Requirements on the LFI On-Board Compression

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1. Introduction

1.1 Scope of the Document

The present document describes the requirements for the compression program and the On-Board compression operations for PLANCK/LFI.

1.2 Definitions

Definitions are made accordingly to the Data Model document [3] and the current baseline for the Packet Structure [1].

In this document the syntax to indicate a data structure composed of n, lexicographically ordered components is:

StructureName:= [*component-1*, *component-2*, …, *component-n*]

to be read as:

StructureName **is-composed-of** *component-1*, *component-2*, …, *component-n*.

As an example a packet composed of one Header (H) and a Body (B) is represented as:

Packet := [Header, Body].

Particular features or abbreviations for the components name may be quoted inside the '[.]' by '(.)'. As an example:

Packet := [Header (H), Body (B)].

Radiometer Acquisition Chain

The Radiometer Acquisition Chain (RAC) is the pipeline (hardware plus software) responsible for the production of samples at the output of a radiometer.

Attributes of RAC are:

i) Radiometer Identification Code (RIC)

Data Stream

A Data Stream (DS) is a string of consecutive samples collected at the output of a RAC.

DSs are sons of RACs.

Attributes of DSs are:

i) the RIC of the parent RAC;

ii) the Pointing Period Number (PPN) during which the DS is generated;

iii) its length;

iv) the time stamp (TSMP) of the first sample.

Data Chunk

A Data Chunk (DCK) is a segment of a Data Stream made of consecutive samples.

DCKs are sons of DSs.

Attributes of DCKs are:

i) the parent DS attributes;

i) the index of the first sample (IFS) of the DCK in the data stream.

ii) the length L_{dc}.

Compressed Data Chunk

A Compressed Data Chunk (CDC) is a Data Chunk after compression.

CDCs are sons of DCK

Attributes of DCKs are:

i) the parent DCK attributes;

ii) the CDC length L_{cdc}.

Telemetry Source Packets

A Telemetry Source Packet (TSP) is defined as a packet containing Telemetry Data. Its structure is defined in [2]:

i) TSP:= [Source Packet Header (SPH), Packet Data Field (PDF)];

ii) Maximum Length for a TSP $L_{tsp} = 1024 \times 8$ bits;

iii) Fixed Length for the SPH $L_{sph} = 6 \times 8$ bits;

iv) Maximum Length for the PDF $L_{pdf} = 1018 \times 8$ bits.

Packet Data Field

A Packet Data Field (PDF) is a segment of TSP containing the data to be transmitted. Its structure is defined in [2]:

i) PDF := [Data Field Header (DFH), Source Data (SD), Packet Error Control (PEC)];

ii) Variable PDF Length L_{pdf};

iii) Maximum $L_{pdf} = 1018 \times 8$ bits;

iv) Fixed DFH length $L_{dfh} = 10$ x 8 bits;

v) Fixed PEC $L_{pec} = 2 \times 8$ bits;

vi) Variable Data Field length L_{df};

vii) Maximum $L_{df} = 1006 \times 8$ bits.

Scientific Telemetry Source Packets

A Scientific Telemetry Source Packet (STSP) is a TSP containing only the scientific data produced by the radiometers.

STSPs shall be homogeneous, i.e. they are filled with a set of consecutive samples from the same radiometer. This is assured assuming that each STSP is filled by one and only one Data Chunk stored in the Packet Data Field (PDF).

STSPs shall be generated, stored, transmitted or received in any order. Independently from the radiometer or the chronological order in which the data are acquired from each radiometer.

Scientific Packet Data Field

A Scientific Packet Data Field (SPDF) is the data segment of a STSP.

Summary Telemetry Source Packet

A Summary Telemetry Packet (SuTSP) is a TSP containing a summary of all the relevant alarms generated by the Compression Algorithm Module.

Statistics

Statistical evaluation is required by compression adaptive algorithms so to optimize the coding scheme to the particular statistics of the input data stream.

Compression Metrics

The following quantities are valid metrics for the compression process:

Compression Rate

The ratio between the length (in bits) of the Data Chunk and of the corresponding Compressed Data Chunk stored in the PDF.

$$C_r = L_{dc}/L_{cdc}$$

Memory Budget

The amount of memory (M_{cmp}) required to compressing a Data Chunk.

Time Budget

The amount of time (T_{cmp}) or the number of clock cycles required to compressing the Data Chunk.

Bad Compression Event

A Bad Compression Event (BCE) occurs when the compressor is unable to compress properly the data, so that the compressed data chunk is longer than the uncompressed data chunk.

Compressor Failure Event

A Compressor Failure Event (CFE) occurs when the compressor is unable to complete the compression procedure (as an example: because it receives bad input data, a time out occurs, the allocated memory is not enough, etc.) and is terminated before its end.

1.3 List of Acronyms

BCE	Bad Compression Event
CAM	Compression Algorithm Module
CAMAL	Compression Algorithm Module Alarm
CFE	Compression Failure Event
CRC	Compressed Data Chunk
DCC	Data Coding and Compression
DCK	Data Chunk
DFH	Data Field Header
DPC	Data Processing Centre
ECM	Error Control Module
h/k	House Keeping
PDF	Packet Data Field
PDF_GM	PDF Generation Module
PDFA	PDF Assembler
PEC	Packet Error Control
PPN	Pointing Period Number
RAC	Radiometer Acquisition Chain
RIC	Radiometer Identification Code
s/c	Space Craft
sci	Science
SD	Source Data
SDAEM	Scientific Data Acquisition and Elaboration Module
SEV	Statistical Evaluation
SPDF	Scientific PDF
SPDF_GM	Scientific PDF Generation Module
SPDFH_GM	Scientific PDF Header Generation Module
SPH	Source Packet Header
STSP	Scientific Telemetry Source Packet

STSP_GM	STSP Generation Module
SuT	Summary TSP Tag
SuTSP	Summary Telemetry Source Packet
TBC	To Be Confirmed
TBD	To Be Defined
TOD	Time Ordered Data
TSMP	Time Stamp
TSP	Telemetry Source Packets
ZBPA	Zero Bits Padding Area

1.4 Applicable and Reference Documents

[1] *On-Board Data Processing, Compression and Telemetry Rate* - ISSUE # 3.0 - 21 April 2000

[2] SCI-PT-ICD-07527 *Packet Structure – Interface Control Document* – Issue: 1 September 2000

[3] PL-COM-OAT-SP-001 *Planck IDIS Data Model Specification Document* – Issue: 2.1, 21 July 2000

[4] *Data streams from the Low Frequency Instrument On-Board the Planck Satellite* – Vol. 147 No. 1 November II 2000, p.51

[5] ECSS-E-70/41 *Telemetry and Telecommand Packet Utilization Standard*

[6] PL-LFI-OAT-TN-011 *Quantization Errors on Simulated LFI Signals* – ISSUE # 0.1 – 10 July 2000

2. Assumptions

2.1 Assumptions on Software Structure

From the point of view of this document, a STSP and TSP are structured as two-layers packets with the upper layer represented by the SPH, and the lower layer represented by the PDF.

In this document it is assumed that a hierarchical structure of applications or services is responsible for the packet generation. Each application or service is responsible for the generation of a single layer or part of it. The detailed structure of the packet generation mechanism, as the detailed interaction between applications or services is not defined here. It is assumed that the STSP Generation Module (STSP_GM) is an already existing general purpose module. The STSP_GM is responsible of the generation of the SPH and its assembling with a PDF generated by a dedicated PDF Generation Module (PDF_GM).

The PDF_GM relevant for this document is responsible for the production of a PDF containing science data. It is called Scientific PDF_GM (SPDF_GM). It is interfaced with the Scientific Data Acquisition and Elaboration Module (SDAEM) which is responsible for the data acquisition from the radiometers and its elaboration.

The SPDF_GM shall be composed of:

1. Compression Algorithm Module (CAM) which generates the PDF containing a compressed data chunk. This module incorporates the following functions:
   1.1 On line Statistical Evaluation (SEV) for each Data Chunk received in input
   1.2 Data Coding and Compression (DCC)
2. An interface with the Scientific Data Acquisition and Elaboration Module or the dump memory area in which the output of the SDAEM is stored.
3. Science PDF Header Generator Module (SPDFH_GM) which generates the Science PDF Header.
4. Error Control Module (ECM) which generates the PEC. It assumed that the ECM is a part of the general purpose services implemented in the framework of the telemetry packets libraries.
5. PDF Assembler (PDFA) which assembles packets using the products of the other modules and manages activity and communications between them.

It assumed that the CAM will send to the SPDFH_GM and the ECM the Compressed Data Chunk together with all the information required by them in order to generate a proper SPDFH and PEC.

2.2 Assumptions on Level 1 Decompressing and Decoding Process

It is assumed the following (simplified) model for Level 1 processing (TBC) of an STSP, to be performed at the LFI Data Processing Centre (DPC). Part of the processing is in common with TSP processing (TBC). Note that not all of these steps have to be regarded as true steps or single steps of the final Level 1 processing. The reason for this model is simply to recognize compression and packing constraints introduced by the requirements of Level 1 operations.

1 A TSP is received and recognized by Level 1.

2 The TSP is split in its TPH and PDF.

3 The PDF is split into its DFH, SD, PEC

4 The error detection test is performed to check consistency between PEC and PDF content.

5 If this fails an attempt is performed to fix the error (TBC) or if this is not possible an error message is generated and the packet is discarded.

6 If the packet is valid the Packet Type is identified (h/k, s/c, sci).

7 If the packet is a STSP (i.e. sci) it is sent to the STSP processing pipeline

8 Looking at the DFH, the STSP processing pipeline checks if the packet is compressed, if it is, the packet is decompressed,

9 If decompression fails an error message is generated and the decompressed Data Chuck is rejected.

10 The parent detector is recognized looking at the DFH content.

11 The Data Chunk location in the detector TOD is recognized looking at the DFH content.

12 The Data Chunk is joined to the detector TOD in the proper location.

13 A success message is generated and the processing is terminated.

2.3 Scope of the Summary Telemetry Source Packet and Usage Scenario

The proposal for the generation of a SuTSP is motivated by the need to skip the worst delay time (more than 24 hours) between the generation of one alarm by the radiometers and its detection at the MOC and at the Ground Segment (GS). This prevents both MOC and GS (MOC/GS) from to have a prompt detection, analysis and reaction to a severe failure in the acquisition chain.

A failure in the acquisition chain is considered severe when it causes the continuos production of bad data and/or a continuous inability of the Onboard Compression Module to compress efficiently them. Such problems may be harmful for the entire mission since they may result in data loss and/or the inability to download the data (given the limited bandwidth).

The scope of the SuTSP is to alert the MOC and the Ground Segment of a severe problem occurring between the last data download and the new one, even if the problem is no more occurring at the beginning of the new connection period. The MOC and the Ground Segment will accord priority to the analysis of the data tagged in the SuSTP as severely alarmed.

The SuSTP shall be compiled starting from the alarms generated by the Compression Algorithm Module.

The SuSTP is made of a list of SuSTP Tags (SuT), each SuT will carry information which will allow to reconstruct which detector is suspected to have a severe failure, which part of the data stream is affected, the most frequent alarm or the type of failure.

A SuT shall be generated if the data produced by a detector will cause frequent compressor alarms (CAMAL).

The rationale to look at the compressor alarms to generate SuTs is the fact that the compressor must process all the data streams. Any relevant alteration of data due to a relevant radiometer failure will be reflected in an alteration of the data statistics (detected by the compressor statistical module), and/or in alterations of the compressor performances (as the compression efficiency).

The frequency, the number and the type of alarms generated by a given detector in order to trigger a SuT generation, i.e. to hypothesize the existence of a severe problem is TBC and will be tuned on a working prototype of the compressor installed on the REBA.

In order of reduce the amount of time between the on board alarm generation and the MOC/ground segment reaction, a mechanism to generate a summary of all the alarms from the compression stage may be included.

Of course, to prevent any significant increase in the h/k telemetry, if a large number of alarms is generated, the number of the Summary TSPs generated and sent to Earth shall be limited (no more than 1 or 2 packets per day – TBC). In this case the SuTSP sent to Earth will contain a specific SuT remarking this kind of problem while the SuT generation mechanism will be stopped till the begin of the next connection period.

3. Requirements

3.1 General Requirements

General requirements are listed in this section (see also [1]):

OBC-GEN-01.The compressor shall be lossless. It shall assure the full reconstruction of the scientific content of each STSP, without any added noise or distortion.

OBC-GEN-02. The compressor shall be adaptive respect to data stream statistic fluctuations.

> *The compression shall be optimal even after stochastic changes in the statistical distribution of the data stream samples, provided that the range of these changes is acceptable for a properly working radiometer.*

OBC-GEN-03. The compressor shall be adaptive respect to effects induced by relevant anomalies or failures in the acquisition chain.

> *The compression shall be as high as possible even if unexpected changes in the statistics of the data stream occurs, due to important anomalies or failures in the detection chain.*

OBC-GEN-04. The compressor never shall increase the Data Chunk Length even in case of Bad Compression Event or Compressor Failure Event.

> *In the case of failure or bad compression, the resulting output stream length from the compressor shall not exceed the length of the input data stream.*

OBC-GEN-05. The compressor always shall give in output the full Data Chunk received in input.

> *In short the compressor output never shall contain less samples than those received in ouput.*

OBC-GEN-06. In the case of Compressor Failure Events or Bad Compression Events the input Data Chunk will be given in output uncompressed.

OBC-GEN-07.The generated packets shall be independent.

OBC-GEN-08. Each STSP shall be self-consistent. I.e. any information required to perform the decompression/decoding and reconstruction of the scientific content of a given STSP shall be included in its SPH.

OBC-GEN-09.The loss of a STSP shall not influence the interpretation of any other STSP.

3.2 Compression Algorithm

A baseline algorithm has been defined [2]. However as noticed in [2] and [4] its definitive acceptance is conditioned by a practical demonstration of a working prototype, installed on the REBA. Test shall be performed also with the aid of the flight simulator. Test shall demonstrate the compression efficiency, the computational feasibility (i.e. that the cost in term of memory and elaboration time is sustainable), and the compressor robustness in case of unexpected events. More over, the testing phase will evaluate the *quality* of the compression algorithm defined in terms of the distribution of STSP packets lengths and the variance of the compression rate induced by the sampling variance of the input data stream. This set of requirements is related to all these aspects. Note that the definition of the validation and testing protocol is outside the scope of this document.

OBC-CA-01 On the hypothesis of a quantization step σ/q ~ 2 the compression efficiency shall be at least 3.8.

OBC-CA-02 The baseline compression method should be 16 bits, Adaptive Arithmetic Compression order 0 (TBC)

OBC-CA-03 The demonstration of the compression efficiency (OBC-CA-01) of the baseline compression code shall be performed operating the prototype on the flight simulator and, in suborder, on the REBA, both in nominal working conditions or assuming different damages scenarios.

OBC-CA-04 The computational feasibility of the compressor (execution time and memory demand) shall be demonstrated using a working prototype installed on the REBA, both in nominal working conditions and assuming different REBA overload scenarios.

OBC-CA-05 The robustness against unexpected failures of the compression code shall be demonstrated using a working prototype installed on the REBA and, in suborder, on the flight simulator, both in nominal working conditions or assuming different damages scenarios.

OBC-CA-06 The *quality* of the compressed data stream shall be evaluated looking at the distribution of PDF lengths, the number of packets not fulfilling the requirement (OBC-PS-02) and at the C_r variability induced by the sampling variability in the input data stream.

OBC-CA-07 The C_r variability in time shall not exceed the entropy sampling variance of the input data stream.

OBC-CA-08 If after the tests required in (OBC-CA-03, 04, 05, 06 and 07) the Baseline Compression Code (OBC-CA-02) would reveal unfeasible, Bit Coding schemes may be looked as a backup solution.

3.3 I/O Data Format Requirements

I/O data format are subject to the constrains imposed by

i) interfacing with the acquisition and onboard processing chain;

ii) interfacing with the PDF Field Header and Error Control Generator.

OBC-IOF-01 To limit the number of operations and to assure modularity the compressor shall be able to handle in input numbers generated by the acquisition and onboard processing chain without any translation.

OBC-IOF-02 The CAM shall accept in input 2×8 bits numbers;

OBC-IOF-03 The CAM shall accept in input the bit ordering scheme used by the REBA for the acquisition and onboard processing. It may be little or big endian ordering scheme (TBD).

OBC-IOF-04 The CAM shall generated a Compressed Data Chunk which will be in a format suitable for a prompt storing in the PDF.

OBC-IOF-05 The Compressed Data Chunk shall be composed of an integer, even number of octets.

OBC-IOF-06 The maximum number of octets shall be 1006.

In other words each PDF shall not be longer than 1006×8 bits.

OBC-IOF-07 A Zero Padding Area (ZBPA) shall be chained to the end of the Compressed Data Chunk in order to fulfil (OBC-IOF-05).

This requirement as (OBC-IOF-08, 09 and OBC-IPS-07) are valid if the final compression algorithm will not cope with (OBC- IOF-05). The need of a ZBPA depends in effect on the particular implementation of the compression algorithm so that it is still TBC.

OBC-IOF-08 The Maximum Length of the ZBPA shall not exceed 15 bits.

OBC-IOF-09 The size of the ZBPA (L_{pad}) shall be stored in the PDF Data Field Header, not in the Compressed Data Chunk.

OBC-IOF-10 The L_{pad} in the PDF Data Field Header is represented as a 4 bits unsigned integer.

3.4 Packet Content and Structure

OBC-PS-01 To ensure Packet Homogeneity each STSP shall contain data from only one radiometer.

OBC-PS-02 The compression algorithm shall assure *Maximal Packet Filling*. I.e. each PDF shall fit as more as possible the maximum PDF size derived from (OBC-IOF-06).

This and the next requirement assure maximum compression efficiency and minimal packetization overhead.

OBC-PS-03 The fraction of Data Fields generated by the compressor shorter than the maximum size specified in (OBC-IPS-06) shall be minimized.

3.5 Interfacing of CAM with Other Modules

Requirements in this section are related to how the CAM shall be interfaced to the rest of the compression and packing module.

OBC-IPS-01 The CAM shall receive in input the Radiometer Identification Code (RIC).

OBC-IPS-02 The CAM shall receive in input the index indicating the position of the first sample to be compressed in the related radiometer stream.

OBC-IPS-03 The CAM shall put in output the length of the Compressed Data Chunk in octets (L_{cdc}).

OBC-IPS-04 The CAM shall put in output the length of the Data Chunk in octets (L_{dc}).

OBC-IPS-05 The CAM shall put in output the RIC.

OBC-IPS-06 The CAM shall put in output the indexes indicating the position of the Compressed Data Chunk in the related radiometer Data Stream.

OBC-IPS-07 The CAM shall put in output the ZBPA size.

This requirement is consistent with (OBC-IOF-09) and shall be neglected if a Zero Bits padding should be not required.

OBC-IPS-08 The CAM shall put in output the alarms it generates.

This is more detailed by requirements in subsection 3.6.

OBC-IPS-09 The CAM shall put in output the results of the monitoring of its activity.

This is more detailed by requirements in subsection 3.6.

3.6 Activity Monitor and Alarms

OBC-AFS-01 The compression algorithm shall monitor its activity and performances.

In particular the parameters to be monitored are: Compression Efficiency, Compression Time, Memory Requirement, Compression Failures, Statistical Alarms.

OBC-AFS-02 Anomalies in the compression algorithm activity shall generate alarms.

OBC-AFS-03 Alarms shall be managed in the framework of normal h/k telemetry.

OBC-AFS-04 The result (i.e. success/failure) of each compression attempted shall be a compression module output.

OBC-AFS-05 If compression fail an alarm shall be generated.

OBC-AFS-06 The Compression module shall evaluate for each Compressed Data Chunk the related compression efficiency.

OBC-AFS-07 The compression efficiency shall be given in output to the compression module.

OBC-AFS-08 If the compression efficiency is smaller than a nominal working range an alarm shall be generated.

OBC-AFS-09 The amount of time or clock cycles (T_{cmp}) required to perform the compression shall be evaluated for each Compressed Data Chunk.

OBC-AFS-10 The T_{cmp} shall be an output of the compression module;

OBC-AFS-11 If T_{cmp} is over a nominal working range ($T_{cmp,th}$) an alarm shall be generated.

OBC-AFS-12 The amount of memory (M_{cmp}) required to perform the compression shall be evaluated for each Compressed Data Chunk.

OBC-AFS-13 The M_{cmp} shall be an output of the compression module;

OBC-AFS-14 If M_{cmp} is larger than a nominal working range ($M_{cmp,th}$) an alarm shall be generated.

OBC-AFS-15 The statistical module shall generates estimates for signal average and variance for each Compressed Data Chunk;

OBC-AFS-16 If average and variance are outside a working range an alarm shall be generated.

3.7 Summary Telemetry Source Packet

This section describes the requirements for the Summary Telemetry Source Packet and the SuTSP generator.

OBC-STP-01 A Summary Telemetry Source Packet (SuTSP) Tag shall be generated if the amount and/or frequency or time distribution of alarms specified in (OBC-AFS-02) will be outside a given working range.

4. Further Comments, Suggestions for the Implementation

Further comments and suggestions to create an effective implementation are reported here.

4.1 Storage of Data Structures from the Statistical Module

In order to have a faster and more effective compression scheme the time required to the statistical module in order to fit the signal statistics should be as small as possible.

At the same time the compressor module has to compress many, short Data Chunks coming in a more or less unpredictable order from different detectors.

To improve efficiency statistics generated by the statistical module should be saved at the end of the compression of a given Data Chunk and reused when another Data Chunk from the same radiometer is processed.

To reduce the processing time avoiding useless exchanges of data, a possible suggestion is to save statistics vectors in a separated, external table, accessible from the compression module through pointers.