Deep Space Network

0222-Science
Open Loop Data Interface

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Review Acknowledgment

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--		07/11/2017	All	Initial release of document.

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Section 1
Introduction

1.1 Purpose and Scope

This Deep Space Network (DSN) module defines the format and contents of the data records recorded by Open Loop receivers that follow the Consultative Committee for Space Data Systems (CCSDS) standard. This format is used by the Open Loop Receiver (OLR) in the Deep Space Network (DSN) and represents the output format of the OLR. This format is also used by other Agencies around the world and represents the format of open loop data provided to the DSN from external tracking stations that follow the CCSDS standard. Each record contains data and ancillary information required for post processing by Radio Science users, Delta Differential One-way Range (DDOR) users, the Entry, Descent and Landing (EDL) Data Analysis (EDA), or any other user. The interfaces defined herein describe the detailed data descriptions and formats, and dependencies.

The DDOR application has some restrictions on the open loop recording conventions that do not apply to other users. These restrictions apply to DDOR data files received by the DSN from external Agencies and to DDOR data files recorded on the OLR. Such restrictions are noted in this document using italic font.

The allowable digital channel configurations for data recording on the OLR are also defined in this document.

The OLR is a computer controlled open loop receiver that records previously digitized emissions from astronomical bodies or spacecraft. First a low-noise receiver converts the RF signal to IF which is then packetized through the use of an analog to digital converter and digital filter sub-bands. The OLR then gathers digital samples for each channel, partitions, applies a predicted frequency, and formats the data into a sequence of one second data records, which are stored to disk in real time. At least part of this same general description also applies to open loop receivers in use at tracking stations of other Agencies.

1.2 Applicability

This document is the initial release and applies to the current version of the OLR software and current version of CCSDS standards.

1.3 Revision Control

Revisions or changes to the information herein presented may be initiated according to the procedure specified in the *Introduction* to Document 820-013.

Documents controlling this version include

813-109, D-17818	*Preparation Guidelines and Procedures for Deep Space Network (DSN) Interface Specifications.* October 27, 2009 [DSN internal]

1.4 Relationship to Other Documents

NA

1.5 Terminology and Notation

1.5.1 Endian order

The Integer, Unsigned Integer, Floating Point, and Double Floating Point multi-byte binary data formats described below will follow the “Little Endian” byte order convention. "Little Endian" means that the low-order byte of a binary number is stored at the lowest address, and the high-order byte at the highest address. (The little end comes first.) A four byte binary integer would then be stored as:

Base Address+0	Byte0
Base Address+1	Byte1
Base Address+2	Byte2
Base Address+3	Byte3

1.5.2 Integer (int)

An integer format is used to express integral quantities, using two’s complement notation. The range for an integer field is $[-1 * (2^n/2)]$ to $[(2^n/2) - 1]$, where n is the number of bits in the field. For example, an 8 bit integer field would have the following range, $[-1 * (2^8/2)]$ to $[(2^8/2) - 1] = -128$ to 127.

1.5.3 Unsigned Integer (uint)

An unsigned integer format is used to express integral quantities using the base 2 number system, also known as binary. The range for an unsigned integer field is 0 to $(2^n - 1)$, where n is the number of bits in the field.

1.5.4 Floating Point (float)

Floating point numbers are represented in the basic single format defined in document American National Standards Institute / Institute of Electrical and Electronic Engineers (ANSI/IEEE) Standard (Std) 754-1985. This representation is commonly referred to as the 32-bit IEEE floating point format.

1.5.5 Double Floating Point (double)

Double floating point numbers are represented in the basic double format defined in document ANSI/IEEE Std 754-1985. This representation is commonly referred to as the 64-bit IEEE floating point format.

1.5.6 American Standard Code for Information Interchange (ASCII)

The set of ASCII characters as defined in ANSI/IEEE Std 754-1985.

1.6 References

Documents

754-1985	*ANSI/IEEE Std*
820-013	*OPS-6-21 DSN External Interface Specification—Standard Code Assignments* *OPS-6-21-47 DSN Facilities and Antenna Identifiers* *0159-Science, Radio Science Experiment Access*
DSN 837-083	*Open Loop Receiver (OLR) Software Operations Manual*
CCSDS Standards	
500.1-G-1	*Delta-DOR – Technical Characteristics and Performance, Green Book, Issue 1* http://public.ccsds.org/publications/archive/500x1g1.pdf
506.1-B-1	*Delta-DOR Raw Data Exchange Format, Blue Book, Issue 1* *http://public.ccsds.org/publications/archive/506x1b1.pdf*

Web Sites

https://dsnprocess.jpl.nasa.gov/dart	DSN Acronym Reference Tool (DART)

1.7 Abbreviations

Abbreviations used in this document are defined with the first textual use of the term.

A/D	Analog to Digital
AMC	Advanced Mezzanine Card
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Exchange
CCSDS	Consultative Committee for Space Data Systems
DDCLO	Digital DownConverter Local Oscillator
DIS	Digital IF Switch
DDOR	Delta Differential One-way Range
DOR	Differential One-way Range Subsystem
DPC	Data Processing and Control
EDA	Entry, Descent, and Landing Data Analysis
EDL	Entry, Descent, and Landing
FLTOPS	Flight Operations
GCN	Ground Communications Network
I	In-Phase (component of digital signal)
ID	Identifier
IF	Intermediate Frequency
IFD	IF to Digital converter
IGC	IF Gain Control assembly
IP	Internet Protocol

LAN	Local Area Network
LSB	Least Significant Bit
MSB	Most Significant Bit
OLR	Open Loop Receiver
Pc/No	Ratio of Power in the Carrier to Noise Power in a 1 Hz Bandwidth
Q	Quadrature-Phase (component of digital signal)
RDEF	Raw Data Exchange Format
RF	Radio Frequency
RSP	Realtime Signal Processor
SFTP	Secure File Transfer Protocol
SPC	Signal Processing Center
ST	Station Time, approximation to UTC as realized at receiver
Std	Standard
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UTC	Universal Time Coordinated
VLBI	Very Long Baseline Interferometry

Section 2
Functional Overview

2.1 General

The DSN provides open loop data to internal and external customers. Other Agencies provide open loop data to NASA or the DSN as specified in cross-support agreements. The CCSDS has developed a standard for exchange of open loop data known as Raw Data Exchange Format (RDEF), documented in the CCSDS 506.1-B-1 Blue Book. The current release of the OLR conforms to this standard. Many Agencies that NASA has cross-support agreements with also conform to this standard. As such, the data format given in this document applies to open loop data both provided by and provided to the DSN.

For DDOR users, predicts generated by Service Preparation Subsystem must be provided to the OLR. The OLR automatically generates a recording script for DDOR based on the SPS predicts. File exchange servers are used to exchange DDOR data with external customers when needed. Agreements for data exchange must be documented in an Operations Interface Control Document in the DSN 875-xxx series.

For Radio Science users, the Radio Science group at JPL generates a recording script for the OLR following the rules for header content and naming convention in the OLR Software Operations Manual DSN 837-083. Data may be provided to external customers in either the 0222-Science or the 0159-Science format. Data are provided on the Planetary Data System.

It is noted in Section 3 that some fields of the header portion of an RDEF record are reserved for internal Agency use. This document defines the header records as output by the OLR. The data in these internal reserved fields, from other Agencies, are not defined in this document.

Capabilities of open loop receivers in use at some external Agencies are documented in the CCSDS 500.1-G-1 Green Book.

2.2 OLR Signal Processing

The diagram in Figure 2-1 shows the relationship between the input digital IF groups and sub bands from the station digitizer and the one to sixteen channels of the OLR. The OLR covers 100 to 600 MHz. The OLR has 16 channels.

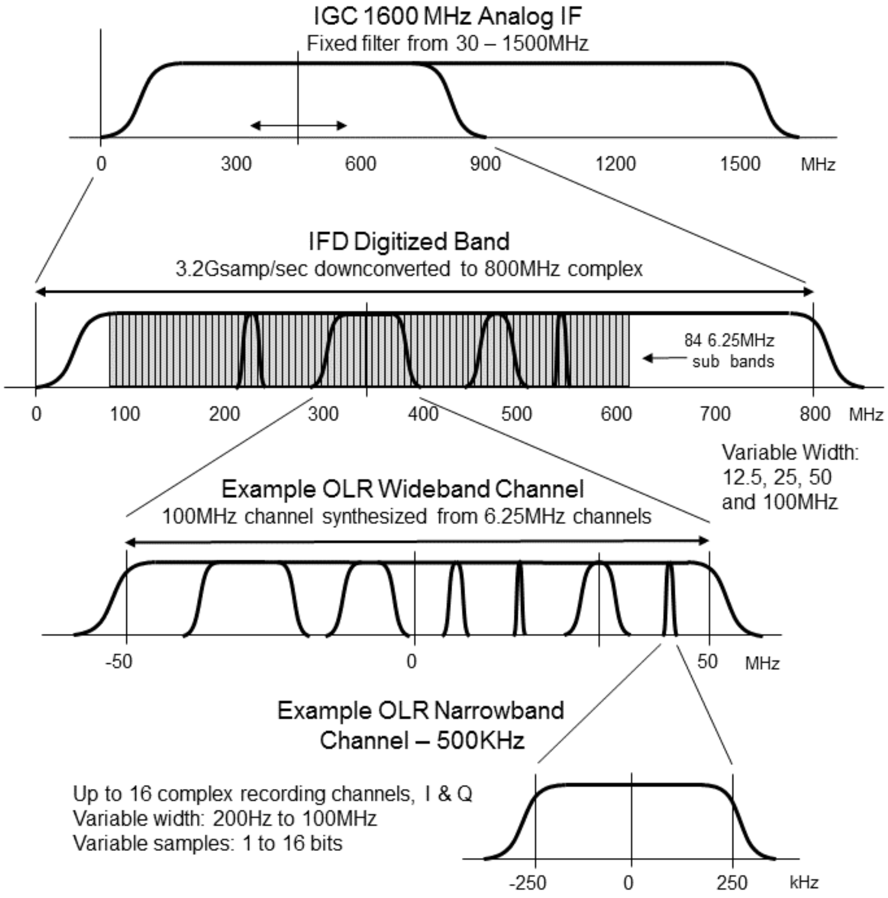

Figure 2-1 OLR Filter Processing

A spacecraft transmits a signal at Radio Frequency (RF), S-Band, X-Band, or Ka-band, to a receiving antenna on earth. Once received, the RF signal is down converted to an Intermediate Frequency (IF) signal of about 300 MHz and then fed to an IF Digitizer that sends 525 MHz of digitized signal to a 10Gb Digital IF Switch (DIS) that broadcasts the desired groups to the OLR upon request.

The switch allows each OLR to select from any of the IF signals feeding the DIS. Each output of the DIS feeds digital packets into one input of the OLR Realtime Signal Processor (RSP). Figure 2-2 illustrates the signal path from the antenna to the OLR and the signal path within the OLR that includes the Receiver Signal Processor Advanced Mezzanine Card (AMC) and the Data Processing and Control (DPC) computer.

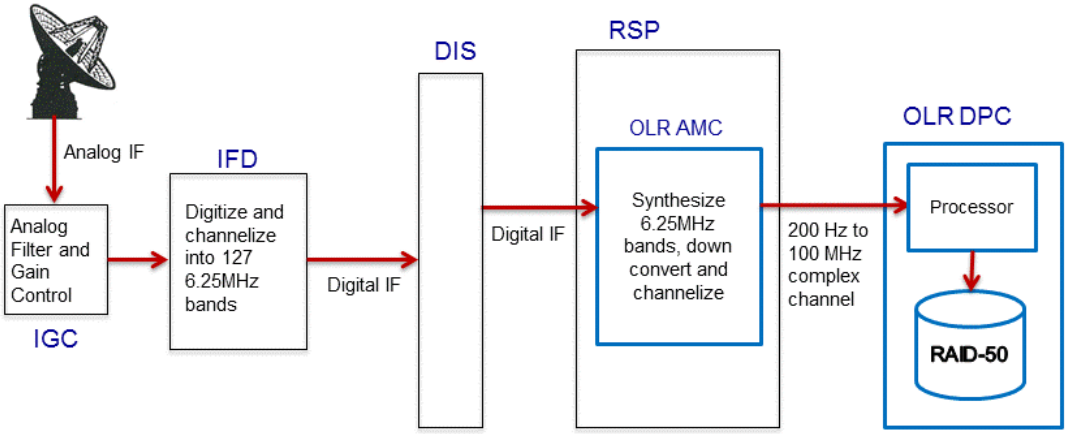

Figure 2-2 End-to-End OLR Data Flow Diagram

In the IF Gain Control assembly (IGC), the IF signal first passes through a programmable attenuator which is automatically adjusted at the start of each pass to provide the proper signal level at the IFD. Next, the signal passes through a Band Pass Filter which selects a frequency band from 10 to 610 MHz. The filtered signal is then digitized by the IFD and down converted to 800 MHz complex. The IFD breaks the 800MHz signal into 127 6.25MHz channels. A total of 84 of the 127 channels are fed into the Digital IF Switch (DIS). These 6.25MHz channels are then synthesized into larger channels by the RSP. The IFD also uses a 1 Pulse Per Second (1PPS) signal and a 1280 MHz data clock. The 1PPS signal marks the digital sample taken at the start of each second. The OLR AMC card downconverts and channelizes the data for recording on the RAID storage in the OLR servers.

The IF channels are downconverted to baseband by either a fixed frequency downconverter or a tuned downconverter that follows a Doppler profile. In the standard usage of the OLR, a tuned downconverter is represented by a cubic phase polynomial for each one second. The polynomial coefficients are stored in the header.

In the “Millisecond Predict” usage of the new OLR, rather than the “cubic phase polynomial” usage, a downlink frequency predict is calculated and used for each one millisecond of data recording. This predict representation is useful if the downlink signal is expected to have a sharp change in frequency within a one second interval, due perhaps to a change in the uplink ramp rate. Only the accumulated phase point in the header file remains valid. The three higher order phase polynomial coefficients are "NaN" ("not a number," or "7fffffffffffffff" in Hexadecimal) as indicated in section 3.4. It is not expected that the OLR will be run in Millisecond Predict mode for anything other than Radio Science with millisecond tracking.

The recorded data files are retrieved by users at JPL.

NOTE – The DDOR application does not use millisecond downlink frequency predicts.

2.3 Open Loop Receiver Data from Other Agencies

Through cross-support agreements, open loop data from tracking stations managed by other Agencies may be provided to the DSN for use by projects supported by the DSN. Examples include backup recordings for launch, EDL and other critical events, visible from non-DSN sites. Examples also include Delta-DOR data recorded at non-DSN stations. The format given in this document applies to open loop data from any non-DSN station that follows the CCSDS standard for RDEF.

Open loop data from other Agencies are normally transferred to JPL as specified in Operational Interface Control Documents that are written for cross-support agreements.

Section 3
Detailed Interface Description

3.1 OLR Data Exchange

The OLR is connected to the SPC LAN. This network interface is used for all operational communications with the OLR. The application software running on the OLR uses standard network protocols (TCP, IP, SFTP, UDP) for all communication. The transfer to JPL is via the Ground Communications Network (GCN). OLR data flows to the Differential One-way Range (DOR) subsystem, Radio Science, VLBI, and Radio Astronomy users through secure copy. External users will need to download, or be sent data from one of the internal JPL customers.

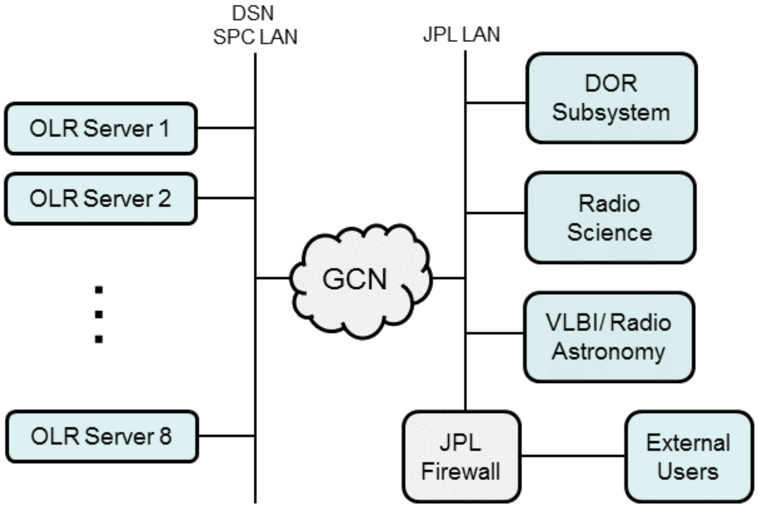

Figure 3-1 OLR to User Data Flow

The OLR partitions and formats the digital samples produced by its channel filters into a sequence of data records that can be stored to disk in real time, one file for each channel. Each data record contains one second of data samples. In addition, the header of each record contains the information necessary to reconstruct the signal represented by the recorded data samples in that record.

3.2 Allowed OLR Digital Channel Configurations

The OLR has 16 independent baseband channels. Each channel can receive a digital IF signal from any of the downconverted RF front ends available on the DIS. The channel input signal is downconverted from IF to baseband and filtered. The first stage digital downconversion is by a Digital DownConverter Local Oscillator (DDCLO) that is set to one of a discrete set of fixed frequencies. The second stage digital downconversion has fine resolution and can be at either a fixed frequency or can be tuned to follow a frequency profile.

A channel configuration is specified by 3 parameters:

(i) DDCLO, Hz
(ii) Bandwidth, Hz
(iii) Sample Resolution, bits/sample

The OLR synthesizes its channel input from 10 GbE multicast packets, each of which covers 12.5 MHz. The allowable values for DDCLO are:

DDCLO = N*25 MHz

for integer values of N that satisfy 100 MHz < DDCLO < 600 MHz .

There are 380 possible recording channel bandwidth configurations from 1KHz up to 100MHz. The following rules cover these:

all multiples of:

- 2 or 2.5 MHz up to 100 MHz
- 1 MHz up to 50 MHz
- 500 KHz up to 25 MHz
- 200 or 250 KHz up to 10 MHz
- 100 KHz up to 5 MHz
- 50 KHz up to 2.5 MHz
- 20 or 25 KHz up to 1 MHz
- 10 KHz up to 500 KHz
- 5 KHz up to 250 KHz
- 2 KHz up to 100 KHz
- 1 KHz up to 50 KHz

which should be adequate to cover the needs of OLR users. Note that this includes the supported bandwidths used in legacy JPL open loop receivers like the RSR, VSR, WVSR, PRSR and DVP.

The sample resolution can be set to 1, 2, 4, 8, or 16 bits/sample.

The maximum aggregate data rate for all channels in use on a single OLR is 1 Gbits/s.

3.3 RDEF Record Structure and Content

An RDEF file consist of several Records, each one containing exactly one second of data and related ancillary information for such second of data. Each Record consists of data represented in binary format, with two Sections:

a) The *Header* Section (see Section 3.4)

b) The *Data* Section (see Section 3.5)

NOTE – Figure 3-2 shows the general structure of one RDEF Record.

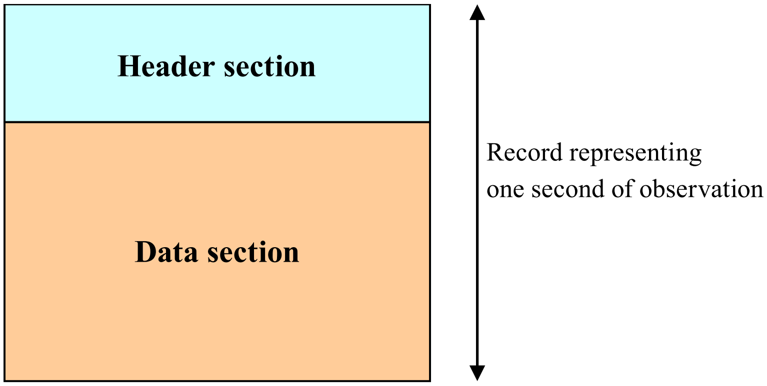

Figure 3-2 General Structure of one RDEF Record

Each RDEF File contains data for one channel and one station.

NOTE – The DDOR application also requires a separate file for each scan (continuous recording). For a typical 2-station DDOR sequence with 7 scans and 4 channels there will be 56 RDEF files.

The length of the Header Section is fixed as per Figure 3-3; 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.

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

NOTE – The structure of a Record is shown in Figure 3-3.

```
      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 3-3 Detailed Structure of the RDEF Record

3.4 RDEF Record – Header

The Header Section of the Record contains information related to the station configuration and the basic parameters used in the Record itself. The structure of the Header is fixed, as per Figure 3-4. The Header contains 31 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)                                                        |
      |                                               …                                               |
      +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
      | DOWNLINK BAND         | UPLINK BAND           | PREDICT PASS NUMBER                           |
      +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
      | OLR SOFTWARE VERSION  | OLR ID                | UPLINK DSS ID         | TRACK MODE            |
      +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
      | CHANNEL POWER CALIBRATION FACTOR                                                              |
      +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
      | TOTAL FREQUENCY OFFSET            (8 bytes)                                                   |
      +                                                                                               +
      +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
      | EMPTY FIELDS INTERNAL AGENCY USE  (3 bytes)                           | CHANNEL NUMBER        |
      +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
      | EMPTY FIELDS INTERNAL AGENCY USE  (16 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 3-4 General Structure of the Header

A detailed description of the Header is provided in Table 3-1, 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.

Data types conform to the notation and terminology introduced in Section 1.4.

NOTE – The DDOR application does not support the special values 'NaN', '-Inf', '+Inf', and '-0'.

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

NOTE – The station time at the receiver is referred to as 'ST' in Table 3-1.

Downconversion is represented as the sum of a fixed frequency plus a variable frequency signal.

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 3-1);

- $f_{IF-CHAN}$ = IF to channel downconverter frequency, Hz, (item IF_TO_CHANNEL DOWNCONV in Table 3-1);
- 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, when set to an integer Hz value, has integer cycle phase on the integer second boundary, that is $f_{IF-CHAN}\left(t-t_b\right)$ 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.

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

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

where

- $\Phi = \Phi(t_c, t_0)$ = integer part of accumulated downconverter phase at time t_0 (item CHANNEL ACCUMULATED PHASE in Table 3-1); 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 3-1);
- c_i = channel phase polynomial coefficient i, i=1,2,3 (items CHANNEL PHASE POLYNOMIAL COEFFICIENT 1 to 3 in Table 3-1);
- 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 3-1).

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

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

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 3-1: 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)	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
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

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
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
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

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
IF_TO_CHANNEL DOWNCONV	8	FLOATING POINT	Second downconversion stage: from IF to channel center frequency Resolution: 1micro-Hz	Hz NOTE 1 – The downconversion from IF to the channel center 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. *NOTE 2 – The DDOR application uses a value for IF_TO_CHANNEL_DOWNCONV that is an integer number of Hz.*	Y
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 day of year of the data contained in the record	1 to 366	Y
TIME TAG SECOND OF DAY	4	UNSIGNED INTEGER	Specifies the ST second of the day of the data contained in the record	0 to 86400	Y

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
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. Set to 0 if unknown. Should be the same for all channels and should not change during a recording session. Allowed range is 0 to 100,000	Y
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. Allowed range is -1 to +1 turn	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	Set to "NaN" for Millisecond Predict mode when millisecond downlink frequency predicts are used	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	Set to "NaN" for Millisecond Predict mode when millisecond downlink frequency predicts are used	Y
CHANNEL PHASE POLYNOMIAL COEFFICIENT3	8	FLOATING POINT	The 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	Set to "NaN" for Millisecond Predict mode when millisecond downlink frequency predicts are used	Y
EMPTY FIELDS (FUTURE EXTENSION)	36		Total number of bytes free to be used for future common use format extension		Y

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
PREDICT PASS NUMBER[*]	2	UNSIGNED INTEGER	DSN pass number from frequency predict file		Y
UPLINK BAND[*]	1	UNSIGNED INTEGER	Uplink band ID	0 => Unknown or not applicable 1 => S-band 2 => X-band 3 => Ka-band 4 => Ku-band 5 => L-band	Y
DOWNLINK BAND[*]	1	UNSIGNED INTEGER	Downlink band ID	0 => Unknown 1 => S-band 2 => X-band 3 => Ka-band 4 => Ku-band 5 => L-band	Y
TRACK MODE[*]	1	UNSIGNED INTEGER	Tracking Mode	1 or 2 or 3; 4 is allowed if signal is a relay	Y
UPLINK DSS ID[*]	1	UNSIGNED INTEGER	Uplink station ID		Y
OLR ID[*]	1	UNSIGNED INTEGER	Open Loop Receiver ID	31=>OLR1, 32=>OLR2, …, 38=>OLR8	Y
OLR SOFTWARE VERSION[*]	1	UNSIGNED INTEGER	Open Loop Receiver software version	=1 for initial version	Y
CHANNEL POWER CALIBRATION FACTOR[*]	4	FLOATING POINT	This factor provides conversion from dB full scale (dBfs) to dBm of channel at input to A/D converter, (IFD)		Y

---

[*] The content of this field is only defined for the DSN OLR.

Item Name	Bytes	Type	Item description	Allowed values	Mandatory Value
TOTAL FREQUENCY OFFSET*	8	FLOATING POINT	Offset of channel center frequency from predict	Hz	Y
CHANNEL NUMBER*	1	UNSIGNED INTEGER	Recording frequency channel number	1, 2, 3, …, 16	Y
EMPTY FIELDS (INTERNAL AGENCY USE)*	19		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

3.5 RDEF Record – Data

The Data Section of each Record of the RDEF file contains only the in-phase (I) and quadrature-phase (Q) samples recorded at the receiver.

Samples are packed into 32-bit words. A record contains an integer number of 32-bit words.

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 3-2 shows all possible cases.

Table 3-2: 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]

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

Truncation is 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.

To compensate for this offset, each sample must 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 3-5.

```
        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 3-5 General Structure of the Data Section of the Record

More detail about the packing of bits into the 32-bit words in provided in Tables 3-3 through 3-7 for 16-bit down to 1-bit samples.

Table 3-3: OLR Recorded Data Ethernet Packet Payload Section Description for 16-bit Samples

Bit #	*31 (msb)*	*30*	*29*	*28*	*27*	*26*	*25*	*24*	*23*	*22*	*21*	*20*	*19*	*18*	*17*	*16*	*15*	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
Content	I_n [m-8]	I_n [m-9]	I_n [m-10]	I_n [m-11]	I_n [m-12]	I_n [m-13]	I_n [m-14]	I_n [m-15]	I_n [m]	I_n [m-1]	I_n [m-2]	I_n [m-3]	I_n [m-4]	I_n [m-5]	I_n [m-6]	I_n[m-7]	Q_n [m-8]	Q_n [m-9]	Q_n [m-10]	Q_n [m-11]	Q_n [m-12]	Q_n [m-13]	Q_n [m-14]	Q_n [m-15]	Q_n [m]	Q_n [m-1]	Q_n [m-2]	Q_n [m-3]	Q_n [m-4]	Q_n [m-5]	Q_n [m-6]	Q_n[m-7]

Note: I_n/Q_n is a sample recorded at time n, with bit m as its most significant bit.

Table 3-4: OLR Recorded Data Ethernet Packet Payload Section Description for 8-bit Samples

Bit #	*31 (msb)*	*30*	*29*	*28*	*27*	*26*	*25*	*24*	*23*	*22*	*21*	*20*	*19*	*18*	*17*	*16*	*15*	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
Content	I_n [m]	I_n [m-1]	I_n [m-2]	I_n [m-3]	I_n [m-4]	I_n [m-5]	I_n [m-6]	I_n[m-7]	Q_n [m]	Q_n [m-1]	Q_n [m-2]	Q_n [m-3]	Q_n [m-4]	Q_n [m-5]	Q_n [m-6]	Q_n[m-7]	I_{n+1} [m]	I_{n+1} [m-1]	I_{n+1} [m-2]	I_{n+1} [m-3]	I_{n+1} [m-4]	I_{n+1} [m-5]	I_{n+1} [m-6]	I_{n+1}[m-7]	Q_{n+1} [m]	Q_{n+1} [m-1]	Q_{n+1} [m-2]	Q_{n+1} [m-3]	Q_{n+1} [m-4]	Q_{n+1} [m-5]	Q_{n+1} [m-6]	Q_{n+1}[m-7]

Note: I_{n+1}/Q_{n+1} is the samples recorded at time n+1 where 1 is the recording period.

Table 3-5: OLR Recorded Data Ethernet Packet Payload Section Description for 4-bit Samples

Bit #	*31 (msb)*	*30*	*29*	*28*	*27*	*26*	*25*	*24*	*23*	*22*	*21*	*20*	*19*	*18*	*17*	*16*	*15*	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
Content	Q_n [m]	Q_n [m-1]	Q_n [m-2]	Q_n [m-3]	I_n [m]	I_n [m-1]	I_n [m-2]	I_n [m-3]	Q_{n+1} [m]	Q_{n+1} [m-1]	Q_{n+1} [m-2]	Q_{n+1} [m-3]	I_{n+1} [m]	I_{n+1} [m-1]	I_{n+1} [m-2]	I_{n+1} [m-3]	Q_{n+2} [m]	Q_{n+2} [m-1]	Q_{n+2} [m-2]	Q_{n+2} [m-3]	I_{n+2} [m]	I_{n+2} [m-1]	I_{n+2} [m-2]	I_{n+2} [m-3]	Q_{n+3} [m]	Q_{n+3} [m-1]	Q_{n+3} [m-2]	Q_{n+3} [m-3]	I_{n+3} [m]	I_{n+3} [m-1]	I_{n+3} [m-2]	I_{n+3} [m-3]

Table 3-6: OLR Recorded Data Ethernet Packet Payload Section Description for 2-bit Samples

Bit #	Content
31 (msb)	Q_{n+1} [m]
30	Q_{n+1} [m-1]
29	I_{n+1} [m]
28	I_{n+1} [m-1]
27	Q_n [m]
26	Q_n [m-1]
25	I_n [m]
24	I_n [m-1]
23	Q_{n+3} [m]
22	Q_{n+3} [m-1]
21	I_{n+3} [m]
20	I_{n+3} [m-1]
19	Q_{n+2} [m]
18	Q_{n+2} [m-1]
17	I_{n+2} [m]
16	I_{n+2} [m-1]
15	Q_{n+5} [m]
14	Q_{n+5} [m-1]
13	I_{n+5} [m]
12	I_{n+5} [m-1]
11	Q_{n+4} [m]
10	Q_{n+4} [m-1]
9	I_{n+4} [m]
8	I_{n+4} [m-1]
7	Q_{n+7} [m]
6	Q_{n+7} [m-1]
5	I_{n+7} [m]
4	I_{n+7} [m-1]
3	Q_{n+6} [m]
2	Q_{n+6} [m-1]
1	I_{n+6} [m]
0	I_{n+6} [m-1]

Table 3-7: OLR Recorded Data Ethernet Packet Payload Section Description for 1-bit Samples

Bit #	Content
31 (msb)	Q_{n+3} [m]
30	I_{n+3} [m]
29	Q_{n+2} [m]
28	I_{n+2} [m]
27	Q_{n+1} [m]
26	I_{n+1} [m]
25	Q_n [m]
24	I_n [m]
23	Q_{n+7} [m]
22	I_{n+7} [m]
21	Q_{n+6} [m]
20	I_{n+6} [m]
19	Q_{n+5} [m]
18	I_{n+5} [m]
17	Q_{n+4} [m]
16	I_{n+4} [m]
15	Q_{n+11} [m]
14	I_{n+11} [m]
13	Q_{n+10} [m]
12	I_{n+10} [m]
11	Q_{n+9} [m]
10	I_{n+9} [m]
9	Q_{n+8} [m]
8	I_{n+8} [m]
7	Q_{n+15} [m]
6	I_{n+15} [m]
5	Q_{n+14} [m]
4	I_{n+14} [m]
3	Q_{n+13} [m]
2	I_{n+13} [m]
1	Q_{n+12} [m]
0	I_{n+12} [m]