INTERNATIONAL STANDARD

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Space data and information transfer systems — Flexible advanced coding and modulation scheme for high rate telemetry applications

Systèmes de transfert des informations et données spatiales — Schéma de modulation et de codage flexible avancé pour applications en télémesure à haut débit

Reference number
ISO 17854:2013(E)

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2. www.iso.org/directives

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ISO 17854 was prepared by the Consultative Committee for Space Data Systems (CCSDS) (as CCSDS 131.2-B-1, March 2012) and was adopted (without modifications except those stated in Clause 2 of this International Standard) by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 13, *Space data and information transfer systems*.

Space data and information transfer systems — Flexible advanced coding and modulation scheme for high rate telemetry applications

1 Scope

This International Standard defines an efficient and comprehensive coding and modulation solution able to support a wide range of spectral efficiency values and data rates. The main target is given by high data rate telemetry applications, i.e. Earth Exploration Satellite Service (EESS) telemetry payload, where the increase of the system throughput by means of advanced adaptive techniques is deemed essential in order to fulfil the requirements imposed by future missions.

This International Standard presents a turbo-like coding/modulation scheme based on one possible realization of a Serial Concatenated Convolutional Code (SCCC). This scheme makes use of a set of a large variety of modulation techniques (including QPSK, 8PSK, 16APSK, 32APSK, and 64APSK) and a wide range of coding rates. The number of different modulation schemes available, combined with a properly selected coding rate, allows the overall system to make efficient use of the available bandwidth, adapting itself to the variable conditions of the link. The proposed scheme can implement Variable Coding and Modulation (VCM) mode, which varies the transmission scheme to the channel conditions following a predetermined schedule (for example, as a function of the elevation angle). When a channel is available to provide feedback (e.g. via Telecommand), the transmission scheme can be dynamically adjusted using the Adaptive Coding and Modulation (ACM) mode. The proposed coding scheme is easily adapted to any of the available modulation formats thanks to the pragmatic approach adopted: the outputs of the binary encoders are mapped to the considered modulation scheme, after being interleaved. In other words, a bit-interleaved coded modulation scheme is proposed (reference [F1]).

The use of SCCC is intended mainly for high data rate applications. The Forward Error Correction (FEC) scheme is based on the concatenation of two simple four-state encoder structures. The SCCC scheme implies a Physical Layer frame of constant length, with pilots inserted in fixed positions. This architecture simplifies the synchronization procedure, thus further allowing fast and efficient acquisition at very high rates for the receiver.

This International Standard describes a technique incorporating multiple modulation formats paired with a flexible coding and synchronization method in a tightly integrated fashion. In particular, this International Standard provides a series of recommended formats where each format pairs a modulation technique with a tailored implementation of the coding and synchronization method. However, where these modulations and/or codes are recommended in other CCSDS documents, this International Standard does not limit the choice of modulations and/or codes consistent with those recommendations.

The scope and field of application are furthermore detailed in subclause 1.3 of the enclosed CCSDS publication.

2 Requirements

Requirements are the technical recommendations made in the following publication (reproduced on the following pages), which is adopted as an International Standard:

CCSDS 131.2-B-1, March 2012, Flexible advanced coding and modulation scheme for high rate telemetry applications.

For the purposes of international standardization, the modifications outlined below shall apply to the specific clauses and paragraphs of publication CCSDS 131.2-B-1.

Pages i to v

This part is information which is relevant to the CCSDS publication only.

Page 1-5

Add the following information to the reference indicated:

[1] Document CCSDS 131.0-B-2, August 2011, is equivalent to ISO 22641:2012.

[2] Document CCSDS 132.0-B-1, September 2003, is equivalent to ISO 22645:2005.

[3] Document CCSDS 732.0-B-2, July 2006, is equivalent to ISO 22666:2007.

3 Revision of publication CCSDS 131.2-B-1

It has been agreed with the Consultative Committee for Space Data Systems that Subcommittee ISO/TC 20/SC 13 will be consulted in the event of any revision or amendment of publication CCSDS 131.2-B-1. To this end, NASA will act as a liaison body between CCSDS and ISO.

The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

FLEXIBLE ADVANCED CODING AND MODULATION SCHEME FOR HIGH RATE TELEMETRY APPLICATIONS

RECOMMENDED STANDARD

CCSDS 131.2-B-1

BLUE BOOK

March 2012

AUTHORITY

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Location:	Washington, DC, USA

This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS documents is detailed in *Organization and Processes for the Consultative Committee for Space Data Systems*, and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

This document is published and maintained by:

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STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of its members. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommended Standards** and are not considered binding on any Agency.

This **Recommended Standard** is issued by, and represents the consensus of, the CCSDS members. Endorsement of this **Recommendation** is entirely voluntary. Endorsement, however, indicates the following understandings:

- o Whenever a member establishes a CCSDS-related **standard**, this **standard** will be in accord with the relevant **Recommended Standard**. Establishing such a **standard** does not preclude other provisions which a member may develop.
- o Whenever a member establishes a CCSDS-related **standard**, that member will provide other CCSDS members with the following information:
  - -- The **standard** itself.
  - -- The anticipated date of initial operational capability.
  - -- The anticipated duration of operational service.
- o Specific service arrangements shall be made via memoranda of agreement. Neither this **Recommended Standard** nor any ensuing **standard** is a substitute for a memorandum of agreement.

No later than three years from its date of issuance, this **Recommended Standard** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

In those instances when a new version of a **Recommended Standard** is issued, existing CCSDS-related member standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such standards or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommended Standard.

FOREWORD

This document describes a Serially Concatenated Convolutional turbo Coding (SCCC) scheme for telemetry applications. The flexibility, performance, and proper architecture of the proposed coding scheme together with a new frame structure make the scheme suitable for achieving a significantly high spectral and power efficiency while maintaining compatibility with the existing data layer protocols.

The proposed coding scheme and its associated frame structure are specifically designed to support reconfiguration of the downlink channel (variable or adaptive coding and modulation) and to provide means for reliable synchronization at the Physical Layer and the Data Link Layer.

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

http://www.ccsds.org/

Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

At time of publication, the active Member and Observer Agencies of the CCSDS were:

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- Agenzia Spaziale Italiana (ASI)/Italy.
- Canadian Space Agency (CSA)/Canada.
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- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
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- UK Space Agency/United Kingdom.

Observer Agencies

- Austrian Space Agency (ASA)/Austria.
- Belgian Federal Science Policy Office (BFSPO)/Belgium.
- Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
- China Satellite Launch and Tracking Control General, Beijing Institute of Tracking and Telecommunications Technology (CLTC/BITTT)/China.
- Chinese Academy of Sciences (CAS)/China.
- Chinese Academy of Space Technology (CAST)/China.
- Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
- CSIR Satellite Applications Centre (CSIR)/Republic of South Africa.
- Danish National Space Center (DNSC)/Denmark.
- Departamento de Ciência e Tecnologia Aeroespacial (DCTA)/Brazil.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Geo-Informatics and Space Technology Development Agency (GISTDA)/Thailand.
- Hellenic National Space Committee (HNSC)/Greece.
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- Ministry of Communications (MOC)/Israel.
- National Institute of Information and Communications Technology (NICT)/Japan.
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- Naval Center for Space Technology (NCST)/USA.
- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 131.2-B-1	Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications, Recommended Standard, Issue 1	March 2012	Current issue

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this Recommended Standard is to define an efficient and comprehensive coding and modulation solution able to support a wide range of spectral efficiency values and data rates. The main target is given by high data rate telemetry applications, i.e., Earth Exploration Satellite Service (EESS) telemetry payload, where the increase of the system throughput by means of advanced adaptive techniques is deemed essential in order to fulfil the requirements imposed by future missions.

1.2 SCOPE

The current specification presents a turbo-like coding/modulation scheme based on one possible realization of a Serial Concatenated Convolutional Code (SCCC). This scheme makes use of a set of a large variety of modulation techniques (including QPSK, 8PSK, 16APSK, 32APSK, and 64APSK) and a wide range of coding rates. The number of different modulation schemes available, combined with a properly selected coding rate, allows the overall system to make efficient use of the available bandwidth, adapting itself to the variable conditions of the link. The proposed scheme can implement Variable Coding and Modulation (VCM) mode, which varies the transmission scheme to the channel conditions following a predetermined schedule (for example, as a function of the elevation angle). When a channel[1] is available to provide feedback (e.g., via Telecommand), the transmission scheme can be dynamically adjusted using the Adaptive Coding and Modulation (ACM) mode. The proposed coding scheme is easily adapted to any of the available modulation formats thanks to the pragmatic approach adopted: the outputs of the binary encoders are mapped to the considered modulation scheme, after being interleaved. In other words, a bit-interleaved coded modulation scheme is proposed (reference [F1]).

The use of SCCC is intended mainly for high data rate applications. The Forward Error Correction (FEC) scheme is based on the concatenation of two simple four-state encoder structures. The SCCC scheme implies a Physical Layer frame of constant length, with pilots inserted in fixed positions. This architecture simplifies the synchronization procedure, thus further allowing fast and efficient acquisition at very high rates for the receiver.

This document describes a technique incorporating multiple modulation formats paired with a flexible coding and synchronization method in a tightly integrated fashion. In particular, the document provides a series of recommended formats where each format pairs a modulation technique with a tailored implementation of the coding and synchronization method. However, where these modulations and/or codes are recommended in other CCSDS documents, this document does not limit the choice of modulations and/or codes consistent with those recommendations.

[1] Such a channel is often referenced as a 'return channel'; however, in CCSDS the 'return link' is associated with space-to-ground transmission of telemetry data.

1.3 APPLICABILITY

This Recommended Standard applies to the creation of Agency standards and to future data communications over space links between CCSDS Agencies in cross-support situations. This Recommended Standard includes comprehensive specification of the data formats and procedures for inter-Agency cross support. It is neither a specification of, nor a design for, real systems that may be implemented for existing or future missions.

The Recommended Standard specified in this document is to be invoked through the normal standards programs of each CCSDS Agency and is applicable to those missions for which cross support based on capabilities described in this Recommended Standard is anticipated. Where mandatory capabilities are clearly indicated in sections of this Recommended Standard, it is mandatory to implement them when this document is used as a basis for cross support. Where options are allowed or implied, implementation of these options is subject to specific bilateral cross support agreements between the Agencies involved.

1.4 DOCUMENT STRUCTURE

This document is divided into nine numbered sections and six annexes:

a) section 1 presents the purpose, scope, applicability, and rationale of this Recommended Standard and lists the conventions, definitions, and references used throughout the document;

b) section 2 provides an overview of the system architecture;

c) section 3 specifies the mode adaptation;

d) section 4 specifies the SCCC encoding;

e) section 5 specifies the Physical Layer framing;

f) section 6 specifies baseband filtering;

g) section 7 specifies frame synchronization;

h) section 8 specifies the Pseudo-Randomizer;

i) section 9 specifies managed parameters;

j) annex A provides the service definition;

k) annex B provides the description of the interleaver;

l) annex C specifies the Physical Layer pseudo-randomization;

m) annex D discusses security, SANA, and patent considerations;

n) annex E lists acronyms and terms used within this document;

o) annex F provides a list of informative references.

1.5 CONVENTIONS AND DEFINITIONS

1.5.1 NOMENCLATURE

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

a) the words 'shall' and 'must' imply a binding and verifiable specification;

b) the word 'should' implies an optional, but desirable, specification;

c) the word 'may' implies an optional specification;

d) 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.

1.5.2 INFORMATIVE TEXT

In the normative sections of this document (sections 3 through 9 and annexes A through C), informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

1.5.3 CONVENTIONS

In this document, the following convention is used to identify each bit in an *N*-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0', the following bit is defined to be 'Bit 1', and so on up to 'Bit *N*-1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 1-1).

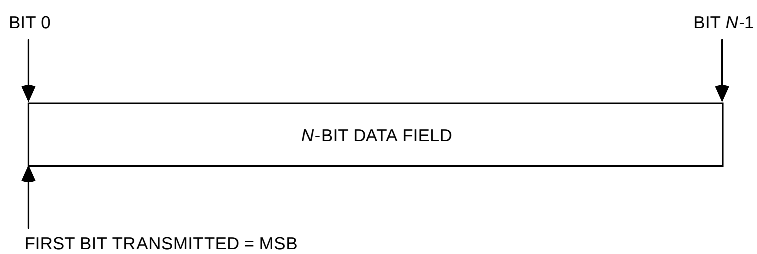

Figure 1-1: Bit Numbering Convention

In accordance with standard data-communications practice, data fields are often grouped into 8-bit ‘words’ which conform to the above convention. Throughout this Recommended Standard, such an 8-bit word is called an ‘octet’.

The numbering for octets within a data structure starts with ‘0’.

1.6 PATENTED TECHNOLOGIES

The CCSDS draws attention to the fact that it is claimed that compliance with this document may involve the use of patents.

The CCSDS takes no position concerning the evidence, validity, and scope of these patent rights.

The holders of these patent rights have assured the CCSDS that they are willing to negotiate licenses under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statements of the holders of these patent rights are registered with CCSDS. Notwithstanding the statement provided to CCSDS, the holder of U.S. Patent No. 6,023,783 patent rights will negotiate licenses under reasonable and non-discriminatory terms and conditions, provided:

a) the CCSDS Recommended Standard CCSDS 131.2-B-1 is incorporated in its entirety into each applicant’s technology, including the intended limitations on scope and applicability set forth in the CCSDS Recommended Standard;

b) the incorporation of the CCSDS Recommended Standard CCSDS 131.2-B-1 into applicant’s technology is mandatory for the operability of applicant’s technology;

c) the applicant seeks a license only for extraterrestrial spaceflight (commercial and/or non-commercial) missions and spacecraft; and

d) applicant’s license will exclude land-based communications except those land-based communications supporting extraterrestrial spaceflight missions.

Information can be obtained from the CCSDS Secretariat at the address indicated on page i. Contact information for the holders of these patent rights is provided in annex D.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. The CCSDS shall not be held responsible for identifying any or all such patent rights.

1.7 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommended Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Standard are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

[1] *TM Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 131.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, August 2011.

[2] *TM Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 132.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[3] *AOS Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 732.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, July 2006.

[4] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Recommendation for Space Data System Standards, CCSDS 401.0-B-21. Blue Book. Issue 21. Washington, D.C.: CCSDS, July 2011.

NOTE – Informative references are listed in annex F.

2 OVERVIEW

2.1 ARCHITECTURE

Figure 2-1 illustrates the relationship of this Recommended Standard to the Open Systems Interconnection reference model (reference [F2]). Two sublayers of the Data Link Layer are defined for CCSDS space link protocols. The TM and AOS Space Data Link Protocols specified in references [2] and [3], respectively, correspond to the Data Link Protocol Sublayer, and provide functions for transferring data using the protocol data unit called the Transfer Frame. The Synchronization and Channel Coding Sublayer provides methods of synchronization and channel coding for transferring Transfer Frames over a space link while the Physical Layer provides the RF and modulation methods for transferring a stream of bits over a space link in a single direction.

This Recommended Standard covers the functions of both the Synchronization and Channel Coding Sublayer and the Physical Layer.

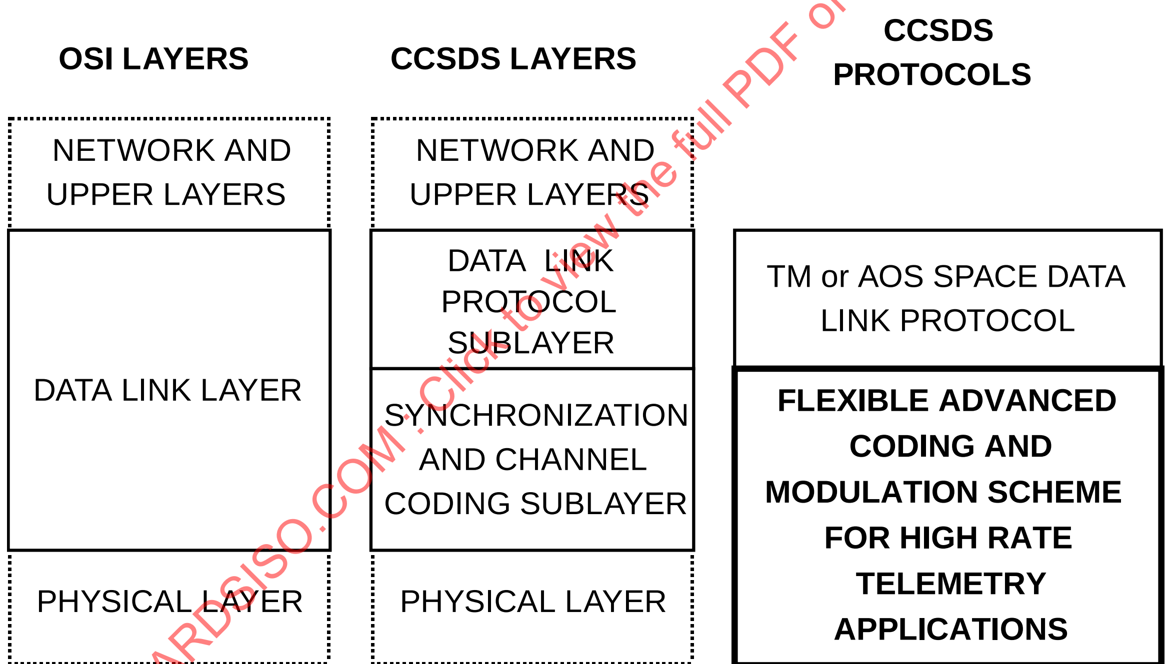

Figure 2-1: Relationship with OSI Layers

2.2 SUMMARY OF FUNCTIONS

2.2.1 GENERAL

This Recommended Standard provides the following functions for transferring Transfer Frames via a stream of bits over a space link:

a) error-control coding (based on serially concatenated convolutional coding), including frame validation;

b) Transfer Frame synchronization and pseudo-randomization; and

c) Physical Layer framing, bit synchronization, and pseudo-randomization.

2.2.2 ERROR-CONTROL CODING

This Recommended Standard specifies a turbo-like coding/modulation scheme based on Serial Concatenated Convolutional Code (SCCC) that makes use of a set of a large variety of modulation techniques and a wide range of coding rates.

NOTE – In this Recommended Standard, the characteristics of the codes are specified only to the extent necessary to ensure interoperability and cross-support. The specification does not attempt to quantify the relative coding gain or the merits of each approach discussed, nor does it specify the design requirements for encoders or decoders.

2.2.3 FRAME VALIDATION

After decoding is performed, the upper layers at the receiving end also need to know whether or not each decoded Transfer Frame can be used as a valid data unit; i.e., an indication of the quality of the received frame is needed. This function is called Frame Validation.

The SCCC code ensures a very low error probability and there is an extremely low probability of additional undetected errors that may escape this scrutiny. However, these errors may affect the system in unpredictable ways and the Frame Error Control Field is used to enforce the detection of residual errors; i.e., the Frame Error Control Field defined in references [2] and [3] is used for Frame Validation.

2.2.4 SYNCHRONIZATION

This Recommended Standard specifies a method for synchronizing Transfer Frames using an Attached Sync Marker (ASM) (see section 7).

2.2.5 PSEUDO-RANDOMIZING

This Recommended Standard specifies a pseudo-randomizer to improve several aspects of the telemetry link that aid receiver acquisition, bit synchronization, and code synchronization.

2.3 INTERNAL ORGANIZATION

2.3.1 SENDING END

A general view of the functional blocks of the architecture for the sending end is presented in figure 2-2. This figure identifies functions performed by the system and shows logical relationships among these functions. The figure is not intended to imply any hardware or software configuration in a real system.

At the sending end, the system accepts Transfer Frames of fixed length from the Data Link Protocol Sublayer, performs functions selected for the mission, and transmits a continuous and contiguous stream of physical channel symbols.

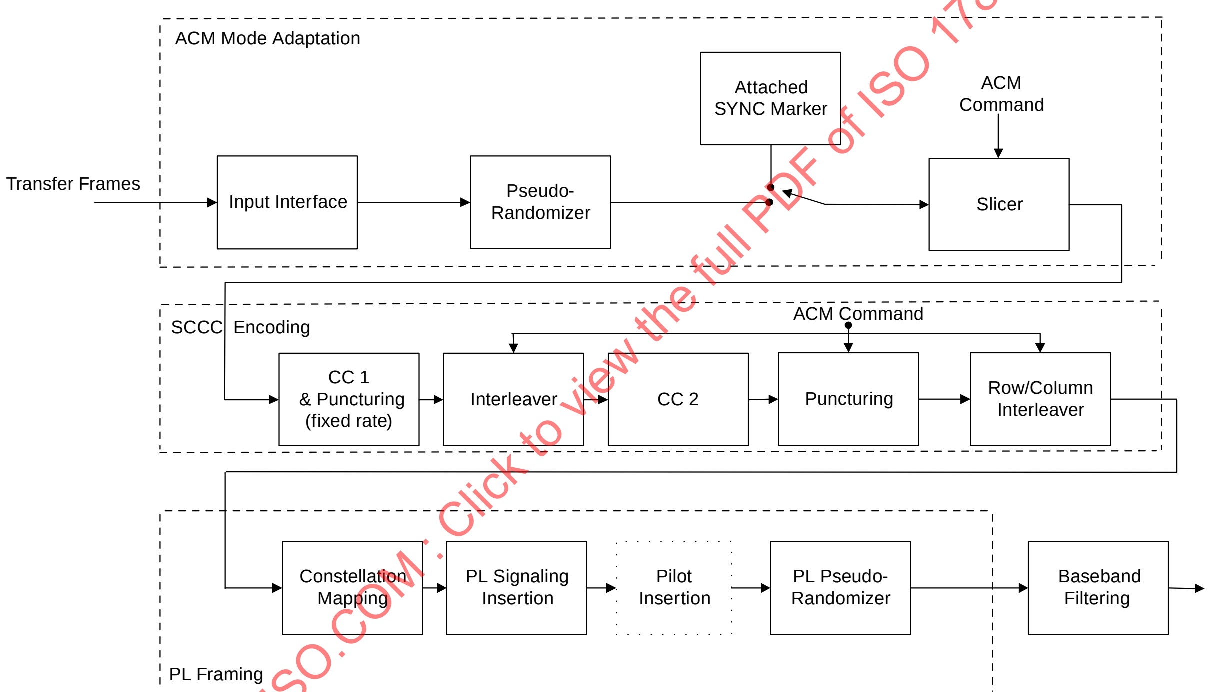

Figure 2-2: Functional Diagrams at Sending End

Figure 2-3 illustrates the frame structures and stream formats at different stages of processing. The input stream of Transfer Frames is compliant with the data link protocols in TM (reference [2]) and AOS (reference [3]).

Attached SYNC Markers (ASMs) are inserted between Transfer Frames prior to encoding. The information blocks at the input of the encoder are formed by slicing the input data stream (after ASM insertion) into blocks of length K. The information block size varies depending on the selected modulation and coding scheme (see table 4-3). A similar coding and modulation scheme is applied to every 16 consecutive blocks that form a Physical Layer (PL) frame. The length of encoded blocks (N bits) is determined according to the modulation scheme (independent of the coding rate as shown in table 4-3). The length of encoded symbol blocks after encoding and mapping to modulation symbols is constant (8100 symbols), independent of the modulation and coding scheme. Maintaining a constant symbol block size facilitates frame synchronization at the PL.

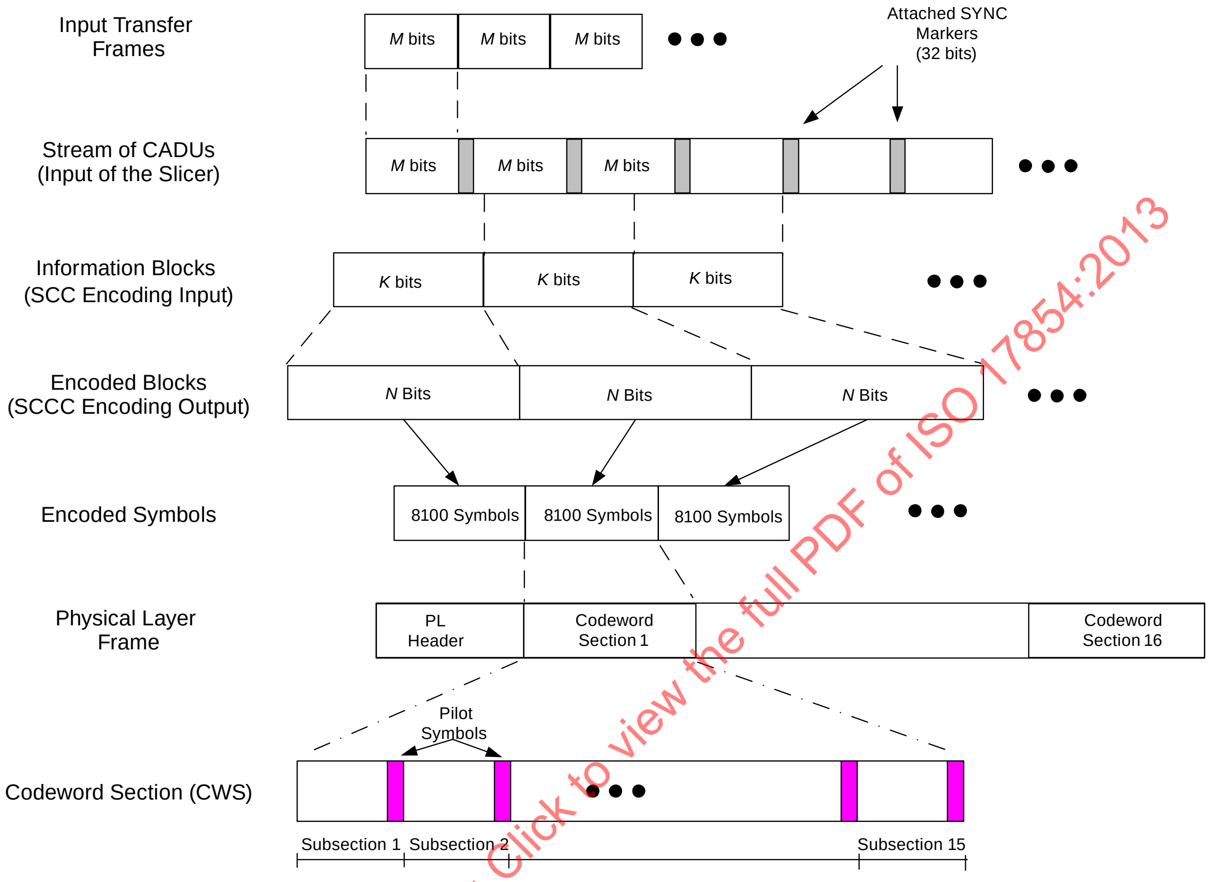

Figure 2-3: Stream Format at Different Stages of Processing

2.3.2 RECEIVING END

At the receiving end, the Synchronization and Channel Coding Sublayer accepts a continuous and contiguous stream of physical channel symbols, performs functions selected for the mission, and delivers Transfer Frames to the Data Link Protocol Sublayer.

3 MODE ADAPTATION

3.1 OVERVIEW

The mode adaptation unit provides the interface to the incoming stream units. The input interface of the mode adaptation unit maps the input electrical format into a stream of logical bit format.

3.2 SCCC SYSTEM INPUT AND INITIAL OPERATIONS

3.2.1 The SCCC system shall accept TM or AOS Transfer Frames from the Data Link Protocol sublayer.

3.2.2 The Transfer Frame length shall vary between the following minimum and maximum values: 223 octets and 2048 octets (i.e., 16384 bits).

NOTE – The Transfer Frame length is denoted as *M* in figure 2-3. Neither the TM Space Data Link Protocol (reference [2]) nor AOS Space Data Link protocol (reference [3]) specifies the Transfer Frame length. For backward compatibility with legacy data link subsystems, the following values are preferable:

a) 1784 bits (=223 × 1 octets);

b) 3568 bits (=223 × 2 octets);

c) 7136 bits (=223 × 4 octets);

d) 8920 bits (=223 × 5 octets).

3.2.3 The SCCC system shall randomize each frame with the randomizer described in reference [1].

3.2.4 For each (randomized) Transfer Frame, the SCCC system shall construct a Channel Access Data Unit (CADU) containing the ASM and the Transfer Frame.

NOTE – The CADU is defined in reference [1] as the data unit that consists of the ASM and the Transfer Frame, where the Transfer Frame in the CADU may or may not be randomized.

3.2.5 The SCCC system shall build a stream of CADUs and provide it to the Slicer.

3.2.6 The Slicer shall split the CADU stream into a sequence of information blocks of length *K*, corresponding to the information block size of the selected ACM format.

NOTE – No particular alignment between the Transfer Frame and the information blocks is considered.

3.2.7 The value of the information block size *K* shall be one of those specified in table 3-1.

NOTE – Changes of the value of the information block size *K* are done by a system to adjust the modulation and coding schemes. This is achieved through, e.g., one of the following approaches: the ground receiver provides the signal quality estimation (or prediction) through a feedback channel (e.g., via telecommand) or the change of modulation and coding schemes is pre-scheduled for each satellite pass based on geometrical information (elevation angle).

3.2.8 The value of *K* shall be set/modified via the 'ACM Command' according to the parameter 'ACM Format' as shown in table 3-1.

NOTE – The 'ACM Command' adjusts at the same time interleaving, puncturing, and bit-to-symbol mapping to ensure synchronized operations.

Table 3-1: Information Block Sizes for Different ACM Formats

ACM Format	Information Block Size (bits)	ACM Format	Information Block Size (bits)
1	5758	15	23518
2	6958	16	25918
3	8398	17	28318
4	9838	18	25918
5	11278	19	28318
6	13198	20	30958
7	11278	21	33358
8	13198	22	35998
9	14878	23	33358
10	17038	24	35998
11	19198	25	38638
12	21358	26	41038
13	19198	27	43678
14	21358		

3.2.9 When the value of *K* is modified via the 'ACM Command', the Slicer shall apply the change without losing Transfer Frames.

3.2.10 The mode adaptation unit shall provide each information block to the SCCC Encoder.

4 SCCC ENCODING

4.1 GENERAL

4.1.1 GENERAL STRUCTURE

4.1.1.1 The input to the encoder shall be information blocks of size K bits.

NOTES

1 The structure of the SCCC encoder is illustrated in figure 4-1.

2 The information block size is specified as described in 3.2.7, according to the applicable ACM format, with the objective of maintaining a constant length of the encoded blocks (N bits) at SCCC encoding output such that the number of modulation symbols generated by each information block will be constant and equal to 8100 symbols.

4.1.1.2 Each information block of size K shall be encoded by the outer convolutional encoder and then punctured to a rate 2/3, maintaining all the systematic bits while decimating the parity bits by half as shown in figure 4-3.

NOTE – The resulting outer encoder punctured output consists of [3/2 (K+2)] bits because of trellis termination. The overall coding rate adjustment is carried out by puncturing the output bits of the inner convolutional encoder. A detailed description of that puncturing scheme is provided in 4.4.

4.1.1.3 The punctured output of the outer convolutional encoder shall be interleaved according to the ad hoc permutation law defined in annex B.

4.1.1.4 The interleaver parameters shall be taken from tables B-1 and B-2.

4.1.1.5 The output of the interleaver shall be encoded by the inner convolutional encoder.

4.1.1.6 The output of the inner convolutional encoder shall be processed as defined in 4.4 and 4.5 to produce an encoded block.

NOTE – The puncturing rule determines the actual SCCC code rate. The length of the encoded block is N bits, with $N = 8100 \times m$, where m is the modulation order.

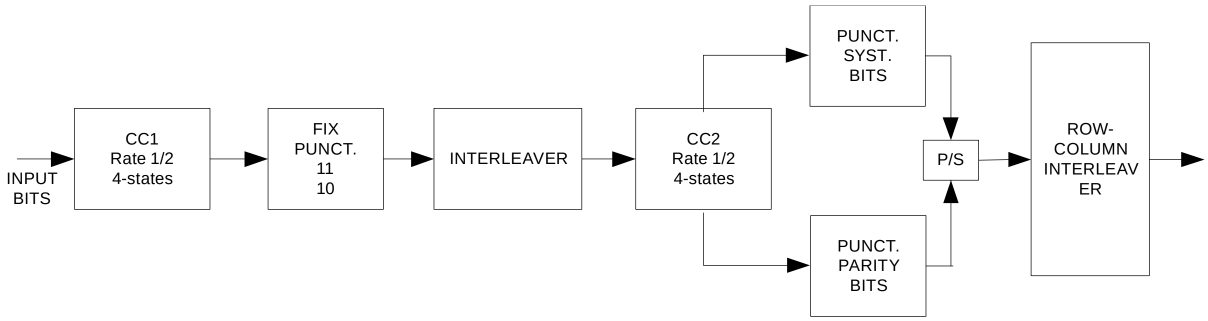

Figure 4-1: Block Diagram of the SCC Turbo Coding Scheme

4.2 CONVOLUTIONAL ENCODING

The outer (CC1) and inner (CC2) convolutional encoders shall use the code structure as detailed in figure 4-2 with the following rules.

a) The encoder initialized with '0's in all registers.

b) Defining 'u', the size of the input stream, the encoder runs for a total of u+2 bit times, producing an output of [2 (u+2)] encoded bits.

NOTE – The outputs on the outer and inner convolutional encoders are eventually subject to puncturing.

c) For the first u bit times, the input switch is in the upper position (as indicated in figure 4-2) to receive input data.

d) For the final two bit times, the switch moves to the lower position to receive feedback from the shift registers.

NOTE – This feedback cancels the same feedback sent (unswitched) to the leftmost adder (i.e., Exclusive OR) and causes all two registers to become filled with zeros after the final two bit times. Filling the registers with zeros is called terminating the trellis.

e) During trellis termination the encoder continues to output encoded bits.

f) In particular, the 'systematic uncoded' output (line 'C_1' in the figure) includes an extra two bits from the feedback line in addition to the u input bits.

NOTE – These encoders are based on the same 4-state, rate 1/2 recursive, systematic encoder.

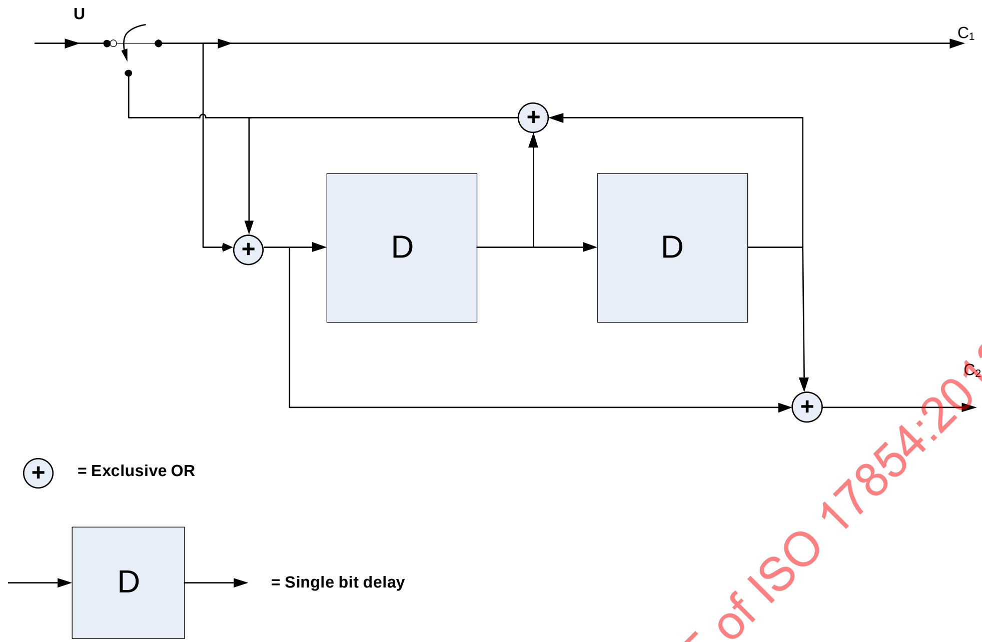

Figure 4-2: The Convolutional Encoder Block Diagram for CC1 and CC2

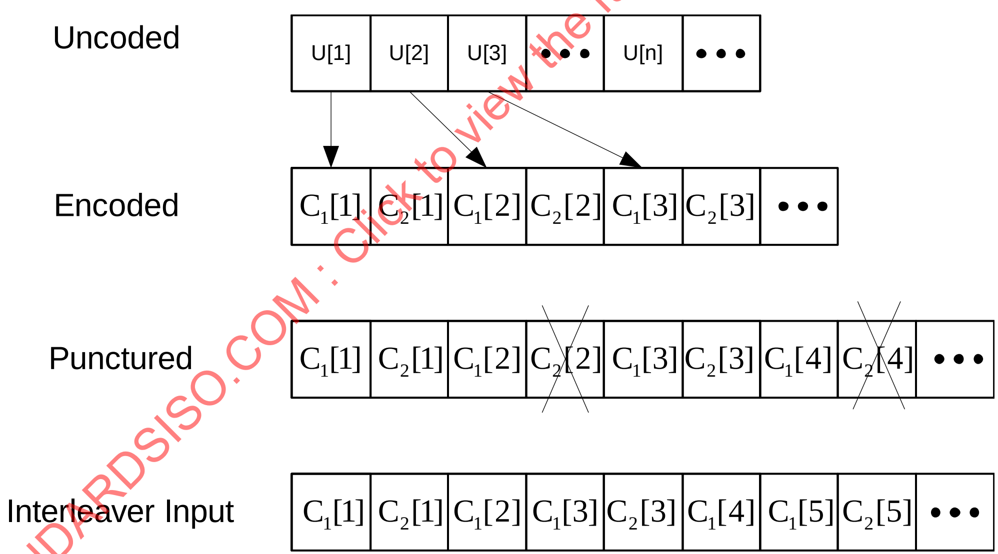

Figure 4-3: Outer Code Puncturing Scheme

4.3 INTERLEAVER

4.3.1 The interleaver length *I* and the corresponding permutation law shall be selected according to the parameter 'ACM Format' of the 'ACM Command'.

NOTES

1 This is done to keep the length of the SCCC Encoder output to a constant 8100 modulated symbols.

2 The interleaver is described by the ad hoc permutation law specified in annex B.

4.3.2 The Interleaver Length shall be according to table 4-1.

NOTE – It is worth noting that for the 27 selected ACM formats there are 19 different interleaver sizes.

Table 4-1: Interleaver Sizes for Different ACM Formats

ACM Format	Interleaver Length (bits)	ACM Format	Interleaver Length (bits)
1	8640	15	35280
2	10440	16	38880
3	12600	17	42480
4	14760	18	38880
5	16920	19	42480
6	19800	20	46440
7	16920	21	50040
8	19800	22	54000
9	22320	23	50040
10	25560	24	54000
11	28800	25	57960
12	32040	26	61560
13	28800	27	65520
14	32040		

4.4 CODING RATE ADJUSTMENT

4.4.1 OVERVIEW

Puncturing is performed at the output of the inner convolutional encoder to obtain the desired coding rate. Two different puncturing algorithms are used to puncture the systematic output C_1 and the parity output C_2 of the inner convolutional encoder.

4.4.2 GENERAL

4.4.2.1 The upper register at the output of the inner convolutional encoder (as specified in figure 4-1) shall contain the inner systematic bits, which coincide with the interleaved outer codeword, as well as two additional bits terminating the inner trellis.

4.4.2.2 The lower register shall contain the I+2 parity-check bits generated by the inner convolutional encoder.

4.4.2.3 The systematic output C_1 of the inner convolutional encoder shall be punctured excluding the two inner code-terminating bits (that are always transmitted) according to the periodic puncturing pattern described in 4.4.3.

4.4.2.4 The last two terminating bits of the inner convolutional encoder shall be always transmitted.

4.4.3 PUNCTURING SYSTEMATIC C_1 BITS

4.4.3.1 The puncturing of the systematic bits C_1 at the output of the inner convolutional encoder shall operate according to the parameters of table 4-2, where S_{sur} denotes the number of surviving bits in each 300-bit segment of the upper register after puncturing and is selected from table 4-3 based on the ACM format.

NOTE – Since in table 4-3 S_{sur} for ACM Format 1 and 2 has value 300, no puncturing of the systematic bits C_1 is performed in those cases.

4.4.3.2 Given the parameter S_{sur}, the puncturing of the systematic bits shall be performed according to the following algorithm:

a) After selecting the applicable S_{sur} in table 4-3 according to the current ACM format, a puncturing pattern of 300 elements (from 0 to 299) is obtained, inserting zeros at all the positions indicated by the column 'puncturing positions' of table 4-2 till (and including) the row for the applicable S_{sur} value, and ones elsewhere (e.g., for ACM Format 7, being S_{sur} = 292, the puncturing pattern will contains zeros in the positions 76, 1, 145, 214, 256, 37, 109, 181).

b) For each position i of the upper register containing the systematic bits, from i=0 to i=I-1 (i.e., excluding the two terminating bits, always transmitted), an index j is computed as

$$j = \pi(i) \bmod 300$$

where the $\pi()$ is the function described in annex B and $\pi(i)$ is the interleaved position corresponding to i.

c) The position i in the upper register is punctured if the puncturing pattern of point a) contains a 0 at position j.

Table 4-2: Best Incremental Puncturing Positions

Index	S_{sur}	Rate	Punct. Pos.	Index	S_{sur}	Rate	Punct. Pos.
1	299	0.6689	**76**	51	249	0.8032	**72**
2	298	0.6711	**1**	52	248	0.8065	**15**
3	297	0.6734	**145**	53	247	0.8097	**297**
4	296	0.6757	**214**	54	246	0.8130	**211**
5	295	0.6780	**256**	55	245	0.8163	**138**
6	294	0.6803	**37**	56	244	0.8197	**102**
7	293	0.6826	**109**	57	243	0.8230	**174**
8	292	0.6849	**181**	58	242	0.8264	**39**
9	291	0.6873	**277**	59	241	0.8299	**250**
10	290	0.6897	**235**	60	240	0.8333	**57**
11	289	0.6920	**55**	61	239	0.8368	**120**
12	288	0.6944	**127**	62	238	0.8403	**156**
13	287	0.6969	**163**	63	237	0.8439	**84**
14	286	0.6993	**19**	64	236	0.8475	**229**
15	285	0.7018	**199**	65	235	0.8511	**193**
16	284	0.7042	**91**	66	234	0.8547	**283**
17	283	0.7067	**289**	67	233	0.8584	**262**
18	282	0.7092	**244**	68	232	0.8621	**25**
19	281	0.7117	**64**	69	231	0.8658	**238**
20	280	0.7143	**268**	70	230	0.8696	**60**
21	279	0.7168	**223**	71	229	0.8734	**201**
22	278	0.7194	**136**	72	228	0.8772	**294**
23	277	0.7220	**172**	73	227	0.8811	**132**
24	276	0.7246	**28**	74	226	0.8850	**96**
25	275	0.7273	**100**	75	225	0.8889	**159**
26	274	0.7299	**190**	76	224	0.8929	**34**
27	273	0.7326	**10**	77	223	0.8969	**265**
28	272	0.7353	**46**	78	222	0.9009	**114**
29	271	0.7380	**118**	79	221	0.9050	**177**
30	270	0.7407	**154**	80	220	0.9091	**225**
31	269	0.7435	**81**	81	219	0.9132	**79**
32	268	0.7463	**207**	82	218	0.9174	**12**
33	267	0.7491	**259**	83	217	0.9217	**151**
34	266	0.7519	**292**	84	216	0.9259	**51**
35	265	0.7547	**232**	85	215	0.9302	**274**
36	264	0.7576	**67**	86	214	0.9346	**204**
37	263	0.7605	**280**	87	213	0.9390	**105**
38	262	0.7634	**247**	88	212	0.9434	**4**
39	261	0.7663	**147**	89	211	0.9479	**241**
40	260	0.7692	**30**	90	210	0.9524	**169**
41	259	0.7722	**111**	91	209	0.9569	**69**
42	258	0.7752	**183**	92	208	0.9615	**124**
43	257	0.7782	**6**	93	207	0.9662	**22**
44	256	0.7813	**48**	94	206	0.9709	**216**
45	255	0.7843	**93**	95	205	0.9756	**285**
46	254	0.7874	**165**	96	204	0.9804	**141**
47	253	0.7905	**129**	97	203	0.9852	**252**
48	252	0.7937	**219**	98	202	0.9901	**187**
49	251	0.7968	**195**	99	201	0.9950	**206**
50	250	0.8000	**270**	100	200	1.0000	**36**

4.4.4 PUNCTURING PARITY C_2 BITS

4.4.4.1 General

4.4.4.1.1 The *I*+2 parity-check bits C_2 generated by the inner convolutional encoder shall be punctured using the rate-matching algorithm specified in 4.4.4.2.

NOTE – The puncturing of parity bits results in deleting a set of equally spaced bits.

4.4.4.1.2 The number of deleted parity bits shall be determined based on the rate matching parameter Δ/I, representing the ratio between the number of deleted parity bits Δ and the overall number of parity bits *I* before puncturing:

$$\Delta = I - (P - 2) \tag{4-1}$$

where $P=N-S$ is the total number of transmitted parity check bits.

NOTE – The last two terminating parity check bits are always transmitted.

4.4.4.2 Rate Matching Algorithm

4.4.4.2.1 Given the two parameters Δ (number of bits to be deleted) and *I* (total number of bits), the rate-matching algorithm shall use the following procedure:

a) Set the variable e=1.

b) For all possible positions *i* from 0 to I–1:

   1) if $e>0$ transmit the i^{th} bit; else set $e=e+I$;

   2) set $e=e-\Delta$.

c) Continue.

NOTE – The last two terminating bits are always transmitted.

4.4.4.2.2 For each SCCC overall coding rate the parameter S_{sur} and the positions of the upper register punctured bits shall be determined in accordance with table 4-2.

NOTES

1 This is to optimize the coding scheme.

2 In each case, the value of S_{sur} determines the overall number of transmitted systematic bits *S* and, subsequently, the number of transmitted parity check bits *P* and the parameter Δ used by the rate-matching algorithm.

4.4.4.2.3 The parameter describing the encoder structure in each of the 27 ACM formats shall be taken from table 4-3.

Table 4-3: Main Encoder Parameters for 27 Selected ACM Formats

ACM format	m	S_{sur}	K	I	S	P	N	Δ
1	2	300	5758	8640	8642	7558	16200	1084
2	2	300	6958	10440	10442	5758	16200	4684
3	2	274	8398	12600	11510	4690	16200	7912
4	2	251	9838	14760	12351	3849	16200	10913
5	2	234	11278	16920	13200	3000	16200	13922
6	2	218	13198	19800	14390	1810	16200	17992
7	3	292	11278	16920	16470	7830	24300	9092
8	3	240	13198	19800	15842	8458	24300	11344
9	3	250	14878	22320	18602	5698	24300	16624
10	3	234	17038	25560	19939	4361	24300	21201
11	3	221	19198	28800	21218	3082	24300	25720
12	3	214	21358	32040	22857	1443	24300	30599
13	4	255	19198	28800	24482	7918	32400	20884
14	4	241	21358	32040	25741	6659	32400	25383
15	4	230	23518	35280	27051	5349	32400	29933
16	4	220	25918	38880	28515	3885	32400	34997
17	4	211	28318	42480	29880	2520	32400	39962
18	5	245	25918	38880	31755	8745	40500	30137
19	5	234	28318	42480	33137	7363	40500	35119
20	5	224	30958	46440	34677	5823	40500	40619
21	5	217	33358	50040	36197	4303	40500	45739
22	5	210	35998	54000	37802	2698	40500	51304
23	6	236	33358	50040	39366	9234	48600	40808
24	6	228	35998	54000	41042	7558	48600	46444
25	6	220	38638	57960	42507	6093	48600	51869
26	6	214	41038	61560	43915	4685	48600	56877
27	6	208	43678	65520	45429	3171	48600	62351

4.5 ROW-COLUMN INTERLEAVER

4.5.1 The input to the row-column interleaver shall be built with punctured systematic bits C_1 followed by punctured parity bits C_2.

4.5.2 Prior to the bit-to-symbol mapping at the transmitter, a row-column interleaver shall be used to pseudo-randomize the selection of bits that are assigned to one modulation symbol.

NOTE – This is to ensure that the correlation between bits assigned to one symbol does not adversely affect the decoding process. To implement the pragmatic code permutation, the output of the inner encoder, after puncturing, is bit interleaved. This technique is known as Bit Interleaved Coded Modulation (BICM) as introduced in reference [F1].

4.5.3 The bit-interleaving scheme shall follow figure 4-4, such that the interleaver depth (number of rows) is equal to the size of one codeword section (i.e., 8100 symbols) and the number of columns is equal to m, where m is the modulation order.

NOTES

1 The bit interleaving structure has 8,100 rows, independent of the ACM format, and *m* columns, where *m* is the modulation order. The first symbol carries the bits positioned at index 0, 8100, 16200, 24300, 32400, 40500, 48600, for 64 APSK for instance. The second symbol carries bits at position 1, 8101, 16201, 24301, 32401, 40501, 48601 and so on up to the last symbol (carrying bits 8099, 16199, 24299, 32399, 40499, 48599).

2 The maximum memory size to implement the bit-interleaver is $m \times 8100 = 6 \times 8100 = 48600$ locations, each containing one bit, for the 64 APSK modulation scheme. The memory can be seen as a matrix composed of *m* columns and 8100 rows. The number of rows is independent of the code rate and modulation scheme.

3 The modulation order *m* can be mapped to the selected modulation as follows: 2=QPSK, 3=8PSK, 4=16APSK, 5=32APSK and 6=64APSK.

4.5.4 The input data shall be serially written into the interleaving column-wise and serially read out row-wise (the most significant bit shall be read out first).

4.5.5 Punctured Systematic bits C_1 (corresponding to the upper branch of the inner convolutional encoder) shall be first written sequentially in the register followed by the punctured parity check bits C_2 (corresponding to the lower branch of the convolutional encoder).

NOTE – The SCCC encoding unit provides each encoded block to the PL Framing.

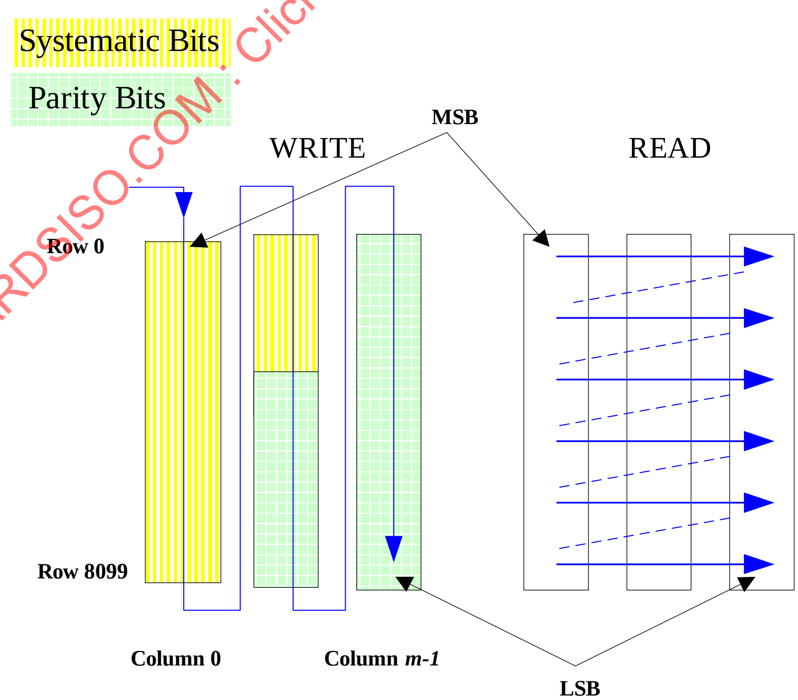

Figure 4-4: Row-Column Bit-Interleaving Scheme

5 PHYSICAL LAYER FRAMING

5.1 GENERAL

5.1.1 The SCCC encoding unit shall provide the PL Framing with encoded blocks of N=8100 × m bits, where m is the modulation order, that are used to generate PL Frames.

NOTE – In this section, when used alone, the term frame always refers to a PL Frame.

5.1.2 Each encoded block shall be mapped to 8100 modulation symbols as defined in 5.2.

5.2 CONSTELLATION MAPPING

5.2.1 GENERAL

5.2.1.1 One of the following constellation mappings shall be used:

a) PSK modulations

1) QPSK modulation, as specified in subsection 2.4.10 of reference [4] (and illustrated in 5.2.2.1).

2) 8PSK modulation, as specified in 5.2.2.2.

b) APSK modulations

1) 16APSK modulation, as specified in 5.2.3.1.

2) 32APSK modulation, as specified in 5.2.3.2.

3) 64APSK modulation, as specified in 5.2.3.3.

5.2.1.2 For all the constellation mappings the Bit Numbering Convention shall be applied (see 1.5.3).

NOTE – Figure 5-1 shows the selected modulation constellations along with the associated bits-to-symbols mapping laws.

5.2.2 PSK MODULATIONS

5.2.2.1 QPSK

If used, a QPSK modulation scheme shall be the conventional Gray-Coded QPSK modulation with absolute mapping (no differential coding), following the specification in subsection 2.4.10 of reference [4].

NOTES

1 The normalized average energy per symbol is equal to 1 (Radius=1).

2 The normalization for QPSK and the modulations hereafter sets the level of the pilot symbols (5.3.4.3) relative to modulated data symbols.

5.2.2.2 8PSK

If used, an 8PSK modulation scheme shall be a conventional Gray-Coded 8PSK modulation with absolute mapping (no differential coding).

NOTE – The normalized average energy per symbol is equal to 1 (Radius=1).

5.2.3 APSK MODULATIONS

5.2.3.1 16APSK

5.2.3.1.1 If a 16APSK scheme is used, the constellation shall be composed of 2 concentric circumferences, whose number of points shall be set to $N_1 = 4$ and $N_2 = 12$.

5.2.3.1.2 If a 16APSK scheme is used, the values of $\gamma_1 = R_2/R_1$ for 16APSK modulation schemes and linear channels shall be those shown in table 5-1.

5.2.3.1.3 If a 16APSK scheme is used, the average signal energy shall be set to one; i.e.,

$$[R_1]^2 + 3\,[R_2]^2 = 4.$$

5.2.3.2 32APSK

5.2.3.2.1 If a 32APSK scheme is used, the constellation shall be composed of 3 concentric circumferences whose number of points shall be set to $N_1 = 4$, $N_2 = 12$, and $N_3 = 16$.

5.2.3.2.2 If a 32APSK scheme is used, the values of $\gamma_1 = R_2/R_1$ and $\gamma_2 = R_3/R_1$ for 32APSK modulation schemes shall be those shown in table 5-1.

5.2.3.2.3 If a 32APSK scheme is used, the average signal energy shall be set to one; i.e.,

$$[R_1]^2 + 3\,[R_2]^2 + 4\,[R_3]^2 = 8.$$

5.2.3.3 64APSK

5.2.3.3.1 If a 64APSK scheme is used, the constellation shall be composed of 4 concentric circumferences, whose number of points shall be set to $N_1 = 4$, $N_2 = 12$, $N_3 = 20$, and $N_4 = 28$.

5.2.3.3.2 If a 64APSK scheme is used, the following set of parameters shall be used to maximize the minimum Euclidean distance:

a) $\gamma_1 = R_2/R_1 = 2.73$;

b) $\gamma_2 = R_3/R_1 = 4.52$; and

c) $\gamma_3 = R_4/R_1 = 6.31$.

5.2.3.3.3 If a 64APSK scheme is used, the average signal energy shall be set to one; i.e.,

$$[R_1]^2 + 3\,[R_2]^2 + 5\,[R_3]^2 + 7\,[R_4]^2 = 16.$$

Table 5-1: Constellation Radius Ratios for 16APSK and 32APSK

ACM Format	Modulation	Coding Rate	γ_1	γ_2
13	16-APSK	0.5925	3.15	N/A
14	16-APSK	0.6592	3.15	N/A
15	16-APSK	0.7259	2.85	N/A
16	16-APSK	0.7999	2.75	N/A
17	16-APSK	0.8740	2.60	N/A
18	32-APSK	0.6400	2.84	5.27
19	32-APSK	0.6992	2.84	5.27
20	32-APSK	0.7644	2.84	5.27
21	32-APSK	0.8237	2.72	4.87
22	32-APSK	0.8888	2.54	4.33

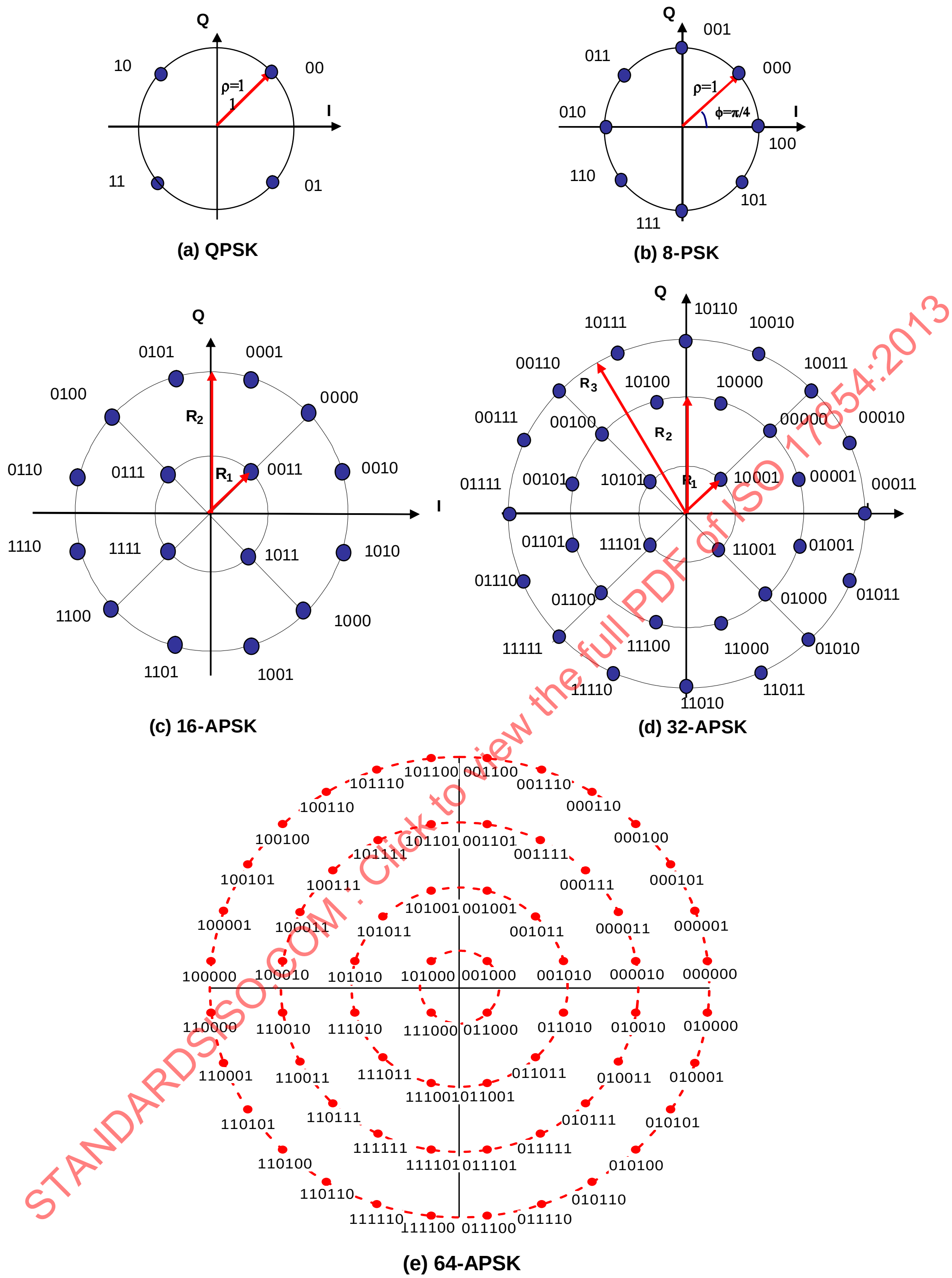

Figure 5-1: Bit Mapping into Constellations

5.2.4 SUPPORTED SET OF ACM FORMATS

The coding and modulation schemes (ACM formats) shall use the parameters specified in table 5-2.

NOTE – The two highest spectral efficiencies for each modulation scheme have also been included with the modulation scheme with higher cardinality. This overlap is necessary since the coded-modulator performance can be different depending on the channel impairments. In summary, a total of 27 ACM formats are supported, providing about 20 dB range in the required E_s/N_o for the link budget.

Table 5-2: ACM Formats of the SCCC Encoder

	ACM Format	***K*** **Information block size**	***I*** **Interleaver length**	***N*** **Number of encoded bits**	**Code rate Overall rate of the code (*K*/*N*)**
QPSK	1	5758	8640	16200	0.36
	2	6958	10440	16200	0.43
	3	8398	12600	16200	0.52
	4	9838	14760	16200	0.61
	5	11278	16920	16200	0.7
	6	13198	19800	16200	0.81
8PSK	7	11278	16920	24300	0.46
	8	13198	19800	24300	0.54
	9	14878	22320	24300	0.61
	10	17038	25560	24300	0.7
	11	19198	28800	24300	0.79
	12	21358	32040	24300	0.88
16APSK	13	19198	28800	32400	0.59
	14	21358	32040	32400	0.66
	15	23518	35280	32400	0.73
	16	25918	38880	32400	0.8
	17	28318	42480	32400	0.87
32APSK	18	25918	38880	40500	0.64
	19	28318	42480	40500	0.7
	20	30958	46440	40500	0.76
	21	33358	50040	40500	0.82
	22	35998	54000	40500	0.89
64APSK	23	33358	50040	48600	0.69
	24	35998	54000	48600	0.74
	25	38638	57960	48600	0.80
	26	41038	61560	48600	0.84
	27	43678	65520	48600	0.9

5.3 PL SIGNALLING INSERTION

5.3.1 GENERAL

The PL frame structure shall consist of the following segments:

a) frame header segment, which consists of two fields:

1) Frame Marker (FM), as specified in 5.3.2;

NOTE – Frame Marker consists of 256 known symbols used for start-of-frame detection and synchronization.

2) Frame Descriptor (FD), as specified 5.3.3;

NOTE – Frame Descriptor consists of 64 symbols to identify the ACM format used per each physical frame as well as the presence or absence of pilot symbols.

b) codeword segment, which consists of 16 codeword sections of modulation symbols (with additional optional pilot symbols, as specified in 5.3.4).

NOTE – The PL frame structure is illustrated in figure 5-2.

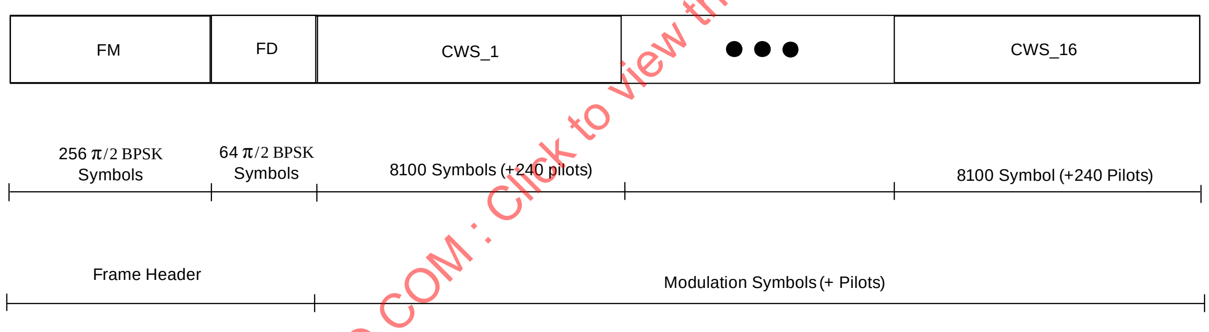

Figure 5-2: Physical Layer Frame Structure

5.3.2 FRAME MARKER

5.3.2.1 Overview

As explained in 5.4.1, the Frame Marker will consist of a 256-bit sequence mapped to 256 $\pi/2$-BPSK modulated symbols. The Frame Marker is used to detect the start of the PL frame as well as initial timing and coarse carrier synchronization. The length and the modulating bit sequence of the Frame Marker is selected such that the start of frame can be detected with a low probability of detection error (misdetection as well as false alarm) in the presence of severe channel impairments.

5.3.2.2 Frame Marker Generation

5.3.2.2.1 The Frame Marker shall be generated using the Gold sequence using the following polynomials for the feedback loop:

$$g_1(x) = x^8 + x^6 + x^5 + x^4 + 1$$
$$g_2(x) = x^8 + x^6 + x^5 + x^4 + x^3 + x + 1 \quad (5\text{-}1)$$

NOTE – Figure 5-3 shows the logical block diagram of the sequence generator using shift registers and exclusive-OR operators.

5.3.2.2.2 The upper and the lower shift registers of the Frame Marker Sequence Generator shall be initialized as shown in figure 5-3.

NOTE – The first 40 bits of the Frame Marker sequence for the generator are shown below. The left-most bit corresponds to the first modulating bit of the Frame Marker:

```
1111 1011 0100 0100 0001 1111 0001 1101 1011 1101 …
```

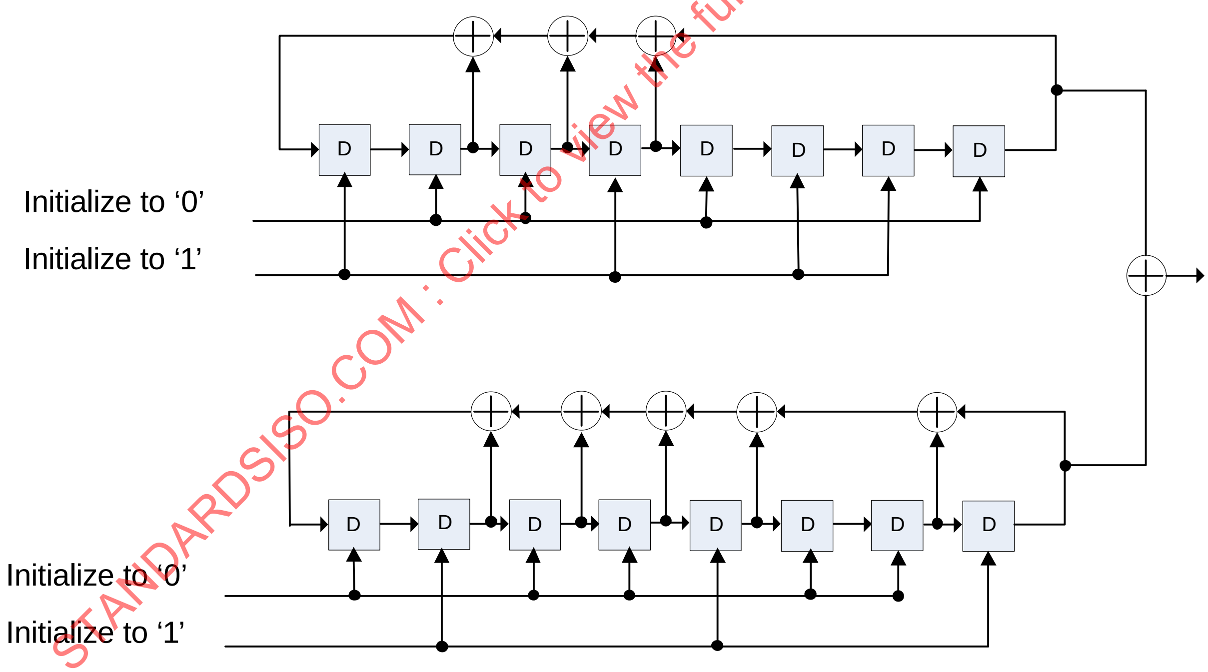

Figure 5-3: Frame Marker Sequence Generator

5.3.3 FRAME DESCRIPTOR STRUCTURE

5.3.3.1 Overview

The Frame Descriptor is generated by encoding 7 input bits with the non-systematic binary code of length 64 and dimension 7 with minimum distance d_{min}=32 shown in figure 5-3. The 7 input bits identify the ACM format of codeword sections within a PL frame (5 bits) as well as the absence or presence of distributed pilots. The code is similar to that used in reference [F3] for PL Signalling.

5.3.3.2 Frame Descriptor Content and Construction

5.3.3.2.1 The content of the seven input bits shall be as shown in table 5-3.

Table 5-3: Frame Descriptor Input Bits Content

Bit Number	Content
b_1-b_5	ACM Formats (Decimal values 1 to 27 are used with bit b_1 being the most significant bit)
b_6	Distributed Pilot On (=1) / Off (=0)
b_7	Reserved (set to 0)

5.3.3.2.2 The Frame Descriptor shall be constructed using the bi-orthogonal (32,6) code shown in figure 5-4, as follows:

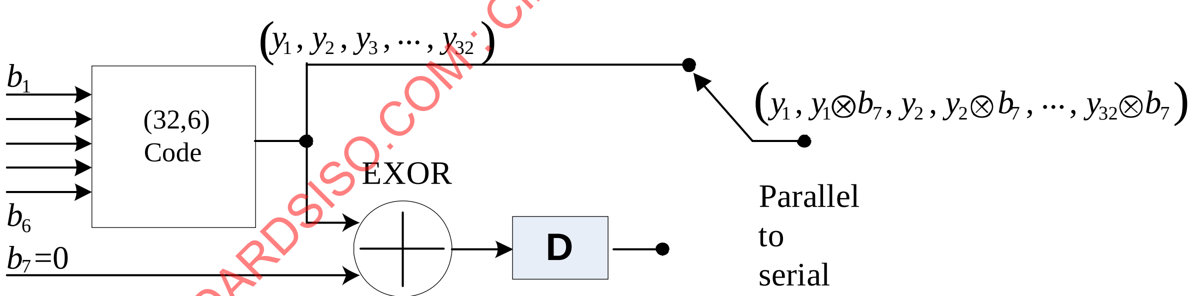

Figure 5-4: Frame Descriptor Code Structure

a) The first 6 bits, b_1-b_6, shall be encoded using a linear block code of length 32 with the generator matrix in figure 5-5.

$$G = \begin{bmatrix} 01010101010101010101010101010101 \\ 00110011001100110011001100110011 \\ 00001111000011110000111100001111 \\ 00000000111111110000000011111111 \\ 00000000000000001111111111111111 \\ 11111111111111111111111111111111 \end{bmatrix}$$

Figure 5-5: Generator Matrix for (32,6) Code

b) The most significant bit b_1 shall be multiplied with the first row of the matrix, the following bit with the second row, and so on till bit b_6 to generate 32 coded bits denoted (y_1, y_2, …, y_{32}).

c) The least significant bit b_7 of the Frame Descriptor shall be set to 0 and the final output is therefore the 64-bit output code (y_1, y_1, y_2, y_2,…, y_{32}, y_{32}) where each symbol is present twice.

d) The 64-bit output code shall be further scrambled (i.e., EXORed) by the following binary sequence:

0111000110011101100000111100100101010011010000100010110111111010.

5.3.4 CODEWORD SEGMENT GENERATION AND PILOT INSERTION

5.3.4.1 Each encoded block mapped to 8100 modulation symbols shall be used to generate a codeword section optionally containing pilot symbols.

NOTE – A codeword section includes either 8100 or 8340 modulation symbols in case pilot symbols are used.

5.3.4.2 If insertion of distributed pilots is performed, it shall follow the format specified in figure 5-6.

NOTES

1 Each codeword section is composed of 15 subsections and each subsection is composed of 540 data symbols optionally followed by 16 pilot symbols. The use of distributed pilot symbols in codeword sections is an option to facilitate carrier and phase synchronization.

2 The presence or absence of pilot symbols can be changed using one bit (b_6) of the 7 input bits (see table 5-3).

5.3.4.3 Each pilot shall be an un-modulated symbol, with equal In-phase and Quadrature components: I=(1√2), Q=(1√2).

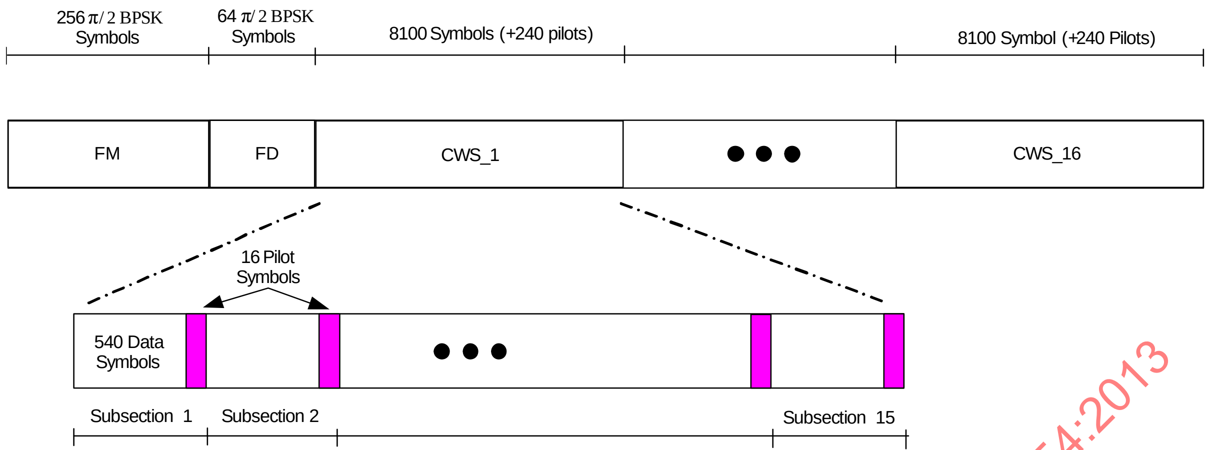

Figure 5-6: Distributed Pilot Pattern

5.3.4.4 The parameters to specify the pilot distribution pattern within each PL frame shall be those presented in table 5-4.

NOTE – The total overhead due to pilot insertion is around three per cent.

Table 5-4: Frame Parameters Related to Pilot Distribution

Parameter	Value
Codeword section length without pilot symbols	8100 symbols
Number of codeword sections per frame	16 sections
Number of subsections per codeword section	15 subsections
Number of data symbols per subsection	540 symbols
Number of pilots per subsection	16 symbols
Total number of pilots per section	240 Symbols
Total section length including pilot symbols	8340 symbols

5.4 FRAME HEADER MODULATION

5.4.1 The frame header shall be modulated into 320 π/2-BPSK symbols.

NOTE – As specified in 5.3, the frame header consists of the Frame Marker (256 bits) and Frame Descriptor (64 bits).

5.4.2 The frame header shall be modulated using the following mapping:

Assuming that the Frame Header binary sequence is denoted as (x_1, x_2, …, x_{320}), the In-phase (*I*) and Quadrature (*Q*) components of 320 π/2-BPSK modulated symbols are determined according the following rule:

$$\begin{aligned} I_{2i-1} &= Q_{2i-1} = \frac{1}{\sqrt{2}}(1-2x_{2i-1}) \\ I_{2i} &= -Q_{2i} = \frac{-1}{\sqrt{2}}(1-2x_{2i}) \end{aligned} \quad \text{for } i = 1,2,\ldots,160 \qquad (5\text{-}2)$$

5.5 PHYSICAL LAYER *I*/*Q* PSEUDO-RANDOMIZATION

5.5.1 PL randomization shall be applied to all 16 codeword sections of a PL frame, including the data symbols as well as the pilots.

NOTE – This is done to disperse the signal energy in order to avoid any spectral spur due to repetitive data or pilot patterns. PL randomization is fixed for all Transfer Frames on a Physical Channel during a given Mission Phase (see section 9).

5.5.2 PL randomization shall use the PL pseudo-randomizer specified in annex C.

6 BASEBAND FILTERING

6.1.1 The baseband pulse shaping filter applied to In-phase and Quadrature signals shall be a square-root raised cosine filter using the following:

$$H(f) = \begin{cases} 1 & |f| < f_N(1-\alpha) \\ \left\{ \frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left(\frac{f_N - |f|}{\alpha}\right) \right\}^{1/2} & f_N(1-\alpha) < |f| < f_N(1+\alpha) \\ 0 & |f| > f_N(1+\alpha) \end{cases} \quad (6\text{-}1)$$

Where $f_N = \frac{1}{2T_s} = \frac{R_s}{2}$ is the Nyquist frequency and α is the roll-off factor.

6.1.2 The roll-off factor shall have one of the following values: α=0.2, 0.25, 0.30 or 0.35.

7 FRAME SYNCHRONIZATION

7.1 OVERVIEW

7.1.1 SYNCHRONIZATION

Frame synchronization is necessary for subsequent processing of the Transfer Frames. Furthermore, it is necessary for synchronization of the pseudo-random generator, if used (see section 8).

7.1.2 CHANNEL ACCESS DATA UNIT

The data unit that consists of the ASM and the Transfer Frame, consistent with reference [1], is called the Channel Access Data Unit (CADU). The Transfer Frame in the CADU is randomized.

7.2 THE ATTACHED SYNC MARKER

7.2.1.1 Transfer Frames shall be synchronized by using a stream of fixed-length Transfer Frames with an Attached Sync Marker (ASM) between them.

NOTE – Synchronization is acquired on the receiving end by recognizing the specific bit pattern of the ASM in the data stream; synchronization is then verified by making further checks.

7.2.1.2 The ASM shall be SCCC encoded.

7.3 ASM BIT PATTERNS

The ASM shall consist of a 32-bit (4-octet) marker with a pattern shown in table 7-1.

Table 7-1: ASM Bit Patterns

ASM length	32 bits
ASM sequence (Hex)	1ACFFC1D

7.4 LOCATION OF ASM

7.4.1 The ASM shall be attached to (i.e., shall immediately precede) the Transfer Frame.

7.4.2 The ASM shall immediately follow the end of the preceding Transfer Frame; i.e., there shall be no intervening bits (data or fill) preceding the ASM.

7.5 ASM FOR EMBEDDED DATA STREAM

NOTE – A different ASM pattern (see figure 7-1) may be required where another data stream (e.g., a stream of Transfer Frames played back from a tape recorder in the forward direction) is inserted into the data field of the Transfer Frame of the main stream appearing on the communications channel.

The ASM for the embedded data stream, to differentiate it from the main stream marker, shall consist of a 32-bit (4-octet) marker with a pattern as follows:

```
FIRST TRANSMITTED BIT
(Bit 0)
↓
0011  0101  0010  1110  1111  1000  0101  0011
                                             ↑
                            LAST TRANSMITTED BIT
                                        (Bit 31)
```

Figure 7-1: Embedded ASM Bit Pattern

NOTE – This pattern is represented in hexadecimal notation as:

352EF853

8 PSEUDO-RANDOMIZER

8.1 OVERVIEW

In order for the receiver system to work properly, every data capture system at the receiving end requires that the incoming signal have sufficient bit transition density (see recommendation 2.4.9 in reference [4]), and allow proper synchronization of the decoder.

In order to ensure proper receiver operation, the data stream must be sufficiently random. The Pseudo-Randomizer defined in this section is the preferred method to ensure sufficient randomness for all combinations of CCSDS-recommended modulation and coding schemes. The Pseudo-Randomizer defined in reference [1] is always required by SCCC.

8.2 PSEUDO-RANDOMIZER DESCRIPTION

8.2.1 The pseudo-randomizer shall be applied to the Transfer Frame before SCCC encoding.

8.2.2 On the receiving end, it shall be applied to de-randomize the data after SCCC decoding and Transfer Frame synchronization.

NOTES

1 The method for ensuring sufficient transitions is to exclusive-OR each bit of the codeblock, codeword, or Transfer Frame with a standard pseudo-random sequence.

2 The configuration at the sending end is shown in figure 8-1.

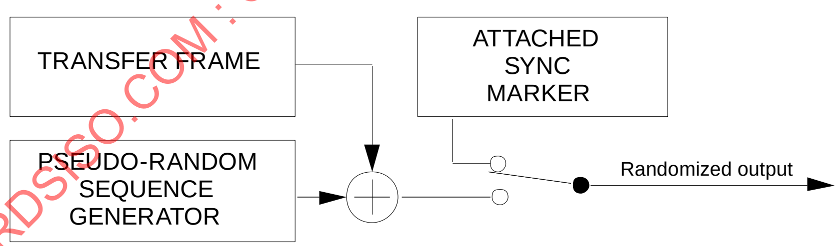

Figure 8-1: Pseudo-Randomizer Configuration

8.3 SYNCHRONIZATION AND APPLICATION OF PSEUDO-RANDOMIZER

8.3.1 The ASM shall be used for synchronizing the pseudo-randomizer.

NOTE – The ASM is already optimally configured for synchronization purposes.

8.3.2 The pseudo-random sequence shall be applied starting with the first bit of the Transfer Frame.

8.3.3 On the sending end, the Transfer Frame shall be randomized by exclusive-ORing the first bit of the Transfer Frame with the first bit of the pseudo-random sequence, followed by the second bit of the Transfer Frame with the second bit of the pseudo-random sequence, and so on.

8.3.4 On the receiving end, the original Transfer Frame shall be reconstructed (i.e., derandomized) using the same pseudo-random sequence.

8.3.5 After locating the ASM in the received data stream, the data immediately following the ASM shall be derandomized.

NOTES

1 The ASM was not randomized and is not derandomized.

2 Derandomization can be accomplished by performing exclusive-OR with hard bits or inversion with soft bits.

8.4 SEQUENCE SPECIFICATION

8.4.1 The pseudo-random sequence shall be generated using the following polynomial:

$$h(x) = x^8 + x^7 + x^5 + x^3 + 1$$

8.4.2 This sequence shall begin at the first bit of the Transfer Frame and shall repeat after 255 bits, continuing repeatedly until the end of the Transfer Frame. The sequence generator shall be initialized to the all-ones state at the start of each Transfer Frame.

NOTE – The first 40 bits of the pseudo-random sequence from the generator are shown below. The leftmost bit is the first bit of the sequence to be exclusive-ORed with the first bit of the Transfer Frame; the second bit of the sequence is exclusive-ORed with the second bit of the Transfer Frame, and so on.

1111 1111 0100 1000 0000 1110 1100 0000 1001 1010 . . . .

8.5 LOGIC DIAGRAM

NOTE – Figure 8-2 represents a possible generator for the specified sequence.

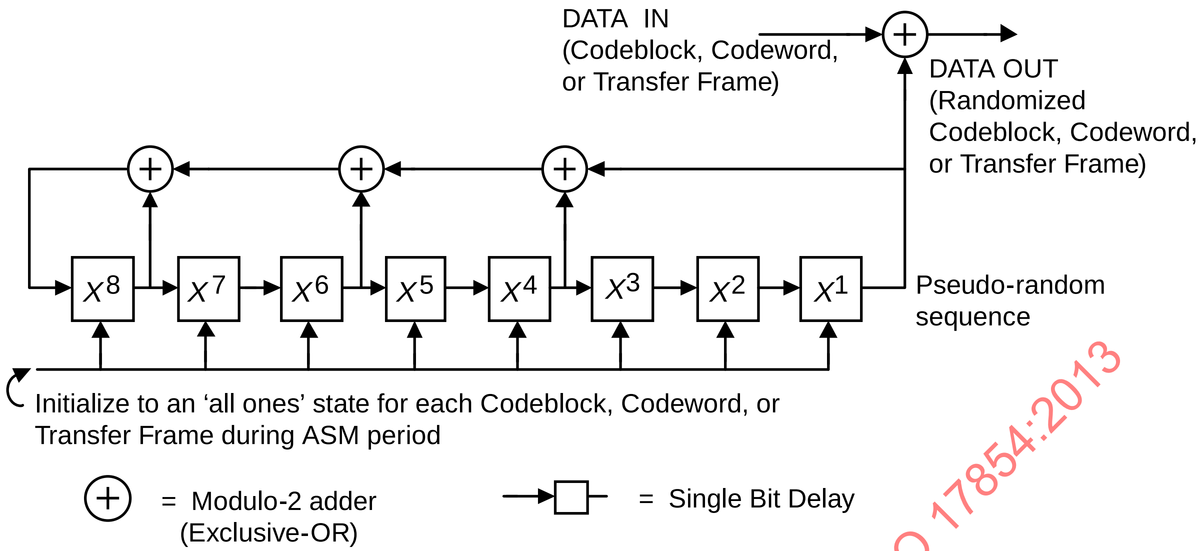

Figure 8-2: Pseudo-Randomizer Logic Diagram

9 MANAGED PARAMETERS

9.1 OVERVIEW

In order to conserve bandwidth on the space link, some parameters associated with modulation, synchronization, and channel coding are handled by management rather than by inline communications protocol. The managed parameters are generally those which tend to be static for long periods of time, and whose change generally signifies a major reconfiguration of the modulation, synchronization, and channel coding systems associated with a particular mission, i.e., parameters that are fixed within a mission phase. However, as mentioned in annex A, the coding and modulation scheme defined in this book also supports parameters that can be changed from one time interval to the next, within a sequence of time intervals in a mission phase. These two types will be referenced in this section respectively as Permanent Managed Parameters and Variable Managed Parameters.

Through the use of a management system, management conveys the required information to the modulation, synchronization, and channel coding systems.

In this section, the managed parameters used by systems applying this recommended standard are listed. These parameters are defined in an abstract sense and are not intended to imply any particular implementation of a management system.

9.2 PERMANENT MANAGED PARAMETERS

9.2.1 GENERAL

9.2.1.1 All the managed parameters specified in this section shall be fixed for all Transfer Frames on a Physical Channel during a given Mission Phase.

9.2.1.2 The Frame Error Control Field defined in reference [2] or [3] shall be present.

NOTE – The Frame Error Control Field is used for Frame Validation as mentioned in 2.2.3.

9.2.2 MANAGED PARAMETERS FOR FRAME SYNCHRONIZATION

The managed parameters for frame synchronization shall be those specified in table 9-1.

Table 9-1: Managed Parameters for Frame Synchronization

Managed Parameter	Allowed Values
Transfer Frame Length (octets)	Integer: 223 to 2048 octets

9.2.3 MANAGED PARAMETERS FOR CODING AND MODULATION

The managed parameters for coding and modulation shall be those specified in table 9-2.

Table 9-2: Managed Parameters for Coding and Modulation

Managed Parameter	Allowed Values
Baseband pulse shaping roll-off factor	0.2, 0.25, 0.3, 0.35
Pilot symbols insertion	ON, OFF
Scrambling code number *n*	INTEGER from 0 to 2^{18}–2

9.2.4 MANAGED PARAMETERS FOR SUPPORTED ACM FORMATS

The managed parameters for supported ACM Formats shall be those specified in table 9-3.

Table 9-3: Managed Parameters for Supported ACM Formats

Managed Parameter	Allowed Values
Number of ACM Formats supported during a given Mission Phase	Integer: 1 to 27
List of ACM Formats supported during a given Mission Phase	List of Integers (dimension = 'Number of ACM Formats supported during a given Mission Phase'). Each integer is in the range 1 to 27 as per 9.3.2 below.

9.3 VARIABLE MANAGED PARAMETERS

9.3.1 GENERAL

All the managed parameters specified in this section shall be fixed for all Transfer Frames on a Physical Channel within one interval of a given Mission Phase.

NOTE – Variable managed parameters apply to reconfiguration of the modulation, synchronization, and channel coding systems during a mission phase.

9.3.2 CURRENT ACM FORMAT

The managed parameters for ACM Format shall be those specified in table 9-4.

NOTE – ACM Format can range from 1 to 27. As a consequence of this parameter several systems parameters shall be changed consistently. The complete set of parameters with their corresponding values is shown in table 9-5.

Table 9-4: Managed Parameters for ACM Format

Managed Parameter	Allowed Values
Current ACM Format	Integer: 1 to 27

Table 9-5: Variable Managed Parameters for 27 Selected ACM Formats

ACM format	*m*	S_{sur}	*K*	*I*	*S*	*P*	*N*	Δ
1	2 = QPSK	300	5758	8640	8642	7558	16200	1084
2	2 = QPSK	300	6958	10440	10442	5758	16200	4684
3	2 = QPSK	274	8398	12600	11510	4690	16200	7912
4	2 = QPSK	251	9838	14760	12351	3849	16200	10913
5	2 = QPSK	234	11278	16920	13200	3000	16200	13922
6	2 = QPSK	218	13198	19800	14390	1810	16200	17992
7	3 = 8PSK	292	11278	16920	16470	7830	24300	9092
8	3 = 8PSK	240	13198	19800	15842	8458	24300	11344
9	3 = 8PSK	250	14878	22320	18602	5698	24300	16624
10	3 = 8PSK	234	17038	25560	19939	4361	24300	21201
11	3 = 8PSK	221	19198	28800	21218	3082	24300	25720
12	3 = 8PSK	214	21358	32040	22857	1443	24300	30599
13	4 = 16APSK	255	19198	28800	24482	7918	32400	20884
14	4 = 16APSK	241	21358	32040	25741	6659	32400	25383
15	4 = 16APSK	230	23518	35280	27051	5349	32400	29933
16	4 = 16APSK	220	25918	38880	28515	3885	32400	34997
17	4 = 16APSK	211	28318	42480	29880	2520	32400	39962
18	5 = 32APSK	245	25918	38880	31755	8745	40500	30137
19	5 = 32APSK	234	28318	42480	33137	7363	40500	35119
20	5 = 32APSK	224	30958	46440	34677	5823	40500	40619
21	5 = 32APSK	217	33358	50040	36197	4303	40500	45739
22	5 = 32APSK	210	35998	54000	37802	2698	40500	51304
23	6 = 64APSK	236	33358	50040	39366	9234	48600	40808
24	6 = 64APSK	228	35998	54000	41042	7558	48600	46444
25	6 = 64APSK	220	38638	57960	42507	6093	48600	51869
26	6 = 64APSK	214	41038	61560	43915	4685	48600	56877
27	6 = 64APSK	208	43678	65520	45429	3171	48600	62351

ANNEX A

SERVICE

(NORMATIVE)

A1 OVERVIEW

A1.1 BACKGROUND

This annex provides service definition in the form of primitives, which present an abstract model of the logical exchange of data and control information between the service provider and the service user. The definitions of primitives are independent of specific implementation approaches.

The parameters of the primitives are specified in an abstract sense and specify the information to be made available to the user of the primitives. The way in which a specific implementation makes this information available is not constrained by this specification. In addition to the parameters specified in this annex, an implementation can provide other parameters to the service user (e.g., parameters for controlling the service, monitoring performance, facilitating diagnosis, and so on).

A2 OVERVIEW OF THE SERVICE

The Flexible Advanced Coding and Modulation scheme for High Rate Telemetry Applications provides unidirectional (one way) transfer of a sequence of fixed-length TM or AOS Transfer Frames at constant frame rate over a Physical Channel across a space link, with optional error detection/correction.

The value of the constant frame rate can be changed from one time interval to the next, within a sequence of time intervals in a mission phase. There can be multiple time intervals within a mission phase. This annex does not specify the method for synchronizing the data exchange between the service user and the service provider when there is a change of frame rate: the synchronization is considered to be part of system management and is out of the scope of this annex.

Only one user can use this service on a Physical Channel, and Transfer Frames from different users are not multiplexed together within one Physical Channel.

A3 SERVICE PARAMETERS

A3.1 FRAME

A3.1.1 The Frame parameter is the service data unit of this service and shall be either a TM Transfer Frame defined in reference [2] or an AOS Transfer Frame defined in reference [3].

A3.1.2 The length of any Transfer Frame transferred on a Physical Channel must be the same, and is established by management.

A3.2 QUALITY INDICATOR

The Quality Indicator parameter shall be used to notify the user at the receiving end of the service that there is an uncorrectable error in the received Transfer Frame.

A3.3 SEQUENCE INDICATOR

The Sequence Indicator parameter shall be used to notify the user at the receiving end of the service that one or more Transfer Frames of the Physical Channel have been lost as the result of a loss of frame synchronization.

A4 SERVICE PRIMITIVES

A4.1 GENERAL

A4.1.1 The service primitives associated with this service are:

a) ChannelAccess.request;

b) ChannelAccess.indication.

A4.1.2 The ChannelAccess.request primitive shall be passed from the service user at the sending end to the service provider to request that a Frame be transferred through the Physical Channel to the user at the receiving end.

A4.1.3 The ChannelAccess.indication shall be passed from the service provider to the service user at the receiving end to deliver a Frame.

A4.2 ChannelAccess.request

A4.2.1 Function

The ChannelAccess.request primitive is the service request primitive for this service.

A4.2.2 Semantics

The ChannelAccess.request primitive shall provide a parameter as follows:

ChannelAccess.request (Frame)

A4.2.3 When Generated

The ChannelAccess.request primitive is passed to the service provider to request it to process and send the Frame.

A4.2.4 Effect On Receipt

Receipt of the ChannelAccess.request primitive causes the service provider to perform the functions described in 2.3.1 and to transfer the resulting channel symbols.

A4.3 ChannelAccess.indication

A4.3.1 Function

The ChannelAccess.indication primitive is the service indication primitive for this service.

A4.3.2 Semantics

The ChannelAccess.indication primitive shall provide parameters as follows:

ChannelAccess.indication (Frame,
Quality Indicator,
Sequence Indicator)

A4.3.3 When Generated

The ChannelAccess.indication primitive is passed from the service provider to the service user at the receiving end to deliver a Frame.

A4.3.4 Effect On Receipt

The effect of receipt of the ChannelAccess.indication primitive by the service user is undefined.

ANNEX B

PARALLELIZED INTERLEAVER

(NORMATIVE)

B1 OVERVIEW

In order to support 27 distinct ACM formats, it is necessary to designate only 19 permutations that allow a parallel implementation of the decoder with a degree of parallelism of 120. Thus the sizes of all 19 interleavers are integer multiples of 120.

As defined in 4.1.1.3, the punctured output of the outer convolutional encoder is interleaved according to the ad hoc permutation law defined here. In the SCCC encoding functional block, the outer convolutional encoder writes the output data in natural order and those data are eventually punctured to a code rate 2/3. This data, before being submitted in input to the inner convolutional encoder are permuted according to the Parallelized Interleaver algorithm described here.

B2 SPECIFICATIONS

B2.1 The interleaver shall process the punctured output of the outer encoder that will write its I bits data (numbered from 0 to I-1) in the memory in natural order.

NOTE – The allowed values of I are defined in table 4-1.

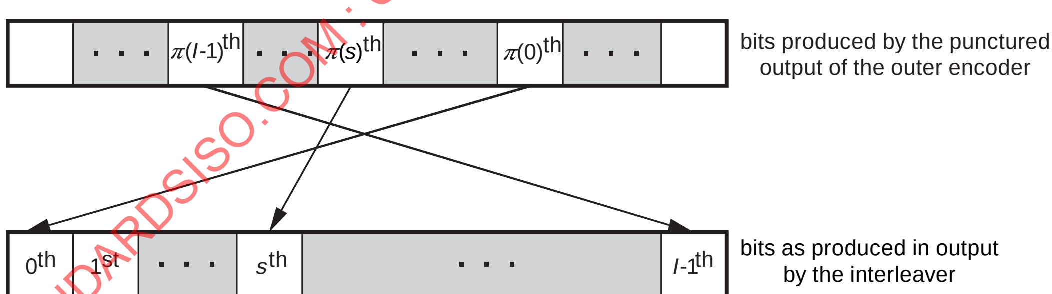

Figure B-1: Interpretation of Interleaver Algorithm

B2.2 The interleaver algorithm shall produce an output of I bits (numbered from 0 to I-1) according to the following relationship, which gives the reading address at time i:

$$\pi(i) = W \times [(\lfloor i/W \rfloor + \beta(i_W)) \bmod 120] + \alpha(i_W) \quad i = 0,\ldots,I-1 \qquad \text{(B-1)}$$

where α and β are two vectors of length equal to $W=I/120$, and

$$i_W \equiv i \bmod W \qquad \text{(B-2)}$$

where the elements of α (addresses of macrodata) range in [0,W-1] and the elements of β (cyclic shifts of macrodata) range in [0,119].

NOTES

1 In the equation above, $\lfloor x \rfloor$ denotes the largest integer less than or equal to x.

2 The interleaver can be thought of as a 120 x W memory block that is written to row by row, left to right, starting with bit 0 in column 0 of row 0, and ending with bit I-1 in column W-1 of row 119. Within each column c, bits are cyclically shifted by beta(c); then, each column c is assigned a new column position according to alpha(c). Finally, bits are read out row by row, left to right. In this way, the ith bit written is identified by its row r = $\lfloor i/W \rfloor$ and column c = i mod W, with i = rW + c, and the ith bit read from the memory block is pi(i) = r′W + c′, where r′ = (r + beta(c)) mod 120 and c′ = alpha(c).

B2.3 The interleaver parameters shall be obtained from tables B-1 and B-2.

Table B-1: Interleaver Parameters (1-10)

	1		2		3		4		5		6		7		8		9		10	
	I=8640 W=72		I=10440 W=87		I=12600 W=105		I=14760 W=123		I=16920 W=141		I=19800 W=165		I=22320 W=186		I=25560 W=213		I=28800 W=240		I=32040 W=267	
	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β
0	63	116	70	82	85	97	106	1	60	14	116	87	18	114	50	32	109	98	63	93
1	33	69	53	27	91	27	82	89	107	55	42	34	95	1	134	71	179	66	238	10
2	64	103	63	101	1	47	115	49	4	31	66	36	68	116	200	47	129	13	92	78
3	56	92	67	106	0	69	17	43	102	68	77	47	108	72	68	89	214	109	189	72
4	59	77	10	59	35	104	58	20	87	53	13	38	11	119	74	15	186	45	73	25
5	5	73	29	22	3	90	81	24	89	76	99	25	104	61	1	18	128	72	172	68
6	58	58	47	105	77	66	113	41	117	42	84	69	118	108	32	40	60	8	94	96
7	52	46	52	49	98	57	28	3	68	19	123	8	172	20	102	69	112	91	49	14
8	61	107	82	33	51	50	12	78	67	113	1	80	181	84	33	79	8	93	228	6
9	47	1	58	15	13	29	2	111	96	58	102	60	19	95	154	119	183	117	219	5
10	57	52	65	111	63	60	76	107	15	110	73	101	121	92	21	29	170	64	197	46
11	35	90	72	7	97	86	10	67	140	105	109	82	106	93	22	111	225	114	173	47
12	29	32	2	74	78	35	40	10	114	44	21	77	75	88	103	61	35	15	232	111
13	60	119	40	86	49	37	108	117	112	17	48	89	73	60	162	108	97	77	195	108
14	36	3	4	70	68	25	9	38	22	28	6	30	109	16	130	54	87	35	144	42
15	24	68	31	71	7	84	74	51	9	109	47	57	142	101	83	16	88	85	21	80
16	10	60	36	100	103	117	64	74	34	16	142	52	69	32	38	99	188	6	134	102
17	20	30	7	31	96	53	92	40	21	34	124	93	117	100	190	105	47	99	161	104
18	66	83	23	13	57	72	31	87	116	11	150	73	103	80	180	55	165	107	135	19
19	17	63	77	62	75	115	35	94	62	24	104	112	116	70	61	116	156	88	102	67
20	31	41	45	39	67	59	101	14	28	79	72	19	113	62	104	75	52	55	259	31
21	16	50	17	1	58	106	26	63	105	95	4	118	83	87	167	114	233	15	101	97
22	67	6	79	80	25	7	27	44	79	35	119	10	78	118	168	21	151	95	200	43
23	28	24	35	104	59	52	69	64	121	20	135	78	138	0	100	101	0	20	3	72
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79			54	82	28	9	65	73	93	31	14	8	7	103	71	114	162	94	124	54
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86			81	75	55	68	42	19	14	71	59	78	60	75	75	81	3	61	181	93
87					62	74	107	47	16	3	160	105	176	23	52	95	222	118	242	1
88					80	22	50	96	124	19	144	49	51	5	113	43	204	7	146	10
89					8	95	99	7	136	55	7	25	8	4	11	15	58	42	118	89
90					41	102	79	31	45	9	32	29	166	79	188	77	202	104	170	70
91					101	59	53	78	103	91	57	93	10	105	53	103	137	54	127	105
92					71	57	60	116	104	112	114	50	124	84	57	70	45	52	257	8
93					92	46	33	13	25	68	61	79	74	54	109	42	135	93	156	3
94					89	44	16	1	10	65	75	104	24	10	128	118	15	88	205	110
95					94	66	117	86	118	33	67	111	131	49	157	116	31	39	55	16
96					40	4	88	58	75	110	158	57	17	88	127	85	2	103	47	52
97					43	19	119	28	91	102	92	64	80	114	195	11	11	65	151	62
98					27	50	85	68	49	116	33	14	6	47	152	12	48	98	221	101
99					64	39	30	20	128	83	134	72	177	96	96	104	62	118	119	57
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103					26	64	3	47	59	75	132	66	71	63	58	68	23	96	82	47
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105							15	36	0	5	105	99	56	72	171	100	111	115	122	108
106							103	98	40	14	146	37	154	110	209	68	166	103	241	55
107							120	62	138	71	55	77	107	30	60	106	215	42	111	7
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110							78	57	122	63	19	5	182	15	169	61	158	110	260	22
111							116	100	3	69	45	105	52	48	63	113	171	27	213	21
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116							44	103	88	88	12	36	114	97	69	77	85	109	18	84
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118							11	97	69	117	111	41	26	28	7	116	77	72	252	82
119							104	81	24	0	157	75	92	14	147	59	65	38	10	55
120							52	59	46	82	36	110	183	105	153	40	150	21	139	39
121							96	56	126	1	62	45	1	29	136	45	153	119	141	53
122							110	99	19	21	17	109	49	74	2	3	142	33	110	65
123									115	113	120	86	35	110	187	30	9	59	158	75
124									47	53	98	117	63	34	25	52	149	45	100	103
125									20	86	140	0	163	40	210	90	181	61	168	87
126									42	7	91	84	9	99	163	28	180	56	223	100
127									65	73	15	28	179	90	23	115	19	66	217	26
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129									64	95	122	31	50	93	12	16	56	7	222	64
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131									134	93	83	91	125	20	91	119	95	47	17	112
132									130	39	94	6	135	118	131	82	40	89	133	79
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134									129	86	152	22	62	76	155	60	197	50	59	104
135									58	105	145	12	40	23	185	62	218	3	112	5
136									30	79	161	25	31	83	132	44	81	69	116	90
137									94	2	89	118	72	107	97	79	219	85	44	45
138									43	61	137	98	174	31	20	39	139	19	246	42
139									12	98	65	24	148	10	144	71	205	91	37	25
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141											24	65	98	55	77	109	213	13	187	12
142											108	8	162	65	86	26	118	24	45	113
143											164	68	47	95	175	9	133	6	120	63
144											82	89	156	91	119	99	209	32	140	29
145											79	42	64	1	0	9	119	90	206	36
146											100	97	110	12	148	105	189	52	138	14
147											101	2	30	52	55	0	55	29	66	59
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154											81	106	141	7	211	74	28	93	216	30
155											147	95	155	42	161	23	132	64	38	86
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158											50	17	23	51	197	50	92	44	36	85
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160											16	72	42	49	198	104	208	14	182	9
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163											28	74	126	108	40	28	61	80	93	119
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165													151	54	193	69	125	25	54	42
166													39	40	15	27	114	48	107	76
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169													165	38	82	97	86	3	87	44
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177													134	74	174	37	63	22	125	83
178													99	11	24	35	14	75	148	58
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181													66	69	181	63	124	106	207	0
182													160	9	159	103	239	89	230	68
183													15	85	59	14	212	105	40	78
184													159	18	13	40	74	13	0	28
185													161	75	186	73	16	20	8	57
186															129	89	228	18	250	20
187															123	38	36	91	210	35
188															94	93	167	66	11	61
189															124	65	143	34	62	22
190															203	86	89	26	83	77
191															99	2	5	50	224	18
192															9	21	121	11	194	52
193															126	67	184	69	237	93
194															89	13	138	100	27	116
195															95	54	211	97	58	80
196															93	116	164	77	5	47
197															172	31	144	58	171	106
198															208	85	110	79	179	117
199															107	46	104	104	261	49
200															27	85	226	98	57	0
201															18	81	24	6	77	73
202															72	7	131	43	6	82
203															5	11	38	76	113	112
204															150	98	168	71	105	84
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206															116	3	230	45	85	101
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209															146	110	18	32	84	27
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211															137	27	123	59	204	10
212															44	45	200	44	218	113
213																	21	55	109	110
214																	227	83	254	59
215																	53	81	117	4
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217																	172	51	152	72
218																	199	113	71	91
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221																	82	97	78	75
222																	185	10	215	94
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227																	12	27	180	41
228																	163	30	266	71
229																	176	102	186	61
230																	169	107	264	13
231																	98	39	199	65
232																	7	25	265	86
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238																	78	15	28	9
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252																			15	117
253																			154	1
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255																			192	74
256																			159	25
257																			163	119
258																			247	3
259																			52	88
260																			147	37
261																			203	42
262																			169	70
263																			157	82
264																			177	100
265																			42	118
266																			4	31