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Space data and information transfer systems — Delta-DOR Raw Data Exchange Format

Systèmes de transfert des informations et données spatiales — Format d'échange des données brutes Delta-DOR

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Recommendation for Space Data System Standards

DELTA-DOR RAW DATA EXCHANGE FORMAT

RECOMMENDED STANDARD

CCSDS 506.1-B-1

BLUE BOOK
June 2013

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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*, and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

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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 of the CCSDS Systems Engineering (SEA) area.

The Delta-DOR Raw Data Exchange Format described in this Recommended Standard is the baseline concept for Delta-DOR 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 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.

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

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CONTENTS

CONTENTS (continued)

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 inter-agency 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. 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 reduced 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); units are either SI base units, SI derived units, or units outside the SI that are accepted for use with the SI (see reference [2]), e.g.,

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 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 DELTA-DOR 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: meteorological data (consisting of pressure, temperature, and relative humidity).

1.5 STRUCTURE OF THE DOCUMENT

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.

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*. 2nd ed. IEEE Std. 754-2008. New York: IEEE, 2008.

[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]   *Delta-Differential One Way Ranging (Delta-DOR) Operations*. Recommendation for Space Data System Practices, CCSDS 506.0-M-1. Magenta Book. Issue 1. Washington, D.C.: CCSDS, April 2011.

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 [5] and [D2]. 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 THE 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.

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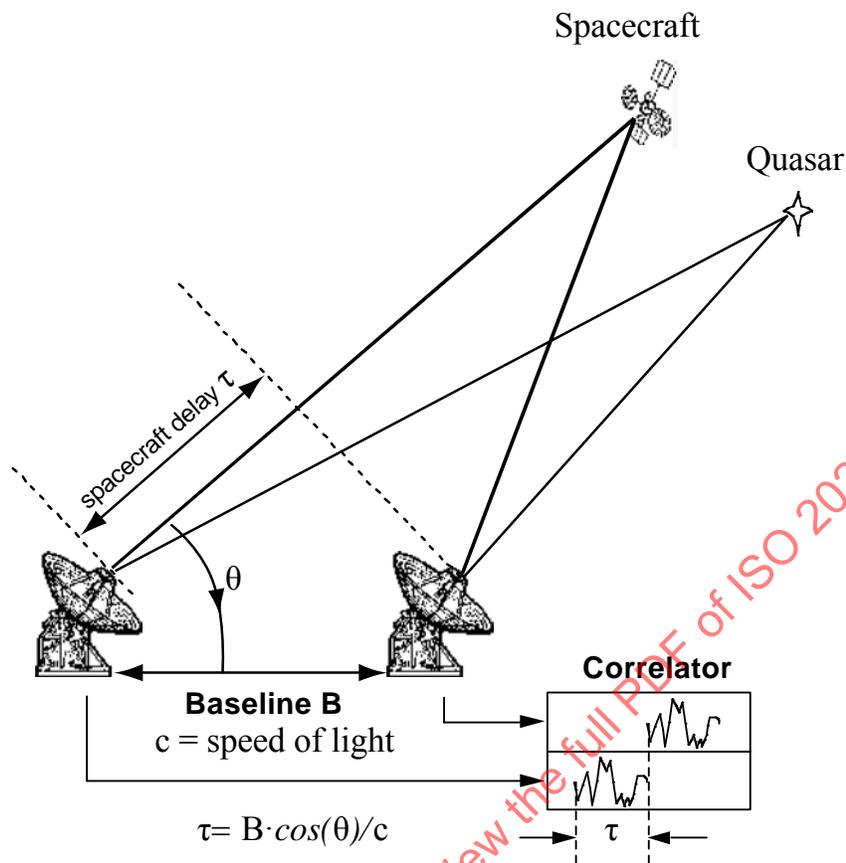
Figure 2-1 Delta-DOR Observation Geometry

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, at the same two

stations, of the quasar signal. 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. Either a pure waveform may be used, producing a spectrum of pure tones, or a modulated waveform may be used, producing a spectrum that more closely resembles the spectrum 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 GPS 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. While no agency has enough station complexes to provide orthogonal baselines by itself, the existing assets of more than one agency today could provide two or more pairs of angularly separated baselines and good 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. Current missions using Delta-DOR for navigation, as of this writing, include Messenger, New Horizons, Dawn, EPOXI, Rosetta, and Hayabusa. The technique is planned for future missions such as Mars Science Laboratory (NASA), BepiColombo (ESA), and Ikaros (JAXA), and its use 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   THE NEED 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 [D9], [D10], [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 [5]) and will not be included here.

2.4   CONVENTIONS FOR IDENTIFIERS

This Recommended Standard does not specify the conventions to be used for identifiers of tracking stations, spacecraft, and radio sources. While these objects must be identified to give meaning to the data, it is outside the scope of this Recommended Standard to specify the names to be used. These parameters are described as they are introduced throughout the Recommended Standard and are collected in annex A. Conventions to be used for such parameters should be negotiated among the participating agencies and formalized as specified in annex A of reference [5].

If accessible and agreed catalogues for identifiers of tracking stations, spacecraft, and radio sources are available, they should be preferentially used.

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

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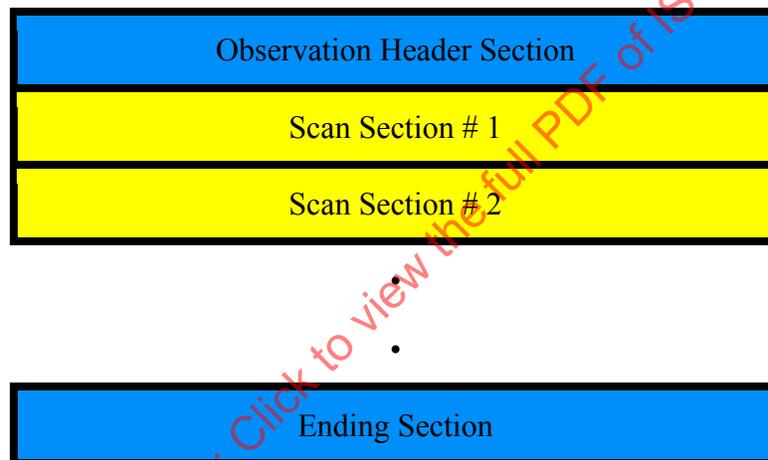
Figure 4-1:   General Structure of the RDEF Observation File

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

4.1.3   Each line shall be as follows:

a)   It may have variable length up to 180 characters (excluding the termination character).

b)   Only printable ASCII characters and blanks shall be used. Control characters such as TAB, etc., shall not be used.

c)   No blank lines can be used.

d)   Each of the specified Sections may contain comment lines. Each comment line shall start with the character '#'.

e) The first character in each line of an Observation File shall identify the type of information contained in that line.

NOTE – Details regarding each line type are provided in 4.1.4 and in the following subsections, as appropriate.

f) One or more 'blank' characters shall be used to separate each of the various items within each line.

g) Each line shall be terminated by a single Line Feed or a single Carriage Return or a Carriage Return/Line Feed pair or a Line Feed/Carriage Return pair.

4.1.4 Each Section (except for the Ending Section) shall end with a line starting with character 'Z'.

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. This line shall start with the character 'V'.

4.2.3 The structure of the line shall be as follows:

V VERSION = <version>

4.2.4 where <version> is the version identifier, integer. The version number shall be synchronised with the one given in the Product File

4.2.5 The Observation Header Section shall contain a single receive station line. This line shall start with the character 'R'.

4.2.6 The structure of the line shall be as follows:

R STATION = <station>

4.2.7 where <station> is the station identifier, four ASCII characters long. The Observation Header Section may optionally contain a single transmitting station line. This line shall start with the character 'T'.

4.2.8 The structure of the line shall be as follows:

T STATION = <station>

where <station> is the station identifier, 4 ASCII characters long.

4.2.9 If the data are one-way, the transmitting station line shall be omitted.

4.3 CONTENT OF SCAN SECTION

NOTE – The Scan Section describes the observation and 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 should also contain comment lines providing labels for the scan line and the Product File lines.

4.3.3 The scan line shall start with character 'S'.

4.3.4 The structure of the scan line shall be as follows:

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

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

Table 4-1: Description of the Scan Line

Item Name	Item Description	Format	Units/ Precision/Range
SCAN_NUM	Identifies the scan number, in a progressive order.	3 digit integer	No units, range 001-999
SRC_ID	Specifies the source, SC ID or Quasar ID.	Up to 16 ASCII characters. Syntax is referenced in annex A.	No units, up to 16 characters for quasar, 4 characters for spacecraft
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
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
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.
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.
TFREQ	Specifies the Transmitted Frequency if the source is a Spacecraft; if not, TFREQ= 0.	Decimal notation	Hz, decimal notation with no more than 16 significant digits.

4.3.5 The Product File line shall start with character 'D'.

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

4.3.7 The structure of each Product File line shall be as follows:

```
D <datafile> <coherence_flag> <dor_mult> <fsub> <harmonic>
```

NOTE –   The parameters are defined in table 4-2.

Table 4-2: Description of the Product File Line

Item Name	Item Description	Format	Units/ Precision/Range
DATAFILE	Specifies the name of a Product File recording	39 ASCII characters, as specified in 6.2	No units
COHERENCE_F LAG	Identifies whether or not the signal is coherent with the carrier. If True the fields DOR-MULT and HARMONIC are used to compute the tone frequency. If False the fields FSUB and HARMONIC are used to compute the tone frequency.	1 ASCII character	No units, 'T' for True, 'F' for False
DOR_MULT	Specifies two integers used as the numerator and denominator of a number, which represents the fundamental tone as a fraction of the TFREQ, in case COHERENCE-FLAG='T'; example: 11/18440. In case COHERENCE-FLAG='F', any number is allowed.	A fraction of two integer numbers	No units
FSUB	Specifies the fundamental subcarrier frequency, in all cases where such subcarrier is not coherent with the carrier. In case COHERENCE-FLAG='T', any value is allowed.	Decimal notation	Hz, decimal notation with no more than 16 significant digits
HARMONIC	Specifies the subcarrier or coherent tone harmonic number.	Integer	No units

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 related information to correlate such second of data.

5.1.2   Each Record shall consist of data represented in binary format. It shall be made of two Sections:

a)   The *Header* Section (see 5.2)

b)   The *Data* Section (see 5.3)

NOTE   –   Figure 5-1 shows the general structure of one Product File Record.
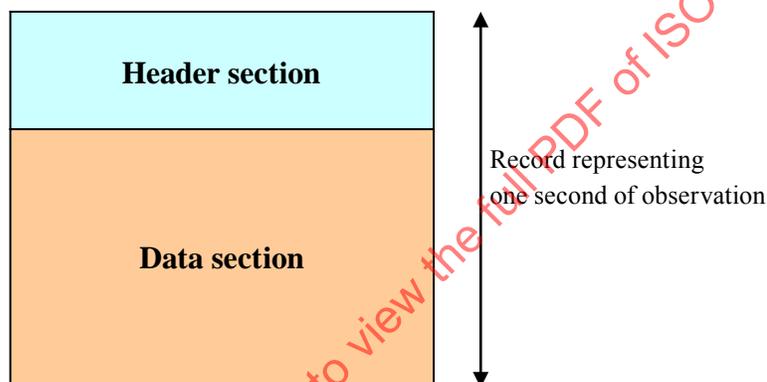
Figure 5-1:   General Structure of one Product File Record

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

5.1.4   The length of the Header Section is fixed as per figure 5-2; the length of the Data Section is variable and shall be determined by the sample rate and sample size of the recorded data. The total length of the Data Section shall be fully determined by the information written in the Header Section.

5.1.5   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
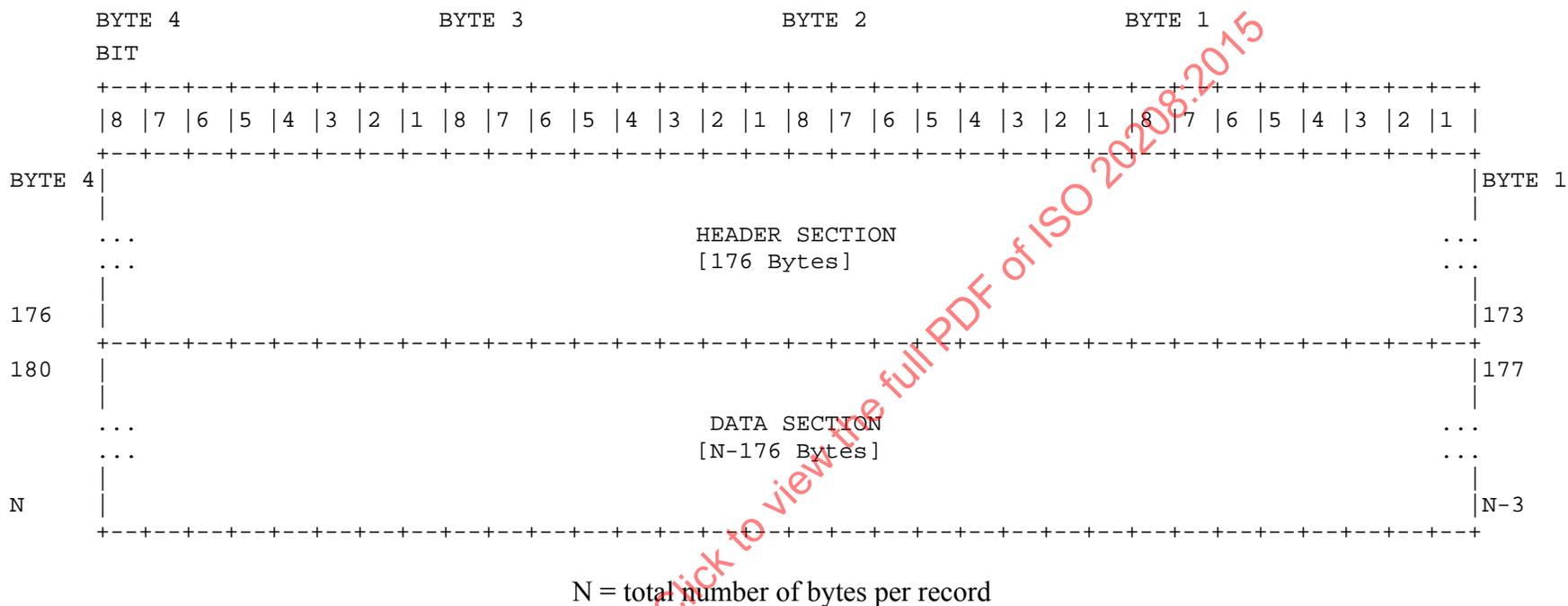
Figure 5-2: Detailed Structure of the Product File Record

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 5.2.2).

The structure of the Header shall be fixed, as per figure 5-3. The Header contains 23 parameters and 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                                                                                |
        +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
        | STATION  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 |
        +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```
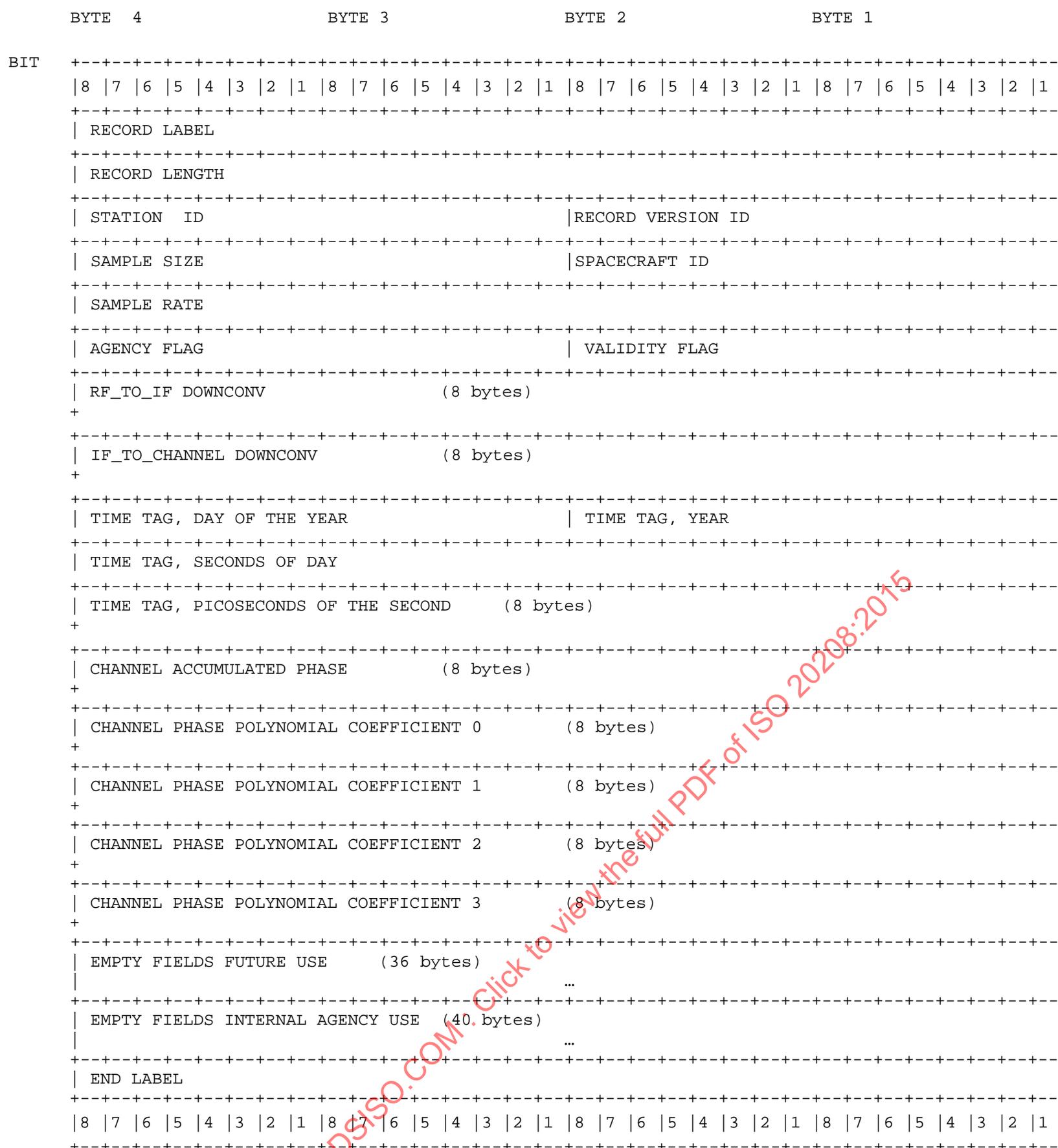
Figure 5-3: General Structure of the Header

5.2.2 A detailed description of the Header is provided in table 5-1, which specifies for each item:

    – the name of the item;

    – the length (in Bytes) of the item;

    – the data type of the item;

    – a short description of the item;

    – examples of allowed values;

    – whether a value for the item is mandatory or not.

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

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

5.2.5 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 'ST' in table 5-1.

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

5.2.6.1 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:

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

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

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.

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

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

where

- $\Phi = \Phi(t_c, t_0)$ = integer part of accumulated downconverter phase at time t_0 (item CHANNEL ACCUMULATED PHASE in table 5-1); this phase is accumulated between the instant t_c and t_0;

- 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_c = downconversion time reset, which shall happen prior to scan start, s;

- t_0 = start time of data record, s (item TIME TAG SECOND OF DAY in table 5-1).

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

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

5.2.6.4 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.

RECOMMENDED STANDARD FOR DELTA-DOR RAW DATA EXCHANGE FORMAT

Table 5-1: Product File Header

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
RECORD LABEL	4	CHARACTER	ASCII sequence needed to identify data type	'RDEF'	Y
RECORD LENGTH	4	UNSIGNED INTEGER	Indicates the 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	Y
RECORD VERSION ID	2	UNSIGNED INTEGER	Version number of the data record structure	(=1 for the current version) The version number shall be synchronised with the one given in the Observation File	Y
STATION ID	2	UNSIGNED INTEGER	Internal network identifier for the station	Integer	N
SPACECRAFT ID	2	UNSIGNED INTEGER	Internal network identifier for the spacecraft	Integer	N

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
SAMPLE SIZE	2	UNSIGNED INTEGER	Specifies the resolution of the data samples contained in this data record	1, 2, 4, 8, 16	Y
SAMPLE RATE	4	UNSIGNED INTEGER	Specifies the 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	Y
VALIDITY FLAG	2	UNSIGNED INTEGER	Contains a value to indicate whether an error was detected during recording	The value 0 shall mean no error (or no check was performed) A positive value is an implementation-dependent error code	Y
AGENCY FLAG	2	UNSIGNED INTEGER	Specifies the Agency creating the file	The value 0 shall mean that this field is not in use. 1= ESA 2 =JAXA 3 = NASA	Y

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
RF_TO_IF DOWNCONV	8	FLOATING POINT	First downconversion stage: from RF to IF Resolution: 1 Hz	Hz NOTE – The downconversion value given here can either represent a physical ground station frequency difference or a logical downconversion	Y
IF_TO_CHANNEL DOWNCONV	8	FLOATING POINT	Second downconversion stage: from IF to channel centre frequency Resolution: 1micro-Hz	Hz NOTE – 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	Y

RECOMMENDED STANDARD FOR DELTA-DOR RAW DATA EXCHANGE FORMAT

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
TIME TAG YEAR	2	UNSIGNED INTEGER	Specifies the ST year of the data contained in the record		Y
TIME TAG DOY	2	UNSIGNED INTEGER	Specifies the ST DOY of the data contained in the record	1 to 366	Y
TIME TAG SECOND OF DAY	4	UNSIGNED INTEGER	Specifies the ST SOD of the data contained in the record	0 to 86400	Y
TIMETAG PICOSECONDS OF THE SECOND	8	FLOATING POINT	Specifies the ST picoseconds of the second of the first sample contained in the record	A positive non-zero value is used when there is a known delay between the time of the first data sample and the beginning of the second one. Set to 0 if unknown.	Y

RECOMMENDED STANDARD FOR DELTA-DOR RAW DATA EXCHANGE FORMAT

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
CHANNEL ACCUMULATED PHASE	8	FLOATING POINT	The 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 should give the total accumulated phase at the beginning of the frame except the additional channel phase polynomial contribution	Y
CHANNEL PHASE POLYNOMIAL COEFFICIENT0	8	FLOATING POINT	The 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	NOTE – 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	Y

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
CHANNEL PHASE POLYNOMIAL COEFFICIENT1	8	FLOATING POINT	The 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	See before	Y
CHANNEL PHASE POLYNOMIAL COEFFICIENT2	8	FLOATING POINT	The 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	See before	Y

RECOMMENDED STANDARD FOR DELTA-DOR RAW DATA EXCHANGE FORMAT

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

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 data and the 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

2-Bit Samples: Q8 I8 Q7 I7 Q6 I6 Q5 I5 Q4 I4 Q3 I3 Q2 I2 Q1 I1

1-Bit Samples: [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.