The Consultative Committee for Space Data Systems

Research and Development for
Space Data System Standards

SERIALLY CONCATENATED CONVOLUTIONAL CODES— EXTENSION (SCCC-X)

EXPERIMENTAL SPECIFICATION

CCSDS 131.21-O-1

Note:
This current
issue includes
all updates through
Technical Corrigendum 1,
dated April 2022

ORANGE BOOK

May 2021

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FOREWORD

This document describes an extension to the Serially Concatenated Convolutional turbo Codes (SCCC-X) scheme for telemetry applications. The scheme completes existing coding and modulation options and caters for providing higher spectral efficiencies for high rate telemetry systems with particular favorable link budgets.

To each implementation, the SCCC-X fully reuses coding, framing and signaling elements of the existing standard.

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 *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). Current versions of CCSDS documents are maintained at the CCSDS Web site:

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PREFACE

This document is a CCSDS Experimental Specification. Its Experimental status indicates that it is part of a research or development effort based on prospective requirements, and as such it is not considered a Standards Track document. Experimental Specifications are intended to demonstrate technical feasibility in anticipation of a 'hard' requirement that has not yet emerged. Experimental work may be rapidly transferred onto the Standards Track should a hard requirement emerge in the future.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 131.21-O-1	Serially Concatenated Convolutional Codes—Extension (SCCC-X), Experimental Specification, Issue 1	May 2021	Original issue
CCSDS 131.21-O-1 Cor. 1	Technical Corrigendum 1	April 2022	– replaces CADU with SMTF; – adds applicability of CCSDS 401.0; – editorially updates references to current issues.

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CONTENTS (continued)

1 INTRODUCTION

1.1 PURPOSE

The purpose of this Experimental Specification is to extend the existing Blue Book CCSDS 131.2-B-1, *Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications* (reference [1]), in order to add new Modulation and Coding (MODCODs) options, that is, increasing the range of operating conditions to higher signal-to-noise ratios. Because the extension retains the same underlying coding scheme for error correction as CCSDS 131.2-B-1, the book is entitled Serially Concatenated Convolutional Codes—Extension (SCCC-X).

Cor. 1

As is the case with CCSDS 131.2-B-1, the main applications that this book is targeting are high data rate telemetry applications, that is, Earth Exploration Satellite Service (EESS) telemetry payload, in which 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. However, this Experimental Specification can be also adopted for other high data rate applications (either space-to-ground, ground-to-space, or space-to-space) and services (e.g., the Space Research service), as long as compliance to CCSDS recommendations for radio frequency modulations in reference [5] is ensured.

1.2 SCOPE

Despite the wide range of MODCODs[1] in the existing Blue Book CCSDS 131.2-B-1 (reference [1]) (up to 64APSK 9/10), recent studies performed by space agencies have demonstrated that, depending on the ground station location, the available set of MODCODs already saturates above a certain elevation angle, beyond which a growing gap with respect to achievable capacity is witnessed. The more favorable the geometrical visibility and the propagation impairments are for the ground station location (e.g., polar regions), the lower this saturating elevation is, leading to link spectral efficiency saturation. Furthermore, future Geostationary Earth Orbit (GEO)-to-ground EESS systems and/or Data Relay Systems (DRS) consider the use of large reflectors in space (e.g., in the order of five meters, using Unfurlable Mesh Reflector Antennas) along with large-size ground stations antennas, leading to extremely favorable link budgets. Hence, to fully exploit the advantages offered by K-band (26 GHz) and possibly higher frequency bands, there is a need for future direct Low Earth Orbit (LEO)-to-ground and GEO-to-ground EESS and DRS to further increase their offered spectral efficiency.

Making use of new MODCODs, the bandwidth available for Earth Observation missions can be fully exploited in the high elevation regime without saturating the data rate, while still respecting realistic constraints, for example, limited available power and hardware resources.

Both LEO-to-ground and GEO-to-ground EESS missions will benefit from higher spectral efficiencies as this feature is related to better data timeliness, higher volumes of data return, and an overall reduction of cost. Technology preparation activities are required well in advance to allow future missions to take advantage of these features. Documentation in CCSDS and experimental specification of the proposed techniques will provide the manufactures with the confidence necessary to initiate the relative investments.

[1] In the context of CCSDS 131.2-B-1 (reference [1]), MODCODs are referred to as ACM modes.

Compared to the existing Blue Book CCSDS 131.2-B-1, this Experimental Specification includes an option for ten (10) new MODCOD options (termed Adaptive Coding and Modulation (ACM) formats in the CCSDS 131.2-B-1 parlance) in the high spectral efficiency range, by introducing 128APSK and 256APSK modulations and an accompanying two stage encoding scheme of affordable complexity. These 10 new MODCODs come on top of the ones already in the standard, covering up to 64APSK (ACM#1 to ACM#27). Therefore these new MODCODs will be referred to herein as ACM#28 to ACM#37.

It is noted that the 27 MODCOD included in CCSDS 131.2-B-1 (reference [2]) (ACM#1 to ACM#27) will remain completely unchanged and thus unaffected by the proposed Orange Book.

By extending the set of available MODCODs, this document enlarges the possible options for use in dynamic transmission schemes, such as Variable Coding and Modulation (VCM) or ACM.

1.3 APPLICABILITY

This Experimental Specification document applies to future data communications in cross-support situations. This Experimental Specification 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.

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 Experimental Specification 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 two-stage SCCC-X 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 discusses security, SANA, and patent considerations;

l) annex D lists acronyms and terms used within this document;

m) annex E 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 Experimental Specification:

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 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, that is, ‘Bit 0’ (see figure 1-1).

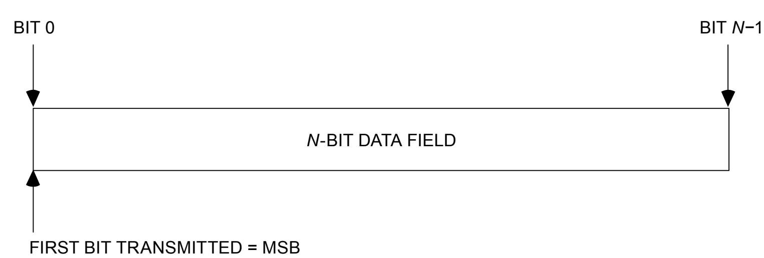

Figure 1-1: Bit Numbering Convention

In accordance with standard data-communications practice, data fields are often grouped into 8-bit ‘words’ that conform to the above convention. Throughout this Experimental Specification, 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 Consultative Committee on Space Data Systems (CCSDS) draws attention to the fact that it is claimed that compliance with this document may involve the use of patents concerning APSK modulations given in section 5.

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. 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 B.

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 Experimental Specification. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Experimental Specification 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] *Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.2-B-1. Washington, D.C.: CCSDS, March 2012.

[2] *TM Space Data Link Protocol*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 132.0-B-3. Washington, D.C.: CCSDS, October 2021.

[3] *AOS Space Data Link Protocol*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-4. Washington, D.C.: CCSDS, October 2021.

[4] *Unified Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.1-B-2. Washington, D.C.: CCSDS, October 2021.

[5] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Issue 32. Recommendations for Space Data System Standards (Blue Book), CCSDS 401.0-B-32. Washington, D.C.: CCSDS, October 2021.

Cor. 1

NOTE – Informative references are listed in annex E.

2 OVERVIEW

2.1 ARCHITECTURE

Figure 2-1 illustrates the relationship of this Experimental Specification to the Open Systems Interconnection reference model (reference [E2]). Two sublayers of the Data Link Layer are defined for CCSDS space link protocols. The TM, AOS, and USLP Space Data Link Protocols, specified in references [2], [3], and [4], 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.

Cor. 1

This Experimental Specification covers the functions of both the Synchronization and Channel Coding Sublayer and the Physical Layer, the latter for what concerns the modulation schemes. CCSDS 401.0-B (reference [5]) covers additional features of the Physical Layer, such as frequency bands and polarizations, that are not described or referenced here.

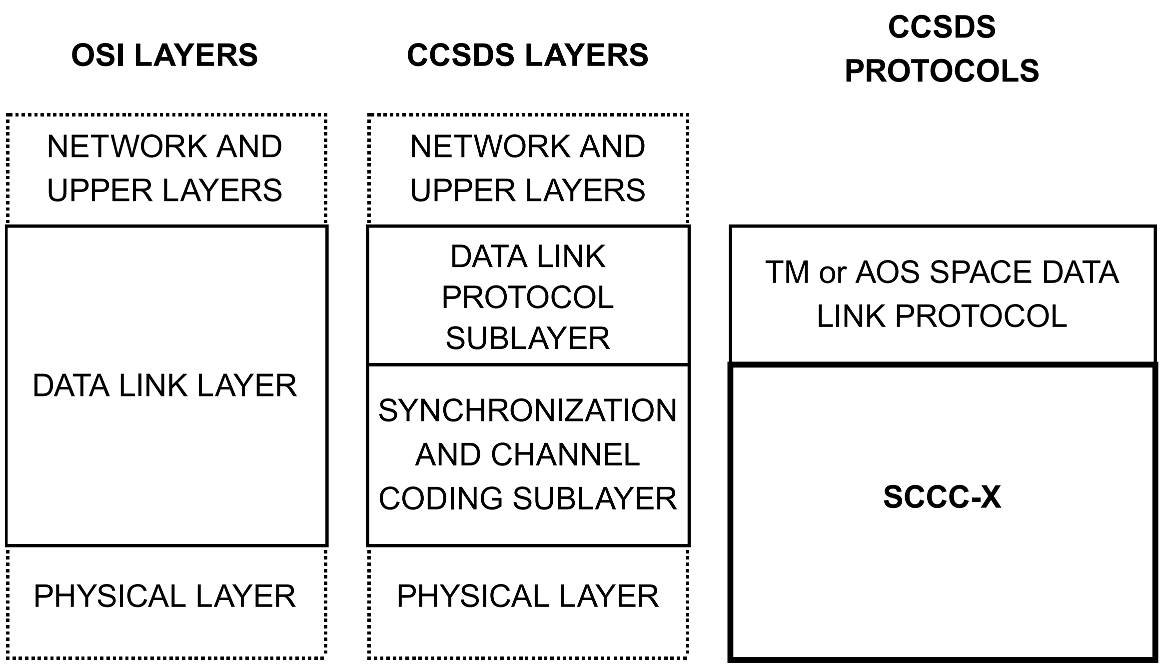

Figure 2-1: Relationship with OSI Layers

2.2 SUMMARY OF FUNCTIONS

2.2.1 GENERAL

This Experimental Specification provides the following functions for transferring Transfer Frames via a stream of bits over a space link with a higher spectral efficiency than in CCSDS 131.2-B-1 (reference [1]):

a) error-control coding based on a two-stage encoding process;

b) Physical Layer framing; and

c) Physical layer frame signaling.

Apart from these functions, all the rest of the functions are exactly as in the standard (reference [1]).

To ease implementation and hardware complexity, this Experimental Specification describes a two-stage encoding scheme, in which the first stage fully relies on the Serial Concatenated Convolutional Code (SCCC) described in the existing standard (reference [1]), and the second stage implements a Bose–Chaudhuri–Hocquenghem (BCH) code.

The two-stage encoding scheme offers a number of code rates that are paired with two Amplitude Phase Shift Keying (APSK) modulation constellations. In particular, this Experimental Specification defines 128APSK and 256 APSK, as well as a way to signal the new MODCODs employing the Physical Layer (PL) frame structure.

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.

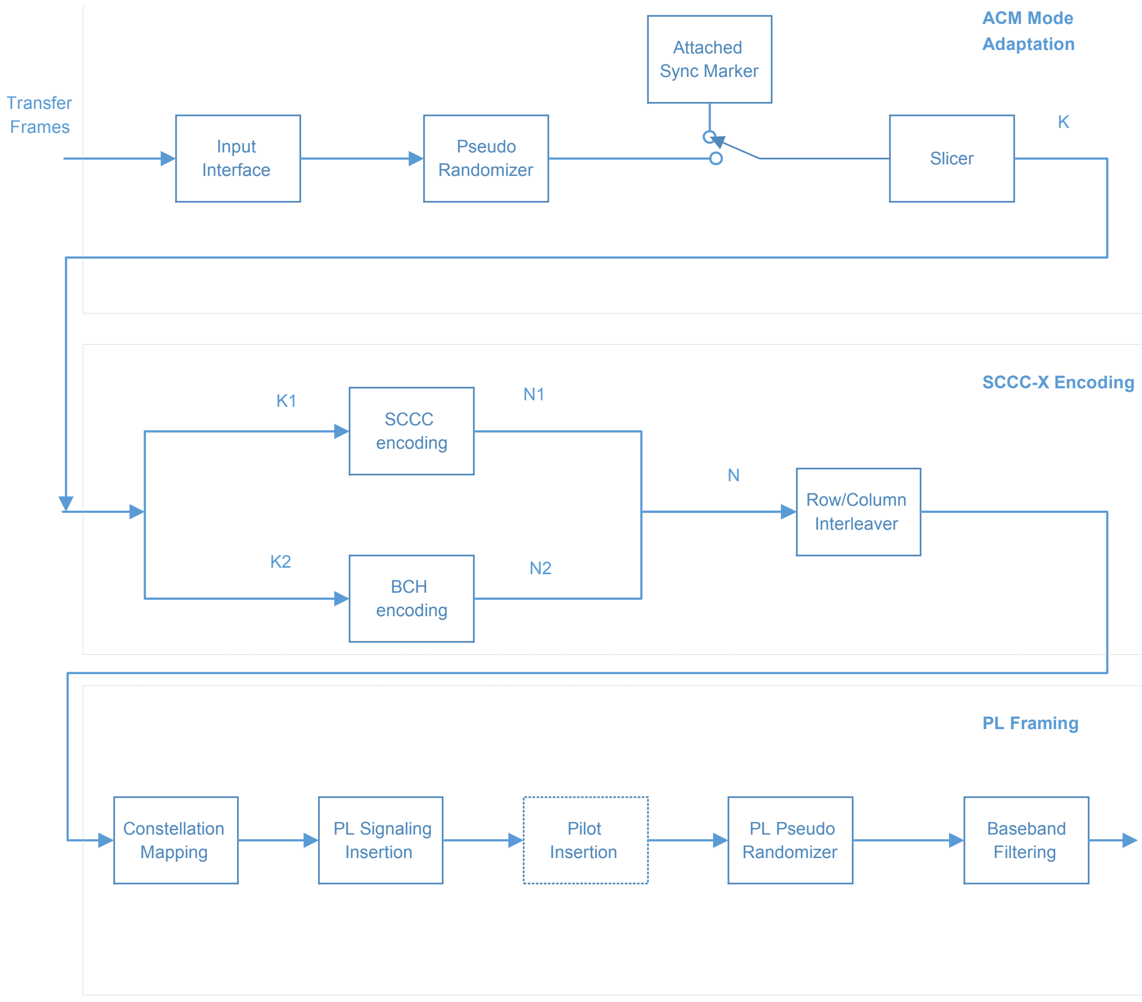

Figure 2-2: Functional Diagrams at Sending End

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]), AOS (reference [3]), and USLP (reference [4]).

Cor. 1 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, which is split in a block K_1 and a block K_2 in order to apply the two-stage encoding. The information block size of $K = K_1 + K_2$ varies depending on the selected modulation and coding scheme. The same coding and modulation scheme is applied to every 16 consecutive blocks that form a PL frame. The length of encoded blocks (N bits) is determined by the modulation scheme. In line with reference [1], the length of encoded symbol blocks after encoding and mapping to modulation symbols is constant (8100 channel symbols), independent of the modulation and coding scheme. Maintaining a constant symbol block size facilitates frame synchronization at the PL.

Cor. 1

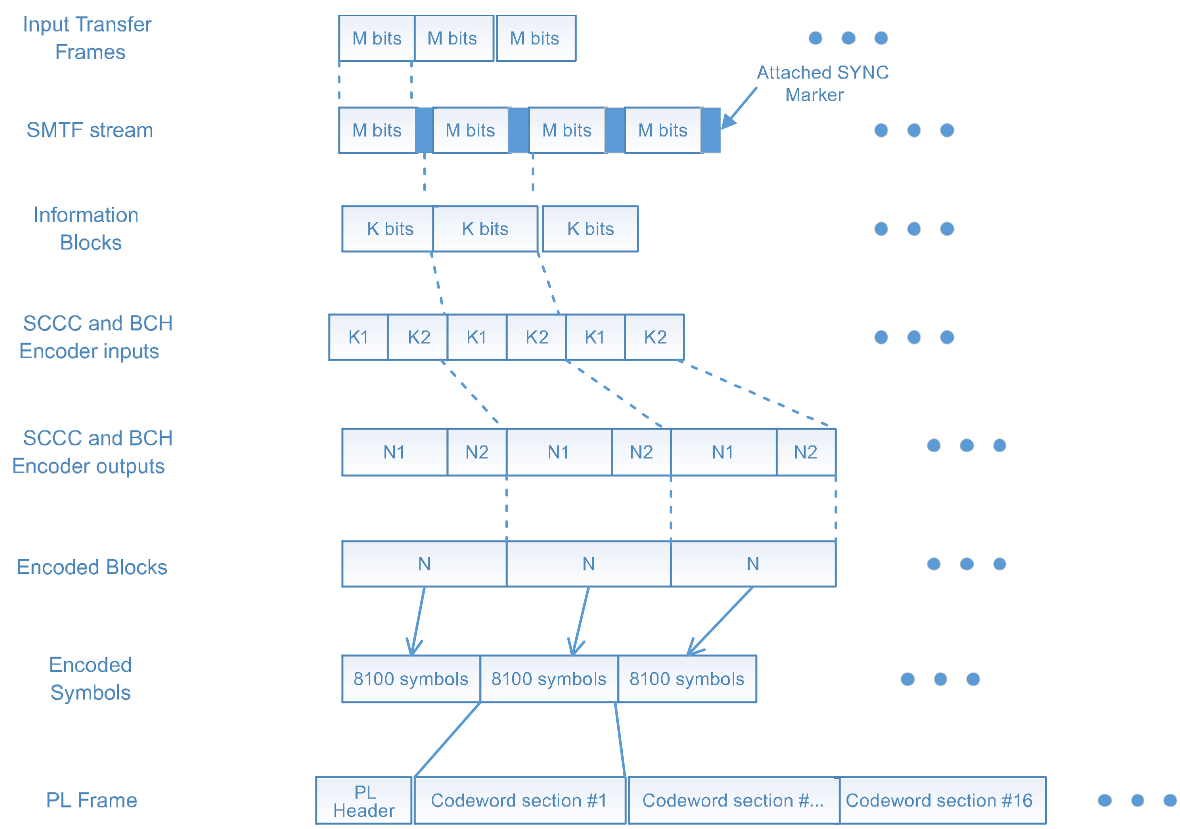

Figure 2-3: Stream Format at Different Stages of Processing

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-X SYSTEM INPUT AND INITIAL OPERATIONS

3.2.1 The SCCC-X system shall accept TM, AOS, and USLP 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 65536 octets.

NOTE – The Transfer Frame length is denoted in figure 2-3 as having a length of M bits. TM Space Data Link Protocol (reference [2]), AOS Space Data Link protocol (reference [3]), and USLP (reference [4]) do not specify the Transfer Frame length.

3.2.3 The SCCC-X system shall randomize each frame with the randomizer described in the Recommended Standard (reference [1]).

Cor. 1

3.2.4 For each (randomized) Transfer Frame, the SCCC system shall construct a Synch-Marked Transfer Frame (SMTF) containing the ASM and the Transfer Frame.

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

3.2.6 The Slicer shall split the SMTF stream into a sequence of information blocks of length K, corresponding to the total information block size of the selected ACM format. The information block of K bits is further split into block K_1 bits and block K_2 bits to facilitate the two-stage encoding scheme that follows.

3.2.7 The value of the information block sizes K, K_1, and K_2 shall be the one specified in table 3-1.

NOTES

1 Changes of the value of the information block size K (and hence of K_1 and K_2) are done by a system to adjust the MODCOD selection. Some options on how to achieve this are offered in subsection 3.2.7 of the Recommended Standard (reference [1]).

2 The numbering of the MODCOD options in table 3-1 is starting from ACM#28 in continuation of the numbering of MODCODs in the Recommended Standard (reference [1]), which stops at ACM#27.

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 for SCCC encoding K_1 (bits)	Information Block Size for BCH encoding K_2 (bits)	Total Information Block Size $K=K_1+K_2$ (bits)
28	19,198	24,144	43,342
29	21,358	24,144	45,502
30	23,518	24,144	47,662
31	25,918	24,144	50,062
32	28,318	24,144	52,462
33	19,198	32,192	51,390
34	21,358	32,192	53,550
35	23,518	32,192	55,710
36	25,918	32,192	58,110
37	28,318	32,192	60,510

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-X Encoder.

4 TWO STAGE 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. Out of the K bits, the K_1 MSBs are encoded using the soft SCCC encoder of reference [1], and the K_2 LSBs are encoded with a BCH encoder. The apportionment of K between K_1 and K_2 shall be according to table 3-1.

NOTES

1 The structure of the overall two-stage SCCC-X encoder is illustrated in figure 4-1. For the first K_1 bits, the ganged switch is connected to the SCCC encoder, while for the last K_2 bits it moves and connect to the BCH encoder.

2 The information block size is specified as described in table 3-1, according to the applicable ACM format, with the objective of maintaining a constant length of the encoded blocks (N bits) at the output of the dual stage SCCC-X encoding, 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_1 shall be SCCC encoded as shown in the upper part of figure 4-1; that is, the input bits are encoded by the outer convolutional encoder (CC1), then punctured, interleaved, encoded by an inner convolutional encoder (CC2), and finally punctured.

4.1.1.3 For ACM#28-37, the SCCC encoding functions shall be as described for ACM#13-17 in section 4 of reference [1].

4.1.1.4 Each information block of size K_2, shall be encoded by a cyclic BCH encoding scheme described in 4.3.

4.1.1.5 The encoded block of N_1 bits out of the SCCC encoder and the encoded block of N_2 bits out of the BCH encoder are then fed into the row-to-column interleaver described in 4.4.

NOTE – For ACM#1-27, it holds $K_2 = 0, N_2 = 0$, and thus the block diagram of the encoder simplifies to the one provided in Figure 4-1 of the Recommended Standard (reference [1]).

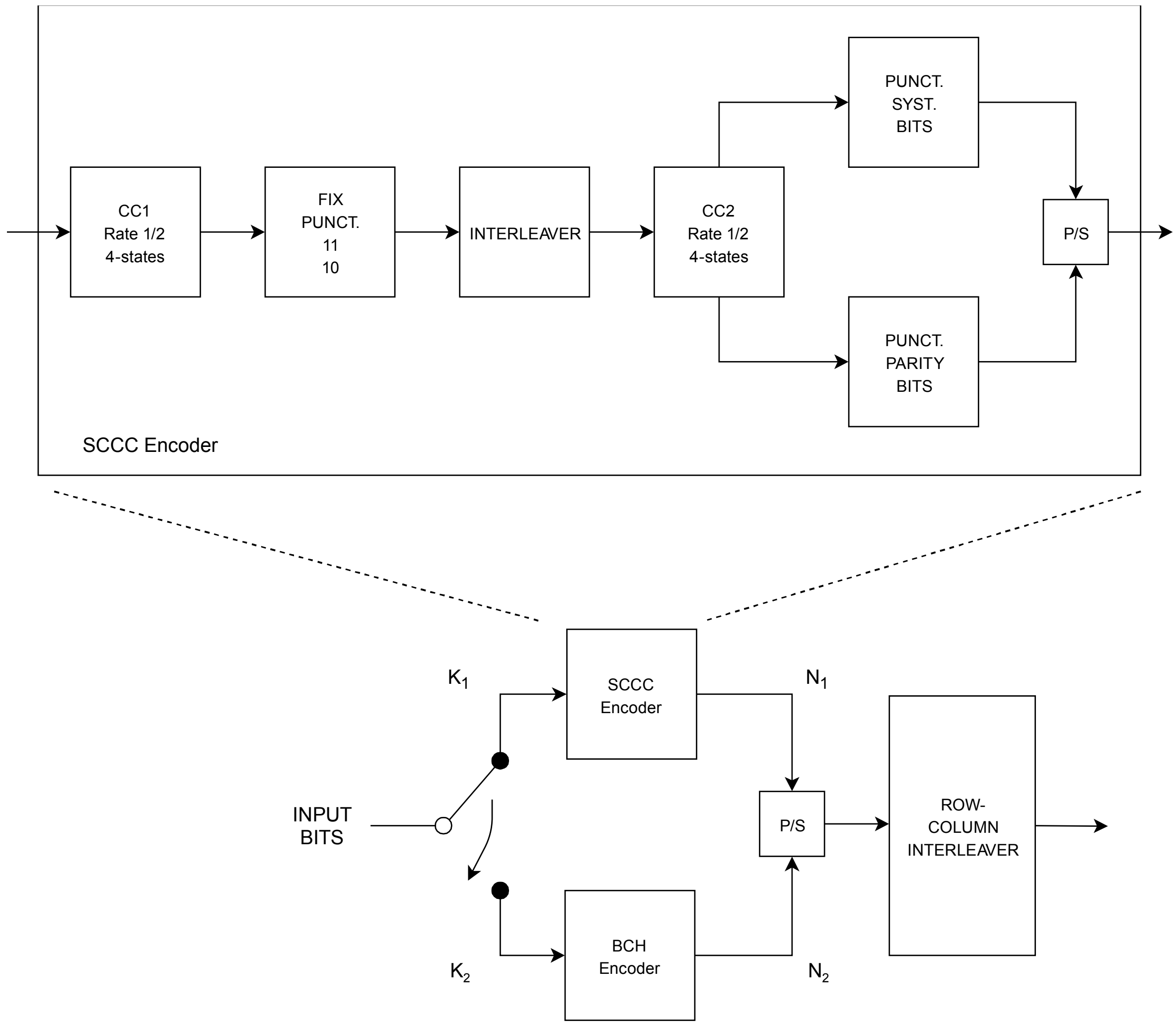

Figure 4-1: Block Diagram of the Two-Stage SCCC-X Encoding Scheme

4.2 SCCC ENCODING

For ACM#28-37, the processing of the K_1 bits by the SCCC encoder is exactly the same as for ACM#13-17. In particular, all the parameters for encoding the K_1 bits for ACM#28-32 match exactly the ones for ACM#13-17, and all the parameters for encoding the K_1 bits for ACM#33-37 match exactly the ones for ACM#13-17. This involves all the stages of SCCC encoding, such as the outer and inner interleaver, fixed and variable puncturing, and the interleaving (see figure 4-1 of reference [1] for a block diagram of SCCC).

To ease the connection between this Experimental Specification and reference [1], the main encoder parameters for the extended MODCODs ACM#28-37 are provided in table 4-1 (complementing those reported in table 4-3 of reference [1]).

Table 4-1: Main Encoder Parameters for 10 Additional ACM Formats (MODCODs)

ACM format	S_{sur}	K_1	I	S	P	N_1	Δ
28	255	19198	28800	24482	7918	32400	20884
29	241	21358	32040	25741	6659	32400	25383
30	230	23518	35280	27051	5349	32400	29933
31	220	25918	38880	28515	3885	32400	34997
32	211	28318	42480	29880	2520	32400	39962
33	255	19198	28800	24482	7918	32400	20884
34	241	21358	32040	25741	6659	32400	25383
35	230	23518	35280	27051	5349	32400	29933
36	220	25918	38880	28515	3885	32400	34997
37	211	28318	42480	29880	2520	32400	39962

The parameters listed in table 4-1 refer to the input bits to the SCCC encoder K_1, the number of surviving bit S_{sur} interleaver length I, number of systematic bits S, number of deleted parity bits Δ, number of bits output from the SCCC encoder N_1 and $P = N_1 - S$. To put these parameters into context, the reader is referred to subsections 4.2, 4.3, and 4.4 of reference [1].

4.3 BCH ENCODING

A single (8100, 8048) encoding process is used for all MODCODs ACM#28-37, derived by means of shortening of a (8191, 8139) BCH encoder.

The codeword is formulated as provided in figure 4-2, which contains 8048 information bits in the leading MSBs and the error control field in the 52 LSBs. The codeword error control field has 52 redundancy bits and correction capability of 4 errors. The BCH encoding process has rate of $R_2 = 0.9936$, and by referring to table 3-1, three (3) BCH codewords are generated ($K_2 = 3 \cdot 8048$) for each PL frame for MODCODs ACM#28 to 32, while four (4) BCH codewords are generated ($K_2 = 4 \cdot 8048$) for each PL frame for MODCODs ACM#33 to 37.

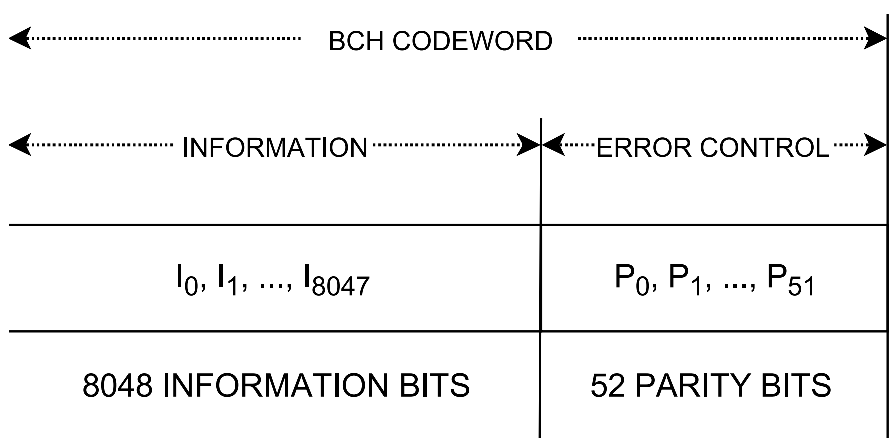

Figure 4-2: BCH Codeword Format

4.3.1 ENCODING PROCEDURE

The 52 parity bits of the error control field are obtained by the 8048 information bits by means of the following procedure:

1. The information block of 8048 bits is extended to 8139 bits by adding 91 zeros (zero filling) as shown in the upper part of figure 4-3;
2. The error control field of 52 parity bits is derived by means of (8191,8139) BCH with the generator polynomial

$$g(x) = \sum_{i=0}^{52} g_i x^i,$$

where the coefficients g_i are given in hexadecimal representation

`1AAC3AB8418945`

or, equivalently, in a binary representation

`1 1010 1010 1100 0011 1010 1011 1000 0100 0001 1000 1001 0100 0101`

where the MSB is g_0, while the LSB is g_{52}.

3. The 91 zeros from the encoded block, as shown in lower part of figure 4-3, are removed for obtaining the BCH codeword in figure 4-2.

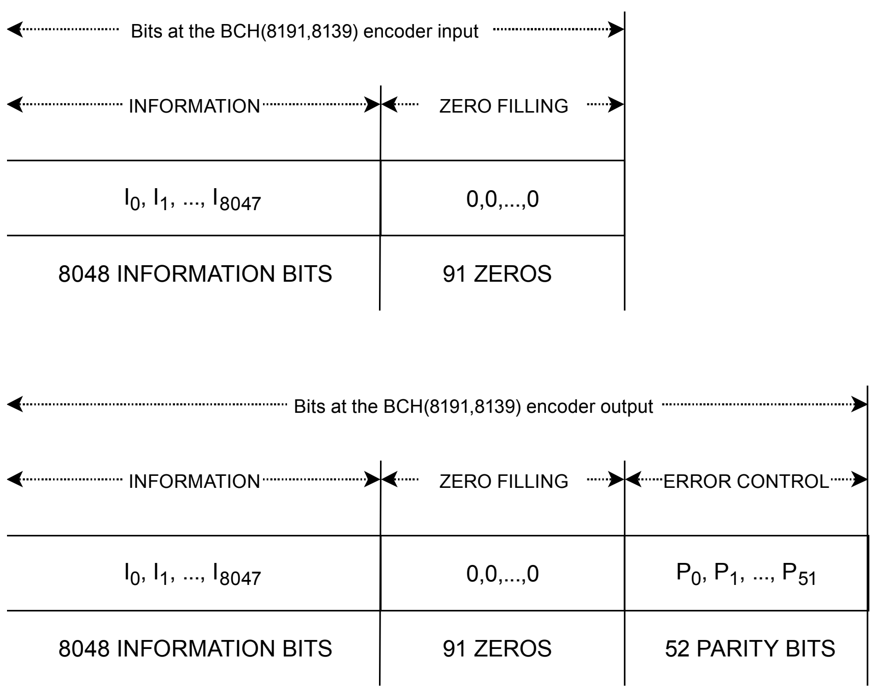

Figure 4-3: Zero Filling for BCH Encoding

NOTE – A possible code generator for the polynomial g(x) is shown in figure 4-4. The shift registers are initialized to zero. The switch is in position 1 while the 8139 bits (i.e., 8048 information bits and 91 zeros) are being transmitted, and in position 2 for the 52 parity bits.

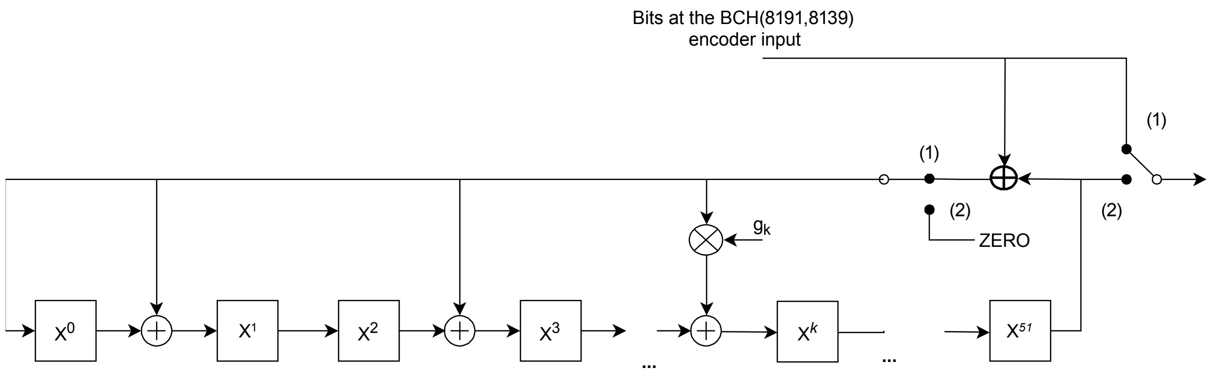

Figure 4-4: (8191, 8139) BCH Code Generator

4.4 ROW-COLUMN INTERLEAVER

4.4.1 Prior to the bit-to-symbol mapping at the transmitter, a row-column interleaver shall be used to collect the encoded bits N_1 and N_2 output from the SCCC encoder and the BCH encoder, respectively, and also to pseudo-randomize the selection of bits that are assigned to one modulation symbol.

The bit-interleaving scheme shall correspond to an interleaver depth (number of rows) equal to 8100 bits and a number of columns equal to m, where m is the modulation order. Thus, the N_1 and N_2 bits generated by the two-stage encoding fill an $8100 \times m$ row-by-column interleaver, column by column. The rows of the interleavers are the binary labels identifying 8100 symbols of the constellation sets described in the following 5.2.

NOTE – For ACM#28-32 (128APSK), it holds $m = 7$, and for ACM#33-37, it holds $m = 8$ (256APSK). The row-to-column interleaver filling for these two cases is illustrated in figure 4-5, where the first $m_1 = 4$ columns (32,400 bits) are filled by bits generated by the SCCC encoder, in the same way explained in subsection 4.5 of reference [1]. The following $m_2 = m - m_1 = m - 4$ columns are filled by the BCH codewords generated by the second stage.

4.4.2 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). Consequently, MSBs for each modulation symbol are generated by the SCCC encoder.

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

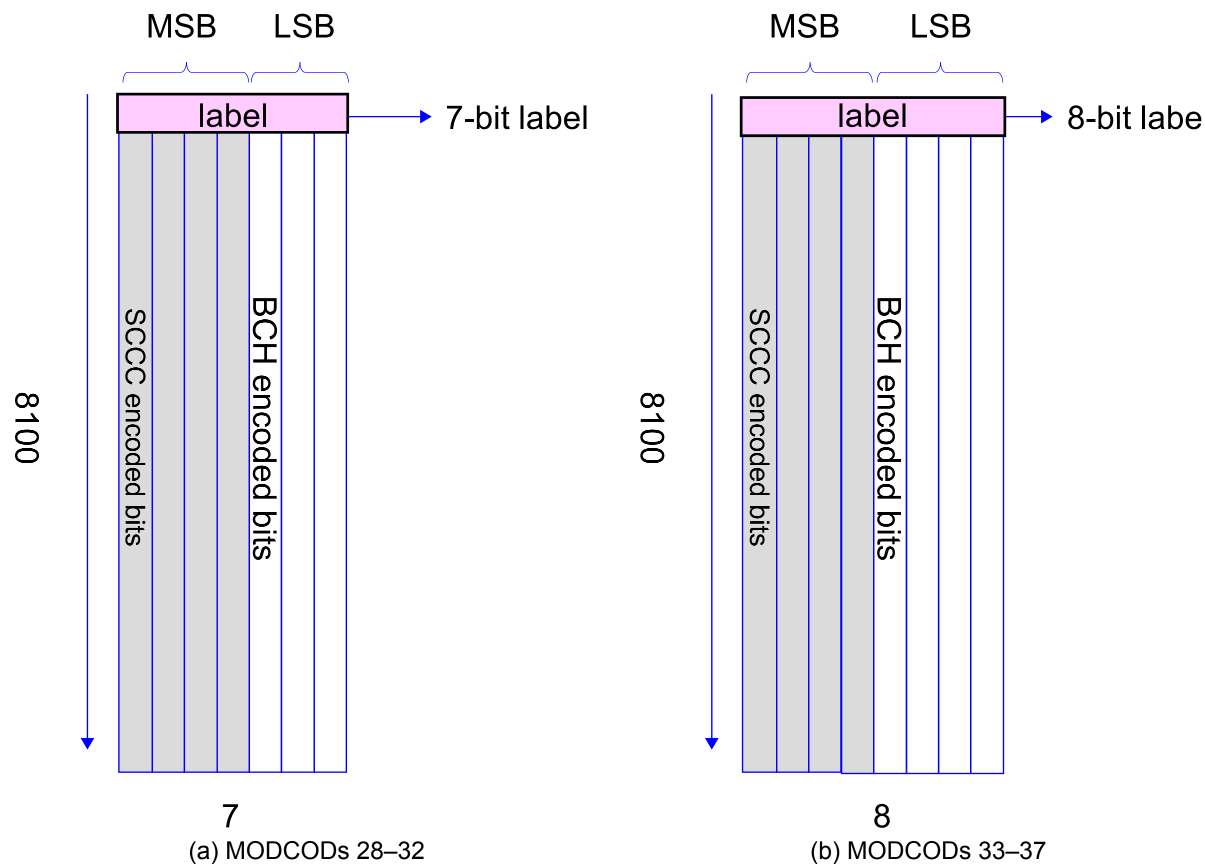

Figure 4-5: Row-Column Bit-Interleaving Scheme for (a) ACM#28-32 and (b) ACM#33-37

5 PHYSICAL LAYER FRAMING

5.1 GENERAL

5.1.1 The SCCC-X encoding unit shall provide the PL Framing with encoded blocks of $N = N_1 + N_2 = 8100 \times m$ bits that are used to generate PL Frames, where m is the modulation order.

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 There are two options for the constellation mappings:

1) 128APSK modulation, as specified in 5.2.2;

2) 256APSK modulation, as specified in 5.2.3.

5.2.1.2 For all the constellation mappings, the Bit Numbering Convention shall be applied (see 1.5.2).

NOTE – 128APSK and 256APSK constellations and labeling have been designed using a general optimization methodology presented in reference [E3].

5.2.2 128APSK MODULATION

5.2.2.1 If the 128APSK scheme is used, the constellation shall be as provided in figure 5-1, composed of six concentric circumferences whose number of points is 4, 12, 20, 28, 32, and 32, respectively.

5.2.2.2 The 128APSK concentric circumferences shall have ratio γ_i with respect to the most inner circumference equal to:

a) $\gamma_1 = R_2/R_1 = 3$;

b) $\gamma_2 = R_3/R_1 = 5$;

c) $\gamma_3 = R_4/R_1 = 7$;

d) $\gamma_4 = R_5/R_1 = 9$; and

e) $\gamma_5 = R_6/R_1 = 11$.

5.2.2.3 The average signal energy of the 128APSK shall be set to one, that is,

$$[R_1]^2 + 3[R_2]^2 + 5[R_3]^2 + 7[R_4]^2 + 8[R_5]^2 + 8[R_6]^2 = 32.$$

5.2.2.4 The points in each circumference are equally spaced in phase, and the phase offset of the first point in each circumference (pointed out by the red vector in figure 5-1) shall be $\pi/4$, $\pi/12$, $\pi/20$, $\pi/28$, $\pi/32$, $\pi/32$, respectively.

NOTE – Figure 5-1 shows also the bit labelling in hexadecimal notation. Therefore, for example, point 0x4E sitting on the third ring from the center corresponds to the bit label 1001110. Instead, table 5-1 provides the coordinates of all the 128APSK constellation points in in-phase/quadrature (I/Q) coordinates.

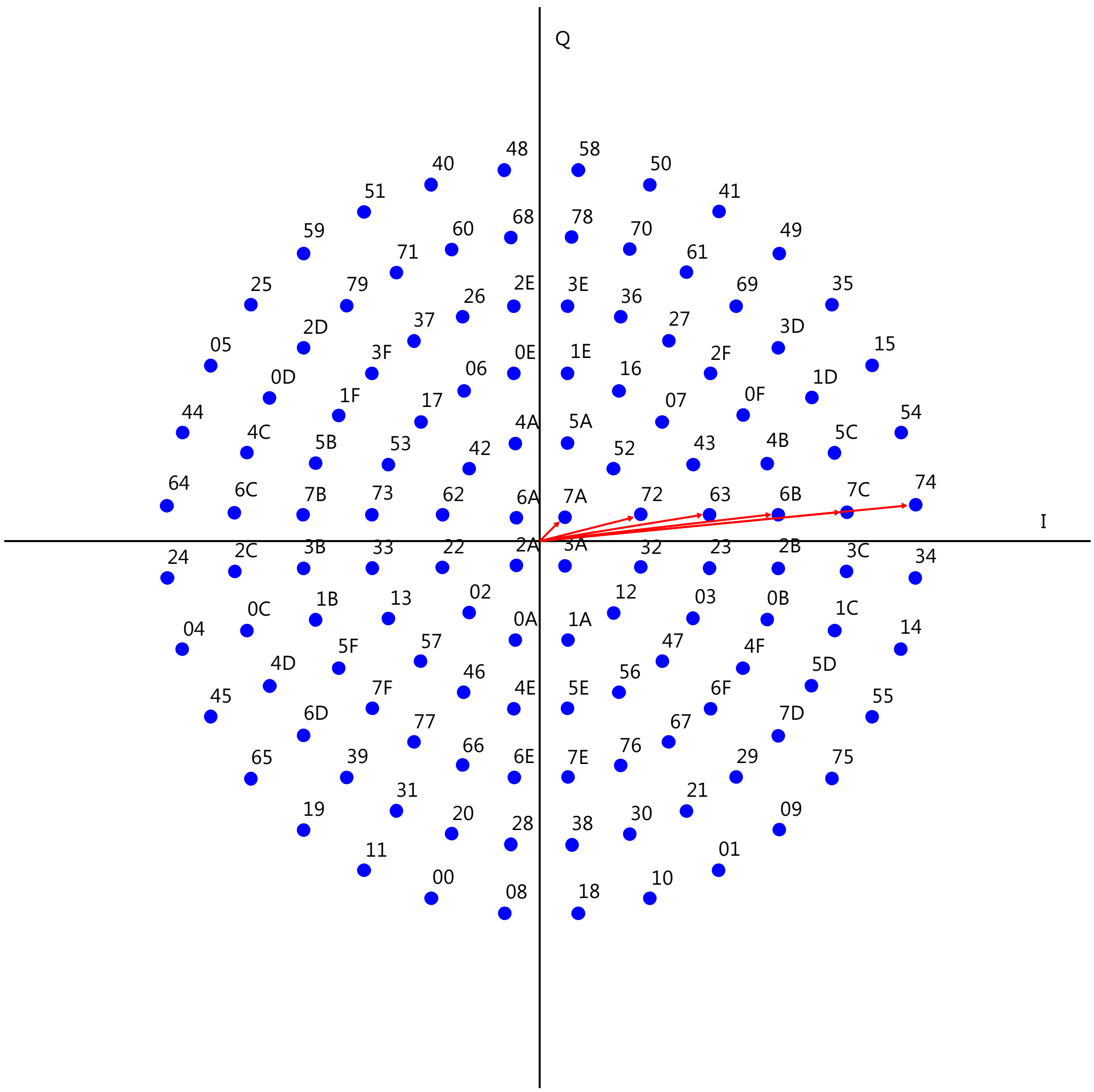

Figure 5-1: Bit Mapping into 128APSK Constellation

Table 5-1: Coordinates of Points for 128APSK Constellation in an I/Q Coordinate System

Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.
0	00	-0.3930	-1.2957	32	20	-0.3216	-1.0601	64	40	-0.3930	1.2957	96	60	-0.3216	1.0601
1	01	0.6383	-1.1941	33	21	0.5222	-0.9770	65	41	0.6383	1.1941	97	61	0.5222	0.9770
2	02	-0.2611	-0.2611	34	22	-0.3567	-0.0956	66	42	-0.2611	0.2611	98	62	-0.3567	0.0956
3	03	0.5484	-0.2794	35	23	0.6079	-0.0963	67	43	0.5484	0.2794	99	63	0.6079	0.0963
4	04	-1.2957	-0.3930	36	24	-1.3475	-0.1327	68	44	-1.2957	0.3930	100	64	-1.3475	0.1327
5	05	-1.1941	0.6383	37	25	-1.0467	0.8590	69	45	-1.1941	-0.6383	101	65	-1.0467	-0.8590
6	06	-0.2794	0.5484	38	26	-0.2846	0.8133	70	46	-0.2794	-0.5484	102	66	-0.2846	-0.8133
7	07	0.4352	0.4352	39	27	0.4584	0.7296	71	47	0.4352	-0.4352	103	67	0.4584	-0.7296
8	08	-0.1327	-1.3475	40	28	-0.1086	-1.1025	72	48	-0.1327	1.3475	104	68	-0.1086	1.1025
9	09	0.8590	-1.0467	41	29	0.7028	-0.8564	73	49	0.8590	1.0467	105	69	0.7028	0.8564
10	0A	-0.0956	-0.3567	42	2A	-0.0870	-0.0870	74	4A	-0.0956	0.3567	106	6A	-0.0870	0.0870
11	0B	0.8133	-0.2846	43	2B	0.8562	-0.0965	75	4B	0.8133	0.2846	107	6B	0.8562	0.0965
12	0C	-1.0601	-0.3216	44	2C	-1.1025	-0.1086	76	4C	-1.0601	0.3216	108	6C	-1.1025	0.1086
13	0D	-0.9770	0.5222	45	2D	-0.8564	0.7028	77	4D	-0.9770	-0.5222	109	6D	-0.8564	-0.7028
14	0E	-0.0963	0.6079	46	2E	-0.0965	0.8562	78	4E	-0.0963	-0.6079	110	6E	-0.0965	-0.8562
15	0F	0.7296	0.4584	47	2F	0.6093	0.6093	79	4F	0.7296	-0.4584	111	6F	0.6093	-0.6093
16	10	0.3930	-1.2957	48	30	0.3216	-1.0601	80	50	0.3930	1.2957	112	70	0.3216	1.0601
17	11	-0.6383	-1.1941	49	31	-0.5222	-0.9770	81	51	-0.6383	1.1941	113	71	-0.5222	0.9770
18	12	0.2611	-0.2611	50	32	0.3567	-0.0956	82	52	0.2611	0.2611	114	72	0.3567	0.0956
19	13	-0.5484	-0.2794	51	33	-0.6079	-0.0963	83	53	-0.5484	0.2794	115	73	-0.6079	0.0963
20	14	1.2957	-0.3930	52	34	1.3475	-0.1327	84	54	1.2957	0.3930	116	74	1.3475	0.1327
21	15	1.1941	0.6383	53	35	1.0467	0.8590	85	55	1.1941	-0.6383	117	75	1.0467	-0.8590
22	16	0.2794	0.5484	54	36	0.2846	0.8133	86	56	0.2794	-0.5484	118	76	0.2846	-0.8133
23	17	-0.4352	0.4352	55	37	-0.4584	0.7296	87	57	-0.4352	-0.4352	119	77	-0.4584	-0.7296
24	18	0.1327	-1.3475	56	38	0.1086	-1.1025	88	58	0.1327	1.3475	120	78	0.1086	1.1025
25	19	-0.8590	-1.0467	57	39	-0.7028	-0.8564	89	59	-0.8590	1.0467	121	79	-0.7028	0.8564
26	1A	0.0956	-0.3567	58	3A	0.0870	-0.0870	90	5A	0.0956	0.3567	122	7A	0.0870	0.0870
27	1B	-0.8133	-0.2846	59	3B	-0.8562	-0.0965	91	5B	-0.8133	0.2846	123	7B	-0.8562	0.0965
28	1C	1.0601	-0.3216	60	3C	1.1025	-0.1086	92	5C	1.0601	0.3216	124	7C	1.1025	0.1086
29	1D	0.9770	0.5222	61	3D	0.8564	0.7028	93	5D	0.9770	-0.5222	125	7D	0.8564	-0.7028
30	1E	0.0963	0.6079	62	3E	0.0965	0.8562	94	5E	0.0963	-0.6079	126	7E	0.0965	-0.8562
31	1F	-0.7296	0.4584	63	3F	-0.6093	0.6093	95	5F	-0.7296	-0.4584	127	7F	-0.6093	-0.6093

NOTE – In correspondence to the two-stage encoding process in section 4, the SCCC-X receiver is expected to decode the incoming data with a two-stage decoding process. For each constellation point, the first 4 MSBs are decoded by a first stage SCCC (soft) decoder. The rest of the bits are decoded by a second BCH (hard) decoder that operates on a subset that has larger minimum distance with respect to the original constellation. For instance, for the 0000110 (0x06) constellation point, once bits 0000 are SCCC decoded, the BCH will have to perform decoding on the subset depicted in figure 5-2.

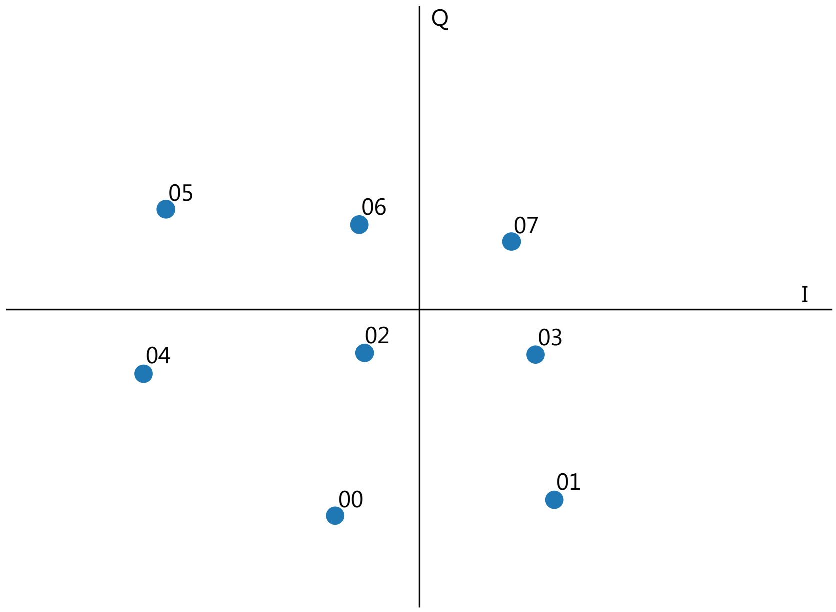

Figure 5-2: Example of 128APSK Subset to Be Decoded by the Second Stage BCH Decoder If the MSB 0000 Bits Are Estimated by the First Stage SCCC Decoder

5.2.3 256APSK MODULATION

5.2.3.1 If the 256APSK scheme is used, the constellation shall be as provided in figure 5-3, composed of eight (8) concentric circumferences, whose number of points is 4, 12, 20, 28, 36, 44, 52, 60.

5.2.3.2 The 256APSK concentric circumferences shall have ratio γ_i with respect to the most inner circumference equal to:

a) $\gamma_1 = R_2/R_1 = 3$;

b) $\gamma_2 = R_3/R_1 = 5$;

c) $\gamma_3 = R_4/R_1 = 7$;

d) $\gamma_4 = R_5/R_1 = 9$;

e) $\gamma_5 = R_6/R_1 = 11$;

f) $\gamma_6 = R_7/R_1 = 13$; and

g) $\gamma_7 = R_8/R_1 = 15$.

5.2.3.3 The average signal energy of the 256APSK shall be set to one, that is,

$$[R_1]^2 + 3[R_2]^2 + 5[R_3]^2 + 7[R_4]^2 + 9[R_5]^2 + 11[R_6]^2 + 13[R_7]^2 + 15[R_8]^2 = 64.$$

5.2.3.4 The points in each circumference are equally spaced in phase, and the phase offset of the first point in each circumference (pointed out by the red vector in figure 5-3) shall be $\pi/4$, $\pi/12$, $\pi/20$, $\pi/28$, $\pi/36$, $\pi/44$, $\pi/52$, and $\pi/60$, respectively.

NOTE – Figure 5-3 also shows the bit labelling in hexadecimal notation. Therefore, for example, point 0xE5 sitting on the second ring from the center corresponds to the bit label 11100101. Instead, table 5-2 provides the coordinates of all the 256APSK constellation points in in-phase/quadrature (I/Q) coordinates.

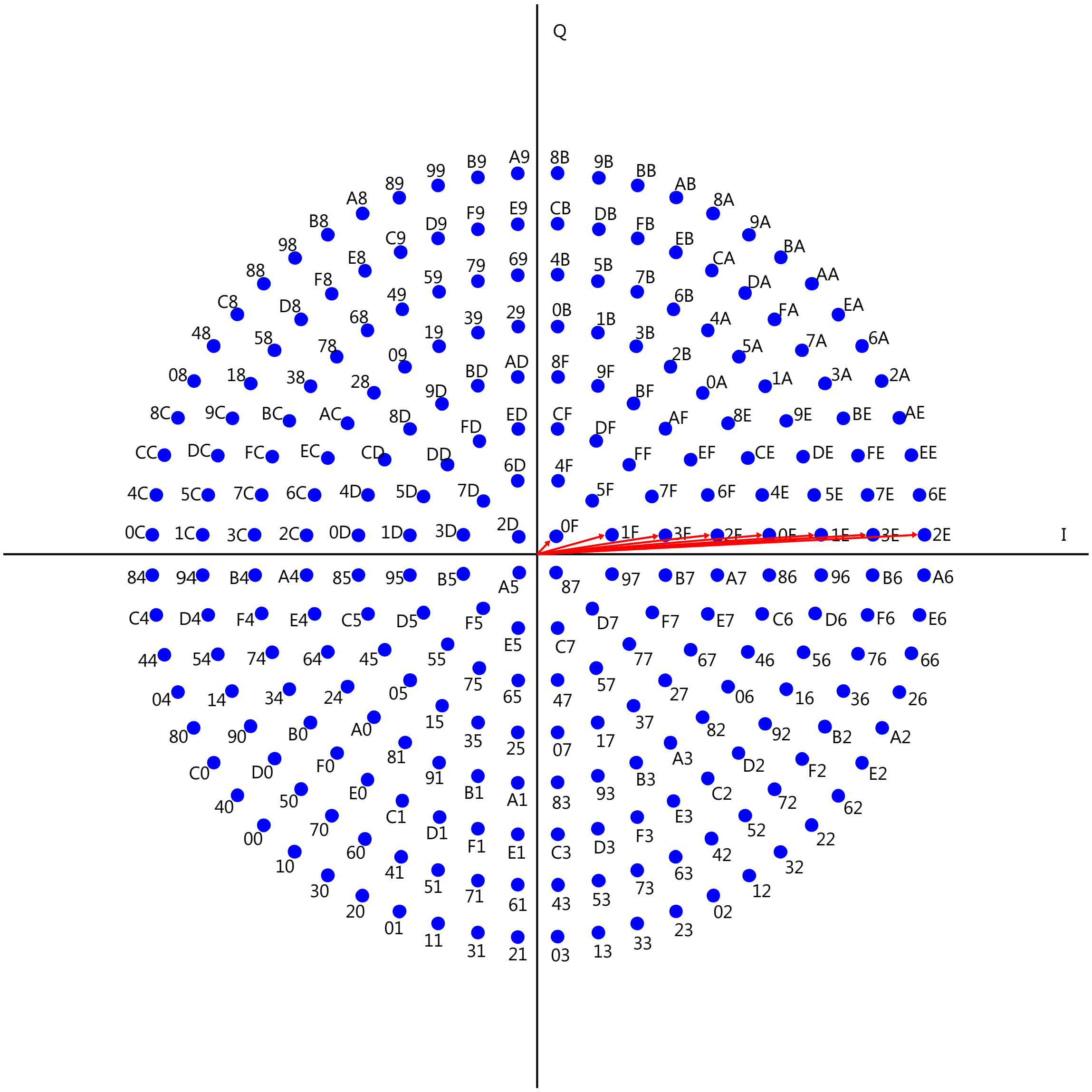

Figure 5-3: Bit Mapping into 256APSK Constellation

Table 5-2: Coordinates of Points for 256APSK Constellation in an I/Q Coordinate System

Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.
0	00	-0.9412	-0.9412	32	20	-0.6043	-1.1860	64	40	-1.0344	-0.8376	96	60	-0.5968	-0.9872
1	01	-0.4770	-1.2426	33	21	-0.0697	-1.3292	65	41	-0.4734	-1.0519	97	61	-0.0697	-1.1515
2	02	0.6043	-1.1860	34	22	0.9412	-0.9412	66	42	0.5968	-0.9872	98	62	1.0344	-0.8376
3	03	0.0697	-1.3292	35	23	0.4770	-1.2426	67	43	0.0697	-1.1515	99	63	0.4734	-1.0519
4	04	-1.2426	-0.4770	36	24	-0.6542	-0.4581	68	44	-1.2857	-0.3445	100	64	-0.7238	-0.3375
5	05	-0.4392	-0.4392	37	25	-0.0695	-0.6172	69	45	-0.5259	-0.3305	101	65	-0.0694	-0.4382
6	06	0.6542	-0.4581	38	26	1.2426	-0.4770	70	46	0.7238	-0.3375	102	66	1.2857	-0.3445
7	07	0.0695	-0.6172	39	27	0.4392	-0.4392	71	47	0.0694	-0.4382	103	67	0.5259	-0.3305
8	08	-1.1860	0.6043	40	28	-0.5647	0.5647	72	48	-1.1163	0.7249	104	68	-0.5850	0.7814
9	09	-0.4581	0.6542	41	29	-0.0696	0.7956	73	49	-0.4678	0.8567	105	69	-0.0696	0.9736
10	0A	0.5647	0.5647	42	2A	1.1860	0.6043	74	4A	0.5850	0.7814	106	6A	1.1163	0.7249
11	0B	0.0696	0.7956	43	2B	0.4581	0.6542	75	4B	0.0696	0.9736	107	6B	0.4678	0.8567
12	0C	-1.3292	0.0697	44	2C	-0.7956	0.0696	76	4C	-1.3147	0.2082	108	6C	-0.7714	0.2067
13	0D	-0.6172	0.0695	45	2D	-0.0627	0.0627	77	4D	-0.5863	0.2052	109	6D	-0.0689	0.2571
14	0E	0.7956	0.0696	46	2E	1.3292	0.0697	78	4E	0.7714	0.2067	110	6E	1.3147	0.2082
15	0F	0.0627	0.0627	47	2F	0.6172	0.0695	79	4F	0.0689	0.2571	111	6F	0.5863	0.2052
16	10	-0.8376	-1.0344	48	30	-0.7249	-1.1163	80	50	-0.8157	-0.8157	112	70	-0.7114	-0.9081
17	11	-0.3445	-1.2857	49	31	-0.2082	-1.3147	81	51	-0.3432	-1.1013	113	71	-0.2079	-1.1347
18	12	0.7249	-1.1163	50	32	0.8376	-1.0344	82	52	0.7114	-0.9081	114	72	0.8157	-0.8157
19	13	0.2082	-1.3147	51	33	0.3445	-1.2857	83	53	0.2079	-1.1347	115	73	0.3432	-1.1013
20	14	-1.0519	-0.4734	52	34	-0.8567	-0.4678	84	54	-1.1013	-0.3432	116	74	-0.9145	-0.3411
21	15	-0.3305	-0.5259	53	35	-0.2052	-0.5863	85	55	-0.3137	-0.3137	117	75	-0.2014	-0.3953
22	16	0.8567	-0.4678	54	36	1.0519	-0.4734	86	56	0.9145	-0.3411	118	76	1.1013	-0.3432
23	17	0.2052	-0.5863	55	37	0.3305	-0.5259	87	57	0.2014	-0.3953	119	77	0.3137	-0.3137
24	18	-0.9872	0.5968	56	38	-0.7814	0.5850	88	58	-0.9081	0.7114	120	78	-0.6902	0.6902
25	19	-0.3375	0.7238	57	39	-0.2067	0.7714	89	59	-0.3411	0.9145	121	79	-0.2075	0.9538
26	1A	0.7814	0.5850	58	3A	0.9872	0.5968	90	5A	0.6902	0.6902	122	7A	0.9081	0.7114
27	1B	0.2067	0.7714	59	3B	0.3375	0.7238	91	5B	0.2075	0.9538	123	7B	0.3411	0.9145
28	1C	-1.1515	0.0697	60	3C	-0.9736	0.0696	92	5C	-1.1347	0.2079	124	7C	-0.9538	0.2075
29	1D	-0.4382	0.0694	61	3D	-0.2571	0.0689	93	5D	-0.3953	0.2014	125	7D	-0.1882	0.1882
30	1E	0.9736	0.0696	62	3E	1.1515	0.0697	94	5E	0.9538	0.2075	126	7E	1.1347	0.2079
31	1F	0.2571	0.0689	63	3F	0.4382	0.0694	95	5F	0.1882	0.1882	127	7F	0.3953	0.2014

Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.	Bit-to-symbol mapping (Decimal)	Bit-to-symbol mapping (Hexadecimal)	I comp.	Q comp.
128	80	-1.1860	-0.6043	160	A0	-0.5647	-0.5647	192	C0	-1.1163	-0.7249	224	E0	-0.5850	-0.7814
129	81	-0.4581	-0.6542	161	A1	-0.0696	-0.7956	193	C1	-0.4678	-0.8567	225	E1	-0.0696	-0.9736
130	82	0.5647	-0.5647	162	A2	1.1860	-0.6043	194	C2	0.5850	-0.7814	226	E2	1.1163	-0.7249
131	83	0.0696	-0.7956	163	A3	0.4581	-0.6542	195	C3	0.0696	-0.9736	227	E3	0.4678	-0.8567
132	84	-1.3292	-0.0697	164	A4	-0.7956	-0.0696	196	C4	-1.3147	-0.2082	228	E4	-0.7714	-0.2067
133	85	-0.6172	-0.0695	165	A5	-0.0627	-0.0627	197	C5	-0.5863	-0.2052	229	E5	-0.0689	-0.2571
134	86	0.7956	-0.0696	166	A6	1.3292	-0.0697	198	C6	0.7714	-0.2067	230	E6	1.3147	-0.2082
135	87	0.0627	-0.0627	167	A7	0.6172	-0.0695	199	C7	0.0689	-0.2571	231	E7	0.5863	-0.2052
136	88	-0.9412	0.9412	168	A8	-0.6043	1.1860	200	C8	-1.0344	0.8376	232	E8	-0.5968	0.9872
137	89	-0.4770	1.2426	169	A9	-0.0697	1.3292	201	C9	-0.4734	1.0519	233	E9	-0.0697	1.1515
138	8A	0.6043	1.1860	170	AA	0.9412	0.9412	202	CA	0.5968	0.9872	234	EA	1.0344	0.8376
139	8B	0.0697	1.3292	171	AB	0.4770	1.2426	203	CB	0.0697	1.1515	235	EB	0.4734	1.0519
140	8C	-1.2426	0.4770	172	AC	-0.6542	0.4581	204	CC	-1.2857	0.3445	236	EC	-0.7238	0.3375
141	8D	-0.4392	0.4392	173	AD	-0.0695	0.6172	205	CD	-0.5259	0.3305	237	ED	-0.0694	0.4382
142	8E	0.6542	0.4581	174	AE	1.2426	0.4770	206	CE	0.7238	0.3375	238	EE	1.2857	0.3445
143	8F	0.0695	0.6172	175	AF	0.4392	0.4392	207	CF	0.0694	0.4382	239	EF	0.5259	0.3305
144	90	-0.9872	-0.5968	176	B0	-0.7814	-0.5850	208	D0	-0.9081	-0.7114	240	F0	-0.6902	-0.6902
145	91	-0.3375	-0.7238	177	B1	-0.2067	-0.7714	209	D1	-0.3411	-0.9145	241	F1	-0.2075	-0.9538
146	92	0.7814	-0.5850	178	B2	0.9872	-0.5968	210	D2	0.6902	-0.6902	242	F2	0.9081	-0.7114
147	93	0.2067	-0.7714	179	B3	0.3375	-0.7238	211	D3	0.2075	-0.9538	243	F3	0.3411	-0.9145
148	94	-1.1515	-0.0697	180	B4	-0.9736	-0.0696	212	D4	-1.1347	-0.2079	244	F4	-0.9538	-0.2075
149	95	-0.4382	-0.0694	181	B5	-0.2571	-0.0689	213	D5	-0.3953	-0.2014	245	F5	-0.1882	-0.1882
150	96	0.9736	-0.0696	182	B6	1.1515	-0.0697	214	D6	0.9538	-0.2075	246	F6	1.1347	-0.2079
151	97	0.2571	-0.0689	183	B7	0.4382	-0.0694	215	D7	0.1882	-0.1882	247	F7	0.3953	-0.2014
152	98	-0.8376	1.0344	184	B8	-0.7249	1.1163	216	D8	-0.8157	0.8157	248	F8	-0.7114	0.9081
153	99	-0.3445	1.2857	185	B9	-0.2082	1.3147	217	D9	-0.3432	1.1013	249	F9	-0.2079	1.1347
154	9A	0.7249	1.1163	186	BA	0.8376	1.0344	218	DA	0.7114	0.9081	250	FA	0.8157	0.8157
155	9B	0.2082	1.3147	187	BB	0.3445	1.2857	219	DB	0.2079	1.1347	251	FB	0.3432	1.1013
156	9C	-1.0519	0.4734	188	BC	-0.8567	0.4678	220	DC	-1.1013	0.3432	252	FC	-0.9145	0.3411
157	9D	-0.3305	0.5259	189	BD	-0.2052	0.5863	221	DD	-0.3137	0.3137	253	FD	-0.2014	0.3953
158	9E	0.8567	0.4678	190	BE	1.0519	0.4734	222	DE	0.9145	0.3411	254	FE	1.1013	0.3432
159	9F	0.2052	0.5863	191	BF	0.3305	0.5259	223	DF	0.2014	0.3953	255	FF	0.3137	0.3137

NOTE – As with the 128APSK, the 256APSK has been designed taking into account that the SCCC-X receiver is expected to decode the incoming data with a two-stage decoding process. Once the first 4 MSBs are decoded by the SCCC (soft) decoder, the rest of the bits are decoded by a second BCH (hard) decoder that operates on a subset that has larger minimum distance with respect to the original constellation. For instance, the 00000101 (0x05) constellation point, once bits 0000 are SCCC decoded, the BCH will have to perform decoding on the subset depicted in figure 5-4.

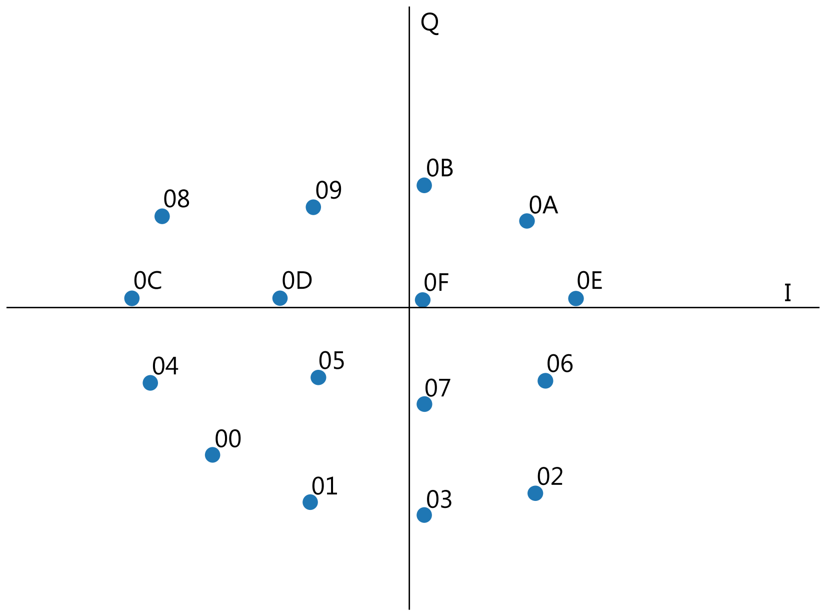

Figure 5-4: Example of 256APSK Subset To Be Decoded by the Second Stage BCH Decoder If the MSB 000 Bits Are Estimated by the First Stage SCCC Decoder

5.2.4 SUPPORTED SET OF ACM FORMATS

The additional MODCODs (ACM formats) of the SCCC-X Experimental Specification (in addition to ones in the Recommended Standard in reference [1]) shall follow the parameters listed in table 5-3.

The table also distinguishes between the first stage of (soft) SCCC encoding and second stage of (hard) BCH encoding by including K_1, I, N_1, K_2, N_2 for each of the MODCODs ACM#28-37.

Table 5-3: ACM Formats of SCCC-X by Distinguishing between the First Stage of (Soft) SCCC and Second Stage of (Hard) BCH

			SCCC stage				BCH stage			Total		
	ACM	*m*	Soft bits	*K1*	*I*	*N1*	Hard bits	*K2*	*N2*	*K*	*N*	Efficiency [bit/ch. symbol]
128APSK	28	7	4	19 198	28 800	32 400	3	24 144	24 300	43 342	56 700	5.35
	29	7	4	21 358	32 040	32 400	3	24 144	24 300	45 502	56 700	5.62
	30	7	4	23 518	35 280	32 400	3	24 144	24 300	47 662	56 700	5.88
	31	7	4	25 918	38 880	32 400	3	24 144	24 300	50 062	56 700	6.18
	32	7	4	28 318	42 480	32 400	3	24 144	24 300	52 462	56 700	6.48
256APSK	33	8	4	19 198	28 800	32 400	4	32 192	32 400	51 390	64 800	6.34
	34	8	4	21 358	32 040	32 400	4	32 192	32 400	53 550	64 800	6.61
	35	8	4	23 518	35 280	32 400	4	32 192	32 400	55 710	64 800	6.88
	36	8	4	25 918	38 880	32 400	4	32 192	32 400	58 110	64 800	7.17
	37	8	4	28 318	42 480	32 400	4	32 192	32 400	60 510	64 800	7.47

5.3 PL SIGNALING INSERTION

5.3.1 GENERAL

5.3.1.1 The PL frame structure of SCCC-X 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 5-5.

5.3.1.2 The SCCC-X PL frame structure follows exactly the frame structure of the Recommended Standard (reference [1]).

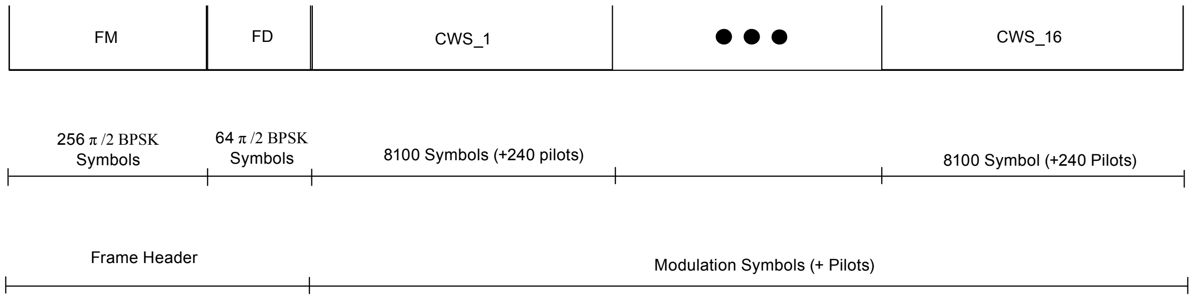

Figure 5-5: Physical Layer Frame Structure

5.3.2 FRAME MARKER

The Frame Marker of the SCCC-X is identical to the one described in subsection 5.3.2 of the Recommended Standard (reference [1]).

5.3.3 FRAME DESCRIPTOR STRUCTURE

The Frame Descriptor is generated by encoding 8 input bits. The 8 input bits identify the ACM format of codeword sections within a PL frame (6 bits) as well as the absence or presence of distributed pilots. The content of the eight (8) input bits shall be as shown in table 5-4.

The intention of the FD in table 5-4, is to signal both MODCODs ACM#1-27 of the existing standard (reference [1]) as well as the additional MODCODs ACM#28-37 described in the present Experimental Specification document. This explains the need for devoting six (6) bits b0–b5 for this purpose. This way, SCCC-X receivers will be able to identify which ACM format out of the full range ACM#1-ACM#37 has been transmitted.

Table 5-4: Frame Descriptor Input Bits Content

Bit Number	Content
b_0–b_5	ACM Formats (Decimal values 1 to 37 are used with bit b_0 being the most significant bit)
b_6	Distributed Pilot On (=1)/Off (=0)
b_7	Reserved (set to 0)

Since bits b_0–b_5 allow for more than 37 combinations, they shall attain the following values for signaling MODCODs ACM#28-37.

ACM#	b0	b1	b2	b3	b4	b5
28	0	1	1	1	0	0
29	0	1	1	1	0	1
30	0	1	1	1	1	0
31	0	1	1	1	1	1
32	1	0	0	0	0	0
33	1	0	0	0	0	1
34	1	0	0	0	1	0
35	1	0	0	0	1	1
36	1	0	0	1	0	0
37	1	0	0	1	0	1

The eight (8) input bits are encoded by the non-systematic binary code of length 64 and dimension 8 with minimum distance d_{min}=32 shown in figure 5-6. Following this figure, the 8-bit FD field shall be coded with a (64,8) code constructed starting from a (32,7) code.

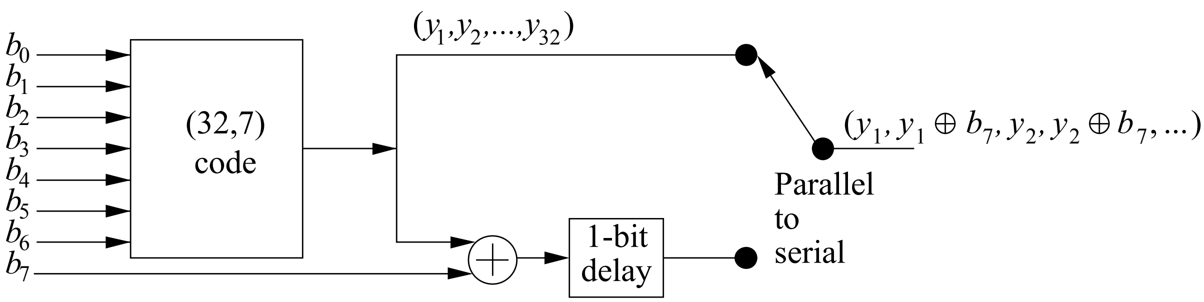

Figure 5-6: Frame Descriptor Code Structure

The 7 most significant bits (b_0, …, b_6) of the FD shall be encoded by a linear block code of length 32 with the generator matrix in figure 5-7, whose rows are (in hexadecimal notation):

```
0x90AC2DDD;
0x55555555;
0x33333333;
0x0F0F0F0F;
0x00FF00FF;
0x0000FFFF;
0xFFFFFFFF.
```

The MSB of the 8-bit FD is multiplied with the first row of the matrix, the following bit with the second row, and so on.

$$\mathbf{G} = \begin{bmatrix} 10010000101011000010110111011101 \\ 01010101010101010101010101010101 \\ 00110011001100110011001100110011 \\ 00001111000011110000111100001111 \\ 00000000111111110000000011111111 \\ 00000000000000001111111111111111 \\ 11111111111111111111111111111111 \end{bmatrix}$$

Figure 5-7: Generator Matrix for (32,7) Code

The 32 coded bits are denoted as $(y_1 y_2 \ldots y_{32})$. Being b7 = 0, the final FD code will generate $(y_1 y_1 y_2 y_2 \ldots y_{32} y_{32})$ as the output, that is, each symbol shall be repeated. The 64-bit output of the FD code shall be further scrambled (i.e., XORed) by the binary sequence:

0111000110011101100000111100100101010011010000100010110111111010.

5.3.4 CODEWORD SEGMENT GENERATION AND PILOT INSERTION

Codeword segment generation and pilot insertion shall be as in subsection 5.3.4 of the Recommended Standard (reference [1]).

5.4 FRAME HEADER MODULATION

Frame header and modulation shall be as in subsection 5.4 of the Recommended Standard (reference [1]).

5.5 PHYSICAL LAYER *I/Q* PSEUDO-RANDOMIZATION

Physical Layer *I/Q* pseudo-randomization shall be as in subsection 5.3.4 of the Recommended Standard (reference [1]).

6 BASEBAND FILTERING

Baseband filtering shall be as in section 6 of the Recommended Standard (reference [1]).

7 FRAME SYNCHRONIZATION

Frame synchronization shall be as in section 7 of the Recommended Standard (reference [1]).

8 PSEUDO-RANDOMIZER

Pseudo-randomizer shall be as in section 8 of the Recommended Standard (reference [1]).

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, that is, 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. 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 Experimental Specification 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.

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

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 65536 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	Integer: 28 to 37
List of ACM Formats supported	List of Integers (dimension = 'Number of ACM Formats supported'). Each integer is in the range 28 to 37 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.

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

9.3.2 CURRENT ACM FORMAT

NOTE – ACM Format can range from 28 to 37. 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 9-4.

Table 9-4: Variable Managed Parameters for SCCC-X ACM Formats

ACM format	m	K	N
28	7=128APSK	43342	56700
29	7=128APSK	45502	56700
30	7=128APSK	47662	56700
31	7=128APSK	50062	56700
32	7=128APSK	52462	56700
33	8=256APSK	51390	64800
34	8=256APSK	53550	64800
35	8=256APSK	55710	64800
36	8=256APSK	58110	64800
37	8=256APSK	60510	64800

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).

A2 OVERVIEW OF THE SERVICE

The SCCC Extension provides unidirectional (one-way) transfer of a sequence of fixed-length TM, AOS, or USLP 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], an AOS Transfer Frame defined in reference [3], or a USLP Transfer Frame defined in reference [4].

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

ANNEX B

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

B1 SECURITY CONSIDERATIONS

B1.1 SECURITY BACKGROUND

It is assumed that security is provided by encryption, authentication methods, and access control to be performed at higher layers (Application and/or Transport Layers). Mission and service providers are expected to select from recommended security methods, suitable to the specific application profile. Specification of these security methods and other security provisions is outside the scope of this Experimental Specification. The coding layer has the objective of delivering data with the minimum possible amount of residual errors. The Serially Concatenated Convolutional Codes ensure a very low error probability, and the Frame Error Control Field is used to ensure that residual errors are detected and the frame flagged. There is an extremely low probability of additional undetected errors that may escape this scrutiny. These errors may affect the encryption process in unpredictable ways, possibly affecting the decryption stage and producing data loss, but will not compromise the security of the data.

B1.2 SECURITY CONCERNS

Security concerns in the areas of data privacy, authentication, access control, availability of resources, and auditing are to be addressed in higher layers and are not related to this Recommended Standard. The coding layer does not affect the proper functioning of methods used to achieve such protection at higher layers, except for undetected errors, as explained above.

The physical integrity of data bits is protected from channel errors by the coding systems specified in this Experimental Specification. In case of congestion or disruption of the link, the coding layer provides methods for frame re-synchronization.

B1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

An eavesdropper can receive and decode the codewords, but will not be able to get to the user data if proper encryption is performed at a higher layer. An interferer could affect the performance of the decoder by congesting it with unwanted data, but such data would be rejected by the authentication process. Such interference or jamming must be dealt with at the Physical Layer and through proper spectrum regulatory entities.

B1.4 CONSEQUENCES OF NOT APPLYING SECURITY

There are no specific security measures prescribed for the coding layer. Therefore consequences of not applying security are only imputable to the lack of proper security measures in other layers. Residual undetected errors may produce additional data loss when the link carries encrypted data.

B2 SANA CONSIDERATIONS

The recommendations of this document do not require any action from SANA.

B3 PATENT CONSIDERATIONS

B3.1 APSK MODULATIONS

Implementers should be aware that the APSK modulations are covered by U.S. Patents 7123663 and 7239668. Potential user agencies should direct their requests for licenses to:

Mr Luz Becker
Legal Department
European Space Agency
8-10 Rue Mario Nikis
75738 Paris Cedex 15
Tel: +33 1 536 97152
E-mail: lux.becker@esa.int

ANNEX C

SUMMARY OF PERFORMANCE

(INFORMATIVE)

C1 PERFORMANCE OF THE EXPERIMENTAL CODES AND MODULATIONS ON THE ADDITIVE WHITE GAUSSIAN NOISE CHANNEL WITH IDEAL SYNCHRONIZATION

C1.1 GENERAL

This section reports the performance of the experimental codes and modulations over the linear channel affected by Additive White Gaussian Noise (AWGN). In particular, C1.2 describes the channel model adopted, while C1.3 and C1.4 show the numerical results derived by means of computer simulations.

C1.2 CHANNEL MODEL

The baseband model of the transmitted signal by the sending end is

$$x(t) = \sum_k x_k p(t - kT) \ , \qquad (1)$$

where x_k are the transmitted channel symbols at the output of the PL framing function (described in 2.3.1), $p(t)$ is the shaping pulse, and T the channel symbol duration. The constellation of symbols is properly normalized such that $E\{|x_k|^2\} = E_s$, where E_s denotes the energy-per-channel symbol. The shaping pulse is Square-Root Raised-Cosine (SRRC); hence in ideal conditions, it satisfies the intersymbol-interference-free condition (the so called Nyquist condition), that is,

$$\int_{-\infty}^{\infty} p(t)p(t - kT)dt = \begin{cases} 1, & k = 0 \\ 0, & k \neq 0 \end{cases} \ .$$

The channel is considered affected only by AWGN; hence the baseband model of the received signal is given by

$$y(t) = \Sigma_k x_k p(t - kT) + w(t) \ ,$$

where $w(t)$ is white complex Gaussian noise with power spectral density N_0. A sufficient statistic for the computation of the Log-Likelihood Ratios (LLRs) is sampled at the output of a matched filter. The received samples after the matched filter read

$$y_k = x_k + w_k \ , \qquad (2)$$

where w_k are independent Gaussian random variables with variance equal to N_0. For this discrete-time received signal, the *Signal-to-Noise Ratio* (SNR) can be expressed as E_s/N_0 or E_b/N_0, where E_b is the energy per information bit. The E_b/N_0 is related to the E_s/N_0 by

$$\frac{E_b}{N_0}\left(\frac{K}{N}\right)m = \frac{E_s}{N_0}, \tag{3}$$

where m and K/N are the modulation order (number of bits per channel symbol) and the coding rate, respectively (with K and N as defined in 2.3.1).

C1.3 NUMERICAL RESULTS

The performance results of the Experimental modulation and coding scheme have been evaluated over the AWGN channel described in the previous section, by means of computer simulations and under the assumption of ideal synchronization. Clearly, being the channel with the AWGN channel model, results are independent of the channel symbol rate and roll-off.

Figures figure C-1 and C-2 show the Bit Error Rate (BER) and Codeword Error Rate (CER) as functions of the E_b/N_0 for all the 10 new ACM formats, when 10 iterations of the SCCC turbo decoder are performed.

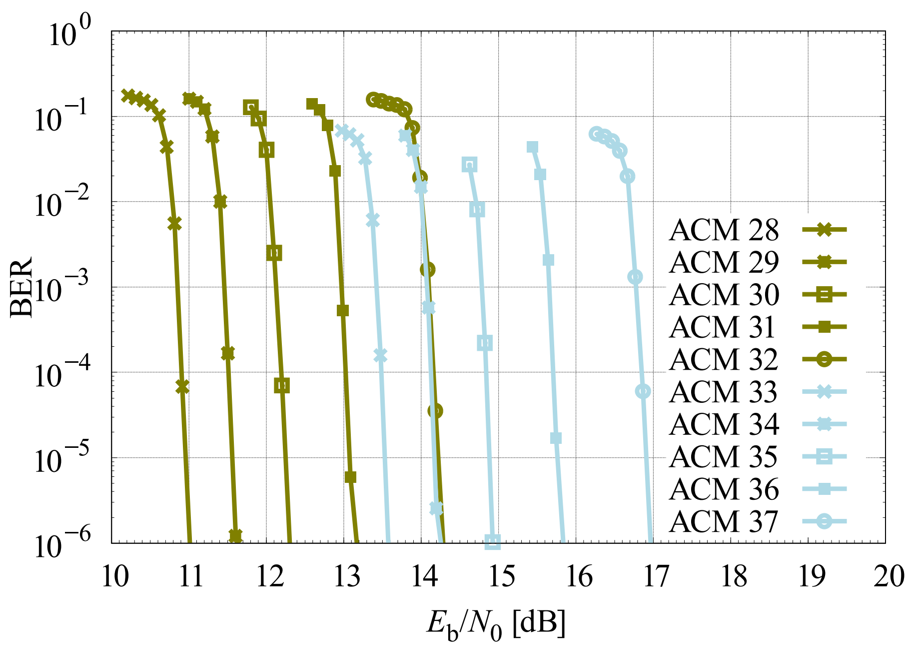

Figure C-1: BER on Linear AWGN Channel for ACM Formats from 28 to 37 (128APSK and 256APSK)

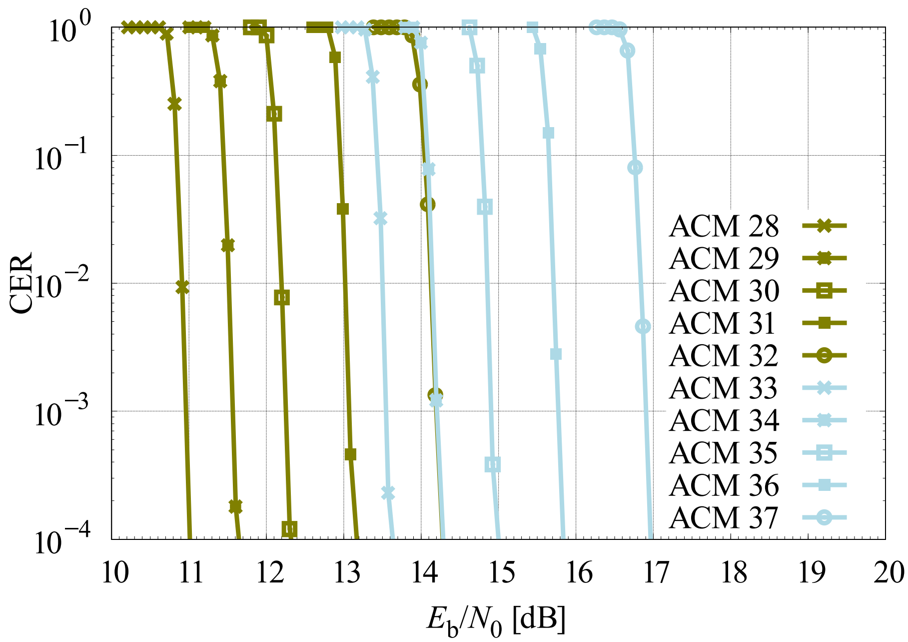

Figure C-2: CER on Linear AWGN Channel for ACM Formats from 28 to 37 (128APSK and 256APSK)

Table C-1 shows the required signal-to-noise ratio (in terms of both E_s/N_0 and E_b/N_0) for achieving a target CER of 10^{-4}, and the corresponding efficiency in terms of bits per transmitted channel symbol. These values complement the SCCC results in table 3-1 of the Green Book (reference [E1]) and can also be shown in a plane with the efficiency versus E_b/N_0, as shown in figure C-3.

Table C-1: SNR Thresholds for CER=1e-4, Achieved on the AWGN Channel by the Experimental ACM Formats

	ACM	E_s/N_0 [dB]	E_b/N_0 [dB]	Efficiency
128APSK	28	18.29	11.00	5.35
	29	19.11	11.62	5.62
	30	20.10	12.41	5.88
	31	21.03	13.12	6.18
	32	22.35	14.24	6.48
256APSK	33	21.62	13.59	6.34
	34	22.46	14.26	6.61
	35	23.33	14.95	6.88
	36	24.38	15.83	7.17
	37	25.67	16.94	7.47

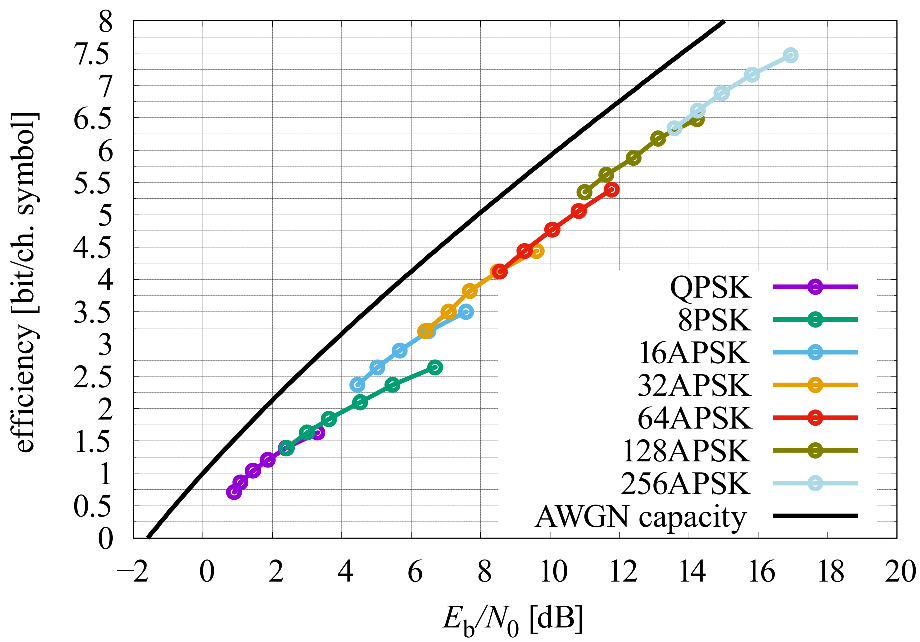

Figure C-3: Efficiency of the Experimental ACM Formats (128APSK and 256APSK) on the Linear AWGN Channel with Respect to Channel Capacity and SCCC (Reference [E1], Table 3-1)

C1.4 FRAME DESCRIPTOR DECODING

The FD encoding matrix for SCCC-X (5.3.3) is the same of SCCC with an additional row. This allows to encode an additional FD bit (b0) while keeping compatibility with SCCC; that is, the SCCC-X FD encoder and decoder can also be adopted for SCCC by simply setting b0 equal to '0'. On the other hand, this decreases the FD code rate, hence providing a (slightly) worse error rate performance than the SCCC FD code.

Assuming ideal synchronization, the performance of the SCCC-X FD code described in 5.3.3 has been analyzed with a Maximum Likelihood (ML) soft decoder, versus an ML hard decoder, and compared with the performance of the SCCC FD code. Figure C-4 shows the FD error rate as function of the E_s/N_0. It can be seen that the rate for SCCC-X FD code is about 0.4 dB worse than that for SCCC, and in case of hard implementation, achieves FD error rate 10^{-5} at $E_s/N_0 \sim -1.6$ dB. This guarantees about 1 dB margin below the minimum E_s/N_0 required for decoding all SCCC and SCCC-X ACM formats (table 3-1 of reference [E1] and table C-1) when the target CER is 10^{-4}. However, this margin decreases as the target CER decreases. Hence, in case an implementation of both SCCC and SCCC-X requires lower CER values that those considered here, a soft-decoding of the SCCC-X FD code is recommended at the receiver, rather than hard-decoding.

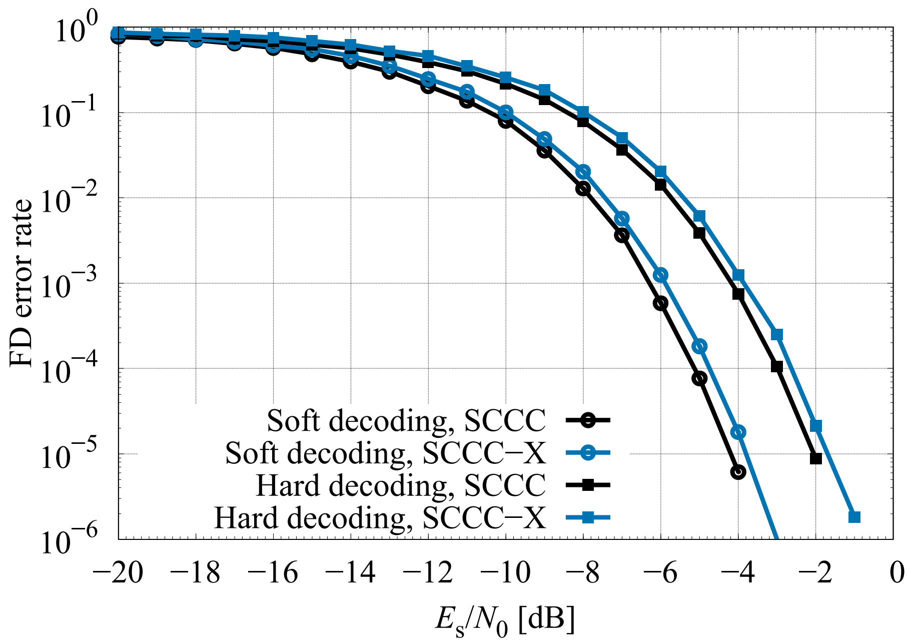

Figure C-4: SCCC-X FD Error Rate with Hard and Soft Decoding, in Comparison with SCCC FD Error Rate

C2 PERFORMANCE OF THE EXPERIMENTAL CODES AND MODULATIONS ON NONLINEAR CHANNELS WITH IDEAL SYNCHRONIZATION

C2.1 OVERVIEW

This section focuses on the performance of the experimental codes and modulations over a nonlinear channel model with ideal synchronization. In particular, C2.2 provides a channel model that includes nonlinear distortions typically due to a Travelling Wave Tube Amplifier (TWTA), an output filter (aimed at mitigating spectral regrowth), and AWGN. Starting from this channel model, C2.3 describes how to optimize the Input and Output Back-Off (IBO/OBO) by means of the Total Degradation (TD), and C2.4 how to improve performance using static pre-distortion. Finally, C2.5 shows the numerical results for the recommended codes and modulations, in particular their BER/FER curves.

C2.2 NONLINEAR CHANNEL MODEL

The linearly modulated signal of equation (1) is applied to the nonlinear channel as shown in figure C-5, which includes a TWTA and a RF output filter (mitigating spectral regrowth). The distorted signal is then further corrupted by AWGN.

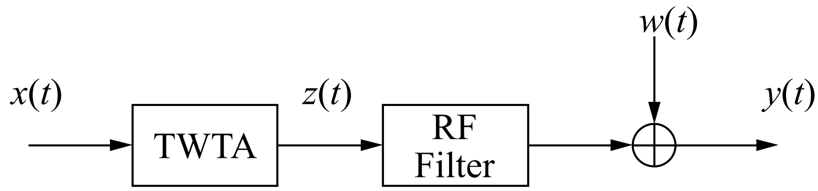

Figure C-5: Block Diagram of the Overall Channel Model Considered in Simulations

The TWTA was modelled by means of the input/output relationship

$$z(t) = f_{AM}(|x(t)|)e^{j\angle x(t)+f_{PM}(|x(t)|)} \ ,$$

where $f_{AM}(|x(t)|)$ and $f_{PM}(|x(t)|)$ are the AM/AM and AM/PM characteristics, respectively.

For all simulations, a channel symbol rate of 100 MBaud and SRRC with roll-off 0.35 was assumed, while at the receiver, a symbol-by-symbol demapper was adopted for computing the soft information (the LLRs), that are the input of the decoder. A maximum of 10 decoding SCCC turbo iterations were assumed for the simulations. The specific AM/AM and AM/PM characteristics adopted for simulations (modelling a typical TWTA operating in the 25.5-27 GHz band) are as shown in figure C-6, while the output filter is a 5th order Elliptical filter with frequency response as shown in figure C-7, having ripple 0.1 dB, and passband and stopband 75 MHz and 93.75 MHz, respectively.

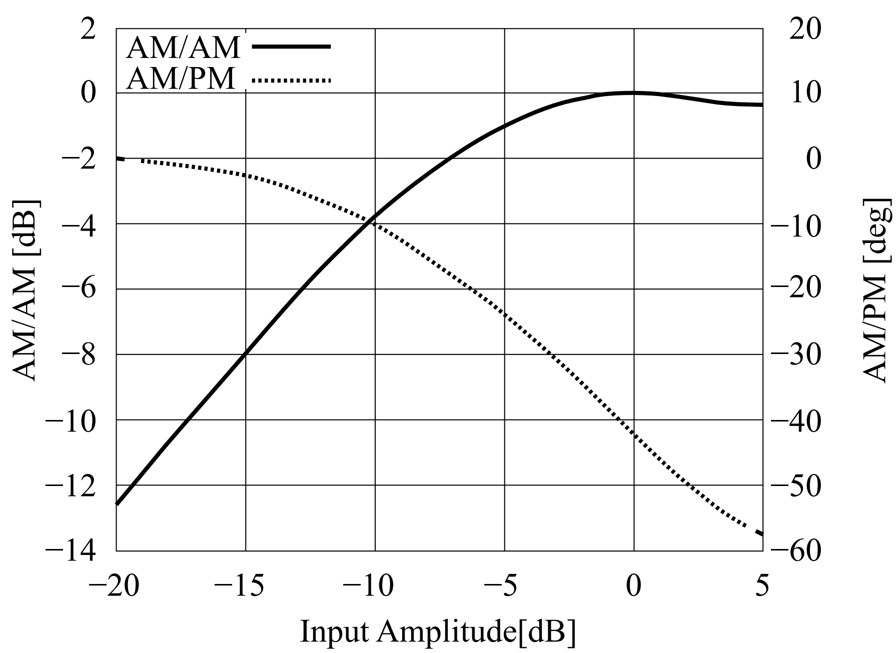

Figure C-6: AM/AM and AM/PM Nonlinear Transfer Characteristics Adopted for Simulations

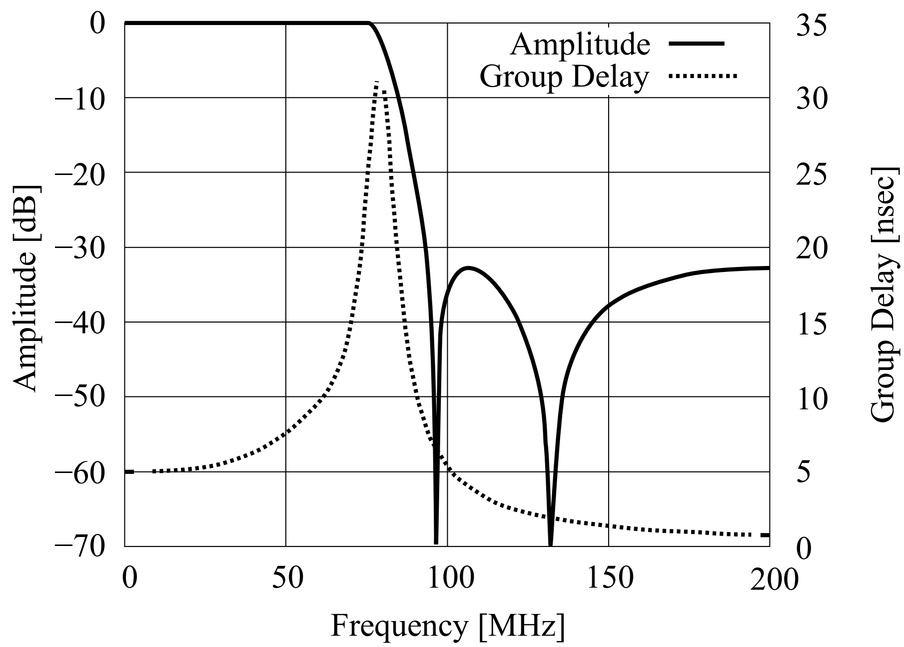

Figure C-7: RF Filter Frequency Response

C2.3 IBO/OBO OPTIMIZATION BY MEANS OF TOTAL DEGRADATION

Using the same approach of section 4 of the SCCC Green Book (reference [E1]), results are here presented by using the optimal IBO/OBO found by minimizing the total degradation (see subsection 4.2 in reference [E1] for optimization examples) defined as

$$TD = \left(\frac{E_b}{N_0} + \mathrm{OBO}\right) - \left(\frac{E_b}{N_0}\right)_{\mathrm{AWGN}} \qquad \text{[dB]},$$

where $\left(\frac{E_b}{N_0} + \mathrm{OBO}\right)$ is the signal-to-noise ratio and OBO required for obtaining a specific target CER with the assumed channel model and receiver. The value $\left(\frac{E_b}{N_0}\right)_{\mathrm{AWGN}}$ instead represents the signal-to-noise ratio required on the ideal AWGN channel with ideal synchronization to achieve the same target CER. A target CER equal to 10^{-4} has been adopted.

C2.4 STATIC PRE-DISTORTION

Using the same approach as section 4 of the SCCC Green Book (reference [E1]), the total degradation can be effectively decreased by means of pre-distortion. A static data pre-distorter (at the transmitter), as the one in reference [E4], was assumed for the simulations presented in this section. Such pre-distortion is basically a simple look-up table that transmits the constellation symbols with a fixed correction of the radii amplitudes and phases (computed off-line).

It is pointed out that the pre-distortion algorithm adopted here is just a reference and shall not be considered as optimal. For instance, it is expected that pre-distortion based on more complex model, for example, a polynomial representation of the amplifier (see reference [E5]), can provide better gains, in addition to reducing the spectral occupation.

C2.5 NUMERICAL RESULTS

Numerical simulations have been carried out with the channel model described in the previous sections in order to assess the impact of the TWTA together with the RF filter.

Figures C-8 to C-9 show the BER and CER for all the possible ACM using the optimal IBO found by means of the total degradation analysis. The corresponding SNR thresholds for CER equal to 10^{-4} and OBO for each individual ACM mode (to be taken into account when performing system-level design) can be found in table C-2. This table can be adopted as a complement to the SCCC results in table 4-2 of the Green Book (reference [E1]).

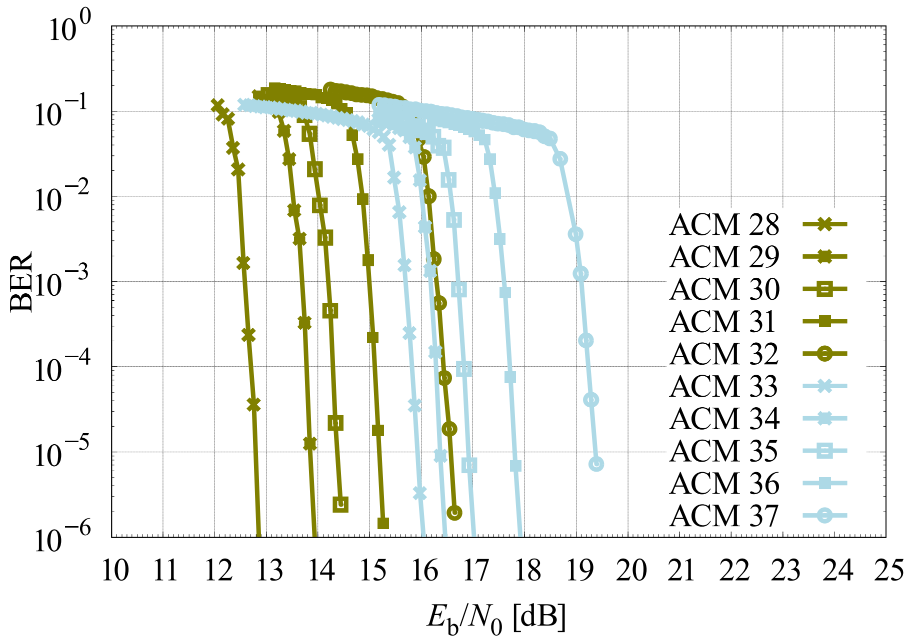

Figure C-8: BER on Nonlinear AWGN Channel for ACM Formats 28 to 37 with the Optimal IBO and with Pre-Distortion

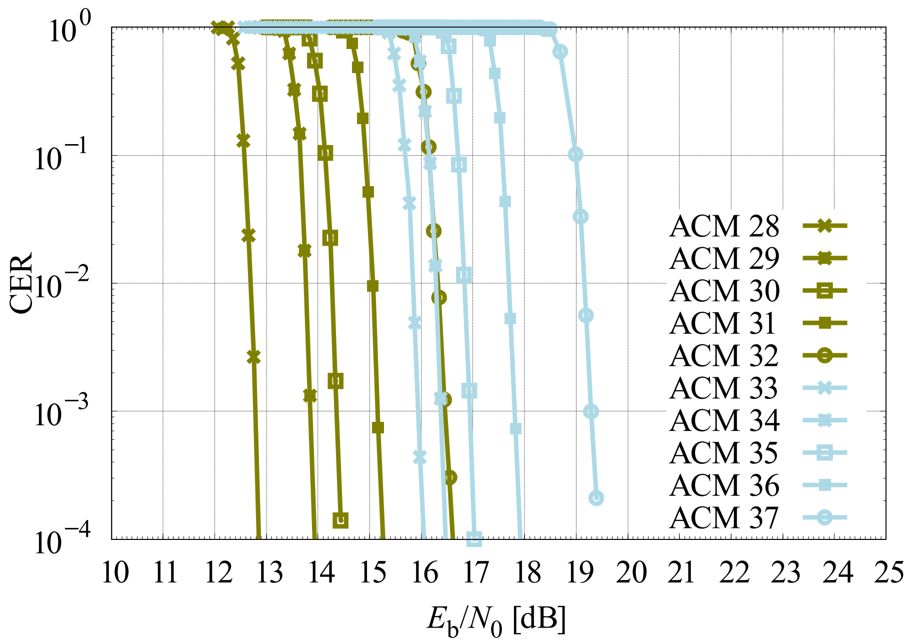

Figure C-9: CER on Nonlinear AWGN Channel for ACM Formats 28 to 37 with the Optimal IBO and with Pre-Distortion

Table C-2: SNR Thresholds for CER=1e-4, and Corresponding OBO and TD, Achieved by the Experimental ACM Formats on the Nonlinear AWGN Channel with Pre-Distortion

	ACM	**E_s/N_0 [dB]**	**E_s/N_0 [dB]**	**OBO [dB]**	***TD* [dB]**	**Efficiency**
128APSK	28	20.13	12.84	3.66	5.50	5.35
	29	21.42	13.93	3.66	5.97	5.62
	30	22.15	14.46	4.26	6.31	5.88
	31	23.17	15.26	4.92	7.06	6.18
	32	24.70	16.59	5.64	7.99	6.48
256APSK	33	24.06	16.03	4.90	7.34	6.34
	34	24.66	16.46	5.63	7.83	6.61
	35	25.40	17.03	6.40	8.47	6.88
	36	26.45	17.89	7.21	9.28	7.17
	37	28.18	19.44	8.07	10.58	7.47

C3 CONCLUSIONS

This annex provides additional informative material to the experimental specification SCCC-X.

Annex subsection C1 assessed the performance of the experimental codes and modulations by means of BER/CER curves on the AWGN channel, assuming ideal synchronization. The reported numerical results can be adopted as a complement to the SCCC results in section 3 of the Green Book (reference [E1]). Additionally, the performance of the SCCC-X FD code has been evaluated and compared with that of SCCC: it has been found that in case backward compatibility and low target CER are required, it is recommended that the SCCC-X receiver performs soft-decoding of the FD code.

Finally, C2 provided the performance of the recommended codes and modulations in presence of a nonlinear distortions, aimed at modelling nonlinear effects due to amplification. A preliminary optimization of the IBO/OBO was carried out, and performance was reported by means of BER/CER curves when static pre-distortion at the transmitter is adopted. The reported numerical results can be adopted as a complement to the SCCC results in subsection 4.4.2 of the Green Book (reference [E1]).

ANNEX D

ACRONYMS AND ABBREVIATIONS

(INFORMATIVE)

Term	Meaning
ACM	adaptive coding and modulation
AOS	Advanced Orbiting Systems
APSK	amplitude phase shift keying
ASM	attached sync marker
AWGN	additive white Gaussian noise
BCH	Bose–Chaudhuri–Hocquenghem code
BER	bit error rate
CCSDS	Consultative Committee for Space Data Systems
CER	codeword error rate
DRS	data relay satellite
EESS	Earth Exploration Satellite Services
FD	frame descriptor
FER	frame error ratio
FM	frame marker
GEO	geostationary Earth orbit
LEO	low Earth orbit
LLR	log-likelihood ratio
MODCOD	modulation and coding
MSB	most significant bit
PL	Physical Layer
SANA	Space Assigned Numbers Authority
SCCC	serially concatenated convolutional (turbo) code
SCCC-X	serially concatenated convolutional (turbo) code - extension
SMTF	synch-marked transfer frame
SRRC	square-root raised-cosine
TM	telemetry
TWTA	travelling wave tube amplifier
USLP	Unified Space Data Link Protocol
VCM	variable coding and modulation

Cor. 1

Cor. 1

ANNEX E

INFORMATIVE REFERENCES

(INFORMATIVE)

[E1] *SCCC—Summary of Definition and Performance*. Issue 1. Report Concerning Space Data System Standards (Green Book), CCSDS 130.11-G-1. Washington, D.C.: CCSDS, April 2019.

[E2] *Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model*. 2nd ed. International Standard, ISO/IEC 7498-1:1994. Geneva: ISO, 1994.

[E3] G. Montorsi. “Design of Constellation Sets for Multistage Systems.” In *2016 IEEE Global Communications Conference (GLOBECOM) (4–8 December 2016, Washington, DC, USA)*. Piscataway, New Jersey: IEEE, 2016.

[E4] G. Karam and H. Sari. “A Data Predistortion Technique with Memory for QAM Radio Systems.” *IEEE Transactions on Communications* 39, no. 22 (1991): 336–344.

[E5] Lei Ding, et al. “A Robust Digital Baseband Predistorter Constructed Using Memory Polynomials.” *IEEE Transactions on Communications* 52, no. 1 (2004): 159–165.