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Raumfahrtproduktsicherung – Raumfahrt-Datenübertragung – Telemetriesynchronisation und Kanalkodierung; Englische Fassung EN 16603-50-01:2014

Space engineering –
Space data links –
Telemetry synchronization and channel coding;
English version EN 16603-50-01:2014

Ingénierie spatiale –
Liaison de données spatiales –
Synchronisation et codage canal de la télémesure;
Version anglaise EN 16603-50-01:2014

Gesamtumfang 71 Seiten

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Nationales Vorwort

Dieses Dokument (EN 16603-50-01:2014) wurde vom Technischen Komitee CEN/CLC/TC 5 „Raumfahrt“ erarbeitet, dessen Sekretariat vom DIN (Deutschland) gehalten wird.

Das zuständige deutsche Normungsgremium ist der Arbeitsausschuss NA 131-10-01 AA „Interoperabilität von Informations-, Kommunikations- und Navigationssystemen“ im DIN-Normenausschuss Luft- und Raumfahrt (NL).

Dieses Dokument (EN 16603-50-01:2014) basiert auf ECSS-E-ST-50-01C.

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Dieses Dokument wurde speziell zur Behandlung von Raumfahrtsystemen erarbeitet und hat daher Vorrang vor jeglicher Europäischer Norm, da es denselben Anwendungsbereich hat, jedoch über einen größeren Geltungsbereich (z. B. Luft- und Raumfahrt) verfügt.

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Nationaler Anhang NA
(informativ)

Begriffe und Abkürzungen

3 Begriffe und Abkürzungen

3.1 Begriffe aus anderen Normen

Für die Anwendung dieses Dokuments gelten die Begriffe nach ECSS-S-ST-00-01.

3.2 Für diese Norm spezifische Begriffe

3.2.1
Kategorie A
Kategorie von Raumfahrzeugen, deren Höhe über der Erdoberfläche weniger als 2×10^6 km beträgt

3.2.2
Kategorie B
Kategorie von Raumfahrzeugen mit einer Höhe über der Erdoberfläche gleich oder größer 2×10^6 km

3.2.3
Oktett
Satz von acht Binärziffern (Bits)

ANMERKUNG 1 Die Benummerung von Oktetten innerhalb einer Datenstruktur beginnt mit 0.

ANMERKUNG 2 Siehe 3.4 für die Konvention zur Benummerung von Bits.

3.2.4
Bitübertragungskanal
physikalischer Kanal
Strom der in einer Richtung über eine Weltraum-Übertragungsleitung übertragenen Bits

3.3 Abkürzungen

Für die Anwendung dieses Dokuments gelten die Abkürzungen in ECSS-S-ST-00-01 und die folgenden Abkürzungen:

Abkürzung	Bedeutung
8PSK	Achtphasenumtastung (en: phase shift keying of eight states)
AOS	Hochleistungs-Orbitalsysteme (en: advanced orbiting systems)
APP	A-posteriori-Wahrscheinlichkeit (en: a posteriori probability)
ASM	zugeordneter Synchronisationsmarker (en: attached sync marker)
AWGN	additives weißes gaußsches Rauschen (en: additive white Gaussian noise)
BER	Bitfehlerquote (en: bit error rate)

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BPSK binäre Phasenumtastung (en: binary phase shift keying)

CADU Kanalzugriff-Dateneinheit (en: channel access data unit)

CCSDS Beratender Ausschuss für Weltraumdatensysteme (en: Consultative Committee for Space Data Systems)

CRC zyklische Redundanzprüfung (en: cyclic redundancy check)

FER Bitfehlerrate (en: frame error rate)

GF(n) aus genau n Elementen bestehendes Galois-Feld (en: Galois field consisting of exactly n elements)

GMSK gaußsche Minimumumtastung (en: Gaussian minimum shift keying)

MSB höchstwertiges Bit (en: most significant bit)

MS/S Megasymbole je Sekunde (en: mega symbols per second)

NRZ-L Non-Return-to-Zero-Level (en: non-return to zero level)

NRZ-M Non-Return-to-Zero-Mark (en: non-return to zero mark)

QPSK Quadratur-Phasenumtastung (en: quadrature phase shift keying)

R-S Reed-Solomon (en: Reed-Solomon)

TCM Trellis-Code-Modulation (en: trellis-coded modulation)

3.4 Konventionen

3.4.1 Bit 0, Bit 1, Bit N–1

Um jedes Bit in einem N-Bit-Feld zu identifizieren, ist das erste zu übertragende Bit im Feld (d. h. das in einer graphischen Darstellung am weitesten links gelegene) als Bit 0 definiert; das folgende Bit ist als Bit 1 definiert usw. bis zum Bit N-1.

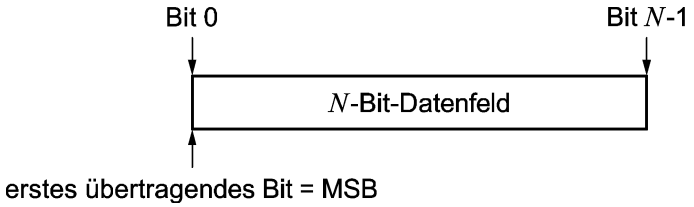


Bild 3-1 — Benummerungskonvention für Bits

3.4.2 Höchstwertiges Bit

Wird ein N-Bit-Feld zur Angabe eines Binärwerts genutzt (z. B. bei einer Zählvorrichtung), handelt es sich beim höchstwertigen Bit um das erste Bit im Feld, d. h. Bit 0 (siehe Bild 3-1).

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

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English version

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Ingénierie spatiale - Liaison de données spatiales - Synchronisation et codage canal de la télémesure

Raumfahrtproduktsicherung - Raumfahrt-Datenübertragung - Telemetriesynchronisation und kanalkodierung

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Full document details: DIN EN 16603-50-01:2014-12

Table of contents

Foreword **6**

1 Scope **7**

2 Normative references **8**

3 Terms, definitions and abbreviated terms **9**

3.1 Terms from other standards 9

3.2 Terms specific to the present standard 9

3.3 Abbreviations 9

3.4 Conventions 10

4 Overview **11**

4.1 Introduction 11

4.2 Coding 11

4.2.1 Channel codes 11

4.2.2 Connection vectors 12

4.3 Convolutional codes 12

4.4 Reed-Solomon codes 12

4.5 Concatenated codes 13

4.6 Turbo codes 13

4.7 Synchronization and pseudo-randomization 13

5 Convolutional coding **16**

5.1 Properties 16

5.2 General 16

5.3 Basic convolutional code 17

5.4 Punctured convolutional code 18

6 Reed-Solomon coding **20**

6.1 Properties 20

6.2 General 20

6.3 Specification 21

6.3.1 Parameters and general characteristics 21

6.3.2 Generator polynomials 21

Documents
Document Sharing Hub

Full document details: DIN EN 16603-50-01:2014-12

6.3.3 Symbol interleaving depth 22
6.3.4 Symbol interleaving mechanism 22
6.3.5 Reed-Solomon codeblock partitioning 23
6.3.6 Shortened codeblock length 24
6.3.7 Dual basis symbol representation and ordering 25
6.3.8 Synchronization 26
6.3.9 Ambiguity resolution 26
6.4 Reed-Solomon with *E*=8 26
6.4.1 Introduction 26
6.4.2 General 27

7 Turbo coding 28
7.1 Properties 28
7.2 General 28
7.3 Specification 29
7.3.1 General 29
7.3.2 Parameters and general characteristics 29
7.3.3 Turbo code permutation 30
7.3.4 Backward and forward connection vectors 32
7.3.5 Turbo encoder block 33
7.3.6 Turbo codeblock specification 33
7.3.7 Turbo codeblock synchronization 34

8 Frame synchronization 35
8.1 Introduction 35
8.2 The attached sync marker (ASM) 35
8.2.1 Overview 35
8.2.2 Encoder side 36
8.2.3 Decoder side 36
8.3 ASM bit patterns 36
8.4 Location of ASM 37
8.5 Relationship of ASM to Reed-Solomon and turbo codeblocks 37
8.6 ASM for embedded data stream 38
8.6.1 Overview 38
8.6.2 Embedded ASM 38

9 Pseudo-randomizer 39
9.1 General 39
9.1.1 Overview 39

Documents
Document Sharing Hub
Full document details: DIN EN 16603-50-01:2014-12

9.1.2 Application 39
9.2 Pseudo-randomizer description 39
9.3 Synchronization and application of pseudo-randomizer 40
9.3.1 Overview 40
9.3.2 Application 40
9.4 Sequence specification 41

Annex A (informative) Transformation between Berlekamp and conventional representations 43

Annex B (informative) Expansion of Reed-Solomon coefficients 50

Annex C (informative) Compatible frame lengths 52

Annex D (informative) Application profiles 54

Annex E (informative) Changes from ESA-PSS-04-103 60

Annex F (informative) Differences from CCSDS recommendations 61

Annex G (informative) Mission configuration parameters 62

Annex H (informative) Turbo code patent rights 66

Bibliography 67

Figures

Figure 3-1: Bit numbering convention 10
Figure 4-1: Coding, randomization and synchronization (1) 14
Figure 4-2: Coding, randomization and synchronization (2) 15
Figure 5-1: Convolutional encoder block diagram 18
Figure 5-2: Punctured encoder block diagram 19
Figure 6-1: Functional representation of R-S interleaving 23
Figure 6-2: Reed-Solomon codeblock partitioning 24
Figure 7-1: Interpretation of permutation 31
Figure 7-2: Turbo encoder block diagram 32
Figure 7-3: Turbo codeblocks for code rates 1/2 and 1/4 34
Figure 7-4: Turbo codeblock with attached sync marker 34
Figure 8-1: Format of channel access data unit (CADU) 35
Figure 8-2 ASM bit pattern for non-turbo-coded data 36
Figure 8-3: ASM bit pattern for rate 1/2 turbo-coded data 36
Figure 8-4: ASM bit pattern for rate 1/4 turbo-coded data 37
Figure 8-5: Embedded ASM bit pattern 38

Documents
Document Sharing Hub
Full document details: DIN EN 16603-50-01:2014-12

Figure 9-1: Pseudo-randomizer configuration 40
Figure 9-2: Pseudo-randomizer logic diagram 42
Figure A-1 : Transformational equivalence 44

Tables

Table 5-1: Basic convolutional code characteristics 17
Table 5-2: Punctured convolutional code characteristics 19
Table 5-3: Puncture code patterns for convolutional codes 19
Table 7-1: Specified information block lengths 30
Table 7-2: Codeblock lengths (measured in bits) 30
Table 7-3: Parameters k_1 and k_2 for specified information block lengths 31
Table 7-4: Forward connection vectors 32
Table 8-1: ASM bit patterns in hexadecimal notation 37
Table A-1 : Equivalence of representations (Part 1 of 4) 46
Table B-1 : Expansion for *E*=16 50
Table B-2 : Expansion for *E*=8 51
Table C-1 : Maximum frame lengths for *E*=16 53
Table C-2 : Maximum frame lengths for *E*=8 53
Table D-1 : Preferred coding schemes 56
Table D-2 : Coding gains and bandwidth expansions 58
Table D-3 : Coding gains for R-S(255, 239) and 4D-8PSK-TCM 59

Documents
Document Sharing Hub
Full document details: DIN EN 16603-50-01:2014-12

Foreword

This document (EN 16603-50-01:2014) has been prepared by Technical Committee CEN/CLC/TC 5 “Space”, the secretariat of which is held by DIN.

This standard (EN 16603-50-01:2014) originates from ECSS-E-ST-50-01C.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2015, and conflicting national standards shall be withdrawn at the latest by March 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

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1 Scope

This Standard establishes a common implementation of space telemetry channel coding systems.

Several space telemetry channel coding schemes are specified in this Standard. The specification does not attempt to quantify the relative coding gain or the merits of each scheme, nor the design requirements for encoders or decoders. However, some application profiles are discussed in Annex D. Performance data for the coding schemes specified in this Standard can be found in CCSDS 130.1-G-1. Annex G describes the related mission configuration parameters.

Further provisions and guidance on the application of this standard can be found in the following publications:

- ECSS-E-ST-50, Communications, which defines the principle characteristics of communication protocols and related services for all communication layers relevant for space communication (physical- to application-layer), and their basic relationship to each other.
- The handbook ECSS-E-HB-50, Communications guidelines, which provides information about specific implementation characteristics of these protocols in order to support the choice of a certain communications profile for the specific requirements of a space mission.

Users of this present standard are invited to consult these documents before taking decisions on the implementation of the present one.

This standard may be tailored for the specific characteristics and constraints of a space project in conformance with ECSS-S-ST-00.

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2
Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of any of these publications, do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references the latest edition of the publication referred to applies.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system - Glossary of terms

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3 Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-ST-00-01 apply.

3.2 Terms specific to the present standard

3.2.1 category A

category of spacecraft having an altitude above the Earth's surface less than 2×10^6 km

3.2.2 category B

category of spacecraft having an altitude above the Earth's surface equal to, or greater than 2×10^6 km

3.2.3 octet

group of eight bits

NOTE 1 The numbering for octets within a data structure starts with 0.

NOTE 2 Refer to clause 3.4 for the convention for the numbering of bits.

3.2.4 physical channel

stream of bits transferred over a space link in a single direction

3.3 Abbreviations

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01and the following apply:

Abbreviation	Meaning
8PSK	phase shift keying of eight states
AOS	advanced orbiting systems
APP	a posteriori probability
ASM	attached sync marker

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AWGN	additive white Gaussian noise
BER	bit error rate
BPSK	binary phase shift keying
CADU	channel access data unit
CCSDS	Consultative Committee for Space Data Systems
CRC	cyclic redundancy check
FER	frame error rate
GF(n)	Galois field consisting of exactly n elements
GMSK	Gaussian minimum shift keying
MSB	most significant bit
MS/S	mega symbols per second
NRZ-L	non-return to zero level
NRZ-M	non-return to zero mark
QPSK	quadrature phase shift keying
R-S	Reed-Solomon
TCM	trellis-coded modulation

3.4 Conventions

3.4.1 bit 0, bit 1, bit N–1

To identify each bit in an N-bit field, the first bit in the field to be transferred (i.e. the most left justified in a graphical representation) is defined as bit 0; the following bit is defined as bit 1 and so on up to bit N–1.

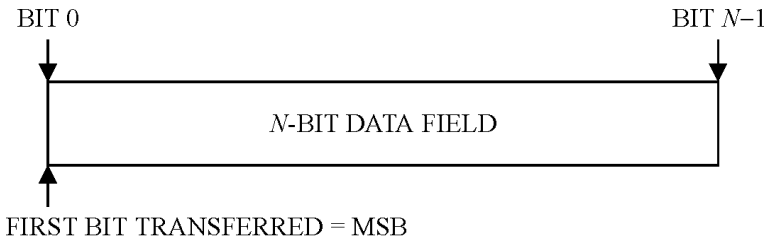


Figure 3-1: Bit numbering convention

3.4.2 most significant bit

When an N-bit field is used to express a binary value (such as a counter), the most significant bit is the first bit of the field, i.e. bit 0 (see Figure 3-1).

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Full document details: DIN EN 16603-50-01:2014-12

4 Overview

4.1 Introduction

Telemetry channel coding is a method of processing data that is sent from a source to a destination so that distinct messages are created that are easily distinguishable from one another and thus enable reconstruction of the data with low error probability, thus improve the performance of the channel.

4.2 Coding

4.2.1 Channel codes

A channel code is the set of rules that specify the transformation of elements of a source alphabet to elements of a code alphabet. The elements of the source alphabet and of the code alphabet are called symbols.

Depending on the code, the symbols can consist of one or more bits. The source symbols are also called information symbols. The code symbols are called channel symbols when they are the output of the last or only code applied during the encoding process.

Block encoding is a one-to-one transformation of sequences of length k source symbols to sequences of length n code symbols. The length of the encoded sequence is greater than the source sequence, so $n > k$.

The ratio k/n is the code rate, which can be defined more generally as the average ratio of the number of binary digits at the input of an encoder to the number of binary digits at its output.

A codeword of an (n,k) block code is one of the sequences of n code symbols in the range of the one-to-one transformation.

A codeblock of an (n,k) block code is a sequence of n channel symbols which are produced as a unit by encoding a sequence of k information symbols. The codeblock is decoded as a unit and, if successful, delivers a sequence of k information symbols.

A systematic code is one in which the input information sequence appears in unaltered form as part of the output codeword.

A transparent code has the property that complementing the input of the encoder or decoder results in complementing the output.

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4.2.2 Connection vectors

Convolutional and turbo coding use connection vectors.

A forward connection vector is a vector which specifies one of the parity checks computed by the shift register(s) in the encoder. For a shift register with s stages, a connection vector is an s-bit binary number. A bit equal to "1" in position i (counted from the left) indicates that the output of the ith stage of the shift register is used in computing that parity check.

In turbo coding, a backward connection vector is a vector which specifies the feedback to the shift registers in the encoder. For a shift register with s stages, a backward connection vector is an s-bit binary number. A bit equal to "1" in position i (counted from the left) indicates that the output of the ith stage of the shift register is used in computing the feedback value, except for the leftmost bit which is ignored.

4.3 Convolutional codes

A convolutional code is a code in which a number of output symbols are produced for each input information bit. Each output symbol is a linear combination of the current input bit as well as some or all of the previous $k-1$ bits, where k is the constraint length of the code. The constraint length is the number of consecutive input bits that are used to determine the value of the output symbols at any time.

The rate 1/2 convolutional code is specified in clause 5. Depending on performance requirements, this code can be used alone.

For telecommunication channels that are constrained by bandwidth and cannot accommodate the increase in bandwidth caused by the basic convolutional code, clause 5 also specifies a punctured convolutional code which has the advantage of a smaller bandwidth expansion.

A punctured code is a code obtained by deleting some of the parity symbols generated by the convolutional encoder before transmission. There is an increase in the bandwidth efficiency due to puncturing compared to the original code, however the minimum weight (and therefore its error-correcting performance) is less than that of the original code.

4.4 Reed-Solomon codes

The Reed-Solomon (R-S) code specified in clause 6 is a powerful burst error correcting code. In addition, the code has the capability of indicating the presence of uncorrectable errors, with an extremely low undetected error rate.

The Reed-Solomon code has the advantage of smaller bandwidth expansion than the convolutional code.

The Reed-Solomon symbol is a set of J bits that represents an element in the Galois field GF(2^J), the code alphabet of a J-bit Reed-Solomon code. For the code specified in clause 6, $J = 8$ bits per R-S symbol.

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4.5 Concatenated codes

Concatenation is the use of two or more codes to process data sequentially, with the output of one encoder used as the input to the next.

In a concatenated coding system, the first encoding algorithm that is applied to the data stream is called the outer code.

The last encoding algorithm that is applied to the data stream is called the inner code. The data stream that is input to the inner encoder consists of the codewords generated by the outer encoder.

To achieve a greater coding gain than the one that can be provided by the convolutional code or Reed-Solomon code alone, a concatenation of the convolutional code as the inner code with the Reed-Solomon code as the outer code can be used for improved performance.

This Standard also specifies the concatenation of the Reed-Solomon code with the 4-dimensional 8PSK trellis-coded modulation (4D-8PSK-TCM) defined in ECSS-E-ST-50-05. In this case, the Reed-Solomon code with E=8 is the outer code and the 4D-8PSK-TCM is the inner code.

4.6 Turbo codes

A turbo code is a block code formed by combining two component recursive convolutional codes. A turbo code takes as input a block of information bits. The input block is sent unchanged to the first component code and bit-wise interleaved to the second component code. The interleaving process, called the turbo code permutation, is a fixed bit-by-bit permutation of the entire input block.

The output is formed by the parity symbols contributed by each component code plus a replica of the information bits.

The turbo codes specified in clause 7 can be used to increase the coding gain in cases where the environment tolerates the bandwidth overhead.

4.7 Synchronization and pseudo-randomization

The methods for synchronization specified in clause 8 apply to all telemetry channels, coded or uncoded. An attached sync marker (ASM) is attached to the codeblock or transfer frame. The ASM can also be used for resolution of data ambiguity (sense of ‘1’ and ‘0’) if data ambiguity is not resolved by the modulation method used.

Successful bit synchronization at the receiving end depends on the incoming signal having a minimum bit transition density. Clause 9 specifies the method of pseudo-randomizing the data to improve bit transition density.

Figure 4-1 and Figure 4-2 provide an overview of how pseudo-randomization and synchronization are combined with the different coding options at the sending and receiving end.

At the sending end, the order of convolutional encoding and modulation is dependent on the implementation. At the receiving end, the order of

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demodulation, frame synchronization and convolutional decoding are dependent on the implementation.

The figures do not imply any hardware or software configuration in a real system. When designing a communications system, the system designer usually takes into account radio regulations and modulation standardization requirements from other standards, such as ECSS-E-ST-50-05.

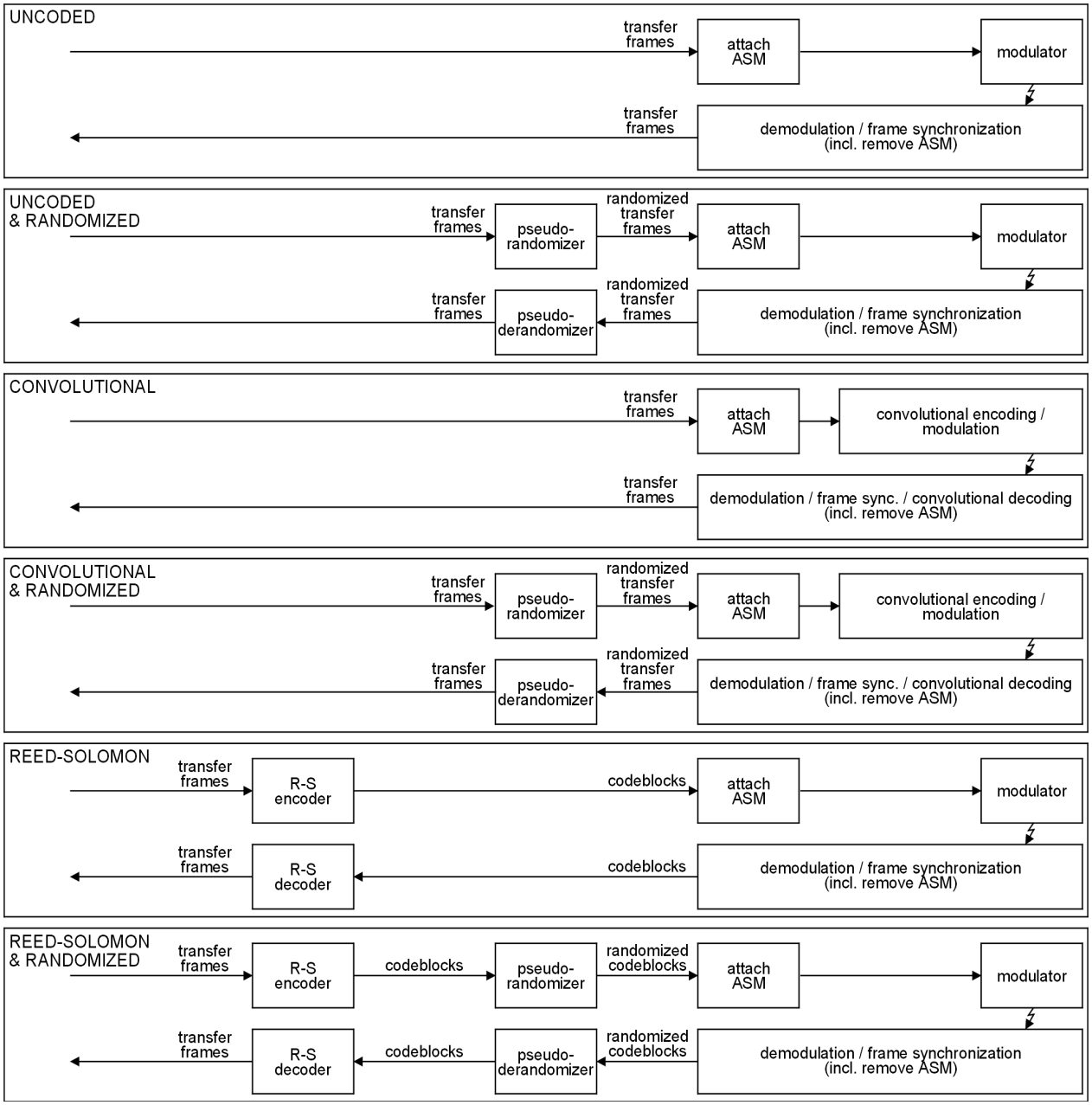


Figure 4-1: Coding, randomization and synchronization (1)

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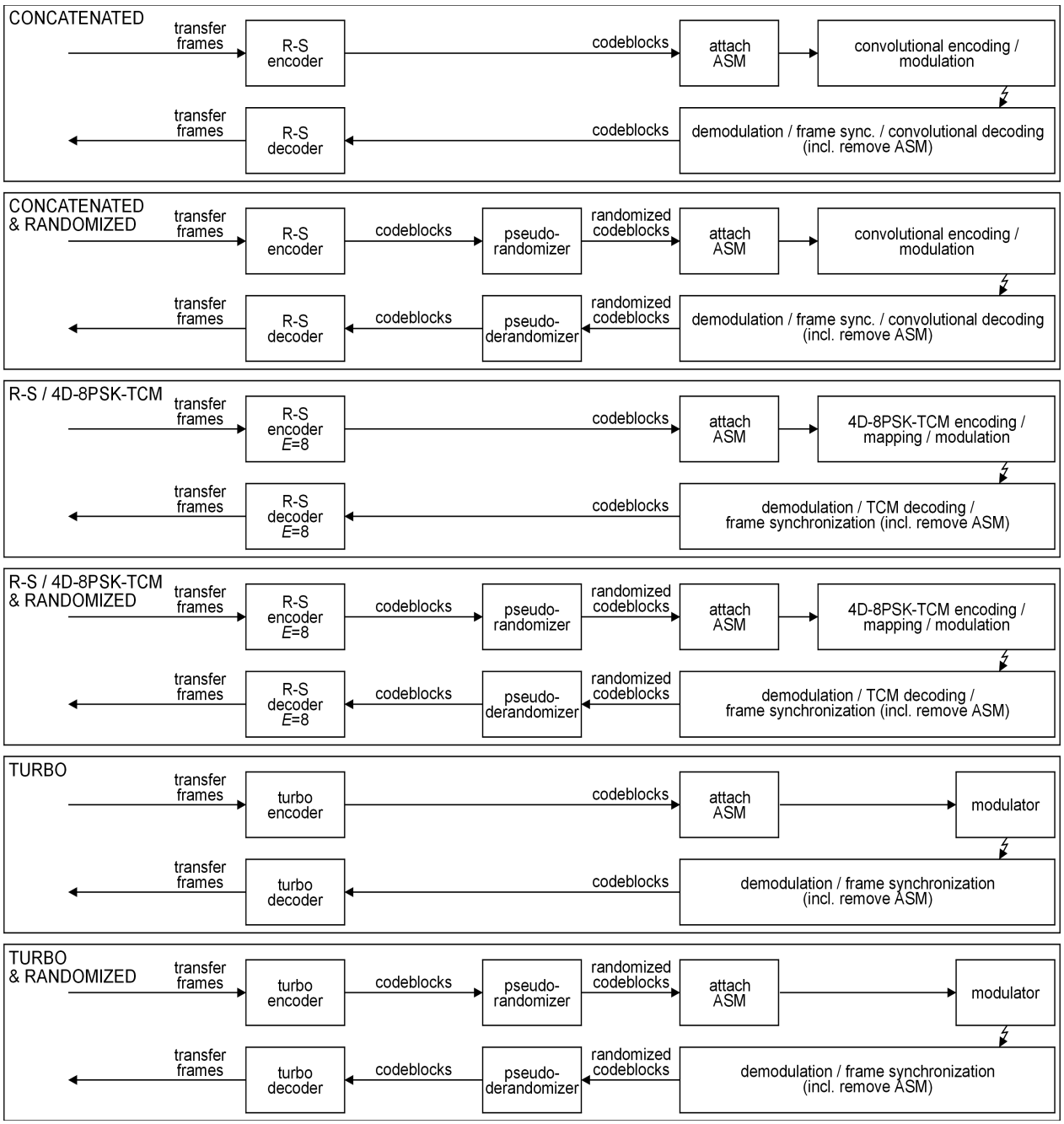


Figure 4-2: Coding, randomization and synchronization (2)

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5 Convolutional coding

5.1 Properties

Convolutional coding is suitable for channels with predominantly Gaussian noise.

The basic convolutional code defined in clause 5.3 is a rate 1/2, constraint-length 7 transparent code. The basic code can be modified by puncturing, which removes some of the symbols before transmission, thus providing lower overhead and lower bandwidth expansion than the original code, but with reduced error correcting performance. The punctured convolutional codes are defined in clause 5.4

The codes are non-systematic. The convolutional decoder is a maximum-likelihood decoder using the Viterbi decoding scheme. Decoding failures are not signalled and produce error bursts.

The requirements in clause 5.2 apply to the basic and punctured convolutional codes.

The convolutional code, by itself, cannot guarantee sufficient symbol transitions when non-binary modulation schemes such as QPSK are used. The pseudo-randomizer defined in clause 9 can be used to increase the symbol transition density.

If the decoder's correction capability is exceeded, undetected burst errors can appear in the output. For this reason, when telemetry transfer frames are used, reference ECSS-E-ST-50-03 specifies that a cyclic redundancy check (CRC) field be used to validate the frame unless the Reed-Solomon code is used. Similarly, the CRC is used for the AOS transfer frames defined in CCSDS 732.0-B-2.

5.2 General

a. Soft bit decisions with at least 3-bit quantization shall be used for the decoder.

b. The frame synchronization defined in clause 8 shall be used.

c. If differential encoding (i.e. conversion from NRZ-L to NRZ-M) is used at the sending end, the conversions should be as follows:

   — the conversion is performed at the input to the convolutional encoder;

   — the corresponding conversion at the receiving end from NRZ-M to NRZ-L is performed at the output of the convolutional decoder.

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NOTE 1 This prevents avoidable link performance loss.

NOTE 2 When suppressed-carrier modulation systems are used, NRZ-M or NRZ-L can be used as a modulating waveform. In NRZ-M a data "1" is represented by a change in level and a data "0" is represented by no change in level. In NRZ-L a data "1" is represented by one of two levels, and a data "0" is represented by the other level.

NOTE 3 When a fixed pattern (the fixed part of the convolutionally encoded attached sync marker) in the symbol stream is used to provide node synchronization for the Viterbi decoder, the modulating waveform conversion can cause a modification of the pattern.

5.3 Basic convolutional code

a. The basic convolutional code shall have the characteristics shown in Table 5-1.

NOTE 1 The encoding rule can be represented by the following equations:

$$s1(t) = i(t) + i(t-1) + i(t-2) + i(t-3) + i(t-6) \quad \text{modulo 2}$$

$$s2(t) = i(t) + i(t-2) + i(t-3) + i(t-5) + i(t-6) + 1 \quad \text{modulo 2}$$

where the equations use modulo 2 addition, and $s1$ is the first output symbol, $s2$ is the second output symbol and $i(t)$ is the input information at time t.

NOTE 2 An encoder block diagram is shown in Figure 5-1.

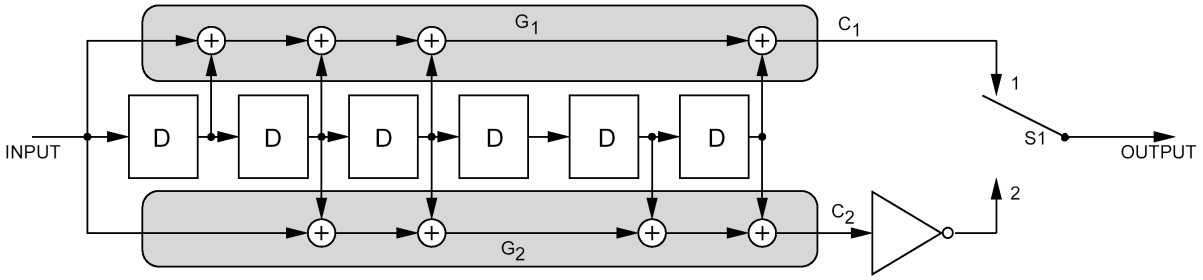
NOTE 3 The output symbol sequence is:

$C_1(1), \underline{\quad}, C_2(1), C_1(2), \underline{\quad}, C_2(2) \ldots$.

Table 5-1: Basic convolutional code characteristics

Characteristic	Value
Nomenclature	Convolutional code with maximum-likelihood (Viterbi) decoding
Code rate	1/2 bit per symbol
Constraint length	7 bits
Connection vectors	G1 = 1111001 (171 octal); G2 = 1011011 (133 octal)
Symbol inversion	On output path of G2

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NOTES:

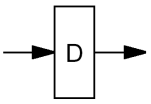
1.  = SINGLE BIT DELAY.
2. FOR EVERY INPUT BIT, TWO SYMBOLS ARE GENERATED BY COMPLETION OF A CYCLE FOR S1: POSITION 1, POSITION 2.
3. S1 IS IN THE POSITION SHOWN (1) FOR THE FIRST SYMBOL ASSOCIATED WITH AN INCOMING BIT.
4. ⊕ = MODULO-2 ADDER.
5.  = INVERTER.

Figure 5-1: Convolutional encoder block diagram

5.4 Punctured convolutional code

a. The punctured convolutional code shall have the characteristics shown in Table 5-2.

NOTE 1 A single code rate of 2/3, 3/4, 5/6 or 7/8 is selected when it provides the appropriate level of error correction and symbol rate for a given service or data rate.

NOTE 2 Figure 5-2 depicts the punctured encoding scheme.

NOTE 3 The punctured convolutional code does not include the symbol inverter associated with G2 in the rate 1/2 code defined above.

b. The puncturing patterns for each of the punctured convolutional code rates shall be the patterns defined in Table 5-3.

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