

**Digital Video Broadcasting (DVB);  
Frame structure channel coding and modulation  
for a second generation digital transmission system  
for cable systems (DVB-C2)**

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**Reference**

REN/JTC-DVB-288

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**Keywords**

audio, broadcasting, cable, data, digital, DVB,  
MPEG, TV, video

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## Foreword

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**NOTE:** The EBU/ETSI JTC Broadcast was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC Broadcast became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva.

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The Digital Video Broadcasting Project (DVB) is an industry-led consortium of broadcasters, manufacturers, network operators, software developers, regulatory bodies, content owners and others committed to designing global standards for the delivery of digital television and data services. DVB fosters market driven solutions that meet the needs and economic circumstances of broadcast industry stakeholders and consumers. DVB standards cover all aspects of digital television from transmission through interfacing, conditional access and interactivity for digital video, audio and data. The consortium came together in 1993 to provide global standardisation, interoperability and future proof specifications.

National transposition dates	
Date of adoption of this EN:	18 April 2011
Date of latest announcement of this EN (doa):	31 July 2011
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	31 January 2012
Date of withdrawal of any conflicting National Standard (dow):	31 January 2012

# 1 Scope

The present document describes a second generation baseline transmission system for digital television broadcasting via Hybrid Fibre Coax (HFC) cable networks and Master Antenna Television (MATV) installations. It specifies the channel coding, modulation and lower layer signalling protocol system intended for the provision of digital television services and generic data streams.

The scope is as follows:

- it gives a general description of the Baseline System for digital cable TV;
- it specifies the digital signal processing in order to establish compatibility between pieces of equipment developed by different manufacturers. This is achieved by describing in detail the signal processing at the transmitting side, while the processing at the receiving side is left open to individual implementations. However, for the purpose of securing interoperability it is necessary in this text to refer to certain implementation aspects of the receiving end.

DVB-C [i.4] was introduced as a European Norm in 1994. It specifies single carrier QAM modulation and Reed-Solomon channel coding and is used today by many cable operators worldwide for television and data broadcasting as well as for forward channel transmission of the Data Over Cable System defined in [i.7].

Since 1994 enhanced digital transmission technologies have evolved somewhat:

- New channel coding schemes, combined with higher order modulation, promise more powerful alternatives to the DVB-C coding and modulation schemes. The result is a capacity gain in the order of 30 % at a given cable channel bandwidth and CATV network performance.
- Variable Coding and Modulation (VCM) may be applied to provide different levels of error protection to different services (e.g. SDTV and HDTV, audio, multimedia).
- In the case of interactive and point-to-point applications, the VCM functionality may be combined with the use of return channels, to achieve Adaptive Coding and Modulation (ACM). This technique provides more exact channel protection and dynamic link adaptation to propagation conditions, targeting each individual receiving terminal.
- DVB-C is strictly focused on a unique data format, the MPEG Transport Stream (ISO/IEC 13818-1 [i.1] or a reference to it). Extended flexibility to cope with other input data formats (such as multiple Transport Streams, or generic data formats) is now possible without significant complexity increase.

The present document defines a "second generation" modulation and channel coding system (denoted the "C2 System" or "DVB-C2" for the purposes of the present document) to make use of the improvements listed above. DVB-C2 is a single, very flexible standard, covering a variety of applications by cable, as described below. It is characterized by:

- a flexible input stream adapter, suitable for operation with single and multiple input streams of various formats (packetized or continuous);
- a powerful FEC system based on LDPC (Low-Density Parity Check) codes concatenated with BCH (Bose Chaudhuri Hocquenghem) codes, allowing Quasi Error Free operation close to the Shannon limit, depending on the transmission mode (AWGN channel, modulation constrained Shannon limit);
- a wide range of code rates (from 2/3 up to 9/10); 5 constellations, ranging in spectrum efficiency from 1 to 10,8 bit/s/Hz, optimized for operation in cable networks;
- Adaptive Coding and Modulation (ACM) functionality, optimizing channel coding and modulation on a frame-by-frame basis.

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## 2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

### 2.1 Normative references

The following referenced documents are necessary for the application of the present document.

- [1] ETSI TS 101 162: "Digital Video Broadcasting (DVB); Allocation of Service Information (SI) and Data Broadcasting Codes for Digital Video Broadcasting (DVB) systems".

### 2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- [i.1] ISO/IEC 13818-1: "Information technology - Generic coding of moving pictures and associated audio information: Systems".
- [i.2] ETSI TS 102 606: "Digital Video Broadcasting (DVB); Generic Stream Encapsulation (GSE) Protocol".
- [i.3] ETSI EN 302 307: "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2)".
- [i.4] ETSI EN 300 468: "Digital Video Broadcasting (DVB); Specification for Service Information (SI) in DVB systems".
- [i.5] ETSI EN 300 429: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".
- [i.6] ETSI EN 302 755: "Digital Video Broadcasting (DVB); Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)".
- [i.7] CENELEC EN 50083-2:2006: "Cable networks for television signals, sound signals and interactive services - Part 2: Electromagnetic compatibility for equipment".
- [i.8] ETSI EN 300 421: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services".



## 3 Definitions, symbols and abbreviations

### 3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

**⊕:** Exclusive OR / modulo-2 addition operation

**0xkk:** digits 'kk' should be interpreted as a hexadecimal number

**active cell:** OFDM Cell carrying a constellation point for L1 signalling or a PLP

**auxiliary data:** sequence of cells carrying data of as yet undefined modulation and coding, which may be used for stuffing Data Slices or stuffing Data Slice Packets

**BBFrame:** signal format of an input signal after mode and stream adaptation

**BBHeader:** header in front of a baseband data field

NOTE: See clause 5.1.

**BUFS:** maximum size of the requested receiver buffer to compensate delay variations

**BUFSTAT:** actual status of the receiver buffer

**C2 frame:** fixed physical layer TDM frame that is further divided into variable size Data Slices

NOTE: C2 Frame starts with one or more Preamble Symbol.

**C2 system:** complete transmitted DVB-C2 signal, as described in the L1-part2 block of the related Preamble

**common PLP:** special PLP, which contains data shared by multiple PLPs (Transport Stream)

**data cell:** OFDM Cell which is not a pilot or tone reservation cell

**data PLP:** PLP carrying payload data

**data slice:** group of OFDM Cells carrying one or multiple PLPs in a certain frequency sub-band

NOTE: This set consists of OFDM Cells within a fixed range of consecutive cell addresses within each Data Symbol and spans over the complete C2 Frame, except the Preamble Symbols.

**data slice packet:** XFECFrame including the related FECFrame Header

**data symbol:** OFDM Symbol in a C2 Frame which is not a Preamble Symbol

**div:** integer division operator, defined as:

$$x \text{ div } y = \left\lfloor \frac{x}{y} \right\rfloor$$

**dummy cell:** OFDM Cell carrying a pseudo-random value used to fill the remaining capacity not used for L1 signalling, PLPs or Auxiliary Data

**elementary period:** time period which depends on the channel raster and is used to define the other time periods in the C2 System

**FECFrame:** set of  $N_{\text{LDPC}}$  (16 200 or 64 800) bits of one LDPC encoding operation

NOTE: In case of Data Slices carrying a single PLP and constant modulation and encoding is applied, FECFrame Header information may be carried in Layer1 part2 and the Data Slice Packet is identical with the XFECFrame.

**FFT size:** nominal FFT size for a DVB-C2 receiver is 4K

NOTE: Further details are discussed in clause 10.1.

**for i=0..xxx-1:** when used with the signalling loops, this means that the corresponding signalling loop is repeated as many times as there are elements of the loop

NOTE: If there are no elements, the whole loop is omitted.

**Im(x):** Imaginary part of x

**Layer 1 (L1):** name of the first layer of the DVB-C2 signalling scheme (signalling of physical layer parameters)

**L1 block:** set of L1-part2 COFDM Cells, cyclically repeated in the frequency domain

NOTE: L1 Blocks are transmitted in the Preamble.

**L1-part1:** signalling carried in the header of the Data Slice Packets carrying modulation and coding parameters of the related XFECFrame

NOTE: L1-part1 parameters may change per XFECFrame.

**L1-part2:** Layer 1 Signalling cyclically transmitted in the preamble carrying more detailed L1 information about the C2 System, Data Slices, Notches and the PLPs

NOTE: L1-part2 parameters may change per C2 Frame.

**Layer 2 (L2):** name of the second layer of the DVB-C2 signalling scheme (signalling of transport layer parameters)

**mod:** modulo operator, defined as:

$$x \bmod y = x - y \left\lfloor \frac{x}{y} \right\rfloor$$

**mode adapter:** input signal processing block, delivering BBFrames at its output

**nn<sub>D</sub>:** digits 'nn' should be interpreted as a decimal number

**notch:** set of adjacent OFDM Cells within each OFDM Symbol without transmitted energy

**null packet:** MPEG Packet with the Packet\_ID 0x1FFF, carrying no payload data and intended for padding

**OFDM cell:** modulation value for one OFDM carrier during one OFDM Symbol, e.g. a single constellation point

**OFDM symbol:** waveform Ts in duration comprising all the active carriers modulated with their corresponding modulation values and including the guard interval

**Physical Layer Pipe (PLP):** logical channel carried within one or multiple Data Slice(s)

NOTE 1: All signal components within a PLP share the same transmission parameters such as robustness, latency.

NOTE 2: A PLP may carry one or multiple services. In case of PLP Bundling a PLP may be carried in several Data Slices. Transmission parameters may change each XFECFrame.

**PLP bundling:** transmission of one PLP via multiple Data Slices

**PLP\_ID:** this 8-bit field identifies uniquely a PLP within a C2 transmission signal

**preamble header:** fixed size signalling transmitted in the first part of the Preamble, carrying the length and Interleaving parameters of Layer 1 part 2 data

**preamble symbol:** one or multiple OFDM Symbols, transmitted at the beginning of each C2 Frame, carrying Layer 1 part 2 signalling data

**Re(x):** Real part of x

**reserved for future use:** value of any field indicated as "reserved for future use" shall be set to "0" unless otherwise defined

**START\_FREQUENCY:** index of lowest used OFDM subcarrier of a C2 System. The value of START\_FREQUENCY shall be a multiple of  $D_X$

**$x^*$ :** Complex conjugate of  $x$

**XFECFrame:** FECFrame mapped onto QAM constellations:

- $\lfloor x \rfloor$ : round towards minus infinity: the most positive integer less than or equal to  $x$ .
- $\lceil x \rceil$ : round towards plus infinity: the most negative integer greater than or equal to  $x$ .

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

$\Delta$	Absolute guard interval duration
$A$	LDPC codeword of size $N_{\text{ldpc}}$
$\lambda_i$	LDPC codeword bits
$\lambda_i^{RM}$	32 output bits of Reed-Muller encoder
$\lambda_i^{RM}$	Bit number of index $i$ of 32 bit long output bits of Reed-Muller encoder
$\eta_{MOD}, \eta_{MOD}(i)$	Number of transmitted bits per constellation symbol (for PLP $i$ )
$\pi_p$	Permutation operator defining parity bit groups to be punctured for L1 signalling
$\pi_s$	Permutation operator defining bit-groups to be padded for L1 signalling
$A_{m,l}$	Output vector of the frequency interleaver of OFDM Symbol $l$ and C2 Frame $m$
$A_{CP}$	Amplitude of the continual pilot cells
$A_{SP}$	Amplitude of the scattered pilot cells
$a_{m,l,q}$	Frequency-Interleaved cell value, cell index $q$ of symbol $l$ of C2 Frame $m$
$B(n)$	Location of the first Data Cell of symbol $l$ allocated to Data Slice $n$ in the frequency interleaver
$b$	16 bit long FECFrame signalling data vector
$b_{e,d_i}$	Output from the demultiplexer, depending on the demultiplexed bit sub-stream number $e$ and the input bit number $d_i$ of the bit interleaver demultiplexer
$b_i$	Bit number of index $i$ of 16 bit long FECFrame signalling data vector
$C/N$	Carrier-to-noise power ratio
$C/N+I$	Carrier-to-(Noise+Interference) ratio
$C_i$	Column of index $i$ of time interleaver
$c_i$	Column of index $i$ of bit interleaver
$c(x)$	Equivalent BCH codeword polynomial
$c_{m,l,k}$	Cell value for carrier $k$ of symbol $l$ of C2 Frame $m$
$DFL$	Data field length
$D_P$	Difference in carrier index between adjacent preamble-pilot-bearing carriers
$D_X$	Difference in carrier index between adjacent scattered-pilot-bearing carriers
$D_y$	Difference in symbol number between successive scattered pilots on a given carrier
$d(x)$	Remainder of dividing message polynomial by the generator polynomial $g(x)$ during BCH encoding
$d_i$	Input bit number $d_i$ of the bit interleaver demultiplexer
$d_o$	Bit number of a given stream at the output of the demultiplexer of the bit interleaver
$e$	Demultiplexed bit sub stream number ( $0 \leq e < N_{\text{substreams}}$ ), depending on input bit number $d_i$ of the bit interleaver demultiplexer
$f_q$	Constellation point normalized to mean energy of 1
$G$	Reed-Muller encoder matrix
$g(x)$	BCH generator polynomial

$g_1(x), g_2(x), \dots, g_{12}(x)$	Polynomials to obtain BCH code generator polynomial
$g_q$	Complex cell of index $q$ of a Data Slice Packet
$H(q)$	Frequency interleaver permutation function, element $q$
$I$	Output codeword of BCH encoder
$i_j$	BCH codeword bits which form the LDPC information bits
$j$	$\sqrt{-1}$
$K_{bch}$	Number of bits of BCH uncoded Block
$K_i$	L1 signalling part 2 parameter selected as $N_{L1part2}(K_i) \leq N_{L1part2\_Cells} \times \eta_{MOD}$
$K_{ldpc}$	Number of bits of LDPC uncoded Block
$K_{L1\_PADDING}$	Length of L1_PADDING field
$K_{L1part2}$	Length of L1-part2 signalling field including the padding field
$K_{L1part2\_ex\_pad}$	Number of information bits in L1-part2 signalling excluding the padding field
$K_{N,min}$	Lowest frequency carrier index of a frequency Notch
$K_{N,max}$	Highest frequency carrier index of a frequency Notch
$K_{sig}$	Number of signalling bits per FEC block for L1 signalling part 2
$K_{min}$	Lowest frequency carrier index of a C2 signal, shall be identical to the START_FREQUENCY and shall be multiple of $D_X$
$K_{max}$	Highest frequency carrier index of a C2 signal, shall be multiple of $D_X$
$K_{total}$	Number of OFDM carriers per OFDM symbol
$k$	Absolute OFDM carrier index
$L_{data}$	Number of data OFDM Symbols per C2 Frame (excluding Preamble)
$L_F$	Number of OFDM Symbols per C2 Frame including excluding preamble
$L_P$	Number of preamble OFDM Symbols within the C2 Frame
$l$	Index of OFDM Symbol within the C2 Frame (excluding preamble)
$l_P$	Index of preamble OFDM Symbol in C2 Frame
$m$	C2 Frame number
$m(x)$	Message polynomial within BCH encoding
$m_i$	Input bit of index $i$ from uncoded bit vector $M$ before BCH encoder
$M$	Uncoded bit vector before BCH encoder
$M_{max}$	Maximum Sequence length for the frequency interleaver
$N_{bch}$	Number of bits of BCH coded Block
$N_{bch\_parity}$	Number of BCH parity bits
$N_c$	Number of columns of bit or time interleaver
$N_{data}$	Number of Data Cells in a Data Slice in frequency interleaver
$N_{DP}$	Number of complex cells per Data Slice Packet
$N_{group}$	Number of bit-groups for BCH shortening
$N_{L1part2}$	Length of punctured and shortened LDPC codeword for L1-part2 signalling
$N_{L1part2\_Cells}$	Number of available cells for L1 signalling part 2 in one OFDM Symbol
$N_{L1part2\_FEC\_Block}$	Number of LDPC blocks for the L1 signalling part 2
$N_{L1part2\_max\_per\_Symbol}$	Maximum number of L1 information bits for transmitting the encoded L1 signalling part 2 through one OFDM Symbol
$N_{L1\_TI\_Depth}$	Time interleaving depth for L1 signalling part 2
$N_{L1part2\_temp}$	Intermediate value used in L1 puncturing calculation
$N_{ldpc}$	Number of bits of LDPC coded Block
$N_{MOD\_per\_Block}$	Number of modulated cells per FEC block for the L1-part2 signalling
$N_{MOD\_Total}$	Total number of modulated cells for the L1-part2 signalling
$N_{pad}$	Number of BCH bit-groups in which all bits will be padded for L1-part2 signalling
$N_{punc}$	Number of LDPC parity bits to be punctured
$N_{punc\_groups}$	Number of parity groups in which all parity bits are punctured for L1 signalling
$N_{punc\_temp}$	Intermediate value used in L1 puncturing calculation
$N_r$	Number of bits in Frequency Interleaver sequence
$N_r$	Number of rows of bit or time interleaver

$N_{RT}$	Number of reserved carriers
$N_{substreams}$	Number of substreams produced by the bit-to-sub-stream demultiplexer
$n$	Data slice number
$P_k(f)$	Power spectral density
$p_i$	LDPC parity bits
$Q_{ldpc}$	Code-rate dependent LDPC constant
$q$	Data Cell index within the OFDM Symbol prior to frequency interleaving and pilot insertion
$R_{eff\_16K\_LDPC\_1\_2}$	Effective code rate of 16K LDPC with nominal rate $\frac{1}{2}$
$R_{eff\_L1part2}$	Effective code rate of L1-part2 signalling
$R_i$	Row of index $i$ of time interleaver
$R_i$	Value of element $i$ of the frequency interleaver sequence following bit permutations
$R'_i$	Value of element $i$ of the frequency interleaver sequence prior to bit permutations
$r_i$	Row of index $i$ of bit interleaver
$r_k$	DBPSK modulated pilot reference sequence
$S_0$	List of reserved carriers
$T$	Elementary period
$T_{Ci}$	Column-twist value for column $C$ of time interleaver
$T_{CH}$	Component set of carrier indices for reserved carriers
$T_F$	Duration of one C2 Frame
$T_P$	Time interleaving period
$T_S$	Total OFDM Symbol duration
$T_U$	Useful OFDM Symbol duration
$t$	BCH error correction capability
$t_c$	Column-twist value for column $c$ of bit interleaver
$U$	Parity interleaver output
$UPL$	User Packet Length
$u_i$	Parity-interleaver output bits
$u^{RM}$	32 bit output vector of the cyclic delay block in the FECFrame header encoding
$u_{(i+2)mod32}^{RM}$	Output of the cyclic delay block for input bit $i$ in the FECFrame header encoding
$V$	Column-twist interleaver output
$v_i$	Column-twist interleaver output bits
$v_{m,l,i}$	Output vector of frequency interleaver, starting at carrier index $i$ (= Data slice start carrier) of the current OFDM Symbol $l$ and C2 Frame $m$
$v^{RM}$	Scrambled output sequence in the lower branch of the FECFrame header encoder
$v_i^{RM}$	Bit $i$ of scrambled output sequence in the lower branch of the FECFrame header encoder
$w_i$	Bit $i$ of the data scrambling sequence
$w^{RM}$	32 bit scrambling sequence in the lower branch of the FECFrame header encoder
$w_i^{RM}$	Bit $i$ of scrambling sequence in the lower branch of the FECFrame header encoder
$w^P$	Pilot synchronization sequence, build out of $w_i$ and $w'$
$w_k^P$	Bit of index $k$ of pilot synchronization sequence
$w'$	L1 block specific pilot synchronization sequence
$w'_i$	Bit of index $k$ of L1 block specific pilot synchronization sequence
$X_j$	The set of bits in group $j$ of BCH information bits for L1 shortening
$X_{m,l}$	Frequency interleaver input Data Cells of the OFDM Symbol $l$ and the C2 Frame $m$
$x$	Address of the parity bit accumulator according to $i_{360}$ in LDPC encoder
$y_{i,q}$	Bit $i$ of cell word $q$ from the bit-to-cell-word demultiplexer
$z_q$	Constellation point prior to normalization

The symbols  $s$ ,  $t$ ,  $i$ ,  $j$ ,  $k$  are also used as dummy variables and indices within the context of some clauses or equations.

In general, parameters which have a fixed value for a particular PLP for one processing block (e.g. C2 Frame, Interleaving Frame, TI-block) are denoted by an upper case letter. Simple lower-case letters are used for indices and dummy variables. The individual bits, cells or words processed by the various stages of the system are denoted by lower case letters with one or more subscripts indicating the relevant indices.

### 3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

1024QAM	1024-ary Quadrature Amplitude Modulation
16QAM	16-ary Quadrature Amplitude Modulation
256QAM	256-ary Quadrature Amplitude Modulation
4096QAM	4096-ary Quadrature Amplitude Modulation
64QAM	64-ary Quadrature Amplitude Modulation
ACM	Adaptive Coding and Modulation
AWGN	Additive White Gaussian Noise
BB	BaseBand
BBFrame	BaseBand Frame
BCH	Bose-Chaudhuri-Hocquenghem multiple error correction binary block code
BCHFEC	BCH Forward Error Correction
BICM	Bit Interleaved Coding and Modulation
C/N	Carrier to noise ratio
C/N+I	Carrier to noise and intermodulation power ratio
CATV	Community Antenna Television
CBR	Constant Bit Rate
CCM	Constant Coding and Modulation
CRC	Cyclic Redundancy Check
D	Decimal notation
DBPSK	Differential Binary Phase Shift Keying
DEMUX	DEMultipleXer
DFL	Data Field Length
DNP	Deleted Null Packets
DVB	Digital Video Broadcasting project
DVB-C	DVB System for cable transmission

NOTE: As defined in EN 300 429 [i.5].

DVB-C2          DVB-C2 System

NOTE: As specified in the present document.

DVB-S          DVB System for digital broadcasting via satellites

NOTE: As specified in EN 300 421 [i.8].

DVB-S2          Second Generation DVB System for satellite broadcasting

NOTE: As specified in EN 302 307 [i.3].

DVB-T          DVB System for terrestrial broadcasting

NOTE: As specified in EN 302 755 [i.6].

DVB-T2          Second Generation DVB System for terrestrial broadcasting

NOTE: As specified in EN 302 755 [i.6].

EBU	European Broadcasting Union
EIT	Event Information Table (DVB SI Table)
EMM	Entitlement Management Message
FEC	Forward Error Correction
FFT	Fast Fourier Transformation
FIFO	First In First Out
GCS	Generic Continuous Stream

GF	Galois Field
GFPS	Generic Fixed-length Packetized Stream
GI	Guard Interval
GS	Generic Stream
GSE	Generic Stream Encapsulation
HDTV	High Definition Television
HEM	High Efficiency Mode
HFC	Hybrid Fibre Coax
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
IS	Interactive Services
ISCR	Input Stream Clock Reference
ISI	Input Stream Identifier
ISSY	Input Stream SYNchronizer
ISSYI	Input Stream SYNchronizer Indicator
Kbit	$2^{10} = 1\,024$ bits
LDPC	Low Density Parity Check (codes)
LDPCFEC	LDPC Forward Error Correction
LSB	Least Significant Bit
MATV	Master Antenna Television
Mbit	$2^{20} = 1\,048\,576$ bits
MIS	Multiple Input Stream
MPEG	Moving Pictures Experts Group
MSB	Most Significant Bit

NOTE: In DVB-C2 the MSB is always transmitted first.

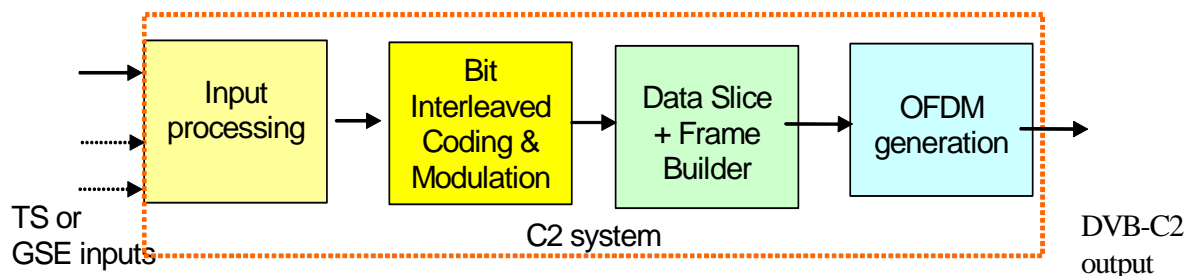
NA	Not Applicable
NM	Normal Mode
NPD	Null Packet Deletion
OFDM	Orthogonal Frequency Division Multiplex
PAPR	Peak to Average Power Ratio
PCR	Presentation Clock Reference
PER	(MPEG TS) Packet Error Rate
PID	Packet IDentifier
PLL	Phase-Locked Loop
PLP	Physical Layer Pipe
PRBS	Pseudo Random Binary Sequence
QAM	Quadrature Amplitude Modulation
QEF	Quasi Error Free
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
SDT	Service Description Table (DVB SI Table)
SDTV	Standard Definition TV
SIS	Single Input Stream
TDM	Time Division Multiplex
TF	Time/Frequency
TI	Time Interleaver
TS	Transport Stream
TSPS	Transport Stream Partial Stream
TSPSC	Transport Stream Partial Stream Common
TSPSS	Transport Stream Partial Stream Synchronized
UP	User Packet
UPL	User Packet Length
VCM	Variable Coding and Modulation
XFECFrame	XFEC Frame

## 4 DVB-C2 System architecture

### 4.1 System overview

The generic C2 System model is represented in figure 1. The system input(s) may be one or more MPEG-2 Transport Stream(s) [i.1] and/or one or more Generic Stream(s) [i.2]. The Input pre-processor, which is not part of the C2 System, may include a service splitter or a demultiplexer for Transport Streams (TS) used to separate the services into the C2 System inputs, which are one or more logical data streams. These are then carried in individual Physical Layer Pipes (PLPs).

The system output is a single signal to be transmitted on a single RF channel.



**Figure 1: High level C2 block diagram**

The input data streams shall be subject to the constraint that, over the duration of one physical-layer frame (C2 Frame), the total input data capacity (in terms of cell throughput, following Null Packet Deletion, if applicable, and after coding and modulation), shall not exceed the C2 available capacity (in terms of Data Cells, constant in time) of the C2 Frame for the current frame parameters. One or more PLPs are arranged in a group of PLPs and one or more of such groups of PLPs form a Data Slice. A C2 System may consist of one or more Data Slices. Each group of PLPs may contain one Common PLP, but a group of PLPs need not contain a Common PLP. When the DVB-C2 signal carries a single PLP there is no Common PLP. It is assumed that the receiver will always be able to receive one Data PLP and its associated Common PLP, if any.

More generally, the group of statistically multiplexed services can use Variable Coding and Modulation (VCM) for different services, provided they generate a constant total output capacity (i.e. in terms of cell rate including FEC and modulation).

When multiple input MPEG-2 TSs are transmitted via a group of PLPs, splitting of input TSs into TSPS streams (carried via the Data PLPs) and a TSPSC stream (carried via the associated Common PLP), as described in annex D, shall be performed immediately before the Input processing block shown in figure 1. This processing shall be considered an integral part of an extended DVB-C2 System.

### 4.2 System architecture

The C2 input processing block diagram is shown in figures 2, which is split into several parts. Figure 2(a) shows the input processing in case of multiple PLPs. Figure 2(a) shows the BICM module and figure 2(c) shows the frame builder module. Figure 2(d) shows the OFDM generation module.



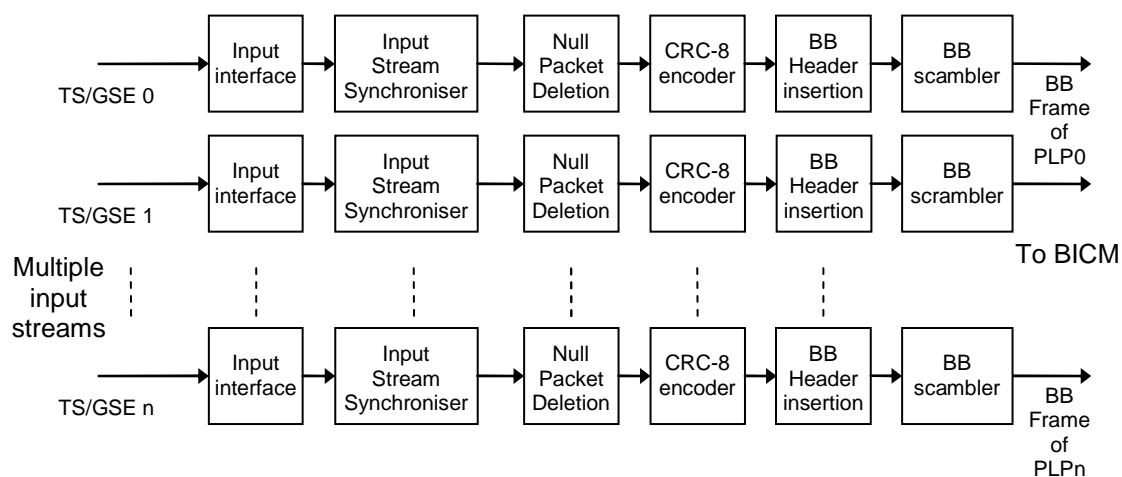


Figure 2(a): Mode adaptation for multiple input streams (PLP)

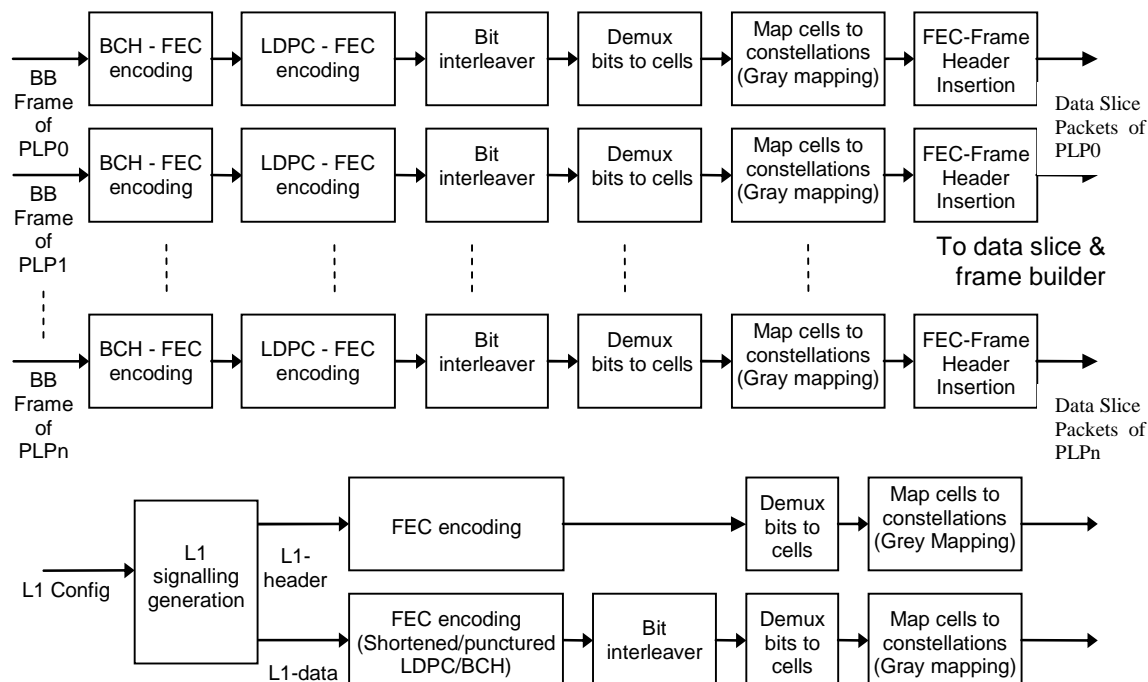
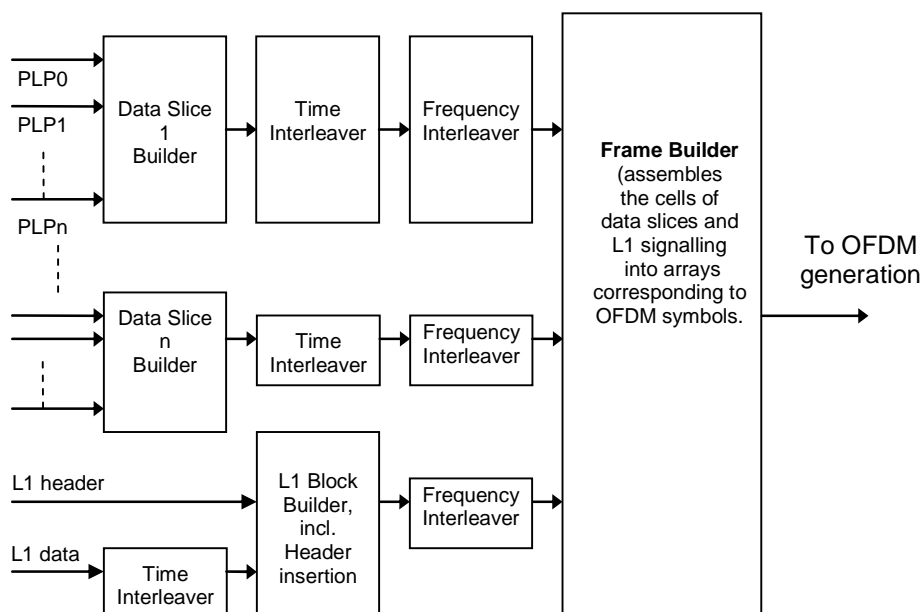
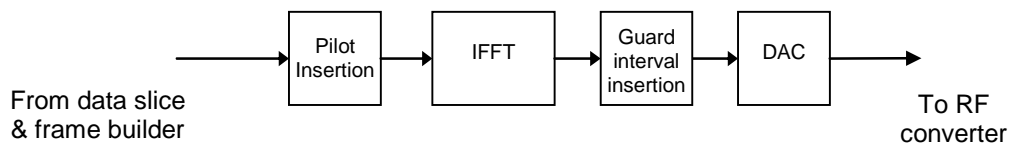


Figure 2(b): Bit Interleaved Coding and Modulation (BICM)



**Figure 2(c): Data Slice + Frame builder**



**Figure 2(d): OFDM generation**

Figure 2(e) combines the functions given in figures 2(a) to 2(d) in one simplified overall DVB-C2 block diagram.

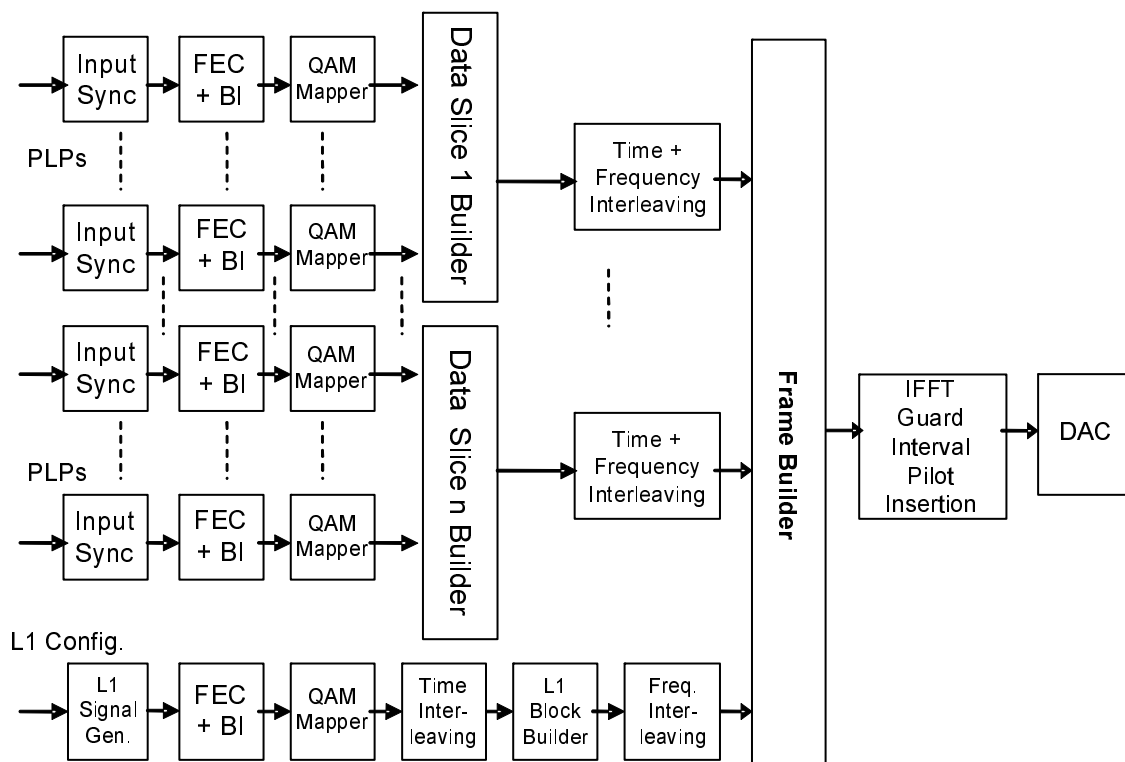


Figure 2(e): DVB-C2 modulator block diagram

## 4.3 Target performance

If the received signal is above the  $C/N+I$  threshold, the Forward Error Correction (FEC) technique adopted in the C2 System is designed to provide a "Quasi Error Free" (QEF) quality target. The definition of QEF adopted for DVB-C2 is "less than one uncorrected error-event per transmission hour at the level of a 5 Mbit/s single TV service decoder", corresponding to a Transport Stream Packet Error Rate of approximately  $PER < 10^{-7}$  measured at the input of the demultiplexer unit at the receiving end.

# 5 Input processing

## 5.1 Mode adaptation

The input to the C2 System shall consist of one or more logical data streams. One logical data stream is carried by one Physical Layer Pipe (PLP). The mode adaptation modules, which operate separately on the contents of each PLP, slice the input data stream into data fields which, after stream adaptation, will form baseband frames (BBFrame). The mode adaptation module comprises the input interface, followed by three optional sub-systems (the input stream synchronizer, the Null Packet deletion unit and the CRC-8 encoder) and then finishes by slicing the incoming data stream into data fields and inserting the baseband header (BBHeader) at the start of each data field. Each of these sub-systems is described in the following clauses.

Each input PLP may have one of the formats specified in clause 5.1.1. The mode adaptation module can process input data in one of two modes, normal mode (NM) or high efficiency mode (HEM). These modes are described in clauses 5.1.6 and 5.1.7 respectively. NM is in line with the Mode Adaptation in [i.3], whereas in HEM, further stream specific optimizations may be performed to reduce signalling overhead. The BBHeader (see clause 5.1.6) signals the input stream type and the processing mode.

### 5.1.1 Input Formats

The input signals in terms of either single or multiple streams (one connected to each Mode Adaptation Module) (see figure 1) shall be supplied to the Mode Adaptation Module(s). In the case of a Transport Stream (TS), the packet rate will be a constant value, although only a proportion of the packets may correspond to service data and the remainder may be Null Packets.

Each input stream (PLP) of the C2 System shall be associated with a modulation and FEC protection mode which is statically configurable.

Each input PLP may take one of the following formats:

- Transport Stream (TS).
- Generic Encapsulated Stream (GSE) [i.2].
- Generic Continuous Stream (GCS) (a variable length packet stream where the modulator is not aware of the packet boundaries).
- Generic Fixed-length Packetized Stream (GFPS); this form is retained for compatibility with DVB-S2, but it is expected that GSE would now be used instead.

A Transport Stream shall be characterized by User Packets (UP) of fixed length  $O\text{-UPL} = 188 \times 8$  bits (one MPEG TS packet), the first byte being a SYNC byte ( $47_{\text{HEX}}$ ) and shall be signalled in the BBHeader TS/GS field, see clause 5.1.6.

A GSE stream shall be characterized by variable length packets or constant length packets, as signalled within GSE packet headers, and shall be signalled in the BBHeader by TS/GS field, see clause 5.1.6.

A GCS shall be characterized by a continuous bit-stream and shall be signalled in the BBHeader by TS/GS field and  $UPL = 0_D$ , see clause 5.1.6. A variable length packet stream where the modulator is not aware of the packet boundaries, or a constant length packet stream exceeding 64 kbit, shall be treated as a GCS, and shall be signalled in the BBHeader by TS/GS field as a GCS and  $UPL = 0_D$ , see clause 5.1.6.

A GFPS shall be a stream of constant-length User Packets (UP), with length  $O\text{-UPL}$  bits (maximum  $O\text{-UPL}$  value 64 K), and shall be signalled in the BBHeader TS/GS field, see clause 5.1.6.  $O\text{-UPL}$  is the Original User Packet Length.  $UPL$  is the transmitted User Packet Length, as signalled in the BBHeader.

### 5.1.2 Input Interface

The input interface sub-system shall map the input into internal logical-bit format. The first received bit will be indicated as the Most Significant Bit (MSB). Input interfacing is applied separately for each single Physical Layer Pipe (PLP), see figure 2(a).

The Input Interface shall read a data field, composed of DFL bits (Data Field Length), where:

$$0 \leq \text{DFL} \leq (K_{\text{bch}} - 80)$$

where  $K_{\text{bch}}$  is the number of bits protected by the BCH and LDPC codes (see clause 6.1).

The maximum value of DFL depends on the chosen LDPC code, carrying a protected payload of  $K_{\text{bch}}$  bits. The 10-byte (80 bits) BBHeader is appended to the front of the data field, and is also protected by the BCH and LDPC codes.

The input interface shall either allocate a number of input bits equally to the available data field capacity, thus breaking UPs in subsequent data fields (this operation being called "fragmentation"), or shall allocate an integer number of UPs within the data field (no fragmentation). The available data field capacity is equal to  $K_{\text{bch}} - 80$ . When the value of  $\text{DFL} < K_{\text{bch}} - 80$ , a padding field shall be inserted by the stream adapter (see clause 5.2) to complete the LDPC/BCH code block capacity.

### 5.1.3 Input Stream Synchronization (Optional)

Data processing in the DVB-C2 modulator may produce variable transmission delay on the user information. The Input Stream Synchronizer sub-system shall provide suitable means to guarantee Constant Bit Rate (CBR) and constant end-to-end transmission delay for any input data format. The use of the Input Stream Synchronizer subsystem is optional, except that it shall always be used for PLPs carrying transport streams where the number of FEC blocks per C2 Frame may vary. This process shall follow the specification given in annex C, which is similar to [i.3]. Examples of receiver implementation are given in annex G. This process will also allow synchronization of a single PLP travelling in different Data Slices, since the reference clock and the counter of the input stream synchronizers shall be the same (see annex F).

The ISSY field (Input Stream Synchronization, 2 bytes or 3 bytes) carries the value of a counter clocked at the modulator clock rate ( $1/T$  where  $T$  is defined in clause 10.) and can be used by the receiver to regenerate the correct timing of the regenerated output stream. The ISSY field carriage shall depend on the input stream format and on the Mode, as defined in clauses 5.1.6 and 5.1.7 and figures 4 to 8. In Normal Mode the ISSY Field is appended to UPs for packetized streams. In High Efficiency Mode a single ISSY field is transmitted per BBFrame in the BBHeader, taking advantage that UPs of a BBFrame travel together, and therefore experience the same delay/jitter.

When the ISSY mechanism is not being used, the corresponding fields of the BBHeader, if any, shall be set to '0'.

A full description of the format of the ISSY field is given in annex C.

### 5.1.4 Null Packet Deletion (optional, for TS only, NM and HEM)

Transport Stream rules require that bit rates at the output of the transmitter's multiplexer and at the input of the receiver's demultiplexer are constant in time and the end-to-end delay is also constant. For some Transport Stream input signals, a large percentage of Null Packets may be present in order to accommodate variable bit-rate services in a constant bit-rate TS. In this case, in order to avoid unnecessary transmission overhead, TS Null Packets shall be identified ( $PID = 8191_D$ ) and removed. The process is carried out in a way that the removed Null Packets can be re-inserted in the receiver in the exact place where they were originated, thus guaranteeing a constant bit rate and avoiding the need for time stamp (PCR) updating.

When Null Packet Deletion is used useful packets (i.e. TS packets with  $PID \neq 8191_D$ ), including the optional ISSY appended field shall be transmitted while Null Packets (i.e. TS packets with  $PID = 8191_D$ , including the optional ISSY appended field may be removed (see figure 3).

After transmission of a UP, a counter called DNP (Deleted Null Packets, 1 byte) shall be first reset and then incremented at each deleted Null Packet. When DNP reaches the maximum allowed value  $DNP = 255_D$ , then if the following packet is again a Null Packet this Null Packet is kept as a useful packet and transmitted.

Insertion of the DNP field (1 byte) shall be after each transmitted UP according to clause 5.17 and figure 3.

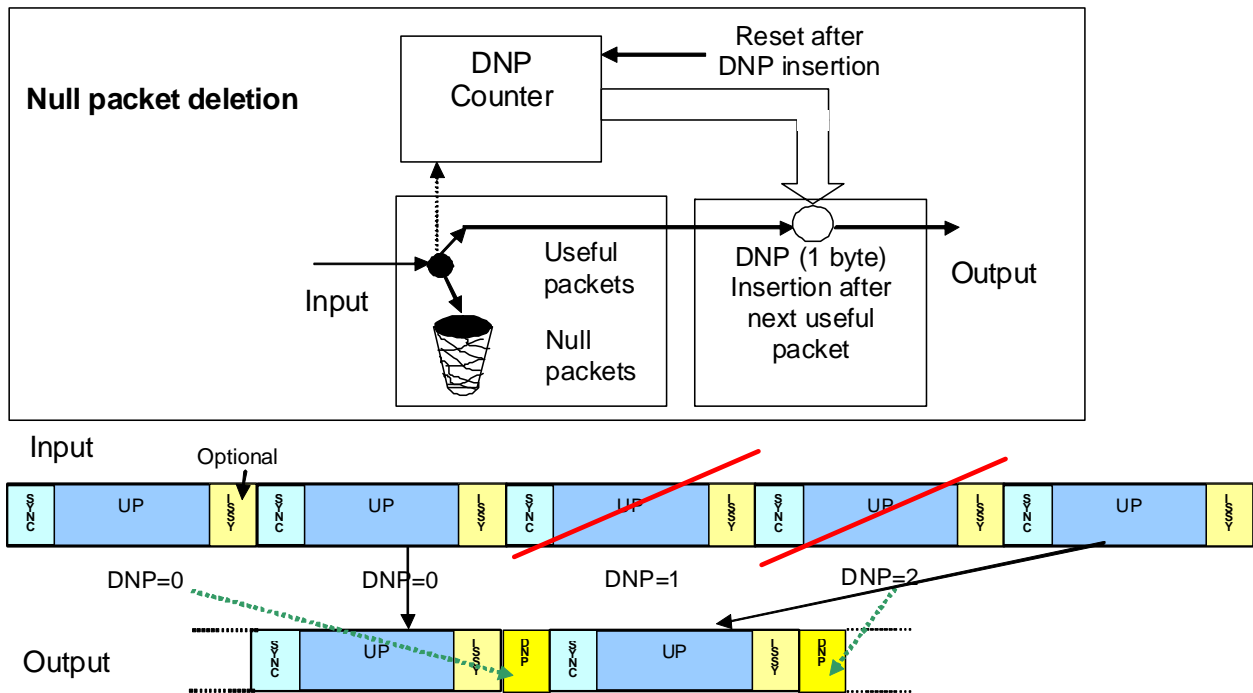


Figure 3: Null Packet deletion scheme

### 5.1.5 CRC-8 encoding (for GFPS and TS, NM only)

CRC-8 is applied for error detection at UP level (Normal Mode and packetized streams only). When applicable (see clause 5.1.7), the UPL minus 8 bits of the UP (after SYNC byte removal, when applicable) shall be processed by the systematic 8-bit CRC-8 encoder defined in annex E. The computed CRC-8 shall be appended after the UP according to clause 5.1.7.

### 5.1.6 Baseband Header (BBHeader) insertion

A fixed length BBHeader of 10 bytes shall be inserted in front of the baseband data field in order to describe the format of the data field. The BBHeader shall take one of two forms as shown in figure 4(a) for Normal Mode (NM) and in figure 4(b) for High Efficiency Mode (HEM). The current mode (NM or HEM) may be detected by the MODE field (EXORed with the CRC-8 field).

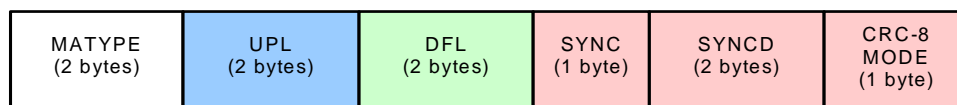


Figure 4(a): BBHeader format (NM)

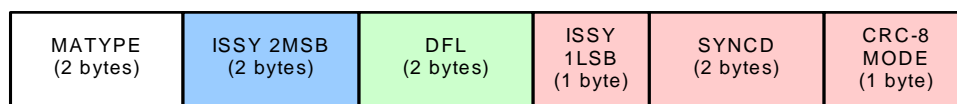


Figure 4(b): BBHeader format (HEM)

**MATYPE (2 bytes):** describes the input stream format and the type of Mode Adaptation as explained in table 1.

The use of the bits of the MATYPE field is described below.

**First byte (MATYPE-1):**

- TS/GS field (2 bits), Input Stream Format: Generic Packetized Stream (GFPS); Transport Stream; Generic Continuous Stream (GCS); Generic Encapsulated Stream (GSE).
- SIS/MIS field (1 bit): Single or Multiple Input Streams (referred to the global signal, not to each PLP).
- CCM/ACM field (1 bit): Constant Coding and Modulation or Variable/Adaptive Coding and Modulation.
- ISSYI (1 bit), (Input Stream Synchronization Indicator): If ISSYI = 1 = active, the ISSY field shall be computed (see annex C) and inserted according to clause 5.1.7.
- NPD (1 bit): Null Packet deletion active/not active. If NPD active, then DNP shall be computed and appended after UPs.
- EXT (2 bits), media specific (for C2, EXT=0: reserved for future use).

**Table 1: MATYPE-1 field mapping**

TS/GS (2 bits)	SIS/MIS (1 bit)	CCM/ACM (1 bit)	ISSYI (1 bit)	NPD (1 bit)	EXT (2 bits)
00 = GFPS 11 = TS 01 = GCS 10 = GSE	1 = single 0 = multiple	1 = CCM 0 = ACM	1 = active 0 = not-active	1 = active 0 = not-active	Reserved for future use (see note 1)
NOTE 1: For C2, EXT=reserved for future use and for S2, EXT=RO =transmission roll-off.					
NOTE 2: For compatibility with DVB-S2 [i.3], when GSE is used with normal mode, it shall be treated as a Continuous Stream and indicated by TS/GS = 01.					

**Second byte (MATYPE-2):**

- If SIS/MIS = Multiple Input Stream, then second byte = Input Stream Identifier (ISI); else second byte = '0' (reserved for future use).

NOTE: The term ISI is retained here for compatibility with DVB-S2 [i.3], but has the same meaning as the term PLP\_ID which is used throughout the present document.

The use of the remaining fields of the BBHeader is described in table 2.

**Table 2: Description of the fields of the BBHeader**

Field	Size (Bytes)	Description
MATYPE	2	As described above.
UPL	2	User Packet Length in bits, in the range [0,65535].
DFL	2	Data Field Length in bits, in the range [0,58112].
SYNC	1	A copy of the User Packet SYNC byte. In the case of GCS, SYNC=0x00-0xB8 is reserved for transport layer protocol signalling and shall be set according to [1], SYNC=0xB9-0xFF user private.
SYNCD	2	The distance in bits from the beginning of the DATA FIELD to the beginning of the first transmitted UP which starts in the data field. SYNCD=0 <sub>D</sub> means that the first UP is aligned to the beginning of the Data Field. SYNCD = 65535 <sub>D</sub> means that no UP starts in the DATA FIELD; for GCS, SYNCD is reserved for future use and shall be set to 0 <sub>D</sub> unless otherwise defined.
CRC-8 MODE	1	The XOR of the <b>CRC-8</b> (1-byte) field with the <b>MODE</b> field (1-byte). <b>CRC-8</b> is the error detection code applied to the first 9 bytes of the BBHeader (see annex E). <b>MODE</b> (8 bits) shall be: <ul style="list-style-type: none"> <li>• 0<sub>D</sub> Normal Mode.</li> <li>• 1<sub>D</sub> High Efficiency Mode.</li> <li>• Other values: reserved for future use.</li> </ul>

### 5.1.7 Mode adaptation sub-system output stream formats

This clause describes the mode adaptation processing and fragmentation for the various modes and input stream formats, as well as illustrating the output stream format.

#### Normal Mode, GFPS and TS

See clause 5.1.6 for BBHeader signalling.

For Transport Stream, O-UPL=188x8 bits, and the first byte shall be a SYNC byte (47<sub>HEX</sub>). UPL (the transmitted User Packet Length) shall initially be set equal to O-UPL.

The mode adaptation unit shall perform the following sequence of operations (see figure 5):

- Optional input stream synchronization (see clause 5.1.3); UPL increased by 16<sub>D</sub> or 24<sub>D</sub> bits according to ISSY field length; ISSY field appended after each UP. For TS, either the short or long format of ISSY may be used; for GFPS, only the short format may be used.
- If a SYNC byte is the first byte of the UP, it shall be removed, and stored in the SYNC field of the BBHeader, and UPL shall be decreased by 8<sub>D</sub>. Otherwise SYNC in the BBHeader shall be set to 0 and UPL shall remain unmodified.
- For TS only, optional Null Packet Deletion (see clause 5.1.4); DNP computation and storage after the next transmitted UP; UPL increased by 8<sub>D</sub>.
- CRC-8 computation at UP level (see clause 5.1.5); CRC-8 storage after the UP; UPL increased by 8<sub>D</sub>.
- SYNCDC computation (pointing at the first bit of the first transmitted UP which starts in the Data Field) and storage in BBHeader. The bits of the transmitted UP start with the CRC-8 of the previous UP, if used, followed by the original UP itself, and finish with the ISSY and DNP fields, if used. Hence SYNCDC points to the first bit of the CRC-8 of the previous UP.
- For GFPS: UPL storage in BBHeader.

NOTE 1: O-UPL in the modulator may be derived by static setting (GFPS only) or un-specified automatic signalling.

NOTE 2: Normal Mode is compatible with DVB-S2 BBFrame Mode Adaptation [i.3]. SYNCDC=0 means that the UP is aligned to the start of the Data Field and when present, the CRC-8 (belonging to the last UP of the previous BBFrame) will be replaced in the receiver by the SYNC byte or discarded.

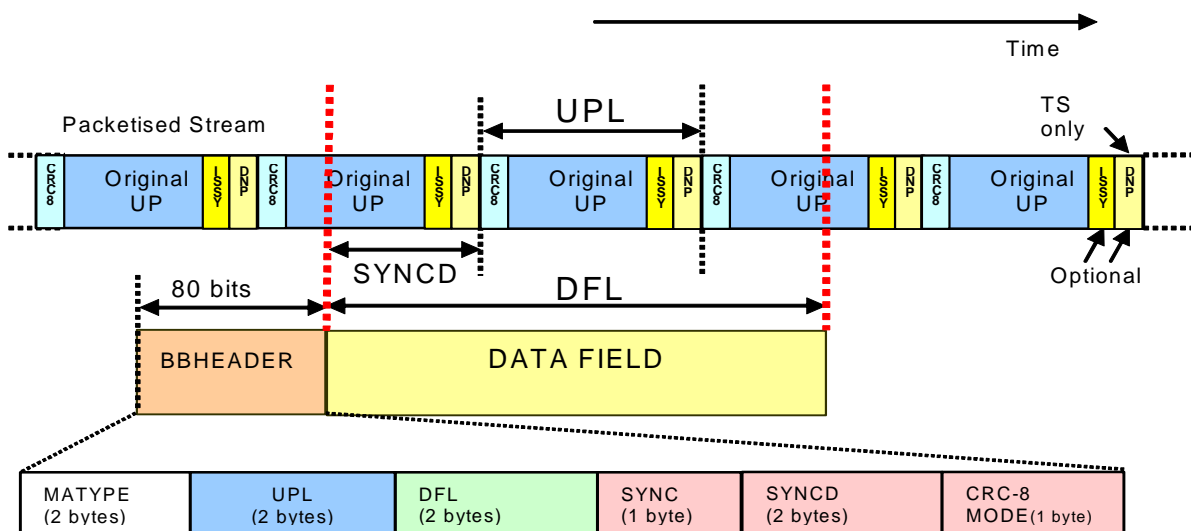


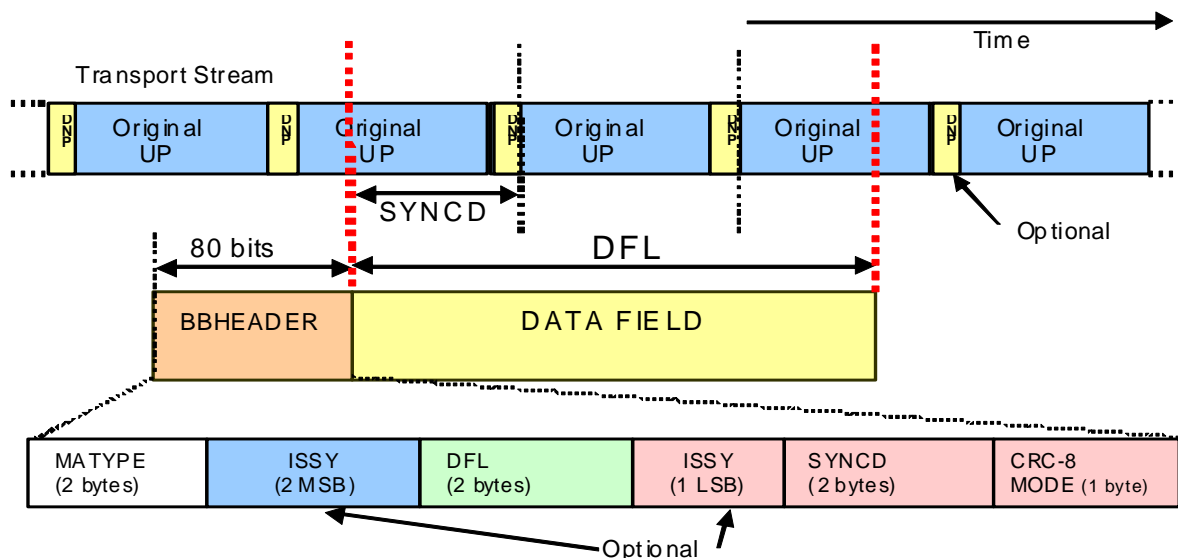
Figure 5: Stream format at the output of the Mode Adapter, Normal Mode, GFPS and TS



### High Efficiency Mode, Transport Streams

For **Transport Streams**, the receiver knows a-priori the SYNC byte configuration and O-UPL=188x8 bits, therefore UPL and SYNC fields in the BBHeader shall be re-used to transmit the ISSY field. The Mode Adaptation unit shall perform the following sequence of operations (see figure 6):

- Optional input stream synchronization (see clause 5.1.3) relevant to the first complete transmitted UP of the data field; ISSY field inserted in the UPL and SYNC fields of the BBHeader.
- Sync-byte removed, but not stored in the SYNC field of the BBHeader.
- Optional Null Packet Deletion (see clause 5.1.4); DNP computation and storage after the next transmitted UP.
- CRC-8 at UP level shall not be computed nor inserted.
- SYNCN computation (pointing at the first bit of the first transmitted UP which starts in the Data Field) and storage in BBHeader. The bits of the transmitted UP start with the original UP itself after removal of the SYNC byte, and finish with the DNP field, if used. Hence SYNCN points to the first bit of the original UP following the SYNC byte.
- UPL not computed nor transmitted in the BBHeader.



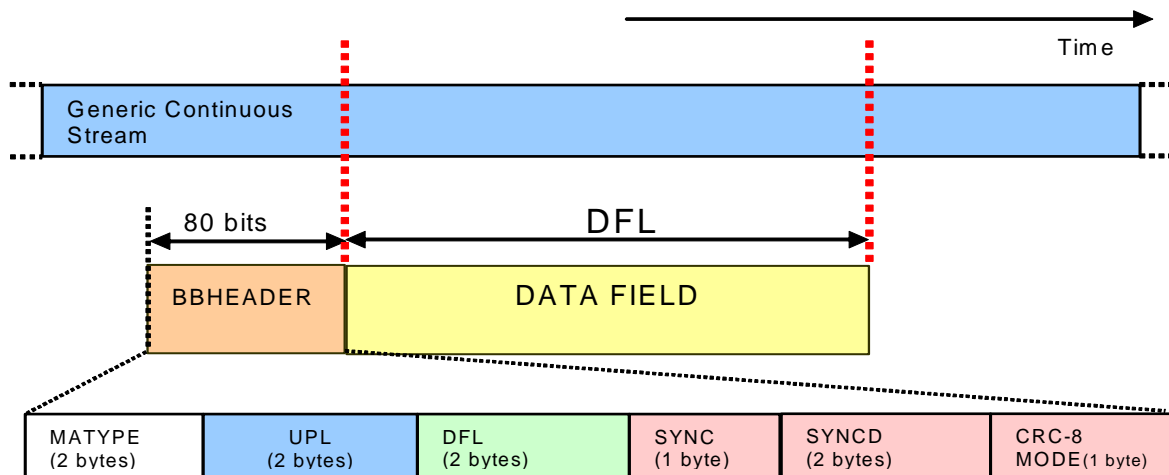
**Figure 6: Stream format at the output of the Mode Adapter, High Efficiency Mode for TS, (no CRC-8 computed for UPs, optional single ISSY inserted in the BBHeader, UPL not transmitted)**

### Normal Mode, GCS and GSE

See clause 5.1.6 for BBHeader signalling. For GCS the input stream shall have no structure, or the structure shall not be known by the modulator. For GSE the first GSE packet shall always be aligned to the data field (no GSE fragmentation allowed).

For both GCS and GSE the Mode Adaptation unit shall perform the following sequence of operations (see figure 6):

- Set UPL=0<sub>D</sub>; set SYNC=0x00-0xB8 is reserved for transport layer protocol signalling and should be set according to Reference [1], SYNC=0xB9-0xFF user private; SYNCN is reserved for future use and shall be set to 0<sub>D</sub> when not otherwise defined.
- Null Packed Deletion (see clause 5.1.4) and CRC-8 computation for Data Field (see clause 5.1.5) shall not be performed.



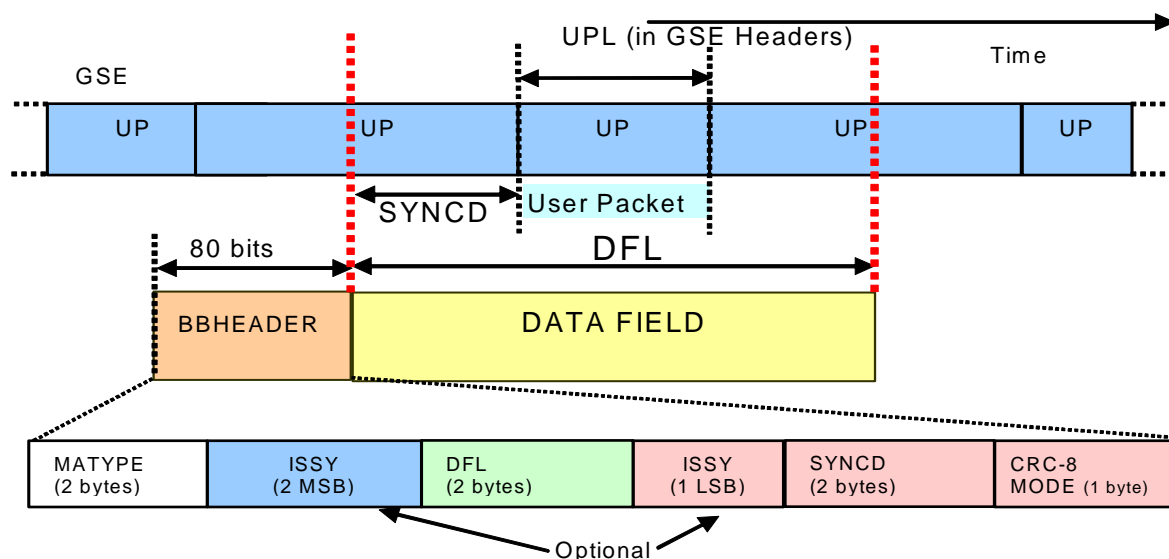
**Figure 7: Stream format at the output of the Mode Adapter, Normal Mode (GSE & GCS)**

### High Efficiency Mode, GSE

GSE variable length or constant length UPs may be transmitted in HEM. If GSE packet fragmentation is used, SYNCDC shall be computed. If the GSE packets are not fragmented, the first packet shall be aligned to the Data Field and thus SYNCDC shall always be set to 0<sub>D</sub>. The receiver may derive the length of the UPs from [i.2], therefore UPL transmission in BBHeader is not performed. As per TS, the optional ISSY field is transmitted in the BBHeader.

The Mode Adaptation unit shall perform the following sequence of operations (see figure 7):

- Optional input stream synchronization (see clause 5.1.3) relevant to the first transmitted UP which starts in the data field; ISSY field inserted in the UPL and SYNC fields of the BBHeader.
- Null Packet Deletion and CRC-8 at UP level shall not be computed nor inserted.
- SYNCDC computation (pointing at the first bit of the first transmitted UP which starts in the Data Field) and storage in BBHeader. The transmitted UP corresponds exactly to the original UP itself. Hence SYNCDC points to the first bit of the original UP.
- UPL not computed nor transmitted.



**Figure 8: Stream format at the output of the Mode Adapter, High Efficiency Mode for GSE, (no CRC-8 computed for UPs, optional single ISSY inserted in the BBHeader, UPL not transmitted)**

### High Efficiency Mode, GFPS and GCS

These modes are not defined (except for the case of TS, as described above).

## 5.2 Stream adaptation

Stream adaptation (see figures 2(a) to 2(c)) provides:

- a) scheduling (see clause 5.2.1);
- b) padding (see clause 5.2.2) to complete a constant length ( $K_{\text{bch}}$  bits) BBFrame;
- c) scrambling (see clause 5.2.3) for energy dispersal.

The input stream to the stream adaptation module shall be a BBHeader followed by a DATA FIELD. The output stream shall be a BBFrame, as shown in figure 9.

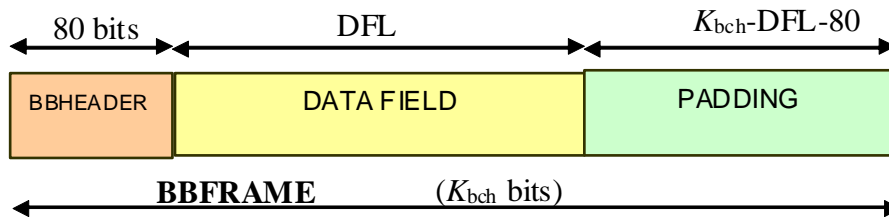


Figure 9: BBFrame format at the output of the stream adapter

### 5.2.1 Scheduler

In order to generate the required L1-part2 signalling information, the scheduler shall decide together with the Data Slice builder which Data Slices of the final C2 System will carry data belonging to which PLPs, as shown in figures 2(a) to 2(c). Although this operation has no effect on the data stream itself at this stage, the scheduler shall already define the composition of the Data Slice and C2 Frame structure, as described in clause 7.

### 5.2.2 Padding

$K_{\text{bch}}$  depends on the FEC rate, as reported in tables 3(a) and 3(b). Padding may be applied in circumstances when the user data available for transmission is not sufficient to completely fill a BBFrame, or when an integer number of UPs has to be allocated in a BBFrame.

$(K_{\text{bch}} - \text{DFL} - 80)$  zero bits shall be appended after the DATA FIELD. The resulting BBFrame shall have a constant length of  $K_{\text{bch}}$  bits.

### 5.2.3 BB scrambling

The complete BBFrame shall be randomized. The randomization sequence shall be synchronous with the BBFrame, starting from the MSB and ending after  $K_{\text{bch}}$  bits.

The scrambling sequence shall be generated by the feed-back shift register of figure 10. The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be:

$$1 + X^{14} + X^{15}$$

Loading of the sequence (100101010000000) into the PRBS register, as indicated in figure 10, shall be initiated at the start of every BBFrame.

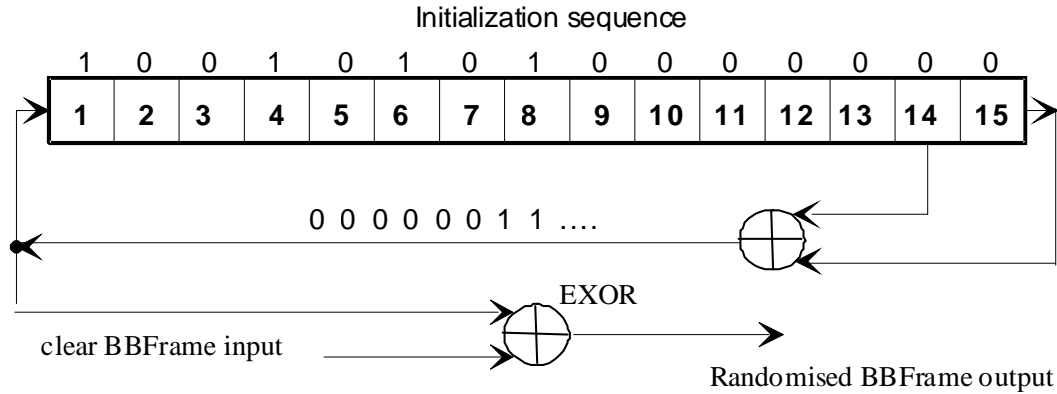


Figure 10: Possible implementation of the PRBS encoder

## 6 Bit-interleaved coding and modulation

### 6.1 FEC encoding

This sub-system shall perform outer coding (BCH), inner coding (LDPC) and bit interleaving. The input stream shall be composed of BBFrames and the output stream of FECFrames.

Each BBFrames ( $K_{\text{bch}}$  bits) shall be processed by the FEC coding sub-system, to generate a FECFrame ( $N_{\text{ldpc}}$  bits). The parity check bits (BCHFEC) of the systematic BCH outer code shall be appended after the BBFrame, and the parity check bits (LDPCFEC) of the inner LDPC encoder shall be appended after the BCHFEC field, as shown in figure 11.

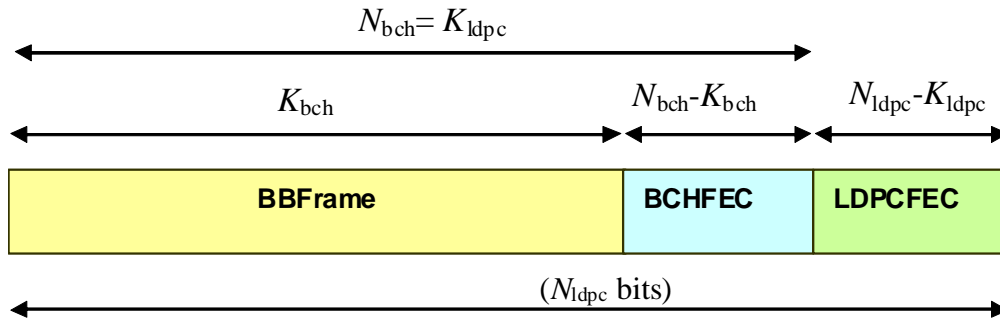


Figure 11: Format of data before bit interleaving  
( $N_{\text{ldpc}} = 64\,800$  bits for normal FECFrame,  $N_{\text{ldpc}} = 16\,200$  bits for short FECFrame)

Table 3(a) defines the FEC coding parameters for the normal FECFrame ( $N_{\text{ldpc}} = 64\,800$  bits) and table 3(b) for the short FECFrame ( $N_{\text{ldpc}} = 16\,200$  bits).

**Table 3(a): Coding parameters (for normal FECFrame  $N_{ldpc} = 64\ 800$ )**

LDPC Code	BCH Uncoded Block $K_{bch}$	BCH coded block $N_{bch}$ LDPC Uncoded Block $K_{ldpc}$	BCH t-error correction	$N_{bch} - K_{bch}$	LDPC Coded Block $N_{ldpc}$
2/3	43 040	43 200	10	160	64 800
3/4	48 408	48 600	12	192	64 800
4/5	51 648	51 840	12	192	64 800
5/6	53 840	54 000	10	160	64 800
9/10	58 192	58 320	8	128	64 800

**Table 3(b): Coding parameters (for short FECFrame  $N_{ldpc} = 16\ 200$ )**

LDPC Code Identifier	BCH Uncoded Block $K_{bch}$	BCH coded block $N_{bch}$ LDPC Uncoded Block $K_{ldpc}$	BCH t-error correction	$N_{bch} - K_{bch}$	Effective LDPC Rate $K_{ldpc}/16\ 200$	LDPC Coded Block $N_{ldpc}$
1/2 (see note)	7 032	7 200	12	168	4/9	16 200
2/3	10 632	10 800	12	168	2/3	16 200
3/4	11 712	11 880	12	168	11/15	16 200
4/5	12 432	12 600	12	168	7/9	16 200
5/6	13 152	13 320	12	168	37/45	16 200
8/9	14 232	14 400	12	168	8/9	16 200

NOTE: This code rate is only used for protection of L1 pre-signalling and not for data.

NOTE: For  $N_{ldpc} = 64\ 800$  and for  $N_{ldpc} = 16\ 200$  the LDPC code rate is given by  $K_{ldpc} / N_{ldpc}$ . In table 3(a) the LDPC code rates for  $N_{ldpc} = 64\ 800$  are given by the values in the 'LDPC Code' column. In table 3(b) the LDPC code rates for  $N_{ldpc} = 16\ 200$  are given by the values in the 'Effective LDPC rate' column, i.e. for  $N_{ldpc} = 16\ 200$  the 'LDPC Code identifier' is *not* equivalent to the LDPC code rate.

### 6.1.1 Outer encoding (BCH)

A t-error correcting BCH ( $N_{bch}$ ,  $K_{bch}$ ) code shall be applied to each BBFrame to generate an error protected packet. The BCH code parameters for  $N_{ldpc} = 64\ 800$  are given in table 3(a) and for  $N_{ldpc} = 16\ 200$  in table 3(b).

The generator polynomial of the t error correcting BCH encoder is obtained by multiplying the first t polynomials in table 4(a) for  $N_{ldpc} = 64\ 800$  and in table 4(b) for  $N_{ldpc} = 16\ 200$ .

**Table 4(a): BCH polynomials (for normal FECFrame  $N_{ldpc} = 64\ 800$ )**

$g_1(x)$	$1+x^2+x^3+x^5+x^{16}$
$g_2(x)$	$1+x+x^4+x^5+x^6+x^8+x^{16}$
$g_3(x)$	$1+x^2+x^3+x^4+x^5+x^7+x^8+x^9+x^{10}+x^{11}+x^{16}$
$g_4(x)$	$1+x^2+x^4+x^6+x^9+x^{11}+x^{12}+x^{14}+x^{16}$
$g_5(x)$	$1+x+x^2+x^3+x^5+x^8+x^9+x^{10}+x^{11}+x^{12}+x^{16}$
$g_6(x)$	$1+x^2+x^4+x^5+x^7+x^8+x^9+x^{10}+x^{12}+x^{13}+x^{14}+x^{15}+x^{16}$
$g_7(x)$	$1+x^2+x^5+x^6+x^8+x^9+x^{10}+x^{11}+x^{13}+x^{15}+x^{16}$
$g_8(x)$	$1+x+x^2+x^5+x^6+x^8+x^9+x^{12}+x^{13}+x^{14}+x^{16}$
$g_9(x)$	$1+x^5+x^7+x^9+x^{10}+x^{11}+x^{16}$
$g_{10}(x)$	$1+x+x^2+x^5+x^7+x^8+x^{10}+x^{12}+x^{13}+x^{14}+x^{16}$
$g_{11}(x)$	$1+x^2+x^3+x^5+x^9+x^{11}+x^{12}+x^{13}+x^{16}$
$g_{12}(x)$	$1+x+x^5+x^6+x^7+x^9+x^{11}+x^{12}+x^{16}$

**Table 4(b): BCH polynomials (for short FECFrame  $N_{ldpc} = 16\ 200$ )**

$g_1(x)$	$1+x+x^3+x^5+x^{14}$
$g_2(x)$	$1+x^6+x^8+x^{11}+x^{14}$
$g_3(x)$	$1+x+x^2+x^6+x^9+x^{10}+x^{14}$
$g_4(x)$	$1+x^4+x^7+x^8+x^{10}+x^{12}+x^{14}$
$g_5(x)$	$1+x^2+x^4+x^6+x^8+x^9+x^{11}+x^{13}+x^{14}$
$g_6(x)$	$1+x^3+x^7+x^8+x^9+x^{13}+x^{14}$
$g_7(x)$	$1+x^2+x^5+x^6+x^7+x^{10}+x^{11}+x^{13}+x^{14}$
$g_8(x)$	$1+x^5+x^8+x^9+x^{10}+x^{11}+x^{14}$
$g_9(x)$	$1+x+x^2+x^3+x^9+x^{10}+x^{14}$
$g_{10}(x)$	$1+x^3+x^6+x^9+x^{11}+x^{12}+x^{14}$
$g_{11}(x)$	$1+x^4+x^{11}+x^{12}+x^{14}$
$g_{12}(x)$	$1+x+x^2+x^3+x^5+x^6+x^7+x^8+x^{10}+x^{13}+x^{14}$

BCH encoding of information bits  $M = (m_{K_{bch}-1}, m_{K_{bch}-2}, \dots, m_1, m_0)$  onto a codeword is achieved as follows:

- Multiply the message polynomial  $m(x) = m_{K_{bch}-1}x^{K_{bch}-1} + m_{K_{bch}-2}x^{K_{bch}-2} + \dots + m_1x + m_0$  by  $x^{N_{bch}-K_{bch}}$ .
- Divide  $x^{N_{bch}-K_{bch}}m(x)$  by  $g(x)$ , the generator polynomial. Let  $d(x) = d_{N_{bch}-K_{bch}-1}x^{N_{bch}-K_{bch}-1} + \dots + d_1x + d_0$  be the remainder.
- Construct the output codeword  $I$ , which forms the information word  $I$  for the LDPC coding, as follows:

$$I = (i_0, i_1, \dots, i_{N_{bch}-1}) = (m_{K_{bch}-1}, m_{K_{bch}-2}, \dots, m_1, m_0, d_{N_{bch}-K_{bch}-1}, d_{N_{bch}-K_{bch}-2}, \dots, d_1, d_0)$$

NOTE: The equivalent codeword polynomial is  $c(x) = x^{N_{bch}-K_{bch}}m(x) + d(x)$ .

### 6.1.2 Inner encoding (LDPC)

The LDPC encoder treats the output of the outer encoding,  $I = (i_0, i_1, \dots, i_{K_{ldpc}-1})$ , as an information block of size  $K_{ldpc} = N_{BCH}$ , and systematically encodes it onto a codeword  $A$  of size  $N_{ldpc}$ , where:

$$\Lambda = (\lambda_0, \lambda_1, \lambda_2, \dots, \lambda_{N_{LDPC}}) = (i_0, i_1, \dots, i_{K_{ldpc}-1}, p_0, p_1, \dots, p_{N_{ldpc}-K_{ldpc}-1}).$$

The LDPC code parameters  $(N_{ldpc}, K_{ldpc})$  are given in tables 3(a) and 3(b).

#### 6.1.2.1 Inner coding for normal FECFrame

The task of the encoder is to determine  $N_{ldpc} - K_{ldpc}$  parity bits  $(p_0, p_1, \dots, p_{N_{ldpc}-K_{ldpc}-1})$  for every block of  $k_{ldpc}$  information bits,  $(i_0, i_1, \dots, i_{K_{ldpc}-1})$ . The procedure is as follows:

- Initialize  $p_0 = p_1 = p_2 = \dots = p_{N_{ldpc}-K_{ldpc}-1} = 0$
- Accumulate the first information bit,  $i_0$ , at parity bit addresses specified in the first row of tables A.1 through A.5. For example, for rate 2/3 (A.1), (all additions are in GF(2)):

$$p_{317} = p_{317} \oplus i_0 \qquad p_{6700} = p_{6700} \oplus i_0$$

$$p_{2255} = p_{2255} \oplus i_0 \qquad p_{9101} = p_{9101} \oplus i_0$$

$$p_{2324} = p_{2324} \oplus i_0$$

$$p_{10057} = p_{10057} \oplus i_0$$

$$p_{2723} = p_{2723} \oplus i_0$$

$$p_{12739} = p_{12739} \oplus i_0$$

$$p_{3538} = p_{3538} \oplus i_0$$

$$p_{17407} = p_{17407} \oplus i_0$$

$$p_{3576} = p_{3576} \oplus i_0$$

$$p_{21039} = p_{21039} \oplus i_0$$

$$p_{6194} = p_{6194} \oplus i_0$$

- For the next 359 information bits,  $i_m, m=1, 2, \dots, 359$  accumulate  $i_m$  at parity bit addresses  $\{x + m \bmod 360 \times Q_{ldpc}\} \bmod (N_{ldpc} - K_{ldpc})$  where  $x$  denotes the address of the parity bit accumulator corresponding to the first bit  $i_0$ , and  $Q_{ldpc}$  is a code rate dependent constant specified in table 5(a). Continuing with the example,  $Q_{ldpc} = 60$  for rate 2/3. So for example for information bit  $i_1$ , the following operations are performed:

$$p_{377} = p_{377} \oplus i_1$$

$$p_{6760} = p_{6760} \oplus i_1$$

$$p_{2315} = p_{2315} \oplus i_1$$

$$p_{9161} = p_{9161} \oplus i_1$$

$$p_{2384} = p_{2384} \oplus i_1$$

$$p_{10117} = p_{10117} \oplus i_1$$

$$p_{2783} = p_{2783} \oplus i_1$$

$$p_{12799} = p_{12799} \oplus i_1$$

$$p_{3598} = p_{3598} \oplus i_1$$

$$p_{17467} = p_{17467} \oplus i_1$$

$$p_{3636} = p_{3636} \oplus i_1$$

$$p_{21099} = p_{21099} \oplus i_1$$

$$p_{6254} = p_{6254} \oplus i_1$$

- For the 361<sup>st</sup> information bit  $i_{360}$ , the addresses of the parity bit accumulators are given in the second row of the tables A.1 through A.5. In a similar manner the addresses of the parity bit accumulators for the following 359 information bits  $i_m, m=361, 362, \dots, 719$  are obtained using the formula  $\{x + (m \bmod 360) \times Q_{ldpc}\} \bmod (N_{ldpc} - K_{ldpc})$  where  $x$  denotes the address of the parity bit accumulator corresponding to the information bit  $i_{360}$ , i.e. the entries in the second row of tables A.1 through A.5.
- In a similar manner, for every group of 360 new information bits, a new row from tables A.1 through A.5 are used to find the addresses of the parity bit accumulators.

After all of the information bits are exhausted, the final parity bits are obtained as follows:

- Sequentially perform the following operations starting with  $i = 1$ .

$$p_i = p_i \oplus p_{i-1}, \quad i = 1, 2, \dots, N_{ldpc} - K_{ldpc} - 1$$

- Final content of  $p_i, i = 0, 1, \dots, N_{ldpc} - K_{ldpc} - 1$  is equal to the parity bit  $p_i$ .

**Table 5(a):  $Q_{ldpc}$  values for normal frames**

Code Rate	$Q_{ldpc}$
2/3	60
3/4	45
4/5	36
5/6	30
9/10	18

### 6.1.2.2 Inner coding for short FECFrame

$K_{ldpc}$  BCH encoded bits shall be systematically encoded to generate  $N_{ldpc}$  bits as described in clause 6.1.2.1, replacing table 5(a) with table 5(b) and the tables of annex A with the tables of annex B.

**Table 5(b):  $Q_{ldpc}$  values for short frames**

Code Rate	$Q_{ldpc}$
1/2	25
2/3	15
3/4	12
4/5	10
5/6	8
8/9	5

### 6.1.3 Bit Interleaver

The output  $A$  of the LDPC encoder shall be bit interleaved, which consists of parity interleaving followed by column-twist interleaving. The parity interleaver output is denoted by  $U$  and the column-twist interleaver output by  $V$ .

In the parity interleaving part, parity bits are interleaved by:

$$u_i = \lambda_i \text{ for } 0 \leq i < K_{ldpc} \text{ (information bits are not interleaved);}$$

$$u_{K_{ldpc}+360t+s} = \lambda_{K_{ldpc}+Q_{ldpc} \cdot s+t} \text{ for } 0 \leq s < 360, 0 \leq t < Q_{ldpc};$$

where  $Q_{ldpc}$  is defined in tables 5(a) and 5(b).

The configuration of the column-twist interleaving for each modulation format is specified in table 6.

**Table 6: Bit Interleaver structure**

Modulation	Rows $N_r$		Columns $N_c$
	$N_{ldpc} = 64\ 800$	$N_{ldpc} = 16\ 200$	
16QAM	8 100	2 025	8
64QAM	5 400	1 350	12
256QAM	4 050	-	16
	-	2 025	8
1024QAM	3 240	810	20
4096QAM	5 400	-	12
	-	675	24



In the column-twist interleaving part, the data bits  $u_i$  from the parity interleaver are serially written into the column-twist interleaver column-wise, and serially read out row-wise (the MSB of BBHeader is read out first) as shown in figure 12, where the write start position of each column is twisted by  $t_c$  according to table 7. This interleaver is described by the following:

- The input bit  $u_i$  with index  $i$ , for  $0 \leq i < N_{ldpc}$ , is written to column  $c_i$  row  $r_i$  of the interleaver, where:

$$c_i = i \div N_r$$

$$r_i = i + t_{c_i} \bmod N_r$$

- The output bit  $v_j$  with index  $j$ , for  $0 \leq j < n_{ldpc}$ , is read from row  $r_j$ , column  $c_j$ , where:

$$r_j = j \div N_c$$

$$c_j = j \bmod N_c$$

- So for 64QAM and  $N_{LDPC} = 64\,800$ , the output bit order of column twist interleaving would be:

$$(v_0, v_1, v_2, \dots, v_{64799}) = (u_0, u_{5400}, u_{16198}, \dots, u_{53992}, u_{59231}, u_{64790}).$$

A longer list of the indices on the right hand side, illustrating all 12 columns, is: 0, 5 400, 16 198, 21 598, 26 997, 32 396, 37 796, 43 195, 48 595, 53 993, 59 392, 64 791, ..... 5 399, 10 799, 16 197, 21 597, 26 996, 32 395, 37 795, 43 194, 48 594, 53 992, 59 391, 64 790.

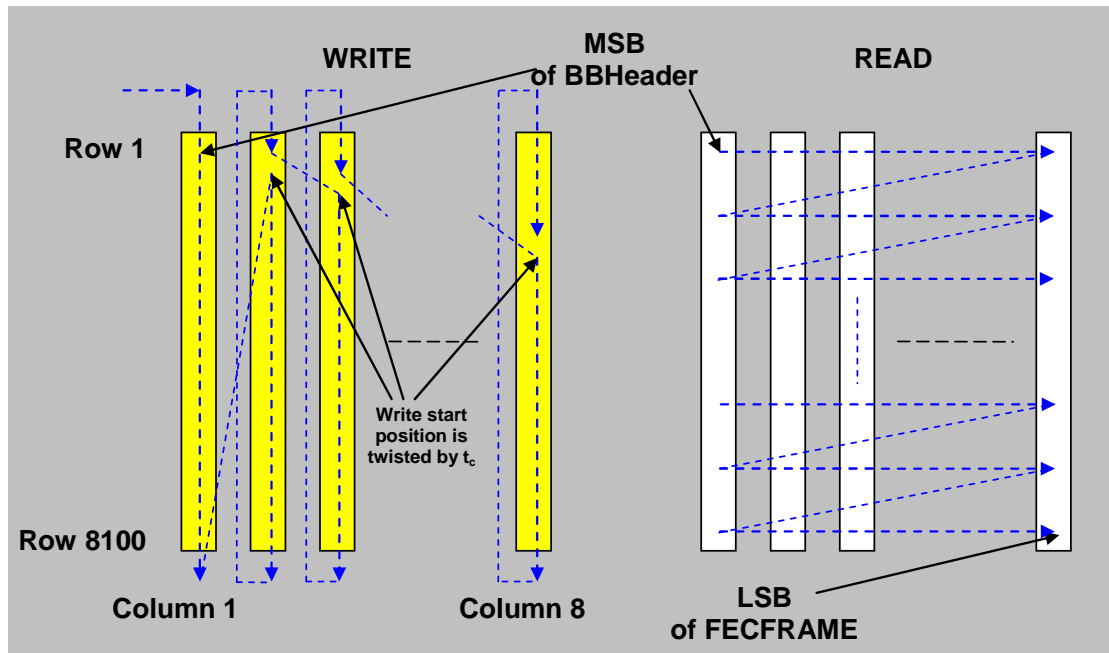


Figure 12: Bit interleaving scheme for normal FECFrame length and 16QAM

Table 7(a): Column twisting parameter  $t_c$  (column 0 to 11)

Modulation	Columns $N_c$	$N_{ldpc}$	Twisting parameter $t_c$											
			Col. 0	1	2	3	4	5	6	7	8	9	10	11
16 QAM	8	64 800	0	0	2	4	4	5	7	7	-	-	-	-
		16 200	0	0	0	1	7	20	20	21	-	-	-	-
64 QAM	12	64 800	0	0	2	2	3	4	4	5	5	7	8	9
		16 200	0	0	0	2	2	2	3	3	3	6	7	7
256 QAM	16	64 800	0	2	2	2	2	3	7	15	16	20	22	22
	8	16 200	0	0	0	1	7	20	20	21	-	-	-	-
1024 QAM	20	64 800	0	1	3	4	5	6	6	9	13	14	14	16
		16 200	0	0	0	2	2	2	2	2	5	5	5	5
4096 QAM	12	64 800	0	0	2	2	3	4	4	5	5	7	8	9
	24	16 200	0	0	0	0	0	0	0	1	1	1	2	2

Table 7(b): Column twisting parameter  $t_c$  (column 12 to 23)

Modulation	Columns $N_c$	$N_{ldpc}$	Twisting parameter $t_c$											
			Col. 12	13	14	15	16	17	18	19	20	21	22	23
16 QAM	8	64 800	-	-	-	-								
		16 200	-	-	-	-								
64 QAM	12	64 800	-	-	-	-								
		16 200	-	-	-	-								
256 QAM	16	64 800	27	27	28	32								
	8	16 200	-	-	-	-								
1024 QAM	20	64 800	21	21	23	25	25	26	28	30				
		16 200	5	7	7	7	7	8	8	10				
4096 QAM	12	64 800												
	24	16 200	2	3	7	9	9	9	10	10	10	10	10	11

## 6.2 Mapping bits onto constellations

Each FECFrame (which is a sequence of 64 800 bits for normal FECFrame, or 16 200 bits for short FECFrame), shall be mapped to a coded and modulated FEC block by first demultiplexing the input bits into parallel cell words and then mapping these cell words into constellation values. The number of output Data Cells and the effective number of bits per cell  $\eta_{MOD}$  is defined by table 8. Demultiplexing is performed according to clause 6.2.1 and constellation mapping is performed according to clause 6.2.2.

Table 8: Parameters for bit-mapping into constellations

LDPC block length ( $N_{ldpc}$ )	Modulation mode	$\eta_{MOD}$	Number of output Data Cells
64 800	4096QAM	12	5 400
	1024QAM	10	6 480
	256QAM	8	8 100
	64QAM	6	10 800
	16QAM	4	16 200
16 200	4096QAM	12	1 350
	1024QAM	10	1 620
	256QAM	8	2 025
	64QAM	6	2 700
	16QAM	4	4 050
	QPSK	2	8 100

### 6.2.1 Bit to cell word demultiplexer

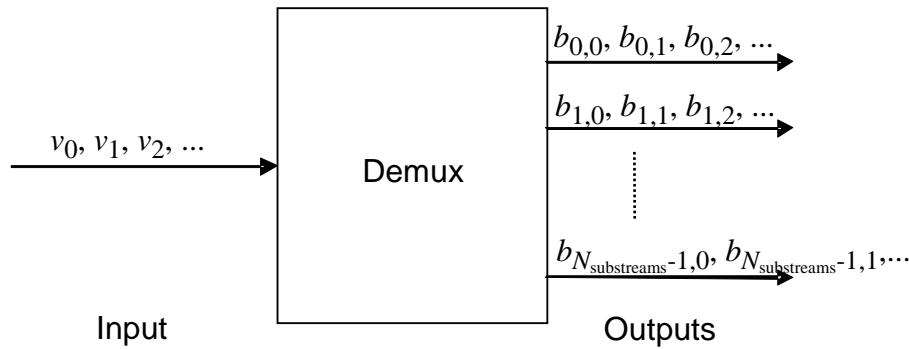
The bit-stream  $v_i$  from the bit interleaver is demultiplexed into  $N_{substreams}$  sub-streams, as shown in figure 13. The value of  $N_{substreams}$  is defined in table 9.

**Table 9: Number of sub-streams in demultiplexer**

Modulation	$N_{ldpc}$	Number of sub-streams, $N_{substreams}$
QPSK	Any	2
16QAM	Any	8
64QAM	Any	12
256QAM	64 800	16
	16 200	8
1024QAM	Any	20
4096QAM	64 800	12
	16 200	24

The demultiplexing is defined as a mapping of the bit-interleaved input bits,  $v_{di}$  onto the output bits  $b_{e,do}$ , where:

- $do = di \text{ div } N_{substreams}$ ;
- $e$  is the demultiplexed bit sub stream number ( $0 \leq e < N_{substreams}$ ), which depends on  $di$  as defined in table 10;
- $v_{di}$  is the input to the demultiplexer;
- $di$  is the input bit number;
- $b_{e,do}$  is the output from the demultiplexer;
- $do$  is the bit number of a given stream at the output of the demultiplexer.



**Figure 13: Demultiplexing of bits into sub-streams**

**Table 10(a): Parameters for demultiplexing of bits to sub-streams for codes rates 1/2, 3/4, 4/5, 5/6, 9/10(8/9)**

Modulation format		QPSK																			
		0	1																		
		0	1																		
Modulation format		16QAM																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7												
Output bit-number, $e$		7	1	4	2	5	3	6	0												
Modulation format		64QAM																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11								
Output bit-number, $e$		11	7	3	10	6	2	9	5	1	8	4	0								
Modulation format		256QAM ( $N_{ldpc} = 64\ 800$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15				
Output bit-number, $e$		15	1	13	3	8	11	9	5	10	6	4	7	12	2	14	0				
Modulation format		256QAM ( $N_{ldpc} = 16\ 200$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7												
Output bit-number, $e$		7	3	1	5	2	6	4	0												
Modulation format		1024QAM ( $N_{ldpc} = 64\ 800$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Output bit-number, $e$		8	16	7	19	4	15	3	12	0	11	10	9	13	2	14	5	17	6	18	1
Modulation format		1024QAM ( $N_{ldpc} = 16\ 200$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Output bit-number, $e$		8	3	7	10	19	4	9	5	17	6	14	11	2	18	16	15	0	1	13	12
Modulation format		4096QAM ( $N_{ldpc} = 64\ 800$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11								
Output bit-number, $e$		8	0	6	1	4	5	2	3	7	10	11	9								
Modulation format		4096QAM ( $N_{ldpc} = 16\ 200$ ), part 1																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11								
Output bit-number, $e$		10	15	4	19	21	16	23	18	11	14	22	5								
Modulation format		4096QAM ( $N_{ldpc} = 16\ 200$ ), part 2																			
Input bit-number, $di \bmod N_{substreams}$		12	13	14	15	16	17	18	19	20	21	22	23								
Output bit-number, $e$		6	17	13	20	1	3	9	2	7	8	12	0								

Table 10(b): Parameters for demultiplexing of bits to sub-streams for code rate 2/3 only

Modulation format		QPSK																			
		0	1																		
		0	1																		
Modulation format		16QAM																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7												
Output bit-number, $e$		7	1	4	2	5	3	6	0												
Modulation format		64QAM																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11								
Output bit-number, $e$		11	7	3	10	6	2	9	5	1	8	4	0								
Modulation format		256QAM ( $N_{ldpc} = 64\ 800$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15				
Output bit-number, $e$		7	2	9	0	4	6	13	3	14	10	15	5	8	12	11	1				
Modulation format		256QAM ( $N_{ldpc} = 16\ 200$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7												
Output bit-number, $e$		7	3	1	5	2	6	4	0												
Modulation format		1024QAM ( $N_{ldpc} = 64\ 800$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Output bit-number, $e$		8	16	7	19	4	15	3	12	0	11	10	9	13	2	14	5	17	6	18	1
Modulation format		1024QAM ( $N_{ldpc} = 16\ 200$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Output bit-number, $e$		8	3	7	10	19	4	9	5	17	6	14	11	2	18	16	15	0	1	13	12
Modulation format		4096QAM ( $N_{ldpc} = 64\ 800$ )																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11								
Output bit-number, $e$		8	0	6	1	4	5	2	3	7	10	11	9								
Modulation format		4096QAM ( $N_{ldpc} = 16\ 200$ ), part 1																			
Input bit-number, $di \bmod N_{substreams}$		0	1	2	3	4	5	6	7	8	9	10	11								
Output bit-number, $e$		10	15	4	19	21	16	23	18	11	14	22	5								
Modulation format		4096QAM ( $N_{ldpc} = 16\ 200$ ), part 2																			
Input bit-number, $di \bmod N_{substreams}$		12	13	14	15	16	17	18	19	20	21	22	23								
Output bit-number, $e$		6	17	13	20	1	3	9	2	7	8	12	0								

Except for 256QAM with  $N_{ldpc} = 16\ 200$  and 4096QAM with  $N_{ldpc} = 64\ 800$ , the words of width  $N_{substreams}$  are split into two cell words of width  $\eta_{MOD} = N_{substreams}/2$  at the output of the demultiplexer. The first  $\eta_{mod} = N_{substreams}/2$  bits  $[b_{0,do} \dots b_{N_{substreams}/2-1,do}]$  form the first of a pair of output cell words  $[y_{0,2do} \dots y_{\eta_{MOD}-1,2do}]$  and the remaining output bits  $[b_{N_{substreams}/2,do} \dots b_{N_{substreams}-1,do}]$  form the second output cell word  $[y_{0,2do+1} \dots y_{\eta_{MOD}-1,2do+1}]$  fed to the constellation mapper.

In the case of 256QAM with  $N_{ldpc} = 16\,200$  and 4096QAM with  $N_{ldpc} = 64\,800$ , the words of width 8 from the demultiplexer form the output cell words and are fed directly to the constellation mapper, so:

$$[y_{0,do} \dots y_{\eta_{mod}-1,do}] = [b_{0,do} \dots b_{N_{substreams}-1,do}]$$

The application of the parameters in tables 10(a) and 10(b), for the demultiplexing of the bit-stream  $v_i$  from the bit interleaver, is subordinated to the validity of a specific modulation and code rate combination, since DVB-C2 only supports a list of selected ModCod configurations, as shown in tables 11(a) and 11(b) (X indicates a valid configuration).

**Table 11(a): ModCods for  $N_{ldpc} = 64\,800$**

Code rate	Modulation format					
	QPSK	16QAM	64QAM	256QAM	1024QAM	4096QAM
2/3	NA	NA	X	NA	NA	NA
3/4	NA	NA	NA	X	X	NA
4/5	NA	X	X	NA	NA	NA
5/6	NA	NA	NA	X	X	X
9/10	NA	X	X	X	X	X

**Table 11(b): ModCods for  $N_{ldpc} = 16\,200$**

Code rate	Modulation format					
	QPSK	16QAM	64QAM	256QAM	1024QAM	4096QAM
1/2	N/A	X	NA	NA	NA	NA
2/3	N/A	NA	X	NA	NA	NA
3/4	N/A	NA	NA	X	X	NA
4/5	N/A	X	X	NA	NA	NA
5/6	N/A	NA	NA	X	X	X
8/9	N/A	X	X	X	X	X

## 6.2.2 Cell word mapping into I/Q constellations

Each cell word  $(y_{0,q} \dots y_{\eta_{mod}-1,q})$  from the demultiplexer in clause 6.2.1 shall be modulated using either QPSK, 16QAM, 64QAM, 256QAM, 1024QAM, 4096QAM constellations to give a constellation point  $z_q$  prior to normalization.

The exact values of the real and imaginary components  $\text{Re}(z_q)$  and  $\text{Im}(z_q)$  for each combination of the relevant input bits  $y_{e,q}$  are given in tables 12(a-m) for the various constellations:

**Table 12(a): Constellation mapping for BPSK**

$y_{0,q}$	1	0
$\text{Re}(z_q)$	-1	1
$\text{Im}(z_q)$	0	0

**Table 12(b): Constellation mapping for real part of QPSK**

$y_{0,q}$	1	0
$\text{Re}(z_q)$	-1	1

**Table 12(c): Constellation mapping for imaginary part of QPSK**

$y_{1,q}$	1	0
$\text{Im}(z_q)$	-1	1

**Table 12(d): Constellation mapping for real part of 16QAM**

$y_{0,q}$	1	1	0	0
$y_{2,q}$	0	1	1	0
$\text{Re}(z_q)$	-3	-1	1	3

**Table 12(e): Constellation mapping for imaginary part of 16QAM**

$y_{1,q}$	1	1	0	0
$y_{3,q}$	0	1	1	0
$\text{Im}(z_q)$	-3	-1	1	3

**Table 12(f): Constellation mapping for real part of 64QAM**

$y_{0,q}$	1	1	1	1	0	0	0	0
$y_{2,q}$	0	0	1	1	1	1	0	0
$y_{4,q}$	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	-7	-5	-3	-1	1	3	5	7

**Table 12(g): Constellation mapping for imaginary part of 64QAM**

$y_{1,q}$	1	1	1	1	0	0	0	0
$y_{3,q}$	0	0	1	1	1	1	0	0
$y_{5,q}$	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	-7	-5	-3	-1	1	3	5	7

**Table 12(h): Constellation mapping for real part of 256QAM**

$y_{0,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{2,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{4,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{6,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5	7	9	11	13	15

**Table 12(i): Constellation mapping for imaginary part of 256QAM**

$y_{1,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{3,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{5,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{7,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5	7	9	11	13	15

Table 12(j): Constellation mapping for real part of 1024QAM

$Y_{0,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{2,q}$	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
$y_{4,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{6,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{8,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	-31	-29	-27	-25	-23	-21	-19	-17	-15	-13	-11	-9	-7	-5	-3	-1
$Y_{0,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{2,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{4,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{6,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{8,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31

Table 12(k): Constellation mapping for imaginary part of 1024QAM

$y_{1,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{3,q}$	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
$y_{5,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{7,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{9,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	-31	-29	-27	-25	-23	-21	-19	-17	-15	-13	-11	-9	-7	-5	-3	-1
$y_{1,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{3,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{5,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{7,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{9,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31



Table 12(l): Constellation mapping for real part of 4096QAM

$Y_{0,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{2,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{4,q}$	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0
$y_{6,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{8,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$y_{10,q}$																
$\text{Re}(z_q)$	-63	-61	-59	-57	-55	-53	-51	-49	-47	-45	-43	-41	-39	-37	-35	-33
$Y_{0,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{2,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{4,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{6,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{8,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{10,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	-31	-29	-27	-25	-23	-21	-19	-17	-15	-13	-11	-9	-7	-5	-3	-1
$Y_{0,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{2,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{4,q}$	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
$y_{6,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{8,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{10,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
$Y_{0,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{2,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{4,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{6,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{8,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{10,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Re}(z_q)$	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63

Table 12(m): Constellation mapping for imaginary part of 4096QAM

$y_{1,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{3,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{5,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{7,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{9,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$y_{11,q}$																
$\text{Im}(z_q)$	-63	-61	-59	-57	-55	-53	-51	-49	-47	-45	-43	-41	-39	-37	-35	-33
$y_{1,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{3,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{5,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{7,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{9,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{11,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	-31	-29	-27	-25	-23	-21	-19	-17	-15	-13	-11	-9	-7	-5	-3	-1
$y_{1,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{3,q}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$y_{5,q}$	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
$y_{7,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{9,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{11,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
$y_{1,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{3,q}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$y_{5,q}$	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$y_{7,q}$	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
$y_{9,q}$	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
$y_{11,q}$	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
$\text{Im}(z_q)$	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63

The constellations, and the details of the Gray mapping applied to them, are illustrated in figures 14 and 15.

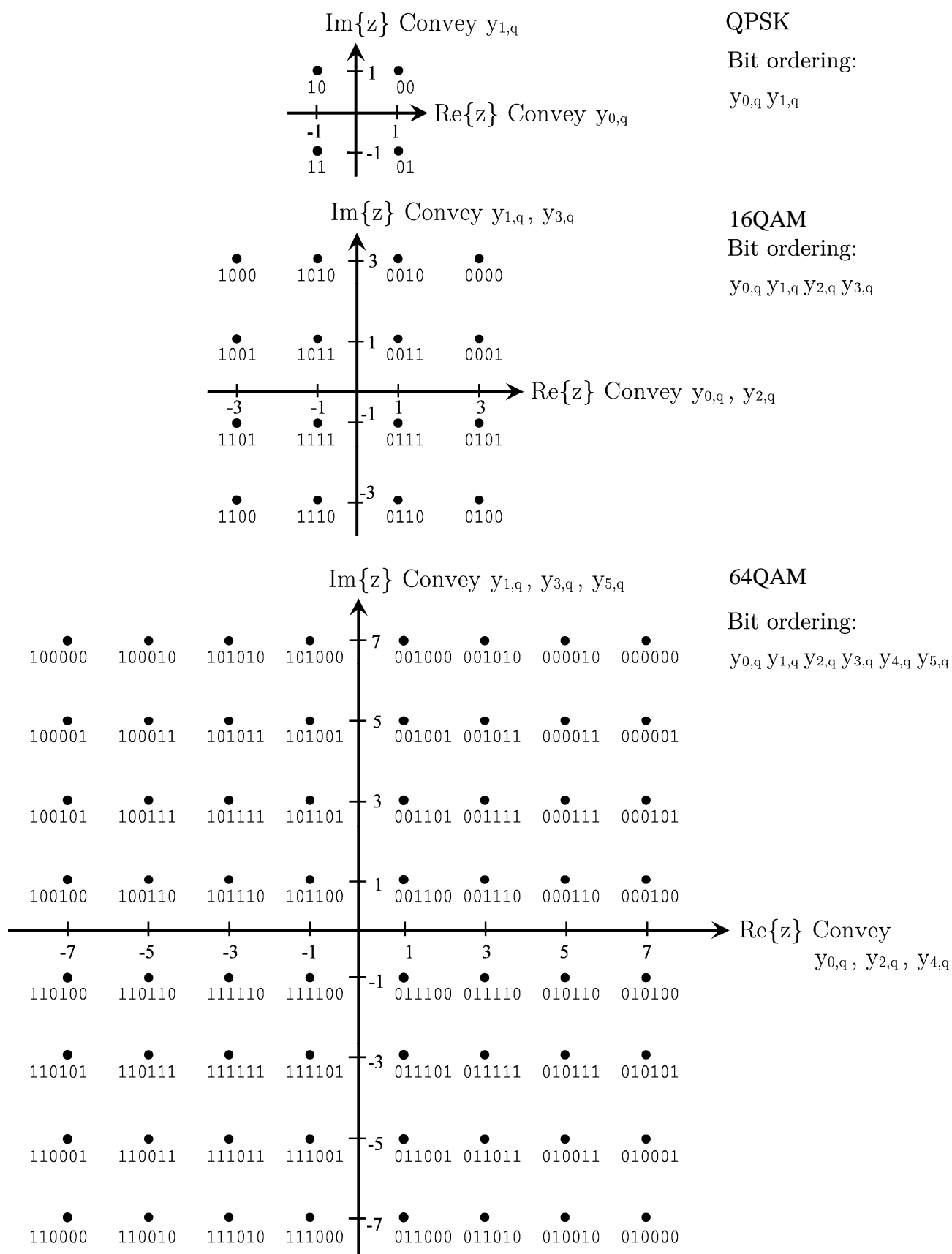


Figure 14: The QPSK, 16QAM and 64QAM mappings and the corresponding bit patterns

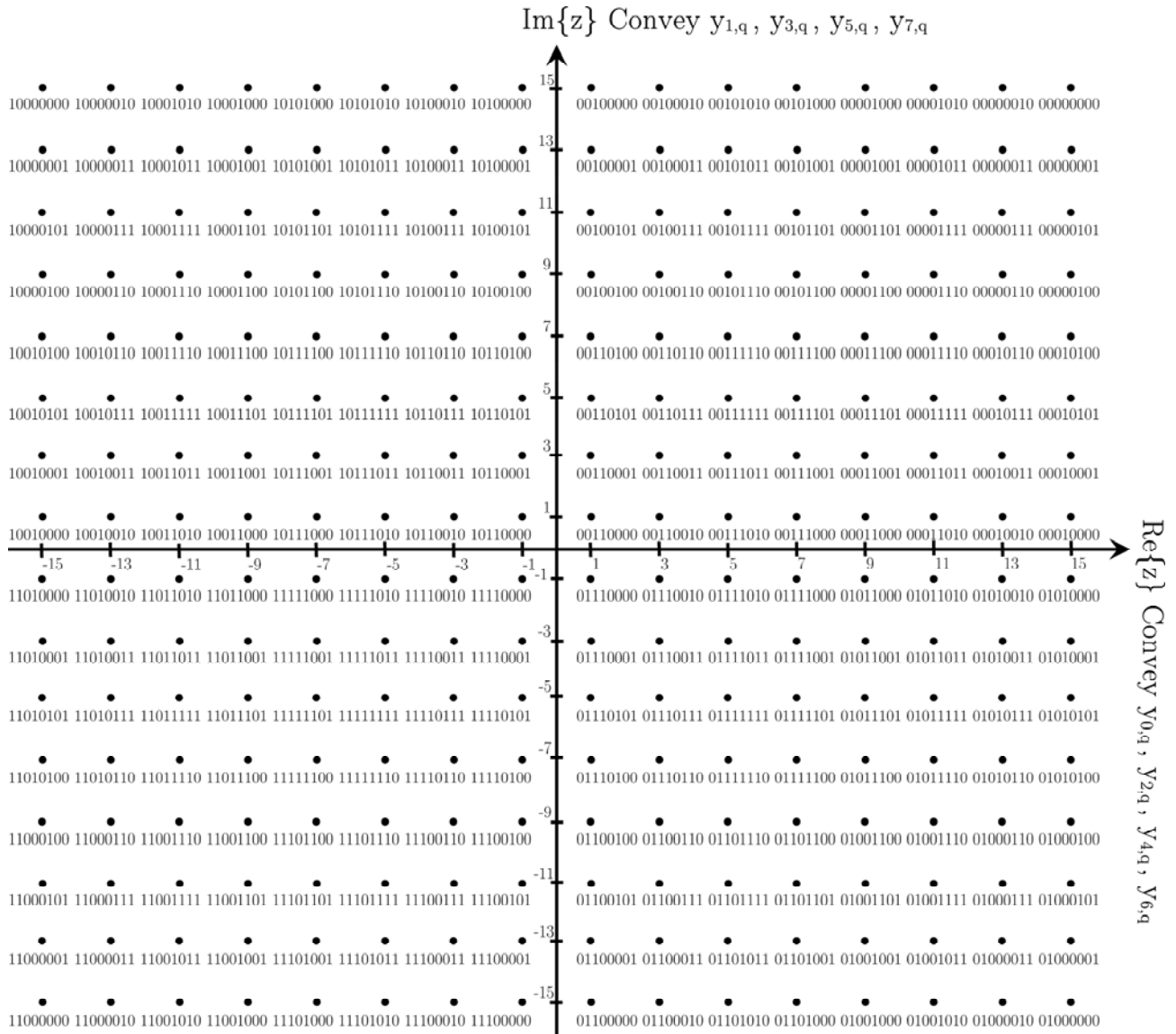


Figure 15: The 256QAM mapping and the corresponding bit pattern

Tables 12(j) and 12(k) provide the description of 1024QAM mapping and the corresponding bit pattern. Tables 12(l) and 12(m) provide the description of 4096QAM mapping and the corresponding bit pattern.

The constellation points  $z_q$  for each input cell word  $(y_{0,q} \dots y_{\eta \bmod L-1,q})$  are normalized according to table 13 to obtain the correct complex cell value  $f_q$  to be used.

**Table 13: Normalization factors for Data Cells**

Modulation	Normalization
QPSK	$f_q = \frac{z_q}{\sqrt{2}}$
16QAM	$f_q = \frac{z_q}{\sqrt{10}}$
64QAM	$f_q = \frac{z_q}{\sqrt{42}}$
256QAM	$f_q = \frac{z_q}{\sqrt{170}}$
1024QAM	$f_q = \frac{z_q}{\sqrt{682}}$
4096QAM	$f_q = \frac{z_q}{\sqrt{2730}}$

## 7 Data Slice Packet Generation

The complex cells of one or two FECFrame shall form a Data Slice Packet. The Data Slice Packets for Data Slice Type 1 only transmit the FECFrame data and rely on a pointer within the Level 1 Signalling Part 2 to detect their start.

The Data Slice Packets for Data Slice Type 2 carry a FECFrame header that allows for synchronization to the Data Slice Packets without any additional information. The FECFrame header also signals the Modulation and Coding parameters and the PLP\_ID, which may change every Data Slice Packet.

### 7.1 Data Slice Packets for Data Slice Type 1

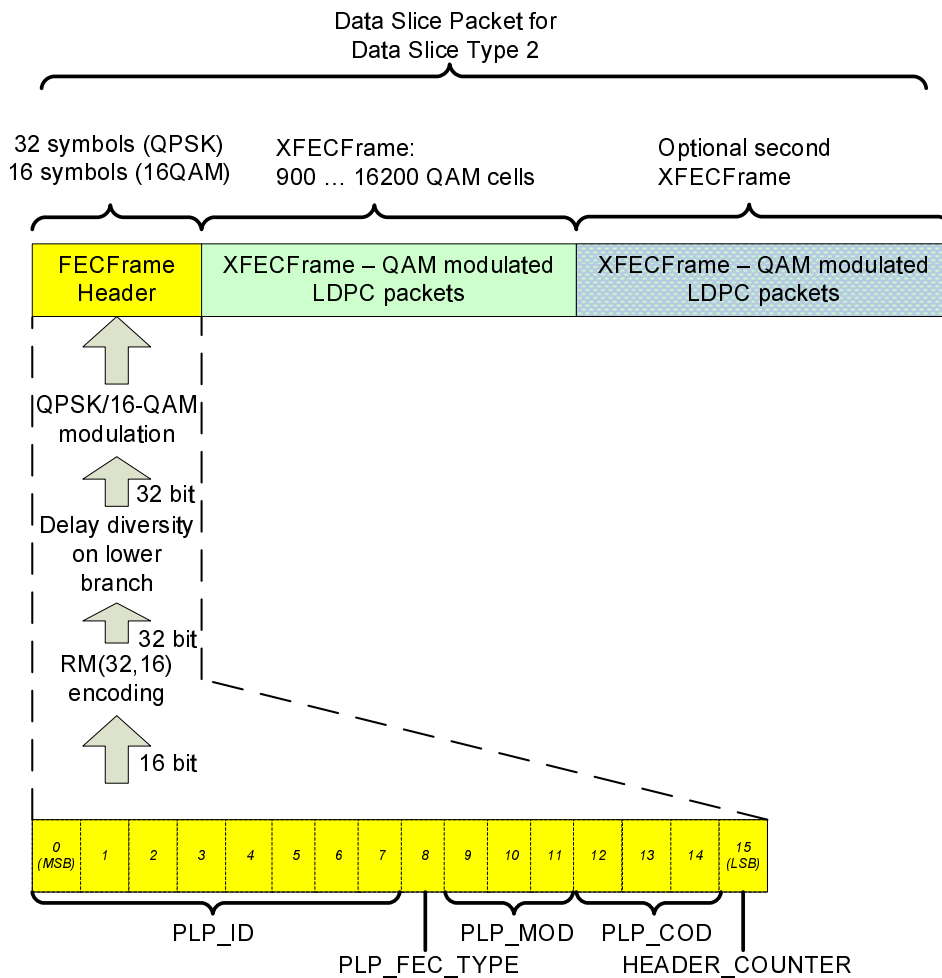
The complex cells  $g$  of Data Slice Packets transmitted in Data Slices of type 1 (DSLICE\_TYPE='0') shall be formed by the  $\left\lceil N_{ldpc}/\eta_{MOD} \right\rceil = N_{DP}$  complex cells of one LDPC codeword, i.e.:

$$g_q = f_q \quad q = 0, 1, \dots, N_{DP} - 1$$

The signalling for Data Slices of type 1 is done within the DVB-C2 preamble, i.e. the Layer 1 - part 2. Additional signalling is not required, as only a single PLP with fixed modulation and coding parameters per DVB-C2 frame is allowed for Data Slices Type 1.

### 7.2 Data Slice Packets for Data Slice Type 2

Data Slice Packets for Data Slice Type 2 shall carry an additional FECFrame Header in front of one or two FECFrames, which signals the PLP\_ID, the Coding and Modulation parameters of the following XFECFrame, and the number of XFECFrames following one header. The structure of these Data Slice Packets is given in figure 16.



**Figure 16: Data Slice Packet, consisting of FECFrame header and following XFECFrame packet**

### 7.2.1 FECFrame header signalling data

The 16 information bits of the FECFrame header are defined as follows, in which the MSB shall always be mapped first:

**PLP\_ID:** This 8-bit field uniquely identifies a PLP within a C2 system.

**PLP\_FEC\_TYPE:** This field shall signal the size of the following FECFrame (0 = 16 200 bits, 1 = 64 800 bits).

**PLP\_MOD:** This 3 bit field signals the used QAM mappings according to table 14.

**Table 14: PLP\_MOD values for the available QAM mappings**

Value	QAM mapping
000	Reserved
001	16QAM
010	64QAM
011	256QAM
100	1024QAM
101	4096QAM
110 to 111	Reserved for future use

**PLP\_COD:** This field signals the LDPC code rate of the following FECFrame according to table 15. Please note that not all possible PLP\_MOD and PLP\_COD combinations are supported (see tables 11(a) and 11(b)).

Table 15: PLP\_COD values for the different code rates

Value	Code rate
000	Reserved
001	2/3
010	3/4
011	4/5
100	5/6
101	8/9 (16K LDPC code) 9/10 (64K LDPC code)
110 to 111	Reserved for future use

**HEADER\_COUNTER:** This 1 bit field signals the number of FECFrames following this FECFrame header. '0' indicates that one FECFrame is following the FECFrame header. '1' indicates that 2 FECFrames are following the FECFrame header, while both FECFrames shall have the same PLP\_ID, PLP\_FEC\_TYPE, PLP\_MOD and PLP\_COD.

## 7.2.2 Coding of the FECFrame header

The encoding of the FECFrame header data shall ensure a robust synchronization and decoding of the L1 signalling part 1 data. Therefore, the encoding scheme as shown in the figures 17(a) and 17(b) is applied. Initially the 16 bits of the L1 signalling part 1 are FEC encoded by a Reed-Muller (32,16) encoder. Subsequently each bit of the 32 bits Reed-Muller codeword is split to form an upper and a lower branch. The lower branch applies a cyclic shift within each Reed-Muller codeword and scrambles the resulting data using a specific PN sequence. The data is then mapped on a QPSK constellation for the robust FECFrame header or on a 16QAM constellation for the high efficiency FECFrame header.

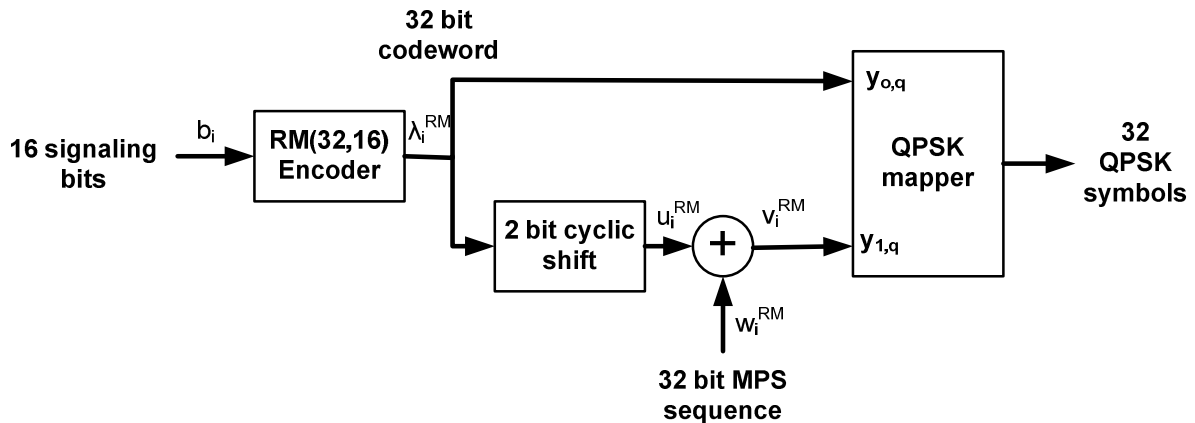


Figure 17(a): Robust FECFrame header

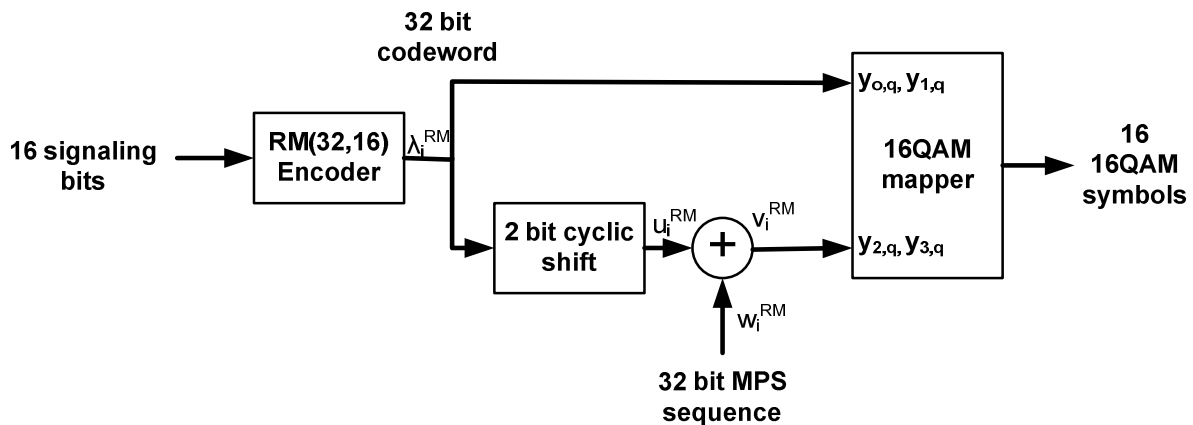


Figure 17(b): High efficiency FECFrame header

### 7.2.2.1 Error Coding

The 16 information bits are FEC encoded by a Reed-Muller (32,16) code. The generator matrix for this Reed-Muller (32,16) code G is shown as follows:

**Table 16(a): Definition of the Reed-Muller encoder matrix**

$$G = \begin{pmatrix} 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix}$$

The 32 Reed-Muller encoded data bits vector  $\lambda^{RM} = [\lambda_0^{RM}, \dots, \lambda_{31}^{RM}]$  is obtained by the matrix multiplication of the 16 bit long FECFrame signalling data vector  $b = [b_0, \dots, b_{15}]$  with the generator matrix, i.e.

$$\lambda^{RM} = b \cdot G$$

All operations are applied modulo 2.

### 7.2.2.2 Cyclic Delay

As depicted in figures 17(a) and 17(b), the 32 Reed-Muller encoded data bits  $\lambda_i^{RM}$  of the lower branch shall be cyclically delayed by two values within each Reed-Muller codeword. The output of the cyclic delay block shall be:

$$u_{(i+2) \bmod 32}^{RM} = \lambda_i^{RM} \quad i = 0, 1, \dots, 31$$

### 7.2.2.3 Scrambling of the lower branch

The data of the lower branch shall be scrambled with the scrambling sequence:

$$w_0^{RM}, w_1^{RM}, \dots, w_{31}^{RM} = 0, 0, 0, 1, 1, 1, 0, 1, 1, 0, 0, 0, 1, 1, 0, 1, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 1, 1$$

This 32 bits output sequence  $v_i^{RM}$  is obtained by applying modulo 2 operation between the cyclically shifted data  $u_i^{RM}$  and the scrambling sequence  $w_i^{RM}$ :

$$v_i^{RM} = u_i^{RM} \oplus w_i^{RM} \quad i = 0, 1, \dots, 31$$



### 7.2.3 Mapping onto QAM constellations

The 32 resulting bits of the upper and the 32 bits of the lower branch shall be mapped onto QAM constellations. Therefore, the same mapping means as described in clause 6.2.2 shall be used. There are 2 different FECFrame header architectures available. While the QPSK based FECFrame header is applied for cable channels with lower C/N, the 16QAM based FECFrame header provides a more efficient implementation (i.e. smaller header length) for cable channels with higher C/N values.

#### 7.2.3.1 Robust FECFrame header

The robust FECFrame header shall be modulated using QPSK as defined in clause 6.2.2 to obtain the 32 complex cell values  $f_q$ . The 32 mapper input cell words shall be defined as:

$$[y_{0,i}, y_{1,i}] = [\lambda_i^{RM}, v_i^{RM}] \quad i = 0, 1, \dots, 31$$

This means that the bits of the upper branch are always mapped onto the real part and the bits of the lower branch are always mapped onto the imaginary part of the QAM cell.

#### 7.2.3.2 High efficiency FECFrame header

The high efficiency FECFrame header shall be modulated using 16QAM as defined in clause 6.2.2 to obtain the 16 complex cell values  $f_q$ . The 16 mapper input cell words shall be defined as:

$$[y_{0,i}, y_{1,i}, y_{2,i}, y_{3,i}] = [\lambda_{2i}^{RM}, \lambda_{2i+1}^{RM}, v_{2i}^{RM}, v_{2i+1}^{RM}] \quad i = 0, 1, \dots, 15$$

This means that the bits of the upper branch are always modulated onto the MSB of the real and imaginary axis, while the bits of the lower branch are always modulated onto the LSB of the real and imaginary axis.

### 7.2.4 Mapping of the XFECFrame cells

The 32 cells for the robust FECFrame Header or the 16 cells for the high efficiency FECFrame Header shall be mapped onto the first cells of the Data Slice Packet, i.e.  $g_0 = f_0$ , etc.

The FECFrame header is followed by the  $\left[ N_{ldpc} / \eta_{MOD} \right]$  complex cells of one complete LDPC codeword. If

HEADER\_COUNT='1', one further FECFrame having the same PLP\_ID, PLP\_MOD and PLP\_COD shall follow the first one.

### 7.2.5 Length of the Data Slice Packet for Data Slice Type 2

The length  $N_{DP}$  of a Data Slice Packet for Data Slice Type 2 can be calculated by means of the FECFrame Header data only. The length for packets using the robust FECFrame header shall be:

$$N_{DP} = 32 + XFECFRAME\_LENGTH \cdot (1 + HEADER\_COUNTER)$$

and

$$N_{DP} = 16 + XFECFRAME\_LENGTH \cdot (1 + HEADER\_COUNTER)$$

for the high efficiency FECFrame header.

The value XFECFRAME\_LENGTH for the different values of PLP\_MOD and PLP\_FEC\_TYPE are listed in table 16(b).

Table 16(b): Length of the FECFrame

PLP_FEC_TYPE	PLP_MOD	XFECFRAME_LENGTH
0	000	NA
	001	4 050
	010	2 700
	011	2 025
	100	1 620
	101	1 350
	110	1 158
	111	1 013
1	000	900
	001	16 200
	010	10 800
	011	8 100
	100	6 480
	101	5 400
	110	4 629
	111	4 050

## 7.2.6 Stuffing Data Slice Packets

Stuffing Data Slice Packets provide a mechanism to fill up Data Slices of Type 2 with Auxiliary Data. Stuffing packets shall use the PLP\_MOD value '000'. Accordingly they have the minimum FECFrame length of 900QAM cells, while their total length shall be defined according to clause 7.2.4. The settings for the related stuffing FECFrame header are:

**PLP\_ID:** n/a (arbitrary value)

**PLP\_FEC\_TYPE:** 1 (= 64 800 bits)

**PLP\_MOD:** 000 (= 900QAM cells length)

**PLP\_COD:** n/a (arbitrary value)

**HEADER\_COUNTER:** 0

Stuffing Data Slice Packets can be used in any Data Slice and any location in the C2 Frame. Both regular Data Slice Packets and stuffing Data Slice Packets overlap over different C2 Frames if their end does not coincide with the end of the C2 Frame.

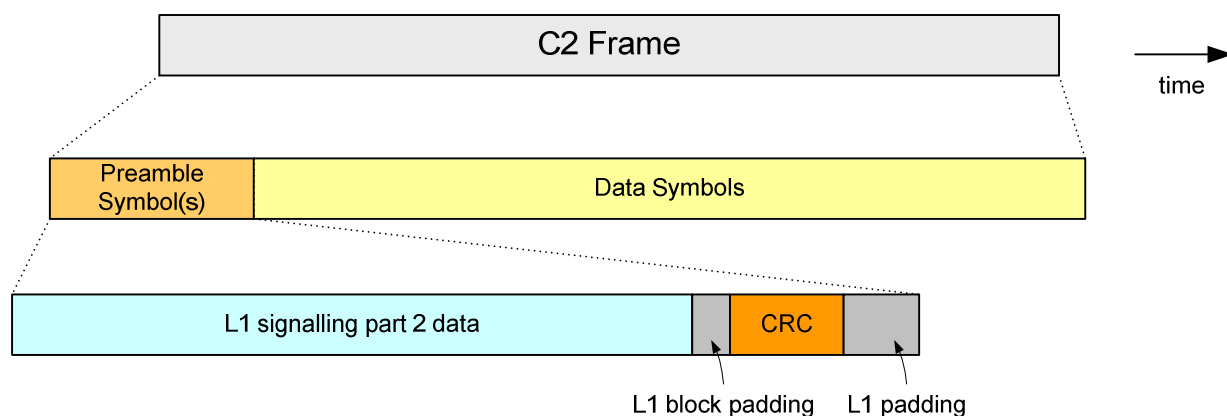
If the Data Slice is discontinued in the following C2 Frame the stuffing Data Slice Packet is only transmitted partially up to the end of the C2 Frame (i.e. not completed in the following C2 Frame). In the case where the remaining part is less than the number of cells in FECFrame header and the data is discontinued the next C2 frame, the remaining cells should be transmitted. The FECFrame headers of stuffing Data Slice Packets shall match with the L1 settings of the related Data Slice.

The data content of the 900QAM stuffing Data Cells is arbitrary but shall meet the average QAM cell energy requirement.

## 8 Generation, coding and modulation of Layer 1 part 2 signalling

### 8.1 Overview

Figure 18 illustrates the C2 Frame structure and the related preamble with embedded L1 signalling part 2. The number of Preamble Symbols depend on the amount of L1 signalling, i.e. the number of underlying Data Slices and PLPs and L1 TI mode. This clause concentrates on the structure and the syntax of the L1 signalling part 2 rather than the preamble coding and modulation (being described in more detail in clause 8.4). L1 signalling part 2 indicates OFDM parameters of the C2 channel as well as all relevant information for the Data Slices, PLPs and Notch bands.



**Figure 18: The L1 part 2 signalling structure**

### 8.2 Preamble Header

A fixed length Preamble Header of 32 OFDM Cells shall be inserted in front of the L1 TI-block at each Preamble Symbol as shown in figure 19. All L1 part 2 headers in one C2 Frame shall be same. The Preamble header describes L1-part2 length and TI mode of L1 block. The 16 information bits of the Preamble header are FEC encoded by a Reed-Muller (32,16) code and encoded by QPSK same as the QPSK based FECFrame header in clause 7.2.2.



Diagram illustrating the structure of L1 signalling part 2:

- The structure consists of a main data field (cyan) labeled "L1 signalling part 2 data", followed by a padding field (grey) labeled "L1 block padding", and a CRC field (orange) labeled "CRC".
- The size of the main data field is indicated as  $L1\_INFO\_SIZE \times 2$ .
- An additional "L1 padding" field (grey) is shown at the end of the structure.

**L1\_TI\_MODE:** This 2-bit field indicates the mode of time interleaving for L1-part2 of current C2 Frame. The time interleaving mode is signalled according to table 17. See clause 8.5 for more information.

Value	Mode
00	No time interleaving
01	Best Fit
10	4 OFDM Symbols
11	8 OFDM Symbols

## 8.3 L1 signalling part 2 data

Table 18 indicates the detailed use of fields for L1 signalling part 2 data.

**Table 18: The signalling fields of L1 signalling part 2 data**

Field	Size (bits)
NETWORK_ID	16
C2_SYSTEM_ID	16
START_FREQUENCY	24
C2_BANDWIDTH	16
GUARD_INTERVAL	2
C2_FRAME_LENGTH	10
L1_PART2_CHANGE_COUNTER	8
NUM_DSLICE	8
NUM_NOTCH	4
for i=0..NUM_DSLICE-1 {	
DSLICE_ID	8
DSLICE_TUNE_POS	14 or 13
DSLICE_OFFSET_LEFT	9 or 8
DSLICE_OFFSET_RIGHT	9 or 8
DSLICE_TI_DEPTH	2
DSLICE_TYPE	1
if DSLICE_TYPE=='1' {	
FEC_HEADER_TYPE	1
}	
DSLICE_CONST_CONF	1
DSLICE_LEFT_NOTCH	1
DSLICE_NUM_PLP	8
for i=0..DSLICE_NUM_PLP-1 {	
PLP_ID	8
PLP_BUNDLED	1
PLP_TYPE	2
PLP_PAYLOAD_TYPE	5
if PLP_TYPE=='00' or '01' {	
PLP_GROUP_ID	8
}	
if DSLICE_TYPE=='0' {	
PLP_START	14
PLP_FEC_TYPE	1
PLP_MOD	3
PLP_COD	3
}	
PSI/SI_REPROCESSING	1
if PSI/SI_REPROCESSING=='0' {	
transport_stream_id	16
original_network_id	16
}	
} RESERVED_1	8
}	
RESERVED_2	8
}	
for i=0..NUM_NOTCH-1 {	
NOTCH_START	14 or 13
NOTCH_WIDTH	9 or 8
RESERVED_3	8
}	
RESERVED_TONE	1
RESERVED_4	16

**NETWORK\_ID:** This is a 16-bit field which uniquely identifies the current DVB-C2 network.

**C2\_SYSTEM\_ID:** This 16-bit field uniquely identifies a C2 System within the DVB-C2 network.

**START\_FREQUENCY:** This 24-bit field indicates the start frequency of the current C2 System by means of the distance from 0 Hz and gives the unsigned integer value in multiples of the carrier spacing of the current C2 System. The value of '0' means 0 Hz. The START\_FREQUENCY shall be identical to the OFDM subcarrier with the smallest absolute carrier index  $k=K_{min}$  that actually transmits the DVB-C2 preamble for the given C2 system. Additionally, the START\_FREQUENCY shall be multiples of the pilot spacing  $D_X$  and the START\_FREQUENCY shall not change between different C2 frames.

**C2\_BANDWIDTH:** This 16-bit field indicates the bandwidth of the current C2 system. The C2\_BANDWIDTH field multiplied with the pilot spacing  $D_X + 1$  represents the bandwidth of the C2 system in OFDM subcarriers. The value shall not change between different C2 frames. The bandwidth of the current C2 system is defined by the frequency spacing between the edge pilots next to the most left and the most right Data Slice of the current C2 system.

**GUARD\_INTERVAL:** This 2-bit field indicates the guard interval of the current C2 Frame, according to table 19.

**Table 19: Signalling format for the guard interval**

Value	Guard interval fraction
00	1/128
01	1/64
10 to 11	Reserved for future use

**C2\_FRAME\_LENGTH:** This 10-bit field gives the number of Data Symbols per C2 Frame ( $L_{data}$ ). The C2 System according to the present document does only allow C2\_FRAME\_LENGTH = 0x1C0 (448 decimal). All other codes for C2\_FRAME\_LENGTH are reserved for future use.

**L1\_PART2\_CHANGE\_COUNTER:** This 8-bit field indicates the number of C2 Frames ahead where the configuration (i.e. the contents of the fields in the L1 signalling part 2 except for the PLP\_START and L1\_PART2\_CHANGE\_COUNTER) will change. The next C2 Frame with changes in the configuration is indicated by the value signalled within this field. If this field is set to the value '0', it means that no scheduled change is foreseen. For example, value '1' indicates that there is change in the next C2 Frame.

**NUM\_DSLICE:** This 8-bit field indicates the number of Data Slices carried within the current C2 Frame. The minimum value of this field shall be '1'.

NOTE 1: Both the number of Data Slices and the number of PLPs for each Data Slice of a C2 System are chosen such that the overall L1-part2 signalling does not exceed 32 766 bits.

**NUM\_NOTCH:** This 4-bit field indicates the number of Notch bands. If there is no Notch band within the current C2 Frame, this field shall be set to '0'.

The following fields appear in the Data Slice loop:

- **DSLICE\_ID:** This 8-bit field uniquely identifies a Data Slice within the C2 System.
- **DSLICE\_TUNE\_POS:** This field indicates the tuning position of the associated Data Slice relative to the START\_FREQUENCY. Its bit width shall be 13 bits or 14 bits according to the GUARD\_INTERVAL value. When GUARD\_INTERVAL is '00', the bit width of this field shall be 13 bits and indicate the tuning position in multiples of 24 carriers within current C2 Frame. Otherwise the bit width of this field shall be 14 bits and indicate the tuning position in multiples of 12 carriers within the current C2 Frame relative to the START\_FREQUENCY. DSLICE\_TUNE\_POS must be a value at least 1 704 carriers from the edge of a broadband notch or the start or end of the C2 system.
- **DSLICE\_OFFSET\_LEFT:** This field indicates the start position of the associated Data Slice by means of the distance to the left from the tuning position and shall be two's complement integer of 8 bits or 9 bits according to the GUARD\_INTERVAL value. When GUARD\_INTERVAL is '00', this field shall be two's complement integer of 8 bits and indicate the distance from the tuning position in multiples of 24 carriers within current C2 Frame. Otherwise this field shall be two's complement integer of 9 bits and indicate the distance from the tuning position in multiples of 12 carriers within current C2 Frame.

- **DSLICE\_OFFSET\_RIGHT:** This field indicates the end position of the associated Data Slice by means of the distance to the right from the tuning position and shall be two's complement integer of 8 bits or 9 bits according to the GUARD\_INTERVAL value. When GUARD\_INTERVAL is '00', this field shall be two's complement integer of 8 bits and indicate the distance from the tuning position in multiples of 24 carriers within current C2 Frame. Otherwise this field shall be two's complement integer of 9 bits and indicate the distance from the tuning position in multiples of 12 carriers within current C2 Frame.

NOTE 2: DSLICE\_OFFSET\_LEFT and DSLICE\_OFFSET\_RIGHT may both have positive or negative values, which means that the complete Data Slice is left or right hand side of the tuning position.

- **DSLICE\_TI\_DEPTH:** This 2-bit field indicates the time interleaving depth within the associated Data Slice according to table 20.

**Table 20: Signalling format for the time interleaving depth**

Value	TI depth
00	No time interleaving
01	4 OFDM Symbols
10	8 OFDM Symbols
11	16 OFDM Symbols

- **DSLICE\_TYPE:** This 1-bit field indicates the type of the associated Data Slice according to table 21. The Data Slice Type 1 is only for the transmission of a single PLP with fixed modulation and coding parameters within a Data Slice. See clause 7 for more information.

**Table 21: Signalling format for the Data Slice type**

Value	Data Slice type
0	Data Slice Type 1
1	Data Slice Type 2

The following field appears only if the DSLICE\_TYPE is '1'.

- **FEC\_HEADER\_TYPE:** This 1-bit field indicates the type of the FECFrame header within the associated Data Slice according to table 22.

**Table 22: Signalling format for the FECFrame header type**

Value	FECFrame header type
0	Robust mode
1	High efficiency mode

- **DSLICE\_CONST\_CONF:** This 1-bit field indicates whether the configuration of the associated Data Slice is variable or fixed. If this field is set to value '1', the configuration of the associated Data Slice shall not change. Otherwise this field shall be set to '0'. A value of '1' is only allowed in combination with Data Slices Type 2.
- **DSLICE\_LEFT\_NOTCH:** This 1-bit field indicates the presence of the left neighboured Notch band of the associated Data Slice. If the start of associated Data Slice is neighboured by Notch band, this field shall be set to '1'. Otherwise this field shall be set to '0'.

NOTE 3: The DSLICE\_LEFT\_NOTCH field can be used by a receiver to assist in finding the number of Data Cells of the current Data Slice. The continual pilots positioned on the edge of the Notch band change the number of Data Cells of its right neighboured Data Slice. See clause 9.6.4.1 for more information.

- **DSLICE\_NUM\_PLP:** This 8-bit field indicates the number of PLPs carried within the associated Data Slice. The minimum value of this field shall be '1'.

NOTE 4: Both the number of Data Slices and the number of PLPs for each Data Slice of a C2 System are chosen such, that the overall L1-part2 signalling does not exceed 32 766 bits.

The following fields appear in the PLP loop:

- **PLP\_ID:** This 8-bit field identifies a PLP within the C2 System.
- **PLP\_BUNDLED:** This 1-bit field indicates whether the associated PLP is bundled with other PLP(s) or not within the current C2 System. If the associated PLP is bundled, this field shall be set to '1'. Otherwise this field shall be set to '0'.
- **PLP\_TYPE:** This 2-bit field indicates the type of the associated PLP. PLP\_TYPE shall be signalled according to table 23.

**Table 23: Signalling format for the PLP\_TYPE field**

Value	PLP type
00	Common PLP
01	Grouped Data PLP
10	Normal Data PLP
11	Reserved for future use

- **PLP\_PAYLOAD\_TYPE:** This 5-bit field indicates the type of the payload data carried by the associated PLP. PLP\_PAYLOAD\_TYPE shall be signalled according to table 24. See clause 5.1.1 for more information.

**Table 24: Signalling format for the PLP\_PAYLOAD\_TYPE field**

Value	Payload type
00000	GFPS
00001	GCS
00010	GSE
00011	TS
00100 to 11111	Reserved for future use

The following field appears only if the PLP\_TYPE is '00' or '01'.

- **PLP\_GROUP\_ID:** This 8-bit field identifies with which PLP group within the C2 System the current PLP is associated. This can be used by a receiver to link the Data PLP to its associated Common PLP, which will have the same PLP\_GROUP\_ID.

The following fields appear only if the DSLICE\_TYPE is '0', i.e. the Data Slice Type 1 is used.

- **PLP\_START:** This 14-bit field indicates the start position of the first complete XFECframe of the associated PLP within the current C2 Frame. It uses the cell addressing scheme defined in clause 9.4.3.
- **PLP\_FEC\_TYPE:** This 1-bit field indicates the FEC type used by the associated PLP. The FEC type shall be signalled according to table 25.
- **PLP\_MOD:** This 3-bit field indicates the modulation used by the associated PLP. The modulation shall be signalled according to table 25.

The signalling is valid for the first XFECframe starting within the DVB-C2 frame.



**Table 25: Signalling format for the PLP\_MOD and the PLP\_COD fields**

PLP_FEC_TYPE	PLP_MOD	PLP FEC type	Modulation	XFECFrame Length
0	000	16K LDPC	Reserved	NA
	001		16QAM	4 050
	010		64QAM	2 700
	011		256QAM	2 025
	100		1024QAM	1 620
	101		4096QAM	1 350
	110		Reserved	1 158
	111		Reserved	1 013
1	000	64K LDPC	Reserved	900
	001		16QAM	16 200
	010		64QAM	10 800
	011		256QAM	8 100
	100		1024QAM	6 480
	101		4096QAM	5 400
	110		Reserved	4 629
	111		Reserved	4 050

NOTE 5: The XFECframe length of the associated PLP is determined by PLP\_FEC\_TYPE and PLP\_MOD as shown in table 25.

- **PLP\_COD:** This 3-bit field indicates the code rate used by the associated PLP. The code rate shall be signalled according to table 26. When PLP\_COD is '101', the code rate is determined by PLP\_FEC\_TYPE. If PLP\_FEC\_TYPE is set to '0', PLP\_COD of '101' means the code rate of 8/9. Otherwise it means the code rate of 9/10. Please note that not all possible PLP\_MOD and PLP\_COD combinations are supported (see tables 11(a) and 11(b)).

**Table 26: Signalling format for the code rate**

Value	Code rate
000	Reserved for future use
001	2/3
010	3/4
011	4/5
100	5/6
101	8/9 (16K LDPC code) 9/10 (64K LDPC code)
110 to 111	Reserved for future use

- **PSI/SI\_REPROCESSING:** This 1-bit field indicates whether PSI/SI reprocessing is performed or not. This can be used by a receiver to recognize if it can rely on the related PSI/SI parts. When PSI/SI reprocessing is performed, this field shall be set to '1', otherwise it shall be set to '0'.

The following fields appear only if the PSI/SI\_REPROCESSING is '0'.

- **transport\_stream\_id:** This is a 16-bit field which serves as a label for identification of this TS from any other multiplex within the delivery system (see also [i.4]).
- **original\_network\_id:** This 16-bit field gives the label identifying the network\_id of the originating delivery system (see also [i.4]).
- **RESERVED\_1:** This 8-bit field is reserved for future use.
- **RESERVED\_2:** This 8-bit field is reserved for future use.

The following fields appear in the Notch loop:

- **NOTCH\_START:** This field indicates the start position of the associated Notch band and gives the unsigned integer value relative to the **START\_FREQUENCY**. Its bit width shall be 13 bits or 14 bits according to the **GUARD\_INTERVAL** value. When **GUARD\_INTERVAL** is '00', the bit width of this field shall be 13 bits and indicate the start position in multiples of 24 carriers within the current C2 Frame. Otherwise the bit width of this field shall be 14 bits and indicate the start position in multiples of 12 carriers within the current C2 Frame.
- **NOTCH\_WIDTH:** This field indicates the width of the associated Notch band and gives the unsigned integer value. Its bit width shall be 8 bits or 9 bits according to the value of **GUARD\_INTERVAL**. When **GUARD\_INTERVAL** is '00', the bit width of this field shall be 8 bits and indicate the width in multiples of 24 carriers within the current C2 Frame. Otherwise the bit width of this field shall be 9 bits and indicate the width in multiples of 12 carriers within the current C2 Frame.
- **RESERVED\_3:** This 8-bit field is reserved for future use.
- **RESERVED\_TONE:** This 1-bit field indicates whether some carriers are reserved. When there are reserved carriers within the current C2 Frame, this bit shall be set to '1', otherwise it shall be set to '0'. The positions of reserved carriers for reserved tones within a C2 Frame are given in clause 9.7.
- **RESERVED\_4:** This 16-bit field is reserved for future use.

### 8.3.1 L1 block padding

This 1-bit field is inserted following the L1 signalling part 2 data to ensure that the length of L1 signalling part 2 including L1 signalling part 2 data and L1 block padding is a multiple of 2 (see figure 20). If the total length of L1 signalling part 2 is not a multiple of 2, this field shall be inserted at the end of the L1 signalling part 2 data. The value of the L1 block padding bit, if any, shall be set to '0'.

### 8.3.2 CRC for the L1 signalling part 2

A 32-bit error detection code is applied to the entire L1 signalling part 2 including L1 signalling part 2 data and L1 block padding. The location of the CRC field can be found from the length of the L1 signalling part 2, which can be calculated using **L1\_INFO\_SIZE** in the Preamble header. The CRC-32 is defined in annex E.

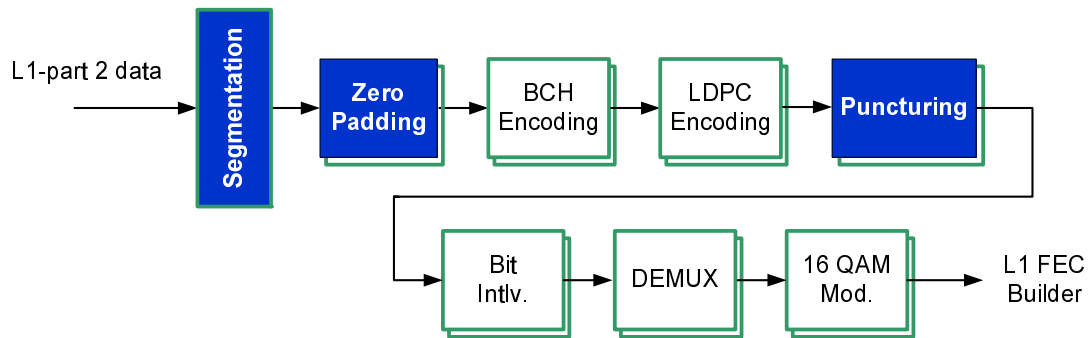
### 8.3.3 L1 padding

This variable-length field is inserted following the L1 signalling part 2 CRC field to ensure that multiple LDPC blocks of the L1 signalling part 2 have the same information size when the L1 signalling part 2 is segmented into multiple blocks and these blocks are separately encoded. Details of how to determine the length of this field are described in clause 8.4. The value of the L1 padding bits, if any, are set to '0'.

## 8.4 Modulation and error correction coding of the L1 part 2 data

### 8.4.1 Overview

The L1 part 2 data is protected by a concatenation of BCH outer code and LDPC inner code. The L1 part 2 data shall be first BCH-encoded. The length of the L1 part 2 data bits varies depending on the complexity of the underlying Data Slices. The L1 part 2 data can be segmented into multiple blocks. A segmented L1 part 2 data has a length less than BCH information length  $K_{bch} = 7\,032$ . Therefore, a shortening operation (zero padding) is required for BCH or LDPC encoding. After BCH encoding with zero padded information, the BCH parity bits of the L1-part2 data shall be appended to the L1 part 2 data. The concatenated L1 part 2 data and BCH parity bits are further protected by a shortened and punctured 16K LDPC code with code rate  $1/2$  ( $N_{ldpc} = 16\,200$ ). Note that the effective code rate of the 16K LDPC code with code rate  $1/2$  is  $4/9$ , where the effective code rate is defined as the information length over the encoder output length. Details of how to shorten and puncture the 16K LDPC code are described in clauses 8.4.3.1, 8.4.3.4 and 8.4.3.5. Each coded L1 signalling part 2 shall be bit-interleaved (see clause 8.4.3.6) and then shall be mapped onto constellations (see clause 8.4.4). Note that only 16QAM is used for encoding of L1 signalling part 2. The conceptual processing of coding and modulation of L1 signalling part 2 is shown in figure 21.

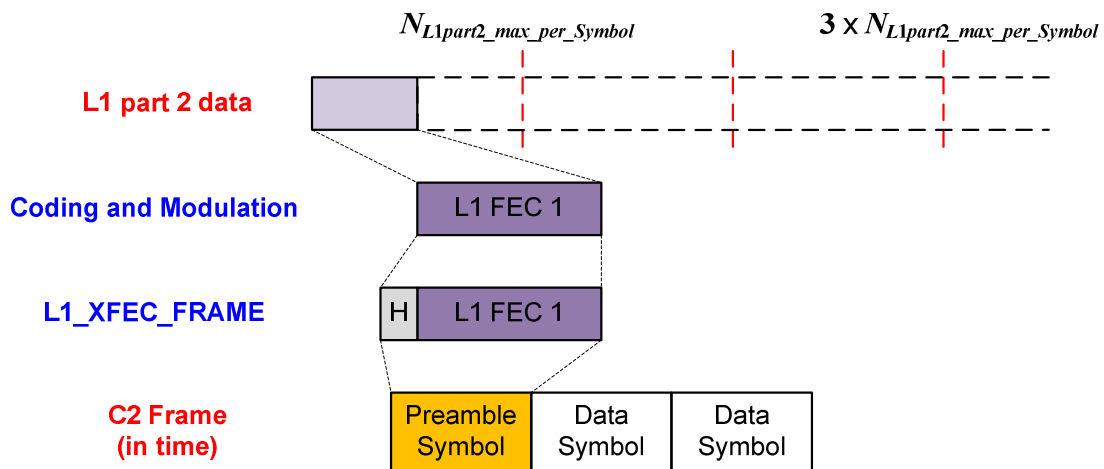


**Figure 21: Encoding and Modulation of L1 signalling part 2**

Since the length of L1 signalling part 2 is variable, the resulting number of needed L1 frames is also varying. Each L1 FECFrame packet corresponds to one L1 block within an OFDM Symbol. As soon as more than one L1 FECFrame packet is needed, the same number of Preamble Symbols in consecutive OFDM Symbols is needed. If the length of L1 part 2 data exceeds a predetermined number  $N_{L1part2\_max\_per\_Symbol}$  (see clause 8.4.2), the L1 part 2 data shall be divided into equidistant blocks.  $N_{L1part2\_max\_per\_Symbol}$  means the maximum number of L1 information bits for transmitting the coded L1 signalling part 2 through one OFDM Symbol. Figures 22 (a) and 22 (b) show the handling example for the following cases:

- L1 part 2 fits into one L1 part 2 LDPC FECFrame (see figure 22 (a)).
- L1 part 2 exceeds one L1 part 2 LDPC FECFrame (see figure 22 (b)).

Details of the segmentation are described in clause 8.4.2.



**Figure 22(a): L1 part 2 fits into one L1 part 2 LDPC FECFrame**

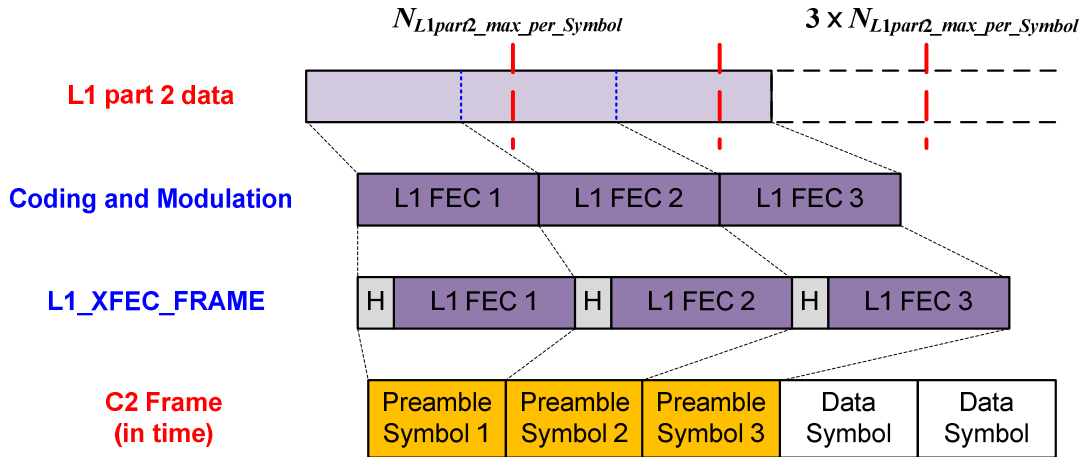


Figure 22(b): L1 part 2 exceeds one L1 part 2 LDPC FECFrame

According to the signalling field for time interleaving in L1 signalling part 2 header, 'L1\_TI\_MODE', the time interleaving can be applied to L1 FECFrame (see clause 8.2). Details of the time interleaving are described in clause 8.5.

If there are cells remaining from each Preamble Symbol after mapping each L1 FECFrame to the Preamble Symbol, the L1 FECFrame including L1 part 2 header is cyclically repeated until the complete preamble block is filled, as shown in figure 23. The information on the structure of a cyclically repeated L1 FECFrame in a Preamble Symbol is obtained by detecting and extracting of L1 part 2 header.

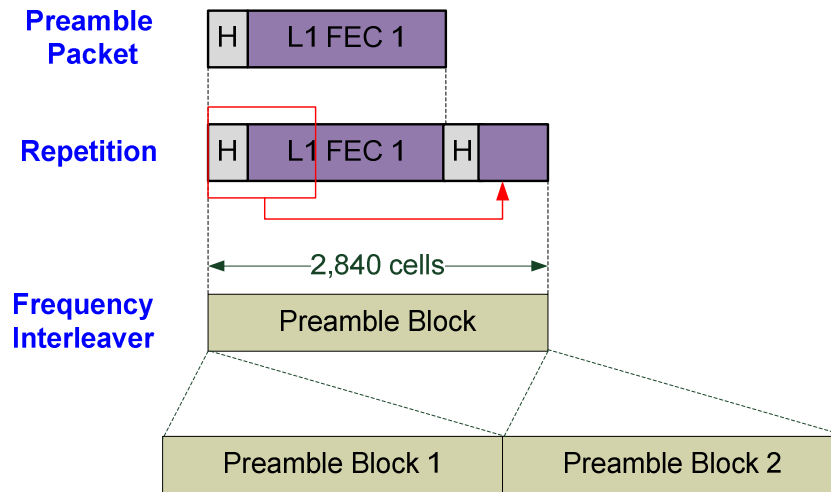


Figure 23: Allocation of L1 FECFrame to L1 blocks (Preamble blocks)

#### 8.4.2 Parameters for FEC encoding of L1 part 2 data

The number of L1 part 2 data bits is variable and the bits shall be transmitted over one or multiple 16K LDPC blocks depending on the length of the L1 part 2 data. The number of LDPC blocks for the L1 part 2 data,  $N_{L1part2\_FEC\_Block}$ , shall be determined as follows:

$$N_{L1part2\_FEC\_Block} = \left\lceil \frac{K_{L1part2\_ex\_pad}}{N_{L1part2\_max\_per\_Symbol}} \right\rceil,$$

where  $\lceil x \rceil$  means the smallest integer larger than or equal to  $x$ , and  $K_{L1part2\_ex\_pad}$ , which can be found by adding 32 to the parameter  $2 \times L1\_INFO\_SIZE$ , denotes the number of information bits of the L1 part 2 signalling excluding the padding field,  $L1\_PADDING$  (see clause 8.3.3).

$N_{L1part2\_max\_per\_Symbol}$  is 4 759 which is chosen as the minimum value among the maximum values of  $K_i$  satisfying that  $N_{L1part2}(K_i)$  is less than or equal to  $N_{L1part2\_Cells} \times \eta_{MOD}$ , for  $i = 1, 2, \dots, 8$ . Here,  $N_{L1part2\_Cells}$  (= 2 808) denotes the number of available cells for L1 signalling part 2 in one OFDM Symbol,  $\eta_{MOD}$  denotes the modulation order 4 for 16QAM, and  $N_{L1part2}(K_i)$  is the length of the encoded L1 signalling part 2 with  $K_i$  information bits for  $N_{L1part2\_FEC\_Block} = i$ . Then, the length of L1\_PADDING field,  $K_{L1part2\_PADDING}$  shall be calculated as:

$$K_{L1part2\_PADDING} = \left\lceil \frac{K_{L1part2\_ex\_pad}}{N_{L1part2\_FEC\_Block}} \right\rceil \times N_{L1part2\_FEC\_Block} - K_{L1part2\_ex\_pad} .$$

The final length of the whole L1 signalling part 2 including the padding field,  $K_{L1part2}$  shall be set as follows:

$$K_{L1part2} = K_{L1part2\_ex\_pad} + K_{L1\_PADDING} .$$

The number of information bits in each of  $N_{L1part2\_FEC\_Block}$  blocks,  $K_{sig}$  is then defined by:

$$K_{sig} = \frac{K_{L1part2}}{N_{L1part2\_FEC\_Block}} .$$

Each block with information size of  $K_{sig}$  is protected by a concatenation of BCH outer codes and LDPC inner codes. Each block shall be first BCH-encoded, where its  $N_{bch\_parity}$  (= 168) BCH parity check bits shall be appended to information bits of each block. The concatenated information bits of each block and BCH parity check bits are further protected by a shortened and punctured 16K LDPC code with code rate 1/2 (effective code rate:  $R_{eff\_16K\_LDPC\_1\_2} = 4/9$ ). Details of how to shorten and puncture the 16K LDPC code are described in clauses 8.4.3.1, 8.4.3.4 and 8.4.3.5.

For a given  $K_{sig}$  and modulation order (16QAM is used for the L1 signalling part 2),  $N_{punc}$  shall be determined by the following steps:

Step 1) Calculate the number of puncturing bits as follows:

$$N_{punc\_temp} = \left\lfloor \frac{6}{5} \times (K_{bch} - K_{sig}) \right\rfloor ,$$

where  $K_{bch}$  is 7 032 for the 16K LDPC code with code rate 1/2, and the operation  $\lfloor x \rfloor$  means the largest integer less than or equal to  $x$ . A temporary size of puncturing bits is calculated by multiplying the shortening length by a fixed number 6/5.

The effective LDPC code rate of the L1 signalling part 2,  $R_{eff\_L1part2}$  is always lower than or equal to  $R_{eff\_16K\_LDPC\_1\_2}$ .  $R_{eff\_L1part2}$  tends to decrease as the information length  $K_{sig}$  decreases. This rate control ensures that the receiving coverage for the L1 signalling part 2 is preserved after the shortening and puncturing. The multiplicative coefficient 6/5 is the ratio of the puncturing length to the shortening length and it is chosen as the best value among those formed of  $(B+1)/B$  for an integer  $B$ .

$$\text{Step 2) } N_{L1part2\_temp} = K_{sig} + N_{bch\_parity} + N_{ldpc} \times (1 - R_{eff\_16K\_LDPC\_1\_2}) - N_{punc\_temp} .$$

For the 16K LDPC code with effective code rate 4/9,  $N_{ldpc} \times (1 - R_{eff\_16K\_LDPC\_1\_2}) = 9\,000$ .

- Step 3) According to the value of time interleaving field, 'L1\_TI\_MODE', in the L1 part 2 header (see clause 8.2),  $N_{L1part2}$  shall be calculated as follows:

$$N_{L1part2} = \begin{cases} \text{If } L1\_TI\_MODE = 00 \text{ or } 01, \\ \left\lceil \frac{N_{L1part2\_temp}}{2\eta_{MOD} \times N_{L1part2\_FEC\_Block}} \right\rceil \times 2\eta_{MOD} \times N_{L1part2\_FEC\_Block} \\ \text{Otherwise,} \\ \left\lceil \frac{N_{L1part2\_temp}}{2\eta_{MOD} \times N_{L1\_TI\_Depth}} \right\rceil \times 2\eta_{MOD} \times N_{L1\_TI\_Depth} \end{cases}$$

where  $\eta_{MOD}$  is 4 for 16QAM, and  $N_{L1\_TI\_Depth}$  is 4 and 8 for  $L1\_TI\_MODE = 10$  and  $11$ , respectively, as shown in clause 8.2.

This step guarantees that  $N_{L1part2}$  is a multiple of the number of columns of the bit interleaver,  $2\eta_{MOD}$ , (described in clause 8.4.3.6) and that  $N_{L1part2}/\eta_{MOD}$  is a multiple of the number of OFDM Symbols for transmitting L1 signalling part 2. Note that the number of OFDM Symbols for transmitting L1 signalling part 2 are  $N_{L1part2\_FEC\_Block}$  and  $N_{L1\_TI\_Depth}$  for 'L1\_TI\_MODE = 00, 01' and 'L1\_TI\_MODE = 10, 11', respectively.

$$\text{Step 4) } N_{punc} = N_{punc\_temp} - (N_{L1part2} - N_{L1part2\_temp}).$$

$N_{L1part2}$  is the number of the encoded bits for each information block. After the shortening and puncturing, the encoded

bits of each block shall be mapped to  $N_{MOD\_per\_Block} = \frac{N_{L1part2}}{\eta_{MOD}}$  modulated symbols. The total number of the

modulation symbols of  $N_{L1part2\_FEC\_Block}$  blocks,  $N_{MOD\_Total}$  is  $N_{MOD\_Total} = N_{MOD\_per\_Block} \times N_{L1part2\_FEC\_Block}$ .

When 16QAM is used, a bit interleaving shall be applied across each LDPC block. Details of how to interleave the encoded bits are described in clause 8.4.3.6. Demultiplexing is then performed as described in clause 8.4.4.1. The demultiplexer output is then mapped to a 16QAM constellation, as described in clause 8.4.4.2.

## 8.4.3 FEC Encoding

### 8.4.3.1 Zero padding of BCH information bits

$K_{sig}$  bits defined in clause 8.4.2 shall be encoded into a 16K ( $N_{ldpc} = 16\,200$ ) LDPC codeword after BCH encoding.

Since the  $K_{sig}$  is always less than the number of BCH information bits ( $= K_{bch} = 7\,032$ ) for a given code rate 1/2, the BCH code shall be shortened. A part of the information bits of the 16K LDPC code shall be padded with zeros in order to fill  $K_{bch}$  information bits. The padding bits shall not be transmitted.

All  $K_{bch}$  BCH information bits, denoted by  $\{m_0, m_1, \dots, m_{K_{bch}-1}\}$ , are divided into  $N_{group}$  ( $= K_{ldpc}/360$ ) groups as follows:

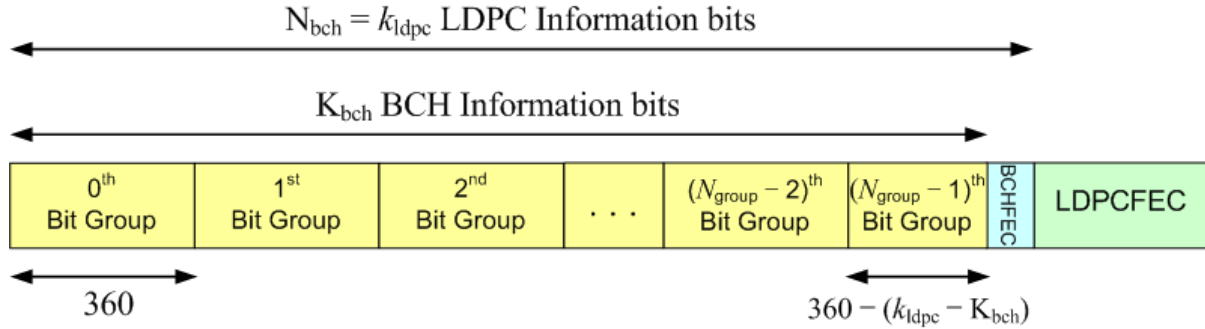
$$X_j = \left\{ m_k \left| j = \left\lfloor \frac{k}{360} \right\rfloor, 0 \leq k < K_{bch} \right. \right\} \text{ for } 0 \leq j < N_{group},$$

where  $X_j$  represents the  $j$ th bit group. The code parameters ( $K_{bch}$ ,  $K_{ldpc}$ ) are given in table 27 for L1 part 2 data.

**Table 27: Code parameters ( $K_{bch}$ ,  $K_{ldpc}$ ) for L1 part 2 data**

	$K_{bch}$	$K_{ldpc}$
L1 signalling part 2	7 032	7 200

For  $0 \leq j \leq N_{group} - 2$ , each bit group  $X_j$  has 360 bits and the last bit group  $X_{N_{group}-1}$  has  $360 - (K_{ldpc} - K_{bch}) = 192$  bits, as illustrated in figure 24.



**Figure 24: Format of data after LDPC encoding of L1 signalling part 2**

For the given  $K_{sig}$ , the number of zero-padding bits is calculated as  $(K_{bch} - K_{sig})$ . Then, the shortening procedure is as follows:

Step 1) Compute the number of groups in which all the bits shall be padded,  $N_{pad}$  such that:

$$\text{If } 0 < K_{sig} \leq 360, N_{pad} = N_{group} - 1$$

$$\text{Otherwise, } N_{pad} = \left\lfloor \frac{K_{bch} - K_{sig}}{360} \right\rfloor$$

Step 2) For  $N_{pad}$  groups  $X_{\pi_S(0)}, X_{\pi_S(1)}, \dots, X_{\pi_S(m-1)} X_{\pi_S(N_{pad}-1)}$ , all information bits of the groups shall be padded with zeros. Here,  $\pi_S$  is a permutation operator depending on the code rate and modulation order, described in table 28.

Step 3) If  $N_{pad} = N_{group} - 1$ ,  $(360 - K_{sig})$  information bits in the last part of the bit group  $X_{\pi_S(N_{group}-1)}$  shall be additionally padded. Otherwise, for the group  $X_{\pi_S(N_{pad})}$ ,  $(K_{bch} - K_{sig} - 360 \times N_{pad})$  information bits in the last part of  $X_{\pi_S(N_{pad})}$  shall be additionally padded.

Step 4) Finally,  $K_{sig}$  information bits are sequentially mapped to bit positions which are not padded in  $K_{bch}$  BCH information bits,  $\{m_0, m_1, \dots, m_{K_{bch}-1}\}$  by the above procedure.

**EXAMPLE:** Suppose for example the value of  $K_{sig}$  is 3 986. In this case, from step (1), 8 groups would have all zero padded bits, and from step (2) these groups would be those with numbers 18, 17, 16, 15, 14, 13, 12, 11. From step (3), and additional 166 bits would be zero padded in Group 4. Finally from step (4) the 3 986 bits would be mapped sequentially to Groups 0, 1, 2, 3 (360 bits each), the first part of Group 4 (194 bits), Groups 5, 6, 7, 8, 9, 10 (360 bits each), and group 19 (192 bits). Figure 25 illustrates the shortening of the BCH information part in this case, i.e. filling BCH information bit positions not zero padded with  $K_{sig}$  information bits.

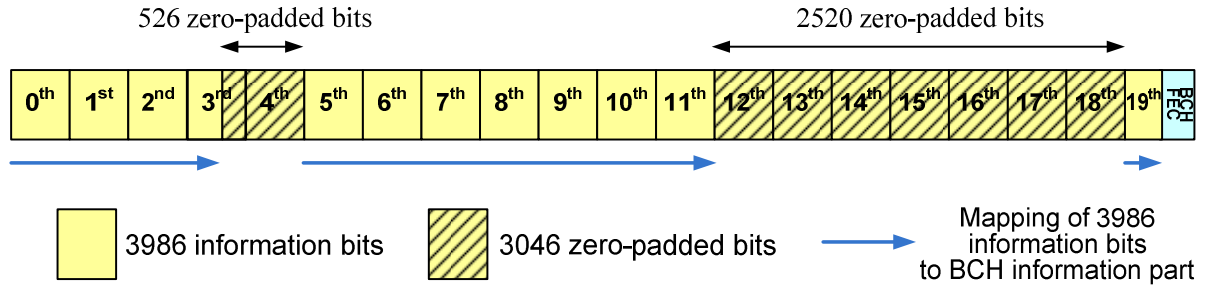


Figure 25: Example of shortening of BCH information part

Table 28: Permutation sequence of information bit group to be padded for L1 signalling part 2

Modulation and code rate		$N_{group}$	$\pi_s(j) \ (0 \leq j < N_{group})$									
			$\pi_s(0)$	$\pi_s(1)$	$\pi_s(2)$	$\pi_s(3)$	$\pi_s(4)$	$\pi_s(5)$	$\pi_s(6)$	$\pi_s(7)$	$\pi_s(8)$	$\pi_s(9)$
			$\pi_s(10)$	$\pi_s(11)$	$\pi_s(12)$	$\pi_s(13)$	$\pi_s(14)$	$\pi_s(15)$	$\pi_s(16)$	$\pi_s(17)$	$\pi_s(18)$	$\pi_s(19)$
16QAM	1/2	20	18	17	16	15	14	13	12	11	4	10
			9	8	7	3	2	1	6	5	19	0

#### 8.4.3.2 BCH encoding

The  $K_{bch}$  information bits (including the  $K_{bch} - K_{sig}$  zero padding bits) shall first be BCH encoded according to clause 6.1.1 to generate  $N_{bch} = K_{ldpc}$  output bits ( $i_0 \dots i_{N_{bch}-1}$ ).

#### 8.4.3.3 LDPC encoding

The  $N_{bch} = K_{ldpc}$  output bits ( $i_0 \dots i_{N_{bch}-1}$ ) from the BCH encoder, including the  $(K_{bch} - K_{sig})$  zero padding bits and the  $(K_{ldpc} - K_{bch})$  BCH parity bits form the  $K_{ldpc}$  information bits  $\mathbf{I} = (i_0, i_1, \dots, i_{K_{ldpc}-1})$  for the LDPC encoder. The LDPC encoder shall systematically encode the  $K_{ldpc}$  information bits onto a codeword  $\mathbf{A}$  of size  $N_{ldpc}$ :

$$\mathbf{A} = (i_0, i_1, \dots, i_{K_{ldpc}-1}, p_0, p_1, \dots, p_{N_{ldpc}-K_{ldpc}-1}) \text{ according to clause 6.1.2.}$$

#### 8.4.3.4 Puncturing of LDPC parity bits

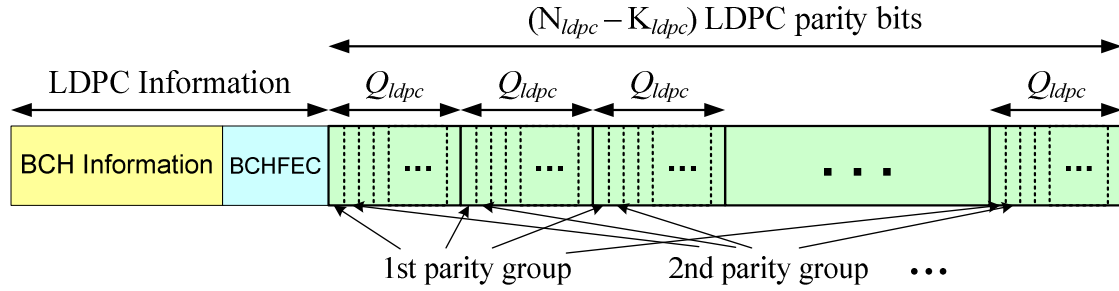
When the shortening is applied to encoding of the signalling bits, some LDPC parity bits shall be punctured after the LDPC encoding. These punctured bits shall not be transmitted.

All  $N_{ldpc} - K_{ldpc}$  LDPC parity bits, denoted by  $\{p_0, p_1, \dots, p_{N_{ldpc}-K_{ldpc}-1}\}$ , are divided into  $Q_{ldpc}$  parity groups where each parity group is formed from a sub-set of the  $N_{ldpc} - K_{ldpc}$  LDPC parity bits as follows:

$$P_j = \left\{ p_k \mid k \bmod Q_{ldpc} = j, 0 \leq k < N_{ldpc} - K_{ldpc} \right\} \quad \text{for} \quad 0 \leq j < Q_{ldpc},$$

where  $P_j$  represents the  $j$ th parity group and  $Q_{ldpc}$  is given in table 5(b). Each group has  $(N_{ldpc} - K_{ldpc})/Q_{ldpc} = 360$  bits, as illustrated in figure 26.





**Figure 26: Parity bit groups in an FEC block**

For the number of parity bits to be punctured,  $N_{punc}$  given in clause 8.4.2.

Step 1) Compute the number of groups in which all parity bits shall be punctured,  $N_{punc\_groups}$  such that:

$$N_{punc\_groups} = \left\lfloor \frac{N_{punc}}{360} \right\rfloor \text{ for } 0 \leq N_{punc} < N_{ldpc} - K_{ldpc}.$$

Step 2) For  $N_{punc\_groups}$  parity bit groups  $P_{\pi_p(0)}, P_{\pi_p(1)}, \dots, P_{\pi_p(N_{punc\_groups}-1)}$ , all parity bits of the groups shall be punctured. Here,  $\pi_p$  is a permutation operator depending on the code rate and modulation order, described in table 29.

Step 3) For the group  $P_{\pi_p(N_{punc\_groups})}$ ,  $(N_{punc} - 360 \times N_{punc\_groups})$  parity bits in the first part of the group shall be additionally punctured.

**Table 29: Permutation sequence of parity group to be punctured for L1 signalling part 2**

Modulation and code rate		Order of parity group to be punctured, $\{\pi_p(j), 0 \leq j < Q_{ldpc} = 25\}$												
		$\pi_p(0)$	$\pi_p(1)$	$\pi_p(2)$	$\pi_p(3)$	$\pi_p(4)$	$\pi_p(5)$	$\pi_p(6)$	$\pi_p(7)$	$\pi_p(8)$	$\pi_p(9)$	$\pi_p(10)$	$\pi_p(11)$	$\pi_p(12)$
		$\pi_p(13)$	$\pi_p(14)$	$\pi_p(15)$	$\pi_p(16)$	$\pi_p(17)$	$\pi_p(18)$	$\pi_p(19)$	$\pi_p(20)$	$\pi_p(21)$	$\pi_p(22)$	$\pi_p(23)$	$\pi_p(24)$	-
16QAM	1/2	6	4	13	9	18	8	15	20	5	17	2	22	24
		7	12	1	16	23	14	0	21	10	19	11	3	-

#### 8.4.3.5 Removal of zero padding bits

The  $(K_{bch} - K_{sig})$  zero padding bits are removed and shall not be transmitted. This leaves a word consisting of the  $K_{sig}$  information bits, followed by the 168 BCH parity bits and  $(N_{ldpc} - K_{ldpc} - N_{punc})$  LDPC parity bits.

#### 8.4.3.6 Bit interleaving for L1 signalling part 2

When 16QAM modulation is used for the L1 signalling part 2, the LDPC codeword of length  $N_{L1part2}$ , consisting of  $K_{sig}$  information bits, 168 BCH parity bits, and  $(9\,000 - N_{punc})$  LDPC parity bits, shall be bit-interleaved using a block interleaver. The configuration of the bit interleaver for the chosen 16QAM modulation is specified in table 30.

**Table 30: Bit Interleaver structure**

Modulation and code rate		Rows $N_r$	Columns $N_c$
16QAM	1/2	$N_{L1part2} / 8$	8

The LDPC codeword is serially written into the interleaver column-wise, and serially read out row-wise (the MSB of the L1 signalling part 2 is read out first) as shown in figure 27.

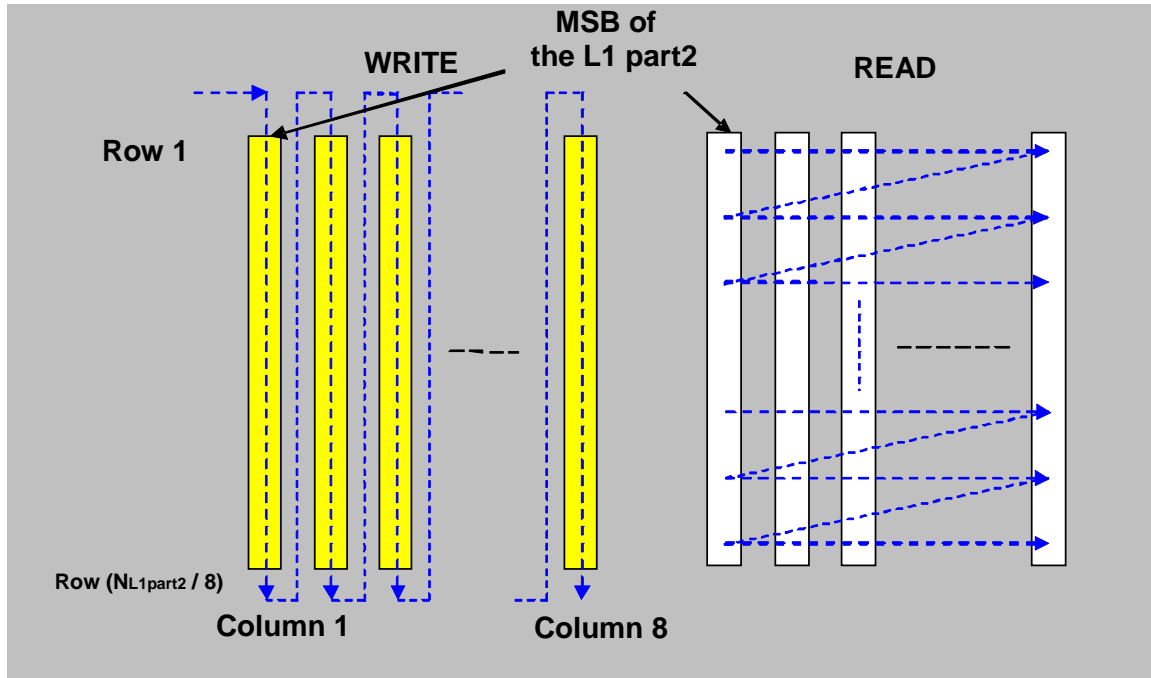


Figure 27: Bit interleaving scheme for L1 part 2 (16QAM)

#### 8.4.4 Mapping bits onto constellations

Each bit-interleaved LDPC codeword shall be mapped onto constellations. The L1 signalling part 2 is first demultiplexed into cell words according to clause 8.4.4.1 and then the cell words are mapped into constellations according to clause 8.4.4.2.

##### 8.4.4.1 Demultiplexing of L1 signalling part 2

Each bit-interleaved LDPC codeword, a sequence of  $N_{L1part2}$  ( $= K_{sig} + 168 + 9\,000 - N_{punc}$ ) bits shall be mapped onto constellations by first demultiplexing the input bits into parallel cell words and then mapping these cell words into constellation values. The number of output Data Cells and the effective number of bits per cell,  $\eta_{MOD}$  are defined in table 31.

The input bit-stream  $v_{di}$  is demultiplexed into  $N_{substreams}$  sub-streams  $b_{e,do}$ , as shown in figure 13 in clause 6.2.1. The value of  $N_{substreams}$  is also defined in table 31. Details of demultiplexing are described in clause 6.2.1. For 16QAM, the parameters for demultiplexing of bits to cells are the same as that of table 10(a) in clause 6.2.1.

Table 31: Parameters for bit-mapping into constellations

Modulation mode	$\eta_{MOD}$	Number of output Data Cells	Number of sub-streams, $N_{substreams}$
16QAM	4	$N_{L1part2} / 4$	8

For 16QAM, the output words from the demultiplexing of width  $N_{substreams}$ ,  $[b_{0,do} \dots b_{N_{substreams}-1,do}]$  are split into two words of width  $\eta_{MOD} = N_{substreams} / 2$ ,  $[y_{0,2do} \dots y_{\eta_{MOD}-1,2do}]$  and  $[y_{0,2do+1} \dots y_{\eta_{MOD}-1,2do+1}]$ , as described in clause 6.2.1.

##### 8.4.4.2 Mapping onto QAM constellations

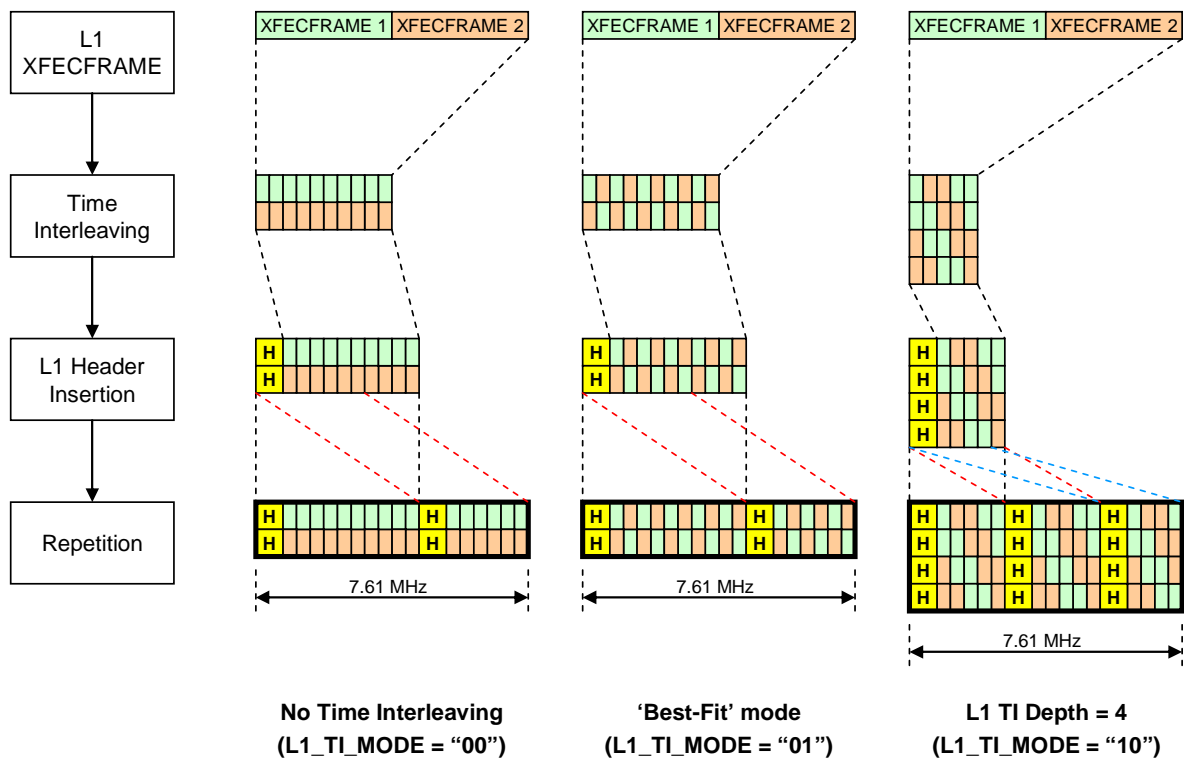
The cell words of each coded L1 signalling part 2,  $[y_{0,q} \dots y_{\eta_{MOD}-1,q}]$  are mapped into constellations  $f_q$  according to clause 6.2.2, where  $q$  is the index of the cells within each bit-interleaved LDPC codeword. For each coded L1 signalling part 2,  $0 \leq q < N_{MOD\_per\_Block}$ .

## 8.5 Time interleaving of L1 signalling part 2 data

The purpose of time interleaving of the L1-part 2 data is to make L1-part2 data transmission more robust than the payload data, especially when time interleaving is applied to Data Slice. Time interleaving of L1-part2 data is identical to that of Data Slice except that pilot and reserved tone positions in a preamble are completely excluded in time interleaving process.

The Time Interleaver (TI) shall operate at L1-part2 data level before the L1 XFECFrame with L1 header is repeated to fill a L1 block symbol bandwidth. The time interleaving and L1 block building with different interleaving parameters are depicted in figure 28.

The L1\_TI\_MODE indicates the depth of L1-part2 data time interleaving and signalled in L1 header signalling. L1\_TI\_MODE = "00" means no time interleaving is applied for L1-part2 data. When L1\_TI\_MODE = "01" (best-fit), the time interleaving depth is the minimum number of OFDM Symbols necessary for carrying a L1 block, or  $N_{L1part2\_FEC\_Block}$  (see clause 8.4.2 for more details of segmentation of L1-part2 data). Otherwise, the time interleaving depth is explicitly signalled and the depth is 4 OFDM Symbols when L1\_TI\_MODE = "10" as shown in figure 28.



**Figure 28: Time interleaving of L1-part2 data**

All L1-part2 Data Cells after constellation mapping are grouped into one L1 TI block. As a result, there exists one L1 TI block per C2 Frame. The length of time interleaving period  $T_P$  is calculated as:

$$T_P = T_S \times N_{L1\_TI\_DEPTH},$$

where  $T_S$  is a total OFDM Symbol duration and  $N_{L1\_TI\_DEPTH}$  is the time interleaving depth determined by L1\_TI\_MODE signalled in L1 header signalling.

The TI shall be a twisted row-column block interleaver like as in the Data Slice. The number of rows  $N_r$  of a TI memory is equal to  $N_{LI\_TI\_DEPTH}$  and the number of columns  $N_c$  is calculated as:

$$N_c = N_{MOD\_Total} / N_{LI\_TI\_DEPTH} ,$$

where  $N_{MOD\_Total}$  is the total number of the L1-part2 Data Cells. Note that  $N_{LI\_TI\_DEPTH}$  should be equal or larger than minimum number of OFDM Symbols required for carrying the L1 block,  $N_{L1part2\_FEC\_Block}$ . Details of required number of bits and cells for carrying L1-part2 data is described in clause 8.4.2.

The input L1-part2 Data Cells are serially written into the TI memory in a diagonal direction, and serially read out row-wise as shown in figure 29.

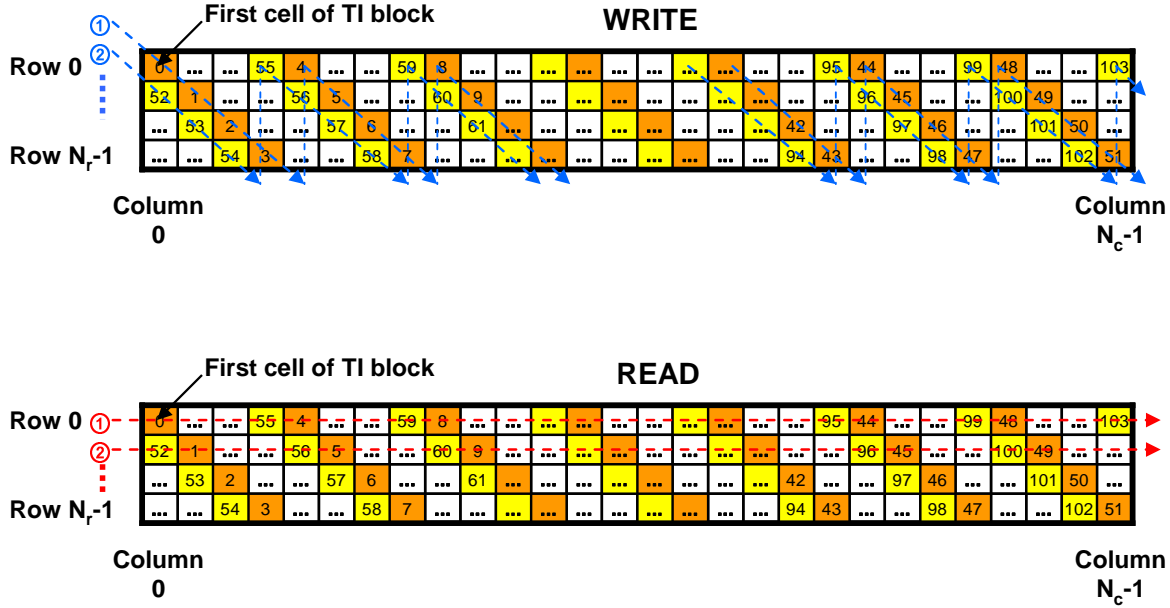


Figure 29: Time interleaving of L1 data ( $N_{MOD\_TOTAL}=208$ ,  $N_{LI\_TI\_DEPTH}=4$ )

Assuming  $d_i$  ( $i = 0, \dots, N_{MOD\_Total}-1$ ) as the L1-part2 Data Cells input to the time interleaver, the column index  $C_i$ , the row index  $R_i$  and associated twisting parameter  $T_{C_i}$  to store  $d_i$  is calculated as:

$$C_i = i \bmod N_c$$

$$T_{C_i} = C_i \bmod N_r$$

$$R_i = (T_{C_i} + (i \div N_c)) \bmod N_r.$$

Every cell position in the TI memory is uniquely defined by a coordinate  $(R_i, C_i)$ . The L1-part2 Data Cells  $d_i$  are written in positions  $(R_i, C_i)$ :

```
for ( $i = 0; i < N_{MOD\_Total}; i = i + 1$ ) {
    GENERATE ( $R_i, C_i$ );
    WRITE  $d_i$  to ( $R_i, C_i$ );
}
```

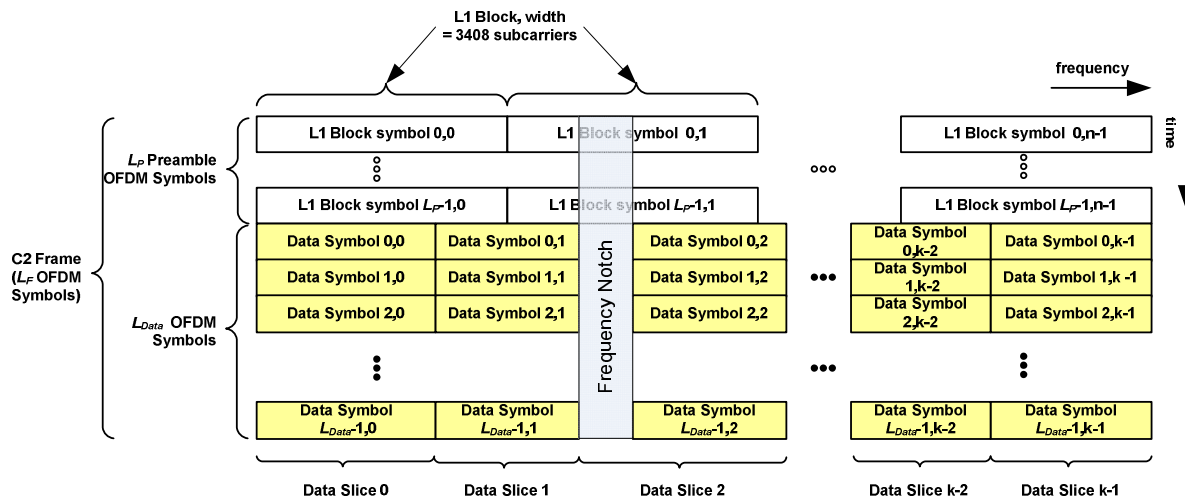
Note that the time interleaving structure shall not be changed after frame building although neither pilot nor reserved tone position is considered in L1-part2 data time interleaving process, which is different from the case of Data Slice.

## 9 Frame Builder

This clause defines the frame builder functions that always apply for a C2 System. The function of the frame builder is to assemble the cells of the Preamble Symbols(s) as well as the cells produced for each of the Data Slices into arrays of active OFDM Cells corresponding to the preamble structure and each of the Data Slices and OFDM Symbols which make up the overall frame structure. The frame builder operates according to the dynamic information produced by the scheduler (see clause 5.2.1) and the configuration of the frame structure.

### 9.1 C2 Frame structure

The C2 Frame structure is shown in figure 30. The C2 Frame structure comprises  $L_P$  Preamble Symbols ( $L_P \geq 1$ ) followed by  $L_{data}$  Data Symbols. The Preamble Symbols are divided in frequency direction into L1 block symbols of same bandwidth (3 408 subcarriers or approximately 7,61 MHz). The Data Slices have an arbitrary bandwidth as a multiple of the pilot pattern specific granularity but shall not exceed the L1 block symbol bandwidth. Frequency Notches can be inserted into the C2 signal across a C2 Frame. The insertion of frequency Notches is described in clauses 9.3.5 and 9.4.1.3.



**Figure 30: The C2 Frame structure: the C2 Frame starts with at least one Preamble Symbol ( $L_P$ ) followed by  $L$  Data Symbols**

The special properties of the Preamble Symbols are explained in clause 9.3. The L1 block symbols of the Preamble Symbol(s) allow reliable time and frequency synchronization and also carry the L1 signalling data part 2. The L1 signalling part 2 data to be carried is described in clause 8.3, its modulation, error correction and coding and the mapping of this data onto the L1 block symbols is described in clause 8.4.

#### 9.1.1 Duration of the C2 Frame

The beginning of the first Preamble Symbol marks the beginning of the C2 Frame. The data part of the C2 Frame consists of  $L_{data} = 448$  symbols (approx. 203,8 ms for  $GI = 1/64$  or 202,2 ms for  $GI = 1/128$ ,  $T_U = 448 \mu s$ ).

The number of Preamble Symbols  $L_P$  can be derived from the length information at the beginning of each L1 signalling part 2 block.

The C2 Frame duration is therefore given by:

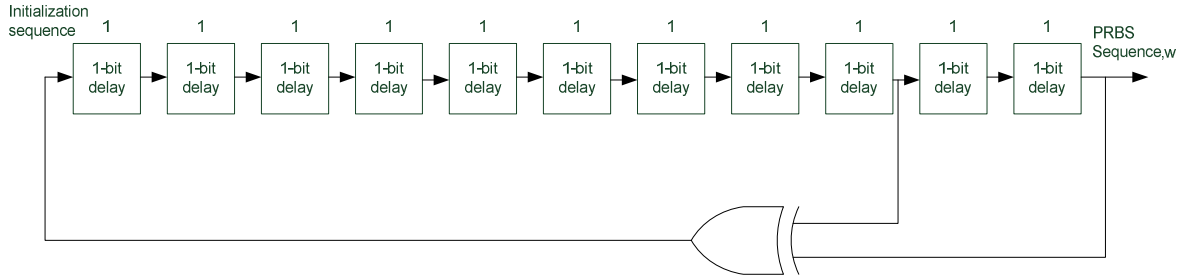
$$T_F = (L_P + L_{data}) \times T_s,$$

where  $T_s$  is the total OFDM Symbol duration.

## 9.2 Pilot Reference Sequence

### 9.2.1 Data Scrambling Sequence

The reference sequence described below is used to scramble the preamble data and is used to generate the pilot's modulation.



**Figure 31: Generation of PRBS sequence**

The PRBS sequence,  $w_i$  is generated according to figure 31, where  $w_i$  is the  $i$ -th output value of the PRBS generator. Its polynomial for the PRBS generator shall be:

$$X^{11} + X^2 + 1$$

The shift register is initialized with all '1's so that the sequence begins with  $w_0, w_1, w_2 \dots = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0 \dots$

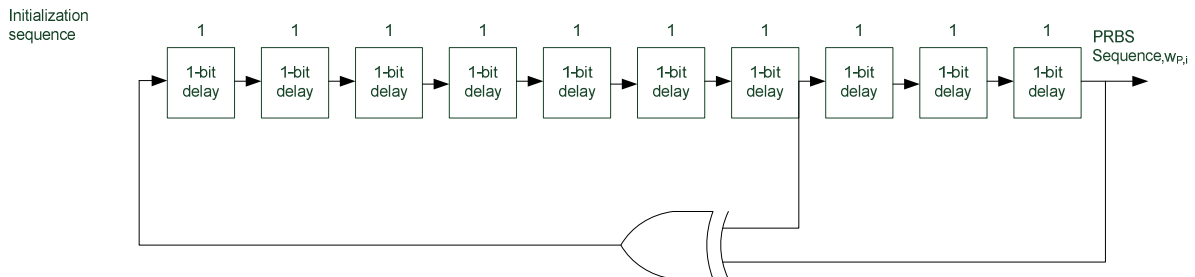
### 9.2.2 Pilot Scrambling Sequence

The pilots shall carry a unique synchronization sequence  $w_k^P$ , where  $k$  is the absolute OFDM carrier index.

The sequence is defined as:

$$w_k^P = w_k \oplus w_i' \text{ with } i = (k \bmod K_{L1}) / D_p$$

Where:  $k$  is the OFDM carrier index,  $w_i'$  is the  $i$ -th output of the PRBS generator defined below,  $w_k$  is the  $k$ -th output of the reference sequence defined in clause 9.2.1 and  $D_p = 6$  is the separation of the preamble pilots. Please note that  $i$  is always an integer value, as the reference sequence is only defined for pilot positions (i.e.  $k \bmod D_p = 0$ ).



**Figure 32: Definition of pilot modulation**

The corresponding sequence  $w_i'$  is generated by the PRBS defined in figure 32. Its polynomial shall be:

$$X^{10} + X^3 + 1$$

The register is initialized to all '1's and the sequence begins  $w_0', w_1', w_2' \dots = 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0 \dots$

### 9.2.3 Pilot Reference Sequence

The preamble pilots shall be differentially BPSK modulated against each other. Therefore, the pilot reference sequence is generated by differential modulation of the pilot scrambling sequence, which is achieved by an XOR operation.

The pilot reference sequence for each OFDM pilot at position  $k$  is therefore given by:

$$r_k = \begin{cases} w_k^P & \text{if } k \bmod K_{L1} = 0 \\ r_{k-6} \oplus w_k^P & \text{otherwise} \end{cases}$$

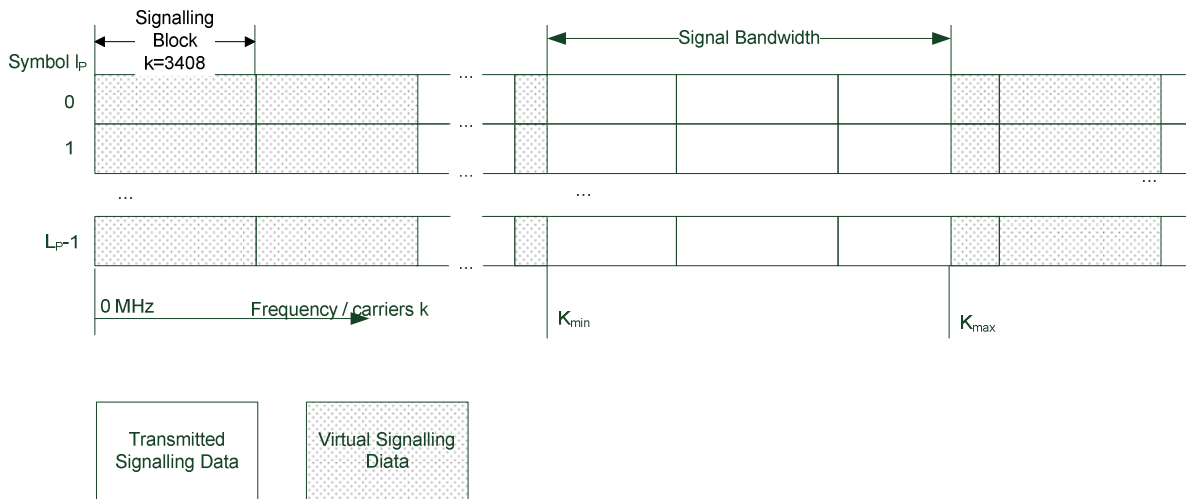
where  $r_k$  only has to be defined if  $k$  is multiple of 6.

## 9.3 Preamble Symbol

### 9.3.1 Preamble Symbol overview

At the beginning of every frame a Preamble Symbol shall be sent. The Preamble Symbol is constructed with  $L_p$  OFDM Symbols, while the Preamble Symbol shares the same OFDM parameters as the normal Data Symbols. In the frequency domain, the preamble is subdivided into L1 Signalling Blocks. Each L1 Signalling Block contains all Layer 1-part 2 information as defined in clause 8.

The definition of the OFDM Cell  $c_{m,l,k}^P$  is calculated generically for  $k = 0, \dots, \infty$ . However, this definition is for simplicity only and only the OFDM carriers  $K_{\min} \leq k \leq K_{\max}$  have to be calculated and are transmitted, where  $K_{\min}$  is the lowest frequency used by the C2 Signal and  $K_{\max}$  is the highest frequency used by the C2 Signal. This structure is also depicted in figure 33. The carriers outside the actual signal bandwidth are referred to as virtual signalling data. Their purpose is the clarification of the cyclic frequency structure of the signalling data.



**Figure 33: Preamble symbol structure in the frequency domain**

### 9.3.2 Frequency Interleaving

The purpose of the preamble frequency interleaver is the separation of neighbouring data cells and to avoid error bursts caused by narrow band interferers or frequency selectivity. Therefore, the same frequency interleaver as for the Data Slices shall be used (see clause 9.4.5), which works on the  $N_{L1} = 2\,840$  data cells of each L1 Block.

The interleaved vector  $A_{l_p}^P = (a_{l_p,0}^P, a_{l_p,1}^P, \dots, a_{l_p,N_p-1}^P)$  is defined by:

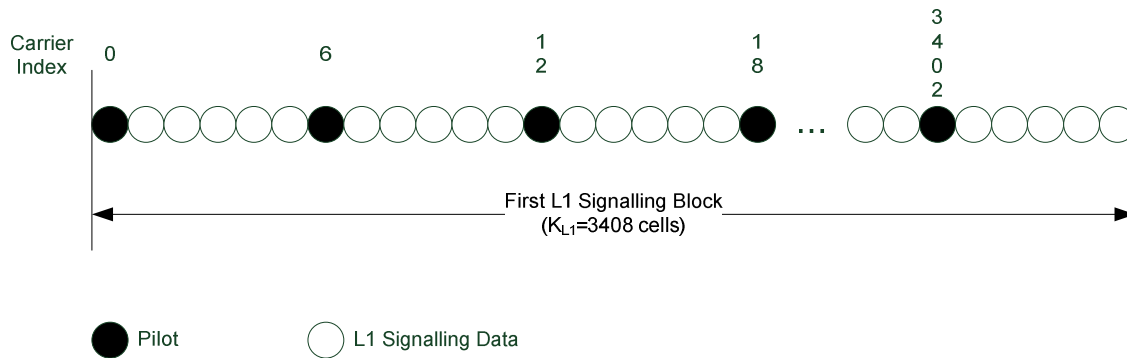
$$a_{l_p,q}^P = x_{l_p, H_0(q)} \text{ for even symbols in the preamble } (l_p \bmod 2 = 0) \text{ for } q = 0, 1, \dots, N_{L1} - 1$$

$$a_{l_p,q}^P = x_{l_p, H_1(q)} \text{ for odd symbols in the preamble } (l_p \bmod 2 = 1) \text{ for } q = 0, 1, \dots, N_{L1} - 1$$

with  $N_{L1} = 2\,840$ .

### 9.3.3 Pilot insertion

The pilots of each Signalling Block are uniquely defined and allow for the time and frequency synchronization to the preamble. Unlike the normal pilots, the pilots within the preamble are transmitted at the same power level as the data, i.e. they are not boosted. The pilots are differentially BPSK modulated against each other, giving a receiver the possibility to synchronize on this differentially encoded reference information.



**Figure 34: L1 Block signalling**

#### 9.3.3.1 Locations of the preamble pilots

A given OFDM carrier  $k$  of the Preamble Symbol is a pilot if the following equation is fulfilled:

$$k \bmod D_p = 0$$

Where:  $k$  is the OFDM carrier index and  $D_p = 6$  is the separation of the preamble pilots.

#### 9.3.3.2 Amplitude and modulation of the preamble pilots

The pilots shall be modulated as:

$$\text{Re}\{c_{m,l_p,k}^P\} = A_{pp} \cdot 2(1/2 - r_k)$$

$$\text{Im}\{c_{m,l_p,k}^P\} = 0$$

Where  $A_{pp}$  is the amplitude of the preamble pilots,  $r_k$  is the pilot reference sequence as defined in clause 9.2.3,  $m$  is the C2 Frame,  $l_p$  is the Preamble Symbol number and  $k$  is the absolute carrier index.

The amplitude of preamble pilots ( $A_{pp}$ ) is fixed to  $A_{pp}=6/5$  in case of 1/128 Guard Interval and fixed to  $A_{pp}=4/3$  in case of 1/64 Guard Interval.



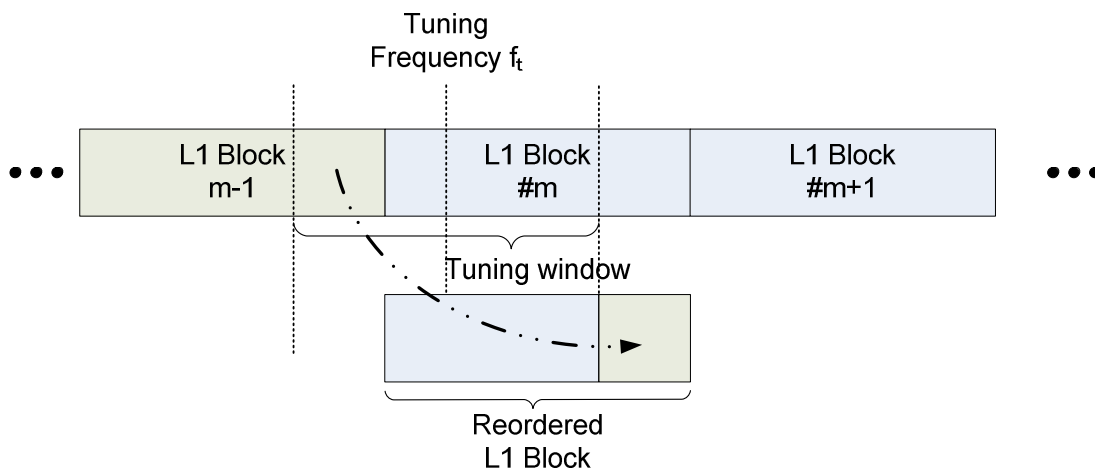
### 9.3.4 Mapping and scrambling of the signalling data

The OFDM Cells that are not occupied by pilots shall carry signalling data. As the signalling data is cyclic in the frequency domain, it shall be scrambled. The content of each data preamble OFDM Cell  $k$  is defined as:

$$\begin{aligned} \text{Re}\{c_{m,l_p,k}^P\} &= \text{Re}\{a_{l_p,q}^P\} \cdot (-1)^{w_k} \\ \text{Im}\{c_{m,l_p,k}^P\} &= \text{Im}\{a_{l_p,q}^P\} \cdot (-1)^{w_k} \end{aligned} \quad \text{with } q = (k \bmod K_{L1}) - \lceil (k \bmod K_{L1}) / 6 \rceil$$

Where  $a_{l_p,q}^P$  is the output of the frequency interleaver of OFDM Symbol  $l_p$  at index  $q$ ,  $w_k$  is the  $k$ -th output of the reference sequence defined in clause 9.2.1 and  $K_{L1} = 3\,408$  is the number of OFDM carriers per L1 Signalling Block.

Since Data Slices are typically not aligned to L1 signalling blocks the receiver tuning window typically contains parts of different L1 signalling blocks. The re-ordering of the included sub-carriers to retrieve the L1 block in the frequency domain (i.e. after FFT on receiver side) is shown in figure 35.



**Figure 35: Retrieving a complete L1 block out of two partial L1 blocks**

Depending on the receiver tuning frequency  $f_t$ , (given as actual tuning position as OFDM subcarrier mod  $K_{L1}$ ) the reordered L1 Block (including pilots) is described as follows (3 584 subcarrier receiver example):

- $f_t \bmod K_{L1} < 1\,704$ :  $L1\_subcarriers = [L1_m(f_t \dots (f_t + 1704)), L1_{m-1}((f_t + K_{L1} - 1703) \dots K_{L1})]$
- $f_t \bmod K_{L1} \geq 1\,704$ :  $L1\_subcarriers = [L1_m((f_t - 1\,703) \dots K_{L1}), L1_{m+1}(1 \dots (f_t - K_{L1} + 1\,704))]$

With  $m$  as the index of the L1 block.

### 9.3.5 Notches within Preamble Symbols

Equivalent to Data Slices Preamble Symbols may contain Notches. The cells within preamble Notches shall not carry any transmit power. Preamble Notches always coincide with Data Slice Notches, i.e. the same OFDM sub-carriers are omitted. Notches can be applied to Preamble Symbols in 2 different ways.

#### 9.3.5.1 Narrowband Notches

Narrowband Notches have a bandwidth below 48 OFDM subcarriers. The Data Slices bandwidth is a multiple of the guard interval granularity (i.e. 11, 23, 35, 47 subcarriers for  $GI = 1/64$  or 23, 47 subcarriers for  $GI = 1/128$ ).

The lack of L1 signalling in narrowband Notches is compensated by the preamble FEC. Only one narrowband Notch shall be allowed at any tuning position of 3408 OFDM subcarriers (i.e. 7,61 MHz for the 8 MHz mode and 5,71 MHz for the 6 MHz mode) bandwidth.

### 9.3.5.2 Broadband Notches

Broadband Notches have a bandwidth higher than 47 subcarriers. For Data Slice decoding the receiver tuner shall not tune to a region with a broadband Notch since a reliable L1 decoding cannot be guaranteed (missing L1 blocks cannot be recovered by the preamble FEC in every case).

Broadband Notches shall not be inserted in the C2 System unless at least one neighbored continuous L1 signalling block region above 3 408 subcarriers is available. During initial acquisition to a C2 System this allows the receiver to recognize the broadband Notch and to retune to a frequency range with consistent L1 signalling data.

Broadband Notches shall always be located between different Data Slices.

In case the set of subcarriers of C2 system neighbored to a broadband notch is below 3 408 subcarriers (i.e. L1 blocks can't be decoded in a reliable way), all Data Slices within this set of subcarriers shall use the Data Slice Type 2 and be configured to 'fixed' (i.e. DSLICE\_CONST\_CONF flag in L1 part 2 signalling is set to 1).

In any case the minimum set of subcarriers of a C2 System neighbored to a broadband notch is 841 subcarriers, ensuring that at least 5 continual pilots are available in the related frequency band for proper signal processing in receivers.

## 9.4 Data Slice generation

Data Slices can be treated as separate channels and no interleaving is performed between different ones. Each Data Slice is identified by a start OFDM carrier  $K_{DS,min}$  and an end OFDM carrier  $K_{DS,max}$ , whereby  $K_{DS,min} \geq K_{min}$  and  $K_{DS,max} < K_{max}$ . Data Slices shall only start and end at scattered pilots positions and end next to a scattered pilot position. Additionally, Data Slices shall not overlap each other.

### 9.4.1 Location of Data Slices

#### 9.4.1.1 Start and end OFDM carrier of Data Slices

The start and the end frequency of the Data Slices is signalled in the Layer 1 Signalling by means of the START\_FREQUENCY, the DSLICE\_TUNE\_POS, the DSLICE\_OFFSET\_LEFT and DSLICE\_OFFSET\_RIGHT values. While the START\_FREQUENCY and the DSLICE\_TUNE\_POS are quasi static between different C2 Frames, the other two values may change every frame, depending on the chosen mode. As the Data Slices shall only start at scattered pilots positions and end next to them, the signalling depends on the value  $D_X$  (which depends on the Guard Interval size). Furthermore, the value of START\_FREQUENCY shall be a multiple of  $D_X$  as well.

Thus, the start frequency and end carrier of a Data Slice shall be:

$$K_{DS,min} = (DSLICE\_TUNING\_POS + DSLICE\_OFFSET\_LEFT) \cdot D_X + START\_FREQUENCY$$

$$K_{DS,max} = (DSLICE\_TUNING\_POS + DSLICE\_OFFSET\_RIGHT) \cdot D_X + START\_FREQUENCY - 1$$

#### 9.4.1.2 Maximum width of Data Slices

The width of each Data Slice shall not exceed 3 408 OFDM carriers (7,61 MHz for  $T_U = 448 \mu s$ ), i.e.:

$$K_{DS,max} - K_{DS,min} < 3408$$

If the width of a Data Slice exceeds 3 408 OFDM carriers, the receiver shall ignore the Data Slice, i.e. treat it as not present.

### 9.4.1.3 Minimum width of Data Slices

The Layer 1 signalling may indicate Data Slices without any payload capacity. Such Data Slices may be used if no payload data has to be transmitted. These Data Slices shall be signalled by:

$$DSLICE\_OFFSET\_LEFT = DSLICE\_OFFSET\_RIGHT$$

No Data Slices with negative width shall be signalled. If Data Slices with negative width are received, these Data Slices shall be ignored by the receiver.

If DSLICE\_TYPE is '0' and the Data Slice has a width > 0, the Data Slice shall be able to transmit at least one complete Data Slice Packet.

### 9.4.1.4 Notches within Data Slices

Data Slices may contain Notches. The cells within these Notches shall not carry any transmit power. The start and the end carrier of each Notch are indicated within the corresponding Layer 1 signalling. Notches always start and end next to scattered pilot positions.

The start carrier and end carrier of each Notch shall be defined as:

$$K_{N,min} = NOTCH\_START \cdot D_X + START\_FREQUENCY + 1$$

$$K_{N,max} = (NOTCH\_START + NOTCH\_WIDTH) \cdot D_X + START\_FREQUENCY - 1$$

where  $D_X$  is the guard interval dependent pilots repartition. Notches having a NOTCH\_WIDTH of 0 shall be ignored by the receiver.

## 9.4.2 Number of payload cells in Data Slice

The number of payload cells per Data Slice per OFDM Symbol  $N_{DS}$  equals  $(K_{DS,max} - K_{DS,min} + 1)$  minus the number of continual pilots, scattered pilots, reserved tones and cells that are located in Notches.

Please note that the number of payload cells in a Data Slice may vary between different OFDM Symbols in one C2 Frame.

## 9.4.3 Mapping of the Data Slice Packets

The Data Slice Packets shall be mapped onto the  $N_{DS}$  Data Cells per OFDM Symbol. Data Cells within a Data Slice are cells, which are not pilots, reserved tones or Notches. The Data Slice Packet data  $g_0, \dots, g_{N_X-1}$  shall be mapped onto the Data Cells  $a_{m,l,k}$  of the OFDM Symbol in an increasing value of the carrier index k within the range:

$$K_{DS,min} \leq k \leq K_{DS,max}$$

If the data of one Data Slice Packet exceeds the length of a C2 Frame, the data shall cross seamlessly into the next C2 Frame. If a Data Slice was not present in the previous C2 Frame (a Data Slice of width 0 was present), the Data Slice Packet data shall be mapped to the first available Data Cell of the Data Slice.

For DSLICE\_TYPE='0' the start of the first complete Data Slice Packet shall be signalled within the PLP\_START value of the Layer 1 signalling. If the Data Slice has zero width, the PLP\_START shall be set to zero.

If no payload data is to be transmitted for DATA\_SLICE\_TYPE '1', dummy Data Slice Packets shall be transmitted instead (see clause 7.2).

### 9.4.4 Time Interleaving

The time interleaver (TI) shall operate at Data Slice level. The parameters of time interleaving may be different for different Data Slices within a C2 System, while it is the same for all PLPs within a Data Slice. The exact number and positions of all pilots and reserved tones within each Data Slice shall be known to the TI prior to frame building.

The Data Cells from a Data Slice builder for each Data Slice shall be grouped into TI blocks. The start and/or end of Data Slice Packets of each PLP constituting the Data Slice may not be aligned with those of TI blocks. Each TI block within the Data Slice shall contain  $N_{DSLICE\_TI\_DATA\_CELL}$  payload Data Cells carried by  $N_{DSLICE\_TI\_DEPTH}$  Data Symbols.  $N_{DSLICE\_TI\_DEPTH}$  is known from DSLICE\_TI\_DEPTH signalled in L1 signalling part2 (see clause 8.3).  $N_{DSLICE\_TI\_DATA\_CELL}$  is calculated as:

$$N_{DSLICE\_TI\_DATA\_CELL} = \sum_{l \in TI\ block} N_{DS}^l$$

where  $N_{DS}^l$  is the number of payload cells of  $l$ -th Data Symbol of the TI block, which is described in clause 9.4.2 in more detail. Every TI block of the Data Slice shall have the same number of payload cells.

The length of time interleaving period  $T_P$  is defined as:

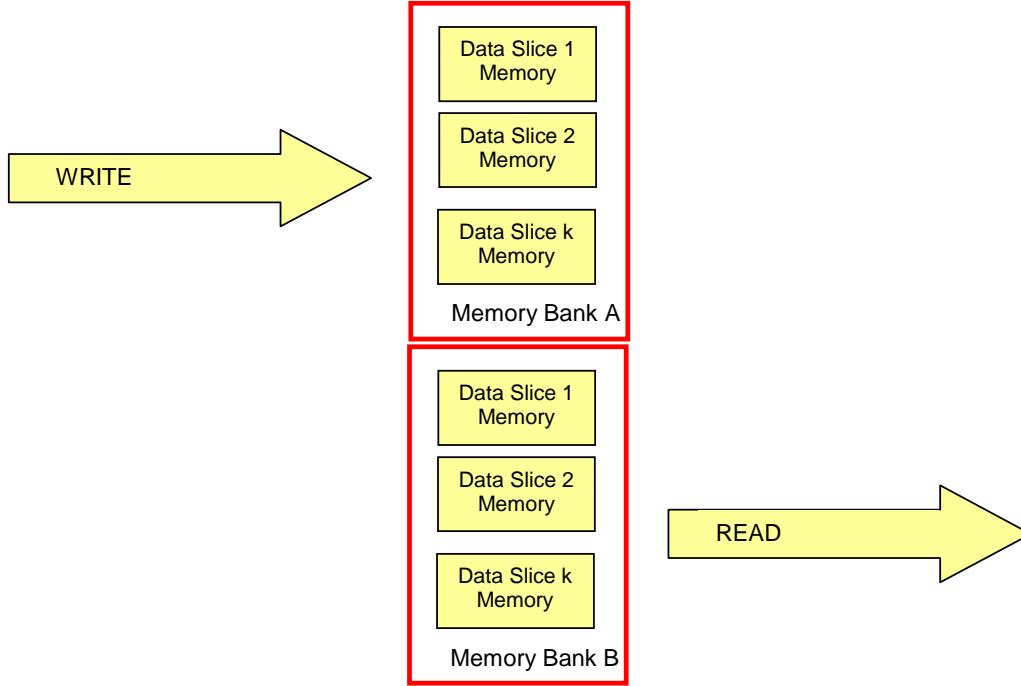
$$T_P = T_S \times N_{DSLICE\_TI\_DEPTH},$$

where  $T_S$  is a total OFDM Symbol duration.

Simple and typical TI memory space (one per Data Slice) is identical to the space of  $N_{DSLICE\_TI\_DEPTH}$  Data Symbols within the Data Slice. In other words, the TI memory space includes the positions of all pilot and reserved tone cells as well as  $N_{DSLICE\_TI\_DATA\_CELL}$  Data Cells. The pilot and reserved tone cell positions within TI memory may be filled with dummy zeros. Notch bands in the Data Slice may be discarded from the TI memory.

The TI shall store in the TI memories the Data Cells from the output of Data Slice builder. As the number and position of all pilots and reserved tones are previously known to the TI, the Data Cells should not be stored in pilot or reserved tone positions. Reserved pilot and reserved tone positions in the TI memory guarantees the time interleaving structure of Data Cells (shown in figure 37) are unchanged after frame building.

Typically, the time interleaver will also act as a buffer for Data Slice cells prior to the process of frame building. This can be achieved by means of two memory banks for each Data Slice. The first TI block is written to the first bank. The second TI block is written to the second bank whilst the first bank is being read from and so on, see figure 36.



**Figure 36: Example of operation of time interleaver memory banks**

The TI shall be a twisted row-column block interleaver: the number of rows  $N_r$  in the interleaver is equal to the time interleaving depth  $N_{DSLICE\_TI\_DEPTH}$  and the number of columns  $N_c$  to Data Slice width  $N_{DSLICE\_WIDTH}$ . The Data Slice width is identified by:

$$N_{DSLICE\_WIDTH} = K_{DS,max} - K_{DS,min} ,$$

where  $K_{DS,max}$  and  $K_{DS,min}$  is the start and end OFDM Cell index of the Data Slice respectively. More details of Data Slice configuration is described in clause 9.4.1.1. The input cells are serially written into the interleaver memory in a diagonal direction, and serially read out row-wise as shown in figure 37.

Assuming the index  $i$  ranging from 0 to  $(N_{DSLICE\_TI\_CELL}-1)$ , where  $N_{DSLICE\_TI\_CELL}$  is the total number of cells within  $N_{DSLICE\_TI\_DEPTH}$  Data Symbols of the Data Slice and calculated as:

$$N_{DSLICE\_TI\_CELL} = N_{DSLICE\_TI\_DEPTH} \times N_{DSLICE\_WIDTH} .$$

The column index  $C_i$ , the row index  $R_i$  and associated twisting parameter  $T_{C_i}$  is calculated as:

$$\begin{aligned} C_i &= i \bmod N_c \\ T_{C_i} &= C_i \bmod N_r \\ R_i &= (T_{C_i} + (i \div N_c)) \bmod N_r . \end{aligned}$$

Then, every cell positions in the TI memory is uniquely defined by a coordinate  $(R_i, C_i)$ . The input Data Cells  $d_k$  ( $k = 0, \dots, N_{DSLICE\_TI\_DATA\_CELL}-1$ ) are written in positions  $(R_i, C_i)$  ( $i = 0, \dots, N_{DSLICE\_TI\_CELL}-1$ ) within the TI memory only if the positions are assigned for payload Data Cells:

```

k = 0;
for (i = 0; i < NDSLICE_TI_CELL; i = i + 1) {
    GENERATE (Ri, Ci);
    if (Ri, Ci) = data cell position {
        WRITE dk to (Ri, Ci);
        k = k + 1;
    }
}

```

Note that the TI outputs only Data Cells from the TI memory excluding dummy pilot cells and reserved tones. As a result, the input and output Data Cell rates are unchanged after time interleaving.

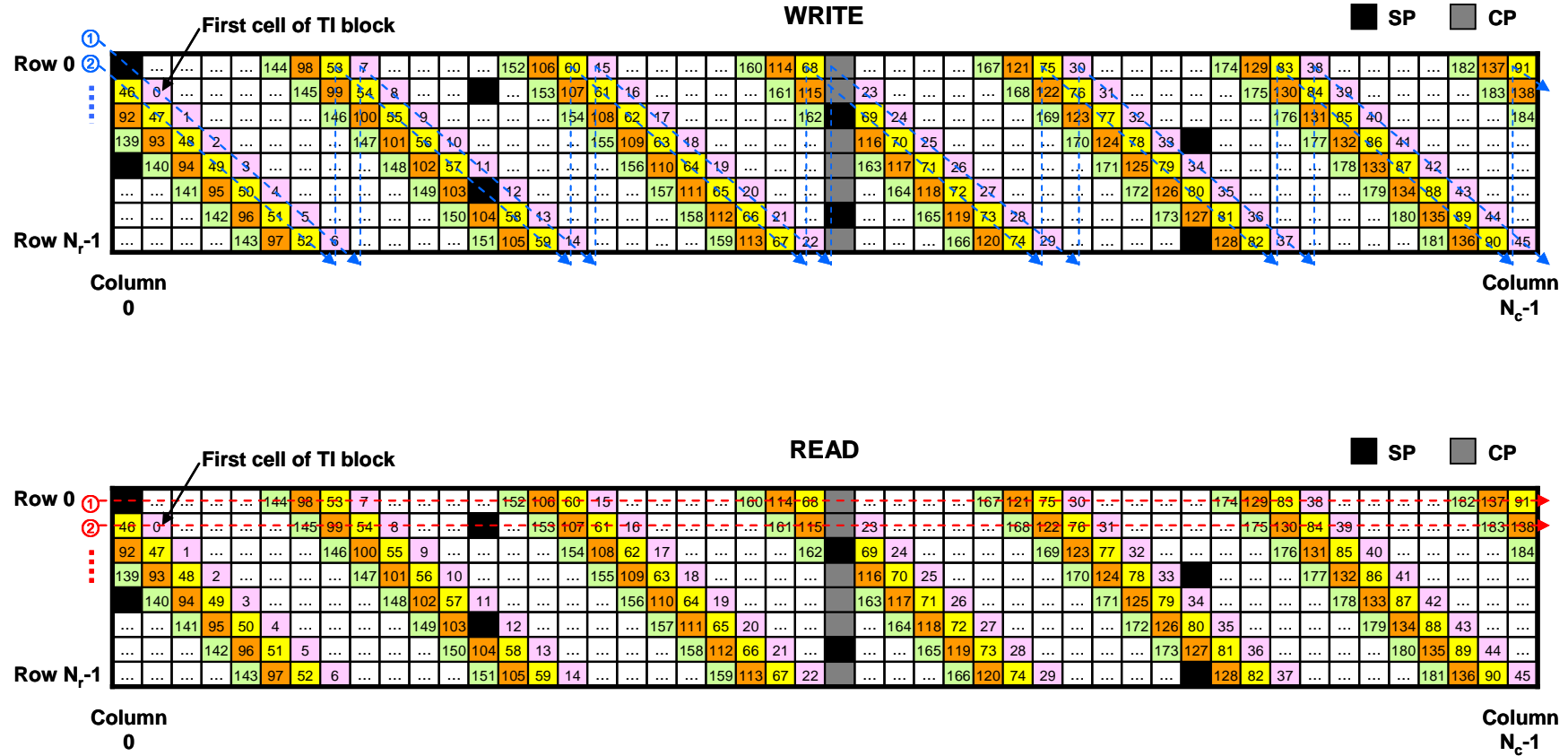


Figure 37: Time interleaver ( $D_X=12$ ,  $G_I=1/64$ ,  $N_r=8$ ,  $N_c=48$ ,  $DSLICE\_WIDTH=4$ )

### 9.4.5 Frequency Interleaving

The frequency interleaver operates on the Data Cells of one OFDM Symbol that comprise the slice of cells allocated to a given Data Slice. Its purpose is to map the Data Cells of this slice from the frame builder onto the  $N_{\text{data}}$  data carriers allocated for the given Data Slice in each OFDM Symbol.

For Data Slice  $n$ , the frequency interleaver shall process the Data Cells  $X_{m,l} = (x_{m,l,0}, x_{m,l,1}, \dots, x_{m,l,N_{\text{data}}(n)-1})$  of the OFDM Symbol  $l$  of C2 Frame  $m$  from the frame builder.

The parameter  $M_{\text{max}}$  is defined as 4 096, i.e. the smallest power of 2 higher than the maximum Data Slice width of 3 408 OFDM Cells.

For Data Slice  $n$  with  $N_{\text{data}}(n)$  data carriers in OFDM symbol  $l$  of  $M_{\text{max}}$  sub-carriers the interleaved vector  $A_{m,l} = (a_{m,l,0}, a_{m,l,1}, a_{m,l,2}, \dots, a_{m,l,N_{\text{data}}(n)-1})$  is defined by:

$$a_{m,l,q} = x_{m,l,H_0(q)} \text{ for even symbols of the frame } (l \bmod 2 = 0) \text{ for } q = 0, \dots, N_{\text{data}}(n)-1$$

$$a_{m,l,q} = x_{m,l,H_1(q)} \text{ for odd symbols of the frame } (l \bmod 2 = 1) \text{ for } q = 0, \dots, N_{\text{data}}(n)-1$$

$H_0(q)$  and  $H_1(q)$  are permutation function based on the sequence  $R'_i$  defined by the following.

An  $(N_r - 1)$  bit binary word  $R'_i$  is defined, with  $N_r = \log_2 M_{\text{max}}$ , where  $R'_i$  takes the following values:

$$i = 0, 1: \quad R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 0$$

$$i = 2: \quad R'_i [N_r-2, N_r-3, \dots, 1, 0] = 0, 0, \dots, 0, 1$$

$$2 < i < M_{\text{max}}: \quad \{ R'_i [N_r-3, N_r-4, \dots, 1, 0] = R'_{i-1} [N_r-2, N_r-3, \dots, 2, 1];$$

$$\text{where: } N_r = 12 \text{ and } R'_i [10] = R'_{i-1} [0] \oplus R'_{i-1} [2].$$

A vector  $R_i$  is derived from the vector  $R'_i$  by the bit permutations given in table 32.

**Table 32: Bit permutations for the 4K mode**

$R'_i$ bit positions	10	9	8	7	6	5	4	3	2	1	0
$R_i$ bit positions ( $H_0$ )	7	10	5	8	1	2	4	9	0	3	6
$R_i$ bit positions ( $H_1$ )	6	2	7	10	8	0	3	4	1	9	5

Each permutation function  $H(q)$  is defined by the following algorithm:

$$q = 0;$$

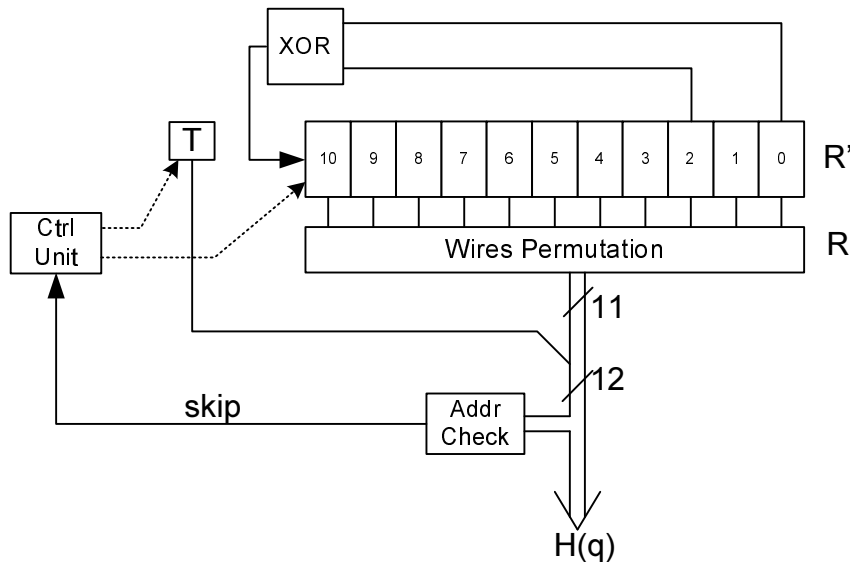
$$\text{for } (i = 0; i < M_{\text{max}}; i = i + 1)$$

$$\{ H(q) = (i \bmod 2) \cdot 2^{N_r-1} + \sum_{j=0}^{N_r-2} R_i(j) \cdot 2^j;$$

$$\text{if } (H(q) < N_{\text{data}}(n)) \quad q = q+1; \}$$

A schematic block diagram of the algorithm used to generate the permutation function is represented in figure 38.





**Figure 38: Frequency interleaver address generation scheme for the 4K mode OFDM**

The output of the frequency interleaver for Data Slice  $n$  is the interleaved vector of Data Cells  $A_{m,l} = (a_{m,l,0}, a_{m,l,1}, a_{m,l,2}, \dots, a_{m,l,N_{\text{data}}(n)-1})$  that is then allocated to Data Cells  $v_{m,l,i}$  of symbol  $l$  of C2 Frame  $m$  according to:

$$v_{m,l,B(n)+i} = a_{m,l,i}$$

where  $B(n)$  is the location of the first Data Cell of symbol  $l$  allocated to slice  $n$  and  $i = 0, 1, 2, \dots, N_{\text{data}}(n)-1$ .

## 9.5 Stuffing Data Slices

Within an OFDM signal Stuffing Data Slices may be transmitted. The Stuffing Data Slices shall not be signalled within the L1 signalling. Pilots and dummy carriers shall be transmitted at the same positions as in normal Data Slices.

The modulation of the cells not mapped to pilots or reserved tones shall carry a mean power value of 1. The transmitter shall ensure a random-like distribution of the modulation values.

## 9.6 Pilot Insertion

### 9.6.1 Introduction

Various cells within the OFDM frame are modulated with reference information whose transmitted value is known to the receiver. Cells containing reference information are transmitted at "boosted" power level. These cells are termed scattered, continual and edge pilots. The locations and amplitudes of these pilots are defined in clauses 9.6.2 to 9.6.4. The value of the pilot information is derived from a reference sequence,  $r_k$  which is a series of values, one for each transmitted carrier on any given symbol. The reference sequence is defined in clause 9.2.3.

The pilots can be used for frame synchronization, frequency synchronization, time synchronization, channel estimation and can also be used to follow the phase noise.

Table 33 gives an overview of the different types of pilot and the symbols in which they appear. This clause only describes pilots inserted to Data Symbols i.e. scattered, continual and edge pilots. Preamble pilots are described in clause 9.3.3.

**Table 33: Presence of the various types of pilots in each type of symbol (X=present)**

Symbol	PILOT TYPE			
	Scattered	Continual	Edge	Preamble
Preamble				X
Data	X	X	X	

The following clauses specify values for  $c_{m,l,k}$ , for certain values of  $m$ ,  $l$  and  $k$ , where  $m$  and  $l$  are the C2 Frame and symbol number as previously defined, and  $k$  is the OFDM carrier index (see clause 3.2).

## 9.6.2 Scattered pilot insertion

Reference information, taken from the reference sequence, is transmitted in scattered pilot cells in every symbol except Preamble Symbol(s) of the C2 Frame. The locations of the scattered pilots are defined in clause 9.6.2.1, their amplitudes are defined in clause 9.6.2.2 and their modulation is defined in clause 9.6.2.3.

### 9.6.2.1 Locations of the scattered pilots

The locations of scattered pilots depend only upon the symbol index  $l$ , carrier index  $k$  and the GI fraction. A given carrier  $k$  of the OFDM signal on a given symbol  $l$  will be a scattered pilot if the appropriate equation below is satisfied:

$$k \bmod (D_X \cdot D_Y) = D_X (l \bmod D_Y)$$

where:  $D_X, D_Y$  are defined in table 34.  
 $k$ : 0 RF origin carrier index.  
 $l$ : Data Symbol index.

**Table 34: Parameters defining the scattered pilot patterns**

GI Fraction	Separation of pilot bearing carriers ( $D_X$ )	Number of symbols forming one scattered pilot sequence ( $D_Y$ )
1/64	12	4
1/128	24	4

The scattered pilot patterns are illustrated in annex H.

### 9.6.2.2 Amplitudes of the scattered pilots

The amplitudes of the scattered pilots,  $A_{SP}$ , are fixed as 7/3. This amplitude is commonly used for continual pilots and edge pilots as well.

### 9.6.2.3 Modulation of the scattered pilots

The phases of the scattered pilots are derived from the reference sequence given in clause 9.3.

The modulation value of the scattered pilots is given by:

$$\text{Re}\{c_{m,l,k}\} = A_{SP} 2^{(1/2 - r_k)}$$

$$\text{Im}\{c_{m,l,k}\} = 0.$$

where  $A_{SP}$  is as defined in clause 9.6.2.2,  $r_k$  is defined in clause 9.3,  $m$  is the C2 Frame index,  $k$  is the frequency index of the carriers.

## 9.6.3 Continual pilot insertion

In addition to the scattered pilots described above, a number of continual pilots are inserted in every symbol of the frame except for Preamble Symbol(s). The number and location of continual pilots are the same for all GI fractions (i.e. for scattered pilot patterns).

### 9.6.3.1 Locations of the continual pilots

The continual pilot locations are defined within a block of  $K_{L1} = 3\,408$  carriers and this pattern is repeated to support the entire range of possible carriers. The  $K_{L1}$  carrier index block is aligned with the L1 signalling block, whose length is also  $K_{L1}$ .

The continual pilot locations within the  $K_{L1}$  carrier index block are defined in table 35. A given carrier index  $k$  of the OFDM signal will be a continual pilot if  $k \bmod K_{L1}$  is matched with one of the numbers in table 34.

**Table 35: Continual Pilot Carrier Indices**

Indices							
96	216	306	390	450	486	780	804
924	1 026	1 224	1 422	1 554	1 620	1 680	1 902
1 956	2 016	2 142	2 220	2 310	2 424	2 466	2 736
3 048	3 126	3 156	3 228	3 294	3 366		

### 9.6.3.2 Amplitudes of the Continual Pilots

The amplitudes of the continual pilots,  $A_{CP}$ , are fixed as  $7/3$ . This amplitude is commonly used for scattered pilots and edge pilots as well.

### 9.6.3.3 Modulation of the Continual Pilots

The phases of the continual pilots are derived from the reference sequence given in clause 9.3.

The modulation value for the continual pilots is given by:

$$\text{Re}\{c_{m,l,k}\} = 2 A_{CP} (1/2 - r_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0.$$

where  $r_k$  is defined in clause 9.3.

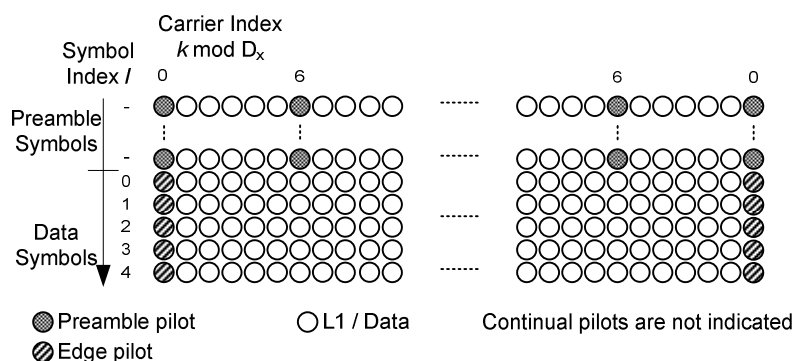
## 9.6.4 Edge pilot insertion

In addition to the scattered and continual pilots, a number of edge pilots are also inserted at the 'edge' carrier locations in every symbol except Preamble Symbol(s). The number of edge pilots depends upon the number of spectrum Notches within an OFDM signal.

### 9.6.4.1 Locations of the edge pilots

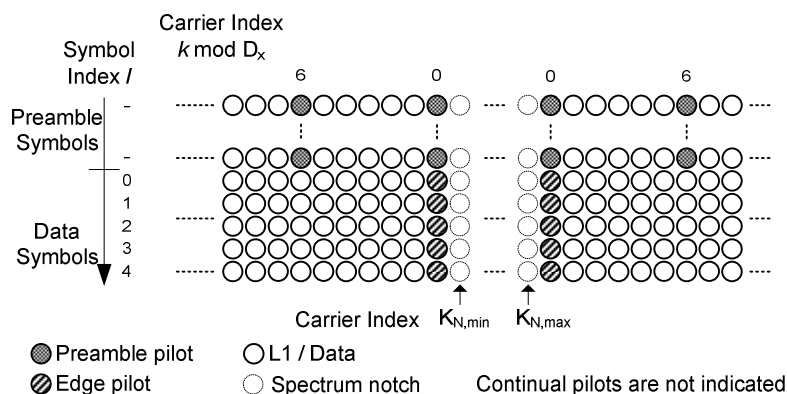
There are two kinds of edge carrier; those carriers at the upper and lower extremes of the OFDM spectrum and those carriers either side of a spectrum Notch. The edge pilots are inserted in both cases.

The lowest frequency edge pilot of the OFDM spectrum is inserted by replacing potential data and scattered pilot carriers. On the other hand the highest frequency edge pilot of the OFDM spectrum is inserted as an extra carrier to the data carriers. This ensures that the edge pilots are on the scattered pilot bearing carriers. These pilot locations are shown in figure 39.



**Figure 39: OFDM spectrum edge pilot locations**

Edge pilots are also placed either side of spectrum Notches. The edge pilot for the lower frequency edge of a Notch is inserted at carrier index  $K_{N,min} - 1$ , whereas the edge pilot for the higher frequency edge of a Notch is inserted at carrier index  $K_{N,max} + 1$ . Where  $K_{N,min}$  and  $K_{N,max}$  are the start and end carrier indices for a spectrum Notch, details are defined in clause 9.4.1.3. These edge pilots will lie on scattered pilot bearing subcarriers. These pilot locations are shown in figure 40.



**Figure 40: Spectrum Notch edge pilot locations**

NOTE: The edge pilot locations are always be at integer multiples of  $D_x$ . They are scattered pilot bearing carriers.

#### 9.6.4.2 Amplitudes of the Edge Pilots

The amplitude of the edge pilots and the scattered pilots is  $7/3$ .

#### 9.6.4.3 Modulation of the Edge Pilots

The modulation of these cells is exactly the same as for the scattered pilots, as defined in clause 9.6.2.3:

$$\text{Re}\{c_{m,l,k}\} = 2 A_{SP} (1/2 - r_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0.$$

## 9.7 Dummy carrier reservation

Some OFDM Cells can be reserved for varying purposes, e.g. PAPR reduction. The amplitudes of these cells can be defined freely, while their power level shall not exceed the power level of pilots within the data OFDM Symbols.

In the Data Symbols excluding Preamble Symbols, the set of carriers corresponding to carrier indices defined in table 36 or their circularly shifted set of carriers shall be reserved depending on the OFDM Symbol index of the Data Symbol, when the reserved tones are activated by a relevant L1 signalling part 2, 'RESERVED\_TONES'. The amount of shift between two consecutive OFDM Symbols shall be determined by the separation of pilot bearing carriers,  $D_X$  and the number of symbols forming one scattered pilot sequence,  $D_Y$  (see table 34 in clause 9.6.2.1). Furthermore, the reserved carrier patterns are repeated at every interval of 8 blocks of  $K_{LI}=3\ 408$  carriers. Thus, in the Data Symbol corresponding to Data Symbol index  $l$  of a C2 Frame, the OFDM Cell is a reserved tone if:

$$[k \bmod (8 \cdot K_{LI})] - D_X (l \bmod D_Y) \in S_0 \quad 0 \leq l < L_{Data}$$

where  $k$  is the absolute carrier index,  $L_{data}$  denotes the number of Data Symbols in a C2 Frame, and  $S_0$  is the set of carrier indices listen in table 36.

Positions of reserved carriers within Notches shall be excluded from the set of reserved carriers.

**Table 36: Reserved carrier indices  $S_0$**

Reserved Carrier Indices $S_0$
161, 243, 296, 405, 493, 584, 697, 741, 821, 934, 1021, 1160, 1215, 1312, 1417, 1462, 1591, 1693, 1729, 1845, 1910, 1982, 2127, 2170, 2339, 2365, 2499, 2529, 2639, 2745, 2864, 2950, 2992, 3119, 3235, 3255, 3559, 3620, 3754, 3835, 3943, 3975, 4061, 4210, 4270, 4371, 4417, 4502, 4640, 4677, 4822, 4904, 5026, 5113, 5173, 5271, 5317, 5426, 5492, 5583, 5740, 5757, 5839, 5935, 6033, 6146, 6212, 6369, 6454, 6557, 6597, 6711, 6983, 7047, 7173, 7202, 7310, 7421, 7451, 7579, 7666, 7785, 7831, 7981, 8060, 8128, 8251, 8326, 8369, 8445, 8569, 8638, 8761, 8873, 8923, 9017, 9104, 9239, 9283, 9368, 9500, 9586, 9683, 9782, 9794, 9908, 9989, 10123, 10327, 10442, 10535, 10658, 10739, 10803, 10925, 11006, 11060, 11198, 11225, 11326, 11474, 11554, 11663, 11723, 11810, 11902, 11987, 12027, 12117, 12261, 12320, 12419, 12532, 12646, 12676, 12808, 12915, 12941, 13067, 13113, 13246, 13360, 13426, 13520, 13811, 13862, 13936, 14073, 14102, 14206, 14305, 14408, 14527, 14555, 14650, 14755, 14816, 14951, 15031, 15107, 15226, 15326, 15392, 15484, 15553, 15623, 15734, 15872, 15943, 16043, 16087, 16201, 16299, 16355, 16444, 16514, 16635, 16723, 16802, 16912, 17150, 17285, 17387, 17488, 17533, 17603, 17708, 17793, 17932, 18026, 18081, 18159, 18285, 18356, 18395, 18532, 18644, 18697, 18761, 18874, 18937, 19107, 19119, 19251, 19379, 19414, 19522, 19619, 19691, 19748, 19875, 19935, 20065, 20109, 20261, 20315, 20559, 20703, 20737, 20876, 20950, 21069, 21106, 21231, 21323, 21379, 21494, 21611, 21680, 21796, 21805, 21958, 22027, 22091, 22167, 22324, 22347, 22459, 22551, 22691, 22761, 22822, 22951, 22981, 23089, 23216, 23290, 23402, 23453, 23529, 23668, 23743, 24019, 24057, 24214, 24249, 24335, 24445, 24554, 24619, 24704, 24761, 24847, 24947, 25089, 25205, 25274, 25352, 25474, 25537, 25612, 25711, 25748, 25874, 25984, 26078, 26155, 26237, 26324, 26378, 26545, 26623, 26720, 26774, 26855, 26953, 27021, 27123

## 10 OFDM generation

The function of the OFDM generation module is to take the cells produced by the frame builder, as frequency domain coefficients and to transform them into the frequency domain.

### 10.1 IFFT - OFDM Modulation

This clause specifies the OFDM structure to use for each transmission mode. The transmitted signal is organized in frames. Each frame has duration of  $T_F$ , and consists of  $L_F$  OFDM Symbols. Each symbol is constituted by a set of  $K_{total}$  carriers transmitted with a duration  $T_S$ . It is composed of two parts: a useful part with duration  $T_U$  and a guard interval with duration  $\Delta$ . The guard interval consists of a cyclic continuation of the useful part,  $T_U$ , and is inserted before it. The allowed combinations of FFT size and guard interval are defined in table 38.

The symbols in a C2 Frame are numbered from 0 to  $L_F-1$ . All symbols contain data and reference information.

Since the OFDM signal comprises many separately modulated carriers, each symbol can in turn be considered to be divided into cells, each corresponding to the modulation carried on one carrier during one symbol.

The carriers are indexed by  $k \in [K_{\min}; K_{\max}]$  and determined by  $K_{\min}$  and  $K_{\max}$ . The spacing between adjacent carriers is  $1/T_U$  while the spacing between carriers  $K_{\min}$  and  $K_{\max}$  are determined by  $K_{\text{total}}/T_U$ .

The emitted signal is described by the following expression:

$$s(t) = \text{Re} \left\{ \sum_{m=0}^{\infty} \left[ \frac{1}{\sqrt{K_{\text{total}}}} \sum_{l=0}^{L_F-1} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \psi_{m,l,k}(t) \right] \right\}$$

Where:

$$\psi_{m,l,k}(t) = \begin{cases} e^{j2\pi \frac{k}{T_U}(t - \Delta - lT_s - mT_F)} & mT_F + lT_s \leq t < mT_F + (l+1)T_s \\ 0 & \text{otherwise} \end{cases}$$

and:

$k$  denotes the carrier number;

$l$  denotes the OFDM Symbol number starting from 0 for the first Preamble Symbol of the frame;

$m$  denotes the C2 Frame number;

$K_{\text{total}}$  is the number of transmitted carriers, i.e.  $K_{\text{total}} = K_{\max} - K_{\min} + 1$ ;

$L_F$  total number of OFDM Symbols per frame (including the preamble);

$T_s$  is the total symbol duration for all symbols, and  $T_s = T_U + \Delta$ ;

$T_U$  is the active symbol duration defined in table 38;

$\Delta$  is the duration of the guard interval, see clause 10.2;

$c_{m,l,k}$  is the complex modulation value for carrier  $k$  of the OFDM Symbol number  $l$  in C2 Frame number  $m$ ;

$T_F$  is the duration of a frame,  $T_F = L_F T_s$ ;

$K_{\min}$  Carrier index of first (lowest frequency) active carrier;

$K_{\max}$  Carrier index of last (highest frequency) active carrier.

The OFDM parameters are summarized in table 38. The values for the various time-related parameters are given in multiples of the Elementary Period  $T$  and in microseconds. The Elementary Period  $T$  is specified for each channel raster bandwidth in table 37.

**Table 37: Elementary period as a function of channel raster bandwidth**

Channel Raster	"6 MHz"	"8 MHz"
Elementary period $T$	7/48 $\mu\text{s}$	7/64 $\mu\text{s}$

Table 38: OFDM parameters

Parameter	"6 MHz" 1/64	"6 MHz" 1/128	"8 MHz" 1/64	"8 MHz" 1/128
Number of OFDM carriers per L1 Block $K_{L1}$	3 408	3 408	3 408	3 408
Bandwidth of L1 Signalling Block (see note)	<i>5,71 MHz</i>	<i>5,71 MHz</i>	<i>7,61 MHz</i>	<i>7,61 MHz</i>
Duration $T_U$	<i>4 096 T</i>	<i>4 096 T</i>	<i>4 096 T</i>	<i>4 096 T</i>
Duration $T_U$ $\mu$ s (see note)	<i>597,3</i>	<i>597,3</i>	<i>448</i>	<i>448</i>
Carrier spacing $1/T_U$ (Hz) (see note)	<i>1 674</i>	<i>1 674</i>	<i>2 232</i>	<i>2 232</i>
Guard Interval Duration $\Delta/T_U$	<i>64T</i>	<i>32T</i>	<i>64T</i>	<i>32T</i>
Guard Interval Duration $\Delta/T_U$ $\mu$ s (see note)	<i>9,33</i>	<i>4,66</i>	<i>7</i>	<i>3,5</i>
NOTE: Numerical values in italics are approximate values.				

## 10.2 Guard interval insertion

Two different guard interval fractions ( $\Delta/T_U$ ) are defined. Further details are given in table 38 in clause 10.1.

## 10.3 Spectrum characteristics

The OFDM Symbols constitute a juxtaposition of equally-spaced orthogonal carriers. The amplitudes and phases of the Data Cell carriers are varying symbol by symbol according to the mapping process previously described.

The power spectral density  $P_k(f)$  of each carrier at frequency:

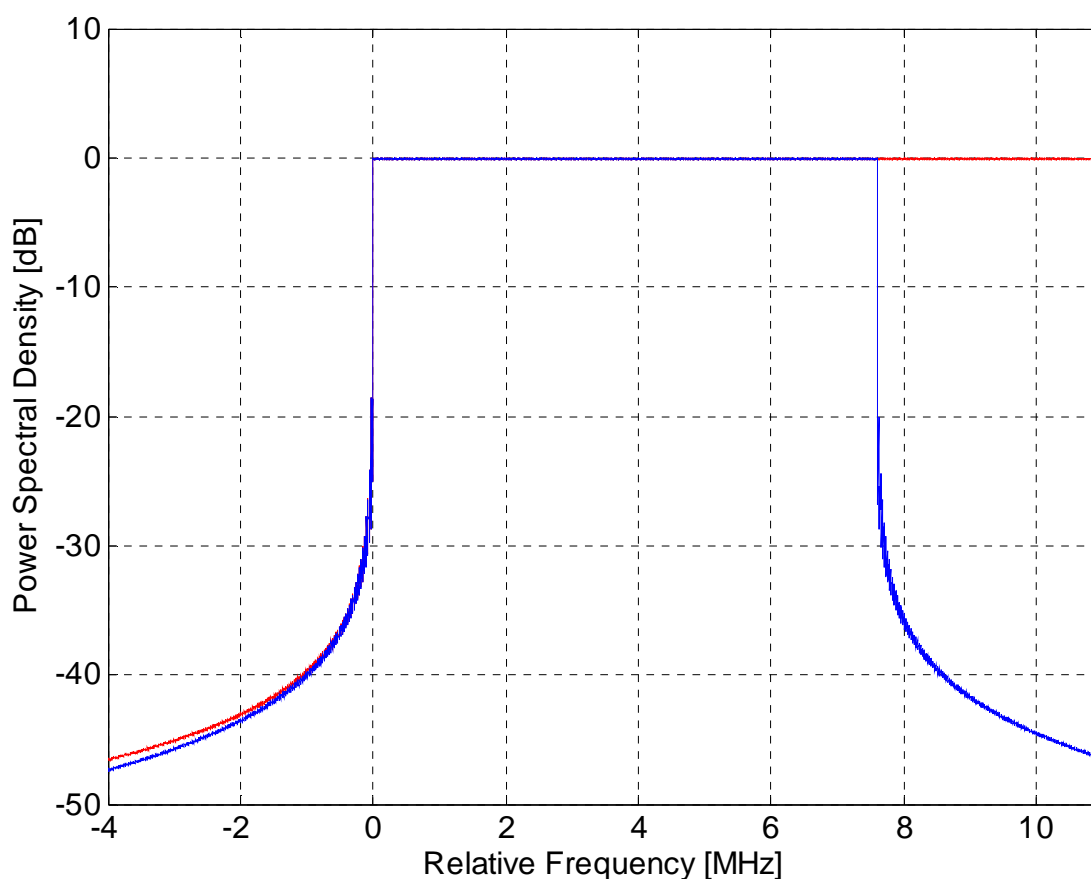
$$f_k = \frac{k}{T_u} \text{ for } K_{\min} \leq k \leq K_{\max}$$

is defined by the following expression:

$$P_k(f) = \left[ \frac{\sin \pi(f - f_k)T_s}{\pi(f - f_k)T_s} \right]^2$$

The overall power spectral density of the modulated Data Cell carriers is the sum of the power spectral densities of all these carriers. A theoretical DVB transmission signal spectrum is illustrated in figure 41. The blue curve illustrates the theoretical spectrum of a 7,61 MHz wide signal (The first used subcarrier  $K_{\min}$  is located at the relative frequency of 0 MHz). The red curve illustrates the lower frequency edge of a 445 MHz wide signal. Because the OFDM Symbol duration is larger than the inverse of the carrier spacing, the main lobe of the power spectral density of each carrier is narrower than twice the carrier spacing. Therefore the spectral density is not constant within the nominal bandwidth.

NOTE: This theoretical spectrum takes no account of the variations in power from carrier to carrier caused by the boosting of the pilot carriers.



**Figure 41: Theoretical DVB-C2 signal spectrum for guard interval fraction 1/128 and different signal bandwidths (8 MHz and 445 MHz (lower edge only))**

No specific requirements are set in terms of the spectrum characteristics after amplification and filtering, since it is considered to be more appropriately defined by the relevant standardization authorities, depending on both the regions and the frequency bands in which the C2 System is to be deployed.



## Annex A (normative): Addresses of parity bit accumulators for Nldpc = 64 800

Example of interpretation of table A.1.

$$\begin{aligned} p_{317} &= p_{317} \oplus i_0 & p_{2255} &= p_{2255} \oplus i_0 & p_{2324} &= p_{2324} \oplus i_0 & p_{2723} &= p_{2723} \oplus i_0 & p_{3538} &= p_{3538} \oplus i_0 \\ p_{3576} &= p_{3576} \oplus i_0 & p_{6194} &= p_{6194} \oplus i_0 & p_{6700} &= p_{6700} \oplus i_0 & p_{9101} &= p_{9101} \oplus i_0 & p_{10057} &= p_{10057} \oplus i_0 \\ p_{12739} &= p_{12739} \oplus i_0 & p_{17407} &= p_{17407} \oplus i_0 & p_{21039} &= p_{21039} \oplus i_0 \end{aligned}$$

$$\begin{aligned} p_{377} &= p_{377} \oplus i_0 & p_{2315} &= p_{2315} \oplus i_0 & p_{2384} &= p_{2384} \oplus i_0 & p_{2783} &= p_{2783} \oplus i_0 & p_{3598} &= p_{3598} \oplus i_0 \\ p_{3636} &= p_{3636} \oplus i_0 & p_{6254} &= p_{6254} \oplus i_0 & p_{6760} &= p_{6760} \oplus i_0 & p_{9161} &= p_{9161} \oplus i_0 & p_{10117} &= p_{10117} \oplus i_0 \\ p_{12799} &= p_{12799} \oplus i_0 & p_{17467} &= p_{17467} \oplus i_0 & p_{21099} &= p_{21099} \oplus i_0 \end{aligned}$$

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$$\begin{aligned} p_{21857} &= p_{21857} \oplus i_{359} & p_{23795} &= p_{23795} \oplus i_{359} & p_{23864} &= p_{23864} \oplus i_{359} & p_{24263} &= p_{24263} \oplus i_{359} \\ p_{25078} &= p_{25078} \oplus i_{359} & p_{25116} &= p_{25116} \oplus i_{359} & p_{27734} &= p_{27734} \oplus i_{359} & p_{28240} &= p_{28240} \oplus i_{359} \\ p_{30641} &= p_{30641} \oplus i_{359} & p_{31597} &= p_{31597} \oplus i_{359} & p_{34279} &= p_{34279} \oplus i_{359} & p_{38947} &= p_{38947} \oplus i_{359} \\ p_{42579} &= p_{42579} \oplus i_{359} \end{aligned}$$

$$\begin{aligned} p_{1958} &= p_{1958} \oplus i_{360} & p_{2007} &= p_{2007} \oplus i_{360} & p_{3294} &= p_{3294} \oplus i_{360} & p_{4394} &= p_{4394} \oplus i_{360} & p_{12762} &= p_{12762} \oplus i_{360} \\ p_{14505} &= p_{14505} \oplus i_{360} & p_{14593} &= p_{14593} \oplus i_{360} & p_{14692} &= p_{14692} \oplus i_{360} & p_{16522} &= p_{16522} \oplus i_{360} \\ p_{17737} &= p_{17737} \oplus i_{360} & p_{19245} &= p_{19245} \oplus i_{360} & p_{21272} &= p_{21272} \oplus i_{360} & p_{21379} &= p_{21379} \oplus i_{360} \end{aligned}$$

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: : : : : : : :

Table A.1: Rate 2/3 ( $N_{\text{ldpc}} = 64\ 800$ )

317	2255	2324	2723	3538	3576	6194	6700	9101	10057	12739	17407	21039	10574	11268	17932
1958	2007	3294	4394	12762	14505	14593	14692	16522	17737	19245	21272	21379	15442	17266	20482
127	860	5001	5633	8644	9282	12690	14644	17553	19511	19681	20954	21002	390	3371	8781
2514	2822	5781	6297	8063	9469	9551	11407	11837	12985	15710	20236	20393	10512	12216	17180
1565	3106	4659	4926	6495	6872	7343	8720	15785	16434	16727	19884	21325	4309	14068	15783
706	3220	8568	10896	12486	13663	16398	16599	19475	19781	20625	20961	21335	3971	11673	20009
4257	10449	12406	14561	16049	16522	17214	18029	18033	18802	19062	19526	20748	9259	14270	17199
412	433	558	2614	2978	4157	6584	9320	11683	11819	13024	14486	16860	2947	5852	20101
777	5906	7403	8550	8717	8770	11436	12846	13629	14755	15688	16392	16419	3965	9722	15363
4093	5045	6037	7248	8633	9771	10260	10809	11326	12072	17516	19344	19938	1429	5689	16771
2120	2648	3155	3852	6888	12258	14821	15359	16378	16437	17791	20614	21025	6101	6849	12781
1085	2434	5816	7151	8050	9422	10884	12728	15353	17733	18140	18729	20920	3676	9347	18761
856	1690	12787											350	11659	18342
6532	7357	9151											5961	14803	16123
4210	16615	18152											2113	9163	13443
11494	14036	17470											2155	9808	12885
2474	10291	10323											2861	7988	11031
1778	6973	10739											7309	9220	20745
4347	9570	18748											6834	8742	11977
2189	11942	20666											2133	12908	14704
3868	7526	17706											10170	13809	18153
8780	14796	18268											13464	14787	14975
160	16232	17399											799	1107	3789
1285	2003	18922											3571	8176	10165
4658	17331	20361											5433	13446	15481
2765	4862	5875											3351	6767	12840
4565	5521	8759											8950	8974	11650
3484	7305	15829											1430	4250	21332
5024	17730	17879											6283	10628	15050
7031	12346	15024											8632	14404	16916
179	6365	11352											6509	10702	16278
2490	3143	5098											15900	16395	17995
2643	3101	21259											8031	18420	19733
4315	4724	13130											3747	4634	17087
594	17365	18322											4453	6297	16262
5983	8597	9627											2792	3513	17031
10837	15102	20876											14846	20893	21563
10448	20418	21478											17220	20436	21337
3848	12029	15228											275	4107	10497
708	5652	13146											3536	7520	10027
5998	7534	16117											14089	14943	19455
2098	13201	18317											1965	3931	21104
9186	14548	17776											2439	11565	17932
5246	10398	18597											154	15279	21414
3083	4944	21021											10017	11269	16546
13726	18495	19921											7169	10161	16928
6736	10811	17545											10284	16791	20655
10084	12411	14432											36	3175	8475
1064	13555	17033											2605	16269	19290
679	9878	13547											8947	9178	15420
3422	9910	20194											5687	9156	12408
3640	3701	10046											8096	9738	14711
5862	10134	11498											4935	8093	19266
5923	9580	15060											2667	10062	15972
1073	3012	16427											6389	11318	14417
5527	20113	20883											8800	18137	18434
7058	12924	15151											5824	5927	15314
9764	12230	17375											6056	13168	15179
772	7711	12723											3284	13138	18919
555	13816	15376											13115	17259	17332

Table A.2: Rate 3/4 ( $N_{ldpc} = 64\ 800$ )

0 6385 7901 14611 13389 11200 3252 5243 2504 2722 821 7374	23 5865 1768
1 11359 2698 357 13824 12772 7244 6752 15310 852 2001 11417	24 2655 14957
2 7862 7977 6321 13612 12197 14449 15137 13860 1708 6399 13444	25 5565 6332
3 1560 11804 6975 13292 3646 3812 8772 7306 5795 14327 7866	26 4303 12631
4 7626 11407 14599 9689 1628 2113 10809 9283 1230 15241 4870	27 11653 12236
5 1610 5699 15876 9446 12515 1400 6303 5411 14181 13925 7358	28 16025 7632
6 4059 8836 3405 7853 7992 15336 5970 10368 10278 9675 4651	29 4655 14128
7 4441 3963 9153 2109 12683 7459 12030 12221 629 15212 406	30 9584 13123
8 6007 8411 5771 3497 543 14202 875 9186 6235 13908 3563	31 13987 9597
9 3232 6625 4795 546 9781 2071 7312 3399 7250 4932 12652	32 15409 12110
10 8820 10088 11090 7069 6585 13134 10158 7183 488 7455 9238	33 8754 15490
11 1903 10818 119 215 7558 11046 10615 11545 14784 7961 15619	34 7416 15325
12 3655 8736 4917 15874 5129 2134 15944 14768 7150 2692 1469	35 2909 15549
13 8316 3820 505 8923 6757 806 7957 4216 15589 13244 2622	36 2995 8257
14 14463 4852 15733 3041 11193 12860 13673 8152 6551 15108 8758	37 9406 4791
15 3149 11981	38 11111 4854
16 13416 6906	39 2812 8521
17 13098 13352	40 8476 14717
18 2009 14460	41 7820 15360
19 7207 4314	42 1179 7939
20 3312 3945	43 2357 8678
21 4418 6248	44 7703 6216
22 2669 13975	0 3477 7067
23 7571 9023	1 3931 13845
24 14172 2967	2 7675 12899
25 7271 7138	3 1754 8187
26 6135 13670	4 7785 1400
27 7490 14559	5 9213 5891
28 8657 2466	6 2494 7703
29 8599 12834	7 2576 7902
30 3470 3152	8 4821 15682
31 13917 4365	9 10426 11935
32 6024 13730	10 1810 904
33 10973 14182	11 11332 9264
34 2464 13167	12 11312 3570
35 5281 15049	13 14916 2650
36 1103 1849	14 7679 7842
37 2058 1069	15 6089 13084
38 9654 6095	16 3938 2751
39 14311 7667	17 8509 4648
40 15617 8146	18 12204 8917
41 4588 11218	19 5749 12443
42 13660 6243	20 12613 4431
43 8578 7874	21 1344 4014
44 11741 2686	22 8488 13850
0 1022 1264	23 1730 14896
1 12604 9965	24 14942 7126
2 8217 2707	25 14983 8863
3 3156 11793	26 6578 8564
4 354 1514	27 4947 396
5 6978 14058	28 297 12805
6 7922 16079	29 13878 6692
7 15087 12138	30 11857 11186
8 5053 6470	31 14395 11493
9 12687 14932	32 16145 12251
10 15458 1763	33 13462 7428
11 8121 1721	34 14526 13119
12 12431 549	35 2535 11243
13 4129 7091	36 6465 12690
14 1426 8415	37 6872 9334
15 9783 7604	38 15371 14023
16 6295 11329	39 8101 10187
17 1409 12061	40 11963 4848
18 8065 9087	41 15125 6119
19 2918 8438	42 8051 14465
20 1293 14115	43 11139 5167
21 3922 13851	44 2883 14521
22 3851 4000	

Table A.3: Rate 4/5 ( $N_{ldpc} = 64\ 800$ )

0 149 11212 5575 6360 12559 8108 8505 408 10026 12828	0 5647 4935
1 5237 490 10677 4998 3869 3734 3092 3509 7703 10305	1 4219 1870
2 8742 5553 2820 7085 12116 10485 564 7795 2972 2157	2 10968 8054
3 2699 4304 8350 712 2841 3250 4731 10105 517 7516	3 6970 5447
4 12067 1351 11992 12191 11267 5161 537 6166 4246 2363	4 3217 5638
5 6828 7107 2127 3724 5743 11040 10756 4073 1011 3422	5 8972 669
6 11259 1216 9526 1466 10816 940 3744 2815 11506 11573	6 5618 12472
7 4549 11507 1118 1274 11751 5207 7854 12803 4047 6484	7 1457 1280
8 8430 4115 9440 413 4455 2262 7915 12402 8579 7052	8 8868 3883
9 3885 9126 5665 4505 2343 253 4707 3742 4166 1556	9 8866 1224
10 1704 8936 6775 8639 8179 7954 8234 7850 8883 8713	10 8371 5972
11 11716 4344 9087 11264 2274 8832 9147 11930 6054 5455	11 266 4405
12 7323 3970 10329 2170 8262 3854 2087 12899 9497 11700	12 3706 3244
13 4418 1467 2490 5841 817 11453 533 11217 11962 5251	13 6039 5844
14 1541 4525 7976 3457 9536 7725 3788 2982 6307 5997	14 7200 3283
15 11484 2739 4023 12107 6516 551 2572 6628 8150 9852	15 1502 11282
16 6070 1761 4627 6534 7913 3730 11866 1813 12306 8249	16 12318 2202
17 12441 5489 8748 7837 7660 2102 11341 2936 6712 11977	17 4523 965
18 10155 4210	18 9587 7011
19 1010 10483	19 2552 2051
20 8900 10250	20 12045 10306
21 10243 12278	21 11070 5104
22 7070 4397	22 6627 6906
23 12271 3887	23 9889 2121
24 11980 6836	24 829 9701
25 9514 4356	25 2201 1819
26 7137 10281	26 6689 12925
27 11881 2526	27 2139 8757
28 1969 11477	28 12004 5948
29 3044 10921	29 8704 3191
30 2236 8724	30 8171 10933
31 9104 6340	31 6297 7116
32 7342 8582	32 616 7146
33 11675 10405	33 5142 9761
34 6467 12775	34 10377 8138
35 3186 12198	35 7616 5811
0 9621 11445	0 7285 9863
1 7486 5611	1 7764 10867
2 4319 4879	2 12343 9019
3 2196 344	3 4414 8331
4 7527 6650	4 3464 642
5 10693 2440	5 6960 2039
6 6755 2706	6 786 3021
7 5144 5998	7 710 2086
8 11043 8033	8 7423 5601
9 4846 4435	9 8120 4885
10 4157 9228	10 12385 11990
11 12270 6562	11 9739 10034
12 11954 7592	12 424 10162
13 7420 2592	13 1347 7597
14 8810 9636	14 1450 112
15 689 5430	15 7965 8478
16 920 1304	16 8945 7397
17 1253 11934	17 6590 8316
18 9559 6016	18 6838 9011
19 312 7589	19 6174 9410
20 4439 4197	20 255 113
21 4002 9555	21 6197 5835
22 12232 7779	22 12902 3844
23 1494 8782	23 4377 3505
24 10749 3969	24 5478 8672
25 4368 3479	25 4453 2132
26 6316 5342	26 9724 1380
27 2455 3493	27 12131 11526
28 12157 7405	28 12323 9511
29 6598 11495	29 8231 1752
30 11805 4455	30 497 9022
31 9625 2090	31 9288 3080
32 4731 2321	32 2481 7515
33 3578 2608	33 2696 268
34 8504 1849	34 4023 12341
35 4027 1151	35 7108 5553

Table A.4: Rate 5/6 ( $N_{ldpc} = 64\ 800$ )

0 4362 416 8909 4156 3216 3112 2560 2912 6405 8593 4969 6723	20 4766 2697	10 7868 5731
1 2479 1786 8978 3011 4339 9313 6397 2957 7288 5484 6031 10217	21 4069 6675	11 6121 10732
2 10175 9009 9889 3091 4985 7267 4092 8874 5671 2777 2189 8716	22 1117 1016	12 4843 9132
3 9052 4795 3924 3370 10058 1128 9996 10165 9360 4297 434 5138	23 5619 3085	13 580 9591
4 2379 7834 4835 2327 9843 804 329 8353 7167 3070 1528 7311	24 8483 8400	14 6267 9290
5 3435 7871 348 3693 1876 6585 10340 7144 5870 2084 4052 2780	25 8255 394	15 3009 2268
6 3917 3111 3476 1304 10331 5939 5199 1611 1991 699 8316 9960	26 6338 5042	16 195 2419
7 6883 3237 1717 10752 7891 9764 4745 3888 10009 4176 4614 1567	27 6174 5119	17 8016 1557
8 10587 2195 1689 2968 5420 2580 2883 6496 111 6023 1024 4449	28 7203 1989	18 1516 9195
9 3786 8593 2074 3321 5057 1450 3840 5444 6572 3094 9892 1512	29 1781 5174	19 8062 9064
10 8548 1848 10372 4585 7313 6536 6379 1766 9462 2456 5606 9975	0 1464 3559	20 2095 8968
11 8204 10593 7935 3636 3882 394 5968 8561 2395 7289 9267 9978	1 3376 4214	21 753 7326
12 7795 74 1633 9542 6867 7352 6417 7568 10623 725 2531 9115	2 7238 67	22 6291 3833
13 7151 2482 4260 5003 10105 7419 9203 6691 8798 2092 8263 3755	3 10595 8831	23 2614 7844
14 3600 570 4527 200 9718 6771 1995 8902 5446 768 1103 6520	4 1221 6513	24 2303 646
15 6304 7621	5 5300 4652	25 2075 611
16 6498 9209	6 1429 9749	26 4687 362
17 7293 6786	7 7878 5131	27 8684 9940
18 5950 1708	8 4435 10284	28 4830 2065
19 8521 1793	9 6331 5507	29 7038 1363
20 6174 7854	10 6662 4941	0 1769 7837
21 9773 1190	11 9614 10238	1 3801 1689
22 9517 10268	12 8400 8025	2 10070 2359
23 2181 9349	13 9156 5630	3 3667 9918
24 1949 5560	14 7067 8878	4 1914 6920
25 1556 555	15 9027 3415	5 4244 5669
26 8600 3827	16 1690 3866	6 10245 7821
27 5072 1057	17 2854 8469	7 7648 3944
28 7928 3542	18 6206 630	8 3310 5488
29 3226 3762	19 363 5453	9 6346 9666
0 7045 2420	20 4125 7008	10 7088 6122
1 9645 2641	21 1612 6702	11 1291 7827
2 2774 2452	22 9069 9226	12 10592 8945
3 5331 2031	23 5767 4060	13 3609 7120
4 9400 7503	24 3743 9237	14 9168 9112
5 1850 2338	25 7018 5572	15 6203 8052
6 10456 9774	26 8892 4536	16 3330 2895
7 1692 9276	27 853 6064	17 4264 10563
8 10037 4038	28 8069 5893	18 10556 6496
9 3964 338	29 2051 2885	19 8807 7645
10 2640 5087	0 10691 3153	20 1999 4530
11 858 3473	1 3602 4055	21 9202 6818
12 5582 5683	2 328 1717	22 3403 1734
13 9523 916	3 2219 9299	23 2106 9023
14 4107 1559	4 1939 7898	24 6881 3883
15 4506 3491	5 617 206	25 3895 2171
16 8191 4182	6 8544 1374	26 4062 6424
17 10192 6157	7 10676 3240	27 3755 9536
18 5668 3305	8 6672 9489	28 4683 2131
19 3449 1540	9 3170 7457	29 7347 8027

Table A.5: Rate 9/10 ( $N_{\text{idpc}} = 64\ 800$ )

0 5611 2563 2900	17 3216 2178	16 6296 2583	15 1263 293	14 3267 649
1 5220 3143 4813	0 4165 884	17 1457 903	16 5949 4665	15 6236 593
2 2481 834 81	1 2896 3744	0 855 4475	17 4548 6380	16 646 2948
3 6265 4064 4265	2 874 2801	1 4097 3970	0 3171 4690	17 4213 1442
4 1055 2914 5638	3 3423 5579	2 4433 4361	1 5204 2114	0 5779 1596
5 1734 2182 3315	4 3404 3552	3 5198 541	2 6384 5565	1 2403 1237
6 3342 5678 2246	5 2876 5515	4 1146 4426	3 5722 1757	2 2217 1514
7 2185 552 3385	6 516 1719	5 3202 2902	4 2805 6264	3 5609 716
8 2615 236 5334	7 765 3631	6 2724 525	5 1202 2616	4 5155 3858
9 1546 1755 3846	8 5059 1441	7 1083 4124	6 1018 3244	5 1517 1312
10 4154 5561 3142	9 5629 598	8 2326 6003	7 4018 5289	6 2554 3158
11 4382 2957 5400	10 5405 473	9 5605 5990	8 2257 3067	7 5280 2643
12 1209 5329 3179	11 4724 5210	10 4376 1579	9 2483 3073	8 4990 1353
13 1421 3528 6063	12 155 1832	11 4407 984	10 1196 5329	9 5648 1170
14 1480 1072 5398	13 1689 2229	12 1332 6163	11 649 3918	10 1152 4366
15 3843 1777 4369	14 449 1164	13 5359 3975	12 3791 4581	11 3561 5368
16 1334 2145 4163	15 2308 3088	14 1907 1854	13 5028 3803	12 3581 1411
17 2368 5055 260	16 1122 669	15 3601 5748	14 3119 3506	13 5647 4661
0 6118 5405	17 2268 5758	16 6056 3266	15 4779 431	14 1542 5401
1 2994 4370	0 5878 2609	17 3322 4085	16 3888 5510	15 5078 2687
2 3405 1669	1 782 3359	0 1768 3244	17 4387 4084	16 316 1755
3 4640 5550	2 1231 4231	1 2149 144	0 5836 1692	17 3392 1991
4 1354 3921	3 4225 2052	2 1589 4291	1 5126 1078	
5 117 1713	4 4286 3517	3 5154 1252	2 5721 6165	
6 5425 2866	5 5531 3184	4 1855 5939	3 3540 2499	
7 6047 683	6 1935 4560	5 4820 2706	4 2225 6348	
8 5616 2582	7 1174 131	6 1475 3360	5 1044 1484	
9 2108 1179	8 3115 956	7 4266 693	6 6323 4042	
10 933 4921	9 3129 1088	8 4156 2018	7 1313 5603	
11 5953 2261	10 5238 4440	9 2103 752	8 1303 3496	
12 1430 4699	11 5722 4280	10 3710 3853	9 3516 3639	
13 5905 480	12 3540 375	11 5123 931	10 5161 2293	
14 4289 1846	13 191 2782	12 6146 3323	11 4682 3845	
15 5374 6208	14 906 4432	13 1939 5002	12 3045 643	
16 1775 3476	15 3225 1111	14 5140 1437	13 2818 2616	

## Annex B (normative): Addresses of parity bit accumulators for $N_{ldpc} = 16\ 200$

**Table B.1: Rate 1/2 ( $N_{ldpc} = 16\ 200$ )**

20 712 2386 6354 4061 1062 5045 5158	5 5924 290
21 2543 5748 4822 2348 3089 6328 5876	6 1467 4049
22 926 5701 269 3693 2438 3190 3507	7 7820 2242
23 2802 4520 3577 5324 1091 4667 4449	8 4606 3080
24 5140 2003 1263 4742 6497 1185 6202	9 4633 7877
0 4046 6934	10 3884 6868
1 2855 66	11 8935 4996
2 6694 212	12 3028 764
3 3439 1158	13 5988 1057
4 3850 4422	14 7411 3450

**Table B.2: Rate 2/3 ( $N_{ldpc} = 16\ 200$ )**

0 2084 1613 1548 1286 1460 3196 4297 2481 3369 3451 4620 2622	1 2583 1180
1 122 1516 3448 2880 1407 1847 3799 3529 373 971 4358 3108	2 1542 509
2 259 3399 929 2650 864 3996 3833 107 5287 164 3125 2350	3 4418 1005
3 342 3529	4 5212 5117
4 4198 2147	5 2155 2922
5 1880 4836	6 347 2696
6 3864 4910	7 226 4296
7 243 1542	8 1560 487
8 3011 1436	9 3926 1640
9 2167 2512	10 149 2928
10 4606 1003	11 2364 563
11 2835 705	12 635 688
12 3426 2365	13 231 1684
13 3848 2474	14 1129 3894
14 1360 1743	
0 163 2536	

**Table B.3: Rate 3/4 ( $N_{ldpc} = 16\ 200$ )**

3 3198 478 4207 1481 1009 2616 1924 3437 554 683 1801	8 1015 1945
4 2681 2135	9 1948 412
5 3107 4027	10 995 2238
6 2637 3373	11 4141 1907
7 3830 3449	0 2480 3079
8 4129 2060	1 3021 1088
9 4184 2742	2 713 1379
10 3946 1070	3 997 3903
11 2239 984	4 2323 3361
0 1458 3031	5 1110 986
1 3003 1328	6 2532 142
2 1137 1716	7 1690 2405
3 132 3725	8 1298 1881
4 1817 638	9 615 174
5 1774 3447	10 1648 3112
6 3632 1257	11 1415 2808
7 542 3694	

**Table B.4: Rate 4/5 ( $N_{\text{ldpc}} = 16\ 200$ )**

5 896 1565	3 465 2552
6 2493 184	4 1038 2479
7 212 3210	5 1383 343
8 727 1339	6 94 236
9 3428 612	7 2619 121
0 2663 1947	8 1497 2774
1 230 2695	9 2116 1855
2 2025 2794	0 722 1584
3 3039 283	1 2767 1881
4 862 2889	2 2701 1610
5 376 2110	3 3283 1732
6 2034 2286	4 168 1099
7 951 2068	5 3074 243
8 3108 3542	6 3460 945
9 307 1421	7 2049 1746
0 2272 1197	8 566 1427
1 1800 3280	9 3545 1168
2 331 2308	

**Table B.5: Rate 5/6 ( $N_{\text{ldpc}} = 16\ 200$ )**

3 2409 499 1481 908 559 716 1270 333 2508 2264 1702 2805	6 497 2228
4 2447 1926	7 2326 1579
5 414 1224	0 2482 256
6 2114 842	1 1117 1261
7 212 573	2 1257 1658
0 2383 2112	3 1478 1225
1 2286 2348	4 2511 980
2 545 819	5 2320 2675
3 1264 143	6 435 1278
4 1701 2258	7 228 503
5 964 166	0 1885 2369
6 114 2413	1 57 483
7 2243 81	2 838 1050
0 1245 1581	3 1231 1990
1 775 169	4 1738 68
2 1696 1104	5 2392 951
3 1914 2831	6 163 645
4 532 1450	7 2644 1704
5 91 974	

**Table B.6: Rate 8/9 ( $N_{\text{ldpc}} = 16\ 200$ )**

0 1558 712 805	4 1496 502	3 544 1190
1 1450 873 1337	0 1006 1701	4 1472 1246
2 1741 1129 1184	1 1155 97	0 508 630
3 294 806 1566	2 657 1403	1 421 1704
4 482 605 923	3 1453 624	2 284 898
0 926 1578	4 429 1495	3 392 577
1 777 1374	0 809 385	4 1155 556
2 608 151	1 367 151	0 631 1000
3 1195 210	2 1323 202	1 732 1368
4 1484 692	3 960 318	2 1328 329
0 427 488	4 1451 1039	3 1515 506
1 828 1124	0 1098 1722	4 1104 1172
2 874 1366	1 1015 1428	
3 1500 835	2 1261 1564	



## Annex C (normative):

### Input stream synchronizer

Delays and packet jitter introduced by DVB-C2 equipment may depend on the transmitted bit-rate and may change in time during bit and/or code rate switching. The "Input Stream Synchronizer" (see figure C.1) shall provide a mechanism to regenerate, in the receiver, the clock of the Transport Stream (or packetized Generic Stream) at the modulator Mode Adapter input, in order to guarantee end-to-end constant bit rates and delays (see also figure C2, example receiver implementation). Table C.1 gives the details of the coding of the ISSY field generated by the input stream synchronizer.

When  $ISSYI = 1$  in MATYPE field (see clause 5.1.6) a counter shall be activated (22 bits), clocked by the modulator sampling rate (frequency  $R_s = 1/T$ , where  $T$  is defined in clause 10.). The Input Stream Synchronization field (ISSY, 2 or 3 bytes) shall be transmitted according to clause 5.1.7.

ISSY shall be coded according to table C.1, sending the following variables:

- ISCR (short: 15 bits; long: 22 bits) (ISCR = Input Stream Time Reference), loaded with the LSBs of the counter content at the instant the relevant input packet is processed (at constant rate  $R_{IN}$ ), and specifically the instant the MSB of the relevant packet arrives at the modulator input stream interface. In case of continuous streams the content of the counter is loaded when the MSB of the Data Field is processed.
- BUFS (2+10 bits) (BUFS = maximum size of the requested receiver buffer to compensate delay variations). This variable indicates the size of the receiver buffer assumed by the modulator for the relevant PLP. It shall have a maximum value of 2 Mbit. When a group of Data PLPs share a Common PLP, the sum of the buffer size for any Data PLP in the group plus the buffer size for the Common PLP shall not exceed 2 Mbit. This field shall not be transmitted in case of PLP bundling as the ISCR field is required in every BBFrame for sorting of the input stream.
- BUFSTAT (2+10 bits) (BUFSTAT = actual status to reset the receiver buffer = number of filled bits). If  $ISSYI=1$ , this variable shall be transmitted at least 5 times per second, replacing ISCR. This value can be used to set the receiver buffer status during reception start-up procedure, and to verify normal functioning in steady state. This field shall not be transmitted in case of PLP bundling as the ISCR field is required in every BBFrame for sorting of the input stream.

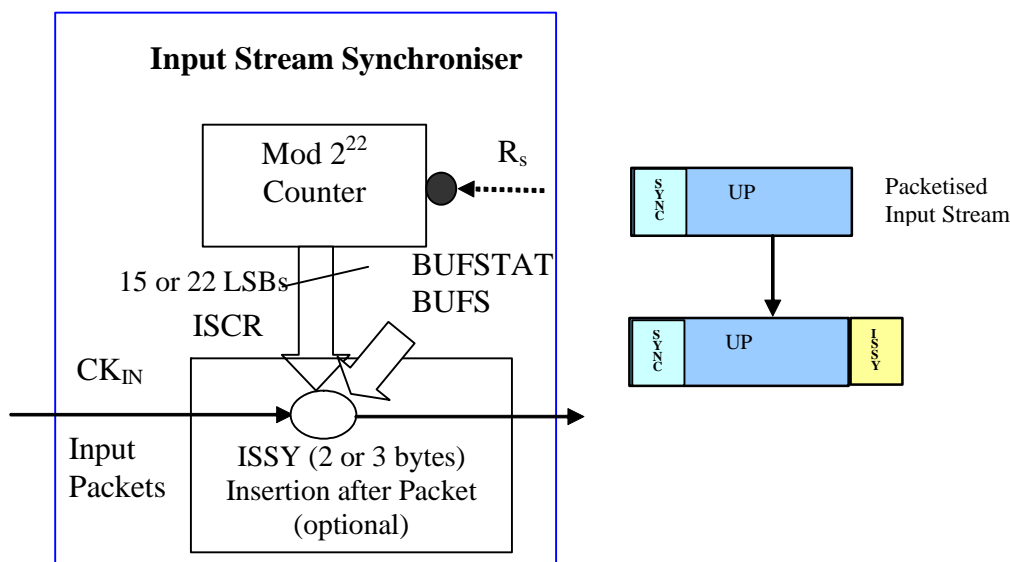


Figure C.1: Input stream synchronizer block diagram

Table C.1: ISSY field coding (2 bytes or 3 bytes)

First Byte					Second Byte	Third Byte
Bit-7 (MSB)	bit-6	bit-5 and bit-4	bit-3 and bit-2	bit-1 and bit-0	bit-7 to bit-0	bit-7 bit-0
0 = ISCR <sub>short</sub>	MSB of ISCR <sub>short</sub>	next 6 bits of ISCR <sub>short</sub>			Next 8 bits of ISCR <sub>short</sub>	Not present
1	0 = ISCR <sub>long</sub>	6 MSBs of ISCR <sub>long</sub>			Next 8 bits of ISCR <sub>long</sub>	Next 8 bits of ISCR <sub>long</sub>
1	1	00 = BUFS	BUFS unit 00 = bits 01 = Kbits 10 = Mbits 11 = 8 Kbits	2 MSBs of BUFS	Next 8 bits of BUFS	Not present when ISCR <sub>short</sub> is used; else reserved for future use
1	1	10 = BUFSTAT	BUFSTAT unit 00 = bits 01 = Kbits 10 = Mbits 11 = BUFS/1 024	2 MSBs of BUFSTAT	Next 8 bits of BUFSTAT	Not present when ISCR <sub>short</sub> is used; else reserved for future use
1	1	Others = reserved for future use	Reserved for future use	Reserved for future use	Reserved for future use	Not present when ISCR <sub>short</sub> is used; else reserved for future use

## Annex D (normative):

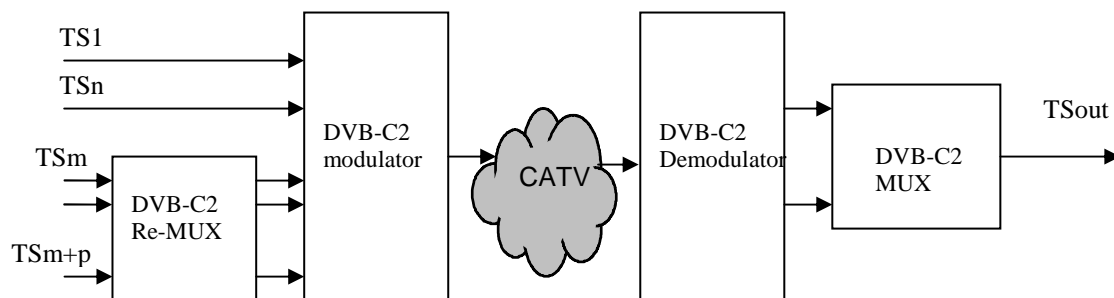
# Input Remultiplexing Subsystem: Splitting of input MPEG-2 Transport Streams into Data PLPs, generation of a Common PLP of a group of PLPs and insertion of Null Packets into Transport Streams

## D.1 Overview

This annex defines a feature of the C2 System applicable in the case of transmission of multiple MPEG-2 Transport Streams [i.1] in a configuration of a group of PLPs and an associated Common PLP. It includes the processing (remultiplexing) that shall be applied for transporting  $N$  ( $N \geq 2$ ) MPEG-2 TSs (TS\_1 to TS\_N) over  $N+1$  Data PLPs (PLP1 to PLP $N+1$ ), one of which is the Common PLP (CPLP) of a group of PLPs, see figure D.1.

If this processing is not applied to a group of Transport Streams, there shall be no Common PLP for this group, and each PLP of the group shall carry the input TS without modification. When several groups of PLPs are used to carry TSs, each such group has its own independent extension functionality.

This annex also describes the processing that can be carried out by the receiver to reconstruct a single input TS from the received Data PLP and its corresponding Common PLP.



**Figure D.1: Extended Re-multiplexing and Multiplexing Functionalities of DVB-C2**

The extension consists on the network side conceptually of a remultiplexer and on the receiver side of a multiplexer. In-between the remultiplexer and the multiplexer we have the C2 System, as described in other parts of the present document. The inputs/outputs to the C2 System are syntactically correct TSs, each with unique `transport_stream_ids`, containing all relevant layer 2 (L2) signalling information (i.e. PSI/SI - see [i.1] and [i.4]). The various input TSs may have PSI/SI tables, or other L2 data, in common with other input TSs. When the extension is used the generated TSPS (Transport Stream Partial Stream) and TSPSC (Transport Stream Partial Stream Common) streams are however typically not syntactically correct MPEG-2 TSs, but are still carried in the MPEG-packet format.

**NOTE:** The parallel TSs may only exist internally in equipment generating the DVB-C2 signal. The parallel TSs may e.g. be generated from a single high bit rate TS source, or may alternatively be generated by centrally-controlled parallel encoders, each producing a constant bit rate TS, with variable proportion of Null Packets. The bit rates of the input TSs may be significantly higher than the capacity of the respective PLPs, because of the existence of a certain proportion of Null Packets, which are removed by the DNP procedure.

An input MPEG-2 TS shall be transported either:

- in its entirety within a single PLP, in which case the TS does not belong to any group of PLPs (and there is no Common PLP); or
- split into a TSPS stream, carried in a Data PLP, and a TSPSC stream, carried in the Common PLP. This annex specifies the splitting and describes how the recombination of the output streams from a Data PLP and a Common PLP can conceptually be achieved by the receiver to form the output TS.

## D.2 Splitting of a group of input TSs into TSPSs streams and a TSPSC stream

### D.2.1 General

When a set of  $N$  TSs ( $TS_1, \dots, TS_N, N \geq 2$ ) are transmitted through a group of  $N+1$  PLPs, one being the Common PLP of a group, all TSs may have a different input bit rate, but shall carry all the data packets, which are intended to be transmitted in a Common PLP. The data packets to be carried in the Common PLP are not necessarily co-timed. However it is assumed that all TS in a group have been generated in the same Playout Centre and there may be a skew between those TS concerning the timing of the signals, caused amongst others by different propagation delays on the contribution links.

There are two steps of processing. In the first step TS packets, which shall be transmitted via the Common PLP shall be replaced by Null Packets and in the second step additional Null Packets are inserted in order to reduce the buffering requirements in the receivers.

Each TSPS shall have the same bit rate as the associated input TS and maintain the same time synchronization. The TSPSC is an elementary stream with the same bit rate as the input TS it was extracted from. It contains data packets common to all transport streams within the group of TSs in a certain Data Slice. TSPSC data shall not require time synchronization with the associated TSPS data. The DVB SI tables SDT or EIT shall not be transported via a Common PLP, as a processing of those tables at table\_ID level is not foreseen in DVB-C2.

**NOTE:** The input TSs may contain a certain proportion of Null Packets. The split operation will not introduce further Null Packets into the TSPSs. Null packets will however be removed in the modulator and reinserted in the demodulator in a transparent way, so that the C2 System will be transparent for the TSPSs, despite Null Packets not being transmitted. Furthermore, the DNP and ISSY mechanism of the C2 System will ensure that time synchronization of the TSPSs and the TSPSC at the output of the demodulator is maintained to a certain extent.

### D.2.2 Extraction of the Common PLP from a group of TS

For the purpose of specifying the split operation the TS packets that may be transmitted in the Common PLP are identified by one or several PIDs and fall into the following three categories:

- 1) TS packets carrying any type of data, which does not require an exact time synchronization with other TS packets carried in other PLPs of the related group of PLPs.
- 2) EPG data, e.g. based on Event Information Table (EIT) format, but not using the 'actual' and 'other' mechanisms as specified in [i.4].
- 3) Conditional Access control data, e.g. Entitlement Management Messages (EMMs).

DVB-SI TS packets that may not be transmitted in the Common PLP, as this would require complex remultiplexing functionalities, fall into the following two categories:

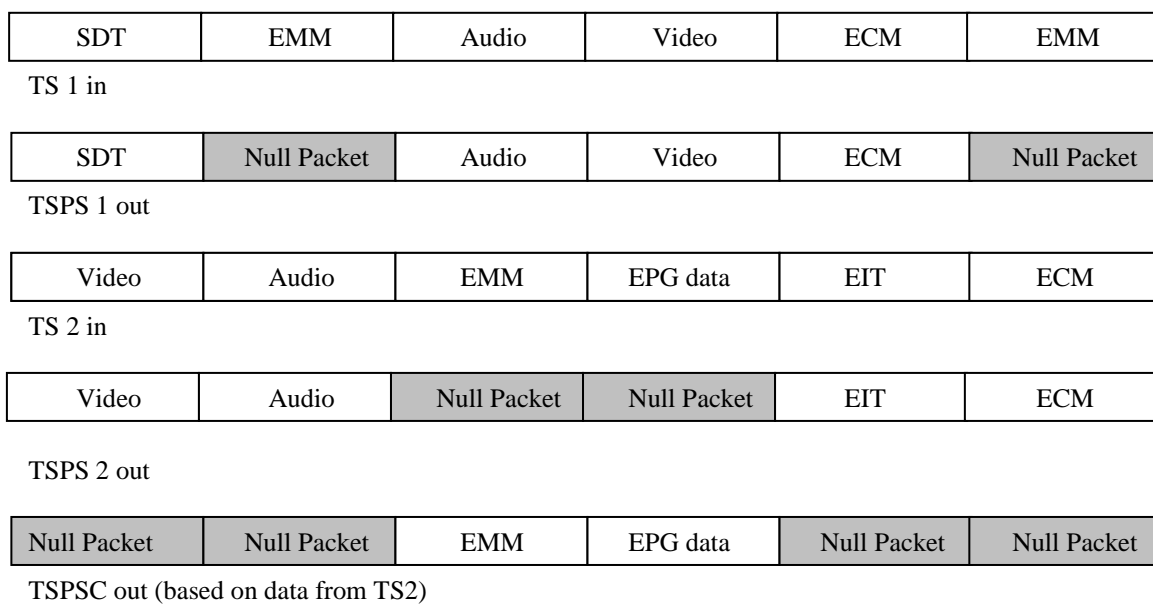
- 1) TS packets carrying Service Description Table (SDT), i.e. with PID value of 0x0011.
- 2) TS packets carrying Event Information Table (EIT), i.e. with PID value of 0x0012.

The TS packets targeted for transmission via the Common PLP shall be extracted from one input TS. If the input stream carrying the Common PLP data is carrying also payload data which is targeted to go into a PLP, those TS packets of that input stream, which were extracted to the Common PLP, shall be replaced by Null Packets (see figure D.2). All TS packets of the other input TSs belonging to that group of PLPs are processed such that all TS packets with the PID associated to the Common PLP are replaced by Null Packets.

During the process of extraction of Common PLP data optionally components of that TS may be deleted by replacement of the related data packets by Null Packets.

By processing one TS in parallel in two of the re-multiplexing lines and replacing complementary TS packets by Null Packets a separation of one TS into two partial TSs, which are targeted to be transmitted via different PLPs (with different level of robustness), can be achieved. This principle is also applicable if a split of one TS into more than two partial streams is required.

Figure D.2 is simplified insofar as it does not show any Null Packets in the input TSs. In real input TSs these are of course to be expected. The absence of these packets in the figures does however not in any way affect the general applicability of the splitting/re-combining process, as described in this annex.



**Figure D.2: Example of generation of two TSPS and a TSPSC from two input TS**

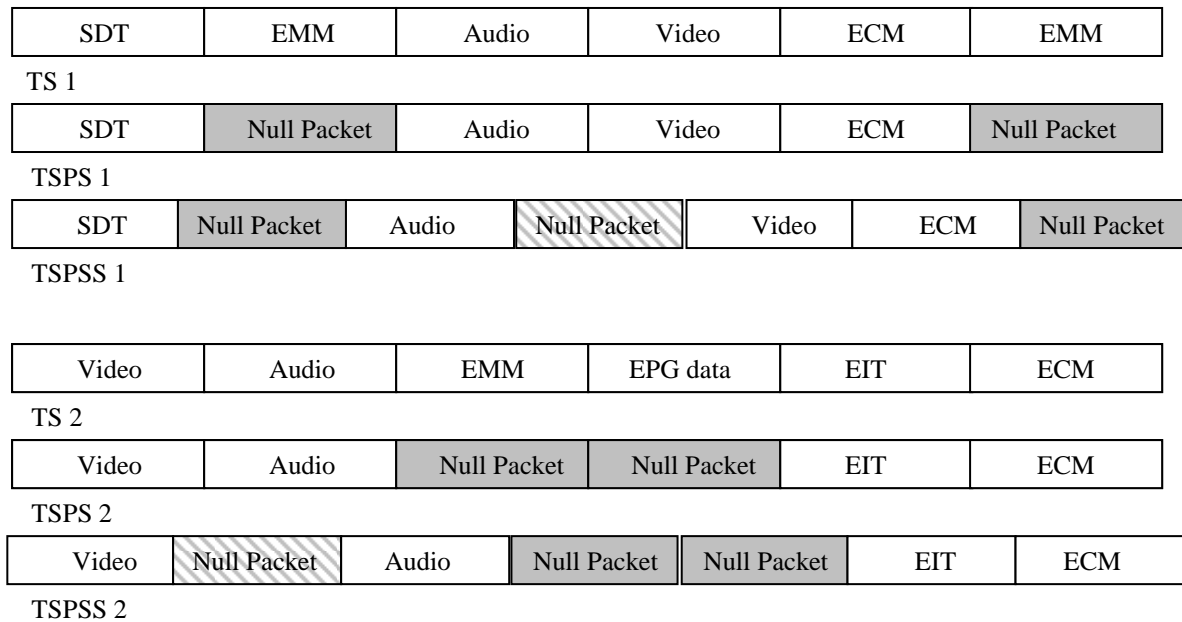
### D.2.3 Insertion of additional Null Packets into TSPSs

TS packets that are not necessarily co-timed but identical on all input TSs of the group before the split shall be replaced by Null Packets in the respective TSPS at the same time positions. Furthermore packets targeted to go into the common. PLP may occur non equidistant in the input stream. If the data packets in the Common PLP do have a "bursty", characteristics and the packets of the Common PLP and the relevant Data PLP are not co-timed, the required buffer size in a receiver could be significantly increased due to the missing time correlation. The insertion of additional Null Packets in the TSPS allows smoothing the characteristics of Null Packets and thus reducing the buffer requirement in receivers.

The number of inserted Null Packets shall be chosen such that a receiver with a 2 Mbit buffer is able to perform the multiplexing of Data PLP and Common PLP properly.

After insertion of Null Packets a PCR restamping has to be performed.

Figure D.3 gives an example of two Transport Streams where after extraction of Common PLP packets additional Null Packets are inserted.



**Figure D.3: Example of insertion of Null Packets into two TS / TSPS**

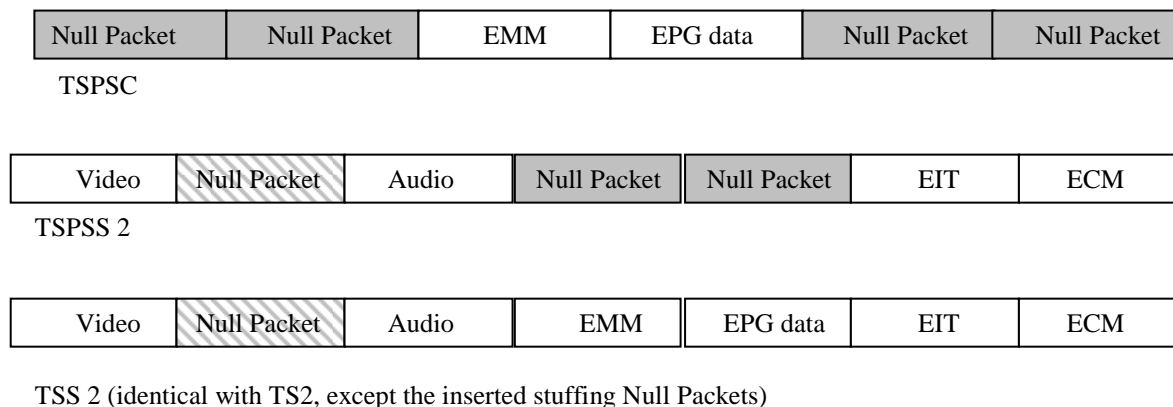
## D.3 Receiver Implementation Considerations

In view of the key role played by the transport stream as a physical interface in many existing and future receivers it is strongly recommended that at least the core of the merging function as described in this annex is implemented in a channel decoder silicon chip. In particular this applies to the generic merging function between TSPSC and TSPS to form a transport stream for generic data as defined in clause D.2 illustrated in figure D.3.

The channel decoder implementations as defined above should ensure correct integration of many existing DVB system hardware and software solutions for DVB with such channel decoders.

### D.3.1 Recombination of TSPSS and TSPSC in a receiver

The receiver shall recreate the targeted TS by multiplexing the received synchronized partial Transport Stream (TSPSS) with the received Common PLP Transport Stream (TSPSC). It shall replace any Null Packets which appear in the received TSPSS, by a packet from its Common PLP (TSPSC) buffer, unless this buffer is empty, see figure D.4. The output signal of the DVB-C2 demodulator delivers the Partial Transport Stream (TSPS) and the Common PLP (TSPSC) multiplexed together. Common PLP packets may be time shifted in relation to the modulator input signal and the amount of additionally inserted Null Packets at the modulator will increase the out data rate of the complete multiplexed output signal accordingly. However, after the PID filtering at the MPEG-Demultiplexer this headroom is removed completely.



**Figure D.4: Example of recombination of input TS from TSPSS and TSPSC**

## Annex E (normative): Calculation of the CRC word

The implementation of Cyclic Redundancy Check codes (CRC-codes) allows the detection of transmission errors at the receiver side. For this purpose CRC words shall be included in the transmitted data. These CRC words shall be defined by the result of the procedure described in this annex.

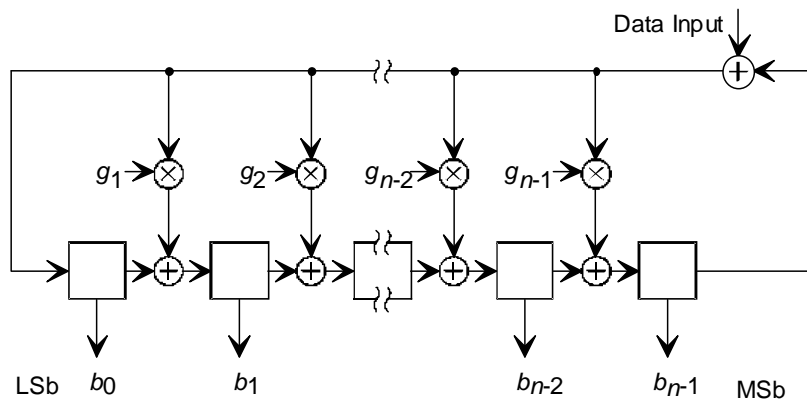
A CRC code is defined by a polynomial of degree  $n$ :

$$G_n(x) = x^n + g_{n-1}x^{n-1} + \dots + g_2x^2 + g_1x + 1$$

with  $n \geq 1$ :

and:  $g_i \in \{0,1\}$ ,  $i = 1 \dots n-1$

The CRC calculation may be performed by means of a shift register containing  $n$  register stages, equivalent to the degree of the polynomial (see figure E.1). The stages are denoted by  $b_0 \dots b_{n-1}$ , where  $b_0$  corresponds to 1,  $b_1$  to  $x$ ,  $b_2$  to  $x^2, \dots, b_{n-1}$  to  $x^{n-1}$ . The shift register is tapped by inserting XORs at the input of those stages, where the corresponding coefficients  $g_i$  of the polynomial are '1'.



**Figure E.1: General CRC block diagram**

At the beginning of the CRC-8 calculation (used for GFPS and TS, NM only and BBHeader), all register stage contents are initialized to zeros.

At the beginning of the CRC-32 calculation, all register stage contents are initialized to ones.

After applying the first bit of the data block (MSB first) to the input, the shift clock causes the register to shift its content by one stage towards the MSB stage ( $b_{n-1}$ ), while loading the tapped stages with the result of the appropriate XOR operations. The procedure is then repeated for each data bit. Following the shift after applying the Last Bit (LSB) of the data block to the input, the shift register contains the CRC word which is then read out. Data and CRC word are transmitted with MSB first.

The CRC codes used in the DVB-C2 system are based on the following polynomials:

- $G_{32}(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$
- $G_8(x) = x^8 + x^7 + x^6 + x^4 + x^2 + 1$

The assignment of the polynomials to the respective applications is given in each clause.

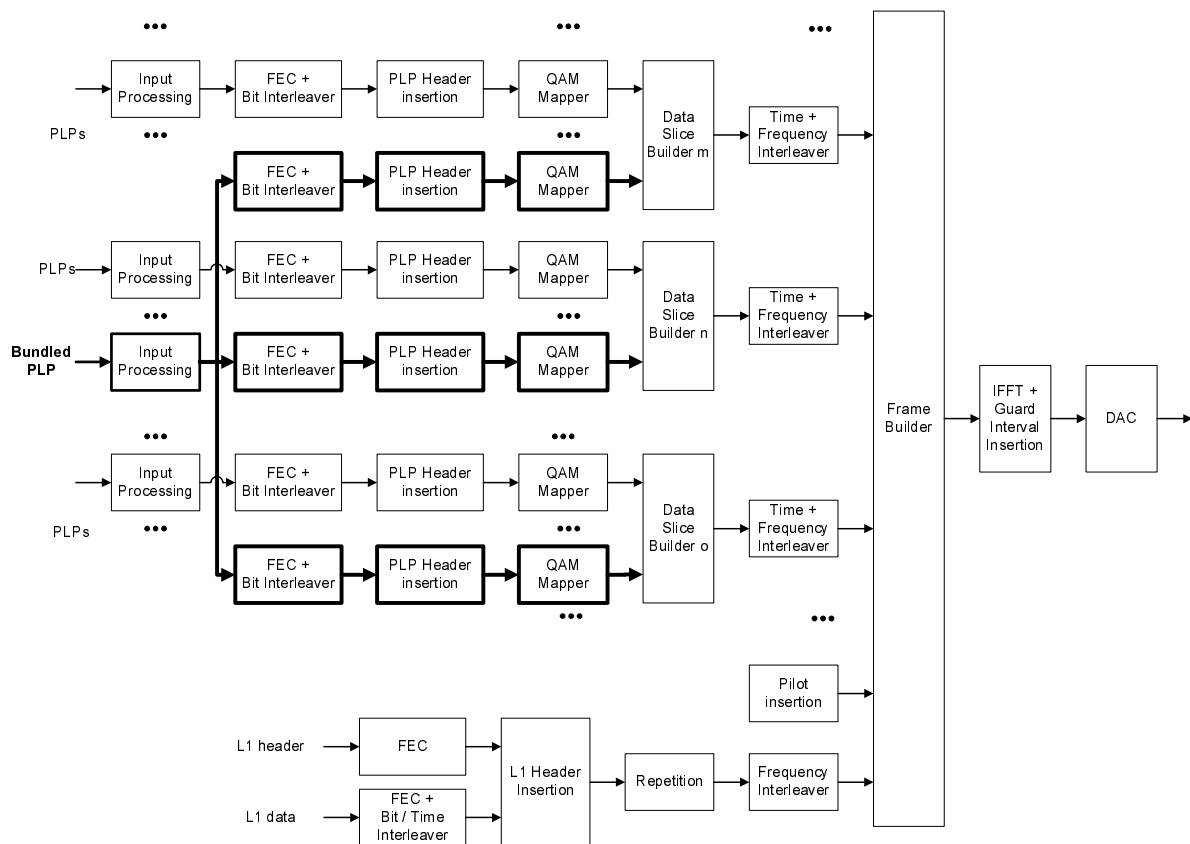
NOTE: The CRC-32 coder defined in this annex is identical to the implicit encoder defined in EN 300 468 [i.4].



## Annex F (normative): Bundling of PLPs

In addition to the basic operation mode (i.e. one or several PLPs are located in one Data Slice) the C2 System allows spreading data of a single PLP connection over different Data Slices (PLP Bundling). As a result, the throughput rate for a single PLP connection can be increased up to the overall throughput rate of the C2 System. This operation mode is intended for advanced services that require throughput rates above the capacity of a single Data Slice.

All data packets of a bundled PLP connection shall pass the same input processing block. Inserting the ISSY timestamp in the mode adaptation block is mandatory for this operation mode in order to allow the correct reordering of the packets from different Data Slices on the receiver side. At the output of the input processing block the BBFrames of the bundled PLP are spread over the different Data Slices. Figure F.1 shows the block diagram for the PLP Bundling operation mode.



**Figure F.1: Bundling PLP - data of a single PLP is spread over different Data Slices**

The bundling PLP operation mode mandates the usage of the FECFrame header for the Data Slices that contain packets from the bundled PLP.

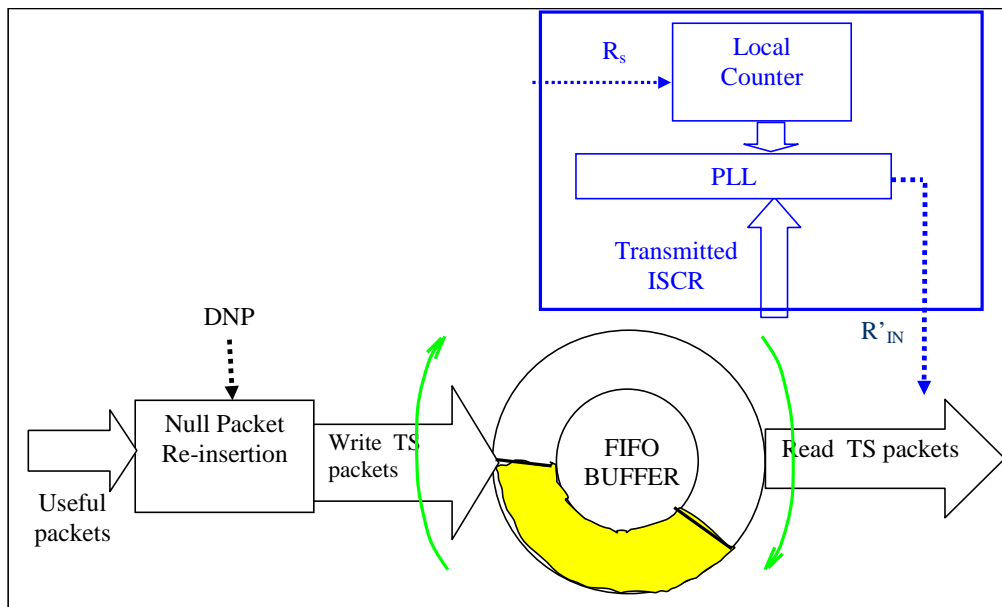
NOTE 1: As for the basic operation mode, Data Slices that include FECFrames from a bundled PLP might also contain FECFrame packets of others PLPs.

NOTE 2: C2 receivers with a single 8 MHz reception tuner do not need to decode bundled PLPs. These C2 receivers will recognize bundled PLPs from the L1 part 2 signalling and will discard associated Data Slice Packets.

## Annex G (informative): Transport Stream regeneration and clock recovery using ISCR

When the modulator operates in a mode that employs Null Packet Deletion, the receiver may regenerate the Transport Stream by inserting, before each useful packet, DNP in the reception FIFO buffer. As shown in figure G.1, the Transport Stream clock  $R'_{IN}$  may be recovered by means of a Phase Locked Loop (PLL). The recovered modulator sampling rate  $R_s$  may be used to clock a local counter (which by definition runs synchronously with the input stream synchronization counter of figure G.1). The PLL compares the local counter content with the transmitted ISCR of each TS packet, and the phase difference may be used to adjust the  $R'_{IN}$  clock. In this way  $R'_{IN}$  remains constant, and the reception FIFO buffer automatically compensates the chain delay variations. Since the reception FIFO buffer is not self-balancing, the BUFSTAT and the BUFS information may be used to set its initial state.

As an alternative, when dynamic variations of the end-to-end delay and bit-rate may be acceptable by the source decoders, the receiver buffer filling condition may be used to drive the PLL. In this case the reception buffer is self-balancing (in steady state half the cells are filled), and the ISSY field may be omitted at the transmitting side.



**Figure G.1: Example receiver block diagram for Null Packet re-insertion  
and  $R_{TS}$  clock recovery**

## Annex H (informative): Pilot patterns

This annex illustrates each of the scattered pilot patterns, showing the pattern of pilots at the low frequency edge of the ensemble for the first a few symbols of a frame. There are two scattered pilot patterns, and each of them has four phases to start with depending upon the frequency of the low frequency edge. Figures H.1 to H.4 shows the patterns in GI 1/64 case with four different phases. Figures H.5 to H.8 show the pilot patterns in GI 1/128 with four different phases. Continual pilot carriers are not shown.

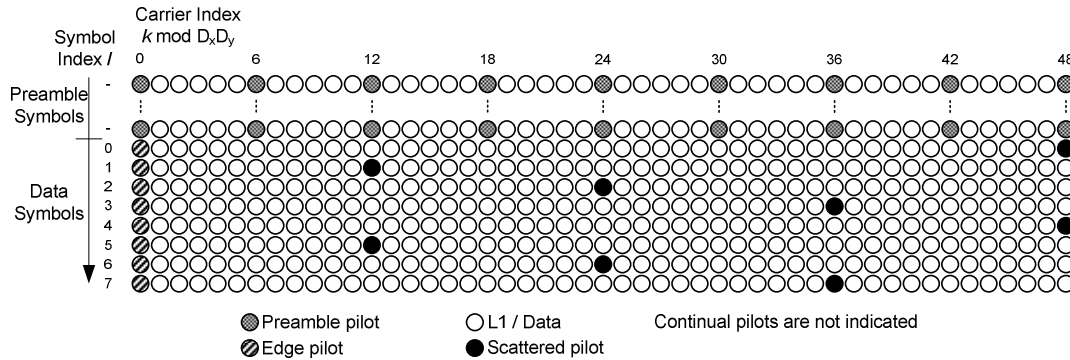


Figure H.1: Scattered pilot pattern for GI 1/64 with the lower edge  $k \bmod D_x D_y = 0$

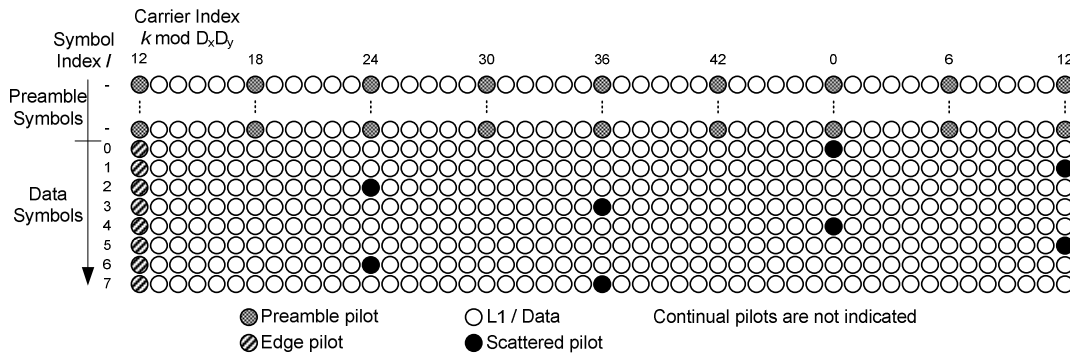


Figure H.2: Scattered pilot pattern for GI 1/64 with the lower edge  $k \bmod D_x D_y = 12$

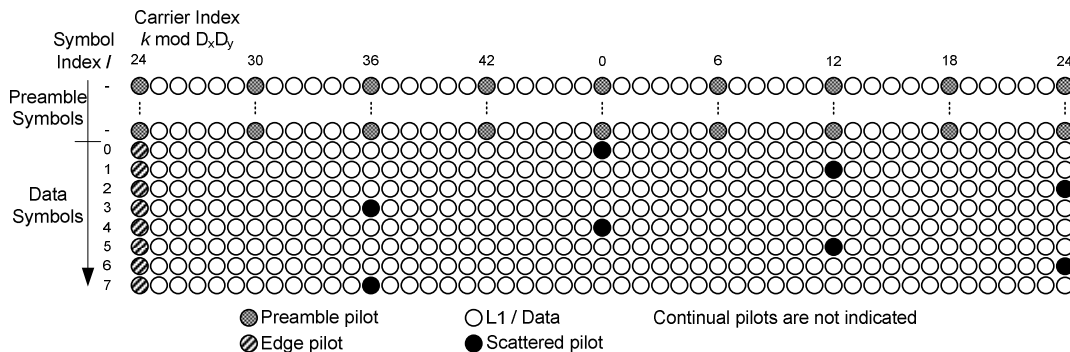


Figure H.3: Scattered pilot pattern for GI 1/64 with the lower edge  $k \bmod D_x D_y = 24$

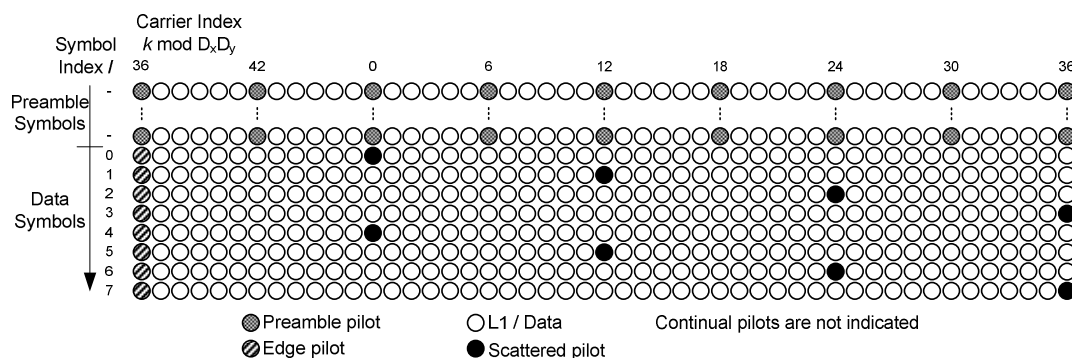


Figure H.4: Scattered pilot pattern for GI 1/64 with the lower edge  $k \bmod D_x D_y = 36$

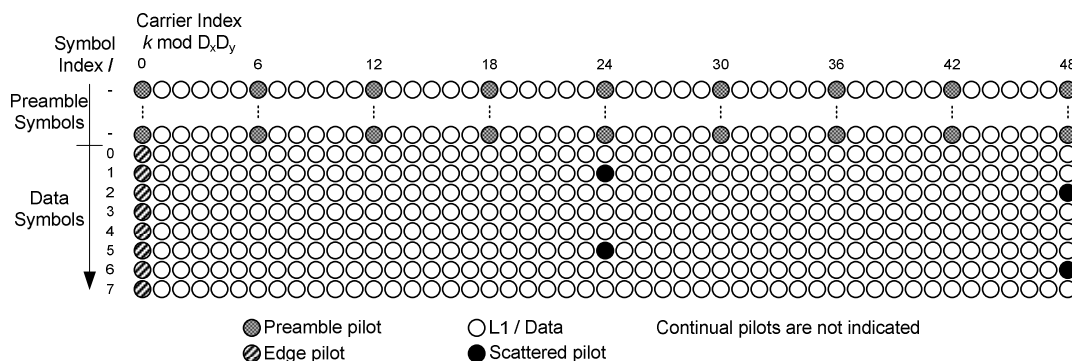


Figure H.5: Scattered pilot pattern for GI 1/128 with the lower edge  $k \bmod D_x D_y = 0$

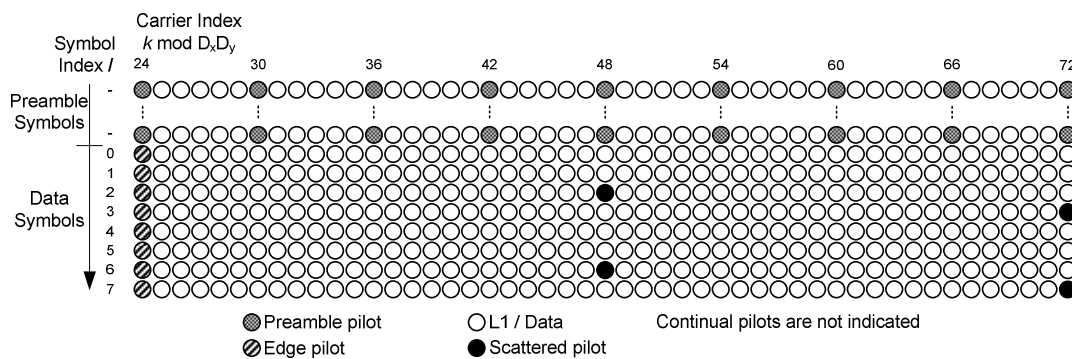


Figure H.6: Scattered pilot pattern for GI 1/128 with the lower edge  $k \bmod D_x D_y = 24$

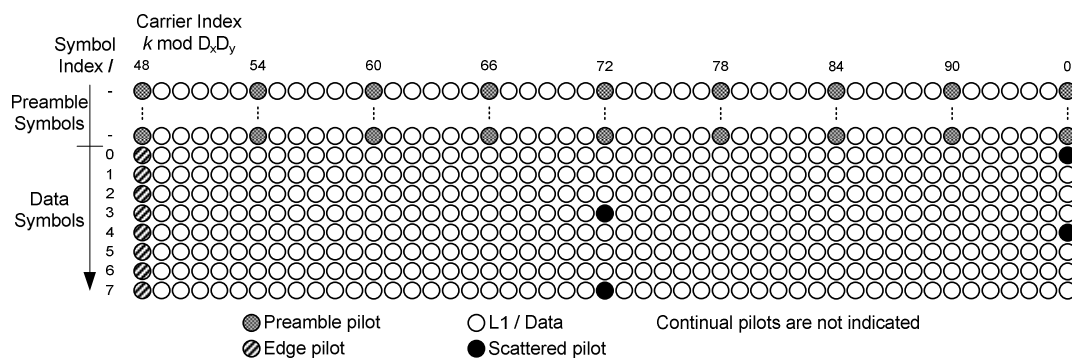


Figure H.7: Scattered pilot pattern for GI 1/128 with the lower edge  $k \bmod D_x D_y = 48$

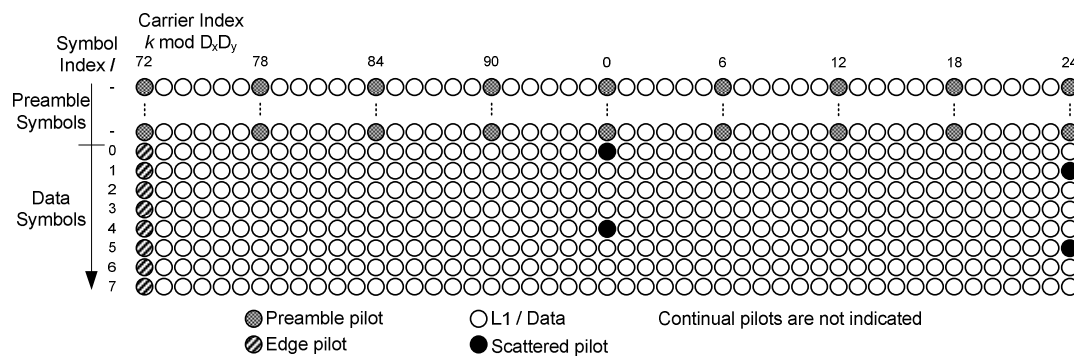


Figure H.8: Scattered pilot pattern for GI 1/128 with the lower edge  $k \bmod D_x D_y = 72$

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## History

Document history		
V1.1.1	April 2010	Publication
V1.2.1	December 2010	One-step Approval Procedure OAP 20110416: 2010-12-17 to 2011-04-18
V1.2.1	April 2011	Publication