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Recommendation for Space Data System Standards

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| ROBUST COMPRESSION OF FIXED-LENGTH HOUSEKEEPING DATA |

Recommended Standard

CCSDS 124.0-W-6

White Book

July 2021

AUTHORITY

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| --- | --- | --- | --- |
|  |  |  |  |
|  | Issue: | Recommended Standard, Issue 0 |  |
|  | Date: | July 2021 |  |
|  | Location: | Washington, DC, USA |  |
|  |  |  |  |

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This document is published and maintained by:

CCSDS Secretariat

Space Communications and Navigation Office, 7L70

Space Operations Mission Directorate

NASA Headquarters

Washington, DC 20546-0001, USA

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FOREWORD

This Recommended Standard specifies a robust method for lossless compression of fixed length housekeeping data and a format for storing the compressed data.

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DOCUMENT CONTROL

|  |  |  |  |
| --- | --- | --- | --- |
| **Document** | **Title** | **Date** | **Status** |
| CCSDS 124.0-W-1 | Robust compression of Fixed-length Housekeeping Data Standard, Issue 1 | September 2018 | Draft |
| CCSDS 124.0-W-2 | Robust compression of Fixed-length Housekeeping Data Standard, Issue 2 | August 2019 | Draft |
| CCSDS 124.0-W-3 | Robust compression of Fixed-length Housekeeping Data Standard, Issue 3 | February 2020 | Draft |
| CCSDS 124.0-W-4 | Robust compression of Fixed-length Housekeeping Data Standard, Issue 4 | Dec 2020 | Draft |
| CCSDS 124.0-W-5 | Robust compression of Fixed-length Housekeeping Data Standard, Issue 5 | May 2021 | Draft |
| CCSDS 124.0-W-6 | Robust compression of Fixed-length Housekeeping Data Standard, Issue 6 | July 2021 | Draft |

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# Introduction

## Purpose

The purpose of this document is to establish a Recommended Standard for a low complexity, robust data compression algorithm applied to fixed-length binary vectors (as commonly arise in telemetry housekeeping data) and to specify the compressed data format.

Data compression is used to reduce the volume of digital data to achieve benefits in areas including, but not limited to,

1. reduction of transmission channel bandwidth;
2. reduction of the buffering and storage requirement;
3. reduction of data-transmission time at a given rate.

In the particular case of housekeeping telemetry data, compression can be used to increase the net retrieval of housekeeping information within the available bandwidth.

## Scope

The characteristics of the data compression algorithm are specified only to the extent necessary to ensure multi-mission support capabilities. The specification does not attempt to quantify the relative bandwidth reduction, the merits of the approaches discussed, or the design requirements for encoders and associated decoders.

This Recommended Standard addresses lossless data compression of fixed-length binary vectors. The compression method specified herein is effective when a subset of the bits tend to be unchanged from one vector to the next. Housekeeping telemetry and some payload data regularly exhibit this property. The algorithm encodes fixed-length input binary vectors losslessly, and has no pre-conditions on the format of the input data or the number of binary vectors required to be processed before compressed output data can be produced. Consequently, the algorithm can be used while compressing files, packet stores or real-time data streams.

Since some packet losses are normal for operations relying on housekeeping telemetry, the Recommended Standard includes mechanisms to continue the decompression of subsequent packets following the loss of one or more packets. Most often, decompression can continue as soon as the next packet is received. When too many packets are lost sequentially, synchronization between the encoder and the decoder may be temporarily broken. Decompression may then resume normally only after a packet with sufficient information is received. The Recommended Standard also guarantees that the sequence of packets successfully received between synchronization and the last lost packet can be losslessly decoded.

## Applicability

This Recommended Standard applies to data compression applications of space missions anticipating packetized telemetry cross support. In addition, it serves as a guideline for the development of compatible CCSDS Agency standards in this field, based on good engineering practice.

## Rationale

The concept and rationale for the robust compression algorithm described herein may be found in reference [B6].

## Document Structure

This document is organized as follows:

1. Section 1 provides the purpose, scope, applicability, and rationale of this Recommended Standard and identifies the conventions and references used throughout the document. This section also describes how this document is organized. A brief description is provided for each section and annex so that the reader will have an idea of where information can be found in the document.
2. Section 2 provides an overview of the compressor.
3. Section 3 specifies the input for the compressor and the parameters used to control it.
4. Section 4 specifies the mask update stage of the compressor.
5. Section 5 specifies the encoding stage of the compressor and the format of the compressed data.

## Conventions and Definitions

### Mathematical Notation and Definitions

For the purposes of this Recommended Standard, the following definitions and conventions apply. Many other terms that pertain to specific items are defined in the appropriate sections.

An integer is denoted by an italic upper or lower case letter without accent, e.g., *a*.

A single bit is denoted by a letter with a single dot accent e.g. . Boldface type is used to indicate a binary vector, i.e., a sequence of bits. An uppercase boldface letter identifies a binary vector of fixed length, e.g., **B**; a lower case boldface letter identifies a binary vector of variable length, e.g., **b**. A binary vector consisting of all ‘0’ bits is denoted by a boldface 0 i.e. **0.** In this document, all fixed length binary vectors have the same length. A binary vector of length zero is denoted by***.***Binary vectors that have fixed bit values are denoted with single quotes e.g. ‘10010’.

When relevant, a time index *t* is included as subscript. E.g. indicates a fixed-length binary vector that is computed on time index *t*. The time index refers to the sequence number of the input binary vector rather than an absolute time.

A subscript is also used to identify a bit within a binary vector. E.g., indicates the bit in position *i* of binary vector . It is clear from context whether a subscript refers to a time index or a bit position within a binary vector.

In this document, the following convention is used to identify each bit in an *N*-binary vector. The first bit in the vector to be transmitted (i.e., the most left justified when drawing a figure) is defined to be ‘bit *N*-1’, the following bit is defined to be ‘bit *N*-2’, and so on down to ‘bit 0’. When the binary vector is used to express an unsigned binary value (such as a counter), the Most Significant Bit (MSB), bit *N*-1, shall correspond to the highest power of two, i.e., 2*N*-1. Similarly, the Least Significant Bit (LSB), bit 0, shall correspond to the lowest power of two, i.e., 2*0*.

bit *N*-1

first transmitted bit = MSB

bit *N*-2

bit 0

Figure 1‑1: Bit Numbering Convention

Given a length-*N* binary vector , the notation denotes the left bit-shift of , that is,

, (1)

denotes the bit-wise inverse of , and denotes the vector formed by reversing the order of the bits in . For example, if = ‘10111’, then =‘01110’, =‘01000’, and =‘11101’.

denotes the Hamming weight of binary vector . That is, is the number of ‘1’ bits in .

The *K*-bit unsigned binary representation of nonnegative integer is denoted . E.g., = ‘00011’.

Given two length-*N* binary vectors , , the logical disjunction of and **,** denoted , is a vector , where

(2)

the exclusive or of and **,** denoted , is a vector , where

(3)

and the logical conjunction of and **,** denoted , is a vector , where

. (4)

The concatenation of binary vectors and is denoted .

For any real number β, the largest integer *N* such that *N*≤ β is denoted by

*N* =  β.

(5)

### NOMENCLATURE

#### Normative Text

The following conventions apply for the normative specifications in this Recommended Standard:

1. the words ‘shall’ and ‘must’ imply a binding and verifiable specification;
2. the word ‘should’ implies an optional, but desirable, specification;
3. the word ‘may’ implies an optional specification;
4. the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

#### Informative Text

In the normative sections of this document (sections 3-5), informative text is set off from the normative specifications either in notes or under the “Overview” subsection headings.

# Overview

## General

This Recommended Standard specifies a method for losslessly compressing a sequence of fixed-length input binary vectors into a sequence of variable-length output binary vectors. The method provides effective compression when a subset of the bits in the input vectors tend to be unchanged from one input vector to the next, as is often the case for housekeeping telemetry and some spacecraft payload data. The algorithm imposes no requirements on the format of the input data except that the input vectors must be fixed length. The compressor has no latency – that is, an encoded binary output vector is produced for each input vector. Consequently, the compressor can be applied to the live transmission of a stream of binary vectors. With live stream transmission, low power and memory requirements in mind, the compressor has been designed so that the mathematical operations required can be implemented with very low-level bitwise operations such as ORs, XORs, ANDs and bit shifts.

For each input bit vector, the compressor updates a state variable binary vector, having the same length as the input binary vector, called the *mask*. Each bit in the mask indicates whether the corresponding bit in the input binary vector is classified as “predictable” or “unpredictable”. When a bit at a given position in an input vector differs from the corresponding bit of the previous input vector, then that position is classified as unpredictable. Unpredictable positions cannot be reclassified as predictable until a user defined parameter called *new mask flag* is set to one. Therefore, the decompressor can assume that all bits in positions classified as predictable have the same value as in the previous input binary vector, while unpredictable bits may not.

Given the input vector length, the decompressor requires three additional elements of information to reconstruct a given input binary vector:

1. The last successfully reconstructed binary vector in the series
2. A mask synchronized with the oneused to compress the input binary vector
3. The unpredictable bit values associated with the input binary vector

The compressor always includes mask change information in the output binary vector from which the decompressor can keep its own mask synchronized. This can work both forwards and backwards in a time series of output binary vectors. The compressor can also opt to encode the entire maskas part of an output binary vector. The compressor includes the unpredictable bit values associated with the input binary vector in the output binary vector or it encodes the original input binary vector. With this information the decompressor can synchronize its maskso that the unpredictable bit values can be allocated to their correct positions. In this way, the last successfully reconstructed binary vector can be updated to reconstruct the associated input binary vector.

runs in discrete cycles which are triggered by the arrival of a new input binary vector and each of which consists ofIn the mask update step, any bit position in which a bit value changes with respect to its previous value is classified as unpredictable. In parallel, a new mask, called *build*, is constructed following the same rules as for the mask. When the user-defined input parameternew mask flag is set to one it results in the present mask being replaced by build. Build is then reset to declare all bit positions as predictable. In this way, it is possible for bit positions to make the transition from predictable to unpredictable every cycle and from unpredictable to predictable only on the cycle when the new mask is requested. This scheme allows the system to track behaviour changes of individual bit positions over time.

In the encoding stage, a variable-length output binary vector is produced by concatenating three binary vectors. The first vector encodes the positions in the mask vector that have changed over a number of cycles and indicates whether each change resulted in a predictable or an unpredictable classification. The second vector encodes the entire mask, depending on the user-defined parameter *send mask flag*. The third vector either encodes the bit values of the unpredictable bits or includes a copy of the input binary vector, depending on the user-defined parameter *uncompressed flag*.

The number of cycles that are included in the mask change information, called the *effective* *robustness level*, is encoded in the output binary vector. This describes the robustness to data loss guaranteed for each output vector: the mask can be synchronized even if the number of consecutive output binary vectors lost immediately before this output bit vector is equal to, or less than, the effective robustness level. The user can specify a minimum value for the effective robustness level by setting the user-defined parameter *minimum required effective robustness level*.

Note that the decompressor is not required to actively change user defined parameters as all the information required for decompression is contained in the output bit vectors. This allows the compressor to change them periodically or on some other condition.

An overview of the whole compression process is given in Figure 2‑1.

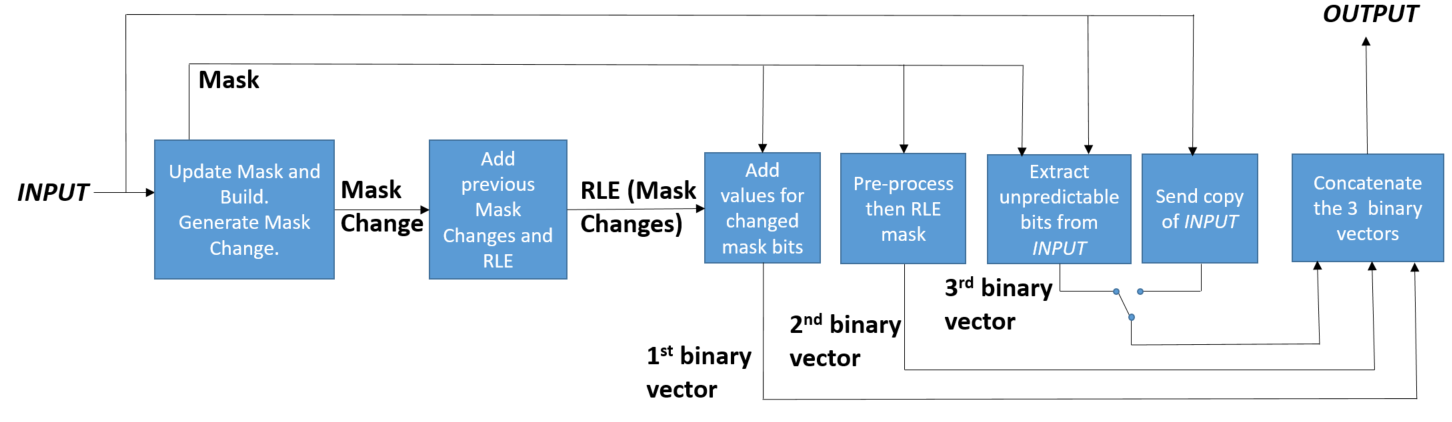


Figure 2‑1: Overview of compression process

## Data transmission

The Recommended Standard describes how to compress a single binary vector stream. If more than one bit stream is compressed, the identification of these streams is mission specific. Application process identifiers (reference [B1]) could be used for example.

The Recommended Standard describes a mechanism to ensure that the compressor and decompressor remain synchronized in the event of the loss of a configurable number of sequential output binary vectors. However, it does not provide a mechanism for identifying the number of sequential output binary vector lost. Such mechanisms are assumed to be mission specific. Packet Sequence Counters (reference [B1]) could be used for example.

The effects of a loss of synchronization between compressor and decompressor or data corruption, can result in the decompressor not knowing where the header of the following output binary vector is located. This Recommended Standard does not incorporate sync markers or other mechanisms to flag the header of the next output binary vector in those cases. Such mechanisms are mission specific. Packet length fields (reference [B1]) could be used for example.

The effects of a small error can result in the loss of synchronization between compressor and decompressor. Although the Recommended Standard provides mechanisms to resynchronize them, such an event will introduce a delay into the decompression and some output binary vectors may not be able to be decoded. Therefore, measures should be taken to minimize errors during the transmission of the output binary vectors.

In case the encoded bitstream is to be transmitted over a CCSDS space link, several protocols can be used to transfer an output binary vector, including but not limited to:

* Space Packet Protocol (reference [B1]);
* CCSDS File Delivery Protocol (CFDP) (reference [B2]);
* packet service as provided by the AOS Space Data Link Protocol (reference [B3]), TM Space Data Link Protocol (reference [B4]), and Unified Space Data Link Protocol (reference [B5]).

When transmission over a CCSDS space link occurs, application of one of the set of Channel Coding and Synchronization Recommended Standards will significantly reduce the loss of portions of transmitted data caused by data corruption.

Limits on the maximum size data unit that can be transmitted may be imposed by the protocol used or by other practical implementation considerations. The user is expected to take such limits into account when using this Recommended Standard.

# Inputs and Parameters

## Overview

The compressor losslessly encodes a sequence of length-*F* binary input vectors , *t*=0,1,*…*. At each time index *t*, the compressor produces a variable-length binary output vector that losslessly encodes . This encoding depends on several user-specified variables defined in section 3.2:

* The *initial mask vector,* , is a length-*F* binary vector used to initialize the mask.
* The *minimum required effective robustness level*, controls the guaranteed number of consecutive output vectors that can be lost prior to the current output vector without affecting the ability to decompress it. The effective robustness level will be equal or greater than this value.
* The *new mask flag*, , when set to one, causes the current mask vector to be replaced with the mask being built. This enables bit positions to change classification from unpredictable to predictable if they have not changed state since the last time the new mask flag was set to one.
* The *uncompressed flag*, , causes the entire input vector to be included in the output vector when it is set to one, otherwise only those bits classified as unpredictable are included.
* The *send mask flag*, , causes the entire mask vector to be encoded in the output vector when it is set to one.

All compressor parameters needed for decompression can be determined from the output binary vectors.

## Input

At each time index *t*= 0, 1, …, the input to the compressor shall be a length-*F* binary input vector , where the input vector length *F* shall be a user-specified integer in the range .

## Parameters

3.3.1 The user-specified initial mask vector, , shall be a length-*F* binary vector.

NOTE – could be derived from analysis of previous mask values, or a stored value of the mask from the last time this was run. Setting (i.e., all positions predictable) is often a reasonable default.

3.3.2 In addition to the initial mask vector, compression parameters at each time index t consist of the following:

1. The user-specified minimum required effective robustness level, which shall be an integer between 0 and 7 at each time index *t*.
2. The user-specified new mask flag, , which shall be zero or one at each time index *t*.
3. The send mask flag, , which shall be for , otherwise is user-specified and shall be zero or one.
4. The uncompressed flag, , which shall be if , otherwise is user-specified and shall be zero or one.

NOTE – The values of user-specified parameters , , , and need not be known in advance, or communicated via means external to the compressor, for successful decompression.

# MASK UPDATE

## Overview

This section specifies the compressor’s mask update stage. Two binary vectors, (the mask)and (the build),are updated in parallel based on the exclusive-or between the current input binary vector and the previous one (see sections 4.2.1 and 4.2.2).

Since no such difference is defined for the first input vector, build is initialized to a zero vector, i.e., . For subsequent input binary vectors, a bitwise XOR of sequential input binary vectors is used to update mask and build. The *change* vector, , is computed as the exclusive-or between the current mask and previous mask (see section 4.2.3)*.*

When the new mask flag, , is set to one, the mask is replaced by build and build is reset to a zero vector, i.e. all positions are classified as predictable (see section 3.3.2). Hence, even though the update processes for mask and build depend on the same calculations, these vectors are not in general identical because they may be reset at different times during the encoding process.

## MASK UPDATE

**4.2.1** For , the build vector is a length-*F* binary vector defined as

(6)

where is defined in section 3.3.2.

4.2.2 For , the mask vector is a length-*F* binary vector defined as

(7)

where is defined in section 3.3.2.

NOTE – At *t*=0, the initial mask vector is user-specified (see 3.3.1).

**4.2.3** For , the change vector is a length-*F* binary vector defined as

(8)

# Encoder

## Overview

This section specifies the encoding stage of the compressor. Section 5.2 defines functions used in the encoding process and section 5.3 specifies the calculation of the output vector from the input vector and compressor parameters.

As specified in 5.3, at any time , the encoder output is a variable-length binary vector, that is a concatenation of three variable-length binary vectors, and described below.

The first binary vector, , encodes information about recent mask changes (see 5.3.3.1). The most recent change vector is ORed with previous change vectors (to provide robustness against packet loss) and the result is run-length encoded. Next, the effective robustness level, is encoded using 4 bits, followed by information on the mask values for each change. This is followed by the value of , which indicates if was set to one more than once in the period covering this cycle and the previous cycles. This information is used in the encoding. The final bit indicates whether user-specified parameters and are both zero. If so, the values of those parameters are not encoded in or .

The second binary vector,, encodes information about the entire mask (see 5.3.3.2). Although mask changes alone would be sufficient to reconstruct the mask, the option to send the entire mask can be requested by setting the send mask flag, to one (see section 3.3.2). In this caseconsists of a ’1’ concatenated with the maskthat has been preprocessed and run-length encoded.

Finally, the third binary vector, , encodes different information depending on the values of and . If , is one (see section 3.3.2) then always contains a bit string that encodes the value of the input block length *F*, followed by the input vector. Otherwise, if is one then contains the unpredictable bit values and the values of any bits that changed from unpredictable to predicable in the present change vector or the previous change vectors. If is not one then contains only the unpredictable bit values. In all cases the output is preceded by if its value was not already specified by the last bit of .

## Basic Encoding Functions

This section defines the counter encoding, run-length encoding, and bit extraction functions used by the encoding procedure specified in 5.3.3.

#### 5.2.1 Counter Encoding Function

Given a positive integer the counter encoding function, denoted COUNT(), maps *A* onto a variable-length binary vector following Table 5‑2.

Table 5‑2: Counter encoding table

|  |  |
| --- | --- |
|  |  |
| = 1 | ‘0’ |
| 2<=<=33 | ‘110’ |
| >=34 | ‘111’ |

Where *E* is calculated as

. (10)

NOTE – The equation above calculates a bit string length consisting of a number of zeros concatenated with a minimum length bit string encoding of the integer**.** As the relationship between the number of preceding zeros and the length of the bit string encoding is unique, it can be used by the decompressor to parse the output.

#### 5.2.2 Run-Length Encoding

Given a binary vector, , the run length encoding of , denoted RLE(), is a variable-length binary vector defined as

, (11)

where is one more than the number of consecutive ‘0’ bits preceding the *i*th ‘1’ bit in , starting at the MSB and decreasing.

NOTE – If the vector ends with one or more zeros, they are not explicitly encoded via the COUNT function, as they can be inferred from the length of the input vector and the number of ‘1’ bits,.

NOTE – When vector does not contain any ‘1’ bits, the COUNT function will yield a bit string.

NOTE – Figure 5-1 provides an illustration of the run to count encoding.

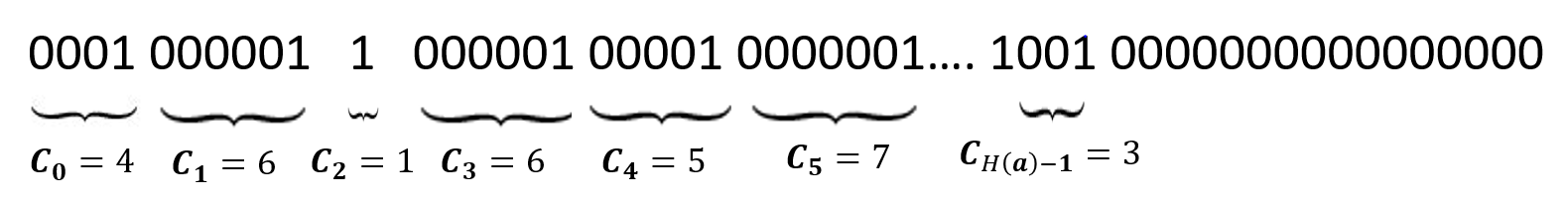


Figure 5‑1: Example of the run to count encoding, converting a binary vectorinto a sequence of integers

#### 5.2.3 Bit Extraction Function

Given two binary vectors , , having the same length, the bit extraction of relative to , denoted , is the sequence of bits in taken from the positions where has a ‘1’ bit. That is,

, (12)

where denotes the position of the *i*th ‘1’ bit in **,** starting from the MSB.

## Encoding Step

### Output binary Vector Structure

The encoder output is comprised of the sequence of variable-length binary output vectors **,**. Each output binary vector shall be defined as

**,** (9)

where variable-length binary vectors , , and are specified in sections 5.3.3.1, 5.3.3.2, and 5.3.3.3 respectively. The calculation of these component vectors depends on intermediate calculations defined in 5.3.2.

### Intermediate Calculations

**5.3.2.1** For *t*0, is defined as

(13)

where and are defined in section 3.3.2.

**5.3.2.2** For *t*0, is defined as

(14)

Where is defined in section 3.3.2 and is the maximum integer where , for which at given time instant all (see section 4.2.3) for .

NOTE – counts the number of consecutive occurrences of no mask changes, starting from the first cycle not covered by the minimum required effective robustness level and working backwards in time.

### Output Vector Components

#### **5.3.3.1** The binary vector is defined as

(15)

where is defined in section 5.3.2.2, is defined in section 5.3.2.1 and and are defined as

(16)

where is the change binary vector defined in section 4.2.3 and is defined in section 3.3.2,

**,** (17)

(18)

(19)

(20)

#### **5.3.3.2** The binary vector is defined as

(21)

where is defined in 3.3.2, and is defined in 5.3.2.1.

#### **5.3.3.3** The binary vector , is defined as

(22)

where and are defined in section 3.3.2, is defined in section 5.3.3.1 and is defined in 5.3.2.1.

1. Implementation Conformance   
   Statement (ICS) Proforma  
     
   (normative)
   1. INTRODUCTION
      1. OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of *Robust Compression of Fixed Length Housekeeping Data*, CCSDS-124.1-B-1, [publication date]. The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation claiming conformance must satisfy the mandatory requirements referenced in the RL.

* + 1. ABBREVIATIONS AND CONVENTIONS

The RL consists of information in tabular form. The status of features is indicated using the abbreviations and conventions described below.

Item Column

The label in the item column identifies the item in the table.

The use of nested item labels indicates subordination of conditional items. E.g., an item with label L*i*.*j* is not applicable unless the parent item L*i* is supported.

Description Column

The description column contains a brief description of the item. It implicitly means “Is this item supported by the implementation?”

Reference Column

The reference column indicates the relevant subsection of *Robust Compression of Fixed Length Housekeeping Data*, CCSDS-124.1-B-1 (this document).

Status Column

The status column uses the following notations:

M mandatory.

O optional.

N/A not applicable.

O.*i* qualified optional—for a group of related optional items labeled by the same numeral *i*, it is mandatory to support at least one of the items.

C.*j* conditional—the requirement on the capability (‘M’, ‘O’, or ‘N/A’) depends on the support of another optional item. The numeral *j* identifies a unique conditional status expression defined immediately following the table.

C:<status> indicates that the status applies for the given subordinate item when the parent item is supported, and is not applicable otherwise.

<condition>:<status> indicates that the status applies only when the given condition is met, and is not applicable otherwise. For example, ‘(Q2 or Q3):M’ indicates that support for the item is mandatory if item Q2 or item Q3 are supported and not applicable otherwise.

Values Allowed Column

The values allowed column contains the list or range of values allowed. The following notations are used:

range of values: <min value> .. <max value>

*example*: 2 .. 16

list of values: <value1>, <value2>, ..., <valueN>

*example*: 3, 6, 9, …, 21

N/A not applicable

Item Support or Values Supported Column

In the item support or values supported column, the support of every item as claimed by the implementer shall be stated by entering the appropriate answer (‘Y’, ‘N’, or ‘N/A’) or the values supported:

Y yes, item supported by the implementation.

N no, item not supported by the implementation.

range or list of values supported.

N/A not applicable.

Prerequisite Line

A prerequisite line takes the form: Prerequisite: <predicate>. A prerequisite line at the top of a table indicates that the table need not be completed if the predicate is FALSE.

* + 1. INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called an ICS. The implementer shall complete the RL by entering appropriate responses in the support or values supported column, using the notation described in A1.2. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

* 1. ICS PROFORMA FOR ROBUST Compression OF FIXED LENGTH HOUSEKEEPING DATA
     1. GENERAL INFORMATION
        1. Identification of ICS

|  |  |
| --- | --- |
| Date of Statement (DD/MM/YYYY) |  |
| ICS serial number |  |
| System Conformance statement cross-reference |  |

* + - 1. Identification of Implementation Under Test

|  |  |
| --- | --- |
| Implementation Name |  |
| Implementation Version |  |
| Function Implemented | Compression\_\_\_\_\_ Decompression\_\_\_\_\_ |
| Special Configuration |  |
| Other Information |  |

* + - 1. Identification of Supplier

|  |  |
| --- | --- |
| Supplier |  |
| Contact Point for Queries |  |
| Implementation Name(s) and Versions |  |
| Other information necessary for full identification, e.g., name(s) and version(s) for machines and/or operating systems;  System Name(s) |  |

* + - 1. Identification of Specification

|  |  |
| --- | --- |
| CCSDS-124.1-B Document Version | |
| Have any exceptions been required?  NOTE – A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming. | Yes [  ]      No [  ] |

* + 1. REQUIREMENTS LIST

[See CCSDS A20.1-Y-1, *CCSDS Implementation Conformance Statements* (Yellow Book, Issue 1, April 2014).]

* + - 1. Parameters

Table A‑1 : Parameters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Item** | **Description** | **Reference** | **Status** | **Values Allowed** | **Item Support or**  **Values Supported** |
| P1 | Input Vector Length,  F supported value. | 3.2 | M | 1 .. 216 -1. |  |
| P2 | Configuration of initial mask vector, | 3.3.1 | M | 0 ..2F-1 |  |
| P3 | Output binary vector, | 5.3.1 | M | N/A |  |

1. REFERENCES   
     
   (INFORMATIVE)
2. *Space Packet Protocol*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 133.0-B-1. Washington, D.C.: CCSDS, September 2003.
3. *CCSDS File Delivery Protocol (CFDP)*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 727.0-B-4. Washington, D.C.: CCSDS, January 2007.
4. *AOS Space Data Link Protocol*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-3. Washington, D.C.: CCSDS, September 2015.
5. *TM Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 132.0-B-2. Washington, D.C.: CCSDS, September 2015.
6. *Unified Space Data Link Protocol*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.1-B-1. Washington, D.C.: CCSDS, October 2018.
7. The ESA POCKET+ Housekeeping Telemetry Compression and Decompression Algorithm, DASIA 2017, Gothenburg (Sweden) from 30 May to 1 June 2017.