI_DELAY_AMBIGUITY is specified.

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3.5.3.8 TDOA

The Time Difference of Arrival (TDOA) keyword represents the difference between signal arrival times: the time measured via PATH_2 minus the time measured via PATH_1. The timetag corresponds to the signal reception time via PATH_1. TDOA measurements can be used either as direct measurements or in combination with FDOA observables. The arrival times are based on signal receipt from sources via one-way, two-way, or three-way paths, depending on the values of the PARTICIPANT_n and PATH keywords. TRANSMIT_FREQ_n shall provide the spacecraft beacon frequency if one-way, or the transmit frequency at the signal source if two-way or three-way, at the signal transmission time. The CORRECTION_TIMETAG_k parameter shall be used to provide the time offsets associated with the collection times of each measurement system involved, when needed. The TDOA measurement shall be a double precision value and may be negative or positive. Units shall be seconds.

Figure A-30 contains an example TDM.

3.5.3.9 FDOA

The Frequency Difference of Arrival (FDOA) keyword represents the difference between measured frequencies: the frequency measured via PATH_2 minus the frequency measured via PATH_1. The timetag corresponds to the signal reception time via PATH_1. This data type may be used exclusively or in combination with TDOA observables. The measured frequencies are based on signal receipt from sources via one-way, two-way, or three-way paths, depending on the values of the PARTICIPANT_n and PATH keywords. TRANSMIT_FREQ_n shall provide the spacecraft beacon frequency if one-way, or the transmit frequency at the signal source if two-way or three-way, at the signal transmission time. The CORRECTION_TIMETAG_k parameter shall be used to provide the time offsets associated with the collection times of each measurement system involved, when needed. The FDOA measurement shall be a double precision value and may be negative or positive. Units shall be Hz.

Figure A-30 contains an example TDM.

3.5.4 ANGLE DATA KEYWORDS

3.5.4.1 General

Angle data is measured ~~at~~or derived by the ~~ground antenna, using downlink data only,~~receiving tracking system, and may be collected 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~~pre-coordinated between exchanging entities by mutual agreement.

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3.5.4.2 ANGLE_1_n

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: $-180.0 \leq \text{ANGLE\_1} < 360.0$. Units shall be degrees. The ANGLE_1_n keyword is indexed to enable association with the PARTICIPANT_n.

3.5.4.3 ANGLE_1_RATE_n

The value assigned to the ANGLE_1_RATE keyword represents the first derivative of the azimuth, right ascension, or 'X' angle of the measurement, depending on the value of the ANGLE_TYPE keyword. The values are specified in degrees per second. This value, when reported, may be a directly measured value; or a derived value from the finite differencing of actual angle measurements. Derived ANGLE_1_RATE values shall only be included in the TDM when the associated measurement covariance values are specified and included in the TDM per 3.5.9.6. The ANGLE_1_RATE_n keyword is indexed to enable association with the PARTICIPANT_n.

~~3.5.4.3~~3.5.4.4 ANGLE_2_n

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: $-180.0 \leq \text{ANGLE\_2} < 360.0$. Units shall be degrees. The ANGLE_2_n keyword is indexed to enable association with the PARTICIPANT_n.

3.5.4.5 ANGLE_2_RATE_n

The value assigned to the ANGLE_2_RATE keyword represents the first derivative of the elevation, declination, or 'Y' angle of the measurement, depending on the value of the ANGLE_TYPE keyword. The values are specified in degrees per second. This value, when reported, may be a directly measured value; or a derived value from the finite differencing of actual angle measurements. Derived ANGLE_2_RATE values shall only be included in the TDM when the associated measurement covariance values are specified and included in the TDM per 3.5.9.6. The ANGLE_2_RATE_n keyword is indexed to enable association with the PARTICIPANT_n.

3.5.5 OPTICAL/RADAR RELATED KEYWORDS

3.5.5.1 MAG

The value assigned to the MAG keyword shall represent the apparent visual magnitude of an object when observed with an optical telescope. The apparent magnitude of an object is a

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measure of its brightness as seen by an observer on Earth, adjusted to the value it would have in the absence of the atmosphere. ~~Units~~The units to employ are ~~not applicable.~~stellar magnitudes. The MAG measurement shall be a double precision value and may be positive, zero, or negative. A value of -999 indicates that no object was detected when interrogating the position indicated by the two reported angles. Reporting value is necessary for optical sensors conducting space surveillance activities.

3.5.5.2 ASTROMETRIC_STAR_COUNT

The ASTROMETRIC_STAR_COUNT keyword shall indicate the number of correlated stars used in the astrometric solution, for a particular frame or set of frames. This is an indication of the durability of the metric quantity estimation. A positive integer value is used.

3.5.5.3 PHOTOMETRIC_STAR_COUNT

The PHOTOMETRIC_STAR_COUNT keyword shall indicate the number of correlated stars used in the photometric solution, as described in 3.5.5.1. A positive integer value is used.

3.5.5.4 PHOTOMETRIC_SNR

The PHOTOMETRIC_SNR keyword shall indicate the signal-to-noise ratio of the total photometric content of the evaluated signal.

3.5.5.5 FRAME_LIMITING_BRIGHTNESS

The FRAME_LIMITING_BRIGHTNESS keyword shall indicate the dimmest object that could be expected to be detected in the particular location interrogated, based on the detection sequence employed. This information is useful in determining whether a particular object of interest could have been expected to be detected within a particular observation frame. Units are stellar magnitudes.

~~3.5.5.2~~3.5.5.6 RCS

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

3.5.6 TIME RELATED KEYWORDS

3.5.6.1 CLOCK_BIAS

In general, the timetags provided for the tracking data should be corrected, but when that is not possible (e.g., for three-way data or differenced data types), then this data type may be used.

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

3.5.6.2 CLOCK_DRIFT

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

3.5.7 MEDIA RELATED KEYWORDS

3.5.7.1 STEC

The Slant Total Electron Count (STEC) keyword 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

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propagation path (electrons/m^2). The path should be specified by "PATH" keyword, except when STEC is valid in either path direction. The charged particles could have several sources, for example, solar plasma, Earth ionosphere, or the Io plasma torus. The units for the STEC keyword are Total Electron Count Units (TECU), where 1 TECU = 10^{16} electrons/m^2 = 1.661 x 10^{-8} mol/m^2 (SI Units). The value shall be a positive double precision value (the TEC along the satellite line of sight may vary between 1 and 400 TECU; larger values may be observed during periods of high solar activity). This keyword should appear in its own TDM Segment with PARTICIPANTs being one spacecraft and one antenna, and a MODE setting of 'SEQUENTIAL'. Exchange partners who wish to distinguish between ionospheric and interplanetary STEC should ~~indicate so in the ICD~~pre-coordinate by mutual agreement, and the data must be provided in separate TDM Segments.

3.5.7.2 TROPO_DRY

The value associated with the TROPO_DRY keyword shall be the dry ~~zenith~~ delay through the troposphere measured at the timetag. By default the value is assumed to be the delay at zenith. There should be agreed upon elevation mappings for the dry zenith component ~~specified in the ICD~~, which can be provided via the ELEVATION_MAPPING system configuration parameter (e.g., the Niell mapping function developed for VLBI applications). Alternatively, the TROPO_DRY value represents a line-of-sight tropospheric delay by listing a PATH keyword among two participants. 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.~~pre-coordinated between exchanging entities by mutual agreement. The units for TROPO_DRY shall be meters (m). The value shall be a non-negative double precision value ($0.0 \leq$ TROPO_DRY).

Figure A-14 contains a TDM example for delays taken at zenith. Figure A-15 contains a TDM example for delays in the line-of-sight.

3.5.7.3 TROPO_WET

The value associated with the TROPO_WET keyword shall be the wet ~~zenith~~ delay through the troposphere measured at the timetag. By default the value is assumed to be the delay at zenith. There should be agreed upon elevation mappings for the wet zenith component ~~specified in the ICD~~, which can be provided via the ELEVATION_MAPPING system configuration parameter (e.g., the Niell mapping function developed for VLBI applications). Alternatively, the value represents a line-of-sight tropospheric delay by listing a PATH keyword among two participants. 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.~~pre-coordinated between exchanging entities by mutual agreement. The units for TROPO_WET shall be meters (m). The value shall be a non-negative double precision value ($0.0 \leq$ TROPO_WET).

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Figure A-14 contains a TDM example for delays taken at zenith. Figure A-15 contains a TDM example for delays in the line-of-sight.

3.5.8 METEOROLOGICAL RELATED KEYWORDS

3.5.8.1 PRESSURE

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

3.5.8.2 RHUMIDITY

The value associated with the RHUMIDITY keyword shall be the relative humidity observable as measured at the tracking participant, specified in percent. RHUMIDITY shall be a double precision type value, $0.0 \leq \text{RHUMIDITY} \leq 100.0$.

3.5.8.3 TEMPERATURE

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

3.5.9 MISCELLANEOUS KEYWORDS

3.5.9.1 COMMENT

The COMMENT keyword is not required. Subsection 4.54.5 provides full details on usage of the COMMENT keyword.

3.5.9.2 CORRECTIONS_n

The CORRECTIONS_n keyword shall provide a comma-separated list of correction values. The order of the values, as they correspond to the different data corrections, shall be as indicated by the Metadata CORRECTIONS_ORDER_n keyword. The CORRECTIONS_n keyword is indexed to enable association with the PARTICIPANT_n. Inclusion of CORRECTION_n keywords shall be utilized in the Data Section to indicate changes in corrections that apply to the different observables for all successive timetagged data values in the Data Section. All correction values must be populated with each CORRECTIONS_n keyword. CORRECTIONS_n keywords supersede all prior CORRECTIONS_n keywords within the Data Section. In the absence of this keyword within the Data Section, the CORRECTIONS_* values defined in the Metadata Section apply to the entire Data Section.

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Correction values provided in the Data Section should be populated by the timestamp of the first applicable observable.

The unit of each correction value shall be as described in 3.3.1.13.

~~3.5.9.2~~3.5.9.3 DATA_START

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

~~3.5.9.3~~3.5.9.4 DATA_STOP

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

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3.5.9.5 TRackingData Quality Indicator Symbols

Data quality symbols represent indicators listed by the Metadata 'DATA_QUALITY' keyword, per table 3-3. When a list of data quality indicators is provided with the Metadata, the relevant symbols shall be provided with each observation in the Data Section to provide an estimate of the quality. The symbol values corresponding to each data quality indicator are defined with a list of possible data quality indicators provided with the DATA_QUALITY keyword in the Metadata Section.

Each observable shall only be tagged with a single data quality indicator symbol. If only one value is provided by the DATA_QUALITY keyword, no indicator shall be applied to the observations, as the single value applies to all the data in the section. Data quality indicator symbols are appended to observations as indicated in Table 3-5.

3.5.9.6 OBS_COVARIANCE_k

The OBS_COVARIANCE_k keyword shall contain a comma-separated vector of variance and covariance value. The ordering and definition of these elements are specified by the OBS_COVARIANCE_OBS_k and the OBS_COVARIANCE_VALS_k metadata keywords. The unit for each field equals the product of the respective observable units, with squared units used for variance values. This field is useful when radar and optical sensors conduct surveillance activities.

NOTE – An OBS_COVARIANCE_k keyword applies to data with matching or subsequent timetags, and remains in effect until a new keyword is specified.

The OBS_COVARIANCE_k keyword is indexed to enable association with the different OBS_COVARIANCE_OBS_k and OBS_COVARIANCE_VALS_k keywords. See annex F5 for additional details on the use of these keywords.

NOTE – Lower Triangle Matrix (LTM) is the default implementation for ordering covariance values. When LTM ordering is used, the OBS_COVARIANCE_VALS_k keyword may be omitted, and the system will assume the standard LTM element order based on the observables listed in OBS_COVARIANCE_OBS_k.

3.5.9.7 SYSTEM_STATUS_n_START

The SYSTEM_STATUS_n_START keyword indicates the beginning of a SYSTEM_STATUS subsegment for PARTICIPANT_n.

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3.5.9.8 System Status Parameters

System Status Parameters shall be provided between SYSTEM_STATUS_n_START and SYSTEM_STATUS_n_STOP keywords. These parameters follow the formatting structure of DATA keyword entries, and serve to deliver system status information and updates that are valuable for processing the keywords contained in the Data Section. A list of common parameters and possible value allocations can be found in table 3-4. Not all possible status parameters need to be included in each SYSTEM_STATUS_n subsegment. Other parameters of interest may be pre-coordinated between exchanging entities by mutual agreement. The SYSTEM_STATUS_n subsegments are indexed to accommodate scenarios, where informing of status for multiple systems is desirable. The 'n' index is associated the corresponding PARTICIPANT system. It is recommended that an initial system status is populated before the first data point is provided. Subsequent system updates can be provided as system updates occur, or otherwise on a regular cadence.

EXAMPLE:

SYSTEM_STATUS_3_START
APERTURE_FILTER = 2023-09-03T23:43:56.000 NONE
SYSTEM_TEMPERATURE = 2023-09-03T23:43:56.000 294.5
SYSTEM_STATUS_3_STOP

NOTE – Table 3-4 defines both system configuration parameters for the Metadata Section, and system status parameters that can be defined and updated throughout the Data section. Definitions within the Metadata Section apply to all the data within the Data section. Definitions within the Data section can be updated dynamically throughout the section.

3.5.9.9 SYSTEM_STATUS_n_STOP

The SYSTEM_STATUS_n_STOP keyword indicates the end of a SYSTEM_STATUS subsegment for PARTICIPANT_n.

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4 TRACKING DATA MESSAGE SYNTAX IN KVN

4.1 GENERAL

The TDM represented in ‘keyword = value’ syntax, abbreviated as KVN, shall observe the syntax described in 4.2 through 4.5.

4.2 TDM LINES

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

4.2.2 Each TDM line shall be one of the following:

– Header line;

– Metadata Section line;

– Data Section line;

– blank line.

4.2.3 All Header, Metadata Section, and Data Section lines, with exceptions as noted below, shall use KVN.

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

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

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

NOTE – Certain keywords are assigned a value that may be composed of a comma-separated list of items and/or a list of values separated by blanks. See specific keyword definitions.

b) TDM lines in the Data Section shall consist of a keyword, followed by an equals sign ‘=’, followed by a value that consists of two primary elements (essentially an ordered pair):) and an optional third: a timetag and the measurement or, calculation or information associated with that timetag (either without the other is unusable for tracking purposes).), and an optional indicator field for the purpose of informing of estimated observation quality.

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NOTE – Certain measurements, calculations or information are assigned a value that may be composed of a comma-separated list of items and/or a list of values separated by blanks. See specific keyword definitions.

c) The optional quality indicator field is formed by a single symbol, as described by the DATA_QUALITY keyword (see section 0).

~~b)~~d) Before and after the equals sign, blank characters (white space) may be added. The timetag ~~and~~, measurement/calculation and indicator in the value must be separated by at least one blank character (white space).

~~c)~~e) The keywords COMMENT, META_START, META_STOP, DATA_START, and DATA_STOP are exceptions to the KVN syntax.

4.2.6 Keywords must be uppercase and must not contain blanks.

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

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

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

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

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

4.3 TDM VALUES

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

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

−~~2147483648~~2,147,483,648 $\leq x \leq$ +~~2147483647~~2,147,483,647 (i.e., $-2^{31} \leq x \leq 2^{31}-1$~~).~~, a 4-byte integer)

or -9,223,372,036,854,775,808 ≤ x ≤ +9,223,372,036,854,775,807 (i.e., $-2^{63} \leq x \leq 2^{63}-1$, an 8-byte integer).

NOTE – The commas in the range of values above are thousands separators and are used only for readability. They are not included in the integer representation in the actual message.

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

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

4.3.5 Non-integer numeric values expressed in floating-point notation ~~shall~~conform to the IEEE binary64 floating point number format (see reference [7]). Such numbers consist of ~~a~~an optional sign, a mantissa, an alphabetic character ~~indicating the division between~~separating the mantissa ~~and~~from the exponent, and an exponent, constructed according to the following rules:

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

b) 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.

c) 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).~~

d) The exponent must be an integer~~,~~ and may have either a '+' or '-' sign (if the sign is omitted, then '+' ~~is~~shall be assumed). Exponent values can range from -324 to +308.

e) 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~~941E−324, with 16 significant decimal digits precision.

~~NOTE These specifications for integer, fixed-point, and floating-point values conform to the XML specifications for the data types four-byte integer 'xsd:int', 'decimal', and 'double', respectively (see reference [5]). The specifications for floating-point values conform to the IEEE 754 double precision type (see reference [6]). Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies because of their implementation specific attributes. The special values 'NaN', '-Inf', '+Inf', and '-0' are not supported in the TDM.~~

4.3.6 For all numeric values, exchange participants may agree to further constrain or even extend beyond the default limit of 16 digits of precision.

~~4.3.6~~4.3.7 Blanks shall not be ~~permitted~~used within numeric values~~ and time values.~~.

4.3.8 ~~Text~~ Comments and free-text value fields may be in any case (or mix of upper and lower case) desired by the user.

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~~4.3.7~~4.3.9 Apart from comments and free-text fields, normative text value fields shall be constructed using ~~mixed case; case shall not be significant. All~~only exclusively all uppercase ~~text values are preferred~~or exclusively all lowercase.

~~4.3.8~~4.3.10 In value fields that are text, an underscore shall be equivalent to a single blank. Individual blanks between non-blank characters shall be retained (shall be significant) but multiple blanks shall be equivalent to a single blank.

~~4.3.9~~4.3.11 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 of the month, 'DDD' is the three-digit day of year, separated by hyphens; 'T' is ~~constant,~~a fixed separator between the date and time portions of the string; and 'hh:mm:ss[.d→d]' is the time in hours, minutes, seconds, and optional fractional seconds~~;~~, separated by colons. As many 'd' characters to the right of the period as required may be used to obtain the required precision, up to the maximum allowed for a fixed-point number. 'Z' is an optional time code terminator (the only permitted value is 'Z' for Zulu, i.e., UTC). All fields shall have leading zeros. (See reference [3], ASCII Time Code A and B.)

~~4.3.10~~4.3.12 There are four types of TDM values that represent a timetag or epoch, as shown in the applicable tables. The time system for the CREATION_DATE, START_TIME, and STOP_TIME ~~shall~~should be UTC. The time system for the timetags in the TDM Data Section shall be determined by the TIME_SYSTEM metadata keyword.

~~4.3.11~~4.3.13 For transmit and receive phase, the value shall be a string representing a real number that can be any number of digits required to convey the necessary precision. The string must not contain any alphabetic or special characters.

4.4 UNITS IN THE TDM

Units are not explicitly displayed in the TDM. The units associated with values in the TDM are as specified ~~in table~~throughout Section ~~3-5~~3.5.

4.5 COMMENTS IN A TDM

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

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

4.5.2 Comment lines, if used, shall only occur:

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

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

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

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

4.5.4 Conventions for particular comments in the TDM that may be required between any two participating agencies should be ~~specified in the ICD~~pre-coordinated between exchanging entities by mutual agreement.

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~~pre-coordinated between exchanging entities by mutual agreement.

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5 TDM CONTENT/STRUCTURE IN XML

5.1 DISCUSSION—THE TDM/XML SCHEMA

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

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

The location ~~of~~where the qualified TDM/XML schema can be found is:

https://sanaregistry.org/r/ndmxml_qualified/

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The location where the unqualified TDM/XML schema can be found is:

https://sanaregistry.org/r/ndmxml~~-1.0-tdm-2.0.xsd~~_unqualified/

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

5.2 TDM/XML BASIC STRUCTURE

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

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

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

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<header>
</header>
<body>
  <segment>
    <metadata>
    </metadata>
    <data>
    </data>
  </segment>
  <segment>
    <metadata>
    </metadata>
    <data>
    </data>
  </segment>
</body>

Figure 5-1: TDM XML Basic Structure

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

5.3 CONSTRUCTING A TDM/XML INSTANCE

5.3.1 OVERVIEW

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

5.3.2 XML VERSION

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

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

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

5.3.3 BEGINNING THE INSTANTIATION: ROOT DATA ELEMENT

5.3.3.1 A TDM instantiation shall be delimited with the <tdm></tdm> root element tags using the standard attributes documented in reference [5].

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

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

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

5.3.3.3 If it is desired to validate an instantiation against the CCSDS Web-based schema, the xsi:noNamespaceSchemaLocation attribute must be coded as a single string of non-blank characters, with no line breaks~~, exactly as shown~~. The location of the TDM/XML schema is per Section 5.1. After identifying the full https path to the master schema filename, use it to replace <filename> from the following line:

xsi:noNamespaceSchemaLocation="~~https://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd~~<filename>"

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

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

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

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

5.3.3.6.1 The 'id' attribute shall be 'id="CCSDS_TDM_VERS"'.

5.3.3.6.2 The 'version' attribute shall be 'version="23.0"'.

NOTE – The following example root element tag for a TDM instantiation combines all the directions in the preceding several subsections:, where <filename> needs to be replaced per instructions in 5.3.3.3:

```
<?xml    version="1.0" encoding="UTF-8"?>
<tdm     xmlns:xsi="http://www.w3.org/2001/XMLSchema-instancehttp://www.w3.org/2001/XMLSchema-instance"
         xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd<filename>"
         id="CCSDS_TDM_VERS" version="23.0">
```

5.3.4 THE TDM/XML HEADER SECTION

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

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

5.3.4.3 The TDM header may have a <CLASSIFICATION></CLASSIFICATION> tag pair.

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

a) <CREATION_DATE>;

b) <ORIGINATOR>.

5.3.4.5 An optional <MESSAGE_ID> may be used in the TDM header after the <ORIGINATOR> keyword.

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

```
<header>
  <COMMENT>Some comment string, which is not required.</COMMENT>
  <CLASSIFICATION> UNCLASSIFIED</CLASSIFICATION>
  <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
  <ORIGINATOR>NASA</ORIGINATOR>
  <MESSAGE_ID>201113719190</MESSAGE_ID>
```


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</header>

5.3.4.41.1.1.1 An optional <MESSAGE_ID> may be used in the TDM header after the <ORIGINATOR> keyword.

5.3.5 THE TDM/XML BODY SECTION

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

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

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

5.3.5.4 The keywords in the <metadata> and <data> sections shall be those specified in table 3-3 and table 3-53-6, respectively.

5.3.5.5 Tags for TDM keywords shall be all uppercase.

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

5.3.6 THE TDM/XML METADATA SECTION

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

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

5.3.6.3 The <SYSTEM_CONFIG_n> tag shall be used to encapsulate the keywords associated with tracking system configuration parameters in the TDM.

5.3.6.4 The <SYSTEM_CONFIG_n> tag shall consist of at least one subcomponent:

a) One or more specific system configuration parameters (e.g., <FRONT_END_ID>).

NOTE – Thus a system configuration could appear defined in an NDM/XML TDM as follows:

```
< SYSTEM_CONFIG_3>
   <FRONT_END_ID>OPT1</FRONT_END_ID>
   <SYSTEM_PATH>CCD2x2</SYSTEM_PATH>
</SYSTEM_CONFIG_3>
```

5.3.6.5 In this version of the TDM, the XML validation schema would not work for keywords with index numbers greater than 9. Therefore the maximum number of participants per segment should be nine, corresponding with the "_n" indexer. Similarly, a limit of 9 should be

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applied to keywords utilizing the "_k" indexer (e.g. OBS_COVARIANCE_k, OBS_COVARIANCE_OBS_k, OBS_COVARIANCE_VALS_k).

NOTE – If more than nine participants are defined (i.e., PARTICIPANT_10 +), then special arrangements between exchange participants are necessary. These arrangements should be pre-coordinated between exchanging entities by mutual agreement. A limitation of nine participants allows the user to describe the great majority of tracking scenarios. Scenarios requiring many participants may involve coherent tracking that includes several relays, crosslinks and/or tracking sensors required to define a single 'PATH' string that includes all links. 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 may appear to be ten or more. However, because of the nature of the 'PATH' keyword, several TDM Segments with nine or fewer participants would be required to describe the full set of tracking data. For the critical event example scenario just given, one TDM Segment would be used to describe the two-way connection, and one additional segment would be required for each three-way connection; it would not be possible to provide a single 'PATH' statement that would convey the multiple signal paths.

5.3.7 THE TDM/XML DATA SECTION

5.3.7.1 Each ~~data section~~Data Section shall follow the corresponding ~~metadata section~~Metadata Section and shall be set off by the <data></data> tag combination.

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

5.3.7.3 Between the <data> and </data> tags, the keywords shall be those specified in table ~~3-5~~3-6.

5.3.8 SPECIAL TDM/XML TAGS

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

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

5.3.8.2 The <observation> tag shall consist of at least two subcomponents:

~~a)~~b) the time tag (<EPOCH> tag); and

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

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

```
<observation>
   <EPOCH>2008-200T12:34:56.789</EPOCH>
   <RECEIVE_FREQ>8415000000</RECEIVE_FREQ>
</observation>
```

5.3.8.3 An "ind" attribute may be affixed to a data type tag for the purpose of providing indicators for observation quality. The format of the indicator field is common to NDM/XML TDM and KVN TDM.

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

```
<observation>
   <EPOCH>2008-200T12:34:56.789</EPOCH>
   <RECEIVE_FREQ ind="V">8415000000</RECEIVE_FREQ>
</observation>
```

5.3.8.4 Additional data types may be added to the <observation> tag, provided all data types under the same <observation> tag share the same time tag.

NOTE – Thus angle observations could also appear in an NDM/XML TDM as follows:

```
<observation>
   <EPOCH>2008-200T12:34:56.789</EPOCH>
   <ANGLE_1 ind="A">131.359323</ANGLE_1>
   <ANGLE_2 ind="A">62.325279</ANGLE_2>
</observation>
```

5.3.8.5 The <SYSTEM_STATUS_n> tag shall be used to encapsulate the keywords associated with tracking system status updates in the TDM.

5.3.8.6 The <SYSTEM_STATUS_n> tag shall consist of at least two subcomponents:

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

e) one or more specific system status parameters (e.g., `<APERTURE_FILTER>`).

NOTE – Thus a system status update could appear in an NDM/XML TDM as follows:

```
< SYSTEM_STATUS_2>
   <EPOCH>2008-200T12:34:56.789</EPOCH>
   <APERTURE_FILTER>NONE</APERTURE_FILTER>
</ SYSTEM_STATUS_2>
```

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5.3.9 UNITS IN THE TDM/XML

The units associated with values in the TDM/XML shall be the same units used in the KVN-formatted TDM and are as specified ~~in table 3-5.~~throughout Section 3.5. As in the TDM/KVN, units are not displayed in the TDM/XML.

5.4 DISCUSSION—TDM/XML EXAMPLE

Figure ~~E-21~~A-24 provides a sample of a TDM in XML format.

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ANNEX A

IMPLEMENTATION CONFORMANCE STATEMENT ~~(ICS)~~PROFORMA

(NORMATIVE)

A1 INTRODUCTION

A1.1 OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of *Tracking Data Message* (CCSDS 503.0-~~B~~P-2.0.3). The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation shall satisfy the mandatory conformance requirements referenced in the RL. (For further information on Implementation Conformance Statements, see reference [H6].)

Field Code Changed

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

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

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

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

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

A1.2 ABBREVIATIONS AND CONVENTIONS

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

Item Column

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

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Feature Column

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

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

Keyword Column

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

Reference Column

The reference column indicates the relevant subsection or table in *Tracking Data Message* (CCSDS 503.0-~~B~~P-2.0.3) (this document).

Status Column

The status column uses the following notations:

- M mandatory.
- O optional.
- C conditional
- N/A not applicable.

Support Column Symbols

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

- Y Yes, supported by the implementation.
- N No, not supported by the implementation.
- N/A Not applicable.

A1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called an ICS. The implementer shall complete the RL by entering appropriate responses in the support or values-supported column, using the notation described in A1.2. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

A2 ICS PROFORMA FOR TRACKING DATA MESSAGE

A2.1 GENERAL INFORMATION

A2.1.1 Identification of ICS

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

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A2.1.2 Identification of Implementation Under Test (IUT)

Implementation name	
Implementation version	
Special Configuration	
Other Information	

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A2.1.3 Identification of Supplier

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

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A2.1.4 Document Version

CCSDS 503.0-~~BP~~-2.0.3 Document Version	
Have any exceptions been required? (Note – A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming.)	Yes _____ No_____

A2.1.5 Requirements List

Seq #	Feature	Keyword	Reference (Blue Book)	Status	Support
1	TDM Header	N/A	~~Table 3-2~~Table 3-2	M	
2	TDM version	CCSDS_TDM_VERS	~~Table 3-2~~Table 3-2	M	
3	Comment	COMMENT	~~Table 3-2~~Table 3-2	O	
4	Message Classification	CLASSIFICATION	Table 3-2	O	
~~4~~5	Message creation date/time	CREATION_DATE	~~Table 3-2~~Table 3-2	M	
~~5~~6	Message originator	ORIGINATOR	~~Table 3-2~~Table 3-2	M	
~~6~~7	Message ID	MESSAGE_ID	~~Table 3-2~~Table 3-2	O	
~~7~~8	TDM Metadata	META_START	~~Table 3-3~~Table 3-3	M	
~~8~~9	Comment	COMMENT	~~Table 3-3~~Table 3-3	O	
~~9~~10	Track identifier	TRACK_ID	~~Table 3-3~~Table 3-3	~~O~~C	
11	Segment of Track	TRACK_ID_SEGMENT	Table 3-3	O	
12	Identifier of prior message	PREVIOUS_MESSAGE_ID	Table 3-3	O	
13	Identifier of next message	NEXT_MESSAGE_ID	Table 3-3	O	
~~10~~14	Specifies data types in ~~data section~~Data Section	DATA_TYPES	~~Table 3-3~~Table 3-3	O	
15	Modality of transmission	TDM_BASIS	Table 3-3	O	
16	Tasking/collection identifier	TDM_BASIS_ID	Table 3-3	O	
~~11~~17	Specifies time system relevant to timetags	TIME_SYSTEM	~~Table 3-3~~Table 3-3	M	
~~12~~18	Start time of data	START_TIME	~~Table 3-3~~Table 3-3	O	
~~13~~19	Stop time of data	STOP_TIME	~~Table 3-3~~Table 3-3	O	
~~14~~20	Participants in the tracking session	PARTICIPANT_n	~~Table 3-3~~Table 3-3	M	

Seq #	Feature	Keyword	Reference (Blue Book)	Status	Support
21	Relevant attitude data message	ADM_MSG_LINK_n	Table 3-3	O	
22	Relevant conjunction data message	CDM_MSG_LINK_n	Table 3-3	O	
23	Relevant orbit data message	ODM_MSG_LINK_n	Table 3-3	O	
24	Relevant pointing request message	PRM_MSG_LINK_n	Table 3-3	O	
25	Relevant reentry data message	RDM_MSG_LINK_n	Table 3-3	O	
~~15~~26	Mode of the tracking session	MODE	~~Table 3-3~~Table 3-3	O	
~~16~~27	Signal path in the tracking session	PATH PATH_1, PATH_2	~~Table 3-3~~Table 3-3	~~O~~C	
~~17~~28	Name of the ephemeris file used, if any.	EPHEMERIS_NAME_n	~~Table 3-3~~Table 3-3	O	
~~18~~29	Frequency band of the transmitted data	TRANSMIT_BAND_n	~~Table 3-3~~Table 3-3	O	
~~19~~30	Frequency band of the received data	RECEIVE_BAND_n	~~Table 3-3~~Table 3-3	O	
~~20~~31	Numerator of the turnaround ratio	TURNAROUND_NUMERATOR_n	~~Table 3-3~~Table 3-3	O	
~~21~~32	Denominator of the turnaround ratio	TURNAROUND_DENOMINATOR_n	~~Table 3-3~~Table 3-3	O	
~~22~~33	Specifies whether data timetag is transmitted or received	TIMETAG_REF	~~Table 3-3~~Table 3-3	O	
34	Observable timetag uncertainty	TIMETAG_UNCERTAINTY	Table 3-3	O	
~~23~~35	Data compression rate	INTEGRATION_INTERVAL	~~Table 3-3~~Table 3-3	O	
~~24~~36	Reference point of the timetag	INTEGRATION_REF	~~Table 3-3~~Table 3-3	O	
~~25~~37	Specifies a base frequency to which frequency data is referenced.	FREQ_OFFSET	~~Table 3-3~~Table 3-3	~~O~~C	
~~26~~38	Specifies the ranging method	RANGE_MODE	~~Table 3-3~~Table 3-3	O	
~~27~~39	Specifies the ranging modulus	RANGE_MODULUS	~~Table 3-3~~Table 3-3	~~O~~C	
~~28~~40	Specifies the units for ranging data	RANGE_UNITS	~~Table 3-3~~Table 3-3	~~O~~C	
~~29~~41	Specifies the angle type for angle data	ANGLE_TYPE	~~Table 3-3~~Table 3-3	~~O~~C	
~~30~~42	Specifies the reference frame for specific angle types	REFERENCE_FRAME	~~Table 3-3~~Table 3-3	~~O~~C	
~~31~~43	Specifies the interpolation method recommended for phase count data	INTERPOLATION	~~Table 3-3~~Table 3-3	O	
~~32~~44	Specifies the degree of the interpolating polynomial for phase count data	INTERPOLATION_DEGREE	~~Table 3-3~~Table 3-3	O	

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Seq #	Feature	Keyword	Reference (Blue Book)	Status	Support
~~33~~45	Specifies correction factors necessary to reconstruct ~~a Doppler~~certain frequency counter ~~measurement~~measurements	~~DOPPLER_COUNT~~RECEIVE_PHASE_CT_BIAS ~~DOPPLER_COUNT~~RECEIVE_PHASE_CT_SCALE ~~DOPPLER_COUNT_ROLLOVER~~	~~Table 3-3~~Table 3-3	O	
~~34~~46	Specifies a fixed delay time applicable to transmitted data	TRANSMIT_DELAY_n	~~Table 3-3~~Table 3-3	O	
~~35~~47	Specifies a fixed delay time applicable to received data	RECEIVE_DELAY_n	~~Table 3-3~~Table 3-3	O	
48	System configuration parameters	SYSTEM_CONFIG_n_START <System configuration parameters> SYSTEM_CONFIG_n_STOP	Table 3-3	O	
~~36~~49	Indicates the data quality	DATA_QUALITY	~~Table 3-3~~Table 3-3	O	
~~37~~50	Specifies a correction value to be added to each data point	CORRECTION_ANGLE_1_n CORRECTION_ANGLE_2_n CORRECTION_DOPPLER_n CORRECTION_MAG_n CORRECTION_RANGE_n CORRECTION_RCS_n CORRECTION_RECEIVE CORRECTION_TRANSMIT CORRECTION_ABERRATION_YEARLY_ANGLE_1_n CORRECTION_ABERRATION_YEARLY_ANGLE_2_n CORRECTION_ABERRATION_DIURNAL_ANGLE_1_n CORRECTION_ABERRATION_DIURNAL_ANGLE_2_n CORRECTION_TIMETAG_k	~~Table 3-3~~Table 3-3	O	
51	Specified order of corrections provided in Data Section	CORRECTIONS_ORDER_n	Table 3-3	C	
~~38~~52	Specifies whether corrections have been applied, or have not	CORRECTIONS_APPLIED_n	~~Table 3-3~~Table 3-3	~~O~~C	
53	Specifies observables subject to timetag corrections	CORRECTION_TIMETAG_OBS_k	Table 3-3	C	
54	Specifies observables used to populate a variance-covariance matrix	OBS_COVARIANCE_OBS_k	Table 3-3	C	
55	Specifies order of Data Section variance-covariance values	OBS_COVARIANCE_VALS_k	Table 3-3	C	
~~39~~56	End of TDM Metadata	META_STOP	~~Table 3-3~~Table 3-3	M	
~~40~~57	TDM Data	DATA_START	~~Table 3-5~~Table 3-6	M	
~~41~~58	Comment	COMMENT	~~Table 3-5~~Table 3-6	O	
59	Correction values	CORRECTIONS_n	Table 3-6	O	

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Seq #	Feature	Keyword	Reference (Blue Book)	Status	Support
~~42~~60	Angle related data	ANGLE_1_n ANGLE_2_n ANGLE_1_RATE_n ANGLE_2_RATE_n	~~Table 3-5~~Table 3-6	O	
~~43~~60	Carrier signal related data	CARRIER_POWER PC_N0	~~Table 3-5~~Table 3-6	O	
~~44~~61	Clock related data	CLOCK_BIAS CLOCK_DRIFT	~~Table 3-5~~Table 3-6	O	
62	Data quality indicators	<Data Quality Indicator Symbols added to data keywords>	Table 3-6	O	
~~45~~63	Doppler (Range-rate data)	DOPPLER_INSTANTANEOUS DOPPLER_INTEGRATED ~~DOPPLER_COUNT~~	~~Table 3-5~~Table 3-6	O	
~~46~~64	Media related data	STEC TROPO_DRY TROPO_WET	~~Table 3-5~~Table 3-6	O	
~~47~~65	Meteorological data	PRESSURE RHUMIDITY TEMPERATURE	~~Table 3-5~~Table 3-6	O	
~~48~~66	Optical/radar related data	MAG ASTROMETRIC_STAR_COUNT PHOTOMETRIC_STAR_COUNT PHOTOMETRIC_SNR FRAME_LIMITING_BRIGHTNESS RCS	~~Table 3-5~~Table 3-6	O	
~~49~~67	Range related data	RANGE PR_N0	~~Table 3-5~~Table 3-6	O	
~~50~~68	Receive related data	RECEIVE_FREQ_n ~~RECEIVE_FREQ~~ RECEIVE_PHASE_CT_n	~~Table 3-5~~Table 3-6	O	
69	System status information	SYSTEM_STATUS_n_START <System Status parameters> SYSTEM_STATUS_n_STOP	Table 3-6	O	
~~51~~70	Transmit related data	TRANSMIT_FREQ_n TRANSMIT_FREQ_RATE_n TRANSMIT_PHASE_CT_n	~~Table 3-5~~Table 3-6	O	
~~52~~71	~~VLBI~~Differenced modes related data	DOR DOR_RATE DOR_AMBIGUITY VLBI_DELAY VLBI_DELAY_RATE VLBI_DELAY_AMBIGUITY TDOA FDOA	~~Table 3-5~~Table 3-6	O	
72	Variance and covariance data	OBS_COVARIANCE_k	Table 3-6	O	
~~53~~73	End of TDM Data	DATA_STOP	~~Table 3-5~~Table 3-6	M	

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ANNEX B

VALUES FOR TIME_SYSTEM AND REFERENCE_FRAME

(NORMATIVE)

B1 GENERAL

Values for the TIME_SYSTEM and REFERENCE_FRAME keywords should come from the SANA Registry. If exchange partners wish to use different settings, they should be documented in the ICD.

B2 TIME_SYSTEM METADATA KEYWORD

The value associated with this keyword ~~must~~should be selected from the SANA Time Systems Registry (https://sanaregistry.org/r/time_systems). Customary values are shown as examples in table ~~3-3~~3-3.

B3 REFERENCE_FRAME KEYWORD

The value associated with this keyword ~~must~~should be selected from the SANA Celestial Body Reference Frames Registry (https://sanaregistry.org/r/celestial_body_reference_frames.) Customary values are shown as examples in table ~~3-3~~3-3.

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ANNEX C

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

C1 SECURITY CONSIDERATIONS

C1.1 ANALYSIS OF SECURITY CONSIDERATIONS

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

C1.2 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

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

C1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

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

C1.4 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. For example, the "Advanced Encryption Standard (AES)" published by the Federal Information Processing Standards organization is recommended in CCSDS 352 for encryption to ensure data privacy.

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Special Publication 197. Gaithersburg, Maryland: NIST, 2001.

C1.5 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. The use of hash-based Message Authentication Codes (MAC) algorithms or cipher-based MAC as described in CCSDS 352 are recommended to ensure data integrity.

C1.6 AUTHENTICATION OF COMMUNICATING ENTITIES

Authentication of communicating entities involved in the transport of data in compliance with the specifications of this Recommended Standard should be provided by the systems and networks on which this Recommended Standard is implemented. For example, algorithms described in the CCSDS 352 Blue Book "Cryptographic Algorithms" could be used for hash-based, cipher-based, or digital signature-based authentication of communicating entities.

C1.7 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

The transfer of data formatted in compliance with this Recommended Standard between communicating entities should be accomplished via secure mechanisms approved by the Information Technology Security functionaries of exchange participants. For example, the "Advanced Encryption Standard (AES)" published by the Federal Information Processing Standards organization is recommended in CCSDS 352 for encryption to ensure data privacy.

Special Publication 197. Gaithersburg, Maryland: NIST, 2001.

C1.8 CONTROL OF ACCESS TO RESOURCES

Control of access to resources should be managed by the systems upon which originator formatting and recipient processing are performed. For example, access control lists or cryptographic access control mechanisms such as KERBEROS can be used to control access to resources.

C1.9 AUDITING OF RESOURCE USAGE

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

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C1.10 UNAUTHORIZED ACCESS

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

C1.11 DATA SECURITY IMPLEMENTATION SPECIFICS

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

C2 SANA CONSIDERATIONS

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

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– the TDM XML schema;

– values for the TIME_SYSTEM keyword in https://sanaregistry.org/r/time_systems (reference [12]);

– values for the REFERENCE_FRAME keyword in https://sanaregistry.org/r/celestial_body_reference_frames (reference [13]); and

– values for the ORIGINATOR keyword in https://sanaregistry.org/r/organizations/organizations.html (reference [11]). The CCSDS Navigation Working Group has no purview over the contents of this registry. Suggestions should be sent to the SANA Operator at info@sanaregistry.org.

C3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

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ANNEX D

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ADM	Attitude Data Message
ASCII	American Standard Code for Information Interchange
AU	Astronomical Unit
AZEL	Azimuth-Elevation
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee for Space Data Systems
CMC	CCSDS Management Council
CUI	Controlled Unclassified Information
Delta-DOR	Delta Differential One-Way Ranging
DOR	Differential One-Way Ranging
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
FDOA	Frequency Difference of Arrival
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
ICS	Implementation Conformance Statement
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
K	Kelvin
KVN	Keyword = Value Notation
LIDAR	Light Detection and Ranging
LTM	Lower Triangle Matrix

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MOIMS Mission Operations and Information Management Services

N/A or n/a Not Applicable / Not Available

NDM Navigation Data Message

ODM Orbit Data Message

OEM Orbit Ephemeris Message

OPM Orbit Parameter Message

P_c/N_0 Carrier Power to Noise Spectral Density ratio

P_r/N_0 Ranging Power to Noise Spectral Density ratio

PRARE Precise Range and Range Rate Equipment

RADEC Right Ascension-Declination

RCS Radar Cross Section

RINEX Receiver Independent Exchange

RL Requirements List

RTLT Round-Trip Light Time

RU Range Units

SANA Space Assigned Numbers Authority

SCLK Spacecraft Clock

SFTP Secure File Transfer Protocol

SI Système International (SI Units)

SLR Satellite Laser Ranging

STEC Slant Total Electron Count

TDM Tracking Data Message

TDOA Time Difference of Arrival

TDR Tracking Data Record

TEC Total Electron Count

TECU Total Electron Count Units

UTC Coordinated Universal Time

UTDF Universal Tracking Data Format

UUID Universal Unique Identifier

VLBI Very Long Baseline Interferometry

XEYN X:East, Y:North

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XSYE	X:South, Y:East
XML	eXtensible Markup Language

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ANNEX E

RATIONALE FOR TRACKING DATA MESSAGES

(INFORMATIVE)

E1 GENERAL

This annex presents the rationale behind the design of the Tracking Data Message (this document). 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, that is, regardless of pre-existing conditions within the CCSDS or its Member Agencies.

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

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

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E2 PRIMARY REQUIREMENTS ACCEPTED FOR TRACKING DATA MESSAGES

Table E-1: Primary Requirements

ID	Requirement	Rationale	Trace
E-1-1	Data must be provided in digital form.	Facilitates computerized processing of TDMs.	3.1.1
E-1-2	The object being tracked must be clearly identified if unambiguous.[1]	Ensures proper processing of the tracking data in orbit determination.	3.3
E-1-3	All primary resources used in the tracking session must be clearly identified and unambiguous.	Ensures proper processing of the tracking data in orbit determination.	3.3
E-1-4	Time measurements (time stamps, timetags, or epochs) must be provided in a clearly specified time standard.[2]	The CCSDS objective of promoting interoperability is not met if time measurements are produced in ill-defined time systems.	3.3, annex B
E-1-5	The format must provide the means to unambiguously specify the time bounds of the tracking data.	The accuracy of orbit determination is highly dependent on precisely knowing the time at which measurements are taken.	3.3, 3.4
E-1-6	Tracking Data Messages must have means of being uniquely identified and clearly annotated.	If discussions of tracking file content are necessary, parties can ensure they are speaking of the same data.	3.2
E-1-7	The data conveyed in a TDM should be as independent of the equipment that was used to perform the tracking as possible, while maintaining the integrity of the observations.	The producer of a Tracking Data Message has local-network knowledge that may not be available to the user of the data.	3.4
E-1-8	Every tracking instrument should have a defined reference location and orientation that could be defined in the ODM or ODM and ADM formats. This reference location should not depend on the observing geometry. If the reference location changes, the format should provide an avenue to convey the changes.	The accuracy of orbit determination is highly dependent on accurately knowing the location of the tracking instruments.	3.4
E-1-9	The timetag of the tracking data shall always be unambiguously specified and reflect the best estimate of the transmit/receive time at the instrument reference location.	The accuracy of orbit determination is highly dependent on precisely knowing the time at which measurements are taken.	3.4

[1] Forthcoming SANA registries may support this requirement.
[2] Forthcoming SANA registries may support this requirement.

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ID	Requirement	Rationale	Trace
E-1-10	The TDM standard shall allow for corrections of observables, such as media corrections, biases, or as derived from path delay calibrations. The observables should be corrected with the best estimate of all known tracking instrument calibrations, such as pass-specific path delay calibrations between the reference point and the tracking equipment, if applicable.	The producer of a Tracking Data Message has knowledge of his or her network that may not be available to the user of the data.	3.4
E-1-11	The observable shall be converted to an equipment-independent quantity; for example, frequencies shall be reported at the 'sky level' (i.e., actual transmitted/received frequencies).	The producer of a Tracking Data Message has knowledge of the details of the equipment in his or her network that may not be available to the user of the data.	3.4
E-1-12	The data transfer mechanism shall not place constraints on the tracking data content.	The tracking data measurements are taken prior to transfer from originator to user, so data content should not be affected.	3.1.7
E-1-13	The standard must provide for clear specification of units of measure.	Without clear specification of units of measure, mistakes can be made that involve the unit system in effect (e.g., Metric or Imperial) and/or orders of magnitude (e.g., meters or kilometers).	4.4, table 3-6, table 3-7
E-1-14	The TDM standard provides a format to exchange tracking data (and associated parameters) between space organizations.	Main goal of the TDM standard	1.3.4.1

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Table E-2: Heritage Requirements

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

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Table E-3: Desirable Characteristics

ID	Requirement	Rationale	Trace
E-3-1	The standard should apply to non-traditional objects, such as landers, rovers, balloons, spacecraft-spacecraft tracking data exchange, etc.	There are many different types of spacecraft that are tracked by space agencies. The broader the applicability of the standard, the more useful it will be.	3.3, 3.4
E-3-2	The standard should be extensible with no disruption to existing users/uses.	Space agencies and operators upgrade systems and processes on schedules that make sense for their organizations. In practice, some organizations will be early adopters, but others will opt to wait until performance of a new version of the TDM has been proven in other operations facilities.	3.2
E-3-3	Keywords, values, and terminology in the TDM should be the same as those in the other CCSDS standards, where applicable.	Helps to ensure similar 'look and feel' across the various CCSDS flight dynamics standards.	3.2, 3.3, 3.5, 4
E-3-4	The standard shall not preclude an XML implementation.	The CCSDS Management Council (CMC) has indicated that the Navigation Working Group must produce standards that can be represented in XML.	3, 5
E-3-5	The standard should make it clear to the user whether corrections have been applied or not. Corrections applied to the data, such as media corrections, should be agreed upon by the service-providing and the customer Agencies.	The user of the data must know what types of corrections and calibrations have been applied to the data in order to process it correctly.	3.4
E-3-6	The TDM shall seek to minimize the need for development of non-standard conventions or extensive ICD arrangements.	Ensures flexibility in the use of the TDM, avoiding unnecessary deviations from the standard.	1.2.2
E-3-7	The TDM standard shall progressively accommodate new tracking data types or sensor phenomenologies that may become prevalent for space object tracking or navigation. The standard must be extensible, while maximizing backwards compatibility.	Ensures the TDM evolves according with user needs.	3.4.16
E-3-8	The TDM standard should minimize the keywords needed to represent equivalent observables. The observables' units should provide flexibility to most closely represent the native system implementation.	Limits the inclusion of unnecessary keywords into the TDM standard.	3.4.16

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ANNEX F

TECHNICAL MATERIAL AND CONVENTIONS

(INFORMATIVE)

F1 OVERVIEW

This annex details the conventions used in this document for the definition of tracking data.

F2 USING THE RECEIVE_FREQ KEYWORD

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

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

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

NOTE – Doppler definitions for different systems or entities may have a sign discrepancy. In the example above, positive Doppler values correspond to an increase in the distance of the line-of-sight.

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

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

The limits of integration are determined by the INTEGRATION_REF keyword in the Metadata Section; 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 [H4]).

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INTEGRATION_REF	END	MIDDLE	START
α	α = –½	α = 0	α = ½
Upper Limit	t	$t + ½\Delta t$	$t + \Delta t$
Lower Limit	$t - \Delta t$	$t - ½\Delta t$	t

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F3 USING THE RECEIVE_PHASE_CT KEYWORD

The value associated with the RECEIVE_PHASE_CT keyword represents the number of phase cycles measured at the receiver. If the received phase difference over a time interval is not based on the true frequency but an intermediate frequency from which the true received frequency is calculated, the FREQ_OFFSET metadata keyword should be specified to provide the applicable frequency difference.

The RECEIVE_PHASE_CT keyword may be used in conjunction with the RECEIVE_PHASE_CT_BIAS and RECEIVE_PHASE_CT_SCALE metadata. The relationship between the RECEIVE_PHASE_CT and the RECEIVE_FREQ (in units of Hz) keywords can be defined by the following expression:

$$RECEIVE\_FREQ(T_0) = \frac{\left[\frac{RECEIVE\_PHASE\_CT(T_0) - RECEIVE\_PHASE\_CT(T_{-1})}{T_0 - T_{-1}} - RECEIVE\_PHASE\_CT\_BIAS\right]}{RECEIVE\_PHASE\_CT\_SCALE} + FREQ\_OFFSET$$

With:

- T_0 representing the subject time tag of the RECEIVE_PHASE_CT, and T_{-1} representing the prior time tag.
- Results from the relationship above produce: INTEGRATION_REF = END; $INTEGRATION\_INTERVAL = T_0 - T_{-1}$, when using consecutive phase count measurements.

F3.1 DOPPLER COUNT AND RECEIVE PHASE COUNT

The removed DOPPLER_COUNT keywords were intended to capture received frequency values that could be employed to derive Doppler observations, per the formulation described in F2. However, Doppler frequencies are derived and not directly measured, hence it is recommended to maintain a keyword set that best represents the information being conveyed. In this case, this would be in the form of unwrapped, integrated phase counts via RECEIVE_PHASE_CT keywords.

This required the inclusion of keywords RECEIVE_PHASE_CT_BIAS and RECEIVE_PHASE_CT_SCALE.

F3.1.1 Backwards compatibility for RECEIVE_PHASE_CT

In order to maintain backwards compatibility, keywords that were not present in the prior TDM version could be omitted (if not required). The default values indicated below would apply:

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RECEIVE_PHASE_CT_BIAS = 0

RECEIVE_PHASE_CT_SCALE = 1

This yields the following relationship, coinciding with the prior functionality available with the 503.0-B-2 standard:

$$RECEIVE\_FREQ(T_0) = \frac{RECEIVE\_PHASE\_CT(T_0) - RECEIVE\_PHASE\_CT(T_{-1})}{T_0 - T_{-1}} + FREQ\_OFFSET$$

F3.1.2 Backwards compatibility with DOPPLER_COUNT (compatibility for transition from UTDF)

This section describes how the current keywords provide the prior capability intended by the removed DOPPLER_COUNT keywords in TDM version 2. The following is the relationship of the removed DOPPLER_COUNT keyword, with the estimated Doppler measurement (as described in annex F2) in Hertz:

$$Doppler(T_0) = -\frac{\left[\frac{DOPPLER\_COUNT(T_0) - DOPPLER\_COUNT(T_{-1})}{T_0 - T_{-1}}\right] - DOPPLER\_COUNT\_BIAS}{DOPPLER\_COUNT\_SCALE}$$

With assumptions:

– T_0 representing the subject time tag of the DOPPLER_COUNT and T_{-1} representing the prior time tag.

– TRANSMIT_FREQ = CONSTANT

– FREQ_OFFSET = TRANSMIT_FREQ * TURNAROUND_NUMERATOR / TURNAROUND_DENOMINATOR

NOTE 1 – Results produce Doppler with a time tag associated with the END of the integration interval.

NOTE 2 – $INTEGRATION\_INTERVAL = T_0 - T_{-1}$, when using consecutive receive phase count measurements.

NOTE 3 – The transmit frequency must be static (i.e. no frequency ramping or forward frequency compensation).

The equivalent relationship with the recent changes is represented by:

$$Doppler(T_0) = -\frac{\left[\frac{RECEIVE\_PHASE\_CT(T_0) - RECEIVE\_PHASE\_CT(T_{-1})}{T_0 - T_{-1}}\right] - RECEIVE\_PHASE\_CT\_BIAS}{RECEIVE\_PHASE\_CT\_SCALE}$$

With:

Same assumptions as above.

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F4 FORWARD FREQUENCIES AND TRANSMIT_PHASE_CT

A series of TRANSMIT_PHASE_CT observables represents a sequence of phase-time points. Each point gives the phase of the transmitted signal at the corresponding value of time for the transmitting tracking system. Interpolation of the phase values for each transmitted signal is necessary to obtain the relevant phase φ, the frequency f and its time derivative $\dot{f}$ (the ramp rate) at a desired interpolation time t, which represents a transmission time at the transmitting electronics for the particular tracking system.

The interpolation applied should be aligned with the interpolation method indicated by the INTERPOLATION Metadata keyword. For example Hermite, Lagrange or linear interpolation. Furthermore, the interpolation should match the degree indicated by the INTERPOLATION_DEGREE Metadata keyword.

F4.1 LINEAR INTERPOLATION

In the case of linear interpolation, the $\dot{f}$ (frequency ramp-rate in Hz/s) is a constant time derivative of f at time t. Interpolation of the phase values requires three phase-time pairs on the same ramp: φ_1 at t_1, φ_2 at t_2, and φ_3 at t_3. Note: this assumes the three pairs used for interpolation do not include ramp transitions. The interpolation time t will be between t_1 and t_3, and it may be before or after t_2. The phase differences φ_2 - φ_1 and φ_3 - φ_2 can be expressed as a function of the frequency f_2 at t_2, the ramp rate $\dot{f}$ (which is constant from t_1 to t_3), and the time differences:

$$T_A = t_2 - t_1; \text{ and } T_B = t_3 - t_2 \text{ [seconds]}$$

Utilizing these two equations (T_A and T_B) for f_2 and $\dot{f}$ gives:

$$f_2 = \frac{1}{(T_A + T_B)}\left[(\varphi_2 - \varphi_1)\left(\frac{T_B}{T_A}\right) + (\varphi_3 - \varphi_2)\left(\frac{T_A}{T_B}\right)\right] \text{ [Hz]}$$

and

$$\dot{f} = \frac{2}{(T_A + T_B)}\left[\frac{(\varphi_3 - \varphi_2)}{T_B} - \frac{(\varphi_2 - \varphi_1)}{T_A}\right] \text{ [Hz/s]}$$

Define Δt to be the interpolation time t minus the time argument t_2 for the phase φ_2 obtained from the phase values:

$$\Delta t = t - t_2 \text{ [seconds]}$$

Also, define $\Delta\varphi(\Delta t)$ to be the phase $\varphi(t)$ of the transmitted signal at the interpolation time t, minus the phase obtained from the phase values at t_2:

$$\Delta\varphi(\Delta t) = \varphi(t) - \varphi_2 \text{ [cycles]}$$

Given f_2 and $\dot{f}$, the phase difference that accumulates from the tabular time t_2 to the interpolation time t is given by:

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$\Delta\varphi(\Delta t) = f_2\Delta t + \frac{1}{2}\dot{f}\Delta t^2$ [cycles]

Adding this phase difference to the tabular phase φ_2 obtained from the phase values at t_2 gives the phase of the transmitted signal at the interpolation time t. The ramped transmitted frequency, f_T, at the interpolation time t is given by:

$f_T(t) = f_2 + \dot{f}\Delta t$ [Hz]

F5 USING THE OBS_COVARIANCE KEYWORDS

The OBS_COVARIANCE_k data keyword should be derived from a variance-covariance matrix that describes the estimation error of each observable and their expected cross-correlations. It is a symmetric, positive definite matrix produced by the tracking filter or other calculation technique that assembles the observation. The following example provides an explanation for the usage of the relevant keywords.

The OBS_COVARIANCE_OBS_k Metadata keyword provides the ordered, comma-separated, list of observables used to populate the diagonal of the covariance matrix (from top-left to bottom-right). The rest of the elements in the matrix are covariance values among the intersecting observables. See the example variance-covariance matrix below, which aligns with the following keyword definition:

```
OBS_COVARIANCE_OBS_1 = ANGLE_1, ANGLE_2, RANGE, ANGLE_1_RATE, ANGLE_2_RATE
```

$$\begin{bmatrix} \sigma^2_{Angle1} & \sigma_{Angle1}\sigma_{Angle2} & \sigma_{Angle1}\sigma_{Range} & \sigma_{Angle1}\sigma_{Angle1Rate} & \sigma_{Angle1}\sigma_{Angle2Rate} \\ \sigma_{Angle2}\sigma_{Angle1} & \sigma^2_{Angle2} & \sigma_{Angle2}\sigma_{Range} & \sigma_{Angle2}\sigma_{Angle1Rate} & \sigma_{Angle2}\sigma_{Angle2Rate} \\ \sigma_{Range}\sigma_{Angle1} & \sigma_{Range}\sigma_{Angle2} & \sigma^2_{Range} & \sigma_{Range}\sigma_{Angle1Rate} & \sigma_{Range}\sigma_{Angle2Rate} \\ \sigma_{Angle1Rate}\sigma_{Angle1} & \sigma_{Angle1Rate}\sigma_{Angle2} & \sigma_{Angle1Rate}\sigma_{Range} & \sigma^2_{Angle1Rate} & \sigma_{Angle1Rate}\sigma_{Angle2Rate} \\ \sigma_{Angle2Rate}\sigma_{Angle1} & \sigma_{Angle2Rate}\sigma_{Angle2} & \sigma_{Angle2Rate}\sigma_{Range} & \sigma_{Angle2Rate}\sigma_{Angle1Rate} & \sigma^2_{Angle2Rate} \end{bmatrix}$$

The OBS_COVARIANCE_VALS_k Metadata keyword is then populated with an ordered list of comma-separated matrix elements that will be provided with each OBS_COVARIANCE_k keyword in the Data Section. Each element from the matrix is identified by its "row column" pair, separated by a space. See the example matrix below, which is an ordered list that follows a Lower Triangle Matrix (LTM) pattern defined by the following OBS_COVARIANCE_k keyword definition:

```
OBS_COVARIANCE_VALS_1 = 1 1, 2 1, 2 2, 3 1, 3 2, 3 3, 4 1, 4 2, 4 3, 4 4, 5 1, 5 2,
5 3, 5 4 ,5 5
```

$$\begin{bmatrix} \sigma^2_{Angle1} & \sigma_{Angle1}\sigma_{Angle2} & \sigma_{ANGLE1}\sigma_{Range} & \sigma_{Angle1}\sigma_{Angle1Rate} & \sigma_{Angle1}\sigma_{Angle2Rate} \\ \sigma_{Angle2}\sigma_{Angle1} & \sigma^2_{Anlge2} & \sigma_{Angle2}\sigma_{Range} & \sigma_{Angle2}\sigma_{Angle1Rate} & \sigma_{Angle2}\sigma_{Angle2Rate} \\ \sigma_{Range}\sigma_{Angle1} & \sigma_{Range}\sigma_{Angle2} & \sigma^2_{Range} & \sigma_{Range}\sigma_{Angle1Rate} & \sigma_{Range}\sigma_{Angle2Rate} \\ \sigma_{Angle1RATE}\sigma_{Angle1} & \sigma_{Anlge1Rate}\sigma_{Angle2} & \sigma_{Angle1Rate}\sigma_{Range} & \sigma^2_{Angle1Rate} & \sigma_{Angle1Rate}\sigma_{Angle2Rate} \\ \sigma_{Angle2RATE}\sigma_{Angle1} & \sigma_{Angle2Rate}\sigma_{Angle2} & \sigma_{Angle2Rate}\sigma_{Range} & \sigma_{Angle2Rate}\sigma_{Angle1Rate} & \sigma^2_{Angle2Rate} \end{bmatrix}$$

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NOTE – LTM is the default implementation for ordering covariance values. When LTM ordering is used, the OBS_COVARIANCE_VALS_k keyword may be omitted, and the system will assume the standard LTM element order based on the observables listed in OBS_COVARIANCE_OBS_k.

In the Data Section, the OBS_COVARIANCE_k keywords provide timestamped updates to the variance-covariance values associated with the observables. The data example below aligns with the definitions of the Metadata keywords provided above at a timestamp of “2012-10-29T17:46:39.02”.

```
OBS_COVARIANCE_1 = 2012-10-29T17:46:39.02 4.54, 0.32, 1.6, 0.42, 0.78, 2.3, 0.2, 0.1, 0.14, 4.3, 0.21, 0.01, 0.23, 0.34, 5.38
```

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ANNEX G
EXAMPLE TRACKING DATA MESSAGES

(INFORMATIVE)

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ANNEX DANNEX A

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

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

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

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

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

Another thought on ICDs is that it might be feasible for participating agencies to have a generic baseline ICD ('standard service provider ICD') that specifies mission/spacecraft-independent entities on the interface, for example, 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:

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Item	Section
1. Definition of accuracy requirements pertaining to any particular TDM.	1.2.3
2.1.Method of exchanging TDMs (e.g., post-processed SFTP, real-time stream, etc.).	1.2.4, 3.1.7
3.1.Whether the KVN or XML format of the TDM will be exchanged.	2.2.3
4.1.Frequency of exchange and special types of exchange.	2.2.6
5.1.TDM file naming conventions.	3.1.6
6.1.Specific TDM version number(s) that will be exchanged.	3.2.5
7. Antenna geometry, if not accommodated by built-in values of 'ANGLE_TYPE' keyword.	table 3-3
8. The list of eligible names that is used for PARTICIPANT_n keywords.	table 3-3, 3.3.1.10
9. Definitions of 'RAW', 'VALIDATED', and 'DEGRADED' as they apply to data quality for a particular exchange (DATA_QUALITY keyword).	table 3-3
10. The range of frequencies associated with each value of the 'TRANSMIT_BAND' and 'RECEIVE_BAND' metadata keywords.	table 3-3
11. If more than five participants are necessary, special arrangements are necessary.	3.3.1.11, 3.3.2.4.4
12. The methods used to extrapolate the measurements to other antennas when all the data in a TDM Segment is media related or weather related and the observable may be relative to a reference location within the tracking complex.	3.3.2.7.2
13.1. Complete description of the station locations and characteristics.	3.4.13
14.1. Whether TRANSMIT_DELAY and RECEIVE_DELAY are processed by the producer or the consumer of the tracking data.	3.4.15.2
15.1. Special sort orders that may be required by the producer or recipient.	3.4.10, 3.5.4.1
16.1. Spin correction arrangements (who will do the correction, the agency providing the tracking or the agency that operates the spacecraft).	3.4.15.5
17.1. Correction algorithms that are more complex than a simple scalar value.	3.4.15.6
18.1. Standard corrections that will (or will not) be applied to the data (e.g., tropospheric, meteorological, media, transponder, etc.), miscellaneous corrections.	3.4.15.7
19. Definition of the range unit, if it is not kilometers or seconds.	3.5.2.7, table 3-3
20. Equation for calculation of four-way Doppler shift, if applicable.	3.5.2.8.5

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Item	Section
21. Transponder turnaround ratios necessary to calculate predicted downlink frequency and the Doppler measurement; also includes cases such as dual uplink where a 'beacon' or 'pilot' frequency is used (e.g., TDRS, DRTS, COMETS).	3.5.2.8.4, 3.5.2.9, table 3-3
22.1. Whether or not it is necessary to distinguish the separate Slant Total Electron Count contributions between ionospheric and interplanetary STEC.	3.5.7.1
23.1. Elevation mapping function for the tropospheric data.	3.5.7.2, 3.5.7.3
24.1. Recommended polynomial interpolations for tropospheric data.	3.5.7.2, 3.5.7.3
25.1. If non-standard floating-point numbers in extended-single or extended-double precision are to be used, then discussion of implementation-specific attributes is required.	4.3.5
26.1. Information which must appear in comments for any given TDM exchange.	4.5.4
27.1. Description of any ancillary data not already included in the Tracking Data Record definition.	4.5.5
28.1. Interagency Information Technology (IT) security requirements in TDMs.	annex C
29.1. Time systems not shown in annex B.	annex B
30.1. Reference frames not shown in annex B.	annex B
31.1. Whether the mean range rate for 2W and/or 3W Doppler is based on the one-way light time or two-way light time.	3.5.2.3
32. Whether the RANGE observable for 2W and/or 3W range is based on the round trip light time, or half the round trip light time.	3.5.2.7
33. The usage and composition of a tracking data identifier specified by 'TRACK_ID' keyword.	table 3-3

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ANNEX EANNEX A
EXAMPLE TRACKING DATA MESSAGES

(INFORMATIVE)

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```
CCSDS_TDM_VERS = 23.0
COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down
CREATION_DATE = 2005-160T20:15:00Z
ORIGINATOR = NASA

META_START
COMMENT Data quality degraded by antenna pointing problem...
COMMENT Slightly noisy data
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = COMMENT StarTrek 1-way data, Ka band down
CREATION_DATE = 2005-160T20:15:00Z
ORIGINATOR = NASA

META_START
COMMENT Data quality degraded by antenna pointing problem...
COMMENT Slightly noisy data
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = yyyy-nnnA
2005-999A
MODE = SEQUENTIAL
PATH = 2,1
INTEGRATION_INTERVAL = 1
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 0
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
DATA_QUALITY = DEGRADED
META_STOP

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

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

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```
CCSDS_TDM_VERS = 23.0

COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
COMMENT StarTrek 1-way data, Ka band down

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

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-159T17:41:00
STOP_TIME = 2005-159T17:41:40
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = yyyy-nnnA2005-999A
MODE = SEQUENTIAL
PATH = 2,1
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 32021035200.0
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
DATA_QUALITY = RAW
META_STOP

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

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

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```
CCSDS_TDM_VERS=23.0
COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
CREATION_DATE=2005-184T20:15:00
ORIGINATOR=NASA
META_START
TIME_SYSTEM=UTC
START_TIME=2005-184T11:12:23
STOP_TIME=2005-184T13:59:43.27
PARTICIPANT_1=DSS-55
PARTICIPANT_2=yyyy-nnnA2005-999A
MODE=SEQUENTIAL
PATH=1,2,1
INTEGRATION_INTERVAL=1.0
INTEGRATION_REF=MIDDLE
META_STOP
DATA_START
TRANSMIT_FREQ_1=2005-184T11:12:23      7175173383.615373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:23  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:24      7175173384.017573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:24  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:25      7175173384.419773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:25  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:26      7175173384.821973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:26  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:27      7175173385.224173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:27  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:28      7175173385.626373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:28  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:29      7175173386.028573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:29  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:30      7175173386.430773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:30  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:31      7175173386.832973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:31  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:32      7175173387.235173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:32  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:33      7175173387.637373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:33  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:34      7175173388.039573
TRANSMIT_FREQ_RATE_1=2005-184T11:12:34  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:35      7175173388.441773
TRANSMIT_FREQ_RATE_1=2005-184T11:12:35  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:36      7175173388.843973
TRANSMIT_FREQ_RATE_1=2005-184T11:12:36  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:37      7175173389.246173
TRANSMIT_FREQ_RATE_1=2005-184T11:12:37  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:38      7175173389.648373
TRANSMIT_FREQ_RATE_1=2005-184T11:12:38  0.40220
TRANSMIT_FREQ_1=2005-184T11:12:39      7175173390.050573
RECEIVE_FREQ_1=2005-184T13:59:27.27  8429753135.986102
RECEIVE_FREQ_1=2005-184T13:59:28.27  8429749428.196568
RECEIVE_FREQ_1=2005-184T13:59:29.27  8429749427.584727
RECEIVE_FREQ_1=2005-184T13:59:30.27  8429749427.023103
RECEIVE_FREQ_1=2005-184T13:59:31.27  8429749426.346252
RECEIVE_FREQ_1=2005-184T13:59:32.27  8429749425.738658
RECEIVE_FREQ_1=2005-184T13:59:33.27  8429749425.113143
RECEIVE_FREQ_1=2005-184T13:59:34.27  8429749424.489933
RECEIVE_FREQ_1=2005-184T13:59:35.27  8429749423.876996
RECEIVE_FREQ_1=2005-184T13:59:36.27  8429749423.325228
RECEIVE_FREQ_1=2005-184T13:59:37.27  8429749422.664049
RECEIVE_FREQ_1=2005-184T13:59:38.27  8429749422.054996
RECEIVE_FREQ_1=2005-184T13:59:39.27  8429749421.425801
RECEIVE_FREQ_1=2005-184T13:59:40.27  8429749420.824186
RECEIVE_FREQ_1=2005-184T13:59:41.27  8429749420.204178
RECEIVE_FREQ_1=2005-184T13:59:42.27  8429749419.596043
RECEIVE_FREQ_1=2005-184T13:59:43.27  8429749418.986191
DATA_STOP
```

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

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```
CCSDS_TDM_VERS = 23.0
   COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
   CREATION_DATE = 2005-191T23:00:00
   ORIGINATOR = NASA
META_START
   COMMENT Range correction applied is range calibration to DSS-24.
   COMMENT Estimated RTLT at begin of pass = 950 seconds
   COMMENT Antenna Z-height correction 0.0545 km applied to uplink signal
   COMMENT Antenna Z-height correction 0.0189 km applied to downlink signal
   TIME_SYSTEM = UTC
   PARTICIPANT_1 = DSS-24
   PARTICIPANT_2 = yyyy-nnnA2005-999A
   MODE = SEQUENTIAL
   PATH = 1,2,1
   INTEGRATION_REF = START
   RANGE_MODE = COHERENT
   RANGE_MODULUS = 2.0e+26
   RANGE_UNITS = RU
   TRANSMIT_DELAY_1 = 7.7e-5
   RECEIVE_DELAY_1  = 7.7e-5
   CORRECTION_RANGE = 46.7741
   CORRECTIONS_APPLIED = YES
META_STOP
DATA_START
   TRANSMIT_FREQ_1      =  2005-191T00:31:51    7180064367.3536
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:31:51    0.59299
   RANGE                =  2005-191T00:31:51    39242998.5151986
   PR_N0                =  2005-191T00:31:51    28.52538
   TRANSMIT_FREQ_1      =  2005-191T00:34:48    7180064472.3146
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:34:48     0.59305
   RANGE                =  2005-191T00:34:48    61172265.3115234
   PR_N0                =  2005-191T00:34:48    28.39347
   TRANSMIT_FREQ_1      =  2005-191T00:37:45    7180064577.2756
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:37:45    0.59299
   RANGE                =  2005-191T00:37:45    15998108.8168328
   PR_N0                =  2005-191T00:37:45    28.16193
   TRANSMIT_FREQ_1      =  2005-191T00:40:42    7180064682.2366
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:40:42    0.59299
   RANGE                =  2005-191T00:40:42    37938284.4138008
   PR_N0                =  2005-191T00:40:42    29.44597
   TRANSMIT_FREQ_1      =  2005-191T00:43:39    7180064787.1976
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:43:39    0.60774
   RANGE                =  2005-191T00:43:39    59883968.0697146
   PR_N0                =  2005-191T00:43:39    27.44037
   TRANSMIT_FREQ_1      =  2005-191T00:46:36    7180064894.77345
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:46:36    0.60989
   RANGE                =  2005-191T00:46:36    14726355.3958799
   PR_N0                =  2005-191T00:46:36    27.30462
   TRANSMIT_FREQ_1      =  2005-191T00:49:33    7180065002.72044
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:49:33    0.60989
   RANGE                =  2005-191T00:49:33    36683224.3750253
   PR_N0                =  2005-191T00:49:33    28.32537
   TRANSMIT_FREQ_1      =  2005-191T00:52:30    7180065110.66743
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:52:30    0.60983
   RANGE                =  2005-191T00:52:30    58645699.4734682
   PR_N0                =  2005-191T00:52:30    29.06158
   TRANSMIT_FREQ_1      =  2005-191T00:55:27    7180065218.61442
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:55:27    0.60989
   RANGE                =  2005-191T00:55:27    13504948.3585422
   PR_N0                =  2005-191T00:55:27    27.29589
   TRANSMIT_FREQ_1      =  2005-191T00:58:24    7180065326.56141
   TRANSMIT_FREQ_RATE_1 =  2005-191T00:58:24    0.62085
   RANGE                =  2005-191T00:58:24    35478729.4012973
   PR_N0                =  2005-191T00:58:24    30.48199
   TRANSMIT_FREQ_1      =  2005-191T01:01:21    7180065436.45167
   RANGE                =  2005-191T01:01:21    57458219.0681689
   PR_N0                =  2005-191T01:01:21    27.15509
DATA_STOP
```

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

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```
CCSDS_TDM_VERS = ~~2~~3.0

COMMENT TDM example created by ~~yyyyy-nnnA~~2005-999A Nav Team (NASA/JPL)

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

META_START
TIME_SYSTEM = UTC
START_TIME =  2005-184T11:12:23
STOP_TIME  =  2005-184T13:59:40.27
PARTICIPANT_1 = DSS-55
PARTICIPANT_2 = ~~yyyy-nnnA~~2005-999A
PARTICIPANT_3 = DSS-15
MODE = SEQUENTIAL
PATH = 1,2,3
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
META_STOP

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

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

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```
CCSDS_TDM_VERS = 23.0
COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (JAXA)
CREATION_DATE = 1998-06-10T01:00:00
ORIGINATOR = JAXA
META_START
TIME_SYSTEM = UTC
START_TIME =  1998-06-10T00:57:37
STOP_TIME  =  1998-06-10T00:57:44
PARTICIPANT_1 = NORTH
PARTICIPANT_2 = F07R07
PARTICIPANT_3 = E7
MODE = SEQUENTIAL
PATH = 1,2,3,2,1
INTEGRATION_INTERVAL = 1.0
INTEGRATION_REF = MIDDLE
RANGE_MODE = CONSTANT
RANGE_MODULUS = 0
RANGE_UNITS = km
ANGLE_TYPE = AZEL
META_STOP
DATA_START
RANGE    =   1998-06-10T00:57:37          80452.7542
ANGLE_1       =   1998-06-10T00:57:37           256.64002393
ANGLE_2       =   1998-06-10T00:57:37            13.38100016
TRANSMIT_FREQ_1 = 1998-06-10T00:57:37    2106395199.07917
RECEIVE_FREQ =   1998-06-10T00:57:37     2287487999.0

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

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

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

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

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

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

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

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

```
CCSDS_TDM_VERS = 23.0
COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
COMMENT This example TDM describes a scenario such as might occur with a
COMMENT spacecraft like Cassini, which has 3 transponders:  X/S, X/X, X/Ka.
COMMENT In this tracking session all 3 transponders were used.
```

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```
COMMENT This requires a TDM with 3 segments, because a single segment would
COMMENT not be able to specify a 'PATH' statement that would describe the
COMMENT S-down, X-down, and Ka-down signal paths.
CREATION_DATE = 2006-347T22:51
ORIGINATOR = NASA

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-X
MODE = SEQUENTIAL
PATH = 1,2,1
TRANSMIT_BAND = X
RECEIVE_BAND = X
INTEGRATION_INTERVAL = 300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
META_STOP
DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34  7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  8430849716.68
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-KA
MODE = SEQUENTIAL
PATH = 1,2,1
TRANSMIT_BAND = X
RECEIVE_BAND = KA
INTEGRATION_INTERVAL = 300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 0.000077
RECEIVE_DELAY_1 = 0.000077
META_STOP
DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34   7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  32037228923.40
DATA_STOP

META_START
TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-25
PARTICIPANT_2 = 1997-061A-S
PARTICIPANT_3 = DSS-24
MODE = SEQUENTIAL
PATH = 1,2,3
TRANSMIT_BAND = X
RECEIVE_BAND = S
INTEGRATION_INTERVAL = 300.0
INTEGRATION_REF = MIDDLE
TRANSMIT_DELAY_1 = 7.7e-5
RECEIVE_DELAY_3 =  7.7e-5
META_STOP
DATA_START
TRANSMIT_FREQ_1 = 2006-347T03:50:34  7175802770.23
RECEIVE_FREQ_1  = 2006-347T06:17:49  2299322650.01
DATA_STOP
```

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

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```
CCSDS_TDM_VERS = 23.0
COMMENT GEOSCX_INP
CREATION_DATE = 2007-08-30T12:01:44.749
ORIGINATOR = DLR
META_START
TIME_SYSTEM = UTC
START_TIME = 2007-08-29T07:00:02.000
STOP_TIME = 2007-08-29T14:00:02.000
PARTICIPANT_1 = HBSTK
PARTICIPANT_2 = SAT
MODE = SEQUENTIAL
PATH = 1,2,1
INTEGRATION_INTERVAL =  1.0
INTEGRATION_REF = END
ANGLE_TYPE = XSYE
DATA_QUALITY = RAW
META_STOP
DATA_START
DOPPLER_INTEGRATED    = 2007-08-29T07:00:02.000         -1.498776048
ANGLE_1               = 2007-08-29T07:00:02.000          67.01312389
ANGLE_2               = 2007-08-29T07:00:02.000          18.28395556
DOPPLER_INTEGRATED    = 2007-08-29T08:00:02.000         -2.201305217
ANGLE_1               = 2007-08-29T08:00:02.000          67.01982278
ANGLE_2               = 2007-08-29T08:00:02.000          21.19609167
DOPPLER_INTEGRATED    = 2007-08-29T12:00:02.000          2.248620597
ANGLE_1               = 2007-08-29T12:00:02.000         -84.79697583
ANGLE_2               = 2007-08-29T12:00:02.000           4.11574444
DOPPLER_INTEGRATED    = 2007-08-29T13:00:02.000          1.547592295
ANGLE_1               = 2007-08-29T13:00:02.000         -85.14762500
ANGLE_2               = 2007-08-29T13:00:02.000           4.35471389
DOPPLER_INTEGRATED    = 2007-08-29T14:00:02.000          0.929545817
ANGLE_1               = 2007-08-29T14:00:02.000         -89.35626083
ANGLE_2               = 2007-08-29T14:00:02.000           2.78791667
DATA_STOP

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

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

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```
CCSDS_TDM_VERS = 23.0
COMMENT  This TDM example contains range data timetagged at transmit time
CREATION_DATE = 2005-09-17T23:59:59
ORIGINATOR = JAXA

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-09-17T00:41:38.0000
STOP_TIME =  2005-09-17T00:42:58.0000
PARTICIPANT_1 = yyyy-nnnA2005-999A
PARTICIPANT_2 = USC1
MODE = SEQUENTIAL
PATH = 2,1,2
TRANSMIT_BAND = S
RECEIVE_BAND = S
TIMETAG_REF = TRANSMIT
INTEGRATION_REF = START
RANGE_MODE = CONSTANT
RANGE_MODULUS = 1.0E7
RANGE_UNITS = km
DATA_QUALITY = VALIDATED
CORRECTION_RANGE = 0.0
CORRECTIONS_APPLIED = YES
META_STOP
DATA_START
RANGE = 2005-09-17T00:41:38.000000  3198.03679519614
RANGE = 2005-09-17T00:41:40.000000  3199.82505720811
RANGE = 2005-09-17T00:41:42.000000  3201.61631714467
RANGE = 2005-09-17T00:41:44.000000  3203.40832656236
RANGE = 2005-09-17T00:41:46.000000  3205.20108546120
RANGE = 2005-09-17T00:41:48.000000  3206.99384436004
RANGE = 2005-09-17T00:41:50.000000  3208.79110014575
RANGE = 2005-09-17T00:41:52.000000  3210.58535800688
RANGE = 2005-09-17T00:41:54.000000  3212.38336327374
RANGE = 2005-09-17T00:41:56.000000  3214.18136854059
RANGE = 2005-09-17T00:41:58.000000  3215.98012328859
RANGE = 2005-09-17T00:42:00.000000  3217.78037699888
RANGE = 2005-09-17T00:42:02.000000  3219.58287915260
RANGE = 2005-09-17T00:42:04.000000  3221.38613078747
RANGE = 2005-09-17T00:42:06.000000  3223.19013190349
RANGE = 2005-09-17T00:42:08.000000  3224.99488250065
RANGE = 2005-09-17T00:42:10.000000  3226.80113206010
RANGE = 2005-09-17T00:42:12.000000  3228.60963006298
RANGE = 2005-09-17T00:42:14.000000  3230.41587962244
RANGE = 2005-09-17T00:42:16.000000  3232.22587658761
RANGE = 2005-09-17T00:42:18.000000  3234.03662303393
RANGE = 2005-09-17T00:42:20.000000  3235.84886844254
RANGE = 2005-09-17T00:42:22.000000  3237.65961488886
RANGE = 2005-09-17T00:42:24.000000  3239.47560770319
RANGE = 2005-09-17T00:42:26.000000  3241.28860259295
RANGE = 2005-09-17T00:42:28.000000  3243.10384592614
RANGE = 2005-09-17T00:42:30.000000  3244.92133770276
RANGE = 2005-09-17T00:42:32.000000  3246.73882947939
RANGE = 2005-09-17T00:42:34.000000  3248.55856969945
RANGE = 2005-09-17T00:42:36.000000  3250.37681095722
RANGE = 2005-09-17T00:42:38.000000  3252.19879962071
RANGE = 2005-09-17T00:42:40.000000  3254.02003880307
RANGE = 2005-09-17T00:42:42.000000  3255.84352642885
RANGE = 2005-09-17T00:42:44.000000  3257.66851301693
RANGE = 2005-09-17T00:42:46.000000  3259.49125116157
RANGE = 2005-09-17T00:42:48.000000  3261.31848619307
RANGE = 2005-09-17T00:42:50.000000  3263.14572122459
RANGE = 2005-09-17T00:42:52.000000  3264.97295625609
RANGE = 2005-09-17T00:42:54.000000  3266.80169024990
RANGE = 2005-09-17T00:42:56.000000  3268.63267268713
RANGE = 2005-09-17T00:42:58.000000  3270.46440460551
DATA_STOP
```

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

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```
CCSDS_TDM_VERS = 23.0


COMMENT  This TDM example contains single differenced Doppler data.


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


META_START
TIME_SYSTEM = UTC
START_TIME = 2003-07-08T04:45:25.0000
STOP_TIME =  2003-07-08T04:48:25.0000
PARTICIPANT_1 = yyyy-nnnA2005-999A
PARTICIPANT_2 = DSS-24
PARTICIPANT_3 = DSS-25
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
INTEGRATION_INTERVAL = 10.0
INTEGRATION_REF = MIDDLE
RECEIVE_DELAY_2 = 0.00007732
RECEIVE_DELAY_3 = 0.00007732
DATA_QUALITY = VALIDATED
META_STOP


DATA_START

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

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

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

DATA_STOP
```

Figure A-10: TDM Example: Differenced Doppler Observable

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```
CCSDS_TDM_VERS = 23.0
COMMENT This TDM example contains Delta-DOR data.

COMMENT Quasar CTD 20 also known as J023752.4+284808 (ICRF), 0234+285 (IERS)

CREATION_DATE = 2005-178T21:45:00

ORIGINATOR = NASA

META_START

TIME_SYSTEM = UTC

START_TIME = 2004-136T15:42:00.0000

STOP_TIME = 2004-136T16:02:00.0000

PARTICIPANT_1 = VOYAGER1

PARTICIPANT_2 = DSS-55

PARTICIPANT_3 = DSS-25

MODE = SINGLE_DIFF

PATH_1 = 1,2

PATH_2 = 1,3

TRANSMIT_BAND = X

RECEIVE_BAND = X

TIMETAG_REF = RECEIVE

RANGE_MODE = ONE_WAY

RANGE_MODULUS = 1.674852710000000E+02
RECEIVE_DELAY_3 = 0
RECEIVE_DELAY_3 = 0.000077

DATA_QUALITY = VALIDATED

META_STOP


DATA_START

COMMENT Timetag is time of signal arrival at PARTICIPANT_2.
, per TDM standard.
COMMENT Transmit frequency is spacecraft beacon a OWLT before receive time.
DOR = 2004-136T15:42:00.0000 -4.911896106591159E-03
DOR = 2004-136T16:02:00.0000 1.467382930436399E-02
TRANSMIT_FREQ_1 = 2004-136T14:42:00.0000 8.415123456E+09
DOR = 2004-136T15:42:00.0000 -4.911896106591159E-03
DOR_AMBIGUITY = 2004-136T15:42:00.0000 1.674852710000000E+02
DOR = 2004-136T16:02:00.0000 1.467382930436399E-02

DOR_AMBIGUITY = 2004-136T16:02:00.0000 1.710264580000000E+02
DATA_STOP


META_START

TIME_SYSTEM = UTC

START_TIME = 2004-136T15:52:00.0000
```

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```
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
0
RECEIVE_DELAY_3 = 0.000077

DATA_QUALITY = VALIDATED

META_STOP


DATA_START

COMMENT Timetag is time of signal arrival at PARTICIPANT_2.
, per TDM standard.
TRANSMIT_FREQ_1 = 2004-136T15:42:00.0000 8.415123000E+09
COMMENT Transmit frequency is reference for 2 station interferometer.
VLBI_DELAY = 2004-136T15:52:00.0000 -1.911896106591159E-03
TRANSMIT_FREQ_1
VLBI_DELAY_AMBIGUITY = 2004-136T15:4252:00.0000 8.415123000E+09
1.674852710000000E+02
DATA_STOP


META_START

TIME_SYSTEM = UTC
PARTICIPANT_1 = DSS-55

PARTICIPANT_2 = DSS-25
DATA_QUALITY = VALIDATED
META_STOP

DATA_START

DATA_QUALITY = VALIDATED
META_STOP

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

DATA_STOP
```

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

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```
CCSDS_TDM_VERS = 3.0
COMMENT This TDM example contains Delta-DOR data.
COMMENT Quasar CTD 20 also known as J023752.4+284808 (ICRF), 0234+285 (IERS)
CREATION_DATE = 2024-311T13:45:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2024-309T23:30:00.0000
STOP_TIME = 2024-310T00:30:00.0000
PARTICIPANT_1 = BEPI
PARTICIPANT_2 = DSS-14
PARTICIPANT_3 = DSS-35
MODE = SINGLE_DIFF
PATH_1 = 1,2
PATH_2.0 = 1,3
TRANSMIT_BAND = X
RECEIVE_BAND = X
TIMETAG_REF = RECEIVE
RANGE_MODE = ONE_WAY
RANGE_MODULUS = 0.000
RECEIVE_DELAY_2 = 0.000077
DATA_QUALITY = VALIDATED
OBS_COVARIANCE_OBS_1 = DOR, DOR_RATE
OBS_COVARIANCE_VALS_1 = 1 1, 2 2
META_STOP

DATA_START
COMMENT Timetag is time of signal arrival at PARTICIPANT 2.
COMMENT Transmit frequency is spacecraft beacon a OWLT before receive time.
TRANSMIT_FREQ_1 =  2024-309T23:42:00.0000 8.420429871353E+09
DOR =              2024-309T23:42:00.0000 -7.359501790580E-03
DOR_RATE =         2024-309T23:42:00.0000 -1.70478860E-06
DOR_AMBIGUITY =    2024-309T23:42:00.0000 200.063E-09
OBS_COVARIANCE_1 = 2024-309T23:42:00.0000 1.28924E-21 2.96458E-28
TRANSMIT_FREQ_1 =  2024-309T23:57:20.0000 8.420429871503E+09
DOR =              2024-309T23:57:20.0000 -8.896818889291E-03
DOR_RATE =         2024-309T23:57:20.0000 -1.71020441E-06
DOR_AMBIGUITY =    2024-309T23:57:20.0000 200.063E-09
OBS_COVARIANCE_1 = 2024-309T23:57:20.0000 1.29492E-21 7.94366E-29
DATA_STOP

META_START
TIME_SYSTEM = UTC
START_TIME = 2024-309T23:30:00.0000
STOP_TIME = 2024-310T00:30:00.0000
PARTICIPANT_1 = P 1622-253
PARTICIPANT_2 = DSS-14
PARTICIPANT_3 = DSS-35
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 = 0.000
RECEIVE_DELAY_2 = 0.000077
DATA_QUALITY = VALIDATED
OBS_COVARIANCE_OBS_1 = VLBI, VLBI_RATE
OBS_COVARIANCE_VALS_1 = 1 1, 2 2
META_STOP

DATA_START
COMMENT Timetag is time of signal arrival at PARTICIPANT 2.
COMMENT Transmit frequency is reference for 2-station interferometer.
TRANSMIT_FREQ_1 =      2024-309T23:49:50.0000 8.421127960000E+09
VLBI_DELAY =           2024-309T23:49:50.0000 -7.132084132088E-03
VLBI_DELAY_RATE =      2024-309T23:49:50.0000 -1.65405287E-06
OBS_COVARIANCE_1 =     2024-309T23:49:50.0000 1.28924E-21 2.09284E-29
DATA_STOP
```

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Figure A-12: TDM Example: Delta-DOR Observable, Rate and Variance

```
CCSDS_TDM_VERS = 3.0

COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
COMMENT StarTrek: one minute of launch angles from DSS-16

CREATION_DATE = 2005-157T18:25:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2004-216T07:44:00
STOP_TIME =  2004-216T07:45:00
PARTICIPANT_1 = DSS-16
PARTICIPANT_2 = yyyy-nnnA2005-999A
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = XSYE
CORRECTION_ANGLE_1 = -0.09
CORRECTION_ANGLE_2 = 0.18
CORRECTIONS_APPLIED = NO
META_STOP

DATA_START

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

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

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

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

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

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

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

DATA_STOP
```

Figure A-13: TDM Example: Angle Data Only

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```
CCSDS_TDM_VERS = 23.0

COMMENT TDM example created by NASA/JPL Navigation System Engineering

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

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-274T12:00:00
STOP_TIME =  2005-280T12:00:00
PARTICIPANT_1 = DSS-14
SYSTEM_CONFIG_1_START
ELEVATION_MAPPING = NIELL
SYSTEM_CONFIG_1_STOP
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
DATA_QUALITY = VALIDATED
META_STOP

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

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



META_START
COMMENT Line of verticalsight ionospheric calibration for, yyyy-nnnACTD 20
COMMENT Time tags are end time of 15 minute measurement interval
TIME_SYSTEM = UTC
START_TIME = 2005-280T21:45:00
STOP_TIME =  2005-281T00:00:00
PARTICIPANT_1 = DSS-14
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT Time tags are end time of 15 minute measurement interval
TIME_SYSTEM = UTC
START_TIME = 2005-280T21:45:00
STOP_TIME =  2005-281T00:00:00
PARTICIPANT_1 = DSS-14
PARTICIPANT_2 = CTD-20
MODE = SEQUENTIAL
PATH = 2,1
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
STEC = 2005-280T21:45:00  23.1
```

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

Figure A-14: TDM Example: Media Data Only

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```
CCSDS_TDM_VERS = 23.0

COMMENT TDM example created by NASA/JPL Navigation System Engineering

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

META_START
TIME_SYSTEM = UTC
START_TIME = 2005-274T12:00:00
STOP_TIME =  2005-280T12:00:00
PARTICIPANT_1 = DSS-14
PARTICIPANT_2 = CTD-20
MODE = SEQUENTIAL
PATH = 2,1
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
COMMENT Line of sight delays for CTD-20
TROPO_DRY = 2005-274T12:00:00  2.0526
TROPO_WET = 2005-274T12:00:00  0.1139
TROPO_DRY = 2005-275T12:00:00  2.0530
TROPO_WET = 2005-275T12:00:00  0.1126
TROPO_DRY = 2005-276T12:00:00  2.0533
TROPO_WET = 2005-276T12:00:00  0.1113
TROPO_DRY = 2005-277T12:00:00  2.0537
TROPO_WET = 2005-277T12:00:00  0.1099
TROPO_DRY = 2005-278T12:00:00  2.0540
TROPO_WET = 2005-278T12:00:00  0.1086
TROPO_DRY = 2005-279T12:00:00  2.0544
TROPO_WET = 2005-279T12:00:00  0.1074
TROPO_DRY = 2005-280T12:00:00  2.0547
TROPO_WET = 2005-280T12:00:00  0.1061
DATA_STOP

META_START
COMMENT Line of sight ionospheric calibration for CTD-20
COMMENT Time tags are end time of 15 minute measurement interval
TIME_SYSTEM = UTC
START_TIME = 2005-280T21:45:00
STOP_TIME =  2005-281T00:00:00
PARTICIPANT_1 = DSS-14
PARTICIPANT_2 = yyyyy-nnnACTD-20
MODE = SEQUENTIAL
PATH = 2,1
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 900
INTEGRATION_REF = END
DATA_QUALITY = VALIDATED
META_STOP

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

Figure A-15: TDM Example: Line-of-Sight Media Data

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```
CCSDS_TDM_VERS = 3.0
COMMENT TDM example created by 2005-999A Nav Team (NASA/JPL)
COMMENT JPL/DSN/Goldstone (DSS-10) weather for DOY 156, 2005
CREATION_DATE = 2005-156T06:15:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2005-156T00:03:00
STOP_TIME =  2005-156T06:03:00
PARTICIPANT_1 = DSS-10
DATA_QUALITY = VALIDATED
META_STOP

DATA_START

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

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

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

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

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

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

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

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

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

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

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

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

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

DATA_STOP
```

Figure A-16: TDM Example: Meteorological Data Only

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```
CCSDS_TDM_VERS = 23.0
COMMENT TDM example created by yyyyy-nnnA2005-999A Nav Team (NASA/JPL)
COMMENT The following are clock offsets, in seconds between the
COMMENT clocks at each DSN complex relative to UTC(NIST).  The offset
COMMENT is a mean of readings using several GPS space vehicles in
COMMENT common view.  Value is "station clock minus UTC”.
CREATION_DATE = 2005-161T15:45:00
ORIGINATOR = NASA


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

META_STOP

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

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

META_STOP

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

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

META_STOP

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

Figure A-17: TDM Example: Clock Bias/Drift Only

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```
CCSDS_TDM_VERS = 23.0
COMMENT All the angular data provided are free of any aberration effect.
CREATION_DATE = 2012-10-30T20:00
ORIGINATOR = ESA

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

META_START
TIME_SYSTEM = UTC
START_TIME = 2012-10-29T17:57:14.02
STOP_TIME = 2012-10-29T18:01:28.02
PARTICIPANT_1 = TFRM
PARTICIPANT_2 = TRACK NUMBER 003
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
REFERENCE_FRAME = EME2000
META_STOP
DATA_START
ANGLE_1 = 2012-10-29T17:57:14.02     335.1698333
ANGLE_2 = 2012-10-29T17:57:14.02     -17.7212861
MAG =     2012-10-29T17:57:14.02    11.8
ANGLE_1 = 2012-10-29T17:59:21.02     335.7062083
ANGLE_2 = 2012-10-29T17:59:21.02     -17.6950278
MAG =     2012-10-29T17:59:21.02    12.4
ANGLE_1 = 2012-10-29T18:01:28.02     336.2425833
ANGLE_2 = 2012-10-29T18:01:28.02     -17.6673694
MAG =     2012-10-29T18:01:28.02    13.1
DATA_STOP
```

Figure A-18: TDM Example: Ground Based Optical Tracking with Magnitude

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```
CCSDS_TDM_VERS = 23.0
COMMENT Test file
CREATION_DATE = 2011-05-12T00:00:00.000
ORIGINATOR = ESA
META_START
COMMENT
TIME_SYSTEM = UTC
PARTICIPANT_1 = CAMRA
PARTICIPANT_2 = CRYOSAT
MODE = SEQUENTIAL
PATH = 1,2,1
EPHEMERIS_NAMEODM_MSG_LINK_2 = 3203_2013-11-09T23-02-30
RANGE_UNITS = km
ANGLE_TYPE = AZEL
CORRECTION_RANGE =  -1.48
CORRECTIONS_APPLIED = NO
META_STOP
DATA_START
RANGE =         2011-05-11T10:26:33.2613    2808.2696
ANGLE_1 =       2011-05-11T10:26:33.2613     191.40208435
ANGLE_2 =       2011-05-11T10:26:33.2613      25.44166756
CARRIER_POWER = 2011-05-11T10:26:33.2613     -36.73723984
RCS =           2011-05-11T10:26:33.2613       2.984
RANGE =         2011-05-11T10:26:33.7008    2803.1731
ANGLE_1 =       2011-05-11T10:26:33.7008     191.43959045
ANGLE_2 =       2011-05-11T10:26:33.7008      25.51874924
CARRIER_POWER = 2011-05-11T10:26:33.7008     -35.88296509
RCS =           2011-05-11T10:26:33.7008       2.992
RANGE =         2011-05-11T10:26:33.9686    2799.8754
ANGLE_1 =       2011-05-11T10:26:33.9686     191.46458435
ANGLE_2 =       2011-05-11T10:26:33.9686      25.56875038
CARRIER_POWER = 2011-05-11T10:26:33.9686     -36.67897415
RCS =           2011-05-11T10:26:33.7008     2.986
DATA_STOP
```

Figure A-19: TDM Example: Ground Based Radar Tracking with RCS

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```
CCSDS_TDM_VERS=23.0
COMMENT TDM example created by yyyy-nnnA2005-999A Nav Team (NASA/JPL)
CREATION_DATE=2005-184T20:15:00
ORIGINATOR=NASA
MESSAGE_ID=DSN-2005-184-yyyynnnA-001
META_START
TIME_SYSTEM=UTC
START_TIME=2005-184T11:12:23
STOP_TIME=2005-184T11:12:32
PARTICIPANT_1=DSS-55
PARTICIPANT_2=yyyy-nnnA2005-999A
MODE=SEQUENTIAL
PATH=1,2,1
FREQ_OFFSET=0.0
INTERPOLATION = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP
DATA_START
TRANSMIT_PHASE_CT_1=2005-184T11:12:23       7175173383.615373
TRANSMIT_PHASE_CT_1=2005-184T11:12:24      14350346766.632946
TRANSMIT_PHASE_CT_1=2005-184T11:12:25      21525520150.052719
TRANSMIT_PHASE_CT_1=2005-184T11:12:26      28700693531.874692
TRANSMIT_PHASE_CT_1=2005-184T11:12:27      35875866917.098865
TRANSMIT_PHASE_CT_1=2005-184T11:12:28      43051040300.725238
TRANSMIT_PHASE_CT_1=2005-184T11:12:29      50226213683.753811
TRANSMIT_PHASE_CT_1=2005-184T11:12:30      57401387067.184584
TRANSMIT_PHASE_CT_1=2005-184T11:12:31      64576560451.017557
TRANSMIT_PHASE_CT_1=2005-184T11:12:32      71751733834.252730
DATA_STOP

META_START
TIME_SYSTEM=UTC
START_TIME=2005-184T13:59:27.27
STOP_TIME=2005-184T13:59:36.27
PARTICIPANT_1=DSS-55
PARTICIPANT_2=yyyy-nnnA2005-999A
MODE=SEQUENTIAL
PATH=1,2,1
FREQ_OFFSET=0.0
INTERPOLATION = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP
DATA_START

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

DATA_STOP
```

Figure A-20: TDM Example: Two-Way Phase Data for Doppler Calculation

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```
CCSDS_TDM_VERS = 23.0
COMMENT CREATED BY TTC PGM V33.0.2
CREATION_DATE = 2010-050T20:15:02.000
ORIGINATOR = NASA/JPL/DSN

META_START
COMMENT SEQUENTIAL RANGE
COMMENT RANGE IS ADJUSTED FOR CORRECTION_RANGE; MEASUREMENT MINUS CORRECTION_RANGE
COMMENT CORRECTION_RANGE INCLUDES STATION DELAY, Z-HEIGHT CORRECTION, AND S/C DELAY
COMMENT DOWNLINK CHANNEL NUMBER 4
TIME_SYSTEM = UTC
START_TIME = 2010-215T20:04:24.000
STOP_TIME = 2010-215T20:53:24.000
PARTICIPANT_1 = DSS-14
PARTICIPANT_2 = CAS
MODE = SEQUENTIAL
PATH = 1,2,1
TRANSMIT_BAND = X
RECEIVE_BAND = X
TURNAROUND_NUMERATOR = 880
TURNAROUND_DENOMINATOR = 749
TIMETAG_REF = RECEIVE
INTEGRATION_REF = START
RANGE_MODE = COHERENT
RANGE_MODULUS = 262144
RANGE_UNITS = RU
TRANSMIT_DELAY_1 = 2.1E-07
RECEIVE_DELAY_1 = 2.1E-07
DATA_QUALITY = VALIDATED
CORRECTION_RANGE = 4999.392714
CORRECTIONS_APPLIED = YES
META_STOP

DATA_START
RANGE  = 2010-215T20:04:24.000  65249.6771931631
PR_N0  = 2010-215T20:04:24.000  30.2351
RANGE  = 2010-215T20:11:24.000  52234.4753877508
PR_N0  = 2010-215T20:11:24.000  32.7846
RANGE  = 2010-215T20:18:24.000  68142.6393474573
PR_N0  = 2010-215T20:18:24.000  31.0379
RANGE  = 2010-215T20:25:24.000  113059.469322535
PR_N0  = 2010-215T20:25:24.000  33.0883
RANGE  = 2010-215T20:32:24.000  187471.102944516
PR_N0  = 2010-215T20:32:24.000  32.0965
RANGE  = 2010-215T20:39:24.000  29568.3320810896
PR_N0  = 2010-215T20:39:24.000  33.7465
RANGE  = 2010-215T20:46:24.000  163212.340789491
PR_N0  = 2010-215T20:46:24.000  31.0563
RANGE  = 2010-215T20:53:24.000  64457.0270879461
PR_N0  = 2010-215T20:53:24.000  30.0224
DATA_STOP
```

Figure A-21:– TDM Example: Two-Way Range Data with Ranging Power to Spectral Density

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```
CCSDS_TDM_VERS = 23.0
COMMENT CREATED BY JPL TTC PGM V33.0.2
CREATION_DATE = 2010-050T20:15:02.000
ORIGINATOR = NASA/JPL/DSN

META_START
COMMENT DOWNLINK CHANNEL NUMBER 4
TIME_SYSTEM = UTC
START_TIME = 2010-049T16:49:43.000
STOP_TIME = 2010-049T17:04:43.000
PARTICIPANT_1 = DSS-26
PARTICIPANT_2 = CAS
MODE = SEQUENTIAL
PATH = 1,2,1
TRANSMIT_BAND = X
RECEIVE_BAND = X
TURNAROUND_NUMERATOR = 880
TURNAROUND_DENOMINATOR = 749
TIMETAG_REF = RECEIVE
INTEGRATION_INTERVAL = 60.0
INTEGRATION_REF = MIDDLE
FREQ_OFFSET = 8427221784.667
RECEIVE_DELAY_1 = 0.00000556
DATA_QUALITY = VALIDATED
META_STOP

DATA_START
RECEIVE_FREQ_1 = 2010-049T16:49:43.000  60255.16982
RECEIVE_FREQ_1 = 2010-049T16:50:43.000  60271.18801
RECEIVE_FREQ_1 = 2010-049T16:51:43.000  60287.20579
RECEIVE_FREQ_1 = 2010-049T16:52:43.000  60303.22356
RECEIVE_FREQ_1 = 2010-049T16:53:43.000  60319.24150
RECEIVE_FREQ_1 = 2010-049T16:54:43.000  60335.25922
RECEIVE_FREQ_1 = 2010-049T16:55:43.000  60351.27720
RECEIVE_FREQ_1 = 2010-049T16:56:43.000  60368.00758
RECEIVE_FREQ_1 = 2010-049T16:57:43.000  60387.66759
RECEIVE_FREQ_1 = 2010-049T16:58:43.000  60407.64419
RECEIVE_FREQ_1 = 2010-049T16:59:43.000  60427.62086
RECEIVE_FREQ_1 = 2010-049T17:00:43.000  60447.59751
RECEIVE_FREQ_1 = 2010-049T17:01:43.000  60467.57420
RECEIVE_FREQ_1 = 2010-049T17:02:43.000  60487.55087
RECEIVE_FREQ_1 = 2010-049T17:03:43.000  60507.52741
RECEIVE_FREQ_1 = 2010-049T17:04:43.000  60527.50426
DATA_STOP
```

Figure A-22: TDM Example: Two-Way Received Frequency

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```
CCSDS_TDM_VERS = 3.0
COMMENT All angular data provided are free of aberration effects
CLASSIFICATION = UNCLASSIFIED
CREATION_DATE = 2012-10-30T20:00
ORIGINATOR = NASA
MESSAGE_ID = 2012-784

META_START
TRACK_ID = 20121002_1703035-0001
PREVIOUS_MESSAGE_ID = 2012-776
NEXT_MESSAGE_ID = 2012-797
DATA_TYPES = ANGLE_1, ANGLE_2
TDM_BASIS = OPERATIONAL
TDM_BASIS_ID = REQ236-2019SEN3S04
TIME_SYSTEM = UTC
START_TIME = 2012-10-29T17:46:39.02
STOP_TIME = 2012-10-29T17:50:53.02
PARTICIPANT_1 = SSN-211
PARTICIPANT_2 = NORAD-27715
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
ANGLE_UNITS = deg
REFERENCE_FRAME = EME2000
SYSTEM_CONFIG_1_START
OBS_UNCERTAINTY = MAG, 0.01
SYSTEM_CONFIG_1_STOP
DATA_QUALITY = VERIFIED V, INVALID I
OBS_COVARIANCE_OBS = ANGLE_1, ANGLE_2
OBS_COVARIANCE_VALS = 1 1, 1 2, 2 2
META_STOP

DATA_START
ANGLE_1 = 2012-10-29T17:46:39.02 332.2298750 I
ANGLE_2 = 2012-10-29T17:46:39.02 -16.3028389 I
OBS_COVARIANCE = 2012-10-29T17:46:39.02 0.0031 0.0063 0.0042
MAG = 2012-10-29T17:46:39.02 12.1
SYSTEM_STATUS_1_START
APERTURE_FILTER = 2012-10-29T17:46:39.02 NONE
SYSTEM_STATUS_1_STOP
ANGLE_1 = 2012-10-29T17:48:46.02 332.7485833 V
ANGLE_2 = 2012-10-29T17:48:46.02 -16.1876917 V
OBS_COVARIANCE = 2012-10-29T17:46:39.02 0.0029 0.0060 0.0044
MAG = 2012-10-29T17:48:46.02 12.3
ANGLE_1 = 2012-10-29T17:50:53.02 333.2668750 V
ANGLE_2 = 2012-10-29T17:50:53.02 -16.0716806 V
OBS_COVARIANCE = 2012-10-29T17:46:39.02 0.0030 0.0068 0.0040
MAG = 2012-10-29T17:50:53.02 12.3
SYSTEM_STATUS_1_START
APERTURE_FILTER = 2012-10-29T17:50:53.02 NONE
SYSTEM_STATUS_1_STOP
DATA_STOP
```

Figure A-23: TDM Example: Ground Based Optical Tracking with Magnitude

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```xml
<?xml version="1.0" encoding="UTF-8"?>
<tdm xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
     xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml/ndmxml-1.0-
master.xsd"
     id="CCSDS_TDM_VERS" version="3.0">

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

Figure A-24: TDM Example: XML Format

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```
CCSDS_TDM_VERS = 23.0
CREATION_DATE = 2019-10-21T22:17:21
ORIGINATOR = GSOC

META_START
TRACK_ID = S_191021_18593902_3
TIME_SYSTEM = UTC
START_TIME = 2019-10-21T18:59:38.869008
STOP_TIME = 2019-10-21T19:00:39.023021
PARTICIPANT_1 = SMARTNET-01-A-SUTH
PARTICIPANT_2 = UNKNOWN
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
REFERENCE_FRAME = EME2000
CORRECTION_RECEIVE = -0.145
CORRECTION_ABERRATION_YEARLY_ANGLE_1 = 0.0056932
CORRECTION_ABERRATION_YEARLY_ANGLE_2 = 0.0063524
CORRECTIONS_APPLIED = YES
META_STOP

DATA_START
ANGLE_1 = 2019-10-21T18:59:38.869008 333.64830529
ANGLE_2 = 2019-10-21T18:59:38.869008   5.23646136
MAG =   2019-10-21T18:59:38.869008  10.66
ANGLE_1 = 2019-10-21T19:00:24.405696 333.83841725
ANGLE_2 = 2019-10-21T19:00:24.405696   5.23617947
MAG =   2019-10-21T19:00:24.405696  10.77
ANGLE_1 = 2019-10-21T19:00:39.023021 333.89958508
ANGLE_2 = 2019-10-21T19:00:39.023021   5.23604417
MAG =   2019-10-21T19:00:39.023021  10.80
DATA_STOP
```

Figure A-25: TDM Example: Use of 'TRACK_ID'

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```
<?xml version="1.0" encoding="UTF-8"?>
<tdm xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
     id="CCSDS_TDM_VERS" version="23.0">

    <header>
        <CREATION_DATE>2019-344T12:50:06.940</CREATION_DATE>
        <ORIGINATOR>GSFC</ORIGINATOR>
    </header>
    <body>
        &lt;segment&gt;
            <metadata>
                <TIME_SYSTEM>UTC</TIME_SYSTEM>
                <START_TIME>2019-081T14:39:02.0</START_TIME>
                <STOP_TIME>2019-081T14:39:07.0</STOP_TIME>
                <PARTICIPANT_1>STGT central antenna</PARTICIPANT_1>
                <PARTICIPANT_2>TDRS 10</PARTICIPANT_2>
                <PARTICIPANT_3>1874</PARTICIPANT_3>
                <PARTICIPANT_4>TDRS 10</PARTICIPANT_4>
                <PARTICIPANT_5>STGT central antenna</PARTICIPANT_5>
                <PARTICIPANT_6>STGT central antenna</PARTICIPANT_6>
                <PARTICIPANT_7>TDRS 10</PARTICIPANT_7>
                <PARTICIPANT_8>STGT central antenna</PARTICIPANT_8>
                <PARTICIPANT_9>TDRS 10</PARTICIPANT_9>
                <MODE>SEQUENTIALRELAY</MODE>
                <PATH_1>1,2,3,4,5</PATH_1>
                <PATH_2>6,7</PATH_2>
                <PATH_3>8,9</PATH_3>
                <TRANSMIT_BAND>S</TRANSMIT_BAND>
                <RECEIVE_BAND>S</RECEIVE_BAND>
                <TURNAROUND_NUMERATOR>240</TURNAROUND_NUMERATOR>
                <TURNAROUND_DENOMINATOR>221</TURNAROUND_DENOMINATOR>
                <TIMETAG_REF>RECEIVE</TIMETAG_REF>
                <INTEGRATION_INTERVAL>1.0</INTEGRATION_INTERVAL>
                <INTEGRATION_REF>END</INTEGRATION_REF>
                <DOPPLER_COUNTFREQ_OFFSET>2269728000.00</FREQ_OFFSET>

<RECEIVE_PHASE_CT_BIAS>2.4E8</DOPPLER_COUNTRECEIVE_PHASE_CT_BIAS>

<DOPPLER_COUNTRECEIVE_PHASE_CT_SCALE>1000</DOPPLER_COUNTRECEIVE_PHASE_CT_SCAL
E>
                <DOPPLER_COUNT_ROLLOVER>NO</DOPPLER_COUNT_ROLLOVER>
                <TRANSMIT_DELAY_3>0.20967</TRANSMIT_DELAY_3>
                <DATA_QUALITY>RAW</DATA_QUALITY>
            </metadata>
            <data>
                <observation>
                    <EPOCH>2019-081T14:39:02.0</EPOCH>

<DOPPLER_COUNTRECEIVE_PHASE_CT>0</DOPPLER_COUNTRECEIVE_PHASE_CT>
                    <TRANSMIT_FREQ_2>2090041200.00</TRANSMIT_FREQ>
                    <TRANSMIT_FREQ_6>23090041200.00</TRANSMIT_FREQ>
                    <TRANSMIT_FREQ_8>23090041200.00</TRANSMIT_FREQ>
                    <ANGLE_1_5>121.346</ANGLE_1_5>
                    <ANGLE_2_5>47.243</ANGLE_2_5>
                    <ANGLE_1_4>64.656</ANGLE_1_4>
                    <ANGLE_2_4>31.321</ANGLE_2_4>
                </observation>
                <observation>
                    <EPOCH>2019-081T14:39:03.0</EPOCH>

<DOPPLER_COUNTRECEIVE_PHASE_CT>0</DOPPLER_COUNTRECEIVE_PHASE_CT>
                    <ANGLE_1_5>121.764</ANGLE_1_5>
                    <ANGLE_2_5>46.537</ANGLE_2_5>
                    <ANGLE_1_4>65.766</ANGLE_1_4>
                    <ANGLE_2_4>31.981</ANGLE_2_4>
                </observation>
                <observation>
                    <EPOCH>2019-081T14:39:04.0</EPOCH>
                    <DOPPLER_COUNT>0</DOPPLER_COUNT>
```

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```
                </observation>
                <observation>
                    <EPOCH>2019-081T14:39:05.0</EPOCH>
                    <DOPPLER_COUNT>0</DOPPLER_COUNT>
                </observation>
                <observation>
                    <EPOCH>2019-081T14:39:06.0</EPOCH>
                    <DOPPLER_COUNT>0</DOPPLER_COUNT>
                </observation>
                <observation>
                    <EPOCH>2019-081T14:39:07.0</EPOCH>
                    <DOPPLER_COUNT>0</DOPPLER_COUNT>
                </observation>
             </data>
        &lt;/segment&gt;
    </body>
</tdm>
```

Figure A-26: TDM Example: Use of ~~Doppler Counts~~RECEIVE_PHASE_CT and Relay Mode

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```
CREATION_DATE = 2022-075T11:42:28.000
CCSDS_TDM_VERS = 3.0
ORIGINATOR = JPL

META_START
TRACK_ID = 2007-0075_TxFreq-0001
TRACK_ID_SEGMENT = 1
TIME_SYSTEM = UTC
START_TIME = 2007-075T11:50:43.000
PARTICIPANT_1 = DSS-26
MODE = SEQUENTIAL
TRANSMIT_BAND = X
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2007-075T11:50:43.000 7175510611.700343
DATA_STOP

META_START
TRACK_ID = 2007-0075_TxFreq-0001
TRACK_ID_SEGMENT = 2
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2007-075T11:50:48.000 7175510611.700343
DATA_STOP

META_START
TRACK_ID = 2007-0075_Range-0001
TIME_SYSTEM = UTC
START_TIME = 2007-075T11:50:48.000
PARTICIPANT_1 = DSS-26
PARTICIPANT_2 = XENOSAT
MODE = SEQUENTIAL
PATH = 1,2,1
INTEGRATION_REF = START
RANGE_MODE = COHERENT
RANGE_MODULUS = 2.0e+26
RANGE_UNITS = km
META_STOP

DATA_START
RANGE = 2007-075T11:50:48.000 80452.7025
DATA_STOP

META_START
TRACK_ID = 2007-0075_TxFreq-0001
TRACK_ID_SEGMENT = 3
STOP_TIME = 2007-075T11:50:53.000
META_STOP

DATA_START
TRANSMIT_FREQ_1 = 2007-075T11:50:53.000 7175510611.700343
DATA_STOP

META_START
TRACK_ID = 2007-0075_Range-0001
TRACK_ID_SEGMENT = 2
META_STOP

DATA_START
RANGE = 2007-075T11:50:53.000 80492.4025
DATA_STOP
```

Figure A-27: TDM Example: Use of TRACK_ID in Multiple Segments

```
CCSDS_TDM_VERS = 3.0
CREATION_DATE = 2019-10-21T22:17:21
ORIGINATOR = GSOC

META_START
TRACK_ID = S_191021_18593902_3
TIME_SYSTEM = UTC
START_TIME = 2019-10-21T18:59:38.869008
STOP_TIME = 2019-10-21T19:00:39.023021
PARTICIPANT_1 = SMARTNET-01-A-SUTH
PARTICIPANT_2 = UNKNOWN
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
REFERENCE_FRAME = EME2000
CORRECTIONS_APPLIED_1 = ABER_Y1, ABER_Y2
CORRECTIONS_ORDER_1 = ABER_D1, ABER_D2, ABER_Y1, ABER_Y2
META_STOP

DATA_START
ANGLE_1 = 2019-10-21T18:59:38.869008 333.64830529
ANGLE_2 = 2019-10-21T18:59:38.869008 5.23646136
MAG = 2019-10-21T18:59:38.869008 10.66
CORRECTIONS_1 = 2019-10-21T18:59:38.869008 7.54052969e-05, 2.64771106e-07,
0.00289477, 0.00239135
ANGLE_1 = 2019-10-21T19:00:24.405696 333.83841725
ANGLE_2 = 2019-10-21T19:00:24.405696 5.23617947
MAG = 2019-10-21T19:00:24.405696 10.77
CORRECTIONS_1 = 2019-10-21T19:00:24.405696 7.54052359e-05, 2.64768829e-07,
0.00290977, 0.00239045]
ANGLE_1 = 2019-10-21T19:00:39.023021 333.89958508
ANGLE_2 = 2019-10-21T19:00:39.023021 5.23604417
MAG = 2019-10-21T19:00:39.023021 10.80
CORRECTIONS_1 = 2019-10-21T19:00:39.023021 7.54052183e-05, 2.64749185e-07,
0.00291458, 0.00239016
DATA_STOP
```

Figure A-28: TDM Example: Use of Dynamically Updated Data Correction Values

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```
CCSDS_TDM_VERS = 3.0
CREATION_DATE = 2018-06-11T22:17:21
ORIGINATOR = ISAS/JAXA

META_START
COMMENT ABER_Y1 is short for CORRECTION_ABERRATION_YEARLY ANGLE_1
COMMENT ABER_Y2 is short for CORRECTION_ABERRATION_YEARLY ANGLE_2
COMMENT ABER_D1 is short for CORRECTION_ABERRATION_DIURNAL ANGLE_1
COMMENT ABER_D2 is short for CORRECTION_ABERRATION_DIURNAL ANGLE_2

TIME_SYSTEM = UTC
START_TIME = 2018-06-11T07:20:12.8
STOP_TIME =  2018-06-11T21:00:12.3
PARTICIPANT_1 = Hayabusa-2
PARTICIPANT_2 = 162173-RYUGU
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = RADEC
REFERENCE_FRAME = ICRF
OBS_COVARIANCE_OBS_1 = ANGLE_1, ANGLE_2

SYSTEM_CONFIG_1_START
CORRECTIONS_NOT_APPLIED = ABER_Y1_1, ABER_Y2_1, ABER_D1_1, ABER_D2_1
FRONT_END_ID = CAMERA-1
ASTROMETRY_CATALOGUE = TYCHO-2
SYSTEM_CONFIG_1_STOP

META_STOP

DATA_START

ANGLE_1 = 2018-06-11T07:20:12.8 197.2036
ANGLE_2 = 2018-06-11T07:20:12.8 -20.4855
OBS_COVARIANCE_1 = 2018-06-11T07:20:12.8 3.293e-6 3.085e-7 2.89e-6

ANGLE_1 = 2018-06-11T21:00:12.3 197.4060
ANGLE_2 = 2018-06-11T21:00:12.3 -20.4506
OBS_COVARIANCE_1 = 2018-06-11T21:00:12.3 1.925e-6 1.804e-7 1.69e-6

DATA_STOP
```

Figure A-29: TDM Example: Optical Observations

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```
CCSDS_TDM_VERS = 3.0
CREATION_DATE = 2023-09-10T17:59:31.962
ORIGINATOR = GMV

META_START
TIME_SYSTEM = UTC
START_TIME = 2023-09-03T23:43:56.501
STOP_TIME = 2023-09-03T23:43:58.501
PARTICIPANT_1 = AA29
PARTICIPANT_2 = AA4J
PARTICIPANT_3 = 45807
MODE = SINGLE_DIFF
PATH_1 = 3,2
PATH_2 = 3,1
INTEGRATION_INTERVAL = 0.001
FREQ_OFFSET = 0.0
CORRECTIONS_APPLIED_1 = TT_1
CORRECTIONS_APPLIED_2 = TT_2
CORRECTIONS_ORDER_1 = TT_1
CORRECTIONS_ORDER_2 = TT_2
CORRECTION_TIMETAG_OBS_1 = TDOA, FDOA
CORRECTION_TIMETAG_OBS_2 = TDOA, FDOA
META_STOP

DATA_START
TRANSMIT_FREQ_3 = 2023-09-03T23:43:56.000 2.35e06
TDOA = 2023-09-03T23:43:56.501 0.003817889787938507
FDOA = 2023-09-03T23:43:56.501 -0.00487
CORRECTIONS_1 = 2023-09-03T23:43:56.501 -0.000156475
CORRECTIONS_2 = 2023-09-03T23:43:56.501 0.000353522
TDOA = 2023-09-03T23:43:57.501 0.003817582487936025
FDOA = 2023-09-03T23:43:57.501 -0.00493
CORRECTIONS_1 = 2023-09-03T23:43:57.501 -0.000135489
CORRECTIONS_2 = 2023-09-03T23:43:57.501 0.000353215
TDOA = 2023-09-03T23:43:58.501 0.003817314967393283
FDOA = 2023-09-03T23:43:58.501 -0.00478
CORRECTIONS_1 = 2023-09-03T23:43:58.501 -0.000155658
CORRECTIONS_2 = 2023-09-03T23:43:58.501 0.000353648
DATA_STOP
```

Figure A-30: TDM Example: Single Difference Mode

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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) spacecraft-to-spacecraft crosslinks;

b) ground-based transponder;

c) ‘DORIS’;

d) arrayed downlink;

e) orbital debris example;

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

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~~ANNEX F~~ANNEX H

INFORMATIVE REFERENCES

(INFORMATIVE)

NOTE – Normative references are provided in 1.5.

[H1] *Standard Frequencies and Time Signals*. Volume 7 in *Recommendations and Reports of the CCIR: XVIIth Plenary Assembly*. Geneva: CCIR, 1990.

[H2] *Radio Metric and Orbit Data*. Issue 1-S. Recommendation for Space Data System Standards (Historical), CCSDS 501.0-B-1-S. Washington, D.C.: CCSDS, (January 1987) November 2003.

[H3] Catherine L. Thornton and James S. Border. *Radiometric Tracking Techniques for Deep-Space Navigation*. JPL Deep-Space Communications and Navigation Series. Joseph H. Yuen, Series Editor. Hoboken, N.J.: Wiley, 2003.

[H4] Theodore D. Moyer. *Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation*. JPL Deep-Space Communications and Navigation Series. Joseph H. Yuen, Series Editor. Hoboken, N.J.: Wiley, 2003.

[H5] *Organization and Processes for the Consultative Committee for Space Data Systems*. Issue 4. CCSDS Record (Yellow Book), CCSDS A02.1-Y-4. Washington, D.C.: CCSDS, April 2014.

[H6] *CCSDS Implementation Conformance Statements*. Issue 1. CCSDS Record (Yellow Book), CCSDS A20.1-Y-1. Washington, D.C.: CCSDS, April 2014.

[H7] *Navigation Data—Definitions and Conventions*. Issue 4. Report Concerning Space Data System Standards (Green Book), CCSDS 500.0-G-4. Washington, D.C.: CCSDS, November 2019.

[H8] *Cross Support Transfer Service – Tracking Data Service*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 922.2-B-2. Washington D.C.: CCSDS, February 2023.

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ANNEX I

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

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

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

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

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

Another thought on ICDs is that it might be feasible for participating agencies to have a generic baseline ICD ('standard service provider ICD') that specifies mission/spacecraft-independent entities on the interface, for example, 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:

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Item	**Section**
1. Definition of accuracy requirements pertaining to any particular TDM.	1.2.3
2. Method of exchanging TDMs (e.g., post-processed SFTP, real-time stream, etc.).	1.2.4, 3.1.7
3. Whether the KVN or XML format of the TDM will be exchanged.	2.2.3
4. Frequency of exchange and special types of exchange.	2.2.6
5. TDM file naming conventions.	3.1.6
6. Specific TDM version number(s) that will be exchanged.	3.2.5
7. Antenna geometry, if not accommodated by built-in values of 'ANGLE_TYPE' keyword.	table 3-3
8. The list of eligible names that is used for PARTICIPANT_n keywords.	table 3-3, 3.3.1.10
9. Definitions of 'RAW', 'VALIDATED', and 'DEGRADED' as they apply to data quality for a particular exchange (DATA_QUALITY keyword).	table 3-3
10. The range of frequencies associated with each value of the 'TRANSMIT_BAND' and 'RECEIVE_BAND' metadata keywords.	table 3-3
11. If more than nine participants are necessary, special arrangements are necessary for XML TDMs.	5.3.6.5
12. The methods used to extrapolate the measurements to other antennas when all the data in a TDM Segment is media related or weather related and the observable may be relative to a reference location within the tracking complex.	3.3.2.8.2
13. Complete description of the station locations and characteristics.	3.4.13
14. Whether TRANSMIT_DELAY and RECEIVE_DELAY are processed by the producer or the consumer of the tracking data.	3.4.15.2
15. Special sort orders that may be required by the producer or recipient.	3.4.10, 3.5.4.1
16. Spin correction arrangements (who will do the correction, the agency providing the tracking or the agency that operates the spacecraft).	3.4.15.5
17. Correction algorithms that are more complex than a simple scalar value.	3.4.15.6
18. Standard corrections that will (or will not) be applied to the data (e.g., tropospheric, meteorological, media, transponder, etc.), miscellaneous corrections.	3.4.15.7
19. Definition of the range unit, if it is not kilometers or seconds.	3.5.2.6, table 3-3
20. Equation for calculation of four-way Doppler shift, if applicable.	3.5.2.7.4

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Item	Section
21. 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, 3.5.2.8, table 3-3
22. Whether or not it is necessary to distinguish the separate Slant Total Electron Count contributions between ionospheric and interplanetary STEC.	3.5.7.1
23. Elevation mapping function for the tropospheric data.	3.5.7.2, 3.5.7.3
24. Recommended polynomial interpolations for tropospheric data.	3.5.7.2, 3.5.7.3
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.	4.3.5
26. Information which must appear in comments for any given TDM exchange.	4.5.4
27. Description of any ancillary data not already included in the Tracking Data Record definition.	4.5.5
28. Interagency Information Technology (IT) security requirements in TDMs.	annex C
29. Time systems not shown in annex B.	annex B
30. Reference frames not shown in annex B.	annex B
31. Whether the mean range rate for 2W and/or 3W Doppler is based on the one-way light time or two-way light time.	3.5.2.3
32. Whether the RANGE observable for 2W and/or 3W range is based on the round trip light time, or half the round trip light time.	3.5.2.6
33. The usage and composition of a tracking data identifier specified by 'TRACK_ID' keyword.	table 3-3

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ANNEX J

CHANGES VERSUS PREVIOUS VERSION

(INFORMATIVE)

The present section gives the main changes in CCSDS 503.0-P-2.0.3 (TDM 3.0) versus the prior CCSDS 503.0-B-2 (TDM 2.0).

J1 DOCUMENT STRUCTURE AND ORGANIZATION

This version updates the document to version 3.0 from the prior version 2.0. Annexes have been reorganized in consonance with other CCSDS navigation standard documents, with the addition of Annex J (this annex) specifically for documenting version changes. Detailed technical material has been moved into separate informative annexes for better reference. The keyword status indicators have been changed from 'Mandatory/Optional' to 'Mandatory/Optional/Conditional' to align with CCSDS Implementation Conformance Specification and other navigation related standards.

J2 SECURITY AND CLASSIFICATION

Version 3.0 introduces the CLASSIFICATION header keyword to support security marking (UNCLASSIFIED, CONFIDENTIAL, SECRET, TOP SECRET), along with support for handling special designators like CUI (Controlled Unclassified Information).

J3 MESSAGE REFERENCING AND LINKING

A comprehensive message referencing framework has been implemented with the addition of TRACK_ID_SEGMENT, PREVIOUS_MESSAGE_ID, and NEXT_MESSAGE_ID. The TRACK_ID can now be referenced across segments to enable efficient real-time data transmission. New message linking keywords (ADM_MSG_LINK, CDM_MSG_LINK, ODM_MSG_LINK, PRM_MSG_LINK, RDM_MSG_LINK) enable cross-referencing to related navigation messages from other CCSDS standards.

J4 NEW TRACKING METADATA

This version adds the TDM_BASIS keyword to specify data modality (OPERATIONAL, TEST, SIMULATED, PLAYBACK) and TDM_BASIS_ID for tracking session identification. A TIMETAG_UNCERTAINTY keyword has been introduced for time uncertainty estimation.

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J5 SYSTEM CONFIGURATION AND STATUS

The system documentation capabilities have been significantly expanded with an extensive configuration parameters framework, by implementing a SYSTEM_CONFIG framework for comprehensive system configuration and SYSTEM_STATUS for dynamic system status reporting. Configuration and status parameters have been incorporated to maximize the use of the tracking data observables.

J6 NEW AND UPDATED DATA TYPES

This version introduces several new data types, including ANGLE_n_RATE keywords for angular rate measurements, DOR_RATE and VLBI_DELAY_RATE, and ambiguity keywords (DOR_AMBIGUITY, VLBI_DELAY_AMBIGUITY). TDOA and FDOA keywords for time/frequency difference of arrival measurements have been added. Optical measurement support has been enhanced with ASTROMETRIC_STAR_COUNT, PHOTOMETRIC_STAR_COUNT, PHOTOMETRIC_SNR, and FRAME_LIMITING_BRIGHTNESS. The DOPPLER_COUNT keyword has been removed in favor of enhanced RECEIVE_PHASE_CT functionality.

J7 MEASUREMENT QUALITY AND CORRECTIONS

DATA_QUALITY has been enhanced to support symbol-based quality indicators with the ability to mark individual observations within the Data Section. The correction framework has been improved with the dynamic CORRECTIONS_n keyword, along with standardized correction abbreviations (ANG1, RNG, etc.). CORRECTIONS_ORDER_n was added for associating corrections with specific observables.

J8 TRACKING MODES

Version 3.0 adds the RELAY mode for complex relay tracking scenarios with PATH_1, PATH_2, PATH_3 specifications. The number of PARTICIPANTs has been expanded from 5 to 9 in XML format and is now unbounded for the KVN format, enabling support for advanced space relay communications and complex tracking geometries.

J9 COVARIANCE FRAMEWORK

A comprehensive measurement uncertainty representation has been implemented through OBS_COVARIANCE keywords, providing a structured framework for representing measurement uncertainties and their relationships.

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J10 XML SUPPORT

XML schema locations have been updated. XML examples have been added to demonstrate proper implementation.

J11 EXAMPLES AND TECHNICAL DOCUMENTATION

Ten new example TDMs demonstrating new capabilities have been added, along with enhanced technical explanations in annexes. Detailed descriptions of measurement relationships and calculations provide additional guidance for implementers.

J12 REFERENCE DOCUMENTATION

References have been updated to current standards.

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ANNEX GANNEX A

RATIONALE FOR TRACKING DATA MESSAGES

(INFORMATIVE)

G1A1 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, that is, regardless of pre-existing conditions within the CCSDS or its Member Agencies.

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

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

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G2A1 PRIMARY REQUIREMENTS ACCEPTED FOR TRACKING DATA MESSAGES

Table G-1: Primary Requirements

ID	Requirement	Rationale	Trace
G-1-1	Data must be provided in digital form.	Facilitates computerized processing of TDMs.	3.1.1
G-1-2	The object being tracked must be clearly identified and unambiguous.[1]	Ensures proper processing of the tracking data in orbit determination.	3.3
G-1-3	All primary resources used in the tracking session must be clearly identified and unambiguous.	Ensures proper processing of the tracking data in orbit determination.	3.3
G-1-4	Time measurements (time stamps, timetags, or epochs) must be provided in a commonly used, clearly specified system.	The CCSDS objective of promoting interoperability is not met if time measurements are produced in esoteric or proprietary time systems.	3.3, annex B
G-1-5	The time bounds of the tracking data must be unambiguously specified.	The accuracy of orbit determination is highly dependent on accurately knowing the time at which measurements are taken.	3.3, 3.4
G-1-6	Tracking Data Messages must have means of being uniquely identified and clearly annotated.	If discussions of tracking file content are necessary, parties can ensure they are speaking of the same data.	3.2
G-1-7	The Tracking Data Message format shall be independent of the equipment that was used to perform the tracking.	The producer of a Tracking Data Message has local-network knowledge that may not be available to the user of the data.	3.4
G-1-8	Every tracking instrument shall have a defined reference location that could be defined in the ODM format, possibly extended to define spacecraft body-fixed axis. This reference location should not depend on the observing geometry.	The accuracy of orbit determination is highly dependent on accurately knowing the location of the tracking instruments.	3.4
G-1-9	The timetag of the tracking data shall always be unambiguously specified with respect to the measurement point or instrument reference point.	The accuracy of orbit determination is highly dependent on accurately knowing the time at which measurements are taken.	3.4

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[1] Forthcoming SANA registries may support this requirement.

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ID	Requirement	Rationale	Trace
G-1-10	The observable shall be corrected with the best estimate of all known tracking instrument calibrations, such as pass-specific path delay calibrations between the reference point and the tracking equipment, if applicable.	The producer of a Tracking Data Message has knowledge of his or her network that may not be available to the user of the data.	3.4
G-1-11	The observable shall be converted to an equipment-independent quantity; for example, frequencies shall be reported at the 'sky level' (i.e., actual transmitted/received frequencies).	The producer of a Tracking Data Message has knowledge of the details of the equipment in his or her network that may not be available to the user of the data.	3.4
G-1-12	The data transfer mechanism shall not place constraints on the tracking data content.	The tracking data measurements are taken prior to transfer from originator to user, so data content should not be affected.	3.1.7
G-1-13	The standard must provide for clear specification of units of measure.	Without clear specification of units of measure, mistakes can be made that involve the unit system in effect (e.g., Metric or Imperial) and/or orders of magnitude (e.g., meters or kilometers).	4.4, table 3-5

Table G-2: Heritage Requirements

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

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Table G-3: Desirable Characteristics

ID	Requirement	Rationale	Trace
G-3-1	The standard should apply to non-traditional objects, such as landers, rovers, balloons, spacecraft-spacecraft tracking data exchange, etc.	There are many different types of spacecraft that are tracked by space agencies. The broader the applicability of the standard, the more useful it will be.	3.3, 3.4
G-3-2	The standard should be extensible with no disruption to existing users/uses.	Space agencies and operators upgrade systems and processes on schedules that make sense for their organizations. In practice, some organizations will be early adopters but others will opt to wait until performance of a new version of the TDM has been proven in other operations facilities.	3.2
G-3-3	Keywords, values, and terminology in the TDM should be the same as those in the other CCSDS standards, where applicable.	Helps to ensure similar 'look and feel' across the various CCSDS flight dynamics standards.	3.2, 3.3, 3.5, 4
G-3-4	The standard shall not preclude an XML implementation.	The CCSDS Management Council (CMC) has indicated that the Navigation Working Group must produce standards that can be represented in XML.	3, 5
G-3-5	Other corrections applied to the data, such as media corrections, should be agreed upon by the service-providing and the customer Agencies via an ICD.	The user of the data must know what types of corrections and calibrations have been applied to the data in order to process it correctly.	3.4

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ANNEX HANNEX A

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ADM	Attitude Data Message
ASCII	American Standard Code for Information Interchange
AU	Astronomical Unit
AZEL	Azimuth-Elevation
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee for Space Data Systems
CMC	CCSDS Management Council
Delta-DOR	Delta Differential One-Way Ranging
DOR	Differential One-Way Ranging
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
ICS	Implementation Conformance Statement
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
K	Kelvin
KVN	Keyword = Value Notation
LIDAR	Light Detection and Ranging
MOIMS	Mission Operations and Information Management Services
N/A or n/a	Not Applicable / Not Available
NDM	Navigation Data Message

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ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
P_c/N_0	Carrier Power to Noise Spectral Density ratio
P_r/N_0	Ranging Power to Noise Spectral Density ratio
PRARE	Precise Range and Range Rate Equipment
RADEC	Right Ascension-Declination
RCS	Radar Cross Section
RINEX	Receiver Independent Exchange
RL	Requirements List
RTLT	Round-Trip Light Time
RU	Range Units
SANA	Space Assigned Numbers Authority
SCLK	Spacecraft Clock
SFTP	Secure File Transfer Protocol
SI	Système International (SI Units)
SLR	Satellite Laser Ranging
STEC	Slant Total Electron Count
TDM	Tracking Data Message
TDR	Tracking Data Record
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

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~~ANNEX I~~ANNEX K

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.

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1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n					
a) either constant uplink frequency or measurements are not directly influenced by uplink frequency					
	Range Data	Doppler Data			
Data Keywords [unit]	RANGE [km, s, or RU]	DOPPLER_INSTANTANEOUS [km/s]	RECEIVE_FREQ_n [Hz] TRANSMIT_FREQ_n [Hz] RECEIVE_PHASE_CT_n TRANSMIT_PHASE_CT_n	DOPPLER_INTEGRATED [km/s]	~~DOPPLER_COUNT~~
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM RANGE_MODE RANGE_MODULUS RANGE_UNITS INTEGRATION_REF	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM TRANSMIT_FREQ_n * RECEIVE_FREQ *	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM RECEIVE_PHASE_CT_SCALE RECEIVE_PHASE_CT_BIAS	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM INTEGRATION_INTERVAL INTEGRATION_REF TRANSMIT_FREQ_n * RECEIVE_FREQ *	~~META_START~~ ~~META_STOP~~ ~~MODE~~ ~~PARTICIPANT_n~~ ~~PATH~~ ~~TIME_SYSTEM~~ ~~DOPPLER_COUNT_SCALE~~ ~~DOPPLER_COUNT_BIAS~~ ~~DOPPLER_COUNT_ROLLOVER~~
Situationally Required Metadata	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_RANGE TIMETAG_REF PR_N0	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_DOPPLER TIMETAG_REF CARRIER_POWER PC_N0	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_~~TRANSMIT~~DOPPLER ~~CORRECTION_RECEIVE~~ TIMETAG_REF INTEGRATION_INTERVAL INTEGRATION_REF FREQ_OFFSET CARRIER_POWER PC_N0	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_DOPPLER TIMETAG_REF CARRIER_POWER PC_N0	~~TRANSMIT_DELAY_n~~ ~~RECEIVE_DELAY_n~~ ~~TURNAROUND_NUMERATOR~~ ~~TURNAROUND_DENOMINATOR~~ ~~DATA_QUALITY~~ ~~CORRECTIONS_APPLIED~~ ~~CORRECTION_DOPPLER~~ ~~TIMETAG_REF~~
Optional Metadata	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK TRANSMIT_BAND RECEIVE_BAND INTEGRATION_INTERVAL	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK TRANSMIT_BAND RECEIVE_BAND	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK TRANSMIT_BAND RECEIVE_BAND	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK TRANSMIT_BAND RECEIVE_BAND	~~COMMENT~~ ~~TRACK_ID~~ ~~DATA_TYPES~~ ~~START_TIME~~ ~~STOP_TIME~~ ~~EPHEMERIS_NAME~~ ~~TRANSMIT_BAND~~ ~~RECEIVE_BAND~~ ~~CARRIER_POWER~~ ~~PC_N0~~

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

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1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n				
b) changing uplink, described in TRANSMIT_FREQ either in tabular form or with the help of TRANSMIT_FREQ_RATE				
	Range Data		Doppler Data	
Data Keywords [unit]	RANGE [km, s, or RU]		RECEIVE_FREQ_n [Hz] TRANSMIT_FREQ_n [Hz] TRANSMIT_FREQ_RATE_n [Hz/s] RECEIVE_PHASE_CT_n TRANSMIT_PHASE_CT_n [n/a]	DOPPLER_COUNT
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM RANGE_MODE RANGE_MODULUS RANGE_UNITS INTEGRATION_REF		META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM DOPPLER_COUNT_SCALE DOPPLER_COUNT_BIAS DOPPLER_COUNT_ROLLOVER
Situationally Required Metadata	TRANSMIT_DELAY_n , RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_RANGE TIMETAG_REF PR_N0 TRANSMIT_FREQ_n [Hz] TRANSMIT_FREQ_RATE_n [Hz/s] or TRANSMIT_PHASE_CT_n INTERPOLATION INTERPOLATION_DEGREE		TRANSMIT_DELAY_n , RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_TRANSMITDOPPLER CORRECTION_RECEIVE INTEGRATION_INTERVAL INTEGRATION_REF TIMETAG_REF FREQ_OFFSET INTERPOLATION , INTERPOLATION_DEGREE CARRIER_POWER , PC_N0 RECEIVE_PHASE_CT_SCALE RECEIVE_PHASE_CT_BIAS	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_DOPPLER TIMETAG_REF
Optional Metadata	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME EPHEMERIS_NAME ODM_MSG_LINK TRANSMIT_BAND RECEIVE_BAND		COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME EPHEMERIS_NAME ODM_MSG_LINK TRANSMIT_BAND RECEIVE_BAND	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME EPHEMERIS_NAME TRANSMIT_BAND RECEIVE_BAND CARRIER_POWER

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	INTEGRATION_INTERVAL		RECEIVE_PHASE_CT_Rollover CARRIER_POWER PC_N0	PC_N0

1. MODE = SEQUENTIAL, described within PATH and PARTICIPANT_n

c) Frequency independent

	Angle Data	Media Related Data	Optical Data	
Data Keywords [unit]	ANGLE_1 ANGLE_2 [deg]	STEC [TECU]	MAG [n/a] PHOTOMETRIC_SNR [n/a] FRAME_LIMITING_BRIGHTNESS [Stellar magnitude] RCS [m**2]	
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM ANGLE_TYPE	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM	META_START META_STOP MODE PARTICIPANT_n PATH TIME_SYSTEM	
Situationally Required Metadata	DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_ANGLE_1 CORRECTION_ANGLE_2 REFERENCE_FRAME CORRECTION_ABERRATION_YEARLY_ANGLE_1 CORRECTION_ABERRATION_YEARLY_ANGLE_2 CORRECTION_ABERRATION_DIURNAL_ANGLE_1 CORRECTION_ABERRATION_DIURNAL_ANGLE_2	DATA_QUALITY	TRACK_ID REFERENCE_FRAME DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_MAG CORRECTION_RCS CORRECTION_ABERRATION_YEARLY CORRECTION_ABERRATION_DIURNAL TDM_BASIS_ID	
Optional Metadata	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME EPHEMERIS_NAME ODM_MSG_LINK RECEIVE_BAND	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME EPHEMERIS_NAMEODM_MSG_LINK	COMMENT DATA_TYPES START_TIME STOP_TIME EPHEMERISODM_MSG_LINK SYSTEM_CONFIG EXPOSURE_TIME ABSORPTION_NORMALIZATION_APPLIED NORMALIZATION_DISTANCE NORMALIZATION_PHASE_ANGLE ASTROMETRY_CATALOG_NAME PHOTOMETRY_CATALOG_NAME RCS_MIN RCS_MAX	

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2. MODE = SINGLE_DIFF, described within PATH_1, PATH_2 and PARTICIPANT_n either constant or changing uplink (as above)					
	Range Data	Doppler Data	Differenced and VLBI Data		
Data Keywords [unit]	RANGE [km, s, or RU]	RECEIVE_FREQ_n [Hz] TRANSMIT_FREQ_n [Hz] TRANSMIT_FREQ_RATE_n [Hz/s] RECEIVE_PHASE_CT_n TRANSMIT_PHASE_CT_n [n/a]	RECEIVE_FREQ~~_n~~ [Hz] ~~TRANSMIT_FREQ_n~~FDOA [Hz] ~~TRANSMIT_FREQ_RATE_n [Hz/s]~~ ~~RECEIVE_PHASE_CT_n~~ ~~TRANSMIT_PHASE_CT_n~~	DOR [s] DOR_RATE [s/s] DOR_AMBIGUITY [s] TDOA [s]	VLBI_DELAY [s] VLBI_DELAY_RATE [s/s] VLBI_DELAY_AMBIGUITY [s]
Required Metadata	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND RANGE_MODE RANGE_MODULUS RANGE_UNITS INTEGRATION_REF	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND FREQ_OFFSET INTERPOLATION INTERPOLATION_DEGREE	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND FREQ_OFFSET ~~INTERPOLATION~~ ~~INTERPOLATION_DEGREE~~	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND RANGE_MODE RANGE_MODULUS TIMETAG_REF	META_START META_STOP MODE PARTICIPANT_n PATH_1 PATH_2 TIME_SYSTEM TRANSMIT_BAND RECEIVE_BAND RANGE_MODE RANGE_MODULUS TIMETAG_REF
Situationally Required Metadata	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_RANGE TIMETAG_REF PR_N0	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_TIMETAG_k INTEGRATION_INTERVAL INTEGRATION_REF CARRIER_POWER PC_N0	TRANSMIT_DELAY_n RECEIVE_DELAY_n TURNAROUND_NUMERATOR TURNAROUND_DENOMINATOR DATA_QUALITY CORRECTIONS_APPLIED CORRECTION_~~TRANSMIT~~TIMETAG_k INTEGRATION_INTERVAL ~~CORRECTION_RECEIVE~~ ~~INTEGRATION_INTERVAL~~ INTEGRATION_REF ~~FREQ_OFFSET~~ CARRIER_POWER PC_N0	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY	TRANSMIT_DELAY_n RECEIVE_DELAY_n DATA_QUALITY
Optional Metadata	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK INTEGRATION_INTERVAL	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ODM_MSG_LINK	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK RANGE_UNITS CORRECTION_TIMETAG_k	COMMENT TRACK_ID DATA_TYPES START_TIME STOP_TIME ~~EPHEMERIS_NAME~~ ODM_MSG_LINK RANGE_UNITS CORRECTION_TIMETAG_k

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