

INFORMATION RELATIVE TO THE CLUSTER WBD LEVEL1 FILES

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1. INTRODUCTION

This document contains information that is useful for understanding and using the Cluster WBD LEVEL1 data files should a user wish to work with this lower level data product. Calibrated WBD data, along with supporting data, can be found at the Cluster Science Archive in CDF (Common Data Format) and CEF (Cluster Exchange Format). It is recommended that if one wishes to work with the original LEVEL1 data files, they should retrieve these files from the Cluster Science Archive and use the information contained below to help them read and work with the data. General information on the WBD instrument, its heritage and the Wideband technique are provided below in Appendix A, along with some useful references.

The LEVEL1 files contain the uncalibrated Cluster WideBand Receiver (WBD) time series data, both electric and magnetic field. Except for a limited amount of burst mode 2 (BM-2) data, this data set is derived primarily (~90%) from real time telemetry (normal science mode TDA-8) received by the NASA Deep Space Network (DSN) and Panksa Ves Observatory, Czech Republic, ground stations and forwarded to the University of Iowa, Iowa City, Iowa, USA, or the Institute for Atmospheric Physics (IAP), Prague, Czech Republic, for processing. The remaining 10% of the data are BM-2 mode, stored onboard, received on the ground, and then processed by the University of Sheffield, Sheffield, UK.

The LEVEL1 files are the result of the first level processing that the raw (telemetry) data have undergone by the University of Iowa, IAP and the University of Sheffield. The raw data files are checked for time and other problems, the time tags associated with each data record are determined (see Section 6 on Time Stamps and Appendix C), and all status and mode parameters are extracted. These values are then written into the LEVEL1 files along with the uncalibrated time series data. The burst mode-2 and real time raw data detailed above are the only sources of Cluster WBD data.

2. USE OF THE LEVEL1 FILES

All users of the WBD LEVEL1 files are encouraged to verify the correctness of the data by comparing their results to the calibrated WBD data archived at the Cluster Science Archive and/or by consulting a member of the WBD science team, a list of which can be found at the Cluster WBD website at Iowa (<http://space.physics.uiowa.edu/plasma-wave/cluster/>) prior to submitting any publication or other work based on these data. Users are encouraged to acknowledge the Principal Investigator of the data used in analysis in all publications.

3. NAMING CONVENTION OF THE LEVEL1 FILES

The LEVEL1 files contain ten minutes of time, at most. They have the following naming convention:

yymmddtt.ivs where:

yy = Last 2 digits of the year
mm = Month
dd = Day of month
tt = Ten-minute period in HEXADECIMAL.

Example:

tt = 20 (hex) = 32 (base 10)
32*10 minutes = 320 minutes of day
320/60 = 5.33333 Hours. 0.33333*60 = 20 minutes
The start time of the file will be 05:20:00.
The file will contain data with 05:20 <= time < 05:30.

Or going the other way, to find the file containing s/c 4 data at 13:47:00 on 23 Nov. 2003:

$(13*60 + 47)/10 = 82.7$ minutes (base 10)
Truncate to integer, 82 (base 10), and convert to hex, 52 (hex)
The file will be 03112352.8C4 (assuming a version 'C' file).

i = Instrument number (6-9)
v = Version number (Will be C, D, E, F, ... X, Y, Z
Later letters = more recent versions, with version A and B files already being obsolete. Most files will be version C, with only a few dates being reprocessed to version D to correct problems)
s = Spacecraft number (1-4)

For version 'C' files, the resulting extensions are: s/c 1 = 9C1,
s/c 2 = 6C2, s/c 3 = 7C3, s/c 4 = 8C4.

4. LEVEL1 FILE FORMAT

A detailed description of the format of the LEVEL1 data files is provided below in Appendix B. The WBD LEVEL1 data format is also provided at the following website:

<https://space.physics.uiowa.edu/plasma-wave/cluster/dvd/WBFORMAT.TXT>

The data files are in binary format (1-, 2-, and 4-byte unsigned integers) and contain no floating point values apart from a few bytes that are related to the telemetry (bytes 66-69 and 72-83). Multi-byte items are "most significant byte first" or "big endian". The only fields to which this applies will be the multi-byte fields, most of which hold time values.

Burst mode-2 data, which were recorded onboard and processed at the University of Sheffield, have been placed into the same LEVEL1 format as the DSN and Panska Ves real time data. There are some differences, primarily in that the burst mode records do not have any of the Ground Received Time fields (see Section 6 on Time Stamps and Appendix C) or any of the DSN-specific elements contained within the Standard Formatted Data Unit (SFDU) header area of the data record. See Appendix B below for the details on these differences.

5. SPACECRAFT NAMING CONVENTIONS

Note that the WBD instrument number that is in one of the status bytes (byte 1271 of LEVEL1 file--see Appendix B) has a value ranging from 4 to 7 and therefore must be mapped to the ESA spacecraft numbering system using the following table.

Instr. Status Value	Instr. #	DSN #	S/C Id	Old Name	Name	Color	Style	Symbol
4	6	185	2	FM6	Salsa	Red	_ _	Plus or Diamond
5	7	194	3	FM7	Samba	Green	. .	asterisk or Circle
6	8	196	4	FM8	Tango	Magenta	_ . .	Star or Triangle
7	9	183	1	FM5	Rumba	Black	_____	Cross or Square
^								^
<-- WBD Values			<-- ESA Values					

6. TIME STAMPS AND RELATIONSHIP TO OTHER CLUSTER DATA SETS

There are two sets of time stamps provided within the WBD LEVEL1 data files. The WBD time of measurement time stamps known as UT_OBT are derived using the On Board Time (OBT) counter and the ESA-supplied time calibration files. These derived times stamps should correlate with the time stamps provided to the other Cluster instruments by ESOC (European Space Operations Centre). The WBD UT_OBT time stamps are found in bytes 1232-1247, byte 1275 and byte 94 of the LEVEL1 record (see Appendix B).

There are also alternative time stamps available in the LEVEL1 files. These time stamps are derived using the DSN or Panska Ves Earth Received Time as a basis, as opposed to the On Board Time counter. These alternative time stamps are referred to as UT_GRT, and can be found in bytes 1224-

1231 of the LEVEL1 file (see Appendix B).

Appendix C describes the origin of these two possible time stamps.

The accuracy associated with both the UT_OBT and UT_GRT times stamps is about +/- 10 microseconds (see Appendix C for how this accuracy is determined).

UT_OBT is directly comparable to time stamps used by all other instruments on the Cluster spacecraft, for which the data are stored onboard and transmitted to ESA ground stations for processing. Thus, WBD UT_OBT is the most appropriate time stamp to use when comparing WBD data to that of other instruments on these spacecraft. UT_GRT is primarily for use in performing high time-resolution comparisons between the WBD data from the various Cluster spacecraft. However, with the introduction of the WEC time correction files, a comparable level of accuracy to UT_GRT can be obtained by applying the WEC time correction to UT_OBT.

7. ERRATA

Included below is a list of some of the known problems associated with the data contained in the LEVEL1 files. For data interpretation issues, please see the Cluster Interpretation Issues web page, available at:

https://space.physics.uiowa.edu/plasma-wave/cluster/caa_docs/interpretation.html

and also at the Cluster Science Archive as an Appendix in the WBD User Guide (<https://csa.esac.esa.int/csa-web/>) under the "Documentation" tab.

1. Known Cluster 2 Problems

(a) Existing Prior to Launch

WBD data received from Baikonour tests just prior to launch in 2000 revealed various problems with the WBD transfer frames that most likely originate in the Cluster Onboard Data Handling System (OBDH) on Cluster 2 only. Because these problems were discovered so late, it was not possible to do further diagnostics and correct the problems since it was felt that most of the problems could be worked around in ground processing. The following are the problems that were identified and how they are handled in LEVEL1 processing:

(i) Instrument Counter Values

The WBD instrument has a counter which is reset every 5.15 seconds. On Spacecraft 2, the value of this counter is not always read out correctly after a reset, resulting in an incorrect counter value being placed in the data record. After processing, these incorrect values remain in the level one files, although any errors they might have introduced into the time stamp calculations have been corrected.

(ii) Science Data Errors

When a science data point on spacecraft 2 has a value of 80 (hexadecimal), the following data point will sometimes have an invalid, but predictable, value. Iowa replaces the invalid value with the value 255 to signify that the value is bad and not deterministic. We provide a simple procedure which replaces the apparently incorrect value with the average of the two adjacent values (see FIX_SC2.C in the SOFTWARE/CLU2_FIX directory at the website

<https://space.physics.uiowa.edu/plasma-wave/cluster/dvd/>).

This procedure should be run before any calibrations are applied.

(iii) WBD Status Errors

Occasionally, any one of the WBD status bits can be corrupted. These status bits provide information about the mode and gain state of the instrument. Iowa corrects the decommutated status bits written into the level 1 files when this status bit is a mode bit, such as antenna being used, and width, and conversion frequency, but does not correct it when it is a gain state bit because it is difficult to determine what the correct gain state should have been. Because the calibration for the WBD data depends on knowing the correct gain state, the calibration that is applied to a frame with an errant gain state will be incorrect. This is usually apparent as a more or less intense frame slice compared to those on either side of it in the 30 second spectrograms (gifs) that are produced for every pass (note, however, that a gain state error is certainly not the only possible cause of such an artifact on the spectrograms). Note that this Status Error is not unique to Cluster spacecraft 2, but is relative to all WBD instruments on all Cluster spacecraft.

(b) Occurring after Launch

The following problems have occurred after launch which affect the timing and calibration of the WBD data obtained on Cluster 2:

(i) Onboard time stamp (UT_OBT) accuracy during period May 5-12, 2007

The onboard time counter contained within the WBD transfer frames is supplied to those transfer frames by the Onboard Data Handler (OBDH) on Cluster 2. ESOC provides WBD with a conversion routine and TCAL file that allows us to take this onboard time counter value and obtain a Universal Time (UT), which we then correct to time of measurement (UT_OBT) knowing the delays onboard from the time the measurement was made until the OBDH supplies a time counter value (see the Section 6 on Time Stamps and Appendix C). ESOC allows the UT time associated with the onboard time counter to drift up to a maximum of 2 milliseconds from "true" UT time, and then performs a time calibration to bring this drift back to zero. Thus, all WBD UT_OBT time stamps included in the WBD Level 1 files are stated to be accurate to within 2 milliseconds. However, in early May, 2007 it was not possible for ESOC to carry out the necessary ranging at the Maspalomas ground station in order to reset the drift back to zero after it had reached the 2 millisecond level. Instead the drift was allowed to reach approximately 8 milliseconds before the ranging was carried out and the drift reset to zero. Thus, for the period from May 5, 2007 through May 12, 2007, all UT_OBT time stamps found in the WBD Level 1 files for Cluster 2 are not guaranteed to be within 2

milliseconds of absolute UT. If UT_OBT time stamps with an accuracy better than 8 milliseconds are required during that period of time, the user will need to obtain the WEC time correction files from the Cluster Active Archive as described in Section 6 on Time Stamps and Appendix C. With the use of these corrections, accuracy to about 10-20 microseconds will be achieved.

(ii) Calibration of Ez antenna data following Probe 1 failure on May 13, 2007

On May 13, 2007 at 03:23:48 UT, Probe 1 of the EFW Ez antenna failed. The primary effect of this failure is that WBD, when using the Ez antenna, has lost one-half of the signal strength, relying only on the signal from Probe 2 of the Ez antenna. However, the situation is more complicated than this based on some special tests carried out on June 13, 2007 and July 29, 2007 in which WBD was switched between the Ez and Ey antennas in both the 9.5 kHz and 77 kHz bandwidth filter modes in order to characterize the exact signal loss while on Ez. The test data indicate that there is probably a frequency dependence related to effective antenna length, and thus the region of space in which the measurements are made. This being the case, WBD decided to switch to using the nominal Ey antenna for all Cluster 2 operations beginning on July 8, 2007. For the Cluster 2 WBD data obtained after the failure on May 13, 2007 the revised calibration routine (see section on Software below, and the link to the the CALIBRATE.C routine at the Iowa website) should be used to supply a 6 dB correction for the calibration. This correction will not take into account any frequency dependent differences, which are probably on the order of an additional 3-5 dB at most. Thus, the user needs to use these calibrated data obtained with the Ez antenna following the Probe 1 failure on Cluster 2 on May 13, 2007 with extreme caution, knowing that the calibrated amplitudes have a larger error bar. Various probe failure throughout the mission created similar changes to antenna length in calibrating the data. Refer to the WBD Calibration Report available at the Cluster Science Archive for all of these changes.

2. Known Problems with all spacecraft due to EFW electric antenna probe failures

Throughout the mission, various probes on each of the spacecraft have failed, necessitating WBD to switch to using the two probes of the other spin plane antenna (keeping full antenna length), or to any one probe and the spacecraft body (switching to an antenna of half length) to make its measurements. This first occurred with Spacecraft 2 as discussed above. The user of the LEVEL1 data files who wishes to calibrate the data should refer to the WBD Calibration Report available at the Cluster Science Archive in order to apply the correct antenna factor when calibrating the electric field measurements.

8. SOFTWARE

There exists a set of example software routines that read the LEVEL1 files. The code should be compatible with most common architectures supporting an ANSI standard C compiler. This software is available at:

<https://space.physics.uiowa.edu/plasma-wave/cluster/dvd/SOFTWARE/>

This website also provides routines to correct known problems found in the data (as noted in the ERRATA above) and routines to calibrate the electric and magnetic field wave data in the time domain for each instrument. Care must be taken when using the provided calibrations as the algorithm for applying the electric field calibration changed over the course of the mission due to the length of the electric field antenna. The correct antenna length for each spacecraft for any point in time can be obtained from the WBD Calibration Report which is archived at the Cluster Science Archive and available through the Cluster WBD website <https://space.physics.uiowa.edu/plasma-wave/cluster/> under “Data & Tools” in the pull-down menu. There is a table provided in this report that gives the antenna length for each of the two possible antennas (E_z and E_y) for each applicable time period for each spacecraft.

APPENDIX A: GENERAL INFORMATION ON THE WBD INSTRUMENT

1.1 Introduction

The Wideband (WBD) Plasma Wave Investigation for Cluster provides wideband waveform measurements of plasma waves in the Earth's magnetosphere. A Wideband Receiver system which measures electric and magnetic fields over the frequency range 100 Hz to 577 kHz is provided by the WBD investigation as part of the Wave Experiment Consortium (WEC) instrumentation. The Wideband Receiver provides unique measurement capabilities required for the detailed study of terrestrial plasma waves and radio emissions.

1.2 Design Heritage

The use of wideband instrumentation was first introduced with the Alouette 1 and Injun 3 satellites, and since that time, wideband measurements have become a standard technique for the study of space plasma waves. Wideband instrumentation has been carried by many spacecraft, including OGO 1 through 6, IMP 6 and 8, S(3), GEOS 1 and 2, S3-3, ISEE 1 and 2, Prognoz 8, Voyager 1 and 2, DE 1, Galileo, Cassini, Polar, and Cluster. The University of Iowa has constructed wideband instrumentation for many of these spacecraft. The Cluster Wideband Receiver is similar in design to instruments flown on ISEE 1, DE 1, and Polar.

1.3 Description of the Wideband Technique

The wideband technique involves transmitting band-limited waveform data to a ground station using a high-rate data link. On Cluster, about 90% of the WBD data that were obtained was transmitted in real time to NASA's Deep Space Network and the Panska Ves Observatory in the Czech Republic. The primary advantage of this approach is that complete, continuous waveforms are available for detailed high resolution frequency-time analysis, which may be performed to a level limited only by the uncertainty principle, $\Delta\omega \times \Delta t \sim 1$. Since the frequency resolution ($\Delta\omega$) and time resolution (Δt) may be selected and modified during data processing on the ground, the wideband technique is an extremely effective and flexible method for resolving features of interest in the plasma wave data. About 10% of the WBD data obtained on Cluster was recorded onboard in burst mode-2, being either digitally filtered, resulting in reduced frequency extent, or duty cycled, resulting in higher duty cycling (larger data gaps) for a chosen bandwidth, but maintaining the high time-frequency resolution aspect of the technique. The high resolution nature of the wideband technique is of particular importance for the proper identification and study of plasma emissions which have very complex frequency-time characteristics. The distinctive fine structures of chorus and auroral kilometric radiation, for example, were first identified using wideband measurements.

1.4 References

Additional sources of information on the Cluster Wideband instrument and investigation are as follows:

1. Home page of the Cluster Wideband Investigation on World Wide Web:

<https://space.physics.uiowa.edu/plasma-wave/cluster/>

2. "The Wideband Plasma Wave Investigation", D. A. Gurnett, R. L. Huff, and D. L. Kirchner, *Space Science Reviews*, Vol. 79, pp. 192-208, 1997. This investigation and instrument paper is also available on the WBD Website provided in Reference 1 under "About" in the pull-down menu.
3. "First results from the Cluster Wideband Plasma Wave Investigation", D. A. Gurnett, R. L. Huff, J. S. Pickett, A. M. Persoon, R. L. Mutel, I. W. Christopher, C. A. Kletzing, U. S. Inan, W. M. Martin, J. Bougeret, H. St. C. Alleyne, and K. H. Yearby, *Ann. Geophysicae*, 19, 1259, 2001.
4. "An investigation into instrumental nonlinear effects", S. N. Walker, M. A. Balikhin, I. Bates, and R. L. Huff, *Adv. Space Res.*, 30, 2815, 2002.
5. "Signal processing for the Cluster wideband data burst mode", K. H. Yearby, S. N. Walker, and J. S. Pickett, *Journal of Geophysical Research: Space Physics*, 131, e2025JA034623, <https://doi.org/10.1029/2025JA034623>, 2026.
6. "Modeling of Cluster's electric antennas in space: Application to plasma diagnostics", C. Beghin, P. M. E. Decreau, J. Pickett, D. Sundkvist, and B. Lefebvre, *Radio Science*, 40, RS6008, doi:10.1029/2005RS003264, 2005.
7. "The Digital Wave Processing Experiment on Cluster", L. J. C. Woolliscroft, H. Alleyne, C. M. Dunford, A. Sumner, J. A. Thompson, S. N. Walker, K. H. Yearby, A. Buckley, S. Chapman, and M. P. Gough, *Space Sci. Rev.*, 79, 209, 1997.
8. "The wave experiment consortium (WEC)", A. Pedersen, N. Cornilleau-Wehrin, B. De la Porte, A. Roux, A. Bouabdellah, P. M. E. Decreau, F. Lefeuvre, F. X. Sene, D. Gurnett, R. Huff, G. Gustafsson, G. Holmgren, L. Woolliscroft, H. S. Alleyne, J. A. Thompson, P. H. N. Davies, *Space Sci. Rev.*, 79, 93-105, 1997.

APPENDIX B: FORMAT OF WBD LEVEL1 FILES

----- Overview of format -----

	SFDU record as received from DSN with bytes 0-2, 94, and 96-103 modified.	
Byte 0	SFDU LABEL	Bytes 0-2 used to store record type and file version info
	HEADER AGGREGATION CHDP LABEL	
	PRIMARY HEADER	
	SECONDARY HEADER	
Byte 96	Uncorrected ERT at CTIB	Bytes 96-103 are used for storage of ERT at the CTIB reset flag
Byte 104	First 1119 bytes of 1279-byte transfer frame for WBD instrument sent from S/C to DSN stations (160 bytes of Reed Solomon code block not included)	See byte 104 for overview of transfer frame
	This is the end of the SFDU record with above noted modifications in Bytes 0-2, 94, and 96-103. The next blocks are generated by the LEVEL1 processing software.	
Byte 1224	UT_OBT and UT_GRT values: Time of measurement for the data, using two different calculation methods	
Byte 1248	Various reference values used in calculating UT	
Byte 1262	Instrument Status	
Byte 1275	Fraction of milliseconds component for UT_OBT	

Real time telemetry data (TDA-8 Mode) contain either VC5 or VC7 transfer frames. The VC5 records contain the WBD data while the VC7 hold fill data, but will contain the On-Board

time fields and usually also the CTIB flag, all of which are used when computing UT.

Burst mode (TDA-5.2 or BM2) records may contain either duty cycled data or filtered data from the solid state recorder. Duty cycled data are received when the spacecraft sends one out of every three normal data records. This type of data is not continuous. The time between these records will be $3 \times 39.718628 = 119.155884$ milliseconds when duty cycling is 100%. Times between records will vary when duty cycling is less than 100%. When not duty cycling, the data are filtered (by WEC-DWP, not by WBD) so that they contain only 1/3 the bandwidth but still maintain continuity. Within the LEVEL1 files, three filtered data records have been combined into one, so that each data set contains 1090 values. (Prior to decommutation by TED, the ESA records contain only $1090/3 \sim 394$ values each.) In the WBD LEVEL1 file, the start time of each filtered data set will be the start time of the first snapshot used to make the record, so that the time between records will also be 119.155884 milliseconds.

The data record contains Universal Times derived from two sources. One source is from the Earth Received Time (ERT) placed in the record by DSN. This time, called UT_GRT, has been corrected for delays in the system and propagation delays between the spacecraft and the ground antenna. Burst mode data records do not contain this time.

The other time is derived from the On-Board Time counter and the calibration data supplied by ESA. This time should be the one closest to the values used by the other instruments. This time is called UT_OBT. The difference between the UT_GRT and the UT_OBT, when both are available, is supposed to be at most 2 milliseconds, but occasionally can be up to 4 milliseconds.

The SFDU header information is described below in the LEVEL1 WBD Format section, for use in the interferometry studies, and in case data quality becomes an issue.

The following JPL documents were used to determine SFDU formats:

For data acquired prior to Dec. 27, 2002:

TLM-3-24 DSMS Document 820-13 Module TLM-3-24
 Deep Space Mission System External Interface
 Specification-Telemetry SFDU Interface for
 ISTP/Cluster

For data acquired after Oct. 13, 2003:

TLM-3-29 DSMS Document 820-13 Module TLM-3-29
 Deep Space Mission System External Interface
 Specification-Telemetry SFDU Interface for
 ISTP/Cluster

For data acquired in the transition period Dec. 27, 2002 to Oct.

13, 2003, both TLM-3-24 and TLM-3-29 were used depending on which antenna was in operation. In all cases, refer to Byte 5, Class Identifier, to determine which format was used for any given raw data file (see explanation of Byte 5 below).

Note that the TLM-3-29 format is 4 bytes shorter than that of TLM-3-24. To compensate, files using the TLM-3-29 format have had their SFDU contents shifted slightly from their original positions during LEVEL1 processing. This allows the same LEVEL1 format (as specified below) to be used for all files.

When differences between formats TLM-3-24 and TLM-3-29 exist, the specific bytes pertaining to the differences will be noted below, and will be labeled with "(3-24)" or "(3-29)".

----- LEVEL1 WBD Format -----

Bytes	Description
0-1	ASCII "55" (hexadecimal 3535) for DSN VC5 records. ASCII "77" (hexadecimal 3737) for DSN VC7 records. ASCII "5" in byte 0 and a zero in byte 1 (hexadecimal 3500) for Burst mode.
2-95	Bytes 2-95 of the JPL Telemetry SFDU, unmodified except byte 94, for DSN mode. In burst mode bytes 2-65 contain the burst mode header information. (See Burst Mode section below.)
The SFDU header in DSN mode contains the following pertinent information:	
Telemetry SFDU Label (bytes 2-19):	
2	LEVEL1 File Version or ASCII "P" for "NJPL" (NASA/JPL) NOTE: If byte 2 is not the ASCII character "P" (equivalent integer value of 80), then the integer value of this byte impacts how bytes 94, 1266, and 1274 are used. See bytes 94, 1266, and 1274.
3	ASCII "L" for "NJPL" (NASA/JPL)
4	Version Identifier: ASCII "2" (equivalent integer value of 50) -> Length Attribute in bytes 12-19 is formatted as a binary unsigned integer
5	Class Identifier:
(3-24)	ASCII "Z" (equivalent integer value of 90)
(3-29)	ASCII "I" (equivalent integer value of 73) -> Indicates that this SFDU is an application data object
6-7	ASCII "00"
8-11	Data Description Identifier:
(3-24)	ASCII "0001"
(3-29)	Integer value of 9999

- 12-19 Length Attribute:
Integer that is the sum of the total lengths (number of bytes) of the aggregation CHDO and the telemetry data CHDO.
- Aggregation CHDO Label (bytes 20-23):
- 20-21 Type Attribute:
Integer value of 1
- 22-23 Length Attribute:
(3-24) Integer value of 76.
(3-29) Integer that is the length (number of bytes) of the aggregation CHDO which is the sum of the lengths of the primary CHDO and secondary CHDO which is 72.
- Primary CHDO (bytes 24-31):
- 24-25 Type Attribute:
Integer value of 2 indicating that this CHDO is a primary CHDO.
- 26-27 Length Attribute:
Integer value of 4 indicating remaining length of primary CHDO.
- 28 Major Data Class:
Integer value of 1 indicating that this SFDU contains spacecraft telemetry.
- 29 Minor Data Class (0-2): See following tables.

----- 3-24 Format -----

CLASS	DESCRIPTION
0	Raw Data Bits are blocked arbitrarily
1	Frame Alignment. An attempt is made to begin each block on a telemetry frame boundary.
2	Decoding. An attempt is made to decode the outer code (RS) in each telemetry frame.

----- 3-29 Format -----

CLASS	FRAME SYNCHRONIZER CONFIGURATION	REED-SOLOMON DECODER CONFIGURATION
0	Disabled	Disabled
1	Enabled	Disabled
2	Enabled	Enabled

- 30 Mission Identifier (0-255):
(3-24) Integer value of 0 for ISTP Cluster.
(3-29) Used only for missions supported by AMMOS. Missions not supported by AMMOS, the value of this field is 254.
- 31 Format Code:
Integer value of 0 indicates this is a DSS-formatted SFDU
- Secondary CHDO (bytes 32-95):
- 32-33 Type Attribute:

- (3-24) Integer value of 70 indicates this CHDO is a telemetry secondary CHDO.
- (3-29) Integer value of 71 indicates this CHDO is a telemetry secondary CHDO.
- 34-35 Length Attribute:
 - (3-24) Integer value of 64 indicates remaining length of secondary CHDO.
 - (3-29) Integer value of 60 indicates remaining length of secondary CHDO.
- 36 Originator Identifier:
 - Integer value of 48 indicates the SFDU originated within DSN.
- 37 Last Modifier Identifier:
 - Integer value of 48 indicates this SFDU was last modified by DSN.
- 38 Spacecraft Identifier
- 39 Data Source (DSN Antenna/Facility Identifier):
 - For example, an integer value of 15 would indicate the data were received by DSS-15 at Goldstone. The Goldstone complex consists of antennas 14, 15, 24, 26, and 27; the Canberra complex of 34, 43, 45, 46; and the Madrid complex of 54, 63, 65, 66.
- 40-41 Flags: See following tables.

----- 3-24 Format -----

Byte	Bit	Description
40	7	0 if ERT is valid or 1 if ERT is known to be invalid
	6-0	Reserved
41	7-0	Reserved

----- 3-29 Format -----

Byte	Bit	Description
40	7	0 if ERT is valid or 1 if ERT is known to be invalid
	6	Reserved
	5	0 if ERT should be ignored or 1 if ERT is valid
	4	0 if ERT refers to trailing edge of last received telemetry bit in SFDU or 1 if ERT refers to leading edge of first telemetry bit in SFDU
	3-0	Reserved
41	7	0 if diagnostic mode is disabled or 1 if diagnostic mode is enabled
	6	0 if SNR (bytes 76-79) is estimated in the symbol domain or 1 if SNR is estimated in the bit domain
	5-0	Reserved

- 42-49 Earth Received Time (ERT)
 - Format: Bytes 42-43 Days since Jan. 1, 1958
 - Bytes 44-47 Milliseconds of day
 - Bytes 48-49 Microseconds of MS

- 50-53 Record Sequence number (should be 1 to $2^{32} - 1$).
 - Caveat: These numbers will probably not be

sequential in places where data from one DSN file has been joined with data from another, or across LEVEL1 file boundaries. There can be discontinuous jumps in value, either forward or backward, in these places.

- 54 Acquisition BET (bit error tolerance):
Integer value of 0-15 indicating number of allowed bit errors in the attached sync marker during search and verify modes.
- 55 Maintenance BET:
Integer value of 0-15 indicating number of allowed bit errors in the attached sync marker during lock and flywheel modes.
- 56 Verify Count (0-15):
Number of within-tolerance telemetry frames required, during verify mode, to transition to lock mode.
- 57 Flywheel Count (0-15):
Number of out-of-tolerance telemetry frames required, during flywheel mode, to transition to search mode.
- 58-59 Number of Received Telemetry Bits:
Indicates number of received telemetry bits contained in telemetry data CHDO. If number is less than length of telemetry data CHDO, then unused bits appear at the end of the field and should be ignored.
- 60 Frame sync mode flags: See following table.

Bit	Description if bit = 1
7	Frame synchronizer is in bypass mode
6	Frame synchronizer is in search mode
5	Frame synchronizer is in verify mode
4	Frame synchronizer is in lock mode
3	Frame synchronizer is in flywheel mode
2	Automatic polarity correction (APC) is enabled
1	Reserved
0	Operator forced resynchronization

- 61 Sync Status (bits 0-4): See following table.

Bit	Description
4-1	Reserved
0	Data Polarity flag. 0 indicates the true sync marker is detected. 1 indicates complemented sync marker is detected, and if APC is enabled (see byte 60), the frame synchronizer inverts all bits in the frame. Ignore this bit if frame synchronizer is in bypass or search mode.

- 61 Bit slip status code (bits 5-7):
A non zero code indicates telemetry data CHDO contains a telemetry frame that is longer or shorter than the nominal length. See following tables.

2 DSS 15, 45, or 65 used.
 1 DSS 12, 42, or 61 used.
 0 DSS 16, 46, or 66 used.

(3-29) Virtual Stream ID

85 Reserved

86-87
 (3-24) Master Antenna & Master Receiver Numbers:
 Byte 86 is the same as byte 84 except that one and only one bit (corresponding to the Master Antenna) will be set.
 Byte 87 shows the Master Receiver used. See following table.

Bit	Description if bit = 1
7	Receiver #8 used.
6	Receiver #7 used.
5	Receiver #6 used.
4	Receiver #5 used.
3	Receiver #4 used.
2	Receiver #3 used.
1	Receiver #2 used.
0	Receiver #1 used.

(3-29) Receiver ID (unsigned integer)

88
 (3-24) DTM Group Number (unsigned integer)

89
 (3-24) TLM Channel Number (unsigned integer)

88-89
 (3-29) Telemetry Processor ID

90-91 Telemetry Lock Status: See following table.

Byte	Bit	Description	Possible Values
90	7-6	Symbol synchronization	0 = not in use or lock status unknown 1 = invalid value 2 = in lock 3 = out of lock
	5-4	Subcarrier demodulation	
	3-2	Array	
	1-0	Carrier demodulation	
91	7-6	Reserved	3 = out of lock
	5-4	Reed-Solomon decoding	
	3-2	Frame synchronization	
	1-0	Convolution decoding	

92-93 Telemetry Software ID:
 Identifies telemetry software version in use. (ASCII)

94 Least significant digit of UT_OBT Microsecond (as derived from On-Board time counter).

The number of microseconds in the UT_OBT Second is given by:

$$\text{UT_OBT Microseconds} = (\text{integer in bytes 1246-1247}) * 1000 + (\text{integer value in byte 1275}) * 10 + \text{integer value in byte 94}$$

NOTE: Byte 94 is used only if byte 2 has an integer value of 2 or greater. If otherwise, then use the above formula as if byte 94 had a value of zero.

95 Reserved

Telemetry Data CHDO: (bytes 96-1223)

96-103 ERT (Earth Received Time, not adjusted) corresponding to current CTIB Flag. See bytes 1224-1231 for format.

----- Burst Mode -----

For burst mode data, most of the SFDU header byte locations will be used for burst mode processing information. Below is the format for this information, as provided by the WEC-DWP team:

2	Software Version (Ted Decommutation software)
3	Software Revision (Ted)
4	Software Patch (Ted)
5	Software User Patch (Ted)
6-7	Spacecraft ID
8-9	Ground Station ID
10-11	Source Instrument
12-13	Diagnostics Word
14-15	Length of Science Data
16-17	SCE_year - 1900
18-19	SCE_month
20-21	SCE_day_of_month
22-23	SCE_hour
24-25	SCE_minute
26-27	SCE_second
28-29	SCE_millisecond
30-31	SCE_usec
36	Gain Index (multiply by 5 to obtain gain)
37	EW4PRCTL (processing control duplicate of byte 1261)
38	EW4VMON0 (WBD Voltage Monitor)
39	EW4VTMON (WBD Temperature Monitor)
40	EW4WBDHK if 1, WBD data is via DIP and is in burst mode; if 0 then the HK bytes assigned to gain contain Whisper information
41	EW4STSCN (WBD status count)
42-57	8 sets of Gain indicators from WEC

Housekeeping, 2 bytes each

- 58-59 WBD STAT1
(STAT1 & 0030) >> 4 indicates
conversion frequency:
0 0 kHz
1 125 kHz
2 250 kHz
3 500 kHz

- 60-61 WBD STAT0

- 62-63 WBD STAT2
(STAT2 & 0003) indicates antenna:
0 Ey
1 Bx
2 By
3 Ez
(STAT2 & 001C) >> 2 indicates Frequency
Mode 0-7

- 64-65 EW5SSOFF

The remaining bytes 66-123, except 94 are filled with zeroes.

Cluster Telemetry Transfer Frame (bytes 104-1222):

----- Overview of Transfer Frame -----

Byte 0	ESA SYNC MARKER
Byte 4	PRIMARY HEADER
Byte 10	SECONDARY HEADER
Byte 14	DATA FIELD (6 WBD sync/status bytes + 1090 data bytes)
Byte 1110	ON BOARD TIME COUNTER
Byte 1117	RFB
Byte 1118	CAB
Byte 1119	REED-SOLOMON CODE BLOCK

Bytes 104 to 1222 in the LEVEL1 files are bytes 0 to 1118 of the transfer frame as illustrated above and sent by the spacecraft; i.e., the transfer frame

minus the Reed-Solomon code block. With the removal of the Reed-Solomon code block a time quality flag has been added and is byte 1223 of the LEVEL1 file.

 Transfer Frame header (bytes 104-117):

104-107

ESA Sync Marker
 (Hex: 1A CF FC 1D)

Primary Header (bytes 108-113):

108-109

Frame Identification
 NOTE: In DSN data, the record type may be found from the low order 3 bits of (byte 109)/2 (i.e. bits 1-3 of byte, 109), which will give the Virtual Channel (VC) ID (should only have a value of 5 or 7).

110

Master Channel Frame Counter
 NOTE: This counter keeps a running count of the total virtual channel frames (VC5 and VC7 combined).

111

Virtual Channel Frame Counter (32 bytes)
 NOTE: The highest order byte for this counter is in byte 117, followed by bytes 116, 115, and 111. If the current frame has a VC ID of 5, then this counter supplies the count of this VC5 frame. If the current frame has a VC ID of 7, then this counter supplies the count of this VC7 frame.

112-113

Frame Data/Field Status
 Secondary Header (bytes 114-117):

114

Secondary Header ID

115-117

Virtual Channel Frame Counter (32 bytes)
 NOTE: See byte 111.

WBD Data block (bytes 118-1213):

118-123

For DSN data these bytes will contain sync and instrument status; for burst mode data these bytes will be all zeros.

	----- Byte number -----					
	118	119	120	121	122	123
Frame 00	FA	F3	34	frame#	count2	count1
Frame 01	FA	F3	34	frame#	count0	stat3
Frame 10	FA	F3	34	frame#	stat2	stat1
Frame 11	FA	F3	34	frame#	stat0	stat3

Four frames (numbered 0-3) comprise a major frame. It takes 1 major frame to get all of the status information. The time between Major Frames is 158.8745116 msec. The time between minor frames depends upon the percent of the duty cycle. See DUTY CYCLE MODE below. The Frame value (0-3) is contained in the low order two bits of byte 121.

See Status Word Formats below for details of status word encoding. We have placed the decoded status information in bytes 1262-1274.

124-1213 Data Field: 1090 data bytes.

Trailer block of transfer frame (bytes 1214-1223):

On Board Time (OBT) Counter (7 bytes):

1214-1217 OBT counter Seconds for this record.

1218-1220 OBT counter Sub-Seconds as a 20 bit integer left justified for this record.

1221 RFB (low order bit = 1 => time is good)

1222 CAB Contains the CTIB flag in low order bit.

NOTE: Byte 1223 of the DSN record contained the Reed-Solomon status and was a part of the trailer block. We have modified it as shown below.

1223 Time quality flag: See following table.

Bit	Description if bit = 1
7	Raw clock value (bytes 1256-1259) was adjusted
6	Frequency mode value (byte 1272) was adjusted
5	Frequency offset value (byte 1269) was adjusted
4	Antenna value (byte 1268) was adjusted
3	Second gain value (byte 1274) was adjusted
2	First gain value (byte 1266) was adjusted
1	Uncorrected ERT value (bytes 96-103) was not expected
0	Uncorrected OBT value (bytes 1248-1255) was not expected

An adjusted value does not mean that the value was bad but that the value computed in the normal manner appeared to be incorrect.

END OF TRANSFER FRAME

The following UT_GRT is the UT time of measurement for the data, as calculated using the Earth Received Time as its basis. It has been corrected for all delays between when the data were acquired at the WBD instrument and the time when the data arrived at the ground:

1224-1231 UT_GRT
Format: Bytes 1224-1225 Days from start of year 2000
Bytes 1226-1229 Milliseconds of day
Bytes 1230-1231 Microseconds of MS

The following UT_OBT is the UT time of measurement for the data, as calculated using the On-Board time counter and the calibration data supplied by ESA.

1232-1233 UT_OBT Year (2xxx)
1234-1235 UT_OBT Month of year
1236-1337 UT_OBT Day of month
1238-1239 UT_OBT Day of year
1240-1241 UT_OBT Hour
1242-1243 UT_OBT Minute

1244-1245 UT_OBT Second
1246-1247 UT_OBT Milliseconds (0 - 999)

The number of microseconds in the UT Second is given by:

$$\text{UT_OBT Microseconds} = (\text{integer in bytes 1246-1247}) * 1000 \\ + (\text{integer value in byte 1275}) * 10 \\ + \text{integer value in byte 94}$$

NOTE: Byte 94 is used only if byte 2 has an integer value of 2 or greater. If otherwise, then use the above formula as if byte 94 had a value of zero.

1248-1255 OBT Counter value corresponding to current CTIB flag (format is the same as for bytes 1214-1220).

NOTE: This is used as the reference time when calculating UT_OBT. The CTIB flag will be set every 5.152221 seconds, when the instrument clock/counter is reset. Thus, this counter value will change every 5.152221 seconds. For UT_GRT, the equivalent reference time is contained in bytes 96-103.

1256-1259 The WBD instrument counter value (WBDClock) for the current major frame. The CTIB flag indicates a reset of this counter.

Symbolically, both the UT_OBT and UT_GRT times are calculated as follows:

$$T = \text{reference_time} + \\ \text{WBDClock} / 1003631.274 \text{ (seconds)} + \\ \text{minor_frame_number} * 39.718628 \text{ (milliseconds)}$$

Note however, that the actual time calculations are more complex than this (see Section 6 on Time Stamps and Appendix C for further information).

1260-1261 In DSN mode these bytes contain the number of bits by which the LEVEL1 software has shifted the WBD Data block (bytes 118-1213) within the transfer frame. In the raw transfer frames, the WBD data block is not aligned such that a single block is wholly contained within a single transfer frame. With this shift, the LEVEL1 software corrects this. In burst mode these bytes contain the processing control, a 2-byte integer: 0 => duty cycled data; non-zero => filtered data. For filtered data the sampling rate is reduced after digital filtering, and:
1 => every third point is saved,
3 => also every third point is saved,
4 => every fourth point is saved.

INSTRUMENT STATUS for both DSN and Burst Mode data (bytes 1262-1274):

In DSN data, these are determined from bytes 122 and 123. In Burst mode this information is obtained from the housekeeping data and placed in the record header by the Ted decommutation software.

1262 1 = VCXO not locked 0 = VCXO locked
 1263 0 = OBDH interface primary 1 = OBDH interface redundant
 1264 0 = no cmds 1 = cmds
 1265 0 = a/d power off 1 = a/d power on
 1266 Gain/Select (Gain in dB = (byte 1266) * 5)
 NOTE: If LEVEL1 File Version (byte 2) is 2 or greater, then
 this gain is that for the current minor frame. For
 earlier versions, the usage depends on the duty cycle
 mode (see byte 1272):
 100% duty cycle -> gain is for frames 1 and 2 of
 the current major frame
 not 100% duty cycle -> gain is for frames 2 and 3 of
 the current major frame

1267 0 = gain auto 1 = gain manual
 1268 Antenna select: 0 = Ez 1 = Bx 2 = By 3 = Ey
 1269 Frequency offset: 0 = 0 Hz 1 = 125.454 kHz 2 = 250.908 kHz
 3 = 501.816 kHz

1270 AGC upper threshold
 1271 Instrument ID
 value Inst. Spacecraft
 4 F6 2
 5 F7 3
 6 F8 4
 7 F9 1

1272 Frequency Mode (0-7): See table of modes & duty cycling
 below.

1273 AGC lower threshold
 1274 Gain/Select (Gain in dB = (byte 1266) * 5)
 NOTE: If LEVEL1 File Version (byte 2) is 2 or greater, then
 this gain is that for the current minor frame. For
 earlier versions, the usage depends on the duty cycle
 mode (see byte 1272):
 100% duty cycle -> gain is for frame 3 of the
 current major frame and frame
 0 of the *next* major frame
 not 100% duty cycle -> gain is for frames 0 and 1 of
 the *next* major frame

1275 Most significant two digits of fractional UT_OBT milliseconds
 (0-99, hundredths of ms)

 The number of microseconds in the UT_OBT Second is given by:

$$\text{UT_OBT Microseconds} = (\text{integer in bytes 1246-1247}) * 1000$$

$$+ (\text{integer value in byte 1275}) * 10$$

$$+ \text{integer value in byte 94}$$

 NOTE: Byte 94 is used only if byte 2 has an integer value of
 2 or greater. If otherwise, then use the above formula
 as if byte 94 had a value of zero.

----- End of LEVEL1 WBD Format -----

NOTE: Unless otherwise noted, all byte values are unsigned integers.

----- Instrument Modes -----

There are eight modes that the WBD instrument can be set to use (although only the first seven are distinct from a user's point of view). The modes are differentiated by:

- Bandwidth - the frequency span of the input bandpass filter.
- Sample Rate - the sampling rate of the instrument.
- Bits/Sample - the number of bits with which each sample is encoded.
- Duty Cycle - the fraction of time that the instrument is sampling.
- Sample Time - the time spanned by one complete minor frame.

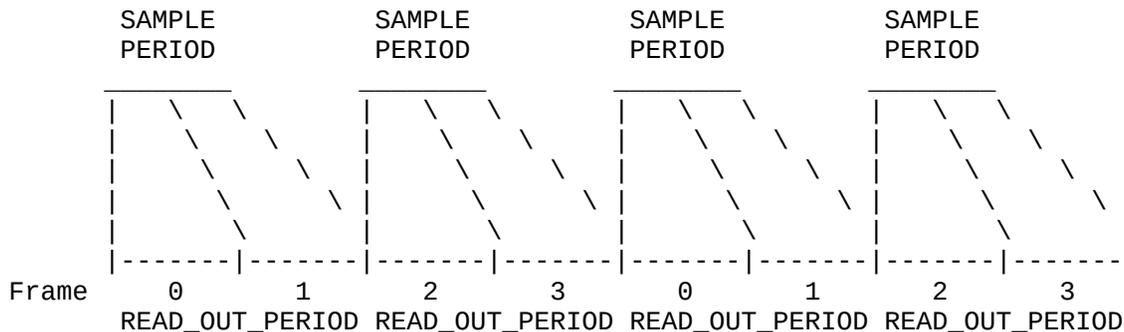
The mode for a data frame is given in byte 1272. The different modes are:

Mode	Bandwidth	Sample Rate	Bits/Sample	Duty Cycle	Sample Time (msec)
0	100Hz-9.5kHz	27.4kHz	8	100%	39.7186279
1	100Hz-9.5kHz	27.4kHz	8	100%	39.7186279
2	100Hz-19kHz	54.9kHz	4	100%	39.7186279
3	100Hz-19kHz	54.9kHz	8	50%	19.85931395
4	700Hz-77kHz	219.5kHz	8	12.5%	4.96482848
5	700Hz-77kHz	219.5kHz	1	100%	39.7186279
6	700Hz-77kHz	219.5kHz	4	25%	9.92965697
7	700Hz-77kHz	219.5kHz	8	12.5%	4.96482848

Note that these parameters are not all independent. Some of the parameters, and their interdependencies, are expanded upon further below.

Duty Cycle Modes:

For some combinations of sample rate and bits/sample, the resulting data stream, if sampled continuously, would be produced at a rate greater than the available downlink rate. In these cases, the instrument instead samples the incident waveform in a duty cycle mode. In such modes, high-rate data is acquired (and saved in an internal WBD buffer) for a fixed sample period, and simultaneously read out to the downlink module at a lower rate over a longer interval. The read-out interval is always two minor frames (2180 data bytes) in length, so the sample period always begins at the start of every second minor frame (specifically, at the start of minor frames 0 and 2). The case of 50% duty cycling is illustrated below:



The length of the sample period is always such that 2048 samples are acquired.

The timestamps on each minor frame of duty cycled data will clearly not be regularly spaced. Frames 0 and 2 will always begin 2×39.718628 milliseconds apart, but frames 1 and 3 will follow their preceding frames by the interval given in the Sample Time column in the instrument mode table above.

Reduced Bits/Sample Modes:

An alternative way to acquire high-rate data, within the constraints of the available downlink rate, is to reduce the number of bits used to encode each sample. In these cases, the samples (either four bits or one bit in length) are packed into bytes as follows:

- 4-bit mode: In each byte, the low order nibble (bits 0-3) contains the oldest sample, so the byte should be unpacked from low nibble to high.
- 1-bit mode: In each byte, the low order bit (bit 0) contains the oldest sample, so the byte should be unpacked from the low bit towards the high.

Burst Mode:

For burst mode data, the data streams described above are further attenuated (by WEC-DWP, not by the WBD instrument), in one of two ways:

- Burst Mode/Duty Cycled - Only every third minor frame is stored on (and later transmitted by) the spacecraft. This means that when the duty cycle is 100%, only 1 out of every 3 minor frames is recovered, at 50%, only 1 out of every 6, at 25% only 1 out of 12, and at 12.5% only 1 out of 24 minor frames is recovered. (See Instrument Modes table above.)
- Burst Mode/Filtered - All frames will be transmitted, but are low pass filtered to one third of the frequency bandwidth. Since each snapshot in this data is 1/3 the usual length of 1090 bytes, data from 3 consecutive frames will be concatenated into one frame by the Ted software. The 1090 sample frames are always constructed with a fixed relation to the repeating sequence of 6 input packets (sizes of 360, then 5 sets of 364 bytes). That is 360+364+364+2 for the first frame, then 362+364+364 for the second.

----- Status Word Formats -----

The following shows how to decode status bits from bytes 122-123 (of minor frames 2-3). The decoded status values are found in bytes 1262 through 1274.

Byte	Bit	Description
stat3	7	VCX0 Lock (1=Not Working; 0=Lock)
	6	OBDH Interface (0=Primary; 1=Redundant)
	5	Command Status (0=No cmds; 1=Cmnds received)
	4	A/D Converter Power
	3-0	Gain Level/Select
stat2	7-6	11
	5	Gain Mode (1=Manual; 0=Auto)
	4-1	Gain Level/Select
	0	OBDH Interface (0=Primary; 1=Redundant)

stat1	7-6	01
	5-4	Antenna Select (see byte 1268 above)
	3-2	Frequency Select (see byte 1269 above)
	1-0	Upper AGC Threshold
stat0	7-5	Instrument ID (see byte 1271 above)
	4-2	Output Mode (see byte 1272 above)
	1-0	Lower AGC Threshold

Glossary:

Burst Mode Data Data stored on the solid state recorder and telemetered non-real-time to the ESA ground station.

CHDO Compressed Header Data Object.

CTIB Coincident Transmission Indication Bit:
This is a bit in the Transfer Frame, which is set whenever the transmission of that frame is coincident with the resetting of the WBD instrument counter (WBDClock).

DSN Deep Space Network:
The NASA ground station network at which most of the WBD data are received.

ERT Earth Received Time:
This time is put in the SFDU header at the time the data were received by the DSN ground station.

ESA European Space Agency.

OBT Spacecraft On Board Time counter, driven by an ultra-stable oscillator. Time calibration (tcal) files provided by ESA allow for the conversion of counter values into UT times.

SFDU Standard Formatted Data Unit.

UT_GRT UT timestamp on data, based on Earth (Ground) Received Time: GRT adjusted time for delays in the system, and all signal propagation effects, so that it is the time when the data were acquired at the WBD instrument, i.e. the time of measurement.

UT_OBT Timestamp on data, based on the On Board Time:
The time calculated using the OBT and the ESA time calibration files.

WEC-DWP The Digital Wave Processor instrument that is part of the Wave Experiment Consortium (WEC) on Cluster.

For C programmers, most of this format information is incorporated in an include file SOFTWARE/EXAMPLES/WBDL1.H which contains macro and table definitions to make extracting the fields described above (and some derived items) much easier. Care was taken to construct macros that should work on most common platforms.

APPENDIX C: DERIVATION OF TIME TAGS CONTAINED IN WBD LEVEL 1 FILES

The following describes the process used in deriving the two types of time tags attached to data records in the WBD LEVEL1 files. These two types are UT_OBT (Universal Time_On Board Time) and UT_GRT (Universal Time_Ground Received Time).

UT_OBT

The origin of UT_OBT is the master ultrastable oscillator on each spacecraft, or more specifically, the counter that is incremented by it. Every WBD transfer frame (the fundamental telemetry unit from the spacecraft) contains the value of this counter at the instant at which the frame is transmitted. During ground processing, the WBD team used this counter value plus the tcal (time calibration) files supplied by ESOC (European Space Operations Centre) to obtain the Universal Time (UT) associated with that counter value. Next, internal delays within the spacecraft (from the instant of measurement at WBD, through processing within the Onboard Data Handling System, which provides the onboard counter value and constructs the transfer frame) are calculated and applied, thus arriving at the UT time of measurement at WBD. This is referred to as UT_OBT. This time stamp will usually be within 2 milliseconds (msec) of "true" UT, as required by the specifications for OBT, but there are brief periods where UT_OBT may differ from "true" UT by up to 4 msec. The difference from "true" UT is primarily the result of slow drifts of the spacecraft oscillators, which result in the tcal files gradually losing accuracy. Once this drift resulted in a difference between calculated UT and "true" UT of more than 2 msec, ESOC carried out a time calibration at its ground station, and then generated revised tcal files that reset the difference back to zero.

The method used to obtain the UT_OBT time stamps for all frames in any given WBD pass (which can be anywhere in length up to about 6-7 hours) is to determine the time of the first full frame, and then apply a "delta time" to this for each successive frame of the pass, where "delta time" is the known time interval between frames based on the data transfer rate and the tick rate of the onboard oscillator.

In order to obtain UT_OBT time stamps with better accuracy, there are WEC (Wave Experiment Consortium) time correction files that can be obtained from the Cluster Science Archive (CSA) (<https://csa.esac.esa.int/>). These files have names in the format

C#_CP_DWP_TCOR_YYYYMMDD_Vnn.cef

where # is the spacecraft number (1 through 4), YYYY is the year, MM is the two-digit month, DD is the two digit day, and nn is a version number. There are three columns in these files, the first containing a Date/Time string (Epoch), the second an offset value (Offset), and the third a difference value (Diff). For WBD data, only the Epoch and Diff values are needed to calculate a time correction. The data in each file are divided into blocks by rows that have the value -1.0e31 entered in both the Offset and Diff columns. Each block consists of a start and end Epoch value, with associated Offset and Diff values. To obtain the correction at a given instant, find the block that contains that instant within its bounds, and linearly interpolate between the two Diff values. The result (which may be negative) is the number of microseconds (usec) to add to UT_OBT to obtain a UT time stamp which should be accurate to at least +/- 10 usec.

UT_OBT is directly comparable to time stamps used by all other instruments on the Cluster spacecraft,

for which the data are stored onboard and transmitted to ESA ground stations for processing. Thus, WBD UT_OBT is the most appropriate time stamp to use when comparing WBD data to that of other instruments on these spacecraft.

UT_GRT

The origin of UT_GRT is the Earth Received Time (ERT) parameter applied to every WBD transfer frame that is received on the ground in real time by Deep Space Network (DSN) and Panska Ves Observatory ground stations. ERT is the UT time at which DSN or Panska Ves received the transfer frame on the ground, and is usually accurate to within 10-50 usec. This time is then adjusted for time of flight and other data path effects to give a UT time stamp corresponding to the time of measurement at the WBD instrument, also accurate to within 10-50 usec. As mentioned above for UT_OBT, there are slow drifts within the spacecraft oscillators, and these also lead to time drifts in UT_GRT. The ESOC-supplied tcal files are used to obtain a value for the oscillator tick rate, but the actual rate will drift relative to one obtained from the tcal. Since UT_GRT is obtained by fixing the time of the first frame of a WBD data pass and then applying a "delta time" (which depends on the tick rate) to it for each successive frame of the pass (anywhere in length up to about 6-7 hours), any drift in the tick rate will show up as a small drift in UT_GRT over the duration of the pass. This small drift rate is not accounted for in the LEVEL1 files.

Occasionally, especially early in the Cluster mission (up to mid 2003) there will be WBD LEVEL1 files that contain only fill data for UT_GRT. The reason for this is that the hardware and software being used by DSN during this period would occasionally introduce time offsets into their ERT time stamps on the order of a few to tens of msec. Since there is no way to determine the exact amount of this offset after the fact, the WBD team was forced to insert fill data for the UT_GRT time stamp. In these cases, UT_OBT should be used, along with the WEC time correction files, to get accuracy of +/- 10 usec.

UT_GRT is primarily for use in performing high time-resolution comparisons between the WBD data from the various Cluster spacecraft. However, with the introduction of the WEC time correction files, a comparable level of accuracy to UT_GRT can be obtained by applying the WEC time correction to UT_OBT.