The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

DELTA-DOR RAW DATA EXCHANGE FORMAT

DRAFT RECOMMENDED STANDARD

CCSDS 506.1-P-1.1

PINK BOOK
July 2026

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STATEMENT OF INTENT

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FOREWORD

This document is a Recommended Standard for Delta-DOR Raw Data Exchange Format and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). It has been developed via consensus of the Delta-DOR Working Group (WG) of the CCSDS Systems Engineering Area (SEA).

The Delta-DOR Raw Data Exchange Format described in this Recommended Standard is the baseline concept for Delta-DOR data interchange applications involving cross-support between Agencies of the CCSDS.

This Recommended Standard establishes a common framework and provides a common basis for the format of Delta-DOR data exchange between space agencies. It allows implementing organizations within each Agency to proceed coherently with the development of compatible derived standards for ground systems that are within their cognizance.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CCSDS shall not be held responsible for identifying any or all such patent rights.

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- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
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- Taiwan Space Agency (TASA)/Chinese Taipei.
- Naval Center for Space Technology (NCST)/USA.
- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- SSC Space/Sweden.
- United States Geological Survey (USGS)/USA.

PREFACE

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

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

Recipients of this draft are invited to submit, with their comments, notifications of any relevant patent rights of which they are aware and to provide supporting documentation.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 506.1-B-1	Delta-DOR Raw Data Exchange Format, Recommended Standard, Issue 1	June 2013	Original issue, superseded
CCSDS 506.1-P-1.0	Delta-DOR Raw Data Exchange Format, Proposed Draft Recommended Standard, Issue 1.0	October 2024	Provides updated recommendations for improved performance for future mission requirements and extended use of the RDEF format.
CCSDS 506.1-P-1.1	Delta-DOR Raw Data Exchange Format, Draft Recommended Standard, Issue 1.1	July 2026	Includes PN DOR; updates Product File Line and Header, adds Annex F, other minor updates

NOTE – When a change bar appears next to the title of a table, section, or annex, it indicates that the entire entity has been revised.

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1 INTRODUCTION

1.1 PURPOSE

Delta-DOR (Delta Differential One-Way Ranging) is a Very Long Baseline Interferometry (VLBI) technique that can be used in conjunction with Doppler and ranging data to improve spacecraft navigation by more efficiently determining spacecraft angular position in the plane of sky. It involves the use of multiple ground stations, possibly belonging to different agencies, for simultaneous acquisition of either spacecraft or quasar signals (see reference [D2]).

This Delta-DOR Raw Data Exchange Format (RDEF) Recommended Standard specifies a standard format for use in exchanging Delta-DOR raw data among space agencies. Delta-DOR raw data exchange is required every time the data correlation involves at least one participating station not belonging to the agency responsible for the correlation. This document includes specifications on the parameter fields that the data format has been designed to meet. For exchanges where these specifications do not capture the needs of the participating agencies, another mechanism may be selected.

1.2 SCOPE AND APPLICABILITY

This Recommended Standard contains the specification for a Delta-DOR RDEF designed for applications involving Delta-DOR raw data interchange among space agencies.

The format here specified can be equally used for collecting and exchanging more general open loop raw data.

This data format is suited to interagency exchanges that involve automated interaction. The attributes of the RDEF make it primarily suitable for use in computer-to-computer communication.

The characteristics of the data recording (sampling rate and quantization) are defined within the RDEF headers. There is no definition of accuracy for raw Delta-DOR data, and hence no assessment of accuracy is provided in the exchange format. An assessment of accuracy for Delta-DOR measurements is outside the scope of this Recommended Standard.

This Recommended Standard defines only the data format and content, but not the means for its transmission. The method of transmitting the data among partners is beyond the scope of this document. Data transmission could be based on a CCSDS data transfer protocol, file-based transfer protocol such as SFTP, stream-oriented media, or other secure transmission mechanism. In general, the transmission mechanism shall not place constraints on the technical data content of an RDEF.

1.3 CONVENTIONS AND DEFINITIONS

1.3.1 NOMENCLATURE

1.3.1.1 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.

1.3.1.2 Informative Text

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

– Overview;

– Background;

– Rationale;

– Discussion.

1.3.2 UNIT NOTATION

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) (base or derived), or units outside the SI that are accepted for use with it (see reference [2]), such as:

Hz: Hertz

s: second

1.3.3 BIT AND BYTE ORDERING

In this document, the following convention is used to identify each bit in an 8-bit byte. The first bit in the byte (i.e., the most right justified when drawing figures and tables) is defined to be 'Bit 1', the following bit is defined to be 'Bit 2', and so on up to 'Bit 8'.

Byte ordering also follows the convention of starting with Byte 1 (i.e., the most right justified when drawing figures and tables) and increasing to the left.

1.4 COMMON TERMINOLOGY

Part of the standardization process involves the agreement on common interagency terminology and definitions that apply to interagency Delta-DOR. The following conventions apply throughout this Recommended Standard:

baseline: The vector joining two tracking stations.

channel: A slice of the frequency spectrum containing a spacecraft or quasar signal.

raw data: Time-ordered samples of received radio signal voltage.

sample: Instantaneous measurement of a radio frequency signal voltage.

scan: An observation of a radio source, with typical duration of a few minutes.

session: The time period of the Delta-DOR measurement including several scans.

meteo data: Atmospheric data, consisting of pressure, temperature, and relative humidity.

1.5 DOCUMENT STRUCTURE

Section 2 provides a general overview of the Delta-DOR technique and introduces the need of the raw data exchange.

Section 3 describes the basic structure and contents of the CCSDS-recommended RDEF for Delta-DOR.

Section 4 provides a description of the RDEF Observation File.

Section 5 provides details on the RDEF Product File.

Section 6 describes the RDEF file naming conventions.

Annex A lists the parameters for which conventions need to be specified.

Annex B discusses security aspects for the RDEF.

Annex C is a list of abbreviations and acronyms applicable to the document.

Annex D provides a list of informative references.

Annex E provides an example of a RDEF Observation File.

Annex F provides some ALIAS examples at various agencies.

1.6 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] *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.

[2] “The International System of Units (SI).” Bureau International des Poids et Mesures (BIPM). <http://www.bipm.org/en/si>

[3] *IEEE Standard for Floating-Point Arithmetic*. 3rd ed. IEEE Std. 754-2019. New York: IEEE, 2019.

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

[5] Radio Frequency and Modulation Systems – Part 1 – Earth Stations and Spacecraft. CCSDS 401.0-B-32 Blue Book, Issue 32, Washington D.C., October 2021.

[6] SANA registry – Delta-DOR Quasar identifiers (https://sanaregistry.org/r/Delta-DOR_Quasar_identifiers)

[7] SANA registry – Delta-DOR Apertures (https://sanaregistry.org/r/Delta-DOR_Apertures)

[8] SANA registry – Delta-DOR Spacecraft (https://sanaregistry.org/r/Delta-DOR_Spacecraft)

[9] SANA registry – Delta-DOR Organizations (https://sanaregistry.org/r/Delta-DOR_Organizations)

[10] SANA registry – Delta-DOR PNDOR seeds (https://sanaregistry.org/r/Delta-DOR_PNDOR_Seeds)

[11] SANA registry – Service Sites and Apertures (https://sanaregistry.org/r/service_sites_apertures)

[12] SANA registry – Spacecraft (https://sanaregistry.org/r/spacecraft)

[13] SANA registry – Organizations (https://sanaregistry.org/r/organizations)

NOTE – Informative references are provided in Annex D.

2 OVERVIEW

2.1 GENERAL

This section provides a high-level overview of the Delta-DOR technique. More details on the technique can be found in references [D2] and [D12]. In particular, reference [D2] provides a detailed description of the Delta-DOR technique, including guidelines for DOR tone spectra, guidelines for selecting reference sources, applicable foundation equations, and a discussion of error sources and measurement accuracy that are not germane to the data exchange recommendation presented in this document.

2.2 DELTA-DOR TECHNIQUE

Very long baseline interferometry (VLBI) is a technique that allows determination of angular position for distant radio sources by measuring the geometric time delay between received radio signals at two geographically separated stations. The observed time delay is a function of the known baseline vector joining the two radio antennas and the direction to the radio source.

An application of VLBI is spacecraft navigation in space missions where delay measurements of a spacecraft radio signal are compared against similar delay measurements of angularly nearby quasar radio signals. In the case where the spacecraft measurements are obtained from the phases of tones emitted from the spacecraft, first detected separately at each station, and then differenced, this application of VLBI is known as Delta Differential One-Way Ranging ('Delta-DOR' or 'ΔDOR') (see figure 2-1). Even though data acquisition and processing are not identical for the spacecraft and quasar, both types of measurements can be interpreted as time delay measurements, and they have similar information content and similar sensitivity to sources of error (see reference [D2]). The data produced in such a measurement session are complementary to Doppler and ranging data.

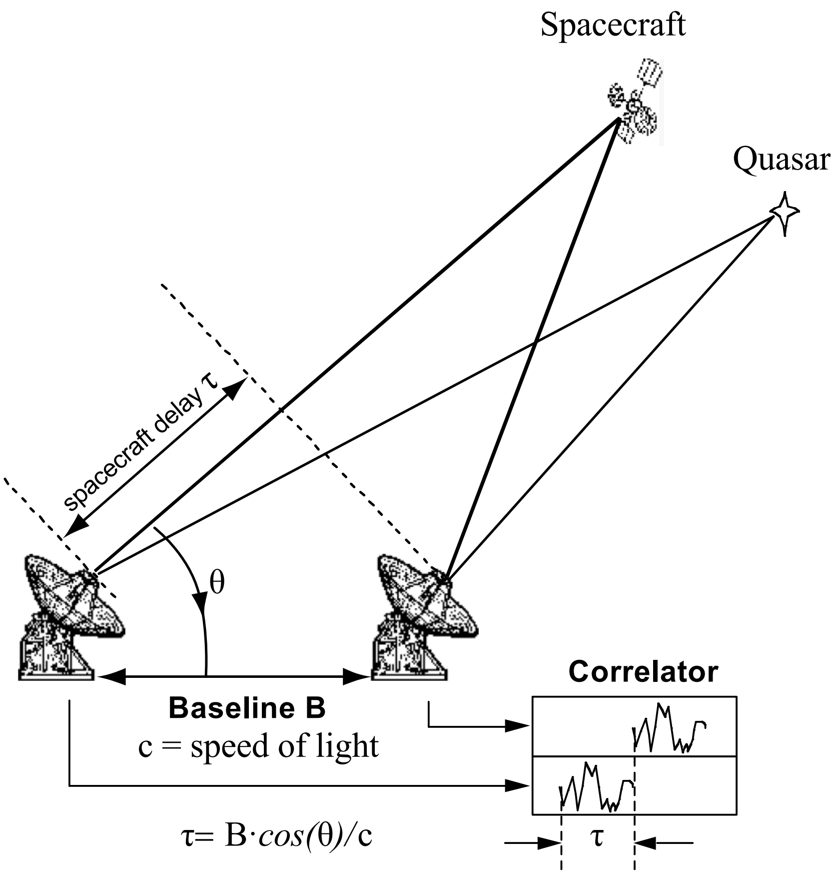

Figure 2-1 Delta-DOR Observation Geometry

To enable a Delta-DOR measurement, a spacecraft must emit several tones or other signal components spanning at least a few MHz. The characteristics of the tones are selected based on the requirements for phase ambiguity resolution, measurement accuracy, efficient use of spacecraft signal power, efficient use of ground tracking resources, and the frequency allocation for space research.

The Delta-DOR technique requires that the same quasar and spacecraft be tracked essentially simultaneously during the same tracking pass, at two distinct radio antennas. Normally, a Delta-DOR pass consists of three or more scans of data recording, each of a few minutes duration. A scan consists of pointing the antennas to one radio source and recording the signal. The antennas must slew to another radio source for the next scan, and so on. The observing sequence is spacecraft-quasar-spacecraft, quasar-spacecraft-quasar, or a longer sequence of alternating observations, depending on the characteristics of the radio sources and the objectives of the measurement session. A minimum of three scans is required to eliminate clock-epoch and clock-rate offsets and then measure spacecraft angular position. Normally a three-scan sequence is repeated several times. Once collected, the received signals are brought to a common site and correlated. A Delta-DOR observable is generated from a differential one-way range measurement made between the spacecraft and the two ground antennas, and by a measurement of the difference in time of arrival of the quasar signal at the same two stations. The observed quantity in a Delta-DOR observation is time delay for each radio source.

For a spacecraft, the one-way range is determined for a single station by extracting the phases of two or more signals emitted by the spacecraft. The DOR tones are generated by modulating a sine wave or square wave onto the downlink carrier at S-band, X-band, or Ka-band. The waveform of a signal can be pure (spectrum of pure tones) or modulated (spectrum resembling that of a natural radio source). DOR observables are formed by subtracting the one-way range measurements generated at the two stations. The station differencing eliminates the effect of the spacecraft clock offset, but DOR measurements are biased by ground station clock offsets and instrumental delays.

For measuring the quasar, each station is configured to acquire data from it in frequency channels centred on the spacecraft tone frequencies. This receiver configuration choice ensures that the spacecraft-quasar differencing eliminates the effects of ground station clock offsets and instrumental delays. By selecting a quasar that is close in an angular sense to the spacecraft, and by observing the quasar at nearly the same time as the spacecraft, the effects of errors in the modelled station locations, Earth orientation, and transmission media delays are diminished.

In navigation processing, the delay or DOR observable is modelled for each scan of each radio source. The measured observable depends on both geometric factors and on delays introduced by transmission media. Meteo data are provided from each tracking site so that, possibly in conjunction with other data such as Global Navigation Sattelite System (GNSS) measurements, corrections can be computed to account for tropospheric and ionospheric path delays. The modelled or 'computed' observable is based on geometric parameters and available calibrations for tropospheric and ionospheric delays. Residuals are formed by subtracting the computed observables from the measured time delay values. The 'Delta' between spacecraft and quasar observations is generated internal to the navigation processing by subtracting residual values of quasar observations from residual values of spacecraft observations.

Because each Delta-DOR measurement requires the use of two antennas, and navigation accuracy is improved by baseline diversity, this technique is highly conducive to interagency cooperation. Measurements from two baselines are required to determine both components of angular position, with orthogonal baselines providing the best two-dimensional coverage. The use of mixed baselines (e.g., assets from different agencies) leads to additional pairs of angularly separated baselines and enhanced geometric coverage for missions throughout the ecliptic plane. Stations from different agencies can be used as Delta-DOR data collectors for navigation purposes, assuming that the infrastructure has been laid to facilitate such cooperation. The use of Delta-DOR has been very beneficial for numerous NASA, ESA, and JAXA missions, beginning with Voyager in 1979, and has become a standard part of many mission navigation plans. CCSDS standardization will help expand the use of the technique by allowing interagency cross support.

2.3 RATIONALE FOR RAW DATA INTERCHANGE

When performing a Delta-DOR measurement involving two (or more) agencies, raw Delta-DOR data must be exchanged at least between one of the agencies that has acquired the data and the agency that runs the correlation process and provides the results. The need of the raw data exchange intrinsically comes with the characteristics of the measurement that, being an interferometric technique, calls for the correlation of at least two data streams simultaneously acquired.

Raw Delta-DOR data are not the only data being exchanged during an interagency Delta-DOR session. Other data (such as tracking data messages, including meteo data, and orbit ephemeris messages) must be exchanged among agencies. Such data are objects of other CCSDS standards (see references [D10] and [D11]) and are not discussed in the present Recommended Standard. The transfer of information other than Delta-DOR raw data is discussed in the Delta-DOR Operations Magenta Book (reference [D12]) and will not be included here.

2.4 CONVENTIONS FOR IDENTIFIERS

This Recommended Standard makes use of identifiers found in various SANA registries [6] [7] [8] [9] [10] . These identifiers are described as they are introduced throughout this document and are collected in Annex A. A description of each of these registries is additionally given in Annex B. New entries (e.g., in case of new missions, apertures, agencies) must be registered in the appropriate SANA registry and conform to the requirements for these identifiers (e.g., length, format). A few examples are given in annex F.

3 RAW DATA EXCHANGE FORMAT BASIC STRUCTURE AND CONTENT

3.1 OVERVIEW

Delta-DOR RDEF is realized with two types of files: an *Observation File* made of a sequence of ASCII text lines and a *Product File* made of a sequence of binary data records. Both files are needed to properly perform the correlation.

The Observation File contains information about the Delta-DOR measurement session.

The Product File contains data collected during the Delta-DOR measurement session.

3.2 DELTA-DOR FILES

3.2.1 OBSERVATION FILE

There shall be one Observation File for each tracking station and for each measurement session. The Observation File shall be made of a sequence of ASCII text lines (reference [1]).

3.2.2 PRODUCT FILE

3.2.2.1 The content of the Product File shall consist of time-ordered records each containing two basic types of data structure:

– A *Header* part;

– A *Data* part.

3.2.2.2 A Product File shall contain data for a single tracking station.

3.2.2.3 A Product File shall contain data for a single Delta-DOR scan (therefore either spacecraft or quasar data).

3.2.2.4 A Product File shall contain data for a single frequency channel.

4 OBSERVATION FILE STRUCTURE AND CONTENT

4.1 GENERAL

The Observation File contains parameters that are needed to describe the data recording session and to support data correlation.

4.1.1 The Observation File shall contain:

a) a single Observation Header Section, followed by

b) one or more Scan Sections, followed by

c) an Ending Section.

NOTE – The organization of the Observation File is shown in figure 4-1.

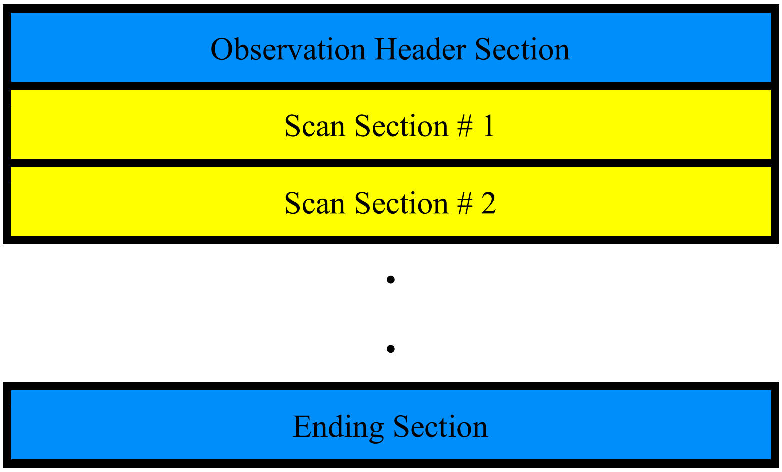

Figure 4-1: General Structure of the RDEF Observation File

4.1.2 Each Section of the Observation File shall consist of data represented in ASCII text lines.

4.1.3 Each line shall:

a) be NOT blank;

b) contain only printable ASCII characters and spaces (control characters, such as TAB, shall not be used);

c) be up to 120 characters long (excluding the termination character);

d) begin with a character that identifies the line type;

e) start with the character '#' if it is a comment line (permitted in all specified Sections);

f) use one or more 'space' characters to separate individual items;

g) be terminated by a single Line Feed (LF) or Carriage Return (CR), a CR/LF pair, or an LF/CR pair.

4.1.4 Each Section shall end with a line starting with character ‘Z’, except for the Ending Section.

4.2 CONTENT OF THE OBSERVATION HEADER SECTION

4.2.1 The Observation Header Section shall consist of as many lines as are needed.

4.2.2 The Observation Header Section shall contain a version line that starts with the character ‘V’ and is structured as follows:

V VERSION = <version>

where <version> is the integer version identifier.

4.2.3 The version number shall match the version of the applicable RDEF Blue book (‘2’ in this case) and shall be synchronised with the version number given in the Product File.

4.2.4 The Observation Header Section shall contain a single receiving aperture line that starts with the character ‘R’ and is structured as follows:

R APERTURE = <aperture>

where <aperture> is the aperture alias from [7], containing four alphanumeric characters.

4.2.5 The Observation Header Section shall contain a single transmitting aperture line for two-way data and shall omit it for one-way data. The line shall start with the character ‘T’ and be structured as follows:

T APERTURE = <aperture>

where <aperture> is the aperture alias from [7], containing four alphanumeric characters.

4.2.6 The PN DOR line shall start with character ‘P’. To improve readability, the PN DOR line shall be preceded by a comment line providing labels for the PN DOR line. If the data does not contain any spread spectrum DOR signals, the PN DOR line and its preceding comment line shall be omitted.

4.2.7 The structure of the PN DOR line (see Annex E for examples) shall be as follows:

```
P <pn_id> <pn_coh_flag> <roll_off> <chip_value> <first_seed> <second
seed> <first_poly> <second_poly>
```

NOTE – The parameters are defined in table **4-1**.

Table 4-1: Description of the PN DOR Line

Item Name	Item Description	Format	Units/ Precision/ Range	Fixed field position
PN_ID	Identifies the PN configuration with a sequentially assigned number, starting from 1.	3-digit integer	No units, range 001-999	3-5
PN_COH_FLAG	Identifies whether the PN chip	1 ASCII character	No units,	10

Item Name	Item Description	Format	Units/ Precision/ Range	Fixed field position
	rate is coherent with the tone value.		'T' for True, 'F' for False	
ROLL_OFF	Specifies the roll-off factor of the PN signal.	Up to 3 decimal places		23-27
CHIP_VALUE	Specifies the chip value of the PN signal. If PN_COH_FLAG='T' the CHIP_VALUE field can be expressed as a fraction or decimal multiplier *Example 1: 8/19* *Example 2: 0.421052631* If PN_COH_FLAG='F', the CHIP_VALUE field is expressed in chips per second. *Example: 7800000.000*	A fraction of two integer numbers or a decimal number	No units if PN_COH_FLAG ='T' Hz (decimal notation with no more than 16 significant digits) if PN_COH_FLAG ='F'	32-47
FIRST_SEED	Specifies the seed used in Register A. Left-most bit corresponds to stage number 1 in A1.1 of rec. 2.5.7.B [5]	Up to 15 ASCII characters ('0' & '1') First_seed field in [10]	No units	50-64
SECOND_SEED	Specifies the seed used in Register B. Left-most bit corresponds to stage number 1 in A1.1 of rec. 2.5.7.B [5]	Up to 15 ASCII characters ('0' & '1') Second_seed field in [10]	No units	67-81
FIRST_POLY	Specifies the 1st polynomial used for PN code generation (Register A). *Examples:* *10000000011011 corresponds to* $1+x^{9}+x^{10}+x^{12}+x^{13}$ *1000000000000011 corresponds to* $1+x^{14}+x^{15}$	Up to 16 ASCII characters ('0' & '1') Polynomials defined in [5] shall be used	No units	84-99
SECOND_POLY	Specifies the 2nd polynomial used for PN code generation (Register B). *Example: Same as above*	Up to 16 ASCII characters ('0' & '1') Polynomials defined in [5] shall be used	No units	102-117

4.3 CONTENT OF SCAN SECTION

The Scan Section provides the list of Product File(s) associated with the scan.

4.3.1 A Scan Section shall contain a single Scan line followed by one or more Product File lines.

4.3.2 To improve readability, the Scan Section shall contain comment lines providing labels for the Scan and Product File lines (see Annex E).

4.3.3 The Scan line shall start with character ‘S’ and have the following structure, with parameters defined in table **4-2**:

```
S <scan_num> <src_id> <start_time> <stop_time> <ra> <dec> <tfreq>
```

Table 4-2: Description of the Scan Line

Item Name	Item Description	Format	Units/Precision/Range	Fixed field position
SCAN_NUM	Identifies the scan number, in a progressive order. This is a sequentially assigned number, starting from 1.	3-digit integer	No units, range 001-999.	3-5
SRC_ID	Specifies the source, SC ID (mission alias from [8]) or Quasar ID (B1950 name, common name or ID number format from [6]).	Up to 16 ASCII characters	No units, up to 16 characters for quasar, 4 characters for spacecraft.	13-28
START_TIME	Specifies the nominal start time for the scan.	YYYY-DDDThh:mm:ss	UTC year, day of the year, hour/minute/second, precision=1 s, range is unlimited. Time format as per reference [4], ASCII time code B.	31-47
STOP_TIME	Specifies the nominal stop time for the scan.	YYYY-DDDThh:mm:ss	UTC year, day of the year, hour/minute/second, precision=1 s, range is unlimited. Time format as per reference [4], ASCII time code B.	50-66
RA	Specifies the Right Ascension of the source. Source position is referred to true equator and equinox of date and it is corrected for aberration.	Decimal notation	Degrees, range 0 to 360, decimal notation with no more than 16 significant digits. This field may be filled with number 999, meaning that no Right Ascension is provided.	69-84
DEC	Specifies the Declination of the source. Source position is referred to true equator and equinox of date and it is corrected for aberration.	Decimal notation	Degrees, range -90 to +90, decimal notation with no more than 16 significant digits. This field may be filled with number 999, meaning that no Declination is provided.	87-102
TFREQ	Specifies the Transmitted	Decimal notation	Hz, decimal notation with	105-120

Item Name	Item Description	Format	Units/Precision/Range	Fixed field position
	Frequency if the source is a Spacecraft; if not, TFREQ= 0.		no more than 16 significant digits.	

4.3.4 There shall be a Product File line for each frequency channel.

4.3.5 The Product File line shall start with character ‘D’ and have the following structure, with parameters defined in table 4-3:

```
D <datafile> <coh_flag> <tone_value> <harmonic> <pn_id>
```

Table 4-3: Description of the Product File Line

Item Name	Item Description	Format	Units/ Precision/ Range	Fixed field position
DATAFILE	Specifies the name of a Product File recording.	37 ASCII characters, as specified in 6.2	No units	3-39
COH_FLAG	Identifies whether or not the tone is coherent with the carrier.	1 ASCII character	No units, ‘T’ for True, ‘F’ for False	42
TONE_VALUE	Specifies the DOR tone position with respect to the carrier. If COH_FLAG=’T’ the TONE_VALUE field can be expressed as a fraction or decimal multiplier of the carrier; *Example 1: 1/440* *Example 2: 0.0027777777* If COHERENCE_FLAG=’F’ the TONE_VALUE field is expressed in Hz. *Example: 375000.0*	A fraction of two integer numbers or a decimal number	No units if COH_FLAG=’T’ Hz (decimal notation with no more than 16 significant digits) if COH_FLAG=’F’	52-67
HARMONIC	Specifies the harmonic number. Product of HARMONIC and TONE_VALUE yields tone frequency.	Integer	No units	70-73
PN_ID	Link to the applicable PN_ID configuration in the Observation Header. Field must be left empty for non-PNDOR channels.	3 digit integer	No units, range 001-999	80-82

4.4 CONTENT OF THE ENDING SECTION

4.4.1 The Ending Section shall contain an end line, optionally preceded by one or more log lines.

4.4.2 Each log line shall begin with the character ‘F’ and may contain information on how to retrieve receiver messages, data, and log.

4.4.3 The end line shall begin with the ‘E’ character and have the following format:

```
E *=END=*
```

NOTE – A sample Observation File is shown in annex E.

5 PRODUCT FILE STRUCTURE AND CONTENT

5.1 GENERAL

5.1.1 The Product File shall consist of several *Records*, each one containing exactly one second of data and the information required to correlate it.

5.1.2 Each Product File Record shall consist of data represented in binary format. It shall be made of two Sections, as shown in Figure 5-1:

a) The *Header* Section (see 5.2);

b) The *Data* Section (see 5.3).

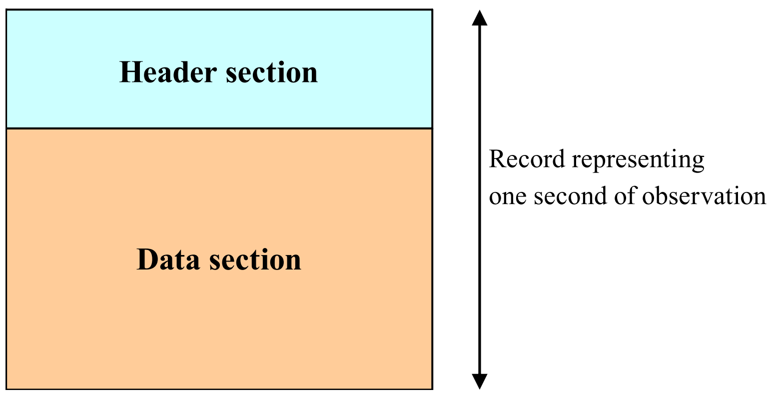

Figure 5-1: General Structure of a Product File Record

5.1.3 Each Product File shall contain data for one scan, one channel, and one aperture (i.e., for a typical 2-station Delta-DOR sequence with 3 scans and 4 channels there will be 24 Product Files).

5.1.4 The length of the Header Section is fixed (see figure 5-2).

5.1.5 The length of the Data Section is variable and shall be determined by the sample rate and sample size of the recorded data. The length of the Data Section shall be derivable from the information written in the Header Section.

5.1.6 The byte order of all integer and floating point values occupying more than one byte contained in the Product File shall be written as Little Endian, with an atomic element size of 8 bits.

NOTE – The structure of a Record is shown in figure 5-2.

```
          BYTE 4                    BYTE 3                    BYTE 2                    BYTE 1
          BIT
          +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
          |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |
          +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    BYTE 4|                                                                                             |BYTE 1
          |                                                                                             |
          ...                                      HEADER SECTION                                    ...
          ...                                      [176 Bytes]                                       ...
          |                                                                                             |
    176   |                                                                                             |173
          +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    180   |                                                                                             |177
          |                                                                                             |
          ...                                       DATA SECTION                                     ...
          ...                                      [N-176 Bytes]                                     ...
          |                                                                                             |
    N     |                                                                                             |N-3
          +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

N = total number of bytes per record

Figure 5-2: Detailed Structure of the Product File Record

5.2 PRODUCT FILE RECORD HEADER DESCRIPTION

5.2.1 The Header Section of the Record shall contain information related to the station configuration and the basic parameters used in the Record itself (see 5.2.3).

5.2.2 The structure of the Header shall be fixed, as per figure 5-3. The Header contains two empty fields for future expansion.

```
     BYTE  4                 BYTE 3                 BYTE 2                 BYTE 1

BIT  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | RECORD LABEL                                                                                  |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | RECORD LENGTH                                                                                 |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | APERTURE  ID                                    |RECORD VERSION ID                            |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | SAMPLE SIZE                                     |SPACECRAFT ID                                |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | SAMPLE RATE                                                                                   |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | AGENCY FLAG                                     | VALIDITY FLAG                               |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | RF_TO_IF DOWNCONV                 (8 bytes)                                                   |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | IF_TO_CHANNEL DOWNCONV            (8 bytes)                                                   |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | TIME TAG, DAY OF THE YEAR                       | TIME TAG, YEAR                              |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | TIME TAG, SECONDS OF DAY                                                                      |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | TIME TAG, PICOSECONDS OF THE SECOND     (8 bytes)                                             |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | CHANNEL ACCUMULATED PHASE         (8 bytes)                                                   |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | CHANNEL PHASE POLYNOMIAL COEFFICIENT 0        (8 bytes)                                       |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | CHANNEL PHASE POLYNOMIAL COEFFICIENT 1        (8 bytes)                                       |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | CHANNEL PHASE POLYNOMIAL COEFFICIENT 2        (8 bytes)                                       |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | CHANNEL PHASE POLYNOMIAL COEFFICIENT 3        (8 bytes)                                       |
     +                                                                                               +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | EMPTY FIELDS FUTURE USE     (36 bytes)                                                        |
     |                                                 …                                             |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | EMPTY FIELDS INTERNAL AGENCY USE  (40 bytes)                                                  |
     |                                                 …                                             |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     | END LABEL                                                                                     |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

Figure 5-3: General Structure of the Header

5.2.3 A detailed description of the Header is provided in table 5-1, which supplies for each item its:

– name;

– length (in Bytes);

– data type;

– short description;

– examples of allowed values.

5.2.4 Floating point values shall conform to the IEEE double precision type 'binary64' (reference [3]).

5.2.5 The special values 'NaN', '-Inf', '+Inf', and '-0' are NOT supported in the Delta-DOR RDEF.

5.2.6 The TIME TAG fields in the Header are approximations to UTC, as realized by station time at the receiver.

NOTE – The station time at the receiver is referred to as 'ST' in table 5-1.

5.2.7 Downconversion shall be represented as the sum of a fixed frequency plus a variable frequency signal.

5.2.7.1 The convention used to represent the downconversion process is expressed by the following formula:

$$e^{i\phi_B(t)} = e^{i\phi_A(t)} e^{-i\phi_{DC}(t)},$$

where:

$\phi_A(t)$ is the signal phase before downconversion;

$\phi_B(t)$ is the signal phase after downconversion;

$\phi_{DC}(t)$ is the downconverter phase.

NOTE – The signal downconversion is typically done in several stages. The data record headers contain all the information necessary to reconstruct the total downconversion frequency and phase for each channel as a function of time.

The downconversion frequency and phase, respectively, for the fixed part is given by:

$$f_{DC,fixed} = f_{RF-IF} + f_{IF-CHAN}$$

$$\phi_{DC,fixed}(t) = \left(f_{RF-IF} + f_{IF-CHAN}\right)\left(t - t_b\right)$$

where

- f_{RF-IF} = RF to IF downconverter frequency, Hz (item RF_TO_IF DOWNCONV in table 5-1);
- $f_{IF-CHAN}$ = IF to channel downconverter frequency, Hz, (item IF_TO_CHANNEL DOWNCONV in table 5-1);
- t = sample time within the scan, s;
- t_b = experiment epoch, s (generally unknown).

NOTE – It is assumed that the fixed frequency IF to channel downconverter has integer phase on the integer second boundary, that is $f_{IF-CHAN}(t-t_b)$ is an exact integer number of cycles for t an integer second. This is equivalent to assuming that the downconverter phase for every channel may be written as above for the full data time span using the same value of t_b.

5.2.7.2 The downconversion phase (cycle) for the variable part, over the time span within any data record, is given by:

$$\phi_{DC,\mathrm{variable}}(t) = \Phi + c_0 + c_1(t-t_0) + c_2(t-t_0)^2 + c_3(t-t_0)^3 \quad \text{[cycles]},$$

where

- $\Phi = \Phi(t_0)$ = integer part of accumulated downconverter phase at time t_0 (item CHANNEL ACCUMULATED PHASE in table 5-1);
- c_0 = channel phase polynomial coefficient 0, fractional part of downconverter phase at time t_0 (item CHANNEL PHASE POLYNOMIAL COEFFICIENT 0 in table 5-1);
- c_i = channel phase polynomial coefficient i, i=1,2,3 (items CHANNEL PHASE POLYNOMIAL COEFFICIENT 1 to 3 in table 5-1);
- t = sample time within a given data record, s;
- t_0 = start time of data record, s (item TIME TAG SECOND OF DAY in table 5-1).

5.2.7.3 The downconversion frequency for the variable part is given by the time derivative of the downconversion phase:

$$f_{DC,\mathrm{variable}}(t) = c_1 + 2c_2(t-t_0) + 3c_3(t-t_0)^2$$

5.2.7.4 The phase polynomial coefficients c_j are updated for each record. In case the downconversion chain is fixed, c_1 is constant and c_2=c_3=0 over the records.

Table 5-1: Product File Header

Item Name	Bytes	Type	Item description	Allowed values
RECORD LABEL	4	CHARACTER	ASCII sequence needed to identify data type	'RDEF'
RECORD LENGTH	4	UNSIGNED INTEGER	Length, in bytes, of the entire Record	The value shall be equal to 2*(SAMPLE RATE*SAMPLE SIZE)/8 + HEADER SIZE in bytes, where HEADER SIZE = 176 bytes
RECORD VERSION ID	2	UNSIGNED INTEGER	Version number of the data record structure, synchronised with the one given in the Observation File	(=2 for the current version)
APERTURE ID	2	UNSIGNED INTEGER	Internal network identifier for the aperture station (standardized aperture alias is defined in OBS file contents and on filename); the value 0 shall mean that this field is not in use	0 to 65535
SPACECRAFT ID	2	UNSIGNED INTEGER	Internal network identifier for the spacecraft (standardized mission alias is defined in OBS file contents and on filename); the value 0 shall mean that this field is not in use	0 to 65535
SAMPLE SIZE	2	UNSIGNED INTEGER	Number of bits per sample contained in this data record	1, 2, 4, 8, 16
SAMPLE RATE	4	UNSIGNED INTEGER	Sample rate of the data contained in this record, in complex samples per second	SAMPLE RATE * 2 * SAMPLE SIZE shall be a multiple of 32, to keep the sample word length to 32 bits

Item Name	Bytes	Type	Item description	Allowed values
VALIDITY FLAG	2	UNSIGNED INTEGER	Value indicating whether an error was detected during recording	The value 0 shall mean no error (or no check was performed), while a positive value is an implementation-dependent error code
AGENCY FLAG	2	UNSIGNED INTEGER	Agency creating the file, as defined in the Agency DDOR identification number in [9]	The value 0 shall mean that this field is not in use.
RF_TO_IF DOWNCONV	8	FLOATING POINT	First downconversion stage: from RF to IF Resolution: 1 Hz	Hz The downconversion value can represent a physical ground station frequency difference or a logical downconversion.
IF_TO_CHANNEL DOWNCONV	8	FLOATING POINT	Second downconversion stage: from IF to channel centre frequency Resolution: 1micro-Hz	Hz The downconversion from IF to the channel centre frequency is represented as the sum of two parameters: a fixed value in IF_TO_CHANNEL_DOWNCONV and a variable value in CHANNEL POLYNOMIAL COEFFICIENTn
TIME TAG YEAR	2	UNSIGNED INTEGER	ST year of the data contained in the record	0 to 65535
TIME TAG DOY	2	UNSIGNED INTEGER	ST DOY of the data contained in the record	1 to 366
TIME TAG SECOND OF DAY	4	UNSIGNED INTEGER	ST SOD of the data contained in the record	0 to 86400
TIMETAG PICOSECONDS OF THE SECOND	8	FLOATING POINT	ST picoseconds of the second of the first sample contained in the record	Any value between second boundary and reciprocal of sampling rate; set to 0 if unknown

Item Name	Bytes	Type	Item description	Allowed values
CHANNEL ACCUMULATED PHASE	8	FLOATING POINT	Value of the accumulated whole turns of the channel variable downconverter represented by the phase polynomial coefficients (expressed in 'turns', i.e., rad/2Π)	This parameter specifies the integer part of the total accumulated phase at the start time of the data record
CHANNEL PHASE POLYNOMIAL COEFFICIENT0	8	FLOATING POINT	Channel phase polynomial coefficient of degree 0 (expressed in rad/2Π). This item has to be referred to the second boundary, as provided by item TIME TAG SECOND OF DAY	This parameter specifies the fractional part of the total accumulated phase at the start time of the data record To facilitate data processing the downconverter phase represented by the phase polynomial should be continuous in phase and phase rate from one second to the next
CHANNEL PHASE POLYNOMIAL COEFFICIENT1	8	FLOATING POINT	Channel phase polynomial coefficient of degree 1 (expressed in rad/2Π/s). This item has to be referred to the second boundary, as provided by item TIME TAG SECOND OF DAY	Any floating point number
CHANNEL PHASE POLYNOMIAL COEFFICIENT2	8	FLOATING POINT	Channel phase polynomial coefficient of degree 2 (expressed in rad/2Π/s^2). This item has to be referred to the second boundary, as provided by item TIME TAG SECOND OF DAY	Any floating point number

Item Name	**Bytes**	**Type**	**Item description**	**Allowed values**
CHANNEL PHASE POLYNOMIAL COEFFICIENT3	8	FLOATING POINT	Channel phase polynomial coefficient of degree 3 (expressed in rad/2Π/s^3). This item has to be referred to the second boundary, as provided by item TIME TAG SECOND OF DAY	Any floating point number
EMPTY FIELDS (FUTURE EXTENSION)	36		Total number of bytes free to be used for future format extension	
EMPTY FIELDS (INTERNAL AGENCY USE)	40		Total number of bytes free to be used by each Agency for its internal purpose	
END LABEL	4	INTEGER	End label for data synchronization check Shall be equal to -99999	-99999

5.3 PRODUCT FILE RECORD DATA DESCRIPTION

5.3.1 The Data Section of each Record of the Product File shall contain only the in-phase (I) and quadrature-phase (Q) samples recorded at the receiver.

5.3.2 Samples shall be packed into 32-bit words.

5.3.3 The Q and I data for a given time sample shall be adjacent. Between 1 and 16 complex samples shall be packed into each 32-bit word, depending on how many bits per sample are used.

NOTE – Table 5-2 shows all possible cases.

Table 5-2: Sample 32-Bit Word Packing

Byte 4 ... Byte 1

MSB — 16-Bit Samples — LSB

Q1	I1

MSB — 8-Bit Samples — LSB

Q2	I2	Q1	I1

MSB — 4-Bit Samples — LSB

Q4	I4	Q3	I3	Q2	I2	Q1	I1

MSB — 2-Bit Samples — LSB

Q8	I8	Q7	I7	Q6	I6	Q5	I5	Q4	I4	Q3	I3	Q2	I2	Q1	I1

MSB — 1-Bit Samples — LSB

[Q16,I16], [Q15,I15], … [Q2,I2], [Q1,I1]

5.3.4 The time order of the packed bits shall be from Least Significant Bit (LSB) to Most Significant Bit (MSB).

5.3.5 Truncation shall be used to reduce the number of bits per sample to the desired value.

NOTE – This truncation creates an offset of –0.5 in the output data stream values that needs to be corrected in post processing software.

5.3.6 To compensate for this offset, each sample shall be put through the transformation 2*k + 1, where k is the 2's complement value of the 1-, 2-, 4-, 8- or 16-bit sample.

NOTES

1 The value zero is not present in this data representation. However, all bits are used and the data are symmetric about zero.

2 A generic description of the Data Section of each Record is given in figure 5-4.

```
     BYTE  4                  BYTE 3                 BYTE 2                 BYTE 1

BIT  +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     +                                       SAMPLE WORD 1                                           +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     +                                       SAMPLE WORD 2                                           +
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     ...                                                                                           ...
     ...                                                                                           ...
     |                                                                                               |
     +                                                                                               +
     |                                                                                               |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
     |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |8 |7 |6 |5 |4 |3 |2 |1 |
     +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

Figure 5-4: General Structure of the Data Section of the Record

6 FILE NAMING CONVENTIONS

6.1 GENERAL

One Observation File is provided per measurement session for each station. A separate Product File is used to contain the data for each scan, channel, and station. As a result, a measurement session typically generates a large number of files, so a naming convention described below facilitates their management.

NOTE – The file name syntax and length should not violate constraints for computing environments in use by Member Agencies for processing Delta-DOR raw data.

6.2 FILE NAMES

6.2.1 The file name shall uniquely define the receiver used to record data, the frequency channel, the spacecraft, the station, the scan, the file type, and the nominal scan start time.

6.2.2 Each file shall be named according to the following convention:

MMMMnNNNtTsAAAArRRcCC-YYDDDHHMMSS.XXX

where:

a) All of the identified fields are represented as alphanumeric characters;

b) **MMMM** is the four uppercase character mission alias from reference [8], which shall be the same as the source ID in the corresponding Observation File (Table **4-2**);

c) **n** is a token indicating that a scan identifier follows;

d) **NNN** is the scan number per session starting from 001 (3-digit integer);

e) **t** is a token to indicate file type;

f) **T** is one uppercase character that identifies the file type:

- **I** for an Observation File;
- **S** for a spacecraft scan Product File;
- **Q** for a quasar scan Product File.

g) **s** is a token to indicate that station's aperture identifier follows (retained for backward compatibility with v1);

h) **AAAA** is the aperture alias expressed as four uppercase characters from reference [7], which shall be the same as the receiving aperture alias in the corresponding Observation File (4.2.4);

i) **r** is a token to indicate that the receiver identifier follows;

j) **RR** is the receiver identifier expressed as two uppercase alphanumeric characters;

k) **c** is a token to indicate that channel identifier follows;

l) **CC** is the channel identifier (2-digit integer);

m) **-** is a token indicating that date follows;

n) **YY** is the last two digits of the year for nominal scan epoch (2-digit integer);

o) **DDD** is the day of the year for nominal scan epoch (3-digit integer);

p) **HHMMSS** is the hour-minute-second for nominal scan epoch (6-digit integer);

q) **.XXX** is the file extension:

– .obs for an Observation File;

– .prd for a Product File.

6.2.3 The mission alias shall refer to the mission that has scheduled the tracking pass.

6.2.4 During simultaneous Delta-DOR sessions, one Observation File shall be generated per spacecraft tracking session. The object observed during a scan may be a quasar or a spacecraft (the tracking one or another one), as indicated in the Observation File (see section 4).

6.2.5 Special conventions are used for some values in the Observation File name:

a) the channel identifier shall be '00';

b) the scan number shall be '000';

c) the nominal epoch time shall be at or before the nominal epoch for scan 001.

ANNEX A

PARAMETER CONVENTIONS

(NORMATIVE)

This annex summarises the various identifiers required by this document, which are found in SANA registries [6] [7] [8] [9] [10] .

A1 OBSERVATION FILE PARAMETERS

The following identifiers and character constraints shall be used for Observation File parameters:

– R APERTURE: Aperture alias from [7] with four alphanumeric characters.

– T APERTURE Aperture alias from [7] with four alphanumeric characters.

– FIRST_SEED: Allocation of up to 15 ASCII character field in First_Seed field in [10] .

– SECOND_SEED: Allocation of up to 15 ASCII character field in Second_Seed field in [10] .

– FIRST_POLY: Allocation of up to 16 ASCII characters in First polynomial field in [10] .

– SECOND_POLY: Allocation of up to 16 ASCII characters in Second polynomial field in [10]

– SRC_ID: Allocation of up to 16 alphanumeric characters in [6] (B1950 source name, Common source name or Source ID number format) or 4 alphanumeric characters in Mission Alias from [8].

When SRC_ID is used for quasar IDs:

– Spaces in common name format shall be replaced in OBS file by underscores.

– Source ID Number format shall be preceded in the OBS file by an ‘S’ character.

A2 PRODUCT FILE PARAMETERS

For the Product File, the Agency Flag parameter shall be an integer from 0 to 65535, corresponding to the Agency DDOR identification number in reference [9].

A2.1 FILE NAME PARAMETERS

The following aliases shall be used for file naming:

- Mission alias: mission alias from [8] with four alphanumeric characters;
- Aperture alias: aperture alias from [7] with four alphanumeric characters.

ANNEX B

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

B1 SECURITY CONSIDERATIONS

B1.1 OVERVIEW

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

B1.2 SECURITY CONCERNS RELATED TO THIS RECOMMENDED STANDARD

B1.2.1 Data Privacy

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

B1.2.2 Data Integrity

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

B1.2.3 Authentication of Communicating Entities

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

The likelihood of any intentional data corruption involving the RDEF transfer is considered negligible. Moreover, the effects of such corruption will be easily recognizable within the data processing.

B1.2.4 Data Transfer between Communicating Entities

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

B1.2.5 Control of Access to Resources

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

B1.2.6 Auditing of Resources Usage

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

B1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

There are no certain threats or attack scenarios that apply specifically to the technologies specified in this Recommended Standard. Potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented should be addressed by the management of those systems and networks. Protection from unauthorized access is especially important if the mission utilizes open ground networks, such as the Internet, to provide ground station connectivity for the exchange of data formatted in compliance with this Recommended Standard.

B1.4 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

There are no known consequences of not applying security to the technologies specified in this Recommended Standard. The consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include potential loss, corruption, and theft of data.

B1.5 DATA SECURITY IMPLEMENTATION SPECIFICS

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

B2 SANA CONSIDERATION

B2.1 OVERVIEW

This part of the annex defines the contents of the referenced SANA Registries and fields [6] [7] [8] [9] and [10]

Per SANA registry policy, changes to these DDOR registries and fields are controlled by an Expert Group (SEA D-DOR WG). Requests for new entries to any of these registries shall be sent to the Chair of the WG (sea-d-dor-owner@mailman.ccsds.org), or, if the WG is no longer operational, to the SEA Area Director. The Expert Group will assign the value for any new or changed entries and request the SANA Operator to create the entry and make the update.

The corresponding OID items in Enterprise registries [11] [12] and [13] shall be entered prior to the local Delta-DOR registries [6] [7] [8] and [9] respectively.

B2.2 SANA REGISTRY – DELTA-DOR QUASAR IDENTIFIERS

The unique identifiers for Quasars that are used as plane-of-sky position references shall consist of the following required fields:

- B1950 source name (16 alphanumeric characters);
- Common source name (16 alphanumeric characters);
- Source ID number format (16 alphanumeric characters).

B2.3 SANA REGISTRY – DELTA-DOR APERTURES

A unique, abbreviated Aperture identifier is assigned by the DDOR WG to provide a short alias for any aperture used to do DDOR observations. It is stored in the Alias field for each Aperture used for DDOR observations. Format in the Alias field is DDOR:aaaa, where each a value corresponds to an alphanumeric character.

Required fields:

- Aperture alias (four alphanumeric characters);
- OID in [11]

B2.4 SANA REGISTRY – DELTA-DOR SPACECRAFT

A unique, abbreviated Spacecraft identifier is assigned by the DDOR WG to provide a short alias for any Spacecraft used in DDOR observations. It is stored in the Alias field for each Spacecraft used for DDOR observations. Format in the Alias field is DDOR:ssss, where each s value corresponds to an alphanumeric character.

Required fields:

- Spacecraft alias (4 alphanumeric character);
- OID in [12]

B2.5 SANA REGISTRY – DELTA-DOR ORGANIZATION

A unique, abbreviated identifier is assigned by the DDOR WG to provide a short alias for any Organization that participates in DDOR observations. It is stored in the Alias field for each

Organization that participates in DDOR observations. Format in the Alias field is DDOR:ooooo, where each o value corresponds to a numeric (0 to 9) ASCII character.

Required fields:

- Agency DDOR Identification Number (00000 to 65535 in ASCII, with leading zeros);
- OID in [13] .

B2.6 SANA REGISTRY – DELTA-DOR PNDOR SEEDS

Required fields:

- First seed (up to 15 ASCII characters);
- Second seed (up to 15 ASCII characters);
- First polynomial (up to 16 ASCII characters);
- Second polynomial (up to 16 ASCII characters).

NOTE – For First seed, Second seed, First polynomial and Second polynomial fields, ASCII characters are limited to ‘0’and ‘1’.

B3 PATENT CONSIDERATION

At time of publication, the material of this Recommended Standard is not known to be the subject of patent rights.

ANNEX C

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

AD	Area Director
ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
DDOR	Delta Differential One-Way Ranging
Delta-DOR	Delta Differential One-Way Ranging
DOR	Differential One-Way Ranging
DOY	Day Of the Year
I	In-phase
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
GNSS	Global Navigation Satellite System
LSB	Least Significant Bit
MSB	Most Significant Bit
OID	Object Identifier
PN	Pseudo-Noise
Q	Quadrature-phase
RDEF	Raw Data Exchange Format
SANA	Space Assigned Numbers Authority
SC	Spacecraft
SEA	Systems Engineering Area

SFTP	Secure File Transfer Protocol
SI	International System (of units)
SOD	Second Of the Day
ST	Station Time, as an approximation of UTC as realized at each station receiver
UTC	Universal Time Coordinated
VLBI	Very Long Baseline Interferometry
WG	Working Group

ANNEX D

INFORMATIVE REFERENCES

(INFORMATIVE)

NOTE – Normative references are provided in section 1.6.

[D1] *Organization and Processes for the Consultative Committee for Space Data Systems*. Issue 4. CCSDS Record (Yellow Book), CCSDS A02.1-Y-3. Washington, D.C.: CCSDS, April 2014.

[D2] *Delta-DOR—Technical Characteristics and Performance*. Issue 2. Report Concerning Space Data System Standards (Green Book), CCSDS 500.1-G-2. Washington, D.C.: CCSDS, November 2019.

[D3] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, May 2010.

[D4] *The Application of CCSDS Protocols to Secure Systems*. Issue 3. Report Concerning Space Data System Standards (Green Book), CCSDS 350.0-G-3. Washington, D.C.: CCSDS, March 2019.

[D5] David W. Curkendall and James S. Border. "Delta-DOR: The One-Nanoradian Navigation Measurement System of the Deep Space Network—History, Architecture, and Componentry." *The Interplanetary Network Progress Report* 42, no. 193 (May 15, 2013).

[D6] 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.

[D7] 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.

[D8] *Delta Differential One-way Ranging*. Module 210 in *DSN Telecommunications Link Design Handbook*. DSN No. 810-005, Rev. E. Pasadena California: JPL, April 8, 2013.

[D9] Timothy McElrath, et al. "Mars Exploration Rovers Orbit Determination Filter Strategy." In *AIAA/AAS Astrodynamics Specialist Conference and Exhibit, August 16-19, 2004* (Providence, Rhode Island). Pasadena, CA: JPL, 2004.

[D10] *Tracking Data Message*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 503.0-B-2. Washington, D.C.: CCSDS, June 2020.

[D11] *Orbit Data Messages*. Recommendation for Space Data System Standards (Blue Book), CCSDS 502.0-B-3. Washington, D.C.: CCSDS, April 2023.

[D12] *Delta-Differential One Way Ranging (Delta-DOR) Operations*. Issue 2. Recommendation for Space Data System Practices (Magenta Book), CCSDS 506.0-M-2. Washington, D.C.: CCSDS, February 2018.

ANNEX E

EXAMPLE OF RDEF OBSERVATION FILE

(INFORMATIVE)

File Name: M01On000tIsDS24r02c00-08001170000.obs

Observation Header

```
# Observation File
V VERSION = 2
# Comments
#
R APERTURE = DS24
T APERTURE = DS25
#
# PN_ID  PN_COH_FLAG  ROLLOFF  CHIP_VALUE        FIRST_SEED       SECOND_SEED      FIRST_POLY        SECOND_POLY
# ------------------------------------------------------------------------------------------------------------------
P 001    T            0.170    0.0037982190      000001011011001  110001011011101  1000000000000011  1001000000001011
P 002    F            0.170    7800000.0000      000001011011001  110001011011101  1000000000000011  1001000000001011
#
Z
```

Scan Section # 1

```
#
# SCAN_NUM  SRC_ID            START_TIME         STOP_TIME          RA                DEC               TFREQ
# ---------------------------------------------------------------------------------------------------------------------
S 001       CTD_26            2008-001T17:00:00  2008-001T17:04:00  60.797422         26.005385         0.0000
#
# DATAFILE                               COH_FLAG  TONE_VALUE        HARMONIC  PN_ID
# ---------------------------------------------------------------------------------
D M01On001tQsDS24r02c01-08001170000.prd  T         0                 0
D M01On001tQsDS24r02c02-08001170000.prd  F         375000.0          1
D M01On001tQsDS24r02c03-08001170000.prd  T         1/440             -1
D M01On001tQsDS24r02c04-08001170000.prd  T         0.0022727272      1
Z
```

Scan Section # 2

```
#
# SCAN_NUM  SRC_ID            START_TIME         STOP_TIME          RA                DEC               TFREQ
# ---------------------------------------------------------------------------------------------------------------------
S 002       M010              2008-001T17:06:00  2008-001T17:10:00  69.849538         22.975839         8403456000.0000
#
# DATAFILE                               COH_FLAG  TONE_VALUE        HARMONIC  PN_ID
# -------------------------------------------------------------------------------------
D M01On002tSsDS24r02c01-08001170600.prd  T         0                 0
D M01On002tSsDS24r02c02-08001170600.prd  F         375000.0          2
D M01On002tSsDS24r02c03-08001170600.prd  T         1/440             -1        001
D M01On002tSsDS24r02c04-08001170600.prd  T         0.0022727272      1         001
Z
```

Scan Section # 3

```
#
# SCAN_NUM  SRC_ID            START_TIME         STOP_TIME          RA                DEC               TFREQ
# ---------------------------------------------------------------------------------------------------------------------
S 003       P_0507+17         2008-001T17:12:00  2008-001T17:16:00  77.533972         18.013694         0.0000
#
# DATAFILE                               COH_FLAG  TONE_VALUE        HARMONIC  PN_ID
# -------------------------------------------------------------------------------------
D M01On003tQsDS24r02c01-08001171200.prd  T         0                 0
D M01On003tQsDS24r02c02-08001171200.prd  T         375000.0          1
D M01On003tQsDS24r02c03-08001171200.prd  T         1/440             -1        002
D M01On003tQsDS24r02c04-08001171200.prd  T         0.0022727272      1         002
Z
```

Ending Section

```
F LOGfile <filename>
E *=END=
```

ANNEX F

ALIAS EXAMPLES BY AGENCY

(INFORMATIVE)

	ESA	***JAXA***	***NASA***
Aperture Alias	NNO1	UDSC	DS14
	NNO3	MISA	DS25
	CEB1	UCHI	DS43
	MLG1		DS63
Mission Alias	BEPI	IKRS	DART
	EXMO	HYB2	LUCY
	GAIA	PRCN	SPP1
	ROSE	PLC1	M01O
	SOLO	MMX1	ORX1